# Ethernet to the Home

A revolutionary technology

for high speed data access over cable

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This analysis has led to the definition of a new access system for high speed data over cable, called 'Ethernet to the Home' (EttH).

# Ethernet to the Home (EttH)

A revolutionary technology for high speed data access over cable

TELESTE is an international technology group founded in 1954, which is specialized in broadband data communication systems and solutions. The group is divided into two Strategic Business Units: Broadband Cable Networks and Video Networks. Both Business Units are among the leading providers in their market areas and are globally recognised for their know-how and ability to produce technically cutting edge solutions year after year. More information can be found at www.teleste.com

## INTRODUCTION

As the leading suppliers of Broadband Cable Networks in Europe, Teleste has been working with a number of strategic customers to analyse key business issues and propose technology-based solutions for the future of cable. The main common drivers of the analysis exercise were:

- To provide increasing levels of IP bandwidth to subscriber homes and overcome the bandwidth and cost restrictions of Docsis/Euro Docsis based solutions

- Minimise capital spend on physical network resegmentation

- Strongly reduce the operational cost of providing services to residential subscribers and business customers

- Create a differentiated offering to increase competitive strength against competing access systems

This analysis has led to the definition of a new access system for high speed data over cable, called 'Ethernet to the Home' (EttH). EttH is the technology that will allow Multiple Service Operators (MSO's) to compete in both the residential and business segments, which are becoming more and more competitive through the emerging of VDSL and deep fibre applications (e.g. FTTH). EttH provides significant technical, operational and commercial advantages compared to currently deployed cable data access solutions.

## A REVOLUTIONARY TECHNOLOGY

Ethernet to the Home (EttH) is a revolutionary technology that provides next generation speeds for data access over cable networks. It is based on the combination of 2 distinct technologies, which have defined as Virtual Fibre and Remote Subscriber Access.

Virtual Fibre (VF) is a system that allows the transportation of Ethernet data at very high speeds (up to 100 Mbit/s) to strategic locations in the coaxial cable plant. As such, Virtual Fibre creates small points of presence (referred to as Mini-POPs) and allows extending the data-headend interface to deep in the network and closer to the customer, without the need of new fibre trenches.

The Remote Subscriber Access (RSA) refers to any type of data-access system that allows distributing the high-speed data from the MiniPOP to the surround-ing residences and businesses. Operators can select from a range of different RSA's, depending on the structure of the network. The first RSA that has been selected for EttH is Ethernet over Coax (EoC), a technology that allows the transport of base-band 10baseT Ethernet together with standard TV signals over coaxial cable. Teleste and Tratec Telecom have entered a strategic relationship for the development of the EoC remote subscriber access.

Through the combination of Virtual Fibre and the EoC Remote Subscriber Access, EttH is a system that allows to deliver 10base-T speeds to every home, without the need of a modem or active device in the house. The subscriber can simply plug his PC in the wall outlet, and get an unequalled Internet experience.

## ETTH SYSTEM ARCHITECTURE

The ETTH system is a true end-to-end Ethernet network. The EttH infrastructure is shown schematically in the figure 1. On the left side the Central IP router acts as the gateway between the ETTH network and the ISP, the provisioning system etc.

On the right side, baseband Ethernet is provided to the end-user using the point-to-point coax cable from the multitap to the wall-outlet. The within the multitap integrated Ethernet switch has a connection to the Ethernet switch port at the node, using QAM modulation techniques. The switch at the node has a Gigabit Ethernet connection with the IP routers, Service Selection Gateway and other data equipment at the Headend.

The main components as shown in the overview figure will be shortly discussed within the next paragraphs

## ETTH SYSTEM COMPONENTS

### EWO or Ethernet WallOutlet

The EWO is a new type of wall outlet for cable television networks. Next to the standard CATV connector you find on traditional wall outlets, the EWO has a RJ45 10BaseT Ethernet port. The EWO is a fully passive device that converts the baseband Ethernet signal from coax to twisted pair cable.

### EMT or Ethernet Multitap

The EMT combines the Ethernet and CATV signals for transport over coaxial cables. This Ethernet multitap is a combination of a normal RF multitap with an Ethernet switch. It enables transparent layer 2 Ethernet connection over coaxial cable by combining an 1-to-12 RF splitter with a 2+12 port Ethernet switch and RF circuits for combining these two signals. The EMT is designed to operate together with the EttH Ethernet POP Modem (EPM), but it can also be used separately where Ethernet connection and external power is available.

### EPM or Ethernet POP Modem

The EPM enables transparent layer 2 Ethernet connection over HFC networks. It communicates with the EttH Ethernet Node Modem (ENM) via an in-band RF channel and provides a local 100BaseT interface. With RF feed-through and remote AC power supply, the EttH EPM is designed to feed the Ethernet Multitap (EMT) or any other remote subscriber access system with Ethernet data.

### ENM or Ethernet Node Modem

The ENM is a modem that transports Ethernet frames over a HFC network by modulating them on QAM channels. It forms a distributed Ethernet switch to multiple Ethernet POP Modems (EPM), and can provide a total capacity of 400 MBps. It is based on standard Gigabit Ethernet switching fabric combined with innovative QAM modulator and upconverter design, making its cost vs. throughput ratio very attractive, when compared to traditional Data over Coax systems.

## DESIGN CONSIDERATIONS AND CHALLENGES OF ETTH

### Virtual Fibre: increasing the throughput, safeguarding transparency

When considering Virtual Fibre, three main requirements dominated the design principles:

**Throughput speed:** In order to provision the trunking speeds needed to supply 10 MBps in both and upstream to a high subscriber penetration, the virtual fibre needs to be capable of delivering very high speeds.

To offer 10baseT to every home of a 50 home miniPOP, with subscriber penetrations of 50% and a contention ratio of 10%, the virtual fibre needs to be capable of providing 25 MBps (10 MBps x 50 homes x 50% x 10%). For a 1000 home optical node, one would require 20 of these miniPOP's, or a total of 500 MBps.

This is why we chose the ENM throughput capacity to be in this range. In order to also optimise the efficient use of frequencies in the coax plant, the ENM has four separate outputs (e.g. one per each node output), each capable of handling up to 100 MBps, to be distributed to a number of EPM's.

The EPM's can handle each one up to 50 MBps, which should be sufficient to feed miniPOP's of 100+ subscribers (still using the above speed , penetration and contention assumptions).

The scalability of the Virtual fibre can be set in 1 MBps steps, so that individual 2 Mbps lines can also be provisioned, e.g. for small business.

**Transparency:** As the virtual fibre technology is supposed to act as fibre, it must be as transparent as possible, meaning it is not affected by the systems in front or beyond the virtual fibre, the applications that run over it, etc. It should in fact act as a piece of Ethernet cable that is agnostic of what happens on either side of it. On the other hand, Virtual Fibre should also accept the existing cable networks as the transparent physical layer. This automatically raises design barriers to the frequencies and signal levels of the Virtual Fibre system.

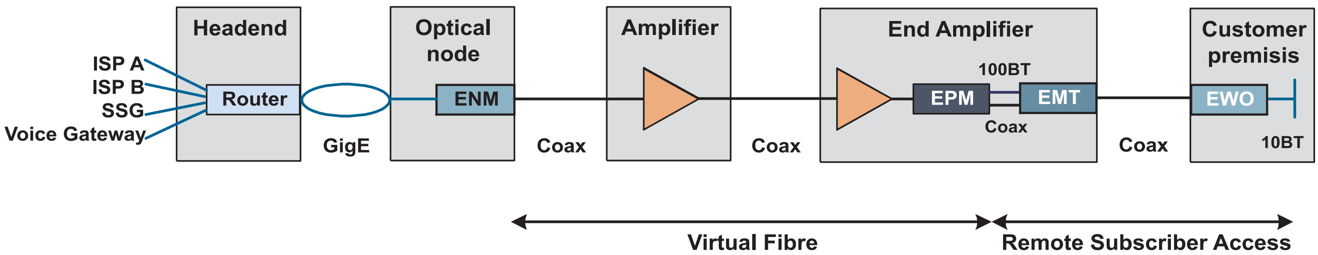


Figure 1. EttH System Architecture overview

The ENM - EPM pair works in the frequency range of 5–65 MHz in upstream and 85–860MHz in downstream, compatible with EuroDocsis frequencies. The signal levels are designed to fit with typical levels used at the optical node (for the ENM) and line extender levels (for the EPM).

Transparency also means that the system should allow provisioning of subscribers with existing provisioning back office infrastructure, or at least through standard available tools. The Virtual Fibre therefore acts as a layer 2 bridge, being totally transparent for VLAN traffic, DHCP requests, priority requests, etc. This allows EttH to be provisioned like a DSL or layer 2 FTTH system, using PPPoE or a dedicated VLAN per sub or service.

**Mechanical design:** The most optimum point to use virtual fibre technology is obviously there where no real fibre is available (although the system also works over broadband AM fibre). In most cable networks fibre availability ends at the fibre optic node, which resides in a non-protected environment with specific characteristics. In order to be able to coexist in the existing networks, Virtual Fibre equipment needs to be flexible to adapt to existing network designs.

Therefore the ENM has been designed to be extremely compact and ready for field use. As it will co-reside with the optical node, its shape is chosen to use any spare space in the ONU cabinet. It is environmentally hardened and has four independent outputs to be able to use the coaxial segmentation existing in many optical nodes (e.g. Teleste's BXX node platform).

The EPM has even tighter space, as it typically co-resides with the last amplifier of the network, which is often placed in a small cabinet or on the wall. This unit obviously can be remote powered by the network and has a power feeding loop to feed the EMT taps.

Although the design of the ENM EPM pair has been based on the requirements of the end-to-end EttH solution, it will fit most networks that want to use the Virtual Fibre solution as such for feeding business customers, or WLAN hot spots.

## EoC : the last 100 meter physical layer

When using Ethernet (10-BASE T) on coaxial cable together with the regular CATV service, several design challenges have to be dealt with. For a start Ethernet has very different characteristics compared to CATV:

- CATV uses F (or IEC) while Ethernet uses RJ-45 connectors

- CATV is an a-symmetric signal using one coaxial cable while Ethernet is a symmetric signal using two twisted pairs, one for transmitting and one for transmitting and one for receiving.

- CATV has a characteristic impedance of 75 Ω, Ethernet has an impedance of 100 Ω.

- CATV uses 40 MHz to 862 MHz while most of the energy is located between 0,5MHz and 15 MHz for an Ethernet signal.

- Baseband Ethernet signal levels are about a million times stronger than the average CATV signal found at the outlet.

In order to fully understand the physical layer some more design considerations have to be accounted for. Ethernet is a full duplex standard but will support half duplex. Since the system uses a single coaxial cable instead of two twisted pairs this consideration is in fact a must for success.

The link budget for Ethernet is 11,5 dB at 10 MHz. Coaxial cable attenuates far less then twisted pairs but the signal will also be attenuated by the passive devices of the system. In designing the system this will be a parameter that has to be closely monitored.

A real design challenge however are the generated spurious of the Ethernet transceiver. The standard states -27 dBc only giving a spurious level of 100 dBµV (with Ethernet at 127 dBµV) which is way too much compared to the humble 65 dBµV of the CATV system. Many transceivers were tested and in the real world the generated spurious are less than 100 dBµV between 15 MHz and 35 MHz but above 35 MHz the generated spurious are less then 90 dBµV. This reduces the design challenge to something that would be achievable. Extensive testing also unveiled that generated spurious are very depending on the data traffic. Usually the generated spurious have a noise-like shape rather than being a single carrier.

Many networks require a 2 KV galvanic isolation between the network and the inhouse installation. Current isolators are designed for use in CATV systems with an operating frequency range of 5 to 862 (or 1000) MHz. Since EttH requires a frequency range down to 0,5 MHz a new type of isolator had to be designed.

Taking all these design considerations into account we designed the CATV/ Ethernet combiner as shown in the block diagram (figure 2).

The BALUN (Balanced to Unbalanced transformer) transforms the original balanced Ethernet signal into an unbalanced signal while at the same time combining both TX and RX into one signal with 75 Ω impedance.

This signal, with a frequency range of 0,5 MHz to 15 MHz, can be combined with the CATV frequency range of 40 MHz to 862 MHz using a diplex filter. The isolation of the diplex filter is a critical design factor and has to be at least 80dB to effectively suppress the spurious generated by the Ethernet transceiver. With 80 dB of isolation only 10 dBµV of spurious will be present at the CATV port giving a s/n ratio of 55 dB (with 65 dBµV of CATV signal).

Combining 80 dB of isolation with a good return loss while maintaining an

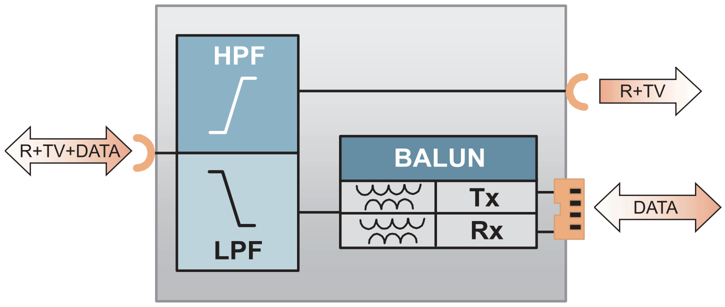


**Figure 2. EoC combiner circuit**

insertion loss as low as possible, is a real challenge and requires a relatively complex filter using high Q components. Such a filter introduces phase non-linearity and therefore group delay equalisation will be necessary. Instead of equalising every single combiner in this system total equalisation is performed at one of the combiners only.

The total physical layer of EoC is shown in figure 3. The in-house combiner is to be build into the cramped mechani-cal outlines of a standard wall outlet. The combiner at the other end of the cable is build into the multitap with the HPF port connected to the RF part of the multitap and the LF port connected to the build in Ethernet switch. The combiner at the multitap also incorporates the group delay equaliser.

The Ethernet link budget is limited to 11,5 dB and therefore the total insertion loss of the EttH system must be limited to this value. All components used in the system introduce insertion loss but the most important one is the BALUN. Since the BALUN also combines both TX and RX Ethernet signals, the theoretical insertion loss would be 3 dB giving a total insertion loss of 6 dB (there are two combiners in cascade). This already eats up a big chunk from the 11,5 dB. It now becomes clear why insertion loss is an important parameter when designing the diplex filters and isolator. There is simply no room for a lossy component, only the best can be used!

The system is designed to operate with at least 100 meter of coaxial cable but some CAT-5 in-house cabling has to be taken in account also. Adding up all components this would mean the introduced insertion loss would be uncomfortably close to the maximum link budget.

This has been solved using an innovative BALUN design at the multitap combiner. This innovative BALUN reduces the total insertion loss with 2 dB compared to the traditional design giving enough headroom to ensure stable and reliable operation.

The mechanical outline of the EoC system components are shown in figure 4.

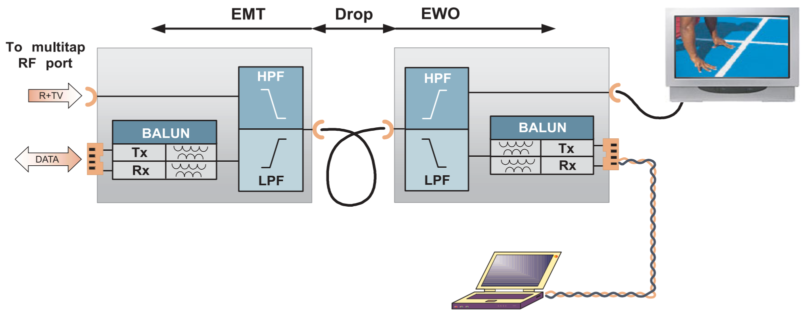


**Figure 3. EoC total physical layer**

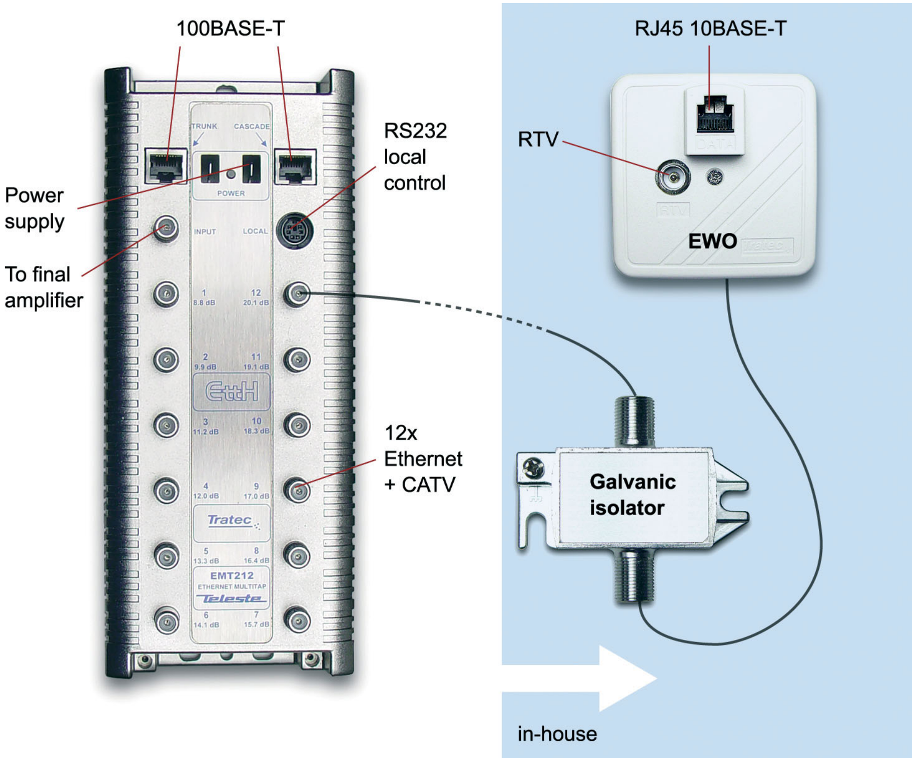


**Figure 4. Mechanical outline of EoC system components**

## SERVICES AND PROVISIONING IN THE ETTH SYSTEM

The ETTH system can support triple play IP solutions (data, voice and video). Each service has it specific demand on class of services (CoS) and delays. The data services are based on best effort "high speed" IP connectivity. IP connectivity is based on a Virtual LAN (VLAN). Voice service will be delivered to the end-user based on VoIP techniques.

A short delay is guaranteed in the ETTH network by giving the VoIP packets a high priority. VoIP at the customer premises can be implemented using a Stand Alone Media Terminal Adapter (S-MTA). For video services which make use of multicasting, IGMP snooping is supported. In total four different priority classes are supported.

Since the ETTH network is a transparent IP pipe, the provisioning is fairly straightforward, especially if the operator is already providing Internet Services to the end customers. Two techniques make it even more straight-forward: first the support of VLAN's per service or port and secondly the possibility to use PPPoE.

These techniques support rate limiting facilities to be able to offer different services with various speeds. For extra security the EMT is also able to support rate limiting per port to prevent network overloading. Rate limiting of the EMT ports is stepwise selectable between 128kbit/s and 8Mbit/s.

When the operator wants to implement an open platform access of multiple service providers a service selection gateway (SSG) can be used. The SSG the lets users activate service offerings on an as needed basis, automatically provisions the network to deliver those services, and accounts for service usage on an individual subscriber basis.

Figure 5 shows in more detail the advantages of the supported VLANs. It first of all shows the traffic separation among users and between users and management traffic. It also shows that it is possible to have a VLAN per services with the advantages of having a clear distinction between traffic types. It is also possible to set up a single VLAN per home with the possibility to access different service providers or different commercial packages (e.g. speed) through a (SSG).

This dynamic activation of services can be implemented via a web portal that is allowed to communicate to the management system and changes network configuration when a new service or bandwidth upgrade is desired. This allows a remote user to dynamically make service changes without placing an order with the service provider or having to login and logout to have the service become active. A simple example is the "turbo button" concept where a user selects a service that changes his data rate to the Internet. With the simple click of the button on a web page, the user's session is immediately changed to a higher bandwidth rate.

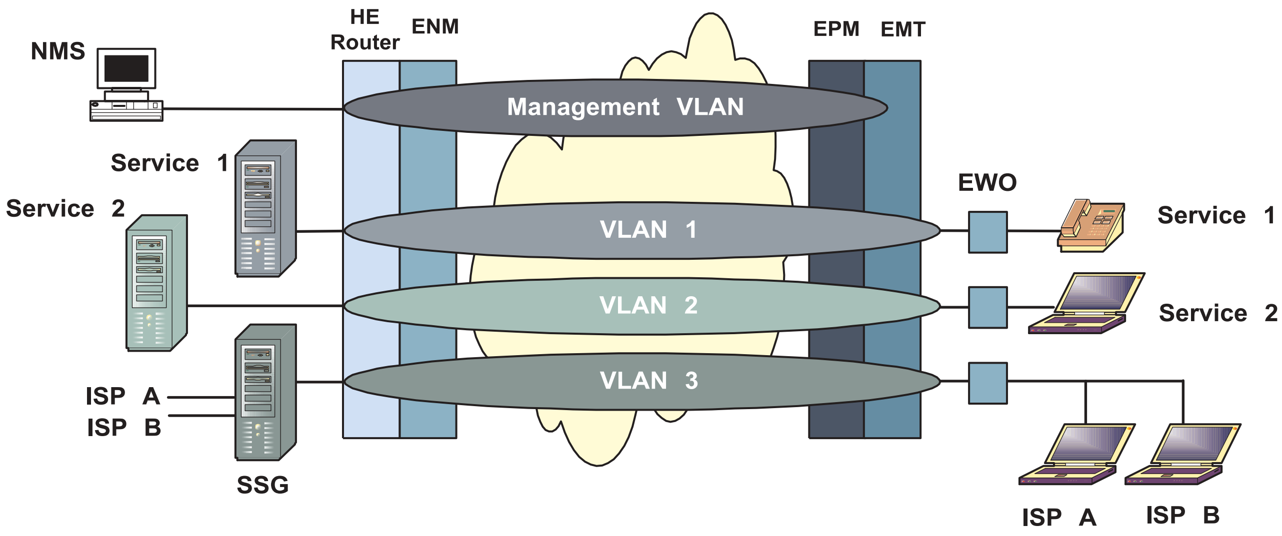


**Figure 5. VLAN provisioning and management in the EttH system**

## ADVANTAGES OF ETTH

Instinctively one can perceive some of the advantages of EttH offered by the higher speeds, the fact that no modem is required, etc. EttH indeed offers a portfolio of important advantages that can be categorized into three main groups:

### Operational advantages

The EoC technology does not require a modem at the subscriber, only a new passive wall outlet. This makes the house installation much easier and even allows self installation. No more active devices in the house means straight-forward (self)installation, decreased truck rolls, higher MTBF in the house, no tampering possibilities, etc.

The EttH approach dramatically reduces ingress in the network, because the subscribers simply don't have access to the lower return path frequencies of the core network anymore. They communicate with the miniPOP, and the miniPOP communicates with the headend, but frequencies below 40 MHz coming from the house are filtered out. This decreases the cost in ingress fault finding, the amount of connection failures and related churn, etc.

Although a build as you grow scenario is possible, EttH is intended to be a full connectivity system, meaning that the system is built to enable every house to be connected without the need of hardware changes in the home or the network. This approach makes connecting and disconnecting subscribers a matter of a click of a button, and in most cases can be organized by a self provisioning system, as described above. This makes the operational cost of connecting and disconnecting subscribers negligible.

### Marketing advantages

In a network with full EttH capability (all wall outlets are of the EttH type), every household is connectable to the data service by plugging in the PC into the Ethernet port of the wall outlet and going through the self-provisioning. This drastically lowers the threshold to become a subscriber for data services and leads to far higher penetrations as of day one, as many marketing trials have proven. Try before you buy marketing becomes economically viable, because there is no cost related to making the try-subs connectable. Similarly, the plug and play nature of EttH allows a subscriber of a competing service provider that experiences some problems, to test the EttH service by simply plugging the Ethernet cable into the EttH wall outlet.

As the EttH technology allows dedicated high bandwidth connections over Coax, it fits perfectly to the need of business users. With EttH it becomes possible to sell leased lines over cable providing E1 up to E3, 10baseT to 100baseT without the need of fiber. This makes entering the attractive business segment more straightforward for MSO's that traditionally were more focused on the residential market.

Another important marketing advantage is the possibility to compete in the dial-up segment. As the network is enabled for all subscribers, it becomes possible to sell profitably services that would normally not be interesting because of operational and capital costs. This will allow to sign up the large public that is not ready yet to pay 30–40 € for a high speed connection. Making an existing customer migrate to a different service later on is far easier than acquiring a new customer in a competitive environment.

Finally, EttH offers new business models to sell the enormous throughput capacity of the cable network. The Virtual Fibre technology can be used to provision WLAN hotspots, Ethernet based CCTV camera's, etc. This allows offering specific applications to customers that could only be served through the installation of new fibre before.

### Technical advantages

Although it is generally assumed that Docsis 2.0 will allow high speed connections (up to 30 MBps in US), it is a fact that Docsis in practice is rather limited in its high speed throughput when we consider a single modem. The mapping cycles of Docsis are designed to allow a large amount of modems to access the network, and this characteristic is limiting the true upstream throughput, resulting in maxima of around 2 MBps per modem. EttH on the other hand is only limited by the physical limits of its remote subscriber access (10 MBps in the case of EoC) and the amount of bandwidth that can be provisioned to the MiniPOP. Through its advanced structure, there are no technical reasons why EttH could not deliver 100 MBps to residential subscribers in the longer term.

The security in the EttH system is very advanced, allowing complete management of the subscriber base and switch-off of subs with fraudulent intentions. This feature makes churn manageable and irrelevant from an operational cost point of view.

Through the better control of ingress, the avoidance of return path laser overload and the data segmenting at the optical node level leads to more and cleaner bandwidth and therefore the possibility to use more QAM channels with higher constellations. This feature of EttH increases the efficiency of spectrum use with a factor 2 to 20, depending on the network architecture in place.

All these advantages combined create a system that through better exploitation of the existing infra-structure improves and widens the service offering to subscribers at a considerably decreased operational cost.

## OTHER APPLICATIONS

This article has focussed on EttH with baseband Ethernet over coax (EoC) as the remote subscriber access technology. One should however not limit its view on EttH by this focus. The interesting aspect of EttH is that there are many possible access mechanisms possible and one does not have to limit oneself to the coaxial plant. Some other RSA technologies that have been identified as interesting alternatives are:

- Home PNA: When considering the basement of large buildings as the miniPOP, one can consider using the existing telephony wiring instead of the cable wiring of the building for subscriber access. The subscriber only requires a HPNA card (like an Ethernet card) in his PC. The Virtual Fibre part of the EttH system could be used to interconnect the HPNA switch in the basement. The Home Phone Networking Alliance has recently launched the third version of the HPNA standard that will allow to transport up to 128 MBps over existing phone wiring.

- CAT-5: More and more buildings constructed today have CAT-5 wiring installed to every apartment. At the same time solutions for transporting video over CAT-5 are becoming available. In these buildings CAT-5 will be the subscriber access solution of choice. The only device needed at the miniPOP is a standard Ethernet switch and again the Virtual Fibre part of the EttH system could be used to interconnect this switch.

- Wireless LAN: From the miniPOP, the operator may decide to access the subscriber premises without fixed line wiring and go wireless. This solution allows to create WLAN hotspots in the coaxial cable network.

- Docsis: Contradictory as it may seem, Virtual Fibre may prove to be a lifeline for Docsis. With growing bitrates per subscriber, operators that want to continue to use Docsis will eventually have to use smaller node sizes (resegmenting) or place the Cable Modem Termination System (CMTS) deeper into the network . The Virtual Fibre part of the EttH system could be used to provision hardened CMTS with the needed data pipe.

- Other: the growing datamarket has seen the emerging of proprietary data access systems that offer a smaller scale and more economical solution than Docsis. In order to properly provision these systems with sufficient speed, Virtual Fibre is the best solution.

## THE FUTURE

The observing reader will have noticed that the proposed EttH system is based on in-band transport, meaning that it uses the existing cable TV frequencies. As much as this in-band choice limits the throughput of the system (around 350MBps in upstream would be the theoretical maximum using today's technologies), our research has shown that at this point in time, most of the operators in Europe are not ready to drastically alter the network, and therefore out-of-band virtual fibre is a solution non grata at this point in time. Nevertheless, one can easily imagine an EttH system with out-of-band virtual fibre, in which Gigabit speeds travel over the existing coaxial cables to the miniPOP, from where individual homes can be served with 100 MBps.

Certainly, a futuristic view, requiring a bold and drastic upgrade, but impossible it certainly is not. At the minimum, the above scenario should show that cable is far from dead and that EttH offers cable operators an alternative with the right strategic direction.

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**Ing. Martien Rijssemus** (1959) graduated from Arnhem Technical University in 1981. He started his career designing satellite TV receivers and low noise converters. He started to work for Tratec in December 1982 as a member of the R&D team, where he worked on the design of FM radio processors, modulators, and satellite reception equipment. In 1985, he became the manager of R&D and production and currently holds the position of technical director of Tratec Telecom BV and is deeply involved in the development of Tratec's products.

**John van der Waal** joined Teleste in 2001 and was mainly involved in the technical sales support for digital headends and backbones. Last year he was appointed as technical specialist for FTTH and ETTH technologies. John has gained a broad experience during his career in the industry following his graduation as BSc-EE in 1989, working for PTT Telecom, Nozema and UPC. He was involved in many international organisations like: ITU-R, DVB, EBU, DAVIC, ACTS , RACE , DRM and World DAB forum.