

# Connecting the “Last Mile”: A Comparison Among Fiber-to-the-Home (FTTH), WiMax, and Broadband over Power Line (BPL)

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**Abstract**—In a competing business world, telecommunication companies are struggling to decide which “last mile” solution to implement and how to further extend their century old copper-based network. Recent innovations in communication-based computer and multimedia applications are forcing the industry into a new horizon, which may force them to ante up a large initial investment to provide such services. Alternatives to the “last mile” problem include Fiber-to-the-Home (FTTH), WiMax, and Broadband over Power Line (BPL). Each alternative provides cost/benefit tradeoffs to existing solutions. This paper compares the three alternatives based on cost, performance, and community support to determine which solution is most likely to surpass the others. It shows how the demand for higher transfer rates makes FTTH services appealing for most communication companies. This paper concludes that the exponentially increasing demand for bandwidth intensive services, decreasing equipment cost, and worldwide support, will cause FTTH to surpass WiMax and BPL as the next big “last mile” connection. The paper also shows that deployment of FTTH provides the network capacity to enable innovative futuristic services.

**Index Terms**— Fiber-to-the-Home (FTTH), broadband access Wireless communications, power line communications (PLC)

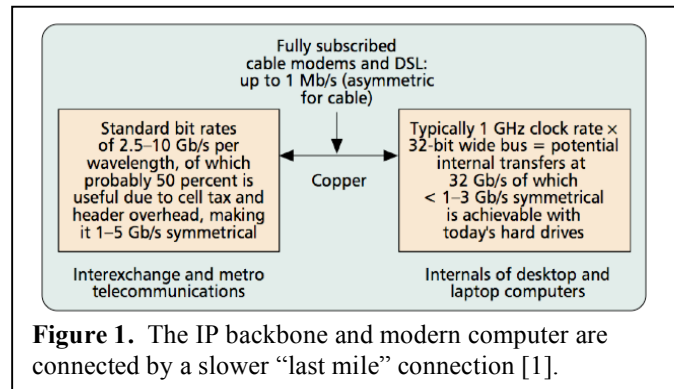
## I. INTRODUCTION

MULTIMEDIA rich services have significantly increased in the past decade and are fueling the demand to provide high-speed, reliable, “last mile” connections between the 1-10 Gb/s transfer rates of the IP backbone and the 1-5 Gb/s transfer rates of the average modern hard drive [1]. The “last mile” is therefore defined as the network, typically a Digital Subscriber Line (DSL) or cable Internet, connecting the two higher speed networks together. Figure 1 shows graphically the “last mile” connection between the two networks.

### A. Background

Historically, the connecting network has been built on top of the Plain Old Telephone Service (POTS), providing end users a 56 kb/s connection using a dial-up modem and up to 8 Mb/s with a typical Asymmetric Digital Subscriber Line (ADSL) connection, both using a single pair of twisted copper wires [2]. Even with these transfer rates, the demand for services such as video conferencing, video on demand (VOD), and remote storage solutions quickly exhausts the available bandwidth. Combinations of such advanced services can require bandwidths exceeding 100 Mb/s for feasible

functionality and end-user satisfaction.



**Figure 1.** The IP backbone and modern computer are connected by a slower “last mile” connection [1].

From the viewpoint of the consumer, it is becoming increasingly apparent that extending and improving the “last mile” connection to homes/businesses is no longer a luxury but a necessity. According to Paul Green, a retired consultant from the MIT Lincoln Laboratory, “Nobody needs to be reminded of the present stagnation in the telecommunications business, brought on partly by development of excess capacity in the interoffice backbone” [1]. Green says there is also slow progression on the personal computer side of the bottleneck because rapid innovation in both hardware and software technology and their applications are being halted due to the slow “last mile” connection. This is because most of these new innovations are communication-based. The Web 2.0 is a perfect example of an industry concept of moving traditional computer-based applications, such as Word, Excel, and PowerPoint, to online applications, offering the same functionality but making them accessible anywhere in the world through a modern web browser. To offer these types of services, users need to have higher speed access to the interoffice backbone in order to provide the same performance and experience of running the application as if it were on their personal computer. Ideally, users can access information on their hard drive within a gigabit per second window and should be capable of the same speed to access information all over the world [1].

There are several other reasons why improving the “last mile” is a necessity. One does not need to visualize futuristic applications and technology that will require faster connections; there are several existing technologies and applications that are limited by the “last mile” bottleneck. For example, basic Internet surfers have become increasingly impatient with low-resolution images and sluggish download

times for large files [1]. There are also services that require low latency but moderate file size transfers such as VoIP, video conferencing and collaborate document environments. Additionally, emerging services such as online video rentals, video on demand (VOD), and HDTV will, according to Green, “spell the death” of DSL and cable [1]. There are several other reasons why one could argue that “last mile” connectivity will soon need improvement, and that the main aspect of improvement is transfer speed.

### B. Traditional Technologies

Although POTS has considerably increased in performance since the dial-up modem, it still falls short of the Gb/s rates of the networks it connects. Recent deployment of Very-high-bit-rate Digital Subscriber Lines 2 (VDSL2) in European countries allows rates up to 100 Mb/s, but requires a 0.5 km distance from a fiber connection to achieve these rates [3]. Although appealing to some, most users are not geographically located to receive this type of service, and many telecommunication companies would need to extend their existing fiber infrastructures in order to offer the service. Likewise, cable Internet has improved to speeds of 6 Mb/s, but suffers from upstream noise and crosstalk accumulation [1]. Many think HDTV and video related services will trigger the end of copper wire communications and force the industry into a new horizon [1].

### C. Emerging Technologies

To continue to support the demand for improved “last mile” connections, telecommunication companies are looking for new solutions, while continuing to squeeze every last bit-per-second out of their century old twisted-pair copper wires. Although there is no clear-cut solution that outweighs the others, alternatives currently being deployed include Fiber-to-the-Home (FTTH), WiMax, and Broadband over Power Line (BPL).

This paper compares these three “last mile” solutions in terms of cost, performance, and community-support by examining implementation results. According to Green, cost is the most important criterion in determining “last mile” communications. The cost of a “last mile” connection is defined in this paper from the service provider standpoint, including initial cost per resident and life cycle cost of implementing the service. Maintenance and upgrade cost were excluded from this analysis because the newer technologies are just now being implemented and do not have a solid track record for comparison. Performance is defined as the data transfer rates achieved by each technology measured in bits-per-second. Lastly, community support examines the deployment of technologies throughout the world and their popularity towards current implementations. The paper argues that improvements in existing services, along with consumer demands and decreasing technology costs, are forcing the industry towards fiber deployment. It concludes that FTTH is the best long-term solution to the “last mile” problem because of its high transfer rates, worldwide support, and declining equipment cost.

## II. DESCRIPTION OF TECHNOLOGY

### A. FTTH

Fiber-to-the-home (FTTH), also called fiber to the premises (FTTP), refers to a broadband communication system consisting of fiber-optic cables and associated electronic equipment that terminates at the end user’s residence, as opposed to ending within the telecommunications company’s system [2]. By extending the fiber connection to the premises, advanced services can be provided such as tripleplay [3], which provides television, telephone, and Internet over a single communication link.

Fiber optics are long, thin strands of pure glass roughly the diameter of a human hair, or about eight microns, and represent cylindrical dielectric waveguides used to transmit light along their center axis by a phenomenon know as total internal reflection [4]. Fiber is favored in long distance telecommunications networks because of its lower optical attenuation, lighter weight, and flexibility. The light typically used in fiber communications is infrared; having a wavelength between 850 nm and 1550 nm. Fiber achieves full-duplex communications by utilizing wavelength division multiplexing (WDM), allowing multiple communication links to exist on a single fiber at different wavelengths. Multiplexing can be broken into *coarse* WDM (CWDM) where only a few wavelengths are used and *dense* WDM (DWDM) where typically eight or more wavelengths are utilized. CWDM can provide networks with bidirectional communications, while DWDM further enhances this by theoretically providing 40 Gb/s over a distance of 80 miles using a single fiber link [4].

FTTH is comprised of two main types of system architectures, Active FTTH and Passive Optical Networks (PON). Active FTTH networks utilize electronic equipment in neighborhoods that provides layer 2 and layer 3 switching and routing to the carrier’s central office. PON networks avoid placing electronic equipment in the field by using passive splitters to deliver fiber to each home and leave the switching and routing to be performed at the carrier’s central office. Figure 2 shown a graphical layout of a basic PON fiber network [10].

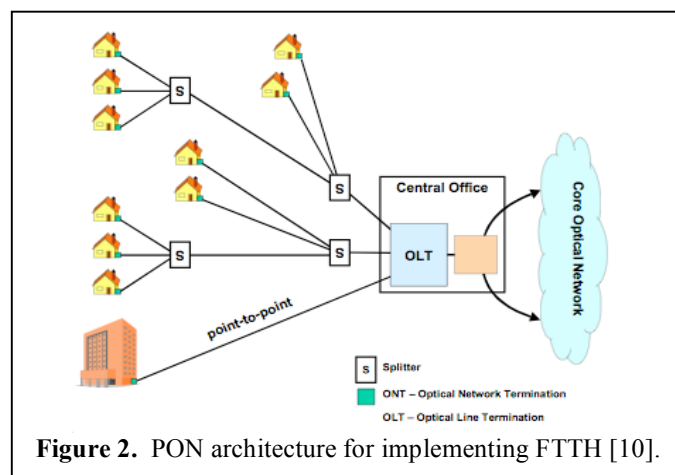
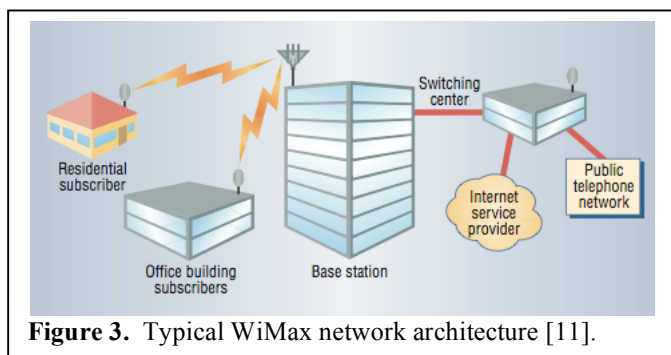


Figure 2. PON architecture for implementing FTTH [10].

PON networks have single fibers split into 16, 32, or 64 fibers (typically a power of two) depending on the manufacturer and are widely supported in the US by companies such as Verizon and AT&T [2]. FTTH cost and comparisons for the remainder of this paper are implicitly referring to the PON network architecture.

### B. WiMax

Worldwide Interoperability for Microwave Access (WiMax) is a wireless digital communication system for metropolitan area networking (MAN) and has been standardized as IEEE 802.16. It is another alternative for “last mile” connectivity. However, rather than connecting users through traditional wires, it transmits and receives data wirelessly on both licensed and unlicensed frequencies. WiMax is similar to WiFi except it is intended to be used on a much broader scale, serving 400-500 subscribers per base station within a ten mile radius. Figure 3 shows a typical network configuration of WiMax being implemented in a metropolitan area.



As shown in Figure 3, the base station resides at the top of a business building and provides service to subscribers through the buildings wired Internet connection. Theoretically a single channel can support data rates up to 70 Mbps and shares the spectrum with other users via orthogonal frequency-division multiplexing (OFDM) [5].

OFDM is a transmission technique based on traditional frequency-division multiplexing (FDM). In traditional FDM, multiple signals are sent out at the same time but at different frequencies to avoid interference and signal collision [5]. OFDM further advances this concept by transmitting on thousands of frequencies, which are orthogonal to one another. Orthogonal frequencies are those that are independent with respect to the relative phase relationship between frequencies. OFDM is not only used in wireless communications, but also in ADSL. The main benefits of OFDM are its high spectrum efficiency (i.e., it can transmit more data in a given bandwidth than traditional modulation schemes), resistance to interference, and ease of noise filtering.

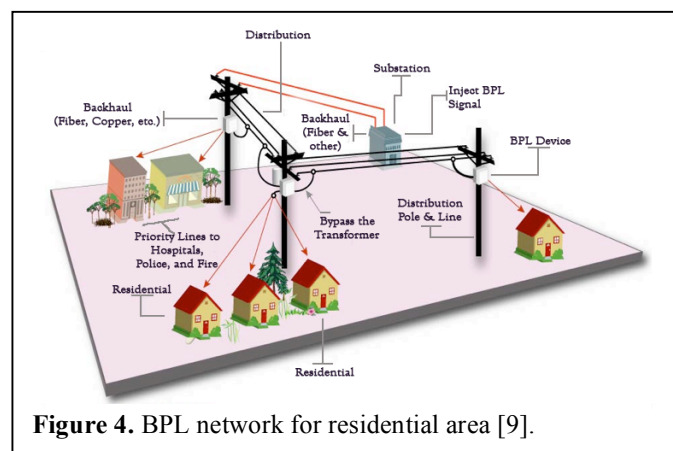
An example of OFDM being implemented to provide superior performance was in the 802.11 WiFi protocols 802.11b and 802.11g. Both transmit in the 2.4 GHz frequency range, but 802.11b achieves rates up to 11 Mb/s and 802.11g rates up to 54 Mb/s. This is because 802.11b uses direct-

sequence spread spectrum (DSSS) to modulate the signal and 802.11g uses OFDM. For this example, using the same bandwidth, OFDM modulation provides five times the transfer rates compared to DSSS.

### C. BPL

Broadband over power line, also called power line communications, refers to communicating over the existing aluminum and steel wire network, built by the power industry to provide electricity to businesses and homes, by transmitting data at medium and high frequencies. In the US, electric power is transmitted as a 60 Hz signal at various voltages over varying sized wires to our homes and businesses [6]. BPL introduces the concept of communicating information over medium voltage lines, around 12 – 64 kilovolts, at frequencies excluding 60 Hz, typically 1.6 – 30 MHz [6]. This technique allows broadband Internet service to be provided to anyone connected to the electric grid. The power grid network far surpasses the existing high-speed telecommunications network in the US. Using OFDM, BPL can deliver theoretical speeds of up to 130 Mb/s from end users to the nearest power substation [6].

BPL works by incorporating the utility companies into the telecommunication loop by running higher-speed connections, typically fiber, to substations throughout a designated area and having those substations serve users via the power lines. Multiplexing and de-multiplexing equipment is then installed into the substation to allow the transmission of the data onto the power lines leaving and entering the station [6]. The customers will also need hardware equipment on their end, but it will be on a smaller scale, typically the same size and functionality of a DSL or cable modem. In addition to multiplexing, impedance matching must be considered and plays an important role in the transmission rate and noise generation of the line. An impedance matching technique was developed using a ferrite toroidal core and a flat cable to create a matching transformer with one of the following impedances: 75  $\Omega$ , 200  $\Omega$ , 300  $\Omega$ , 460  $\Omega$ , and 800  $\Omega$  [6]. Figure 4 shows a BPL network for a typical residential area with few businesses.



BPL has to overcome the “harsh” environments associated with the noise and chaos on the electrical grid. Large industrial customers introduce this noise to the line because of the abrupt

changes in loads when powering on or off their equipment. For example, when a steel mill is turned on, it produces very disruptive noise onto the power line due to the abrupt change in voltage and current in the mill. This effect can cause the lights to flicker in a residential house several miles down the road. Similarly, this makes it difficult, maybe impossible, to decode a communications signal and retain the transmitted data within a given window of time. Any additional noise on the power line will decrease the overall achievable transfer rates [6].

### III. ANALYSIS

To determine which of the three “last mile” alternatives is likely to succeed, they will be compared based on cost, performance via transfer rates, and community support. Cost is the most important criterion telecommunication companies are considering when implementing “last mile” solutions [1]. Additionally, the performance of the service must be considered. Depending on the types of service being implemented, performance of the medium is a significant consideration because it limits the network’s physical capabilities to perform tasks. This makes the transfer rates of a “last mile” solution an important criterion. Lastly, the community support for a technology is important to the success of its deployment. The larger the worldwide support for a technology, the more manufacturers will produce related electronic equipment helping drive down the cost of implementation [1].

#### A. Cost Comparison

Among all three alternatives considered, FTTH is the most expensive initially due to its lack of existing infrastructure. Unfortunately, cost dominates everything in the “last mile” due to the low number of subscribers and the long-term payback on capital investments [1]. FTTH requires an immense initial investment to implement, making its seemingly unlimited bandwidth less appealing. In the US, the current per-resident cost of PON equipment has been around \$1500, which according to Green represents about 55 to 75 percent of the total cost to the provider and would have a payback of 2-3 years selling tripleplay services [1]. However, like most technology cost, widespread deployment of FTTH services will help significantly decrease the per-resident cost and allow extended deployment of FTTH. Even with a prohibitively high initial cost, if a company needed to run a DSL or cable connection to a new residence, the difference, in cost, between laying copper wires or fiber optics cables is small and negligible. These initial investment cost are minute in comparison to the life cycle return on implementing FTTH services. FTTH technology has the appealing benefit of currently being able to support the estimated future demand for bandwidth without need to develop new techniques or supplement technology. Figure 5 shows a plot of the consumer demand for bandwidth in the US over the past 26 years.

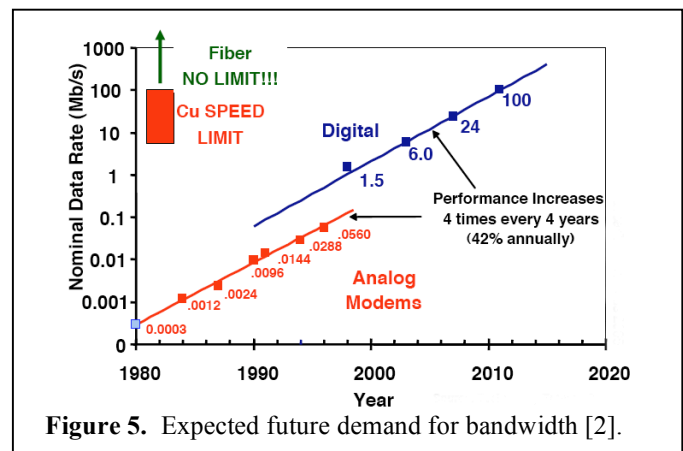


Figure 5. Expected future demand for bandwidth [2].

As shown in Figure 5, the demand for bandwidth increases exponentially and will continue to increase into the near future. Implementing FTTH will allow telecommunications companies to cash in on bandwidth intensive services, and, as HDTV becomes a *de facto* broadcast standard, it will be the only “last mile” connection capable of providing these services. According to Corning, a worldwide research company for telecommunications technology, current deployments of FTTH are expected to have a life cycle of 40 years and investors willing to start FTTH deployment can have a return similar to the plot in Figure 6.

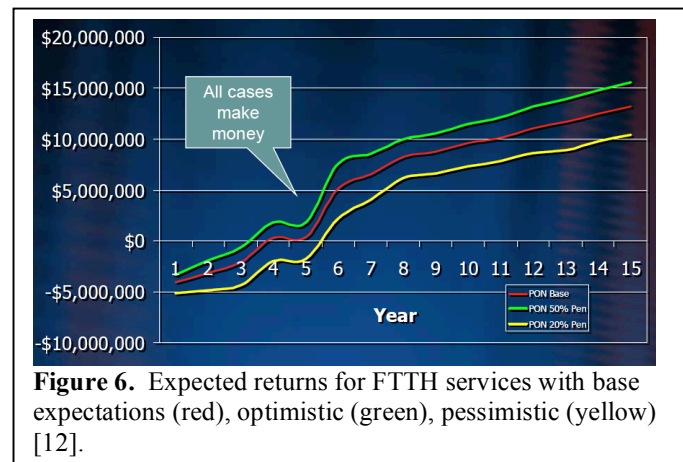


Figure 6. Expected returns for FTTH services with base expectations (red), optimistic (green), pessimistic (yellow) [12].

As shown in Figure 6, FTTH has a large initial investment but financially breaks even between year three and year five after deployment. In all cases, FTTH is a good investment given its long expected life and ability to meet the future bandwidth demand.

WiMax has many advantages in cost-per-resident because the standard itself is built to support 400 – 500 subscribers per base station. The cost per-resident would be around \$300 – \$400 to set up a service area and would then decrease to only the maintenance cost, because the investment in equipment has a quick payback [7]. WiMax does not need to have a dedicated tower to serve an area. Antennas can be placed on top of buildings or existing cell phone towers, helping to decrease the cost. According to Corning, the majority of the cost associated with many “last mile” solutions comes from the installation labor of laying wires. Because the technology

is wireless, it also does not need to account for these installation costs, making it more appealing. Adding or removing a customer is as simple as adding or deleting an account in a database. Licensing costs are ignored on a per-resident comparison because the specific licensed frequency would be standardized for the entire US, and could therefore be neglected due to the large number of consumers contributing to the license cost. Because WiMax has an expected life of 5-10 years and a quick return on initial investments of 1-2 years, investors can expect a quick payback on their investments.

BPL has a relatively low cost-per-resident, primarily because the infrastructure already exists and the only investment is in the associated equipment needed at the substations and residencies. Depending on the manufacturer, cost-per-resident can run around \$250 – \$500. Not only is the initial investment low, it also allows users to save money when bundling broadband communications systems together with electrical power [6]. Primary investors of BPL are the local utility companies themselves. By adding additional services to their existing infrastructure, distributors can decrease the initial and lifetime maintenance cost per-resident.

Comparing the cost associated with each technology suggests that WiMax and BPL are superior to FTTH. However, FTTH is likely to have a longer lifetime than both WiMax and BPL, which would need replacing in an expected 5 – 10 years [1] [8] [9]. Including both the current cost of implementing these alternatives to FTTH and upgrading them years later to continue to compete with FTTH makes the initial investments of FTTH more attractive to telecommunication companies because of the longer product life.

### B. Transfer Rates

FTTH surpasses all other known technologies in the performance category. All FTTH connections can provide speeds exceeding 100Mb/s but most ISPs limit these to lower ranges sold in packages, typically 10 Mb/s, 20 Mb/s, and 30 Mb/s simply because most users do not currently have a high demand to transmit data at such large rates to offset the higher monthly cost for the service [2]. This also is attractive, because even though FTTH currently offers packages of lower transfer speeds, the physics associated with the technology allows transfer rates far beyond the current demand. This means that telecommunication companies will only need to adjust network administration settings to support futuristic services.

WiMax implementations in the US have shown test results of only 2 Mb/s, a disappointing three percent of the theoretical 70 Mb/s [7]. The low efficiency of the implemented technology results from a crowded frequency spectrum, where the best frequencies are already licensed for other usage (best in regards to the physics behind wave propagation and attenuation). Although these rates can serve a large radial distance, they do not surpass the current WLAN technology WiFi, which has transfer rates of 54 Mb/s but requires a 100 ft radial distance to an access point.

BPL implementation in Euiwang, Korea over 22.9 kV

power lines achieved 3 – 5 Mb/s transfer rates at every point on the line [6]. Deployment of BPL in Manassas, Virginia offers a 10 Mb/s service to 35,000 city residents at an attractive \$30 per month [9]. With these attractive transfer rates, BPL appears to offer great performance for the price, but still falls short of the rates achieved by FTTH. BPL is, however, capable of the current and near future demand for data transfer rates as discussed in Figure 5.

### C. Community Support

FTTH is the most supported “last mile” solution currently being deployed in the US and around the world. Japan currently has over one million FTTH subscribers and is leading the world in FTTH deployment [2]. Even improvement of existing DSL and cable Internet services have extended the fiber communications network in the US, but the expensive cost to continue the deployment to the home may slow its extension. Verizon has led the way on FTTH connections in the US, offering service in several New England states as well as Texas, California, Florida, and California. They offer a variety of packages including 5, 15, and 30 Mb/s connections for \$35, \$45, and \$55 a month, respectively, and offer television, Internet, and telephone services [2]. WiMax is being widely supported by Intel and has already been implemented in San Francisco, CA. One obstacle with WiMax is the fierce competition it has with the Universal Mobile Telecommunications System (UMTS) 4G protocols. Countries, such as France and Finland, have already invested heavily in UMTS and have consequently banned further development of WiMax within manufacturers in their countries [8]. BPL is a somewhat controversial method primarily because the electrical grid supplying power consists of unshielded wires, allowing interference among various frequencies. Steps have been taken to help reduce and remove interference problems and have been standardized as the IEEE BPL protocols. BPL also has non-engineering related issues of merging with the power industry with the telecommunications industry.

Summarizing the quantitative advantages of each technology is shown in Table 1. FTTH has superiority in performance but lags the other technologies in cost.

**Table 1.** Comparing FTTH, WiMax, and BPL, Based on Cost and Performance

	<b>FTTH</b>	<b>WiMax</b>	<b>BPL</b>
<b>Cost per resident</b>	\$1500	\$300-\$400	\$250-\$500
<b>Data transfer rates</b>	10 Mb/s, 20 Mb/s, 100 Mb/s	2 Mb/s	2-10 Mb/s
<b>Years to meet future demands</b>	15+	6-7	9-10

WiMax and BPL overlap for the cheapest initial cost but fall short in the performance category. FTTH is the only “last mile” technology that is expected to meet the bandwidth demand for future consumers.

#### IV. CONCLUSIONS

Considering all three technologies, FTTH surpasses the other in sheer performance, allowing transfer rates up to 100 Mb/s, not only supplying the current demand for bandwidth but also the future demand. Its high initial investment makes it an unattractive solution, but when considering all aspects of implementing the technology and the longer life span fiber has over WiMax and BPL, the initial investment is one telecommunication companies are willing to take. FTTH is expected to have a higher return for long term used because of its excess capacity. As new services come about, such as HDTV for every channel, FTTH will be the only connection capable of handling the substantially large data rates needed and therefore allow companies who invested in FTTH to monopolize on providing these services.

When implementing “last mile” solutions, telecommunication companies will be focused on reliable long-term solutions to the problem. A cheaper initial investment does not justify semi-annual upgrades of equipment and protocols to serve the ever-increasing demand for faster Internet connections. Wireless solutions are almost always going to help complement an existing wired solution such as FTTH and will never surpass the available performance achieved by wired solutions. WiMax may provide users moderate Internet connections but will not be capable of the services offered by FTTH thereby, being forced to serve as a complementary technology similar to WiFi. BPL may extend the use of “copper” wired communications, but the eventual increases in consumer demands will exhaust its capacity. BPL also requires the power industry to get involved in the communications industry further succeeding their natural monopolistic power and causing potential disputes on Capitol Hill.

Improvement of the “last mile” will continue to be fueled by emerging and innovated services that will bring high quality, multimedia rich experiences into the homes and lives of consumers. The demand for faster connections will force the telecommunications industry to become more innovative about implementing “last mile” connections to help foresee bandwidth usage and future communication applications to ensure the success of the industry. FTTH allows the industry to continue to meet the demand for bandwidth for years to come.

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