Municipal Broadband Networks

A Local Paradigm

By

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Abstract

This paper addresses the issue of deploying broadband in a local environment. It focuses on the "edge" issues associated with such deployment and make observations and recommendations as how best to deploy such systems. The key recommendation is to strengthen the key elements of local networks; localism, openness, connectivity, and minimalism. The approach recommended in this paper is that with evolving local broadband networks, that a minimalist approach be taken to ensure connectivity between the networks, facilitate openness on and between the networks, and balance that with the localism of deployment and operations. The author believes that this is best achieved with a full IP based form of inter-connectivity.

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1. INTRODUCTION

Municipal Broadband is evolving into a credible and achievable deployment of technology which is anticipated to have significant social and economic benefits. First it is important to make several observations:

1. In the 1990s, a trend developed wherein the term "silicon is almost" free meant that we could do a great many things with silicon that it was cheaper to put functions in hardware that twenty years earlier were unheard of. Chips now allowed for the rapid evolution of wireless, computers, appliances, and many other areas. The growth of the 90s was a "silicon was free" growth spurt.

2. In the early 2000s, there is a second similar impact, what we call, "fiber is almost free". We have seen that with the almost collapse of telecom. The fiber in international markets and in backbone networks is almost free. The costs are dropping and new fiber technologies mean to continue to lower this. The next question is how far to the end user does this observation hold. We argue herein that it goes all the way, under certain circumstances. We further argue that if extended then we would expect a second surge as we saw in the 1990s. However, in this potential surge there are many players who see their ox being gored, namely the incumbents, CATV and ILECs. In the first case of silicon there was no government intervention, in this case the government is all over the place, a helter skelter movement, undirected and misdirected. This government action may result in value destruction rather than creation, and move this next spurt to those counties with the wisdom to let this process flourish.

3. On Net, Off Net, Interconnection, Access, and protection of incumbents is a major barrier to entry. The current use of the Internet requires a great deal of "off-net". By this I mean going from the ISP to the Tier 1 Internet provider. This interconnection or access off the ISP network to the Tier 1 ISP backbone is very costly, namely $100-$500 per Mbps per month! That means that is I want a 1 Mbps connection I must be willing to pay the Tier 1 carrier $500 a month in addition to whatever transport costs I have incurred. Thus FTTH is relatively free in this world. All of the money goes to interconnection. This is also a totally unregulated oligopoly. It is controlled by 5 major companies who dominate the world market. They make OPEC look like philanthropists! By changing the paradigm in this space and allowing on-net, namely peering and interconnection on the broadband network, we change the economics totally.

4. Economics dictates the network structure, not technology and not regulation. However, regulation may distort economics.[2] The current debate over VOIP is really a debate about regulation of interconnection and access. The regulatory artifacts distort reality and create technical distortions as well. One is reminded of the story Bob Kahn, the father of the Internet when he was head of IPTO at ARPA in the 60's and 70's, who relates his meeting with ATT Bell Labs. He states that when they first started the Internet he went to Bell Labs to try to get cooperation on using the ATT network. The asked for the specs on the Bell modem so they could work with it to design the ARPA Net. In a meeting with dozens of ATT/Bell Lab types he we summarily informed that only ATT would be allowed to touch the network and the technology and that he should just hand the project over to them. He deferred. He then handed contracts out to universities who then developed modems, computer chips, routers, and the like. In a way, that meeting between intelligence and arrogance was the beginning of the end of what was ATT. Fortunately this was a Government network and the FCC did not have power or authority. If it did it too would have been destroyed.

[2] See Witt, MCI paper. In this paper Witt describes a technological paradigm using the layered architecture t help control regulation. He attempts in a logical fashion to relate technology and regulatory policy. Regrettably people have been trying this for years. The economists however continually throw technology and operational realism out the window and create new ad hoc propiter hoc arguments, such as Baumol Willig Theorems.

1.1 Broadband: A Definition

Let us first define municipal broadband.

First, broadband is defined in a more expansive manner than most regulatory agencies have defined it to date. It is more than DSL and more than cable modems. Broadband is truly data provided in as fast a manner as is possible by having direct fiber connectivity to each user.[3] Broadband is a VLAN technology set employed over a very wide area. This is a very powerful definition, because we have seen that fiber capacity is a never decreasing value, in fact it has been increasing dramatically over the past few years. For a benchmark we mean that the fiber supports at a minimum 100 Mbps or more per user. Moreover, broadband is further defined as an enabler. It is devoid of any content or service but it is capable of providing an open pathway to facilitate any and all applications.

Second, Municipal may mean many things. It has meant the fact that the network is "owned" by a municipality. It has meant that it "covers" only the municipality. It has also meant that it is provided for the "benefit" of the municipality. For our benchmark, we focus on the coverage characteristic, independent of who may own, operate, or benefit from the network. To date, in the US alone, there are over 400 municipal broadband networks. [4]

In summary, What is broadband? Is it 200 Kbps, more, 1 Mbps, or more, 10 Mbps or more? In our definition, broadband is:

1. 10/100 BT connections to each user at a minimum with a 10+ Gbps backbone locally. It is also growable and scaleable. It would allow direct connection with backbone speeds.

2. An Open network, allowing any user to connect to any other user, at zero marginal cost. It is an outlet or portal.

3. Fully interconnected regionally and ultimately nationally. It is a network which allows local to local interconnection. It is not an island network, allowing only interconnection via proprietary and hierarchical points of entry.

4. An Open network allowing any purveyor of services to connect in any manner and any place to any user. It is a network which creates an electronic open and competitive marketing and distribution channel.

Interconnectivity and opens are key elements as are key factors as is the ability to have an expandable and scaleable network. A mere fifteen years ago there were discussions on bringing TCP/IP up to the speed of DS3 or 45 Mbps network. It was thought at the time that such a high speed would be prohibitive. In fact it has scaled way beyond that. Moreover the same was felt to be true about the scalability of Ethernet, limited to 10 Mbps, but now scaleable to 10 Gbps and beyond.

This then leads us to asking the first of a set of questions.

The ***first*** question we then pose is; *What is the future of municipal broadband and how will that future impact the existing telecommunications providers; Internet, telco and cable purveyors?*

The current mode of evolution of municipal broadband is one driven by the deployment of local networks. By local we mean small self contained networks which have direct end user connectivity. Each local network may be considered a closed island of communications capability with a single point of egress to the Internet backbone or some similar third party content provider. The current state of deployment now

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[3] See paper by Ismail and Wu on OECD Broadband Internet Access.

[4] See: http://www.tiaonline.org/media/press_releases/uploads/FTTH04list.pdf for some recent statistics.

also begins to consider regional, state, and possible national deployment. This next stage of deployment of these networks will require significant thought and planning to ensure that what is achieved has the capabilities of a truly open broadband network. This will be the only way in which both the economic and social benefits may be achieved.

The ***second*** question we pose in this paper is; *What are the goals and concomitant architectural parameters for the successful deployment of interconnectable municipal broadband networks?*

This paper addresses broadband from the perspective of the local deployment, first, and then the integratability of those local networks into the existing national and international networks currently in operations. The overriding principle of this analysis is to ensure a fully open and scaleable and integratable network, one that empowers both economic and social development. This calls for a set of overall criteria and a means to allow those criteria to take hold.

Thus the ***third*** question for this paper is; *What are the minimum standards for the deployment of municipal broadband networks and how should those standards be set, managed, and updated?*

In the initial development of the Internet, the U.S. Advanced Research Projects Agency, ARPA, set the base for commonality and openness. Following that IETF, the Internet Engineering Task Force, was a brilliant and effective colloquium that provided a truly evolutionary like stands process, what work survived, what did not disappeared. The same paradigm of establishing an agreement in a survival of the fittest mode is called upon for local broadband as well.

The development of infrastructure for municipalities has been shown time over time to be the basis for significant economic development of the municipality as well as enhancing the services available to the members of the community. Infrastructures such as schools, roads, water and sewer, power systems have been typical examples. The current development of broadband communications services, driven by Internet access and related services, is the current example of such a new infrastructure. [5]

The current typical positioning of broadband is that it can do what the telephony and CATV providers can do today but “better, faster, and cheaper”. This is what we call the “double-triple” play; three services (Internet access, telephony, and video) with three elements of improvement (better, faster, cheaper). In fact, as one explores the market and listens to what the users are really saying, they see broadband as having two key characteristics; openness and localism. Neither of these two characteristics relate to the standard services proposed nor do they relate to the characteristics of those services.

1.2 Broadband Evolution

Before continuing with the overview, we should first stop and look at where broadband and broadband-like networks are progressing. The following is a brief summary which sets the framework for evaluating municipal networks:

Phase 1: The Internet started with local communities needing a backbone network to provide interconnection between the communities. The IP protocol allowed the routing of the packets in the most efficient fashion over the backbone network.

Phase 2: The DARPA spins off the commercial Internet backbone and multiple large scale players take positions as what we now call Tier 1 Internet carriers; ATT, MCI, now Level 3 and others. They need to interconnect and the evolution of the MAEs, East and West (Virginia and California), occurred as well as the introduction of the regional NAPs with the support of Sprint. The Internet is becoming broadband BUT from the top down. This interconnection is called peering, since the Tier 1 ISPs agree to interconnect at no cost to each other, but not to anyone else.

[5] For economic development analyses see the papers by Samuelson and Varian, and Gillette, Lehr and Osorio, OTP Paper of US Dept of Commerce, September 2002,

Phase 3: ISPs, local and national, evolved allowing dial up connections. The ISPs need to interconnect to the backbone and they do that via Transit agreements agreeing to pay the Tier 1 carriers. In this phase the local end users has to connect via phone, local ISP, transit connections, then peering, and eventually as it goes back down the chain to the information they seek. Typically this may entail 50-100 packet hops. This further entails an individual seeking information for a collection of larger purveyors.

Phase 4: Ersatz broadband; enter cable and telcos. This is the phase of DSL and cable modems. The only material change from Phase 3 is the slightly higher speed of local access. The same backbone bottlenecks exist.

Phase 5: This is an interesting Phase an generally not noted by many. It is the development of the NIXs. The NIX is the national Internet exchange. Take for example the Czech Republic. There are many small ISPs and a few larger ones, such as that of Czech Telecom. In 1995, almost all Czech Internet traffic went from a user to some web site in the US, or possible Western Europe. By 2002, it was 50% to the US and Western Europe but the other was all within the Czech Republic. This super “municipal” network saw that they need not pay for transit fees in Frankfurt to connect all Czech users. They instead agreed to create a NIX, National Internet Exchange, to interconnect all Czech networks who talk with Czech Networks. Two observations come from this; first, when one allows localism and openness of the network, people have a tendency to communicate within their regional group, second, costs can be avoided and performance increased by local interconnection. This step is the first step towards localism. All members of the NIX agree to peer at no cost. Thus the high and almost extortionary fees of the Tier 1 carriers were eliminated. This did not happen in the US!

Phase 6: Municipal networks in the US and other countries have deployed what are best described as wide area LANs, local area networks, and these networks allow any user to communicate with any other user of the network and the interconnections are performed in the network using IP. This is NOT the approach of the proprietary networks such as cable and DSL. In the proprietary cases they still use Tier 1 interconnection architecture. They go to a Tier 1 node and pay the fee and go back again. Municipal networks connect “within” the network! This means lower costs, zero marginal costs in fact, and improved performance, 2-5 hops, not 50-100.

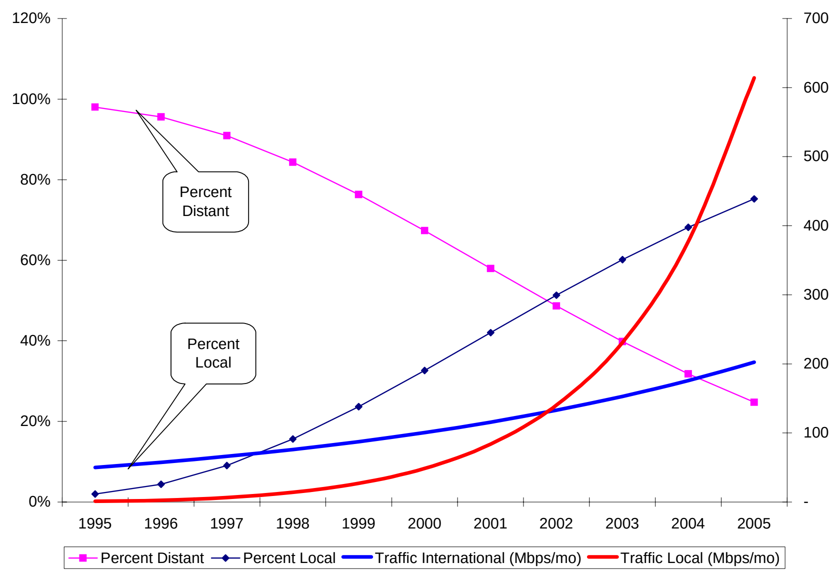
Phase 7: Regional Municipal Clusters: This we believe is the next step. There are some initial efforts in this stage already. One may consider this being what a smaller country may do, such as the Netherlands. In the Netherlands, the cities may build their own Municipal Networks, then agree to interconnect, and then the entire country is one Clustered set of Municipal Networks. The economic power is now within the network not external to it. This is the contrast of externalities to internalities. We discuss this latter.

The following Figure is characteristic of NIX countries and we believe is characteristics of Phase 7 Municipal Clusters. It shows several characteristics:

First, total distant traffic continues to grow at a steady rate. This is in many ways consistent with the theory of externalities, namely one has more people to connect with.

Second, local traffic grows at a much more rapid rate, this is the most significant factor in total growth. This is consistent with the corollary of externalities, namely internalities.

Third, there reaches a point where percent of internal traffic exceeds percent external traffic. This stage is the stage of true economic development. It is this point of inflection that we anticipate occurring with the deployment of truly open local networks. The existence proof is the projection of the deployment of NIXs.



The following is a list of towns and municipalities who are already affecting networks of the type we have been proposing. The list is quite extensive, there are at this time over 200 such efforts out of almost 40,000 town and municipalities in the US.

State	*Towns*
Alabama	Lincoln, Opp, Foley, Scottsboro
Alaska	Angoon, Kake, Kiana, Kotlik
Arkansas	Conway, Lockesburg, Paragould
California	Anaheim, Alameda, Burbank, Los Angeles, Palo Alto, San Bruno, Santa Rosa
Colorado	Center, Copper Mountain, Longmont
Florida	Gainesville, Key West, Lakeland, Leesburg, Newberry, Ocala, Valparaiso
Georgia	LaGrange, Fairburn, Marietta, Newnan, Thomasville
Iowa	Akron, Algona, Alta, Bancroft, Cedar Falls, Coon Rapids, Danbury, Dayton, Denison, Grundy Center, Harlan, Hartley, Hawarden, Hull, Independence, Indianola, Lake View, Laurens, Lenox, Manilla, Manning, Mount Pleasant, Muscatine, New London, Orange City, Primghar, Rock Rapids, Sac City, Sanborn, Sibley, Spencer, Tipton, Wall Lake, Waterloo, Westwood
Kansas	Altamont, Baxter, Cawker, Columbus, Courtland
Kentucky	Bardstown, Barbourville, Bowling Green, Frankfort, Glasgow, Williamstown
Maryland	Easton
Massachusetts	Braintree, Chicopee, Holyoke, Shrewsbury, Westfield
Michigan	Clearwater, Coldwater, Crystal Falls, Hillsdale, Holland, Lowell, Negaunee, Norway, Wyandotte

Minnesota	Bagley, Coleraine, Elbow Lake, Fosston, Jackson, Marble, Westbrook, Windom
Missouri	Newburg, Springfield, Unionville
Nebraska	Lincoln
North Carolina	Morganton
New Hampshire	Keene
Ohio	Archbold, Butler County, Celina, Cuyahoga Falls, Hamilton, Lebanon, Niles, Wadsworth
Oregon	Cascade Locks, Eugene, Lexington, Lincoln County Public Utility District, Springfield
Pennsylvania	New Wilmington, Pitcairn
South Dakota	Beresford
Virginia	Blacksburg, Leesburg, Lynchburg
Washington	North Bonneville, Sumas, Tacoma
West Virginia	Phillipi
Wisconsin	Oconto Falls, Two Creeks
Wyoming	Lusk, Bailroil

Thus the conclusion that can be drawn from this list is that there is a significant interest in this opportunity as well as a growing experience base in effecting such utility services.[6]

1.3 Openness, Localism, Connectivity and Minimalism

There are certain characteristics which broadband must adhere, like those of the Internet as discussed above, to if it is going to achieve its full potential. Most of these characteristics have been learned from the steps we have taken with the development of the internet over the past twenty years.

1.3.1 Openness

Openness is a powerful concept. It means that there is no proprietary control, that anyone may interconnect via a portal and that peer to peer communications is readily achievable. Moreover, openness means that anyone wanting commercial access can gain that access in a standard and predictable fashion.

Openness further implies an open and free flow of communications on both a global and local landscape. The localism element must become an integral part of openness.

Openness means that the network allows any user to communicate with any and all other users. It further means a minimalism of implementation of broadband, as it is with the Internet, and an ability to move all of the intelligence and creativity to the edge of the network, in the hands of the user. The essence of the Internet has always been openness. This was accomplished via the use of the minimalistic approach of IP technology and allowing the intelligence to move to the edge of the net. Furthermore, openness also has the characteristic of empowering and enabling any user to connect to any other user or sets of users. Thus openness means that the network deployed should be IP based and should allow individual access to any and all other users of the network in the broadest sense.

1.3.2 Localism

Localism is a similar characteristic. Localism means that the power to create is left in the hands of the user. It is the complement of openness, which is the network looking outward. Localism is the complement of the network looking inwards. This paper describes how one can view broadband not just as a local or regional embodiment of openness and localism, but how it can play as both a national and international fabric for these concepts.

[6] See recent TIA report on municipalities.

Localism further means a participatory process driven by some form of co-ownership in the MBN. The participatory process and the ownership issue go hand in hand. The ownership may mean nothing more than a seat at the table with guarantees of openness. The participatory process demands an ability to allow those with vested interest to have their voices heard. Localism also means that there can be a focusing of the interactions and communications on a local level.

The major observation here is that as little as five years ago 95% or more of Internet traffic went to MAE East or West and then back again. Thus Europe communicated with web sites in the US and then back. India had over 99% of its traffic sent back and forth to the US. This has changed. Poland talks to Poland more than 50% of the time, France to France in excess of 70% of the time, and now India has over 70% of its Internet traffic to and from itself. Localism thus has a second dimension of internal communications and facilitating the process as well.

If one were to look at the Internet traffic over the past fifteen years one would observe a fascinating pattern of change. In 1994, for example, over 98% of the Internet traffic from Mexico went to the US and back. In 1998, the same amount went from India to the US and back. The tremendous flow was driven by two factors; lack of local content and lack of local infrastructure. At the present time the flow in India is now less than 50% to the US, the majority if to and from India. This means a growth of Indian content and a growth of Indian infrastructure. Similar but even more dramatic changes are prevalent in Europe. Czech traffic was predominantly to the US and Western Europe, today it is predominantly to and from Czech. This is the result again of local content and local infrastructure. This moreover is an example of localism. Namely that there exist natural communities of interest wherein the predominant communications occur. There are thus natural clusters of commonality. The question then is can these cluster be brought down more locally, albeit by expanding the communications local fabric.

Specifically, if one were to provide a local and open broadband fabric does one enable and empower true localism and at what level. Is the country, the region, the town? If anyone were able to communicate with anyone else in a broadband manner and at de minimis costs, what is the area for 50%+ of the traffic flow?

Is the area of majority communications a truly local phenomenon? That is the question of and driver for true localism.

1.3.3 Connectivity

Connectivity means allowing the networks to build and connect to one another. By having a minimalist connection criteria, a standard accepted by all, then connectivity can be achieved. Connectivity also demands that the local networks must agree to connect. The connection must also be done on a peer to peer basis with no economic limitations or fees. It is critical to eliminate the current transit fee construct which the Tier 1 Internet backbone carriers have which make for prohibitively costly interconnection to other networks.

The agreement to connect, local, open networks, then will circumvent the strangle hold of the Tier 1 Internet carriers. It will create a collection of locally interconnected open networks which will aggregate to a national and possible global open broadband infrastructure.

1.3.4 Minimalism

Minimalism is the essence of the Internet. The Internet is not the telephone networks of the past. The use of TCP/IP creates a minimalist schema for interconnecting, for expanding, and for achieving scale. This is the hour glass construct. Keep the internal parts of the network simple, move the intelligence to the edge of the network.

1.4 Municipal Broadband Networks, a Paradigm

The principal concern of this paper is the recent development of local open networks, which we have termed Municipal Broadband Networks, "MBN"s, which have been deployed in hundreds of locations as of this time. We do not mean DSL or cable modems, neither of which are open and neither of which empower localism. Specifically, DSL and cable modems are proprietary network extensions which allow connection to the Internet backbone via third party backbone access providers such as the Tier 1 Internet providers. The DSL and cable modem model is one where the "gatekeeper" not only still exists but is duplicated in bother the presence of the telephone company or cable company and the Tier 1 Internet service provider. MBNs on the other hand can be islands of connectivity unto themselves. That is a fundamental difference, a difference totally compliant with the essence of openness and localism.

The ***fourth*** and most important question one can pose is as follows:

If one accepts openness and localism as the principles of true MBN deployment, then what are the minimalistic principles against which MBNs should be deployed. Namely what standards should they reflect, how best to establish and manage these standards, and how best to grow and evolve those standards?

We argue herein that the answer to this questions needs significant debate but that many of the issues have already been both voiced and answered in the very deployment of the Internet backbone. The next step is to carry this to what we call the Internet reticulum, the local Internet.

2. BROADBAND

Broadband is many things to many people. The FCC defines it as anything in excess of 200 Kbps. The FCC in many ways has created the confusion and chaos over broadband by trying to appease the incumbents so as to say that whatever they deliver is broadband. In addition, certain wireless contenders have also tried to confuse the facts with the ongoing land grab on spectrum. We attempt in this paper to expand the definition to encompass what true broadband can accomplish as a change agenda. This means that we address the issues of what broadband can do for the introduction of new and innovative services and in addition change the old paradigm of telecommunications. Broadband in our definition demands as an integral part the provision of fiber. It may also include wireless as a key adjunct.[7] Thus it is technology neutral to a degree.

2.1 Broadband Goals

Building an open-access local broadband infrastructure provides a town with numerous benefits that easily compensates for the costs of the project. It is becoming increasing evident that towns in suburban and rural areas are deriving much more than the most apparent benefits of publicly owned broadband infrastructure such as the addition of jobs and tax revenue; in fact, there is an overall better quality of life to be gained as indicated in the following points.

1. *Ubiquitous Coverage:* As indicated before, the current business economic climate will not permit private enterprise to establish and operate broadband networks, especially in sparsely populated areas. A mission-driven project by a town to bring broadband to its citizens appears to be the only solution to the quandary.

2. *Efficiency:* A town may be able to leverage existing fiber strands installed by a municipally owned power utility, as well as corresponding telecommunications systems and facilities like backup power equipment, network monitoring systems, remote terminals and associated real estate. In addition, the town may be able to utilize expensive Rights of Way owned by municipally owned utilities as well as tap into their existing telecom personnel for expertise.

[7] For wireless see the recent paper by Lehr, Sirbu, and Gillete, May 2004.

3. *Enhanced Services:* Through unbundling of its broadband network to service providers, the town could spur a diversity of value-added products including Voice over IP, flexible bandwidth, digital cable, video on demand, streaming media, etc.

4. *Economic Development:* A broadband network could act as a magnet to businesses. A common concern for both new technology as well as traditional businesses is the presence of a reliable high-speed communications system.

5. *A Community Asset:* A local pervasive broadband system operating profitably could improve the tax base and be a real asset to the town. It could also favorably change the property taxes in the area as well as improve the credit standing of the town so that cost of borrowing is reduced.

6. *Competition:* It is a common fact that a town, by operating its own broadband network, can favorably influence the pricing as well as quality of communications service provided by private operators to its citizens.

7. *Lower Life Cycle Costs:* By installing an open-access fiber broadband system that is marginally over-engineered, the need for future upgrades and installations can be minimized. In addition, street-diggings can be avoided as well since fiber cables have a life span of 20 years.

8. *Improved Government IT Integration and E-Government:* Government data systems could be better integrated and business/technical processes standardized. E-government services such as tax collection, payroll, utility services and billing could be offered online in a broadband environment.

9. *Security:* The need for an integrated high-speed communications infrastructure at both a national and a local level has taken on new meaning after September 11th, 2001. No local government can ignore the importance of having a reliable broadband communications network connecting hospitals, schools, businesses and broadcast companies to provide notification and rapid response in the event of emergencies.

2.2 Broadband Benefits

There must be a established set of goals for the deployment of broadband. We mention here a few. Many more will evolve as we better understand the functions of a truly broadband network.

2.2.1 Economic Development

The broadband environment, if aligned with an open network affording localism can become a Petri dish for the development of new services and technologies. It further can become a new marketing and distribution channel. This factor is of significant merit. For example, the Internet, at the lower speed, has limited abilities of promotion and persuasion. It to state it simply, lacks the human touch. It is like going to a bazaar in Istanbul with just pictures and price tags, no smells, no human interaction, no facilitation of the sales process. It is a “here it and this is the price”. Rather is empowers the promoter of the sales to do that promotion, to interact in a manner consistent with human communications, a communications demanding a true broadband communications channel. It must include voice, image, interaction, and facilitation so that parties can reach a better common understanding.

2.2.2 Local Participation and Communications

The local broadband network is akin to local roads, power, and other utilities. It becomes an integrated element of the community. The MBN is an active facilitator of community communications, whether it be for business, person, or overall community purposes.

2.2.3 Enhanced Services Deployment

The MBN provides a new platform for the deployment of new services. These services are both on-net and off net services. For example, the MBN may become an integral part of the health delivery network.[8] In addition, there are other new services such as home security using interactive broadband web cams, home management of utilities, school and parent-teacher conferences, distance learning, training, and support for a variety of security applications.

2.2.4 Competition in New Services

New service development is facilitated by the existence of and access to an MBN. Municipal broadband systems can help communities retain current key industries and businesses by providing essential communication infrastructure. At the same time, a high bandwidth broadband network can attract businesses and jobs. The specific benefits are as follows:

2.3 Design Features: The Internet as an Example[9]

We can look at the Internet and its evolution and ask ourselves the question:

"What elements of the Internet design do we want to bring to the MBN development to ensure that it meets its overall goals of openness and localism?"

We address these issue here as first examples from the Internet and then as design goals for the MBN evolution. The Internet as a global backbone has been very successful. The MBN as a local infrastructure must be responsive to the best elements of the Internet qua national/ international network. Why has the Internet been so successful? Much of the answer lies in unique design principles and features, which have led to a uniquely global, open, innovative network.

Indeed, the Internet is different than most if not all communications systems of the past 150 years. Fundamentally it is a system that has been developed from the outside inwards, and that has afforded end-users the freedom to innovate at the edges to the utmost degree. This unique freedom afford the users of this network has been the seminal elements in the Internet's ability to offer a rapidly changing environment. These principles and features distinguish the Internet from other parts of the information infrastructure such as today's Public Switched Telecommunications Network (PSTN).

Many of the characteristics of the Internet can be traced to a set of basic principles adopted by the community that was responsible for its development. These principles, set forth in the document IETF RFC 1958, have been recognized as a set of guiding architectural principles for technical design, which are also pointed to as a statement of the fundamental political and ethical beliefs of the researchers and engineers who designed the Internet.[10] The same principles which we discuss below for the Internet as a national and international backbone network can be directly applied to the MBN architectures. Specifically some of the unique design principles should include:

2.3.1 Use of a Minimalist Architecture

The Internet can operate over different, changing underlying technologies, and applications are free to evolve above the transport layer. This has been described as the "hour glass" architecture. In this architecture, bits are bits and the network does not optimize for any class of applications. The network is minimal at its heart and the intelligence, via appliances or whatever, are at the edges.

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[8] See McGarty, Investigative Radiology, for a detailed description on how the author implemented this system in Boston with the Harvard Medical School affiliated hospitals.

[9] From "The Internet Coming of Age" National Academy of Science, 2001.

[10] See IETF, Internet Engineering Task Force, Request for Comment, RFC. http://www.ietf.org/

The Internet is a very complex system of computers, protocols, and applications. This tends toward complexity in individual components as well. However, this tendency towards complexity works against both the complex hardware or software, and against the systems which depend on its correct behavior, as it becomes difficult for those who designed it to debug, and for those who depend on it to deploy and use. For this reason, components and protocols must be designed with serviceability in mind, which means that they must be simple to deploy and use. We note that much in the Internet today is not as simple as the end user would like; the trend must be towards increased simplicity in the components.

Decentralized and global in scope, the Internet is difficult to control. Governments are now considering regulation but in an environment designed for maximum freedom, regulation and control are and will continue to be difficult.

2.3.2 Provide for Unique names and addresses

The Internet has adopted a single set of unique addresses which permit any connected device to communicate with any other. A common, unique set of names, which are mapped into addresses through a name service, allows each device to be uniquely identified.

The use of the IP based naming construct was a key factor in common addressing and the ability to expand that to a wealth of appliance like devices. The limitations of the numbering, seen now by the attempts to expand into Ipv6, is only a positive proof of that fact.

2.3.3 Ensure easy many-to-many transmission via packet addressing

If I connect anywhere, I have access everywhere. There are no segregated communities: all networks are interconnected and share the same address and name spaces.

The Internet is drastically different from the traditional hierarchical and one to one telecommunications services. It is a packet system, allowing control and enhancement at the periphery of the network and allowing for the “broadcasting” of packet to many destinations simultaneously. In many ways the Internet is the blending of characteristics peculiar to telephony and broadcast.

2.3.4 Allow innovation to take place at the edge via open interfaces

The Internet is highly creative and innovative. This is because the point of innovation is at the edge of the network, through software running on devices connected to the network. Because of the hourglass architecture, the interface used by edge devices is standardized and open to all. Placing the intelligence at the ends permits rapid change (e.g., by adding new devices or loading new software into existing devices) that do not have to wait for changes or investment in the network infrastructure.

The Internet has already gone through several iterations. Routing protocols have been deployed in bounded domains, for example, and replaced with other protocols as technology has matured. IP addresses were at one time given out in blocks of fixed sizes, whereas today they are assigned in blocks defined by economic penalties and demonstrated needs. What has worked, over a period of twenty-five years, has been continual gradual change, with interoperate*ion between newer and older hardware and software. Sudden revolutionary changes have not worked as well, such as the sudden phasing out of one protocol in favor of another. For this reason, it is unrealistic to believe that major infrastructure components, hardware or software, can be changed without a significant period of coexistence and interoperation.

2.3.5 Ensure Scalability in the network for expansion

Design with scalability in mind and strong architecture supervision guarantees future evolution. This is particularly important for "infrastructure" applications (a.k.a. middleware) and is guaranteed, today, by the open discussions in the IETF standard process.

2.3.6 Provide a Distributed and Adaptive design for innovation and survivability

The Internet is more distributed and adaptive than other information networks. The Internet Protocol (IP) enables distributed control of the network except for the assignment of the highest level of addresses and Domain Name System (DNS) names. This distributed control provides for more rapid development and introduction of innovative applications and services.

This is the principle of robustness. It was written down by Jon Postel in the 1979 Internet protocol specification: "In general, an implementation must be conservative in its sending behavior, and liberal in its receiving behavior."[11] The same text appears in September 1981, in RFC 791, page 23 and a variant appears in the TCP specification[12], under the heading "robustness principle:" "TCP implementations should follow a general principle of robustness: be conservative in what you do, be liberal in what you accept from others."[13] In other words, it is necessary that each system see to its own predictability, reliability, and security. This is not to say that it cannot use other services—that a parent might not turn to an Internet Service Provider to reduce the amount of objectionable material, for example—but the robustness principle argues that each system provide its own last line of defense. The service provider might, for example, control content delivery to whatever extent it may, but the service provider cannot be expected to know the latest creations of a prolific criminal mind; the end system must be willing to authenticate the sender of a message, and protect itself as appropriate.

The robustness principle is, in addition, a rule for interpreting standards and other specifications which are not quite as precise as they might be in a perfect world (i.e. if there were multiple possible interpretations of what one might do), the sender should design and implement on the basis of the narrowest of them (or the intersection of all possible interpretations) and the receiver should be prepared for the broadest possible interpretation (or the union of all possible interpretations). [14]

Since innovation is the key that has propelled the Internet into its place, innovation is to be encouraged. To that end, fundamental connectivity is also a necessary factor. Balkanization would be a fundamental mistake. If a set of systems is hidden behind a firewall, something which is commonly done, a gateway system must be provided which enables an authorized person to have access to them. If this is not true, application innovation is stifled.

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[11] Jon Postel. August 1979. Internet Experiment Note (IEN) 111 (the IP specification), page 22

[12] IEN 112, August 1979, page 13

[13] A prior mention of a conservative approach in Internet protocol design appear in IEN # 12, "Issues in Reliable Host-to-Host Protocols," published on June 8, 1977 by Lawrence L. Garlick, Raphael Rom and Jonathan B. Postel, all from SRI/ARC. However, this paper falls short of enunciating a "robustness principle."

14 There is a case to be made that, especially for Internet applications, that while an important principle, robustness has on occasions used to create near-disasters for Internet interoperability. There have been repeated examples [e.g.,] in many areas, of vendors of products putting out protocol elements that, by a narrow (or even reasonable) reading of the standards, are egregious nonsense, then complaining that implementations that do not interoperate with them are inadequate because they are not robust enough. That stunt has been pulled with special frequency by dominant, or potentially dominant vendors or platforms, especially those who have expressed the position that standards are important and their products define them. When other implementations adapt toward the norm thus set in the interest of interoperability, the overall quality of implementations and of the protocol as practiced has regressed toward the mediocre.

2.3.7 Quality-of-Service can be achieved by design

As noted above the Internet is more distributed and adaptive but more difficult to control if a given level of QOS is to be achieved. In the PSTN traffic congestion is managed such that under overloads connections may not be made. In the Internet originating traffic will access the destination endpoint and receive some level of service even though that service level may not be useful – referred to as "best effort". Thus, certain applications, e.g., voice or video, may be restricted in their use unless service management capabilities are introduced to ensure acceptable performance levels. And, although higher-priced high-speed links may be made available, there is no guarantee that the unmanaged core of the network will provide high-speed throughput.

2.3.8 Low barriers to entry for innovation.

Consistent with the "Criteria for an Open Data Network"[15] the Internet is open to users, service providers, network providers, and to change. Relatively low entry barriers provide for greater content creation and accessibility and resulting innovation. The Internet is not structured with low-cost applications-specific solutions but abides by the principle of generality and flexibility. Due to deliberate design choices, there is no monopoly control over the current Internet. The success of the Internet shows that not only is openness possible but that such an approach surpasses other approach in stimulating the creative design of applications and services.

Also part of the low barriers for innovation is the fact that the Internet is based upon agreed to standards. Standards can be developed, which enable open competition between compatible implementations. Standards are only developed on a perceived need basis, and follow the actual development of the technology. There does not have to be a single dominant player.

The Internet has been well served by an insistence that there is often more than one "right" answer to a question, and on multiple independent implementations of common technology. There is no single technology that solves all problems well, or even well enough, and therefore no single technology that should be considered as a sole solution. There is no single vendor that has cornered the market in good technology, and when was has gotten close to a monopolistic position, the result has not been good. Such an environment would be threatened by the rise of a sole-source vendor, or vendor so dominant as to effectively be sole-source. The problem is not proprietary extensions or protocols for optional features, but rather that any required infrastructure must have multiple independent implementations, and multiple vendors from which those implementations may be obtained.

Furthermore, owing to the hourglass layers, there is no limitation to the communications media that can be used, and ubiquity of access is facilitated. For example, one can deploy a wireless Internet service without having to develop extensive interoperation facilities—a router is sufficient.

2.4 Service Providers and Services

The MBN provider must deal with the service providers who in turn deal directly and separately with the subscribers. The service providers may fall within two general categories.

2.4.1 External Providers

The basic three external providers are:

Internet Service Providers: Typically this would be someone like AoL, msn (Microsoft), Earthlink, AT&T or Verizon. Typically, the customer already has a relationship on a dial up basis with that provider; it is the service provider's duty to move the customer to the MBN. Such agreements would have to be struck between the providers and the town and not the town and the customers. The ISPs could provide low speed

[15] Computer Science and Telecommunications Board (CSTB). 1994. *Realizing the Information Future*. CSTB, National Research Council. National Academy Press, Washington, DC.

(1-10 Mbps), medium speed (10-100 Mbps) or high speed (100-1000 Mbps) data services on the MBN, with varying pricing and service level (shared/dedicated), tailored to subscriber needs.

Cable TV / Dish Providers: The incumbent CATV provider may or may not want access to the MBN. Notwithstanding, the town may allow access to other CATV / dish providers. Also, ISPs like AoL and msn may themselves want to provide video services over the MBN, now that they have speed of data interconnection that supports high quality video. The network will be able to provide the user with access to analog and digitized video services. This may also enable the provisioning of interactive video services. The MBN will also support high definition TV (HDTV) services.

Telephone Providers: The alternative telephone carriers, including CLECs, may also want access. This network provides an open interface, which is highly conducive to other telephony options. The MBN system may be used to provide fully switched toll-grade quality voice service. In addition, the network may support the emerging Internet Protocol (IP) phone technology, whereby, a user with an IP phone[16] can dial another IP phone user anywhere else in the world who is also on a broadband network, for practically free!

2.4.2 Internal Providers

This is the new challenge for an MBN provider. It is the essence of openness and localism, the integration of the internal providers. Some of the internal providers are:

1. Public Safety
2. Schools
3. Local Government
4. Health Care
5. Local Business
6. Local Public Interest
7. Educational
8. Media Providers
9. Interactive Games

3. INTERNET EVOLUTION

In order to place the evolution of the MBN concepts in context, we must first review several key issues; network architectures, network evolution, and the principles of externalities. The three issues are done in this fashion to focus on the issues of; first, what is the difference between the current dominant “broadband” players and the potential provided by true MBN, second, what are the evolutionary paths and drivers which will most likely impact MBN, and third, what are the economic benefits from a truly local/open MBN?

3.1 Network Architectures

The current regulatory community and investment community as well, often failed to recognize the fundamental difference in networks as expressed in their fundamental architectures. We briefly review these difference here.

3.1.1 Proprietary Networks

Cable and telco based DSL systems are proprietary networks. This means that they are closed and furthermore are of a hierarchical design. This means that in the proprietary design, all communications is between the use and some element of the network operator, whether the headend or central office, and that via this bottleneck, there are added costs and barriers to local interconnectivity.

[16] Manufactured by Cisco, Siemens et. al.

The proprietary network allows for single points of management and control and these networks generally attempt to bundle service elements in a vertically integrated fashion. They are closed networks, and they control all elements of connectivity and interconnectivity.

For example, in a CATV cable modem based design, the headend controls all communications and all connectivity is done via the Internet backbone. There is no capability for local connectivity. IP facilitation is moved back into a backbone interconnection and is not considered as part of any local infrastructure. The same holds true for DSL.

3.1.2 Open Networks

The open networks architecture is as we have discussed it. It facilitate IP locally at each user and it provides for IP connectivity within the network fabric. It is not a vertically integrated structure, it facilitates the provision of services by multiple vendors, internal and external to the network.

3.2 Internet Architecture: Growth Inwards

As we have described before, the Internet has evolved from Tier 1 peering to National Internet Exchanges. We believe that the next step is local Internet Exchanges using MBN fabrics.

3.2.1 Elements

It is best to start with a set of Definitions:

MAE East/West is a point at which multiple Tier 1 ISPs have agreed to interconnect. These points are interconnected by the broadband Internet backbone network. At the MAEs, one in Reston Virginia and on in San Jose California, the Tier 1 Carriers agree to both inter-exchange traffic as well as provide IP address switching facilitation. For a customer on ISP to connect to a provider on ISP 2’s network, the two must agree to share addresses and allow interconnection.

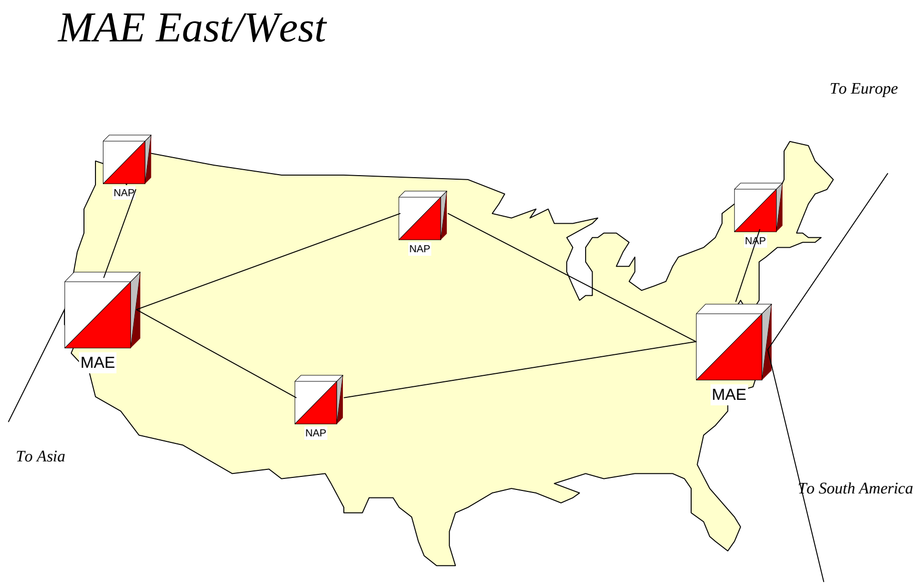
Network Access Points (NAPs) are one of several locations where ISPs interconnect their networks. A NAP also includes a route server that supplies each ISP with reachability information from the routing arbiter system.

Domain Name Systems (DNS) are the on-line distributed database systems used to map machine names into IP addresses. DNS servers throughout the connected Internet implement a hierarchical namespace that allows sites freedom in assigning machine names and addresses.

3.2.2 MAEs

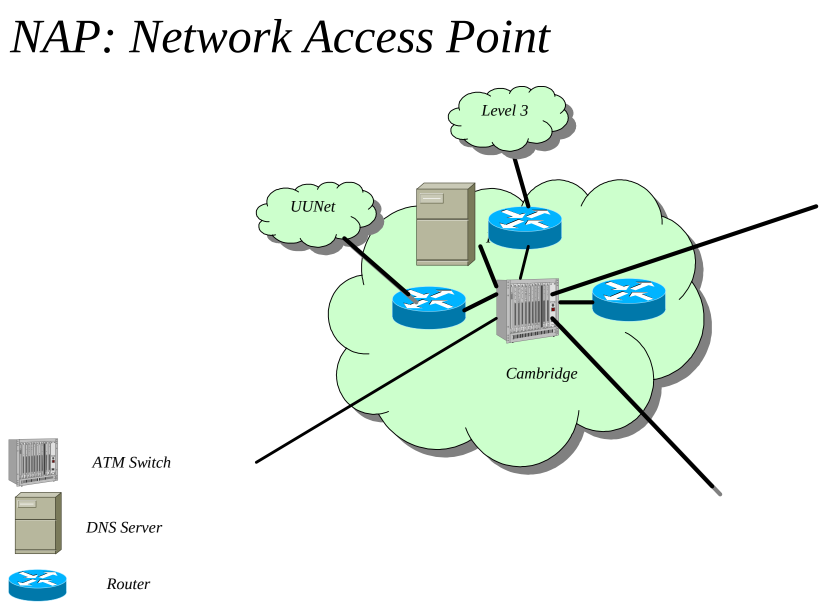
MAE, the Merit Access Exchange, is a peering point of ISPs who then interconnect into the vBNS, the broadband Internet backbone. The MAE in many ways look like a NAP.

ISPs maintain IP networks, connected to the Internet through network access points (NAPs), at key locations currently California, Chicago, Washington, D.C., and New York, or by connecting to other ISPs. NAPs are the entry points to the Internet, where ISPs share information. There are other means of sharing such data between networks, such as the Commercial Interexchange (CIX). Netcom’s star-shaped points of presence and telecommunications backbone are centered on the NAPs’ hookups. Note that the ISP network is a 45 mbps backbone of T-3s that connect the major points, as well as to the Texas area, where there is no NAP (also see UUNET’s backbone network topology in Figure 6.2). Typically, larger ISP networks are cell-switched and framerelay- based. For reliability, ISPs usually depend on more than one interexchange carrier (IXC) to provide time division multiplexing (TDM) point-to-point (or permanent leased line) T-1 and T-3 circuits, which interconnect the POPs. ISPs provide two types of service: leased line and dial-up. We have seen the emergence of another class of ISP, those which interconnect POPs by leasing frame-relay service directly from IXCs, which reduces somewhat the capital an ISP must make to its own network.



3.2.3 Network Access Points: NAPs

The Network Access Point is an inter/intra country or region point for ISP interconnectivity. A typical example is shown below.



The original system of peering has evolved over time. Initially, most exchange of traffic under peering arrangements took place at the NAPs, as it was efficient for each backbone to interconnect with as many backbones as possible at the same location, as shown in the example in Figure 2. Each backbone must only provide a connection to one point, the NAP, rather than providing individual connections to every other backbone. The rapid growth in Internet traffic soon caused the NAPs to become congested, however, which led to delayed and dropped packets. For instance, Intermedia Business Solutions asserts that at one point packet loss at the Washington, D.C. NAP reached up to 20 percent. As a result, a number of new NAPs have appeared to reduce the amount of traffic flowing through the original NAPs. For example, MFS, now owned by WorldCom, operates a number of NAPs known as Metropolitan Area Exchanges(MAEs), including one of the original NAPs, the Washington, D.C. NAP known as MAE-East, as well as MAE-West in San Jose, and other MAEs in Los Angeles, Dallas, and Chicago.

Another result of the increased congestion at the NAPs has been that many backbones began to interconnect directly with one another. This system has come to be known as *private peering*, as opposed to the public peering that takes place at the NAPs. Backbones *A* and *B* have established a private peering connection through which they bypass the NAP when exchanging traffic for each other, they both only use the NAP when exchanging traffic with backbone *C*. This system developed partly in response to congestion at the NAPs, yet it may often be more cost-effective for the backbones. For instance, if backbones were to interconnect only at NAPs, traffic that originated and terminated in the same city but on different backbones would have to travel to a NAP in a different city or even a different country for exchange. With private peering, in contrast, it can be exchanged within the same city.

This alleviates the strain on the NAPs. At one point it was estimated that 80 percent of Internet traffic was exchanged via private peering. Because each bilateral peering arrangement only allows backbones to exchange traffic destined for each other's customers, backbones need a significant number of peering arrangements in order to gain access to the full Internet. UUNET, for instance, claims to "peer with 75 other ISPs globally." As discussed below, there are few backbones that rely solely on private or public peering to meet their interconnection needs.

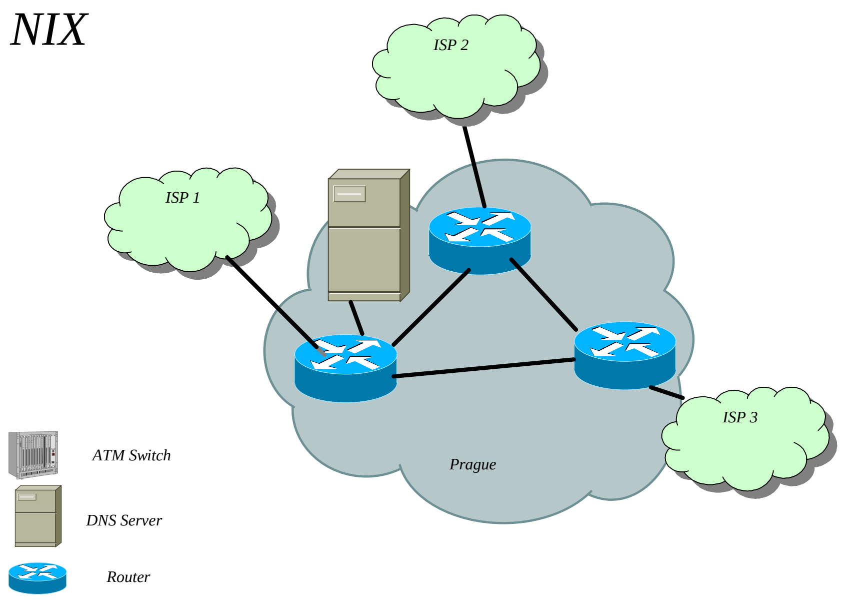
The alternative to peering is a transit arrangement between backbones, in which one backbone pays another backbone to deliver traffic between its customers and the customers of other backbones. Transit and peering are differentiated in two main ways. First, in a transit arrangement, one backbone pays another backbone for interconnection, and therefore becomes a wholesale customer of the other backbone. Second, unlike in a peering relationship, with transit, the backbone selling the transit services will route traffic from the transit customer to its peering partners.

Those few large backbones that interconnect solely by peering, and do not need to purchase transit from any other backbones, will be referred to here as *top-tier backbones*. Because of the non-disclosure agreements that cover interconnection between backbones, it is difficult to state with accuracy the number of top-tier backbones; according to one industry participant, there are: MCI, Sprint, AT&T, and Level 3 (formerly Genuity or GTE Internetworking).

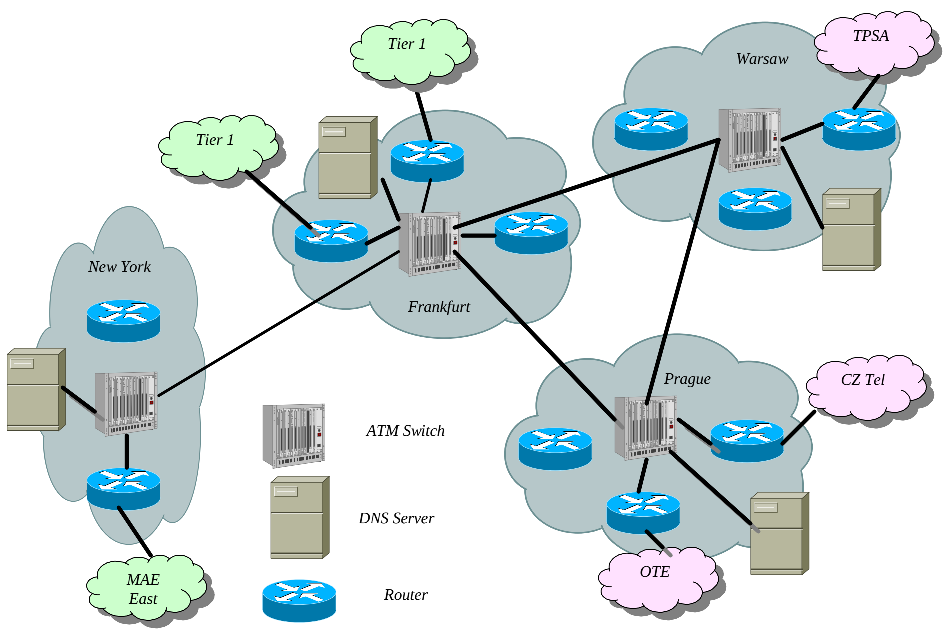
In addition, as noted above, transit gives a backbone access to the entire Internet, not just the customers of the peering partner. In order to provide transit customers with access to the entire Internet, the transit provider must either maintain peering arrangements with a number of other backbones or in turn must pay for transit from yet another backbone. In other words, a backbone providing transit services is providing access to a greater array of end users and content than it would as a peer, thereby incurring correspondingly higher costs that are recuperated in the transit payments. In a competitive backbone market, transit prices should reflect costs and should not put entering backbones at a competitive disadvantage.

3.2.4 National Internet Exchanges: NIXs

The NIX, the National Internet Exchanges, is simply a local intra country DNS type facility allowing local ISPs to have interconnectivity. It is shown below in simple form. The NIXs are quite prevalent in Central Europe. They evolved from the academic institutions and generally provide intra-country peering. It is possible to use a Polish ISP and be able to access only Polish web sites and send mail only to Polish subscribers. The ISP has no external connection. The NIX has no connection to the outside world and the ISPs who connect do so only with each other and block any attempts by others to transit.



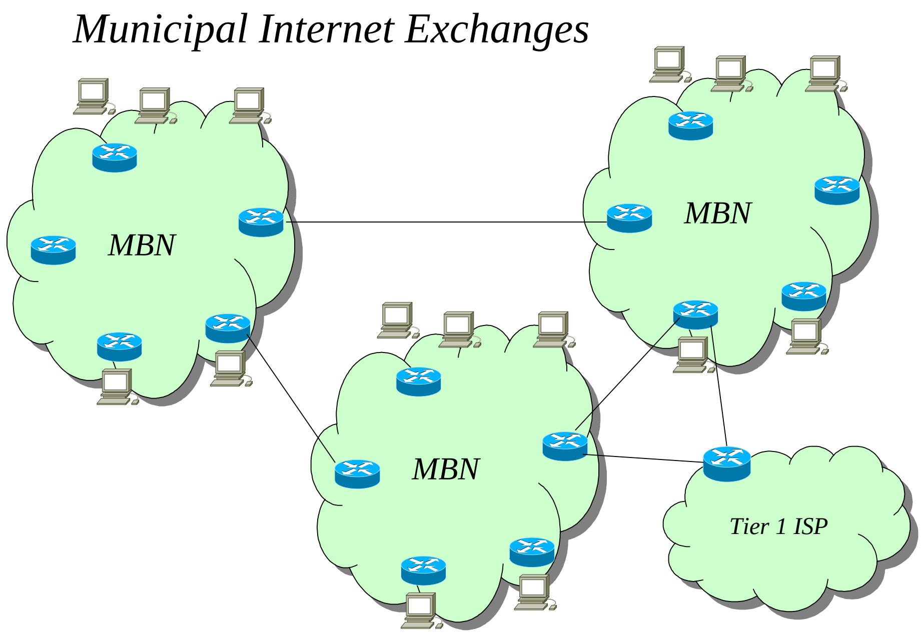
We could expand this NIX concept to multiple countries as shown below.



3.2.5 *Municipal Internet Exchanges: MIXs*

The final step is the local Internet Exchange or MBN Internet Exchange, MIX. The MIX is the next evolutionary step in the evolution of this network. It is the peering point for local participants in the network. In many ways it looks like a NIX except the countries become municipalities and in each municipality there is a connection point. Thus the NIX approach is the forerunner of a MIX. The following

Figure depicts a collection of MIXs and their interconnection to the Internet backbone via a Tier 1 ISP. Multiple other connections are also possible.



3.3 Inside Municipal Broadband Networks

A Municipal Broadband Network (MBN) is best characterized as Fiber to the Home (FTTH) providing 100 Mbps capacity or higher to the home or local business, open to all service providers, but financed and controlled by the municipality. This type of network is uniquely different from the current DSL or cable modem networks, which use older technologies. DSL utilizes copper wires, or “twisted pair”. The technology of copper wires dates to before the founding of the Bell System by Alexander Graham Bell in 1875, actually originating with the telegraph. The physical attributes of the copper medium severely limit both speed as well as range of broadband capabilities.

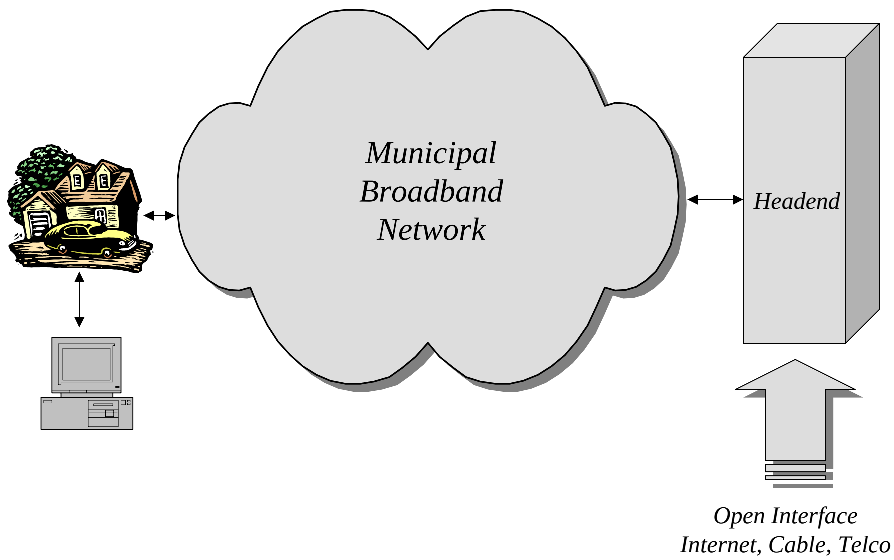
In the case of cable model, the networks are generally hybrid fiber-coaxial (HFC) systems, using co-axial cable at the terminating points of the subscribers. Cable technology goes back to 1940 to the beginning of microwave transmission. On the other hand, fiber technology is twenty years old, having been used initially in cable backbone networks and then in telephony. Today, advanced fiber-optic technology makes it possible to provide a terabit per second, or a trillion bits per second, of capacity on a single strand of fiber!

As far as wireless technologies are concerned, the recent advent of “Wi-Fi” or 802.11 wireless capabilities have made it possible to have 2-5 Mbps speeds, albeit over very short distances of 100-200 feet. Wi-Fi represents a cost-effective and appealing solution to share broadband within small vicinity, like inside a home or business, or around an installed “hotspot”. However, it does not present itself as a pervasive broadband network solution for a town or even a neighborhood because of debilitating range and line-of-sight issues. In addition, there are severe capacity, security and scale problems with wireless technologies, which makes it an unsuitable medium for data, voice and video beyond highly localized applications.

The overall network can be perceived in three steps; local network with generic boundaries, local network as an open infrastructure, interconnected open networks.

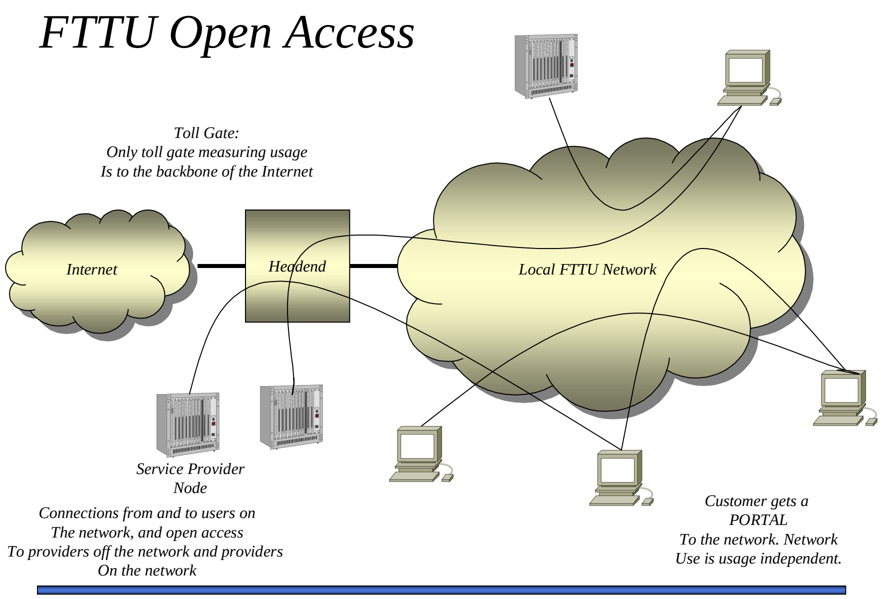
3.3.1 Local Network Interconnection

The MBN can be depicted as below. One end of the MBN, the head end, has an open interface suitable for interconnection to a variety of service providers. The interface is open to any and all, and is not proprietary in any fashion. The other end of the MBN has an interconnection to the home. The interconnection may also be to educational institutions, fire, police, libraries, municipal facilities, and to commercial entities as they may request. The network in-between the two interconnecting points is an optical fiber network with drops of fiber to each subscriber. The fiber drops are provided on an as-requested basis. The network does not have to be deployed fully day one. It can be built out as demand warrants.



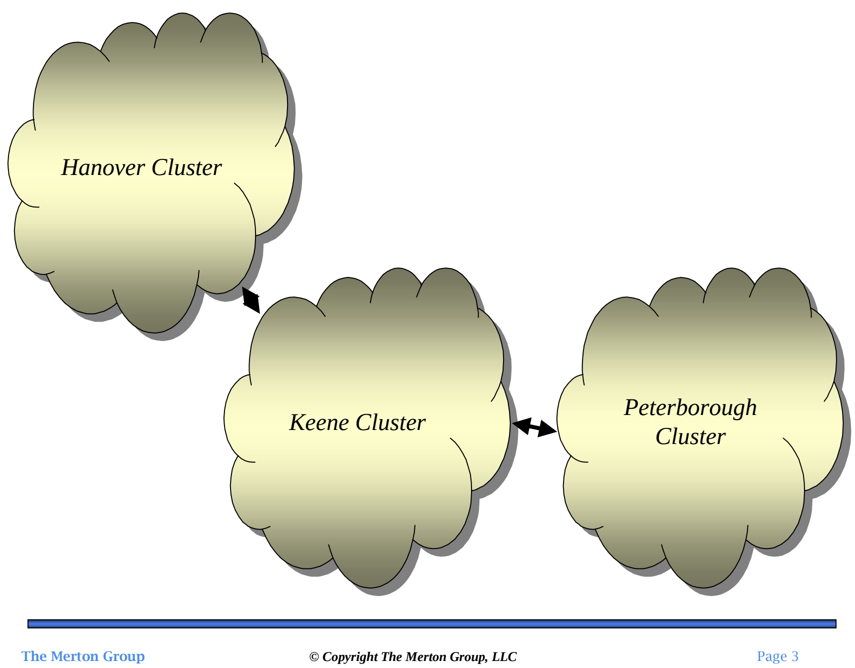
3.3.2 Local Open Networks

The following depicts the local openness of the network. Each user of the network can connect to any and all other local users via the IP capabilities of the network. Each connection to the network has an IP or IP addressable port. The connection is via ports, elements which can enable communications and interconnectivity between any user. The network is flat and open not hierarchical and closed. This is a key fundamental difference in network architecture design and implementation.



3.3.3 *Interconnected Open Networks*

The following depicts the interconnection of three regional MBNs. This interconnection is readily achievable via the use of the IP standard interface. Clearly some form of DNS, Domain Name Servers must also be employed and naming and address management will be an issue however the ability to interconnect at layer 3 is critical.



3.4 Architectures, Interfaces and Technologies

This section briefly overviews various architectures for MBNs. We look here at the current options available and this provides a look “inside” the MBN. The key point is that whatever the local architecture, it is critical for openness and scalability to follow a minimalist approach with common protocols and interfaces. This drives the IP direction. In effect, each acceptable architecture and its embodiment must be able in a ready fashion to interconnect to other networks while at the same time permitting local access between and amongst all its users.

As we have stated, the MBN is a fiber connection that provides a minimal capacity from 100 Mbps to 1 Gbps or more to each user using either an Active Optical Network (AON) or Passive Optical Network (PON) technology. The AON and PON are fundamentally similar. They take a headend location and using fiber, distribute it to users.

3.4.1 Popular Broadband Network Designs

There are multiple network designs that can be used to deploy local fiber broadband services via fiber to the home (FTTH). The factors that control what speeds are provided are the technology components that are installed at the end points of the fiber network; the residence/business and the service provider’s Point of Presence (PoP), which may be the head end, local hub or Central Office (CO). The main forms of FTTH architecture are the following:

(i) “Home Run” systems: a separate fiber or fiber pair runs all the way from each home/business to the PoP. In this design, there is no sharing of fiber; therefore, this offers the ultimate performance with the most flexibility. Independent providers can deploy technology of their choice with minimal compatibility and interoperability issues. In addition, the end-point equipment attached to each fiber can be independently upgraded. However, the costs of installation of this design are usually prohibitively high and are overkill in terms of performance capabilities.

(ii) Passive Optical Network (PON) systems: a single fiber or fiber pair runs from the head end to a passive optical splitter that is located at a local hub (also called a remote terminal or just “remote”). Single strands of fiber then run to a group of homes or individual homes or businesses. The optical splitters are quite compact and simple. The absence of active electronics in the field and the simplicity of design yield lower life cycle costs. In addition, the passive nature of the optical splitters avoids the need to have power systems at the remotes, thus increasing the reliability of the entire system. In addition, overall maintenance costs are reduced. The disadvantage of this design is that terminal and head end equipment may have to be simultaneously upgraded to ensure compatibility and interoperability. Capacity may be constrained in the upstream circuits, which become shared resources.

(iii) Active Optical Network (AON): in this architecture, fiber runs from the head end to one or more stages of remote terminals at which the signals are switched among fibers that then feed individual premises. Ethernet switches are typically used at the remotes. Unlike PON systems, here one may have the problem of powered elements in the field and also the risk of increased maintenance.

Fiber-optic technology, offering virtually unlimited bandwidth potential, is widely considered to be the ultimate solution to deliver broadband access to the last mile. Today's narrowband telecommunications networks are characterized by low speed, service-provisioning delays, and unreliable quality of service. This limits the ability of a consumer to enjoy the experience at home or the ability of workers to be efficient in their jobs. The last mile is the network space between the carrier's headend and the subscriber location. This is where bottlenecks occur to slow the delivery of services. The subscriber's increasing bandwidth demands are often unpredictable and challenging for telecommunications carriers. Not only must carriers satisfy today's bandwidth demands by leveraging the limits of existing infrastructure, they also must plan for future subscriber needs.

3.4.2 Network Elements

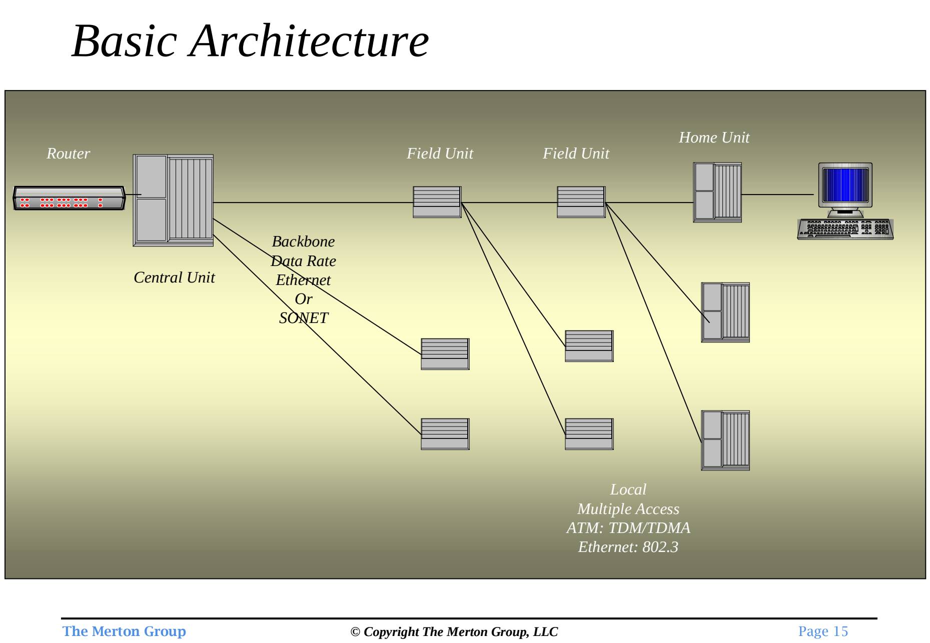
A new network infrastructure that allows more bandwidth, quick provisioning of services, and guaranteed quality of service (QoS) in a cost-effective and efficient manner is now required. Today's access network, the portion of a public switched network that connects CO equipment to individual subscribers, is characterized by predominantly twisted-pair copper wiring.

The basic architecture for local PON or AON is shown below. The elements are:

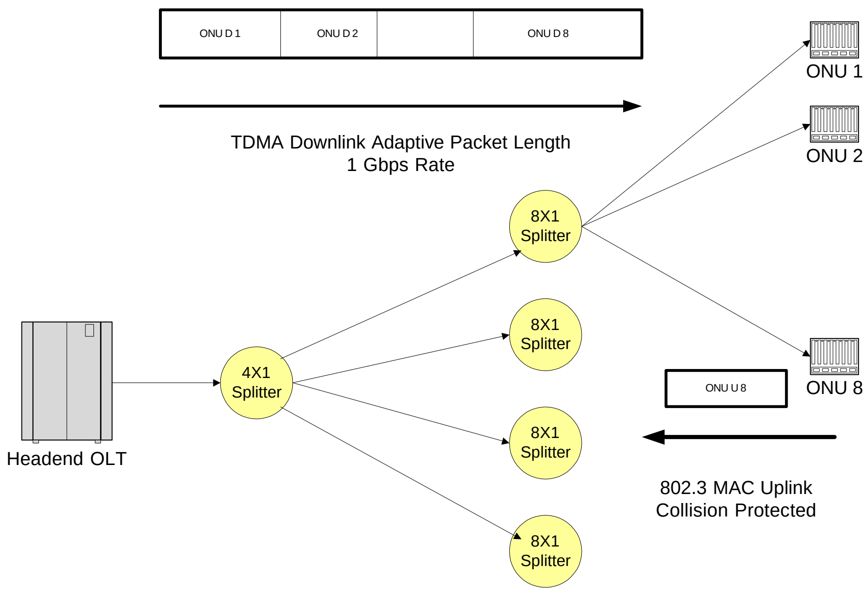
1. Central Unit or Hubs: This is at a headend or some similar central location and provides for central management and interface.

2. Field Units or Sub Hubs: These units are the n:1 splitting devices, active or passive, which take a backbone signal and share it amongst several home units. For PON the devices are passive splitters and use layer 2 protocols to share bandwidth. For AON the devices are layer 2 switches which do the sharing. The difference between PON and AON lie here. The AON active layer 2 switch allows connection control between the users at a point closer t the user. It also allows for expanding a longer distance. The PON mode, if one uses Ethernet, is TDMA down and 802.3 MAC layer up.

3. Home Units: These are the devices in the home made to support data, voice, and video.



We depict an E PON design below using the above schema. We use Ethernet protocol as the down link and up link. Down link is TDMA with each user having as much capacity as it may demand at any one time, and on the up link from the ONU each user can demand as much but must contend with Ethernet like collisions. IP sits atop of this layer 2 protocol. If we were to use AON, then replace the splitter with a layer 2 switch.



In general, the optical section of a local access network can either be a point-to-point, ring, or passive point-to-multipoint architecture. As these components are ordered in volume for potentially millions of fiber-based access lines, the costs of deploying technologies become economically viable. One optical-fiber strand appears to have virtually limitless capacity. Transmission speeds in the terabit-per-second range have been demonstrated. The speeds are limited by the endpoint electronics, not by the fiber itself.

The other issues are about whether the fiber cables should be pole-mounted or buried (trenched). Pole-mounted is generally less costly, but is potentially subject to delays in obtaining access depending on current configuration of existing telecom, cable TV and power system cables on the poles. However, in most cases, this “make-ready” process of reconfiguring existing cables on poles may not be an issue. Buried fiber may be more expensive but could be less of a delay depending on pole “make-ready” requirements, and has somewhat less life cycle maintenance.

3.5 PON vs. AON

This section is a more detailed presentation of the elements of the communications infrastructure. It is a high level view of the communications elements which are part of the overall network design and operations.

The first step is to understand that there are generically two major options: PON or passive optical networks and Gigabit Ethernet, GigE.

1. PON is a passive technology which “splits” signal in a set of passive optical splitters, allowing each residence to have a share of the data link. A PON system has the ability through several n:1 and M:1 splitting devices to share bandwidth. The typical example is a 32:1 or a 4:1 followed by an 8:1 splitter, and even 5 2:1 splitters can be used. The limitation is that the maximum loss may be 25 dB total loss. This total loss is a sum of end device loss, plus splitter loss, plus fiber loss. The fiber loss is a loss per mile time number miles. In an E PON system the down stream is TDMA and the up stream is IEEE 802.3 Ethernet layer 2 protocol. Some vendors use ATM in place of Ethernet but we believe that this is not at all acceptable.

2. AON uses active splitters, which are layer 2 active switches, which provide Ethernet as the transmission approach all the way throughout the network. This means that the distance is greater than PON plus there may be better control over date allocation.

3.5.1 Protocols

Protocols are agreed to standards for the purpose of establishing communications between two or more computers. The development of protocols has been significant ever since the development of computer communications in the mid 1960s with Project Multics at MIT. In that project the intent was to have large university computers talk with each other. This evolved into the AREA Net, which is the predecessor in an evolutionary fashion of the Internet. In 1974 Kahn and Cerf proposed a protocol called TCP/IP. This was a packet based protocol for communications. It was different that the X.25 protocol used by the Europeans and the larger networks in the US which was a very overhead intensive protocol.

In the late 1970s Clarke at MIT and Cerf now with Kahn in CNRI created an operational basis for TCP/IP. It became the backbone protocol of the AREA Net, using the IETF, Internet Engineering Task Force, as the "club" to make it a reality. In the late 80s AREA Net spilt into commercial and government, the commercial is what we now call the Internet.

In the mid 70s, IBM proposed and pushed with the ISO, the International Standards Organization, a seven layer protocol. The IBM version was SNA, System Network Architecture, the ISO version was a bit more complex in certain areas. The following figure presents the seven layers and their proposed functions. The performance, costs, expandability, scalability, and many other factors are highly dependent on the protocol set chosen. In this report we focus on layer 2 and 3, and the two choices are PON and Gigabit Ethernet, each has advantages and disadvantages, both are separated at layer 2.

Protocol Layers

Application	*The applications software, it is what the end user sees and uses.*
Presentation	*Provides for such things as security and security management.*
Session	*Controls communications between applications, flow management, and creates sessions between applications at end user level.*
Transport	*Ensures reliable end to end transport and flow control*
Network	*Provides point to point and point to end point reliable links*
Data Link	*Provides for reliable physical link transport; can be divided into LLC and MAC functions*
Physical	*Provides physical connections and electrical connections, including modulation.*

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3.5.1.1 TCP/IP

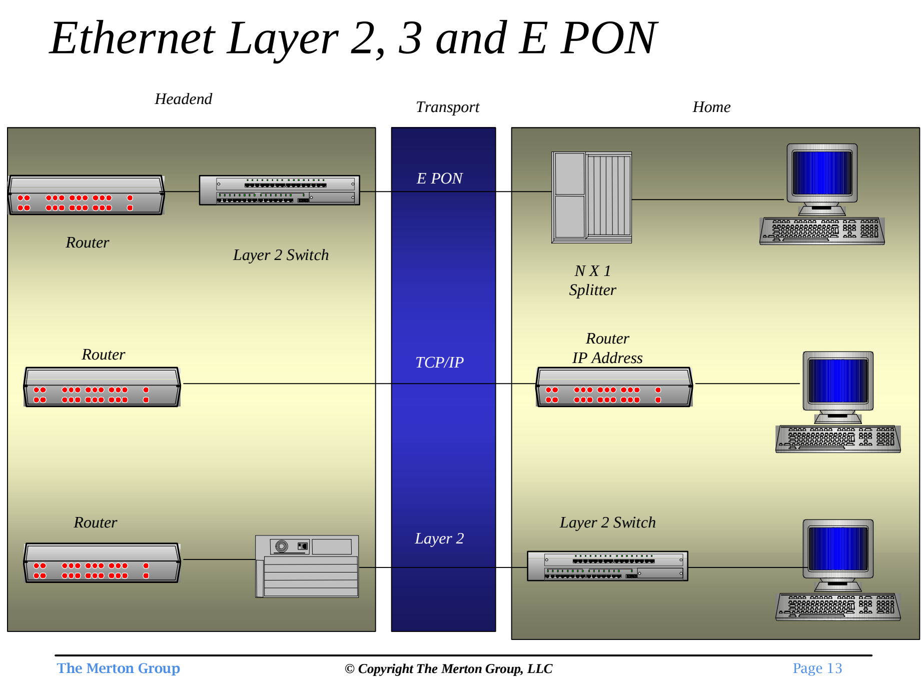
TCP/IP is the key protocol used in the Internet. It is a protocol which is what is called a "best efforts" approach to telecommunications. In effect, it takes a set of headers, TCP and IP, and then attaches a data packet, a packet of variable length. It then sends this over a network and "hopes" that it gets there. In the early days it was stated, "every packet was an adventure". It has been learned however that the basic networks are highly reliable so lost packets are not a serious problem, packet delays may be a very serious one, depending on the network traffic.

3.5.1.2 Ethernet

In contrast to layer 2 ATM networks, there is a layer 2 computer protocol called Ethernet, and TCP can ride on this as well. Ethernet, albeit older that ATM, is truly a packet approach. It anticipates full flexible packet capabilities. The following is the layer 2 level of Ethernet, as specified by the IEEE 802.3 standard. Ethernet at layer 1 uses 10 Base T and 100 Base T forms of 10 Mbps and 100 Mbps. Also the signalling is CSMA/CD. Carrier sensed multiple access with collision detection.

3.5.2 Interconnectivity

These network schemes can be laid out in the following categories. It must be remembered that TCP is layer 4, IP layer 3, and Ethernet is layer 2. We show the structure of the different schemes in the following figure.

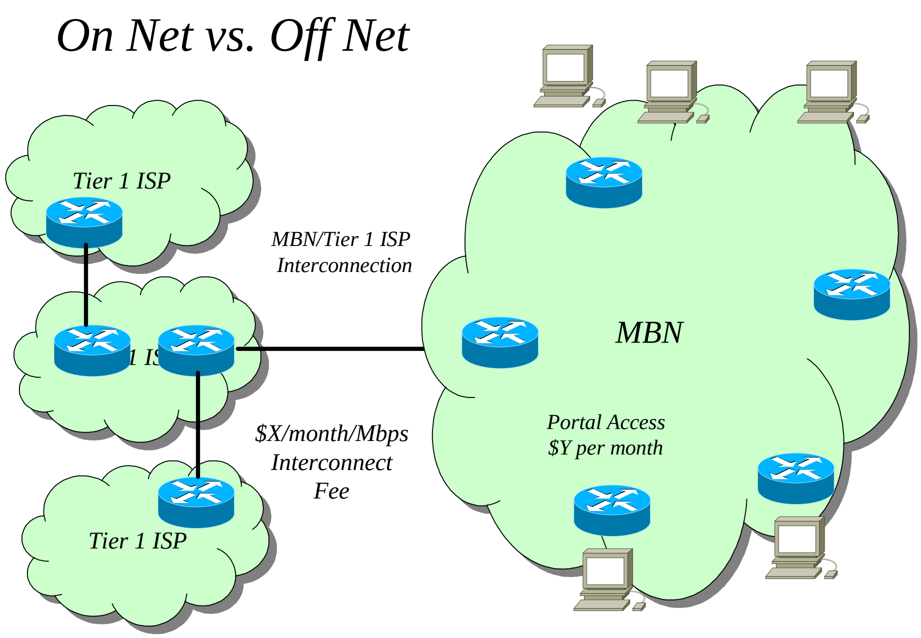


4. EXTERNALITIES VS. INTERNALITIES: ECONOMICS OF ON NET AND OFF NET

The concept of network externalities has been around for quite a while in some form or another. It has been used extensively by the economists supporting the incumbent telephone companies to justify the continuation of interconnection or access fees. In many ways the logic has been a tautologistic exercise of ad hoc propiter hoc reasoning. However, the concept has some conceptual merit when applied to MBNs as a contrast to intern and external values or utilities.

4.1 The Network Paradigms

We consider the networks as shown below. Namely, we have the MBN which is a local network where the fee for access is fixed per portal. The second connection it to a Tier 1 ISP via a direct connection or via intermediaries. The cost is a price per Mbps per month plus a fixed fee.



4.2 Utility Functions and Externalities

If we consider, as an example, the utility to an individual of owning a word processing program. It has to me the user a certain utility or value given by two factors, the first it helps me write a letter or report and second it has the utility or value in that I may share that letter or report with someone else who then could edit or manage that document. Thus the utility of a word processing program has a utility which is composed of two elements; self utility and utility as a result of external use. This utility can be modeled as follows:[17]

$$U(n,t) = b_0 + k_0 f(n,t)$$

Where U is the utility and n the number of other people having the same word processing package and t some specific time. The constant b is the value or utility to me alone, assuming no other person has the word processing package and the function f is a measure of how much more it has utility if there are n other people with this same word processing program.

This simple idea can be expanded to state that if a company has a telephone network with N users and another company has a network with M users, and M<N, then the larger network has more value than the smaller. There are in addition certain constraints on the elements of the utility function.[18]

Now we define a broader function:

$$U(N_{External}, N_{Internal}, t) = k_1 + f_1(N_{External}, N_{Internal}, t))$$

[17] We use the approach of Mason as well as Economides (June, 2003) for this development.

[18] See Economides, 1995 pp-6-7 for externality structure.

Where we have separated internal and external users. This expressions begs the question; is utility dependent on internal and external users or just on the sum of the two, namely just total users. An argument can be made that there is substantially different value depending on the user class, so that network externality utility will be dependent on the number in any class of users.

For example if I have an accounting program, then the utility is clearly much more reliant on the number of accountant who use the program not just the total number of users, those of my peers and all others. Thus the analysis of utility of externalities are based upon both external users as well as internal users. We call this latter class the *internalities* of a network as contrasted to its externalities.[19] The question is which of these factors is the most valuable; externalities or internalities.

4.3 Determination of the Demand Function

Demand can be determined by a simple maximization. Namely, we can maximize the utility subject to some price constraint. Let us first relate a quantity q purchased to the number of entities connected to a network, namely:

$$q_{on} = h_{on}\left(N_{on}\right), q_{off} = h_{off}\left(N_{off}\right)$$

Here the function h is monotonic for both relationships. Furthermore we assume there exists an inverse:

$$\exists h_k^{-1}(N_k) = q_k \forall h, N, q$$

Then we have:

$$U = U\left(N_{on}, N_{off}, t\right) = U\left(h_{on}^{-1}\left(N_{on}\right), h_{off}^{-1}\left(N_{off}\right), t\right) = U\left(q_{on}, q_{off}, t\right)$$

Assume a price per quantity, p, for each quantity, q, and assume some fixed total expenditure amount for the purchase of both quantities. The we can pose the constrained optimization equation as:

$$V = U\left(q_{on}, q_{off}\right) + \lambda\left(y^0 - p_{on}q_{on} - p_{off}q_{off}\right)$$

Consider a simple example:

Let

$$U(q_{on}, q_{off}) = k_0 q_{on} q_{off}$$

Then simple optimization yields:[20]

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[19] One can note that the restrictions as discussed by Economides can be expanded to this argument for the two classes. In addition the consideration of $\frac{\partial U}{\partial N_{Internal}} \geq \frac{\partial U}{\partial N_{External}}$ is also of concern.

[20] See p. 19 of Henderson and Quandt.

$$q_{on} = \frac{y^0}{2p_{on}}$$

$$q_{off} = \frac{y^0}{2p_{off}}$$

This is a simple demand equation for the two network quantities. The actual demand is more complex.

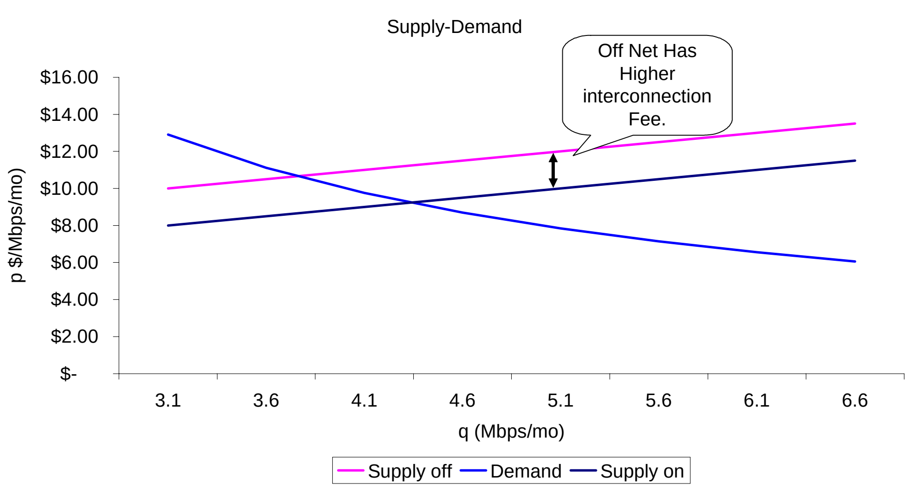
Several additional observations are important:

First, in this simple supply-demand world, the higher the price the lower the demand. That means that increased demand will move supply from the off net world to the on net world. Namely there is a disintermediation resulting from the basic economic structure of a MBN architecture. This is a critical observation.

Second, the time dynamics have not been included. It is essential to have them as part of the economics. This will further shown a rapid dynamic flow from off net to on. Namely it will be economically more efficient depending on the cost of interconnection, to place servers via private networks on net rather than to use Tier 1 ISPs!

We can observe these facts in the following supply demand analysis. This is the long term industry supply demand curve. We have justified the demand curve and the supply curve is based upon an industry analysis. They are separated by a difference due to the cost of Tier 1 interconnection. This is a curve as appears to the consumer. Clearly there is greater demand for on net services than off net.

Now one of two things can occur. First, there is greater demand for on net thus driving the off net base down and further increasing its cost. Then the cost to on net providers can actually be reduced thus driving don their costs. This cycle ends with the dramatic reduction of off net connections if the costs of access is not reduced to zero.



We can then also address the issues of marginal substitution of "access" from the Internet backbone to the local point of presence. The issue can be simply stated; if a users has two alternative access modes, via the Internet and a Tier 1 ISP at a price and via a local on net node, what will be the dynamics of market substitution.[21] Using the standard microeconomic tools of substitution based on costs, one can see that there will be a drive to migrate suppliers from the Internet backbone via a Tier 1 interconnect to the local

[21] See Henderson and Quandt, p. 73 or Pindyck and Rubinfeld pp. 131-132.

"costless" on net interface. Namely there would be a economic advantage to provide a video server at local clusters of MBN on net interfaces and avoid the costs of the Tier 1 carriage. This can have a potentially unstable effect on the Internet architecture.

4.4 Interconnection and Access

Interconnection and access fee pricing is a key elements in the overall process of network evolution. [22] The major work here is the classic tautology of Baumol and Baumol and Willing. Namely the form as describes as follows.[23] Let us assume a consumer surplus for using a network as S. Let us assume that there is a local service and two long distance services, one being an incumbent. That is S is the consumer surplus. Let:[24]

Let the consumer surplus for local telephone calls be: $= S(p_0)$

and:

Let the consumer surplus for long distance with carrier 1 and carrier 2 be: $= S(p_1, p_2)$

Then we want to maximize overall consumer surplus:

$$\max_{\{p_0, p_1, p_2\}} \{S_0(p_0) + S(p_1, p_2) + \lambda\pi(p_0, p_1, p_2)\}$$

Subject to the constraint that the incumbents profit is always positive

$$\pi(p_0, p_2, p_2) \geq 0$$

If we followed Baumol or Tirole we would tax the consumer to the level where the local on net carrier would pay the Tier 1 ISP a fee to compensate for the fact that the local network is more efficient than the backbone, actually the prices are extortionary and unrealistic, and it would sustain the backbones oligopoly. This logic can only come from academics who have little to no understanding of the business or little or no regard for the consumer. However, this logic enters the regulatory fray due to the panache of academia.

The issue of access and interconnection fees has also been discussed at length by others. One view is to look at this problem a one which is a Coase Conjecture problem. Simply stated the Coase conjecture is that any monopolist, such as an ILEC or collection of Tier 1 ISPs will be forced to marginal cost pricing in a dynamic fashion. [25]

[22] See Mason, Internet Telephony, for the application to IP traffic. Also see Economides and Lopomo on issues relating to Reciprocity of Interconnection Pricing.

[23] See Economides and White and their discussion of the Efficient Component Pricing Rule, ECPR, which is the Baumol Willig Theorem. Simply stated the ECPR states that the access fee to a new entrant should be adequate to compensate the inefficnet old incumbent for their inefficiencies. Since Baumol and Willig consulted for the incumbent one could wonder why the result would ever be anything else but pay the incumbent.

[24] See Laffont and Tirole, pp 102-103. This is a classic ad hoc propiter hoc argument. They state "plus subject to the constraint that the incumbent breaks even" Who cares about the incumbent in a competitive market. Adam Smith desires to clear the market by efficient production means. The authors have a clear continental socialistic bent on retain incumbents and having the consumer pay for their inefficiencies.

[25] See papers by Inderest or that by McAfee and Wiseman. Both address the issue of the Coase Conjecture and the issue of interconnection and access.

5. CONCLUSIONS

This paper is directed at establishing a dialog on what should really go into the deployment of broadband on a local level. Unlike the Internet deployment, where the dialog was mostly amongst academics, since that is where the original nexus was most strong, local broadband, also know as municipal broadband, demands a dialog amongst its users, and in that case it is a local dialog amongst a broad base of people. Rather than dealing with the group of technically sophisticated technologists, the municipal broadband efforts is a political process as much as it is technological. It entails "listening" to the users and ensuring a flexible and scalable network which empowers the end user rather than restricting the user. It is a network which is not proprietary and hierarchical, but one which is open and distributed.

We have attempted in this paper to begin that dialog, to set parts of an agenda and to frame the discussion in broader terms not just technological terms familiar to a closed group. The overall recommendation is:

Any MBN should follow the overall design principles of the Internet. The MBN should be readily open and should be interconnectable at its edge with IP connectivity and IP should be at every point within the MBN interfaces.

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