The Fundamental Component of Telecommunications Cabling

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Abstract

The fundamental building block of last mile broadband connections for the telecommunications industry is the copper cabling systems that have traditionally underpinned the networks. Time has seen tremendous change in this core component of the network, with result being silica-based fiber optics are championed as the de facto replacement technology for traditional copper cabling in the last mile.

This paper will provide a survey and discussion of the current status of copper cabling in networks. It will examine the strengths of copper verses fiber optics. It will explore the effectiveness of recent technological advances made in delivering broadband over copper. It will also review the current economic models relating to cable deployments. Finally, an analysis will be presented that attempts to answers the question of phasing out copper.

Keywords-Telecommunication cables, copper cable, fiber optics, last mile, digital subscriber line, passive optical networks.

I. Introduction

The fundamental component of telecommunications is the actual physical cable that connects the world's networks to each other and to end-users. The internet introduced the greatest change in the history of telecommunications. It forced copper based networks originally designed for single service applications such as voice to multi-service applications including voice, video, and broadband data. It has also changed the network policy the world over with legislation and cultural attitudes that advocate phasing copper based solutions out of the last mile of the telecommunications network in favor of fiber optics.

This paper will explore the question "Should copper cables be phased out as last mile broadband solutions?" In order to determine an answer to this question, many aspects of cabling will be reviewed, including the current political and social climate relating to last mile broadband technologies. It will explore the physical and reliability characteristics of the different cable types. It will review the economics relating to cable types from a service provider and a user perspective.

The findings will note there is limited evidence suggesting that copper cables should be phased out as last mile broadband solutions. Costs, technological advances, existing infrastructure, political climate, and macroeconomics all play a role in determining what cables best will serve the needs of the network owners and users.

Section II gives brief history of copper cabling. Section III discuses brief history of fiber optic cabling. In Section IV, we discuss about the current climate and attitudes relating to the copper verses fiber debate. Section V discusses physical characteristics of copper and fiber based Telecommunication cables. In Section VI, we discuss about consumer economics of fiber optic vs. copper networks. Section VII discusses service provider economics of fiber optic vs. copper networks.

II. A Brief History of Copper Cabling

The birth of current copper based telecommunications systems can be traced to May 1st 1844. It was on this date that Alfred Vail and Samuel Morse used their partially completed electrical telegraph to send the news of Henry Clay's nomination from Annapolis Junction, Maryland to members of Congress at the Capitol in Washington DC. This was full hour-and-a-half quicker than the message was able to get to the Capitol by human carrier. It was this event that proved how much more effective even the most basic telecommunications system was at transferring information than any other method used throughout the whole of human history [1].

Even as rudimentary as the electrical telegraph was, the cost to build it was prohibitive, so monies had to be appropriated from the federal government. The amount required at the time was $30,000, or close to $773,000 in today's dollars [www.measuringworth.com]. This very first example of the prohibitive costs of network deployments has been echoed throughout the history of communications up until the modern era. It also directly affects the ability of modern day broadband service providers to phase out existing networks in lieu of newer equivalents.

The telephone network used the same type of network cable as the telegraph, but could carry a modulated signal that could recreate complex sounds such as voice. The popularity of voice service eventually replaced telegraph service as the primary communication network in use. In many instances, electrical and telephone networks were simultaneously located on similar, parallel paths. The electrical networks caused telephone signal interference, which necessitated the invention of a process known as "wire transposition" [2]. In a wire transposition implementation, the wires exchange position every few phone poles, thus eliminating the interference. Wire transposition eventually led to the creation of unshielded twisted pair cabling (UTP). The following Fig.1 shows an example of wire transposition. Transposition was implemented approximately every 3-4 poles which resulted into approximately five to six twists per mile.

An alternative means to offer broadband over copper cable is coaxial cable (coax). Lloyd Espenschied and Herman A. Affel, engineers who worked for the American Telephone & Telegraph Company, were awarded U.S. Patent No. 1,835,031 in 1931 for a "concentric conducting system". This invention was the core of coax. [3]. It is named "coaxial" because two conductors share the same axis: one conductor is at the center of the cable, and the second is wrapped around it. This design minimizes signal degradation from external electromagnetic sources as the signal only transmits between the two conductors. The design had a specific goal in mind: to meet the need for "An enormously wide frequency range" which would facilitate both the new television technology as well as offer a more effective solution for telephone systems.

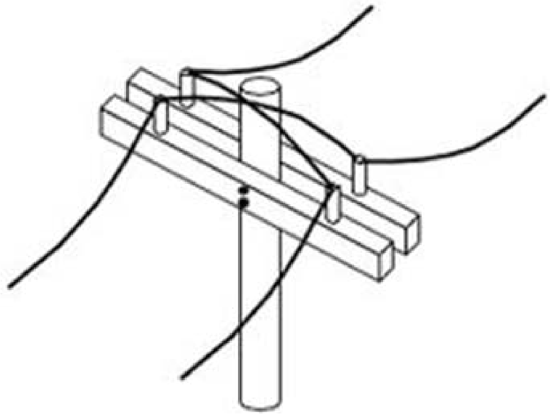

Figure 1. Example of wire transposition.

From its inception, coax was designed to provide much greater bandwidth than UTP—depending upon the age of the cable, coax can deliver between 100 MHz to 1000 MHz [4].

The different types of coax cable are labeled with an RG number. For example, some popular types are RG6, RG11, RG58, etc. The 'RG' designation has its root as a military based nomenclature for cables listed in a World War II era military specification formerly referred to as the Radio Guides. The acronym RG now stands for Radio-Frequency Government [5]. The numerical designation is not related to the actual cable, or to its reliability and effectiveness, but to the pages in the guide where the cable specifications are located. For example, RG6 is on page 6 of the radio guide it is listed in. Following World War II, veterans who maintained a strong familiarity with the numbering scheme secured jobs in the broadcasting industry and extended its use there. Thus, the standard coax nomenclature was permanently adopted [6].

UTP became the standard cable used by traditional telecom companies to provide the last mile link for broadband services via a technology known as Digital Subscriber Line (DSL). There are several variants of DSL including multiple versions of Asynchronous Digital Subscriber Line (ADSL), as well as multiple versions of Very-high-bit-rate digital subscriber line (VDSL). The main difference between these different flavors of DSL technology is the speed offered and the distance that broadband can be offered in the last connection the digital subscriber line access multiplier (DSLAM) at the local exchange (LE) to the premise [7]. Fig. 2 shows distance range for different standards of cables

Coax became the standard cable used to deliver broadband services via the Data Over Cable Service Interface Specification (DOCSIS). There have been several generations of DOCSIS with the latest being DOCSIS 3.0. This latest generation of DOCSIS achieves speeds of up to120 Mb/sec up and 160 Mb/sec down.

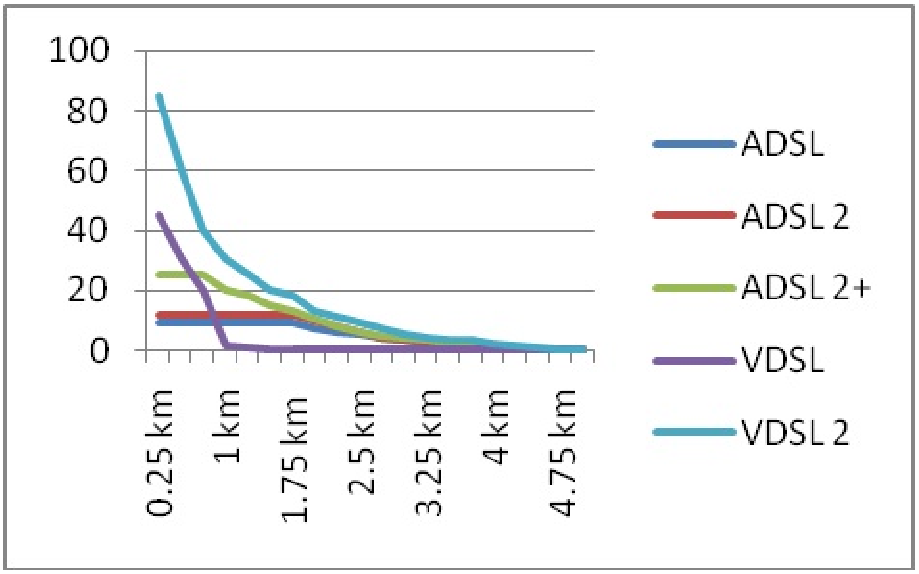

Figure.2 Distance range for different types of cables.

III. A Brief History of Fiber Optic Cabling

Comparatively speaking, of the types of telecommunication cabling, fiber optic cable has a history of the most disparate contributions. The invention and use of fiber optic cable occurred in stages. For example, initial research involved the use of glass tubes for dental and medical applications including dental illumination and internal imaging. Clear tongue depressors were developed for dental offices to deliver light into the mouths of patients. Additionally, the insertion into the body of an optical tube was less invasive than an operation for seeing inside a human body. Further research was done throughout the 1930's on transporting images through clear tubing, but the next critical development that moved fiber optics forward occurred in 1954 when Abraham an Heel invented a cladding fiber with a lower refractive index when applied over a core of glass. By the 1950's, glass-clad fiber had an attenuation of one decibel (dB) per meter, adequate for the original purpose of medical imaging but too high for the purposes of communications [8].

The laser was invented in 1960, and this spurred interest and experimentation in using optical fibers as a communications technology. For optical fiber to be effective for communication purposes, researchers needed a cable with attenuation of less than 20dB/KM. This was accomplished in September 1970 by Corning Glass researchers who created a fiber optic cable out of fused silica with attenuation below 20dB/km. Robert Maurer, Donald Keck and Peter Schultz invented fiber optic wire or "Optical Waveguide Fibers" (patent#3,711,262) through which information carried by a pattern of light waves could be decoded at a destination even a thousand miles away. The fiber optic wire was capable of carrying 65,000 times more information than copper wire [9]. This achievement heralded the beginning of modern fiber optic networks. In 1977, the first optical telephone communication system was installed about 1.5 miles under downtown Chicago, and each optical fiber carried the equivalent of 672 voice channels [10].

IV. The Current Climate and Attitude Relating to the Copper vs. Fiber Debate

Let's examine the coax cable used for cable television. It has lots of bandwidth, but it even cheaper than telephone wire to install. CATV systems are using this coax for everything including television signals, Internet connections, and even voice over IP. However with the rapid evolution in data transmission, it is now being quickly converted to fiber, which provides the backbone connectivity due to lower loss and much greater reliability which in turn, translate into cost savings. In most data transmission, fiber and copper coexist, with each being used where the economics dictate.

The wire we use for LANs is a lot younger than fiber optics. Fiber use is over 20 years old, but computer networks on unshielded-twisted-pair cable (UTP) have only been around about 15 years. In that time, UTP has gone through at least 5 generations, each time to keep up with the increasing bandwidth requirements of LANs. Today, voice over IP has replaced the "telephone wire" that once was.

The copper cabling manufacturers technical efforts to expand the capacity of UTP cabling in order to keep up with the ever expanding networks has produced extraordinary results in terms of product development which include the electronic platform that assist in getting the signals off and on the cabling.

When we examine the down side, the achievement of maximum performance is still in question. Recently, a number of magazine articles and even a representative of AMP were quoted as saying that as much as 80-90% of all Cat 5 cabling was improperly installed and would not provide the rated performance. Contractors have told us that 40% of their Cat 6 installations pass certification tests.

The performance of the Cat 5 cable is dependent on close control of the physical characteristics of the cable and the materials used in the insulation. Untwist the wires too much at a connection or remove too much jacket and the cable may fail crosstalk testing. Pull it too hard (only 25 pounds tension allowed!) or kink it and loss the performance you paid for.

Even if top performance is not necessary, getting all 8 of the wires connected correctly requires a lot of care.

The genesis of the question underpinning this paper comes from the current world-wide attitudes on telecommunications cable. Currently, political pressure is being exerted against the use UTP in favor of fiber [11]. The general consensus among world leaders is clear: they are supporting legislation driving universal access to broadband, the preference being for fiber optics over copper. There are differing regional attitudes about cable deployment, and it is important to emphasize that attitudes in one part of the world may impact attitudes and adoption rates elsewhere.

Starting in 2001, for example, nearly no Fiber to the Home or Business (FttH/B) solutions was deployed. Today, the number stands at approximately 50 million—this many homes and business receives broadband via FttH/B. The breakdown in subscriber numbers and regional preferences can be seen in the following graph. The highest numbers belong to the United States, Japan, China, Europe and Russia. Fig. 3 shows same 2011 FTTH/B subscribers.

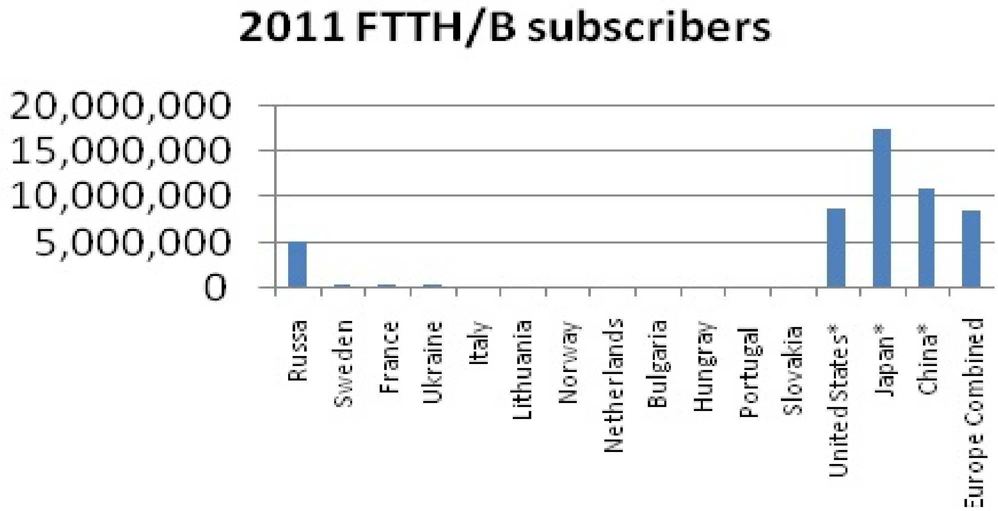

Figure 3. 2011 FTTH/B subscribers

In October, 2011, Neelie Kroes, vice-president of the European Commission in charge of the Digital Agenda, unveiled proposals to accelerate investment in fiber networks. She proposed two models targeting changing the wholesale access pricing on existing copper networks. The first forecasts a gradual reduction in wholesale prices for universal access to existing copper networks, the resulting fall in retail broadband prices encouraging incumbents to move to fiber networks. The second forecasts incumbents escaping at least part of the price cuts if they agree to switch off their copper networks switch within a certain period and adopt fiber [11].

Despite the growth rate of FttH, abandonment of copper-based solutions, as espoused by Kroes, may be premature because copper—the older, time-tested solution—is entrenched in certain markets, and technological advances involving the deployment of copper are still occurring and making their way into the market. British Telecom in the United Kingdom, for example, has been marketing 20 Mbit/sec connections over legacy twisted pair using ADSL2+ since 2011[12]. According to the British approvals service for cables, network cable has a life span that can reach 50 years [13]. It is for this reason network build outs are amortized over decades by large service providers. Comparatively speaking, fiber optic cable has been in service for less than 25 years as a viable communications platform. From the service provider's perspective, in some instances fiber has to compete with network cabling that is still expected to provide 25 years more service. The economics of cable types will be discussed further in this study.

V. Physical Characteristics of Copper and Fiber Based Telecommunications Cables.

In order to answer the question, "Should copper cables be phased out as last mile broadband solutions?", a review of the physical characteristics of the different cable types is of interest. The outside plant can be a harsh environment- weather, human interaction, animals, and many other factors can negatively affect cable. Operating expenditures associated with maintaining an outside plant are very costly to fixed line telecommunications service providers. The physical characteristics and reliability of different types of cable will have a direct impact on what types of cables continued to be deployed. There are many similarities between UTP and coax based on the fact that both are made of copper and depend on a dual conductor arrangement for effective communications. Although there are some reliability issues unique to each cable type, both suffer from many of the same deteriorative factors. Fiber optic cables are based on a completely different technology and only require a single conductor for transmission of light. In terms of use, each cable type has strengths and weaknesses which make it difficult to determine which one is the most reliable.

Twisted pair cable is unique in that its conductor and insulating jacket are very small. This makes twisted pair highly susceptible to breaks, stress, and improper twists. Additionally, twisted pair is manufactured and deployed in very large bundles so the potential for splitting pairs and electromagnetic crosstalk between pairs is very high. This crosstalk is one of the major limiting factors in using UTP to provide higher broadband speeds. A new technology called Phantom Mode may correct the problem and allow for speeds in excess hundreds megabits per second[14]. Coaxial cable jackets are susceptible to ultra violet radiation, and will deteriorate over time when exposed to the sun or another source of ultra-violet (UV) light. Coaxial cable also tends to have more issues with its larger connectors if they are not affixed properly.

Some similarities between the two cable types involve moisture and interference. Moisture causes two main detrimental effects to copper telecommunications cable. First, when moisture is present in a copper conductor it can cause oxidation. This will give rise to an increase in the level of attenuation in copper based cable. Second, when water vapor is absorbed into the dielectric insulating member of the conductor and power is passed through the cable, the reduced dielectric properties of a vapor filled insulator will conduct some of the electromagnetic energy and convert it into heat. In all cases the cable becomes less effective. Because both UTP and coax are metallic, both are susceptible to interference by high levels of electromagnetic energy which can couple onto the cable. Coupling can be an especially acute problem if there is a flaw in the cable jacket [15].

When considering the reliability of fiber optic cable, two areas affect its viability. Degradation can be caused by stress and fatigue, but also by slow changes in the cable over time. Abrasion caused by foreign particles on the fiber surface can cause fatigue and damage to the fiber. These particles generally result from poor manufacturing, handling, or installation. Stress also affects cable viability. “High stress” typically is encountered during installation, repair, or reconfiguration of the cable while “low stress” is sustained under normal conditions over long periods of time [15].

High stress failures are easy to visualize. A technician who bends a fiber too tightly may see the fiber break. A failure of a component on the manufacturing line may produce highly flawed fiber that meets minimum specification, but undoubtedly will fail over time.

Low stress failures are more difficult to envision. It is important to remember that fiber is made of glass. As an example, anyone who has ever experienced a rock hitting the windshield of a car knows that glass cracks. Over time, the cracks will spread as a result of the stress the windshield is under due to various driving and weather-related conditions. A fiber works much the same way, micro abrasions causing cracks that will spread over time and eventually cause failure [16].

Ultimately, there are benefits and detriments to the physical aspects of each cable type. These pros and cons make it difficult to determine if a cable type should be removed from use in the last mile of the outside plant based upon these differences alone. Other aspects must be considered to determine copper's viability as a broadband solution in the outside plant.

VI. Consumer Economics Of Fiber Optic vs. Copper Networks

Business and government are generally early adopters of new technologies, and earlier the authors cited how government became involved with telecommunications from the very first transmission. This is primarily due to the higher initial cost of implementing any new technology. As economies of scale ramp up and refinements are made in manufacturing and distribution, services and technologies generally tend to evolve into consumer offerings. At that point, mass adoption lowers cost.

Globally, broadband costs have shrunk dramatically in recent years. Consumers and businesses are paying on average 18% less for entry-level Information and Communication Technology (ICT) services than they were two years ago - and more than 50% less for high-speed Internet connections, according to figures released by the International Telecommunications Union [17]. Fixed broadband (hard line) pricing is dropping the most (at over 52%) while wireless broadband access is also dropping appreciably (at nearly 22%) as the following table illustrates

According to the World Bank, in Ireland the price of an ADSL connection for a business user fell 74 percent between 2005 and 2008. In Turkey, the drop was 57 percent; and in Peru, 17 percent [18]. Table I gives different price basket over the years. Although pricing is dropping quickly, in many parts of the world, broadband is prohibitively costly based on per capita income. For example, in heavily-populated developed countries with mature economies —France, England, Germany, the United States—the price for broadband has fallen so much that it's approaching only 1% of monthly income.

This is due to aggressive competition and government /private partnerships aimed at expanding fixed line based broadband to a broad base. One further example can illustrate this point: in late 2011, Comcast and Century Link started offering a $9.95/month service that provides 1.5 Mbps downstream to low income families in many cities across America, and their respective programs also included subsidized computer hardware [19].

By contrast, in 32 less-developed countries, the monthly price of an entry-level fixed broadband subscription corresponds to more than half of the average monthly income. In 19 of those countries, a broadband connection costs more than 100% of monthly Gross National Income per capita (GNI), and in certain developing countries the monthly price of a fast Internet connection is still more than ten times the monthly average income [17]. The following graph in Fig. 4 illustrates this data.

Table 1. Different price basket over the years.

Price Basket	2008	2010	Average Absolute value change	Average Percentage Value Change
ICT Price Basket	15.2	12.4	2.8	18.3
Fixed phone sub-basket	6.2	5.8	0.4	6.9
Mobile service sub-basket	11.0	8.6	2.4	21.8
Broadband sub-basket	165.0	78.9	86.1	52.2

These prohibitively expensive scenarios have resulted in a market that is underserved. In short, there is ample opportunity for existing copper-based broadband networks to grow worldwide. Worldwide, less than a quarter of fixed telephone lines have been upgraded to DSL broadband connections [18]. Additional data can be seen in the following table which shows by region the percentage of DSL penetration compared to total voice lines.

There are different aspects to consider when we debate displacing copper cable with fiber optics. One major difference between the two technologies is bandwidth. Fiber optics can provide superior levels of bandwidth to end users. A generally accepted belief is that for greater functionality users of broadband will need higher speeds. There are numerous estimates of bandwidth requirements for various types of digital content. For instance, The Organization for Economic Co-operation and Development (OECD) suggests that bandwidth requirements for online games, video on demand, and videoconferencing range from 2 to 14 Mbit/sec [20].

Booz & Company, an international broadband consulting firm, approaches broadband speeds as generational. They consider the first generation offering 512 Kbit/s to 2 Mbit/sec to be adequate for rich media, social networking, and videoconferencing. Their belief is that next generation broadband will include applications such as next generation TV and tele-learning. As a result, Booze & Company estimates next generation bandwidth requirements at more than 20 Mbit/s, and that future data services should also be of high quality [21]. What is most interesting about the above information and the resulting conclusions is that copper solutions including DOCSIS and many of the implementations of DSL are compatible with all such scenarios.

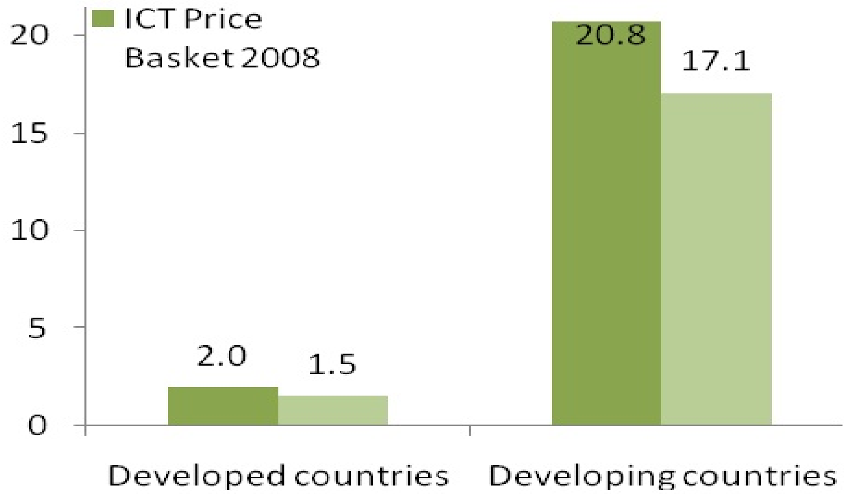

Figure 4. ICT Price basket in developed and developing countries

Table 2. Different regions with DSL/Total Mainlines Percentage.

Region	DSL/Total mainlines
East Asia & Pacific	15.1%
Eastern Europe & Central Asia	4.8%
European Union (EU-27)	29.1%
Latin America & Caribbean	4.0%
Middle East & North Africa	6.2%
North America	37.9%
South Asia	0.2%
Sub-Saharan Africa	4.6%
World	12.8%

According to a study based on business class internet service that was commissioned for the United States Small Business Association (SBA), DSL offers the lowest cost broadband service by type. The following graph in Fig. 5 shows the average monthly price for internet connection by type and compares xDSL verses the cost of competitive technologies [22].

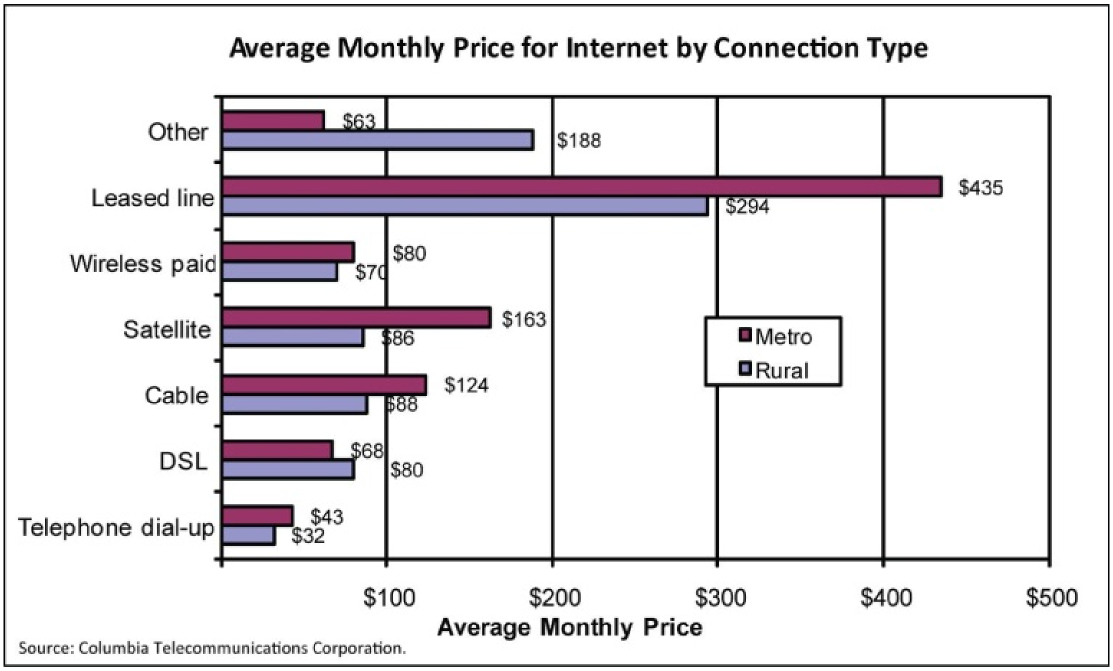

Figure 5. The average monthly price for internet connection by type and compares xDSL verses the cost of competitive technologies

The European Union commissions an annual comparative study on broadband internet access costs in 27 member states of the European Union as well as Canada, Croatia, Iceland, Japan, South Korea, Liechtenstein, Macedonia (FYROM), Norway, State of California, State of Colorado, State of New York, Switzerland and Turkey. As illustrated in the following chart, the latest data from the 2011 report shows that copper solutions such as cable broadband and DSL maintains the lowest cost option for broadband consumers. Fig. 6 shows different market share of technology.

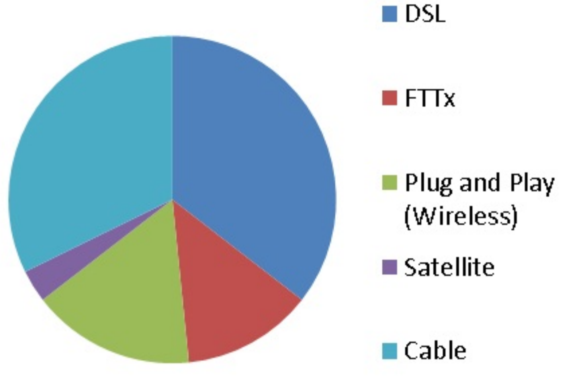

Figure 6. Different market share of technology.

When considering the total market for all speeds and all technologies, twisted pair copper has commanded a historical lead, and even with tremendous competition from fixed wireless, Fiber to the x (FTTX), and cable, DSL still maintains roughly 80% market share [23]. This can be seen in the Fig. 7.

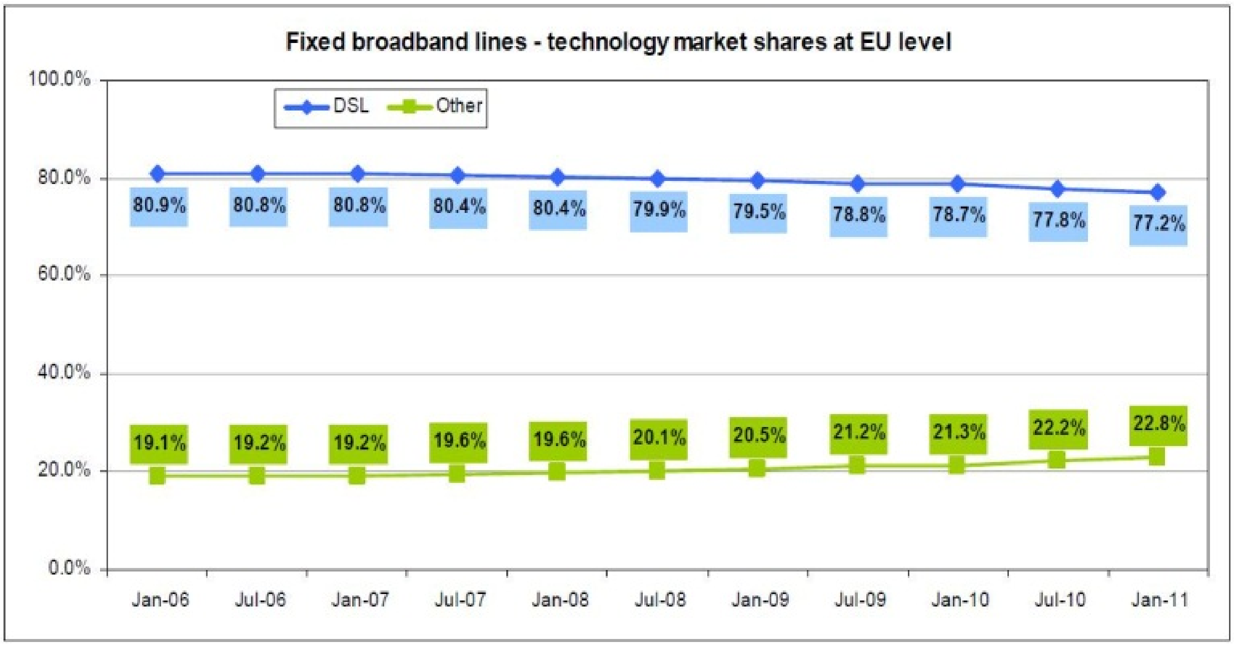

Figure 7. Fixed broadband lines-technology market shares at EU level.

From the perspective of the broadband consumer, the data clearly shows a distinct benefit to keeping copper based solutions for the foreseeable future. Copper based solutions offer the best prices and the greatest opportunity for broadband growth.

VII. Service Provider Economics Of Fiber Optic vs. Copper Networks

The bandwidth benefits of fiber optics are well known and fiber is the standard for back haul operations of almost all telecommunications networks. The deployment question concerns its lack of mass adoption by network providers for the last mile of their networks. The answer has much more to do with economics of network operations than it does in the effectiveness of it. It is simply not cost effective to deploy a Fiber to the Home/Business (FttH/B) end to end fiber optic network.

As an example, CATV companies currently prefer a Hybrid Fiber-Coax (HFC) network where fiber is used in the backbone and Coax is used for the distance from the fiber termination point to the home. This provides enough bandwidth to allow the CATV companies to offer a plethora of services including traditional video entertainment, video on demand, high speed internet, and telephony. It also significantly reduces the need for expensive fiber optic electronics at both the headend and at the customer premise.

In an all fiber Passive Optical Network (PON), the cost for the “drop” from the WAN to the customer premise is $748.00. In a HFC deployment only a traditional coax drop is required, which costs an estimated $125.00. The savings are just as stark when it comes to headend equipment. In a network cost analysis costs are measured per Outside Plant mile. Costs are incurred for both the Outside Plant and headend equipment. In an FttH PON deployment the costs for headend equipment is $16,118 per mile. The cost for outside plant deployment is $26,084 per mile. Comparatively in a HFC deployment, the costs for outside plant deployment is

$28,682 per mile but the headend equipment is $820 per mile [24]. The stark nature of the difference of these numbers can be seen in the following graph in Fig. 8.

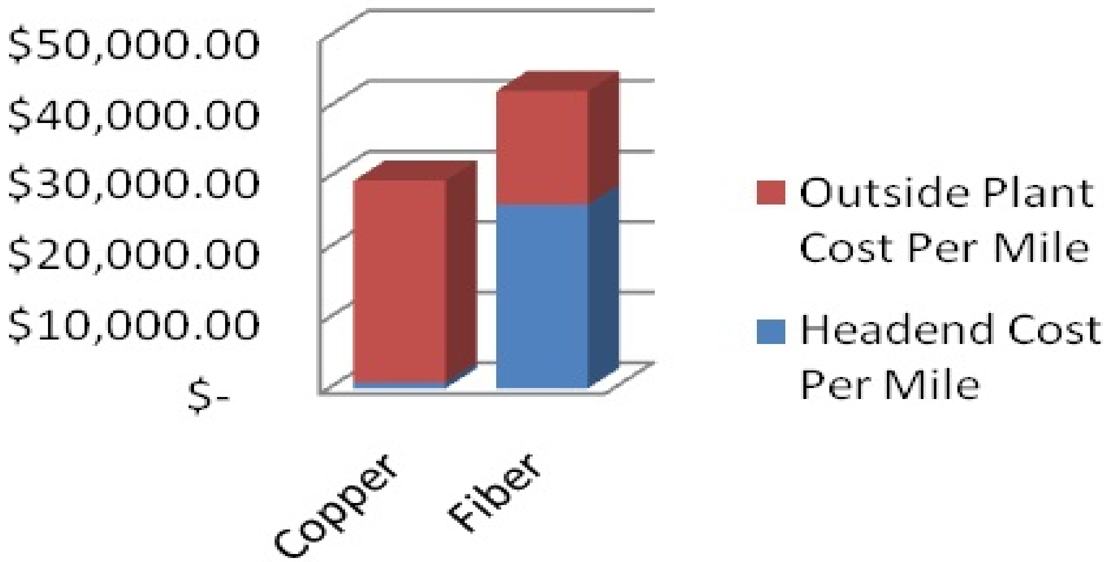

Figure 8. The copper vs. Fiber cost comparison.

The market continues to remain dynamic as major corporations such as Google experiment with their own FttH/B build outs [25]. It will take time to see how this new competitive pressure affects the industry.

From a purely economic model, displacing copper cable in favor of fiber optics does not make economic sense for service providers or for consumers. It is especially true for service providers who would need a significant return on investment to replace copper with fiber. In fact, there are examples of telecom companies that have stopped deploying fiber optics because of the economics. Verizon, the largest fixed-line provider in the United States, started deploying an FttH/B across its entire network, recently pulled back its fiber deployment and has decided to maintain a focus on services they can deliver over their existing copper cable based plant [26].

VIII. Conclusions

Both copper cable and fiber optic cable exhibit strengths and weakness that do not identify either as a clearly superior technology.

Even with copper cable being the significantly older technology, continued improvements such as updates to DOCSIS and updates to DSL including phantom mode are driving greater bandwidth for broadband offerings. Copper cable has the added benefit of currently being the primary connection method for last mile broadband connections.

The economics of copper based solutions are stronger than they are for fiber optics for both the service provider as well as the broadband consumers. Using economic modeling alone a case can be made that it is in the best interest of telecommunications users and service provider to maintain and potentially even extend the copper networks.

Ultimately the combination of all of the above factors of technology, economics, and market share combine to provide a clear answer the question that underpins this paper. Without a doubt, there is no clear benefit to phasing out copper from the last mile of the outside plant.

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