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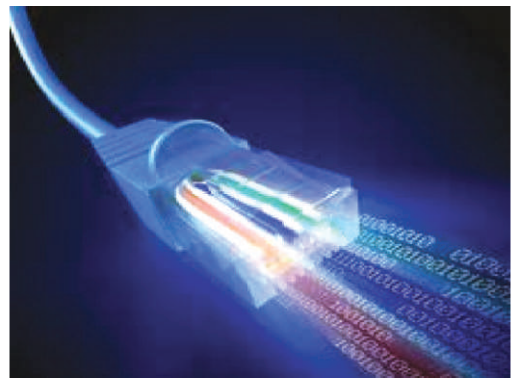
100 Gigabit Ethernet and Beyond

Significant growth of IP-based traffic in broadband access networks, service providers' aggregation networks and optical core networks is doubling the Internet backbone bandwidth every 12 to 18 months. The introduction of triple/ quadruple-play services and cloud services has increased the demand for more bandwidth for various multimedia and corporate applications. The demand is further fueled by increased penetration of broadband, 3G mobile networks, 4G mobile networks and rapid advances in cloud computing. The steady march from 2.5 Gigabit Ethernet to 100 Gigabit Ethernet on the back haul has been primarily driven by the exponential growth in Internet traffic and to commensurate the increase in broadband access speeds available to consumers. Organizations that track Internet backbone traffic growth have reported a 40-50% year over year (Minnesota Internet Traffic Studies) increase in traffic. At this rate of growth, one would expect that the majority of high traffic backbone routes will be utilizing 100G transport equipment by 2016. Apart from these factors the rapid advances in IP video and cloud computing are also driving the need for high bandwidths.



Ethernet is a physical and data link layer technology for local area networks (LANs). It was developed as a way of connecting computers, printers and other devices, situated in different rooms in a building, together on a network using a single, shared cable. The term 'Ethernet' came from 'ether', a term used in 19^{th} century physics to describe the medium through which light was thought to propagate.

Since the conception of Ethernet, the Ethernet technology has continued to evolve to meet the ever-increasing bandwidth, affordability, diversity, and reliability requirements. It has become the underlying technology that enables communications via the Internet and other networks using Internet Protocol (IP). Due to its proven low cost, reliability and simplicity, the majority of today's internet traffic starts or ends on an Ethernet connection and as such Ethernet has become the de facto standard for all applications including voice, video, data storage, cloud computing, data centers, and large scale high bandwidth FTTH deployments.

Ethernet was originally developed as a random media access network protocol designed to run with many users asynchronously accessing the same network. For Ethernet data rates lower than 10Gbps, the protocol was designed to run asynchronous using techniques like collision detection and avoidance to handle the random media access. However, as Ethernet become more pervasive (over alternative protocols like ATM) and evolved to a high-speed transport protocol at 10-Gigabit per second and beyond, media access with collision detection was set aside, and only the low cost transport features remained in the protocols to reduce the cost of transport over more traditional SONET protocols. As a transport protocol, framing was introduced into originally variable sized asynchronous packet communications in order to facilitate transmission requirements over fiber media. The 10Gbps Ethernet approach was extended to 100GbE. At these faster data rates new modulation techniques were employed to overcome fiber transmission impairments for medium to long haul distances[4]. Ethernet technology will continue to evolve as network and bandwidth requirements transform to fulfill future requirements to scale and reduce costs.

The evolution of Ethernet and some details pertaining to 40Gbit, 100Gbit & beyond 100Gbit Ethernet are discussed in subsequent paragraphs.

Evolution of Ethernet

- 1973 : Bob Metcalfe, working at Xerox's Palo Alto Research Center, was asked to come up with a way to link hundreds of computers to the company's new laser printers. Metcalfe's initial thoughts are captured in figure 1, which was part of his memo describing a design for Ethernet at 3Mbps over shared coaxial cable.

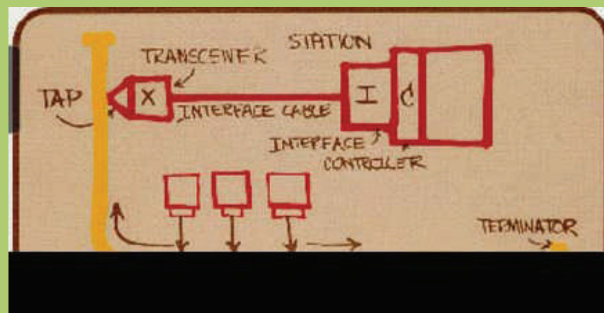


Figure 1 : Bob Metcalfe Memo

- 1976 : Metcalfe and David Boggs published paper entitled: "Ethernet: Distributed Packet-Switching for Local Computer Networks." Paper describes multipoint data communication system with collision detection.
- 1979 : Metcalfe left Xerox and founded 3Com. The next year, he published standard for 10Mbps Ethernet, known as the DIX standard (for Ethernet backers Digital, Intel and Xerox).
- 1985 : The IEEE became the official standards body for Ethernet. Open standards help make Ethernet the dominant LAN technology.
- 1986 : The IEEE published standard for 10Base5 Ethernet, also known as thick Ethernet because it ran over yellow coax that resembled a garden hose. (Figure 2)

Figure 2 : Ethernet over garden hose

- 1989 : Start-up Kalpana introduced first Ethernet switch, which eventually replaced bridges and hubs. Later Cisco bought Kalpana.
- 1991 : IEEE approved 10Base-T Ethernet over Cat-3 twisted pair cabling, which became the standard for LAN deployments.
- 1994 : IEEE approved 10BaseF, Ethernet over fibre for use in data centers.
- 1995 : IEEE adopted standard for Ethernet at 100Mbps. It became known as Fast Ethernet.
- 1998 : Standard for 1000Base-T or Gigabit Ethernet was approved.
- 2002 : Pre-standard products started shipping in 2001, but formal standard for 10Gigabit Ethernet was approved in 2002.
- 2008 : IEEE P802.3ba Task Force was formed to develop the 40 Gigabit and 100 Gigabit Ethernet standards.
- 2010 : The IEEE approved the 802.3ba standard for 40 Gigabit and 100 Gigabit Ethernet on June 17, 2010, as an amendment to the IEEE 802.3-2008 specification.
- 2011 : 'IEEE 802.3 Industry Connections Ethernet Bandwidth Assessment Ad Hoc group' formed for assessment of next rate Ethernet.

IEEE 802.3ba 40 and 100 Gigabit Ethernet

The IEEE 802.3 Working Group constituted a Higher Speed Study Group (HSSG) in July 2006, which subsequently became the IEEE 802.3ba 40GbE/100GbE Task Force in January 2008. On June 17, 2010, the 40 Gigabit and 100 Gigabit Ethernet standards were adopted by the IEEE 802.3 Working Group. The IEEE P802.3ba Task Force developed a single architecture capable of supporting both 40 and 100 Gigabit Ethernet, while producing physical layer specifications for communication across backplanes, copper cabling, multi mode fibre, and single mode fibre.

40 Gigabit and 100 Gigabit Ethernet were designed with specific target applications and markets in mind, though the flexibility of the new speeds and interfaces allow each technology to be used in a variety of different applications. 40 Gigabit and 100 Gigabit Ethernet target applications are shown in figure 3.

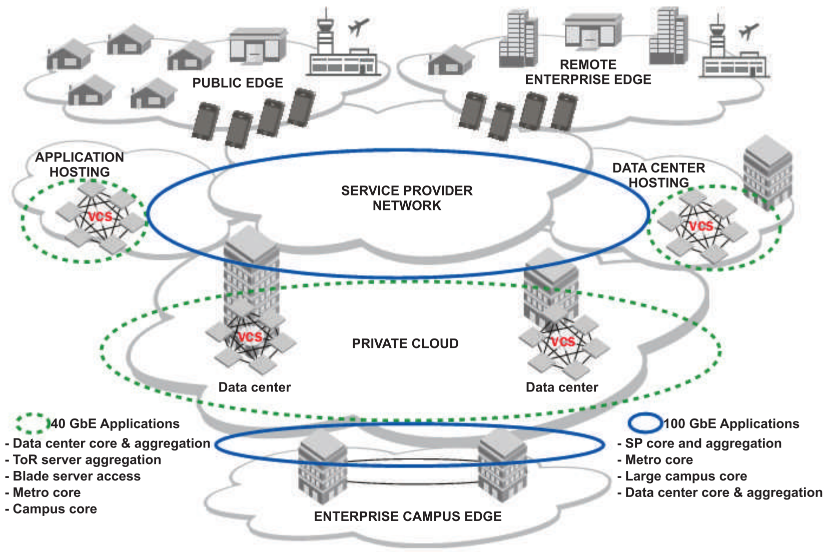


Figure 3 : 40 Gb/s and 100 Gb/s Ethernet target applications

The 802.3ba standard specifies extensible architectures that accommodate 40 Gigabit Ethernet, 100 Gigabit Ethernet, and a variety of other physical layer media. The architecture is flexible and scalable to adapt to the existing and future needs. They also enable vendors to reuse their existing technology and intellectual property, as the architecture is flexible enough to support physical layer specifications that are technically feasible and cost effective, using existing technologies as well as future technologies.

The Physical Layer Specifications of IEEE 802.3ba 40Gigabit and 100 Gigabit Ethernet are summarised in the table 1 below:

Port Type	Description	40 GbE	100 GbE	Solution Space
40GBASE-KR4	Up to at least 1m backplane	✓		4 x 10 Gb/s
40GBASE-CR4 100GBASE-CR10	Up to at least 7m cu (twin-ax) cable	✓	✓	4 x 10 Gb/s 10 X 10 Gb/s
40GBASE-SR4 100GBASE-SR10	Up to at least 100m OM3 MMF (150m OM4 MMF)	✓	✓	4 x 10 Gb/s 10 X 10 Gb/s
40GBASE-LR4	Up to at least 10km SMF	✓		4 x 10 Gb/s
100GBASE-LR4	Up to at least 10km SMF		✓	4 x 25 Gb/s
100GBASE-ER4	Up to at least 40km SMF		✓	4 x 25 Gb/s

Table 1 : Summary of Physical Layer Specifications of IEEE 802.3ba 40 Gigabit and 100 Gigabit Ethernet

These Physical layer (PHY) specifications for 40 Gigabit Ethernet (40 GbE) &100 Gigabit Ethernet (100GbE) are described below:

40 Gigabit Ethernet (40GbE)

- 40GBASE KR4 : It supports backplane transmission.
- 40GBASE CR4 : It supports transmission across copper cable assemblies. 40GBASE KR4 and 40GASE CR4 Physical Media Dependents (PMDs) support transmission of 40 Gigabit Ethernet over 4 differential pair in each direction over either a backplane or twin axial copper cabling medium.
- 40GBASE-SR4 : It is based on 850nm technology and supports transmission over at least 100m OM3 parallel fibers and at least 150m Optical Multimode 4 (OM4) parallel fibers. The effective rate per lane is 10 gigabit per second, which when 64B/66B encoded results in a signaling rate of 10.3125 gigabaud per second. Therefore, 40GBASE SR4 supports transmission of 40 Gigabit Ethernet over a parallel fibre medium consisting of 4 parallel Optical Multimode 3(OM3) fibers in each direction.
- 40GBASE-LR4 : It is based on 1310nm, coarse wave division multiplexing (CWDM) technology and supports transmission over at least 10km on SMF. The grid is based on the ITU G.694.2 specification using wavelengths of 1270, 1290, 1310, and 1330nm. The effective data rate per lambda is 10 gigabit per second, which when 64B/66B encoded results in a signaling rate of 10.3125 gigabaud per second. This will help provide maximum re use of existing 10G PMD technology. In this way, the 40GBASE LR4 PMD supports transmission of 40 Gigabit Ethernet over 4 wavelengths on each single-mode fibers (SMFs) in each direction.

Network Virtualization

While today's Internet and its protocols are apparently reaching their limits, a new technology is emerging which promises to overcome many of the deficiencies of the current system. This technology is denoted as Network Virtualization (NV). NV is a set of technologies which has a very high potential for becoming the major paradigm for the Future Internet.

NV is the technology that allows the simultaneous operation of multiple logical networks (also known as overlays) on a single physical platform. NV might be able to reduce significantly the operational expenditures (OPEX) of networks since it can consolidate multiple virtual structures efficiently into only a single topology requiring small configuration efforts and potentially lesser hardware than before. In addition, NV has appealing features for its use in the Future Internet.

It permits distributed participants to create almost instantly their own network with application-specific naming, topology, routing, and resource management mechanisms such as server virtualization, and enables users to use even a whole computing center arbitrarily as their own personal computer. Based on these features, NV technologies received recently tremendous attention and is expected to be one of the major paradigms for the Future Internet as proposed by numerous international initiatives on future networks.

Source : ECEASST 2009

100 Gigabit Ethernet (100GbE)

- **The 100GBASE-CR10** : It supports transmission of 100GbE over 7 m of twin axial copper cable across 10 differential pairs in each direction.
- **The 100GBASE-SR10** : It is based on 850 nm multimode fiber (MMF) optical technology and supports transmission of 100GbE across 10 parallel fibers in each direction. The effective date rate per lane is 10 Gb/s. Optical Multimode 3(OM3) grade fiber, which has an effective modal bandwidth of 2000 MHz/km, can support reaches up to at least 100 m, while Optical Multimode 4 (OM4) grade fiber, which has an effective modal bandwidth of 4700 MHz/km, can support reaches up to at least 125 m.
- **The 100GBASE-LR4** : It is based on dense wavelength division multiplexing (DWDM) technology and supports transmission of at least 10 km over a pair of single-mode fibers (SMFs). The four center wavelengths are 1295 nm, 1300 nm, 1305 nm and 1310 nm. The center frequencies are spaced at 800 GHz. The effective data rate per lambda is 25 Gb/s. Therefore, the 100GBASE-LR4 PMD supports transmission of 100GbE over four wavelengths on a single SMF in each direction.
- **The 100GBASE-ER4** : It is also based on DWDM technology and supports transmission of at least 40 km over a pair of single-mode fibers. The four center wavelengths are 1295 nm, 1300 nm, 1305 nm and 1310 nm. The center frequencies are spaced at 800 GHz. The effective data rate per lambda is 25Gbit/s. Therefore, the 100GBASE-LR4 PMD supports transmission of 100GbE over four wavelengths on a single SMF in each direction.

The 40 Gigabit Ethernet and 100 Gigabit Ethernet Architecture

The IEEE Std 802.3ba 2010 amendment specifies a single architecture, shown in Figure 4, that accommodates 40 Gigabit Ethernet and 100 Gigabit Ethernet and all of the physical layer specifications under development. The Media Access Control (MAC) layer, which corresponds to Layer 2 of the OSI model, is connected to the media (optical or copper) by an Ethernet PHY device, which corresponds to Layer 1 of the OSI model. The PHY device consists of a physical medium dependent (PMD) sublayer, a physical medium attachment (PMA) sublayer, and a physical coding sublayer (PCS). The backplane and copper cabling PHYs also include an auto negotiation (AN) sublayer and a forward error correction (FEC) sublayer.

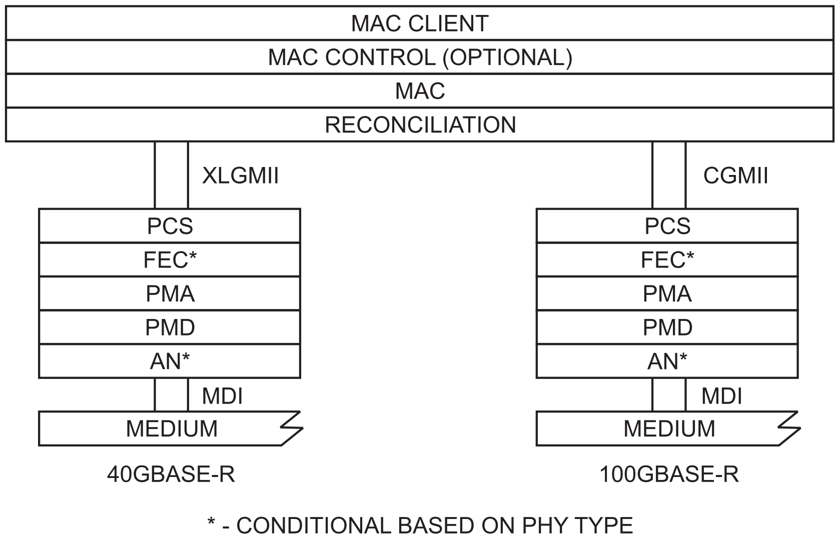


Figure 4 : IEEE 802.3ba Architecture

Beyond 100 Gigabit Ethernet : 400 Gigabit Ethernet or 1 Terabit Ethernet

With ever-increasing dominance of Ethernet, Terabit Ethernet seems to be the next step in data rate although some stakeholders feel that 400 Gigabit Ethernet may be a likely next step either as an independent standard or along with 1 Terabit standard.

The main reason for this speculation seems to be the simultaneous standardisation of 40G and 100G in IEEE 802.3. It is learnt that the requirement for increased bit rate to one terabit (1 Tb/s) has already been expressed by few stakeholders to keep up with the plethora of data services. While a few companies like Facebook and Google have expressed a need for 1 Terabit Ethernet, some other stakeholders like the component companies think that 400 Gigabit Ethernet is a more practical goal.

In response to the Industry request, the IEEE has announced the formation of "IEEE 802.3 Industry Connections Ethernet Bandwidth Assessment Ad Hoc," to assess the next rate of Ethernet.

Target dates between 2015 and 2020 have been named for the desired completion of a 1T Ethernet standard, even though the question of whether the customer base will be big enough to start serious standardization efforts is not yet fully settled [6].

Interfaces at 400 G seem to be a technologically viable next step for standardization, in both the LAN and the WAN. Due to widening gap between serial transmission research and commercialization, 400G LAN interfaces will likely continue the parallel transmission approach that has been exclusively taken by 100G Ethernet. The degree of optical parallelization is expected to increase further compared to the 100G Ethernet standards, demanding for denser photonic integration to make 400G commercially viable. With 400G, some optical parallelization may be entering the WAN, from the interface bit rate and spectral efficiency point of view. Significant optical parallelization will be need for 1T interfaces in LAN and WAN, even when taking into account the anticipated serial bit rate research until 2020. The need for optical parallelization will require substantial improvements in photonic integration technologies to meet some of the explicit requirements for Ethernet standardization, which include technical feasibility, economic feasibility and a broad market potential[6].

Ethernet will continue to evolve with increased network and bandwidth requirements to meet scale and cost requirements. Terabit Ethernet transport technologies can increase the capacity of optical fibers and therefore will form an alternative to new fiber deployments, with minimal impact on other network aspects.

The use of Terabit Ethernet will provide an opportunity to reduce the number of types of interface, as well as to reduce network latency and the number of managed wavelengths. Terabit Ethernet may be required in high capacity interconnections between switches and routers, notably at Internet exchanges (IXC), Internet Service Providers (ISP) and Points of Presence (PoP) for Core routers.

Visible Light Communication (VLC)

VLC systems are very similar to existing wireless systems. But they use electromagnetic waves (or, in this case, photons) to transmit signals over open air to receivers. The signals are modulated using an appropriate scheme upon transmission and then demodulated at the receiver for use by the end user. The unique characteristic of VLC technology is that the transmission media is the part of electromagnetic spectrum which falls into the visible range for the human eye.

Present day systems are based on LED lighting as transmitters. LED's, unlike fluorescent and incandescent lights, can be modulated in such a way that the changing power output is not visible to the human eye. LED's operate on the principal of electroluminescence. A LED, when forward biased with the proper voltage, will force electrons and holes to recombine and release photons of various wavelengths. Since these are semiconductor devices, the rate at which the power output can be modulated is very high. All, or a portion, of the LED spectrum can be utilized as a signal carrier. In quasi white LED's, the blue portion of the spectrum has the highest relative output power and therefore makes the best carrier. In RGB (Red, Green, and Blue) LED's any or all of the three separate LED's can be used to send a signal. The modulation scheme should be selected to achieve the highest data rate with minimum complexity possible. This is accomplished in the design of the drive circuitry. Receivers can be any type of module that is capable of detecting and then converting an optical transmission into a formatted data stream. Avalanche photodiodes make excellent receivers as they too are semiconductor devices that are not only fast, but can be very sensitive and designed with very high gains. Receiver modules will have the necessary circuitry to use the desired networking protocol such as Ethernet or DNP3.0 (Distributed Network Protocol). More sensitive receivers can improve system performance. VLC technology is protocol agnostic. It is typically targeted at being the "last leg" of the network, transmitting data from a router to the user. In fact, the simplest way to think of how VLC is used is to simply replace the standard "Wi Fi" transmitting modem with a LED. The LED serves as the transmission "antenna" and the optical receiver serves as the receiving antenna.

Source: Visilink (White Paper), 2012

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