Hybrid Fiber/Coax Options Explode for Last Mile

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As the bandwidth needs of the business customer continue to rise, the reach- and scalability-limited twisted-pair wiring that serves most premises becomes less and less attractive as a viable access medium. Though attractive, all-fiber access networks or a combination of deep fiber and twisted pair are still expensive alternatives. New technology that is currently under trial will allow less-expensive hybrid fiber/coax (HFC) access networks to provide a compelling alternative to purely fiber and hybrid fiber/twisted-pair solutions. These HFC options are many and varied, but all face the inevitable HFC trade-offs of reliability and availability, power, and potentially disruptive upgrades, as well as scalability, cost and data rate symmetry.

While above-1-GHz solutions seem to offer many advantages, they have their own issues with respect to loss, flatness and group delay. And at gigabit rates, clocking and timing issues rear their ugly heads. Fortunately, however, many of these challenges are on the road to being solved, though the designer has many decisions to make before settling on above-1-GHz solutions as the way to go. Decision points include the medium that is currently in place and how quickly the provider wants to get up and running.

The access network of customers wishing to be served by the central office or headend is generally a classic tree-and-branch topology, which spreads the service provider's facilities and related resources. While cable operators often deploy fiber ring technology as a means of reaching the customer, fiber rings only economically reach the clustered or higher-density customers (low-hanging fruit). The choice to serve the more widely dispersed customers becomes one of either point-to-point or tree-and-branch technology to match the physical topology. Until wavelength-division multiplexing (WDM) becomes cost-effective, a wavelength per customer is not really viable. Therefore, tree-and-branch is the only viable access technology topology for much of the access market.

The two tree-and-branch choices available today are fiber-based passive optical networks and HFC networks. Each has its advantages and challenges.

Fiber options
Fiber-based access schemes such as passive optical networks (PONs) are inherently simpler than traditional copper-based access configurations or Sonet and ATM ring configurations, since PONs
have very few plant electronics. But PONs still have high fiber-construction costs. This is particularly true when customers are dispersed, as is the case in tree-and-branch distributions. Deep or deeper fiber is an economical way to bring the necessary bandwidth closer to the customer, but the real expense of reaching a customer is in the last few hundred feet. If an all-fiber connection is made to the premises, costs soar.

While laying fiber is expensive, supporters of fiber project that the cost of installation will in part be offset by lower ongoing maintenance costs due to the reduction in active electronics. However, neither APON (ATM PON) nor EPON (Ethernet PON) fully addresses the service needs of broadband customers with respect to symmetrical data streams, practical bandwidth limitations, quality-of-service (QoS), security, dynamic bandwidth allocation and contention.

Almost by definition, PON translates to some form of time-shared upstream access. A distributed "many-to-one" upstream funneling mechanism limits the overall bandwidth compared with downstream, which is generally a straight, "one-to-many" broadcast format. Thus, it is difficult for any PON-based technology to both provide symmetrical bandwidth configurations and maximize potential throughput. An APON vs. EPON article in Communication Systems Design (March 2002) expands on many of the advantages and drawbacks to each technology choice and predicts that the eventual winner will be a hybrid (probably EPON) that incorporates the best of both technologies.

The HFC network that the multisystem operators (MSOs) now have in place is positioned to provide a viable, cost-effective alternative to PON, but trade-offs including cost, network complexity and service features. The HFC plant brings into question reliability/availability, powering and potentially disruptive upgrades. However, there are several technology choices available for HFC today that reduce those trade-offs.

**Drawbacks of Docsis**

The Data over Cable Systems Interface Specification (Docsis), which is being managed and enhanced by CableLabs, is the basis for cable modem services currently being offered by the cable operators. However, Docsis services suffer many of the same drawbacks as PON-based services, such as time-shared bandwidth, nonsymmetry and lack of adequate QoS and security. An enhanced physical layer is being developed to allow HFC data services to increase the usable throughput and symmetry over what exists today. Projections of symmetrical data rates up to 30 Mbits/second are being made with the new synchronous code-division multiple-access (S-CDMA) scheme recently adopted in Docsis 2.0. In addition, it is expected that, because of the noise funneling that occurs with a time-shared upstream access, the number of customers being served will have to be further reduced via node splitting.

Other HFC technologies extend traditional services based on frequency-division multiplexing (FDM) beyond present 860-MHz systems. To overcome the higher losses above 1 GHz, vendors are supplying higher outputs and other means to provide additional downstream bandwidth to the MSO. However, none of these approaches resolves the more pressing problem of upstream bandwidth limitations. Still, the potential exists to place additional upstream bandwidth above the 860-MHz frequency spectrum, which will help the severely inadequate 50-MHz upstream frequency allocation.

These new technology choices provide a relatively narrow spectrum per transceiver of 6 MHz. The result is that multiple transceivers need to be deployed in the headend to cover the spectrum of 1 to
2 GHz and beyond. If the transceiver is traditional broadcast downstream and time-division multiple access (TDMA) upstream, the additional bandwidth is time-shared, as with today’s Docsis technology. Thus, much more of the potential above-1-GHz bandwidth would have to be allocated to upstream traffic to address data symmetry.

Some vendors are trying to increase the existing upstream-bandwidth allocation by moving the frequency split between upstream and downstream (now a 50-/700-MHz split). While this may be attractive to cable overbuilders, such a strategy is incompatible with the basic configuration of all incumbent MSOs and hence is difficult to achieve.

Still other HFC options involve leveraging unused bandwidth in the existing spectrum under 1 GHz. Although seemingly less disruptive to the existing plant, identifying underused spectrum inside the existing spectrum is difficult since the availability is sparse and will need concatenating to be useful. Trying to exploit multiple technologies in the same frequency space as traditional community-access TV (CATV) equipment will most certainly be at least confusing, if not harmful, to end-of-line performance.

In the end, two goals are critical to providing next-generation data networks on HFC. First, the traditional time-shared nature of the upstream spectrum has to be eliminated to increase upstream bandwidth. Second, symmetrical bidirectional data streams must be available to address the needs of the business customer. If the traditional TDMA upstream is abandoned for a point-to-point switched architecture, higher-bandwidth data networks can be implemented, since the time-sharing compromises that limit maximum throughputs are eliminated. Unlike their PON counterparts, FDM schemes naturally allow for symmetrical bidirectional data streams, since upstream and downstream can be frequency-separated.

**Fiber/copper combos**

One route to accomplishing these goals is a switched-Ethernet-over-fiber architecture that provides Ethernet data to users on a link-to-link basis. In this architecture, Ethernet switches can be mounted along the HFC plant at each data path decision point. As in a LAN or a WAN, traffic traverses either fiber or CAT-6 copper pairs with intelligent routing algorithms allowing user-to-user connectivity and user-to-network access. A typical deployment using a fiber and copper overlay to HFC is shown in **Figure 1**. This technology is currently working at 100 Mbits/s and has a development track to 1 and 10 Gbits/s.
One advantage to divorcing the data technology from the CATV network is that no design considerations are required to ensure compatibility between CATV and data. Data switches can be placed where needed, regardless of the location of CATV actives. If CATV ac power is used to power the data switches, the existing HFC power plant can be leveraged. The drawback to this particular approach is that no attempt is made to integrate the data on the existing legacy HFC network, so a separate fiber overlay is required for data. That can be costly.

A small number of HFC vendors have provided switched-Ethernet data streams on integrated fiber transceivers out to the HFC CATV node (Figure 2). This solution utilizes separate fiber or wavelength-division multiplexing to carry both CATV and Ethernet data out to the HFC node where Ethernet is available to customers. However, as in the previous case, the Ethernet data has yet to be integrated onto the CATV coax. Ethernet availability at the HFC node must be within CAT-6 reach of the end user, or a portion of the Ethernet data is fed into a CMTS blade residing in the CATV optical node.
RF challenges for coax

One other technology area being explored by multiple vendors is wide-spectrum single-carrier transceivers, or virtual channel carriers, that can provide large contiguous bandwidths both upstream and downstream directly on the HFC coax. Both wavelet and quadrature-amplitude modulation (QAM) schemes are being explored as candidates for single-carrier-like transceiver technology. The idea is to provide FDM-separated transceivers that can deliver broad symmetrical data streams on the HFC in a cost-effective manner. Frequency bands up to 1 GHz and beyond are projected. If this technology is further enhanced to transmit point-to-point down the HFC with appropriate switching and aggregation mechanisms, the available data bandwidth becomes non-time-shared and has the potential to provide both the security and QoS of APON and the flexibility and efficiencies of EPON.

Pushing the envelope brings its own challenges, however. Solving the limitations of traditional Docsis access and existing PON solutions also raises issues. Placing signals above 1 GHz is no easy matter. Loss, flatness and group delay are even more critical in maintaining reliable performance than they are below 1 GHz. At gigabit wire speeds, clocking and timing constraints are very tight. Unless all of these factors are closely controlled, a single-carrier broadband access channel is not possible. But there are solutions.

Boosting coax

Wavelet chip technology, now available as proof of concept, is expected to deliver 100 Mbits/s within an 18-MHz frequency spectrum. At the same time, the modulation chip is projected to be cost-competitive with similar digital RF spectrum transceivers and is targeted at the digital set-top market as a method of maximizing the capacity of digital video delivery. The advantage of wavelet modulation is that, within the 18-MHz signal spectrum, subbands can be activated or deactivated, via a noise-mitigation technique similar to the frequency hopping of Docsis, to avoid noise on HFC. The penalty for turning off certain subbands, of course, is a lowering of overall throughput.

Whereas QAM is an all-or-nothing technology (it works at full throughput only), wavelet can continue to operate under extreme stress and will simply keep reducing its bandwidth until it becomes stable.
and returns to full capacity whenever it's able to do so. This technology is a complex math-based modulation concept and thus will take longer to mature. Working products are not expected for at least another year.

One of the more near-term attempts at single-carrier 100-Mbit/1-Gbit transmission is QAM-based. Such a technology became available early this year and can transmit up to 1 Gbit of symmetrical data on typical coax distribution cable with a useful dynamic range of up to 45 dB. The goal is to provide an effective QAM data transmission scheme without compromising traditional HFC design. Thus, typical HFC active placement is not affected when this new technology is deployed.

In designing a single-carrier broadband QAM technology, a great deal of attention needs to be paid to the design of the HFC plant and how the QAM transceiver is controlled, to maintain frame and packet synchronization with the changing nature of the coax plant. Attention must also be paid to lowering the wattage of actives, ensuring that the overall impact on the existing HFC ac power requirements is minimized. Similarly, redundant-powering configurations, built-in-self-test functions, error correction and bypass functions are required in each active element to ensure acceptable reliability numbers (uptime) and data integrity. If the fiber portion of the hybrid transport technology is ringed with either fully redundant switched optics or data path redundancy via a form of dynamic packet transport (where packets are rerouted when facility interruptions occur), reliability increases dramatically. Those extra measures allow the technologies to meet the conventional Bellcore reliability expectations (five-nines) and approach that of an all-fiber network.

Transmitting QAM data only from one active node to the next active node—and not from end-to-end on the coax—introduces a fundamental shift in how data is transported across the HFC. As a result, each HFC active node becomes a data-switching point, eliminating the aggregate HFC noise that plagues traditional end-to-end CATV signals. Figure 3 shows an overview of an integrated data-switching HFC architecture and functional depictions of some HFC elements. This point-to-point coax-based switched-data network functions much like switched-Ethernet networks and, as such, provides true symmetrical data at standard Ethernet wire speeds of 100 Mbits/s and 1 Gbit/s. The entire HFC access network becomes a unified, fully switched Ethernet network.
Switching mechanisms

Once the basic Layer 1 and 2 FDM PHY challenges are met, the next challenge is to implement a logical and reliable point-to-point switching scheme that allows gigabit wire-speed data transfers up and down the HFC tree-and-branch architecture without introducing appreciable packet delay. Such an approach can eliminate the typical time-shared upstream data transport that limits maximum bandwidth in most other HFC and PON data access solutions. Additionally, this on-HFC switching mechanism has the potential to provide other advantages over Docsis or PON access implementations such as enhanced QoS, throughput and, of course, symmetry.

Several switching mechanisms can be implemented that both streamline the HFC data access network and provide an environment that will support a host of real-time services, including those requiring high data throughputs. If the data is moved up and down the HFC over Layer 2, latency on the HFC is reduced dramatically, to less than 2 milliseconds from end to end. Generally it is expected that these Layer 2 HFC access switching times will not be a barrier when deploying latency-sensitive services such as voice or real-time video. Similarly, at Layer 2, weighting and queuing mechanisms are available that ensure fairness on the HFC segment such that no special consideration need to be made at the data ingress and egress points for packet prioritization.

Straightforward packet classification, filtering and tagging mechanisms can enhance the overall security of the user’s data. If such packet-management measures are implemented at the ingress point from the premises to the HFC, the user’s data can effectively and securely be transported up the HFC access network to the MSO’s edge router. Data in the return direction can be similarly delivered to the originating premises.

The cable operators will have several new technology choices at their disposal this year, including Docsis 2.0, APON, EPON and above-1-GHz RF solutions. These technology choices will allow the MSOs to challenge the incumbent local-exchange telco carriers for both the residential- and business-customer dollar.
Related Articles

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