HFC networks evolutions for service convergence

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1 Introduction

The cable industry has been undergoing rapid changes these recent years with the introduction of digital TV and the massive deployment of interactive services in the CATV networks. The latter has required major efforts both to upgrade the plants for two ways and master the impairments problem, and to standardize the protocol layers for data and telephony services.

The standardization work has been successfully achieved under the leadership of CableLabs, with the successful launch of DOCSIS 1.0 and 1.1 products, and the finalization of the DOCSIS 2.0 [1] specification. Definition of an interoperable Voice over IP architecture covering signaling, provisioning, security has been achieved [2], allowing MSO to deploy data and voice access systems on an economical way.

The paper addresses the following next crucial issues for HFC, which are the different architectural alternatives for supporting broadband access, and the new requirements introduced by a common IP architecture for video, voice and data services.

2 Alternatives For Architecture Evolution

There are two classes of architecture solutions for fiber – Hybrid-Fiber and Fiber-To-The-Building/Home. Hybrid-Fiber delivers fiber to a point within the network that can be much nearer the end customer/subscriber than today's architectures. The ultimate architecture, Fiber To The Building/Home, delivers the digital fiber directly to the building/home of the end customer/subscriber, the building being connected via a LAN rather then an access network.

2.1 HFC/HFW (Hybrid Fiber Coaxial / Wireless)

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

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In *Proceedings of the 1st International Workshop on Shaping the Broadband Society*, pages 21-30
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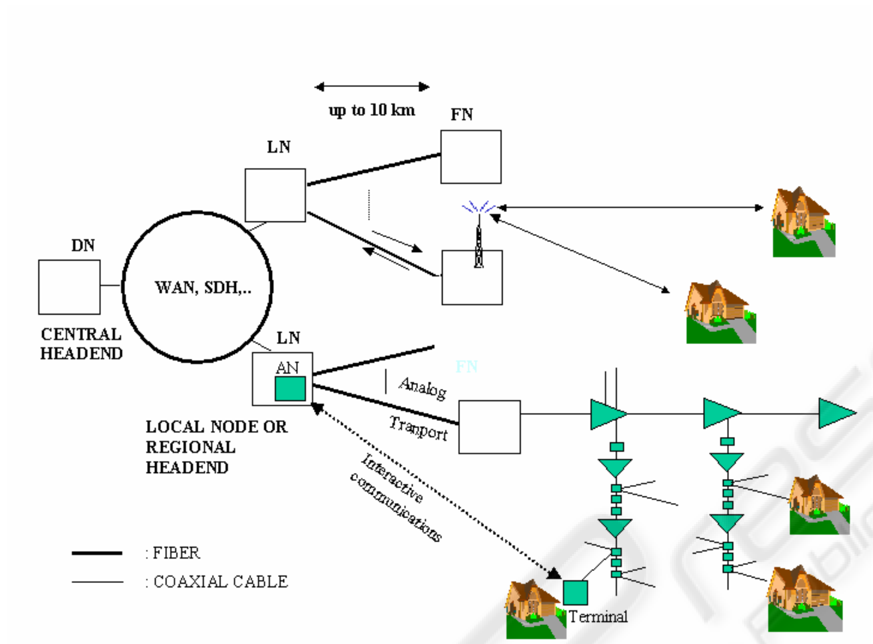

Fig. 1. HFC / W architecture

In these actual configurations, a central Headend (DN) feeds the broadcast video services through a WAN ring, or star infrastructure. Analog transport at 1.55 µm can be used in dense areas where the central Headend is closed to the local Headends (LN or Local Node). Typically a local Headend connects areas containing 50000 to 200000 homes passed; each Fiber Node feeds 500 to 2000 homes passed.

The Access Node (AN, also called CMTS) supports the HFC network downstream and upstream traffic management, and interface to the Backbone.

The network capacity can be increased in 2 different ways:

- By segmenting the cell size, and therefore increasing the traffic capacity per subscriber
- By improving the bandwidth usage upstream and downstream for a cell; this can be done:
  - By using more efficient physical and MAC layers upstream and downstream while keeping the cell identical
  - While decreasing the cell size, the physical impairment situation within a cell will improve, and allow to use better physical layer parameters

2.2 Traffic Capacity

Downstream and upstream spectrum are usually 88-860 MHz and 5-50 or 5-65 MHz respectively; the RF channel width is 6-8 MHz downstream, and up to 6MHz upstream. The current DOCSIS standard (EuroDOCSIS for Europe) brings in practice a typical channel average capacity of 6 bits/Hz downstream and 3 bits/Hz upstream.

This highlights the limitations of current HFC networks, as at high penetration rates 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 high frequency LMDS, where the available spectrum is larger, but lower efficiency modulation like QPSK are used.

A segmentation of the coaxial cells into smaller cells, while keeping an analog fibre transport architecture allows to increase the capacity simply.

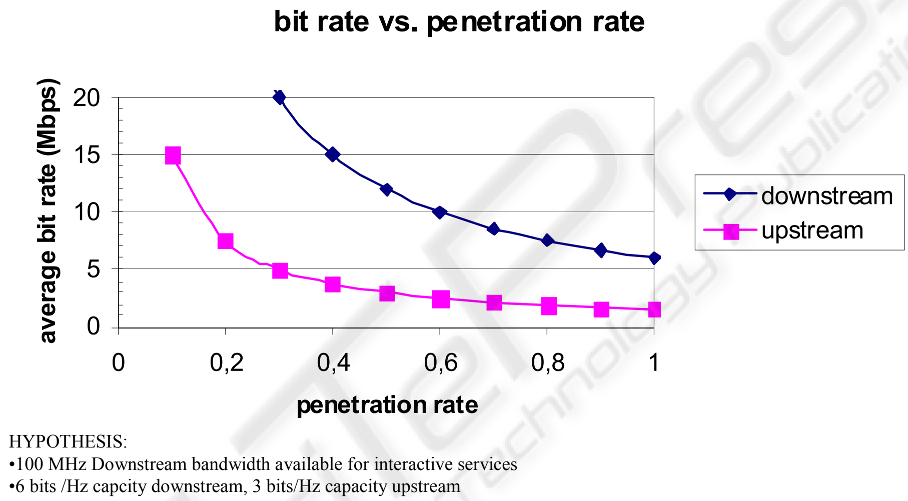

Fig. 2. Traffic capacity with 100 passing per coaxial cell

Figure 2 shows that downstream capacity can easily be extended when digital switchover occurs, whereas upstream capacity is limited; however transporting interactive services downstream requires the additional expensive installation of analog narrowcast downstream optical links for each cell.

2.3 Return Channel Digitization

In order to overcome the cost and performance issues introduced by analog optical components, the whole return band can be digitized like in the diagram shown in figure 3; the 2 main issues associated with this solution are:

- The sub-optimal use of the bandwidth: as high order constellation (up to 256 QAM) and mixed TDMA and SCDMA techniques are used in upstream, 12 bit digitization is required, requiring 2 Gb/s links for each upstream.

- The use of DWDM can be necessary to optimize the fiber utilisation, making this technology expensive.

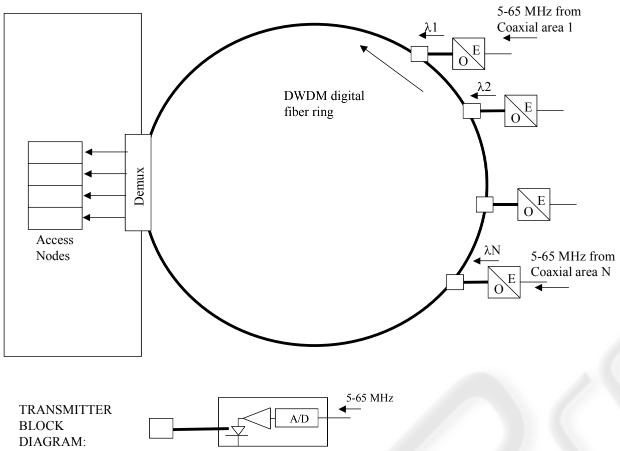

Fig. 3. Return channel architecture

2.4 FTTC/Mini Fiber Node Architecture

Classical analog HFC has the advantage 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, even if return channel digitization is made, as described above.

In the FTTC, also called Mini Fiber node architecture, the HFC network can now be separated into 2 separate networks , both at the physical and protocol levels:

- The optical network which ensures digital bidirectional data communication between the Local Node, and the Mini Fiber Node;
- The coaxial local network, using classical DOCSIS FDMA/TDMA-SCDMA access in the RF spectrum.

However classical FTTC architectures do not scale well for HFC, as they do not support legacy broadcast video; a more scalable alternative is the hybrid architecture shown below, which preserves the legacy analogue architecture, and introduces progressively broadband “islands” in the network.

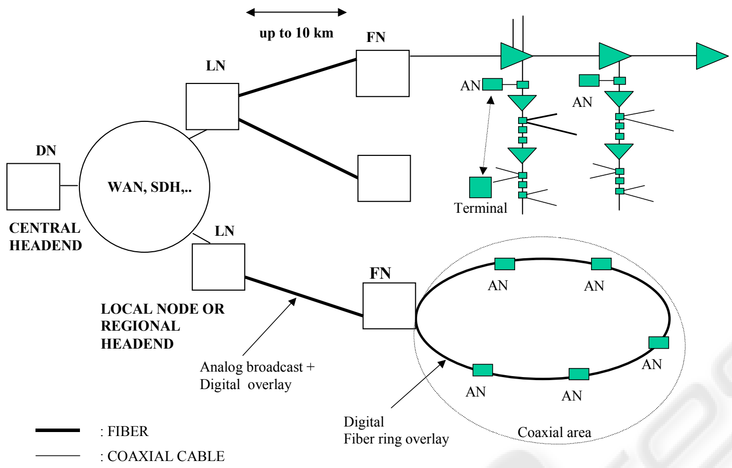

Fig. 4. Hybrid architecture with digital overlay for interactive services

Both "mini-fiber node" architectures introduce important technological and cost challenges, the main one being to integrate the Access Node very close to the subscriber. As the Access Node serves a low number of subscribers (50 to 200), the product cost is critical and requires the integration of all the Access Node functions in a "System on chip" architecture. Recent studies and realizations show that this SOC is achievable by using the next available (10 µm and below) technologies and multi-CPU integration.

Let us note that (Euro)DOCSIS standard was designed for large cable areas, and it is appropriate in this new situation where the AN serves "micro-cells" to evolve current standards; new projects are now investigating both backward compatible solutions, and new solutions (different use of the cable bands, new physical layers, baseband Ethernet,..).

2.5 Physical Layer Improvements

Regardless the solution selected, there will always be a requirement to optimize the HFC network capacity;

EuroDOCSIS 2.0 upstream physical and MAC layer schemes provide an efficient framework for keeping a good upstream and downstream capacity. The standard main features can be mentioned:

- Burst by burst adaptation, with flexible TDMA or SCDMA schemes on the same upstream carrier;

- Reed Solomon FEC or interleaved schemes to improve resistance to long impulse;
- BSPK to QAM64 constellation;
- Per session header suppression mechanisms to optimize the capacity;
- The shared total capacity per RF channel is around 30 Mbps and 60 Mbps in upstream and downstream respectively.

Research in physical layer aspects can be performed in the following areas to improve the overall plant capacity:

- Impairment on cable networks can be frequency selective, [3], [4], [5], and single carrier technique may not be the optimal solution if large spectral width have to be used: frequency multicarrier techniques like OFDMA variants, or wavelet may be the right solution to mitigate more efficiently the cable impairment in that case.
- More efficient FEC techniques (like block turbo codes for example) may be analyzed.
- Dynamic frequency hopping schemes can be adopted to cope with the varying impairment environment.
- Impact of clipping introduced by optical transport systems: current hybrid single carrier TDMA/SCDMA schemes can be sub-optimal on that aspect, and each new solution has to be benchmarked against this parameter.

2.6 Multicast/unicast rather then broadcast model

The paradigm for video services tends to evolve from a centralized to a distributed model where the video content providers (Broadcast and VOD) are localized anywhere in the backbone; moreover the content (or part of the content) can be pushed to local servers closer to the subscriber premises, or at the subscriber home.

When very small cells are served (50-200 subscribers), much downstream bandwidth can be saved by adopting a “Broadcast on demand” model rather then pure broadcast paradigm, as when referring to subscribers viewing statistics [6], a small number of video programs will be viewed simultaneously within a cell.

These observations can be extrapolated to VOD, or more generally COD (content on demand): if the user terminal includes local hard disk storage, a significant part of the downstream capacity can be saved by multicasting content in advance into the subscriber hard-disk.

3 IP architecture

3.1 QoS aspects

The current HFC networks QoS architecture is based on an Intserv paradigm, supporting a per-flow QoS. The EuroDOCSIS MAC layer uses a reservation scheme where the subscriber terminal can request transmission opportunities to the Access

Node, and therefore can supports CBR and VBR type of services; moreover a MAC service flow can be associated to a particular session of group of sessions. Initial resources reservation for a session can be made either directly via RSVP (more particularly a variant of RSVP optimized for cable access networks), or indirectly via signaling (like SIP or RTSP) where the session description can be translated into MAC QoS parameters.

Current Packet Cable VOIP architectures are built on a centralized model based on a variant of MGCP signaling adapted for cable ;

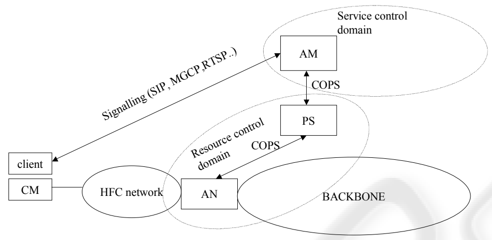

Fig. 5. Packet Cable Multimedia policy architecture

More generally for multimedia services, the ongoing Packet cable Multimedia project (see figure 5) is defining a policy architecture, which recognizes that a variety of signaling protocols will be used (MGCP, SIP, proprietary), and allows to differentiate clearly between network provider and applications provider.

2 distinct domains are defined:

- The Resource Control Domain (RCD) which is defined as a logical grouping of elements that provide connectivity and network resource level policy management in the access cable network domain. The Resource Control Domain includes the AN and the Policy Server (PS).
- The Service Control Domain (SCD), which is defined as a logical grouping of elements that offer applications and content to service subscribers. The Application Manager resides in the SCD. Note that there may be one or more SCDs related to a single RCD. Conversely, each RCD may interact with one or more SCDs.

Fundamentally, the roles of the various PacketCable Multimedia components are the following:

- The Application manager is responsible for application or session-level state, and applying SCD policy.
- The Policy Server is responsible for applying RCD policy and for managing relationships between Application Managers and AN (therefore the PS acts as a PEP for SCD and a PDP for RCD).

The AN is responsible for performing admission control and managing network resources through DOCSIS Service Flows.

3.2 Example of architectures addressing convergence

The introduction of high bit rate real time video services, using different family of coding techniques (block transform like MPEG2 or H264, or wavelet) introduces new constraints:

- Video QoS has to be described so that both admission control and SLA work on an optimal way within the network; this is a crucial issue since a video service can represent a significant part of the upstream or downstream channel capacity;
- Appropriate mechanisms have to be set up in downstream and upstream to respect the service quality requirements;
- The particular security constraints of video services have to be included in a overall framework.

The following 2 examples highlight a simplified possible scheme that can be applied for streaming video services, in complement to voice and multimedia services:

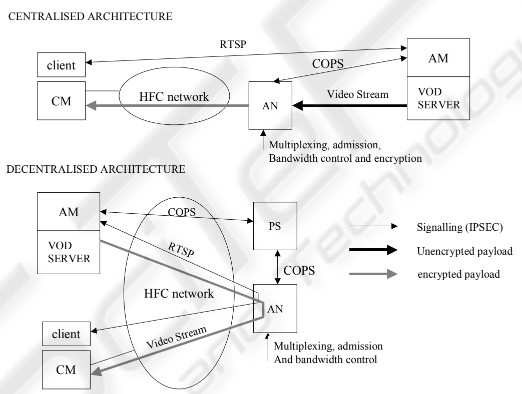

Fig. 6. Different architectures for streaming services

- The client can request and control a video stream using the RTSP protocol (including announcement, session set-up, and stream control)
- The Application Managers checks their respective service and resource policy, and communicate with the Access Node to reserve the necessary bandwidth resources; the Access Node performs admission control for upstream and downstream bandwidth, bandwidth control, and eventually stream encryption.
- In a decentralized architecture, the Application Manager would support the security features of the application, like devices and client authentication, and content encryption; a solid security framework exists for cable, as BPI+ allows to

authenticate the user terminal, and provides traffic encryption of unicast and multicast communications:
  - IPSEC can be used to secure signaling between the different entities;
  - Client provisioning and authentication methods are already defined for Voice over IP, and can be extended to multimedia applications in general.
- In the case of a centralized architecture, the operator can extend the current Conditional Access paradigms to the cable IP environment (bidirectional media, distributed storage).

4 Conclusion

The Hybrid Fiber Coaxial technology has some inherent advantage over competitive architectures (XDSL, FTTH), like its scalability and capability to support simultaneously broadcast, multicast and unicast services. Both the centralized and decentralized architecture solutions are possible to support future very high bit rate access; a priori the decentralized digital FTTC solution is the most scalable, but the mentioned technological challenges have to be solved to make the solution affordable. Multicarrier techniques associated with capacity approaching error codes appear to be an attractive candidate solution to optimize the plant capacity, and should be investigated for the next generation of layer 1 and layer 2 standards.

Significant work is still needed to define a unique architecture for voice, data and video; however the examples detailed in the paper show that the Packet cable multimedia architecture is suitable to build a complete system; moreover many elements coming from the Packet cable architecture can be leveraged to define this common infrastructure.

References

1. Data-over-cable service interface specifications, available at: http://www.cablemodem.com.
2. PacketCable 1.0 Architecture Framework Technical Report, available: http://www.PacketCable.com.
3. Point J. C. « *Very high bit rate access on HFC: Requirements and alternatives*", proceedings of Western Cable Show conferences, dec. 2002.
4. J. Vandenbruaene, E. Claus, L. Martens, B. Merchie, J. Haspeslagh, P. Gabriel "*Ingress and impulse noise measurements on hybrid fiber-coax (HFC) networks*", Communications Cables and Related Technologies, 1998, pp. 425-431
5. Moeyaert V. et al. (1999*), Physical layer characterization of hybrid fibre coax (HFC) networks*, Annals of telecommunications, vol. 54, n° 5-6, May-June 1999
6. IST EMBRACE project deliverables, available at : http://www.telenor.no/embrace

Abbreviations

AM	Application Manager
AN	Access Node
CA	Conditional Access
COPS	Common Open Policy Services
DWDM	Dense Wavelength Division Multiplexing
LMDS	Local Multipoint Distribution System
MAC	Media Access Control
PDP	Policy Decision Point
PEP	Policy Enforcement Point
RCD	Resource Control Domain
RTSP	Real Time Streaming Protocol
SCD	Service Control Domain
SCDMA	Synchronous Code Division Multiple Access
SIP	Session Initiation Protocol
SLA	Service Level Agreement
TDMA	Time Division Multiple Access
CM	Cable Modem
OFDMA	Orthogonal Frequency Division Multiple Access