RCOMP - Redes de Computadores (Computer Networks)

2023/2024

Lecture 04

- WAN Technologies: ATM/ISDN
- Local loop: WLL, DSL, and cable

WAN – ATM Networks

ATM (Asynchronous Transfer Mode) technology is available for some time, but its expansion wasn’t as initially anticipated. In WAN domain, it's currently used in internet backbones for routers interconnection. Despite that, its initial goal to provide a global end-node to end-node interconnection was never truthfully achieved.

Precisely when ATM was beginning to be used in LAN environment, Ethernet networks evolved to switching and increased the transmission rate. And this ultimately condemned ATM use in local networks due to its higher cost.

Currently, we see an extension of this process. Ethernet networks now begin to break into the ATM WAN domain, with ethernet connections at 10 Gbps and 100 Gbps in distances of up to hundreds of kilometres.

ATM – Virtual paths and channels

ATM has several significant features, one of them is the use of virtual circuits. Unfortunately, the advantages of virtual circuits are only meaningful for end-node to end-node communications, and not simple dedicated connections between IP routers.

In ATM, virtual circuits are known as **virtual channels**, they are identified by 16-bit numbers (VCI – Virtual Channel Identifier). Virtual channels are logical connections between applications running on different end-nodes.

Though, the ATM network only needs to route data between end-nodes, not applications. ATM intermediate nodes are the ATM switches, to simplify ATM switches work, virtual paths are also defined, they are identified by 12-bit numbers (VPI – Virtual Path Identifier).

- Each virtual channel (outside the network) belongs to a virtual path (inside the network).

- All virtual channels with the same origin and destination end-nodes belong to the same virtual path (inside the network).

ATM Networks – Cells

Another important facet is the use of very small, and fixed size, packets (PDUs). These small packets are called **cells**, they have only 53 bytes of length, that includes 5 bytes for control (PCI) and the remaining 48 bytes for data payload (SDU). Overhead is, therefore, rather high, nearly 10% (5/53).

Despite the high overhead, cells offer two advantages:

- **Fixed size**: this means when an ATM switch is receiving a cell it already knows its size, this makes memory management inside an ATM switch very efficient, it can be managed in 53 bytes size slots.

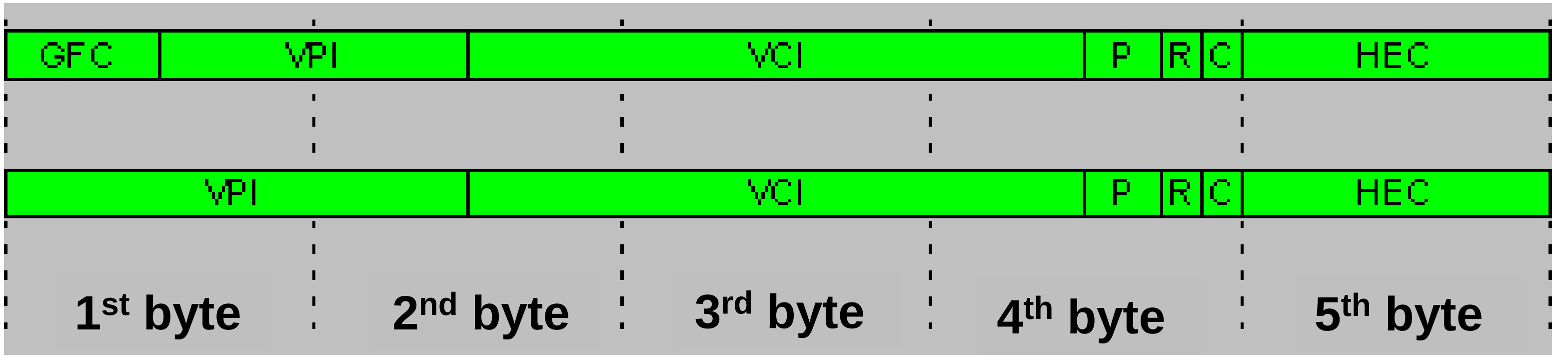
- Small size: this means receiving and sending a cell doesn't take much time, thus, the delay (latency) for cells crossing ATM switches is very low.

The use of virtual circuits <u>ensures the cells sequence is preserved</u>, however, <u>neither cells delivery nor data integrity is guaranteed</u>, not even error detection for the payload is provided. If upper layers required any of those features, the implementation is up to them.

Notice that, error detection may not be that relevant for some real-time applications, for instance, real-time sound or image transmission.

ATM Networks – Cells formats

The image below shows the header (5 bytes) of two ATM cells. On the top, an external cell (UNI – User-Network Interface), and below, an internal cell (NNI – Network-Network Interface).



In UNI cells (top) VPI is zero, VPI is defined only in cells traveling inside the network. The GFC field (Generic Flow Control) only exists in UNI cells, it's used for local flow control and multiplexing.

P/R fields (Payload Type) specifies the type of transported data. The C field (Cell Loss Priority) contains the priority of the cell in the event of congestion, if this bit is one the cell is eliminated first than cells where this bit is zero.

HEC (Header Error Correction) contains a header error detection code which is self-correcting for one-bit errors (FEC) and detects errors of more than one bit.

ATM Networks - ISDN

One goal for ATM networks is providing an ISDN (Integrated Services Digital Network) platform. Specifically, ATM was designed to be the main technology for B-ISDN (Broadband - ISDN).

ISDN implies a wide range of application types, some applications require real-time, others do not, some applications require error detection, others do not. This somewhat justifies options taken in ATM: the use of very small packets with virtual paths and no error detection on transported data. These features ensure minimum delays, a key feature to support real-time transmissions.

To support several classes of services (video, voice, and data) specific adaptation layers are required for each. They are known as AAL (ATM Adaptation Layer). The AAL implementations focused on supporting network layer packets transport are AAL3/4 and AAL5.

With nowadays internet, the ISDN philosophy no longer makes much sense, and the ATM technology is now mostly used to interconnect routers on the internet itself by using AAL5.

ATM Networks – AAL5

To support higher-level protocols packets' transport, ATM originally included a dual-layer implementation known as AAL3/4. With the internet expansion, this kind of ATM usage became increasingly important and an effort was made to improve and eliminate unnecessary features, this effort resulted in AAL5. The AAL5 layer PDU is characterised by its simplicity:

Data (0 to 65535 bytes)	Alignment (0 to 47 bytes)	CTL (2 bytes)	LEN (2 bytes)	CRC (4 bytes)

The alignment field is used to ensure the total PDU length is a multiple of 48 bytes, and thus, it can be split into 48 bytes blocks to be directly fitted into ATM cells payload. CTL is not currently used.

The LEN field stores the data length (alignment not included) and the CRC field allows error detection covering the entire PDU.

AAL5 PDU lacks a protocol multiplexing field, instead the VCI value is used for that purpose.

WAN – IP connectivity

The internet expansion has drastically affected the way WAN networks are faced today.

Before IP protocol generalization, WAN networks provided a layer two service for data transfer between end-nodes (subscribers). This layer two service was then used to transport various types of subscriber's data (ISDN approach). Among others, network layer protocol packets such as IP, IPX or AppleTalk.

Nowadays WAN subscribers only want IP connectivity to the internet, nothing else. Even for the most demanding applications such as real-time voice and image, there's now an increasing number of IP based solutions, e.g. VoIP.

Using IP (layer three) has two major advantages:

- It's universally supported, any node connected to the internet supports it. This means all nodes can exchange information directly.
- It doesn't require a uniform layer two technology extending from emitter to receiver. Routers are able to transfer IP packets between layer two networks, even if they are of different technologies.

WAN – IP nodes interconnection

Layer two WAN interconnection between end-nodes is now mostly a solution for very specific deployments. Being the IP protocol a common standard, it's much more reasonable and simpler to use it directly than trying to impose a uniform layer two technology extended to every end-node.

End-node to end-node data delivery by WAN networks operating at layer two is now almost entirely replaced by layer three IP end-nodes. IP nodes known as routers retransmit IP packets ensuring IP end-node to end-node communications.

Nevertheless, interconnecting IP routers still requires part of the layer two technology previously used, including ATM.

Layer two WAN technology is now mostly used to create simple point-to-point dedicated connections between IP routers. In this perspective, advanced features of some technologies such as ATM virtual circuit switching are totally unexploited.

WAN - Telecommunications Operators

Long distance communications (WAN) can only be carried out by authorized (legally licensed) operators.

- Private radio emissions are subject to several, country dependent, legal restrictions, such as frequencies (channels) and transmission power. These restrictions make it impossible to be used in WAN. For example, in many countries, the Wi-Fi use outdoors is illegal.

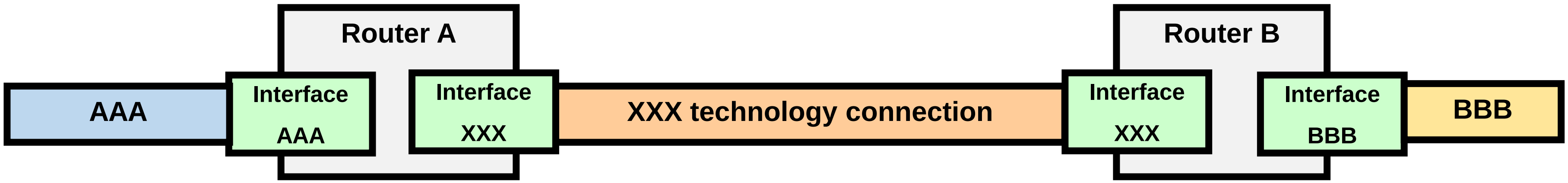
- Private wire connections can not pass-through public areas. For example, one cannot simply pass a network cable over a public street. To be able to connect two buildings on opposite sides of a public street a licensed operator must be enrolled.

- One possible alternative is the use of laser light beams. Of course, this requires a line of sight between the points to be connected. This option is free of legal constraints, but has technical limitations, particularly with regard to propagation conditions and is typically limited to distances of less than 3 Km.

WAN – Technologies

One of the advantages of using a global layer three network protocol (IP) is that several layer two connection technologies can be combined together to ensure data transportation along the way.

To interconnect two routers using a given XXX layer two technology, we simply install in each an XXX technology network interface card.



A wide variety of technologies is made available by authorized telecommunications operators.

- Dedicated leased lines, analogue or digital, copper or fibre.

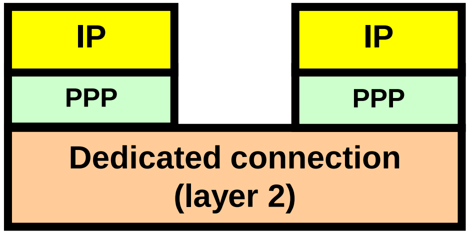
- ISDN and public analogue telephone network (PSTN).

- X.25, Frame-relay, Ethernet and ATM.

WAN – Dedicated connections

Largely, the current use of the layer two WAN technologies is limited to IP routers interconnection. Although routers interconnection may use a switched network, such as ATM or Frame-relay, a dedicated connection is all it takes.

On dedicated connections, the PPP (Point-to-Point Protocol) is commonly used, it was specially designed to control network packets transport in these circumstances.

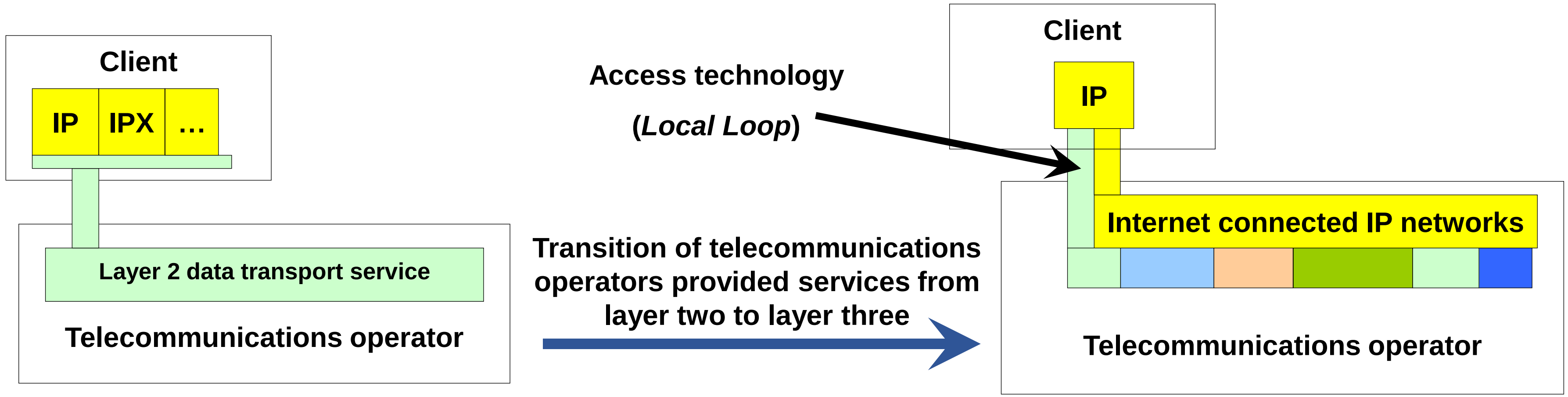


These technologies are now used by telecommunications operators to provide IP transport services to customers (subscribers) in replacement of the old traditional layer two end-node to end-node transport service.

The layer two dedicated connection, provided to the subscriber, ensures the transport of IP packets between the subscriber and the operator only. On the operator side, there will be an IP router capable of receiving IP packets from the subscriber and retransmit them to the internet, using another independent layer two connection.

WAN – Access technologies – Local Loop

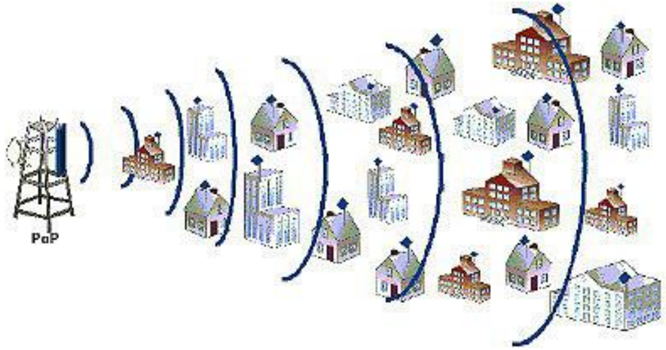
The image below represents the change we have been talking about (left to right):



A layer two technology is still required to transport IP packets between the costumer and the operator. This connection is known as **Local Loop**. The local loop can be based on a new wiring installation, typically optical fibre, but that's always an expensive option. There are other solutions:

- Wireless (WLL - Wireless Local Loop).
- Use an existing analogue telephone network (PSTN).
- Use an existing cable television network (CATV).
- Use the power supply cables infrastructure (Power Line Communication).

WLL – Wireless Local Loop



The recent development of wireless network technology begins to make it a sustainable solution for connecting the operator to the subscriber.

The 802.11 standards are clearly inappropriate for this type of application. The 802.16 standards, also known as Wireless MAN and WiMAX (Worldwide Interoperability for Microwave Access) are more appropriate, allowing data rates up to 70 Mbps for distances of less than 2 km and reaching up to a hundred of kilometres for lower data rates (at 10 Km the maximum rate is about 10 Mbps).

Cellular networks (mobile networks) have the advantage of a widely installed coverage:

3G supports rates up to 16 Mbps.

4G and new 802.16 standards reach above 100 Mbps in mobile mode or 1 Gbps in fixed mode.

5G is planned to reach up to 100 Gbps.

DSL – Digital Subscriber Line/Loop

DSL techniques take advantage of existing analogue telephone lines. Each subscriber has its own PSTN (Public Switched Telephone Network) analogue telephone line connecting its home to the nearest local telephone exchange.

This connection contains a pair of copper wires, is capable of carrying **analogue electric signals** up to several MHz frequency. The subscriber may keep the use of the phone line for traditional analogue voice calls. Analogue voice calls equipment simply transform voice sound waves into an equivalent analogue electrical signal, and vice versa, thus resulting in signals ranging from 300 Hz to 3400 Hz. The use of signals above 4 KHz is therefore available for DSL.

Even though the available bandwidth is reasonable, the quality of such lines is very poor and the signal is subjected to severe distortions and noise at some frequencies. To handle this issue, DSL techniques divide the available spectrum into several independent **channels** with about 4 KHz bandwidth each.

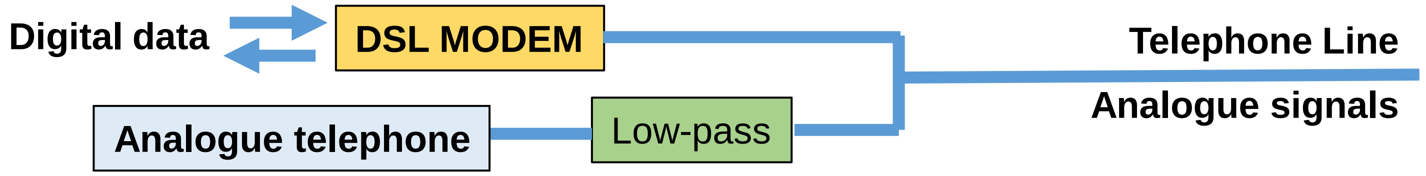
The subscriber's side

Don't let the name misled you, DSL uses analogue signals, not digital signals. Telephone lines don't support digital signals. On each end of the telephone line, there will be a modem performing digital modulation and demodulation.

Each channel is unidirectional (simplex), to support full-duplex transmissions, some channels are used to emit data from one side and others to emit data from the other side.

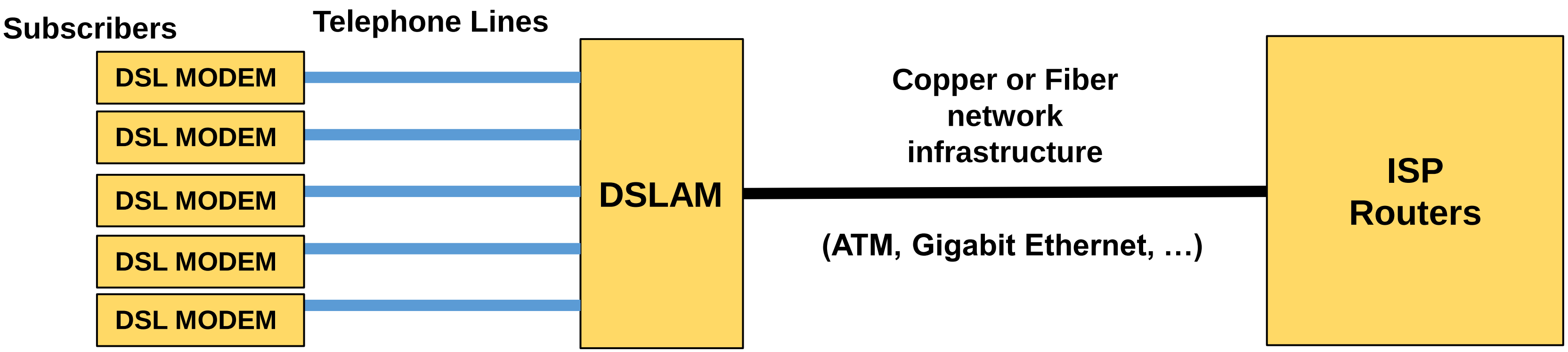
On both sides, DSL modems test each channel to check if operating conditions are acceptable. If not, the channel is disabled. The achievable transmission rate depends on how many channels are available. HDSL (High-data-rate DSL), now obsolete, allowed data rates of up to 2 Mbps.

Because the subscriber may still use analogue telephone equipment, a high frequencies filter (low-pass filter) is deployed to avoid DSL signals interference.



DSLAM - Digital Subscriber Line Access Multiplexer

On the operator side, a bunch of DSL modems is required, one for each subscriber. The DSLAM is a device that contains several DSL modems, it aggregates all corresponding digital data in a single multiplexed communication using an additional networking infrastructure, usually ATM or Ethernet.

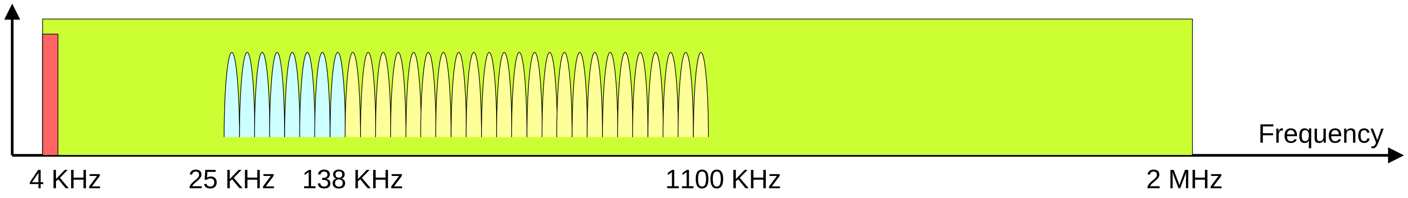


Each subscriber's traffic is sent separately over the network infrastructure by using different virtual channels (ATM) or different VLANs (Ethernet).

One major advantage of the DSLAM is that it can be placed in an enclosure near subscribers' homes. This reduces the telephone lines length between the two connected modems, and thus, allows a higher data rate than if the modem was placed at the telephone exchange.

ADSL – Asymmetric Digital Subscriber Line

ADSL is one of the most successful local loop access technologies. It's a DSL variant in which the number of channels dedicated to receiving data from the operator is far greater than the number of channels dedicated to sending data to the operator.



This asymmetry stems from the finding that the use by the most subscribers is in itself asymmetrical with a great predominance for download traffic. The original ADSL standard uses roughly the frequency ranges showed in the image above and allows maximum data rates of 8 Mbps / 1 Mbps.

ADSL2 standard achieves data rates of up to 12 Mbps / 3.5 Mbps. More recent, ADSL2+ standard uses the frequency spectrum up to 2.2 MHz and achieves data rates of up to 24 Mbps / 3.5 Mbps.

We must emphasize thought, that real data rates obtained in practice strongly depend on the lines quality and cables length/distance.

VDSL – Very-high-bit-rate Digital Subscriber Line

The purpose of VDSL (or VHDSL) is providing higher rates by using even more bandwidth and possibly placing further restrictions concerning the distance.

At 300 meters VDSL can reach a 26 Mbps rate in a symmetric configuration or 52/12 Mbps in asymmetrical mode. To accomplish this, it uses a bandwidth extending up to 12 MHz.

VDSL2 is capable of using even more bandwidth, up to 35 MHz. It provides aggregate data rates (sum of the two directions) up to 300 Mbps, this value can be divided symmetrically or asymmetrically.

As with other DSL technologies, VDSL performance deteriorates with distance, at 500 meters data rates are roughly half the maximum attained near the DSLAM.

To achieve a maximum download rate of up to 300 Mbps, VDSL2 uses up to a total of 8192 channels, each with approximately 4 KHz bandwidth up to 35 MHz, most of these channels become unavailable as the distance increases.

Data Over Cable Service Interface Specification (DOCSIS)

Traditional cable television networks (CATV) use coaxial cables to transport analogue radio frequency television signals to subscribers. For CATV networks to be used as access technique, they must be prepared for that purpose, originally they were designed for a simplex data flow.

The bandwidth available in a CATV network is huge, starts at 50 MHz and can go up to 1 GHz (950 MHz bandwidth).

This wide frequency spectrum is divided into channels with 6 MHz each (USA/NTSC) or 8 MHz each (Europe/PAL). Due to different channels widths up to DOCSIS version 3.1 all standards had a modified version called EuroDOCSIS using 8 MHz channels. Each analogue television channel (6 or 8 MHz) can be shared by several subscribers.

With more recent DOCSIS 3.1, the traditional channels division was abandoned, channels are only 20 to 50 kHz wide, nevertheless several contiguous channels can be used together making a channel of up to 200 MHz wide. Analogue radio frequency television signals are now supposed to be replaced by digital television, each channel uses an analogue signal to transport digital data (digital modulation).

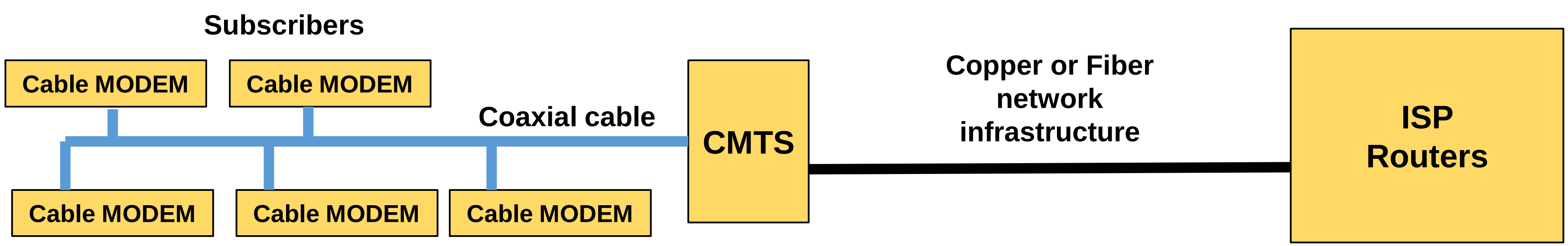
The cable MODEM and the CMTS

At the subscriber side, a cable modem is required to send and receive digital data, modulated into an analogue signal, corresponding to one channel. DOCSIS 3.0 and above allow a single modem to use several channels at the same time.

Analogue signals (carriers) for each channel are transported by a coaxial cable connected to the provider side where another modem is placed, this side is called the Cable Modem Termination System (CMTS).

The CMTS is rather similar to the DSLAM of DSL systems, for each subscriber, there will be a traffic flow between the subscriber cable modem and the CMTS modem, the CMTS will then aggregate all subscribers traffic in a single multiplexed network infrastructure, usually Ethernet with VLANs.

Each subscriber traffic is then delivered through the network infrastructure to a router that provides the DHCP service.



DOCSIS - shared channels

Unlike DSL, where each subscriber has its own dedicated physical telephone line, with CATV the transmission medium is shared between several subscribers. Each single channel may also be shared by several subscribers, therefore, encryption based privacy and channel access control mechanisms are required.

Access control to the channel is based on TDMA (Time Division Multiple Access) and CDMA-S (Synchronous Code Division Multiple Access).

Privacy is provided by BPI (Baseline Privacy Interface), improved in DOCSIS 3.1 and renamed as SEC (Security). One objective of BPI/SEC is avoiding subscribers to capture other subscribers' data but it's also used for restricting access to authorized subscribers only.

DOCSIS 3.1 also expands the used channels up to 1.7 GHz, theoretically, it could be used to achieve data rates of up to 10 Gbps, however, service providers impose limits to subscriber modems to avoid any abuse. We must remember this is a shared medium, if no limits were imposed one subscriber excessive traffic would disturb other subscribers.

Broadband over power lines (BPL)

Generically known as Power Line Communication (PLC). The idea here is taking advantage of the existing public electric power distribution system for data transmission and create subscribers' local loops. This is also known as Power Line Digital Subscriber Line (PDSL).

However, using power lines for local loop has revealed itself a failure, especially because there are simpler, cheaper and more efficient options. Most companies that started projects for providing this local loop technique have now switched to other techniques, reporting economic reasons.

The use of power lines to transmit data is, however, a reasonable option for some specific cases, for instance, X10 standards for home automation use this technique to exchange information between devices within a home.

Power-line communication is also being used by some electric suppliers to control devices at their infrastructure up to the electric meter on the user's home, providing among others, automated meter reading.

Internet Protocol and PPP

The purpose of the local loop in delivering layer two packets between two nodes, these nodes are the subscriber equipment attached to the modem (usually a router or an end-node) and the service provider router.

The local loop is as point-to-point layer two connection, IP packets are placed inside layer two packets with the help of PPP (Point-to-Point Protocol). PPP provides several desired mechanisms like initialization procedures, user authentication, and multiplexing.

When PPP is used over an ATM infrastructure it’s usually called PPPoA (PPP over ATM), whereas if running over an Ethernet infrastructure, it’s called PPPoE (PPP over Ethernet):

IP
PPPoE
ETHERNET
LOCAL LOOP

IP
PPPoA
AAL5
ATM (Cells)
LOCAL LOOP