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Ethernet Provides the Solution for Broadband Subscriber Access

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Authors: Wael William Diab
wdiab@broadcom.com
Howard M. Frazier
hfrazier@broadcom.com
Gerry Pesavento
gerrypez@yahoo.com

ethernet alliance | p.o. box 200757 | austin, tx | 78720-0757 | usa
www.ethernetalliance.org

Overcoming the obstacle of the last mile—the connection between an Internet service provider and a business or home—has been the final frontier, the holy grail of networking. The last mile has inhibited the Internet from being the ultimate multimedia delivery system because it has a bad case of bandwidth bottleneck. In the last decade, the gulf has grown between high-capacity metropolitan networks on one side and user needs on the other. Maybe it really is the “last” mile, because it is the last item that network designers think about when building broadband infrastructure.

The most important step in solving this problem is to change our thinking and put the customer first. A revolution is underway that is transforming the telecommunications landscape. Deregulation and bandwidth-hungry applications are creating unprecedented opportunities to develop broadband subscriber access networks. The number of people using the Internet grows each year, and the amount of information traveling over it has increased 200 percent each year. Businesses rely on the Internet for Web access, virtual private networks, e-commerce, video streams, training, and customer support.

Ethernet has emerged as the frontrunner for transporting broadband Internet protocol transmissions. Ethernet in the first mile (EFM) provides a means to transport Ethernet packets in their *native* format, without the need for complex and costly protocol conversions. This in turn allows local carriers to build a converged broadband infrastructure that enhances the local subscriber network with IP-centric broadband services. Ethernet promises to bring about the same revolution in access networking that it created in enterprise networking: fast, simple, inexpensive, reliable, interoperable, and ubiquitous connectivity.

what is the first mile?

The first mile is the part of the communications infrastructure that connects the service provider’s central office to a business or residential subscriber. Also referred to as the subscriber access network or local loop, it is the infrastructure at the neighborhood level. And, no, the first mile is not really a mile—this connection can span several miles.

At one end of the first mile sits the central office, which itself has many aliases: local exchange, hub, head end, and point of presence. It is the building where switching and routing equipment accepts, concentrates and directs data to metropolitan and core networks. This is the carrier’s entrance point to the high-speed-packet and circuit-switched networks that span the world, now reaching up to terabit-per-second capacity.

On the other side of the first mile sits the subscriber, who may be located at a residence, campus, or business. Sometimes, the first mile is located within a building: An in-building distribution network can connect through a router to a service provider via some high-speed network. Such buildings may be apartments (multi-dwelling units or MDUs), office buildings (multi-tenant units or MTUs), hotels, and so on. Collectively, network designers refer to these buildings as MXUs.

why use ethernet in the first mile?

Nothing beats Ethernet—a bold claim, but one that has held true for the past 33 years. Ethernet technology is now ubiquitous, with roughly a billion ports deployed worldwide. More than 85 percent of all installed network connections and more than 95 percent of all local area networks (LANs) are Ethernet based, making it the most widely deployed type of network in history.

IP's emergence as the dominant internetworking protocol positions Ethernet technology to break out of the LAN environment and become even more pervasive because Ethernet is a packet-based network optimized to carry IP traffic. IP packets now carry more than 90 percent of all traffic, including voice, data, and video.

The networking industry has done an admirable job of evolving Ethernet to meet increasing bandwidth and functionality demands. Initially conceived as a shared-media protocol over coaxial cable, Ethernet has evolved to support dedicated full-duplex connections at speeds up to 10 Gbps. Structured wiring, management tools, and long-established interoperability have combined to create the inherent reliability that is of utmost importance to carriers.

Ethernet is well positioned to capture the first mile as the data-link-layer protocol of choice. Interestingly, it has been digital subscriber line (DSL) and cable modems that, by interfacing to the user's system with an Ethernet port, have helped promote the perception that Ethernet is "the" universal broadband access port. In this way, the Ethernet RJ-45 connector has become the door to the Internet.

Although traffic from subscribers begins and ends as IP over Ethernet, in the telecom world it often must travel end to end over an array of protocols that include point to point (PPP), asynchronous transfer mode (ATM), and synchronous optical network (SONET). Protocol translations add cost, inefficiency, management complexity, and long provisioning times to the network. An EFM solution flattens and simplifies the network, letting data be preserved in a *native* Ethernet size and format.

Viewed as a reliable, simple, and low-cost IP network, Ethernet is becoming carrier class as both new and incumbent service providers shift their networks toward efficient Ethernet use. Service providers are taking advantage of this ability to deliver traffic in Ethernet packets from the LAN through a metropolitan network using Ethernet technology at a fraction of the price of a T3 or OC-3 (Optical Carrier 3) circuit. In addition, the ability to provision extra bandwidth as soon as it is needed and in small increments up to 1 Gbps offers costs savings and revenue potential.

The first mile contains a mix of media: twisted-pair copper wire, fiber optics, coaxial cable, and (of course) air. Ethernet has been applied to all of these media over the past 33 years. But the first mile is unique in terms of the environment, the customer's concerns, the type and quality of cable already in the ground, and the distances involved. IEEE Std. 802.3ah-2004 for Ethernet in the First Mile defines several new interfaces that are optimized to transport Ethernet natively in this diversified environment.

scope of efm

In true fashion, the IEEE 802.3ah task force tackled the broad range of wired access technologies for the first mile. Specifically, EFM looked at the following areas:

- Point-to-Point Copper Connections
- Point-to-Point Optical Connections
- Point-to-Multi-Point Optical Connections

In some cases more than one PMD (Physical Medium Dependent) specification was introduced to address the diverse geographic, economic and density needs of all the participants around the world. The EFM task force also recognized that low CapEx (Capital Expenditure) had to be complemented by low OpEx (Operational Expenditure) for successful first mile deployments. This meant coupling new low-cost Ethernet interfaces with an OA&M (Operations, Administration & Maintenance) scheme that reduces the cost of managing these technologies in the field.

The EFM standard defines PMDs to address the following objectives:

- PHY for single pair non-loaded voice grade copper distance ≥ 750m and speed ≥ 10Mbps full duplex
- PHY for single pair non-loaded voice grade copper distance ≥ 2700m and speed ≥ 2Mbps full duplex
- 1000BASE-X ≥ 10 km over single SM fiber
- 100BASE-X ≥ 10 km over SM fiber
- PHY for PON, ≥ 10 km, 1000Mbps, single SM fiber, ≥ 1:16
- PHY for PON, ≥ 20 km, 1000Mbps, single SM fiber, ≥ 1:16
- 1000BASE-LX extended temperature range optics

ethernet over point-to-point copper-wire connections

In the beginning, there was copper cable—lots of it. Originally installed for analog voice traffic (Plain Old Telephone Service or POTS), twisted-pair copper-cable deployments dominate the first mile. There are various grades of twisted-pair copper cables, and these have been given category designations by the Telecommunications Industry Association (TIA). The higher the category number, the better the grade of cable. Copper cables serve an estimated 95 percent of buildings, and within buildings it is primarily Category 1 to 5 copper wiring that reaches the tenant.

Recently, DSL technologies have added high-speed digital signal transmission capacity to these copper networks. Although DSL comes in many flavors, they are all kissing cousins of each other that operate at different data rates. For many consumers, DSL has been the first taste of real Internet bandwidth. According to Telechoice, a market research firm, over 10 million people subscribed to DSL in North America alone in 2004.

Vendors and telecommunications network operators alike target Ethernet over copper in the first mile for short-distance point-to-point drops to the user: from the outside plant to the dwelling, and/or inside buildings and residences. The lengths of these drops typically reach up to 3,000 feet; often the copper-wire pairs were installed as 24- or 26-gauge wire designed for voice traffic. Using the existing cable infrastructure keeps deployment costs low; there's no digging up streets. Telecommunications companies often see Ethernet-over-copper technology as both an immediate solution for high-speed data to businesses and residences, and as a stepping-stone toward running fiber to homes.

Several standards bodies, including the International Telecommunications Union and its telecommunications standardization sector (ITU-T), Accredited Standards Committee T1E1.4 and the European Telecommunications Standards Institute (ETSI) worked to create standards for the transmission of high-speed data over POTS wiring. Because telecommunications network operators developed much of the high-speed copper access before the IP explosion, virtually all DSL technologies deployed prior to the EFM standard—such as symmetric DSL (SDSL) and asymmetric DSL (ADSL)—actually transport ATM cells, rather than Ethernet packets. With the aim of incorporating standards and technologies from existing data-over-POTS wiring solutions, the IEEE Std. 802.3ah-2004 defined complementary high-speed DSL protocols that are optimized for delivery of IP/Ethernet packets. Specifically, the EFM standard defined 2BASE-TL, which is uses enhanced Single-Pair High-Speed Digital Subscriber Line (SHDSL) and 10PASS-TS, which uses Very-high bit rate Digital Subscriber Line (VDSL).

ethernet over point-to-point fiber

Optical fiber is the highest bandwidth medium available today. It satisfies the need for speed. Certainly, Ethernet is no stranger to fiber. In July 1998, the IEEE approved IEEE Std. 802.3z, which defined Gigabit Ethernet. Today, Gigabit Ethernet and 10-Gigabit Ethernet use mostly optical fiber in point-to-point full-duplex deployments. Therein lies the opportunity for Ethernet over point-to-point fiber in the first mile: as a dramatically simpler and less expensive alternative to ATM and SONET. Even still, there is room to add a new Gigabit Ethernet point-to-point physical-layer specification optimized for the first mile. In enterprise networks, Ethernet is deployed over two fibers—one for transmitting and one for receiving—because fiber optic cable strands are plentiful in building and campus backbones. If a single fiber can support data flowing in both directions simultaneously, then connections require half the numbers of fibers, connectors, and splices, saving considerable cost. As a bonus, there is no confusion as to which fiber transmits and which receives. Service providers desire a 10-km reach on single-mode fiber (as opposed to the 5 km specified in the IEEE 802.3z standard) to cover almost all first-mile applications. Therefore, the EFM includes a new physical-layer specification, which is a modification of the single-mode-fiber Gigabit Ethernet specification, 1000BASE-LX. It has a speed of 1,000 Mbps and can span lengths of 10-km. This specification is known as 1000BASE-BX10.

Like 1000BASE-LX, this new specification uses the 8B/10B encoding method (exactly as defined for Gigabit Ethernet), and a technique called coarse wavelength division multiplexing (CWDM) to keep the transmit and receive data streams separated. This technique modulates data traveling downstream (from the central office to the subscriber) on to a relatively longer wavelength of light (1,490 nm). When data travels upstream (from the subscriber to the central office), CWDM modulates on to a relatively shorter wavelength of light (nominally 1,300 nm). Inexpensive, passive wavelength-division-multiplexing components combine and split the two wavelengths of light onto a single strand of single-mode fiber, as shown in Figure 1.

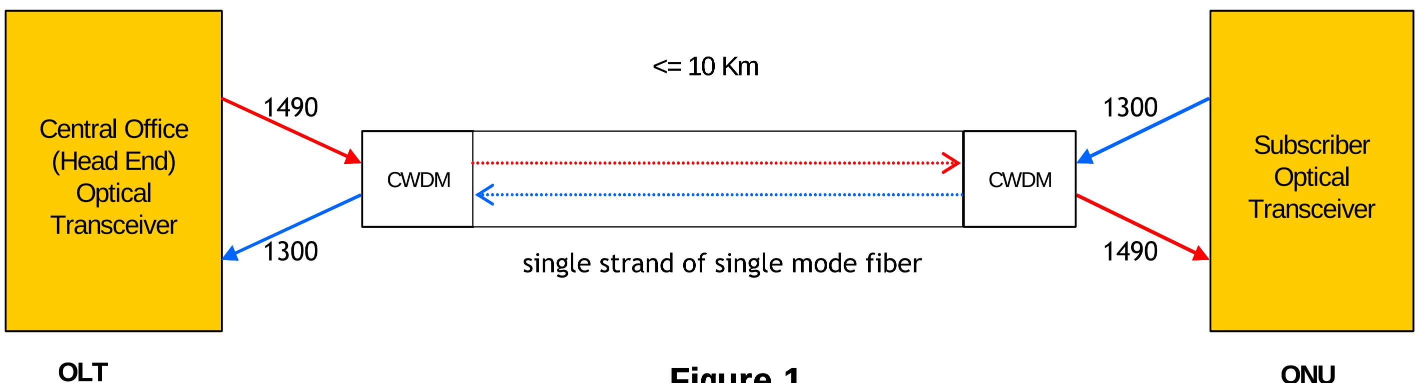

Figure 1
Coarse wavelength division multiplexing in 1000BASE-BX10

A single-fiber, point-to-point optical Gigabit Ethernet specification offers immediate opportunities in business subscriber applications as a replacement for ponderously slow repeater-amplified T1 lines, and as an alternative to expensive DS3 lines and optical-carrier circuits. It may also find applications within enterprise networks in situations where fiber is precious.

ethernet passive optical networks

Passive optical networks (PONs) are point-to-multipoint fiber optical networks. A PON consists of a single, shared optical fiber connecting a central office to an optical fan-out device—an optical splitter—located near customers. Each customer receives a dedicated optical fiber but shares the long distribution trunk fiber. Other than the two endpoints, no component in the PON requires electrical power; hence the term “passive.” Ethernet PONs (EPONs) are designed to carry Ethernet frames natively.

A single PON typically serves up to 32 customers. Telecommunications network operators deploy them in a 1:N tree or tree-and-branch topology by using either 1:2 asymmetrical optical tap couplers or 1:N optical couplers. Operators can move optical splitters closer to or further away from the local central office, without affecting active end terminals. In this way, they can optimize network costs and topology. Ethernet passive optical networks (EPONs) are well suited to "deep" fiber applications, such as fiber to the business (FTTB), fiber to the curb (FTTC), and fiber to the home (FTTH).

The advantages of point-to-multipoint optical networks are that they:

- Reduce the amount of fiber deployed in the outside cable plant and inside the local central office,
- Reduce the amount of optical transceivers in the network; and
- Eliminate the need for an electrically powered box in the field, which would be necessary for a hybrid fiber/copper network.

PONs, however, are not without challenges, which stem from a media access communications protocol that is more complex than a dedicated full-duplex point-to-point link.

In the downstream direction, an EPON operates as a broadcast network. The Optical Line Terminal (OLT) located in the central office transmits Ethernet frames to all endpoints, which are referred to as optical network units (ONUs). Each ONU extracts packets based on a Logical Link Identifier (LLID) that is pre-pended to the frame. In the upstream direction, EPON behaves as a time-shared network. The ONU sends IEEE 802.3 Ethernet frames within an assigned time slot, and the central-office unit receives a continuous stream of collision-free IEEE 802.3 frames from the ONUs.

Because the first mile can span 10 km, Ethernet PONs do not use the CSMA/CD protocol, which has distance limitations. In addition, the 1:N optical splitter in the field is a directional coupler, which has different physical properties than a coaxial tap coupler; thus an Ethernet PON is not a shared-bus network. For example, one ONU cannot talk directly to another ONU; it can talk only to the OLT located in the central office. Thus, EPONs operate as a full-duplex star network—not a bus network—and require a time division multiple access (TDMA) protocol in the upstream direction.

Building on the success that EPON has achieved in mass deployments, the IEEE 802.3 working group recently decided to form a study group to begin working on a

10 Gbps EPON project. This increase in transmission speed will support the ongoing convergence on IP as the delivery vehicle for advanced video, data and telephony services.

operations, administration, and maintenance

Imagine being in charge of operating and maintaining a high bandwidth network in a hostile environment, where users are not your coworkers. Welcome to the local-carrier world. Here cable faults mean revenue lost, billing mistakes create accounting nightmares, service calls ("truck rolls" in telecommunications network operator parlance) are expensive, and troubleshooting may take you to the corner of Main and Nowhere Streets in the snow.

Operations, administration, and maintenance (OAM) for the first mile have requirements that differ significantly from those of a LAN environment. OAM definitions and methods are important to all EFM study areas; these specifications can be thought of as an umbrella that covers both Ethernet over copper and fiber networks.

Typical OAM issues include performance monitoring, loop-back testing (which permits an end-to-end test of a communications link from the central office), fault detection and isolation, and autodiscovery. In support of these functions, the EFM standard defines a set of OAM frames that can be used to convey status and management attributes, and conduct loop-back tests. The format of these frames is shown in Figure 2.

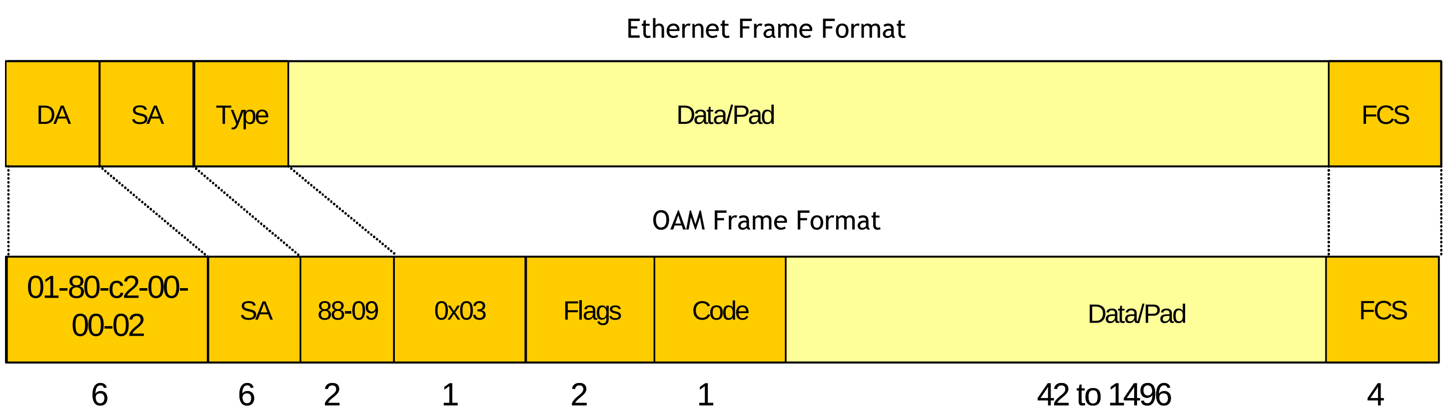

Figure 2
Format of OAM Frames

access-network architecture using efm

It is important to understand that the four components of EFM described in the preceding sections are complementary technologies. Each can be applied to maximum advantage within a given market segment, as illustrated in Figure 3.

Ethernet over point-to-point copper wire is probably the best fit for established neighborhoods, business parks, and MXUs, because it can reuse the existing first mile of twisted-pair copper cable. For new residential and commercial developments, Ethernet over point-to-multipoint optical fiber is probably the best fit because of its long potential service life.

For high-end commercial customers, Ethernet over point-to-point fiber may provide the best solution because it can scale to meet future bandwidth demands. Also, when the distance between the central office and subscriber exceeds a mile, either point-to-point or point-to-multipoint optical fiber can be used as a back haul. OAM is an integral part of all three of these physical-layer technologies, and it provides a consistent look and feel for the management facilities.

Figure 3 demonstrates how point to point copper, point to point fiber, and point to multi-point fiber (EPON) technologies can be used together to provide broadband subscriber access networks that transport Ethernet frames natively.

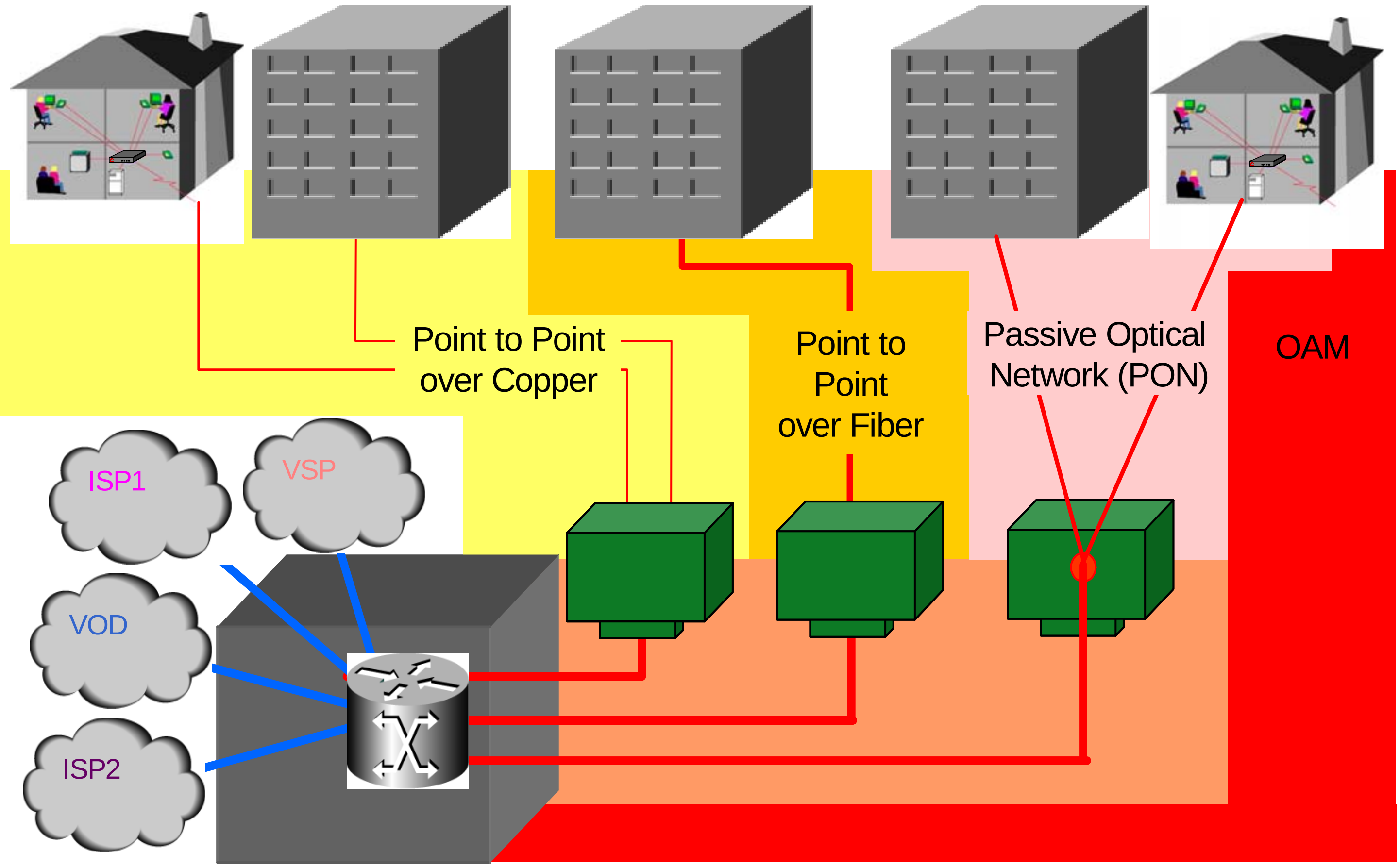

Figure 3
Ethernet in the first mile used in various access networks

The first mile represents a vast opportunity, but thus far the promise of truly universal broadband access has gone unfulfilled. Proponents of Ethernet in the first mile are girding themselves for the challenge of succeeding where others have failed. In their favor, they have a winning technology, a winning attitude, and a long track record of success.

If they are successful, the world of the not too distant future will be far different from today. Voice, video, and data will flow to and from our homes and offices with the same reliability and ease of use that we take for granted with other utilities. We will never think twice about how large our e-mail attachments are, even if they routinely include video clips. Web surfing will happen at the speed of thought, and we'll banish the World Wide Wait once and for all.

We'll have access to any movie we wish to see, any time we wish to see it. We won't dial up, because we'll always be connected. Telecommuters will have access to exactly the same resources at the same speed as their coworkers in the office.

Delivering these capabilities is a tall order, to be sure. But Ethernet made network computing a reality in the enterprise, and it's poised to do it again in the first mile.

authors biographies

Wael Diab is a Director of Marketing at Broadcom Corporation, and Secretary of the IEEE 802.3 Working Group. He was the Chief Editor of the IEEE 802.3ah Ethernet in the First Mile task force. Mr. Diab has authored over 12 patents. Contact him at wdiab@broadcom.com.

Howard Frazier is a Technical Director at Broadcom Corporation, and a co-inventor of Fast Ethernet, Gigabit Ethernet, and 10-Gigabit Ethernet. He was the chairman of the IEEE 802.3ah Ethernet in the First Mile task force. Contact him at hfrazier@broadcom.com.

Gerry Pesavento is the former CEO of Alloptic, and Teknovus, Inc. He was the chairman of the P2MP sub-task force for the IEEE 802.3ah Ethernet in the First Mile task force. Contact him at gerrypez@yahoo.com.

Diab and Frazier have authored a book titled Ethernet in the First Mile: Access for Everyone, published by the IEEE Standards Information Network/ IEEE Press. For more on the book please go to:

http://shop.ieee.org/ieeestore/Product.aspx?product_no=SP1144