SCTE Network Architecture and Design Course

Working for the Benefit of the Broadband Industry

Reference Manual

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Welcome to the SCTE Manual

This handbook is designed as a stand-alone reference manual for technicians working in the broadband telecommunications industry. It may be used either on its own or as an integral part of a classroom course including practical work to enable the student to progress to examination and certification.

We hope you and your career benefit greatly from this handbook and associated training course. Please consider joining the SCTE and taking advantage of the benefits that come from being part of the industry's foremost technical institution.

About the SCTE

Founded in 1945, the SCTE is a non-profit making organisation, managed by an Executive Committee of elected volunteers, whose aim is to raise the standard of broadband engineering in the telecommunications industry. The Society particularly concerns itself with the training and career advancement of technical professionals in this field.

First introduced in 1994, the SCTE training courses have achieved wide acceptance as the standard for young technicians wishing to enter the field of cable telecommunications and for those wishing to advance their knowledge and career prospects. They are used in-house by a number of operating companies and SCTE engineers can be found working in a variety of international organisations.

As a Learned Society, SCTE is able to provide accreditation and certification for its members, giving them professional standing within the industry. Full Members and Fellows are allowed to use the designations MSCTE and FSCTE after their names whilst Technician Members may use TMSCTE. There are also categories for Student and Associate Members which carry the designations SMSCTE and AMSCTE respectively.

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Section One

1.1 Introduction

This section provides an overview of the proposed access network for access networks in general. It covers the main components of the network and provides details of the equipment used. Since network architecture and design are closely inter-related; some of the information in this Section is repeated in Section 3. Details on designing the individual parts of the networks are given in Section 3.

1.2 Hypothetical Network

Before looking in detail at the access networks, a brief overview of the main components of a complete infrastructure will be made. Figure 1.1 below shows the six main components of a complete end-to-end high level infrastructure. Not all of these components are needed for every end-to-end network but will be dependent on the technology in use and the services to be provided. The detailed arrangements at the customer/user premises have not been included.

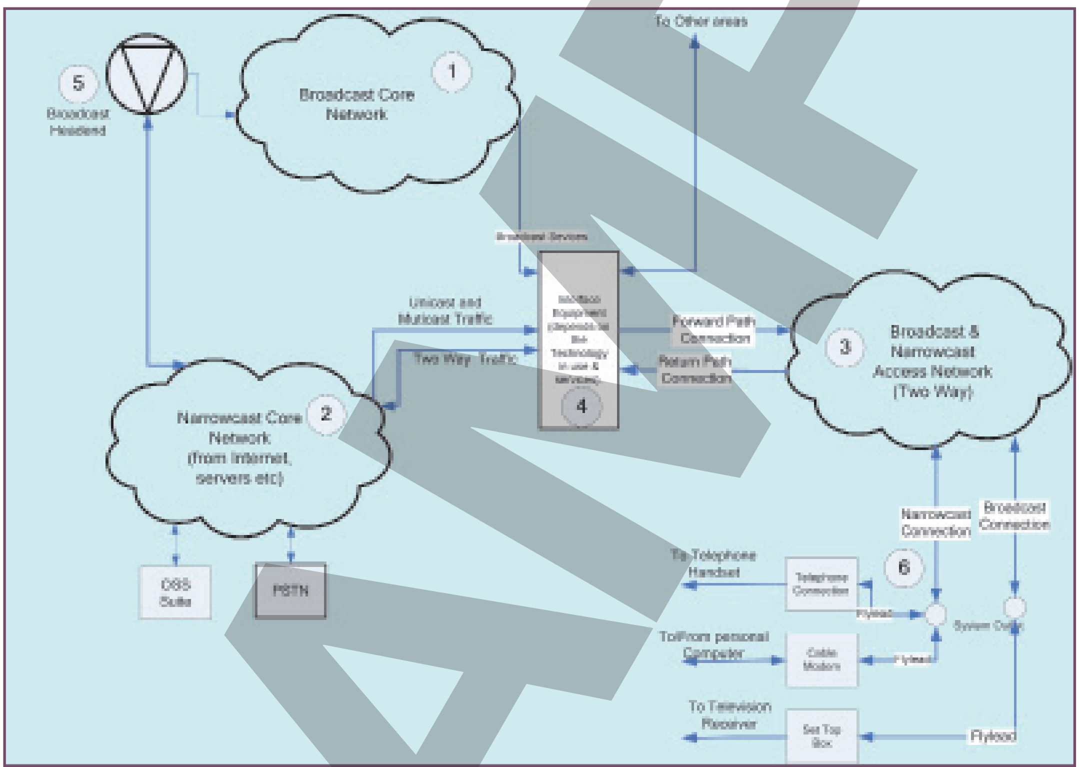

Figure 1.1: Hypothetical End-to-End Network Architecture & Components

There are three main network types and three distinct groups of equipment. These physical, or wireless, networks can use any combination of metallic cables, fibre optic cables or wireless, they can be considered as separate networks but may use the same cables or signal routes.

The three networks can be categorised as follows (Note: The number refers to the component numbering in Figure 1.1):

1. The "broadcast core network" – this is a one way network which delivers signals from a central headend/origination point (5) to the areas being served. This will usually be fibre optic and carries

broadcast channels either on radio frequency carriers or baseband signals via direct optical modulation or SDH/SONET.

2. The “narrowcast core network” – this is a two way network which provides connectivity to bi-directional services. This narrowcast network will usually be fibre optic cabling carrying telephony, IP traffic (gigabit ethernet or 10 gigabit ethernet) or IP/ATM over SDH/SONET but could also be wireless.
3. The “access network” - which interfaces with both the broadcast and narrowcast core networks and provides connectivity to the end users. This can be any of a number of physically different types such as fibre cable, coaxial cable, twisted pair or wireless. The access network will usually carry a combination of different services.

In addition to the three networks, there are three main areas where equipment is needed. These are:

4. Equipment to interface between the broadcast, narrowcast and access networks. This may consist of optical transmission equipment, servers, RF hardware, xDSL hardware, wireless base stations etc. The actual equipment and arrangements will depend on the technology, services required and detailed architecture.
5. Headend equipment which is needed to provided broadcast signals. This will be a combination of content origination equipment (satellite dishes, VOD servers, encoders, multiplexers etc) and transmission equipment. Internet connections and telephone exchanges may also be located here depending on the service offering.
6. Customer premises equipment which consists of modems, optical termination hardware, set top television receivers, telephone handsets, personal computers etc.

Different types of networks and service provision will require different combinations of networks and equipment. For example, if broadcast service is not to be provided then the headend and broadcast network is not required. However, with all types of technology, architecture and services, some kind of access network will be needed to connect the end users.

The architecture for the different network types will now be considered further in the following sections.

1.3 HFC Networks

1.3.1 High Level Architecture

This subsection provides a high level overview of the end-to-end architecture and associated components of a modern HFC network. This shows an arrangement for digital and analogue (optional) broadcast television channels with two way DOCSIS/EuroDOCSIS interactive services.

1.3.1.1 Architecture Overview

From the master headend 1550nm optical rings feed hubs distributed at suitable locations. Any remote town or city may have a local headend building, where all the television programmes are sourced and process for distribution to the hubs. In addition there may be an internet point of presence and a local management facility. The links from the headend to each hub consist of a fault tolerant fibre optic cable

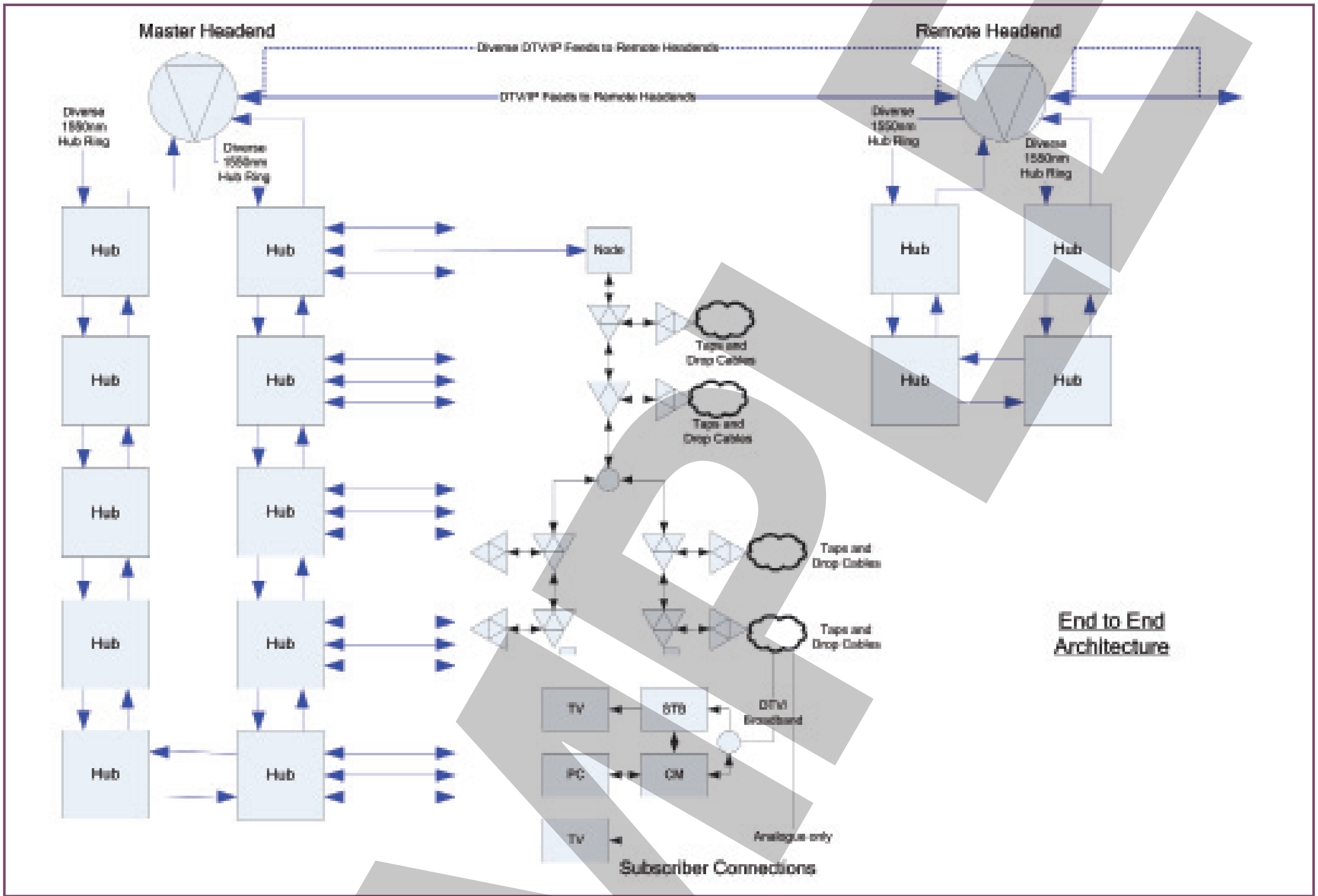

Figure 1.2: High Level Architecture Arrangements of a Modern HFC Network

route; carrying both the RF broadcast television channels, either by direct modulation or over 10Gbit/s IP links, and a bi-directional high speed data connection. In addition the headend often provides multiple gigabit ethernet feeds to the remote headends located in other towns and cities.

"Hubs" are arranged to serve up to a maximum of 50,000 homes passed with a typical size in practice of between 10,000 and 40,000. A primary, or main hub, is co-located with the headend to feed homes within a 10km radius of the headend. Most towns and cities of less than 50,000 homes passed may only require a single hub co-located with the headend; unless the local distribution of homes dictates otherwise. In large cities which are expected to serve nearly 500,000 homes passed, there may be a central hub and 12 to 20 remote hubs. The final number depends on the detailed planning and local topology.

Individual fibre cables from the hubs will be used to feed the "nodes". At these nodes the two way HFC/CATV optical nodes and Metroethernet routers/switches (if needed), are located. The node equipment is installed in a street cabinet together with 1) a "break out" box. 2) A provision for optical splitters enabling FTTH to be offered as an alternative for the future (splitters not fitted) and 3) a local power supply. The optical node for CATV has coaxial RF outputs (with optional line power) to feed both the local distribution and also remote amplifiers, when needed.

The final connections to the subscribers are via a local CATV (or MATV in apartments) network. For the CATV and broadband over DOCSIS/EuroDOCSIS, the connections will be via a single coaxial cable (RG6 or RG11) together with an optional CAT5 twisted pair data cable for high speed data connections from the Metroethernet router and associated switches. A future option may be to install a single fibre pair to each subscriber enabling the migration to fibre to the home (FTTH).

1.3.1.2 Hub Design

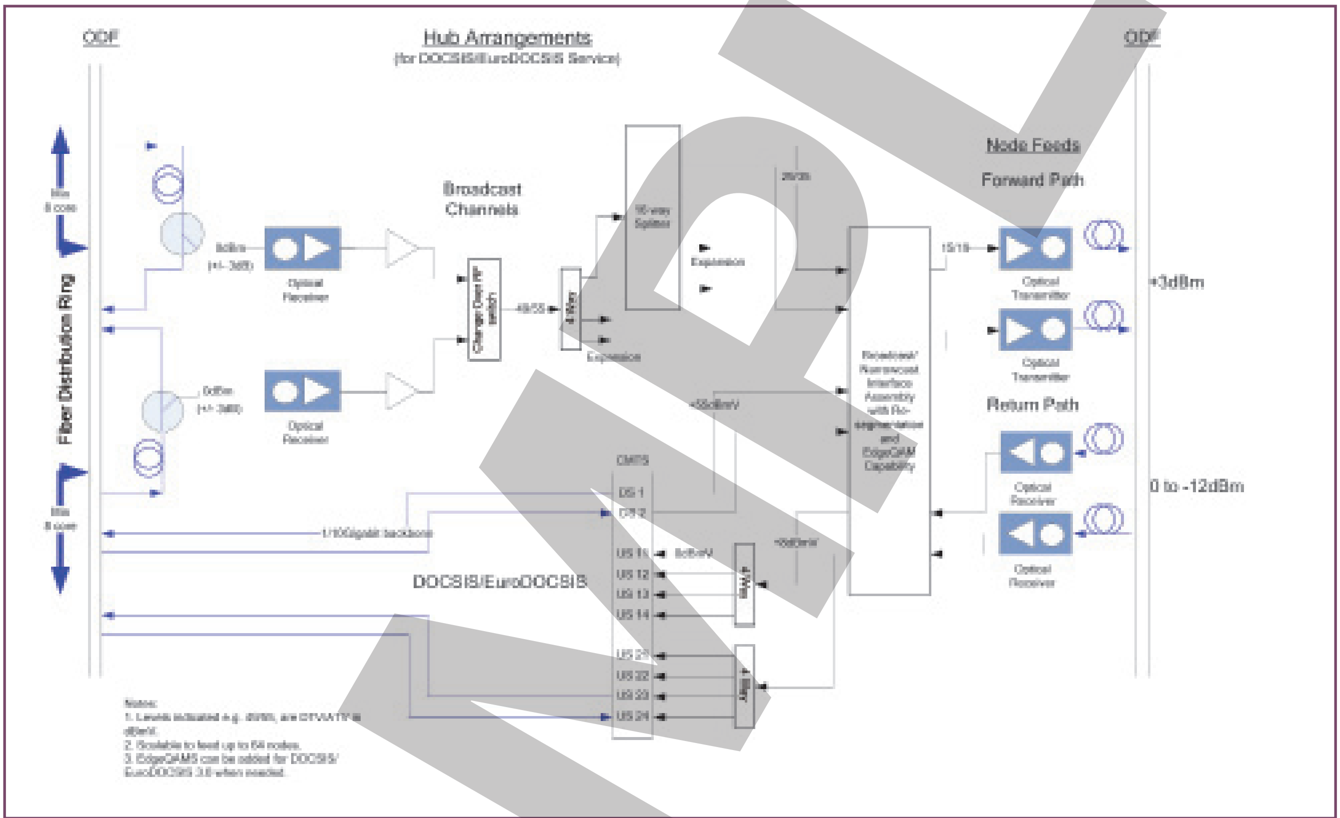

Figure 1. 3: Generic HFC Hub Design

Figure 1.3 above provides details of the HFC arrangements in hubs where RF is broadcast from the headend. Alternatively "EdgeQAMS" could be interfaces onto Gbit/s feeds from the headend. "EdgeQAMS" convert incoming IP streams to multiple QAM modulated RF channels which need to be combined. Again most hubs use the same configuration but are sized differently; dependent on the number of nodes/homes passed it serves. The two fibre feeds from the headend (primary and secondary) terminate on patch fields and individual cores routed to the broadcast HFC/CATV equipment and the router used for high speed data services. All input and output connections to/from the hubs are via fibre optic patch fields. Hubs require a fault tolerant power supply (UPS) and air handling to control the ambient temperature.

Detailed records of the hub configuration, rack layouts, cabling, floor plans etc need to be produced and updated as any changes are made.

Note: the diagram has been simplified (only 2 nodes connected) to show single configurations for the sake of clarity.

When necessary, optical amplifiers (EDFAs) may be required to extend the reach of the headend to hub rings. This can be implemented by installing optical amplifiers in the fibre rings. The following diagram shows how these are arranged. Two amplifiers are used, one each for the main and diverse routes.

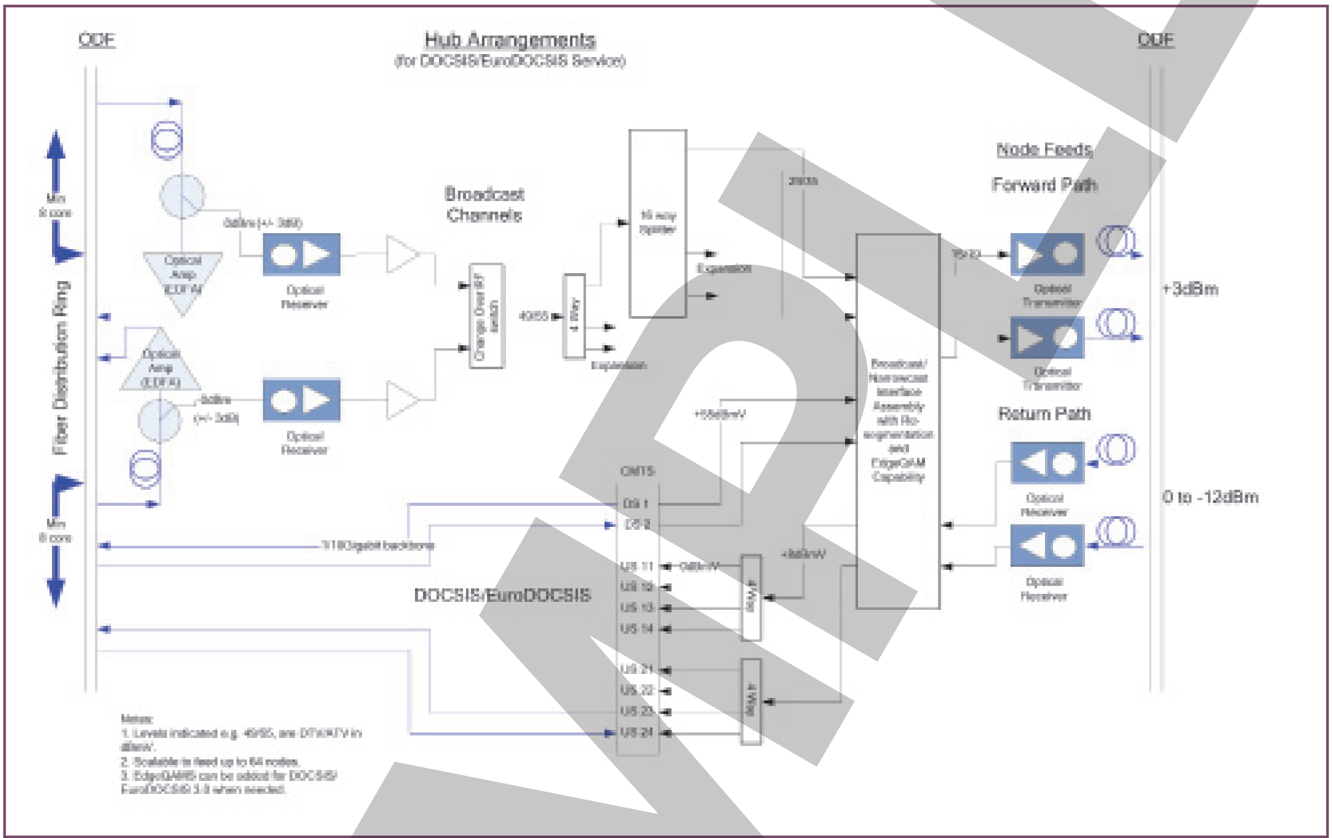

Figure 1.4: Hub with Optical Amplifiers Installed

1.3.2 HFC Forward Path

Referring to Figure 1.2 the HFC forward path is usually arranged as follows:

1. Broadcast signals are launched from the headend – IP (N x 1Gbit/s) or RF channels are fed to the hubs via fault tolerant fibre optic links (dual routes).
2. At the hubs, the optical broadcast channels are received and presented as RF. Services which are streamed via IP are fed to "EdgeQAM" processors, the outputs of which are RF QAM channels.
3. The RF QAM channels are combined with narrow cast downstream DOCSIS or EuroDOCSIS RF channels on a "Per Segment" basis. Segmentation is carried out by the use of forward and return path splitting/combining referred to as a forward path matrix.
4. The combined broadcast and DOCSIS/EuroDOCSIS channels are then fed, via fibre optic links, to the hubs which can vary in size anything between 1,200 and about 32 (more recently) homes passed. At the hubs the optical signals are received and presented as RF in the forward path spectrum (typically 85 to either 750 or 860MHz).
5. From the hubs the RF signals are distributed using coaxial trunks typically with up to four trunk amplifiers in cascade on any single leg. Trunk feeds are split where needed to provide routes to the

serving network. Bridger amplifiers are coupled off the trunks to feed to subscriber taps and drop connections to the individual subscribers.

1.3.3 HFC Return Path

The HFC return path follows the same route as the forward path between the hubs and subscriber connections. This is as follows:

1. From the cable modem the return path signal is routed back through the subscriber taps, combined with other return path modem signals and presented at the return path input to both the bridger and trunk amplifiers. Note: cable modem transmitter levels can have a spread of as much as 35dB which can cause issues with return path carrier to noise/ingress on the lower signal levels.
2. At the amplifier inputs all RF return path signal levels are equal. Note: The DOCIS/EuroDOCSIS ranging adjusts the individual cable modem return path transmitter levels such that they are presented to the CMTS return path receiver at the same level (within +/- 1dB).
3. The trunk and distribution amplifiers are fitted with return path receivers covering the return path frequency spectrum (5 to 30MHz, 5 to 42MHz or 5 to 65MHz). Future upgrades may increase the return path spectrum (5 to 85MHz). It is important that all return path amplifiers allocated to a specific hub use the same return path spectrum. When upgrading the return path frequency spectrum it is important that all return path amplifiers are changed to cover the intended operating spectrum.
4. The return path RF signals from the nodes to the hubs are carried over a fibre optic link and received back to RF for splitting/combining using a return path matrix.
5. This return path matrix must be configured such that the forward path DOCSIS/EuroDOCSIS channels (see 1.3.2 above) and return path channels to/from a particular node are connected to the same CMTS.
6. From the CMTS the return path back to the headend is an IP link (N x 1Gbit/s). See Figure 1.3 & Figure 1.4.

1.4 Fibre Optic Networks

1.4.1 Passive Optical Networks

1.4.1.1 What is a PON?

A Passive Optical Network (PON) is a network with no active elements in the signals' path from source Optical Line Terminal (OLT) to destination Optical Network Unit (ONU). The only components used by such networks are fibre, passive optical combiners, couplers, and splitters. This means that a PON is always a single section network. The main application of a PON is in the local access network; the "last mile" before reaching the customer.

1.4.1.2 PON Topology

PONs may be deployed in several basic topologies: tree, bus and ring (a variant of the bus topology using a dual fault tolerant configuration). All transmissions in a PON are performed between the Optical Line Terminal (OLT) and Optical Network Units (ONU). Therefore in the downstream direction PON is a point-to-multipoint network, and in the upstream direction it is a multipoint-to-point network.

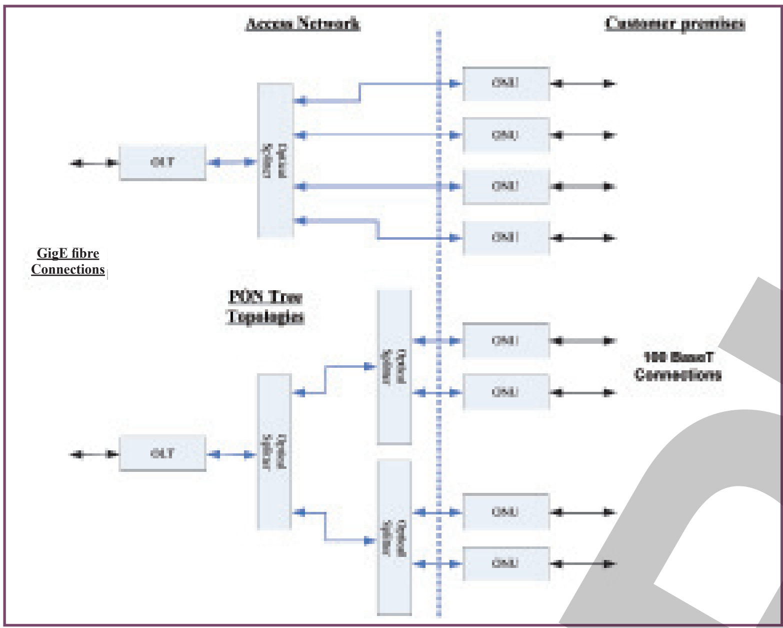

Figure 1.5: PON Tree Topology

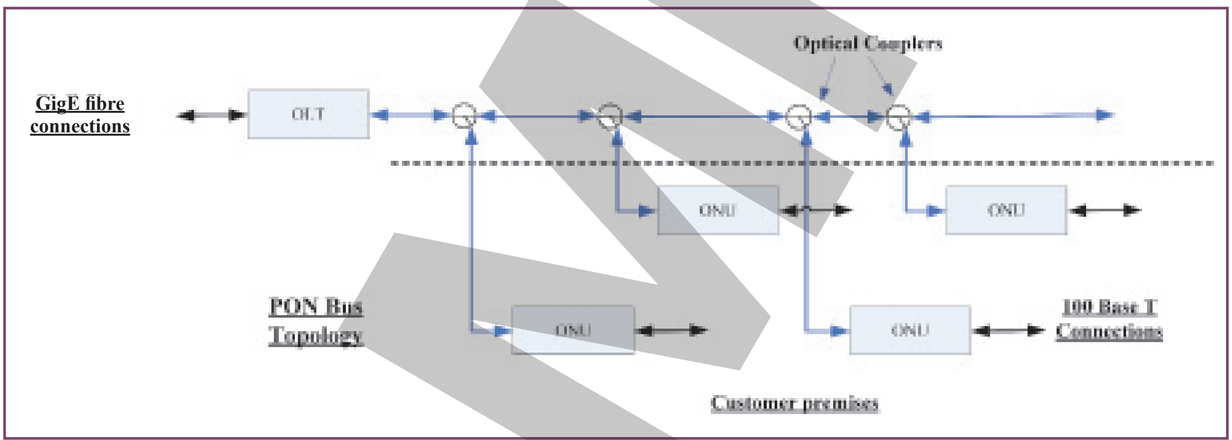

Figure 1.6: PON Bus Topology

Because there is very little internal reflection in the passive elements of the network, PONs can utilise bi-directional transmission (WDM) over the same fibre on the same wavelength. Since there is no signal amplification or regeneration within the network, and there are also insertion and splitting losses, the maximum distance between OLT and ONU should be in the range 20 – 25km. This distance depends on the signal attenuation in the PON, mainly due to the losses of the optical splitters and number of splitters installed.

1.4.1.3 PON Variants

Passive optical networks were originally proposed in 1990 and were ATM based (A-PON). This has since developed into a family of different “flavours” which are listed below. The ITU G.983 and G. 984 family of standards relate to PONs.

PON Type	Base	Speeds	Relevant Standards
A-PON	ATM		ITU G.983 family
B-PON	Broadband	622Mbit/s (symmetrical) 1.2Gbit/s (asymmetrical) 622Gbit/s (asymmetrical	ITU G.983 family
G-PON	Gigabit	asymmetrical up to 2.5Gbit/s full duplex	ITU G.984.1 and ITU G.984.2
E-PON	Ethernet	gigabit ethernet	

Table 1.1: PON Information and Standards

The G.983 family of specifications covers a wide range of issues. G.983.1 covers the end-to-end signalling protocol and enables efficient passive multiplexing in the return path. It also addresses security in the forward path.

The access signalling is similar in many respects to DOCSIS using TDM in the downstream and TDMA in the upstream. Upstream timing issues are also addressed: the more distant ONU's need to transmit earlier compared to nearer units in order that packets arrive in the correct time slot. The distance between the OLT and ONU is limited to 20km and there is a current limit of 32 ONU's per OLT, although consideration is being given to increasing this number to 64.

There are different classes of PON based on the loss budget between the OLT (Optical Line Terminal) and ONU (Optical Network Unit). A "Class A" network caters for 5dB to 20dB of optical loss, "Class B" 10dB to 25dB and "Class C" 15dB to 30dB.

The bandwidth of the PON is shared between all the users connected. For example a 1 gigabit PON serving 32 users at 1:1 contention means that each user could have a service of approximately 30Mbit/s symmetrical.

1.4.1.4 PON Architecture

The architecture of a PON network is relatively straight forward. A typical arrangement is shown in Figure 1.7 opposite.

At the exchange, or hub, rack mounting OLTs are installed; together with the broadcast transmitters and optical amplifiers (EDFAs) if required. These are connected via network interface panels onto high count fibre trunk cables. The OLT cards typically have 8 or 16 ports, which maps well onto a 96 fibre core cables.

The outgoing cables are then routed to "fibre aggregation points" where they are spliced onto smaller cables. These cables are then fed to "fibre distribution points" where they sub-divide again and spliced onto lower count distribution fibre cables (say 24 fibres). These distribution cables feed "splitter nodes" where individual fibres are broken out and spliced onto 32 way optical splitters. A splitter node can typically feed anywhere between 32 and 256 subscriber connections (1 to 8 distribution fibre cores). Drop cables (1 + 1 spare) from the splitter nodes feed individual subscriber connections where they are interfaced at the customer premises onto the ONU. Cables can be installed underground in ducts but the smaller distribution and drop cables can also be installed overhead between poles.

The aggregation points, distribution points and splitters nodes can all be installed underground, or in small cabinets. In addition the splitter nodes can be pole mounting and individual drop cables interfaced using a “manifold” assembly.

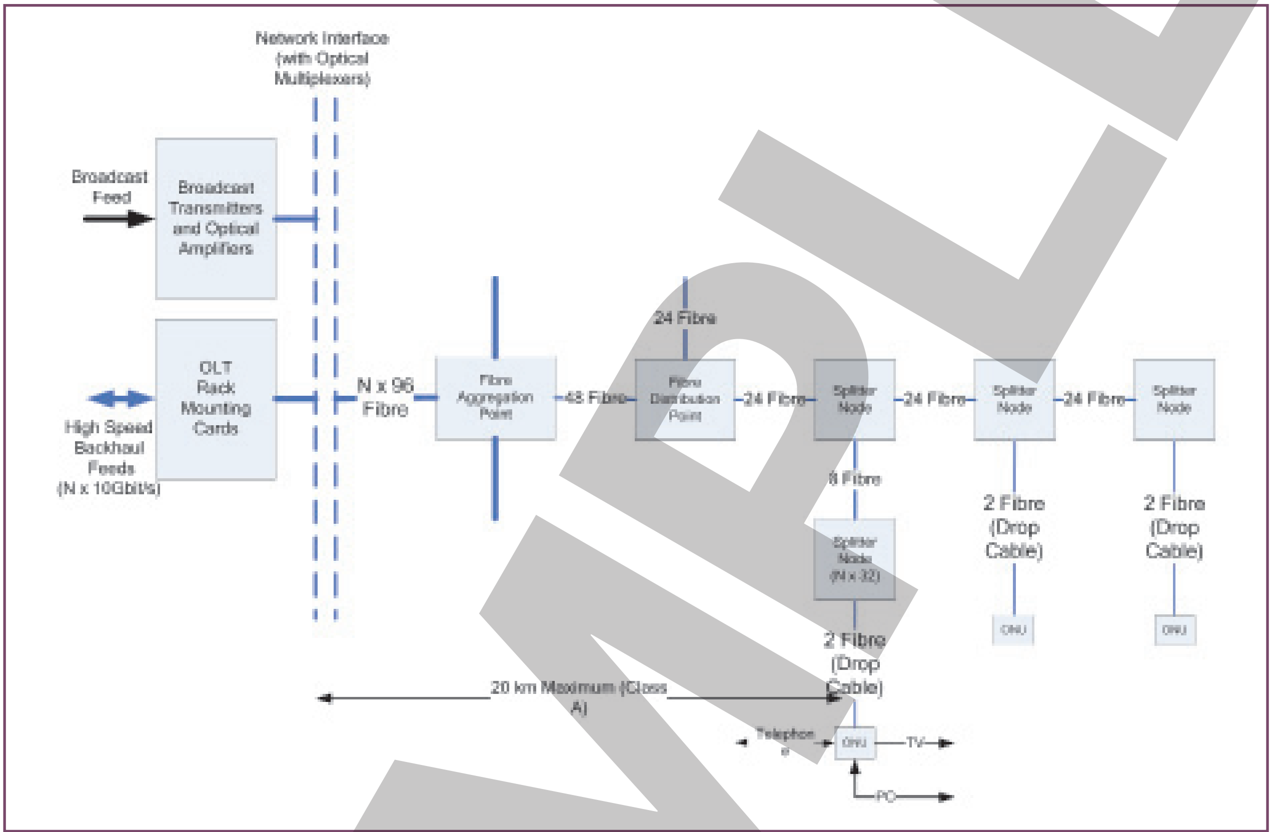

Figure 1.7: PON Network Architecture (single fibre working)

1.4.2 Metroethernet

1.4.2.1 Metroethernet Arrangements

The network layout from the hubs to the subscriber connections is as shown below in Figure 1.8. An alternative arrangement could use fibre to the final subscriber connections.

The high speed data links (10Gbit/s) are taken off the two fault tolerant feeds from the headend and connected to the routers in the hubs. Other ports from this router could be used to feed the local CMTS backhaul network connections (shown in Figure 1.8).

From the hub(s) 1 gigabit ethernet feeds are arranged, using dedicated fibre pairs within the node feeds (12 core fibre cables). Assuming 600 homes are passed per node (co-located with the HFC node) with 60% subscriber penetration (360 connections), a 20Mbit/s service and a contention ratio of 8:1 this equates to 1Gbit/s per node. This allows some spare capacity for higher a penetration of connections. Alternatively each node can be arranged with two dedicated fibre pairs with each connection being sized for a 1Gbit/s service. With this arrangement the fibre management is easier since only a single cable sub unit is needed per node. However, as both pairs of fibre are in the same cable, in the event of the cable being damaged,

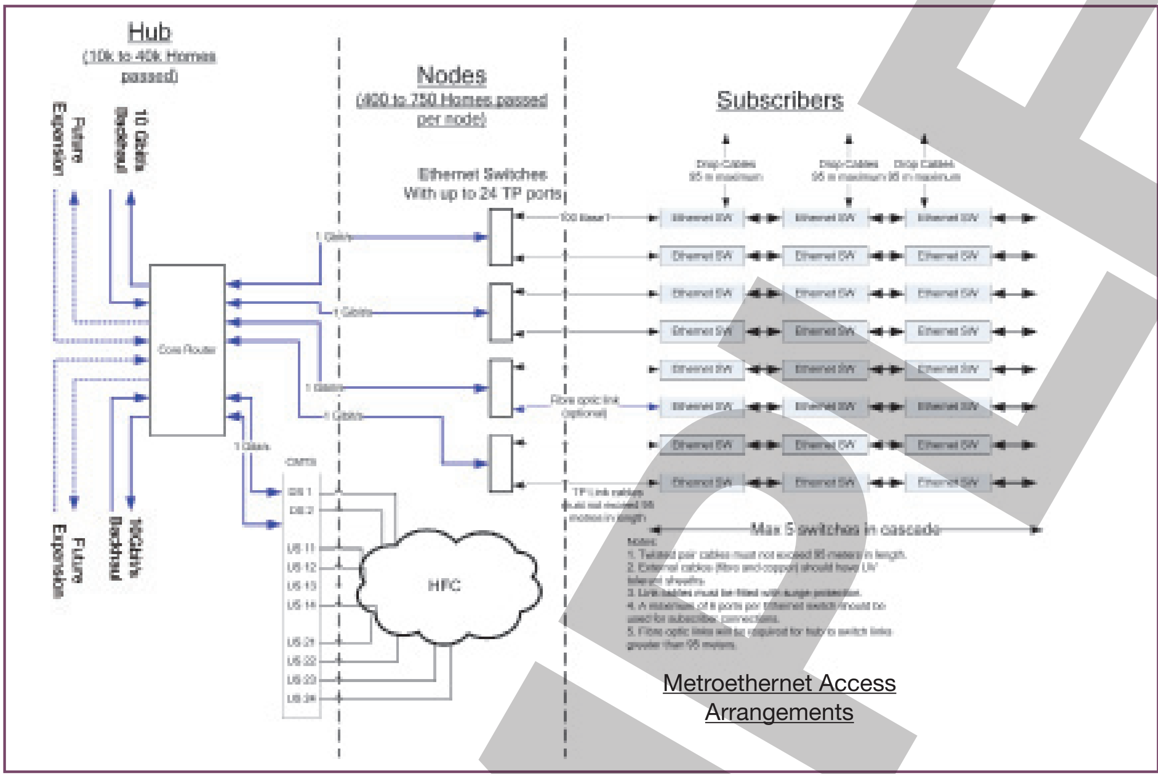

Figure 1.8: Metroethernet Arrangements

service would be lost. The contention ratio will be reduced to about 4:1 although a second node switch may be needed. These numbers are for illustration only.

At the node cabinet access switches would be located to interface the optical fibres onto the 100BaseT, CAT5 UTP cables feeding the ethernet switches and final subscriber connections.

1.5 Telephony Networks

1.5.1 SDH Networks

Telephone networks based on Synchronous Digital Hierarchy (SDH) are based on distribution “Rings” with the final subscriber connection from a primary multiplexer (PMux). The PMux breaks out a 2Mbit/s circuit into 32 x 64kbit/s, being a twisted pair point to point: see Figure 1.9. Two of these are used for management and control, the remaining 30 of these 64kbit/s circuits are converted to analogue voice.

The core rings usually use fibre optic cables connected to the multiplexer aggregate ports. In event of a cable fault, or transceiver failure, the multiplexer automatically reconfigures and raises an alarm.

Inter exchange rings are usually higher order such as SDH16 or SDH64. Tributary cards fitted into the multiplexers provide either further, lower orders of SDH or PDH such as 2, 8, 34 or 140Mbit/s. Interfaces to legacy PDH equipment can therefore be provided.

A reference master clock synchronises all the multiplexers, this reference can be either from a central master or by designating one of the multiplexers as a master.

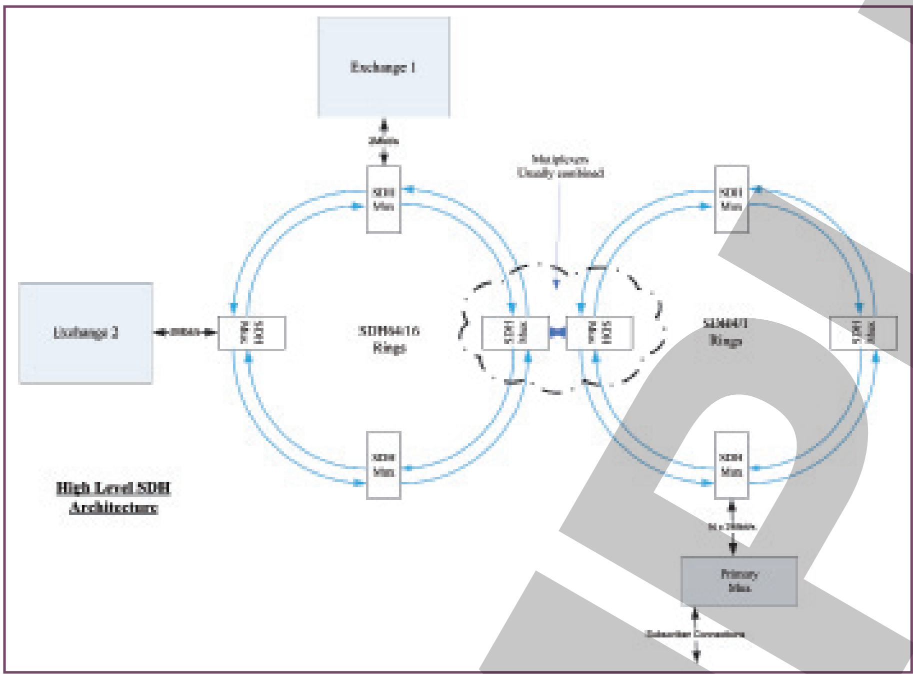

Figure 1.9: High Level SDH Network Arrangements

1.5.2 PDH Networks

Plesiochronous Digital Hierarchy (PDH) networks use layers of multiplexing as shown in Figure 1.10. This is still in use on older networks but is tending to be replaced by SDH. The PDH connections are usually via coaxial copper cables except for the final subscriber connection which is a twisted pair.

In the exchange, the interface to the "switch" is usually multiple 2Mbit/s. Any higher order incoming links need to be de-multiplexed down to 2Mbit/s to provide this interface.

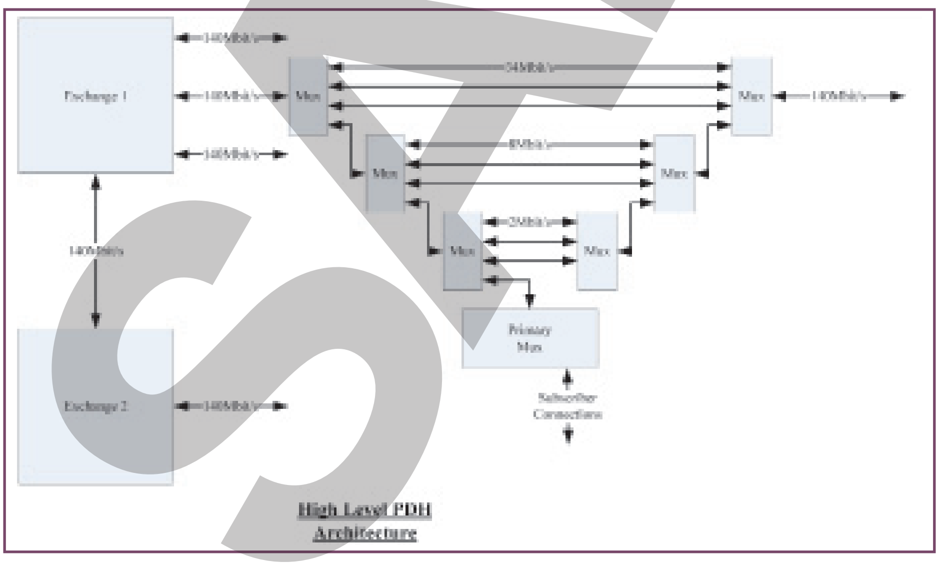

Figure 1.10: High Level PDH Network Arrangements showing a "Multiplexer Mountain"

One of the big problems with PDH is that if a 2Mbit/s circuit is to be dropped, for remote distribution, then a “multiplexer mountain” must be used to break this out.

1.6 Wireless Networks

1.6.1 Introduction

The network technician would not normally be involved with wireless access networks. However, most base stations are fed, via fibre, from a core network (Metroethernet or PON) typically at 1Gbit/s. A typical arrangement is shown in Figure 1.11 below.

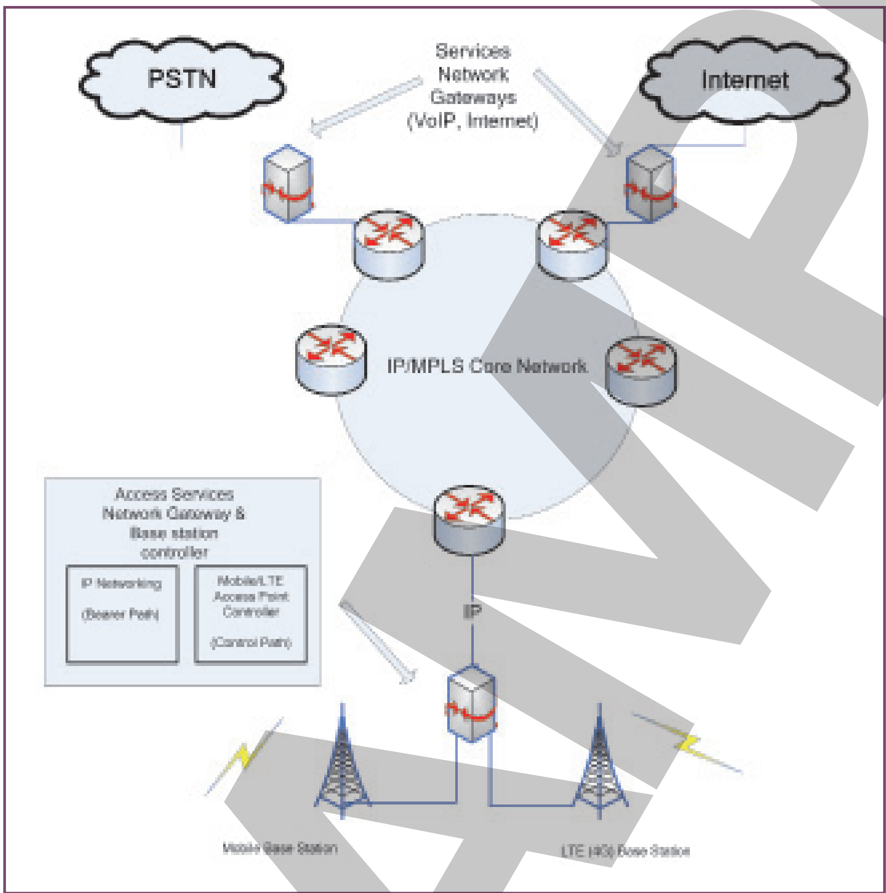

Figure 1.11: Mobile Base Station Feed Arrangements