

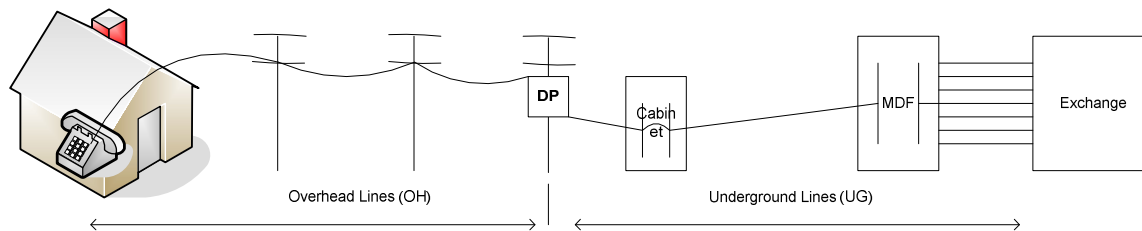
4. Access Network Technologies

4.1 Introduction

A main component of a public network is Access network. The Access network is connected to the core network. Customers are connected to the core network via the Access network. In other words this is the section between customer premises and service provider premises. Normally the length of the Access network can be in the range of 0.5km to 5km. Therefore this is also called “Subscriber Loop”. Also it is called ‘last mile access’. The Access network transmission media can be copper fiber or radio.

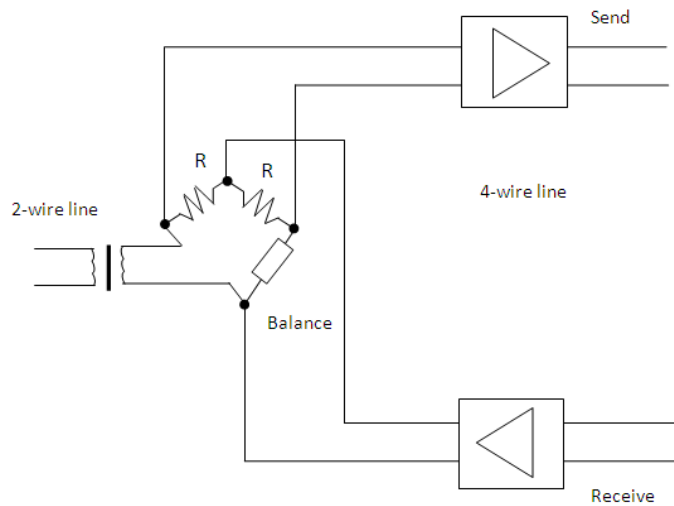
4.2 Copper Access Network

This was originally designed for the PSTN network where telephone is connected to the telephone exchange.



Normally two copper wires are required for transmit and another two wire are required for receive. This is called a 4 wire (4w) circuit. However in order reduce the amount of copper wires, only two wires (2w) are used in the local loop for both transmit and receive (simplex). At the exchange 4w/2w and 2w/4w connection is done.

4.2.1 4w/2w Connection using a bridge circuit



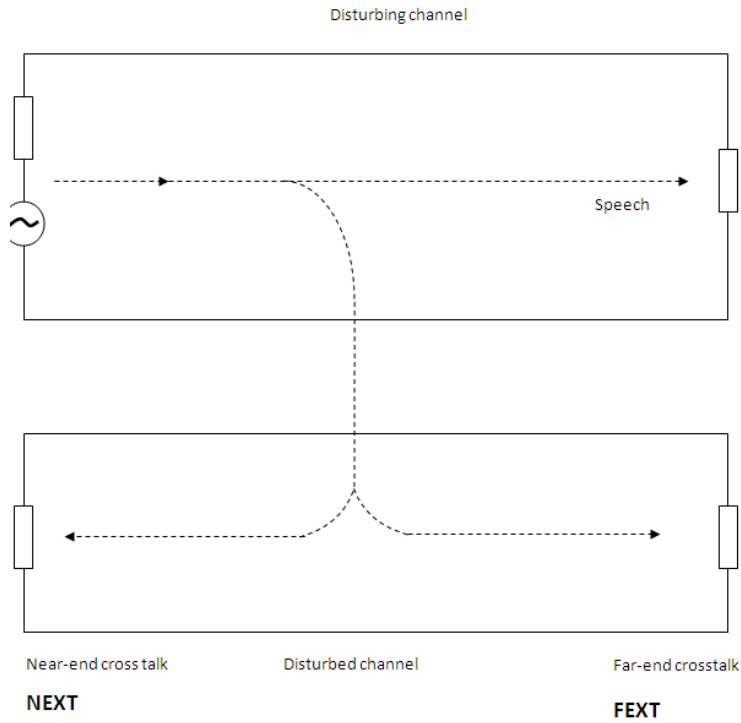
4.2.2 Echoes

In a 4-wire circuit part of the signal energy transmitted in one direction may return in the other direction. Both the talker and the listener may hear the reflected signal and the effect is called 'echo'.

In order to minimize the echo, "echo suppressor" or "echo canceller" is used at the telephone exchange for each circuit.

4.2.3 Cross talk (X talk)

Multi-pair cables are used between telephone exchange and cabinet, also cabinet and DP. The signal of one pair can be induced in another 2-wires. This effect is called "Cross talk".



The cross talk can have two types and it is explained in the above diagram. They are called,
 Near End Cross Talk (NEXT)
 Far End Cross Talk (FEXT)

Note: The cross talk can be minimized by twisting the pairs of cable as shown below.
 Diagram

4.2.4 Attenuation

The attenuation of the cable also an important parameter. The attenuation depends on the diameter of the cable. Normally the diameter represented by the “gauge”.

Diameter	Gauge	Maximum distance to telephone

A telephone signal has a bandwidth of 0.3 - 3.4kHz. The table shows the maximum distance of a telephone signal works according to the gauge of the cable.

4.2.5 Noise

Noise also another important parameter. The amount of noise depends on the insulation of a cable and the distance.

The quality of the signal measured as S/N.

4.2.6 Characteristic Impedance

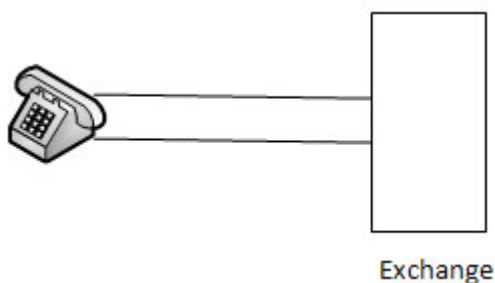
The characteristic Impedance [Z_0] of a cable is defined as,

$$Z_0 = \frac{R + j\omega C}{G + j\omega C}$$

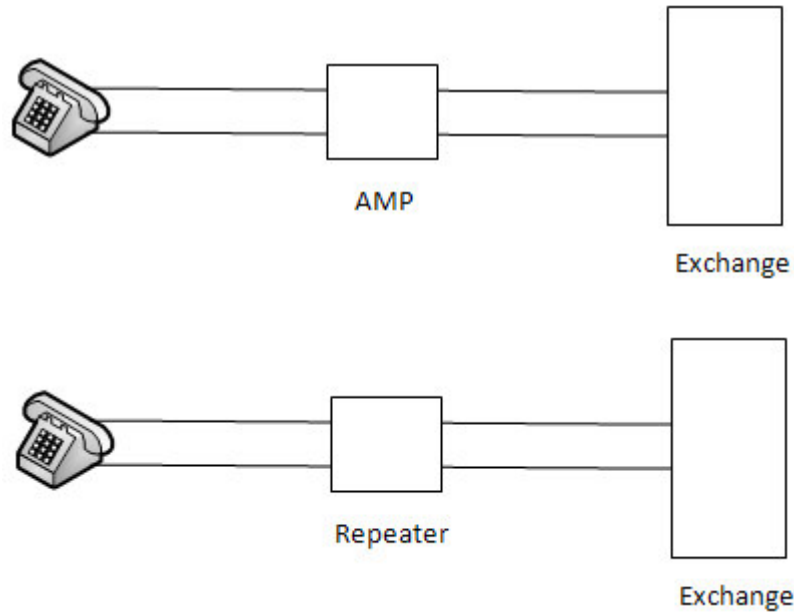
The Characteristic Impedance can be calculated from the above equation. Typical characteristic impedances are 75, 120, 150, 300 ohms.

When cable is joint to another cable or to end device the impedance should be matched. If not a part of signal can be reflected.

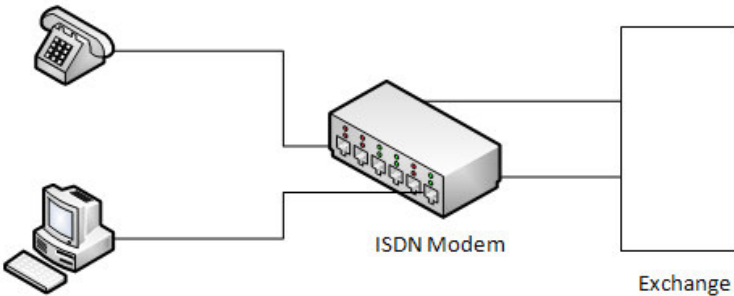
4.2.7 Telephone Connected to exchange



The bandwidth of the signal is 0.3 – 3.4 kHz. The distance between the telephone and exchange can be increased by using a low gauge cable. Further increase the distance can be done by using. Line amplifier or repeater.



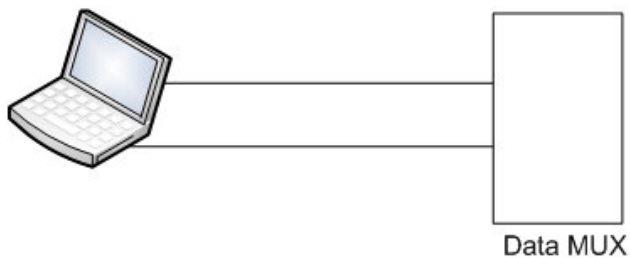
4.2.8 ISDN Connection through copper loop



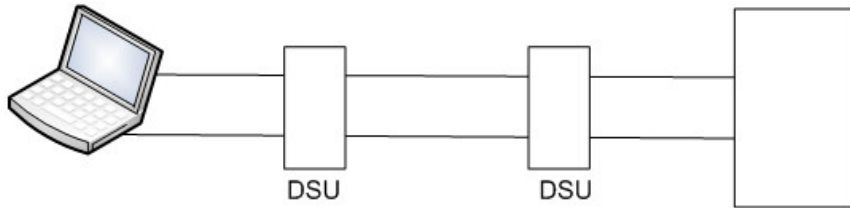
The 2B + D ISDN channel is a digital channel which has a bit rate of 192kb/s. However a unipolar digital signal cannot be transmitted over a several kilometers. Therefore a coded signal (line code) is used between ISDN Modem and exchange.

4.2.9 Leased Line

The leased line can be 2w or 4w. If 4w leased line is used, two loops are required.



The leased line is connected to data Mux



Since a unipolar digital signal cannot transmit a longer distance coded signal is sent between the computer and the data Mux. A DSU is used for this purpose.

4.3 Asymmetric Digital Subscriber Line (DSL)

4.3.1 ADSL

ADSL is a technique used to increase the usable bandwidth of the copper loop. There are many versions of ADSL as shown below.

What does ADSL mean?

- **Asymmetric** - The data can flow faster in one direction than the other. Data transmission has faster downstream to the subscriber than upstream
- **Digital** - No type of communication is transferred in an analog method. All data is purely digital, and only at the end, modulated to be carried over the line.
- **Subscriber Line** - The data is carried over a single twisted pair copper loop to the subscriber premises

ADSL standards:

Standard name	Common name	Downstream rate	Upstream rate
ITU G.992.1	ADSL (G.DMT)	8 Mbit/s	1.0 Mbit/s
ITU G.992.2	ADSL Lite (G.Lite)	1.5 Mbit/s	0.5 Mbit/s
ITU G.992.3/4	ADSL2	12 Mbit/s	1.0 Mbit/s
ITU G.992.3/4 Annex J	ADSL2	12 Mbit/s	3.5 Mbit/s
ITU G.992.3/4 Annex L	RE-ADSL2	5 Mbit/s	0.8 Mbit/s
ITU G.992.5	ADSL2+	24 Mbit/s	1.0 Mbit/s
ITU G.992.5 Annex L	RE-ADSL2+	24 Mbit/s	1.0 Mbit/s
ITU G.992.5 Annex M	ADSL2+	28 Mbit/s	3.5 Mbit/s

ADSL Range

- In general, the maximum range for DSL without a repeater is 5.5 km
- As distance decreases toward the telephone company office, the data rate increases

Data Rate	Wire gauge	Wire size	Distance
1.5 or 2 Mbps	24 AWG	0.5 mm	5.5 km
1.5 or 2 Mbps	26 AWG	0.4 mm	4.6 km
6.1 Mbps	24 AWG	0.5 mm	3.7 km
1.5 or 2 Mbps	26 AWG	0.4 mm	2.7

- For larger distances, you may be able to have DSL if your phone company has extended the local loop with optical fiber cable

ADSL Speed Factors

- The distance from the local exchange
- The type and thickness of wires used

- The number and type of joins in the wire
- The proximity of the wire to other wires carrying ADSL, ISDN and other non-voice signals
- The proximity of the wires to radio transmitters.

ADSL network components

- The ADSL modem at the customer premises(ATU-R)
- The modem of the central office (ATU-C)
- DSL access multiplexer (DSLAM)
- Broadband Access Server (BAS)
- Splitter - an electronic low pass filter that separates the analogue voice or ISDN signal from ADSL data frequencies DSLAM.

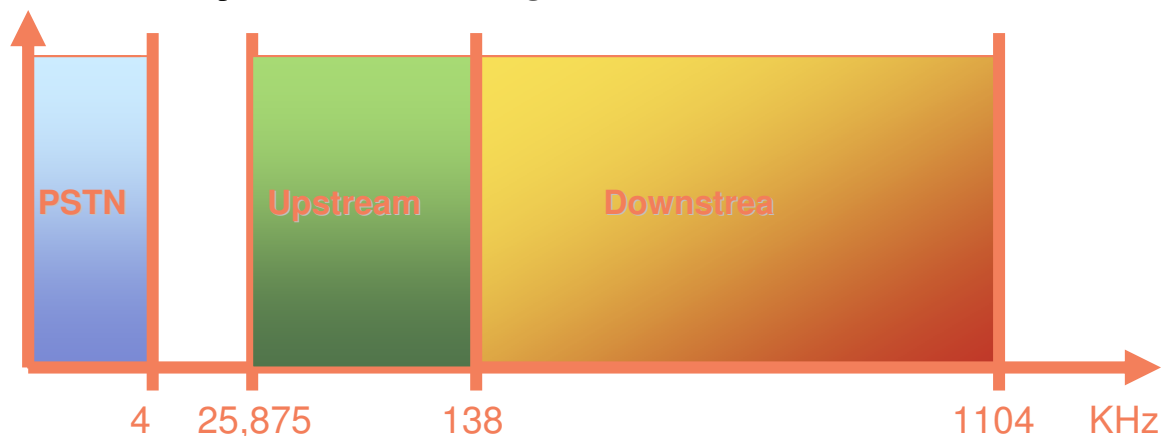
ADSL Loop Architecture

ADSL Requirements

- Phone-line, activated by your phone company for ADSL
- Filter to separate the phone signal from the Internet signal
- ADSL modem
- Subscription with an ISP supporting ADSL

How does ADSL work

- ADSL exploits the **unused analogue bandwidth** available in the wires



- ADSL works by using a frequency splitter device to split a traditional voice telephone line into two frequencies

ADSL Modulation

- Modulation is the overlaying of information (or the signal) onto an electronic or optical carrier waveform
- There are two competing and incompatible standards for modulating the ADSL signal:
 - Carrierless Amplitude Phase (CAP)
 - Discrete Multi-Tone (DMT)

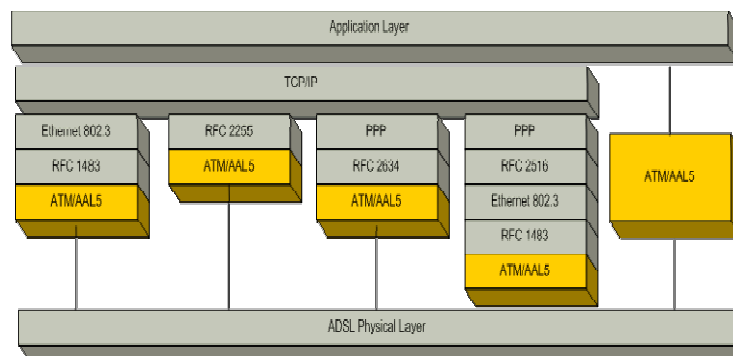
Carrierless Amplitude Phase

- Carrierless Amplitude Phase (CAP) is an encoding method that divides the signals into two distinct bands:
 1. The upstream data channel (to the service provider), which is carried in the band between 25 and 160kHz
 1. The downstream data channel (to the user), which is carried in the band from 200kHz to 1.1MHz .
- These channels are widely separated in order to minimize the possibility of interference between the channels.

Discrete Multi-tone (DMT)

- Discrete Multi-Tone (DMT) separates the DSL signal so that the usable frequency range is separated into 256 channels of 4.3125kHz each.
- DMT has 224 downstream frequency bins (or carriers) and 32 upstream frequency bins.
- DMT constantly shifts signals between different channels to ensure that the best channels are used for transmission and reception.

ADSL Protocol stacks



4.4 WIMAX

What is WiMAX?

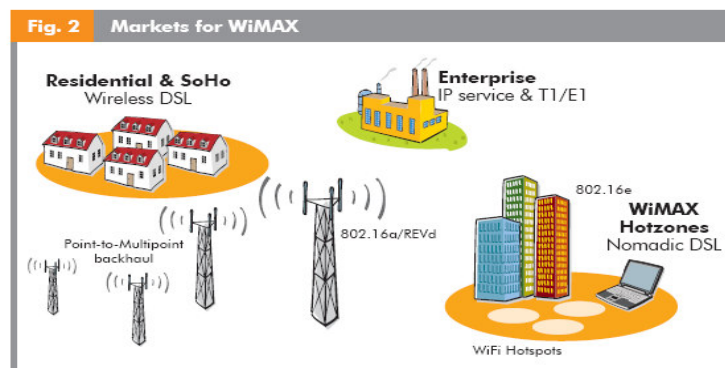
- Worldwide Interoperability for Microwave Access (WiMAX) is the common name associated to the IEEE 802.16a/REVd/e standards.
- These standards are issued by the IEEE 802.16 subgroup that originally covered the Wireless Local Loop technologies with radio spectrum from 10 to 66 GHz.

IEEE 802.16 -- Introduction

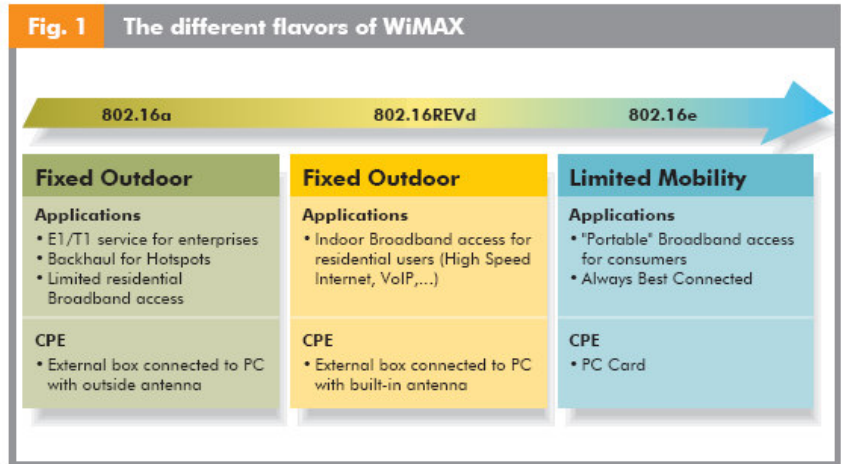
- IEEE 802.16 (2001)
 - Air Interface for Fixed Broadband Wireless Access System MAC and PHY Specifications for 10 – 66 GHz (LoS)
 - One PHY: Single Carrier
 - Connection-oriented, TDM/TDMA MAC, QoS, Privacy
- IEEE 802.16a (January 2003)
 - Amendment to 802.16, MAC Modifications and Additional PHY Specifications for 2 – 11 GHz (NLoS)
 - Three PHYs: OFDM, OFDMA, Single Carrier
 - Additional MAC functions: OFDM and OFDMA PHY support, Mesh topology support, ARQ
- IEEE 802.16d (July 2004)
 - Combines both IEEE 802.16 and 802.16a
 - Some modifications to the MAC and PHY
- IEEE 802.16e (2005?)
 - Amendment to 802.16-2004
 - MAC Modifications for limited mobility

IEEE 802.16 -- Introduction

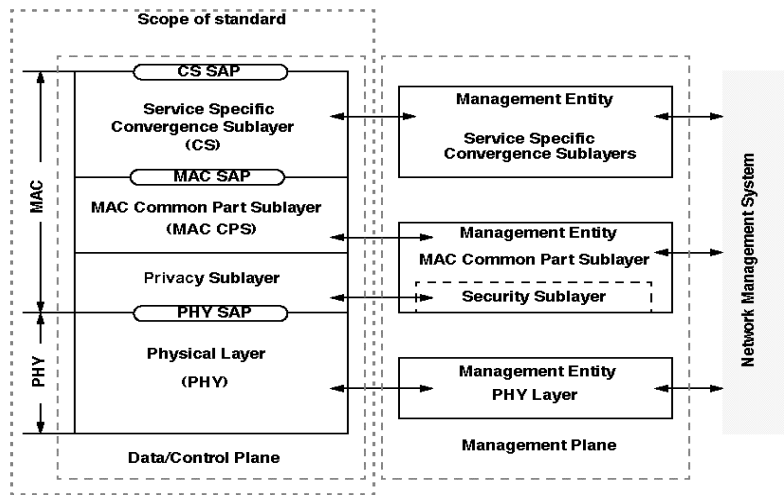
Coverage range up to 50km and speeds up to 70Mbps(shared among users).



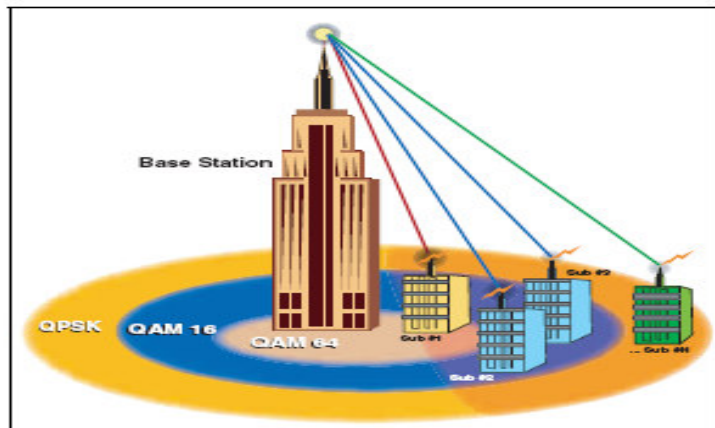
IEEE 802.16 -- Introduction



Reference Model



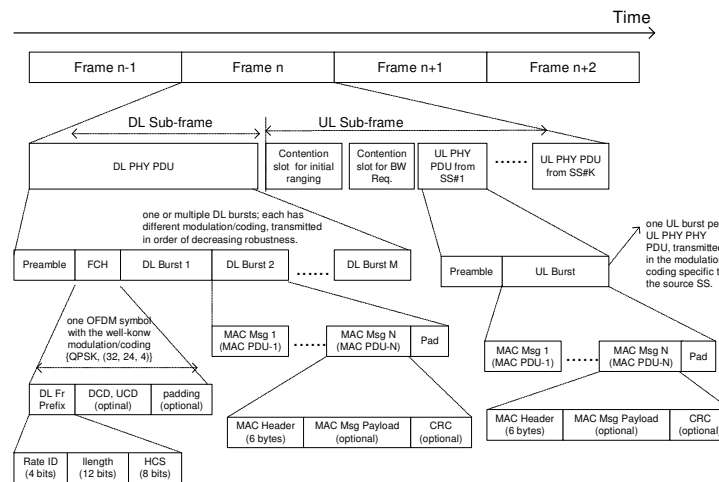
Adaptive PHY



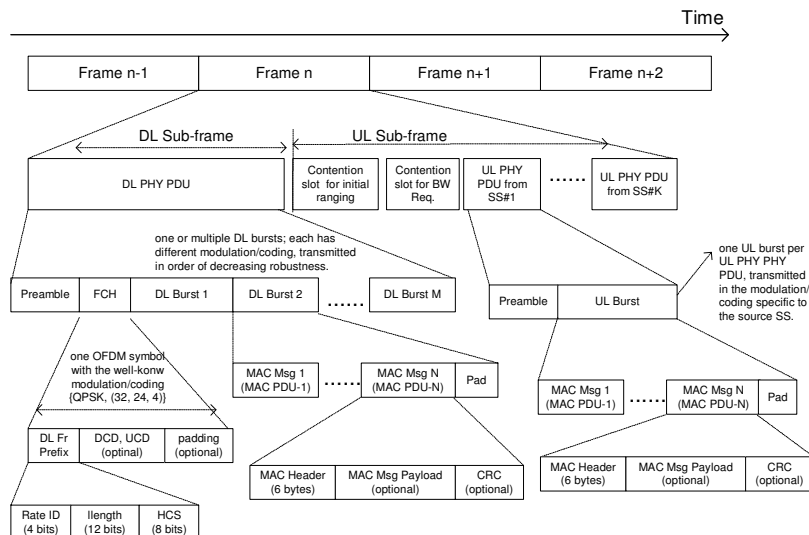
Duplex Scheme Support

- The duplex scheme is Usually specified by regulatory bodies, e.g., FCC
- Time-Division Duplex (TDD)
 - Downlink & Uplink time share the same RF channel
 - Dynamic asymmetry
 - does not transmit & receive simultaneously (low cost)
- Frequency-Division Duplex (FDD)
 - Downlink & Uplink on separate RF channels
 - Full Duplexing (FDX): can Tx and Rx simultaneously;
 - Half-duplexing (HDX) SSs supported (low cost)

IEEE 802.16 MAC – OFDM PHY TDD Frame Structure



IEEE 802.16 MAC – OFDM PHY FDD Frame Structure



IEEE 802.16 MAC addressing and Identifiers

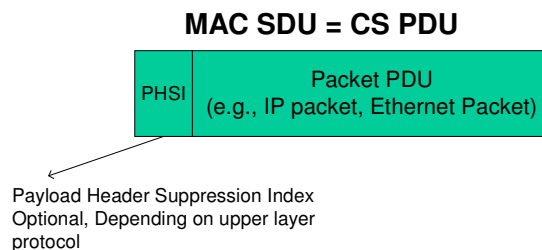
- SS has 48-bit IEEE MAC address
- BS has 48-bit base station ID
 - Not a MAC address
 - 24-bit operator indicator
- 16-bit connection ID (CID)
- 32-bit service flow ID (SFID)
- 16-bit security association ID (SAID)

IEEE 802.16 MAC – Convergence Sub-Layer (CS)

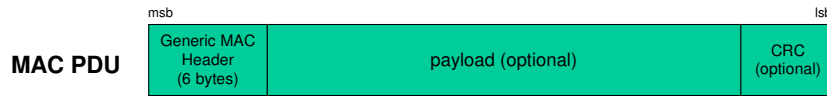
- ATM Convergence Sub-Layer:
 - Support for VP/VC switched connections
 - Support for end-to-end signaling of dynamically created connections
 - ATM header suppression
 - Full QoS support
- Packet Convergence Sub-Layer:
 - Initial support for Ethernet, VLAN, IPv4, and IPv6
 - Payload header suppression
 - Full QoS support

IEEE 802.16 MAC – CS – Packet Convergence Sub-Layer

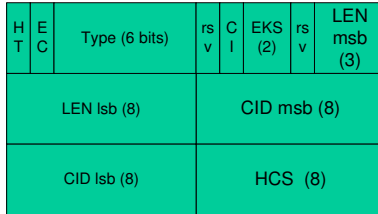
- Functions:
 - Classification: mapping the higher layer PDUs (Protocol Data Units) into appropriate MAC connections
 - Payload header suppression (optional)
 - MAC SDU (Service Data Unit), i.e, CS PDU, formatting



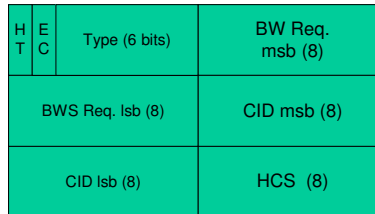
IEEE 802.16 MAC – CPS – MAC PDU Format



Generic MAC Header Format (Header Type (HT) = 0)



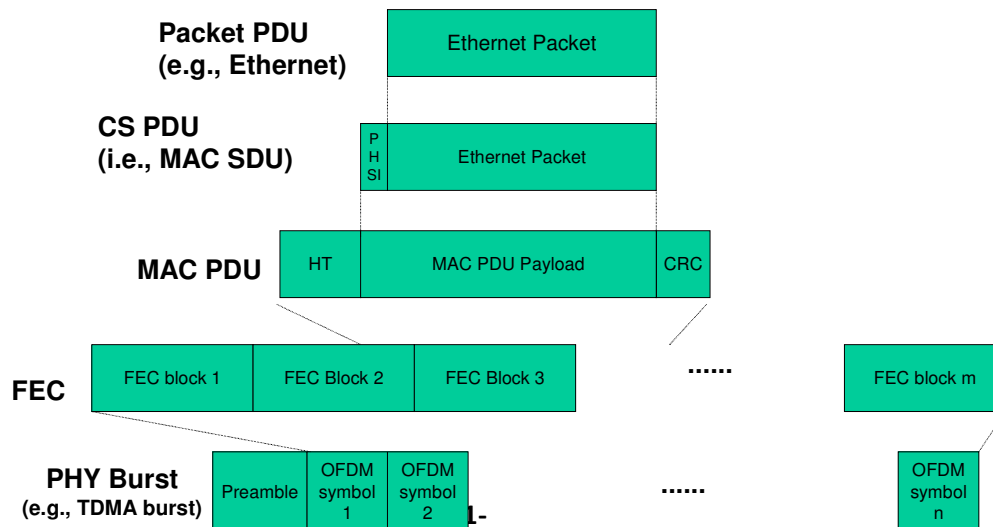
BW Req. Header Format (Header Type (HT) = 1)



IEEE 802.16 MAC -- CPS -- Three Types of MAC PDUs

- Data MAC PDUs
 - HT = 0
 - Payloads are MAC SDUs/segments, i.e., data from upper layer (CS PDUs)
 - Transmitted on data connections
- Management MAC PDUs
 - HT = 0
 - Payloads are MAC management messages or IP packets encapsulated in MAC CS PDUs
 - Transmitted on management connections
- BW Req. MAC PDUs
 - HT = 1; and no payload, i.e., just a Header

IEEE 802.16 MAC – CPS – Data Packet Encapsulations

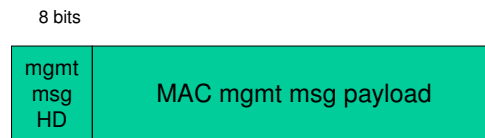


IEEE 802.16 MAC – CPS -- MAC Management Connections

- Each SS has 3 management connections in each direction:
 - **Basic Connection:**
 - short and time-urgent MAC management messages
 - MAC mgmt messages as MAC PDU payloads
 - **Primary Management connection:**
 - longer and more delay tolerant MAC mgmt messages
 - MAC mgmt messages as MAC PDU payloads
 - **Secondary Management Connection:**
 - Standard based mgmt messages, e.g., DHCP, SNMP, ...etc
 - IP packets based CS PDU as MAC PDU payload

IEEE 802.16 MAC – CPS – MAC Management Messages

- MAC mgmt message format:



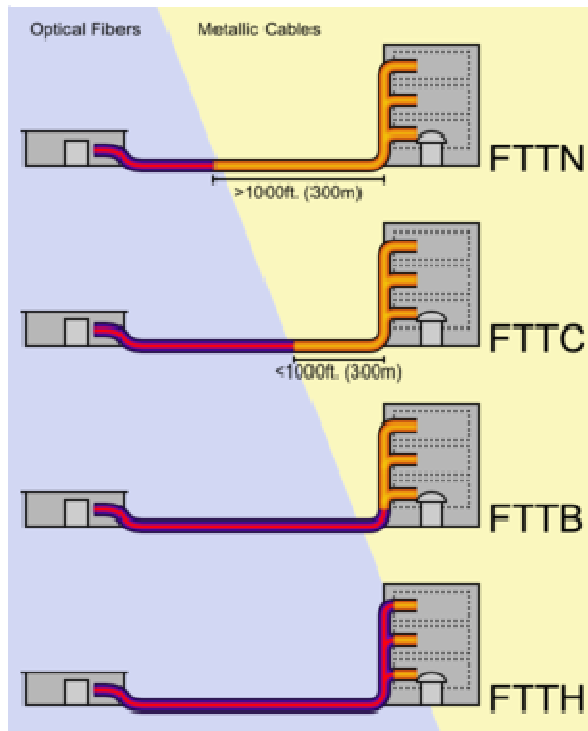
- MAC mgmt msg can be sent on: Basic connections; Primary mgmt connection; Broadcast connection; and initial ranging connections
- 41 MAC mgmt msgs specified in 802.16
- The TLV (type/length/value) encoding scheme is used in MAC mgmt msg, e.g., in UCD msg for UL burst profiles,
 - (type=1, length=1, value=1) → QPSK modulation
 - (type=1, length=1, value=2) → 16QAM modulation
 - (type=1, length=1, value=3) → 64QAM modulation

IEEE 802.16 MAC – CPS – MAC PDU Transmission

- MAC PDUs are transmitted in PHY Bursts
- The PHY burst can contain multiple FEC blocks
- MAC PDUs may span FEC block boundaries
- Concatenation
- Packing
- Segmentation
- Sub-headers

4.5 Fibre To the x

Fiber to the x (FTTx) is a generic term for any broadband network architecture that uses optical fiber to replace all or part of the usual metal local loop used for last mile telecommunications. The generic term originated as a generalization of several configurations of fiber deployment (FTTN, FTTC, FTTB, FTTH...), all starting by FTT but differentiated by the last letter, which is substituted by an *x* in the generalization.



The telecommunications industry differentiates between several distinct configurations. The terms in most widespread use today are:

- FTTN - Fiber-to-the-node - fiber is terminated in a street cabinet up to several kilometers away from the customer premises, with the final connection being copper.
- FTTC - Fiber-to-the-cabinet - this is very similar to FTTN, but the street cabinet is closer to the user's premises; typically within 300m.
- FTTB - Fiber-to-the-building or Fiber-to-the-basement - fiber reaches the boundary of the building, such as the basement in a multi-dwelling unit, with the final connection to the individual living space being made via alternative means.
- FTTH - Fiber-to-the-home - fiber reaches the boundary of the living space, such as a box on the outside wall of a home.

- FTTP - Fiber-to-the premises - this term is used in several contexts: as a blanket term for both FTTH and FTTB, or where the fiber network includes both homes and small businesses.

To promote consistency, especially when comparing FTTH penetration rates between countries, the three FTTH Councils of Europe, North America and Asia-Pacific have agreed upon definitions for FTTH and FTTB.^[1] The FTTH Councils do not have formal definitions for FTTC and FTTN.

It is worth pointing out that fiber to the telecom enclosure (FTTE) is not considered to be part of the FTTx group of technologies, despite the similarity in name. FTTE is a form of structured cabling typically used in the enterprise local area network, where fiber is used to link the main computer equipment room to an enclosure close to the desk or workstation.^[2] Similarly, in fiber-to-the-desk a fiber connection is installed from the main computer room to a terminal at the desk.

4.5.1 Electrical portion

Once on private property, the signal typically travels the final distance to the end user's equipment using an electrical format.

A device called an Optical Network Terminal (ONT), also called an Optical Network Unit (ONU), converts the optical signal into an electrical signal. (ONT is an ITU-T term, whereas ONU is an IEEE term, but the two terms mean exactly the same thing.) Optical network terminals require electrical power for their operation, so some providers connect them to back-up batteries in case of power outages. Optical network units use thin film filter technology to convert between optical and electrical signals.

For fiber to the home and for some forms of fiber to the building, it is common for the building's existing phone systems, local area networks, and cable TV systems to connect directly to the ONT.

If all three systems cannot directly reach the ONT, it is possible to combine signals and transport them over a common medium. Once closer to the end-user, equipment such as a router, modem, and/or network interface module can separate the signals and convert them into the appropriate protocol. For example, one solution for apartment buildings uses VDSL to combine data (and / or video) with voice. With this approach, the combined signal travels through the building over the existing telephone wiring until it reaches the end-user's living space. Once there, a VDSL modem copies the data and video signals and converts them into Ethernet protocol. These are then sent over the end user's category 5 cable. A network interface module can then separate out the video signal and convert it into an RF signal that is sent over the end-user's coaxial cable. The voice signal continues to travel over the phone wiring and is sent through DSL filters to remove the video and data signals. An alternative strategy allows data and / or voice to be transmitted over coaxial cable. In yet another strategy, some office buildings dispense with the

telephone wiring altogether, instead using voice over Internet Protocol phones that can plug directly into the local area network.

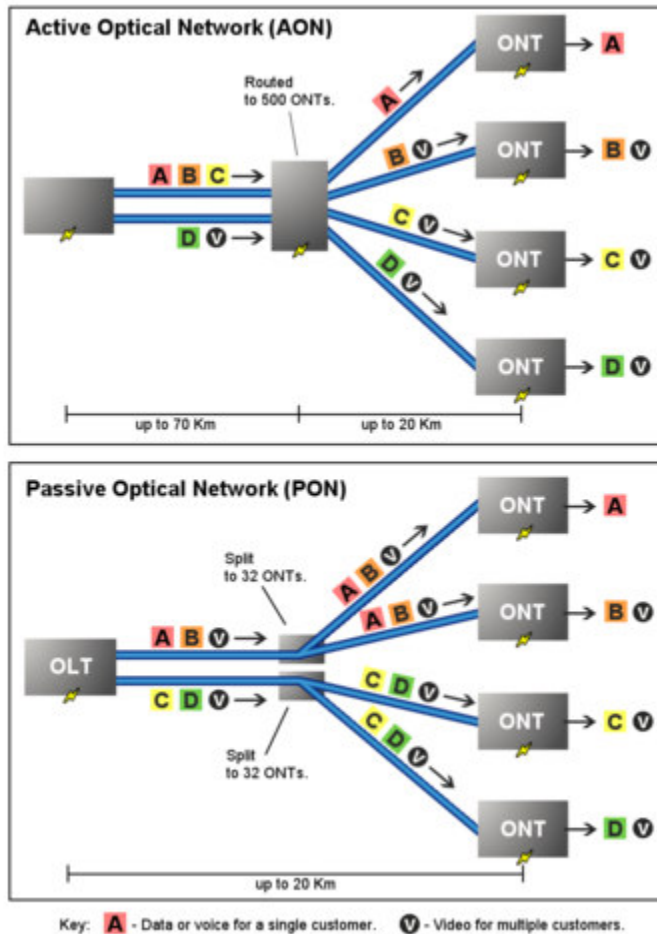
4.5.2 Direct fiber

The simplest optical distribution network can be called direct fiber. In this architecture, each fiber leaving the central office goes to exactly one customer. Such networks can provide excellent bandwidth since each customer gets their own dedicated fiber extending all the way to the central office. However, this approach is about 10% more costly due to the amount of fiber and central office machinery required.^[8] The approach is generally favored by new entrants and competitive operators. A benefit of this approach is that it doesn't exclude any layer 2 networking technologies, be they Passive optical network, Active Optical Network, etc. From a regulatory point of view it leads to least implications as any form of regulatory remedy is still possible using this topology.^[9]

Shared fiber

More commonly each fiber leaving the central office is actually shared by many customers. It is not until such a fiber gets relatively close to the customers that it is split into individual customer-specific fibers. There are two competing optical distribution network architectures which achieve this split: active optical networks (AONs) and passive optical networks (PONs).

4.5.2.1 Active optical network



Comparison showing how a typical active optical network handles downstream traffic differently than a typical passive optical network. The type of active optical network shown is a star network capable of multicasting. The type of passive optical network shown is a star network having multiple splitters housed in the same cabinet.

Active optical networks rely on some sort of electrically powered equipment in Optical Distribution Network(ODN) to distribute the signal, such as a switch or router. Normally, optical signals need O-E-O transformation in ODN. Each signal leaving the central office is directed only to the customer for which it is intended. Incoming signals from the customers avoid colliding at the intersection because the powered equipment there provides buffering.

As of 2007, the most common type of active optical networks are called active Ethernet, a type of Ethernet in the first mile (EFM). Active Ethernet uses optical Ethernet switches to distribute the signal, thus incorporating the customers' premises and the central office into one giant switched Ethernet network. Such networks are identical to the Ethernet computer networks used

in businesses and academic institutions, except that their purpose is to connect homes and buildings to a central office rather than to connect computers and printers within a campus. Each switching cabinet can handle up to 1,000 customers, although 400-500 is more typical. This neighborhood equipment performs layer 2/layer 3 switching and routing, offloading full layer 3 routing to the carrier's central office. The IEEE 802.3ah standard enables service providers to deliver up to 100 Mbit/s full-duplex over one single-mode optical fiber to the premises depending on the provider. Speeds of 1Gbit/s are becoming commercially available.

4.5.2.2 *Passive optical network*

Main article: Passive optical network

A passive optical network (PON) is a point-to-multipoint, fiber to the premises network architecture in which unpowered optical splitters are used to enable a single optical fiber to serve multiple premises, typically 32-128. A PON configuration reduces the amount of fiber and central office equipment required compared with point to point architectures.

Downstream signal coming from the central office is broadcast to each customer premises sharing a fiber. Encryption is used to prevent eavesdropping.

Upstream signals are combined using a multiple access protocol, invariably time division multiple access (TDMA). The OLTs "range" the ONUs in order to provide time slot assignments for upstream communication.

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4.6 Metro Ethernet

A **Metro Ethernet** is a computer network that covers a metropolitan area and that is based on the Ethernet standard. It is commonly used as a metropolitan access network to connect subscribers and businesses to a larger service network or the Internet. Businesses can also use Metro Ethernet to connect branch offices to their Intranet.

Ethernet has been a well known technology for decades. An Ethernet interface is much less expensive than a SONET/SDH or PDH interface of the same bandwidth. Ethernet also supports high bandwidths with fine granularity,^[clarification needed] which is not available with traditional SDH connections. Another distinct advantage of an Ethernet-based access network is that it can be easily connected to the customer network, due to the prevalent use of Ethernet in corporate and, more recently, residential networks. Therefore, bringing Ethernet in to the Metropolitan Area Network (MAN) introduces a lot of advantages to both the service provider and the customer (corporate and residential)

A typical service provider Metro Ethernet network is a collection of Layer 2 or/and Layer 3 switches or/and routers connected through optical fiber. The topology could be a ring, hub-and-spoke (star), or full or partial mesh. The network will also have a hierarchy: core, distribution (aggregation) and access. The core in most cases is an existing IP/MPLS backbone, but may migrate to newer forms of Ethernet Transport in the form of 10G or 100G speeds.

Ethernet on the MAN can be used as pure Ethernet, Ethernet over SDH, Ethernet over MPLS or Ethernet over DWDM. Pure Ethernet-based deployments are cheap but less reliable and scalable, and thus are usually limited to small scale or experimental deployments. SDH-based deployments are useful when there is an existing SDH infrastructure already in place, its main shortcoming being the loss of flexibility in bandwidth management due to the rigid hierarchy imposed by the SDH network. MPLS based deployments are costly but highly reliable and scalable, and are typically used by large service providers.

The Metro Ethernet Forum (MEF) has defined three types of services that can be delivered through Metro Ethernet:

- E-Line also known as Virtual Private Wire Service (VPWS), Virtual Leased Line (VLL), Point-to-Point, or Ethernet Private Wire Service (EPVS).
- E-LAN also known as Virtual Private LAN Services (VPLS), Transparent LAN Services and MultiPoint-to-MultiPoint.
- E-TREE also known as Rooted-MultiPoint.

5. Core Network Technologies

5.1 Introduction

The core network is similar to highways of a road network. The highway network connects the major towns of the country by using highways which consists of wide roads. This road is shared by many vehicles.

The core network of a communication network is own and managed by the service providers. They look after the redundancy, reliability, availability etc. of the core network. If one route has a problem it will be switched to an alternative route. If one route to a particular destination has high traffic, another route also can be used to the same destination. Normally such things are managed by a protocol used in the network.