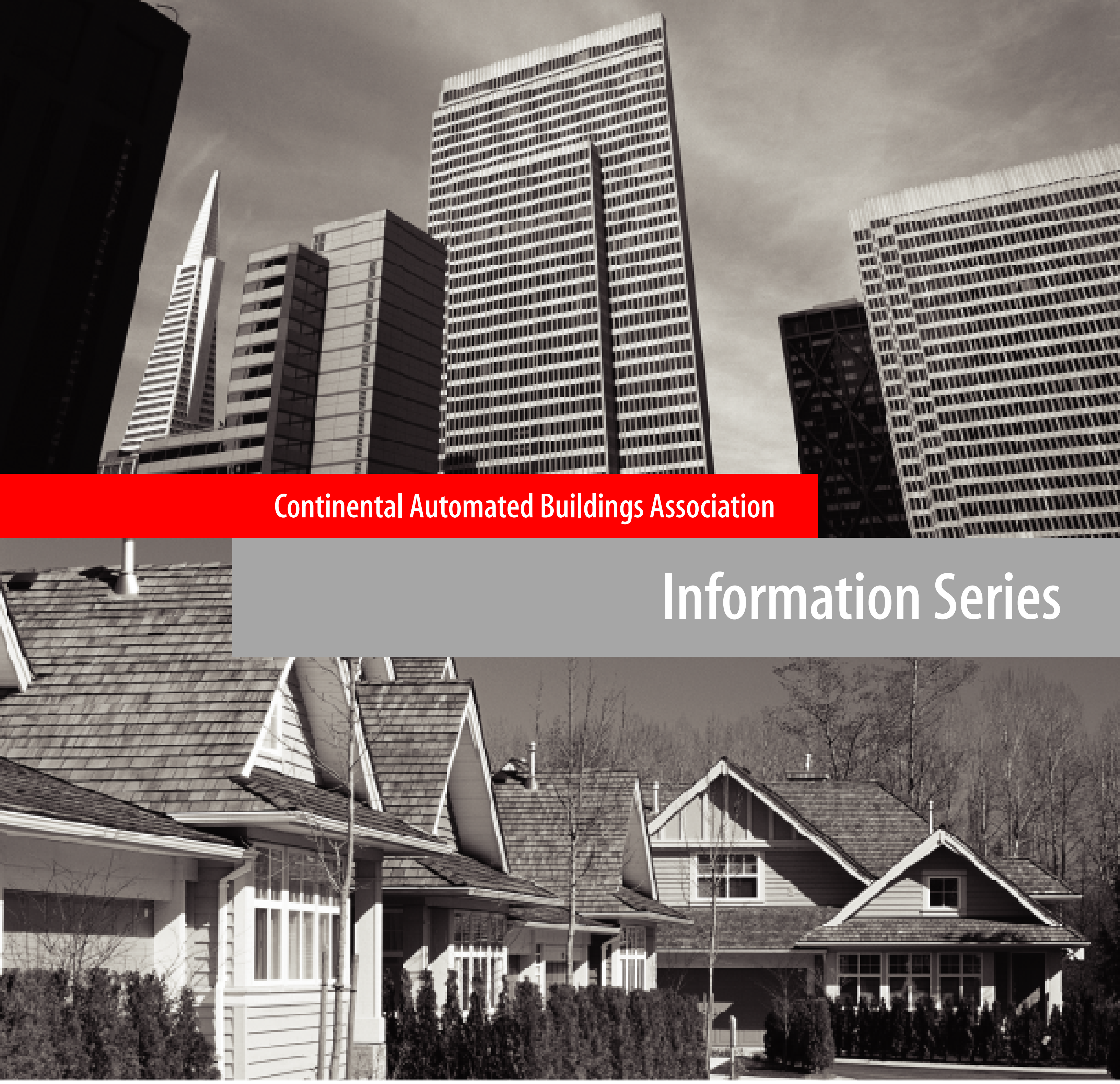

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Fiber-to-the-Home White Paper

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Fiber-to-the-Home White Paper

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Fiber-to-the-Home White Paper

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Why talk about fiber to the home just now?

For almost as long as fiber optic communications has been around, recurrent optimistic predictions have appeared to the effect that soon this communication medium would extend into user premises, both business and residential (FTTB and FTTH, respectively). And just as frequently, these visions have succumbed to the realities of economics, regulation, the persistence of entrenched existing technologies, and just plain inertia. Given this dreary history, why should one think that today's picture is any different? And especially now, when the telecommunications sector is in such bad shape financially? Well, there are actually one or two very large motivations plus a number of small, disconnected pieces of progress underway that weren't there as recently as two years ago, that argue a much more favorable view at this time. Things are happening with **user** pressures for faster, cheaper access solutions, with movement in the **technology** community to respond with solutions, and with the opportunities to break the current **regulatory** disincentives that are impeding the ability of the technology to serve the users.

This white paper reviews these recent events, technical, economic, regulatory and societal, and comes to a favorable conclusion about the prospects for a real turnaround within the next two to three years. In this discussion, we shall lump together homes and small businesses (those having less than, say, several hundred employees), since the access requirements for residences and businesses only diverge strongly for larger business, e.g. those that require some form of protection switching of their communication routes.

From the broadest viewpoint, that of society as a whole, one can make the argument that extending fiber to the premises is not a mere luxury, but almost a necessity. Nobody needs to be reminded of the present stagnation in the telecommunications business, brought on partly by the development of excess capacity in the interoffice facility backbone. But there is also stagnation at the premises end - in the computer part of the information industry, as evidenced by the fact that the time span between new innovations and new generations of both hardware and software are growing ever longer, and also by the fact that few of these innovations are communication-based. A computer is more than a Gb/s window into what's on the hard drive; it is (or can be) a Gb/s window into the entire information world. When one sees the telecommunication capacity going to waste while the computer industry's innovations, such as they are, are almost completely intra-machine innovations, not inter-machine, one begins to sense the economic potential and societal benefit in opening up the bandwidth bottleneck between them.

To put this bottleneck in quantitative perspective, one need only consider Figure 1, which portrays the multi-gigabit per second environment inside the typical laptop or desktop, connecting the long haul and metro facilities of the carriers by means of a local "last mile" link typified today by rates like 28.8 to 56 Kb/s. The bandwidth starvation imposed by the bottleneck is huge – up to five orders of magnitude.

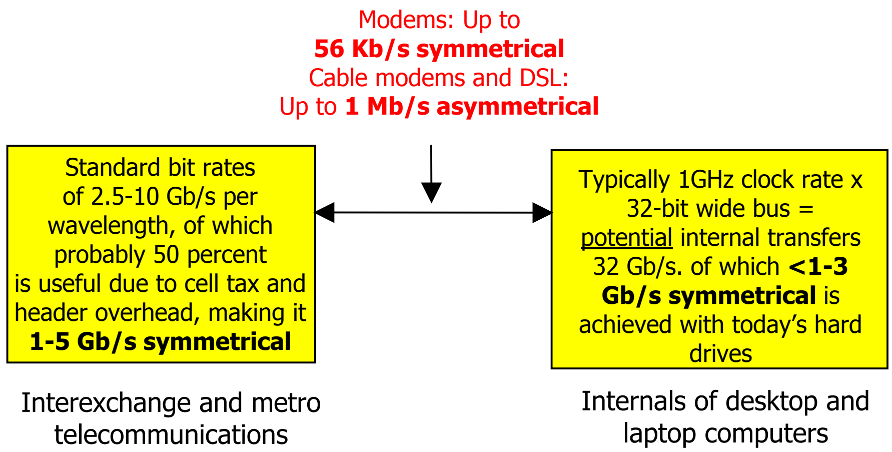

Figure 1 – The "last mile" bottleneck between telecommunications and the desktop

But - I hear you say – won't the rapidly proliferating "broadband" in the form of Digital Subscriber Line (DSL) or cable modems satisfy all reasonable demands for a long time? DSL is the broadband solution of the incumbent local exchange carriers (ILECs), particularly the large ILECs (the former Regional Bell Operating Companies - RBOCs), while cable modems are being deployed by the cable operators, sometimes called multiple service offerers (MSOs).

The answer, in my view, is that both these systems offer such modest bit rate increases (Fig. 1) that they are at best only interim solutions and most unlikely to lead to a truly significant improvement in the state of the electronic information industries or in the productivity of us end users served by them. Both systems are limited to rates per subscriber on the order of several Mb/s downstream and a few hundred kilobits upstream due to propagation, congestion and crosstalk considerations. Thus, at best, they offer no more than one to two orders of magnitude improvement over voice grade modems. There still remain some four more orders of magnitude of bandwidth starvation compared to the usable internal rates of both telco and computers. Furthermore, the high degree of bit rate asymmetry of both DSL and cable is counter to the trend toward more peer-symmetric traffic loads for some important new applications. And both DSL and cable modem solutions, while featuring fairly inexpensive modems have high lifetime maintenance and service costs. Thus, while they are interesting and sophisticated, they hardly represent a game-changing revolution.

Enter the Passive Optical Network

On the other hand, there are FTTH installations that are going in today, based either on Gigabit Ethernet or Asynchronous Transfer Mode (ATM), providing at least OC-12 rates (0.6 Gb/s), time shared by contention between users at typical user burst rates of 100 Mb/s to 1 Gb/s (e.g. 100BaseT or 1000BaseT Ethernet), at least four orders of magnitude improvement over voice grade modems.

Service	Medium	Intrinsic bandwidth	Per-user offered peak bit rate down//up	Standard	Issued by
DSL	24-gauge twisted pr.	10 KHz. 10 KHz.	ADSL: 1//0.1 Mb/s* VDSL: 6/6 Mb/s @1Kft.	G.992 Emerging	ITU ITU/ETSI
Cable modems	Coax (HFC)	1 GHz.	2 //0.4Mb/s*	DOCSIS 1.1	CableLabs
APON	Fiber	25,000 GHz.	622Mb/s//155Mb/s[2]	G.983 (FSAN)	ITU
EPON[+]	Fiber	25,000 GHz.	10 – 1000Mb/s//10-1000Mb/s[1, 3]	802.3ah[+]	IEEE

Figure 2 – Summary of last mile technologies and standards. + = not completely standardized. * = user rates delivered for significantly loaded systems in the New York area (N.Y. Times, Oct. 17, 2002).

Figure 2 tabulates the bit rates and standardization activities involved in DSL and cable modems on the one hand, and Ethernet-based and ATM-based "passive optical networks" (EPONs[1] and APONs[2], respectively) on the other. PONs, one of several options for FTTH/B, are all-optical solutions wherein there are only passive splitters between the central facility and the customer premises (Figure 3). A PON is not really a true optical network in the topological sense, but simply an all-glass tree, sending outgoing and incoming signals on different wavelengths (coarse wavelength division multiplexing – CWDM, as distinguished from DWDM – D for dense) or perhaps using two coterminous fiber trees, one in and the other out.

As Figure 3 shows, the typical PON being deployed today provides one-stop shopping for a complete **triple play** set of end user services:

- Several RJ-11 twisted pair **telephone** connections (POTS – plain old telephone service), served at the head end (also called the CO – central office, or POP – point of presence) from one or more 155 MB/s G.303 traffic and control interfaces to the central office switch that is part of the public switched telephone network,
- 10, 100 or even 1000BaseT Ethernet **data** services from RJ-45 connectors and Category 5 cable, served at the CO by one or more IP routers with IP over Ethernet interfaces, and finally
- **Television** distribution, derived from satellites or microwave facilities.

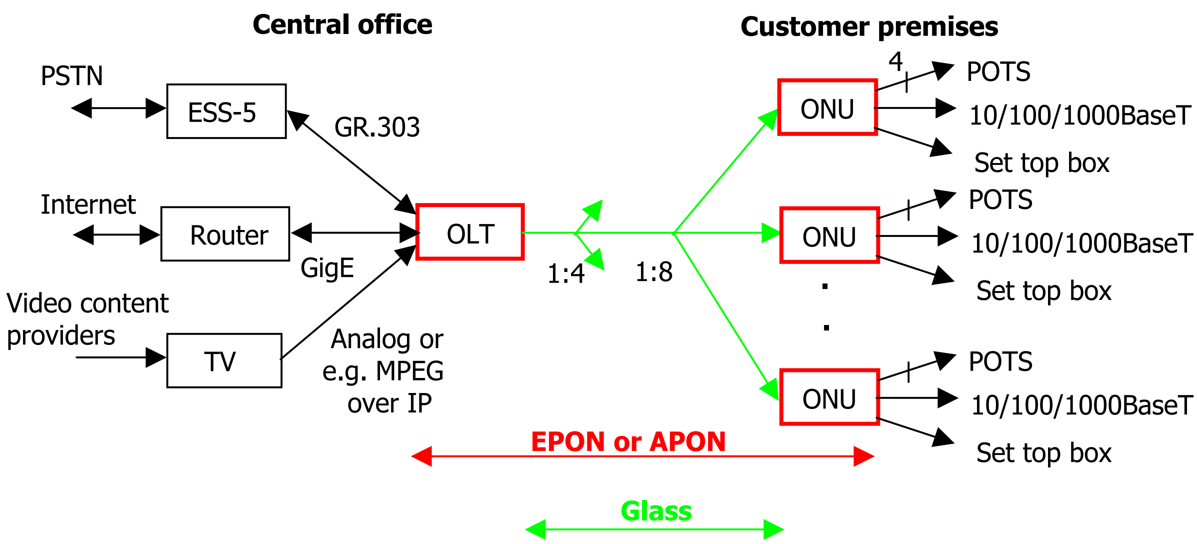

Figure 3 – A typical residential passive optical network using a single bidirectional fiber for all of the one-stop triple-play services: voice, data, and video. For businesses, bidirectional T1/E1 and T3 service for PBXs replaces the unidirectional TV service to set top boxes.

Not shown in Figure 3 is the fact that for fiber to the business, some of the capacity otherwise going for television is replaced by T1 and T3 appearances to serve customer PBXs. Also, larger businesses tend to format their communication resources into virtual private networks (VPNs), today's (often IP-based) successor to earlier enterprise networks of leased private voice-grade and T-carrier lines.

For video, there has been little standardization; some PON system providers offer over intra-premises coax an analog sum of many analog RF TV channels to a set-top box using very linear 1550 nm lasers at the CO to minimize intermodulation products, while others provide MPEG digital video to the set top box over premises coax in the style of direct broadcast satellite video. If digital video is sent from the CO, the CWDM wavelengths (C for coarse) are 1550 nm downstream for all three services and 1310 upstream for voice and data. If analog video is to be delivered all the way from the head end on the same fiber tree as POTS and data, then it travels outbound at 1550 nm while the data travels outbound at 1490; voice and data travel inbound at 1310 nm, as before. The optical splits shown in the figure are being standardized at 1:4 and 1:8, as shown, but these numbers are arbitrary in practice.

FTTB and FTTH can be regarded as the logical endpoint of an ongoing evolution that is shown in Figure 4. In the pre-fiber days, telco COs were interconnected by coax and microwave, while cable headends were fed by microwave or satellite. The first step in "fiberizing" the entire system was Hybrid Fiber Coax (HFC) (being widely deployed by the cable industry today) or VDSL (Very High Speed Subscriber Line) its telco twisted pair rough equivalent, in which the **node** becomes an **optical network unit**. HFC serves several hundred homes per fiber end, each using copper (coax) in both directions between "node" and subscriber, but with limited bit rate and very demanding design rules. Similarly, DSL is supplied to residences[4] over twisted pair from either a centrally located DSLAM, a remote DSLAM[4] or a VDSL ONU, with some remnant crosstalk problems.

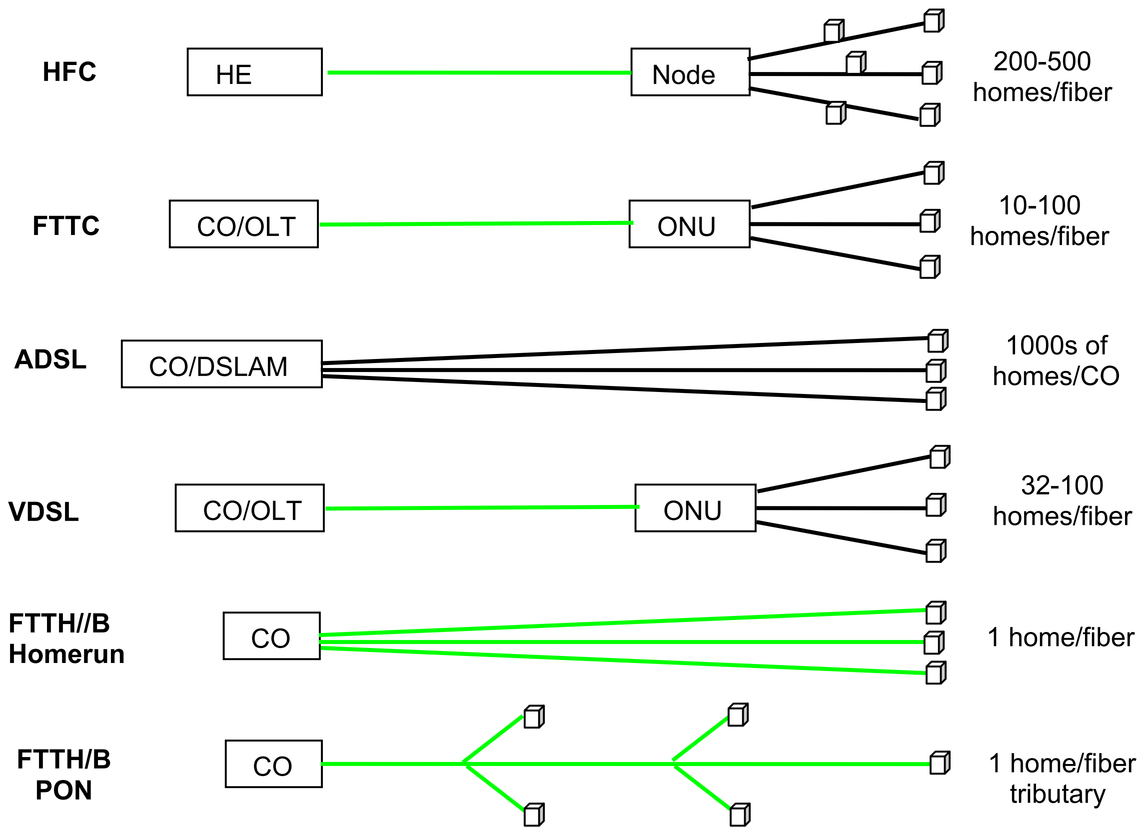

Figure 4 – The evolution to one fiber appearance per home or business - From HFC to FTTH/B. Fiber is represented by green lines, copper by black.

Figure 5 takes a different cut at the evolution, and shows the historical and predicted percent penetration of all fiber carrying both telco and cable traffic whose ultimate terminus is at residences.

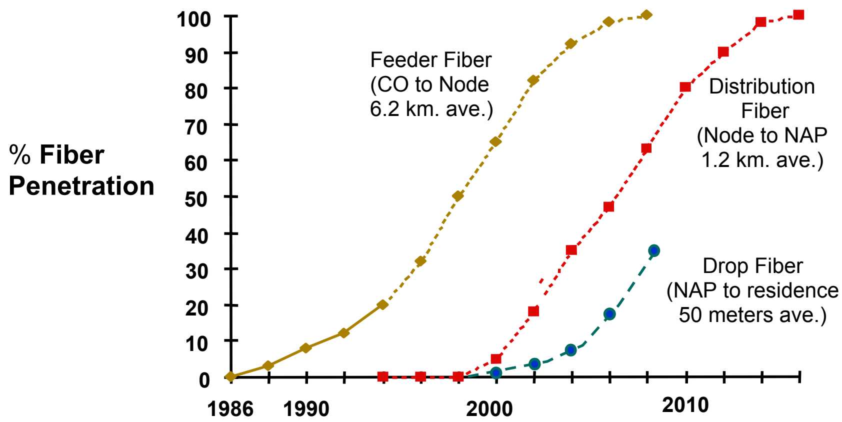

Figure 5 – Depth of fiber penetration to node, curb and residences.
NAP = network access point (pedestal) (Data courtesy of Corning, Inc., 2001)

The slowly emerging fiber to the curb (FTTC) systems split each upstream or downstream fiber into 10-100 subscriber copper paths. It is not clear that FTTC systems offer any economic advantage over full FTTH/B, which is just the logical extension of HFC to FTTC to a single subscriber per fiber. Because of their non-optimum economics, both FTTC and deep-fiber DSL (specifically VDSL – very high speed DSL) are likely to be overtaken by the clean passive-all-the-way FTTH option, and thus never really make a strong appearance outside the history books, in my opinion.

Another all-fiber solution is the homerun architecture also shown in Figure 4, which some providers are finding attractive, since long runs of multifiber cable are almost as economical in both material and installation costs as the same lengths of cables with one or a few fibers. The problem is the large electrooptic port count at the central office. However, there is the option of mitigating this by doing an optical split right at the CO, so that one optoelectronic port serves a number of subscribers in TDM mode, whereupon the homerun system becomes a PON, by my definition.

In my opinion, such home-run PONs represent a wastage of resources, since for the foreseeable future, the duty factor for most user services will remain low, so that it is not necessary to provide a complete 100-percent duty factor optical path between CO and each user. What drives the user to require high bit rate for his chosen broadband services service is the fast response time required; each user is unlikely to need full bandwidth all the time for the foreseeable future.

The same argument of low TDM duty factor being sufficient argues against DWDM PONs, which make an appearance in the literature from time to time. These PONs suffer from the high logistic costs of stocking and providing frequency-stable subscriber laser diodes at a great many specified wavelengths.

Today, both APONs and EPONs have their enthusiastic partisans. APON promoters argue that the Full Services Access Network (FSAN) standard is approaching maturity faster than that for EPONs (802.3ah), that significant APON volumes have already been achieved, that the significance of the infamous “cell tax” overhead of ATM (with its processor interrupts every 53 bytes) is partially mitigated by the large IP and Ethernet header overheads, that ATM software and hardware is already qualified with the ILECs, and that quality of service guarantees (e.g. constant and low latency for POTS) are established attributes. EPON partisans, on the other hand, argue that Ethernet (with 350 million ports already installed) will always be the lower-cost solution, that POTS traffic (for which ATM was invented) constitutes a negligible part of the PON traffic anyhow, that any remaining quality of service issues have been resolved by small architectural changes to Voice Over IP (VOIP), that the addressing limitations of the old IPv4 are being fixed in Ipv6, that the ATM cell tax and segmenting-reassembly processing overheads are significant, that time jitter does not occur anyhow since there is no packet/cell queuing between subscriber and CO, only at the CO, that the offered bit rates are higher (Figure 2), that Ethernet is easier to manage, that APONs are seen nowhere except North America with Ethernet the norm elsewhere, and that most data begins and ends its life as IP/Ethernet traffic anyhow, so why interpose still another protocol encapsulation? If the world is not all-IP today, it is certainly rapidly moving in that direction.

It is my opinion that it really makes little difference architecturally whether the internals of the PON speak Ethernet or ATM, since the interfaces to the user and to the CO equipment are identical in both cases (Figure 3). The important issue will be cost to the end user and speed of acceptance. In view of the superior component cost for Ethernet chips compared to ATM chips, perhaps the only thing that will give the race to APONs is that, if the large incumbent local exchange ever get moving with PONs, they may cling to ATM because of its familiarity and its existing certifications. If I had to make a prediction, I would say that in the long run APONs will go the way of ISDN – not completely dead, but a minority player.

What's driving FTTH?

Just because the pictures of Figures 3 and 4 are structurally pretty, and Figure 5 shows ever deeper fiber deployment going on routinely, what are the real, cold-blooded, compelling factors, if any, that support the claim that FTTH (whether or not in PON form) is irresistibly preferable to the emerging HFC or FTTC and is going to happen within a few years?

The many drivers toward FTTH can be broken down into several classes:

- Technology cost and performance improvements
- Pressure from emerging applications to break the bandwidth and symmetry limitations of DLC and cable in all their forms, and
- The actions of federal and state regulators.

In the next three sections we shall dig into each of these drivers in more detail.

The technology cost and performance drivers

In most optoelectronic systems the cost of the optics dominates the cost of the electronics, and FTTH systems are no exception. The expensive optical items include the lasers, especially the highly linear 1550 nm lasers required at the OLT for FDM analog TV service, the lower powered lasers at the ONUs and the splitters and WDMs associated with the coarse WDM basis of the system. Photodetectors and their associated electronic amplifiers are less of an economic factor.

Here are some recent data on relative costs to the provider of a PON fiber installation and the PON optoelectronics [5, 6]. Averaging over subscriber link length, type of terrain, and take rate, per-residence cost of the PON equipment averages about $1500 dollars today, compared to the total cost of PON equipment plus fiber facilities installation of $2000 to $2500 per residence, so that the PON equipment represents between 55 and 75 percent of the total cost to the provider. These numbers are low enough that providers are now able to create positive business cases for providing triple play services (with POTS perhaps being priced as distance-independent) for numbers like $70 per month (2.4 to 3 years payback period). This $70 per month figure for triple play services is to be compared to current household bills for POTS plus data and cable TV as separate monthly bills.

The optoelectronic equipment cost is a significant enough fraction of the total cost in the last mile that the future of FTTH is going to depend significantly on cost reduction in the optics. For example, one recent estimate [7] cites 15% of the cost as lying in central office optoelectronics, 40% in the distribution network and its installation, and 45% in the customer premises optoelectronics and its installation. The same source breaks down the 40% for the infrastructure as follows: 53% in construction, 10% in engineering, 20% in couplers and splitters, 9% in splice closures, and only 8% in the cost of the fiber itself.

A lot of optoelectronic cost reduction is already happening. The same kind of creativity that has been applied by the optical networking fraternity for the last decade to increasing functionality is now being applied to the problem of cost. For example, passive splitters, which cost over $100 per port a year ago, are now available at $25 per port in large quantities.

While clever things are happening in the optical component world, equally inventive things are happening in the civil engineering of fiber installation. Machines can now cut narrow grooves in the pavements along city streets to lay in fiber bundles, provided the bundles are limited to a few tens of fibers. Small trenching machines install plastic ducts one to two feet underground and remotely controlled directional drilling robots extend the path of the duct under driveways, under highways, and in one case, for some 6000 feet under the Hudson River from the World Trade Center to Jersey City. If the shorter ducts do not already contain the fiber, it can be later blown in by compressed air, a technique that allows upgrades and rehabs without further excavation. It is now possible to send a craftsman up a utility pole to perform single or multiple (ribbon) fusion splices, a process that was thinkable only in the laboratory not many years ago.

Thus, the costs, particularly the lifetime costs, of the all-glass solution are comparable to or less than those of any of the copper-based solutions, since the latter include along the right-of-way hot, finite-lifetime electronics with periodically spaced localized backup power sources. Some of the electronics cost is for data compression and decompression, unnecessary with fiber because of its huge offered bandwidth. Cost dominates everything in the last mile to a much greater extent than with the more traditional metro and long-haul situations, which are supported by aggregated revenues from many subscribers.

As with full DWDM optical networks, the glass is transparent with respect to legacy or future bit rates and formats. The need to support protocol variegation becomes more acute the farther one progresses outward from the telco backbone (using almost exclusively SONET/SDH today) toward the premises, with its infamous “protocol zoo” of dozens of new and legacy protocols.

As part of this future-proofness, there are fiber’s enormous available and scalable room for growth in bandwidth (See Figure 2) and its freedom from crosstalk and tappability by intruders.

Also, fiber’s low attenuation translates into low power transmitters and relatively insensitive receivers, but also into much more convenient design rules for the installation than those available for DSL or cable, where great care must be taken about segment length, selection of cable type, variable attenuator and equalizer settings and so forth. Furthermore, the passive nature of the PON medium, and the fact that the electronics is only at the ends means that provisioning and reprovisioning are accomplished much more quickly than with systems embodying electronics along the right of way.

To the technical innovators of the optical communication technical fraternity, the low-tech aspect of FTTH/B, being based on CWDM, not DWDM (D for dense, C for coarse), seems less romantic and exotic area than DWDM optical networks. However, the payoff, both in money and in general societal benefit is likely to be much more significant. When one compares the potential effect that a new FTTH innovation has on hundreds of millions of subscriber facilities, whereas, even in its headiest days a DWDM optical networking advance affected only a few hundred interexchange facilities, one sees why it is important for the optical technical community to become more engaged. A recent perusal of the periodicals of IEEE and similar bodies shows a continuing preoccupation with research results, mostly from university and industry researchers. These publications offer almost zero enlightenment about FTTH challenges and opportunities.

Application pull or technology push?

The answer is both. Fiber to the home seems poised today at the classic point where growing user demands and rapid technological progress converge to enable a significant “paradigm shift.” Today, not only is the technology more practicable, but real businesses can be built and real societally useful deliverables can be gotten by driving the FTTH/B evolution forward.

Skeptics of the immediate user needs for access technologies beyond DSL and cable abound, and their arguments center around the lack of clarity about immediately pressing “bandwidth pig” applications. However, in my opinion, while the application drivers may not be in the front of everyone’s consciousness at the moment, they are nevertheless emerging, and the pressure to accommodate them with post-DSL/cable solutions is becoming clearer daily.

Many of today's broadband applications are being driven by the Internet, others by broadcast television, and still others by Hollywood. They can all be broken down into two classes:

- Medium-size file transfers absolutely requiring low latency, for example video conferencing, interactive games, and telecommuting.
- Transfer of files whose latency is not so important, but for which long transfer times are annoying: video (movies) on demand, video and still-image email attachments, program sharing and downloading, e.g. of entire books.

Many argue that the most immediate application pressure relates to on-line movie rental on demand. Today this potential application suffers from intense user dissatisfactions with a delivery time of several hours to download a full movie, even at cable modem speed. A trip to Blockbuster across town is quicker.

Another immediately useful application is remote disk backup at centralized secure servers, where the remote facility is mapped as a local drive. At the PC level, this has the potential of displacing today's large sales of Zip drives, writeable CDs, etc. At the commercial DP level, this application has been around for a long time, and was the initial motivator for the earliest DWDM systems. Now the earlier point-point connection of a data center to a remote backup facility has evolved into the Storage Area Network (SAN), a more topologically complex structure aimed at even better data availability, high speed and low-latency performance. The potential of this application is constrained today by the excessive time required to communicate large files, much less the entire PC or data center hard drive contents.

Television is evolving in directions requiring broadband capability, even peer-to-peer such capability: HDTV, Napster-like sharing of data files, then music, then video snaps, then movies. In light of the present stagnation of HDTV broadcast, one might argue that HDTV's future is to some extent captive to FTTH's future.

Then there are the unpredictable applications. While history shows that it is usually some unpredicted application that later becomes the most important one, it also shows that it is the predictable ones, like those just listed, that pay for the initial transition. For example, while email turned out unexpectedly to be the most important use of the Internet's parent, the ARPAnet, the promise of resource sharing for a few very expensive specialized computers was enough to justify its introduction economically.

Similarly, there is a set of pressures that allow us to perceive, albeit only dimly, the outlines of what it will mean in handling numbers, words, correspondence, images and games when the last mile bottleneck of Figure 1 is relieved. This will constitute the "Second Coming of the PC," the first one being the 1980s revolution that empowered localized individual use of compute power. Closing the last mile bottleneck will ignite a takeoff of communication-based two-party and collective information processing.

For the post DLC-and-cable-modem world of FTTH/B, several of these application pressures are already recognizable. Starting with the earliest PCs, for which a modem was a luxury option, users have long since come to regard the computer as a communication portal to the rest of the world, albeit one in which the rest of the world cannot be reached as conveniently as can material stored locally on disk or in memory.

Response time plays a key role in human productivity in using computers. A classic psychophysical study [8] some years ago showed that for many kinds of multi-stage processing jobs, when the response time of each step goes below several hundred milliseconds, to the user's mind the individual stages begin to merge into one simple stage, and throughput increases by a large multiple. Thus, one reason the last mile bottleneck is such a constraint is the increased size of the data objects that people use in communication-based information processing. The pressure is to replace email with voicemail or video messages, thumbnail images with full-screen images, static images with video. And yet to keep the productivity of the single step continuum mode of multi-step job handling, we need to be able to communicate all these objects with the same response time we've learned to live with for text commands or mouse clicks for local execution.

Another point is the increasingly peer-to-peer nature of this intercommunication, the example so often cited being music file sharing provided by Napster and its clones. Each of today's standalone ways of handling of numbers, words, correspondence, images and games can be seen to represent a special case of a larger universe of peer communication based versions of the same thing. For example, sociologists have frequently commented on the antisocial nature of children's battles with aliens inside their own machine versus having your aliens battle someone else's aliens. Today, multiparty games are low-resolution, slow response time affairs.

Sustaining the success of DSL and even cable modems is going to be difficult, not just because the bandwidth demand will grow to unsupportable size, but also because of the well-known capacity asymmetry due to upstream noise and crosstalk accumulation. And, satellite broadband has essentially no future in a world in which peer connections represent a sizeable fraction of the total.

One last point concerns videoconferencing. The longstanding vision of being more able to "exchange communication for transportation" has taken on a new urgency since the events of 9/11. The insufficiencies of the available video conferencing technology send a large number of people onto airplanes to attend meetings of fairly simple structure for which today there is no adequate electronic substitute, on providing the needed full interpersonal communication between multiple participants, complete with eye-contact and other cues. The missing link is communication bandwidth, since promising high-resolution display and stereo hi-fi audio technologies are well in hand.

The regulatory and legislative picture

Another important driver of the FTTH trend is the fact that the fiber medium is largely unencumbered by many existing inherited regulatory restrictions, unlike copper, particularly the 24-gauge twisted pair that has served as the jealously fought over crown jewels of the ILECs (incumbent local exchange carriers), classically based on POTS as the cash cow. A new turn of the crank that allows all players to innovate with this new medium without carrying along all the historical regulatory and legislative baggage relieves the carrier industry of its traditional dependence on expensive armies of lawyers and lobbyists as the price of business survival, particularly against the rapidly expanding and relatively less regulated cable industry, which is also allowed control over the content of programs and other services.

Just such a new turn of the deregulatory crank occurred on February 20, 2003, when the FCC ruled by a 3:2 margin to relieve the four large ILECS of the very onerous "unbundling" requirement in the particular case of FTTH, while insisting that the "ILECs must continue to provide access to a transmission path suitable for providing narrowband service [for which read POTS] if the copper loop is retired."

Prior to this, one of the principal justifications cited by the RBOCs for their inaction in introducing new technologies was this unbundling requirement, laid on them by the Telecomm Act of 1996[9] as the price of their being allowed to continue their local monopolies. This requirement said that in an area where a carrier was **dominant** (a monopoly), its facilities (copper and fiber lines, central office floor space, etc.) had to be administered and priced as unbundled physical network elements (UNE-Ps) and shared with competitors at a fair price. While designed to stimulate competition, this backfired, acting on the ILECs as a strong deterrent to innovation in general and the fiber last mile in particular. They saw a strong disincentive to paying for improving the facilities, only to suffer immediately loss of any competitive advantage in doing so. It has been widely thought that, all good reasons to the contrary, the large ILECs would not move into FTTH/B until they get regulatory relief from **all** the unbundling requirements that have been imposed by the regulators, and that continuing "show time" field trial activity, such as SBC's important field trial in Mission Bay, CA and Bell South's in Dunwoody, GA, need not be taken as representing serious corporate directions. In other words, the carriers turned a legislative disaster into something of a short-term asset by holding future technical progress hostage while they negotiated for all the roll-back of regulatory oversight they could get. However, this school of thought also held that a deal might be cut if the regulators declare FTTH/B to be **nondominant**, and thus outside the forced unbundling stipulations of the 1996 Act.

The February 20 FCC ruling now does this and, by removing an important excuse for inaction, challenges the RBOCs to move ahead with FTTH/B. This levels the playing field, and while the telcos are uncomfortable competing on an equal basis, this would seem to me to be their road to future prosperity in a world where POTS recedes in importance to be just a bit rate bump on the larger total broadband access market.

The history leading up to this is interesting. Postponement of this desirable outcome came with the Tauzin-Dingell Bill (H.R. 1542 of the 2001 Congress), which proposed to undo this unbundling, but which is widely regarded as going nowhere, because, since it undoes the unbundling requirement for **any** broadband technology, it has come to be seen as a giveaway to the large ILECs. However, in the same session, matching bills were introduced in both Houses of Congress (S.88 by Senator Rockefeller and H.R. 267 by Rep. Nussle) that skirted the unbundling issue but offered large (20 percent) tax credits for companies deployed bi-directional systems that provided more than 22 Mb/s. service downstream. This figure seems to have been cunningly chosen to be beyond the reach of both DSL and cable for the rural and low-income areas specified, and thus a stimulant to FTTH/B. These two bills are presently being studied in committee. The most recent additions to the litany of bills to deregulate aspects of broadband access are those introduced by Senators McCain (S.2863), Hollings (S.2448) and Breaux-Nickles (S.2430). Many of the bills that have been introduced to liberalize the broadband last mile situation in the U.S. have not only proposed changing the regulatory environment, but furthermore to accelerate the process by offering Federal Government subsidies, a measure with a long and illustrious history whenever a new technology is needed, going back at least as far as the introduction of nationwide railroads.

According to one school of thought, the February 20th ruling, while removing an important excuse for inaction, may not do the trick. It may turn out that the RBOCs are fundamentally disinterested in offering FTTH/B progress in exchange for regulatory relief. They may continue to fight the last war, battling over unbundling of, you guessed it, DSL facilities, in the FCC and in the courts. They may even sue the FCC to try to get the FTTH wording quoted earlier overturned. The decision was, after all, not unanimous.

The large ILECs have many lawyers and many tricks in their bag that amount to mere fingers in the dike, in my opinion. They have managed to get provision of communication facilities by municipalities declared illegal, for the moment, in Arkansas, Florida, Missouri, Minnesota, Nebraska, Nevada, Tennessee, Texas and Utah. In some areas, they have gotten around regulatory oversight (especially the dreaded forced unbundling) in some areas by delegating ownership of the facilities to subcontractors.

As for competition from cable companies forcing the issue, some claim that the current standoff between cable and telco industries will be stable indefinitely [10]. They argue that the current cable/telco duopoly amounts to a gentlemen's agreement of the two industries not to poach on each other's territory. As evidence that this an unstable arrangement, there is the steady march of triple-play offerings by the cable companies, for example Cox Cable, which, as of mid-February, 2003, announced that typically more than 30 percent of its customers get their phone service from Cox.

The players – the FTTH food chain

As the technology, application and regulatory forces evolve, there is a hierarchy of solution providers who must be considered in forming a total picture of the future of FTTH/B.

- Base technology manufacturers (fiber, low-cost uncooled lasers, etc.)
- Box manufacturers (OLTs or OLT blades, ONUs, set-top boxes, etc.)
- Installation technology developers (trenching, fusion splicing, etc.)
- Installers (turnkey trenchers and hangers of fiber)
- System purveyors (PONs, alternatives)
- System owners
  - Large ILECs (RBOCs): Southwestern Bell Company, Verizon, Bell South and most of Qwest.
  - Electrical utilities, state or locally owned, numbering about 2000, with 40 million customers [11] in communities of size typically less than 10,000
  - Small ILECs, numbering about 1300 [12]
  - Multiple System Operators – cable system owners
  - Overbuilders (second system owners where an LEC or cable company preexists)
- Content providers (broadcast networks)

There is a large body of literature listing and tracking the important players in each of these links in the food chain, for example, References 5, 6, 13-15. A perusal of the web sites of these players is most instructive in gauging the pace at which things are likely to happen.

The first wave: current PON installations

What emerges from studying the work of the various players, as they evolve FTTH/B up to the present, is that it is already here in the form of a "first wave" of small fragmented implementations, with a larger "second wave" impending, both driven by the technology, cost, application and regulatory drivers just discussed. Take the first wave first.

Today, fiber-to-the-home activity seems to follow the dictum of Chairman Mao: "Take small and medium cities and extensive rural areas first; take big cities later." This is certainly the way the cable television industry got started [16]. Most of today's FTTH/B activity is being carried out by startups with less than 150 employees each, and is taking place in small, scattered places that are not always considered priority markets for either the large telcos or the large cable companies. Those entities are more susceptible to the philosophy of Ronald Regan ("trickle down" – start with the large users first, large businesses or large multiple unit dwellings - MDUs) than that of Chairman Mao, and indeed there is a significant existing body of fiber access to large businesses, often based on dense WDM.

Figure 5 shows the results of a 2001 and 2002 census of actual North American FTTH/B installations and an extrapolation to 2003 [17].

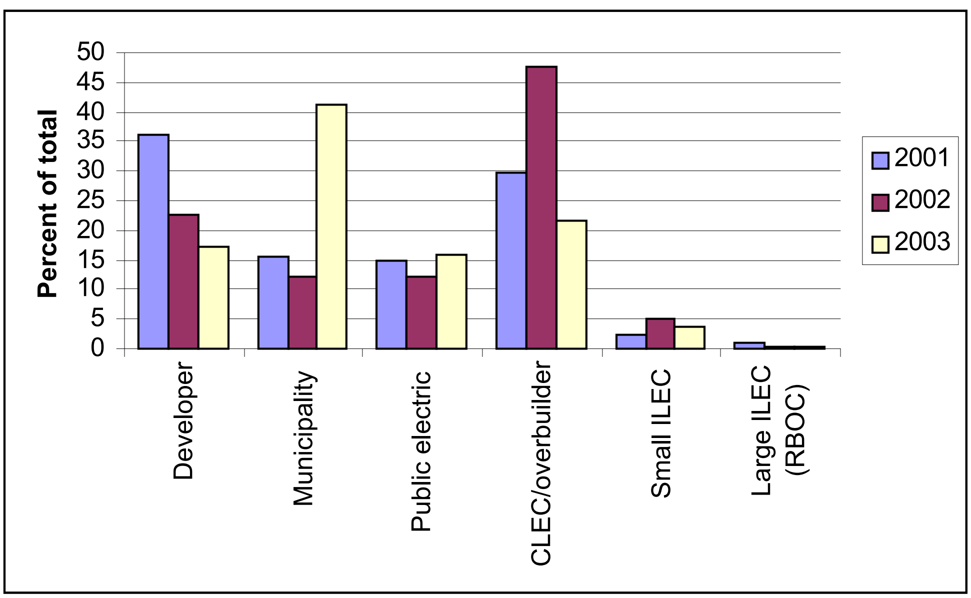

Figure 5 – Render, Vanderslice and Associates results of a US and Canada "census" on percentage installed FTTH base, by provider segment. 2001 and 2002 are actual counts, 2003 are based on providers' stated plans.

The categories include:

- New "Greenfield" housing developments. This is currently the largest immediate market sector for the FTTH system providers. The initial cost of laying fiber is essentially the same as for coax. When it costs the installer only 1 to 2 thousand extra dollars in FTTH equipment costs [5, 6, 13-15] to help sell a house costing hundreds of thousands of dollars, developers are finding that this represents a significant purchase incentive for the new owner.

- Municipalities. Over 1800 small communities own their own electric utilities and therefore have the required rights of way and the utility poles already at hand. Such communities are helped economically by the availability of subsidies from the Universal Service Fund, a pool of money created decades ago to which incumbent carriers must contribute in order to insure that rural and small town citizens not be disadvantaged [18].

- Publicly-owned electric utilities. There are 68 sizeable public utility districts nationwide, serving a total of 1.5 million customers [18]. Also, into this category one should probably lump the many rural coops, who pool resources to buy power or communication services. USF subsidies are available here as well. As with municipality-owned power facilities, fiber resources are sometimes already in place to monitor the power distribution systems all the way to the premises electric meter.

- Competitive local exchange carriers (CLECs) and overbuilders. Often, small CLECs will "overbuild" into the territory of neighboring large ILECs (RBOCs) and take business away from them on the basis of the claim that they can provide better or cheaper service than the resources on top of which they "overbuild".

- Small ILECs Most of the 1300 or so small independent telcos are heavily committed to DSL, at least for the moment.

- Large ILECs (RBOCs). As one can see from Figure 5, there is no present evidence of any commitment to FTTH on the part of the four large ILECs. As we shall discuss, the recipe for a significantly successful fiber last mile on a timely basis depends on their heavy participation.

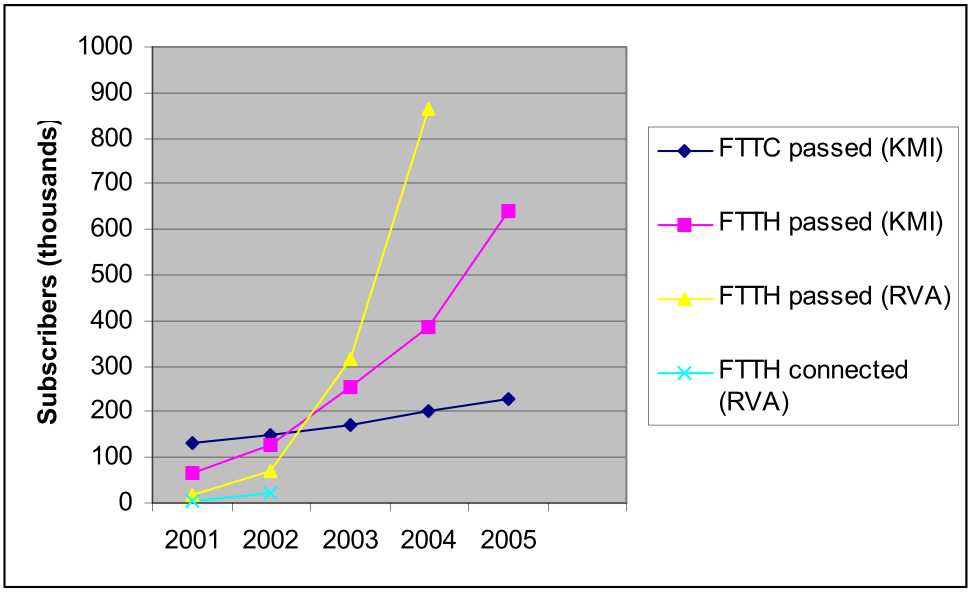

Figure 6 – Projections by KMI Research [5] and Render, Vanderslice and Associates (RVA) [17,] together with census by RVA for 2001 and 2002 of homes passed and North American homes actually connected (5200 for 2001 and 22,500 for 2002). Also included is KMI's projection for FTTC. Both cases assume that the large ILECs do not start serious deployment before 2005.

While Figure 5 presented a percentage-wise breakdown of the current total FTTH installed base, Figure 6 summarizes two recent estimates and projections of the total number of residences nationwide in the U.S. For 2002, RVA counted 72,100 homes passed and 22,500 homes actually connected. Note that for the next several years all numbers are miniscule compared to the 2002 figures of 7.1 million DSL and 14.8 million cable modem U.S. broadband customers today [6], but their significance lies in the rate of growth, the fact that three years ago these numbers were all close to zero, and the fact that FTTH is expected by many to expand rapidly and in fact to supersede FTTC at a rapid rate.

The U.S. will continue to lag in broadband access until we bite the FTTH/B bullet [19]

Meanwhile, other countries seem to have forged far ahead of the U.S. in the deployment of broadband in general and fiber to the home in particular. The U.S. ranks fourth behind Korea, Canada, and Sweden in per capita broadband deployment. While cable dominates DSL in North America, the converse is true in Korea, Japan and the European countries. This difference can be ascribed to the fact that in North America more than 50 percent of the subscribers are more than 15 km. from the CO, whereas in the more compact countries, the figure is more like 1 km.

In spite of the fact that the longer access distances in North America would argue that FTTH/B should be more advanced here than elsewhere, this is not the case. The lack of regulatory encouragement, government subsidies, telco preoccupation with a technology of minimal long range potential, and other factors have put the U.S. far behind several other countries in implementing FTTH/B. There were 97,000 active subscribers by the third quarter of 2002 in Japan, 75,000 in Sweden, and 50,700 in Italy, compared to 33,000 in the U.S.[13] Interestingly, outside the U.S., the architecture of choice was usually point-to-point Ethernet rather than EPONs or even less so, APONs.

When will the Regional Bells launch the second wave?

While the present state of broadband services seems muddy and confused, a closer look leads to the clear-cut conclusion that without FTTH/B the long-range prospects for the large ILECs, as presently structured, are not particularly bright. To be sure, in the present business climate many of their immediate telco competitors, the competitive LECs (CLECs) have retreated significantly or gone out of business altogether, but their disappearance is likely to be only temporary. And there are even more threatening factors at work that have not abated during the present downturn. These pressures may be so serious that the telcos will have to rethink their current survivability strategy of "avoiding CAPEX in favor of OPEX" (capital expenditures vs. operating expenditures).

Aside from capital shortage and cash flow problems together with regulatory difficulties, to be discussed next, the principal one of these factors is competition for the minds, hearts, and one-stop broadband and POTS pocketbooks of residential and small business customers from the cable giants, (currently ATT Comcast, Cox, Cablevision and AOL/Time Warner). These companies are likely to be a far more serious threat to the regional Bells than the traditional POTS-oriented CLECs ever were or could be. And they are allowed to generate and control content, unlike the telcos. The cable companies are playing a very aggressive long-range game in wiring up as many homes as possible, often as loss leaders, to deliver multichannel television as simply the nose under the tent flap in a highly visible multi-step strategy. Concurrently, or immediately after cable TV, comes cable modem service at megabit rates. Once these services are up and running, it is feasible, if expensive, to add several POTS or triple-play connections back to the telco points of presence, displacing (overbuilding) the local ILEC. The addition of POTS service also brings to the cable companies some unfamiliar but tolerable regulatory oversight. To the subscriber, the idea of paying one bill for all these services has great appeal.

With some reengineering and for short distances, a number of the straight NTSC TV channels can then be upgraded to HDTV (19 Mb/s if uncompressed). This is likely to be feasible at useful distances for the cable companies, but essentially impossible for DSL.

In the emerging competition for triple play services that the telcos face from the cable companies, there is some consolation from the fact that so far the cable companies have very little penetration of businesses relative to their penetration of the much larger residence market.

Even the old argument that hard-wired POTS service is required for "lifeline" service in case of emergencies is falling by the wayside, partly because of the widespread availability of cellular technology, the routine inclusion of eight-hour local battery backup with FFTH, the fact that manufacturers of fiber cable that includes copper pairs are finding few takers, and that the increased use of fiber-fed digital loop carrier systems between CO and premises means that power failures often bring the phones down too.

Technically then, the cable companies are moving into position to provide a jumping-off point for the fiber-based "triple play" repertoire of user services (phones, TV and high speed data) referred to earlier, by first capturing the customers' allegiance with these interim substitutes for FTTH/B, namely HFC and possibly FTTC.

Meanwhile, back at the phone companies, their traditional business conservatism, the legal and regulatory stranglehold of Washington and the state capitals, loss of second POTS lines to cellular and triple-play broadband, and comparatively shallow pocketbooks produced by decades of rate-of-return regulation have combined with their reliance on a decaying 120-year old copper-based plant to put them in more of a hole than their public actions and statements would indicate. Recent data [7] indicate that the large ILECs carry the burden of an annual replacement rate of 3-4 percent of their copper subscriber lines, just due to physical deterioration, and that they add 1.5 million new subscriber lines to newly built single family homes (out of a total of 75 million lines)[7]. This is all being done using traditional 24-gauge copper twisted pair and presided over by the onerous OSMINE (Operation System Modification of Intelligent Network Elements) qualification process that has so discouraged entrepreneurship in the introduction of new technologies into the ILECs' plants. Today the four large ILECs are mostly passing up the chance to make these copper replacements with fiber, instead being satisfied with probing this direction with limited and thus noncommittal field trials, such as SBC's Mission Bay and BellSouth's Dunwoody trials. When the time-honored demo field trial mode of testing the envelope is replaced by commitments for large-scale deployments in large geographic areas, then we shall know that the second wave has arrived.

At present the situation does not seem to alarm the incumbent carriers; in fact it seems to be standard telco doctrine today that once the cable industry has significant HFC and FTTC installed to provide TV and data, there will be little incentive for these providers to make a serious investment in POTS with its regulatory encumbrances, and even less to invest in still another round of technology to go to FTTH/B, so why hurry to compete?

This consolation may have some truth to it in the short range, but one might want to ask if a more prudent lower-risk telco strategy might not be to move beyond the passive one of waiting until a significant percentage of both POTS and broadband customers is lost. Is it not likely that their long-term survival demands that they leverage fiber-based PONs proactively to leapfrog the copper-based intrusions of the cable companies into the telcos' POTS-based present and their broadband-based future?

Of course, the longer this move is delayed, the longer the duration of the smaller, more incremental first wave of PONs. While representing a technically interesting development, one that may constitute a small but highly profitable sector of the information industry, the first wave will hardly constitute the revolution that fiber technology is capable of. That will have to wait for the large ILECs to launch the second wave.

Perhaps the thing that will cause the telcos to act is their highly visible losing battle of DSL against cable modems. In areas where both cable modems and DSL are offered, cable modems have been winning consistently by a factor of between 2:1[13, 14, 18] and 3:1[20], and most observers contend that the achieved DSL penetration has only dealt with the easier (shorter distance) customers, so that sustaining even this rate of penetration will prove increasingly difficult. This is eating up CAPEX that could be spent on fiber. Why do the telcos think this is a winning long-term strategy, and how long can they continue to offer this limited-distance, limited-bit rate alternative to even cable as the solution for either corporate profitability or long-term turf preservation or both?

As an extreme scenario, conceivably part of the model for the second wave could lie in the current example of small carriers like Global Crossing to avoid ruin by going to restructuring under Chapter 11 [21], and this might eventually have a certain macabre appeal to one or more of the large ILECs.

Conclusions

As this paper has tried to articulate, there are very large forces at work pushing the world in the direction of FTTH/B as a low cost, stable, futureproof endpoint in the evolution of last mile technology. DSL is in trouble technically and its equally troubled business sponsors badly need a rallying point around which to build their corporate future. The application level and business pressures for going beyond broadband cable and DSL are there, and the first wave of response by FTTH/B deployments has just started rolling in the last two years. Architectures and specifications are being standardized as extensions of ATM, popular with the North American carriers, and Ethernet, popular with everybody else. The regulatory and legislative stirrings that have been visible in small municipalities and rural areas have now had a resounding echo in Washington.

In my opinion, the key to fully deployed FTTH/B as a major component of our future society lies not with the cable companies, nor with the First Wave startups, but with the much-beleaguered ILECs, mainly the Big Four. The cable companies are just now completing their digital broadband build-outs and have almost no incentive to move forward to the all-glass solution. On the other hand, not only are the ILECs in a battle for long-term survival that they can win only by leapfrogging the cable companies, but things are moving in this direction along all three axes: technology cost performance, emergence of bandwidth-greedy applications, and regulatory changes. If the ILECs respond to the FCC's encouragement by doing the FTTH leapfrog of the cable companies, they may lose money short term but will win the competitive battle long term, given their enormous human resources, existing customer relations, service and maintenance experience, and R and D base.

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