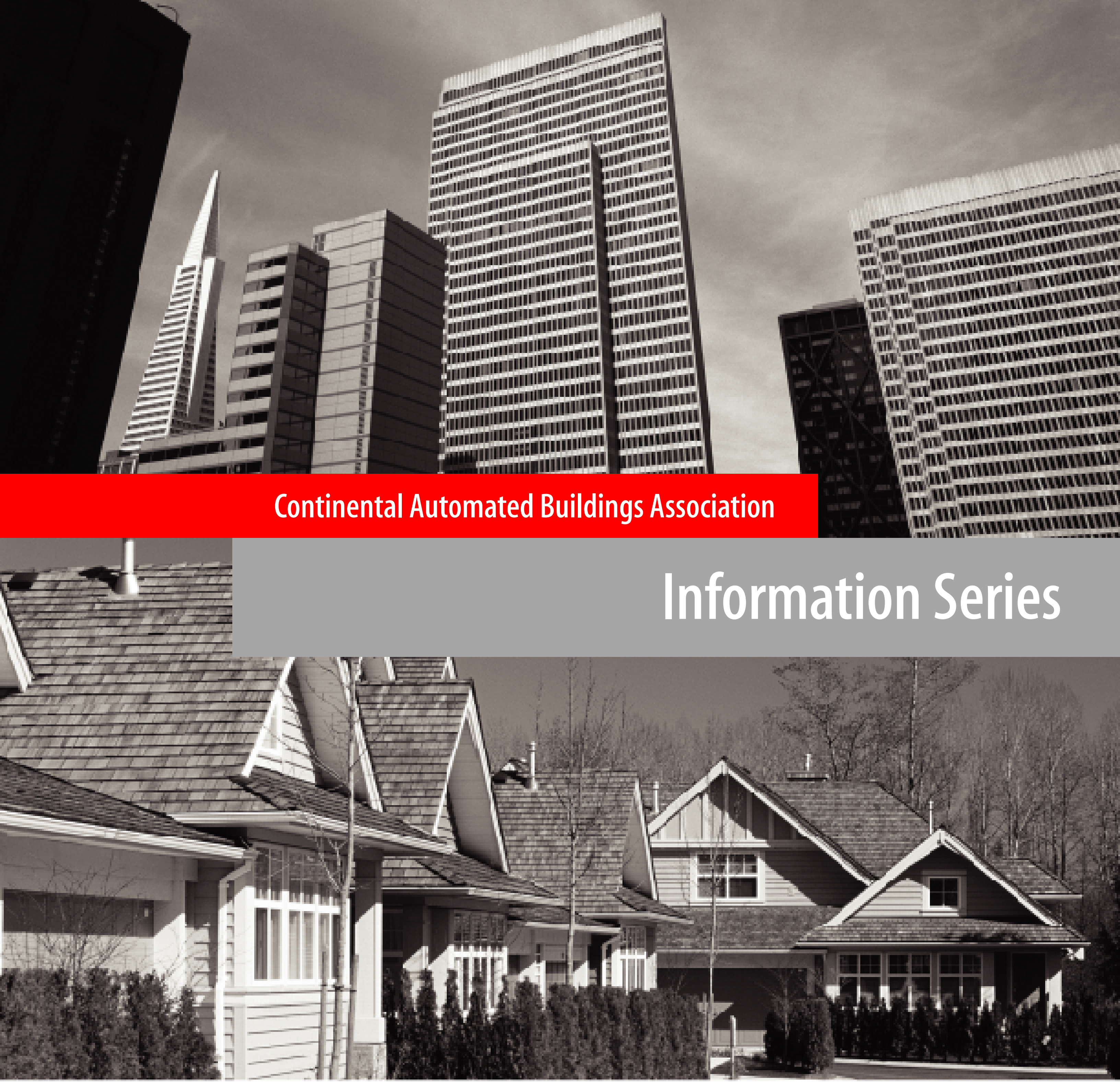

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Creative Ways to Build Broadband Networks And Underground Power Cables Through Strategic Partnerships Among Utilities

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Creative Ways to Build Broadband Networks And Underground Power Cables Through Strategic Partnerships Among Utilities

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Abstract

People from most countries have long had the desire to move their overhead power lines, telephone lines, CATV lines, and optical cables to the underground. It's ironic that, 21st technologies controlling 21st century economies are still relying on 19th century wooden poles. When we the people pose the question why more of these services are not buried, all the service providers are quick to dismiss the idea, saying it would be too costly. But, as regulated entities, this is not their decision. In fact, it's ours who pay the price dearly because power and other service disruptions affect our economy, cost jobs, and create hardships for our households and businesses. With cable companies and sewer, gas, and water departments digging up streets all the time, it's fair for us to ask why public officials are not implementing a policy of utility corridors for burying all services together. The communications industry is also fighting for its survival because of last mile bottleneck and overbuilding in long haul networks without any planning whatsoever. The end users craving for infinite bandwidth already have sanitary sewers, storm drains, waterlines, hot water pipes, and natural gas lines reaching their premises. There are also roads and occupied ducts reaching the same end users. It makes all the sense in the world to build the last mile optical fiber/FTTX and power cables in these existing rights of way on conduits, ducts, sanitary sewers, storm drains, water mains, hot water pipes, and gas pipes. Building FTTX and underground power cables will meet our people's dire needs and paying undue attention to return on investment so early in the game is a futile exercise. When was ever a time we questioned our leaders in charge of our sewers, drinking water lines, hot water pipes, electricity grids, hydro power stations, roads, bridges, transportation systems, hospitals, museums, parks, and our opera halls, what the return on the investment has been for the past 100 years? Would we have enjoyed the same quality of life without these services in our daily lives? Civil engineers are in an ideal position to guide these industries with our unique talents in planning, execution, and our people-serving commitment.

Introduction

A comprehensive global survey by the author given in Table 1 indicates that most countries around the world would prefer to move their overhead power lines underground. This is due to numerous reasons including the following:

- Increasing Pressure From Environmentalists
- Increasing Pressure From City Planners
- Losses From Frequent Outage
- Loss From Bad Weather
- High Cost of Maintenance
- High Transmission Loss
- Electrocution
- Bushfire Risks
- High Greenhouse Emission
- Auto Accidents
- Cost of Tree Pruning
- Better Aesthetics
- Better Real Estate Value

Cost and the underground already being so crowded with water pipes, sewers, storm drains, gas mains, telephone cables, and other conduits have been the reasons given by the power companies for not putting cables underground. Then, there are countries like Denmark, Germany, Holland, Hong Kong, Iceland, Israel, Singapore, Sweden, Switzerland, United Arab Emirates (UAE) that have already moved most of their overhead power lines to the underground despite their GDP/capita being lower than that of America. After the latest ice storm damage and power outage for unduly long periods, HydroQubec in Canada decided to move most of their cables to underground, but is doing at an enormous cost and a project execution time taking several years.

The outage of August 14 in 12 states and provinces of America and Canada for over 50 million people costing over $ 14 billion in the summer of 2003 by a transmission line overheating and touching a tree, the outages of September 28 in Austria, France, Italy, and Slovenia for over 60 million people caused by a tree flashover, the outage in England, the outage for over 10 million people along the east coast of America due to Hurricane Isabel, continue to remind us the vulnerability of our power grids to nature's forces when most of the lines are overhead. Dominion Power alone incurred a cost of $ 128 million for restoration of power that was out due to Hurricane Isabel, and the company will find a way to collect this from it's customers one way or another. It's common in Ontario, Canada to have frequent outages when winds blow faster than 80 Kph, signaling that the utilities simply do not have the people's interest at heart. Jersey Central Power and Light had power outages too many times lasting minutes to hours all through the summer of 2003. A survey completed in 1997 indicates that on the average, an American customer experiences about 40 power outages in a year and matters have gotten worse in the past 6 years, given an investor-owned utility reporting in 2003 that they have at least one outage somewhere in their power grid every single day of the year. Animals contacting the wires, inclement weather, and auto accidents cause about 85% of the outages in North America. When outage occurs, it affects the chain of food supply, drinking water supply, heating or cooling, sewage treatment, transportation, communications, fire-fighting ability, personal security, banking, ability to evacuate high rise buildings in a timely fashion, health care services, crime fighting ability, and numerous others. In Australia, more than 10% of the auto accidents involved power poles costing over $ 250 million per year and in America it would be on the order of $ 5 billion per year.

Salt River Project in Phoenix, Arizona is progressive in that they have been installing all services underground for 20 years with a program to move about 100 km of cables from overhead to underground per year until these are all underground. Even small cities of the size of 70,000 inhabitants are doing something to solve this problem. Last year, the managers of Edmond Electric, the city-owned agency that provides electricity to Edmond, Oklahoma [56], initiated a $1 million program to bury overhead power lines serving the 465 residences in the Henderson Hills neighborhood. This is the first step in a program city officials plan to use to eventually place all residential power distribution cable underground.

Similarly, a much bigger problem has been brewing within the communication industry and this is the last mile bottleneck. Because of this, none of the old and established rules for making money in the communications market would work anymore. The melt down among the stock values in the telecom space over the past few years is a proof of this concept. The case of companies creating an adequate supply to cope with an increasing demand for goods and services is the basic lesson of economics in a modern world. Building at an enormous cost to compete with the assumption that the customers will come, simply did not work. The causes of the current optical fiber glut need to be understood. New rules need to be written with a whole new set of business partners and new financial incentives ought to be considered in the rewriting of the business plan. Therefore, the communications industry needs new ways of doing business. In the old set of rules, the optical cable and the power cable companies always thought in terms of having to make their permit applications to the city council, wait forever for approval, make open cuts of the highly trafficked roads in the busiest parts of our highly populated cities, and lay their cables in their own conduits at an enormous first time cost. These forced most cities to discourage new open cut excavations involved. It makes all the sense in the world to locate the last mile fiber and power cables in the existing rights of way on conduits, ducts, sewers, water mains, and gas pipes particularly when some of these pipes are renovated. This would involve the pipe owners becoming a partner in the moving of the power cables to the underground and in the deployment of last mile communication networks.

Because of the above problems, there is little work for the optical fiber industry in the long haul, backbone, and metro network markets due to these fibers being mostly unlit. The only market that is wide open is the hard to construct last mile. Those optical fiber companies willing to sell into this last mile market using appropriate installation techniques are the ones that will come out of the telecom gloom first and will have a better chance to prosper in the next decade. Investing in dedicated fiber conduits in open cut ditches to solve the last mile and to provide Fiber to the Premises (FTTX) will be too slow because of the many challenges in the last mile. The very governmental, commercial, and residential end users who are craving for FTTX already have roads, conduits, ducts, sanitary sewers, storm drains, waterlines, and natural gas lines reaching their premises.

The fat pipe to carry infinite voice/video/data from multiple providers could be housed in these existing pipes, roads, or conduits by forming creative business partnerships among optical fiber owners, service providers, utilities, municipalities, and vendors. These underground pipes, conduits, ducts, and roads start in the vicinity of the current Points of Presence (POPs) of optical fiber in the metro loops or backbones and finish at the very buildings where the last mile fiber needs to end to provide the on and off ramps for these information highways made of optical fiber. When the municipalities and utilities that own these pipes, roads, and electrical conduits take the initiatives for building the last mile fiber, they could meet the needs of FTTX, renovation of their aging pipeline infrastructure, and improved sensing, surveillance, and security of vital lifelines, pumps, compressors, and treatment plants.

Dealing with the fiber glut among the companies such as AT&T, WorldCom, Global Crossings, Level 3, 360 Networks, Williams, Sprint, Qwest, Genuity, Broadwing, and others that built the long haul and backbone networks spending over $ 100 billion over the past 5 years is to recognize that unless these companies are also involved in solving the last mile bottleneck that has prevented them from having the voice/video/data traffic they so dearly need, their fiber will remain unlit for years to come. These companies spent all this money to increase broadband capacity 1,000 times in long haul yet the capacity in the access increased only 10 fold in the past 5 years due to the efforts of fewer players namely, Time Warner, XO Communications, McLeod, FiberNet, OnFiber, Cogent, Winstar, and other.

In addition to the above, public power companies serving over 40 million Americans will continue to build more fiber networks all the way to providing FTTX to their communities. The recent joint efforts of Bell South, SBC, and Verizon are an indication that RBOCs also will be investing to service major metro FTTX markets, while municipalities and CATV companies servicing less dense markets.

Challenges in the Last Mile

There are numerous challenges for anyone other than local utilities or Incumbent Local Exchange Carriers (ILECS) to build the last mile fiber. Local municipalities control access of much needed rights of way. They charge franchise fees, make the permit process really difficult, and pass numerous ordinances to discourage open cut construction of fiber and even impose network build moratoriums. Some even demand free fiber, where the network provider will lose even their existing revenue from the very municipalities, while requiring that the network builder pass on to them a portion of the gross revenue from the remaining fiber. Often, the areas where municipalities are willing to let fiber construction proceed are not where demand is and even in these, municipalities enforce strict time limits. The ILECS already have infrastructure in place in most locations and only fiber laterals are left to bridge the last mile.

When local utilities enter the business of building their own fiber and running a network provider, unless the private companies join in this effort, they would find even more fierce competition in the only remaining profitable area of fiber business named the last mile. Building owners also erect hurdles such as entrance fees, connection fees while even unwilling to provide permission to many Competitive Local Exchange Carriers (CLECS). Even the regulatory environment has not given the CLECS the legal teeth they needed to compete more aggressively in the marketplace against the ILECS. The result is a mere 10% penetration by CLECS in the local access market even after 7 years of operating in the aftermath of the Telecom Act of 1996, although there is further gain in number of access lines in the last year against RBOCS.

Most significantly, the last mile fiber carrying conduit design and installation has been in the hands of mostly telecom personnel with little or no input from civil engineers, resulting in expensive and laborious implementation adding further to the problems surrounding the last mile. If adequate civil engineering talent were involved in approaching the municipalities for access for rights of way on behalf of fiber installers, given the very municipality public works departments are managed by civil engineers, matters would have proceeded a lot quicker.

World is Hungry for Broadband

More than 110 million North Americans are expected to telecommute to work by 2010. This will increase our productivity and quality of life significantly. The rest of the world also would have similar unprecedented numbers of people working from these home offices. The world needs more bandwidth to meet its demands for better homeland security, better classrooms, better government, better medicine, better science and technology, better entertainment, better quality of life, and better job opportunities. Copeland and Malik [5] reported that without widespread high-speed Internet access, the technology industry and the economy would remain stalled.

The optical fiber industry has kept its pace of inventing better fibers and Dense Wave Division Multiplexing (DWDM) equipment. For example, Hecht [9] reports that Alcatel and NEC independently have squeezed more than 10 Tbps (terabits per sec or 10^{12} bits per sec) through a single strand of fiber. This capacity translates to carrying over 150 million telephone calls simultaneously in a single strand of fiber. Soon, Bell labs will announce its plans to transmit 200 Tbps, enough to send the entire 10 million volume library from the University of California at Berkeley to anyone in the world in 10 seconds, all through a single fiber core that measures less than 7 microns in diameter or less than 5 % of the thickness of the human hair. Despite these major advances, an optical fiber network is only as fast as its weakest link. In America, over 400,000 km of fiber cables are in the ground covering long haul, backbone, and metro loops; however, the missing link is still the last mile of route length as short as 5 to 500 m. This has led to, for example, most companies having only 1 out of every 100 strands of fiber lit to meet the demand for their dark fiber.

What is Broadband?

Broadband is an always on network connection that permits us to send and receive digital content and services at high speeds and this is expected to change the way we live, we play, we work, we learn, we shop, we make things, we entertain ourselves, and the way we interact with other humans. We already are seeing this industry in flux. For example, local exchange carriers once operated as virtual monopolies are losing their core business to mobile phone companies and cable telephony companies. To fight back, most baby bells have agreed to adopt the same technology standards to deploy FTTX and have won some concessions from the FCC in unbundling rules to encourage them to deploy fiber deeper. Wireless companies on one hand have gained many customers from local phone services, while on the other hand is being told by FCC that their customers should be allowed to take their mobile number when moving between competing mobile phone operators. Cable telephonic and TV companies find it easier to stretch their backhaul fiber closer to their customers because of the way FCC defines cable modem service as an interstate information service.

No society in the information age could benefit from the digital knowledge-based economy without affordable broadband connections. America is not an exception to this rule. Broadband still costs too much for too many Americans and this is why out of access being available to over 80 million homes, only 19 million have chosen to subscribe at ~ $ 50/month per connection and this is due to lack of competition and people have not seen the killer application yet. The biggest fault of the telecom act of 1996 is that although it was meant to encourage competition, it has transformed the network to become a commodity than an essential infrastructure needed to deliver services.

South Korea on the other hand has treated their deployment of high-speed national network and last mile connections as a much-needed infrastructure to transform its people from a labor-intensive manufacturing society to a knowledge-based intelligent economy. Korea realized in 1995 that in the information age, a country needs to educate its people, develop products to sell and deliver services for global consumption using their high-speed network. They also realized that the countries that do not invest in such a network will fall behind and will be going outside of their borders seeking help from a knowledge-based economy and will end up paying dearly for such know-how. The high-speed network helps a country in many ways and some examples are provided in the following sections.

The high-speed network impacts electronic commerce most. The online B2C sales in 2002 was about $ 50 billion and this was small compared to the B2B sales of $ 1.5 trillion and about 50% of this comes from the U.S. Because our construction of last mile access is so slow, we will lose much of this momentum to Western Europe and Asia in the coming years and our portion of the global E-commerce will decay from hereon. In areas of networked multimedia, edutainment, career development, and lifelong learning we as Americans will continue to lose our edge to other countries in the coming years because of our disadvantage of being too slow to provide broadband to the masses. While the telecommuting projections point to over 100 million workers in America by year 2010, unless we construct enough last mile connections in fiber by that time, we will have serious problems meeting these demands on our networks. For years, proponents have emphasized the benefits of telecommuting as less traffic, saving time and fossil fuels, cleaner environment, making it much easier for employers to find the best talent without worrying about having to relocate them to key company offices, while encouraging the workers to have better quality of life, then why are we not building the infrastructure to make this become a reality.

IBM was the first company to recognize the multitude of benefits of telecommuting. They took away the offices, fixed phones, etc from their sales staff, put them in the field where they were encouraged to work out of their homes while meeting with clients face to face even more. These staff increased their sales volume while improving the quality of their lives and helping IBM grow faster than if it had kept it’s old style of treating its employees. It also saved IBM, a tremendous cost in real estate and employee down time. The happiest telecommuters are from Sun Microsystems, where 13,000 of the company's 35,000 employees simply don't have offices at work. They use special flat-panel computers, which are activated by a Java smart card to bring up their desktop screen anywhere, and at anytime. The downside is, when we can work anywhere, and at any time, those among us who lack discipline tend to treat these as we can work everywhere, and all the time. When we have aging population while many Americans cannot afford decent healthcare, it makes sense for us to turn to telemedicine. Already we are seeing remote health monitoring for the elderly than having to keep them in assisted living quarters at an exorbitant cost. Likewise, high-resolution imaging and diagnosis would aid in better treatment if we have a high-speed network at affordable cost to most elderly citizens.

Using optical fiber networks would allow us to have convergence of voice, data, photos, music, video, and as well as the whole business of service bundling where on one bill, we will enjoy all these services from one provider. The German RWE has gone even further in providing sewage collection, garbage collection, drinking water, electricity, natural gas along with all of the above in one bundled bill and this is what more and more customers would like in their busy lives when they would rather spend their time in other worthy pursuits than having to deal with multiple providers.

Numerous studies have shown that the IT sector provided 25% of the U.S. GDP growth since 1995, accounted for at least 50% of the increase in our productivity, and was primarily responsible for keeping inflation at lowest level in 2 decades. IT revolution also provided over 1 million new jobs with salaries much higher than in other disciplines. This is exactly the reason why more and more graduates in even developing countries in the past 5 years have gravitated toward IT education.

In summary, building the last mile connections needs to be done not in baby steps but in a major leap by using optical fiber laterals that would serve the needs of our end customers for a long time to come. And this would give us an all-optical Internet in a seamless fashion into town, throughout our vast continent, and out to any parts of the globe whenever we like, as much as we all like and as fast as we like.

Synergies Among Multiple Uses Have Been Around Since 1983

Using existing conduits for multiple uses is not a new concept. Early attempts were in Paris more than 100 years ago but poor results led to abandonment of the concept of installing multiple utilities in the same underground tunnels. There also were a number of projects in America about 100 years ago where telephone companies were permitted to lay their cables inside of drinking waterlines. The innovative idea of using existing fluid conduits for additional functions not originally intended, emerged again in 1983 when Jeyapalan et al. [45-47] designed 2 high pressure hydropower penstocks of size 2144 mm (7 feet) in diameter to hang from the roofs of 6.4m(21 ft) diameter outlet tunnels at Jennings Randolph and Gathright dams in West Virginia and Virginia. These large penstocks were designed in 304L stainless steel to survive the acidic water with a pH of 3 or less flowing through the outlet tunnels. Therefore the technical issues in the current situation of using existing pipelines for housing optical cables are rather minor compared to what we coped with in 1983 and we have progressed in our civil engineering know-how in many fronts in the past 20 years.

Stakes Are High

South Korea has become the global leader when it comes to broadband deployment. They have been doing it with government support and because most of their population are in major cities embracing new fashion faster than most other cultures. South Korea decided in 1995 to become a knowledge-based economy and set a national policy of connecting every home at 100+ Mps by 2004 and they have been well on their way to realize this goal. America on the other hand is being pulled down by lobbyists, interest groups, corporate actions protecting one’s own turf than serving enough public good, lack of long term visionary leadership at the national level, and no government support. Although America leads the world in Internet connections at over 150 million, most of these are outdated dial up technology with the growth rate slowing down while other countries are speeding up. Studies indicate that by 2005, the world will have more than one billion Internet connections, but most of them will be in Western Europe and Asia. In the information age, the nations that invest in a digital highway will have a major advantage. These nations will have the informational infrastructure to educate their people, have ready access to worldwide know-how, develop products, and deliver goods and services much faster than others. America’s share of the e-commerce in the global market will continue to decay if we do not do something soon. The opportunity for our children and adults to participate in distance learning, telecommuting, telemedicine, electronic entertainment, outsourcing will all suffer if we do not invest in the last mile connections using optical fiber.

Although VDSL using twisted copper pair, AHFC using coaxial cable, FTTX using optical fiber, WLAN are all competing in the last mile, there are 3 reasons why this author believes that optical fiber has the potential to win this race, if the fiber industry takes the right steps moving forward and does not become complacent. America already has fiber everywhere spanning 400,000-route km coming within 5 to 500 m of most end users. Those selling VDSL, AHFC, WLAN, and even those from PLC all have fiber for the backhaul networks. Even with expected new innovation, it is predicted that by year 2010, the data rates are likely to be about 20 to 50 Mps for VDSL, 20 to 100 Mps for AHFC, 100 to 1,000 Mps for WLAN, and 500 to 10,000 Mps for FTTX.

National Broadband Policy

America is the only country among the G7 nations without a national broadband policy. When America built the interstate highways, it spent about $ 30 million per mile. It costs over a $ 1 million per mile to build underground power distribution cables in dedicated conduits, about $ 500,000 per mile for fiber in dedicated conduits laid by open cut construction, and a small portion of this if the optical fiber is built in existing pipes, electrical conduits, or in roads. Senator Lieberman wrote in May 2002 [50] “*Much of the technology for broadband is already at hand. Hence, there is not a major technology development challenge here, although some R&D on last mile issues is needed.”* Korea, Japan, Sweden, Belgium, Denmark, Hong Kong, Singapore, and Canada did not wait and their uptake rates ahead of ours prove that Senator Lieberman is so right. Then, why are we waiting for and who ought to ring the bell and say, “ go and get it done.” In America, it is more who has been setting up roadblocks to prevent last mile deployment of fiber and how to remove these hurdles to serve the masses are what we need to address. This is only possible if there is government involvement in the form of a national broadband policy. The government could help us define what is true broadband? How much bandwidth each of us need and for how long we will be satisfied with it before we ask to enlarge the size of these info-pipes?

The government could mold the policies to provide guidance to the owners of existing pipes, conduits, and roads much along the way the Japanese government opened up the usage of sewers to carry more than sewage in 1996 and setting targets to deploy a national broadband network spanning 100,000 km in existing sewers alone [7]. The government could step in to start even shifting funds from highway construction and renovation to deployment of last mile fiber, given less and less people will be driving in the coming years. This would be a logical step in the right direction if the auto makers, oil companies, and tire manufacturers have for years poured their campaign dollars into lobbying to slow down the possible migration of workers to their home offices using faster Internet connections than having to drive to work everyday in highly congested down town buildings. Moving tax dollars that have for years funded highway projects into last mile construction in existing sewers, potable water lines, natural gas lines makes perfect sense also when we recognize that we as a nation have ignored the underground infrastructure for 100 years and we are having major problems finding adequate funds to renovate these pipes to prevent serious health problems to our citizens. How good is it to talk about e-medicine, e-learning, e-entertainment, and Sunday baseball games on high definition television when our people are falling sick recurrently due to leaking sewers contaminating our water supply or we are losing more than 30% of our treated drinking water due to leaking pipes?

If not for the Federal Department of Transportation, the interstate highway system would have never materialized. Just like the road system received funding from federal, state, and local governments, the last mile construction needs help from the same governments. This is only possible if there is national leadership along with a national broadband policy. The proposed national broadband initiative will have to make it through numerous potholes along the way. Powerful lobbyists will continue to erect many obstacles on behalf of incumbent telephone carriers, recording industry, radio broadcasters, TV broadcasters, property owners, landlords, cities that would be unwilling to let too many people work out of their homes fearing loss of their tax base, oil industry fearing less people would drive to work, car manufacturers, universities, teachers, medical practitioners and in particular specialists, and other.

Feds never undertook solely to extend the roads to each home, and that was left mostly to state and local governments, neighborhood developers, and to even individual homeowners. If we apply the same reasoning, the construction of last mile access would fall on the shoulders of cities, municipalities, local utilities, neighborhood developers all following a national broadband policy. A perfect application for the governments to pick to lead by example is to shift as rapidly as possible to running e-governments and encourage development of killer applications in this highly specific space. By doing this, the local, state, and federal governments will have an opportunity to show case to its people, tax payers, businesses, and the IT industry that the information age is here all for real and many more walks of life that we lead could benefit if we kept going at a faster pace like those on South Korea. South Korea has become a global leader in broadband deployment, in building a knowledge-based economy faster than any other country, in providing a better quality of life to its inhabitants, and in encouraging telemedicine, telecommuting, e-government, e-learning, and various forms of entertainment all not by accident but because of its vision and its national broadband policy.

Federal government is in an ideal position to accelerate the last mile construction, by providing tax incentives and matching funds for local governments, using some of the defense and homeland security funds to pay for last mile construction. These are possible ways to pull ourselves out of the security, economy, and technology slump we have all been in for some years now. Since March 2001, we have lost more than 2 million jobs overall in the American economy, while our telecom industry has lost about $ 2 trillion in market valuation while carrying over $ 1 trillion in debt. The above provide much food for thought to solve our problems in a secure and peaceful manner, without playing a role in a global conflict, to create new jobs.

Security of Power Grids, Lifelines, Plants, Pumps, and Compressors

If the optical fiber technology could be rolled out at a faster pace, with less hurdles in rights of way acquisition, and at a lower cost, then end-to-end optical fiber connectivity could win this race in the coming years in the last mile. For this to happen, we need to turn to existing infrastructure to build our communication networks, so that we can avoid additional congestion underground. North America already has invested many trillions of dollars in the past century building an extensive underground pipe network, electrical conduits, and roads. These underground utilities and roads were carefully engineered, constructed, operated, and maintained with mostly public funds. Most of these have been stable well-protected structures deep in the ground forming a vast network as shown in Table 2.

Other countries have similar underground pipe networks. These have served their intended functions meeting our needs for over 100 years. Using them for the un-intrusive housing of broadband fat pipe would speed up significantly the deployment of fiber in the most challenging last mile. These would afford us an opportunity to monitor the security of these underground lifelines. These would also provide us an opportunity to operate treatment plants, compressors, pumps, and other equipment unmanned from remote unknown locations toward better homeland security measures. The power grids also could be monitored with the use of an optical network to improve its reliability and security. Additional details on the win-win solutions from the business plans involving optical fiber deployment in existing sewers and gas pipes have been discussed in more detail in Jeyapalan [11-47] and Welch [58]. There are a number of cities around the world that have used existing utility pipes for building their broadband networks while serving their originally intended functions and Table 3 provides a partial list. It appears the needs of FTTX, renovation of aging pipeline infrastructure, and improved sensing and surveillance could all be accomplished by municipalities taking the lead to build the last mile networks with suitable partners in existing pipeline infrastructure as outlined in Jeyapalan [11-47].

Optical Fiber In Sewers

CableRunner uses a drill and dowel system in sewers of 250 to 700 mm in size. DTI-CableCat uses either a back-reamed anchor or an adhesive bed system in sewers of sizes 200 to 1200 mm, while Nippon-Hume and RCC use drill and dowel systems for the same sized sewers. Ka-te uses a clamp-conduit system in sizes smaller than 700 mm. In addition, there are liner systems vying to do some of this as part of routine sewer maintenance programs. There is a good chance that these liner companies will succeed if they are able to offer value-added relining systems for an attractive incremental fee to the city sewer agencies over the standard lining systems without cutting too much into the current functions of the sewers. Tokyo Metro Government (TMG), Corning Cable Systems MCS-Drain, and Ashimori Industries' offering to use tensioning devices to span the optical fiber cable manhole to manhole to anchor them on the walls of the manhole are quite similar. It is also possible to replace an aging pipe carrying sewage, water, or gas with a new pipe and provide additional smaller sized conduits on the outside of the new pipe for the insertion of optical fiber cables and/or power distribution cables. If the sewer is larger than 700 mm in size, then many possible ways of using humans to attach the optical fiber cables to the walls of the sewer can be used at a relatively low cost of materials and labor and at high production rates. Brugg cables have placed over 280 km of its sewer link at the bottom of sewers in the past 9 years.

Optical Fiber In Natural Gas Pipes

Sempra Fiber Links [54], Alcatel [49], and Gastec [8] are three companies offering new technologies to install optical fiber cables in natural gas pipes. Tokyo gas and Osaka gas also have used such techniques in their gas distribution systems. In Sempra's technology, special fittings are attached after tapping the gas main at two locations to form the entry and exit points for the optical fiber. The gas mains could be even as small as 25 mm in size and the fiber conduit will take up to no more than 10% of gas flow area. In the event a particular gas line cannot handle even a 10% reduction in capacity, additional pipe capacity will be added according to Sempra. In the author’s judgment, if the additional pipe capacity is needed then this approach offers little advantage over the traditional dedicated conduit for placing the optical cable. A small HDPE conduit is threaded through the entrance fitting until it reaches the exit fitting. A special tool is used to grab hold of the threaded conduit and pull it out through the exit fitting. Once this housing conduit is placed in the gas main, the optical fiber cable is pushed through this conduit from one fitting to the next. The fittings and seals are designed to meet all gas pipeline safety rules.

In the Alcatel system, a balloon device is used to pull a specially designed optical fiber cable through the Inlet port clear through the Outlet port shown using a gas pressure differential. The cable itself has a special metallic barrier, to prevent hydrogen gas migration to cause the optical fiber strands going blind. Again, the seals and the ports are designed to meet various safety regulations. More details could be found in Leppert et al. [49]. Gastec offers a solution where a specially designed shuttle pulls a cord from an inlet attached to the gas main all the way to the exit port using a gas pressure differential. This is done by creating an overpressure of about 150 mbar at the inlet side while a negative pressure is created by flaring off gas through a venting safety valve at the outlet side. An added benefit of fiber in gas deployment is that a few strands of the fiber could be used as a leak detection system by collecting spatial resolution data.

Optical Fiber in Potable Water Pipes

Drinking water pipelines also enter most buildings. All fiber cable materials must meet EPA regulations on drinking water. In typical metropolitan regions, numerous valves exist in the drinking water pipeline and are bypassed with the cable. Ideally, each of these bypasses forms a fiber POP. A cable entry point consists of a water pipe flange and a sealed cable inlet. The flange is installed on the water conduit under normal operating conditions and the water flow is interrupted only for the actual cable insertion. The cable is installed by means of a suitable tape, which is fed into a flange and floated to the next flange. The cable is then attached to the tape and pulled manually into the pipe. In drinking water pipeline systems, cable-pulling sections are on the order of 250 meters in length, although some additional cable is stored in the small manhole above each valve to accommodate future fiber links.

Fiber in drinking water pipes is also inexpensive and every valve is a potential customer connection point. There have been installations of communication networks in drinking water pipes owned by the cities of Vancouver and Chicago going as far back as 1896. However, the fears of people drinking water of the same pipelines that carry optical cables need to be alleviated early on during an era when we have potable water contamination making either the front page of the local press or 6 O' clock news.

Optical Fiber in Micro-Trenches or Micro-Ducts

In addition, micro trenching in roads could be used to install the last mile fiber. There are several cities in France that have used this technique. Because fiber is installed in a shallow groove formed by a special saw cut, security of the network is always a concern. When the optical cable is installed at such shallow depths, the impact of the traffic loads on the fiber needs to be taken into consideration. The void between electrical distribution cables in existing conduits or occupied ducts could also be used with micro-duct fiber blowing to finish the last mile construction. Micro-cables also could be blown into place. Some of the names in this business are: Neptco, Nextgen, Sumitomo, Draka, Alcatel, Lancier, Arnco, Condux, Plummetaz, Hubbell, and others. A careful consideration of the strengths and weaknesses of these technologies is warranted before any one of these systems is used for building last mile fiber.

Standardization

Over 270 stakeholders from 20 countries have joined together to form new ASTM Committee F36 on Technology and Underground Utilities. The group is in the process of developing standards for the deployment of fiber-optic cables in underground utilities, FTTX, pipeline rehabilitation methods, and seismic risk assessment procedures. Participants in the new committee include municipal authorities, building owners, robot- manufacturers, pipe manufacturers, optical-fiber cable manufacturers, telcos, and construction, architectural and engineering consultants, to name just a few. This committee usually meets in January and July. Although attendance of members is always preferred because of its value in networking, participation is still encouraged via web forums, teleconferences, emails, and regular correspondence. The first standard from this committee is already available from ASTM [3] and several more are about to be released. Similar efforts are underway within ASCE for this 130,000-member organization of civil engineers to provide their input to the telecommunications industry in this new discipline.

There are a number of FTTH projects underway worldwide and additional communities have undertaken feasibility studies on FTTH deployments. Many of the techniques reported in this paper could be used to lower the overall cost of FTTH deployments while cutting the construction time by a substantial percentage. It should be borne in mind that the inclusion of additional conduits to carry optical fiber either inside or outside of utility pipes planned in new construction projects would add minimal cost to the overall design and construction of conduits in the ground. Therefore, consideration of such utility corridors is a must in every new construction project with provisions to serve multiple functions.

Possible Business Plans

In the new paradigm to make money, we have to consider bridging the last mile as fast as possible with the lowest possible cost. Using the existing pipe networks for deploying last mile fiber could be done in any of the following business plans:

Plan 1: The fiber builder will either purchase or lease existing retired pipelines that are no longer used in active service in exchange for either an upfront payment or an annuity type payment to the owner of this strategic asset. Pacific Gas and Electric, Key Span Energy, Con Edison, Atlanta Gas, Peco Energy, are examples of this business model.

Plan 2: The fiber builder will make the pipe owner a business partner, where reserve capacity in the existing pipe network could be used by the fiber builder for installing last mile fiber in exchange for a negotiated percentage of the gross revenue. Cities of Albuquerque and Indianapolis are examples of this business model.

Plan 3: The owner of the existing pipeline network will take network providers, content providers, and vendors as partners to install fiber in their pipes and operate this network. Other than the few strands needed by the pipe owner for their needs, the rest would be leased to any number of the above partners for additional revenue to the pipe owner, where the cost of the fiber build out will be borne primarily by the pipe owner. City of Berlin is an example of this business model.

Plan 4: In this plan, some elements of the above 3 plans will be combined toward optimum results for all parties concerned. The author is aware of several entities in the middle of active negotiations to reach many forms of business partnerships to deploy last mile fiber and the results will be reported at a later time.

Plan 5: In this plan, the pipe owner will build and own the fiber network. Cities of Tokyo, Hamburg, Vienna, Boston, Dublin, New York, and Los Angeles are examples of this business model.

Plan 6: In this plan, owner of local roads will build and own the fiber network. Some cities in France have followed this model, including Paris.

When power distribution and/or retail companies wish to move their specially designed low voltage distribution cables to the underground at the cheapest cost and without the headaches of rights of way acquisition and the problems resulting from open cut construction, the above business plans and some variations thereof are always available to them. However, just like there was initial resistance from some owners of pipes when optical fiber cables installers were attempting to house these in existing pipes, power cable industry will also face resistance from many pipe owners until they are convinced of the benefits.

Then, there are many ways for us to renovate existing pipes, when they leak or have come to the end of their lives, by replacing with multiple conduits without cutting open the ground, and we could install communication cables and power cables in conduits isolated from one another. When power cables are moved to either inside or outside of existing pipes in the ground, all safety considerations need to be considered. Insulation of the power cables need to be chosen more carefully and the grounding options have to be redesigned depending on whether the pipe materials are good conductors or not.

Holland locating 100% of their LV and MV power lines underground despite more than 50% of the country is below mean sea level is a living proof that the claim moisture is the primary enemy for insulated power cables when located underground is spurious. Just like how the cable engineers in Holland have learned to cope with moisture problems, special moisture protection layers need to be built in the power cables to ensure that the water or sewage does not enter the power cables. Special corrosion protection measures also need to be considered. Because more and more sewers and water lines are built of plastics, the option to move the power cables into the same rights of way become more attractive. Because the power cables are heavier than optical fiber cables, the supports used for holding the cables at the crown of the existing pipes need to be redesigned. The housing conduits through which the optical fiber is threaded need to be made larger if power cables are inserted. The methods used for cleaning, repairing, and inspecting the pipes need to be modified if power cables are installed in the pipes carrying other fluids. The safety of the workers, grounding, and the influence of electricity on other functions of the pipes need to be carefully considered. The cost of cooling the cables when heat is generated from power transmission could be lowered by the secondary use of the fluids already flowing in the pipes in which these power cables are to be installed.

In summary, if the power cable manufacturers and the power distribution and/or retail companies are willing to accommodate changes in the insulated power cable designs, more and more existing utility owners would be turning to these additional revenue streams by becoming partners in these innovative teaming arrangements. Insulated cable manufacturers around the world also need a new beginning and would love to see more and more power lines underground to save their industry.

The people we serve always expect us to provide safe and cost-effective solutions with least damage to our environment. When acquiring rights of way to dig and bury various utilities and cables one by one is becoming increasingly impossible, we engineers and contractors have to learn to share the underground to avoid further conflicts and accidents. Society's problems needing the expertise of just one type of engineering have all been solved many decades ago. The remaining challenging problems require us working together on teams with experts of interdisciplinary skills in technology, business, and social sciences. Initial informal surveys among power engineers indicate that they see some merit to this out-of-the-box proposition and would have an interest in working with civil engineers toward finding cost-effective solutions to the operational problems without compromising safety. The author is inviting the service providers, utilities, municipalities, energy companies, and optical and power cable manufacturers to contact him for ongoing progress reports on this innovative approach and to indicate their desire to use this technology on any of their projects.

Summary

1. Qwest, Level 3, 360 Networks, Broadwing, and others have all offered to provide end-to-end optical network and true broadband to the masses. Offering in words is one thing, showing in actions is another. We have been waiting for true broadband at speeds higher than 100Mps, while these companies also have been waiting to light 99 % of their long haul, backbone, and metro fiber networks.

2. Removing the last mile bottleneck to generate the voice/video/data traffic needed to solve the fiber glut will involve creative business partnerships with existing utility pipe owners. While doing this, power cables also could find homes underground at the cheapest cost without the traditional headaches.
3. U.S. EPA rules have required most cities to upgrade their sewers and waterlines in the coming years. It appears that a viable partnership could be arranged among power companies, telcos, pipe owners, service providers, and vendors, where each party has something to gain by cost sharing.
4. The installation of optical fiber cables or power cables either inside or outside of sewers, waterlines, and gas pipes is a major break through in sharing the underground pipes. However, power and communication companies need to address all the concerns associated with using existing pipes, before fiber deployment and moving of the power cables to the underground could proceed.
5. Working in the sewer, water, or gas pipe will affect the health, safety, and welfare of the people we serve and any shortsighted approach to selecting the suitable sewers or gas pipes for installing and operating optical fiber cable, would expose all those in this new industry to an enormous liability. Developing sound engineering standards to guide this new industry falls well within this obligation.
6. The factors which will continue to provide momentum for the market are:
    - Aging underground infrastructure
    - Doing more work with less funds
    - Protecting the environment
    - Increasing congestion in urban centers
    - Faster rate of knowledge transfer
    - Privatization of utility companies
7. The deployment of optical fiber cables and power cables in existing pipeline rights of way offer a win-win situation for all parties involved if proper standard of care is afforded. However, working in rights of ways of sewers and natural gas pipes requires sound pipeline engineering input and anything less than that would be shortsighted.
8. If telecommunication and power companies did not follow proper engineering know-how, it would only be a matter of time before we will face major problems and the cost to return these sewers, waterlines, and gas lines to normal working order would be far greater than the benefits.
9. The power cable designs need to be modified and owner reactions to the above business plans need to be considered early in the consensus building process. For telecom carriers and network service providers, it’s a true, end-to-end last-mile optical fiber network, which they could control. For sewer, water, and gas pipe owners, it’s a unique and powerful economic development tool, providing added revenue from an existing infrastructure, and of course protection from most damage to roads and disruptions to traffic.
10. Once the various parties involved in such creative partnerships are willing to make the commitment toward the idea of " let us meet our collective needs

together," the solutions to the technical problems in moving power cables underground in the existing rights of ways of utilities will be found.

11. Then, we also have other construction methods for moving cables underground such as ploughing ducts, horizontal directional drilling to install ducts, etc. that could be done at cheaper cost than open-cut construction.
12. In recent years we the public has been sold the idea by elected officials those vital services such as energy, telephone, Internet, CATV can best be provided by private firms, the experience with recent blackouts however has shown that markets tend to under invest when it comes to building and maintaining robust distribution networks.
13. In a competitive market, most private companies cannot recoup the full benefit of their investments because much of it leaks out to the economy due to excessive competition and predatory pricing by the piranhas eating the minnows. This is why our previous generations planned, built, and supported monopolies for sewage disposal, drinking water, and natural gas supplies serving our needs.
14. Market economies in the 21st century don't thrive when essential public good is grossly neglected. The public can either pay for those services such as buried power lines, optical cables, catv lines, and telephone lines directly or will have to bear the burden of lost productivity and lack of economic growth for many years. Sooner or later we will pay in one form or another. Intelligent communities will chose to spend now and enjoy the benefits for many decades to come and what we do not pay for now, our children will have to bear the burden of it during their lifetime.
15. Korea, Japan, Sweden, Hong Kong, Belgium, Denmark, Singapore, and Canada are already ahead of America in embracing broadband and growing knowledge-based economies, using mostly America's technology break-through from the Internet revolution all because their governments have given their people and industries all the help they needed along the way through effective national broadband policies and in some cases the needed funding.
16. The problem of last mile bottleneck in America is so similar to the lack of health care to many Americans. It has never been either the lack of funds when we pool our nation's resources or the lack of technology know-how. As long as we sustain various interest groups among us instead of the national motto "omnia omnibus," we will continue to fall behind in our quest to be the global leader in providing true broadband to the masses.

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References

[1] Aoyagi, M. (1996), " Distribution Cable Operations in Japan," paper in IEEE/PES Meeting in Los Angeles, September.

[2] Arnold, T.P. and Mercier, C.D. (1997), " Power Cable Manual," Southwire Company Design Manual, 2nd Edition.

[3] ASTM Standard (2003), " F 2233: Standard Guide For Safety, Access Rights, Construction, Liability, and Risk Management For Optical Fiber Cables in Existing Sewers," July.

[4] Blechschmidt, H.H. (1997), " Underground Cables in German Distribution Networks," paper in IEEE/PES Meeting in Berlin, Germany, July.

[5] Copeland, M.V. and Mali, O. (2002), " Jilted by Broadband," paper in Red Herring, March.

[6] da Cunha, A.P. (1996), " Distribution Cable Practices in Brazil," paper in IEEE/PES Meeting in Los Angeles, September.

[7] Fujiyoshi, Yoshinobu, and Nomura, Yoshikazu (1996), " The Current Situation and Future of Sewer Optical Fiber Technology in Japan," Research Report by Japan Sewer Optical Fiber Technological Association.

[8] Gastec (2002), " Personal Communications," Apeldoorn, Jan.

[9] Hecht, J. (2001), " Fiber Crosses The 10-Trillion-Bit Barrier," paper in MIT's Techreview, March.

[10] Hiivala, L.J. (1996)," Distribution Cable Practices in North America, " paper in IEEE/PES Meeting in Los Angeles, September.

[11] Jeyapalan, J.K. (2001), " Fiber Cables in Sanitary Sewers," Civil Engineering News, March.

[12] Jeyapalan, J.K. (2001), "A New No-Dig Industry Named Fiber Optic Cables in Sewers in Born," paper at NASTT, 10th annual conference, Nashville, Tennessee, April.

[13] Jeyapalan, J.K. (2001), "Bridging the Last Mile With Fiber Optic Cables in Sewers," IWCS 50th anniversary conference in Orlando, Florida, November, pp 724-731.

[14] Jeyapalan, J.K. (2001), "Fiber Optic Cables Inside of Sewers! Why Not?" paper at UCT, Houston, Texas.

[15] Jeyapalan, J.K. (2001), "How Do You Install Fiber Optic Cables in Sewers?" Parts I and II in Publicworks.com, March.

[16] Jeyapalan, J.K. (2001), "Optical Fiber in City Sewers-An Idea Whose Time Has Come" paper in Trenchless Technology Magazine, March.

[17] Jeyapalan, J.K. (2001), "Future Outlook for Trenchless Pipeline Rehabilitation Technologies," 2nd Asian Regional Civil Engineering Conference, Tokyo, Japan, April.

[18] Jeyapalan, J.K. (2002), " Standards in the Sewers: New Efforts Help Optic Fiber Installations in Underground Utility Pipes," Outside Plant, December.

[19] Jeyapalan, J.K. (2002), "Cables in Sewers the Way Forward," paper in Gulf Construction, October.

[20] Jeyapalan, J.K. (2002), "Developing Standards for the Deployment of Optical Fiber Cable in Underground Utility Systems-Last Mile," ASTM International Standardization News, August.

[21] Jeyapalan, J.K. (2002), "Finding the Rights of Way-Alternate Methods of Optical Fiber Deployment in the Last Mile," Intelligent Cities 2002, Telecom Magazine Conference, Chantilly, Virginia, Sept.

[22] Jeyapalan, J.K. (2002), "Municipal Optical Fiber Networks in Existing Sewers May Complete the Last Mile," paper at the New England Water Environment Association Seminar, Westford, MA, October.

[23] Jeyapalan, J.K. (2002), "Optical Fiber Cables in Existing Pipes Provide Backhaul Networks," Panel Presentation at the 2nd Annual Powerline Communication Association Conference, Washington, DC, December.

[24] Jeyapalan, J.K. (2002), "Optical Fiber Cables in Existing Sewers and Natural Gas Pipes, " paper in No Dig conference of NASTT, Montreal, Canada, May.

[25] Jeyapalan, J.K. (2002), "Optical Fiber Cables in Existing Sewers and Natural Gas Pipes, " paper in No Dig conference of ASTT, Sydney, Australia, August.

[26] Jeyapalan, J.K. (2002), "Optical Fiber Cables in Sewers 2002: What do we know? Where are we Heading?" paper in UCT, Jan. 14-17, Houston, Texas.

[27] Jeyapalan, J.K. (2002), "Optical Fiber Cables in Sewers in the USA," paper in No Dig International, April.

[28] Jeyapalan, J.K. (2002), "Optical Fiber Cables in Sewers Part I- Sewer Selection Criteria," paper in Trenchless Technology Magazine, March.

[29] Jeyapalan, J.K. (2002), "Optical Fiber Cables in Sewers Part II- Sewer Owner's Concerns," paper in Trenchless Technology Magazine, April.

[30] Jeyapalan, J.K. (2002), "Optical Fiber Cables in Sewers, Natural Gas Pipes, Drinking Water Lines, and Storm Drains Provide Backhaul Networks," 2nd Powerline Communication Association Conference, Washington, DC, December.

[31] Jeyapalan, J.K. (2002), "Optical Fiber Connections Through Existing Sewers, Water Pipes, and Natural Gas Pipes," 51st IWCS/FOCUS conference, Orlando, FL, November.

[32] Jeyapalan, J.K. (2002), "Optical Fiber Connections Through Existing Sewers, Water Pipes, and Natural Gas Pipes," 51st IWCS/FOCUS conference, Orlando, FL, November.

[33] Jeyapalan, J.K. (2002), "Optical Fiber Connections Through Existing Sewers, and Natural Gas Pipes," Infra 2002:Mapping Out Best Practices in Urban Infrastructure conference, Montreal, Canada, November.

[34] Jeyapalan, J.K. (2002), "Underground Utilities for the Last Mile: How Secure Are They?" paper at the Homeland Security Exec Briefing on IT Local Network Ops, IGI conference, Burlington, MA, October.

[35] Jeyapalan, J.K. (2002), "Underground Utilities for the Last Mile: How Secure Are They?" paper at the Homeland Security Executive Briefing on IT Local Network Opportunities, IGI conference, Burlington, MA, October.

[36] Jeyapalan, J.K. (2003), " Building Optical Fiber in the Hard-to-Reach Last Mile Using New Developments, " KMI's 26th Annual Research Conference, Newport, Rhode Island, September.

[37] Jeyapalan, J.K. (2003), " Fiber Optic Cable: Spanning The Infamous Last Mile," Constructor Magazine of AGC, August.

[38] Jeyapalan, J.K. (2003), " Future of America's Water is in Our Hands," ASCE Pipelines Conference, Baltimore, Maryland, July.

[39] Jeyapalan, J.K. (2003), " Future Outlook For Pipeline Materials, Methods, and Maintenance," ASCE Pipelines Conference, Baltimore, Maryland, July.

[40] Jeyapalan, J.K. (2003), " Future Outlook For Pipeline Materials, Methods, and Maintenance," ASCE Pipelines Conference, Baltimore, Maryland, July.

[41] Jeyapalan, J.K. (2003), " Innovative Ways to Build Underground Power Cables and Communications Networks with Utility Pipe Owners," paper at Jicable, June, Versailles, France.

[42] Jeyapalan, J.K. (2003), " Municipal Fiber in Existing Sewers, Storm Drains, Waterlines, and Natural gas Pipes May Complete the Last Mile," ASCE Pipelines Conference, Baltimore, Maryland, July.

[43] Jeyapalan, J.K. (2003), " The Weakest Link: Municipal Fiber Installations May Complete the Last Mile," Outside Plant, July.

[44] Jeyapalan, J.K. (2003), "Solving The Last Mile Bottleneck and The Fiber Glut Using Creative Business Partnerships With Existing Utility Pipe Owners, 25th PTC Conference, Honolulu, January.

[45] Jeyapalan, J.K., and Jaramillo, C.A. (1989), " Hydraulic Model Tests of Flow Around Penstock Suspended Inside the Tunnel for Design of Small Hydro," Proc. of WaterPower '89, ASCE Conference, pp. 577-587.

[46] Jeyapalan, J.K., and Thiagaram, M. (1989), " An Evaluation of the Applicability and Cost of Polyester Resin and Cementitious Grouts for the Installation of Rock Anchors at Hydro Projects," Proc. of WaterPower '89, ASCE Conference, pp. 960-965.

[47] Jeyapalan, J.K., Jaramillo, C.A., and Saleira, W. (1989), " Design Considerations for a Penstock Located in an Outlet Tunnel at the Jennings Randolph Dam in West Virginia," Proc. of WaterPower '89, ASCE Conference, pp. 426-436.

[48] Krahenbuhl, F. and Laurent, M. (1996), "The Swiss Practice For Distribution Cables," paper in IEEE/PES Meeting in Los Angeles, September.

[49] Leppert, H-D, Nothofer, K., and Teschner, W. (2001), " Experience From Installation of Fiber Cables in Gas Pipelines," IWCS 50th conference in Orlando, Florida, November.

[50] Lieberman, J.I. (2002), "Broadband: A 21st Century Technology and Productivity Strategy," White Paper authored by the Honorable Senator from the State of Connecticut, May.

[51] Mayer, Hans A. and Garner, M.P. (1996),"Underground Distribution Cable Practices in Australia," paper in IEEE/PES Conference in Los Angeles, September.

[52] Papadopulos, M.S. (1996), " Medium Voltage Extruded Insulation Cables in the United Kingdom," paper in IEEE/PES Meeting in Los Angeles, September.

[53] Pinet, A. (1997), " French Practice For MV Cables and Accessories," paper in IEEE/PES Meeting in Berlin, Germany, July.

[54] Sempra Fiber Links (2002), " Personal Communications," San Diego, Jan.

[55] Song, B.K. and Bae, S.H. (1996), " The Present and Future of Underground Distribution in Korea," paper in IEEE/PES Meeting in Los Angeles, September.

[56] Underground Construction Magazine (2003), “City Elects To Move Electric Underground,” authored by Jeff Griffin for Oildom Publishing, June.

[57] Van Schaik, N. and Steernnis, E.F. (1997), " Dutch Distribution Cable Practice Maintenance and New Construction," paper in IEEE/PES Meeting in Berlin, Germany, July.

[58] Welch, M.C. (2003), " Contractors’ Perspective of Optical Fiber in Sewers or Abandoned Pipelines," ASCE Pipelines Conference, Baltimore, Maryland, July.

Table 1: Global Power Transmission and Distribution Practices

Country	Distribution Voltages (kv)	Dist. Line Length (Km)	% U/G	Trans. Voltages (kv)	Trans. line length (Km)	% U/G for trans.	Popul (Million)	Size (sq km)
Algeria	5.5 to 30	172,424		60, to 500	11,912		28.7	2,381,740
Argentina	6.5 to 66			132 to 500	32,447		35	2,766,890
Australia	11 to 44	314,805	6	66 to 500	75,195		20.0	7,617,930
Austria	1 to 36			110 to 380	9,611	7	8.2	82,738
Belgium	.23 to 29	176,756	64	30 to 380	8,717	32	10.3	30,230
Brazil	.22 to 34.5	4,000,000	1	138 to 750	170,000	0	182.0	8,456,510
Canada					155,328		32.2	9,220,970
Chile	6.6 to 66			110 to 500	10,561		15.7	748,800
China	.5 to 220	7,300,000	20	35 to 500	163,300		1,287	9,326,410
Croatia	.4 to 35	121,465	24	110 to 400	7,236		4.4	56,414
Czech	.4 to 35	97,000	24	110 to 400	6,520	1	4.3	56,600
Denmark	10 to 24	59,299	59	30 to 400	14,481	21	5.4	42,394
Egypt	3 to 30	242,346		66 to 500	18,495		74.8	995,950
Estonia	6 to	61,159		110,330	4,980		1.5	45,000
Finland	.23 to 110	354,243	21	110 to 400	21,526		5.2	305,470
France	.22 to 20	1,206,000	29	220 to 400	100,000	3	60.0	545,630
Germany	.4-110	1,550,800	72	220to 380	36,800	0.5	82.5	357,026
Greece	<150	170,000		66 to 400	10,000		10.7	130,800
Holland	1 to 30	249,936	100	50 to 380	12,352	31	16.0	33,883
HongKong	.22 to 33	17,000	85	132 to 400	1,600	50	7.4	1,042
Hungary	10 to 120	65,800	16	120 to 750	3,900	1	10.2	92,030
Iceland	1 to 24	8,132	100	110 to 400	1,917		0.3	106,000
India	2.2 to 15	5,084,126		32 to 400	35,790		945.0	3,287,590
Iran	6 to 33	433,487		63 to 400	60,516		62.5	1,648,000
Ireland	5 to 38	80,000		110 to 400	5,800		3.6	70,280
Israel	13.2 to 33	21,140	33	161	100	100	6.0	20,330
Italy	.22 to 20	1,031,000		132 to 380	65,863	2	58.0	294,020
Japan	.1 to 6.6	1,274,664	5	22 to 500	165,667	12	127.0	374,744
Jordan	.4 to 33	35,477	16	132,400	3,037		5.3	92,300
Korea (S)	6.6 to 22.9	366,983	10	66 to 765	27,937	7	48.0	98,190
Mexico	2.4 to 85	622,059	2	115 to 400	72,000	1	105.0	1,923,040
Morocco	5.5 to 30	28,769		60 to 225	13,609		31.7	446,300
NZealand	11 to 65	160,739		110 to 350	17,667	12	4.0	268,680
Norway	1 to 72	200,000		60 to 420	18,246		4.5	307,860
Oman	.433 to 33	15,616		33 to 132	6,580		2.8	212,460
Poland	15 to110	644,900		220 to 750	12,610		38.6	304,465
Portugal	1 to 130	187,272		150 to 400	11,918		10.1	91,951
Saudi	13.8 to 33	109,000	35	66 to 380	19,000		24.0	1,960,582
Singapore	.4 to 22		100	66 to 400	100		4.6	683
Slovenia	.4 to 35	57,600	43	110 to 400	2,600	0	2.0	20,000
S. Africa	22 to 165	256,384		220 to 765	26,443		42.8	1,219,912
Spain	.38 to 132	550,000	23	220,400	32,240	1	40.2	504,750
Sweden	.4 to 145		80	132 to 400	30,665		9.0	410,934
Swiss	1 to 20	250,000	80	60 to 400	20,000		7.3	39,770
Tunisia	10 to 30	66,500		90 to 225	3,150		9.0	163,610
Turkey	6.3 to 34.5			66 to 380			68.0	770,760
UAE	11 to 33		80	132 to 400	1,600	10	4.0	82,880
UK	.23 to 132	615,907	60	275,400	13,912	5	60.0	241,590
USA	<69	4,793,656	8	69 to 765	607,494	0.4	290.0	9,158,960
Yugoslav	3.8 to 35	147,072		110 to 400	10,868		10.6	102,173
Venezuela	.12 to 69			115-765	22,212		24.	912,050

Table 2: Underground Utilities in America

Type	Km
Sanitary sewers	1,280,000
Storm drains	720,000
Combined sewers	160,000
Potable waterlines	1,360,000
Natural gas lines	1,800,000
Petroleum pipelines	480,000
Irrigation pipelines	320,000
Industrial waste lines	880,000
Total	7,000,000

Table 3: Broadband Networks in Underground Utilities

City	Length (Km)	Type
Albuquerque	9	sewers
Almelo	50	gas lines
Amsterdam	2	sewers
Berlin	50	sewers
Copenhagen	2	sewers
Donau Ries	2	gas lines
Forth Worth	2	gas lines
Gevelsberg	2	gas lines
Hamburg	100	sewers
Hamm	11	gas lines
Hanau	5	sewers
Helmstedt	2	gas lines
Himeji	5	sewers
Indianapolis	5	sewers
Kawasaki	37	sewers
Kyoto	18	sewers
Long Beach	2	gas lines
Lunen	8	gas lines
Madrid	1	sewers
Minami	13	sewers
Nagoya	18	sewers
New York	140	electrical
Ogaki	24	sewers
Osaka	6	sewers
San Vendemiano	2	gas lines
Sapporo	21	sewers
Sprockhovel	3	gas lines
Taichi	250	gas lines
Taipei	300	gas lines
Tokushima	4	sewers
Tokyo	850	sewers
Toronto	5	sewers
Vienna	400	sewers
Wilksboro	3	gas lines
Yodogawa	11	sewers
Yokohama	42	sewers

