UNIVERSIDAD NACIONAL DE INGENIERÍA
FACULTAD DE INGENIERÍA ELÉCTRICA Y ELECTRÓNICA

“DISEÑO DE UNA RED ÓPTICA METROPOLITANA EN LIMA”

INFORME DE SUFICIENCIA
PARA OPTAR EL TÍTULO PROFESIONAL DE:

INGENIERO ELECTRÓNICO

PRESENTADO POR:

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PROMOCIÓN
1996-II

LIMA – PERÚ

2002

A mis padres, Eldeomira y Joel,
A mis hermanos, Williams, Joel y Katerine.

DISEÑO DE UNA RED ÓPTICA METROPOLITANA EN LIMA

TABLA DE CONTENIDOS

PRÓLOGO

Este documento tiene por objetivo mostrar las tendencias de mercado y actuales tecnologías de transmisión para la implementación de Redes Ópticas Metropolitanas. Así también, se discuten y sugieren algunos criterios de diseño y configuración de una Red Óptica Metropolitana para la ciudad de Lima, haciendo un análisis actual del mercado peruano a fin de elegir la tecnología más conveniente en nuestro contexto: Red Metropolitana SDH. Se detallan aspectos técnicos tales como equipamiento, capacidad instalada y de mantenimiento, sistema de sincronismo, modos de protección, sistema de gestión, entre otros. Finalmente se describen algunas de las actuales aplicaciones que motivaron la implementación de la Red Metropolitana SDH en Lima.

CAPÍTULO I

TENDENCIAS EN REDES METROPOLITANAS

1.1 Prefacio

El advenimiento de la época de la información moderna ha producido un fenomenal crecimiento en los servicios de telecomunicaciones, dirigidos esencialmente por el Internet. Donde alguna vez sólo Megabits fueron necesarios, hoy incluso Terabits no son suficientes, y dado que el florecimiento de la expansión de Internet continua en una ruta impredecible y sin precedentes, se esperan y prevén muchas nuevas aplicaciones. Estas aplicaciones están introduciendo, por parte de clientes privados y empresariales, incrementos en la demanda de servicios de ancho de banda: personalizados, ultra-escalables, flexibles, transparentes y de gran velocidad (Terabits).

En concordancia con lo anterior, los rápidos avances en la tecnología DWDM (Dense Wave División Multiplexing) y la consiguiente explosión de ancho de banda están conduciendo en conjunto a nuevos paradigmas para las redes de telecomunicaciones, tales como el "embotellamiento metropolitano". Guiados por la creciente demanda y la naturaleza del tráfico, DWDM está empezando a expandirse desde ser una tecnología de backbone en la red, hacia las arenas de las redes metropolitanas y de acceso. El exitoso despliegue de varias soluciones DWDM para larga distancia ha producido una herencia inesperada en la capacidad de transporte del backbone. Ahora, el enfoque de los Operadores de Telecomunicaciones está empezando a moverse hacia las Redes Ópticas Metropolitanas (MON: Metropolitan Optical Networks), con el objetivo de brindar a sus usuarios finales los beneficios, de eficiencia en la red y costos, de la revolución de las redes ópticas.

Popularmente, las MON son definidas como el segmento de redes ópticas de transporte que abarcan distancias de varios cientos de kilómetros, típicamente atendiendo grandes y concentradas áreas metropolitanas. Las MON interconectan usuarios dentro de la misma área geográfica y sirven como puente entre las redes de larga distancia y las redes de acceso, interconectando un completo rango de protocolos desde los clientes privados/empresariales en las redes de acceso hasta el backbone de la red del Operador.

Se debe tener en cuenta que la demanda de los servicios en las redes metropolitanas está además evolucionando a un ritmo acelerado. Hasta mediados de los 90, las redes metropolitanas estaban básicamente enfocadas en el transporte de voz sobre circuitos TDM (DS-1, DS-3) y el servicio de líneas privadas. En los últimos años con el crecimiento del Internet y de la interconexión de redes de datos, el enfoque de las redes metropolitanas está en cómo soportar los servicios emergentes de datos basados en IP (Internet Protocol), ATM (Asynchronous Transfer Mode) y longitudes de onda (λ), así como en atender el continuo crecimiento de servicios TDM. Otro punto adicional y muy importante es cómo diseñar la arquitectura de las redes metropolitanas para soportar la transición de los servicios heredados en TDM hacia redes de datos basadas en IP.

Este capítulo direcciona esta predicha transición hacia los servicios de datos en la red metropolitana basados en el crecimiento de LAN a conectividad LAN, el acceso remoto a Internet, y el crecimiento de servicios de longitud de onda con gran ancho de banda. Asimismo, se describe una arquitectura adaptada para las MON empleando una flexible estrategia basada en bloques y que posteriormente será llamada "Arquitectura Multi-Servicios".

A fin de comprender con mayor facilidad este documento resulta oportuno introducir algunos conceptos básicos en redes, los cuales se describen a continuación.

1.2 Conceptos básicos

Típicamente, las redes de transporte metropolitanas se extienden entre dos sectores muy bien diferenciados en la red, denominadas Larga Distancia y Acceso. Esto es ilustrado en la Figura 1, la cual muestra una vista a alto nivel de todas las jerarquías de red. A fin de evaluar mejor los requerimientos y retos afrontados en el diseño de las MON, es útil tomar una muy breve, pero cercana mirada a cada uno de estos respectivos segmentos de red:

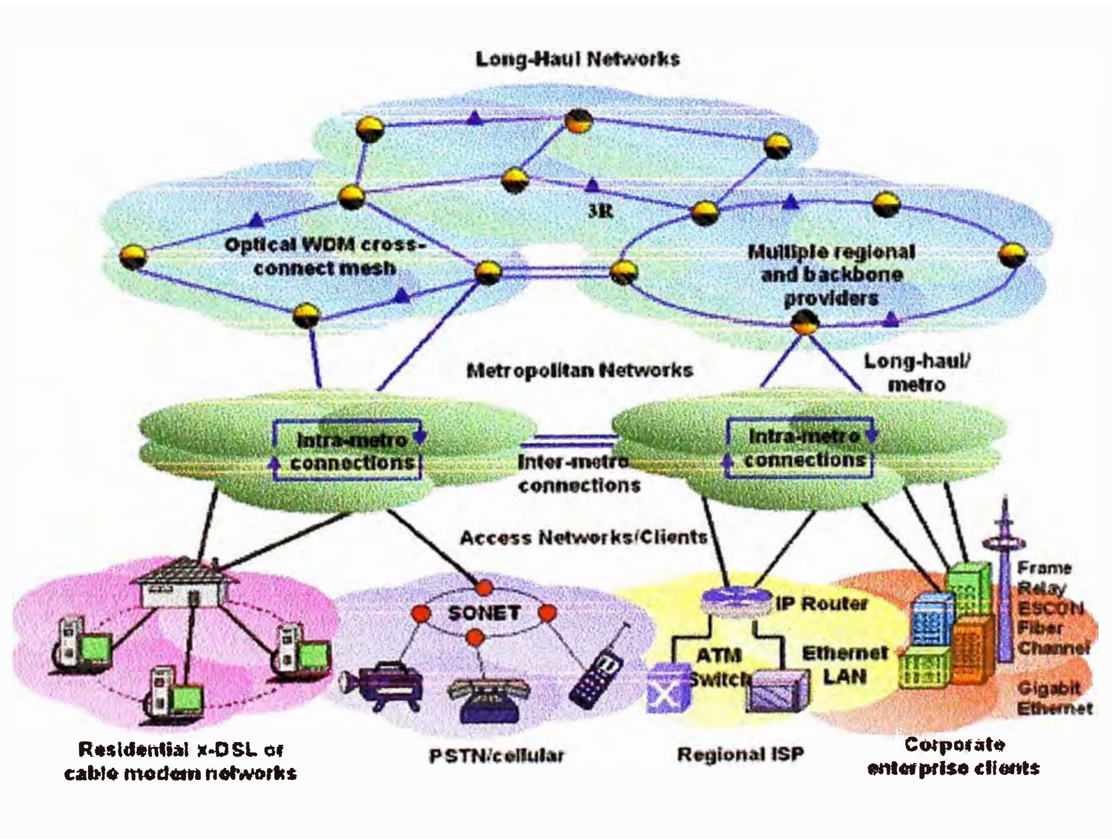


Figura 1 Jerarquías de una Red Óptica: Larga Distancia, Metropolitana y Acceso

1.2.1 Redes de Larga Distancia

Las redes de Larga Distancia son la fortaleza de un selecto grupo de grandes transnacionales y Operadores Globales que pueden cubrir distancias geográficas regionales y extenderse mucho más (hasta miles de kilómetros). Estas redes conectan redes metropolitanas y entre cada otra extienden la conectividad "global" entre dominios regionales.

La principal preocupación en estas redes ha sido la capacidad de transporte, la cual ha sido limitada por las tecnologías fundamentales. Aunque las redes de transporte de Larga Distancia han sido tradicionalmente basadas en SONET/SDH (Synchronous Optical Network/Synchronous Digital Hierarchy), preocupaciones relativas a fibra exhausta han guiado a los Operadores a desplegar tecnología DWDM a gran escala. Dado que severas inutilizaciones pueden originarse por la cantidad de canales DWDM incrementados, se requiere una cuidadosa ingeniería analógica en el provisionamiento para mantener la calidad de los canales sobre largas distancias. En muchos casos se requiere conversión Opto-Electrónica (O-E) junto con una completa regeneración electrónica (3R). Como resultado, las soluciones para Larga Distancia son muy caras y representan a largo plazo, inversiones estratégicas. Sin embargo, con el avance tecnológico (amplificadores, filtros, aislantes, compensadores de dispersión, fibra), las redes de Larga Distancia están viendo incrementar su capacidad a gran escala y migrar hacia Terabits y arquitecturas de backbone multi-longitud de onda.

La próxima generación de redes ópticas para Larga Distancia será capaz de soportar en forma flexible funciones de conmutación y ruteo de longitudes de onda, así como definiciones de servicio de supervivencia. Las redes de Larga Distancia continúan evolucionando con cada generación de mejoras en DWDM, haciéndose más robustas y eficientes en costo. Una evolución positiva se traduce en la necesidad de hacer que la fuente del tráfico (MON) sea más robusta y eficiente para el despliegue total de la red óptica extremo a extremo.

1.2.2 Red de Acceso

Las redes de acceso están caracterizadas por una diversa variedad de protocolos e infraestructura, representando el borde de la MON. Las velocidades en las redes de acceso abarcan un amplio espectro, variando desde canales sub-rate (tales como DS-1, DS-3, OC-3, OC-12, 10 Mbps Ethernet, y 200 Mbps ESCON) hasta capacidades de longitud de onda completas (OC-48, OC-192).

Igualmente el acceso de los clientes está compuesto desde usuarios residenciales Internet hasta todas las modalidades de las grandes corporaciones (privadas, gobierno e instituciones educativas). Para soportar esta amplia base de clientes, las redes de acceso deben llevar un amplio rango de aplicaciones basadas en una variedad de protocolos. Estos protocolos incluyen IP, ATM, SONET/SDH, Ethernet/Fast Ethernet/Gigabit Ethernet, voz multiplexada TDM, video digital, así como otros protocolos más específicos tales como FDDI (Fiber Distributed Data Interface), ESCON (Enterprise System Connectivity), y Fiber Channel.

En conjunto, este segmento de mercado representa una muy dinámica e impredecible oportunidad. Esta oportunidad está dirigida por las nuevas aplicaciones y mejoras hacia el usuario final, tecnologías de acceso de alta velocidad tales como DSL (Digital Subscriber Loop), cable modems, y emergentes servicios inalámbricos de próxima generación. Sin embargo, una tendencia clara es que el tráfico IP continuará incrementándose. Este desarrollo representa muchos retos debido a la explosiva, asimétrica e impredecible naturaleza inherente de los perfiles de tráfico del Internet. Adicionalmente, hay muchas nuevas aplicaciones de usuario final en el horizonte, cualquiera de las cuales puede causar un abrupto crecimiento en la demanda de ancho de banda: Internet video, telemedicina, videoconferencia, por nombrar unos pocos.

En resumen, las redes de acceso están dirigidas por dos principales factores: diversidad de aplicaciones y flexibilidad de arquitecturas. Una característica principal requerida por los Operadores para el desarrollo de eficientes redes de Acceso es el concepto de “transparencia”. Por consiguiente, los proveedores de equipos que puedan proveer plataformas con transparencia multi-servicios desde el mismo chasis (simplificando la red) resultarán ganadores.

1.2.3 Redes Metropolitanas

Las Redes Metropolitanas son una parte integral de toda la jerarquía de red en su conjunto. Específicamente, estas redes canalizan el tráfico en el dominio metropolitano (inter-empresas, inter-oficinas, conectividad metropolitana, etc.), así como también hacia y desde POPs (Points of Presence) de redes de larga distancia.

Como resultado, las redes metropolitanas son conducidas por dos principales factores, los requerimientos de los clientes y la tecnología para soportar estos requerimientos. Las redes metropolitanas están además caracterizadas por una diversa base de protocolos de red y velocidades de canalización, los cuales son detallados más abajo.

Las MON tradicionales fueron diseñadas para transportar un limitado conjunto de tipos de tráfico, principalmente servicios de voz y líneas privadas multiplexados, por lo cual hasta estos días, los Operadores de Telecomunicaciones han desplegado SONET/SDH como la tecnología de su elección en las áreas metropolitanas, la cual es las más indicada para estas necesidades. Las conexiones son permanentes o semi-permanentes con velocidades de acceso que varían desde OC-3/STM-1 hasta OC-48/STM-16. Consecuentemente se requieren complejos mapeos para multiplexar (a bajas velocidades) tráficos en diferentes protocolos dentro de un frame SONET/SDH.

Un concepto equivocado y general ha sido que las MON son esencialmente encarnaciones "miniaturizadas" de las redes de Larga Distancia, y así versiones menores de esta última pueden ser re-desplegadas en mercados metropolitanos. Las MON no son extensiones naturales de las redes de Larga Distancia. Más bien, las MON representan un modelo sinérgico, el cual cuando es apropiadamente implementado, produce una eficiencia que se traduce en una propuesta valiosa que todos los Operadores serán capaz de traspasar a sus clientes.

Los criterios en redes ópticas metropolitanas son significativamente diferentes que en redes de larga distancia. Mientras las redes de larga distancia son diseñadas para transportar eficientemente grandes volúmenes de tráfico de un punto a otro (reducir el costo por bit para transporte global), las redes metropolitanas tienen que alcanzar un diferente conjunto de objetivos, tales como soportar un rápido provisionamiento, frecuente reconfiguración, un gran número de aplicaciones y servicios de alto margen ofrecidos por los Operadores, lo que involucra la transparencia del servicio, así como conectividad extremo a extremo.

Tabla 1 Enfoques de las Redes de Larga Distancia vs. Redes Metropolitanas

Tipo de Red	Enfoque
Red Larga Distancia	• Reducir el costo por bit de transporte
Red Metropolitana	• Transparencia del servicio. • Velocidad de provisionamiento. • Conectividad end-to-end.

1.3 Tendencias de mercado en Redes Metropolitanas

Para comprender las tendencias de las Redes Ópticas Metropolitanas es por lo menos necesario tener nociones acerca de las tendencias de mercado tanto en las Redes de Larga Distancia como en las Redes de Acceso. Por tanto, se requiere analizar la Red de Transporte como un todo, desde un punto de vista sistémico, en el cual los componentes tecnológicos y las variables económicas juegan un papel decisivo.

Además apuntamos que las tendencias del mercado de telecomunicaciones están conducidas básicamente por el mercado de Norteamérica y Europa, pues es allí donde los Proveedores de Tecnología desarrollan soluciones que satisfacen los requerimientos de aquellas regiones y luego con el tiempo las masifican hacia los mercados en desarrollo tales como Latinoamérica.

Como se mencionó anteriormente, el advenimiento de la época de la información moderna ha producido un fenomenal crecimiento en los servicios de telecomunicaciones, dirigidos esencialmente por la expansión del Internet, la cual continua en una ruta impredecible y sin precedentes, por lo que se esperan y prevén muchas nuevas aplicaciones, las cuales introducen, por parte de clientes privados y empresariales, incrementos en la demanda de servicios de ancho de banda: personalizados, ultra-escalables, flexibles, transparentes y de gran velocidad. Un vistazo a los requerimientos de telecomunicaciones a nivel global puede apreciarse en la Figura 2.

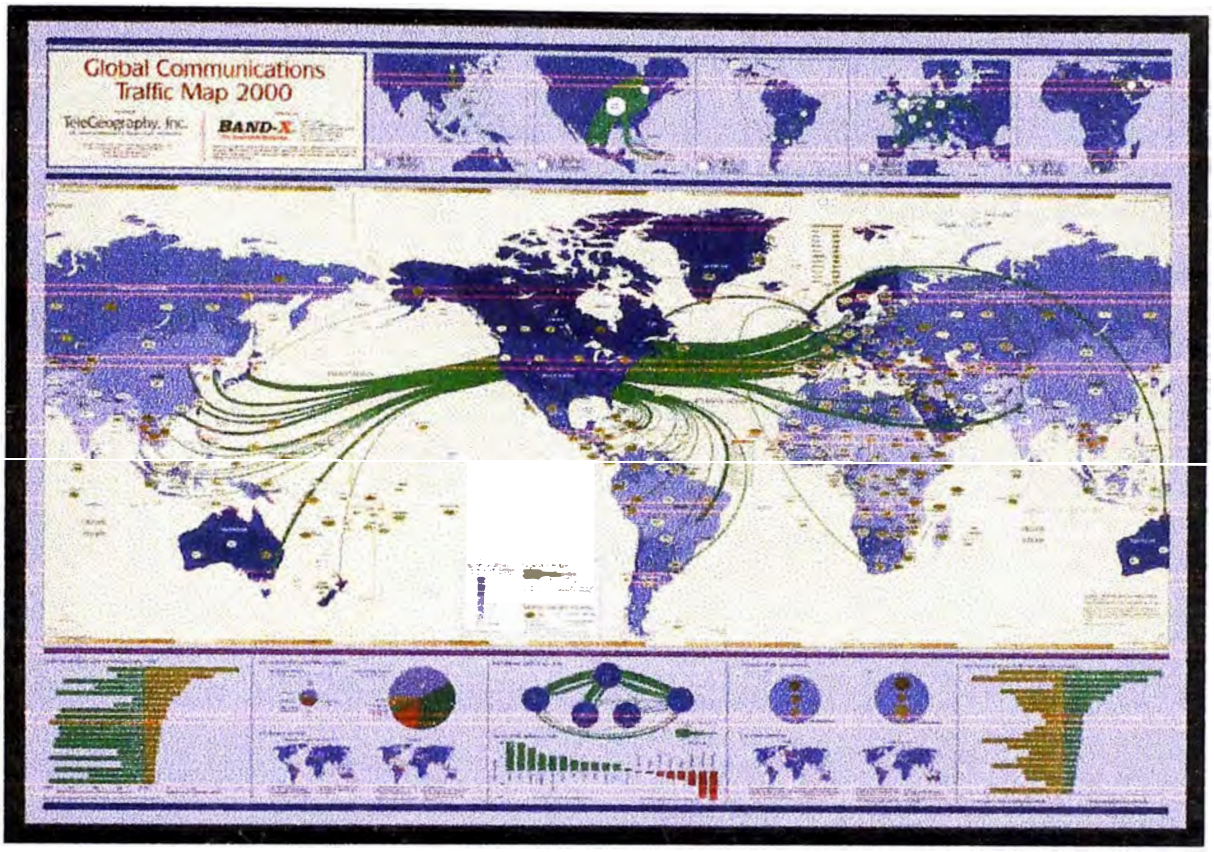


Figura 2 Mapa del Tráfico de Comunicaciones a fines del año 2000

Fuente: Telegeography 2000

Ante el pronosticado agotamiento de los recursos de ancho de banda satelital surge la necesidad de contar con un backbone local y doméstico de gran capacidad en USA, así como también de recursos de ancho de banda internacional suficientes para enlazar a los diferentes países con el Backbone Internet de USA, ante lo cual los estudios en tecnología óptica se enfocan a éste tipo de redes. Inicialmente los costos de ancho de banda con tecnología óptica (SONET/SDH en un inicio) resultaron elevados y superiores a los de la opción satelital, sin embargo con los rápidos avances en WDM y posteriormente con DWDM, la tecnología óptica ha tenido un impacto dramático en el costo y disponibilidad de ancho de banda en ambos extremos de la red (Figuras 3 y 4).

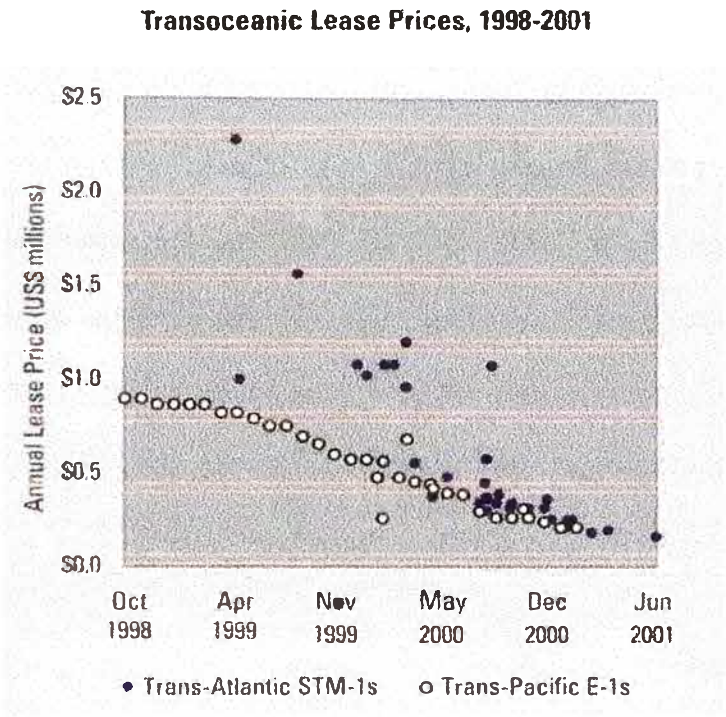


Figura 3 Precios de Alquiler de capacidad trans-oceánica

Fuente: Telegeography 2000

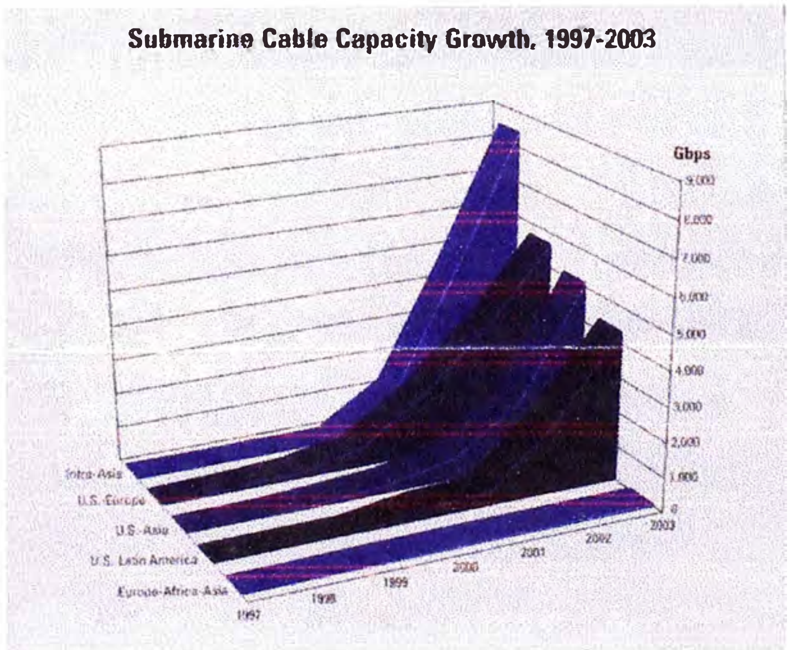


Figura 4 Crecimiento de Capacidad en Cables Submarinos

Fuente: Telegeography 2000

Con respecto al Backbone Internet, la interrogante es cómo se está satisfaciendo la necesidad de nueva capacidad. Aunque la gente está realizando más llamadas telefónicas por año, mucho más ancho de banda está siendo requerido por Proveedores de Servicios Internet (ISP). El año 2000, los ISP empezaron a tomar ventaja de la explosión de la fibra y algunos hicieron upgrade a sus backbones internacionales desde 155 Mbps hasta 2,5 Gbps. Esta tendencia está triplicando o cuadruplicando el ancho de banda en varias rutas, especialmente aquellas que conectan EE.UU. y Europa (13 a 56 Gbps) y a Asia (6 a 20 Gbps). Esto se muestra en las Figuras 4 y 5.

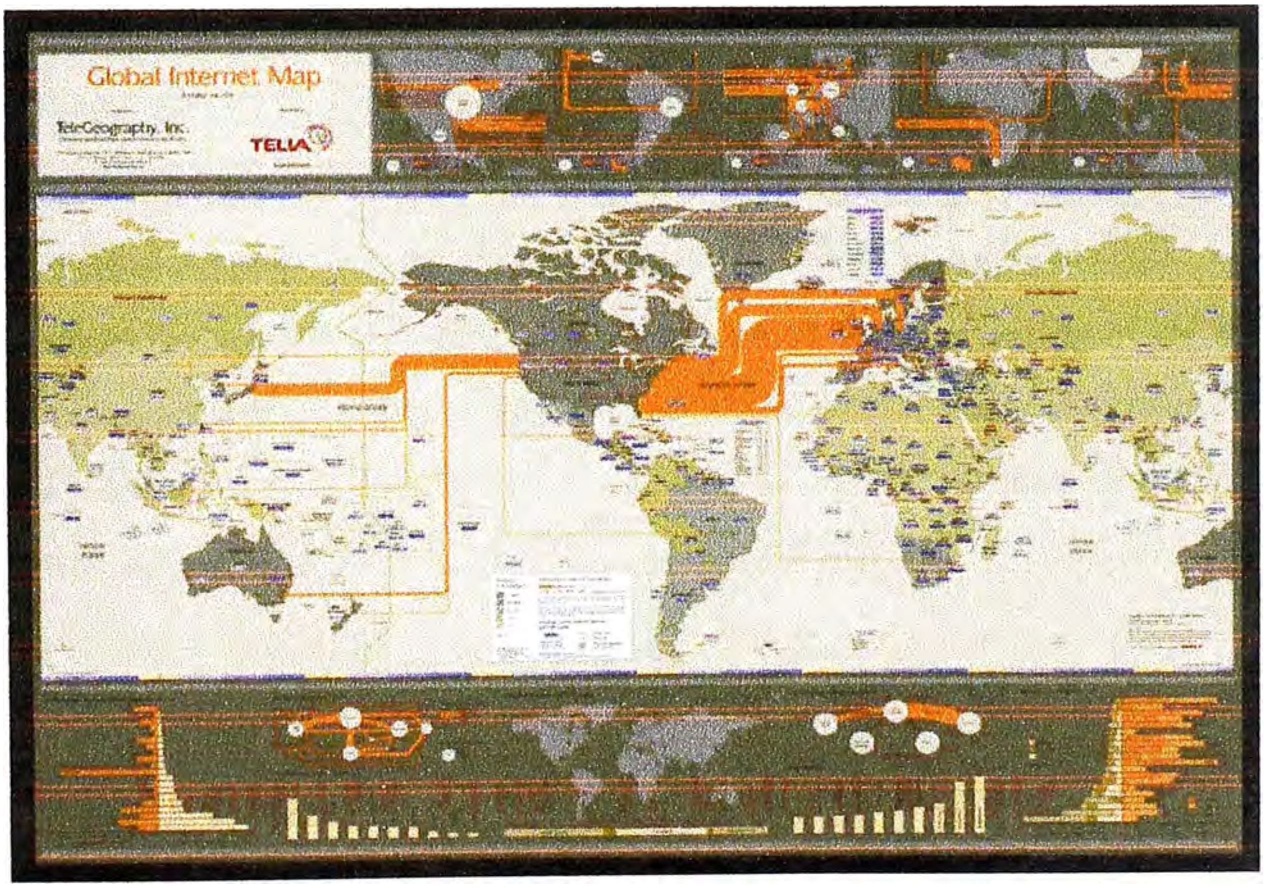


Figura 5 Mapa del Trafico Internet a Junio del 2001

Fuente: Telegeography 2000

Así también, el boom alcanzado por el ancho de banda submarino alcanzó un impredecible crecimiento durante el año 2000. Los cables submarinos instalados el año 2000 incrementaron el ancho de banda trans-Atlántico en un factor de 12 en solo 1 año, pasando los dos Terabits por segundo (Figura 4). Y mientras tanto una enorme tasa de crecimiento en la capacidad en Larga Distancia Doméstica ha estandarizado la tarifa para la última mitad de esta década, el ancho de banda en las puertas de las MAN (Metropolitan Area Network) ha estado en corto suministro hasta hace poco. Esta corta era desencadenó el boom de las construcciones de MAN, primero en USA y luego en Europa. En la mayoría de ciudades de negocios internacionales, al menos tres redes (y frecuentemente más) están siendo construidas, creando una infraestructura de capacidad sin precedentes, compuesta de muchos cientos de pares de fibra.

Originalmente las redes metropolitanas fueron diseñadas para transportar un limitado conjunto de tipos de tráfico, principalmente servicios de voz y líneas privadas multiplexadas, tales como DS-1 y DS-3, por lo cual hasta estos días, los Operadores de Telecomunicaciones han desplegado SONET/SDH como la tecnología de su elección en las áreas metropolitanas, la cual es las más indicada para estas necesidades. Estas tradicionales redes metropolitanas fueron inicialmente estructuradas en anillos de fibra óptica y recorrían distancias de 150 a 200 km. Estos anillos son interconectados mediante cross-conectores (DSC), mientras los multiplexores add/drop (ADM) proporcionan a los clientes acceso a la red, tal como se muestra en la Figura 6.

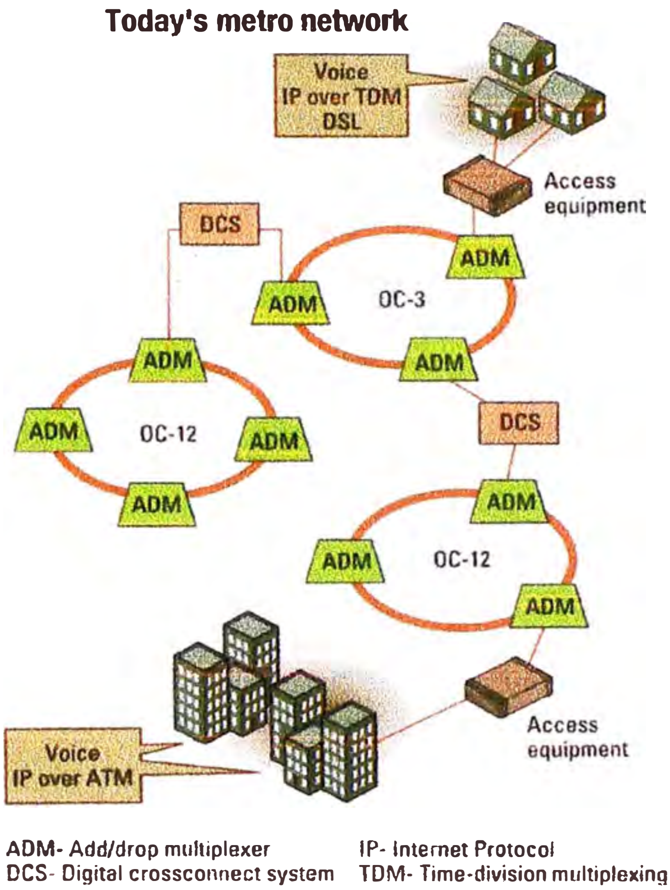


Figura 6 La actual Red Metropolitana está siendo presionada cada vez a más a moverse desde solo voz hacia servicios de voz y datos, mientras que las velocidades de datos están escalando de OC-3 a OC-12 y a OC-48. En las predominantes topologías de anillo, cross-conectores ópticos-eléctricos-ópticos entre anillos están limitando la implementación de nuevos y más rápidos servicios

En estas redes metropolitanas las conexiones son permanentes o semi-permanentes con velocidades de acceso que varían desde OC-3/STM-1 (155 Mbps) hasta OC-48/STM-16 (2,5 Gbps), aunque a partir del tercer trimestre del año 2001 se cuentan con equipos SDH con velocidades de acceso de STM-64 (10 Gbps) para los anillos principales. En consecuencia se requieren complejos mapeos para multiplexar (a bajas velocidades) tráficos en diferentes protocolos dentro de un frame SONET/SDH. Adicionalmente, una arquitectura basada en SONET/SDH no puede producir definiciones de servicio muy flexibles y tiene escalas de tiempo muy grandes en el provisionamiento de capacidad. En muchos casos, los Operadores pueden tener que comprometerse a caras y tediosas operaciones de upgrade de capacidad para satisfacer el incremento de demanda de un solo cliente. Por tanto, SONET/SDH no ofrece la eficiencia de red necesaria, requerida para las redes de próxima generación. La pregunta es ahora qué tecnología y arquitectura de red metropolitana es la que adapta mejor a las tendencias ya mencionadas; para lo cual analizaremos a continuación un poco más en detalle estas limitaciones.

Las diferentes tendencias en el comportamiento y características de las redes metropolitanas han ayudado a formar su arquitectura y hacer preponderar el diseño de la tecnología fundamental. Crecientemente, el cambio es un hecho en la vida de una red metropolitana. En particular, los componentes del transporte metropolitano están siendo presionados para proporcionar altas velocidades de datos y canales de gran capacidad, así como acomodar nuevos servicios y protocolos de datos. Mientras sólo poco años atrás velocidades tales como OC-3 fueron usadas, las redes actuales ostentan velocidades de OC-12, OC-48, y mayores. Las redes metropolitanas tradicionales, tales como las mencionadas en los dos últimos párrafos anteriores, emplean tecnología eléctrica-óptica-eléctrica (E-O-E) en sus puntos de conmutación y han alcanzado su limitación práctica.

Con el avance en las velocidades de transmisión, se están introduciendo nuevos protocolos para soportar nuevas aplicaciones. La popularidad del Internet ha incrementado el uso de TCP/IP (Transmission Control Protocol/Internet Protocol).

MPLS (Multiprotocol Label Switching), considerado por muchos como el mejoramiento de TCP/IP, está incrementando su popularidad e indudablemente jugará un rol importante en las futuras redes metropolitanas.

La localización del tráfico metropolitano, permite parcialmente el uso de redes de área almacenada (SAN: Storage-Area Networks) y data caching, fomentando el uso de los protocolos Fiber Channel y Gigabit Ethernet en la red metropolitana. Protocolos basados en celdas, tales como ATM, también son usados frecuentemente.

Con estos cambios en la velocidad de transmisión y protocolos de los enlaces, los Operadores deben replantear sus redes muy frecuentemente. Estos frecuentes y costosos acondicionamientos en la red han impulsado a los arquitectos de redes a mirar tecnologías tales como redes ópticas, las cuales son transparentes a la velocidad de transmisión, protocolos y contenidos.

A pesar que los anillos SONET/SDH tienen como característica una robusta recuperación de fallas, éstas no son escalables. Éstas utilizan un canal simple por fibra y operan sólo hasta ciertas velocidades. Adicionalmente, la topología en anillo, combinada con anacrónicas herramientas de gestión, no soporta un rápido provisionamiento y reconfiguración, lo cual es considerado crítico por los Operadores. Estas deficiencias están impulsando a los diseñadores de red a migrar de una topología de anillos a una topología de mallas empleando enlaces DWDM.

La necesidad de incrementar la seguridad en redes empresariales y varios servicios de red han originado una mayor demanda por la disponibilidad de red. Ciertamente, por esta razón, encontramos que los grandemente cotizados cinco nueves (99,999%) se han convertido críticamente en el estándar de confiabilidad en redes metropolitanas.

Estas tendencias: gran ancho de banda, capacidad de canales, nuevos protocolos y servicios; piden una red 100% óptica que pueda acomodarlos fácilmente. La principal fortaleza de los nodos en una red óptica, sin traslación entre señales ópticas y eléctricas, es su transparencia a cambios en el contenido, ancho de banda, capacidad de canales y protocolo de la red (ver Figura 7). Nace así el concepto de Red Óptica Metropolitana.

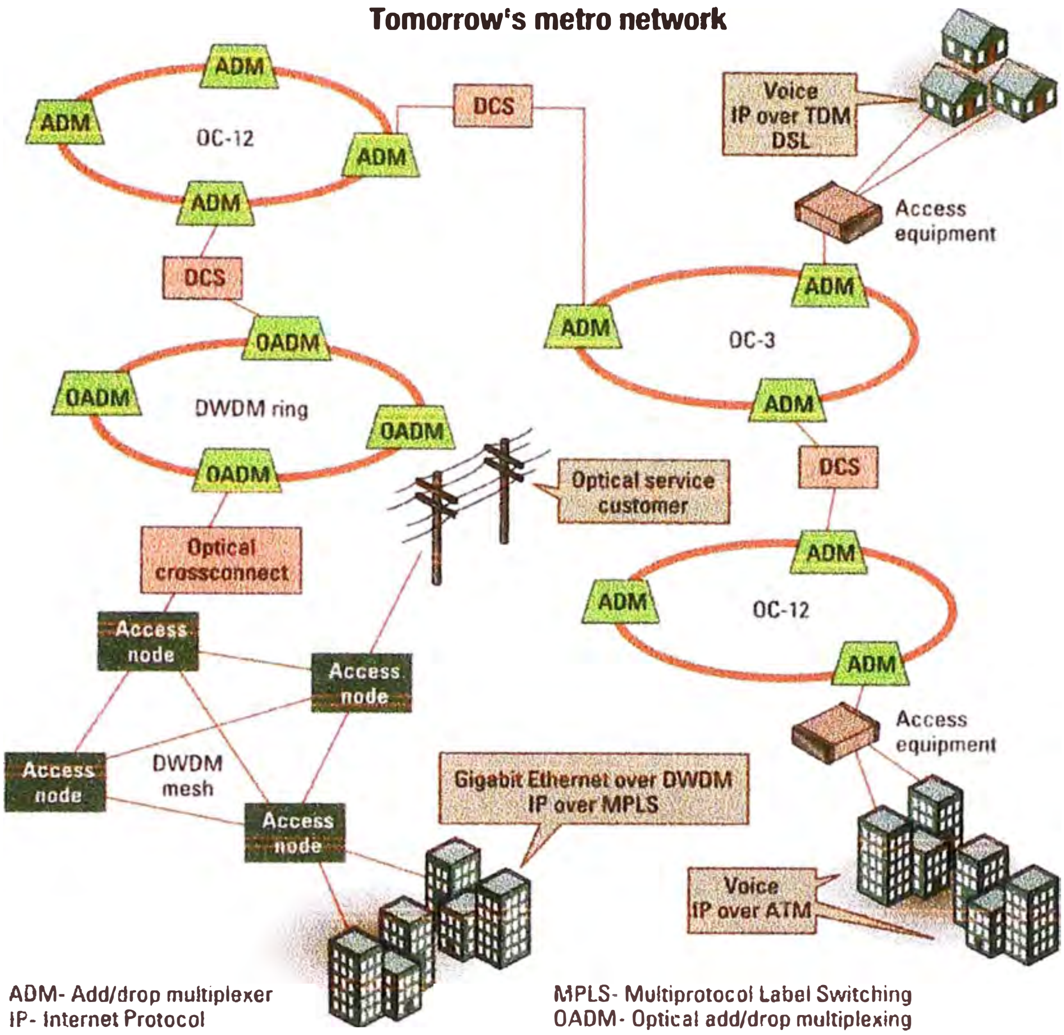


Figura 7 La futura Red Metropolitana debe responder a las demandas de gran ancho de banda, nuevos servicios y protocolos para proveerlos, proporcionando el impulso de las topologías en malla DWDM con conmutadores add/drop y cross-conectores totalmente ópticos.

Los avances en la tecnología óptica DWDM y la consiguiente explosión de ancho de banda, están conduciendo en conjunto a nuevos paradigmas para las redes de telecomunicaciones. En primer lugar, en el lado del backbone óptico de Larga Distancia, DWDM a velocidades de 10 Gbps y superiores, está proporcionando acceso a Terabits de ancho de banda entre áreas metropolitanas. Mientras, en el borde de las empresas, Fast Ethernet se está convirtiendo en algo común; Gigabit Ethernet está estandarizado, y 10 Gigabit Ethernet está emergiendo como un estándar. Entonces, el ancho de banda dentro de una empresa y en el computador se está volviendo abundante. El reto es extender la transparencia y escalabilidad de la LAN dentro de una WAN metropolitana a través del backbone. Todo esto hace que actualmente la MON sea considerada el principal "cuello de botella" para permitir el desarrollo completo del potencial del Internet. De esto puede deducirse que un punto clave es la discontinuidad entre como el tráfico es transportado desde el borde de las empresas a través de la MON y hacia el backbone. Esta deducción será denominada paradigma del "Embotellamiento Metropolitano", tal como se muestra en la Figura 8.

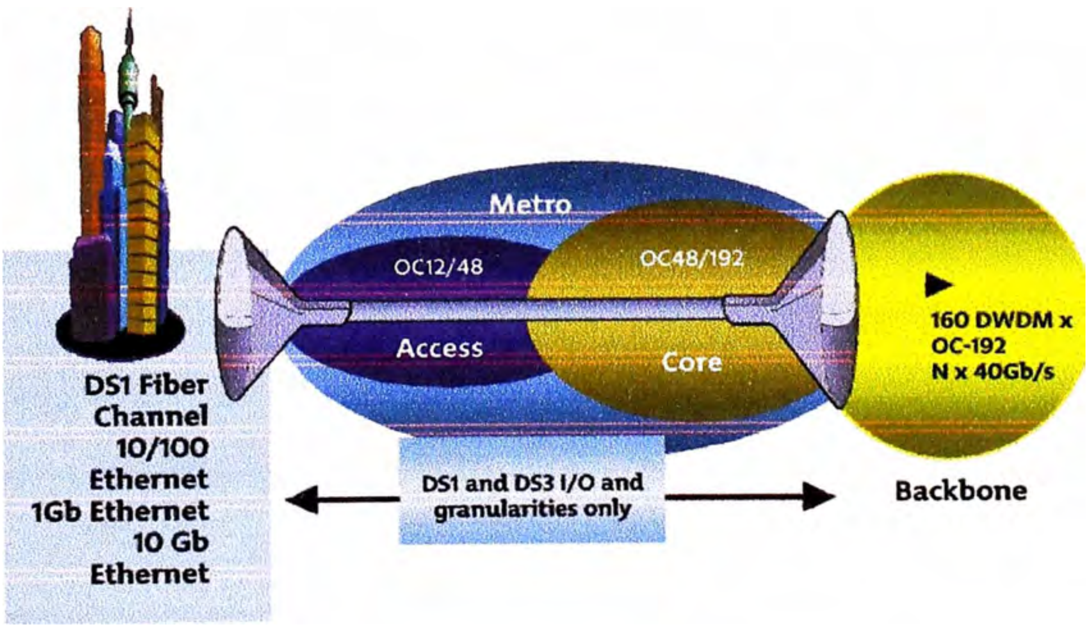


Figura 8 Paradigma del "Embotellamiento Metropolitano"

En segundo lugar, guiados por la creciente demanda y la naturaleza del tráfico, DWDM está empezando a expandirse desde ser una tecnología de backbone en la Red de Larga Distancia, hacia las arenas de las Redes Metropolitanas y de Acceso. Por lo que el exitoso despliegue de varias soluciones DWDM para redes de Larga Distancia ha producido una herencia inesperada en la capacidad de transporte del backbone.

En tercer lugar, analizando el mercado de las redes de acceso se puede notar que una porción significativa del tráfico de las empresas es originada en formato Ethernet (10/100/GE), en tanto que el backbone está implementado a velocidades ópticas de 2,5 Gbps y 10 Gbps con granularidad STS-1. Es más, las MON continúan transportando tráfico empleando granularidad DS-1 y DS-3 dentro de la MAN y a través del backbone.

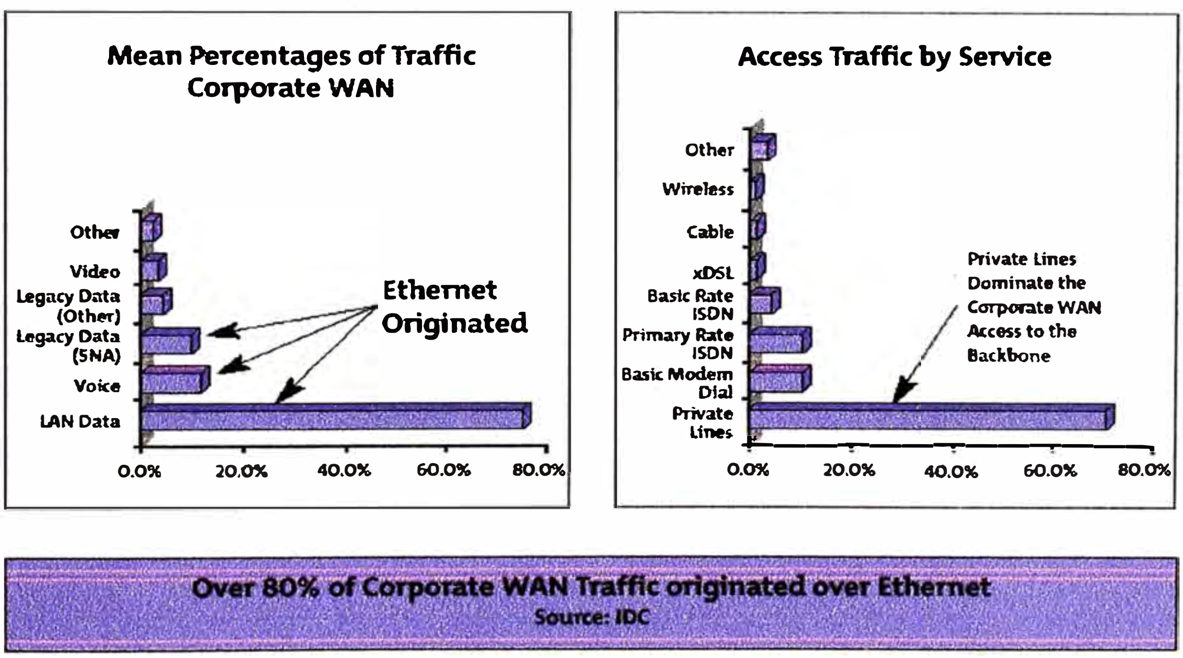


Figura 9 Composición del tráfico LAN y MAN en EE.UU. al año 2000.

Para ilustrar este punto, la Figura 9 muestra que más del 70% del trafico WAN es tráfico de datos (LAN) y que menos del 10% del tráfico WAN es voz. Aún el 70% de los enlaces WAN usan circuitos DS-1 y DS-3 (en la modalidad de líneas privadas) para enlazar otras redes metropolitanas o enlazarse al backbone. Los routers en las empresas están evolucionado hacia el empleo de interfaces OC-3, OC-12c, OC48/192c, a fin de manejar el rápido crecimiento del trafico en las MAN. Estas interfaces en líneas privadas están ampliamente difundidas debido a su omnipresente despliegue en redes ópticas metropolitanas (por ejemplo su extensivo uso en redes de transporte SONET, SDH y cross-connects).

Así también, dado que hoy en día, dentro las redes metropolitanas el tráfico WAN proveniente de las empresas es básicamente Ethernet, y probablemente este continúe predominando en el futuro, debería cuestionarse el convencional punto de vista de que los servicios heredados de líneas privadas son los medios más eficientes para las MON.

Figura 10 Ethernet en líneas privadas Metro

Comentaremos un par de razones de por que las redes ópticas metropolitanas basadas en interfaces LAN Ethernet nativas tendrán probablemente un significativo crecimiento en el futuro:

- Hay un costo adicional para los vendedores de routers Ethernet por adaptar las interfaces de datos nativos a interfaces de líneas privadas (DS-1, DS-3, OC-N) empleando los llamados "adaptadores de telecomunicaciones". Este costo adicional se traslada dentro del costo de la interface de la línea privada, haciéndola de tres a cuatro veces más costosa que una interface LAN nativa (100BT, Gigabit Ethernet). Adicionalmente, se espera que el costo de las interfaces Gigabit Ethernet se reduzcan rápidamente, a fin de que su empleo se incremente en redes empresariales.

- El crecimiento de ancho de banda ha sido limitado a incrementos de ancho de banda en las líneas privadas tales como DS-1, DS-3 u OC-N. Como las interfaces de líneas privadas son provisionadas como conexiones físicas desde el local de los clientes hacia la red metropolitana, las necesidades de incremento de ancho de banda requieren que se establezcan nuevas conexiones físicas. Por ejemplo, un DS-1 adicional requeriría adicionar un nuevo puerto en el router, adicionar una nueva tarjeta de transporte y establecer una nueva conexión a través de las redes atravesando numerosos elementos de red. Este punto no involucra solamente el costo del próximo incremento de ancho de banda, sino además el tiempo de provisión de este para el cliente. Esto puede tomar semanas, a fin de provisionar el circuito a través de la red debido al numero de elementos de red por donde el circuito puede viajar y al tiempo para trasladarse al local del cliente y establecer la conexión fisica incremental.

Por lo expuesto, podemos notar que las redes metropolitanas de hoy están experimentando una rápida metamorfosis como consecuencia de los imprevistos cambios de paradigmas que ocurren en los dominios del acceso y la larga distancia. Adicionalmente al cambio de paradigmas basados en la tecnología y los usuarios, el mercado metropolitano está convirtiéndose rápidamente en una arena ferozmente competitiva. La explosión de capacidad DWDM en la larga distancia acompañada del fenomenal crecimiento de demanda de ancho de banda IP en las redes de acceso ha colocado a las redes metropolitanas en una encrucijada: "Embotellamiento Metropolitano". Es claro que la actual infraestructura basada en TDM presenta retos para alcanzar la eficiencia y flexibilidad necesaria para los clientes, específicamente limitaciones en el escalamiento de capacidad, ineficiencia y apatía a las ráfagas así como al tráfico impredecible. Precipitado por las recientes demandas de varios grandes clientes empresariales por conexiones directas a velocidades de OC-48 (en routers IP o conmutadores ATM) hacia sus locales y al crecimiento pronosticado por los Operadores, la distinción entre redes de acceso y redes metropolitanas está empezando a confundirse. El resultado neto será un incremento significativo de la demanda de ancho de banda y una dispersión geográfica de la base clientes. Con el tiempo, esto sólo aumentará los problemas, originando una mayor rigidez de las infraestructuras basadas en voz.

A fin de resolver esta preocupación, es claro que se requiere migrar hacia una arquitectura proactiva, ultra-escalable y de alta capacidad. Los Operadores necesitarán tales soluciones en un mercado competitivo, donde la capacidad por demanda, la diferenciación de servicios (por QoS y SLA ópticos superiores), los costos y los intervalos de provisionamiento sean las ventajas competitivas. De un comienzo, es además evidente que una arquitectura basada en DWDM es la más efectiva en costos (esto significa que se obtiene escalabilidad en el ancho de banda), capacidad de ofrecer flexibilidad, gestionabilidad y facilidades multi-servicio para las MON. Varios Operadores Metropolitanos ya han desplegado tecnología DWDM, y para el resto, ésta no es una pregunta de sí él lo hizo, pero cuándo, para seguirlo. Sin embargo, la naturaleza inherente de las redes DWDM (llamados circuitos conmutados o gran granularidad) presenta además un gran dilema: discontinuidades con el amplio espectro de protocolos de la red de acceso (llamados paquetes conmutados o pequeño ancho de banda). Por ejemplo, simplemente adicionar capacidad DWDM a la actual infraestructura basada en SONET/SDH no será suficiente debido a la preocupación de la escalabilidad electrónica para grandes cantidades de canales (entre otros). Colectivamente, estos problemas han sido comúnmente llamados "discontinuidades metro".

De lo anterior se desprende que las MON presentan muchos retos de ingeniería, especialmente a luz de la gran base existente redes heredadas SONET/SDH, infraestructura predominante en las actuales redes metropolitanas. Como hoy en día el mercado metropolitano está siendo conducido por la necesidad modernizar la eficiencia de la red (haciéndola simple) bajo los patrones de rápido crecimiento de la demanda de capacidad y el incremento de tráfico variable, entonces hay un fuerte deseo de migrar desde la actual arquitectura de red basada en SONET/SDH a una más proactiva (dinámica e inteligente) red óptica multi-servicios. Esto permite a los Operadores evitar la realización de upgrades o desplegar más fibra (lo cual significa tiempo, costos y resulta jurídicamente retador).

Por todas estas razones, resulta económicamente efectivo migrar hacia una red de prueba que nos sirva de transición a las futuras MON. Esto hace en su conjunto que el mercado de las MON presente muchos nuevos y excitantes retos y oportunidades tanto para los proveedores de equipos como para los Operadores. En particular, los proveedores que han desarrollado oportunamente soluciones efectivas para soportar un amplio rango de servicios pueden esperar capitalizar ingresos en un inmenso mercado de Operadores. Esto da nacimiento a una nueva definición de MON llamadas Redes Ópticas Metropolitanas Proactivas (*Proactive Metro Optical Network*: PMON), basadas en la provisión de soluciones para aplicaciones metropolitanas contrariamente a las soluciones que están basadas en la distancia.

Como parte de la transición a redes ópticas, los diseñadores deben abstenerse de emplear conmutadores O-E-O y por el contrario reemplazarlas por sus contrapartes ópticas. Afortunadamente, la industria de conmutadores ópticos ha producido recientemente nuevas e innovadoras tecnologías para la construcción de cross-conectores ópticos (OXCs), multiplexores ópticos add/drop (OADMs) y conmutadores de protección, permitiendo de esta manera a los arquitectos de redes elegir el producto correcto para su aplicación.

El tamaño de la matriz de conmutación es clave para seleccionar un conmutador óptico. Los diseñadores deberían hacer coincidir el tamaño de la matriz de conmutación con las necesidades de su aplicación para obtener resultados óptimos. Empleando conmutadores del tamaño incorrecto se incrementa el costo total del sistema, originando una performance no óptima. Como referencia, la mayoría de redes metropolitanas actuales requieren conmutadores de 6×6 y 8×8. Futuras redes requerirán conmutadores de 16×16 y 32×32.

Otro factor importante a considerar es la pérdida de potencia óptica. Los dispositivos ópticos se caracterizan por su inherente pérdida, la cual puede atribuirse a cambios en el material a través del cual viaja la luz, imperfecciones geométricas internas del material, y muchas mas razones. Con la pérdida, la calidad de la señal se deteriora y los amplificadores ópticos, así como los regeneradores son necesarios para mantener la calidad de la señal.

Estos dispositivos, sin embargo, incrementan el costo, la complejidad y la probabilidad de falla de la red. Los diseñadores deberían optar por dispositivos que presentan la mínima pérdida total e insensibilidad a variaciones externas. La calidad de la señal es además afectada por “crosstalk” en conexiones vecinas. Valores de “crosstalk” de 40 dB o menores son considerados ideales.

La confiabilidad es siempre una alta prioridad de la red, con algunos Operadores prometiendo un 99,999% de servicio no-interrumpido. Los requerimientos de alta disponibilidad y mínimo tiempo de fuera de servicio de la red, imponen muy estrictos requerimientos en confiabilidad del conmutador. Los conmutadores PLC (Planar Ligth-wave Circuit), los cuales no usan ningún movimiento de partes o transición de estado químico, son considerados como los más confiables. Para minimizar el tiempo de fuera de servicio de red durante la re-configuración del sistema, deben empelarse estrictamente conmutadores de no-bloqueo. Estos conmutadores no re-enrutan las rutas existentes para establecer nuevas conexiones, eliminando de esta manera cualquier interrupción del tráfico debida a la configuración del sistema.

El uso de conmutadores ópticos inteligentes pueden simplificar y hacer mucho más veloz la gestión de la red. Software inteligente puede realizar tareas tales como insertar y extraer clientes a y desde la red, re-configuración de la red, monitoreo del estado de la red por actuales o inminentes fallas, y ajuste de la intensidad de la luz en la red.

Las señales ópticas, en los amplificadores "entering", deben ser ecualizadas para prevenir distorsiones de la señal. Consecuentemente, las salidas del conmutador son normalmente ecualizadas por el uso de atenuadores ópticos variables (VOAs: Variable Optical Attenuators). La necesidad de estos dispositivos externos incrementa el costo, la pérdida total, el espacio, y el consumo de potencia del sistema. La necesidad de VOAs reduce además la confiabilidad del sistema. Los conmutadores que soportan internamente atenuación y ecualización dinámica de la señal ofrecen grandes ahorros de costo.

1.4 Principales requerimientos de la Arquitectura de una MON

Los Operadores Metropolitanos están ya demandando soluciones proactivas que ofrezcan ventajas competitivas sostenibles tanto al corto como al largo plazo. Estos requerimientos por plataformas ultra-escalables, multi-servicios, transparentes y flexibles, deben ser lo suficientemente robustas para alcanzar continuamente las necesidades del desarrollo del mercado, esto es "a prueba del paso del tiempo" Una representación genérica de tal arquitectura de MON se presenta en la Figura 11, donde se muestran una plataforma MON de prueba y las configuraciones de los clientes. Más allá que definir y entender la solución, es importante identificar los principales requerimientos de las MONs basadas en algunas de las características de mercado mencionadas anteriormente.

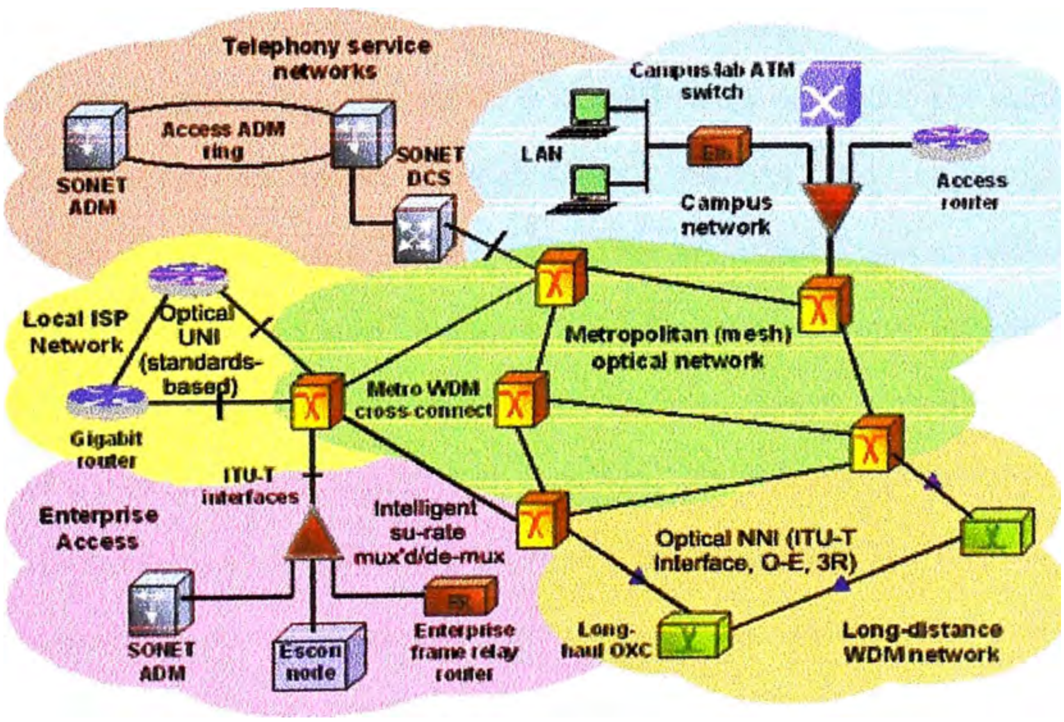


Figura 11 Visión general de una Arquitectura Malla de Red Óptica Metropolitana (MON)

A fin de poder realizar el diseño de una MON o de una red de prueba alternativa que sea útil para la transición hacia las MON, es necesario tener claramente definidos los requerimientos fundamentales de ésta. A continuación se describen con cierto detalle los principales requerimientos de la arquitectura de una MON.

1.4.1 Soporte Multi-Protocolo

Las MON están caracterizadas por un múltiple rango de protocolos y la capacidad de manejar tales o una mezcla de ellos desde una simple plataforma es el principal factor para ventajas competitivas sostenibles. La alternativa de desplegar y mantener múltiples, distintas infraestructuras y protocolos metropolitanas, claramente es una proposición no realista para Operadores que necesitan proveer servicios rápidamente bajo crecientes e impredecibles demandas por parte de los clientes. Este es un modelo prohibido por factores tales como costos de implementación y mantenimiento junto con prolongadas preocupaciones por derechos de paso (para expansión usando fibra). Por tanto, soporte multi-protocolo y multi-servicio sobre una simple, plataforma común e infraestructura de fibra es ideal en MON. Por otra parte, redes con capacidad multi-protocolo permitirán a los Operadores apalancar la fibra existente en sus infraestructuras. Hay muchas ventajas en este modelo: compatibilidad hacia atrás (ejemplo, SONET/SDH-over-WDM); significante reducción de costos (eliminando capas y equipos); simplificación de la gestión de la red; y reducción de los temas de co-ubicación. El soporte multi-protocolo es la piedra angular de las MON porque esta mano da los Operadores una ventaja que claramente los diferencia de sus competidores.

1.4.2 Transparencia Óptica

Estrechamente unido al punto de soportar múltiples protocolos está la transparencia del formato de la señal (a pesar de estar en la capa física). La transparencia óptica ha sido por mucho tiempo perseguido como una fuerte ventaja de cualquier tipo de red con tecnología DWDM, sea ésta de Larga Distancia, Metropolitana, o de Acceso. Dada la diversa mezcla de formatos de señalización de los datos en el lado de Acceso, esta capacidad es crucial en el aislamiento del Operador desde la constante evolución de nuevos estándares de formatos de datos. Los beneficios de la transparencia óptica permiten a los Operadores direccionar muchos temas y traducirlos en ventajas competitivas. Esto reduce la latencia de los canales y no requiere transceivers caros (para conversión E-O), ofreciendo mejoras significativas de escalabilidad y reducción de costos Adicionalmente, la transparencia óptica puede redituar grandes ahorros de costos dado que elimina la necesidad de efectuar por separado el mantenimiento del mezclado electrónico de sub-rates y el de los elementos de red multiplexores de tributarios. Como las distancias en las redes metropolitanas son mucho más cortas que en las redes de Larga Distancia, la transparencia del formato será menos susceptible a averías severas, haciendo por consecuencia mucho más viable su implementación. Considerando esta importante distinción, los Operadores Metropolitanos probablemente empezarán a demandar soluciones de red transparentes. La transparencia óptica no es simplemente un requerimiento de las MON, sino que es claramente uno de los factores que las hará simples y eficientes.

1.4.3 Escalabilidad en Malla

Actuales variaciones en el tráfico de datos de las redes metropolitanas están confirmando ser muy difíciles de verificar, en primer lugar debido al cambio de las aplicaciones y requerimientos de los clientes. La demanda continua llegando antes de las estimaciones y las dispersiones geográficas están incrementando. Esto incita a los Operadores a mirar hacia soluciones que les permitan implementar o extender sus servicios, y hasta la topología de sus infraestructuras, basándose en la demanda de tráfico y el rápido cambio demográfico de los clientes, tal como las variaciones del tiempo en el día. Como resultado, la flexibilidad topológica es un requerimiento. Dado esto, cualquier tipo de restricción topológica puede ser innecesaria restrictivo y posiblemente hasta inaceptable. Las actuales topologías de redes metropolitanas son ampliamente basadas en anillos, por ejemplo, SONET/SDH. Aún mas, algunos proveedores han propuesto extender tales paradigmas a anillos ópticos basados en DWDM usando multiplexores ópticos (*Optical Add-Drop Multiplexer*: O-ADM). Los nodos O-ADM selectivamente proveen, toman, o pasan longitudes de onda y pueden realizar una rápida protección por conmutación (en caso de falla de fibras). Sin embargo, los anillos O-ADM son más una evolución o una ruta de migración desde la actual generación tecnológica y puede presentar en el futuro algunas significantes limitaciones. En general, estos esquemas requieren un cuidadoso pre-planeamiento de red y no son flexibles para demandas geográficas dispersas e impredecibles. Aunque se han propuesto conceptos de multi-anillos o híbridos para cubrir topologías más generales, estas soluciones son verdaderamente escalables. Múltiples-anillos no comparten bien la capacidad de protección y son muy complicados desde el punto de vista de provisionamiento. Por otra parte, este concepto coloca cierta complejidad en los nodos O-ADM que están en múltiples anillos. Dados los extenuantes requerimientos de la arquitectura de las MON, es claramente necesario escoger un esqueleto topológico independiente, denominado estrategia de provisionamiento basada en mallas.

Hay un crecimiento interesante y enfocado en el valor de las redes en malla DWDM, tanto por parte de los Operadores como de los proveedores, basado en el poder del paradigma del ruteo y conmutación de longitudes de onda. Los elementos de red resultantes: Cross-Conector Óptico (Optical Cross-Connect: OXC) o Router-Conmutador Óptico (Wavelength Router-Switch: WRS) son más flexibles y pueden abarcar tanto funcionalidades punto-a-punto y anillos add-drop. El ruteo en una capa óptica en malla provee un despliegue más elegante con estrategias de ruteo homólogas para protocolos de capa 2 y 3 tales como IP y ATM. Es un hecho que el provisionamiento de la conexión en malla es más eficiente en recursos comparado a ruteos restrictivos basados en anillos. Las topologías en malla ofrecen tremendo valor al Operador. Los Operadores requieren un pequeño pre-planeamiento, lo cual les permitirá que sus infraestructuras de red crezcan progresivamente tanto como su demanda de negocios, esto es la capacidad de "paga tanto como crezcas". Esto permite a los Operadores reducir los gastos por despliegue y operación de servicios. Más importante, nodos genéricos OXC pueden además implementar anillos y esquemas punto-a-punto. El provisionamiento en malla es no sólo una visión para las redes del futuro, sino es además una ventaja crucial dado que permitirá una suave ruta de migración de las actuales infraestructuras hacia una red futura de prueba. Por ejemplo, nodos genéricos OXC pueden ser desplegados en existentes topologías de anillo para realizar operaciones de add-drop. En consecuencia, la reconfiguración local "in-service" del nodo OXC puede ser efectuada a fin de facilitar la migración hacia arquitecturas multi-anillos (hubbed) o mallas verdaderas (**Tabla 2** resume la comparación entre estas principales alternativas de arquitectura metropolitana).

Tabla 2 Comparación de soluciones MON

Requirement	SONET	Reconfigurable Optical Ring	Reconfigurable Optical Mesh
Protection Time	Fast	Fast	Fast
Provisioning Time	Slow	Fast	Fast
Topological Flexibility	Low	Low	High
Demand Scalability	Low	Low	High
Resource Efficiency	Low	Average	High
Transparency	No	Yes	Yes
Pricing/Cost	Low	Medium	Medium

1.4.4 Provisionamiento rápido e inteligente

Los intervalos de provisionamiento en actuales redes SONET/SDH basadas en voz están medidos en varias semanas e involucran una compleja planificación de red y actividades de roll-out. Por otra parte, las rígidas topologías de tales redes no permiten flexibles definiciones de servicio para una diversa base de clientes. En contraste, las MON de próxima generación tienen que proveer mucho más proactividad y soluciones "data-aware" para el competitivo mercado metropolitano. Estas soluciones proactivas basadas en software deben ser capaces de provisionar rápidamente ancho de banda automatizado "just-in-time" para alcanzar los siempre decrecientes intervalos de provisionamiento requeridos.

En una arquitectura en malla DWDM, los enlaces longitud de onda y las asociadas capacidades de procesamiento nodal (conmutación, conversión de facilidades a longitud de onda) son los principales recursos a ser administrados. A fin de maximizar la utilización de recursos (y por tanto los ingresos del Operador), se requieren esquemas inteligentes de provisionamiento de canales de longitud de onda. A pesar del incremento de las dimensiones de la red y otros temas computacionales, estos algoritmos de software deben permanecer produciendo una muy rápida configuración de conexiones. Tal provisionamiento "por-demanda" establece identificación de dirección de punto final automatizada, rápida computación de ruta, y baja latencia de configuración. Adicionalmente, para proveer definiciones de servicio más generalizadas y de mayor alcance, deben ser implementados diferentes niveles de QoS (*Quality of Service*) ópticas. Por ejemplo, el nivel de QoS en una conexión óptica puede reflejar su retardo, prioridad, protección, y características de calidad del canal, etc.

El continuo crecimiento del tráfico Internet requiere adicionales consideraciones. Los perfiles de tráfico metropolitanos serán considerablemente más dinámicos que los perfiles de Larga Distancia, debido a la proximidad del cliente y las características del explosivo tráfico IP. Con este escenario, obviamente es más factible reutilizar protocolos de control inteligente basados en IP dentro del espacio óptico. En particular, la próxima generación de protocolos de ingeniería de tráfico IP, tales como MPLS (*multi-protocol label switching*), están ya siendo diseñados para acomodar similares requerimientos en redes de datos; por consiguiente, extender tales paradigmas a las dinámicas arenas de las MON es paso un lógico y oportuno. Varias entidades de estandarización están ya enfocadas en este tema y han surgido propuestas detalladas, la más notable MPLS (*Multi-Protocol Lambda Switching*). Un framework "data-aware" permitirá abarcar tanto el ruteo de conexiones como las actividades de protección bajo la ingeniería de tráfico IP y proveerá una óptima integración de capas IP-WDM. Específicamente, interfaces ópticas de corto alcance en routers IP Terabit se pueden conectar directamente con cross-connects DWDM, permitiendo protocolos de ingeniería de tráfico de capas altas para solicitar/soltar ancho de banda de una manera automatizada. Estas interfaces han sido además denominadas UNI's ópticas (*User Network Interfaces*) (Ver Figura 4) y permitirán a los Operadores Metropolitanos grandes mejoras en la velocidad de respuesta de sus servicios basados en IP. Cortos intervalos de provisionamiento han sido grandes metas de muchos Operadores y su realización dará a cualquier Operador una ventaja competitiva que se traducirá en un incremento en su base de clientes (participación de mercado), incremento de ingresos, y en conjunto satisfacción al cliente.

1.4.5 Múltiples Opciones de Sobrevivencia

Dada la amplia diversidad de protocolos de servicio para usuarios finales, los Operadores Metropolitanos están encontrando que múltiples definiciones de sobrevivencia son necesarias para proveer una mejor definición de servicio a todos sus clientes. Por ejemplo, cliente Acuerdo de Nivel de Servicio (SLA's) para tráfico misión-crítica tal como voz en tiempo real, transacciones financieras especificarán tiempos de recuperación en el rango de los 10 milisegundos. (Nota: Es seguro asumir que el tiempo de recuperación de SONET/SDH es por defecto el tomado por benchmark contra el medido por el esquema óptico de recuperación, normalmente 50 ms.). Inversamente, es bien conocido que una desproporcionadamente gran parte del tráfico Internet es relativamente insensible al retardo, tal como e-mail, fax, telnet, ftp, web caching, etc. Muchos de estos clientes estarán contentos con ofertas de servicios de bajo costo con tiempos de recuperación mayores o posiblemente hasta con bajas probabilidades de recuperación. En resumen, algunos SLA's para tráfico de baja prioridad "best-effort" puede no especificar ningún servicio de recuperación. Adicionalmente, varios protocolos cliente ya proveen varias capacidades de recuperación (Por ejemplo, SONET/SDH protección por conmutación, IP re-enrutamiento) y esto debe tomarse en cuenta. Específicamente, los Operadores deben tener la libertad de contratar selectivamente los esquemas ópticos de recuperación, a fin de prevenir cualquier posible interferencia destructiva (ineficiente) entre múltiples mecanismos recuperadores de protocolos. Esta característica permitirá la coexistencia de los esquemas de protección tanto de la capa SONET/SDH como de la capa DWDM, vitales para una suave migración desde las actuales redes. En general, dado que la protección por conmutación basada en SONET/SDH requiere recursos de fibra completamente redundantes y básicamente ofrece un simple nivel de protección, la redundancia avanzada en malla es lo más calificado para soportar el grado de protección deseado por los Operadores Metropolitanos.

Los esquemas de restauración en malla pueden ser clasificados en dos formas, *protección* y *restauración*. La primera se refiere a una recuperación pre-provisionada mientras la última se refiere una recuperación dinámica de la señal (Por ejemplo: activo, post-falla). En particular, la protección en malla pre-específica la ruta de protección (sub-ruta) en la configuración de conexiones y al detectar la falla, realiza la conmutación de la señal. Por lo tanto, la protección en malla es capaz de alcanzar tiempos de recuperación de SONET/SDH, dada la conveniente detección de fallas, y de modo diferente la protección basada en anillo puede además recuperar desde múltiples fallas de fibras y nodos. Además, pueden definirse diferentes conceptos de la protección en malla para diseñar un rango de definiciones de servicio para varios accesos de clientes. Por ejemplo, servicios caros misión-crítica con requerimiento de backup garantizado pueden tener recursos dedicados (rutas) asignados. Mientras, para servicios menos críticos (menor-costo), las longitudes de onda compartidas pueden estar siendo empleadas entre múltiple conexiones para mejorar la eficiencia de la red y derivar ingresos adicionales. Estos dos casos son ilustrados más claramente en la Figura 12. En conjunto, la naturaleza genérica de la protección en malla ofrece significativas ventajas a los Operadores, y esquemas de protección MPLS han sido recientemente puestos sobre la mesa. En resumen, con un diseño genérico completo OXC, varios esquemas de protección por conmutación punto-a-punto y basados en anillos (nodos O-ADM) pueden además ser implementados. Tales mejoras en la sobrevivencia del servicio permiten a los Operadores establecer nuevas definiciones y elevar el nivel de satisfacción de los clientes como una ventaja sostenible.

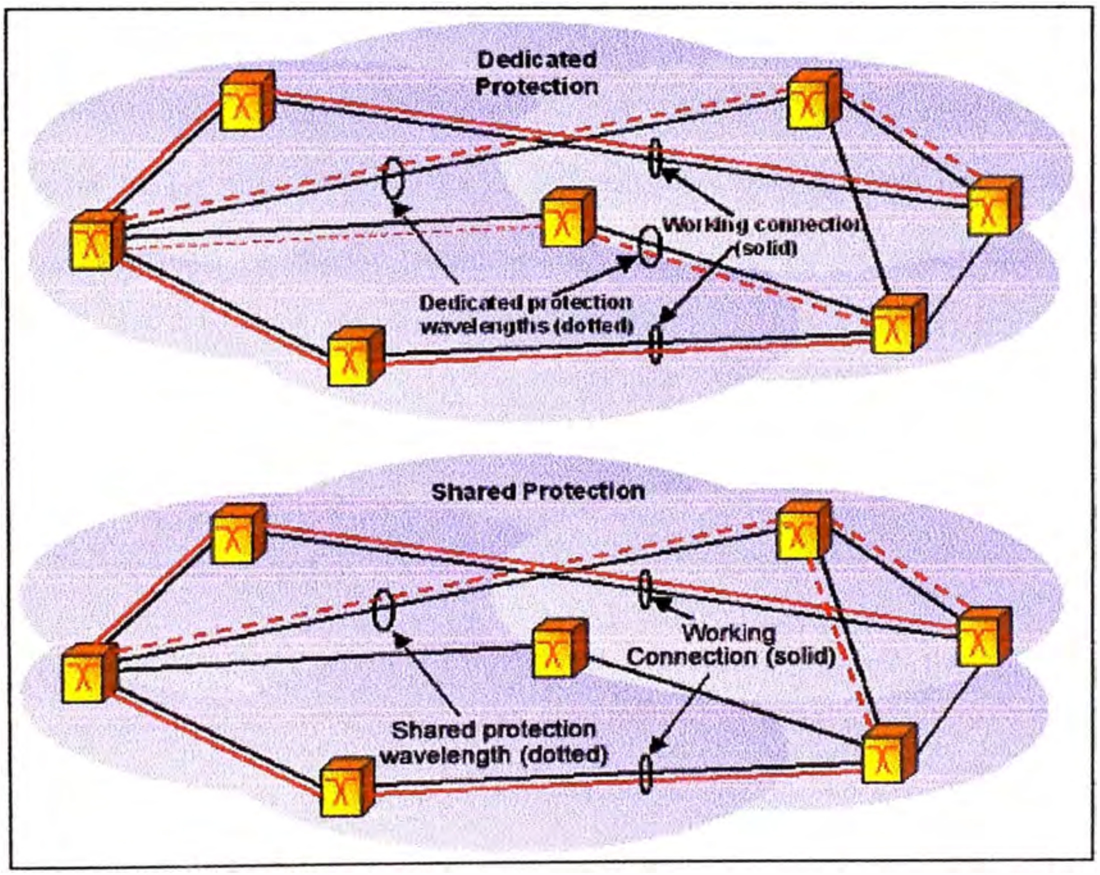


Figura 12 Esquema de protección dedicada y compartida para redes ópticas en malla

1.4.6 Gestión de Red

La gestión de red se está convirtiendo en una tema cada vez más importante (y complejo) para redes multi-protocolo. A pesar del amplio rango de protocolos y servicios soportados, los administradores de red demandarán soluciones de gestión independientes bit-rate, basadas en estándares que permitan configuración integrada, monitoreo de performance, localización de fallas, y arreglo de cuentas, por ejemplo, actividades de OA&M (Operations, Administration, and Management). Debido al incremento de las dimensiones y complejidades de las MONs, se requiere de una interface gráfica de usuario (*graphical user interfaces*: GUI) que sea amigable, proporcionando a los administradores de red una detallada visión de los equipos y de la red. En resumen, es seguro decir que (para la mayoría de operadores) la calidad de la solución de gestión de red y su capacidad de ofrecer gestión unificada puede efectivamente ser el factor primario al momento de escoger que sistema implementar.

1.4.7 Provisionamiento de Ancho de Banda de Fraccionales

Aunque hay un incremento en la demanda de ancho de banda high-end (2.5 a 10 Gbps), las MONs tienen además que satisfacer a los clientes que siguen requiriendo solo canales con capacidades fraccionales (OC-3, OC-12, 200 Mbps ESCON). Esto plantea una "brecha en la granularidad" de ancho de banda entre los dominios óptico y eléctrico. Claramente, asignar un canal de longitud de onda completa para cada señal de baja velocidad no es una solución efectiva en costos para los Operadores dado que esto no hace eficiente el uso de los escasos recursos de longitud de onda. Dada la mixtura de protocolos y el número de clientes transportados en una típica MON, esta estrategia "protocolo-por-longitud de onda" conducirá rápidamente a un problema de agotamiento de longitudes de onda y es, por tanto, no escalable. Más bien, es mucho más eficiente y efectivo en costo provisionar modularmente los canales fraccionales (sub-rates) y agregarlos (multiplexarlos) en una longitud de onda simple y de alta capacidad. Esta técnica ha sido denominada multiplexación de fraccionales (*sub-rate multiplexing)*. La estrategia "múltiple-protocolo-por-longitud de onda" es ilustrada en la Figura 13, donde tanto los protocolos de datos y como los haces de circuitos (por ejemplo, TDM) son agregados en el mismo canal de longitud de onda en el lado de admisión. (Nota: es necesario el complementario de-multiplexador de protocolos al lado de salida). El multiplexado de fraccionales permitirá a los Operadores Metropolitanos de próxima generación extender su filosofía "paga tanto como crezcas " a una base más amplia de clientes, incrementando consecuentemente sus ingresos. Esto además permitirá a los Operadores maximizar la utilización de su ancho de banda y reducir significativamente los costos (a través de la eliminación de capas y equipos). Los ahorros pueden ser pasados a los clientes (mediante menores precios) ofreciendo a los Operadores una clara ventaja competitiva.

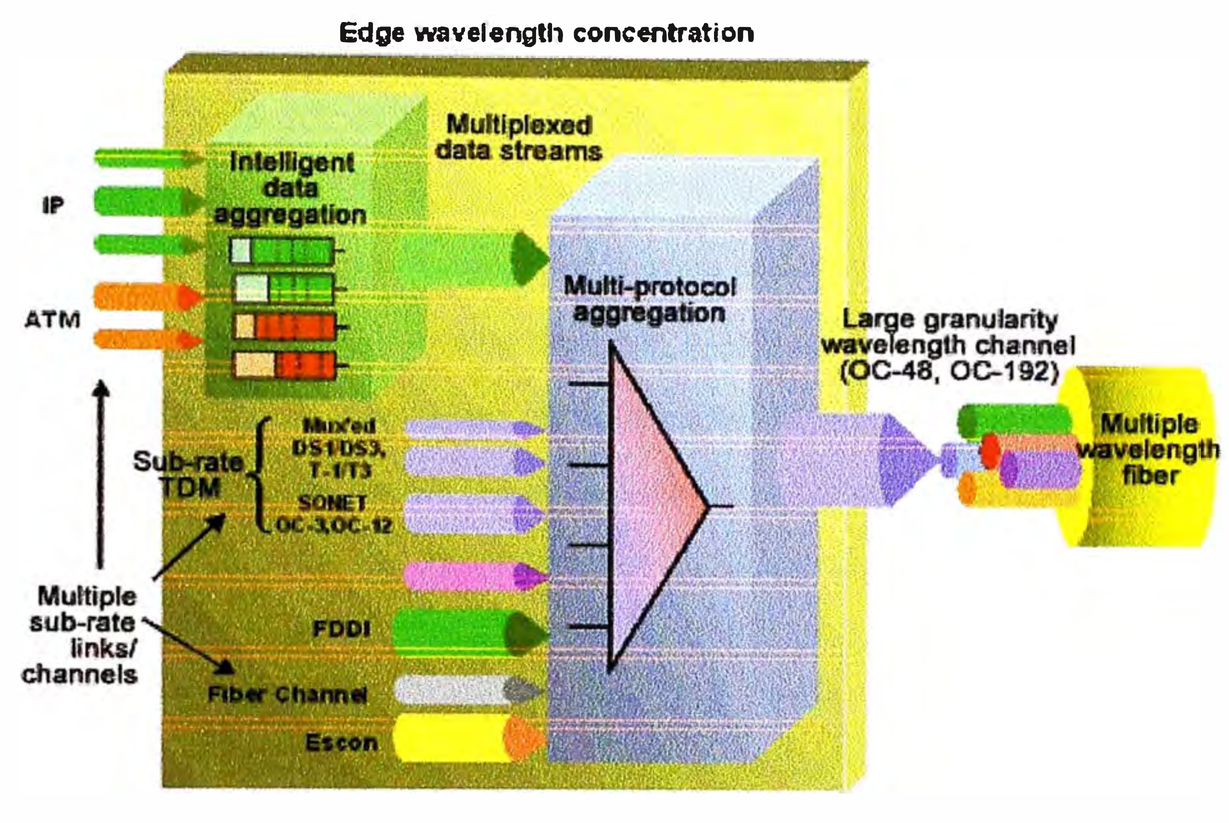


Figura 13 Multiplexación de servicios sub-longitud de onda para una eficiente utilización de las longitudes de onda

1.4.8 Costo

El costo es un factor importante para los Operadores quienes están considerando implementar soluciones DWDM en áreas metropolitanas. Los Operadores esperan que el costo del sistema sea significativamente menor a aquel para redes DWDM de Larga Distancia. Además, dado que los Operadores ya han invertido fuertemente en infraestructuras SONET/SDH y el hecho que esta tecnología ha alcanzado economías de escala, el costo se convierte incluso en el factor más importante. Por consiguiente, a fin de capturar y propulsar el mercado metropolitano, los proveedores deben ofrecer niveles de precio con alternativas competitivas y convincentes, por ejemplo, soluciones "low-first cost". Específicamente, los proveedores deben proporcionar servicios y performance mejorados a casi el mismo o menor nivel de costo, a fin de lograr una fuerte aceptación en el mercado. Sin embargo, mayores costos iniciales de equipamiento (e implementación) pueden ser aceptables, pero solo si los proveedores pueden asegurar que los precios están adecuadamente justificados por beneficios significantes, por ejemplo, costos operacionales reducidos, más pequeños footprints, mejores tiempo de respuesta, suave migración, y redes "futura de prueba". Pueden obtenerse verdaderos beneficios y economías de escala en las MONs ofreciendo una solución end-to-end y los proveedores que ofrezcan tales como una solución completa ganarán el liderazgo en el mercado.

1.4.9 Confiabilidad y Modularidad

Un corte en algún nodo de la MON (o sub-sistema) puede potencialmente desestabilizar muchos más clientes debido al intenso nivel de multiplexación de servicios que esté siendo efectuado en las fibras (y probablemente además longitudes de onda) Por consiguiente, los elementos de red de una MON deben ofrecer un alto grado de confiabilidad. Esto establece que los sub-sistemas críticos sean completamente redundantes y capaces de soportar upgrades "in-service". Adicionalmente, los Operadores Metropolitanos son competentes e intensamente experimentados en espacios de planta, y por lo tanto en diseños modulares capaces de soportar upgrades con suficientes y compactos "footprints".

1.4.10 Recomendaciones

La llegada de la era de las redes ópticas esta prometiendo mejorar la eficiencia de las redes, permitiendo a los Operadores entregar a un costo efectivo un amplio rango de servicios a sus clientes. Los Operadores además serán capaces de ofrecer inteligencia óptica, Calidad de Servicio (QoS) garantizada y Acuerdos de Nivel de Servicio (SLA's) para soportar estos servicios. A fin de que los Operadores puedan ofrecer soluciones totalmente ópticas extremo a extremo (end-to-end) es ideal que implemente tecnología óptica en el espacio metropolitano. Implementando MON, los Operadores serán capaces de ofrecer a sus clientes finales los verdaderos beneficios de la evolución óptica. En particular, estas soluciones ofrecerán soporte dinámico y multi-protocolo basado en estándares con provisionamiento eficiente, supervivencia, y capacidad integrada de gestión de red. A fin de implementar exitosamente este modelo, los Operadores deben considerar todos los principales requerimientos de las MON y asegurar su adherencia. Adoptando este modelo de MON, los Operadores serán capaces de implementar una futura red de prueba que les ofrecerá ventajas competitivas sostenibles a largo plazo.

Tabla 3 Resumen de requerimientos de las MON

Requirement	Summary
Multi-Protocol Support	Diverse protocols/link rates, backwards compatibility
Optical Transparency	Multiple signal formats, reduced O-E costs
Mesh Scalability	Flexible, improved efficiency, "pay-as-you-grow"
Fast Intelligent Provisioning	Rapid connection setup, resource efficient, IP- based
Multiple Survivability Options	Flexible, mesh-based dedicated/shared protection
Network Management	Integrated, standards-based, GUI-driven
Sub-Rate Provisioning	Bandwidth efficient, cost-effective, increased customer base
Pricing/Cost	Competitive pricing, low entry costs, reduced operations costs
Reliability and Modularity	Redundant sub-systems, modular, compact footprints

1.5 Modelo propuesto para futuras Redes Ópticas Metropolitanas

Este parte del capítulo describe una propuesta para la arquitectura de redes ópticas metropolitanas, empleando una flexible estrategia de bloques. Esta arquitectura proporciona una significativa flexibilidad en la administración de la complejidad de las redes ópticas metropolitanas, al mismo tiempo que reduce el riesgo tecnológico en la transición de servicios orientados a circuitos hacia una emergente arquitectura centrada en datos no orientados a la conexión.

1.5.1 Modelo

Ethernet puede ser una extensión completa de las Redes de Área Local (LAN) dentro de las Redes de Área Amplia (WAN). Dado que este es un protocolo nativo de los servicios de datos para Internet, Ethernet puede proporcionar ahorros significativos en el costo por puerto y el costo de instalación, frente a los tradicionales servicios de líneas privadas.

Tabla 4 Métricas de costo para servicios IP sobre varios protocolos Metro

Categories	IP/ATM/SONET	IP/SONET	IP/Ethernet
Electronics	$8K-$40K	$6K-$35K	$2K-$6K
Labor	45K*	$5K	$2K

Fuente: IDC

La Tabla 3 (información citada por el CEO de una LEC Ethernet) muestra que usando como base el costo por Mbps para IP/Ethernet, el costo para IP/ATM/SONET es cuatro veces esta base, mientras que el costo para IP/SONET es tres veces el costo base. Otro dato interesante es que los ahorros son además extendidos a los costos de instalación, por ejemplo el costo para IP/SONET es 2,5 veces el costo para IP/Ethernet.

Este nuevo modelo de costos puede hacer que los Operadores se centren en Ethernet para ofrecer un modelo de precios para ancho de banda tales como servicios de 100 Mbps al 80% del precio de un servicio de línea privada DS-3 (45 Mbps), lo cual representa un ahorro de 64%. Adicionalmente, la naturaleza dinámica de las redes Ethernet permitirían brindar físicamente un tubo de 100 Mbps o 1 Gbps hasta el local del cliente y provisionar un ancho de banda de 1 Mbps.

Mientras los valores económicos de Ethernet parecen imponerse, el punto crítico es como los Acuerdos de Nivel de Servicio (SLA) y la Calidad del Servicio (QoS) pueden ser implementados por los Operadores. Esta ha sido una de las proposiciones claves detrás de ATM vs. Ethernet. La necesidad de implementar QoS en SLA estuvo basada en asumir una escasez de ancho de banda. Mientras que en el pasado esta premisa fue verdadera, hoy en día el ancho de banda se duplica cada nueve meses, duplicando la velocidad de la Ley de Moore para capacidad de los chips. Con precios por servicios de 2,5 Gbps y 10 Gbps cayendo rápidamente debido a los productos DWDM para redes metropolitanas, el costo por Mbps está también cayendo rápidamente para servicios sobre redes ópticas metropolitanas.

Por lo tanto, los significativos costos operacionales y la complejidad de implementar Calidad de Servicio (QoS) a los clientes pueden ser resueltos simplemente reconociendo que el ancho de banda no es más un recurso escaso. Mas allá de gastar significantes recursos para micro-administrar de ancho de banda, se sugiere apoyar el lanzamiento de ancho de banda, resolviendo así el problema de gestión. Más que Calidad de Servicio (QoS), se recomienda implementar Clases de Servicio (CoS) para la mayoría de aplicaciones. Con una significativa capacidad de ancho de banda, la ingeniería de la red reducirá la complejidad de implementar estrictos lineamientos de QoS. Además, cualquier costo de provisionamiento de ancho de banda adicional será mas que compensado por ahorros en los costos operacionales. Actualmente, con las apretadas condiciones del mercado en recursos de gestión de red, los ahorros en costos operacionales se convierten en un punto crítico frente a los costos incrementales de capital por ancho de banda.

Para lo anterior, se ha subrayado que una gran parte del trafico de las empresas en las redes metropolitanas están basadas en Ethernet, mientras que a la fecha el tradicional método de transporte del trafico dentro de la WAN han sido los servicios de líneas privadas tales como DS-1, DS-3 y OC-N. La migración a Ethernet basada en servicios WAN empieza a tener algunas ventajas significativas en costo y provisionamiento comparados con el actual modo de operación.

El reto para muchos Operadores es como migrar sus actuales redes basadas en TDM/ATM a un mundo dominado por paquetes, el cual viene siendo guiado por el crecimiento del Internet.

Claramente la mayoría de Operadores tienen invertido billones de dólares en productos ópticos SONET y SDH, conmutadores ATM y cross-connects (DCS) dentro de sus actuales redes. El desafío es como realizar una migración adecuada de la red actual a una red optimizada para el futuro.

La estrategia propuesta en este capítulo es implementar una red óptica metropolitana empleando una estrategia de bloques por capas, tal como se muestra en la Figura 14. Esta estrategia recomienda implementar una red metropolitana basada en bloques de longitudes de onda (λ: lambda), TDM/ATM e IP. Estas tres estructuras de bloque permitirán una arquitectura multiservicio, permitiendo una transición adecuada de las actuales redes orientadas a la conexión a las redes futuras basadas en paquetes y orientadas a la no conexión.

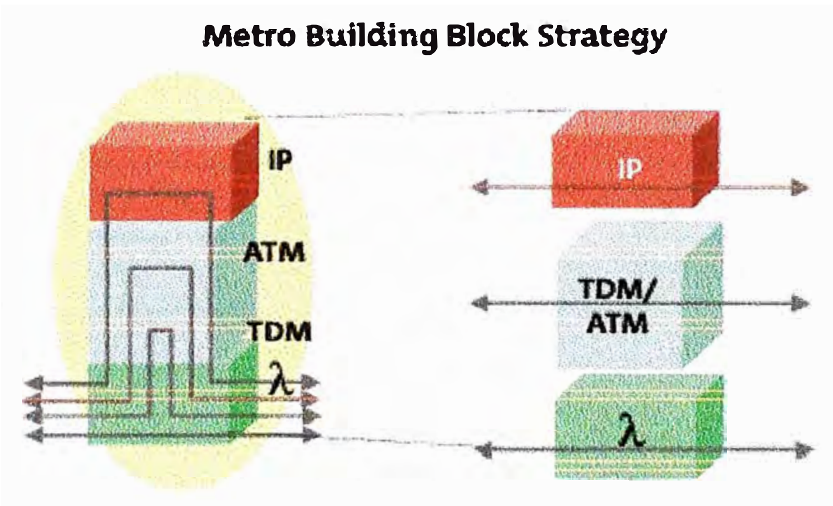


Figura 14 Arquitectura propuesta para Redes Ópticas Metropolitanas

Esta arquitectura para las redes ópticas metropolitanas permite a los Operadores proteger su inversión existente y al mismo tiempo minimiza el riesgo tecnológico al apostar por el futuro.

La Figura 15 intenta ilustrar esto de la siguiente manera: El mapa de matriz tecnológico: ciclo de introducción vs. tiempo de depreciación esperado (ciclo de vida tecnológico).

Los bloques tales como TDM han tomado un aceptable numero de anos para alcanzar su madurez (10 anos para SONET, 20-30 anos para DS-1, DS-3) y probablemente continuaran siendo ampliamente empleados debido a los billones de dólares en inversión existente y a su omnipresencia.

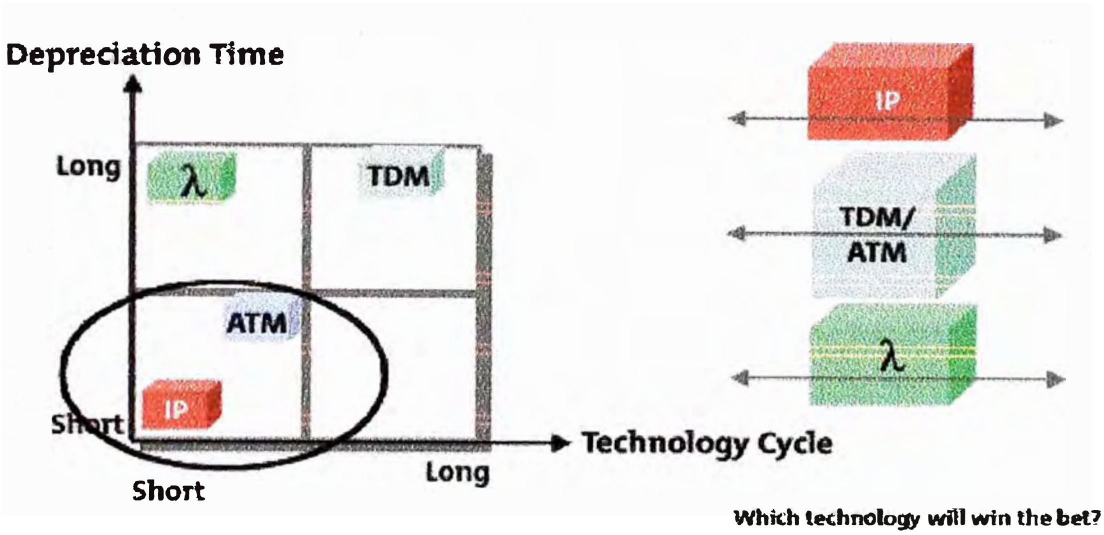


Figura 15 Valor de la Estrategia de Bloques

La tecnología DWDM tiene menos de 5 años de aplicación y tendrá probablemente un largo ciclo de depreciación debido al gran potencial de crecimiento de los servicios ópticos.

IP y ATM han sido además introducidas al mercado con relativa velocidad y aun ninguna ha dominado las redes metropolitanas. ATM ha sido ampliamente desplegado como backbone en redes multi-servicio, mientras IP continua dominando a las empresas y esta empezando a entrar en las WAN metropolitanas. Como en los debates religiosos, es probable que entre estos dos desarrollos uno penetre eventualmente en el panorama metropolitano. Como tal, ambos se encuentran en la esquina inferior izquierda ("short-short") de la matriz.

Las ilustraciones anteriores en las que la estrategia de bloques por capas permiten al Operador implementar su red basándose en la demanda de servicios aún puede adecuarse como bloques que se mueven dentro de la matriz. Como ejemplo, un Operador podría implementar una red empleando longitudes de onda y TDM como base, agregar bloques ATM o IP basados en las condiciones de mercado y la tecnología. Deberían cambiar las condiciones, los bloques superiores podrían ser migrados sin perturbar las capas base TDM y longitudes de onda.

Se examinará la aplicación de la estrategia por bloques en una arquitectura metropolitana.

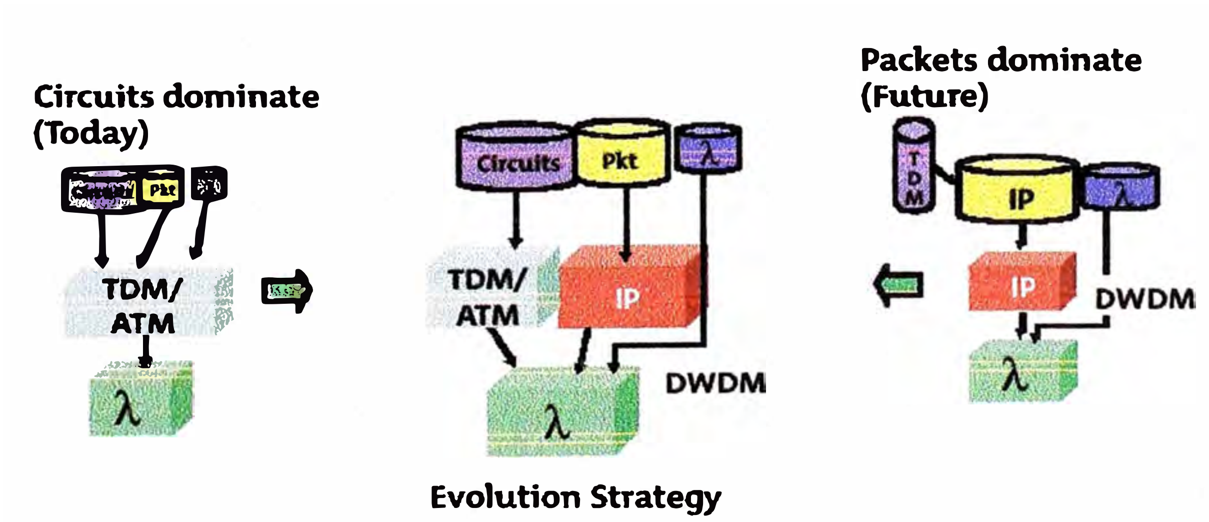


Figura 16 Arquitectura de Bloques para Modelos de Tráfico

En la Figura 16, el diagrama izquierdo muestra la típica y actual estructura del trafico, donde las líneas privadas orientadas a circuitos dominan el tráfico con algunos pequeños porcentajes de trafico IP nativo llevados desde los bordes de la red. Empleando una filosofía de la regla 80/20, esto es desarrollar una arquitectura de procesamiento de servicios para administrar un 80% del trafico del mismo tipo y adaptar el 20% del tráfico restante empleando usando la misma fabrica de procesamiento de servicios. En este caso, el tráfico de circuitos/TDM es el predominante y por consiguiente este resulta económico usando mapeo de servicios TDM (Ejm. STS) para el grueso del tráfico y mapear el tráfico de paquetes remanente dentro de cargas TDM (Ejm. Packet over SONET).

El bloque ATM podría ser substituido por el bloque TDM en el anterior ejemplo. ATM esta siendo ampliamente empleado como una arquitectura multiservicio en los backbone metropolitanos y continuara sirviendo como un medio de transporte para voz y líneas privadas sobre una infraestructura común.

En la Figura 16, se muestra el extremo opuesto. Este es el caso en el que la red tiene que migrarse a un mundo dominado por los paquetes y la arquitectura metropolitana debería estar basada en el procesamiento por paquetes dado que estos predominan en el tráfico. En esta etapa de la evolución de la red, el tráfico orientado a la conexión debería probablemente ser mapeado en paquetes y ruteado empleando técnicas tales como MPLS. Los servicios ópticos deberían probablemente omitir el mapeo en la capa IP y ser mapeados directamente en la capa de longitud de onda.

La realidad es que ningún extremo, circuitos o paquetes, son probablemente representativos de ninguna típica red metropolitana. Es probable que ocurra un periodo de transición en el cual ambos estén presentes en la red y los Operadores requieran una estrategia transitoria para acomodar ambas tecnologías.

La recomendación es que la arquitectura de la red óptica metropolitana emplee tanto TDM e IP en este periodo de transición mientras se pasa al empleo de bloques ópticos para gestionar servicios ópticos puros.

Para bosquejar la arquitectura de la red óptica metropolitana vamos a introducir los conceptos de "borde de la empresa" (enterprise edge), "borde metro" (metro edge) y "núcleo metro" (metro core).

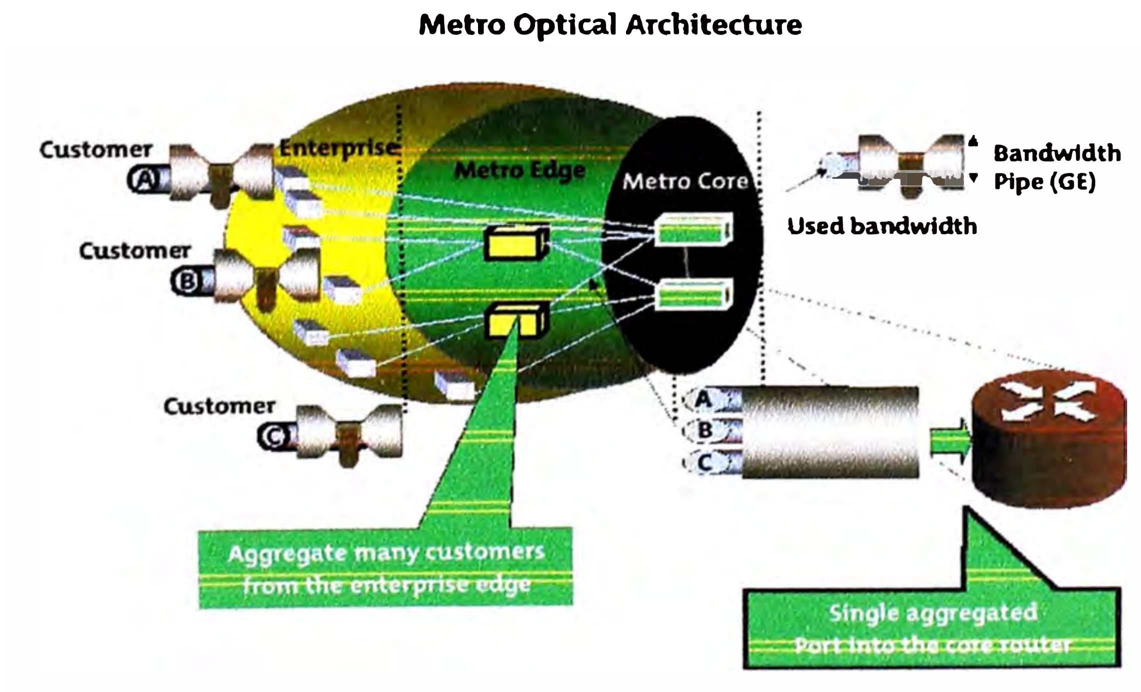


Figura 17 Valor de Acumulación en la Red Metropolitana

El reto del Operador es desplegar una significativa capacidad de ancho de banda hacia los locales de sus clientes empresariales, sin tener que dedicar toda la capacidad de ancho de banda desde el núcleo hacia los bordes ni tampoco desplegar puertos dedicados para cada cliente sobre la plataforma de procesamiento del servicio en el "núcleo metro" (Ejemplo: cross-connects TDM, conmutadores ATM o routers IP). Lo ultimo representa un costo significativo para el operador, tal como puertos en el router o en el conmutador que pueden costar 3 o 4 veces el puerto equivalente en plataformas ópticas.

El concepto de un nodo "borde metro" es aquel que se encuentra entre el nodo central y el "borde de la empresa". El rol de los nodos de borde es agregar numerosos tubos de ancho de banda desde el "borde de la empresa" y condensar estos en un simple tubo de mayor ancho de banda llenos de estos primeros. Este tubo reduce los requerimientos de ancho de banda desde el borde hacia el núcleo y reduce significativamente el número de puertos en la plataforma de servicios del núcleo.

En la Figura 17, tres clientes son atendidos con enlaces Gigabit Ethernet en el borde. Si cada cliente solo requiere 100 Mbps de datos por el momento, la estrategia anterior reduce los requerimientos de ancho de banda de 3 Gigabits a 300 Mbps y reduce el número de puertos de 3 a 1 en el router del núcleo.

Resumiendo, aplicando la estrategia de bloques para el borde metro es deseable una función de acumulación, la cual es multi-servicio, de costo efectivo y proporciona un pequeño espacio para las numerosas ubicaciones de los nodos de borde. Además esto podrá aplicarse a grandes espacios que sean arrendados para múltiples nodos. Como se mostró anteriormente todos los bloques de servicio necesitaran estar en la misma plataforma para alcanzar aquellas necesidades.

En el nodo central, la escalabilidad y la gestión centralizada del servicio es más crucial y en consecuencia se recomienda que los bloques de servicio específicos estén separados y distinguibles. Esto permitirá una mejor clase de soluciones a ser desplegadas para cada bloque.

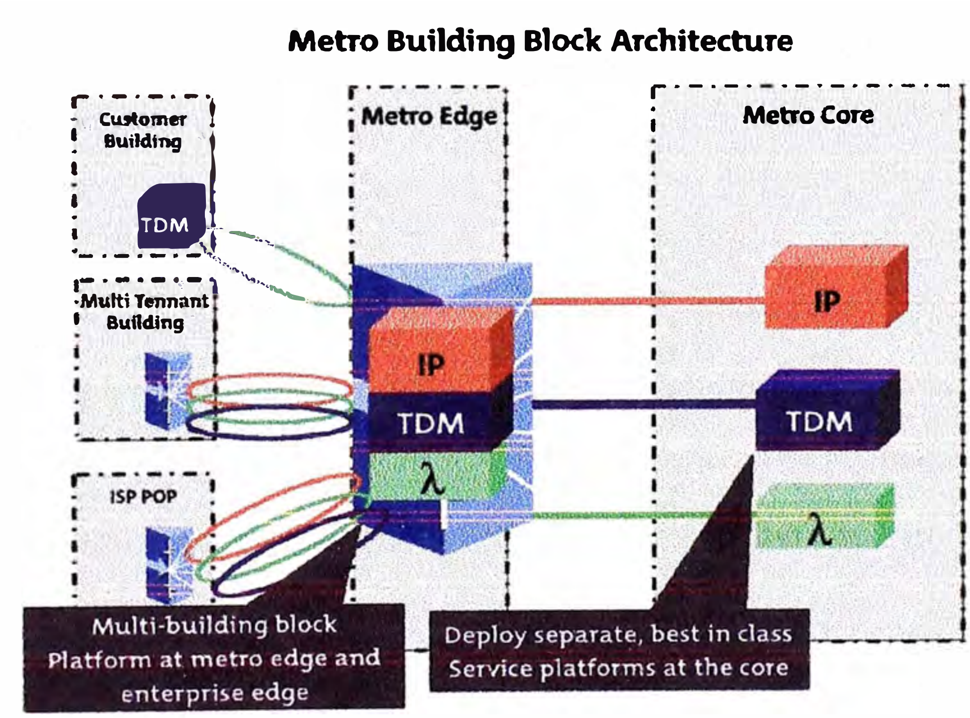


Figura 18 Arquitectura por capas de nodos centrales y nodos de borde en Redes Metropolitanas

Asumiendo que las locaciones de los bordes de las empresas y de la red metropolitana son soportadas con una simple plataforma que sostiene múltiples bloques, en tanto el núcleo es soportado por lo mejor en cales, bloques de servicio específicos, ¿cómo estos están enlazados?. Se recomienda que cada capa de la red sea gestionada en la capa de longitud de onda. En la Figura 18, los servicios basados en IP podrían ser mapeados en una capa de longitud de onda IP desde el borde de la empresa, a través de una plataforma multiservicio en el borde de la portadora y entonces sobre una capa IP agregada atrás de la oficina central. En la oficina central la longitud de onda IP seria dividida en una plataforma de servicio especifica IP.

1.5.2 Conclusiones

En conclusión, se han introducido una gran cantidad de conceptos a lo largo de este capítulo. Se han resaltado los puntos referidos a conectividad WAN en redes metropolitanas empleando líneas privadas TDM y las ventajas de extender LAN usando interfaces Ethernet nativas. Dado que las aplicaciones de Internet crecen para aplicaciones B2C (business to customer) y B2B (business to business), esta tendencia sólo se volverá más prevaleciente.

A fin de que los Operadores manejen esta transición, se propone una estrategia de bloques multiservicio para permitirles proteger sus actuales inversiones y al mismo tiempo reducir su riesgo sobre cual tecnología será tomada para manejar esta transición.

Finalmente se recomienda implementar en el borde una simple plataforma de bloques, en tanto que la mejor plataforma de clases se despliegue en el núcleo usando capas ópticas para separar cada capa de servicio, logrando así una mejor escalabilidad y capacidad de gestión.

CAPÍTULO II

ELECCIÓN DE UNA RED METROPOLITANA EN EL PERÚ

2.1 Situación actual del Mercado Peruano

En la mayor parte del Mundo, los Operadores de Telecomunicaciones han empleado y emplean la tecnología SONET/SDH para implementar sus principales redes de transporte, así como para la interconexión de sus redes con la de otros Operadores. Las razones principales de la preferencia por SONET/SDH son las características y facilidades técnicas prestadas por este tipo de redes.

En el mercado europeo y latinoamericano, la tecnología empleada en Redes Metropolitanas es SDH, en tanto que en los Estados Unidos de Norteamérica el estándar es SONET.

En el caso de Perú, los diferentes Operadores de Telecomunicaciones con redes metropolitanas han desplegado anillos de tecnología SDH a velocidades de STM-16 (Telefónica del Perú y AT&T) y STM-4 (BellSouth). Aunque en algunos casos excepcionales, se han implementado tramos empleando tecnología DWDM y SDH a velocidad de STM-64 (básicamente los proveedores de ancho de banda internacional vía cable submarino, tales como Emergia y Global Crossing).

A pesar que las tendencias descritas en el capítulo anterior nos introducen el concepto de Redes Ópticas Metropolitanas basadas en DWDM, en el mercado peruano (específicamente Lima) aun no es económicamente favorable el empleo de esta nueva tecnología para atender Redes Metropolitanas por parte de los Operadores Entrantes, dado que según la demanda de ancho de banda proyectada en la ciudad de Lima (dependiente de la situación económica del país en el mediano y largo plazo) las inversiones son considerablemente mayores que las requeridas por la tecnología SONET/SDH. Esto tiene mucho sentido, dado que en el entorno actual del mercado peruano de telecomunicaciones, los nuevos entrantes buscan minimizar sus inversiones y reducir el tiempo de retorno de las mismas.

Sin embargo esto no elimina la posibilidad de considerar la opción de implementar una MON en Lima en un futuro de largo plazo, para el caso de los Operadores Entrantes. En tanto que para el Operador Dominante, la opción de implementar MON con plataformas multiservicios basadas en DWDM resultará casi una necesidad en el mediano plazo.

2.2 Elección de la Tecnología: Evaluación Técnico-Económica

Como caso práctico analizaremos que decisión tendrá que tomar un Operador Entrante en el mercado metropolitano de Lima, con respecto a la red metropolitana que deberá desplegar para atender a sus clientes. La premisa fundamental es que este Operador cuenta con una concesión de portador local para la zona metropolitana de Lima, así como también concesión de portador de larga distancia internacional, a fin de poder disponer de facilidades de red internacional para el servicio de Internet.

Como ya se mencionó en forma breve, el análisis técnico-económico (volumen de tráfico vs. costo de la tecnología) para el caso de un Operador Entrante al mercado metropolitano de Lima, da como resultado que el diseño e implementación de una Red Metropolitana SDH representa la opción más conveniente.

A continuación se presentará un resumen de este análisis, sin dejar por ello la rigurosidad y validez práctica de los resultados. Para esto es imprescindible establecer los objetivos del inversionista, en este caso del Operador:

- Minimizar las inversiones.
- Reducido tiempo de retorno de la inversión.
- Minimizar el riesgo tecnológico (tecnología de reconocida confiabilidad).
- Penetración promedio en el mercado: 10% al 2001 y 20% al 2008.

También se requiere conocer la proyección de las principales variables macroeconómicas del Perú, y si fuese posible la del Sector de Telecomunicaciones:

Tabla 5 Proyecciones Macroeconómicas

	1998	1999	2000	2001	2002	2003
Demográficos (miles de habs)						
Población	24 801	25 222	25 651	26 087	26 531	26 982
Actividad y Demanda Interna (Var %)						
PBI	0,7%	2,5%	4,0%	5,0%	5,0%	6,0%
Demanda Interna	-0,3%	-4,2%	4,3%	4,0%	4,0%	4,5%
PBI per cápita (US$ miles)	2 542	2 316	2 402	2 484	2 555	2 669
Precios (Var %)						
Inflación	6,0%	5,5%	6,0%	6,0%	6,0%	5,0%
IPM (Var % fin de período)	6,0%	6,0%	5,5%	6,0%	6,0%	5,5%
Devaluación (fin de período)	15,8%	12,0%	8,0%	6,5%	6,5%	5,0%
Tipo de cambio fin de período (NS/US$)	3,16	3,54	3,82	4,03	4,29	4,51
Tipo de cambio(promedio (NS/US$)	2,93	3,42	3,78	3,93	4,16	4,40
Equilibrio Macroeconómico						
Déficit en cuenta corriente	6,0%	4,1%	4,6%	4,8%	4,6%	4,5%
Superávit Primario	1,2%	0,9%	1,3%	1,6%	1,6%	1,4%

Fuente : Estudios Económicos de Telefónica del Perú

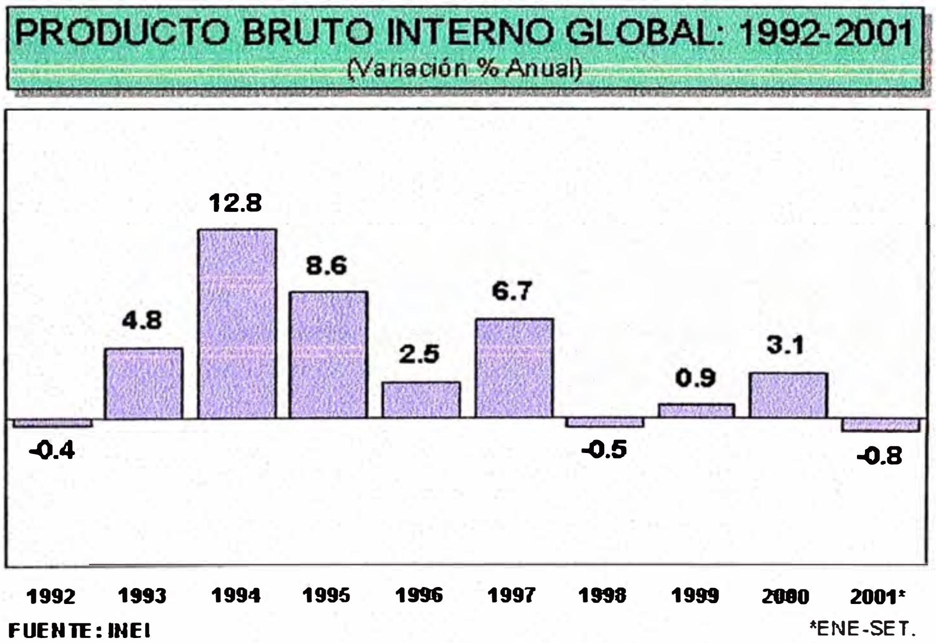


Figura 19 Producto Bruto Interno Global Histórico

Tabla 6 Producto Bruto Interno Global por Sector Económico

PBI POR SECTORES ECONOMICOS: 1995-2001
(Variación % Anual)

SECTORES	1995	1996	1997	1998	1999	2000	2001*
PBI TOTAL	8,6	2,5	6,7	-0,5	0,9	3,1	-0,8
Agropecuario	9,5	5,2	5,4	1,5	11,7	6,2	-1,3
Pesca	-13,9	-4,9	-1,7	-13,4	29,2	9,0	-6,0
Minera e Hidrocarburos	4,2	5,1	9,0	3,8	12,9	2,4	7,1
Manufactura	5,5	1,5	5,3	-3,2	-0,5	6,7	-1,7
Electricidad y Agua	0,2	5,9	12,7	8,3	2,6	4,6	3,3
Construcción	17,4	-2,3	14,9	0,6	-10,5	-4,2	-10,2
Comercio	11,1	0,9	7,8	-3,2	-1,9	5,1	-0,5
Otros	8,5	3,2	5,8	0,2	1,1	2,7	-0,5

FUENTE: INEI

*ENE-SET.

Considerando lo anterior, agregando tendencias y proyecciones de consumo se proyecta que la demanda de ancho de banda en el mercado metropolitano de Lima es la siguiente:

Tabla 7 Demanda de Capacidad del Mercado Metropolitano de Lima

	2001	2002	2003	2004	2005	2006	2007	2008
Total (STM-1)	**18,0**	**33,2**	**53,2**	**77,5**	**104,9**	**139,1**	**181,1**	**229,6**
Datos (STM-1)	8,1	14,9	24,1	36,7	53,1	73,7	100,8	132,7
Voz (STM-1)	1,1	1,8	2,5	3,3	4,2	5,3	6,6	8,0
Internet (STM-1)	8,8	16,5	26,6	37,5	47,6	60,1	73,8	88,9

Fuente. Proyecciones AT&T Perú

Del objetivo de penetración del Operador Entrante en el mercado metropolitano de Lima, se obtiene el dimensionamiento de la Red Metropolitana de Lima de éste:

Tabla 8 Demanda de Capacidad de la Red Metropolitana del Operador Entrante

% de Mercado	10%	11,43%	12,86%	14,29%	15,71%	17,14%	18,57%	20%
	2001	**2002**	**2003**	**2004**	**2005**	**2006**	**2007**	**2008**
Total (STM-1)	**1,8**	**3,8**	**6,8**	**11,1**	**16,5**	**23,8**	**33,6**	**45,9**
Datos (STM-1)	0,8	1,7	3,1	5,2	8,3	12,6	18,7	26,5
Voz (STM-1)	0,1	0,2	0,3	0,5	0,7	0,9	1,2	1,6
Internet (STM-1)	0,9	1,9	3,4	5,4	7,5	10,3	13,7	17,8

Se observa que una red metropolitana de capacidad STM-16 (2,5 Gbps) ó STM-64 (10 Gbps) es suficiente en un horizonte de 5 ó 8 años respectivamente. Teniendo en consideración que existen equipos SDH de capacidad STM-16 y STM-64 con precios mucho menores que los equipos DWDM metro más pequeños (32λ, cada λ de 2,5 Gbps o 10 Gbps). Otro punto a tomar en cuenta es que la tecnología SDH es mucho más madura que la tecnología DWDM Metro (la cual inicio su lanzamiento comercial en el último trimestre del año 2000), por lo que se puede concluir que desde el punto de vista técnico (menor riesgo tecnológico) y económico (inversiones eficientes: menor inversión y tiempo de retorno más corto) resulta mucho más conveniente desplegar una Red Metropolitana SDH en la ciudad de Lima para el caso de un Operador Entrante.

CAPÍTULO III

DISEÑO DE LA RED METROPOLITANA SDH DE LIMA

Tomando en consideración al mismo Operador Entrante que se analizara en el capítulo anterior, se pasará a realizar el diseño de su Red Metropolitana SDH.

3.1 Criterios de Diseño de la Red Metropolitana SDH

Los criterios en el diseño de la red deben obedecer los requerimientos a satisfacer. El Operador Entrante tendrá las siguientes necesidades básicas:

- Interconexión con Proveedores de Ancho de Banda Internacional.
- Interconexión con otros Operadores de Telecomunicaciones Locales.
- Transporte Local de ancho de banda.
  - Troncales para servicios locales.
  - Ultima Milla para proveedores de ancho de banda internacional.

Para cubrir todas estas necesidades se recomienda una configuración en anillo o anillos, por ser esta la más robusta en términos de capacidad de supervivencia.

Dado que es un Operador Entrante la red SDH inicialmente no se dispondrán de muchos nodos, a fin de no incrementar demasiado las inversiones. Elegiremos dos anillos de tres nodos, por ser esta opción la configuración mínima y a la vez estos anillos se interceptarán en dos nodos, a fin de minimizar el número de éstos sin alterar demasiado la funcionalidad.

Un nodo deberá ubicarse dentro del local del proveedor de ancho de banda internacional vía cable submarino, esto es muy típico en todos los mercados de telecomunicaciones y la modalidad es llamada "co-ubicación" ó "collocation".

Debe considerarse ubicar los nodos cerca de los puntos de interconexión establecidos con los otros Operadores de Telecomunicaciones del mercado, sobre todo del Operador dominante. Es también necesario considerar ubicar al menos un nodo en el local que alberga las centrales de conmutación y otro en los puntos de concentración de tráfico.

3.2 Topología de la Red Metropolitana SDH

A fin de facilitar el diseño, la red metropolitana SDH estará conformada básicamente por un total de cuatro nodos agrupados en dos anillos SDH, tomando la Topología de "Anillos Intersectados en Modo Hub":

- Un primer anillo de capacidad STM-16 entre los nodos SDH 1, 2 y 3, y
- Un segundo anillo de capacidad STM-4 entre los nodos SDH 1 y 3 y un nodo adicional (nodo 4) ubicado en modalidad de co-ubicación dentro del local del Proveedor de Ancho de Banda Internacional.

Los nodos de la Red Metropolitana albergarán equipos SDH cuyas capacidades serán las siguientes:

Nodo 1	Nodo 2	Nodo 3	Nodo 4
STM-16	STM-16	STM-16	STM-4

La configuración de la Red Metropolitana SDH se muestra en la figura siguiente:

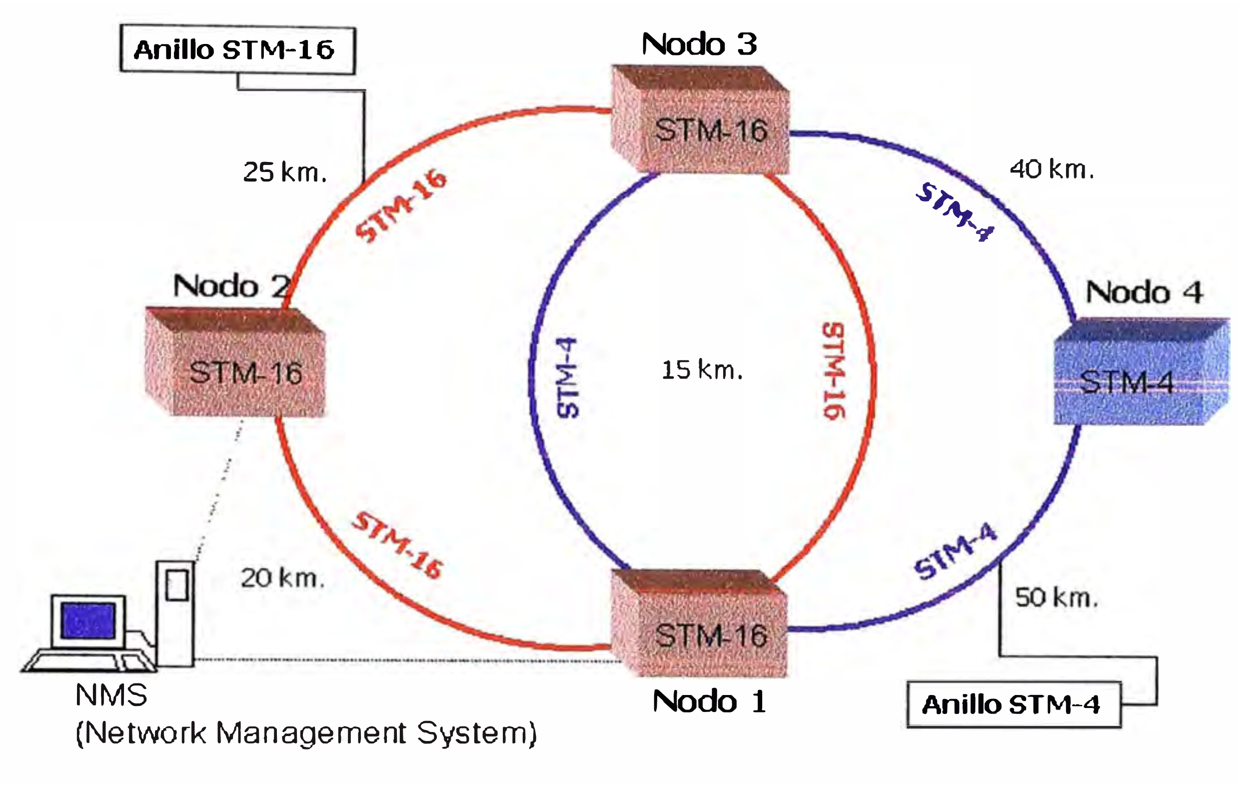


Figura 20 Red Metropolitana SDH

Para facilitar el orden en el diseño y configuración es necesario asignar a cada elemento de red un numero identificador (ID), a fin de asignar un lado Este (E) u Oeste (W) a cada tarjeta de interface y asumir la dirección de los datos de Este a Oeste. En el caso de esta red metropolitana SDH se tiene lo siguiente:

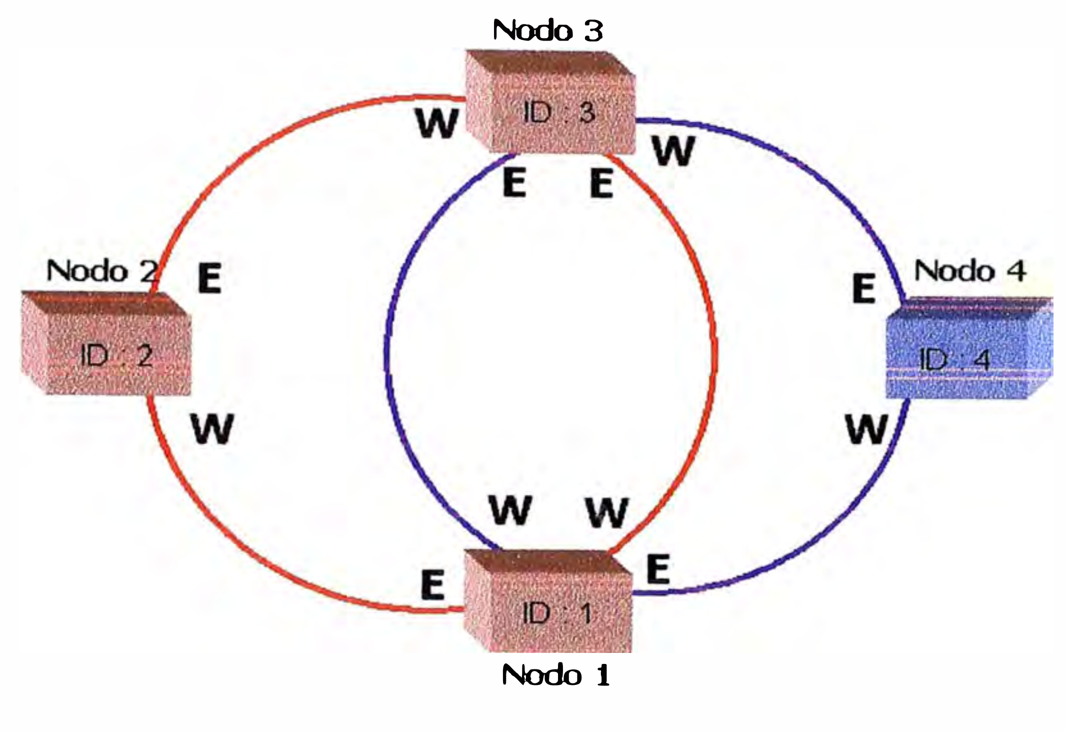


Figura 21 Asignación de la dirección de la Red

3.3 Arquitectura de la Red Metropolitana SDH

3.3.1 Configuración de los Nodos SDH

A fin de representar la configuración de los equipos SDH en cada uno de los nodos, tomaremos los modelos de equipos del Proveedor Huawei Corporation. Según esto tendremos lo siguiente:

3.3.1.1 Nodo SDH #1

Equipo: 1 SBS 2500+

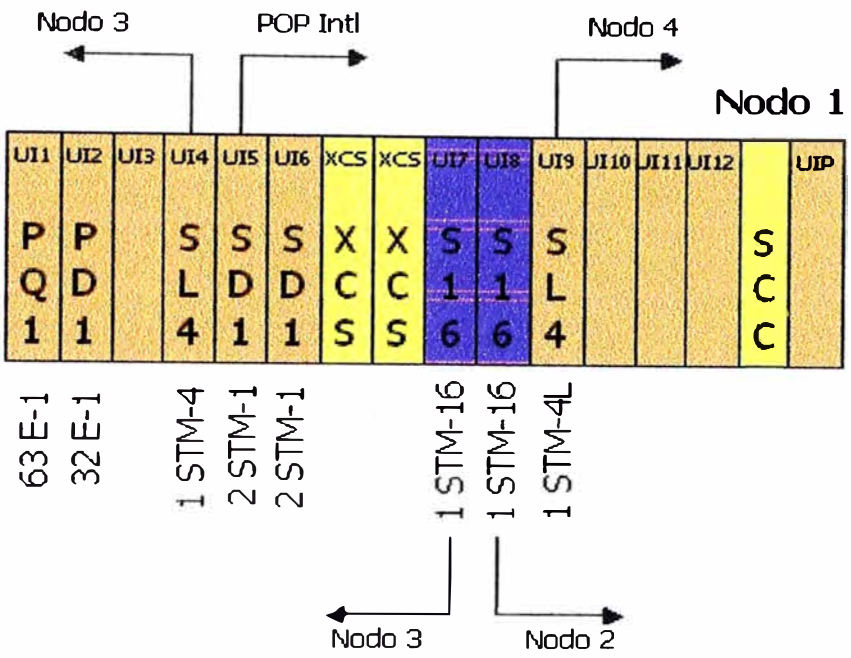


Figura 22 Distribución de tarjetas en el Nodo 1

Tarjetas:

Tarjeta	Rev	Servicio	Slot	Software
SS61PQ1A01	C	63×E1	IU1	2.11
SS61PD1A01	O	32×E1	IU2	2.11
SS61SD1A02	O	2×STM-1	IU5	2.10
SS62SL4A02		1 STM-4	IU6	
SS62XCS2	B		XCS 1	2.17
SS62XCS2	B		XCS 2	2.17
SS62S1603	A	1XSTM-16	IU7	2.11
SS62S1603	A	1XSTM-16	IU8	2.11
SS61SCC5	A		SCC	4.5.2

3.3.1.2 Nodo SDH #2

Equipo: 1 SBS 2500+

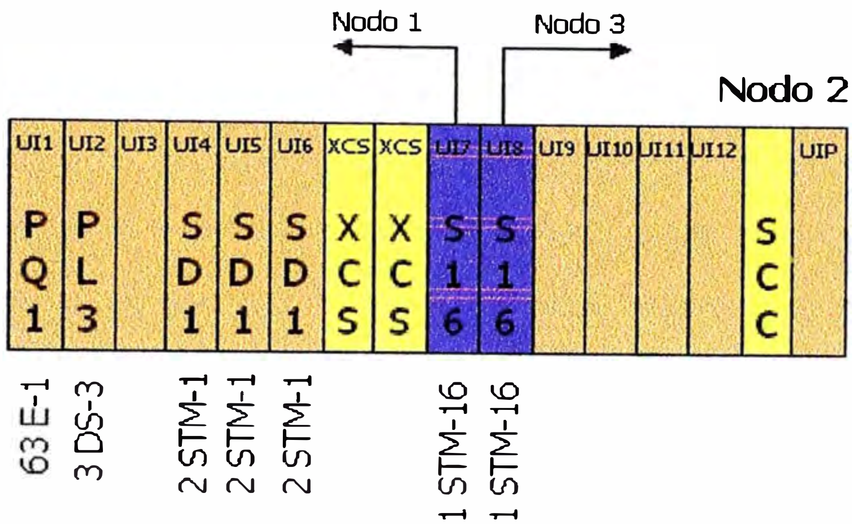


Figura 23 Distribución de tarjetas en el Nodo 2

Tarjetas:

Tarjeta	Rev	Servicio	Slot	Software
SS61PQ1A01	C	63×E1	IU1	2.11
SS62PL3B01		3×DS-3	IU2	
SS61SD1A02	O	2×STM-1	IU6	2.10
SS62XCS2	B		XCS 1	2.17
SS62XCS2	B		XCS 2	2.17
SS62S1603	A	1×STM-16	IU7	2.11
SS62S1601	A	1×STM-16	IU8	2.11
SS61SCC5	A		SCC	4.5.2

3.3.1.3 Nodo SDH # 3

Equipo: 1 SBS 2500+

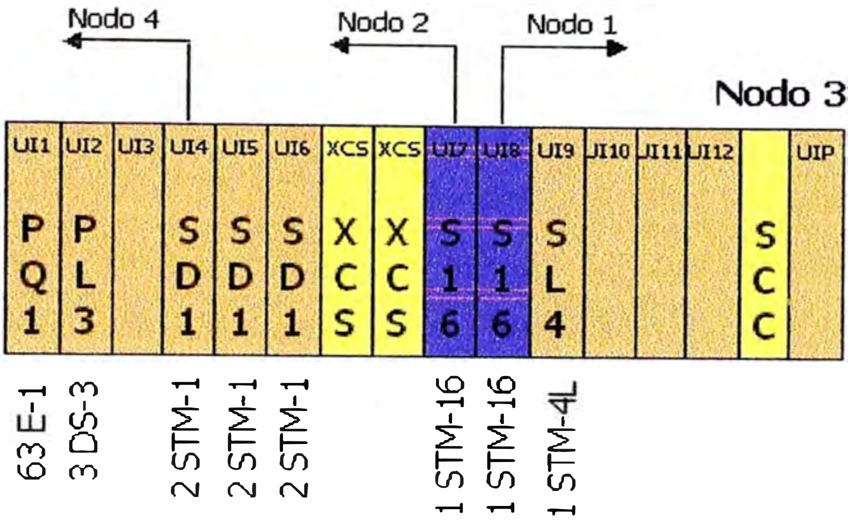


Figura 24 Distribución de tarjetas en el Nodo 3

Tarjetas:

Tarjeta	Rev	Servicio	Slot	Software
SS61PQ1A01	C	63×E1	IU1	2.11
SS62PL3B01		3×DS-3	IU2	
SS62SL4A02		1 STM-4	IU4	
SS61SD1A02	O	2×STM-1	IU5	2.10
SS61SD1A02	O	2×STM-1	IU6	2.10
SS62XCS2	B		XCS 1	2.17
SS62XCS2	B		XCS 2	2.17
SS62S1601	A	1XSTM-16	IU7	2.11
SS62S1603	A	1XSTM-16	IU8	2.11
SS61SCC5	A		SCC	4.5.2

3.3.1.4 Nodo SDH #4

Equipo: 1 SBS 155/622

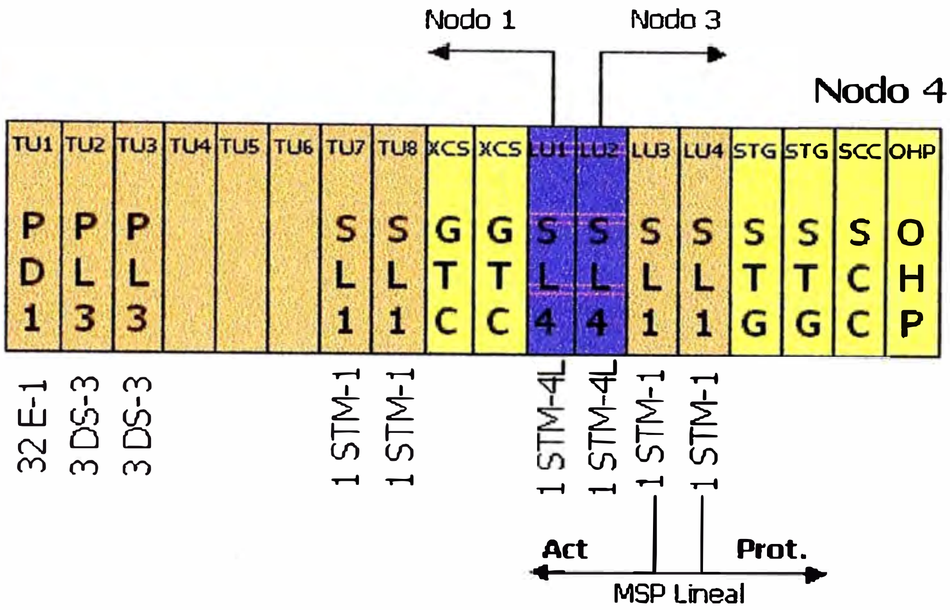


Figura 25 Distribución de tarjetas en el Nodo 4

Tarjetas:

Tarjeta	Rev	Servicio	Slot	Software
SS11PD1A0		32×E1	TU1	
SS11PL3F0		3×DS-3	TU2	
SS11PL3F0		3×DS-3	TU3	
SS11GTCF0			XC	
SS11GTCF0			XC	
SS25SL402		1 STM-4	LU1	
SS25SL402		1 STM-4	LU2	
SS15SL104		1 STM-1	LU3	
SS15SL104		1 STM-1	LU4	
SS13STGB0			STG	
SS13STGB0			STG	
SS13SCC0			SCC	
SS31OHPA0			OHP	

3.3.2 Esquema de Protección

El esquema de protección configurado en la Red Metropolitana SDH es MSP Bidireccional de dos hilos (Two-fiber bi-directional multiplex section shared protection self-healing ring) , tal como se muestra en la siguiente figura:

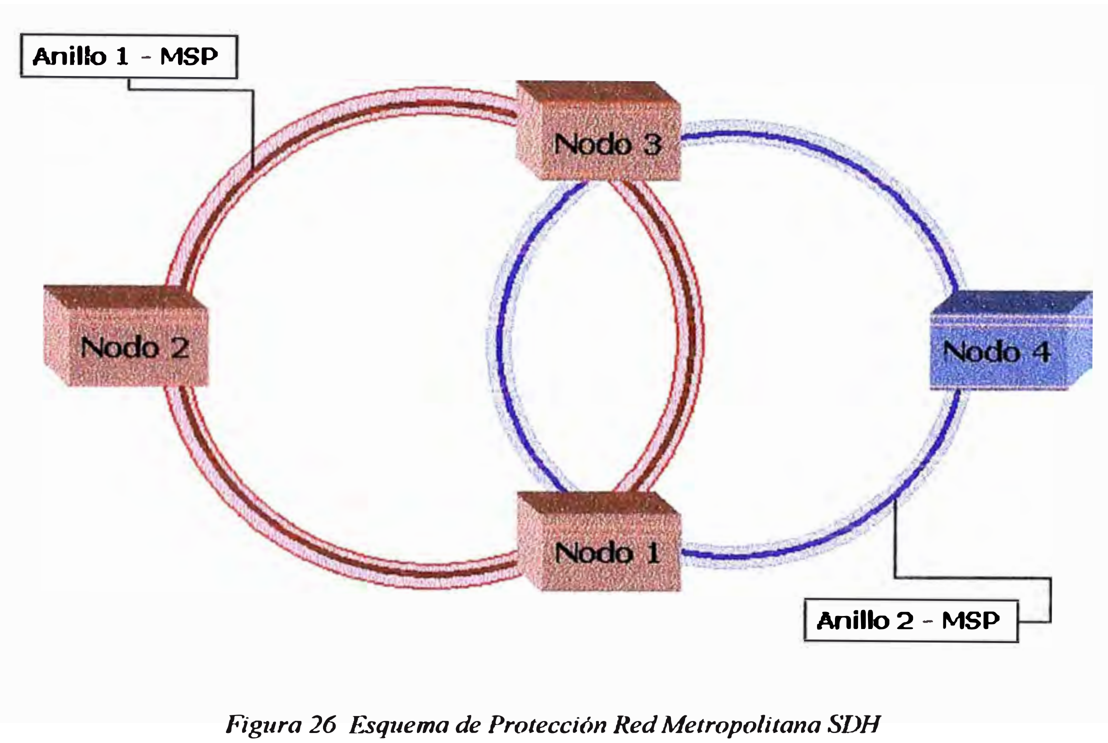


Figura 26 Esquema de Protección Red Metropolitana SDH

Se logra una redundancia al 100%, debido a que el diseño hace que los canales de servicio estén protegidos mientras los canales de protección son reservados para la protección de este servicio. El tráfico en servicio es transportado bi-direccionalmente por tramos: un tributario entrante viaja en la dirección de los canales de servicio mientras su tributario de salida asociado viaja en dirección opuesta sobre el mismo tramo. Así también, los canales en el anillo pueden ser compartidos entre nodos.

En caso de falla o degradación de la fibra óptica, falla de tarjetas o fallas del nodo bajo diferentes situaciones, se tiene que el tiempo de conmutación de la sección de multiplexación de los equipos deber ser menor a 50ms, tal como lo estipula la UIT (Unión Internacional de Telecomunicaciones) en su Recomendación G.841.

Se dispone de una protección para servicio inter-anillos en presencia de más de una ruta de interconexión entre anillos. Para los anillos interconectados dualmente en DNI (Dual Node Interconnection) como en nuestro caso sucede con los anillos 1 y 2, la UIT-T estipula en la Recomendación G.842 la protección de los servicios de interconexión entre redes de anillos (redes de anillos SNCP y MSP) compuestas de equipos diferentes.

3.3.3 Esquema de Sincronismo

Para fines de sincronización de la Red Metropolitana SDH se recomienda instalar 1 GPS (GPS-1), el cual se conectará al Nodo 1, constituyendo el reloj principal. Así también, en el Nodo 4, la fuente de reloj primaria estará dada por el reloj del Proveedor de Ancho de Banda Internacional (GPS-2), puesto que la función de este nodo será la interconexión con el Proveedor de Ancho de Banda Internacional.

La configuración de sincronización de la Red Metropolitana SDH será como sigue:

Tabla 9 Configuración del sincronismo de la Red Metropolitana SDH

Clase	Nodo 1	Nodo 2	Nodo 3	Nodo 4
1°	línea Nodo 4	línea Nodo 1	línea Nodo 4	GPS-2 ext
2°	línea Nodo 3	línea Nodo 2	línea Nodo 1	GPS-2 line
3°	GPS-1	Reloj interno	Reloj interno	línea Nodo 1
4°	Reloj interno	-	-	línea Nodo 3

El diagrama de distribución de reloj se muestra en la figura siguiente:

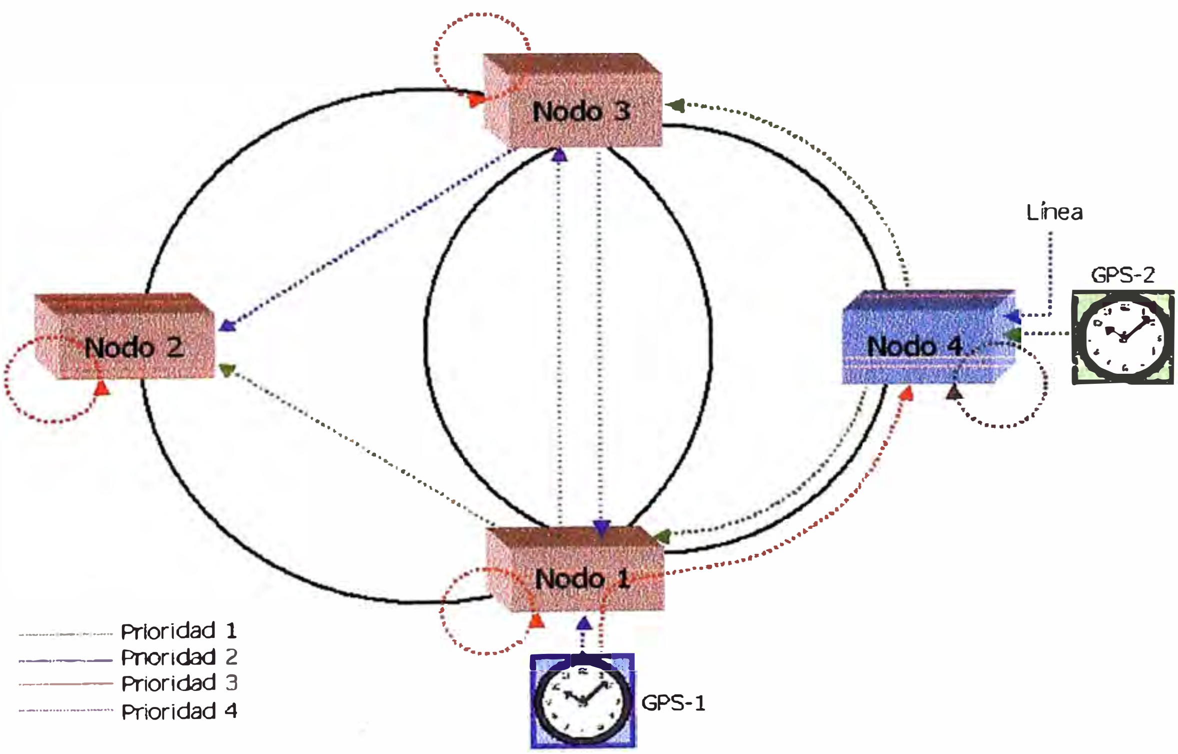


Figura 27 Diagrama de Distribución de Reloj

3.3.4 Sistema de Gestión de la Red SDH

Para la gestión de las redes SDH se emplea generalmente una computadora personal compatible o un computador SUN, dependiendo del proveedor. Este elemento de gestión de red debe estar conectado a través de una red LAN privada a alguno o algunos de los equipos SDH ubicados en los nodos. En este caso vamos a recomendar contar con dos enlaces de gestión, uno hacia el Nodo 1 (Enlace de Gestión Primario) y en el Nodo 2 (Enlace de Gestión Secundario o Back-Up).

El sistema de gestión centralizado debe cumplir con las siguientes características mínimas:

a. Administración del Sistema

- Gestión In-band de los equipos remotos.
- Bases de Datos replicada.
- Niveles de acceso por privilegios y equipos. Log de operaciones

b. Administración de Configuración

- Configuración de Red, Equipos y Tarjetas.
- Administración remota desde terminales Windows vía TCP/IP.

c. Administración de Fallas y Alarmas

- Generación de alarmas audibles y visuales.
- Distribución de alarmas por prioridad.

- Histórico de alarmas.
- Filtro de Alarmas

d. Administración de Estadística y Performance

- Obtención de datos relevantes para estadísticas (Porcentaje de uso CPU, memoria, etc.).
- Medición de performance del sistema. Generación de gráficos estadísticos y en tiempo real.

e. Administración de Mantenimiento

- Capacidad de obtener datos y estado de alarmas on-line.
- Activación y bloqueo de servicios.
- Test y loopback en los diferentes bloques o subsistemas.
- Programación de eventos.

3.4 Equipamiento de backup

Se recomienda tener al menos una tarjeta back-up por cada tipo de tarjeta, por lo que en este caso las tarjetas en almacén de mantenimiento deberán ser las siguientes:

Tarjeta	Equipo	Funcionalidad
SS11PD1A0	Nodo STM-4	32×E1
SS11PL3F0	Nodo STM-4	3×DS-3
SS25SL402	Nodo STM-4	1 STM-4
SS15SL104	Nodo STM-4	1 STM-1
SS11GTCF0	Nodo STM-4	Main Control
SS13STGB0	Nodo STM-4	Timing
SS13SCC0	Nodo STM-4	System & Communication
SS31OHPA0	Nodo STM-4	Overhead Processing
SS61PQ1A01	Nodo STM-16	63×E1
SS61PD1A01	Nodo STM-16	32×E1
SS62PL3B01	Nodo STM-16	3×DS-3
SS61SD1A02	Nodo STM-16	2×STM-1
SS62SL4A02	Nodo STM-16	1×STM-4
SS62S1601	Nodo STM-16	1×STM-16
SS62S1603	Nodo STM-16	1×STM-16
SS62XCS2	Nodo STM-16	Main Control
SS61SCC5	Nodo STM-16	System & Communication

3.5 Planta Externa

3.5.1 Tipo de fibra

Para el diseño e implementación de planta externa de la red metropolitana SDH es necesario el empleo de fibra óptica monomodo G.652. Se considera importante mencionar que este tipo de fibra también puede ser empleado para la implementación de redes metropolitanas DWDM, en tanto que para redes de larga distancia DWDM se requiere de otro tipo de fibras con características especiales de atenuación y dispersión.

La fibra óptica que se ha considerado para el diseño tiene los siguientes parámetros:

Fiber Type	:	Monomodo estándar
Core Number	:	48
Fiber Code	:	9
Attenuation Rate	:	
Attenuation, Loose Tube Cables		
@1310 nm	:	≤ 0,35 dB/km
@1550 nm	:	≤ 0,22 dB/km
Attenuation, Tight Buffer Cables		
@1310 nm	:	≤ 0,45 dB/km
@1550 nm	:	≤ 0,35 dB/km
Dispersión Rate	:	
entre 1285 and 1330 nm	:	≤ 3,5 ps/nm/km
entre 1525 and 1575 nm	:	≤ 19 ps/nm/km
Zero Dispersion Wavelength	:	1310 ± 10 nm

Mode Field Diameter	:	
@1310 nm		9,3 ± 0,5 μm
@1550 nm		10,5 ± 1,0 μm
Cable Cut-off Wavelenght		≤ 1250 nm
Cladding Diameter	:	125 ± 1,0 μm
Core/Cladding Concentricity Error	:	≤ 0,8 μm
Cladding Non-Circularity	:	≤ 1,0 %
Coating Diameter	:	250 ± 15 μm
Proof-Test Level	:	0,7 GN/m^2

3.5.2 Enlaces de fibra

En el Anillo 1 se ha tenido en consideración que la longitud de los enlaces de fibra entre los nodos SDH no superen 30 km., a fin emplear sólo tarjetas de corto alcance.

Enlace	# de hilos
Nodo 1 – Nodo 2	2
Nodo 2 – Nodo 3	2
Nodo 3 – Nodo 1	2
Nodo 1 – Nodo 4	2
Nodo 4 – Nodo 3	2

Esta red SDH empleará básicamente enlaces de 2 hilos de fibra óptica. Sin embargo, podrían emplearse 4 hilos de fibra por enlace a fin de implementar una configuración 4-BLSR, lo cual requeriría 6 tarjetas ópticas STM-16 adicionales. Con esta posibilidad de cambios, la red duplicaría su capacidad con una inversión adicional de alrededor de 30%. Esto debe considerarse cuando se requiera un aumento en la capacidad de la red.

Dado que se han considerado distancias superiores a 30 km. entre el nodo # 4 y los nodos # 1 y # 3, se hace necesario el empleo de tarjetas ópticas de largo alcance en la ventana de 1550 nm en estos tramos. A diferencia de las tarjetas ópticas convencionales (corto alcance) en la ventana de 1310 nm. que se emplearán en el resto de enlaces. El precio de una tarjeta de largo alcance bordea el 110% del precio de una de corto alcance, por lo que en el diseño debe evitarse en lo posible el uso de estas primeras.

3.6 Servicio de Soporte y Mantenimiento

3.6.1 Periodo de soporte

El periodo de garantía de los equipos suele ser de 1 año. Luego de vencido el periodo de garantía se debe acoger a las prorrogas del acuerdo de soporte. El soporte deberá cubrir los casos de asistencia local on-site y/o asistencia remota dial-up en caso de fallas de la Red Metropolitana SDH. Todo bajo el esquema 7×24×365.

3.6.2 Niveles de soporte y escalamiento

Debe procurarse contar con lo siguiente:

- Centro de Soporte Local al Cliente
- Soporte en la Sede Central del fabricante

Con los niveles de soporte claramente definidos en cada uno de los casos. Un esquema de escalamiento general es el mostrado a continuación:

Switch Troubleshooting Flow Diagram

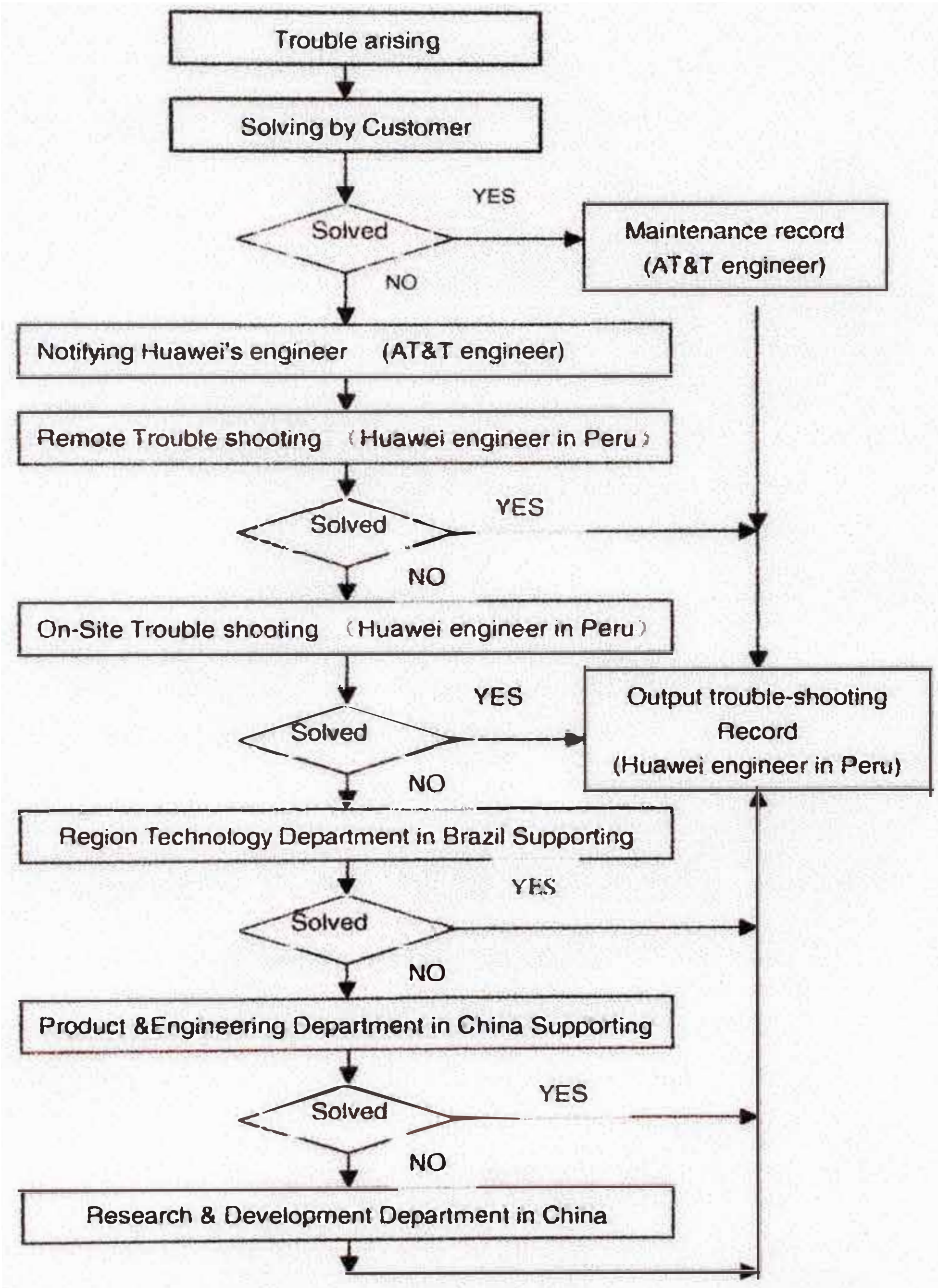


Figura 28 Diagrama de Flujo de Resolución de Problemas (Escalamiento)

CAPÍTULO IV

APLICACIONES DE LA RED METROPOLITANA SDH

4.1 Interconexión con otros Operadores Locales

4.1.1 Situación del mercado

En la mayor parte del Mundo, los Operadores de Telecomunicaciones interconectan sus redes a través de tecnología SDH, debido a las características y facilidades técnicas prestadas por este tipo de redes.

En el Perú con la apertura del mercado de telecomunicaciones, los Operadores Entrantes se ven en la necesidad de interconectarse directamente entre ellos, pero principalmente con el Operador Dominante, Telefónica del Perú. Esta interconexión está limitada básicamente a las redes de telefonía (local o larga distancia, fija o móvil).

Bajo este esquema, una de las aplicaciones para la cual fue implementada la Red Metropolitana SDH es la interconexión del Operador Entrante con los principales Operadores del mercado metropolitano de Lima.

4.1.2 Descripción de la aplicación

La interconexión entre las redes de dos Operadores de Telecomunicaciones surge como una necesidad mutua de éstos, a fin de satisfacer que los usuarios de los servicios del primer Operador tengan comunicación con los usuarios del segundo, y viceversa. El caso específico a describir se refiere a la interconexión de redes de telefonía.

Esta aplicación contempla la interconexión de las centrales telefónicas de ambos Operadores a través de la Red Metropolitana SDH, teniendo como puntos de interconexión los locales previamente acordados y que figuran en los Perfiles Técnicos de Interconexión (PTI) que son parte de los Contratos de Interconexión firmados por ambos Operadores. En estos puntos de interconexión se instalará un equipo SDH para proveer los E-1 de interconexión.

4.1.3 Interfaces y límites de la aplicación

En el Perú, la interface de interconexión a emplearse es el E-1 (Recomendación UIT-T G.703), según acuerdo y factibilidad técnica del Operador Dominante.

Con el crecimiento del tráfico, es muy probable que en unos años sea necesaria la interconexión a nivel de STM-1, para lo cual habrá que habilitar este tipo de interfaces en las centrales de conmutación.

Asimismo la aplicación se limita a la interconexión de las redes de telefonía entre Operadores, ya sea entre el Operador Entrante y otro Operador, la cual es la aplicación primaria. Sin embargo, se abre la oportunidad de brindar el servicio de tránsito local, por ejemplo la Interconexión entre los Operadores A y B puede darse a través de la Red Metropolitana SDH, siempre y cuando exista facilidades de interconexión entre el Operador Dominante y cada uno de los Operadores A y B. Esta última derivación puede darse a nivel de E-1 (tránsito dedicado) o a nivel de minutos (tránsito conmutado).

4.1.4 Gestión de la aplicación

La gestión a nivel de transmisión se debe llevar a cabo a través de los sistemas de gestión centralizados de la Red Metropolitana SDH, en tanto que a nivel de conmutación se debe realizar a través de los sistemas de gestión de las centrales de conmutación, la cual deberá manejar cuidadosamente los "estadísticos" (mediciones de tráfico) de las diferentes interconexiones, a fin de realizar en forma oportuna y confiable el proceso de facturación (relación Operador – usuario) y liquidación (relación Operador – Operador).

4.1.5 Solución Técnica de la aplicación

4.1.5.1 Topología Propuesta de Interconexión con otros Operadores

Para lograr la interconexión del Operador Entrante (cuya central de conmutación se encuentra conectada al Nodo 1) con otros Operadores de Telecomunicaciones se plantea la siguiente solución:

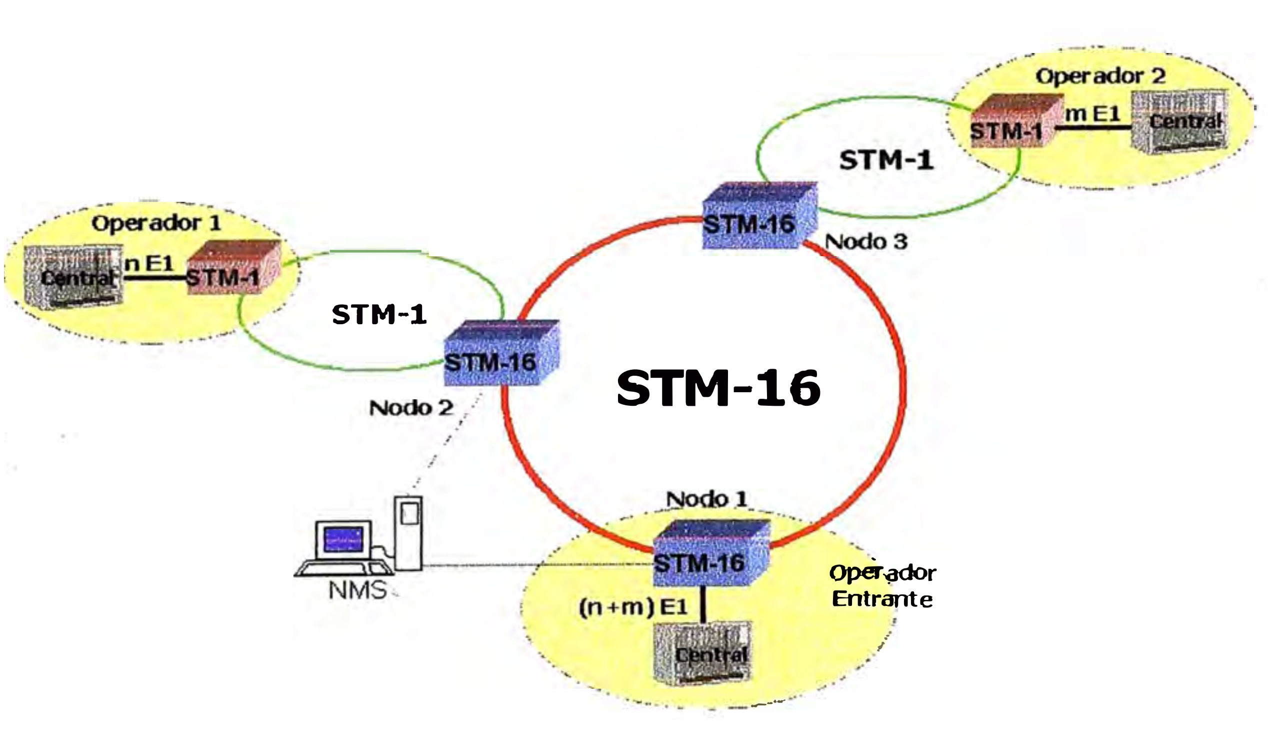


Figura 29 Topologia Propuesta para Interconexión entre Operadores

De acuerdo a la figura 29, la central de conmutación del Operador Entrante está interconectada a la central del Operador 1 ("n" E-1) y a la central del Operador 2 ("m" E-1), en donde todas las interconexiones son a nivel de E-1. Se puede notar que la Red Metropolitana SDH simplemente es la plataforma de transporte de estos E-1. la cual por la topología propuesta y las características propias de esta tecnología se dispone de una óptima redundancia de enlaces hacia ambos Operadores.

El tráfico intercambiado entre el Operador Entrante y los Operadores 1 y 2, fluye de entre los nodos 1-2 y 1-3 respectivamente. Así también, puede brindarse tránsito entre los Operadores 1 y 2:

- Tránsito Conmutado, si el tráfico conmuta por la central del Operador Entrante.
- Tránsito Dedicado, si se dedican E-1s entre los nodos 2 y 3, a fin que interconecten a los Operadores 1 y 2.

4.1.5.2 Plan de Señalización

El PTI define las bases del plan de señalización a seguir entre los Operadores. En general, para el caso peruano se ha establecido el empleo de ISUP CC7 ("señalización C7").

Un ejemplo de plan de señalización puede ser el siguiente:

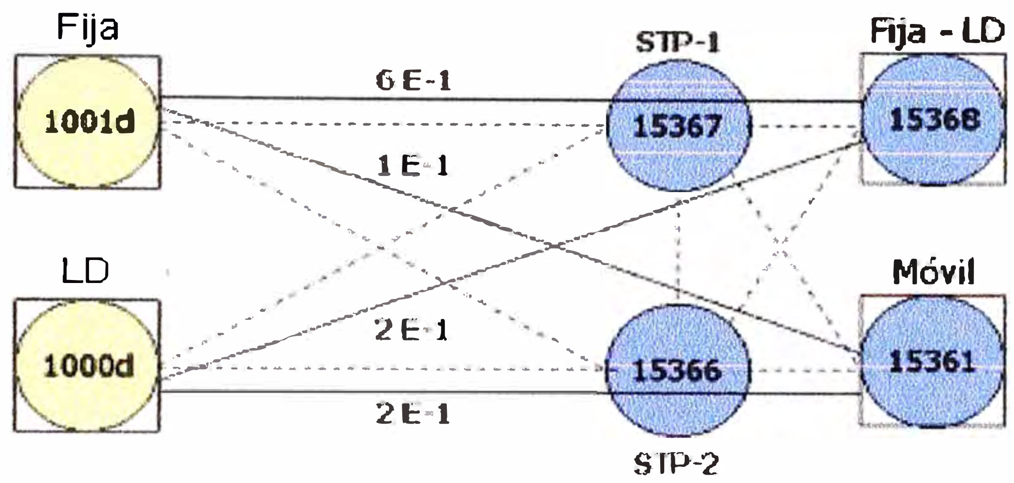


Figura 30 Ejemplo del Plan de Señalización entre Operadores

Donde se conectan dos centrales del Operador A (izquierda) con dos centrales del Operador B (derecha), según:

		Operador B		
		Fija-LD	Móvil	Total
Operador A	Fija	6 E-1	1 E-1	**7 E-1**
	LD	2 E-1	2 E-1	**4 E-1**
	Total	**8 E-1**	**3 E-1**	11 E-1

Las líneas punteadas representan los canales de señalización (64 kbps) que existen en las diferentes rutas. En este ejemplo se cuentan con 4 canales de señalización, uno en cada ruta (Fija A – Móvil B; Fija A - Fija LD B; LD A – Fija

LD B; LD A – Móvil B). Debe recordarse que el canal de señalización sólo va en uno de los E-1 de cada ruta, y que su planificación y programación en las centrales debe contemplar casos de contingencia, pues la supervivencia de los canales de señalización son vitales para el funcionamiento de la interconexión.

Los números dentro de los cuadrados representan los SP (Signaling Point) de la central en tanto que los números en los círculos representan los STP (Signaling Transfering Point), los cuales deben ser intercambiados por ambos Operadores para sus respectivas programaciones en las centrales. Esta información figura en los PTI de los Acuerdos de Interconexión.

4.1.5.3 Planes de Numeración

El Ministerio de Transportes y Comunicaciones (MTC) otorga a los Operadores sus respectivos planes de numeración, luego de que cada uno de ellos sustenta la necesidad de los mismos. Cuando estos Operadores desean interconectarse se requiere que los planes de numeración sean intercambiados entre ellos, a fin de que éstos sean programados en las centrales de conmutación y posteriormente reconocidos. Esta información generalmente figura en el PTI de los Contratos de Interconexión.

4.1.5.4 Plan de Pruebas

Según el Acuerdo de Interconexión, el protocolo de pruebas es el siguiente:

- **Pruebas de Transmisión:** La cual abarca pruebas de B.E.R. durante 24 horas de cada E-1 de interconexión. Luego de que estas pruebas arrojan resultados satisfactorios ($10^{-10} \geq$ B.E.R.) se pasa a la siguiente fase, en caso contrario hay que repetir las pruebas hasta cumplir con los requisitos. Estas pruebas son llamadas pruebas de Nivel 1 y se rigen por la Recomendación UIT-T Q.781.

- **Pruebas de Señalización entre centrales (C7):** Estas pruebas pueden resumirse de la siguiente manera:

  Nivel 2 (Recomendación UIT-T Q.782): Pruebas de control del estado de link: sincronismo, temporización de mensajes, alineamiento de link de señalización, corrección de errores, control de transmisión y recepción de mensajes, etc.

  Nivel 3 (Recomendación UIT-T Q.783): Pruebas de administración de link de señalización: activación y desactivación de link, cambio de link hacia un link adyacente (STP), etc.

Nivel 4 (Recomendación UIT-T Q.784): Pruebas de Parte Usuario del Servicio Integrado (PUSI o ISUP): pruebas de continuidad, pruebas de llamada, pruebas de bloqueo/desbloqueo de llamadas, etc.

- **Pruebas de Conmutación:** Estas pruebas son definidas por ambos Operadores. En forma genérica podemos citar la siguiente secuencia:

  Pruebas de troncal (sólo en centrales Tandem)

  Pruebas de carga/descarga (stress)

  Pruebas de facturación

  Pruebas de rutina de operación y mantenimiento

  Pruebas de confiabilidad (48 horas)

4.2 Ultima Milla a proveedores de ancho de banda internacional

4.2.1 Situación del mercado

Con el advenimiento de los sistemas privados de cable submarino en la región de Sudamérica, tales como Global Crossing, Emergía, Nautilus, etc., surge la necesidad y a la vez oportunidad de negocio de contar con tramos de Ultima Milla desde los Puntos de Presencia (POP) de los sistemas de cable submarino hasta el local de sus usuarios.

Generalmente los anchos de banda manejados son del orden de 45 Mbps a más y por los volúmenes de inversión, los clientes de los sistemas de cable submarino son Operadores de Telecomunicaciones Internacionales, los cuales buscan redes de transporte de la mayor calidad y confiabilidad posible, a fin de lograr enlaces internacionales extremo a extremo de calidad "Carrier".

Para este fin, en la mayor parte del Mundo se emplean redes locales SDH/SONET, las cuales se interconectan a los sistemas de cable submarino, completando de esta manera el tramo local del enlace internacional.

La Red Metropolitana SDH diseñada permite brindar el servicio de Ultima Milla hacia Proveedores de Ancho de Banda Internacional.

4.2.2 Descripción del Servicio

El servicio de Ultima Milla hacia proveedores de ancho de banda vía cable submarino (PABI) consiste en brindar circuitos dedicados SDH entre el POP del PABI y el local del usuario, a fin de completar el tramo local del enlace internacional de éste último, es decir, es un servicio complementario al del PABI. Este circuito puede transportar tráfico de voz, datos y/o multimedia.

El servicio contempla transportar sobre una red SDH, circuitos dedicados de 2048 kbps, 45 Mbps, 155 Mbps y 622 Mbps, para lo cual será necesario instalar un equipo terminal en el local del cliente, el cual debe cumplir con ciertos requerimientos técnicos a fin de albergar dicho equipo terminal.

4.2.3 Solución Técnica del Servicio

4.2.3.1 Interconexión entre el Operador Entrante y el PABI

Primeramente, es necesario interconectar la Red Metropolitana SDH con la Red del PABI. Esto se da dentro del POP del PABI, para lo cual es necesario arrendar un espacio en dicho lugar (esto es llamado "co-ubicación" o en inglés "collocation"). El esquema de interconexión genérico se muestra a continuación:

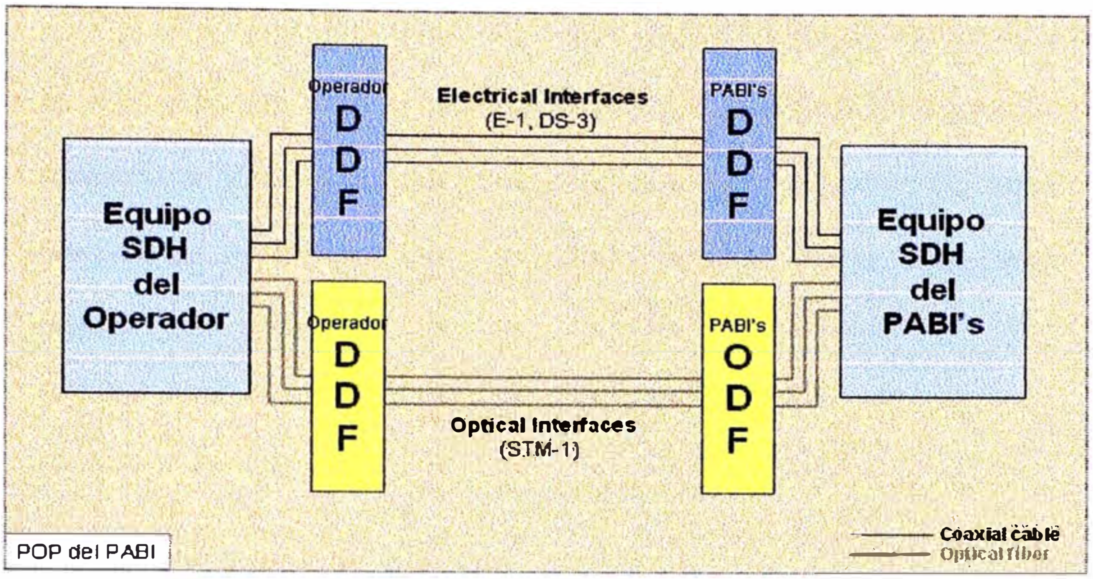


Figura 31 Esquema de Interconexión Operador Entrante – PABI

4.2.3.2 Interfaces y límites del Servicio

Las interfaces a emplearse deben ser las mismas que proporciona el PABI, esto significa que la interface que se entrega en el POP del PABI debe reflejarse en el local del usuario. Los PABI en la zona de Latinoamérica trabajan con interfaces SDH, por lo que las interfaces genéricas son:

	Velocidad	Interface
E-1	2048 kbps	G.703
DS-3	45 Mbps	G.703
STM-1	155 Mbps	G.957
STM-4	622 Mbps	G.957

Debe tenerse en claro que se trata sólo de un servicio de transporte y que las interfaces entregables al usuario están limitadas a interfaces SDH disponibles en la Red Metropolitana SDH. Cualquier servicio adicional como gestión de canales de 64 kbps, servicios de multiplexación y/o demultiplexación no se contemplan en la última milla.

4.2.3.3 Gestión del Servicio

La gestión de este servicio se llevará a cabo a través de los sistemas de gestión centralizados de la Red Metropolitana SDH. Solo se requiere configurar el circuito correspondiente y monitorear su performance.

4.2.3.4 Topología del servicio de Ultima Milla hacia PABI

La topología de la Red Metropolitana SDH permite brindar redundancia al servicio de Ultima Milla dentro de los límites de la Red Metropolitana. El tramo final que va desde el punto más cercano de la Red Metropolitana SDH hacia el local del cliente tiene varias modalidades en su topología.

El servicio de Ultima Milla, en sus diferentes modalidades, presenta el siguiente esquema de solución:

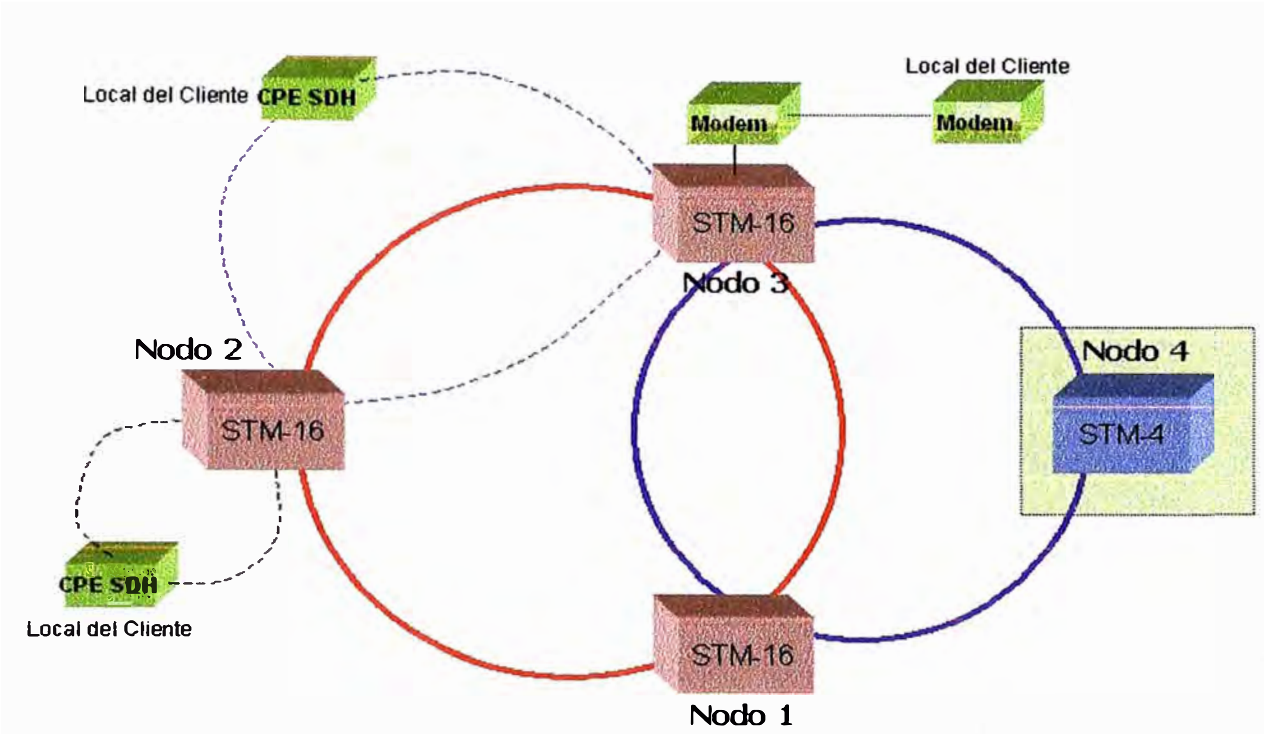


Figura 32 Topologia del servicio de Ultima Milla hacia PABI

De la Figura 32 pueden derivarse tres topologías genéricas en lo que a planta externa se refiere, las cuales son:

- Enlace final sin redundancia (punto a punto)
- Enlace final con redundancia a un mismo nodo
- Enlace final con redundancia a dos nodos diferentes

4.2.3.5 Modalidades del Servicio de Ultima Milla hacia PABI

Las modalidades de este servicio siguen la misma convención de los servicios de circuitos privados brindados en USA, las cuales pueden resumirse en el siguiente cuadro:

<table>
<tr><td colspan="2" rowspan="2"></td><th colspan="2">Entrada al Local del Cliente</th><th colspan="2">Equipo Terminal en el Local del Cliente</th></tr>
<tr><th>Simple</th><th>Doble</th><th>Simple</th><th>Doble</th></tr>
<tr><th rowspan="3">Ruta de Fibra</th><td>Sin redundancia</td><td>OK</td><td>N.A.</td><td>OK</td><td>OK</td></tr>
<tr><td>Con redundancia a un mismo nodo</td><td>OK</td><td>OK</td><td>OK</td><td>OK</td></tr>
<tr><td>Con redundancia a dos nodos diferentes</td><td>OK</td><td>OK</td><td>OK</td><td>OK</td></tr>
</table>

Es decir, existen tres modalidades:

- **Última Milla sin redundancia**
- **Última Milla con redundancia a un mismo nodo**
- **Última Milla con redundancia a dos nodos diferentes**

Por lo general, las modalidades con redundancia de ruta de fibra están orientadas a enlaces cuya capacidad es mayor o igual a 45 Mbps, en tanto que la opción sin diversidad cubre toda la gama de velocidades de transmisión.

Así también, se puede observar del cuadro que hay dos opciones adicionales que puedes combinarse con estas tres modalidades:

- Con doble entrada al local del cliente: Sólo es válida sólo cuando la ruta de fibra tiene redundancia. Básicamente consiste en que cada una de las rutas de fibra ingresen al local del cliente por puntos distintos. Es más, dentro del local del cliente las rutas de fibra deben conducirse canalizaciones diferentes. Esto da una mayor confiabilidad al servicio.

- Con doble equipo terminal en el local del cliente: En el local del cliente se debe instalar un segundo equipo terminal, el cual debe estar preparado para que en caso de falla del equipo terminal primario se conmuten en forma manual los cables y fibras hacia el equipo secundario.

De la figura 32 se puede derivar el siguiente modelo:

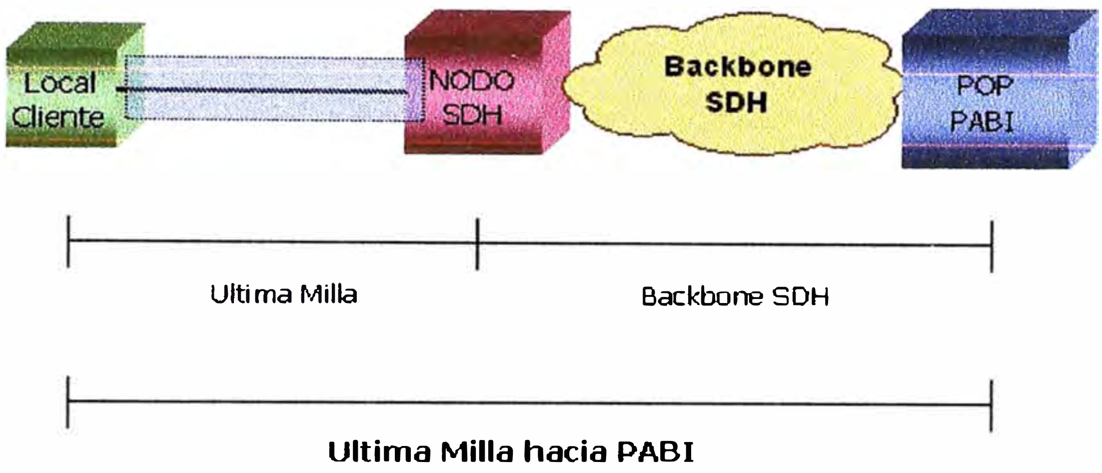


Figura 33 Modelo del servicio de Ultima Milla hacia PABI

La arquitectura de las soluciones en el tramo de Ultima Milla para las tres diferentes modalidades definidas anteriormente se muestran en las páginas siguientes, considerando como equipos terminales en el local del cliente:

Equipo terminal	Aplicación	Redundancia
Mediaconverter	E-1	No
Modem T-3	DS-3	No
Equipo SDH STM-1	E-1, DS-3, STM-1	Si

4.2.3.5.1 Ultima Milla sin redundancia de ruta de fibra

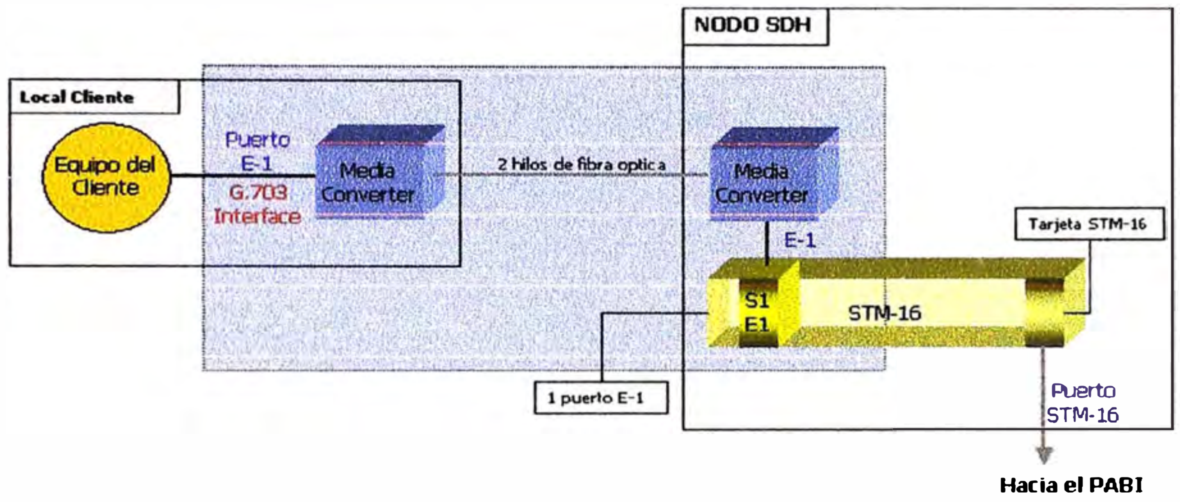


Figura 34 Ultima Milla sin diversidad de ruta de fibra - Caso E-1

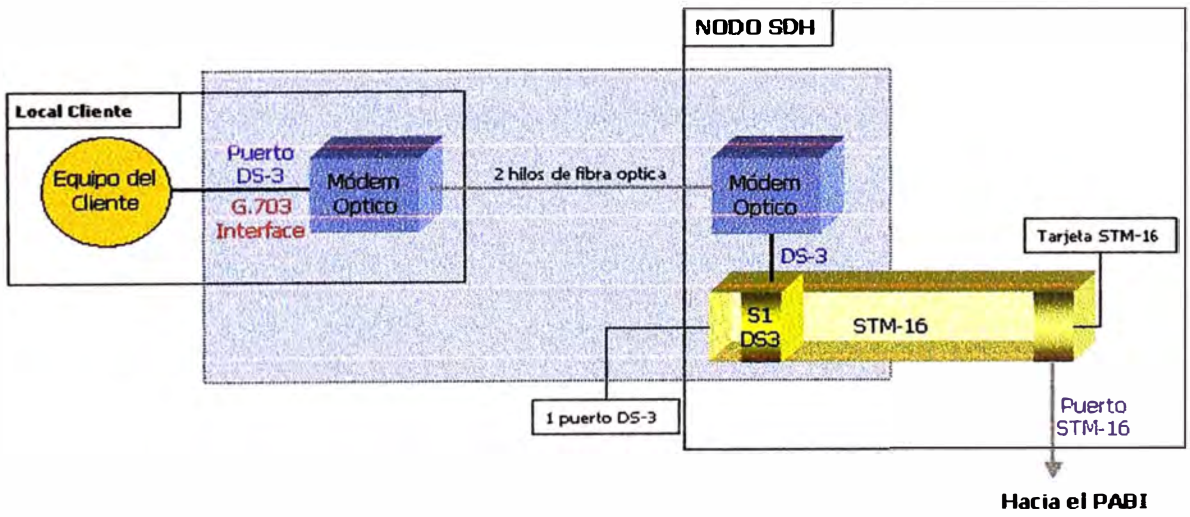


Figura 35 Ultima Milla sin diversidad de ruta de fibra - Caso DS-3

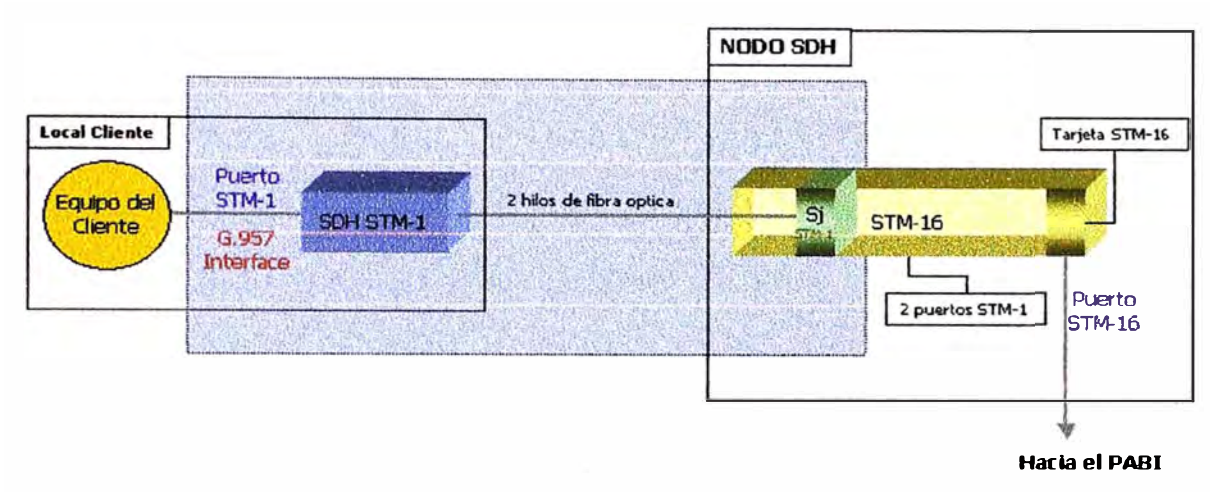


Figura 36 Ultima Milla sin diversidad de ruta de fibra - Caso STM-1

En esta modalidad, de acuerdo a la velocidad de transmisión del circuito solo cambia el tipo de equipo de equipo terminal y el puerto empleado en el nodo SDH de acceso. El circuito es configurado en el Centro de Gestión y luego pasa a las pruebas de transmisión convencionales (B.E.R. de 24 horas). Una vez aceptado el circuito local, pasa al PABI para su respectiva conexión en el POP del PABI.

4.2.3.5.2 Ultima Milla con redundancia de ruta de fibra a un mismo nodo

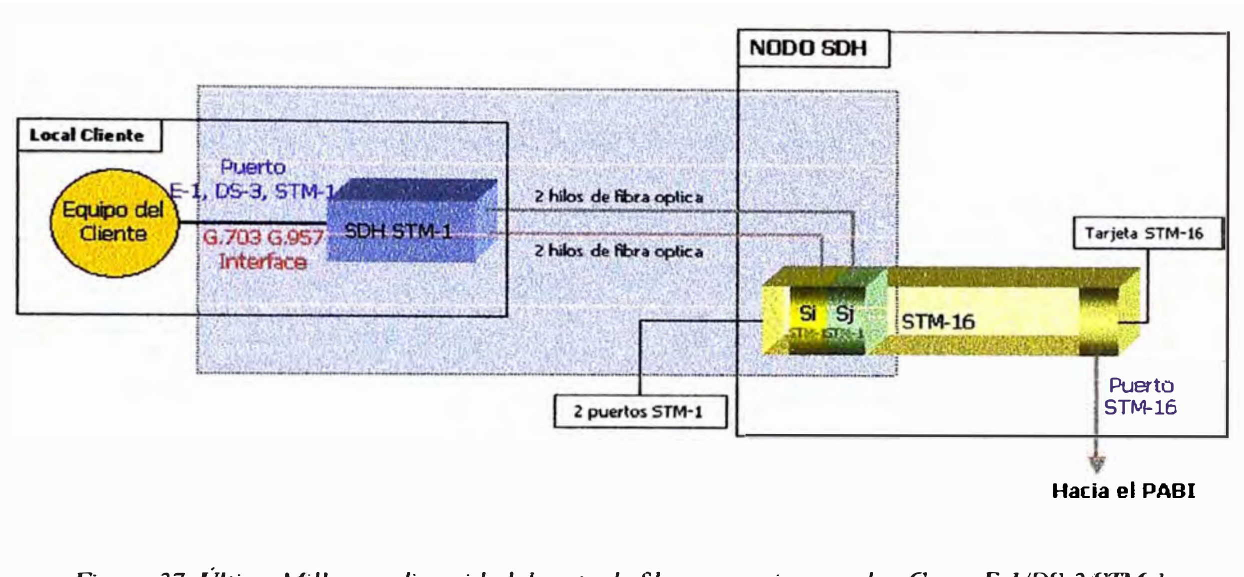


Figura 37 Última Milla con diversidad de ruta de fibra a un mismo nodo - Casos E-1/DS-3/STM-1

En este caso el mismo equipo terminal es empleado para brindar el servicio a diferentes velocidades (E-1, DS-3 y STM-1), es más, pueden brindarse combinaciones de diferentes circuitos hasta alcanzar la capacidad de puertos disponible y/o la matriz de conmutación del equipo terminal.

Esta opción suele ser empleada para capacidades iguales o mayores a DS-3, sin embargo también puede aplicarse para el caso de E-1s.

4.2.3.5.3 Ultima Milla con redundancia de ruta de fibra a dos nodos

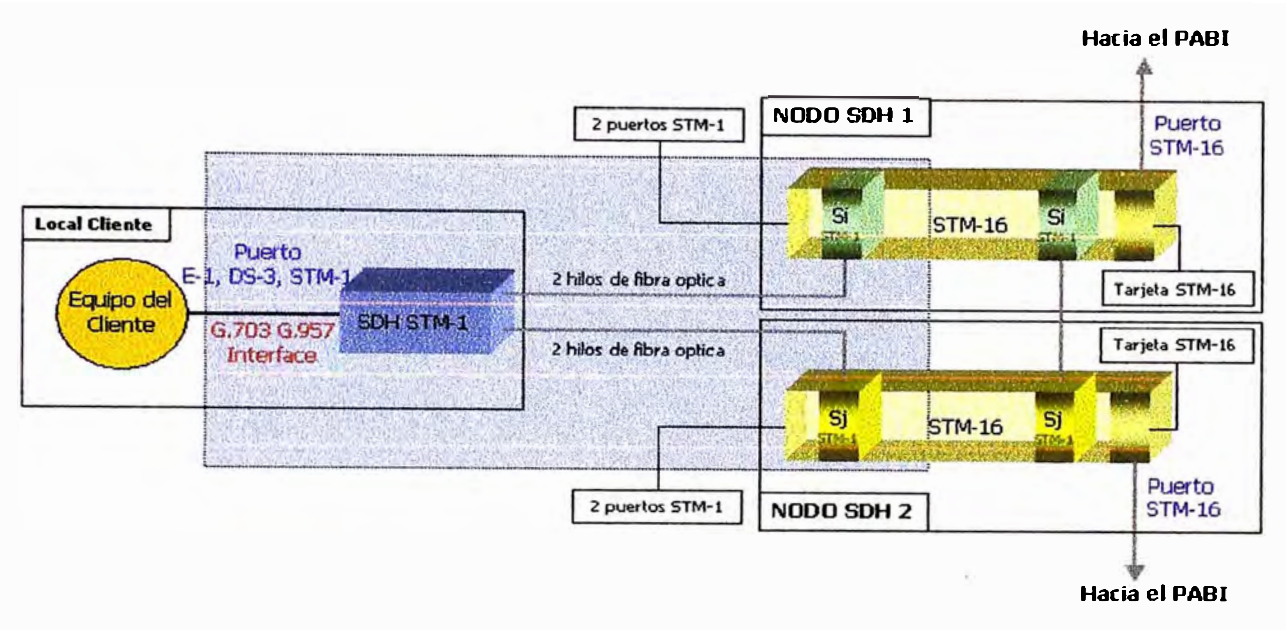


Figura 38 Última Milla con diversidad de ruta de fibra a dos nodos - Casos E-1/DS-3/STM-1

Igual que en el anterior caso, el mismo equipo terminal es empleado para brindar el servicio a diferentes velocidades (E-1, DS-3 y STM-1). También pueden brindarse combinaciones de diferentes circuitos hasta alcanzar la capacidad de puertos disponible y/o la matriz de conmutación del equipo terminal.

La diferencia sustancial con la opción anterior es el mayor uso de recursos de la Red Metropolitana SDH, pues se requiere emplear dos puertos STM-1 adicionales (uno en cada nodo SDH) y un enlace de fibra extra, lo cual además de encarecer la solución, hace que la capacidad de los nodos SDH se reduzca rápidamente.

Esta opción suele ser mucho más cara que la anterior, pero brinda una mayor confiabilidad del servicio, por lo que es solicitada únicamente por importantes Operadores Internacionales ("Carriers") que buscan alcanzar sus altos estándares de calidad (en inglés "brand certification").

CONCLUSIONES

Debido a la caída de costos y la creciente penetración en el sector de la Larga Distancia, DWDM está ahora empezando a migrar hacia las arenas de las MON, por lo que éstas emergen rápidamente como soluciones viables y de costo efectivo para muchos Operadores en todo el mundo, quienes están afrontando un rápido crecimiento de la demanda y de los elevados costos en expansión de fibra. Como esta tendencia continua, muchos temas que están más relacionados a las MON están empezando a emerger. Esto incluye la necesidad por transparencia y diversidad de protocolos adicionales, reducidos costos de entrada, compatibilidad con la tecnología anterior y facilidad de migración, así como rápidas y flexibles estrategias de provisionamiento, entre otras.

Para lograr un mejor entendimiento de este excitante y nuevo campo de las redes ópticas, se requieren examinar cuidadosamente varios temas. Este documento ha buscado dar una introducción a este nuevo escenario y muestra las tendencias y motivos que han empujado y mueven a los proveedores de tecnología a ir en este camino.

Sin embargo, quedan aún varias preguntas que podrían formar parte de otro trabajo de investigación e ingeniería mucho más profundo en el campo de las MON:

- **Paradigmas del provisionamiento de los servicios.**

  ¿Qué protocolos y servicios son transportados en las MONs, y cuál es su impacto en la arquitectura de la red? Esto incluye tanto IP-internetworking y Arquitecturas multi-protocolo.

- **Estrategias para el diseño de topologías.**

  ¿Qué topologías de MON son las mejores, las más escalables y los escenarios evolutivos probables (por ejemplo: anillo, mallas, híbridos) para lograr un costo efectivo de implementación y operación?

  ¿Qué escenarios intermedios de migración son viables?

- **Provisionamiento de Canales.**

  ¿Cuáles son las restricciones para el ruteo en las MON y la asignación de longitudes de onda y como se diferencian de las redes de Larga Distancia (Ejemplo: degradaciones analógicas, pendientes en la topología)?

  ¿Cómo se puede obtener un costo efectivo en la conversión de longitudes de onda?

- **Ingeniería de Tráfico.**

  Dado el creciente predominio del tráfico de datos:

  ¿Qué recursos y algoritmos de ingeniería de tráfico dinámico son requeridos?

  ¿Cómo pueden éstos ser combinados con ingeniería de trafico de alto nivel (ejemplo: IP-MPLS)?

  Adicionalmente, dada la abundancia de velocidades de enlace o canales sub-rate:

  ¿Qué tipos de técnicas de agregación de tráfico de borde (por ejemplo: "sub-wavelength" multiplexing) se requieren para maximizar la utilización de los recursos (incluso entre protocolos basados en paquetes y circuitos)?

- **Esquema de supervivencia de las MON.**

  ¿Qué tipos de algoritmos son los más adecuados para ser empleados (protección, restauración, ambos)?

  ¿Qué tipos de esquemas de detección de fallas son los más viables para redes metropolitanas?

  ¿Cuánta translucidez es necesaria para obtener el nivel requerido de protección y restauración?

- **Arquitectura de Gestión de Red.**

  Dada la amplia base de protocolos de cliente a ser transportados:

  ¿Qué tipos de arquitectura de gestión de red deberían ser usadas?

  ¿Cómo tales sistemas se interconectarían con los esquemas de supervivencia y de ruteo de canales?

- **Implementaciones de prueba**

  Redes de prueba y proyectos experimentales relacionados.

Aunque en el caso peruano las redes metropolitanas tradicionales SDH siguen siendo aún las más recomendables desde el punto de vista técnico-económico, básicamente por la demanda del mercado metropolitano de Lima relacionada con la situación económica del país, esto no debe impedirnos ver más allá y estar siempre pendientes de lo que viene y pueda aplicarse en un futuro cercano en nuestro medio.

Considerando que con el tiempo la tecnología DWDM metro reduzca considerablemente sus precios, como toda tecnología puesta en marcha, no será extraño suponer que tengamos que migrar hacia esta nueva tecnología abrumados por la gran diversidad de nuevas aplicaciones, por lo que debemos estar preparados para ello y satisfacer así, de una manera eficiente, las necesidades del mercado.

ANEXO A

“PRINCIPIOS DE SDH”

Contents

Section 1 SDH Overview

Objectives:

To understand the background of SDH——Why did SDH transmission system emerge?

To understand the advantages and disadvantages of SDH system .

To understand the general concept of SDH for future further study.

1.1 Technical Background of SDH ---- Why did SDH transmission system emerge?

Before learning SDH transmission system, we must understand the concept of SDH. What is SDH? SDH is the abbreviation of Synchronous Digital Hierarchy. Like PDH —– plesiochronous digital hierarchy, SDH is a transmission system (protocol) which defines the characteristic of digital signals, including frame structure, multiplexing method, digital rates hierarchy, and interface code pattern, and so on.

What is the technical background for the emergence of SDH?

As we know, this is a society of informaton. A highly developed information society demands a telecommunication network which can provide a variety of telecommunication services. The information transmitted, switched and processed via the telecommunication network will steadily increase. This requires modern telecommunication networks to be digital, integrate, intelligent and personal.

As an important part of the telecommunication network, the transmission system directly affects the development of the network. Countries all over the world are now making great efforts in building information highways. One of the key projects of the information highway is to establish high-capacity optical fiber transmission networks and to broaden the bandwidth so as to increase signal rates in the transmission lines. This like expanding highways for large traffic flows. Meanwhile, subscribers expect a universal interface standard for telěcommunication networks so that each subscriber in our "global village" can easily communicate at any time and any place.

As the multiplexing method of the transmission network established on the traditional PDH system can not satisfy the requirements of high-capacity transimission and regional standards of the PDH system make it difficult for networks interconnection, PDH system is becoming a more and more serious "bottleneck" of modern telecommunication network which restrains the rapid development of the network towards large capacity and standardization.

The disadvantages of traditional PDH transmission system are as follows:1. Interface

1) There are only some regional provisions, instead of universal standards for electrical interface. The present PDH digital signal hierarchy has three rate levels: European Series, North American Series and Japanese Series. Each of them has different electrical interface rate levels, frame structures and multiplexing methods. This makes it difficult for international interconnection and is far behind the development trend of convenient communication at any time and place. The rate levels of electrical interface of these three signals are shown in Figure 1-1.

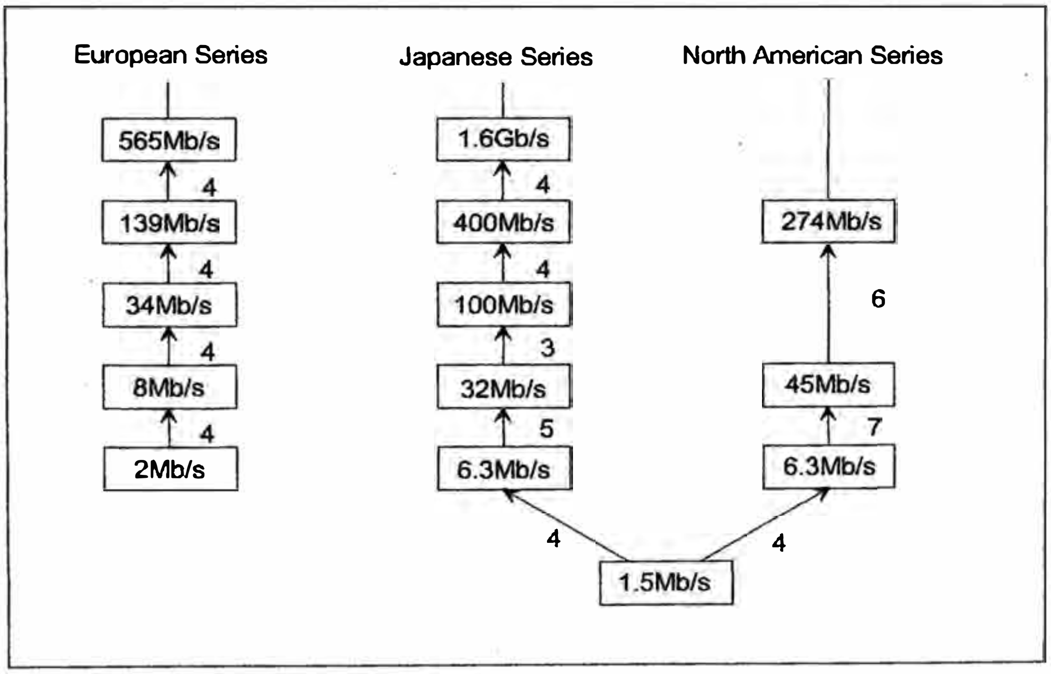


Figure 1-1 The rate hierarchy diagram of electrical interfaces

2) No universal standards for optical interfaces. All PDH equipment manufacturers use their own line codes to monitor the transmission performance in the optical links. A typical example is mBnB code, of which mB is the information code

and nB is the redundancy code. The function of the redundancy code is to realize the monitoring function of the equipment over the transmission performances of the links. Due to the insertion of redundancy codes, the signal rate of optical interface is higher than the standard signal rate of electrical interface of the same rate level. This not only increases the power penalty of the transmitter, but also results in incompatibility of equipment provided by different vendors. Because manufactures add different redundancy codes next to the information codes during line coding in order to achieve line monitoring functions, the optical interface code patterns and rates of the same rate levels employed by different manufactures are different. So equipment at the two ends of a transmission link must be provided by the same vendor. This cause many difficulties for network structuring, management and network interconnection.

2. Multiplexing method

In the present PDH system, only 1.5Mb/s and 2Mb/s rate signals (including Japanese Series 6.3Mb/s rate signal) are synchronous. All other signals are asynchronous and require code rate justification for matching and accepting clock difference. As PDH adopts asynchronous multiplexing method, the locations of the low-rate signals are not regular nor fixed when they are multiplexed into higher-rate signals. That is to say, the locations of the lower signals are unable to be identified from the higher speed signals. But this is the key to directly add/drop lower speed signals from the higher speed signals. This is the same when looking for a stranger in a crowd. You can easily find him if you know which line and which row he stays in when the crowd is arranged in an specific order. But if the crowd is in a mess, you have to compare each person with the photo to locate the man.

Since PDH adopts asynchronous multiplexing method, low-rate signals can not be directly added/dropped from PDH high-rate signals. For example, 2Mb/s signals can not be directly added/droped from 140Mb/s signals. Here arises two problems:

1) Adding/dropping low-rate signals from high-rate signals must be conducted level by level. For example, to add/drop 2Mb/s low-rate signals from 140Mb/s signals, the following procedures must be conducted. (Figure 1-2):

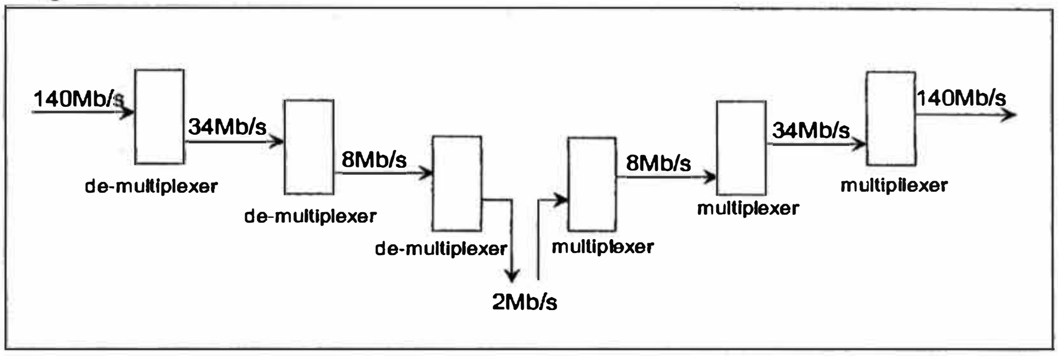


Figure 1-2 Add/drop 2Mb/s signals from 140Mb/s signals

As shown in the figure, lots of "back-to-back" equipment are used during the process of adding/dropping 2Mb/s signals from 140Mb/s signals. Three stages of de-multiplexing equipment are used to drop 2Mb/s low-rate signals from 140Mb/s signals and then three stages of multiplexing equipment are used to add 2Mb/s low-rate signals into 140Mb/s signals. One 140Mb/s signal can be multiplexed into 64 2Mb/s low-rate signals. Multiplexing and de-multiplexing equipment in all three stages are required to add/drop even one 2Mb/s signal from 140Mb/s signals. This not only enlarges the size and increases cost, power consumption and complexity of equipment, but also decreases the reliability of the equipment.

2) Since adding/dropping low-rate signals to high-rate ones must go through many stages of multiplexing and de-multiplexing , impairment to the signals during multiplexing/de-multiplexing processes will increase and transmission performance will deteriorate. This is unbearable in large capacity transmission. That's the reason why the transmission rate of PDH system has not being improved further.

3. Operation maintenance

In the frame structure of PDH signals, there are few overhead bytes used for operation, administration and maintenance (OAM). This is the reason why redundancy codes must be added during optical line coding for the equipment so as to fulfill the monitoring function over line performance. The fact that few overhead bytes are used for the OAM of PDH signals is also a disadvantage for layered management, performance monitoring, real-time service dispatching, bandwidth control, and alarm analyzing and locating of the transmission network.

4. No universal network management interface

When buying a set of equipment from a vendor, you have to buy its network management system. So different parts of the network may use different network mãñagement systems, which are obstacles in forming an integrated. telecommunication management system (TMN).

Because of the above-mentioned disadvantages, the PDH transmission system increasingly impedes the development of transmission network. Therefore, Bell Telecommunication Research Institute in the U.S. first proposed the synchronous optical network (SONET) hierarchy cosisting of a complete set of standard digital transfer structures divided into different levels. The concept of SONET was accepted by CCITT in 1988, and renamed as synchronous digital hierarchy (SDH). SDH is a general technique system both for optical fiber transmission and for microwave and satellite transmission. This course focuses on the applications of the SDH system on optical fiber transmission networks.

? **Questions:**

Maybe you've already learned from some materials that for SDH signals low-rate signals can be directly dropped from high-rate signals, e. g., 2Mb/s signals can be directly dropped from 2.5G signals. Why? This characteristic is related to the special synchronous multiplexing method of SDH. Since SDH adopts synchronous multiplexing method, the location of the low-rate signals in the high-rate signal frame can be predicted. So it is easy to directly drop low-rate signals from high-rate ones.

1.2 Advantages of SDH over PDH

Since SDH transmission system evolves from PDH, it has unparalleled advantages over PDH. Compared with PDH, it is a new transmission system that has made radical revolution in technical system.

First, we wil discuss the basic concept of SDH. The core of this concept is, in view of an integrated national telecommunication network and international intercommunication, to establish digital telecommunication networks, and to make up important parts of integrated services digital networks (ISDN), especially broad-band integrated services digital network (B-ISDN). How to undstand this concept? Different from traditional PDH, the network based on SDH system is a highly uniform, standardized and intelligent network. It uses universal interfaces to achieve compatibility with different equipment from different vendors. It also boasts of highly efficient and coordinated management and operation through out the whole network and transmission process, flexible networking and traffic dispatching, and network self-healing function. It greatly enhances the utilization ratio of network resources and reduces the OAM costs due to the enhanced maintenance function.

Now we will give detail advantages of SDH (they can be regarded as the features of SDH) in several aspects. Please make comparison with PDH system when reading.

1. Interface

1) Electrical interface

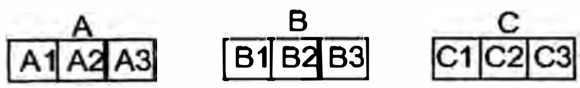
Standardization of interfaces determines the possibility of interconnection among different equipment from different vedors. SDH system provides universal standards for network node interfaces (NNI), including sdandards on digital signal rate level, frame structure, multiplexing method, line interface, monitoring and management, etc.. So SDH equipment of diffenrent vendors can be easily interconnected, i.e. equipment from different vendors can be installed on the same line, which fully demonstrates the system compatibility.

SDH system provides a set of standard information structure levels, i.e. a set of standard rate levels. The basic signal transmission structure level is a synchronous transfer module --- STM-1 at a rate of 155Mb/s. Digital signal hierarchies of higher levels such as 622Mb/s (STM-4) and 2.5Gb/s (STM-16) can be formed by low-rate information modules (e.g. STM-1) via byte interleaved multiplexing. The number of modules to be multiplexed is a multiple of 4. For example, STM-4=4xSTM-1 and STM-16=4xSTM-4.

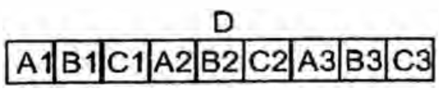
Technical details:

What is byte interleaved multiplexing method?

We can explain it by the following example. There are three signals with the frame structure of 3 bytes in each frame.



If signal D is formed by byte interleaved multiplexing method, it will have a frame structure of 9 bytes in each frame and these 9 bytes are arranged in the order as shown in the following figure:



This multiplexing method is called byte interleaved multiplexing method.

2) Optical interface

Line interfaces (here refers to optical interface) adopt universal standards. Line coding of SDH signals are only scrambling, insteand of inserting redundancy codes.

The standard for scrambling is universal. Therefore the opposite-terminal equipment can be interconnected with SDH equipment of different vendors via standard descrambler alone. The purpose of scrambling is to make the probability of "1" bits and "0" bits occurence gets close to 50% so as to extract clock signals from line signals. As line signals are scrambled only, the line signal rates of SDH are the same with the standard signal rates of the SDH electrical interface. This will not add extra optical power penalty to the transmitting laser.

2. Multiplexing method

As low-rate SDH signals are multiplexed into the frame structure of high-rate SDH signals via byte interleaved multiplexing method, their locations in the frame of high-rate SDH signal are fixed and regular, or say, predictable. Therefore, low-rate SDH signals, e.g. 155Mb/s, (STM-1), can be directly added to or dropped from high-rate signals, e.g., 2.5Gb/s (STM-16). This simplifies the multiplexing and de-multiplexing processes of signals and makes SDH hierarchy especially suitable for high rate and large capacity optical fiber transmission systems.

As synchronous multiplexing method and flexible mapping structure are employed, PDH low-rate tributary signals (e.g., 2Mb/s) can also be multiplexed into SDH signal frame (STM-N). Their locations in STM-N frame are also predictable. So low-rate tributary signals can be directly added to or dropped from STM-N signals. Note that this is different from the above process of directly adding/dropping low-rate SDH signals to/from high-rate SDH signals. Here it refers to direct adding/dropping of low-rate tributary signals, such as 2Mb/s, 34Mb/s, and 140Mb/s, to/from SDH signals. This saves lots of multiplexing/de-multiplexing equipment (back-to-back equipment), enhances reliability, and reduces signal impairment, and the cost, power consumption and complexity of the equipment. Adding/dropping of services is futher symplified.

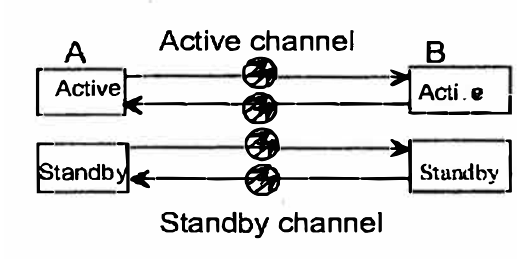
This multiplexing method of SDH helps to fulfill the funciton of digital cross-connection (DXC), and provides the network with powerful self-healing function. Subscribers can dynamically implement networking according to needs and perform real-time traffic dispatching.

Technical details:

What is the network self-healing function?

Network self-healing refers to the automatic protection switching of the network. When service is interrupted due to traffic channel damage, the network will automatically switch to standby traffic channel so that the service can be restored to normal transmission state in a short time (less than 50ms as defined by ITU-T). Please note that self-healing merely restores the services. The fault equipment and channel must be repaired manually.

To achieve network self-healing function, the SDH equipment shall possess not only the DXC function (for switching the service from the active channel to the standby channel), but also redundancy channels (standby channels) and redundancy equipment (standby equipment). The following is a simple example of a transmission network with self-healing function.



3. Operation, administration and maintenance

Abundant overhead bits for operation, administration and maintenance (OAM) function are arranged in the frame structures of SDH signals. This greatly enforces the network monitoring function, i.e. automatic maintenance. Some redundancy bits must be added during line coding for line performance monitoring because few overhead bytes are arranged in PDH signals. For example, in the frame structure of PCM30/32 signals, only the bits in TS0 and TS16 time slots are used for OAM function.

The abundant overheads in SDH signals account for 1/20 of the total bytes in a frame. It greatly enhances the OAM function and reduces the cost of system maintenance which occupies most of the overall cost of telecommunication equipments. The overall cost of SDH system is less than that of PDH system and estimated to be only 65.8% of that of the later.

4. Compatibility

SDH has high compatibility, which means that the SDH transmission network and the existing PDH transmission network can work together while establishing SDH transimission network. SDH network can be used for transmitting PDH services, as well as signals of other hierarchies, such as asynchronous transfer mode (ATM) signals and FDDI signals.

How does the SDH transmission network achieve such compatibility? The basic transfer module (STM-1) of SDH signals in SDH network can accommodate three PDH digital signal hierarchies and other hierarchies such as ATM, FDDI and DQDB. This reflects the forward and backward compatibility of SDH and guarantees smooth transitions from PDH to SDH network and from SDH to ATM. How does SDH accommodate signals of these hierarchies? It simply multiplexes the low-rate signals of different hierarchies into the frame structure of the STM-1 signals at the boundary of the network (e.g. SDH/PDH start point) and then de-multiplexes them at the boundary of the network (end point). In this way, digital signals of different hierarchies can be transmitted in the SDH transmission network.

Tips:

In SDH network, the SDH signal functions as a transport truck. It packs the signals of different hierarchies (refering to PDH signals in this course) into packages of different sizes (rate levels) like packing cargoes, and then loads them onto the truck (STM-N frame) for transmission on SDH main trunk (fiber). At the receiving end, it unloads the packed cargoes (signals of other hierarchies) from the truck, unpacks and restores them to the signals of original hierarchies. This describes the whole process of multiplexing low-rate signals of different hierarchies into SDH signals (STM-N), transmitting on the SDH network and disassembling into signals of their original hierarchies.

1.3 Disadvantages of SDH

One gain, one loss. The above advantages of SDH are achieved at the cost of certain aspects.

1. Low bandwidth utilization ratio

As we know, effectiveness usually contradicts with reliability. Effectiveness increases at the cost of reliability, and vice versa. For instance, as selectivity of a radio increases, the available channels increase either. But the reliability will decrease because the passband becomes narrower and tone quality deteriorates as a result. One significant advantage of SDH is that system reliability is greatly enhanced (highly automatic OAM) since many overhead bytes for OAM function are employed in SDH signals --- STM-N frame. To transmit the same amount of valid information, PDH signals occupy less frequency bandwidth (transmission rate) than SDH signals, i.e. PDH signals use lower rate. For example, SDH STM-1 signals can be multiplexed into 63 2Mb/s or 3 34Mb/s (equal to 48 × 2Mb/s) or 1 140Mb/s (equal to 64 × 2Mb/s) PDH signals. Only when multiplexing PDH signals into STM-1 signal frame with 140Mb/s signals can the STM-1 signal accommodate the information content of 64 × 2Mb/s. Its rate, up to 155Mb/s, is higher than PDH E4 signal (140Mb/s) containing the same amount of information. In other words, STM-1 occupies a frequency bandwidth larger than that needed by PDH E4 signals (they have the same amount of information).

2. Complex mechanism of pointer justification

By directly dropping low-rate signals (e.g. 2Mb/s) from high-rate signals (e.g. STM-1), SDH system eliminates the complex procedures of multilevel multiplexing/de-multiplexing. Such a function is achieved via pointer justification The pointer constantly indicates the location of low-rate signals so that specific low-rate signals can be properly de-multiplexed in time of "unpacking".

However, the pointer function increases the complexity of the system. Most of all, it generates a kind of special jitter in SDH system ---- a combined jitter caused by pointer justification. Such jitter usually occurs on the boundary of networks (SDH/PDH). Due to its low frequency and high amplitude, this jitter will deteriorateion the performance of low-rate signals being de-multiplexed. And such jitter is difficult to be filtered.

3. Influence of excessive use of software on system security

One of the features of SDH is its highly automatic OAM, which means that software constitutes a large proportiong in the system. As a result, SDH system is vulnerable to computer viruses which are rampant in modern world. In addition, manual misoperation and software fault on network layer are also fatal to the system. Security becomes a main consideration of the system.

SDH hierarchy is a new thing. In spite of such-and-such disadvantages, SDH has shown powerful vitality in the development of transmission networks. The transition of the transmission networkds from PDH to SDH is definitely inevitable.

Questions:

What have you learned from this section?

1. What is SDH?
2. Why did the SDH transmission system emerge?
3. What are the advantages of SDH, compared with PDH?
4. What are the disadvantages of SDH?

Have you got a general concept of SDH in mind?

Summary

This section gives the technical background of the emargence of SDH system and the characteristics of SDH system. Its main purpose is to help readers to establish a general concept of SDH.

Exercises

1. Why is the SDH system suitable for large capacity transmission?

Section 2 The Frame Structure and Multiplexing Method of SDH Signals

Objectives:

To understand the frame structure of STM－N signals (taking the example of the frame structure of STM－1 signals).

To understand the basic functions of different parts of the STM-N signal frame.

To understand the entire procedures of multiplexing 2Mb/s, 34Mb/s and 140Mb/s signals into STM－N signals.

To understand the concepts of multiplexing and mapping.

2.1 SDH Signal——STM－N Frame Structure

What kind of frame structure do SDH signals need?

The arrangement of the frame structure shall ensure that the low-rate tributary signals are allocated as evenly and regularly in the frame as possible. Because this makes it easier to implement synchronous multiplexing, cross-connection (DXC), add/drop, and switching of tributaries. In a word, this arrangement facilitates direct adding/dropping of low-rate tributary signals to/from high-rate signals. Therefore, ITU-T defines the frame of STM-N as rectangle block frames structures in unit of byte (8bit), as illustrated in Figure 2-1.

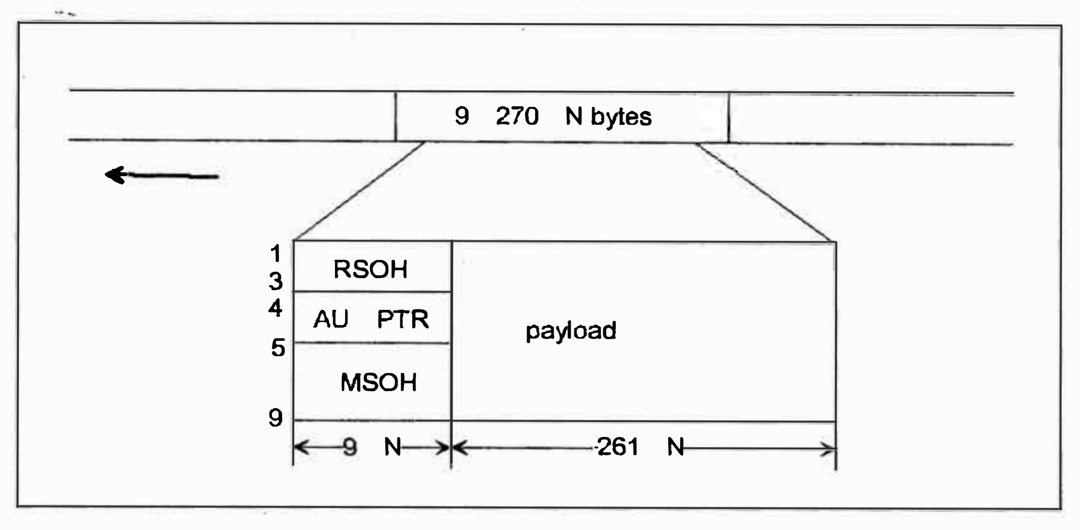


Figure 2-1 STM-N frame structure

Tips:

What is a block frame?

For the convenience of signal analysis, the frame structures of the signals are often illustrated as block frame structures. This is not the unique structure of SDH signals. The frame structures of PDH signals, ATM signals and data packets of packet switching are also block frames. For example, the frame of E1 signals is a block frame of 1 row × 32 columns consisting of 32 bytes. ATM signals have a block frame structure of 53 bytes. To illustrate frames structures of signals as block frames is merely for the convenience of analysis.

As shown in the above figure, the frame structure of STM-N signals is 9 rows × 270 × N columns. The N here is equal to the N in STM-N, ranging from 1, 4, 16, 64,……. The N indicates that this signal is multiplexed by N STM-1 signals via byte interleaved multiplexing. This explains that the frame structure of STM-1 signals is a block structure of 9 rows × 270 columns. When N STM-1 signals are multiplexed into STM-N signal via byte interleaved multiplexing, only the columns of STM-1 signals are multiplexed via byte interleaved multiplexing. While the number of rows remains constantly to be 9.

It is known that signals are transmitted bit-by-bit in lines. But how is the block frame transmitted in the line? Is the entire block transmitted simultaneously? Of course not. STM-N signals are also transmitted bit-by-bit. Then what is the sequence of transmission? Which bits are transmitted first and which later? The principle for SDH signal frame transmission is: the bytes (8-bit) within the frame structure is transmitted bit-by-bit from left to right and from top to bottom. After one row is transmitted, the next row will follow. After one frame is completed, the next frame will start.

What is the frame frequency (i.e. the number of frames transmitted per second) for STM-N signals? ITU-T defines the frequency to be 8000 frames per second for all levels in STM hierarchy. That means the frame length or frame period is a constant value of 125us. Maybe 8000 frames per second is familiar to you, because E1 signals of PDH also have the frequency of 8000 frames per second.

Note that all frame frequencies of any STM hierarchical levels are 8000 frames per second. Constant frame period is a major characteristic of SDH signals. Are the frame periods of signals of different PDH hierarchical levels also the same? The constant frame period makes the rates of STM-N signals regular. For example, the data rate of STM-4 transmission is constantly 4 times as that of STM-1, and STM—16 is 4 times of STM—4 and 16 times of STM—1. But the rate of E2 signals of PDH is not 4 times as that of E1 signals. Such regularity of SDH signals makes it possible to directly add/drop low-rate SDH signals to/from high-rate SDH signals, especially for high-capacity transmission.

? **Questions:**

What is the bit transmission rate of a single byte of STM－N frames?

The frame frequency of STM-N is 8000 frames per second, i.e. a given byte in the signal frames is transmitted 8000 times per second, so the bit rate of this byte is 8000 × 8bit = 64kb/s. This is also a familiar number which is equal to the transmission rate of one digital telephone line, i.e. the bandwidth occupied by one digital telephone line.

As illustrated in the figure, the frame of STM-N consists of three parts: Section Overhead (including Regenerator Section Overhead --- RSOH and Multiplex Section Overhead --- MSOH), Administrative Unit Pointer--- AU-PTR and Information Payload. Next, we will describe the functions of these three parts.

1) The Information Payload is a place in the STM-N frame structure to store various information code blocks to be transmitted by STM-N. It functions as the "wagon box" of the truck---STM-N. Within the box are packed low-rate signals --- cargoes to be shipped. To rmonitor the possible impairment to the cargoes (the packed low-rate signals) on a real-time basis during transmission, supervisory overhead bytes --- Path Overhead (POH) bytes are added into the signals when the low-rate signals are packed. As one part of payload, the POH, together with the information code blocks, is loaded onto STM-N and

transmitted on the SDH network. The POH is in charge of monitoring, administrating and controlling (somewhat similar to a sensor) the path performances for the packed cargoes (the low-rate signals).

Technical details:

What is a path?

Let's take the following example. STM-1 signals can be multiplexed into 63 × 2Mb/s signals. In other words, STM-1 can be regarded as a transmission path divided into 63 bypaths. Each bypath, which is equal to a low-rate signal path, transmits corresponding low-rate signals. The function of the Path Overhead is to monitor the transmission condition of these bypaths. The 63 2Mb/s paths multiplex and form the path of STM-1 signals which can be regarded as a "section" here. Now do you understand? Paths refer to corrresponding low-rate tributary signals. The function of POH is to monitor the performance of these low-rate signals transmitted via the STM-N on the SDH network.

This is consistent with the analogy in which the STM-N signal is regarded as a truck and the low-rate signals are packed and loaded onto the truck for transmission.

Note:

The Information Payload is not equal to effective load ---- low-rate tributary signals, as the signals loaded in the Information Payload are packed low-rate signals, i.e. low-rate signal plus corresponding POH.

2) The Section Overhead (SOH) refers to the auxiliary bytes which is necessary for network operation, administration and maintenance (OAM) to guarantee normal and flexible transmission of Information Payload. For example, the Section Overhead can monitor the impairment condition of all "cargoes" in STM-N during transmission. The function of POH is to locate the certain impaired cargo in case impairments occurred. SOH implements the overall monitoring of cargoes while the POH monitors a specific cargo. SOH and POH also have some administration functions

The Section Overhead is further classified into Regenerator Section Overhead (RSOH) and Multiplex Section Overhead (MSOH). They respectively monitor their corresponding sections and layers. As mentioned above, section can be regarded as a large transmission path. The function of RSOH and MSOH is to monitor this transmission path.

Then, what's the difference between RSOH and MSOH? In fack, they have different monitoring domains. For example, if 2.5G signals are transmitted in the fiber, the RSOH monitors the overall transmission performance of STM-16 while the MSOH monitors the performances of each STM-1 of the STM-16 signals.

Technical details:

RSOH, MSOH and POH provide SDH signals with monitoring functions for different layers. For a 2.5G system, the RSOH monitors the overall transmission performance of the STM-16 signal; the MSOH monitors the transmission performances of each STM-1 signal; and the POH monitors the transmission performances of each packaged low-rate tributary signal (e.g. 2Mb/s) in STM-1. Through these complete monitoring and management functions for all levels, you can conveniently conduct macro (overall) and micro (individual) supervission over the transmission status of the signal and easily locate and analyze faults.

The Regenerator Section Overhead bytes in a STM-N frame are located within row 1-3 of column 1 to 9 × N, 3 × 9 × N bytes in total .The Multiplex Section Overhead bytes in a STM-N frame are located within row 5-9 of column 1 to 9 × N, 5 × 9 × N bytes in total. Compared with the frame structure of PDH signals, the abundant section overhead is a significant characteristic of the frame structures of SDH signals.

3) Administrative Unit Pointer ---- AU-PTR

The Administrative Unit Pointer within column 9 × N of row 4 of the STM-N frame is, 9 × N bytes in total. What's the function of AU-PTR? We have mentioned before that low-rate tributaries (e.g. 2Mb/s) could be added/dropped directly from high-rate SDH signals. Because the locations of low-rate signals within a high-rate SDH frame structure are predictable, i.e. regular. The predictability can be achieved via the pointer overhead bytes function in the SDH frame structure. The AU-PTR indicates the exact location of the first byte of the information payload within the STM-N frame so that the information payload can be properly extracted at the receiving end according to the value of this location indicator (the value of the pointer) . Let's make it more easier. Suppose that there are many goods stored in a warehouse in unit of pile. Goods (low-rate signals) of each pile are regularly arranged (via byte interleaved multiplexing). We can locate a piece of goods within the the warehouse by only locating the pile this piece of goods belongs to. That is to say, as long as the location of the first piece of goods is known, the precise location of any piece within the pile can be directly located according to the regularity of their arrangement. In this way you can directly carry (directly add/drop) a given piece of goods (low-rate tributary) from the warehouse. The function of AU-PTR is to indicate the location of the first piece of goods within a given pile.

In fact, the pointer is further classified into high order pointer and low order pointer. The high order pointer is AU-PTR while the lower order pointer is TU-PTR (Tributary Unit Pointer). The function of TU-PTR is similar to that of AU-PTR except that the former indicates smaller "piles of goods".

2.2 Multiplexing Structure and Procedures of SDH

SDH multiplexing includes two types: multiplexing of lower-order SDH signals into higher-order SDH signals and multiplexing of low-rate tributary signals (e.g. 2Mb/s, 34Mb/s and 140Mb/s) into SDH signals ----STM-N.

The first type of multiplexing mentioned before is conducted mainly via byte interleaved multiplexing by multiplexing four into one, e.g. 4 × STM — 1 → STM — 4 and 4 × STM — 4 → STM — 16. During the multiplexing, the frame frequency remains unchanged (8000-frame per second), which means that the rate of the higher-level STM-N signals is 4 times that of the next lower-level STM-N signals. During the byte interleaved multiplexing, the information payload and pointer bytes of each frame are multiplexed via interleaved multiplexing based on their original values while some SOH will be accepted or rejected. In a multiplexed STM-N frame, the SOH is not effected via byte interleaved multiplexing with the SOHs of all the lower-order SDH frames. Some SOHs of the lower-order frame are rejected. The detailed multiplexing method will be described in the next section.

The second type of multiplexing is mostly used for multiplexing of PDH signals into the STM-N signals.

ITU-T defined a complete multiplexing structure (i.e. multiplexing routes). Through these routes, digital signals of three PDH hierarchies can be multiplexed into STM-N signals via a variety of methods. The routes defined by ITU-T are illustrated in Figure 2-2.

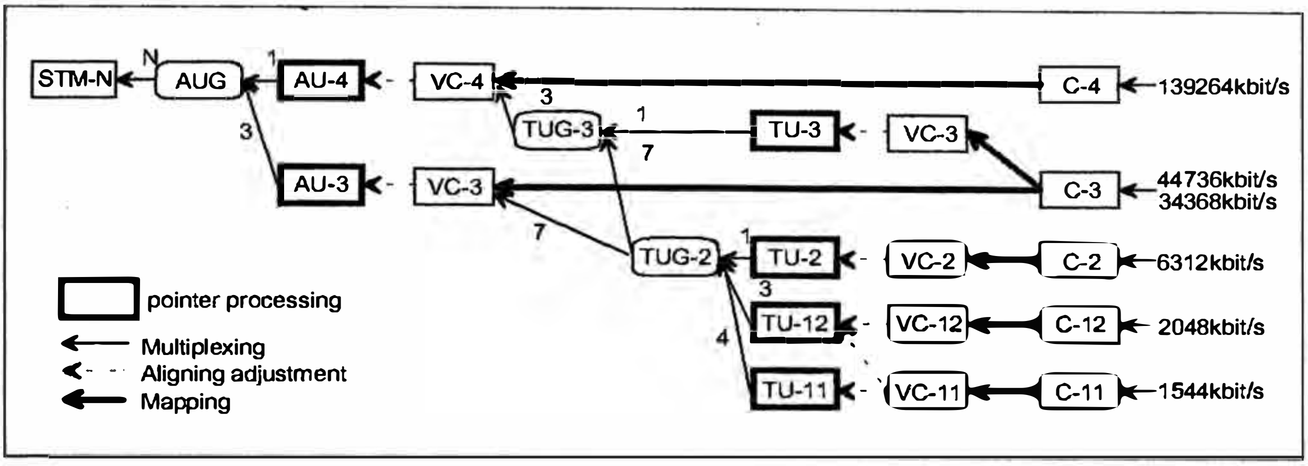


Figure 2-2 The multiplexing mapping structure defined in Rec. G.709

As illustrated in Figure 2-2, this multiplexing structure includes some basic multiplexing units: C - Container, VC - Virtual Container, TU - Tributary Unit, TUG - Tributary Unit Group, AU - Administrative Unit, and AUG - Administrative Unit Group. The suffixes of these multiplexing units denote their corresponding signal levels. As illustrated in the figure, there are several routes (several multiplexing methods) through which a valid payload can be multiplexed into STM-N signals.. For example, there are two multiplexing routes for 2Mb/s signals, i.e. two methods for multiplexing 2Mb/s signals into STM-N signals. You may have noted that 8Mb/s PDH signals can't be multiplexed into STM-N signals.

Although there are several routes for a kind of signals to be multiplexed into SDH STM-N signals, the multiplexing route used in a country or an area must be unique. In China, the SDH optical transmission network technological system stipulates that PDH signals based on 2Mb/s signals shall be regraded as the valid payload of SDH and the multiplexing route of AU-4 shall be employed. This multiplexing route structure is illustrated in Figure 2-3.

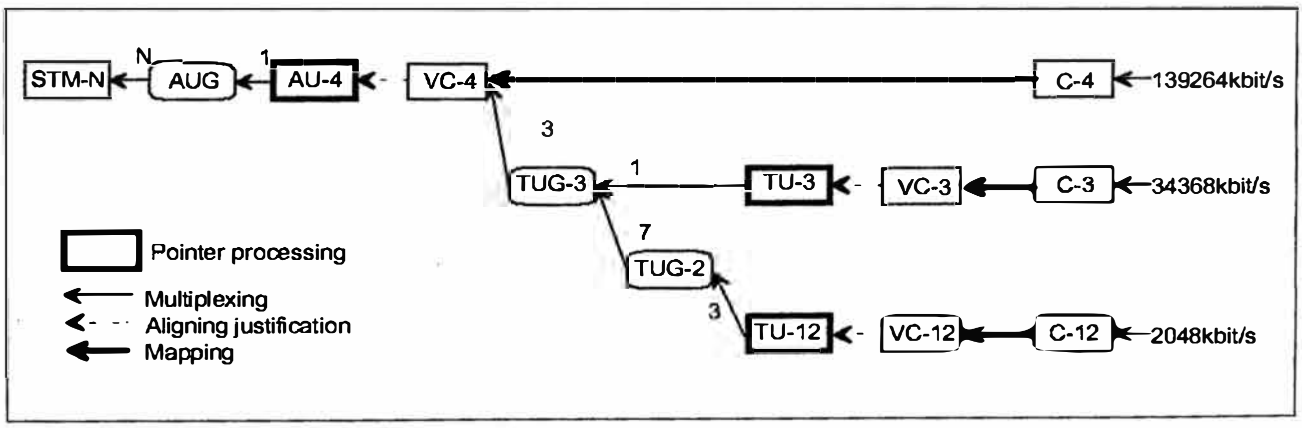


Figure 2-3 Basic multiplexing mapping structure employed in China

Next, we will describe respectively how 2Mb/s, 34Mb/s and 140Mb/s PDH signals are multiplexed into STM-N signals.

2.2.1 Multiplexing of 140Mb/s signals into STM—N signals

1) First, the 140Mb/s PDH signals are adapted via bit rate justification (bit stuffing method) into C4, which is a standard information structure used to accommodate 140Mb/s PDH signals. After being processed via bit rate justification techniques, service signals of various rates involved in SDH multiplexing must be loaded into a standard container corresponding to the rate level of the signal: 2Mb/s——C12, 34Mb/s——C3 and 140Mb/s——C4. The main function of a container is for bit rate justification. Putting 140Mb/s signals into C4 is similar to signal packing. The rate of 140Mb/s signals thus is ajusted to standard C4 rate. This is also similar to the packing of E4 signals in a size equal to standard C4. The frame structure of C4 is block frame in unit of bytes, with the frame frequency of 8000-frame per second. That is to say, the 140Mb/s signals are synchronized to SDH transmission network after being adapted into C4 signals. This process is just like loading C4 to asynchronous 140Mb/s signals. The frame structure of C4 is illustrated in Figure 2-4.

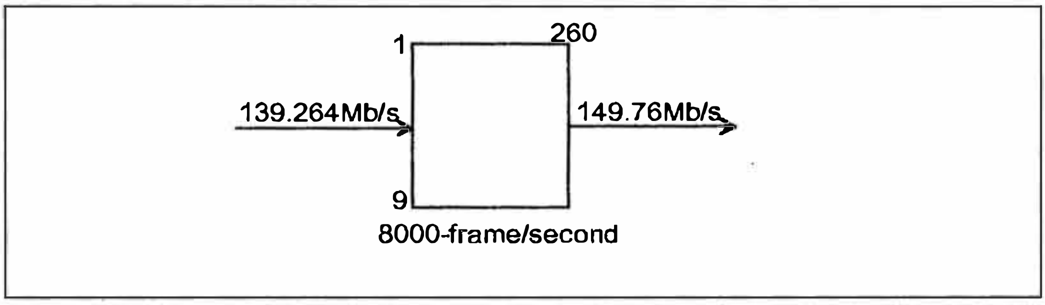


Figure 2-4 C4 frame structure

The frame of C4 signals has 260 columns × 9 rows (the block frame of PDH signals remains constantly to be 9 rows while multiplexing into STM-N). The rate of E4 signal after adaptation (i.e. the rate of C4 signals) is: 8000 frame/second × 9 rows × 260 columns × 8 bits = 149.760Mb/s. Rate adaptation of asynchronous signals means that the rate of asynchronous signals can be changed into standard rate through bit rate justification when they vary within a certain range. Here, the rate range of the E4 signals is: 139.264Mb/s + 15ppm (Rec. G.703 definition) = (139.261 — 139.266)Mb/s. Through rate adaptation, the E4 signals within this rate range can be adjusted into standard C4 rate of 149.760Mb/s, which means that they can be accommodated into C4 containers.

2) A column of path overhead bytes (higher-order path overhead VC4-POH) shall be added in front of the C4 block frame during multiplexing in order to monitor the 140Mb/s path signals. Then the signals become a VC4 information structure, as illustrated in figure 2-5.

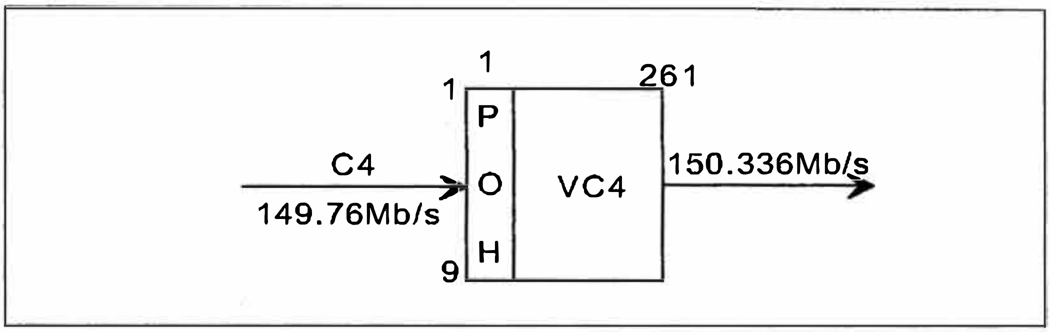


Figure 2-5 VC4 structure

VC4 is a standard virtual container corresponding to 140Mb/s PDH signals. This process is just like enveloping the C4 signals for the second time, so as to enclose the overhead-POH for path monitoring and management into the envelope. The overhead-POH implements real-time monitoring over path signals.

The enveloping rate of the virtual container (VC) is also synchronous with the SDH network. Different VCs (e.g. VC12 for 2Mb/s and VC3 for 34Mb/s) are synchronous with each other. Asynchronous payloads from different containers are allowed to load within the virtual containers. The virtual container, a kind of information structure whose integrity is always maintained during transmission on the SDH network, can be regarded as an independent unit (cargo package). It can be flexibly and conveniently added/dropped at any point of the path for synchronous multiplexing and cross-connection processing.

In fact, it is the VC packet of corresponding signals that is located and added/dropped directly from the high-rate signal. The low-rate tributary signals are added/dropped by packing/unpacking.

When packing C4 into VC4, 9 overhead bytes must be added in the first column of the VC4 frame. Then VC4 has a frame structure of 9 rows × 261 columns. Within STM-N frame structure, the information payload is 9 rows × 261 × N columns. For STM-1, it is 9 rows ×261 columns. Now you might get the idea that VC4 is in fact the information payload of the STM-1 frame. The process of packing PDH signals into C and adding the corresponding path overhead to form the information structure of VC is called mapping.

3) Having been packed into standard packages, the cargoes are now ready to be loaded onto the truck—STM-N. The loading place is the information payload

area. On loading the cargoes (VC) such a problem may be encountered that the locations for the cargoes within the carriage may "float" if the loading speed of cargoes does not match the wait-for-loading time (125us, the frame period of STM-N) of the truck. Then how can cargoes be disassembled correctly at the receiving end? SDH solves this problem by adding an Administrative Unit Pointer -- AU-PTR before the VC4. Thus the signal is changed from VC4 into another information structure-- Administrative Unit AU-4, as illustrated in figure 2-6:

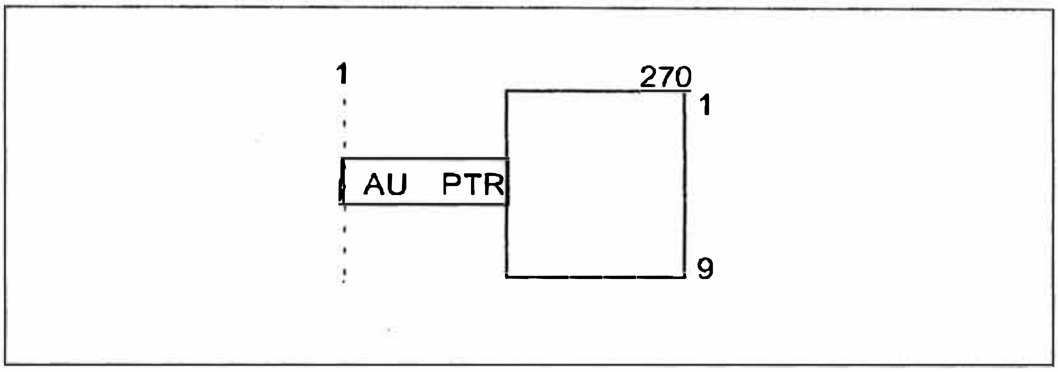


Figure 2-6 AU-4 structure

The information structure AU-4 takes the basic form of STM-1 signals -- 9 rows × 270 columns, only without SOH. In fact, this information structure can be regarded as an envelope of AU-4 ---VC4 packet is enveloped once more (AU-PTR added).

The Administrative Unit, consisting of higher order VC and AU pointer, provides adaptation functions for the higher order path layer and the multiplex section layer. The function of AU-PTR is to indicate the location of the higher order VC within the STM frame, i.e. the specific location of the VC package within the STM-N. Under the pointer function, the higher order VC is allowed to "float" within the STM frame, i.e. the frequency offsets and phase differences to a certain degree between VC4 and AU-4 are tolerable. Or in other words, certain time difference between the loading speed of the cargo and the waiting time of the truck is allowed, i.e. certain difference between the rate of VC4 and the packing rate (loading speed) of AU-4 is allowed. This difference will not affect the correct locating and disassembling of VC4 at the receiving end. Although the package may "float" in the compartment (the information payload area), the location of AU-PTR in the STM frame is fixed. Because the AU-PTR is outside of the payload area and co-located with the section overhead instead. This guarantees that the AU-PTR can be accurately found in the corresponding location. Then the VC4 can be localized by the AU pointer and disassembled from STM-N signals.

One or more AUs with fixed locations within the STM frame form an AUG --- Administrative Unit Group.

4) The last step is to add corresponding SOH to AU-4 to form STM-1 signals. N× STM-1 signals are multiplexed into an STM-N signal via byte interleaved multiplexing.The whole process of multiplexing 140Mb/s into STM－N is illustrated in the attached figure at the end of Section 2.

2.2.2 Multiplexing of 34Mb/s signals into STM－N signals

Similarly, 34Mb/s signals are first adapted into the corresponding standard container -- C3 through bit rate justification. After adding corresponding POH, the C3 is packed into VC3 with the frame structure of 9 rows × 85 columns. For the convenience of locating VC3 at the receiving and separating it from the high-rate signals, a three-byte pointer, TU-PTR (Tributary Unit Pointer), is added to the VC3 frame. Note that an AU-PTR has 9 bytes. This information structure is a tributary unit TU-3 (an information structure corresponding to 34Mb/s signals) serving as a bridge between the lower order path layer (lower-order VC, e.g. VC3) and the higher order path layer. This is a transitional information structure for disassembling the higher order path (higher order VC) into lower order path (lower order VC) or multiplexing the lower order path into the higher order path. For the frame structures of C3 and VC3, refer to the attached figure at the end of Section 2.

Then what is the function of a tributary pointer? The TU-PTR is used to indicate the specific location of the first byte of the lower order VC within the tributary unit TU. It is similar to an AU-PTR which indicates the location of the first byte of the VC4 within the STM frame. Actually, the operating principles of these two kinds of pointers are similar. A TU can be regarded as a small AU-4. Therefore, when loading the lower order VC into the TU, it requires a process of aligning—a process of adding TU-PTR.

The frame structure --- TU-3 is illustrated in Figure 2-7.

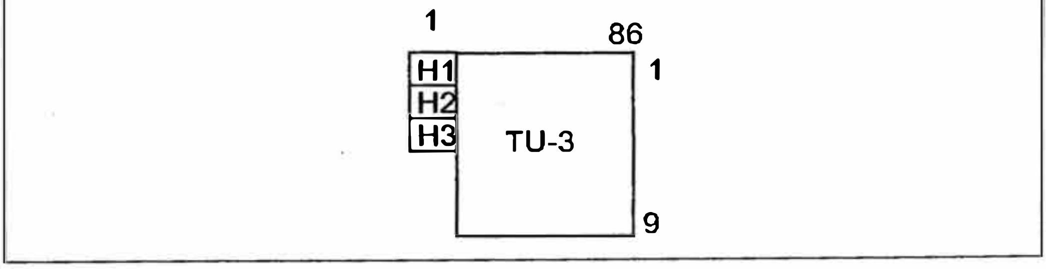


Figure 2-7 The TU-3 structure after the loading TU-PTR

1) The TU-3 frame structure is imcomplete. First fill the gap to form the frame structure as illustrated in Figure 2-8.

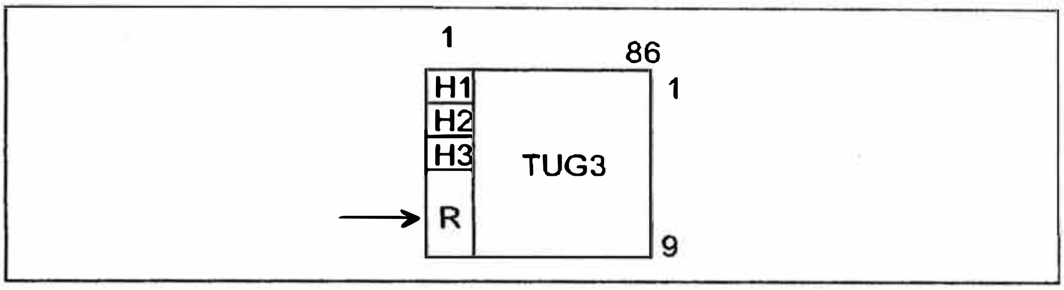


Figure 2-8 The TU-3 frame structure with the gap filled

In this figure, the R is the stuffed pseudo-random data. The information structure is TUG3 ---- Tributary Unit Group.

2) Three TUG3 can be multiplexed into the C4 signal structure via byte interleaved multiplexing method. The process of multiplexing is illustrated in Figure 2-9.

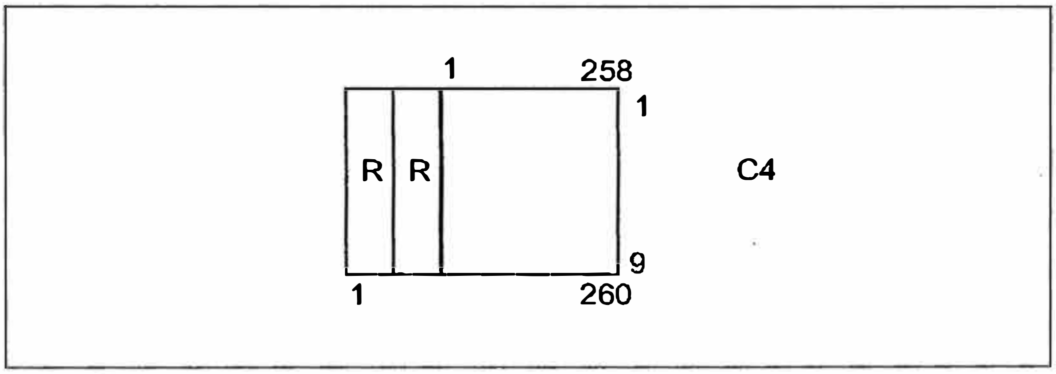


Figure 2-9 The frame structure of C4

Since the TUG3 is an information structure of 9 rows × 86 columns, the information structure composed of three TUG3 via byte interleaved multiplexing is a block frame structure of 9 rows × 258 columns. While C4 is a block frame structure of 9 rows × 260 columns. Two columns of stuffed bits are added to the front of the composite structure of 3 × TUG3 to form a C4 information structure.

The last step is to multiplex C4 into STM-N. This is similar to the process of multiplexing 140Mb/s signals into STM-N signals: C4→VC4→AU—4→AUG→STM—N.

? **Questions:**

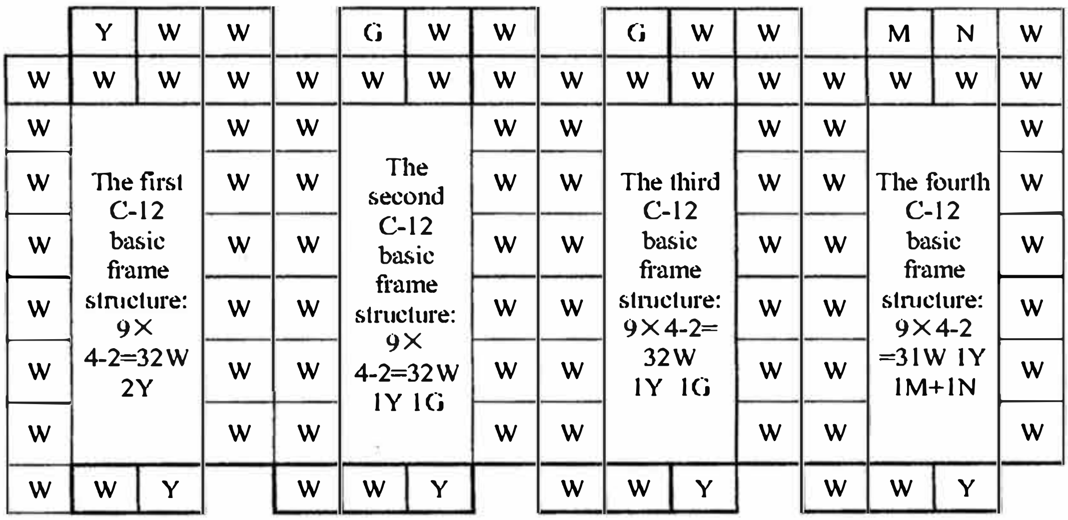
Do you undstand why two pointers AU-PTR and TU-PTR are used here? These two pointers provide aligning functions on two stages. The AU-PTR provides the function of correct aligning and separating of VC4 at the receiving end. Since a VC4 can accommodate three VC3, (Can you figure out why it is 3?), the TU-PTR correspondingly locates the specific location of the first bit of each VC3. At the receiving the VC4 is located via the AU-PTR, and TUG3 is demultiplexed from VC4 by the regularity of byte interleaved multiplexing. The VC3 is located via the corresponding TU-PTR and can be disassembled from TU-3. Then 34Mb/s signals can be dropped

2.2.3 Multiplexing of 2Mb/s signals into STM—N signals

At present, the most frequently used multiplexing method is multiplexing of 2Mb/s signals into STM-N signals. It is also the most complicated method of multiplexing PDH signals into SDH signals.

1) First, the 2Mb/s signal shall be adapted into the corresponding standard container C12 via rate adaptation. During the adaptation of 2Mb/s PDH signals into C12, the concept of multi-frame is introduced for the convenience of rate adaptation, i.e. four C12 basic frames form a multi-frame. Since the frame frequency of the C12 basic frame is 8000-frame per second, the frame frequency of the C12 multi-frame will be 2000-frame per second. Refer to the attached figure at the end of Section 2.

Why is multi-frame used? This is merely for the convenience of rate adaptation. For example, if E1 signals have a standard rate of 2.048Mb/s, each basic frame will accommodate 32-byte (256-bit) payload on mapping the E1 into a C12. Why? The frame frequency of C12 is 8000-frame per second. So is that of the PCM30/32 [E1] signal. However, when the rate of E1 signals isn't a standard rate of 2.048Mb/s, the average bit number accommodated into each C12 is not an integer. For example, when E1 signals of the rate of 2.046Mb/s are accommodated into a C12 basic frame, the average number of bits loaded in each frame is: (2.046 × 106b/second)/(8000-frame/second) = 255.75 bits. Because this number is not an integer, E1 signals can't be accommodated. In this case, if a multi-frame of four basic frames is used, the number of bits can be loaded in the multi-frame is: (2.046 × 106b/second)/(2000-frame/second) = 1023 bits. Each of the first three basic frames accommodates 256-bit (32-byte) payload and the fourth accommodates 255-bit payload. So all E1 signals at this rate can be completely adapted into C12. Then how to adapt the rate of E1 signals (i.e. how to accommodate it into C12)? The C12 basic frame is a notched block frame structure of 9 × 4 − 2 bytes. A multi-frame consists of four basic frames. The multi-frame structure of C12 and its bytes arrangement are illustrated in Figure 2-10.



Each square represents a byte (8 bits). The bytes are classified as follows:

W=IIIIIIII Y=RRRRRRRR G=C1C2OOOORR

M=C1C2RRRRS1 N=S2 IIIIIII

I : Information bit R: Stuffed bit: O: Overhead bit

C1: Negative justification control bit S1: Negative justification opportunity bit C1=0 S1=I; C1=1 S1=R*

C2: Positive justification control bit S2: Positive justification opportunity bit C2=0 S2=I; C2=1 S2=R*

R* represents a justification bit. At time of de-justification at the receiving end, the value of justification bits shall be ignored. The period of a multi-frame is 125x4=500us.

Figure 2-10 C-12 multi-frame structure and bytes arrangement

The contents of the bytes in a multi-frame are illustrated in Figure 2-11. A multi-frame includes: C12 multi-frame = 4 (9 × 4 − 2) = 136 bytes = 127W + 5Y + 2G + 1M + 1N = (1023I + S1 + S2) + 3C1 + 49R + 8O = 1088 bits. The negative and positive justification control bits C1 and C2 respectively control the negative and positive justification opportunity bits S1 and S2. C1C1C1 = 000 indicates that S1 is an information bit I while C1C1C1 = 111 indicates that S1 is a stuffed bit R. C2 controls S2 in the same way.

A multi-frame can accommodate payloads at the rate ranging from C-12Multiframe max to C-12Multi-frame min, as follows:

C-12Multi-framemax = (1023+1+1) ×2000=2.050Mb/s

C-12Multi-framemin = (1023+0+0) ×2000=2.046Mb/s

As long as E1 signals have a rate within the range of 2.050Mb/s—2.046Mb/s, they can be adapted and accommodated into a standard C12 container, i.e. the rate can be justified through rate justification into standard C12 rate --- 2.175Mb/s.

Technical details:

As shown in the attached figure at the end of Section 2, the four C12 basic frames of a multi-frame are arramged side-by-side. When multiplexed into STM-1 signals, these four basic frames are placed in four successive STM-1 frames, instead of one single frame of STM-1 signals. Each basic frame occupies one STM-1. To correctly separate the 2Mb/s signals, you must know the location of each basic frame within the multi-frame --- which basic frame it is in the multi-frame. Note that the four basic frames of the multi-frame represent one 2M signal and the multi-frame consists of one 2M signal.

2) To monitor on a real-time basis the performance of each 2Mb/s path signal during transmission on SDH network, C12 must be further packed --- adding corresponding path overhead (lower order overhead)---- to form a VC12 information structure. As shown in the attached figure at the end of Section 2, the LP-POH (lower order path overhead) is added to the notch in the top left corner of each basic frame. Each multi-frame has a set of lower order path overhead composed of total 4 bytes: V5, J2, N2 and K4. Since the VC can be regarded as an independent entity, dispatching of 2Mb/s services later is conducted in unit of VC12.

A set of path overhead monitors the transmission status of the whole multi-frame on a network. How many frames of 2Mb/s signals does a C12 multi-frame accommodate? One C12 multi-frame accommodates 4 frames of PCM30/32 signals. Therefore a set of LP-POH monitors the transmission status of 4 frames of PCM30/32 signals.

3) For correct aligning of VC12 frames in the receiving end, a four-byte TU-PTR is added to the four notches of the VC12 multi-frame. Then the information structure of the signal changes into TU12 with 9 rows × 4 columns. The TU-PTR indicates the specific location of the start point of the first VC12 within the multi-frame.

4) Three TU12 form a TUG-2 via byte interleaved multiplexing. The TUG2 has the frame structure of 9 rows by 12 columns.

5) Seven TUG2 can be multiplexed into a TUG3 information structure via byte interleaved multiplexing. Note that this information structure formed by the 7× TUG2 is 9-row by 84-column. Two rows of fixed stuff bits shall be added in front of the structure, as illustrated in Figure 2-11.

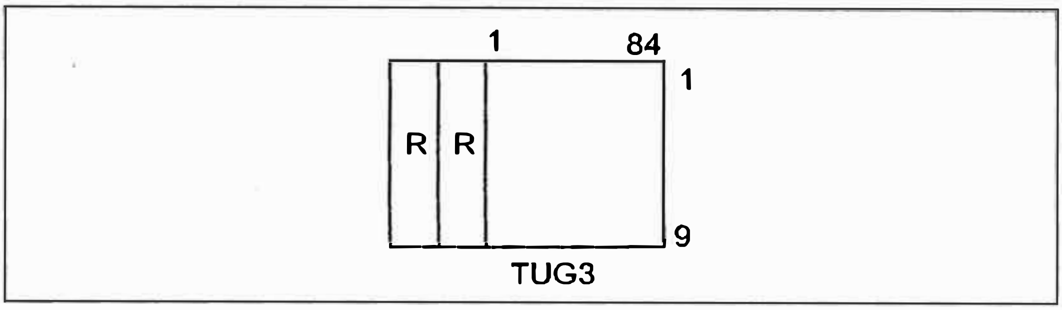


Figure 2-11 TUG3 information structure

6) The procedures of multiplexing the TUG3 information structure into STM-N are the same as mentioned before.

Technical details:

From the procedures of multiplexing 140Mb/s signals into STM-N signals we can see that one STM-N corresponds to N× 140Mb/s, i.e. one STM-1 signal can only be multiplexed into one 140Mb/s. Therefore, the capacity of an STM-1 signal equals to that of 64 2Mb/s signals if 140Mb/s is multiplexed into the STM-1.

Similarly, in the case of multiplexing 34Mb/s signals into STM-1 signals, the STM-1 can accommodate three 34Mb/s signals, i.e. it has a capacity of 48 × 2Mb/s.

In the case of multiplexing 2Mb/s signals into STM-1 signals, the STM-1 can accommodate 3 × 7 × 3 = 63 2Mb/s signals

From above analysis, it can be concluded that in the cases of multiplexing 140Mb/s and 2Mb/s into SDH STM-N, the utilization ratio of the signal is fairly high. However, in the case of multiplexing 34Mb/s into STM-N, the utilization ratio is relatively low.

As shown in the procedures of multiplexing 2Mb/s signals into STM-N signals, 3 TU12s can be multiplexed into one TUG2, 7 TUG2s into one TUG3, 3 TUG3s

These are the methods and procedures of multiplexing PDH signals into STM-N frames used in China. This is the basic knowledges for you to enhance your ability of equipment maintenance and for further study of SDH principle.

2.3 Concepts of Mapping, Aligning and Multiplexing

Low-rate tributaries are multiplexed into STM-N signals through three procedures: mapping, aligning and multiplexing.

Aligning means that the pointer value constantly locates the start point of the lower order VC frame within the TU payload (TU-PTR) or the start point of the higher order VC frame within the AU payload (AU-PTR). So that the receiving end can correctly separate the corresponding VC. Detailed description will be given in the next section.

Multiplexing, a relatively simple concept, is a process through which multiple lower order path layer signals are adapted into higher order path layers or the multiple higher order path layer signals are adapted into multiplex section. It is a process through which the TUs are organized into the higher order VC or the AUs are organized into STM-N via bit interleaving. As all VC tributary signals are phase synchronized through TU and AU pointer justification, this multiplexing procedure is of synchronous multiplexing. Its multiplexing principle is similar to that of the parallel-to-serial conversion.

? **Questions:**

What are the methods of adapting 140Mb/s, 34Mb/s and 2Mb/s PDH signals into the standard containers?

Generally these signals are adapted via asynchronous adaptation methods because justification by adding the corresponding stuff bits is required before adaptation. For example, when adapting 2Mb/s signals into C12, it can't be guaranteed that each C12 can just accomodate one E1 frame.

By far, the contents of this section are finished. Before ending this section, we'd like to emphasize again the relationship between the signals of various PDH rate levels and the information structures employed in SDH multiplexing: 2Mb/s C12 VC12 TU12; 34Mb/s C3 VC3 TU-3; 140Mb/s C4 VC4 AU-4. Usually the signals PDH of various rate levels can also be denoted by corresponding information structures, e.g. 2Mb/s PDH signals can be denoted by VC12.

into one VC4 and one VC4 into one STM-1, i.e. the multiplexing structure of 2Mb/s is 3-7-3. Since the multiplexing method is byte interleaved, the 63 VC12s within a VC4 are not arranged in sequence. The number difference between two adjacent TU12 is 21.

This is a formula for calculating the time-slot number of TU12 at different locations within the same VC4:

VC12 (TU12) time-slot number = TUG3 location number + （TUG2 location number − 1） × 3 + （TU12 location number − 1） × 21. Two adjacent TU12 within the VC4 frame means that they have the same TUG3 location number and TUG2 location number while the difference between their TU12 location numbers is 1.

This formula will be useful when using the SDH transmission analyzer to conduct certain measurements. Is there anything in common between the locations of the two adjacent TU12s within the VC4 frame?

Notes: The range of TUG3 location numbers is 1-3. The range of TUG2 location numbers is 1-7. And the range of TU12 location numbers is 1-3. The VC12 (TU12) number refers to the sequence number of this VC12 (TU12) among the 63 VC12 (TU12) within the VC4 frame according to their sequence of multiplexing, as illustrated in Figure 2-12.

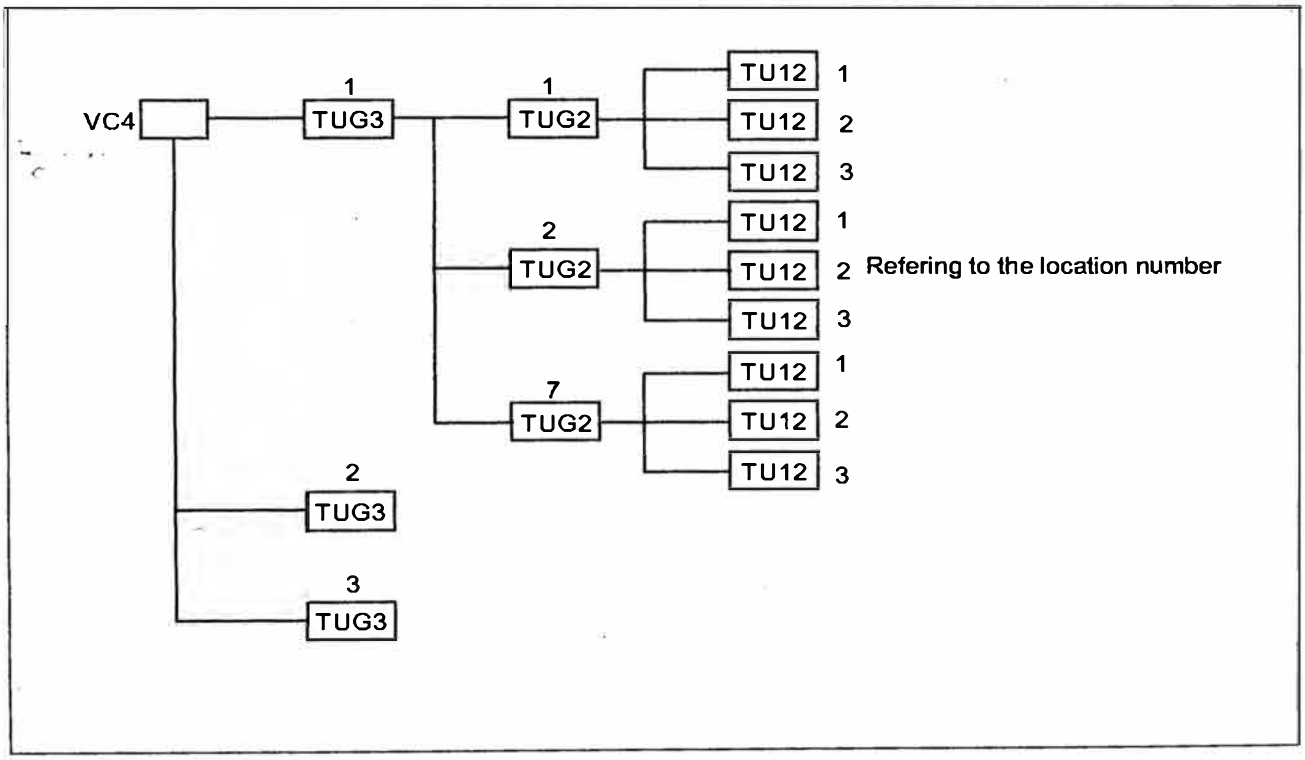


Figure 2-12 The arrangement of TUG3, TUG2 and TU12 in VC4

? **Questions:**

What have you learned in this section?

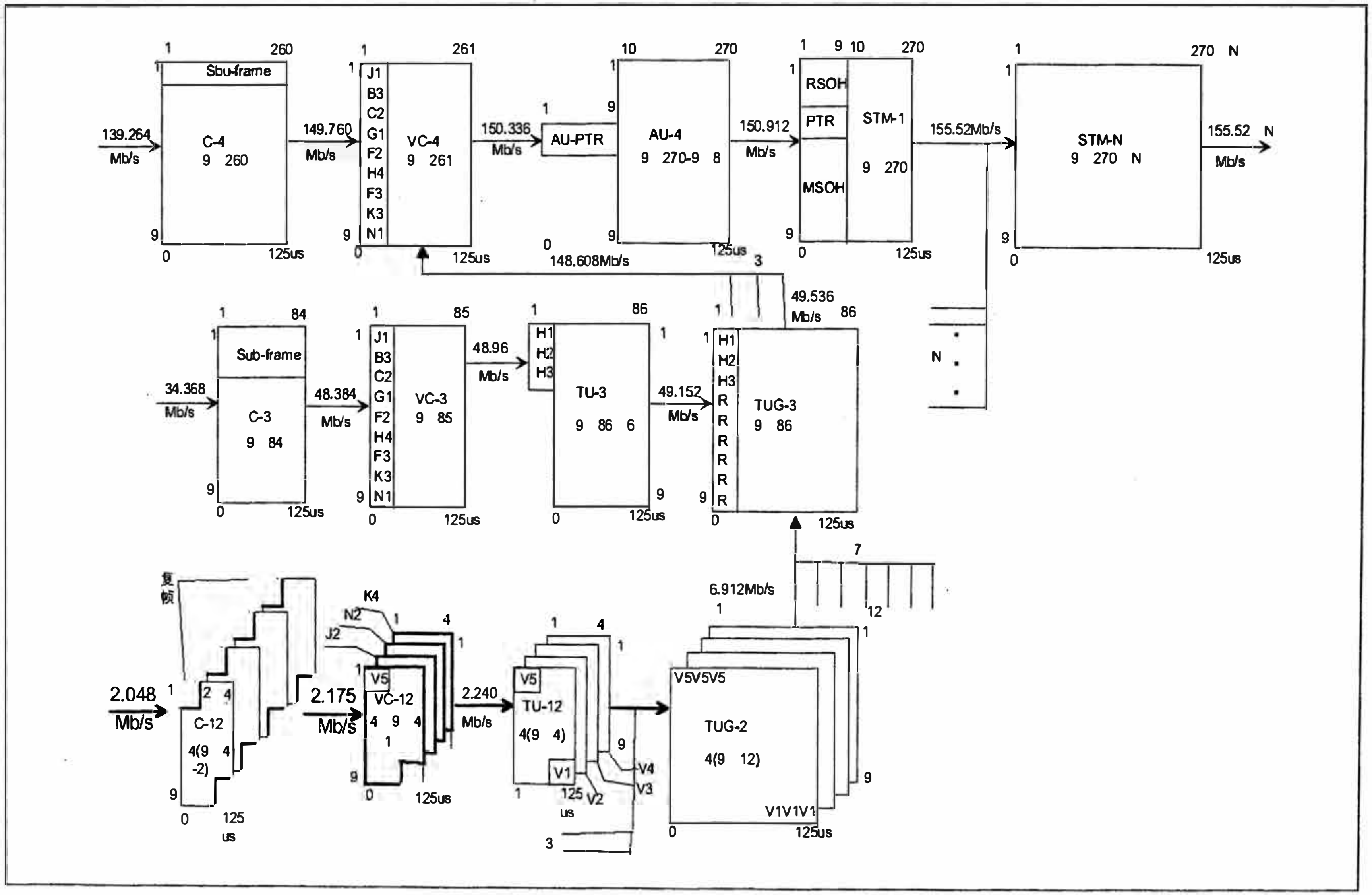
1. The frame structures of STM-N and the functions of their components.

2. The methods and procedures of multiplexing PDH signals of different rates into STM-N signals, as well as the functions of various information structures ---- C, VC, TU, TUG, AU and AUG.

3. The methods of rate adaptation for 2Mb/s and 140Mb/s signals.

4. The basic concepts of multiplexing and mapping.

This section focuses on 1 and 2. Have you understood all these contents?



Attached figure The SDH multiplexing structures used in China

Summary

This section describes the frame structures of SDH and the functions of their major elements, as well as the basic procedures of multiplexing PDH (2M,. 34M and 140M) signals into STM-N frames.

Exercises

1. If the location of a 2M signal is the second TUG3, the third TUG2 and the first TU12 when it is multiplexed into a VC4. Then the time slot number occupied by this 2M signal is ______
2. An STM-1 can multiplex into ______2M signal(s), ______34M signal(s), or___ ____140M signal(s).

Section 3 Overhead and Pointer

Objectives:

To master implementation of section layer monitoring ---- functions of section overhead bytes.

To master implementation of path layer monitoring ---- functions of path overhead bytes.

To master which overhead bytes implement basic alarm and performance monitoring.

To understand the operation mechanism for the pointer ---- AU-PTR and TU-PTR.

To build the concepts of layered SDH monitoring.

3.1 Overhead

As mentioned before, the functions of overhead are to implement layered monitoring management for SDH signals. The monitoring is classified into section layer monitoring and path layer monitoring. The section layer monitoring is further classified into regenerator section layer monitoring and multiplex section layer monitoring while the path layer monitoring is further classified into higher order path layer and lower order path layer. Thus the layered monitoring for STM-N is implemented. For example, in a 2.5G system, the regenerator section overhead monitors the overall STM-16 signal while the multiplex section overhead further monitors each of the 16 STM-1. Furthermore, the higher order path overhead monitors the VC4 of each STM-1 and the lower order path overhead can monitor each of the 63 VC12 in the VC4. Hence the multistage monitoring functions from 2.5Gb/s to 2Mb/s are implemented.

Then, how are these monitoring functions implemented? They are implemented via different overhead bytes.

3.1.1 Section Overhead

The section overhead of the STM-N frame is located in rows 1-9 of columns 1-9N with the frame structure. Notes: with the exception of row 4. We are to describe the function of each section overhead byte with the example of an STM-1 signal. For an STM-1 signal, the SOH is located at rows 1-3 of columns 1-9 ---- RSOH and rows 5-9 of columns 1-9 ---- MSOH within its frame, as illustrated in Figure 3-1.

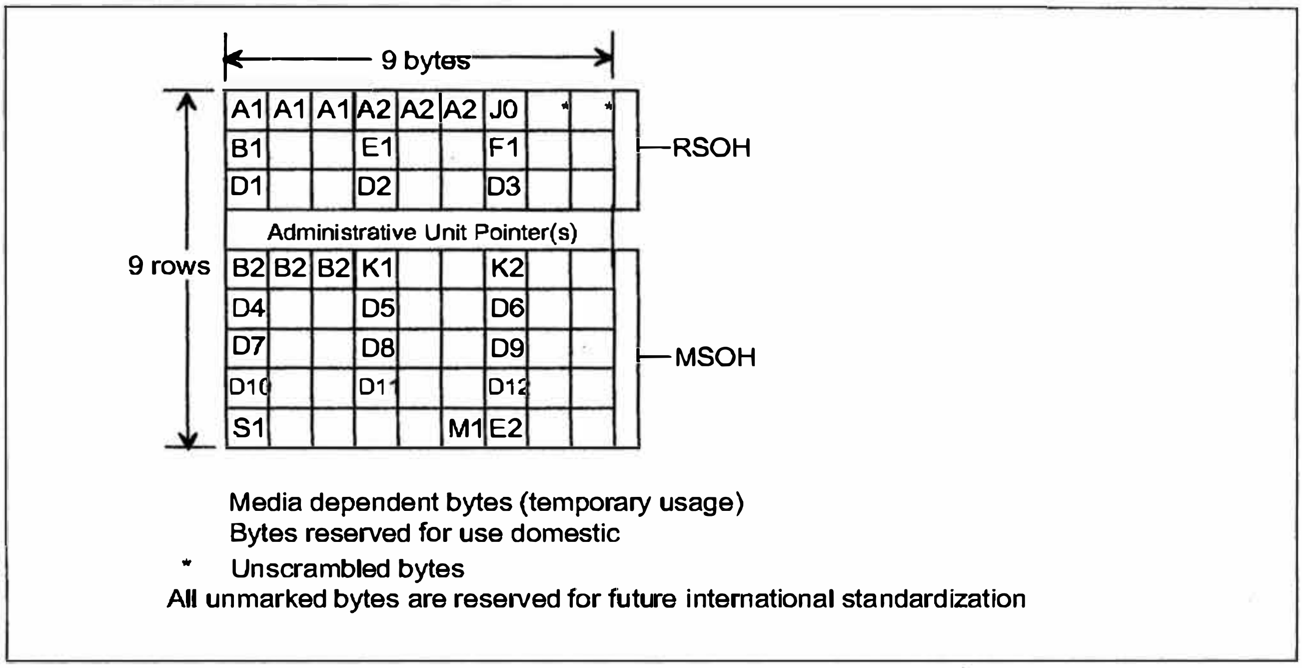


Figure 3-1 The diagram of section overhead bytes within the STM-N frame

Figure 3-1 illustrates the location of regenerator section overhead and multiplex section overhead within the STM-1 frame. What is the difference between them? Their difference is in the monitoring scope, i.e. the RSOH is corresponding to a large scope ---- STM-N while the MSOH is corresponding to a smaller scope ---- STM-1 within the large scope.

- **Framing bytes A1 and A2**

Like a pointer, the function of the frame bytes is alignment. As we know that SDH can add/drop lower-rate tributary signals from higher-rate signals. Why? Because the receiver can align the location of the lower-rate signals within the high-rate signal via the pointers ---- AU-PTR and TU-PTR. The first step of this procedure is to properly extract each STM-N frame from the received signal stream at the receiver, i.e. to align the start location of each STM-N frame, then to align the location of the corresponding lower-rate signals within each frame. This procedure is similar to locating a person in a long queue, you must first align the specific square, then align the person via the row and column within the square he belongs to. The function of the bytes A1 and A2 is to align the square. So the receiver can align and extract the STM-N frame from the information stream via these two bytes and further align a specific lower-rate signal within the frame via the pointers.

How does the receiver align the frames via the A1 and A2 bytes? The A1 and A2 have fixed value, i.e. fixed bit patterns: A1: 11110110 (f6H) and A2: 00101000(28H). The receiver monitors each byte in the stream. After detecting 3N successive f6H bytes followed by 3N 26H bytes (there are three A1 and three A2 bytes within an STM-1 frame), the receiver determines that an STM-N frame starts to be received. By aligning the start of each STM-N frame, the receiver can identify different STM-N frames and disassemble them. In the case of N=1, the frames identified are STM-1 frames.

If the receiver doesn't receive A1 and A2 bytes within five or more successive frames (625us), i.e. it can't identify the start of five successive frames (identify different frames), it will enter out-of-frame status and generate out-of-frame alarm --- OOF. If the OOF keeps for 3ms, the receiver will enter loss-of-frame status ---- the equipment will generate loss-of-frame alarm --- LOF. Meanwhile, an AIS signal will be sent downward and the entire services will be interrupted. Under LOF status, if the receiver stays in normal frame alignment status again for successive 1ms or more, the equipment will restore the normal status.

Technical details:

STM-N signals shall be scrambled before being transmitted via the line so that the receiver can extract timing signals from the line. But the A1 and A2 framing bytes shall not be scrambled for the receiver to properly align them. To take both requirements into consideration, the STM-N signals don't scramble the bytes in the first row (1 row × 9N columns, including A1 and A2 bytes) of the section overhead but transmit them transparently while the other bytes within the STM-N frame are scrambled before transmitting via the line. Thus it is convenient to extract the timing from the STM-N signals and disassemble the STM-N signals at the receiver.

- Regenerator Section Trace byte: J0

This byte is used to repeatedly transmit a Section Access Point Identifier so that a section receiver can verify its continued connection to the intended transmitter.

Within the domain of a single operator, this byte may use any character. But at the boundaries between the networks of different operators, the format of J0 byte shall be the same (i.e. matched) between the receiver and transmitter of the equipment. Via J0 byte the operator can detect and solve faults early and shorten the network restoration time.

Another usage of the J0 byte is that J0 byte in each STM-N frame is defined as an STM identifier C1 and used to indicate the location of each STM-1 within the STM-N ---- indicating which STM-1 within the STM-N this STM-1 is (the value of interleave depth coordinate) and which column this C1 byte is located within the STM-1 frame (the value of the multi-column). It may be used to assist the A1 and A2 bytes in frame alignment.

Data Communication Channel (DCC) byte: D1-D12

One of the features of SDH is its highly automatic OAM function which can conduct commands issue and performance auto poll to the networks element via network management terminals. SDH has some functions which are not possessed by PDH systems, such as real-time service allocation, alarm fault location and on-line performance testing. Where are these OAM data arranged to transmit? The data used for OAM functions, such as sent commands and checked alarm performance data, are transmitted via D1-D12 bytes within the STM-N frame, i.e. the related data for OAM functions are arranged in the locations of the D1-D12 bytes and transmitted by the STM-N signals via the SDH network. Thus the D1-D12 bytes provide a common data communication channel accessible to all SDH network elements. As the physical layer of the embedded control channel (ECC), the D1-D12 bytes transmit operation, administration and maintenance (OAM) information among the network elements and form a transmission channel of the SDH management network (SMN).

D1, D2 and D3 are regenerator section DCC bytes (DCCR) with a rate of 3 × 64kb/s = 192kb/s and are used to transmit OAM information among regenerator section terminals. D4-D12 are multiplex section DCC bytes (DCCM) with a sum rate of 9 × 64kb/s=576kb/s and are used to transmit OAM information among multiplex section terminals.

The DCC has a total rate of 768kb/s which provides a powerful communication base for SDH network management.

- ### Order wire bytes: E1 and E2

Each of these two bytes provides a 64kb/s order wire channel for voice communication, i.e. voice information is transmitted via these two bytes.

E1 is part of the RSOH and is used for regenerator section order wire communication. E2 is part of the MSOH and is used for direct order wire communication between terminals.

For example, the network is as follows:

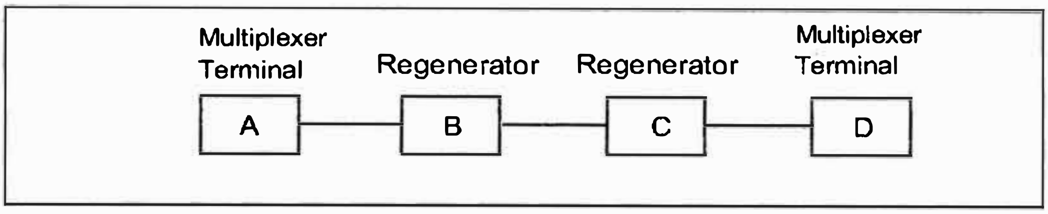


Figure 3-2 Network diagram

If only E1 byte is used as order wire byte, A, B, C and D network elements can communicate order wire. Why? Because the function of multiplexer terminals is add/drop lower-rate tributary signals from SDH signal, RSOH and MSOH are required to process. So both E1 and E2 can be used to communicate order wwire. The function of regenerators is signal regeneration and only RSOH is required to process. So E1 byte can also communicate order wire.

If only E2 byte is used as order wire byte, then order wire voice communication is provided only between A and D. This is because B and C network elements don't process MSOH and E2 byte.

User channel byte: F1

This byte can be used to provide 64kb/s data/voice channel. It is reserved for user (often referring to network provider) to provide temporary order wire connections for special maintenance purposes.

Bit Interleaved Parity 8 (BIP-8) byte: B1

This byte is allocated for regenerator section error monitoring (Byte B1 is located in the regenerator section overhead).

What is the mechanism for monitoring? First, we'll discuss the BIP-8 parity.

Suppose that a signal frame is composed of 4 bytes: A1=00110011, A2=11001100, A3=10101010 and A4=00001111. The method of providing BIP-8 parity to this frame is to divide it into 4 block with 8 bits (one byte) in a parity unit (each byte as a block because one byte has 8 bits, the same as a parity unit) and to arrange these blocks as illustrated in Figure 3-3.

	A1	00110011
	A2	11001100
BIP-8	A3	10101010
	A4	00001111
	B	01011010

Figure 3-3 BIP-8 parity

Compute the number of "1" over each column. Then fill a 1 in the corresponding bit of the result (B) if the number is odd, otherwise fill a ●. That is, the value of the corresponding bit of B makes the number of "1" in the corresponding column of A1A2A3A4 blocks even. This parity method is called BIP-8 parity. In fact this is an even parity since it guarantees that the number of "1" is even. B is the result of BIP-8 parity for the A1A2A3A4 block.

The mechanism for B1 byte is: the transmitting equipment processes BIP-8 even parity over all bytes of the previous frame (1#STM-N) after scrambling and places the result in byte B1 of the current frame (2#STM-N) before scrambling. The receiver processes BIP-8 parity over all bits of the current frame (1#STM-N) before de-scrambling and conducts exclusive-OR operation between the parity result and the value of B1 in the next frame (2#STM-N) after de-scrambling. If these two values are different, the result of exclusive-OR will include 1. According to the number of "1", we can monitor the number of error blocks occurred in 1#STM-N frame during transmission.

Technical details:

Since error performance of higher rate signals is reflected via error blocks, the error status of STM-N signals is actually the status of error blocks. As can be seen from the BIP-8 parity method, each bit of the parity result is corresponding to a bit block, e.g. a column in Figure 3-3. So a B1 byte can at most monitor 8 error blocks from an STM-N frame that occur during transmission (The result of BIP-8 is 8 bits with each bit corresponding to a column of bits --- a block).

- Bit Interleaved Parity N×24 code (BIP-N×24) byte: B2

B2 is similar to B1 in operation mechanism except that it monitors the error status of the multiplex section layer. The B1 byte monitors the transmission error of the complete STM-N frame signal. There is only one B1 byte in an STM-N frame (Why? You'll get the answer when we discuss the interleaved multiplexing of the section overhead during multiplexing of STM-1 into the STM-N). The B2 bytes monitor the error performance status for each STM-1 frame within the STM-N frame. There are N%3 B2 bytes in an STM-N frame with every three B2 bytes corresponding to an STM-1 frame. The mechanism for monitoring is that the transmitting equipment computes BIP-24 (three bytes) over all bits of the previous STM-1 frame except for the RSOH (The RSOH is included in the B1 parity for the complete STM-N frame) and places the result in bytes B2 of the current frame before scrambling. The receiver processes BIP-24 parity over all bits of the current frame STM-1 after de-scrambling except for the RSOH and conducts exclusive-OR operation between the parity result and B2 bytes in the next frame after de-scrambling. According to the number of "1" in the result of the exclusive-OR operation, we can monitor the number of error blocks occurred in this STM-1 within the STM-N frame during transmission. This method can at most monitor 24 error blocks. Notes: after the transmitting equipment writes B2 bytes, the corresponding N STM-1 frames are multiplexed into an STM-N signal (there are 3N B2 bytes). At the receiver the STM-N signal is de-interleaved into N × STM-1 signals, then parity is conducted for the N groups of B2 bytes.

- Automatic Protection Switching (APS) channel byte: K1, K2 (b1-b5)

These two bytes are allocated for transmitting Automatic Protection Switching (APS) signaling which is used to guarantee that the equipment can automatically switch on occurrence of a fault and restore the network traffic --- self-healing. These two bytes are used for the APS self-healing of the multiplex section.

- Multiplex Section Remote Defect Indication (MS-RDI): K2 (b6-b8)

This is an alarm message, returned to the transmit end (source) by the receive end (sink), which means that the receive end has detected an incoming section defect or is receiving the Multiplex Section Alarm Indication Signal (MS-AIS). That is, when the receive end detects receiving deterioration, it returns an MS-RDI alarm signal to the transmit end so that the later obtains the status of the former. If the received b6-b8 bits of the K2 is 110, it means that this signal is an MS-RDI alarm signal returned by the opposite end. If the received b6-b8 bits of the K2 is 111, it means that this signal is an MS-AIS alarm signal received by current end. Meanwhile, the current end is required to send out MS-RDI signal to the opposite end, i.e. insert 110 bit pattern into the b6-b8 of the K2 within the STM-N signal frame to be sent to the opposite end. Notes: Not all deterioration or results in returning MS-RDI. Current end equipment returns MS-RDI only upon receiving R-LOS, R-LOF, and MS-AIS alarm signals.

- Synchronization status byte: S1 (b5-b8)

Different bit patterns, indicating different quality levels of clocks defined by ITU-T, enable the equipment to determine the quality of the received clock timing signal. This helps to determine whether or not to switch the clock source, i.e. switch to higher quality clock source.

The smaller the value of S1 (b5-b8), the lower the level of clock quality.

- Multiplex Section Remote Error Indication (MS—REI) byte: M1

This is an message returned to its transmit end by the receive end. The M1 byte is used to transmit the number of error blocks detected by the receive end via BIP-N × 24 (B2) so that the transmit end can get the receiving error status of the receive end.

- Media dependent bytes: △

△ bytes are used to implement special functions of the specific transmission media. For example, these bytes can be used to identify the direction of the signal when bi-directional transmission is adopted in a single fiber.

- Bytes reserved for use in China: ×

- All unmarked bytes are reserved for future international standardization.

Tips:

SDH vendors usually use the reserved bytes within the section overhead of the STM frame to implement some special functions of their own equipment.

So far, the usage of bytes in the Section Overhead of the STM-N frame has been discussed. Via these bytes, OAM functions of the STM-N section layer are implemented.

N STM-1 frames can be multiplexed into the STM-N frame via byte-interleaved multiplexing. How is the Section Overhead multiplexed? During the byte-interleaved multiplexing, all bytes of the AU-PTR and payload within the STM-1 frames are intact and are byte-interleaved. But the multiplexing method for the Section Overhead is different. Its multiplexing method is that when N STM-1 frames are multiplexed into the STM-N frame via byte-interleaved multiplexing, the Section Overhead of the first STM-1 frame is kept while only the framing bytes and B2 bytes of the other N-1 STM-1 Section Overheads are kept and the overhead bytes left are ignored. Figure 3-4 illustrates the Section Overhead structure of an STM-4 frame.

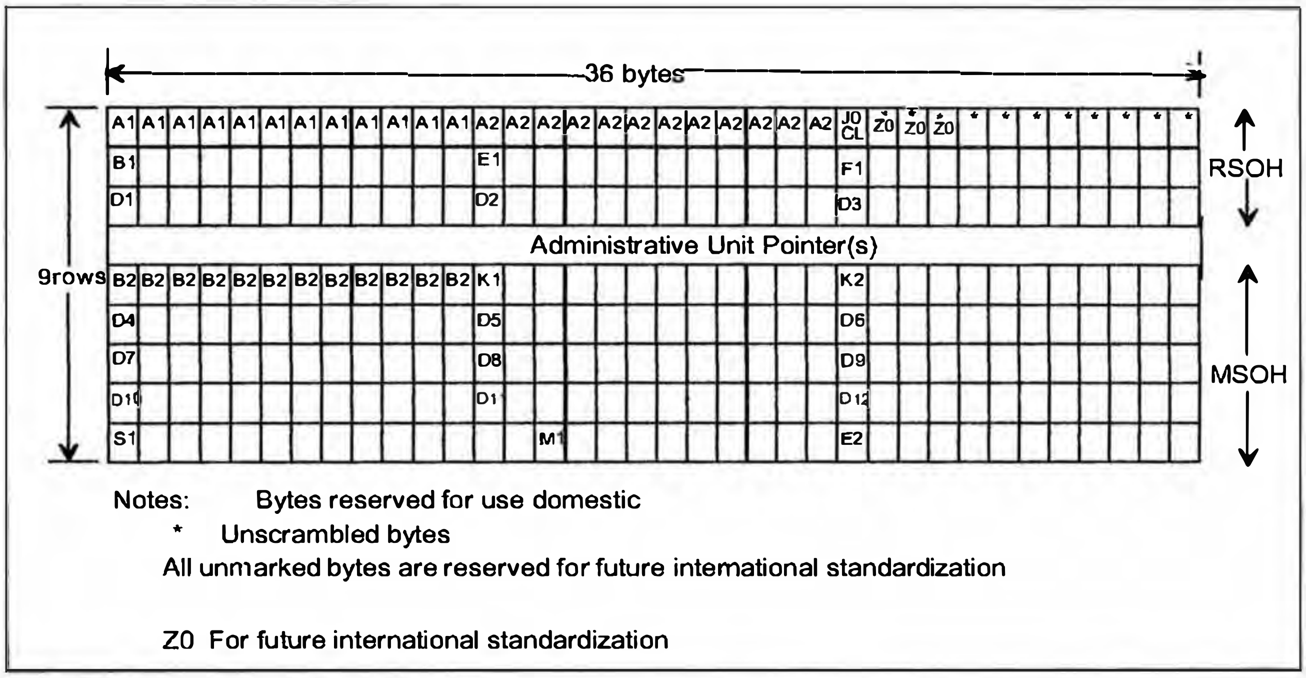


Figure 3-4 Assignment of STM-4 SOH bytes

There is only one B1 in an STM-N while there are N × 3 B2 bytes (Since B2 bytes are the result of the BIP-24 parity, each STM-1 has 3 B2 bytes, 3 × 8=24 bits). There is one D1-D12 byte, one E1 one E2 byte, one M1 byte, one K1 byte and one K2 byte in an STM-N frame. Why?

Figure 3-5 is the structure of the STM—16 Section Overhead.

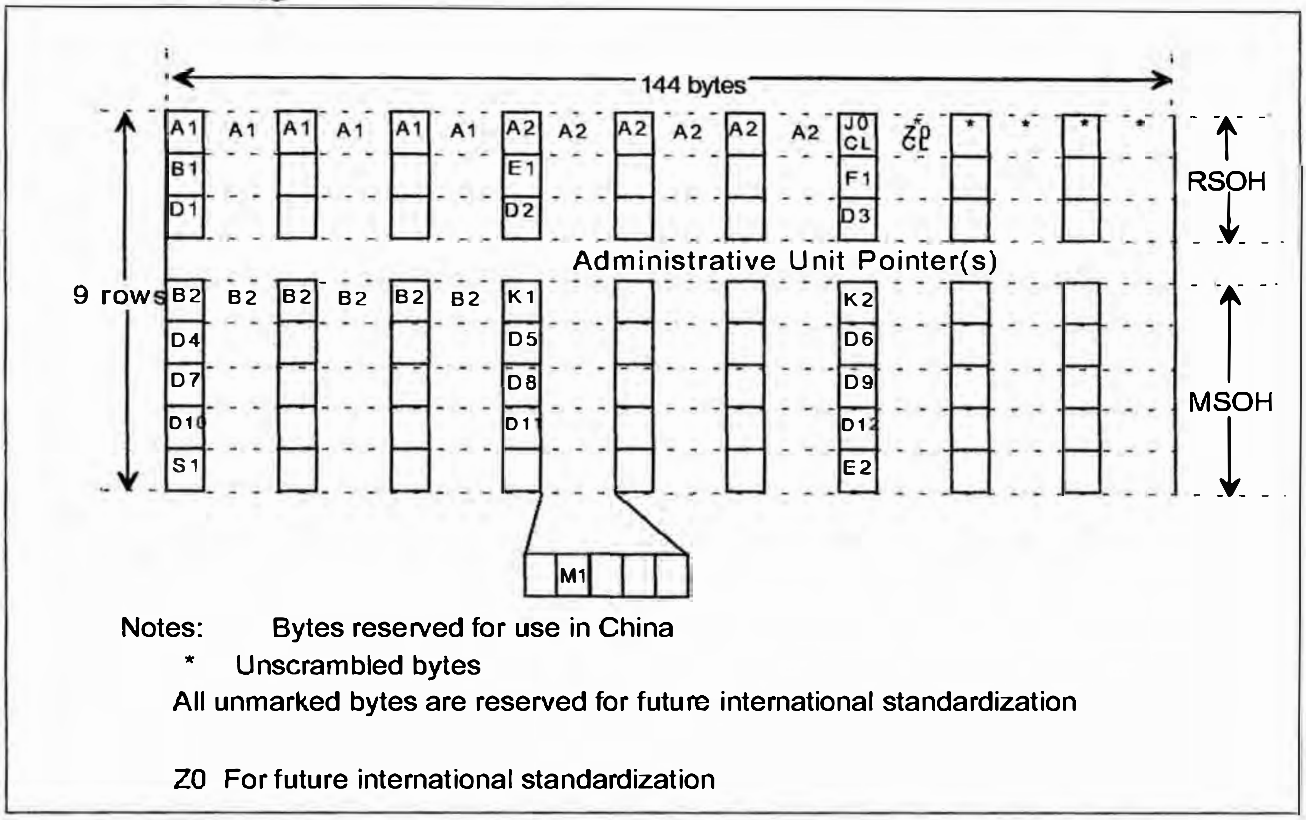


Figure 3-5 Assignment of the STM-16 SOH bytes

3.1.2 Path Overhead

The Section Overhead is responsible for section layer OAM functions while the Path Overhead for path layer OAM functions. Like transporting the cargoes loaded in the container: not only the overall impairment status of the cargoes (SOH) but also the impairnent status of each cargo (POH) shall be monitored.

According to the "width" of the monitored path (the size of the monitored cargo) , the Path Overhead is further classified into Higher Order Path Overhead and Lower Order Path Overhead. In this curriculum the Higher Order Path Overhead refers to the monitoring of VC4 level paths which can monitor the transmission status of 140Mb/s signal within the STM-N frame. The Lower Order Path Overhead implements the OAM functions for VC12 path level, i.e. monitoring the transmission performance of 2Mb/s signals within the STM-N frame.

Technical details:

According to the multiplexing route of the 34Mb/s signal, the POH of the VC3 can be classified into higher order or lower order path overhead. Its bytes structure and function are not different from that of the VC4 Path Overhead. Since the multiplexing of 34Mb/s signals into STM-N method is seldom used, the detailed description of the VC3 POH is omitted here.

1. Higher Order Path Overhead: HO—POH

The Higher Order Path Overhead, consisting of 9 bytes, is located in the first column of the VC4 frame, as illustrated in Figure 3-6.

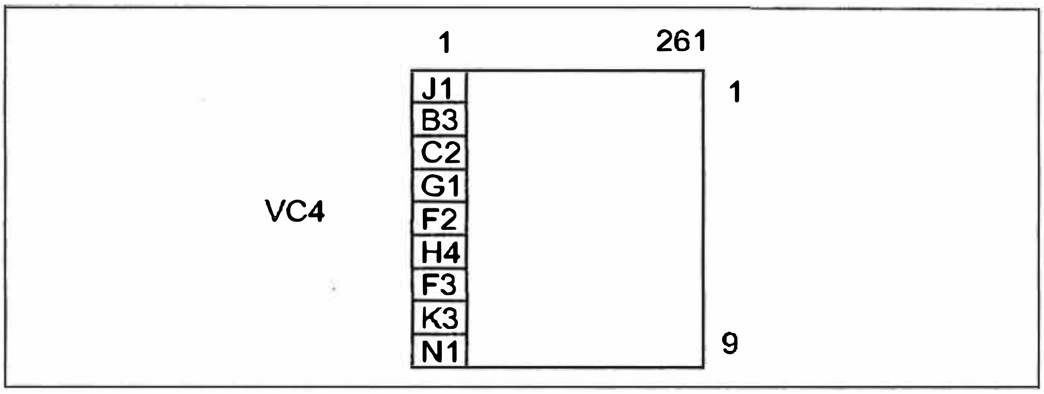


Figure 3-6 The structure of Higher Order Path Overhead

- **J1: Path trace byte**

The AU-PTR pointer indicates the specific location of the start of the VC4 within the AU-4, i.e. the location of the first byte of the VC4, so that the receive end can properly extract VC4 from the AU-4 according to the value of this AU-PTR. The J1 is the start of the VC4, so the AU-PTR indicates the location of the J1 byte.

The function of J1 is similar to that of J0. The J1 byte is used to transmit repetitively a Higher Order Path Access Point Identifier so that a path receiving terminal can verify its continued connection to the intended transmitter (this path is under continued connection). This requires that the J1 bytes of the received and transmit ends match. The default transmit/receive J1 byte values of the equipments provided by Huawei Company are SBS HuaWei . Of course the J1 byte can be configured and modified according to the requirement.

- **B3: Path BIP—8 Code**

The B3 byte is allocated for monitoring the transmission error performance of VC4 within the STM-N frame, e.g. monitoring the transmission error performance of 140Mb/s signal within the STM-N frame. Its monitoring mechanism is similar to that of the B1 and B2 except that it is used to process BIP-8 parity for the VC4 frame.

Once the receive end detects error blocks, the number of error blocks will be displayed in the performance monitoring event ---- HP-BBE (Higher Order Path Background Block Error) of the equipment end. Meanwhile in the corresponding VC4 path performance monitoring event ---- HP-REI (Higher Order Path Remote Error Indication) of the transmit end, the number of received error blocks will be displayed. Like the B1 and B2 bytes, this method can implement real-time monitoring over the transmission performance of the STM-N signal.

Technical details:

If the B1 of the receive end has detected error blocks, the number of error blocks detected by the B1 will be displayed in this end performance event RS-BBE (Regenerator Section Background Block Error). Notes: that doesn't return to transmit end.

If the B2 of the receive end has detected error blocks, the number of error blocks detected by the B2 will be displayed in this end performance event MS-BBE (Multiplex Section Background Block Error). Meanwhile the corresponding number of error blocks will be displayed in the transmit end performance event MS-REI (Multiplex Section Remote Error Indication) (The MS-REI is sent by the M1 byte).

Notes:

When the error detected by the receive end exceeds a given limitation, the equipment will report an error overflow alarm signal.

- C2: Signal label byte

The C2 is allocated to indicate the composition of multiplexing structure and information payload of the VC frame, such as equipped or unequipped status of the path, the type of loaded services and their mapping method. For example, C2=00H indicates that this VC4 path is unequipped. Then the payload TUG3 of the VC4 is required to be inserted all "1" ---- TU-AIS and the higher order path unequipped alarm ---- HP-UNEQ appears in the equipment. C2=02H indicates that the payload of the VC4 is multiplexed via a TUG structure multiplexing route. In China, the multiplexing of 2Mb/s signals into VC4 adopts the TUG structure, as illustrated in the attached figure. C2=15H means that the payload of the VC4 is FDDI (Fiber Distributed Data Interface) signal. To configure the multiplexing of 2Mb/s signals for Huawei equipments, the C2 is required to be configured as TUG structure.

Technical details:

The configuration of J1 and C2 bytes is required to ensure the consistence between the transmit end and the receive end ---- transmit and receive ends match. Otherwise, the receiving equipment will generate HP-TIM (Higher Order Path Trace Identifier Mismatch) and HP-SLM (Higher Order Signal Label Mismatch). These two alarms will make the equipment insert all "1" --- TU-AIS alarm indication signal, into the TUG3 structure of the VC4.

- **G1：Path status byte**

The G1 is allocated to convey the path terminal status and performance back to a VC4 path termination source. This feature permits the status and performance of the complete duplex path to be monitored at either end, or at any point along that path. How to comprehend it? Actually the G1 byte conveys reply messages, i.e. the messages sent from the receive end to the transmit end by which the transmit end can acquire the status of the corresponding VC4 path signal received by the receive end.

Bits 1 through 4 convey the count of error blocks in VC4 to transmit end, i.e. HP-REI, that have been detected by the receive end using the B3 (the path BIP-8 code). If the AIS, error overflow or J1 and C2 mismatch is being detected by the receive end, an HP-RDI (Higher Order Path Remote Defect Indication) is sent back to the transmit end via the fifth bit of the G1 byte so that the source can know the status of the corresponding VC4 signal received by the sink and detect and locate the fault in time. Bits 6 and 8 are reserved for future use.

- **F2, F3: Path user channels bytes**

These bytes are allocated for user order wire communication purpose between path elements and are payload dependent.

- **H4: TU position indicator byte**

This byte provides a type indicator for the multi-frame of effective load and position of payloads. For example, it can be used as a multi-frame indicator for the TU12 or as a cell boundary indicator for an ATM payload when it enters a VC4.

The H4 byte is only effective when the 2Mb/s PDH signals are multiplexed into the VC4. As mentioned before, a 2Mb/s signal is multiplexed into a C12 via multi-frame consisting of 4 basic frames. To properly align and extract the E1 signal, the receiver is required to know the sequence number (1, 2, 3, 4) of current basic frame within the multi-frame. The H4 byte, indicating the number of current TU12 (VC12 or C12) within current multi-frame, has an important function as a position indicator. It ranges from 00H to 03H. If the H4 received by the receive end is out of this range, the receive end will generate a TU-LOM (Tributary Unit Loss of Multi-frame alarm). By H4, receive end can find corresponding TU12, that is to say, can find corresponding TU-PTR bytes (because TU-PTR is in four basic frame), then equipment can de-multiplex corresponding VC12, and VC12 can be dropped to corresponding C12, at last C12 can be demultiplexed to 2Mb/s signal.

- K3: Spare byte

It is allocated for future use. The receiver is required to ignore its value.

- N1: Network operator byte

This byte is allocated for specific management purposes.

2. Lower Order Path Overhead: LO—POH

The LO-POH here refers to the path overhead of the VC12 which monitors the transmission performance of the VC12 path level, i.e. monitors the transmission status of 2Mb/s PDH signals within the STM-N frame.

Where is the LO-POH located within the VC12? Figure 3-7 displays a VC12 multi-frame structure consisting of four VC12 basic frames. The lower order POH are located in the first byte of each VC12 basic frame. An LP-POH consists of four bytes denoted V5, J2, N2 and K4.

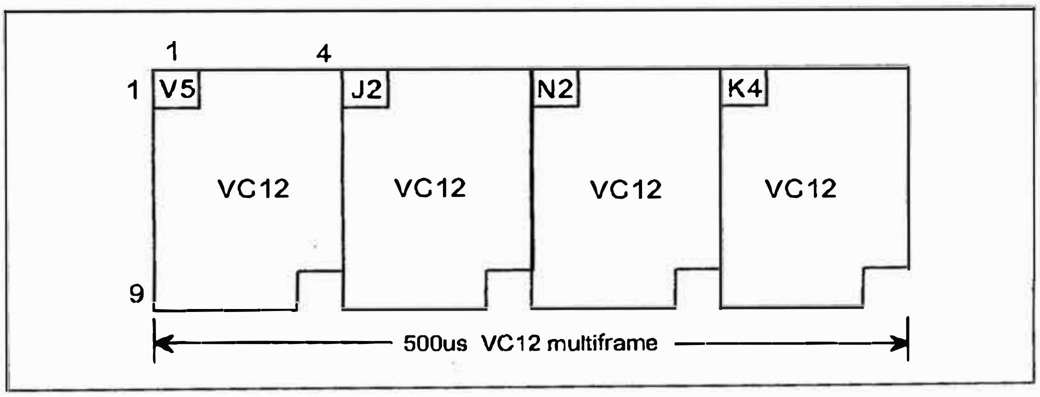


Figure 3-7 The structure of a Lower Order Path Overhead.

- V5: Path status and signal label byte

The V5 byte is the first byte of the multi-frame. The TU-PTR locates the start of the VC12 multi-frame within the TU12 multi-frame, i.e. the TU-PTR locates the specific location of the V5 byte within the TU12 multi-frame.

The V5 provides the functions of error check, signal label and path status of the VC12 paths. So this byte has the functions of the G1 、B3 and C2 bytes within the higher order path overhead. Figure 3-8 illustrates the structure of the V5 byte.

Error Monitoring (BIP-2)		Remote Error Indication (REI)	Remote Failure Indication (RFI)	Signal Label			Remote Defect Indication (RDI)
1	2	3	4	5	6	7	8
Error monitoring: Convey the Bit Interleaved Parity code BIP-2: Bit 1 is set as such that parity of all odd number bits in all bytes in the previous VC-12 is even. Bit 2 is set as such that parity of all even number bits in all bytes is even.		Remote Error Indication (former FEBE): If one or more error blocks were detected by the BIP-2, one is sent back towards the VC12 path originator, and otherwise zero is sent.	Remote Failure Indication: If a failure is declared, this bit sends one, otherwise it sends zero.	Signal Label: The signal label indicates the status and mapping method of the payload. Eight binary values are possible in these three bits: 000 Unequipped VC path 001 Path equipped non specific payload 010 Asynchronous floating mapping 011 Bit synchronous floating mapping 100 Byte synchronous floating mapping 101 Reserved for future use 110 Test signal, O.181 specific mapping 111 VC-AIS			Remote Defect Indication (former FERF): It sends one if a defect is declared, otherwise it sends zero.

Figure 3-8 The structure of the VC12 POH (V5).

If the error blocks were detected by the receiver via the BIP-2, the number of error blocks detected by the BIP-2 is displayed in this end performance event LP-BBE (Lower Order Path Background Block Error) and meanwhile an LP-REI (Lower Order Path Remote Error Indication) is sent back to the transmitter via the b3 of the V5 byte. Thus the corresponding number of block errors can be displayed in the transmitter performance event LP-REI. Bit 8 of the V5 is allocated for the VC12 Path Remote Defect Indication. An LP-RDI (Lower Order Path Remote Defect Indication) is sent back to the source if either a TU12 AIS signal or signal failure condition is being detected by the sink. Notes: In this curriculum, RDI is called remote deterioration indication or remote defect indication.

If the defect condition persists beyond the maximum time allocated to the transmission protection mechanisms, the defect becomes a failure. Then an LP-RFI (Lower Order Path Remote Failure Indication) is sent back to the source via the b4 of the V5 by the sink to inform the source that a receiving failure arises on the corresponding VC12 path at the sink.

Bits 5 through 7 provide a signal label. If only its value is not zero, the VC12 path is equipped, i.e. the VC12 package is not void. If the value of b5-b7 is 000, the VC12 is unequipped and an LP-UNEQ (Lower Order Path Unequipped) alarm is aroused at the termination sink. Then all 0 code is inserted (not all 1 code ---- AIS). If the b5-b7 of V5 at the transmitter and the receiver mismatch, an LP-SLM (Lower Order Path Signal Label Mismatch) alarm is generated at the termination sink.

- J2: VC12 path trace byte

The function of the J2 is similar to that of the J0 and J1. It is used to transmit repetitively a Lower Order Path Access Point Identifier agreed mutually by the transmitter and the receiver so that the path receiving terminal can verify its continued connection to the intended transmitter.

- N2: Network operator byte

This byte is allocated for specific management purposes.

- K4: Reserved byte

It is reserved for future use.

? **Questions:**

What did you learn from this section?

This section described the layered methods of implementing the STM-N OAM functions, such as the Regenerator Section Overhead, Multiplex Section Overhead, Higher Order Path Overhead and Lower Order Path Overhead. Via those overhead bytes, you can completely monitor the whole STM-N signal and lower rate signals equipped in the STM-N frame.

3.2 Pointers

The function of the pointers is aligning via which the receiver can properly extract the corresponding VC from the STM-N and then disassemble the VC and C packages and extract the lower rate PDH signals, i.e. directly drop lower rate tributary signals from the STM-N signal.

What is aligning? Aligning is a procedure by which the frame offset information is incorporated into the Tributary Unit or the Administrative Unit, i.e. via the Tributary Unit Pointer (or Administrative Unit Pointer) attached to the VC to indicate and determine the start of the lower order VC frame within the TU payload (or the start of the higher order VC frame within the AU payload). When relative differences occur in the phases of the frames and make the VC frames "float", the pointer value will be justified to ensure that it constantly and properly designates the start of the VC frame. For a VC4, its AU-PTR indicates the location of the J1 byte while for a VC12, its TU-PTR indicates the location of the V5 byte.

The TU pointer or AU pointer provides a method of allowing flexible and dynamic alignment of the VC within the TU or AU frame because these two pointers are able to accommodate differences, not only in the phases of the VC and the SDH, but also in the frame rates.

Two pointers are provided: AU-PTR and TU-PTR which are used for aligning of the Higher Order VC (here referring to VC4) and the Lower Order VC (here VC12) within the AU-4 and TU12 respectively. Their operation mechanisms are described below.

3.2.1 Administrative Unit Pointer——AU-PTR

The AU-PTR, located in row 4 of columns 1 to 9 within the STM-1 frame, is used to indicate the specific location of the fist byte J1 of the VC4 within the AU-4 payload so that the receiver can properly extract the VC4, as illustrated in Figure 3-9.

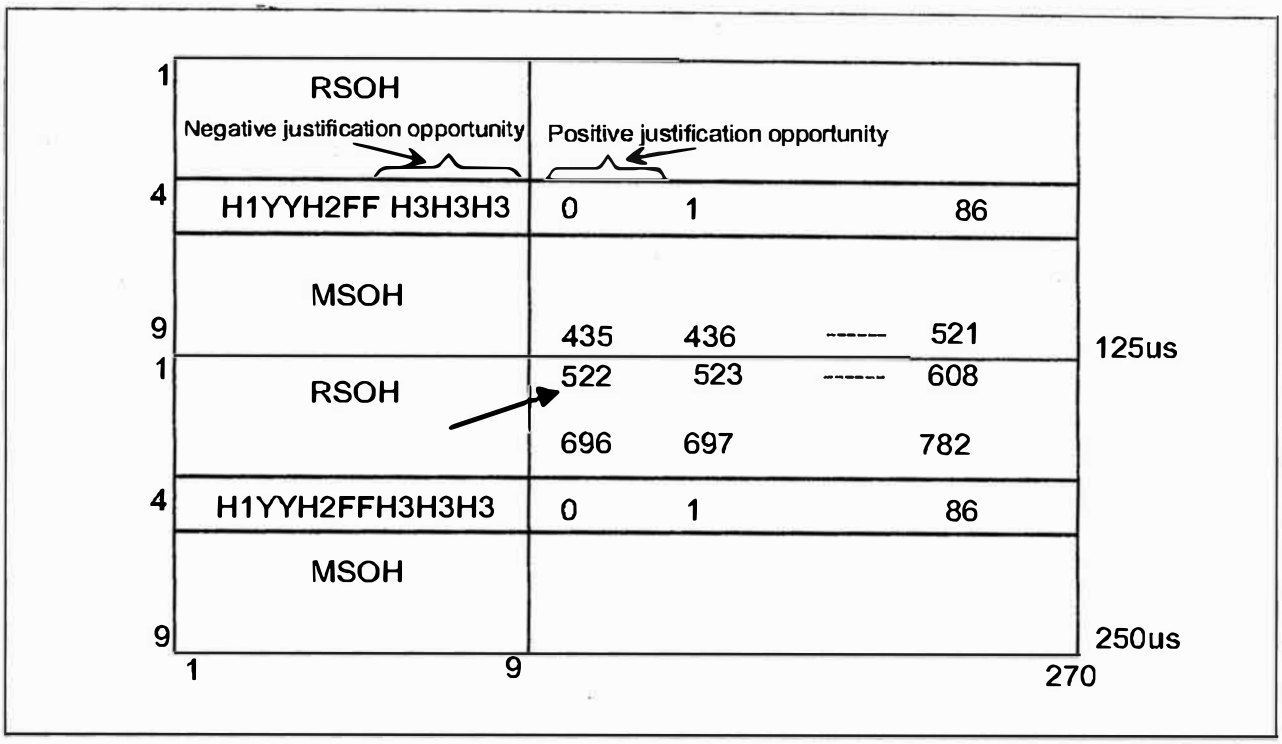


Figure 3-9 The location of the AU-4 pointer in the STM frame

As can be seen from the figure, the AU-PTR consists of 9 bytes: H1YYH2FFH3H3H3 with Y=1001SS11 (S bits are unspecified) and F=11111111. The pointer value is contained in the last ten bits of H1 and H2 bytes. In the frame, three bytes form a justification opportunity --- a cargo unit .

What is the function of the justification opportunity? Let's take the example of transporting cargoes with a truck. The cargoes ---- VC4 are continuously loaded onto the cargo box ---- information payload area three byte (one unit) -by-three byte. The stop time of the truck is 125us.

1) If the frame rate of the VC4 is faster than that of the AU-4, i.e. the package rate of AU-4 is lower than the loading rate of the VC4, then the time for loading a VC4 (cargo) is less than 125us (the stopping time of the truck). The VC4 will be continuously loaded before the truck leaves. However, the cargo box of the truck (the information payload area of AU-4) is already full and unable to accommodate more cargoes. At that time, the three H3 bytes (one justification opportunity) are used to accommodate the cargoes. These three H3 bytes are like a backup space temporarily added to the truck. Then the location of the all cargoes will be displaced forward by one unit (three bytes), so that more cargoes [one VC4 plus 3 bytes] can be added into the AU-4. Thus the location of each cargo unit (one unit includes 3 bytes) will be changed. This justification method is called negative justification. The three H3 bytes appear immediately

-- after the two FF bytes are called negative justification opportunity. At that time, the three H3 bytes are filled with VC4 payload. Via this justification method, the first three bytes of the VC4 of the next truck are loaded on current truck.

2) If the frame rate of the VC4 is slower than that of the AU-4, i.e. a VC4 can't be completely loaded during the stopping time of the AU-4 "truck", then the last three bytes -— cargo unit of the VC4 shall be transported by the next truck. Since the AU-4 hasn't been filled with a complete VC4 (lack of a 3-byte unit), the cargo box has an empty space of 3 bytes. To prevent the cargoes from straggle during transmission due to the empty space within the cargo box, three additional H3 bytes are required to be inserted immediately after the three H3 bytes of the AU-PTR. And the H3 bytes are filled with pseudo-random information (like the stuff inserted into the space of the cargo box). Then all the 3-byte units within the VC4 are required to displace afterward by one unit (3 bytes). Thus the position of these cargo units will be changed. This justification method is called positive justification. The corresponding position of the three inserted H3 bytes is called positive justification opportunity. If the rate of the VC4 is much lower than that of the AU-4, more than one positive justification unit (3 H3 bytes) will be required to insert into the AU-4 payload area. Note that there is only one negative justification opportunity (3 H3 bytes). And the negative justification opportunity is located within the AU-PTR while the positive justification opportunity is located within the payload area of the AU-4.

3) Either positive justification or negative justification will change the location of the VC4 within the AU-4 payload, i.e. the location of the first byte of the VC4 within the AU-4 payload will be changed. Then the AU-PTR will make corresponding positive or negative justification. For the convenience of aligning each bytes of the VC4 (each cargo unit, actually) within the AU-4 payload, each cargo unit is allocated a location value, as illustrated in Figure 3-10. The location value of the 3-byte unit immediately after the H3 bytes is set as zero, and so on. Thus an AU-4 payload area has $261 \times 9/3 = 783$ locations, and the AU-PTR designates the location value of the J1 byte within the AU-4 payload. Admittedly, the AU-PTR shall be in the range of 0 to 782, otherwise it is an invalid pointer value. If invalid pointer values were received consecutively in 8 frames, the equipment will generate an AU-LOP (AU Loss of Pointer) alarm and insert an AIS alarm signal- TU-AIS.

Either positive or negative justification is processed once a unit, then the pointer value will be incremented (pointer positive justification) or decremented (pointer negative justification) by one.

4) If there are no differences in the rates and the phases between the VC4 and the AU-4, i.e. the stopping time of the truck and the rate for loading the VC4 match, the AU-PTR value is 522, as indicated by the frame head illustrated in

-- Figure 3-9. Notes: The AU-PTR indicates the location of the J1 byte within the next VC4 frame. In the case that the network is synchronous, the pointer justification seldom appears. So mostly the H3 bytes are filled with pseudo-random information.

As mentioned before, the pointer value is located in the last ten bits within the H1H2 bytes. Thus the value of the ten bits ranges from 0 to 1023 (210). If the AU-PTR value is not within 0-782, it is an invalid pointer value. How do the 16 bits of the H1H2 implement pointer justification control? Please see Figure 3-10.

<table>
<tr><td>N</td><td>N</td><td>N</td><td>N</td><td>S</td><td>S</td><td>I</td><td>D</td><td>I</td><td>D</td><td>I</td><td>D</td><td>I</td><td>D</td><td>I</td><td>D</td></tr>
<tr><td colspan="4">New Data Flag (NDF)
means that the capacity of the payload has changed.
If no change occurs to the payload, the normal value of NNNN is "0110". Within the frame with its payload changed, the NNNN inverted to "1001" ---- NDF. The pointer value of the frame with a NDF shall be changed into the new location value of the VC, called new data. If the payload no longer changes, the NDF of the next frame shall return the normal value "0110". No subsequent increment or decrement operation is allowed for at least three frames following this operation.</td><td colspan="2">AU/TU type
For AU-4 and TU-3, SS=10</td><td colspan="10">10 bit pointer value
The range for AU-4 pointer is 0~782 with three bytes as an offset unit. The pointer value indicates the offset between the last H3 byte of the AU-4 pointer and the first byte of the VC4 frame.
Pointer justification regulation
(1) During normal work, the pointer locates the start of the VC4 within the AU-4 frame. The NDF is set to "0110".
(2) If the frame rate of the VC4 is slower than that of the AU-4, the inversion of the five I-bits indicates that a positive frequency justification is required. Then the start point of the VC frame is displaced afterward by one unit and in the subsequent frame, pointer value shall be incremented by one.
(3) If the frame rate of the VC4 is higher than that of the AU-4, the inversion of the five D-bits indicates that a negative frequency justification is required. Then the negative justification opportunity H3 bytes are overwritten with the actual information data of the VC4 and the start point of the VC frame is displaced forward by one unit. In the subsequent frame, pointer value shall be decremented by one.
(4) If the NDF appears refreshed value 1001, the change of the payload capacity is indicated. The pointer value shall be incremented or decremented correspondingly, then the NDF shall return to the normal value 0110.
(5) Following a pointer justification operation, no subsequent increment or decrement operation is allowed for at least three frames.
(6) When the pointer is interpreted by the receiver, any variation from the current pointer value is ignored except a consistent new pointer value received three times (three frames) consecutively.</td></tr>
</table>

Figure 3-10 The 16-bit pointer code consisting of H1 and H2 within the AU-4

The pointer value is carried in bits 7-16 of H1 and H2. The odd number bits of the ten bits are denoted I-bits while the even number bits are denoted D-bits. The operation of the pointer value increment or decrement by one is indicated by the inversion of all or the majority of the five I-bits or five D-bits. So the I-bits are also called increment bits while the D-bits are called decrement bits.

No subsequent frame pointer justification is allowed for least three frames, i.e. if the frame in which the pointer value inverts is regarded as the first frame, the subsequent pointer inversion isn't allowed until the fifth frame (the subsequent pointer value will be incremented or decremented by one).

The inversion of the NDF indicates the change of the AU-4 payload. Then the pointer value will leap, i.e. the step-length of the pointer value increment or decrement is not one. If the receiver detects NDF inversion in eight frames consecutively, the equipment will generate an AU-LOP alarm.

The receiver only interprets the received pointer which is consistent in three or more consecutive times (frames), i.e. the system considers that the pointer values of the three frames following the pointer justification are consistent. If a subsequent pointer justification occurs, a VC4 aligning error will appear at the receiver and result in transmission performance defects.

In a word, if the 5 I-bits or 5 D-bits invert at the transmitter, the subsequent AU-PTR value shall be incremented or decremented by one. The receiver determines whether to justify in the subsequent frame according to the inversion status of the majority of the I-bits or D-bits, i.e. to align the first byte of the VC4 and restore the timing of the signal before the pointer adaptation and alignment.

3.2.2 Tributary Unit Pointer——TU-PTR

The TU pointer is used to indicate the specific location of the first byte V5 of the VC12 within the TU12 payload so that the receiver can properly extract the VC12. The TU pointer provides a method of allowing flexible and dynamic alignment of the VC12 within the TU12 multi-frame. The TU-PTR is located in the bytes denoted V1, V2, V3 and V4 within the TU12 multi-frame, as illustrated in Figure 3-11.

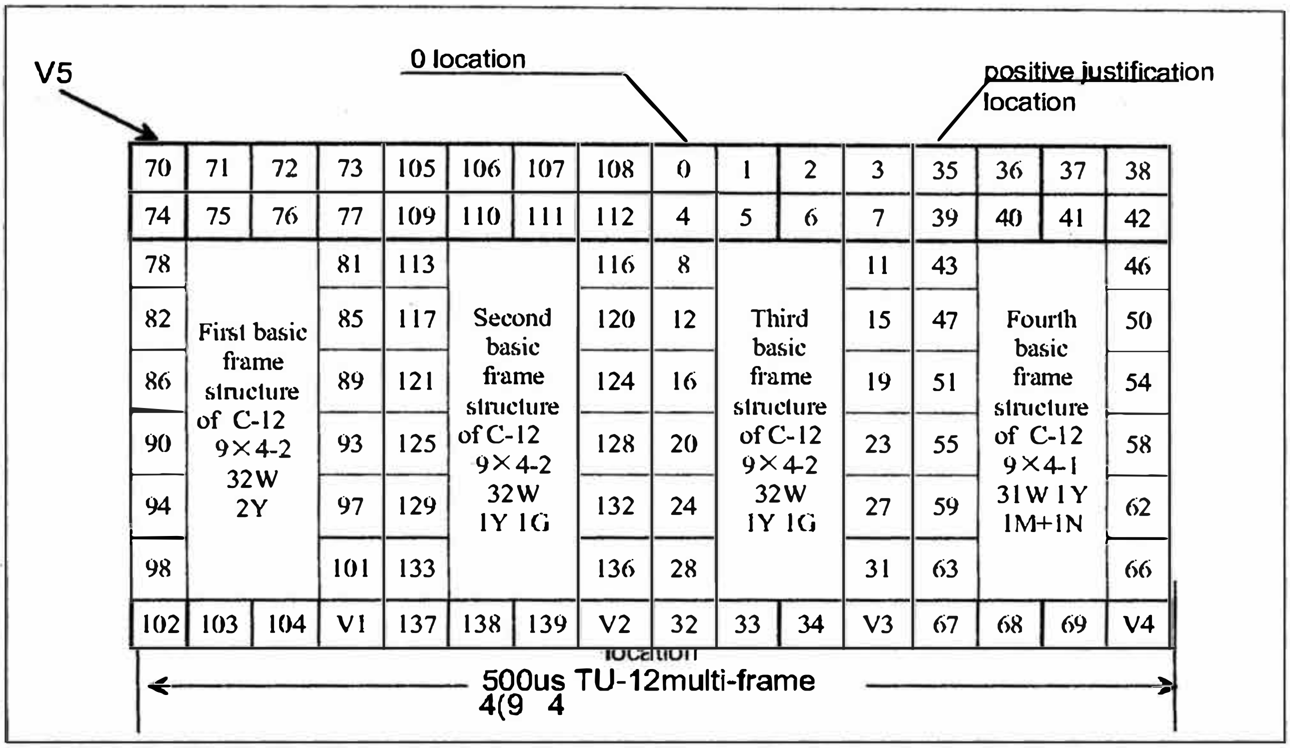


Figure 3-11 Numbering of the TU-12 pointer location and offset

The TU12 PTR consists of four bytes denoted V1, V2, V3 and V4.

From the byte immediately following the V2 within the TU12 payload, each byte is in sequence specified an offset number such as "0" and "1" according to the offset from the byte to the last V2 with one byte as a positive justification unit. Total offset numbers are from 0 to 139. The first byte V5 of the VC12 frame is located in the location with an offset number corresponding to the binary value of the TU12 pointer value.

The V3 byte of the TU12 PTR is the negative justification opportunity. A positive justification opportunity immediately follows it. V4 is a reserved byte. The pointer value is located in the last ten bits of the V1 and V2 bytes. The function of the 16 bits of the V1 and V2 bytes is similar to that of the 16 bits of the H1 and H2 bytes within the AU-PTR.

Notes:

Positive/negative justification is implemented via the V3 byte.

The justification unit of the TU-PTR is one (byte). Thus the range of the pointer value is 0 to 139. If the invalid pointer or NDF is being received in eight frame consecutively, a TU-LOP (Tributary Unit Loss of Pointer) alarm will be generated at the receiver and an AIS alarm signal shall be inserted.

If there are no differences in the phases and frequencies between the VC12 and TU12, the location value of the V5 byte is 70, i.e. the TU-PTR value is 70.

The pointer justification and pointer interpretation methods of the TU-PTR is similar to that of the AU-PTR.

? **Questions:**

What did you learn from this section?

1. How do AU-PTR and TU-PTR align the VC4 and VC12?

2. The reasons for generation of the alarm and performance events pertaining to the pointers.

The second item shall be emphasized.

Summary

This section describes the implementation of monitoring of SDH system signals. The RSOH, MSOH, HP-POH and LP-POH have accomplished the layered monitoring mechanism.

The focus is the mechanism for the bytes to monitor alarms and performances.

Exercises

1. Which bytes are used to monitor the MS-AIS and MS-RDI?
2. What is the mechanism of the R-LOF alarm monitoring?
3. What are the alarms generated when the receiver have detected that the AU-PTR is 800 or 1023?
4. Which bytes implement the layered error monitoring?

Section 4 Logic Composition of SDH Equipment

Objectives:

To understand the common NE types and the basic functions of the SDH transmission network.

To master the functions of the basic logic functional blocks that constitute the SDH equipment, and their corresponding alarms and performance events monitored.

To master the functions of the auxiliary functional blocks.

To understand the functions of the compound functional blocks.

To master the corresponding alarm maintenance signals provided by each functional block, and their corresponding alarm flow charts.

4.1 Common NE of SDH network

The SDH transmission network is composed by connecting different types of NE that are connected through optical fibre. The transmission function of the SDH network is performed through different NE: add/drop services, cross-connect service, network error self-healing, etc. The following is a description of the features and basic functions of common NE in the SDH network.

1. TM – Terminal Multiplexer

Terminal Multiplexer is used in the termination station of the network, e.g. the two ends of a chain, which is a two-port device, as shown in Figure 4-1.

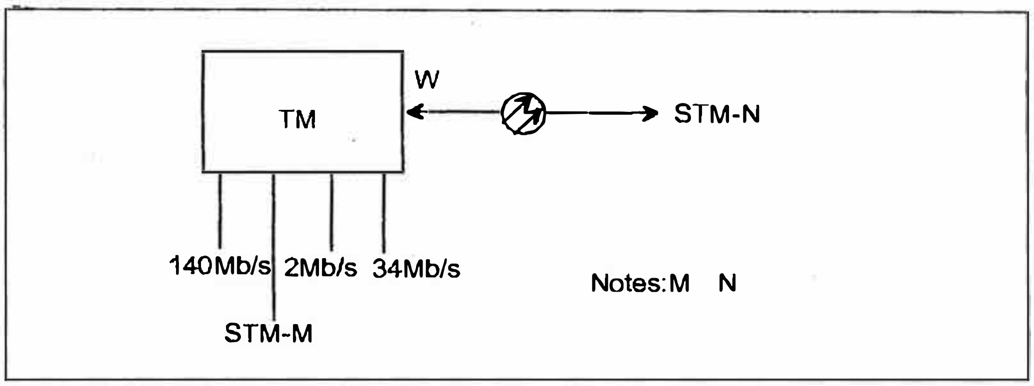


Figure 4-1 TM model

Its function is to multiplex the lower-rate signals in the tributary port to the higher-rate signal STM-N in the line port, or to extract the lower-rate tributary signals from STM-N signal. Please note that its line port inputs/outputs one STM-N signal, while the tributary port can output/input multiple paths of lower-rate tributary signals. When the low rate tributary signals are multiplexed into STM-N frame (to multiplex low rate signal into line), there is a cross function. For example, an STM-1 signal of the tributary can be multiplexed into any position (i.e. any time-slot number) of the STM-16 signal of the line, i.e. into any position of one to sixteen STM-1 time slot. The 2Mb/s signal of the tributary can be multiplexed into any position of the 63 VC12 time slot of any STM-1. For the Huawei-made equipment, the line port of TM (optical interface) takes the western side port as its default port. Notes: TM has only one line port, it's a tow-port equipment.

2. ADM – Add/Drop Multiplexer

Add/drop multiplexer is used in the transfer station of SDH transmission network, e.g. the intermediate node of the link or the node in the ring. It is one of the most widely used and important NE of SDH network. It is a three-port device, as shown in Figure 4-2.

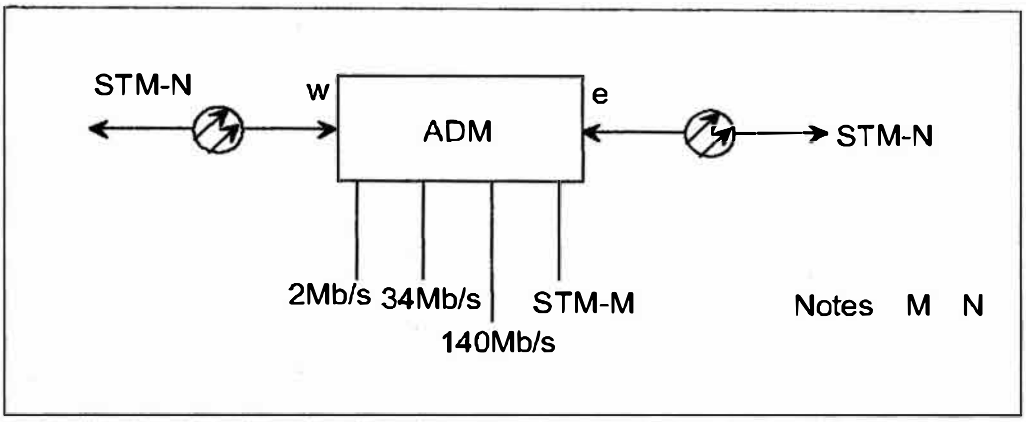


Figure 4-2 ADM model

ADM has two line ports and one tributary port. The two ports of the line are respectively connected to the optical fibre on each side (there are two receive/transmit fibre in each side). For the convenience of description, we classify them into Western side (W) and eastern side (E) line ports. The function of ADM is to cross multiplex the low rate tributary signals into the line on the W or E side, or to de-multiplex low rate tributary signals from the line signal received from the line port on W or E. In addition, it includes the cross-connect of the STM-N signal between the side of the E/W line, e.g. to connect the 3# STM-1 in the E side STM-16 to the 15# STM-1 in the W side STM-16 signal.

ADM is the most important NE of SDH. It can be equivalent to other NE , i.e. the function of other NE can be accomplished. For example, one ADM can be equivalent to two TMs.

3. REG —Regenerator

There are two kinds of regenerators in optical transmission network. One is purely optical REG, serving mainly as amplifier of optical power to increase optical transmission distance, the other is an electric REG, used in pulse regenerating reform, avoiding the accumulation of line noise through optical/electric conversion, electric signal sampling, judging, regenerating and reforming, and electric/optical conversion to ensure perfect transmission of signal wave in the line. What is discussed here is the latter type of regenerator. REG is a two-port device, having only two line ports – w port and e port, as shown in Figure 4-3:

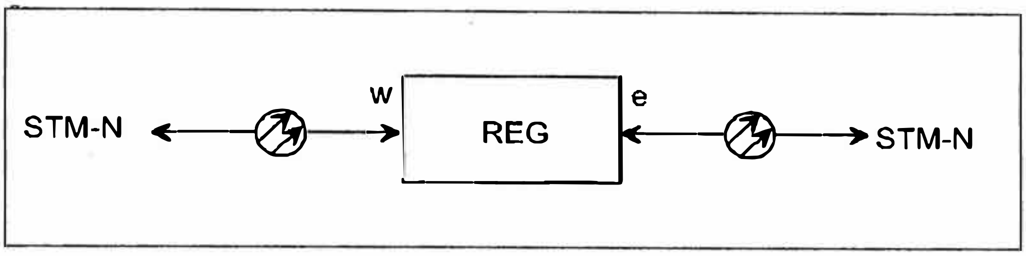


Figure 4-3 Electric REG

Its function is to generate the w side or e side received optical signal through O/E, sampling, judging, regenerating and reforming, E/O, and transmit on the e or w side again. Perhaps you have noticed that REG does not have tributary port as ADM has, so ADM can be equivalent to one REG when the traffic is not added/dropped at the local position (tributary does not add/dropped signals).

True REG needs only to handle the RSOH in the STM-N frame, and needs no cross-connect function, but only through connection from w to e or e to w. While ADM and TM need to handle not only RSOH because they need to add/drop the low rate tributary signals (e.g. 2Mb/s, 34Mb/s, 140Mb/s) to STM-N, but also MSOH. Besides, ADM and TM both have cross multiplex function (cross connect function), so it is not very economical to use ADM as REG equivalent.

4. DXC – Digital Cross-Connect Equipment

The major function of digital cross-connect equipment is to cross connect STM-N signals. It is a multiple-port device (multiple SDH port), actually equals a cross-connect matrix accomplishing the cross connect between signals, as shown in Figure 4-4:

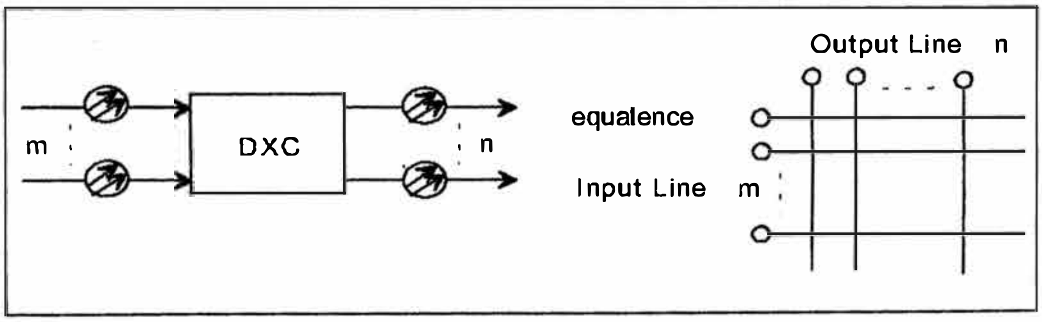


Figure 4-4 DXC function module

DXC may cross connect the input m route STM-N signals to the output n route STM-N signals. The above diagram shows that there are m input optical fibres and n output optical fibres. The core of DXC is the cross connect function. Powerful

DXC can finish low level cross connect (e.g. the cross connect of VC12) of high rate signal (e.g. STM-16) within the cross-connect matrix.

Usually, DXCm/n is used to represent the type and performance of DXC (note m ≥ n), in which m means the top rate level of accessible DXC, while n represents the lowest rate level which can be cross connected within the cross-connect matrix. The greater m is, the larger the load-carrying capability of DXC is; the smaller n is, the more flexible the cross connect function of DXC is. The meanings of the corresponding values of m and n are shown in Table 4-1:

Table 4-1 Corresponding values of the rates of m and n

m or n	0	1	2	3	4	5	6
rate	64kb/s	2Mb/s	8Mb/s	34Mb/s	140Mb/s 155Mb/s	622Mb/s	2.5Gb/s

ADM can serve as DXC of small capacity, e.g. the Huawei-made 2.5G equipment can be equivalent to 6×6 DXC5/1.

4.2 Logic functional block of SDH equipment

We know that the SDH system requires that products made by different manufacturers should be inter-connected, which necessarily requires the equipment should be in accordance to the standard. But manufacturers are different, how can the equipment be standardized so as to meet the requirements of interconnectivity?

ITU-T adopts the function-referenced model to normalize the SDH equipment. It divides the functions performed by the equipment into various basic standard functional blocks. The actualization of the functional blocks have nothing to do with the physical actualization of the equipment (i.e. no limit to actualization methods). Different equipment is flexibly composed of these basic functional blocks to implement different functions of the equipment. Through the standardization of the basic functional blocks, the standard of the equipment is also normalized, and the standardization becomes universal. The description is clear and simple.

Take the typical functional blocks composition of one TM equipment as an example, the following is an account of the functions of each basic functional block. What should be noted is that the alarm monitored by corresponding logic functional block, the performance events, and their detect principle should be understood. Please refer to Figure 4-5:

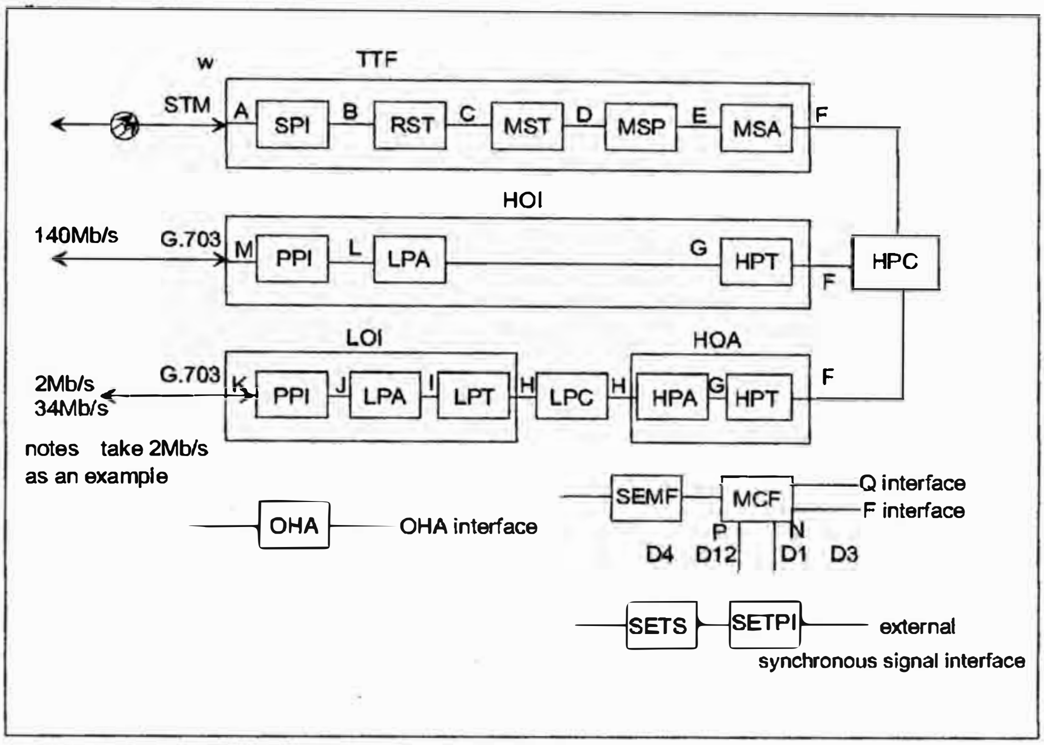


Figure 4-5 Logic functional blocks composition of SDH equipment

To better understand the above figure, the names of the functional blocks in the figure are listed below:

SPI: Synchronous Physical Interface RST: Regenerator Section Termination

MST: Multiplex Section Termination MSP: Multiplex section protection

MSA: Multiplex Section Adaptation PPI: PDH Physical Interface

LPA: Low order Path Adaptation LPT: Low order Path Termination

LPC: Low order Path Connection HPA: High order Path Adaptation

HPT: High order Path Termination TTF: Transmission Termination Function

HOI: High Order Interface LOI: Low Order Interface

HOA: High Order Assembly HPC: High order Path Connection

OHA: Overhead Access

SEMF: Synchronous Equipment Management Function

MCF: Message Communication Function

SETS: Synchronous Equipment Timing Source

SETPI: Synchronous Equipment Timing Physical Interface

Figure 4-5 is the functional block composition figure of a TM. Its signal flow procedure is that the STM-N signal in the line enters the equipment from Reference Point A of the equipment and is demultiplexed to PDH signal of 140Mb/s in the order A→B→C→D→E→F→G→L→M; and STM-N signal is dropped as PDH signal of 2Mb/s or 34Mb/s (here take the 2Mb/s signal as an example) in the order A→B→C→D→E→F→G→H→I→J→K. Here it is defined as the receiving direction of the equipment. The corresponding transmitting direction is the reverse direction of these two paths, it multiplexes the PDH signals of 140Mb/s, 2Mb/s, and 34Mb/s to the STM-N signal frame in the line. These functions of the equipment are performed collaboratively by all the basic functional blocks.

- **SPI: SDH Physical Interface functional block**

SPI is the interface of equipment and optical path, mainly performing optical/electric conversion, electric/optical conversion, extraction timing of line signal (STM-N), and corresponding alarm monitoring.

1) Signal flow from A to B – receiving direction

Optical/electric conversion, extraction timing of line signal, at the same time sends it to SETS (Synchronous Equipment Timing Source functional block) to lock timing phase. After the frequency is locked, the timing signal is sent to other functional blocks by SETS, which is taken as their work timing clock.

When the STM-N signal at Point A fails (e.g. receiving no light or over-low optical power, transmission performance defect as to make BER worse than 10-3), SPI would generate R-LOS alarm (receiving loss of signal) indication, and report it to SEMF (Synchronous Equipment Management Functional block) of the R-LOS state.

2) Signal flow from B to A – transmitting direction

Electric/optical conversion, the timing message is simultaneously attached to the signal of the line (STM-N).

- **RST: Regenerator Section Termination functional block**

RST is the source and sink of RSOH overhead bytes, i.e. RST functional block generates RSOH (transmitting direction) in the course of forming SDH frame signals, and processes (terminates) RSOH in the reverse direction (receiving direction).

1) Signal flow from B to C—receiving direction

The electric signal and timing signal or R-LOS alarm signal (if any) are sent to RST through reference point B. If RST receives R-LOS alarm signal, it will insert all "1" (AIS) signal in Point C. If normal traffic flow is received at Point B, RST then begins to search A1 and A2 bytes to align the frame. The alignment of frames is to check constantly the frame signals to see if they are in accordance with the location of frame head. If a consecutive of more than five frame heads can not be aligned (625us), the equipment enters Out Of Frame state, and RST functional block reports Receiving signal Out Of Frame alarm—ROOF. When out of frame, if a consecutive of two frames are aligned correctly, the ROOF state ends. If ROOF continues for more than 3ms, the equipment enters Loss Of Frame state, and RST reports RLOF alarm, showing all "1" signal at Point C.

After RST correctly aligns the frames for the signal input from Point B, it de-scrambles all the bytes in STM-N frames except the first line of bytes. After the de-scramble, RSOH is extracted and processed. RST verifies B1 bytes. If error blocks are detected, RS-BBE is generated in this terminal. RST at the same time extracts and sends E1 and F1 bytes to OHA (Overhead Access functional block) to process order wire telephone connection. D1-D3 are extracted and sent to SEMF, and the OAM command information of the regenerator section in D1-D3 is processed.

2) Signal flow from C to B transmitting direction

RST writes RSOH, computes B1 bytes, and scrambles all the bytes except the first line of bytes in RSOH. The signal frame structure of equipment at Points A, B, and C is shown in Figure 4-6:

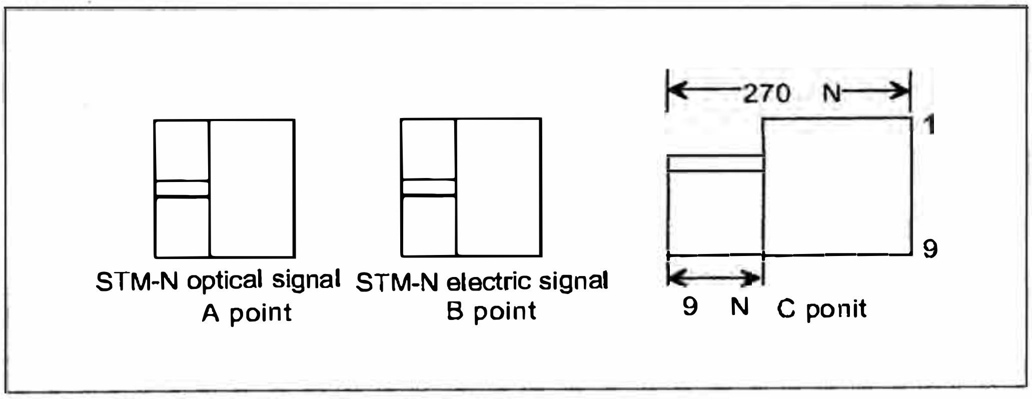


Figure 4-6 Signal frame structure at Points A, B, and C

- MST: Multiplex Section Termination functional block

MST is the source and sink of multiplex section overhead, processing (terminating) MSOH in receiving direction and generating MSOH in transmitting direction.

1) Signal flow from C to D—receiving direction

MST extracts the APS (automatic protection switching) protocol in K1 and K2 bytes to SEMF, so that SEMF can carry out the multiplex section switching at appropriate time (e.g. when error occurs). If what Point C receives from b6-b8 of K2 bytes in three consecutive frames is 111, it shows that the signals input from Point C are all "1" signals (AIS). MST functional block generates MS-AIS (multiplex section -- alarm indication signal) alarm signal.

Tips:

MS-AIS alarm means that the signal at Point C is all "1". It is generated by R-LOS, R-LOF, because when RST receives R-LOS and R-LOF, the signal in Point C will be made to be all "1". So, the b6-b8 of K2 at this time is of course "111". In addition, the MS-AIS alarm in this terminal may be caused by the fact that the signal transmitted by the remote terminal is itself MS-AIS, i.e. the transmitted STM-N frame is composed of valid RSOH and signal whose other parts are all

If the K2 of the signal in Point C is 110, the signal can be judged to the alarm signal sent back by the remote terminal equipment: MS-RDI (multiplex section – remote defect indication), indicating that the remote terminal equipment encounters MS-AIS when receiving signal, and the alarm that B2 error is too great.

MST functional block verifies B2 bytes and monitors the transmission error block of multiplex section signal. If error block is detected, the equipment of this terminal will display the number of the error blocks in the MS-BBE performance event, sending back MS-REI information to the remote terminal. M1 bytes will answer it with the number of the error blocks received by the remote terminal.

If MS-AIS is detected, or the number of the error blocks detected by B2 exceeds the threshold (at this moment MST reports that B2 error exceeds the threshold of alarm MS-EXC), the signal will be made all "1" at Point D.

Besides, MST restores the synchronous state information S1 (b5-b8), sending the received information of synchronous quality hierarchy level to SEMF. At the same time, MST extracts and sends the D4-D12 bytes to SEMF for it to process the

OAM information of the multiplex section; E2 is extracted and sent to OHA for it to process the service connection information of the multiplex section.

2) Signal flow from D to C　transmitting direction

MST written to MSOH: E2 from OHA, D4-D12 from SEMF, and K1, K2 from MSP are written to MSOH. At the same time, the corresponding B2 bytes, S1 bytes, and M1 bytes are written to MSOH. If MST detects MS-AIS or MS-EXC (B2) in the receiving direction, the b6-b8 of K2 bytes will be set as 110 in the transmitting direction. The signal frame structure at Point D is shown in Figure 4-7:

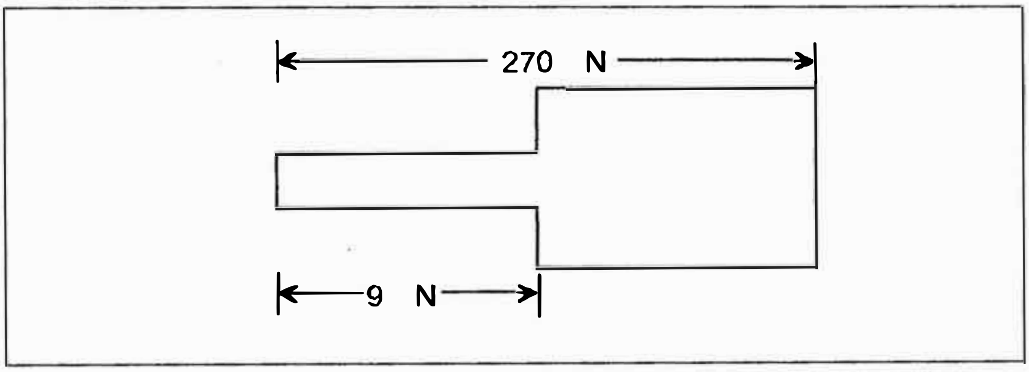
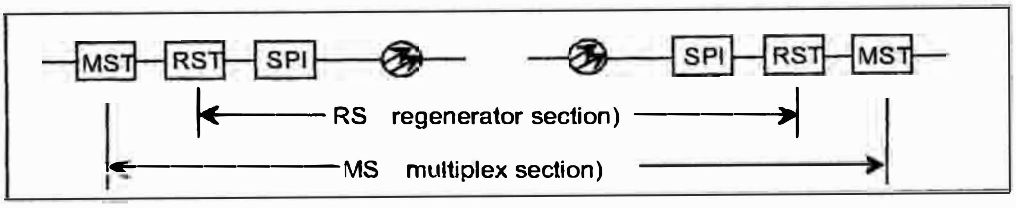


Figure 4-7 Signal frame structure at Point D

Tips:

You have heard many times such names as regenerator section and multiplex section, but do you know what exactly they are?

Regenerator section refers to the maintenance section between the RST of two equipment (including the two RST and the optical fibre between them), while multiplex section refers to the maintenance section between the MST of two equipment (including the two MST、two RST and the optical fibre between them).



The regenerator section processes only the RSOH of STM-N frame, and the multiplex section processes the RSOH and MSOH of STM-N frame.

- MSP: (Multiplex Section Protection functional block)

MSP is used to protect STM-N signal in multiplex section in order to prevent errors that come with it. It switches the signal of the error channel to the protection channel (multiplex section switching) by monitoring STM-N signal and evaluating the system state. ITU-T defines that the time of protection switching is controlled within 50 ms.

The fault condition of multiplex section switching is R-LOS, R-LOF, MS-AIS, or MS-EXC (B2). To actualize the multiplex section protection switching, the equipment must have redundant (standby) channels. Take a terminal-to-terminal TM as an example. Please refer to Figure 4-8:

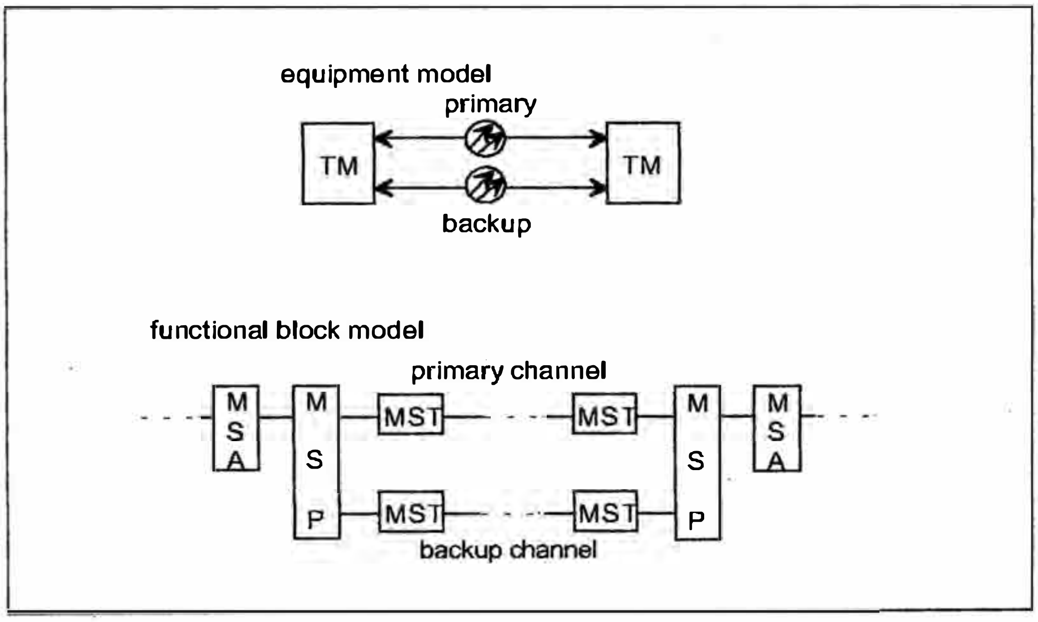


Figure 4-8 Multiplex section protection of TM

1) Signal flow from D to E—receiving direction

If MSP receives MS-AIS sent by MST or protection switching command from SEMF to switch from primary channel to standby channel for the information. Normally the signal flow is transparently sent from D to E.

2) Signal flow from E to D —transmitting direction

The traffic flow at Point E is transparently sent to D.

The waveform of signal at Point E is the same as that at Point D.

Technical details:

Common protection switching modes include 1+1, 1:1, and 1:n. Take the equipment model in Figure 4-8 as an example:

1+1 means that the transmit end transmits the same information (together) from the active channel and the standby channel. The receive end normally chooses the service in the active channel to receive because the services in the active channel and the standby channel are exactly the same (both are main service), the service in the active channel will be restored by switching to the standby channel service to receive when the active channel is damaged. This switching is also called single end switching (only switching the receive end). The switching speed is fast but with a low utilization ratio of the channel.

1:1 means that the transmit end normally transmits main (primary) services in the active channel, and the extra services in the standby (backup) channel (low protection level services. Notes: not backup service). The receive end receives the main services from the active channel and the extra services from the standby channel. But when the active channel is damaged, to ensure the transmission of the main services, the transmit end will switch the main services to the standby channel to transmit, and the receive end will switch to the standby channel to receive the main services. The extra services are presently terminated, and the transmission of the main services are restored. This kind of switching is called double end switching (switch in both receive/transmit end). The switching rate is slow, but with a high utilization ratio of the channel. Because the transmission of the extra services is terminated when the active channel is damaged, the extra services are also called non-protected services.

1:n means that one standby channel protects n active channels. In this case the utilization ratio of the channels is even higher, though one standby channel can protect only one active channel and thus lowering the reliability of the system.

- MSA: Multiplex Section Adaptation functional block

The function of MSA is to process and generate AU-PTR, and to assemble/disassemble the entire STM-N frame, i.e. to assemble/disassemble AUG to VC4.

1) Signal flow from E to F—receiving direction First, MSA dis-byte-interleaves AUG by dividing AUG into n AU-4 structures before processing n AU-PTR of n AU-4. If the value of AU-PTR is invalid pointer value for a consecutive of 8 frames or AU-PTR is NDF for a consecutive of 8 frames, the

--corresponding AU-4 of MSA generates AU-LOP alarm, and the output of the signal on the corresponding channels (VC4) at Point F is all "1". If MSA finds H1, H2, and H3 bytes are all "1" for a consecutive of 3 frames, it is considered that the input at Point E is all "1" signal. MSA at this moment changes the output on the corresponding VC4 at Point F to all "1", and generates AU-AIS alarm of the corresponding AU-4.

2) Signal flow from F to E—transmitting direction The signal at Point F changes to AU-4 through MSA locating and aligning addition of AU-PTR. N AU-4 is multiplexed to AUG by byte-interleaved-multiplexing method. The signal frame structure at Point F is shown in Figure 4-9.

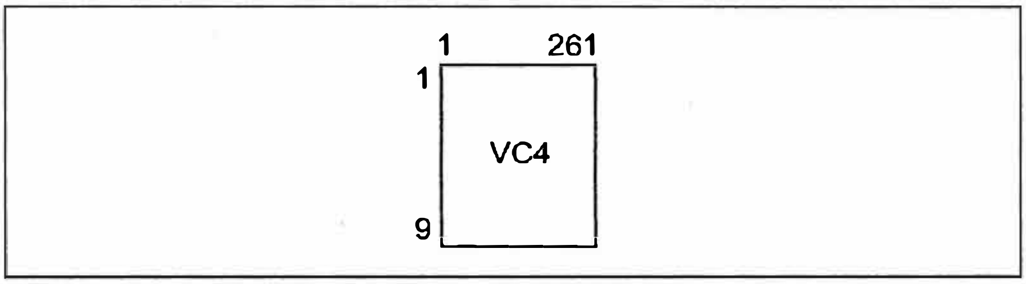


Figure 4-9 The signal frame structure at Point F

- TTF: Transmission Termination Functional block

As mentioned above, several basic functional blocks may form compound functional block by flexible combination to implement some complex work. SPI, RST, MST, and MSA together form compound functional block TTF. Its function is to carry out optical/electric signal conversion (SPI) for STM-N optical line signal in the receiving direction, to process RSOH (RST) and MSOH (MST), to protect the multiplex section signal (MSP), to dis-byte-interleave AUG and process (explain) the pointer AU-PTR, and finally to output n VC4 signals. It is just the opposite for the transmitting direction. What enters TTF is n VC4 signals and what goes out of TTF is STM-N optical signals.

- HPC: Higher order Path Connect functional block

HPC actually equals a cross-connect matrix. It functions as cross connect for the high order path VC4 signal. Except the cross connect of the signals, the traffic flow is transparently sent in HPC (so both ends of HPC are represented by Point F). HPC is the key to the realization of high order path signal DXC and ADM, whose cross connect is to the choice or change of the route of VC4 excluding the process of the signals. The power of an SDH equipment is determined by its cross -connect capability, while cross-connect capability is determined by cross connect functional blocks: high order HPC and low order LPC. To ensure the all cross ability of the service, the minimum capacity of the HPC cross-connect matrix as shown in Figure 4-6 should be 2N VC4 ′ 2N VC4, equaling 2N VC4 input signal lines and 2N VC4 output signal lines.

- HPT: High order Path Termination functional block

The signal coming out from HPC is divided into two routes: one enters the HOI compound functional block outputting 140Mb/s of PDH signal; the other enters HOA compound functional block, outputting 2Mb/s of PDH signal through LOI compound functional block. Whichever route it takes, it must first go through the HPT functional block. The function of the two route HPT is the same.

HPT is the source and sink of high order path overhead bytes, forming and terminating the high order virtual container (VC4).

1) Signal flow from F to G—receiving direction

Terminate POH and check B3. If error blocks occur, the error number will be shown in the HP-BBE of the performance event in this terminal. Meanwhile, in the signals sent back to the remote terminal, b1-b4 of G1 byte is set as the detected error number in order that the error number should be shown in the HP-REI of the performance event in the transmit end.

Tips:

The range of b1-b4 of G1 is 0-15, while B3 can only detect at most 8 error blocks in one frame, i.e. the values 0-8 of b1-b4 of G1 represent 0-8 error blocks, the other 7 values (9-15) are all taken as non-error blocks.

HPT detects J1 and C2 bytes. If they fail to be consistent (what should be received is not consistent with what is received), HP-TIM and HP-SLM alarms will be generated, rendering the output in the corresponding channels on Point G as all "1". The HP-RDI alarm in a corresponding channel is at the same time sent back to the sending terminal through b5 of G1. If it is detected that the content of C2 byte is 00000000 for a consecutive of 5 frames, it can be decided that this VC4 channel is not loaded, which thus renders all "1" as the output of the signal in the corresponding channel in Point G. HP-UNEQ alarm is generated in the corresponding VC4 channel of HPT.

HPT detects J1 and C2 bytes. If they fail to match (what should be received is not consistent with what is received), HP-TIM and HP-SLM alarms will be generated, rendering the output in the corresponding channels at Point G as all "1". The HP-RDI alarm in a corresponding channel is at the same time sent back to the transmit end through b5 of G1. If it is detected that the content of C2 byte is 00000000 (00H) for a consecutive of 5 frames, it can be decided that this VC4 channel is not loaded, which thus results in all "1" as the output of the signal in the corresponding channel at Point G. HP-UNEQ alarm is generated in the corresponding VC4 channel of HPT.

The content of H4 byte contains order number of the four basic frames in multi-frame . HPT transmits it to the HPA functional block of HOA compound functional block (because the order number of four basic frames in multi-frame is only valid to 2Mb/s, but invalid to 140Mb/s).

2) Signal flow from G to F —transmitting direction

HPT writes POH and computes B3. Through SEMF, the corresponding J1 and C2 are sent to HPT which in turn writes to POH.

The frame structure at Point G is actually the frame of C4 signal. In one case, this C4 signal is adapted through 140Mb/s, while sometimes it is multiplexed by 2Mb/s through the structure C12→VC12→TU12→TUG2→TUG3→C4. The following is their descriptions.

First, we'll discuss the C4 adapted from the PDH signal of 140Mb/s. The signal frame structure at Point G is shown in Figure 4-10:

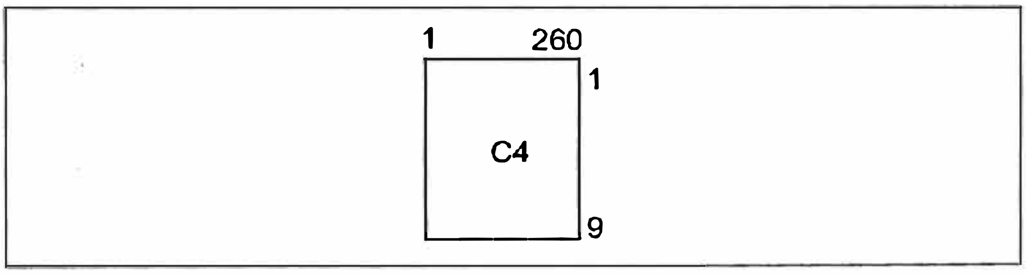


Figure 4-10 Signal frame structure at Point G

- LPA: Low order Path Adaptation functional block

The function of LPA is to adapt PDH signal into C through rate justification mapping, or drop C signal to corresponding PDH signal through demapping procedure. Its function is similar to PDH ⇔ C. In other words, the function of LPA here is simple C4⇔140Mb/s.

- **PPI: PDH Physical Interface functional block**

PPI functions as the interface between the physical transmission media with tributary signal and PDH equipment. Its main function is to change the code types, and to extract the tributary timing signals.

1) Signal flow from L to M---receiving direction

To change the internal code of the equipment to PDH line code for the convenience of transmission, e.g. HDB3 (2Mb/s, 34Mb/s), CMI (140Mb/s).

2) Signal flow from M to L—transmitting direction

To change PDH line code to NRZ code for the convenience of the equipment to process and to extract at the same time the clock of the tributary signal and send it to SETS phase lock. After the phase lock, the clock is sent to each functional block by SETS as their working clock.

When PPI detects no input signal, it will generate tributary loss of signal alarm T-ALOS (2Mb/s) or EXLOS (34Mb/s, 140Mb/s), meaning that the equipment tributary input signal is lost.

- **HOI: High Order Interface**

Here, this compound functional block is composed of three functional blocks: HPT, LPA, and PPI. Its function is: PDH signal of 140Mb/s ⇔C4⇔VC4.

The following description is about 2Mb/s multiplexing into C4, or de-multiplexing from C4.

- **HPA: High order Path Adaptation functional block**

At this moment, the signal at Point G is actually the C4 signal formed by TUG3 though byte-interleaved-multiplexing. And TUG3 is formed by TUG2 through byte-interleaved-multiplexing, and TUG2 by TU12. TU12 is formed by VC12+TU-PTR. Please refer to the attached figure in Chapter Three.

The function of HPA is similar to that of MSA with the only difference that the processing and generation of TU-PTR is on the channel level, dividing the information structure of C4 into VC12 (as far as 2Mb/s signal is concerned).

1) Signal flow from G to H—receiving direction

First, de-byte-interleave C4 to 63 TU12. Then process TU-PTR, and locate, divide VC12 in TU12. The signals coming out of Point H are 63 VC12 signals.

HPA detects V1、V2、V3, if they are all "1", HPA consider it as TU-AIS alarm, and make corresponding VC12 path output all "1" at Point H. If HPA detects the value of TU-PIR is invalid or NDF of consecutive 8 frames, HPA generate TU-LOP alarm at corresponding path and makes corresponding VC12 path output all "1" at Point H.

HPA gives the location of basic TU12 or VC12 frame in multi-frame according to the H4 bytes received from HPT. The value of H4 is compared with the expected value of the single basic frame in the multi-frame sequence. If a consecutive of several frames are not consistent, the alarm of TU-LOM is reported. If the value of H4 is invalid, TU-LOM alarm will report too. H4 valid range is 00H-03H.

2) Signal flow from H to G—transmitting direction

HPA first locates the input VC12 (aligning) – adds TU-PTR, i.e. VC12 Û TU12. Then multiplexes the 63 TU12 through byte interleaving: TUG2→TUG3→C4.

- HOA: High Order Assembly

The function of the high order assembly is to assemble the low order VC signals (VC12 or VC3) into C4 frame by mapping aligning (locating) and multiplexing, or to de-multiplex C4 and into low order VC signals (VC12, VC3).

The signal frame structure at Point H is shown in Figure 4-11.

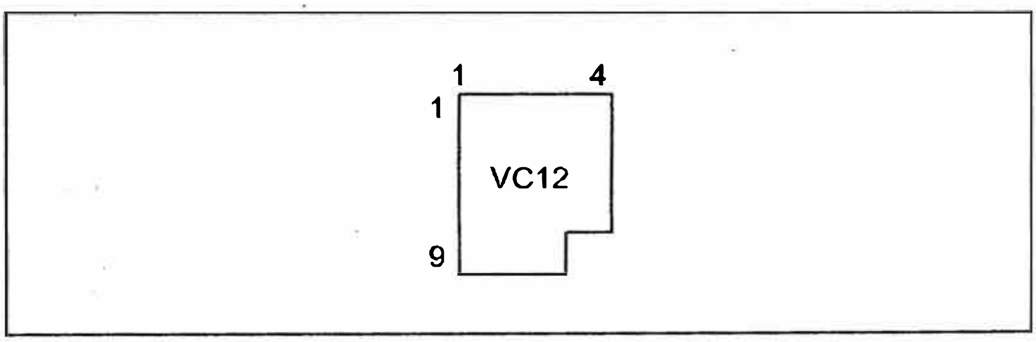


Figure 4-11 Signal frame structure at Point H

- LPC: Low order Path Connection functional block

Similar to HPC, LPC is also a cross connect matrix only with difference that the latter functions as the cross connect of the low order VC (VC12, VC3) to achieve flexible cross connection and allocation among low order VC. If an equipment is to have all-round cross-connect capability, it must include both HPC and LPC. For example, DXC4/1 can accomplish the cross connect of VC4 level and that of VC3 and VC12. That is to say, DXC4/1 must include both the HPC functional block and the LPC functional block. The traffic flow is transparently transmitted in the LPC functional block (so the reference points of LPC are all H).

- LPT: Low order Path Termination functional block

LPT is the source and sink of low order POH bytes. For VC12, it is to process and generate the four POH bytes: V5, J2, N2, and K4.

1) Signal flow from H to J—receiving direction

LPT processes LO-POH, verifies BIP-2 through the b1-b2 of V5 bytes. If block errors of VC12 are detected, the number of the block errors will be displayed in the performance event LP-BBE in the local terminal. And it will be reported back to the equipment in the remote terminal through b3 of V5. The number of the block errors will be displayed in the performance event LP-REI (low order path – remote error indication) in the equipment of the remote terminal. When monitoring J2 and b5-b7 of V5, if mismatch occurs (what should be received is not consistent with what is actually received), LP-TIM (low order path – trace identifier mismatch) and LP-SLM (low order path – signal label mismatch) will be generated in the local terminal. At this moment, the signals in the corresponding channels at Point I of LPT will be output as all "1", and LP-RDI alarm (low order path – remote defect indication) will be at the same time sent back to the remote terminal through b8 of V5 in corresponding path (channel). This makes the remote terminal know that the corresponding VC12 path signal in the receive end is defect. If a consecutive of 5 frames are detected that the b5-b7 of V5 is 000, the corresponding path will be judged as unequipped, and LP-UNEQ (low order path – unequipped) alarm will appear in the corresponding channels of the local terminal.

The signal at Point I has actually become C12 signal. The frame structure is shown in Figure 4-12.

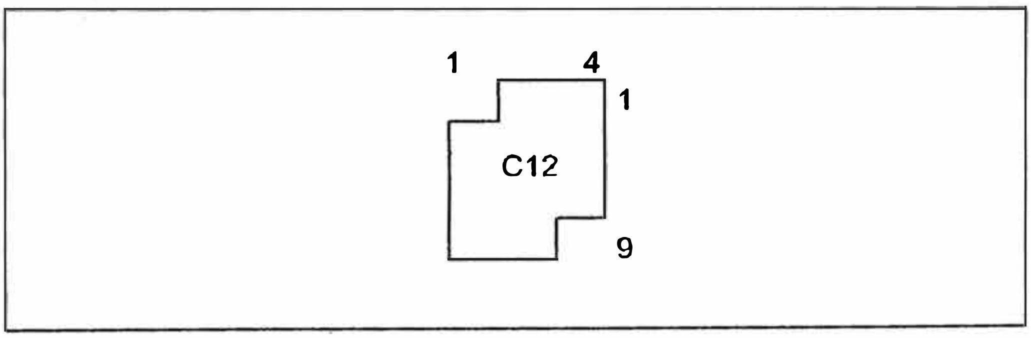


Figure 4-12 Signal frame structure at Point I

- LPA: Low order Path Adaptation functional block

The function of low order path adaptation functional block is the same as mentioned above, that is, to put PDH signal (2Mb/s, 34Mb/s) into or take it out of the C12 (or C3) container. It equals the process of packing/unpacking a package: 2Mb/s Û C12 (or 34Mb/s Û C3). The signal at Point J at this time has actually become the 2Mb/s signal of PDH.

- PPI: PDH Physical Interface functional block

As mentioned above, PPI mainly performs the interface function of changing code types and the function of extracting tributary timing for the system.

- LOI: Low Order Interface functional block

Low order interface functional block mainly unpacks VC 12 signal to PDH 2Mb/s signal (or 34Mb/s to VC3) through receiving direction, or packs PDH 2Mb/s signal to VC12 signal (or VC3 to 34Mb/s) through transmitting direction, performing at the same time the interface function of the equipment between line – code type changing; LOI performs the function of mapping and de-mapping.

These are the basic functional blocks of the equipment, but they may constitute different equipment through flexible combinations, e.g. they can constitute REG, TM, ADM, and DXC and perform their corresponding functions.

The equipment has some other auxiliary functional blocks. They, together with the basic functional blocks, perform the functions required by the equipment. These auxiliary functional blocks include SEMF, MCF, OHA, SETS, and SETPI.

- SEMF: Synchronous Equipment Management functional block

Its function is to collect the state information of other functional blocks, and to perform relevant management operations. This includes: it sends commands to each functional block, collects the alarm and performance events of each functional block, sends OAM information to other NE through DCC channel, reports equipment alarm and performance data to the network management terminal, and responds to the commands given by the network management terminal.

The OAM content of DCC (D1-D12) channel is determined by SEMF. Corresponding SEMF determined bytes are written at RST and MST through MCF, or D1-D12 bytes are extracted from RST and MST through MCF functional block and then sent to SEMF to process.

- MCF: Message Communication Functional block

MCF functional block is actually a communication interface among SEMF, other functional blocks and network management terminal. Message communication of SEMF (through interface F, Q) with the network management is carried out through MCF, and OAM information is interacted with the respective DCC channels in RST and MST through Interface N and Interface P, and thus the communication of OAM information between NE is accomplished.

Interface N in MCF sends D1-D3 bytes (DCCR), while Interface P sends D4-D12 bytes (DCCM). Both Interface F and Interface Q are the interfaces of the network management terminal. Through them the network management can perform unified management of this equipment and the NE of the whole network.

Technical details:

Interface F and Interface Q are both interfaces between the network management and equipment, what are the differences between them?

Interface F provides the interface for the local network management terminal, while Interface Q provides the interface for the remote network management terminal.

- SETS: Synchronous Equipment Timing Source functional block

Digital network needs a timing clock to ensure the synchronization of the network and thus the normal operation of the equipment. The function of the SETS functional block is to provide the timing clock signal for the local SDH NE or perhaps others SDH NE in the network .

The sources of SETS clock signals include:

1) Clock signal extracted from the STM-N signal of the line by SPI functional block;

2) Clock signal extracted from PDH tributary signals by PPI;

3) External clock source extracted by SETPI (synchronous equipment timing physical interface), e.g. 2MHz square wave signal or 2Mb/s;

4) Clock generated by the inner oscillator of SETS to ensure the timing of the equipment when the sources of these clock signals are defected.

After SETS locks the phases of these clocks, one high-quality clock signal will be chosen and sent to all the functional blocks except SPI and PPI of the equipment to use. SETS at the same time exports 2Mb/s and 2MHz clock signals through SETPI functional block, which may be used by other equipment such as switch and SDH NE as external clock source.

Tips:

Those mentioned above are the four clock sources of the SDH equipment. But they only refer to the place where the clock signal used by SDH equipment is "put", i.e. from which place SDH can extract clock signals. Then what is the original source of the clock signals? The timing signal of a country's digital network comes from the national standard timing clock. It is transferred to SDH equipment through layers of the synchronous link.

- SETPI: Synchronous Equipment Timing Physical Interface

It functions as the physical interface between the external clock source and SETS. Through it, SETS receives external clock signals or outputs external clock signals.

- OHA: Overhead Access functional block

The function of OHA is to extract or write corresponding E1, E2, and F1 order wire communication bytes from RST and MST and to carry out the corresponding operations.

We have mentioned before the basic functional blocks which constitute the equipment, together with the alarm performance events monitored by these functional blocks and their monitoring principle. A deep understanding of the alarm and performance events monitored by each of these functional blocks and the principle of these events is the key to correct analysis and error location in the maintenance of the equipment. We hope you will have good mastery of what is discussed here. Because the information in this part is scattered, it is now put together here for you to find out its inner relations.

The following is the major alarm maintenance signals generated by each functional block of SDH equipment and those overhead bytes to which these alarm maintenance signals are related.

- SPI: R-LOS
- RST: R-LOF (A1、A2), ROOF (A1、A2), RS-BBE (B1)

- MST: MS-AIS (K2[b6-b8]) 、MS-RDI (K2[b6-b8]) , MS-REI (M1) MS-BBE (B2) , MS-EXC (B2)
- MSA: AU-AIS (H1、H2、H3) , AU-LOP (H1、H2)
- HPT: HP-RDI (G1[b5]) , HP-REI (G1[b1—b4]) , HP-TIM (J1) , HP-SLM (C2) , HP-UNEQ (C2), HP-BBE (B3)
- HPA: TU-AIS (V1, V2, V3) , TU-LOP (V1, V2) , TU-LOM (H4)
- LPT: LP-RDI (V5[b8]) , LP-REI (V5[b3]) , LP-TIM (J2), LP-SLM (V5[b5—b7]), LP-UNEQ (V5[b5—b7]) , LP-BBE (V5[b1—b2])

The following is a brief account of the principle of the alarm maintenance signals generation mentioned above:

ITU-T recommendation has designated the meaning of each alarm signal:

- R-LOS: loss of receiving signal, input with no optical power, optical power too low, optical power too high, which makes BER worse than 10^{-3}.
- ROOF: out of receiving frame, searching time for A1 and A2 bytes exceeds 625 us.
- R-LOF: loss of receiving frame, ROOF state lasts for 3 ms or longer.
- RS-BBE: regenerator section background block error, B1 verifies the block error of regenerator section signal (STM-N).
- MS-AIS: multiplex section alarm indication signal, K2[6 - 8]=111, which is more than 3 frames.
- MS-RDI: multiplex section remote defect indication, send back the detected MS-AIS、MS-EXC state in local terminal to the remote terminal by K2[6 - 8], in this case, K2=110.
- MS-REI: multiplex section remote error indication, send back the number of the multiplex section block errors detected by B2 in local terminal to the remote terminal through M1 bytes.
- MS-BBE: multiplex section background block error, detected by B2 in receive end.
- MS-EXC: multiplex section excessive errors, detected by B2 in receive end.
- AU-AIS: administrative unit alarm indication signal, H1、H2、H3 all "1".

- AU-LOP： loss of administrative unit pointer， a consecutive of 8 frame receive invalid pointers or NDF.
- HP-RDI： high order path remote defect indication， local terminal receives HP-TIM、 HP-SLM, and sends back HP-RDI to remote terminal through G1 byte.
- HP-REI： high order path remote error indication, sends back the number of block errors detected in local terminal by verifying B3 bytes to the transmit (remote) end.
- HP-BBE： high order path background block error, displays the number the block errors detected by B3 bytes in this terminal.
- HP-TIM： high order path trace identifier mismatch, what J1 should receive is not consistent with it actually receives, generating this alarm in this terminal.
- HP-SLM： high order path signal label mismatch, what C2 should receive is not consistent with it actually receives, generating this alarm in this terminal.
- HP-UNEQ： high order path unequipped, C2=00H exceeds five frames, generating this alarm in this terminal.
- TU-AIS： tributary unit alarm indication signal, V1、 V2、 V3 are all “1”.
- TU-LOP： tributary unit loss of pointer, a consecutive of 8 frames receive invalid pointers or NDF.
- TU-LOM (HP-LOM)： tributary unit – loss of multi-frame, a consecutive of 2-10 frames of H4 are not in the order of the multi-frame or have invalid H4 values.
- LP-RDI： low order path remote defect indication, local terminal receives TU-AIS or LP-SLM, LP-TIM and send LP-RDI back to remote terminal through V5 byte.
- LP-REI： low order path remote error indication, detected by V5[1-2]. It is returned alarm signal sent through V5 byte from local to remote.
- LP-TIM： low order path – trace identifier mismatch, detected by J2.
- LP-SLM： low order path – signal label mismatch, detected by V5[5-7].
- LP-UNEQ： low order path unequipped， V5[5 - 7]=000 exceeds 5 frames.

To get the internal relations of these alarm maintenance signals, we list the following two alarm flow charts.

Figure 4-13 is a brief TU-AIS alarm generation flow chart, which is often seen in TU-AIS when maintaining equipment. Through the analysis in Figure 4-13, TU-AIS and other related alarm error points and causes can be conveniently located.

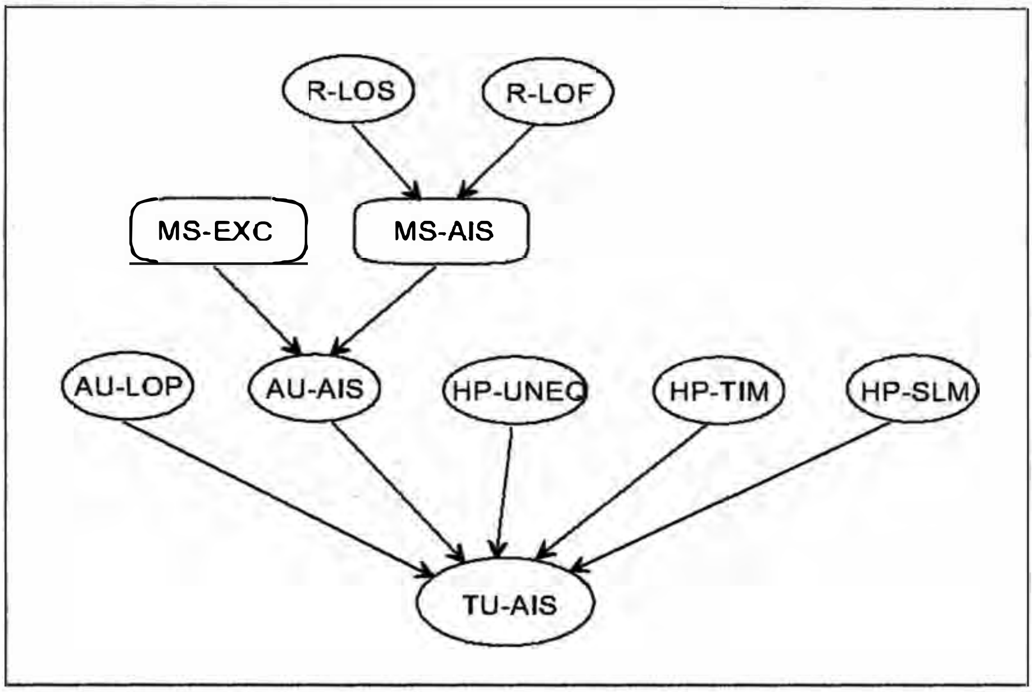
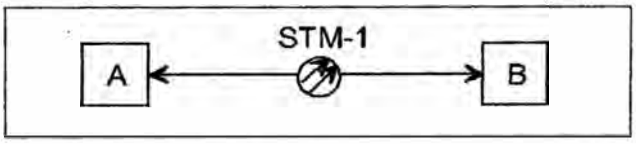


Figure 4-13 Brief flow chart of TU-AIS alarm generation

Tips:

When maintaining the equipment, we can see that TU-AIS is generated because of a common reason, i.e. mismatch of traffic time slot, staggering the traffic time slots on the receive and transmit ends.



There is a 2Mb/s service in the transmit end A which is to be sent to B. A multiplexes this 2Mb/s service to 48# VC12 of the line, while B drops 49# VC12 of the line when dropping the service. If 49# VC12 of the line is not configured with service, Terminal B will generate TU-AIS alarm in the corresponding channel. If 49# VC12 is configured with other 2Mb/s services, such phenomenon as cross-talk will occur (receiving channel signals that should not be received).

Figure 4-14 is a detailed alarm flow chart of each functional block of the SDH equipment, through which the interrelationship between each functional block generating alarm maintenance signals of SDH equipment can be seen.

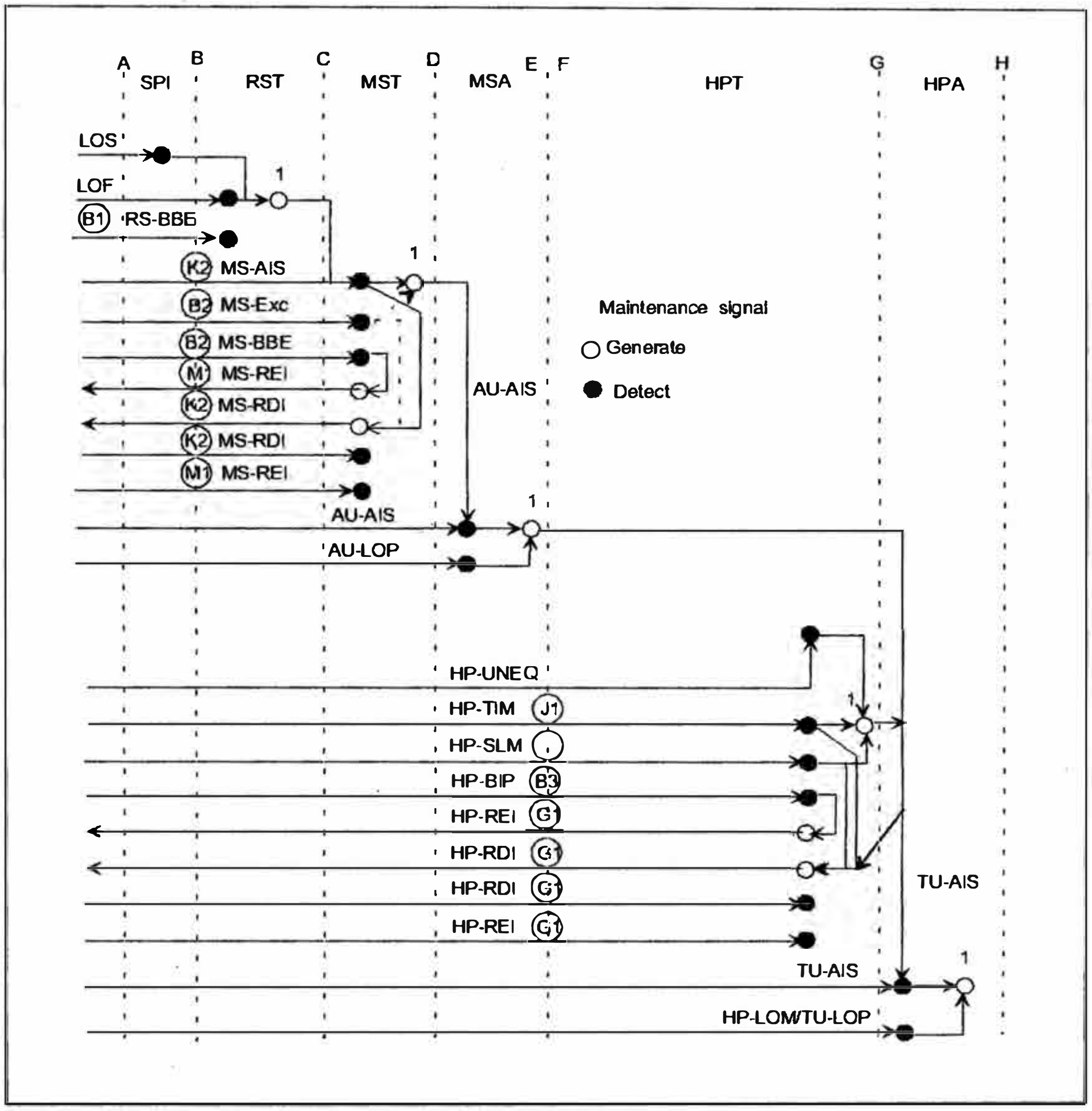


Figure 4-14 Alarm flow chart of each functional block of SDH

We have mentioned several common NE of SDH in the previous part, now we will discuss what functional blocks constitute these NE. From the composition of these blocks, you can master the functions performed by these NE very easily.

- TM – Termination Multiplexer

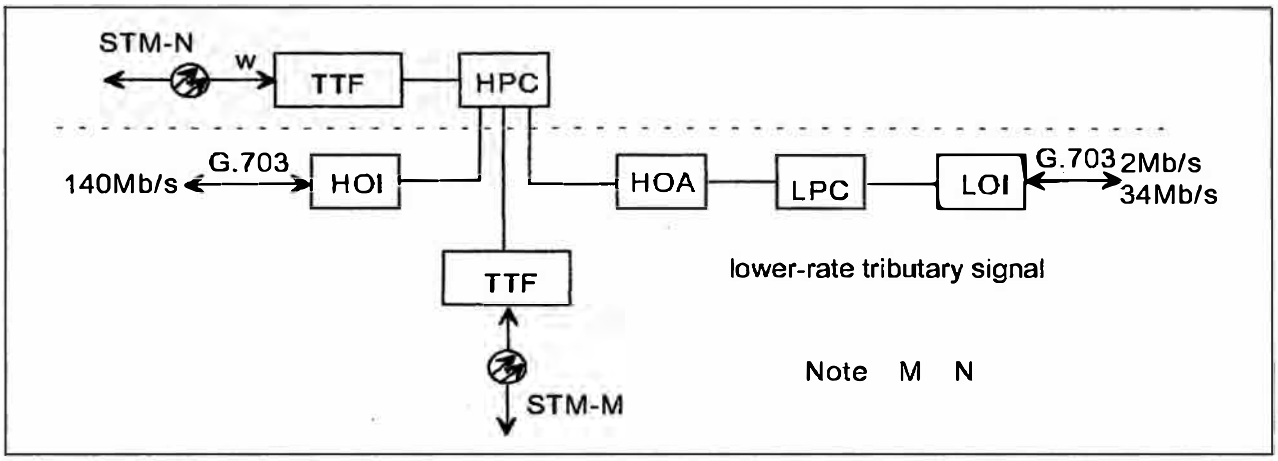


Figure 4-15 TM structure of functional block

The function of TM is to cross multiplex the low rate tributary signal PDH, STM-M (M<N) to high rate line signal STM-N. Because HPC and LPC functional blocks exist, this TM has low order and high order cross multiplex functions.

- ADM – Add/drop Multiplexer

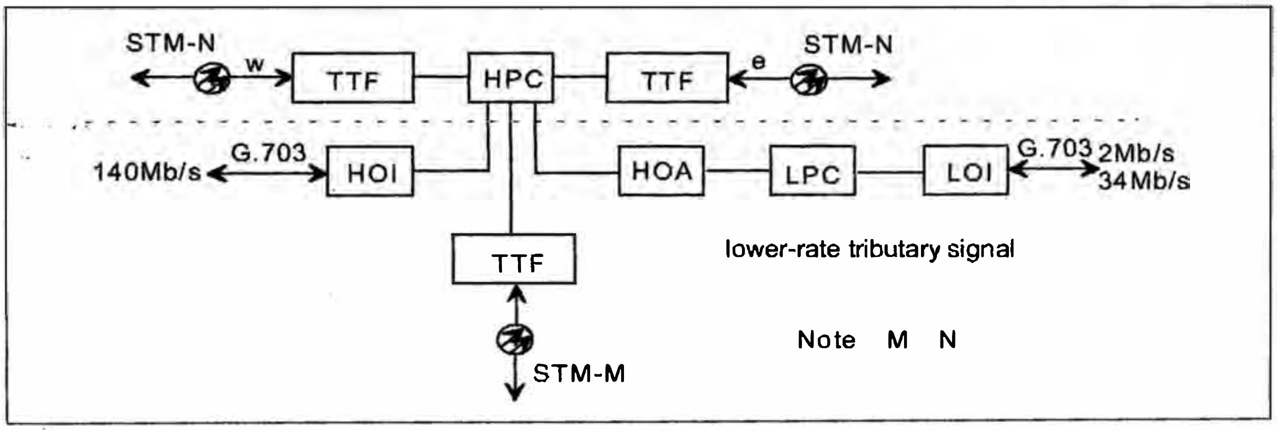


Figure 4-16 ADM structure of functional block

The function of ADM is to cross multiplex/de-multiplex the low rate tributary signal (PDH, STM-M) to the STM-N signals in e or w lines and the STM-N signal cross connect between w or e line port.

- REG – Regenerator

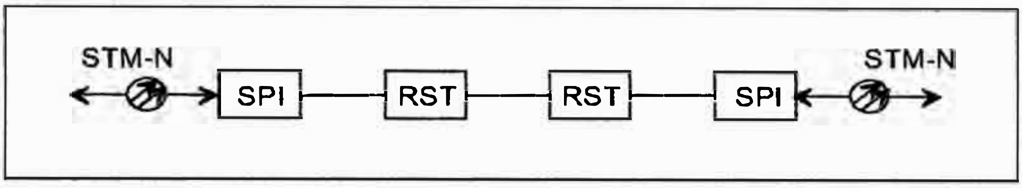


Figure 4-17 REG structure of functional block

The function of REG is to regenerate and reform the signals, sending the STM-N signals on e/w sides to the lines on w/e sides. Note: here no cross capability is necessary.

- DXC – Digital Cross-connect

The logic structure of DXC is similar to that of ADM with the difference that the capability of cross-connect matrix of the former is more powerful, capable of performing the crossing of multiple line signals (STM-N) and multiple tributary signals (much more powerful than the cross capability of ADM), as shown in Figure 4-18.

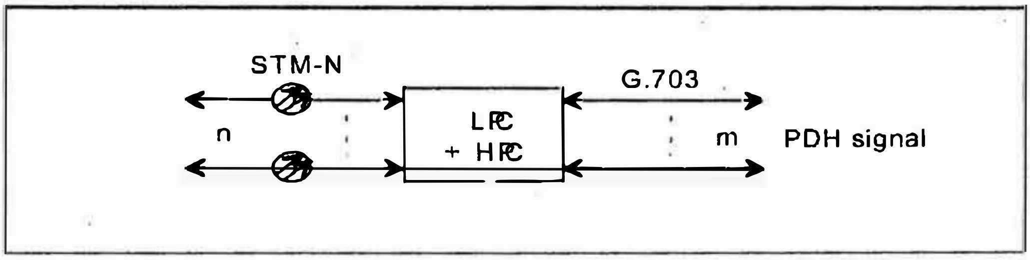


Figure 4-18 DXC structure of functional block

Well, that is all for this chapter. This chapter is the base for your later study, and the key to improve the maintenance of the equipment.

? **Questions:**

What we have learned in this chapter?

The common NE and their functions of SDH network.

1) The function of the functional blocks which constitute the equipment and the generation principle of the detected alarm and performance events.

2) The flow charts of the basic alarm maintenance signals of the SDH equipment.

3) The important parts of this chapter are 2 and 3. Have you mastered them?

Summary

This chapter describes mainly the common NE of the SDH network and the logic functional block composition of the SDH equipment. The important point is the inspection principle of each functional block to alarm maintenance signals.

Exercises

1) The generation principle of MS-AIS alarm.

2) Possible alarm which arouse HP-RDI.

3) The functions of TTF functional blocks.

4) The meanings of DXC4/1.

TermsProfessional Words and Abbreviations

Abbreviation	Full name
ADM	Add/Drop Multiplexer
AIS	Alarm Indication Signal
APS	Automatic Protection Switching
AU	Administration Unit
AU-AIS	Administrative Unit Alarm Indication Signal
AU-LOP	Loss of Administrative Unit Pointer
AUG	Administration Unit Group
AU-PTR	Administration Unit Pointer
BBER	Background Block Error Ratio
BIP-N	Bit Interleaved Parity N code
CMI	Coded Mark Inversion
DCC	Data Communication Channel
DXC	Digital Cross-connect
ECC	Embedded Control Channel
ESR	Errored Second Ratio
FEBE	Far End Block Error
HDB3	High Density Bipolar of order 3 code
HP-RDI	High order Path - Remote Defect Indication
HP-REI	High order Path - Remote Error Indication
HPA	High order Path Adaptation
HPC	High order Path Connection
HPT	High order Path Termination
ISDN	Integrated Services Digital Network
ITU-T	International Telecommunication Union - Telecommunication Sector
R-LOF	Loss Of Frame
LOP	Loss Of Pointer
R-LOS	Loss Of Signal
LPA	Low order Path Adaptation

LPC	Low order Path Connection
LPT	Low order Path Termination
MS-AIS	Multiplex Section - Alarm Indication Signal
MS-RDI	Multiplex Section - Remote Defect Indication
MSA	Multiplex Section Adaptation
MSOH	Multiplex Section Overhead
MSP	Multiplex Section Protection
MST	Multiplex Section Termination
OAM	Operation, Administration and Maintenance
OHA	Overhead Access
ROOF	Out Of Frame
PDH	Plesiochronous Digital Hierarchy
POH	Path Overhead
PPI	PDH Physical Interface
REG	Regenerator
RDI	Remote Defect Indication
RSOH	Regenerator Section Overhead
RST	Regenerator Section Termination
SCC	System Control & Communication
SDH	Synchronous Digital Hierarchy
SEMF	Synchronous Equipment Management Function
SESR	Severely Errored Second Ratio
SES	Severely Errored Second
SETS	Synchronous Equipment Timing Source
SETPI	Synchronous Equipment Timing Physical Interface
SOH	Section Overhead
SPI	SDH Physical Interface
STG	Synchronous Timing Generator
TIM	Trace Identifier Mismatch
TM	Termination Multiplexer
TMN	Telecommunications Management Network
TU-LOM	TU-Loss Of Multi-frame
TUG	Tributary Unit Group
TU-PTR	Tributary Unit Pointer

UAT	Unavailable Time
UNEQ	Unequipped
VC	Virtual Container

ANEXO B

"PRUEBAS TÍPICAS PARA VALIDAR EQUIPOS Y REDES SDH"

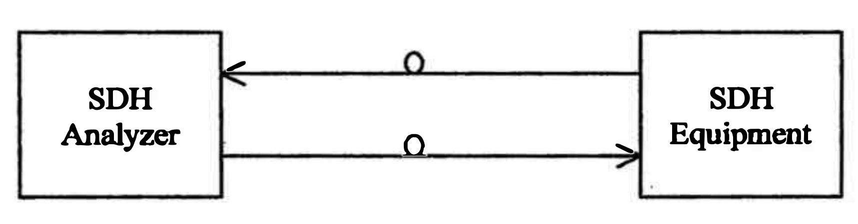
Contents

Typical Test to validate SDH equipments and networks

1 Synchronization and Protection Tests

1.1 Allowable Frequency Deviation at SDH Input Interface

This test is intended to ensure the allowable frequency deviation at STM-1 and STM-16 input interface is not more than 20 ppm, as specified in ITU-T recommendation clause 6.1.1 and table 1/G.825.

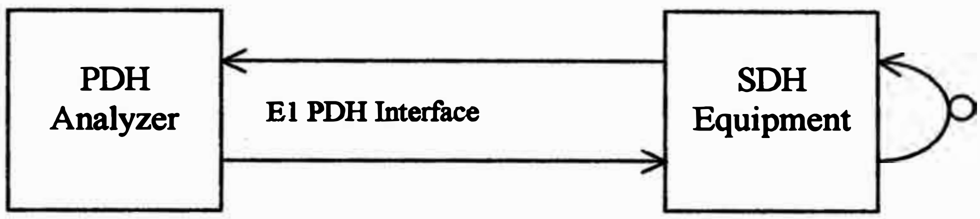


We connected the SDH analyzer and the SDH equipment as showed in the figure above and programmed the analyzer to adjust frequency deviation from –20ppm to +20ppm.

1.2 Allowable Frequency Deviation at E-1 Input Interface

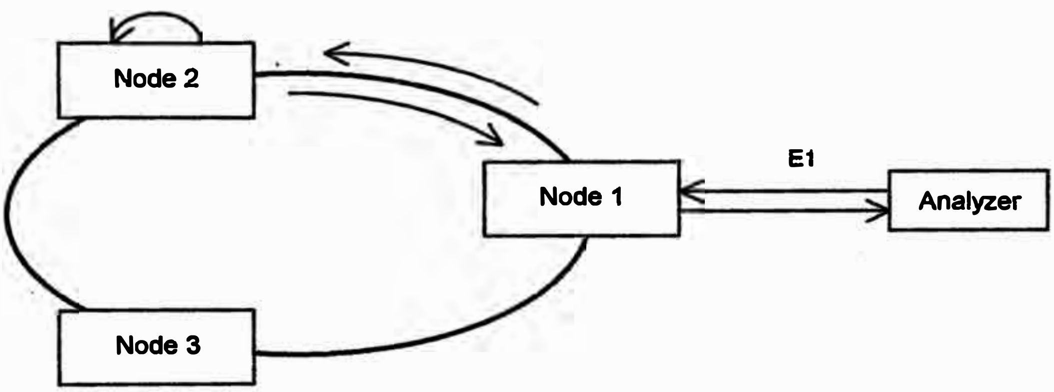
This test is intended to ensure the frequency deviation at E1 interface is not more than 50ppm as specified in ITU-T recommendation clause 6.1/ G.703.

We connected the SDH and measurement equipment as showed in the diagram of the next page and programmed the analyzer to generate a PBRS test sequence at the E1 interface with a frequency deviation varying from –50 ppm to +50 ppm.



1.3 Output Frequency in the Free-run and Locked Mode

This test is intended to ensure the stability of the system synchronization even when there are no external synchronization sources.

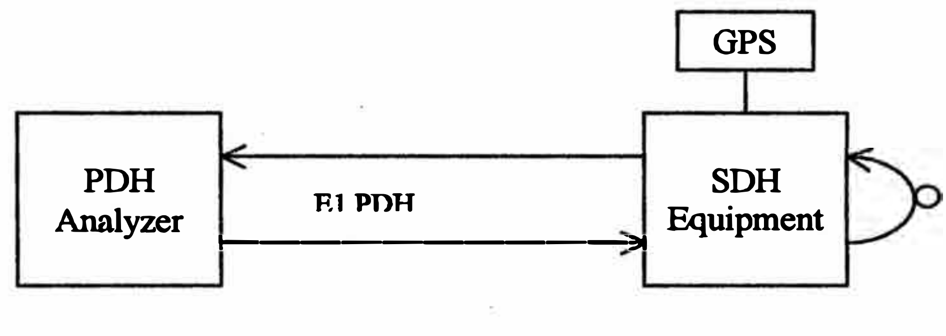


We ran a B.E.R. test according to the configuration above and then disconnected all the synchronization sources, so that the system can run first in holdover mode and, after 24 hours, in free-run mode. There should be no errors.

1.4 Synchronous Source Switching

This test is intended to ensure the system redundancy of synchronization source in one equipment.

First, we connected the equipments as showed in the diagram below:



Then, we disconnected the GPS from the SDH equipment. The equipment should change without any bit error to the next synchronization source configured and finally work in the holdover mode. After 24 hours it should work with the internal clock.

1.5 Synchronous Source Protection with S1 Byte

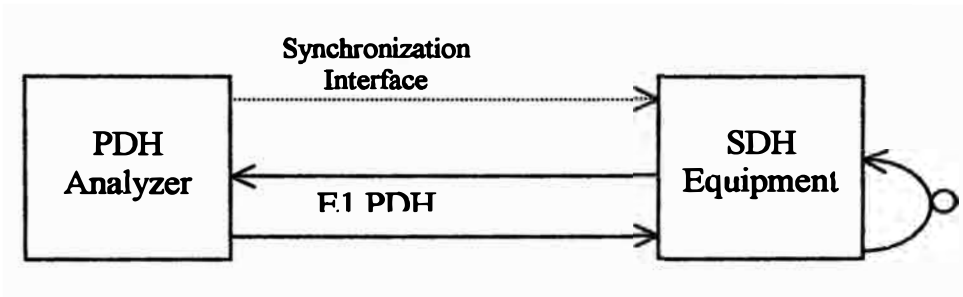
This test is intended to ensure the system redundancy of synchronization source for the whole system.

When the system has two GPS as synchronization sources, the main one in the Node 1 and the secondary one in Node 3. We ran a B.E.R. test and unplugged the main GPS. The system should take the secondary GPS as the main synchronization source without any effect over the service and without any error in the BER test.

1.6 Frequency Accuracy at Synchronization Interface

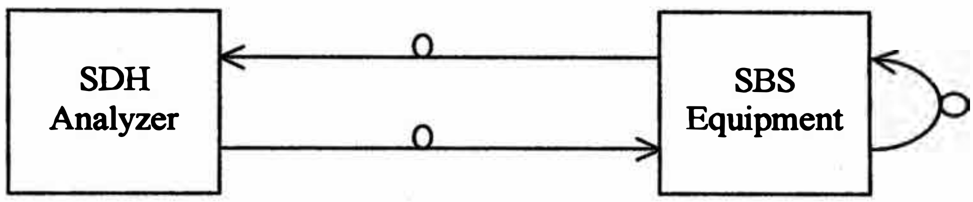
This test is intended to ensure frequency accuracy at synchronization interface is in accordance with ITU-T recommendation clause 5 /G.813.

After connecting the SDH external clock output to the analyzer we programmed the analyzer to make a B.E.R. test overnight and unplugged the synchronization source in the equipment so that both could work with the same clock.



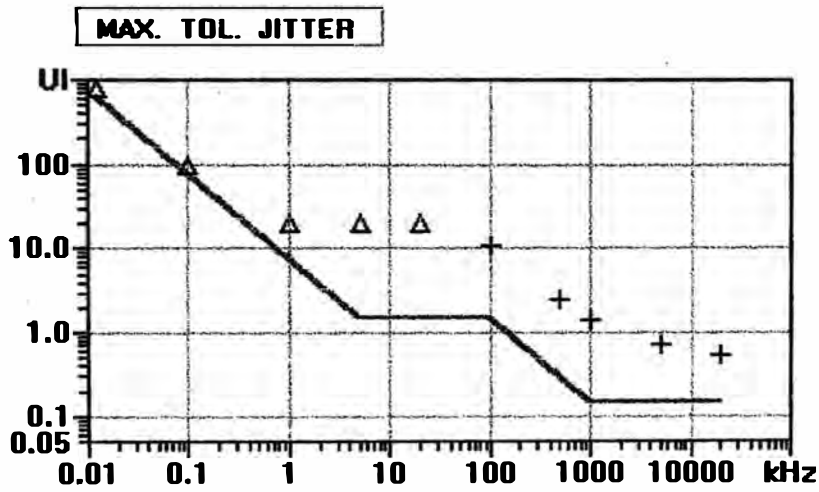
1.7 Jitter Tolerance of the Optical Input

This test is intended to ensure jitter tolerance at STM-16 and STM-1 input interface is in accordance to the mask specified in ITU-T recommendation.

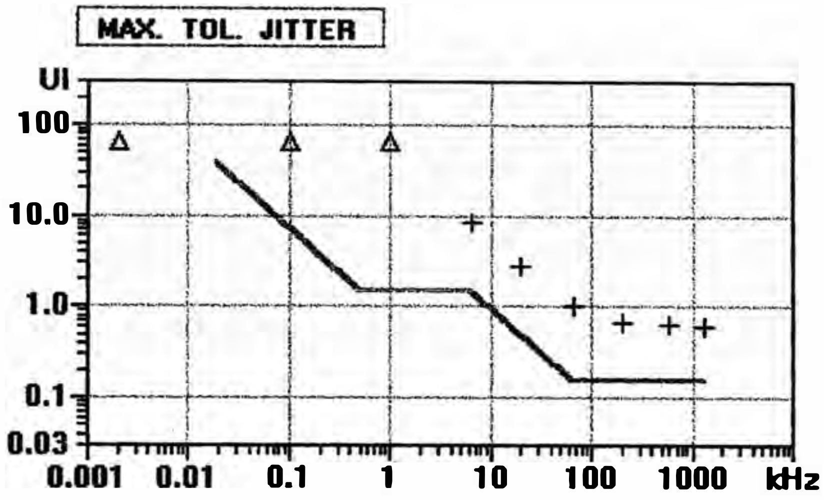


After connecting the equipment as showed above, we programmed the analyzer to vary the jitter of the transmitted signal and verify if the value of the maximum input jitter is according to the ITU-T reccommendation. This test was realized for both STM-16 and STM-1 optical interfaces.

Examples of graphics stored in the analyzer are showed below:



STM-16 Jitter Tolerance



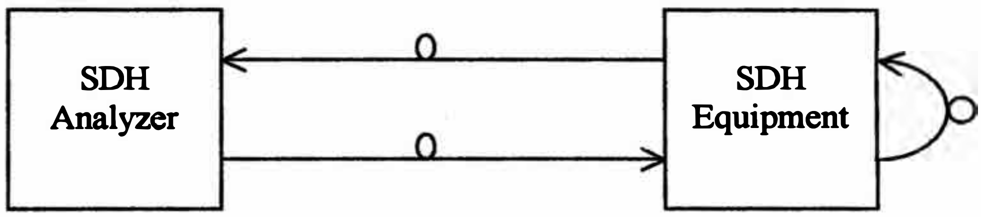
STM-1 Jitter Tolerance

1.8 Output Jitter of the Optical Interface (B1 and B2)

This test in intended to ensure jitter at STM-16 and STM-1 output interface are in accordance with ITU-T recommendation table 6/G.813 which is showed in next table:

Interface	Measuring Filter	Peak-to-Peak Amplitude
STM-16	B1: 5 KHz to 20 MHz	0,50 UI
	B2: 1 MHz to 20 MHz	0,10 UI
STM-1	B1: 500 Hz to 1,3 MHz	0,50 UI
	B2: 65 KHz to 1,3 MHz	0,10 UI
For STM-16: 1 UI = 0,40 ns For STM-1: 1 UI = 6,43 ns		

We connected the equipments as the following picture shows:

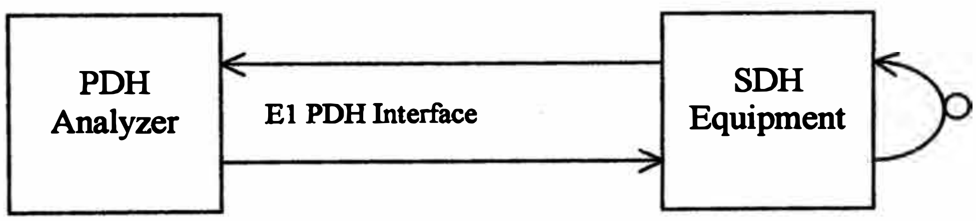


and we programmed the analyzer to make the output jitter test using the filters reccommended by the ITU-T. The output jitter must be lower than the value recommneded by the ITU-T.

1.9 Jitter Tolerance at the E1 Input Interface

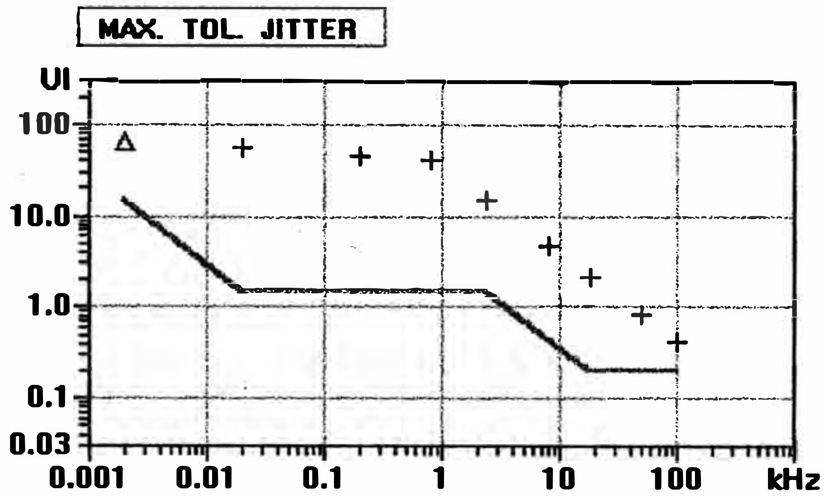
This test is intended to ensure E1 input interface can bear the jitter specified in ITU-T recommendation figure 3 and table 2/G.823

The configuration used is showed below:



After connecting the equipments we programmed the analyzer to perform jitter tolerance test which consists in choosing several frequencies, varying the input jitter to the point of failure and recording this value. This value has to be above the value recommended by the ITU-T.

An example of results stored by analyzer are:

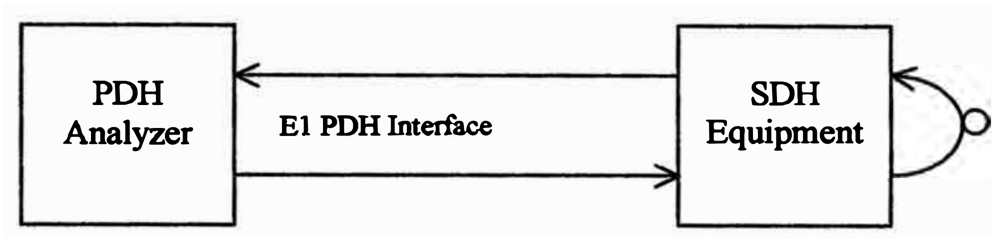


1.10 Mapping of Output Jitter without Input Jitter

This test is intended to ensure that the value of mapping jitter is in accordance with ITU-T table 10-1/G.783 summarized below:

Rate	Measuring Filter	Peak-to Peak Amplitude
E1	B1: 20 Hz to 100 KHz	0,4 UI
	B2: 18 KHz to 100 KHz	0,075 UI

We connected the equipment as showed in the diagram below, ran a B.E.R. test in the analyzer and proceeded to measure the output jitter using the B1 and B2 filters (the ranges are showed in the table above). We varied the offset from –50 to +50 ppm.



1.11 Mapping of Output Jitter with Combine

This test is intended to ensure that the value of mapping jitter is in accordance with ITU-T table 10-1/G.783 showed in the previous test but with a complex pointer management at the input. We tested the following cases:

Case 1: Single pointer with reversed polarities

Case 2: Regular single pointer with a double pointer

Case 3: Regular single pointer losing one

Case 4: Double pointers with reversed polarities

The configuration of the equipment is the same as the one used in the previous test.

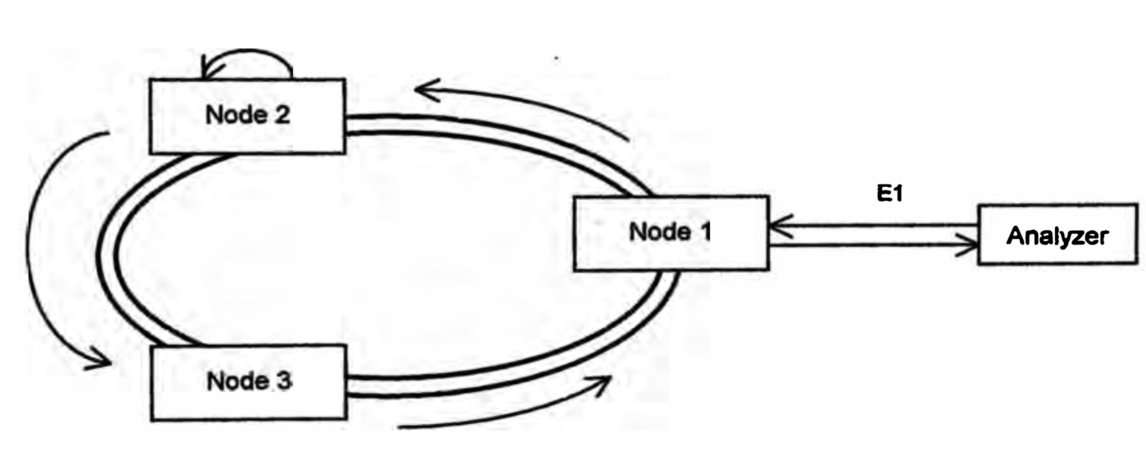
1.12 MSP Unidirectional Rings

This test is intended to ensure the correct working of the MSP Unidirectional protection.

In the STM-16 ring showed below, we configured a path between Node 1 and Node 2. The whole system was configured as a Unidirectional MSP ring so one ring was used as main and the other one was used as backup.

In this kind of protection the working channels and the protection channels are carried over different fibers, The tributary is only added and dropped on the working channel meanwhile the protection channel is left idle.

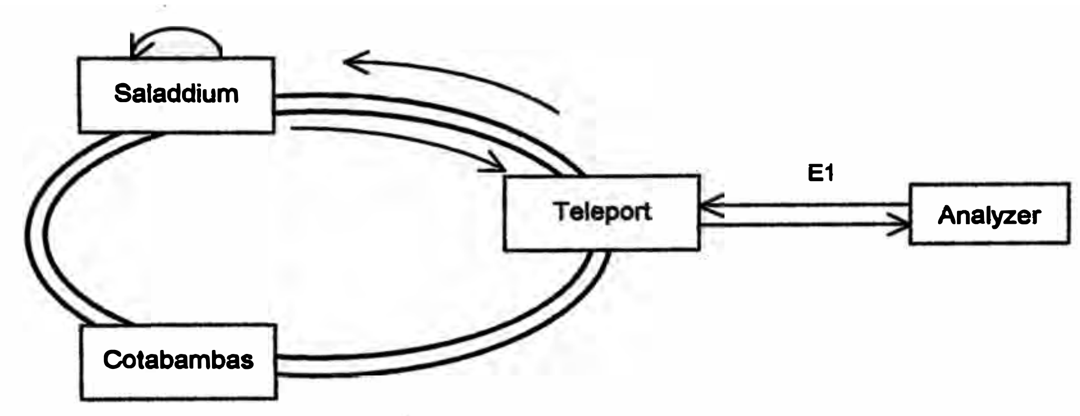
Then, we programmed the analyzer to make a B.E.R. test and unplugged one of the fibers of the active ring. According to the ITU-T recommendation, the maximum switching time is 50 ms. In our case switching time was 37 ms.



1.13 MSP Bidirectional Rings

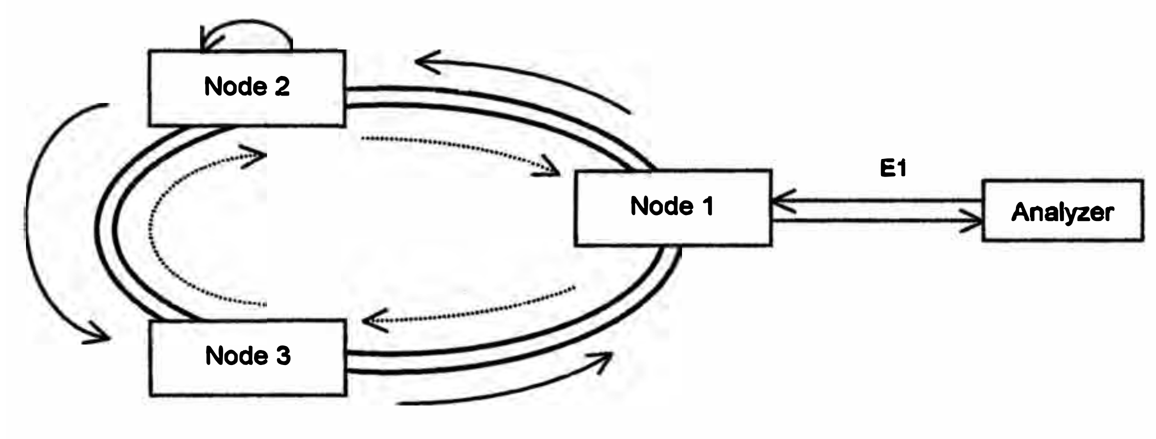
This test is intended to ensure the correct working of the MSP Bidirectional protection.

In the STM-16 ring showed below, we configured a path between Node 1 and Node 2. The whole system was configured as a Bidirectional MSP ring so each fiber uses half of its capacity in carrying working channels and the other half in carrying protection channels. Then, we programmed the analyzer to make a B.E.R. test and unplugged one of the fibers between Node 1 and Node 2. According to the ITU-T recommendation, the maximum switching time is 50 ms. In our case switching time was 23 ms.



1.14 Path Protection Unidirectional Rings

This test is intended to ensure the correct working of the PP Unidirectional protection.



In the STM-16 ring showed before, we configured a path between Node 1 and Node 1. The whole system was configured as a Unidirectional PP ring so that all the information would be sent in two fibers, in oppsite directions and simultaneously. At the receiving end either the active or the standby is chose depending on the signal quality. We unplugged one the active fibers and measured the switching time. According to the ITU-T recommendation, the maximum switching time is 50 ms. In our case switching time values obtained varied between 5 and 14 ms.

2 Performance Tests

2.1 Mean Launched Power

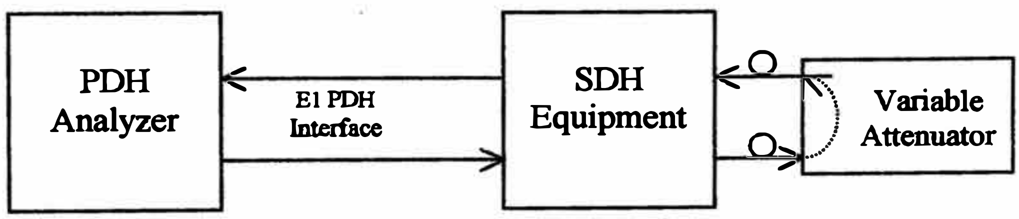
This test is intended to ensure that the transmission optical power is inside the working range of the equipment that it's connected to. We directly measured the Optical power at the output of every optical board. Is necessary to check the provider recommendations.

Typical values are as following:

STM-1 Board	:	-10,50 dBm
STM-16 Board	:	-0,02 dBm

2.2 Receiver Sensitivity

This test is intended to record the value of the minimum optical power each board can receive in order to maintain the power between the working limits.



We connected the equipment as showed in the diagram above and began a B.E.R test in the analyzer. We incremented the attenuation until we reached the maximum attenuation value at which we had no bit errors in the analyzer. At this point we measured with the Optical power meter the value of the optical power at the equipment input interface. Is necessary to check the provider recommendations.

Typical values are as following:

STM-1 Board	:	-40,1 dBm
STM-16 Board	:	-33,0 dBm

2.3 Overloading of the Receiver

This test is intended to record the value of the maximum optical power each board can receive in order to maintain the power between the working limits.

We connected the equipment as we did for the last test and began a B.E.R. test in the analyzer. We diminished the attenuation until we reached the minimum attenuation value at which we had no bit errors in the analyzer. At this point we measured the value of the optical power at the equipment input interface. Is necessary to check the provider recommendations.

Typical values are as following:

STM-1 Board	:	-5,06 dBm
STM-16 Board	:	-4,21 dBm

2.4 Long Term Bit Error

This test is intended to ensure the long term stability of the system. For this test we connected the equipments as showed in the next page.

We made a software loopback in Node 2 and left a B.E.R. test running in the Node 1 for more than two days. Result must be no bit errors.

2.5 Insert and Detect SDH Alarms

This test is intended to ensure the capability of the SDH equipment to generate and detect the SDH alarms in order to guarantee the correct management of the whole system. The items tested were:

- Insert and detect J1
- Detect B1\B2\B3
- Detect E1\E2
- Detect A1\A2

- Detect K2(5-8)
- Insert and detect LOS
- Insert and detect LOF
- Insert and detect MS-AIS
- Insert and detect MS-REI
- Insert and detect MS-RDI
- Insert and detect AU-AIS
- Insert and detect AU-LOP
- Insert and detect HP-TIM
- Insert and detect HP-UNEQ
- Insert and detect HP-SLM
- Insert and detect HP-LOM
- Insert and detect HP-RDI
- Insert and detect HP-REI

2.6 Insert PDH Alarms

This test is intended to ensure the capability of the SDH equipment to generate and detect the PDH alarms in order to guarantee the correct management of the whole system. The items tested were:

- Insert and detect J2
- Insert and detect TU-AIS

- Insert and detect TU-LOP
- Insert and detect LP-SLM
- Insert and detect LP-UNEQ
- Insert and detect LP-RDI
- Insert and detect LP-REI
- Insert and detect E1-AIS

2.7 Power Redundancy

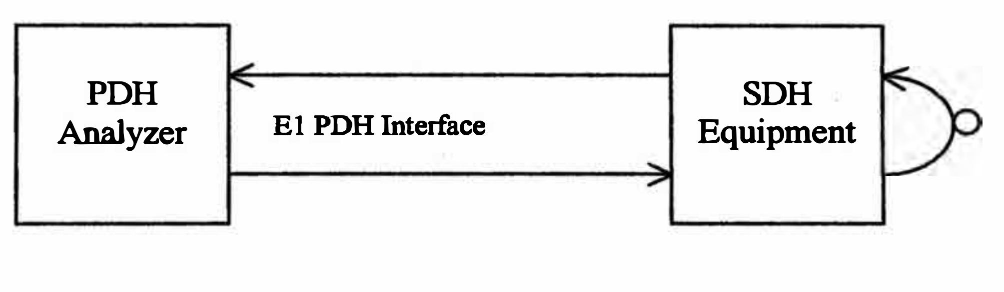
This test is intended to ensure the service is not affected by a power source failure. SDH equipment should be able to work with two power sources and in case one fails the other one should feed the equipment without any influence over the data.

While the equipment was working normally, we turned off the first power source, turned it on again and then turned off the second power source.

2.8 Cross-Connect Redundancy

This test is intended to ensure the correct functioning of the equipment in case of failure of the Cross-connect unit board (XCS). Generally SDH equipment has two XCS boards for redundancy.

We connected the equipments as showed in next diagram:



We programmed the analyzer to measure the out-of-service time in the network element, and we proceeded to unplug the working XCS board. We made this test with both of the boards.

2.9 Save and Restore Facility

This test is intended to ensure the equipment's capability to save a given configuration and restore it if needed.

We saved a payload configuration in a file in the hard disk, then we erased the configuation from the equipment. After this we proceeded with the restore process, measuring the time of the whole procedure. Typical time for restoring is 1 – 2 minutes.

2.10 Software Upgrade/Fallback

This test is intended to verify the procedure of software upgrade for the components of the equipment and its influence over the service.

We made a software upgrade of all the boards of the SDH equipment. At the same time an E1 B.E.R. test was running. The software upgrade took approximmately 3 minutes for one board. The service must not be never affected.

3 Operation and Maintenance Test

3.1 Order Wire Testing

This test is intended to verify the right operation and communication of each order wire phone with all other ones. This test must be performed in each node.

4 Management Test

4.1 Test over SDH Equipments

Type	Class
Management	By Console Port
	By Ethernet Port
	By SBS NM
	By SNMP
	In-band Management
Console Access	Using VT100
	Using Telnet
	Using command line
	Using menus
Security	Local User and password
	Read Access
	Read/Write Access
	Integration with other authentication servers (Ej: Radius, Ldap)
Performance and Accounting	Store information about interface usage
	Store information about connections.
	Store information about processing and memory usage

4.2 Test over Network Management System

Type	Class
General	Graphical Interface
	SNMP Management
	Permit remote management from client workstation using a LAN.
	Permit remote management from client workstation using a modem
	Permit X-Windows emulation (For Unix Version)
	In-band Management
	Out-of-band Management
Configuration Management	Shows network topology
	Self-discovering of devices
	CPU restart (or other cards)
	Software upgrade-downgrade without affecting traffic
	Inventory Data Display
	Permit time alignment between NE and SBS NM
	Show time of each NE
	Show graphical representation of the NE (shelf, cards)
	Connections configuration (add, remove, edit)
	Save and restore configuration files
	Schedule of configuration events (Backups, restart, upgrades)
Fault Management	Collect traps SNMP
	Visual indicators and audible alarms
	Integration with other TNM systems
	Real Time Alerts
	Log reports
	Severity alarm configuration.
	Shows external alarms
Security Management	Each administrator has a unique username and password.
	Different security access levels: read, read and write, system.
	Log of management activities
Performance Management	Send alerts by e-mail or pager
	Graphical data representation in real time.
	Performance data log
	Monitor traffic conditions
	Generate statistic and historic reports

Type	Class
High Availability	Redundancy in management links using 1 NMS
	Permit use of 2 or more NMS at the same time.
	Permit NMS in hot-standby configuration (Automatic replication between 2 NMS)
	Support of site redundancy (Different sites)

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