

# HFC architecture evolution for high bit rates

J. C. Point  
Director European Technology, COM21  
jcpoint@com21.com

## 1 Introduction

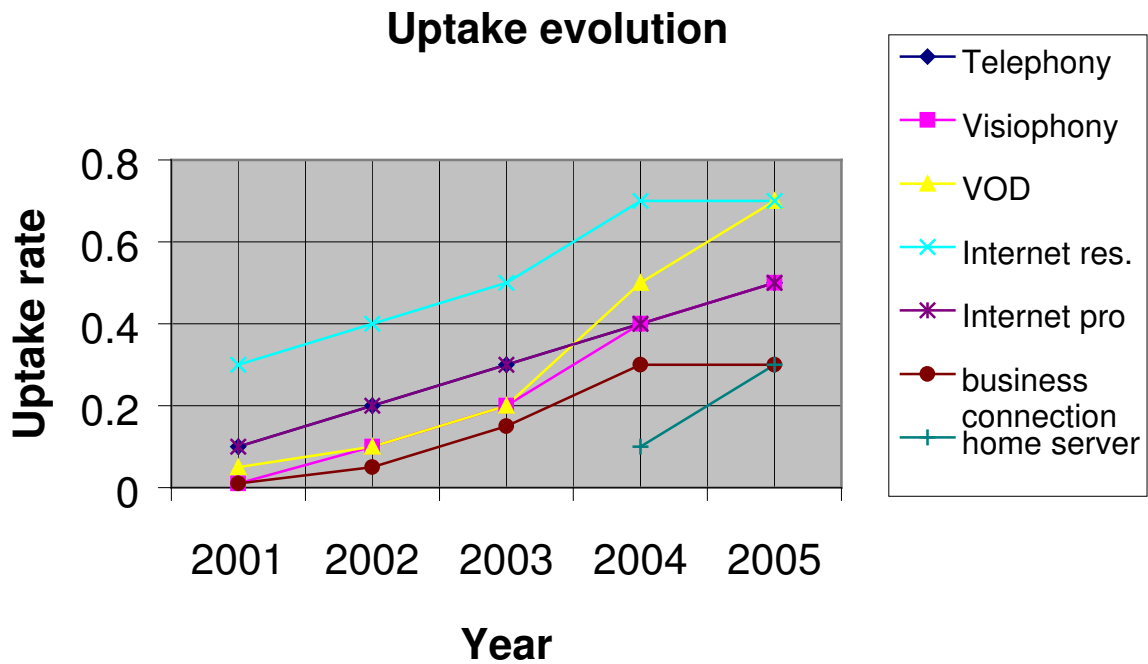
User and application demand for bandwidth are accelerating exponentially. Recent trends such as the popular utilization of streaming audio and streaming video plus the demand for personal servers (Napster, Gnutella) are driving the bandwidth requirements far higher than originally projected by email and web browsing usage. In addition the ability to generate high volume upstream traffic (personal servers) is becoming an important customer requirement. As a result increasing demand is being felt for utilizing digital fiber deeper to deliver a quantum step function improvement in offered bandwidth. The paper presents some examples of such evolutionary scenarios.

## 2 Traffic requirement

As is evidenced from media reports and customer feedback, the subscriber demand for traffic is already accelerating beyond expectations. While the details of the future subscriber traffic profiles are unavailable since the services are relatively undefined, the future bandwidth trend can be anticipated by taking into account the following trends:

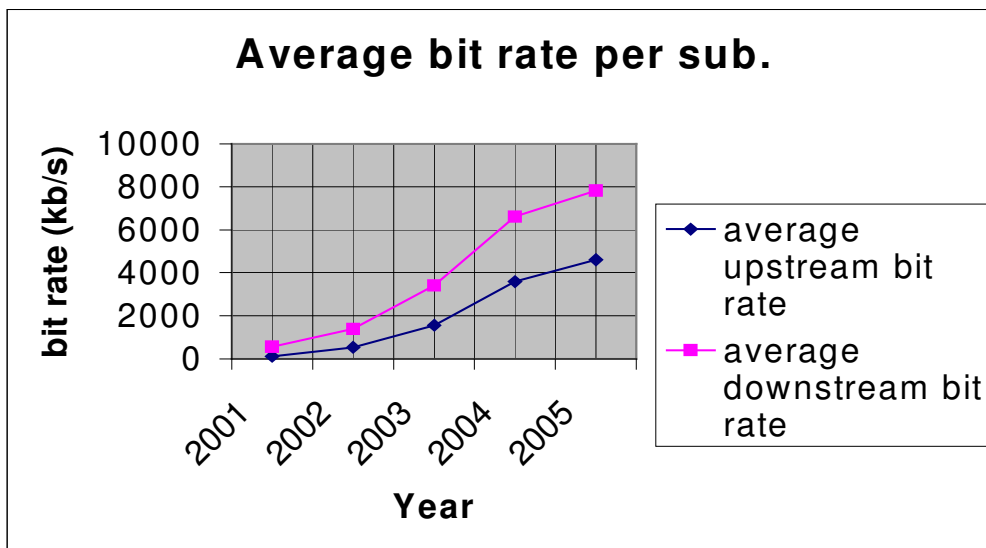
- Gaming applications such as Quake are now online. With the increasing graphics and computational sophistication of personal computers, new applications will drive the always-on bandwidth even higher.
- Some operators are offering VOD on a trial basis; the customer reaction is positive, and deployments are expected
- The cost of VOD server is becoming affordable and the cost of storage is expected to decrease exponentially
- From the customer experience with Internet (real time access), one can extrapolate this to VOD and expect to have real time access paradigm rather than push and local storage paradigm. Nevertheless local storage and local servers will increase both the downloading of video traffic and the uploading of locally stored video traffic;
- Teleworking is expected to expand rapidly
- According to storage cost decrease and availability of low bit rate video coders, the number of residential server is expected to expand rapidly; this will lead to an increase in upstream traffic demand
- Operators want to offer all the services on one media, including video/audio/data for residential and professional applications

According to these trends, we can build an aggressive traffic model on how the bit rate demand can increase according to the mentioned trends:



**Figure 1: example of service penetration scenario**

According to these scenarios, the demand for bit rate can be drawn as follows:



**Figure 2: traffic evolution**

Of course the hypothesis above are very optimistic, and the time scale and service profile/uptake can vary, but the hypothesis described above show that the average bit rate per subscriber is likely to evolve ultimately in the 10-50 Mb/s range for both downstream and upstream traffic. Also, the offered bit rate tends to drive the development of new applications, which applications will tend to drive the needed bit rate even higher (or increase the confidence in the demand for a given bit rate).

### 3 DVB-DAVIC model for interactive services

In order to support interactive services transmission on an HFC network, the DVB-RCCL (Return Channel on Cable and LMDS) group has produced a complete set of specifications, which have been ratified by ETSI and ITU as standards. 2 Standards cover respectively the network dependant layers for cable and LMDS: ES 200 800 and EN 301 199. A summarized description of ES 200 - 800 features follows. An equivalent Standard developed in the USA is DOCSIS, which offers similar capabilities and features.

#### 3.1 System Model

It is worthwhile to state the purpose of this standard using a simplified OSI model shown below, where the ETS 300-800 focuses on the network dependant layer; the network independent layers are described further in the paper, in the particular case of voice.

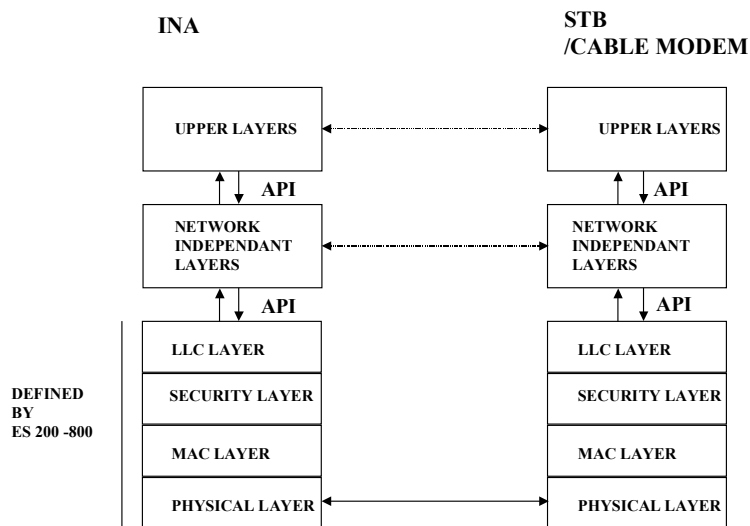


Figure 3 : layer architecture

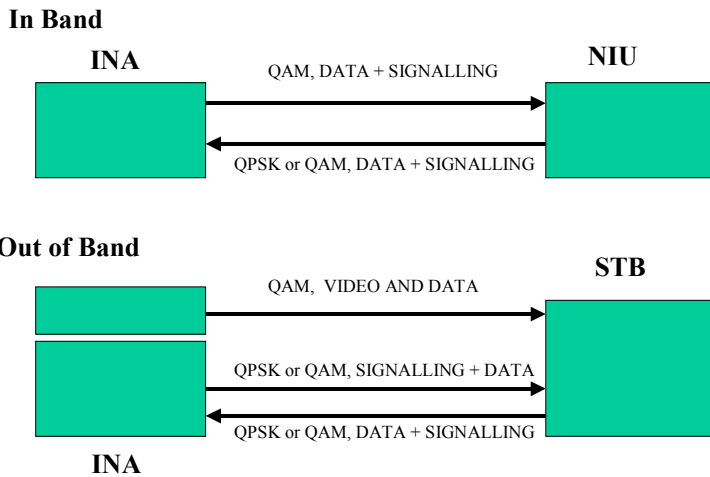
#### 3.2 Standard Overview

The interactive applications described above correspond to a broad range of requirements. It is not expected that every network will support all the applications, and it was considered necessary to describe several options as previously defined currently by the market. Therefore, an Out Of Band and an In Band option are described

**Out of Band** mode refers to a system where data and signaling information is transported in a separate downstream channel; in the first days of the standards this mainly applied to STB application where a downstream QAM channel carries broadcast video embedded with data associated to the program, while a separate downstream QPSK channel carried the signaling information (MAC) for the return channel.

**In Band** referred to Cable Modem application, where data and signaling information are sent on the same downstream channel, namely a QAM channel.

Nowadays there are many variants of these 2 basic modes, where interactive gateway, or interactive STB can contain multiple QAM demodulator to receive simultaneously different types of services like broadcast video and interactive high speed data.



**Figure 4 : basic systems**

The figures above represent the NIU and INA in both In Band and Out of Band options. The INA is located in the Headend (in a broad sense) and is the gateway between the HFC network and the WAN. The main features of the system are:

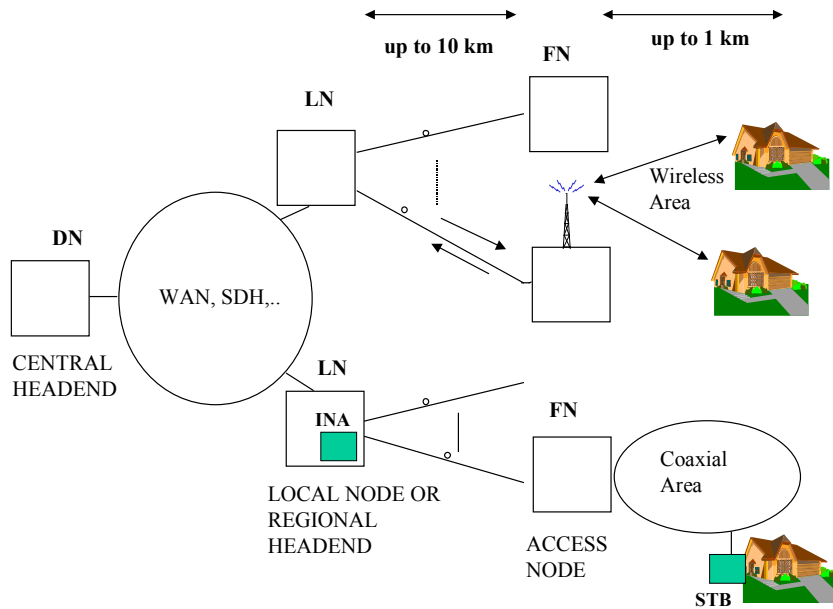
- In the case of Out of Band downstream, a simple QPSK modulation scheme is used in order to allow cost effective implementation in the STB; the physical segmentation is ATM cells embedded into a T1 frame structure, allowing evolution in the future to enhanced signaling ATM schemes.
- In the case of In band downstream, the normal DVB specification is used (QAM modulation in downstream); MAC messages are transmitted in TS packets, while data is transmitted using DSMCC Multiprotocol Encapsulation (DVB-MPE). In the case of LMDS, the DVB-S specification may be used (QPSK modulation).
- The access mode used in upstream is a combination of TDMA and FDMA; frequency agility is possible, allowing a customer device to change frequency in the case of Ingress or traffic overload; upstream bit rate as high as 12 Mb/s is possible
- The access modes supported by the MAC layer are contention, reservation and fixed bit rate simultaneously, allowing to support any type of QoS
- A layer 2 security is defined, in order to support subscriber privacy, and to protect the user against theft of service
- Payload header suppression is possible, allowing removing useless header on the packet transmitted in the cable network; this feature optimizes the traffic capacity especially in the case of Voice over IP traffic.

## 4 Architectures

There are two classes of architecture solutions for fiber – hybrid-fiber and fiber-to-the-building/home. Hybrid fiber delivers digital fiber to a point within the network infrastructure that is much nearer the end customer/subscriber than today's architectures (some times called fiber to the curb). Fiber to the building/home delivers the digital fiber directly to the building/home of the end customer/subscriber.

## 4.1 HFC/HFW (Hybrid Fiber Coaxial / Wireless)

In the hybrid fiber class of solutions a node within the infrastructure interconnects between the digital fiber segment (WAN to neighborhood) and an alternate technology for distribution to the building/home. Alternatives for the last segment include cable, and wireless. The following diagram shows a current typical network configuration, which can apply both to HFC and HFW architectures



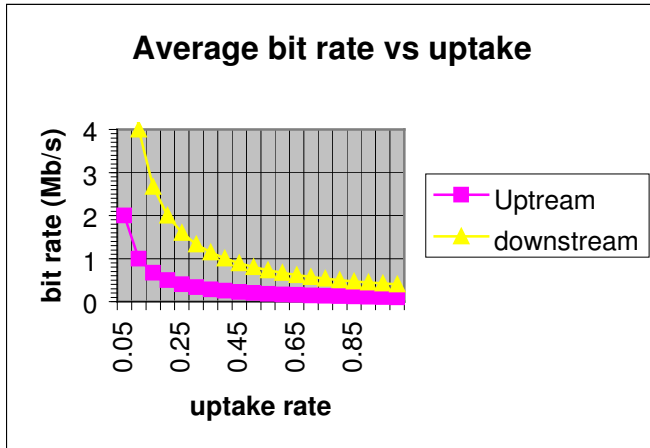
**Figure 5 : HFC / W architecture**

In these actual configurations, a central Headend feeds the broadcast video services through a WAN ring, star, or mesh infrastructure (e.g. SDH MPEG/ATM is some times used). Analog transport at 1.55  $\mu\text{m}$  can be used in dense areas where the central Headend is closed to the local headends.

Typically a local Headend feeds areas containing 50 to 200k homes passed; each fiber node feeds 500 to 2000 homes passed.

### 4.1.1 Initial traffic capacity

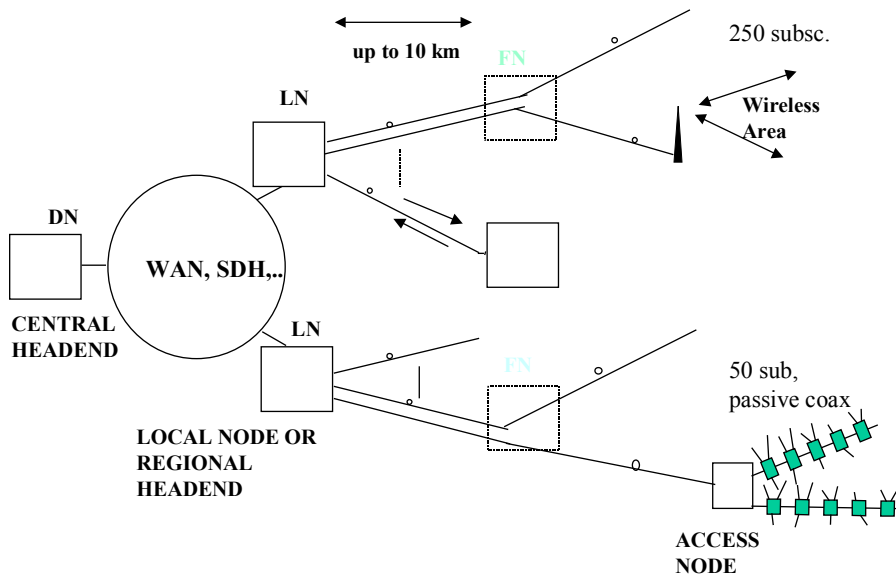
According to this architecture, we can draw the following traffic figures, assuming that the upstream spectrum is fully used:



**Figure 6 : bit rate per subscriber**

This shows the ultimate performances of such a network, meaning that at high uptake the bit rate per subscriber is limited to 100-200 kb/s, even if the full upstream spectrum is used. The same situation occurs in LMDS, where the available spectrum is larger, but lower efficiency modulation like QPSK is to be used.

An upgrade of these architectures can be realized as shown below:



**Figure 7: HFC/W upgrade**

The fiber node is simply pushed further into the distribution network and remains transparent to upstream downstream signals

- This improves some features for both cable and LMDS:
  - o Channel model: in the case of HFC, the ingress noise effect is obviously improved; this allows the use of higher order modulation schemes upstream. In the case of LMDS, the attenuation budget is improved, allowing also the use of QAM16 modulation.

- Furthermore the Ingress noise detection by a management system is facilitated:  
As the cell size is lower and the fiber part of the HFC network is a PON, it is straightforward to locate a source of ingress noise and take necessary actions
- In the case of HFC the availability is improved by the use of a passive coaxial distribution architecture, allowing central Customer terminal battery backup from the Fiber Node

## 4.1.2 Ultimate traffic capacity

The traffic charts are as follows:

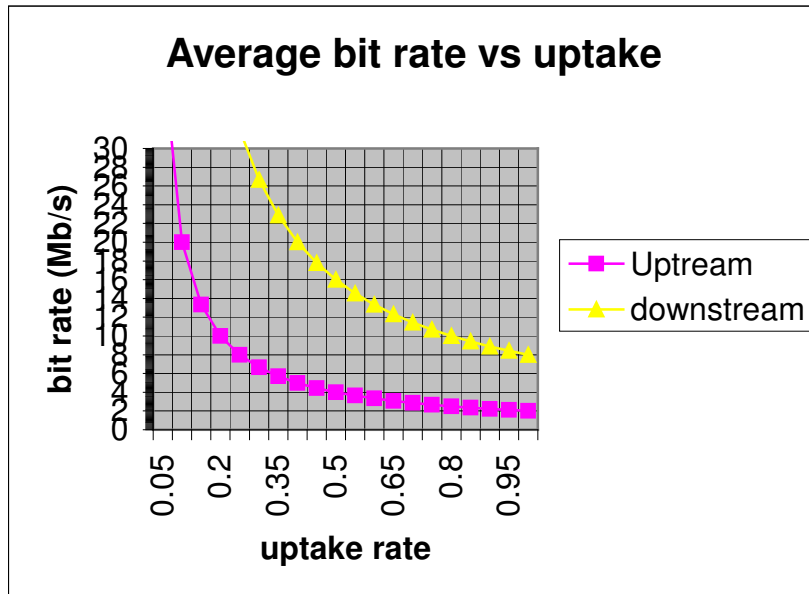


Figure 8: corresponding traffic capacity

The ultimate performance of HFC and HFW are therefore limited to 2 Mb/s upstream and 10 Mb/s downstream in the case of 80 % uptake; nevertheless this evolution presents the following drawbacks:

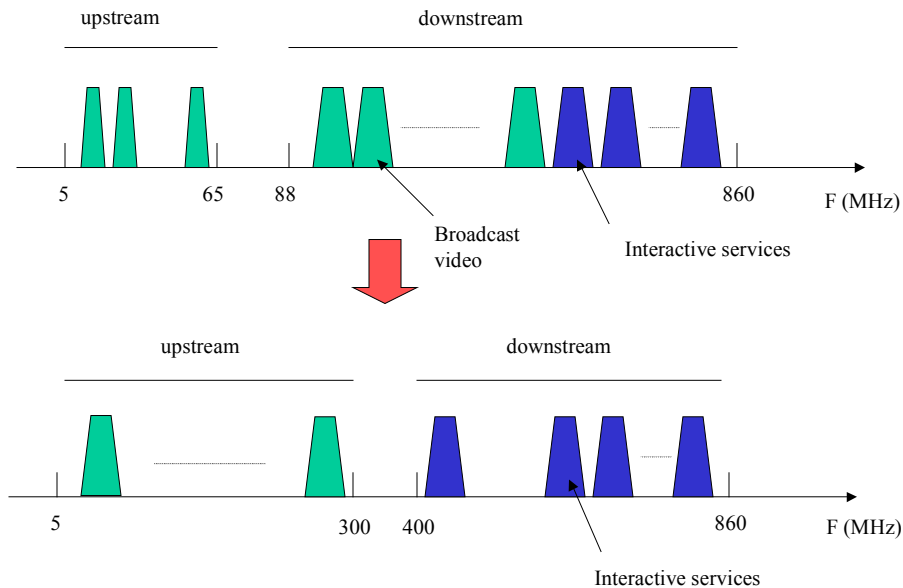
- For HFC, additional RF material is needed, therefore increasing the cost per subscriber
- For HFW, the Fiber Node transmits and receives at frequencies of 28/40 GHz; therefore block conversion from IF to RF is required in addition. The uncertainty is on the cost of 40 GHz RF converter/amplifier;

## 4.1.3 Multicast/unicast rather than broadcast model

The broadcast paradigm has been adopted according to the constraints of one way access network or weakly interactive networks like satellite, terrestrial and one way cable; Multicast has already been introduced (NVOD) in some sense, although the offer is relatively limited, and the content (NVOD server) is localized at the Central Headend usually.

The new architecture tends to evolve from this centralized multicast model to a distributed model where the content is localized anywhere in the backbone; moreover more generally a unicast paradigm can be established where the user finds the content and establishes a point-to-point connection to download it.

The impact on the spectrum allocation is shown below where the RF carriers (QAM modulated) become "data pipes" allocated dynamically to one or several subscribers.



**Figure 9 : use of RF carriers for carrying interactive / broadcast traffic**

## **4.2 FTTC/Mini Fiber Node architecture**

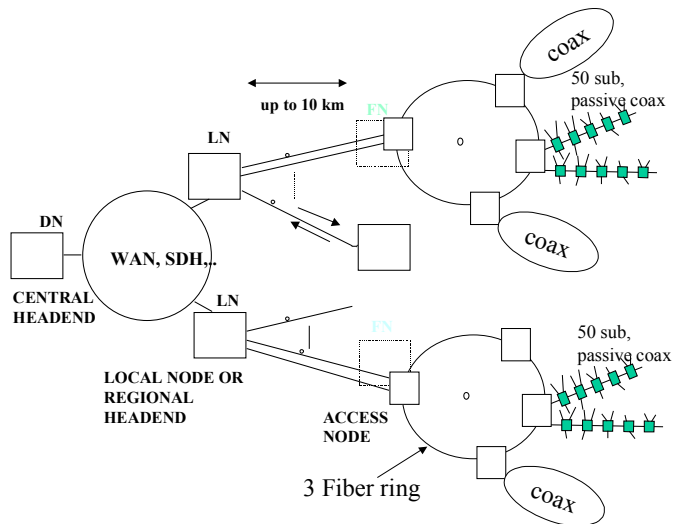
An advantage of classical HFC is to support legacy broadcast video, but the architecture suffers from some issues like:

- The optical transport network is analog in both directions, leading to relatively high cost, especially if the architecture evolves from a broadcast to a narrowcast model
- In the upstream, the cost of analog optical return links can become significant

In the FTTC, or Mini Fiber node architecture, the HFC can be now separated into 2 separate networks:

- The optical network which ensures **digital** bidirectional data communication between the Local Node, and the Mini Fiber Node
- The coaxial local network, which is now a DVB-RCCL network, using classical FDMA/TDMA access in the RF spectrum

The architecture of such a network is shown below; the INA is in that case placed in the Mini Fiber Node.



**Figure 10 : FTTC / Mini Fiber Node architecture**

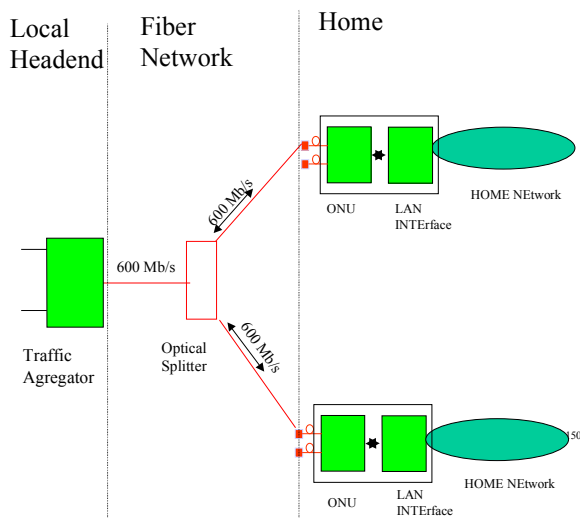
The main advantages of the architecture are the following:

- Easy installation and maintenance
- Cost
- Scalability

The main issue is that the HFC network loses its multistandard support capability for interactive services; therefore legacy devices cannot be supported.

### 4.3 Ultimate architecture: Fiber to the Home/building

If the request for very high bit rates is confirmed, FTTH can become a viable evolution for current operators, or initial architecture for new operators; the cost per subscriber is higher than HFC, but the cost per bandwidth is much lower. The classical PON architecture is shown below.



**Figure 11 : Classical Passive Optical Network (PON)**

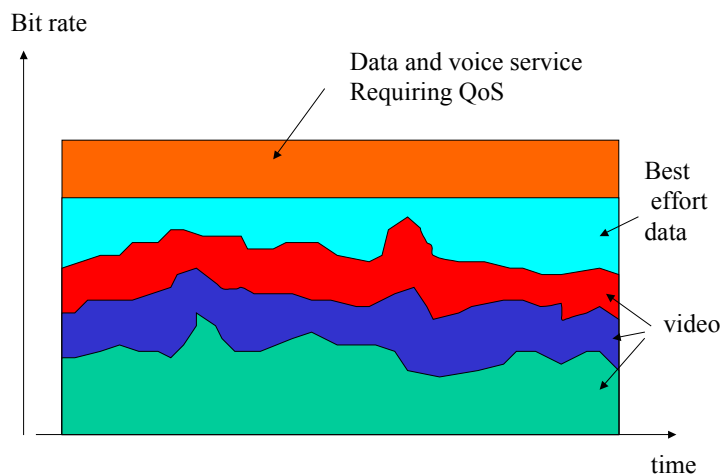
The basic advantages of FTTH are:

- Scalability to very high bit rates
- No powering in the network, meaning high reliability
- Can lead to simple QoS models

## 5 Quality of Service (QoS) requirements

### 5.1 HFC and FTTC architectures

Concerning the content encapsulation, DVB provides a complete solution allowing the integration of broadcast/multicast content, and integration of video with data and voice (in that case, video can be broadcast, multicast or unicast). The advantage of using the transport stream encapsulation defined by DVB is to respect easily the strict QoS requirements of MPEG2, while multiplexing video with data and voice on the same transport stream. Several more or less complex methods can be imagined to multiplex video with interactive services; a simple one is to reserve a virtual constant bit rate pipe to the interactive services requiring QoS, and multiplex best effort data with the video applications as shown below



**Figure 12 : example of bit rate allocation in a Transport Stream**

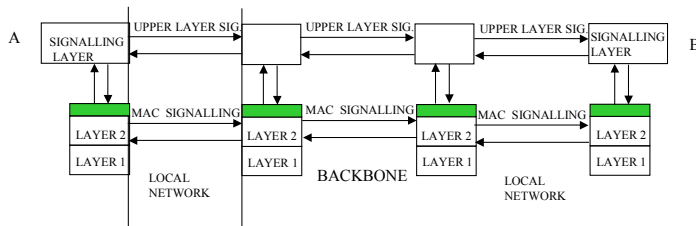
More complex strategies can be imagined if video is transmitted over IP with a relaxed buffer model; usually as shown above video is coded as far as possible with a constant quality in order to optimize the required bit rate. The drawback of the method is the difficulty to describe exactly the required QoS for video.

### 5.1.1 Connection Between Upper Layers and MAC / Physical Layer

According to the OSI model, when an application is initiated, the session / signaling layers have to open the corresponding session and provide the information about required bandwidth /QOS. In the access network, these session / signaling protocols are initiated between the subscriber CPE ( Customer Premise Equipment) and a higher

Layer entity in the network, which can be distinct from the INA.

In order to ensure the required QoS to the application, the INA, or more generally the layer 2 entity, will have to open the corresponding MAC connection, and will receive this request either by the layer entity higher during the session set up, or by the CPE via a MAC layer request.



**Figure 13 : link between upper and lower layers**

A general scheme is shown above where a communication between end points A and B has to occur ( A and B can be clients or servers); the communication flow has to cross several network; in order to respect the communication QoS requirements, the QoS parameters have to be transmitted to the MAC layer of each sub – network, assuming that the MAC layer has mechanism to support that QoS.

### 5.2 Example: Transporting voice communications

A particular case where informations have to be transmitted between the upper layers and the MAC layer is voice communications; some particular constraints exist according to this service like:

- Billing constraints: the subscriber wants to be billed only if the communication establishment is successful
- Traffic optimization constraints: the necessary resources for the communications have to be reserved only when the communication is successful
- Securisation constraints: subscriber privacy has to be ensured; moreover from the operator view point theft of service and cloning must be prevented

Packet cable, which is a project set up by Cable Labs has reviewed these problems and defined a Voice Over IP architecture adapted to the cable medium, which can be further applied to any point to multipoint physical medium. The Packet cable project has defined such upper layer architecture over the DOCSIS

standard. Packet Cable is now working in collaboration with DVB in order to define the interface of Packet cable protocol to the DVB RCC MAC layer; the following gives the main outcome of such a work.

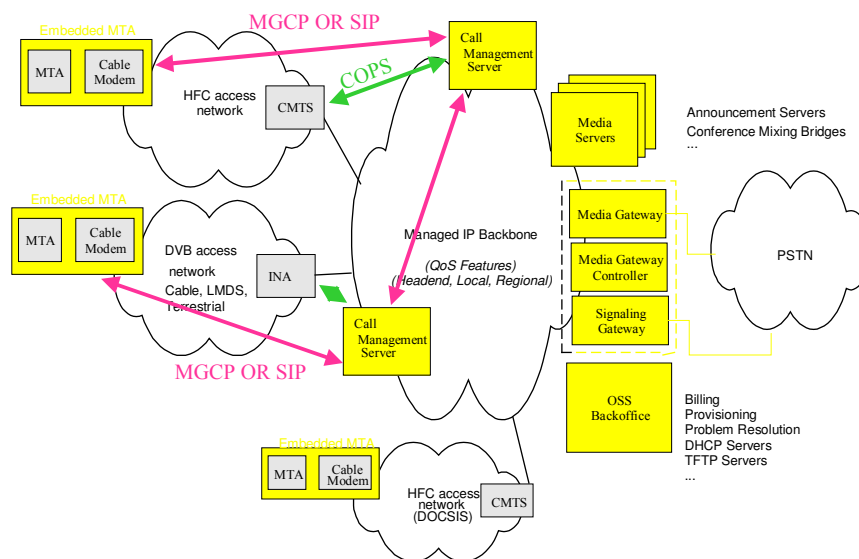
## 5.2.1 Signaling protocols

2 paradigms have been defined, based respectively on MGCP (Network control signaling) and SIP (Distributed Control signaling); an adaptation of these protocols has been produced in order to match the requirement of a shared medium like cable; the main one is a 2 states approach for the set up of a communication:

- The first state is called a reserved state; where the resources are reserved in the network but not allocated; this state is awaiting for a successful call set-up
- In the case of this successful call establishment, a second state (commit) is defined where the resources are really allocated for the communication

This allows resources allocation to be optimized in the access network; moreover the billing process is synchronized with the communication set up.

The figure below shows the general architecture of such a system, concentrating to the access network protocols (the protocols between the Call Management server and the other networks are not shown):



**Figure 14 : general Packet Cable architecture**

The call management server is the signaling entity for MGCP (call agent function) or SIP; moreover it uses the COPS (Common Open Policy service) to signal to the INA the QoS envelope for a given communication; it means that in COPS terms the Call Management server is a PDP (Policy Decision point), and the INA is a PEP (Policy Enforcement Point).

The Customer Premise equipment is subdivided into 2 entities: the Cable Modem, which supports the layer 1 and 2 protocols, and the MTA (Multimedia terminal Adapter) which support the upper layer protocols; the MTA can be embedded with the Cable Modem, or a physically separate box in the home network; in the latter case RSVP is used to request bandwidth in the network.

As stated above, an important feature of such architecture is to communicate the QoS required by an application between the end to end signaling protocols and the MAC layer of each network carrying the corresponding communication. In the case of MGCP and SIP this QoS is described by means of SDP (Session Description Protocol). This QoS description is therefore translated into a MAC QoS requirement for the corresponding MAC connection. This very generic way allows an easy extension of this architecture to any application requiring QoS like video streaming or video conferencing for example.

### **5.3 QoS support with high bit rate architectures**

The above paradigm assumes that the MAC layer will associate the QoS on a per connection basis, i.e. that each time a session requiring a given QoS is set up, the Mac layer will reserve the corresponding resources; this can lead to rather complex traffic management schemes.

In the case where the subscriber is overprovisionned with bit rate (i.e. for example bit rates of 50-100 Mb/s are accessible in the access network), QoS support can be simplified. Several Classes of Services can be defined according to general QoS requirements, and the traffic can just be prioritized at each network node according to the chosen classes; classes of services identification can be made using a simple tagging method like TOS/DSCP field in the IP header of each packet or an equivalent method (this method of classifying the packet on a per type of service rather than on a per flow basis is already used in the backbone).

## **6 Conclusions**

- Current HFC architecture are well suited for the provision of interactive services to the subscriber; the DVB system is well adapted to the integration of these services with digital video.
- A reduction of the coaxial area size can allow to provide moderate bit rates, together with broadcast video services on dedicated carriers. New operators deploying HFC could also evolve to a switched video (VOD) architecture; in this last case the DVB has to be evaluated versus a whole IP architecture in the access network
- For high bit rate delivery, new operators can be attracted by a deep fiber / fiber to the home architecture. The bandwidth cost, easy maintenance, simple QoS model and scalability / reliability of the architecture can be definitive advantages.