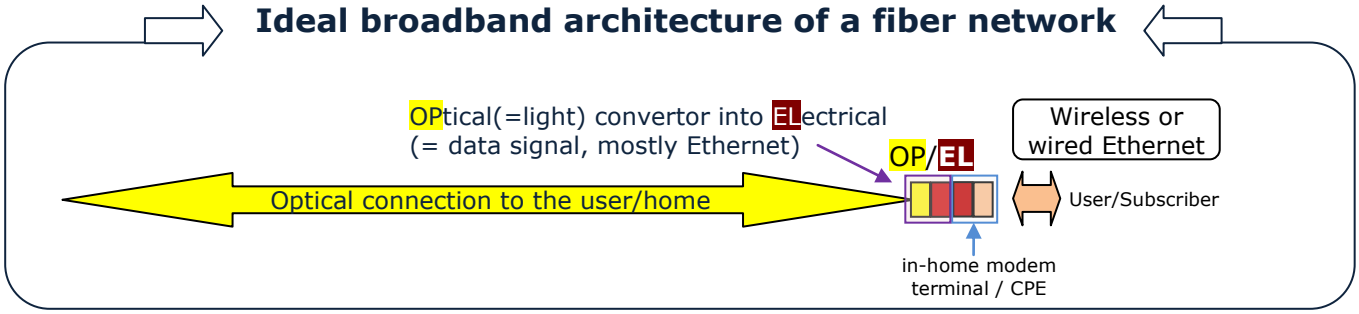
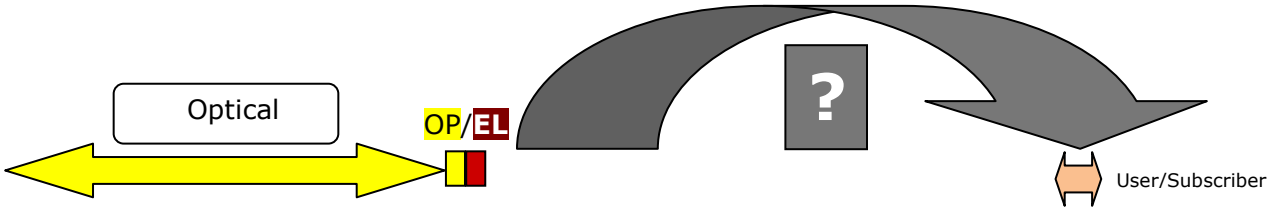
General architecture of a fiber network based on copper in the last lane in order to reach end-user in a short time with high speed broadband interface.

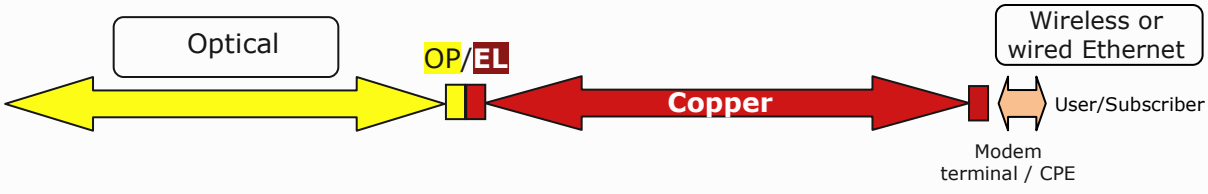
Ideal broadband architecture of a fiber network



What if fiber roll-out has started - but not yet to the end-user?



***New Copper transmission technologies** pass the broadband speed that was assumed as only possible with optical networks/fiber: it is the logical and most economical fastest solution to fulfill the demand for high speed broadband at every home - on short term !*



What is the status of Broadband in terms of network technology today?

In general there are three network parts:

- **Optical transport Network:** This network is provisioned with an optical distribution system like PON (Passive Optical Network) and connects to the Carrier or Network Provider with OLT (Optical Line Terminal). The key-word is 'fiber'

- **Copper Access Network:** This network is using a copper-based technology for the physical layer like xDSL or G.fast or MoCA or DOCSIS .. and transport the high-speed data-signals from the Optical/Electrical interface to the premises of the user. The key-word is 'copper' even though it is the ambition to replace it one day with fiber.

- **Home Distribution Network:** This network provides the broadband in the home or the premises of the users with the appropriate technology like G.hn, Wi-Fi, PLC, distributed wired Ethernet ... the key-word is 'wireless' be it that it can be distributed with copper transmission technology.

The difference between above described networks is in the speed and volume of network data:

- the optical transport and volume of data serve the required capacity of broadband bandwidth for a large number of local users. Speed and volume can be increased if required.

- the access network is provisioning the premises of the users. The broadband speed depends on the deployment strategy and type of modem roll-out of the local telco/carrier and the geographical spread of access points versus subscribers. It is the most important part of the network that will define the final speed that can be obtained in the long run. In terms of possible broadband speed, capacity and quality it shows the need of a sustainable back-bone for connecting spots of a circle surface area of 1 to 2 square km. Within this area there are plenty of transmission technologies that can enable connectivity among people and things, and that can expand the bandwidth as might be required for next step AI controlled society.

- the distribution network is the part in the home that distributes the broadband in the premises of the users. In this part there is no increase of bandwidth: it distributes the incoming broadband connection with wired or wireless connection technology.

Many different transmission technologies have passed the scene over the last 25 years during which a 6MB picture download that took 15 minutes with a 56kbps dial-up modem is possible in 0,2 seconds with a 250Mbps VDSL2 link today.

Optical signals with fiber is for over 50 years considered as the technical superior solution for high volume and low-noise data-transmission in digital transport and access networks. The reality is that the roll-out of fiber -especially in the access network, is a huge, time-consuming and costly challenge for the Service Operators while new players make money with applications that require good quality and high speed broadband but they don't contribute to the cost of the network. Even though fiber installation costs have declined over time, there is another barrier for an end-to-end fiber provisioning: the last part of the network is mostly owned by other people than the Telco or Service Providers. Apart from the juridical discussion who owns the network access point in private homes and buildings it is also a financial issue who is paying for a new fiber cable network when there is yet a telecom service based on

copper infrastructure in place that gives an equivalent broadband performance compared to fiber, and more so, while next generation copper based transmission technologies are evolving to a broadband speed that pass 1 Gbps (1000 Mbps) as was defined for fiber (PON) per subscriber in the access network!

A short overlook of different transmission technologies other than fiber for the provisioning of broadband in multi-tenant buildings, apartments and homes.

Wireless Broadband for the end-user is supposed to be wireless and everywhere available. Users accept though a fixed connection for high-speed, stable and secure broadband in offices and rooms at dedicated working places and office desks. The ultimate goal is to enable high-speed and secure broadband at any place without disturbing other users nor being disturbed by other users. The challenge of wireless availability of broadband services is the same for fiber and for copper based network. Both (fiber and copper infrastructure) are fixed topologies with Ethernet interfaces towards wireless technology of which WiFi and Bluetooth are the most popular ones.

A potential game-changer is the upcoming satellite technology like Starlink (Space-X), Kuiper(Amazon), OneWeb (Bidco UK/Bharti Global), Globestar, Iridium, Boeing, Orbcom, .. initially for the coverage of broadband in rural environments but perfectly suitable for servicing broadband to anyone who is able to pay for it, as well as the 4G/5G/6G networks that promise mobile broadband provisioning across access and distribution networks ... All these technologies will need connection in one or another way to the terrestrial network and a number of these technologies require a back-bone of which fiber is the most convenient and logical one. But since new sophisticated copper transmission technologies have been developed and successfully implemented they now serve as a valid alternative for fiber in the access network and also may act as a backbone for other technologies like 4G, 5G and satellite ground stations. If copper can match the speed of fiber, than it is a no-brainer that copper has now a new momentum given the drastic increase of demand for more bandwidth as consequence of more home-working for which fiber can't sign off on short term.

This paper discusses the different copper transmission technologies and associated parameters when using the existing copper infrastructure.

When talking copper, it is to be understood that there are in general 3 groups of copper based carriers:

- **UTP unshielded twisted pair** like telephony network, is called CAT 3 cable. The connection for telephony networks is made with 1 pair per subscriber/connection, these are 2 wirelines (RJ-11 jacks). These copper pairs are bundled in multi-pairs of tens of pairs. The last end to the subscriber's house is ending with one (or 2) single pairs, and with multi-pairs to multi-tenants. The isolation of the pairs can be paper, PE, PVC, and the thickness is usually 0.4 ~ 0.5 ~ 0.6 mm as indicated in Europe and Asia, or 28 ~ 26 ~ 24 ~ 22 AWG (American Wire Gauge) in the US. Pairs are 'twisted' for EMC reasons and for eliminating crosstalk. Telco cables are different than Ethernet cables. Ethernet cables are normally shielded (with electrical shield over isolation material) and have usually higher diameter and a group of 4 pairs in one connection (as of the nature of Ethernet technology - with RJ-45 connectors). Both Telco cables as well as in-building Ethernet cables can transport high-speed data. The copper modems see a balanced 100 ~135 Ohm network. Today most UTP and STP are balanced 100 Ohm. The attenuation (insertion loss) of a pair per meter is depending on all parameters of the construction of the cable. The longer the line, the less bandwidth is available.

A telephony network is a STAR network where each subscriber has its own start and arrival connection point for data-transport without sharing with other users. The data is carried as an electrical signal between 2 wires, and have no ground reference. The ground of a twisted pair is the real ground where cables are buried. Popular and well known digital transmission communication technology is the rich family of DSL variants (ADSL, SDLS, VDSL ..).
An Ethernet link also has a point-to-point connection from server to server or client to client, but data-signals are cascaded to next connection point while switching of data for different users is on data-link layer with so-called Ethernet switches or with higher-layer protocol switches. When such data-cascaded network is interrupted than all connected users are disconnected unless the network is closed in a ring. In that case the subscriber can be reached from the other end of the closed data-transmission ring. The 4 pairs in a 'shielded' Ethernet cable that is terminated with a shielded RJ-45 is called a CAT 5e. You won't find them in the access network, but they are popular in buildings for office applications and in industrial plants.

- **Coaxial cables**, generally known from television distribution 'Cable networks' have a copper coil and a shield, and have much less attenuation compared to UTP/STP with a much larger frequency band as was needed at the time for transporting analog television signals. The coax modems will see unbalanced 50 Ohm or 75 Ohm cables. RG-6, RG-11 and RG-59 are some of the popular coaxial cables that differ in isolation and thickness of the copper core lead and its electrical shielding that acts as earth reference for the transmission signals. The topology of coaxial networks is a bus-technology where any subscriber that is connected sees the same spectrum and receive the same signals over a long distance with one-way signal amplifiers as they were originally meant as a distribution medium for one-way television. Coaxial cable in data-com networks are equipped with bi-directional signal amplifiers. The coding for digital transmission over coax depends on the application. Most popular (a.o. in the USA) are the MoCA technology (Multimedia over Coax Alliance) and DOCSIS (Data Over Cable Service Interface Specification) in Europe.

- **Electricity network cables** carry electrical signals over copper be it that the cables are thicker since they carry 100 ~ 240 ~ 330 volt @ 50/60 Hz (2 or 3 phase). They are not meant to transmit data-transmission but it is perfectly possible to transmit high-speed data over electricity cable coping with the same parameters like telco, coaxial and Ethernet cables of which insertion loss @ frequency per meter is the most important one. Data-transmission can be carried over electricity networks since the DC and AC current is split in the data-transmission modems. This technology is known as PLC or Power Line Communication. PLC cope with different type of transmission environment compared to telephony networks as of the connection of multiple electricity apparatus to the electricity network and its topology that is not a point-to-point connection but an any-to-any connection. As such the data-transmission signals can be present on any connected cable, even single ended cable.

Copper starts where fiber ends.
The fiber termination point can be located either outside or inside a tenant-building.
The main challenge from that point is to bridge the gap to the user.
Copper modems do that with existing, already installed, copper network. Often there is no other way!

- the time to install fiber up to the premises of the user is a matter of planning and organisation ! with an existing network infrastructure that is yet in place, this is matter of connecting the copper modems (and the subscribers) just in minutes.

- the installation of the fiber is a major cost compared to a 'no' cost with an existing copper network infrastructure.

- the type of broadband service defines the type of terminal/gateway that is to be connected to the infrastructure modem; this terminal use an identical interface for both fiber and copper network as they use the same Ethernet interface.

- the worldwide copper network infrastructure has been a driver for the development of a multiple of data-transmission technologies with ever evolving new high-speed transmission technologies than now are passing the speed of fiber over copper.

- the evolution of the political, social, cultural and business society that liberate protected business areas like Public Networks, allows for competition among network providers which also lead to more universal and open access interfaces offered by broadband transmission chip and equipment vendors making their products appropriate and applicable with minor changes for both protected as well as private and/or open networks. This is increasing the possible solutions for copper network infrastructure drastically compared to fiber that is a new carrier technology of which the investment cost needs to be recovered one day.

The variety of copper based broadband transmission technologies can be listed according so-called 'use cases' for a single or multi-tenant type of connection in a common or single private ownership.

When talking *'copper network'* it includes Telephony network over UPT/STP, as well as Coaxial network over RG-6/RG-59 coax, as well as Power Lines (Electricity network) over thicker cables like 1,5 mm PE.

The topology might be

- **Multi-tenant (**common and share copper network) outside the living unit
  - **UTP/STP cable**
    data or telco twisted pair from the fiber termination to the basement and to the user
  - **COAX cable shared**
    high speed transport of data or telco services from fiber to the building with a common used and multiple used shared coax cable, with cable TV service, and/or DOCSIS service
- **Single-tenant** (individual copper connection) to the home
  - **UTP/STP cable**
    data or telco twisted pair to the user from the tenant access point to the user
  - **COAX cable**
    data to the users over a single coax cable, with or without presence of cable TV service, and/or DOCSIS service
  - **Power Lines / Electricity cable**
    Power Line twisted pair per household that distribute the broadband in the home

Vision for the future of broadband ***CopperGain ~ CopperMatic***

Next generation broadband will depend on the evolution of broadband services and the associated business models. Therefore it is of crucial importance that the decision of broadband provisioning with respect to the required 'hardware' and 'physical connection' is based on a vision that takes a potentially huge increase of broadband need/capacity into account, even when current demand for speed and latency is limited.

Such solution is an architecture that is focusing on the essential part of the network = the design and roll-out of a broadband transmission technology that will sustain for the next decades and that can be replaced and upgraded if new higher speed capacity would be needed.

A new technology called **CopperGain** is based on a technology that has been implemented by the access network equipment industry for the Telco's and the Service providers. Known as G.fast of ITU-T 9700 and 9701 the technology is mature since 5 years with yet a couple of million devices in the field. This technology is designed for ultra-high speed over copper infrastructure and has now gain huge interest as probably the only possible way to bridge the gap between fiber/optical data-networks that can be easily upgraded in terms of high broadband speed available at one end (fiber), and the user at the other end in multi-tenants like hospitals, hotels, business offices as well as private homes like apartments or multi-user communities (copper). The main drivers are cost and time of installation, especially in brown field area's where a fiber infrastructure is always a long-term plan that requires a business case, resources and an architecture that justify the decision.

In the access network the potential speed over TP100 cable, equivalent to 0.5 mm PE or 24 AWG is given in next table.

Length meter	Aggregate data-rate in Mbps	Upstream Downstream SNR margin
20	1,825,000	6 dB
50	1,825,000	6 dB
100	1,650,000	6 dB
200	875,000	6 dB
400	250,000	6 dB

CopperGain implementation is with local power supply, or is powered remotely with DC-power that is made possible with the same copper pair as the one used for the transmission of the high-speed data. Upstream and downstream ratio is programmable per link in a one-way, an asymmetric or a symmetric data-speed. It is still possible to run analog telephony (POTS) over the link when appropriate even though the evolution is towards in-band voice communication as part of a conference setup.

The CopperGain technology runs also over coax networks in a point-to-point connection as single service or combined / in presence of TV cable service with satellite receivers. The attainable data-speed is as given in table hereunder:

Length meter	Aggregate data-rate in Mbps	Upstream Downstream SNR margin
20	1,825,000	6 dB
50	1,825,000	6 dB
100	1,825,000	6 dB
200	1,650,000	6 dB
400	1,050,000	6 dB

The power supply of CopperGain for coax cable is identical to the power supply for twisted pair as described above: DC-power provisioning is possible with the same coax as the one used for the transmission of the high-speed data. Upstream and downstream ratio is programmable per link in a one-way, an asymmetric or a symmetric data-speed.

Any Ethernet gateway, router, bridge .. can be connected to the CopperGain device that behaves identical like a fiber optic electrical Ethernet interface. This can be extend with Wi-Fi 2,4 and 5G wireless enabled with Ethernet connections in case no other service than Internet is required which tends to be the standard use case in the future.

CopperMatic

Once in the home, apartment, or building the data-speed can't be accelerated anymore but a different copper based technology is possible with CopperMatic. CopperMatic is a data distribution technology over the in-house Ethernet cable (CAT 5 RJ-45) or the electricity cable as a multi-point connection, ending in a low-power wireless interface for in-home subscriber use. This way any data-link can be secured without compromise on speed. CopperMatic gives the same interface in house like CopperGain is doing in the access network. Both new technologies are provisioning High Speed Broadband over copper infrastructure and enable the fast speed Internet/broadband service with wireless connection or wired RJ-45 connection.

Business Customers

Other applications for CopperGain are the 'leased lines' over copper for VPN's with full blown monitoring and guaranteed bandwidth in order to allow SLA agreements with end-customers. Distance reach over copper with leased lines is possible over longer length and with adjustable speed in a point-to-point connection, or by bonding several CopperGains over multiple pairs where data over several communication links are bundled in a higher speed that possible with a single modem. This technique is known to Telco'operators as a 'bonding' technology for ADSL2plus and VDSL2. CopperGain is bonding links of 1 Gbps.

Trials of CopperGain and CopperMatic are on-going.

CopperGain takes the legacy services into account with the vision that the service that is yet installed, should remain and not disturbed. Thanks to this approach CopperGain is a copper transmission solution for *any* use case, going from a simple CPE ADSL of 8 Mbps to a 2 Gbps interface as a single-ended broadband speed, or in combination with yet installed services.

Therefore, as has been the case 10, 20, 30 and 50 years ago, the existing copper infrastructure will remain for a long while, probably for the next 30 years as the broadband industry hasn't stopped to develop faster and more reliable broadband transmission technologies over copper in line with the increasing demand for more bandwidth.

Copper based Broadband Transmission Devices allow the network planners to continue the roll-out of optical networks since the copper network provides a bridge to close the current gap between transport hubs and end-user. CopperGain is an instant connection as copper is always available on-site and thus can be considered as the ideal lock-in of customers who are expecting high-speed broadband as is promised by fiber but provisioned thanks to copper.

This is the vision for the future of broadband by the company who designed the first industrialized DSL chipset in 1991. In 2021, 30 years later, Sparnex is implementing a new technology over copper that is made available at a speed that is 1000 times faster than the first generation of 2 Mbps per UTP / CAT 3 giving broadband comfort and profit for the next 10 years, and probably beyond.

Belgium - Antwerp, December 2020

About the author

Jo Maes has been a leading communication technology and product design specialist since 1990. His teams developed the world's first DSL chipset for the digital access network in East Germany after the fall of the Berlin wall. With design experience of more than 80 innovative telecom products and highly sophisticated test and copper infrastructure simulation equipment, he is an Internet pioneer and a privileged witness of the technology evolution that has enabled the Internet infrastructure we know today. Jo was among the first to understand the huge impact of digital connectivity in the history of mankind and recognized how it would change the world. His visionary "Renaissance of Copper" campaign in 1991, and the influential slogans such as "Think fiber, start with copper", "Turn your copper into gold" and "Managing the Crosstalk is Managing the Network" have paved the way for smart and sophisticated transmission technology, products and solutions that made high-speed Internet and other data connectivity possible over an old-fashioned and outdated copper network. Jo claims that the promise of new broadband technologies like 5G, fiber and satellite won't be able to fulfill the expectations of end-users without the installation of copper-based smart transmission technologies.