Beyond Moore's Law

Oleh Sniezko and Xiaolin Lu
AT&T Broadband

Abstract

The computer industry has been proudly riding on the exponential curve based on Moore's law for decades. What Moore did not expect, and perhaps nobody has ever dreamt of, is that the photonic technology, especially its application in cable industry, has similar if not more profound impacts on the communication infrastructure and service delivery mechanism.

Since the advent of linear laser that introduced the optical transport technology into coaxial networks, the cable industry has embarked on extensive network upgrades that continually push fiber deeper into the network to evolve the infrastructure from a broadcast-based trunk-and-branch plant to a two-way broadband network with superior quality and reliability to deliver advanced telecommunication and entertainment services.

This paper will discuss the evolution of cable infrastructure from the point of view of a Photonic Moore's Law that is based on the continuous technology innovation in lightwave, RF, and digital processing. We will describe the new exponential curve that represents this evolution, starting from conventional Fiber-to-the-Serving-Area with fiber node segmentation, through DWDM-based Secondary Ring architecture, to the LightWire™ network with fully-passive coax plant, and to the CoraLight™ architecture based on digital and distributed processing platform with DWDM deployment to the last thousands feet.

PHOTONIC RULES

The innovation and implementation of photonic technology have been accelerating at much higher speed than what Moore projected for computer industry. This has been shown in at least three areas.

Firstly, many barriers in lightwave transmission and applications have been broken. The transmission speed and switching capacity has been increasing exponentially over the past 10 years **(Figure 1)** and reached more than terra-bits per second. 10Gbps system moved from laboratory fantasy to commercial products in 6 years, while the incoming 40Gbps system may only take half of that time.

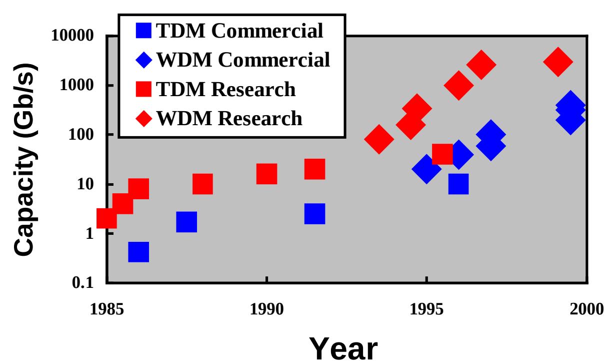

Figure 1. Single fiber capacity

Not only the speed, but also the applications of photonic technology continually broaden their horizon. The advent of linear laser introduced the optical transport technology into cable industry's coaxial networks, which enables tremendous opportunities for emerging service delivery that otherwise would be difficult over conventional twist pair based telephony networks or purely coxial RF networks.

Secondly, with aggressive deployment of lightwave technology, especially in access networks, the price of photonic components and systems has declined at a speed of 1.5 times of that in electronics and DSP **(Figure 2)**. This further motivates deeper fiber penetration and photonic technology deployment on even larger scale **(Figure 3)**.

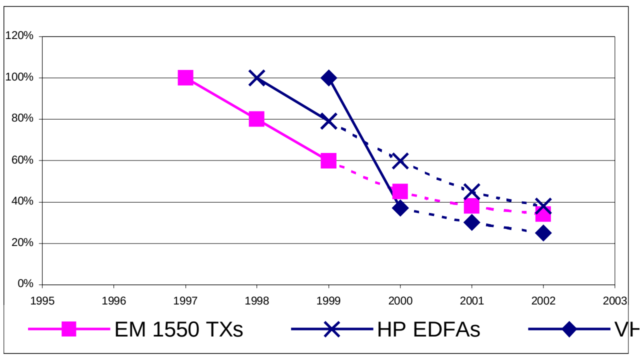

Figure 2. Price decrease of photonic devices

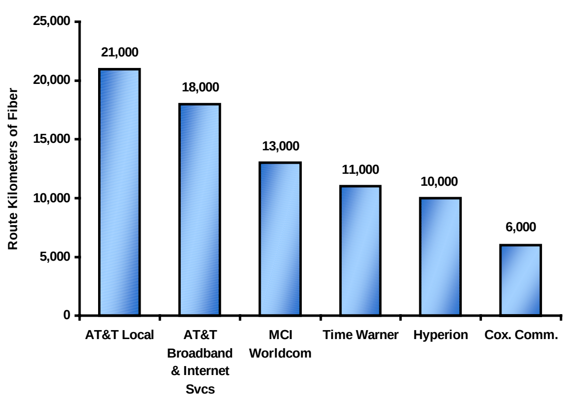

Figure 3. Top CLEC's fiber deployment

Lastly and most importantly, the photonic technology has stuck its head out of pure physical transport and moved to higher layer operation. Many network features and functions that were previously carried by electronic and DSP are now better performed by photonic components and systems. Examples include cross connect, switching, fault protection etc. This allows much more efficient and simpler operation and prevents software and DSP explosion due to the complexity of electronic processing.

All these changes enable new architecture alternatives and different ways of operating the networks with profound impacts on our business.

NETWORK EVOLUTION

Historically, cable networks were established for video broadcasting services. Ever since the advent of linear lasers, the cable industry has been embarking an extensive fiber deployment in the networks (HFC: Hybrid Fiber/Coax) to evolve the infrastructure from a one-way trunk-and-branch plant to a broadband two-way network with superior quality and reliability.

The total bandwidth in a HFC network has expanded exponentially over the past 35 years, enabled by the deployment of fiber optics and technology innovation in RF devices **(Figure 4)**. Most recently, emerging interactive services, always-on applications, and therefore substantially increased network usage increase demand for further bandwidth expansion, especially bases on bandwidth per household passed.

Further, new services, increased customer expectation, and competition motivate network evolution for simple and efficient operation, and continual cost reduction. All these lead to tremendous technology innovation in bringing a traditional broadcast cable network to a broadband two-way infrastructure and further to an end-to-end digital platform with wide implementation of the advances in lightwave and digital technologies.

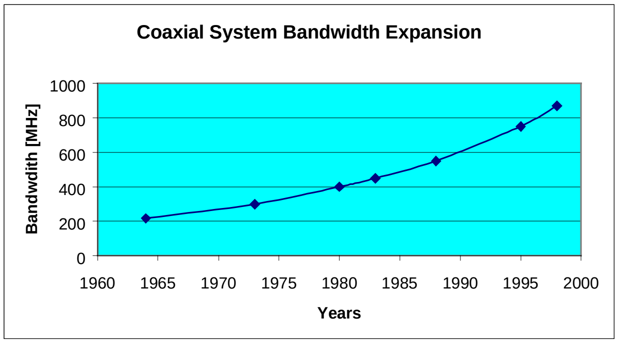

Figure 4: Coaxial Cable System Bandwidth Expansion

DWDM Ring and FN Segmentation

The purpose of fiber node (FN) segmentation is to increase the bandwidth per household passed (HHP) without incurring the cost of relocating fiber nodes and installing new fibers **(Figure 5)**. By dividing the original 1,200 HHP coax bus into four 300 HHP buses, quadrupling of capacity per HHP is realized. Using DWDM technology, end-to-end transparency can be achieved with DWDM Secondary Ring architecture with dedicated wavelength to newly created buses.

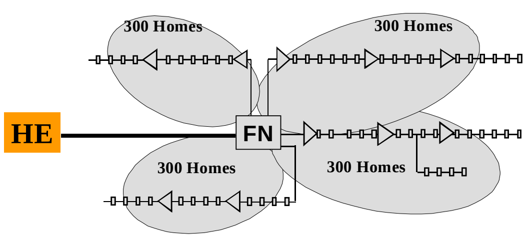

Figure 5. Fiber Node segmentation

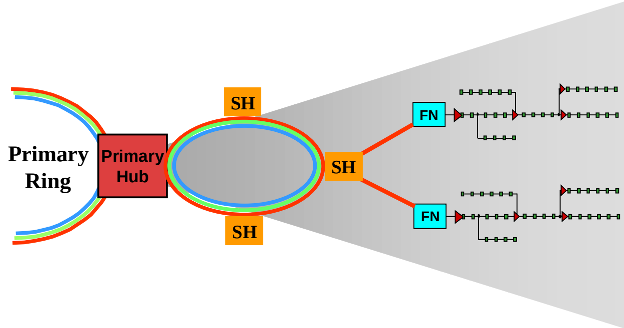

Figure 6. DWDM based secondary ring architecture

Secondary hub concept was introduced as a way of providing route diversity and lowering fiber counts in a single fiber cable route. Since then, secondary hubs have evolved into facilities for signal concentration and distribution, therefore supporting headend consolidation for advanced services **(Figure 6)**. Without this, operating emerging two-way services (telephony, data, etc.) becomes expensive due to the high fiber counts for optical cables connecting primary hub to each fiber node, or the operation cost of allocating HDT and CMTS at each remote headend. **Figure 7** shows the secondary hub architecture using DWDM technology. Combined with DWDM FN segmentation, end-to-end transparency is achieved.

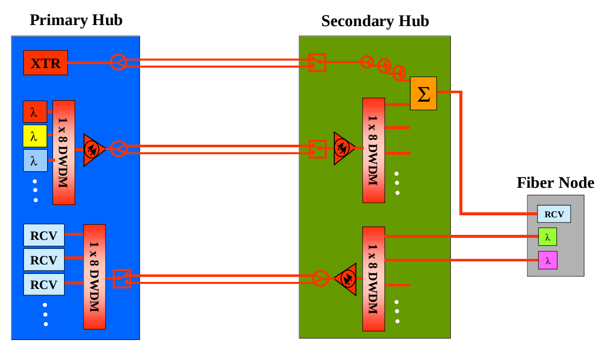

Figure 7. DWDM trunk

Fiber - To - What?

The Photonic Moore's Law enables deeper fiber penetration and deployment of advanced photonic technology in the network. The objectives are to:

1. Establish a future-proof network
2. Simplify operation and reduce operating cost
3. Significantly improve network reliability.

All these considerations lead to industry's continuous efforts in defining and re-defining architectural solutions for HFC networks to capture the ever-changing landscape of service demand and affordability (cost/benefit ratio) of new technological solutions.

LightWire™

The ultimate evolution of the FN based upgrades leads to *LightWire*™ architecture. In this architecture, mini fiber nodes (mFNs) eliminate all the coax amplifiers **(Figure 8)**, and carry both current and new services over passive coax plant.

Fibers connecting multiple mFNs are terminated at the MuxNode that resides either at the original fiber node location or at a location that "consolidates" multiple FNs. As its name implies, the MuxNode performs certain concentration and distribution functions. It "multiplexes" the upstream signals and sends them to the primary hub through the secondary hubs. It also "demultiplexes" the downstream signals received from the PH-SH fiber trunks and distributes them to mFNs.

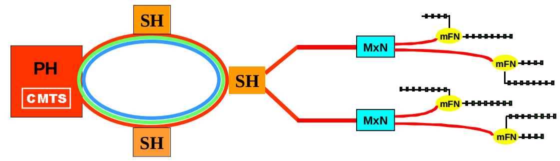

Figure 8. *LightWire*™

One of the interesting features of this architecture is that it maintains the characteristics of conventional HFC networks of being transparent to different signal formats and protocols, therefore fully supporting the existing operation for current services.

CoraLight™

One challenge the industry is facing is to provide flexibility for future expansion and growth provisioning while minimizing the incremental cost and service interruption. To resolve this issue, we proposed a so-called *CoraLight*™ architecture **(Figure 9)**. Based on their geographic locations, mFNs are daisy-chained together with three fibers: one fiber carrying downstream broadcast signals, one carrying the remaining downstream narrowcast signals, and one fiber carrying upstream signals. This therefore implements an optical bus (physical) while the previous *LightWire*™ architecture is a physical star. The advantages are the reduced fiber handling and the cost associated with it, and the flexibility for future expansion and growth (the optical bus can be further expanded to cover more areas). Our preliminary study indicated that, especially in green field situation, the cost of *CoraLight*™ is of parity with that of a traditional HFC network.

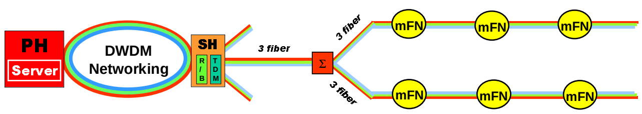

Figure 9. ***CoraLight*™**

Based on the physical bus, logical star or bus operation can be implemented. Using upstream transmission as an example, each mFN could perform repeating function to realize a bus operation **(Figure 10)**. On the other hand, utilizing WDM technology, a logical star can be implemented with the upstream traffic from each mFN being carried by different wavelengths.

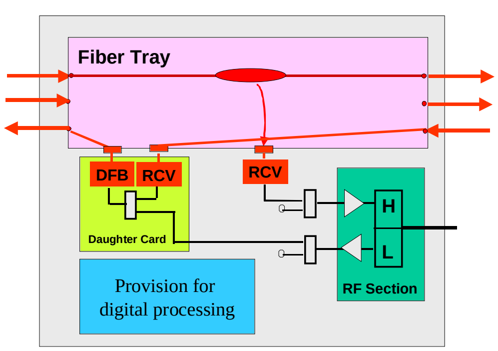

Figure 10. mFN platform with provisioning for the future

Analog to Digital

The linear lightwave technology enabled the implementation of RF subcarrier link over the hybrid fiber/coax infrastructure. This end-to-end format transparent link provides us with many different service delivery mechanisms and new service opportunities. On the other hand, with fiber penetrating deeper into HFC networks, the proliferation of RF technology, together with the power of DSP, motivates distributing certain control functions into the networks to simplify operation and improve network scalability. Terminating RF subcarrier link at the fiber/metallic transition point therefore makes more sense, if not just from cost reduction point of view.

In addition to digitizing the upstream RF bands, the unique position of each mFN enables a considerable simplification in defining media access control (MAC) protocols. Each mFN can do local policing, and resolve upstream contention within its serving area without involving other parts of the networks. The typical headend equipment can therefore be distributed into the network. For example, the RF interface (modulator and demodulator) and MAC functions can be placed at mFNs and the multiplexing/demultiplexing functions can be placed at the secondary hub. By doing this, the current RF optical transmitters and receivers can be replaced by digital ones, and passive optical network (PON) technology, such as spectrum slicing technique with high power LED and DWDM add/drop at each mFN, can be utilized. This further simplifies the transport network, reduces its cost, improves service performance, and enhances network flexibility and scalability.

More On Photonic Rules

The amount of fiber in HFC network has been increasing continuously over the past 12 years from 5% in fiber backbone architecture to 30% in the *LightWire*™ architecture. Different from Moore's prediction, the photonic technology not only contributes to the speed of the transmission, but also adds more features and values to the communication network. DWDM technology, together with the power of DSP and RF technology, provides us with more flexibility in network operation and service provisioning. It is our belief that this trend will continue **(Figure 11)**, and it is certainly to our benefit to take advantage of these opportunities.

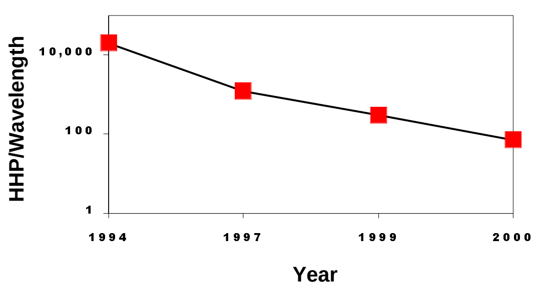

Figure 11. DWDM deployment: HHP per wavelength

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