Wireless Architectural Alternatives:
Current Economic Valuations versus Broadband Options,
The Gilder Conjectures[1]

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Abstract

There has been an assumption that spectrum can be divided into segments and then auctioned off. It has been assumed that this is optimal in terms of its benefit to the public and that the FCC in so doing is optimizing the public good. There has been an alternative conjecture, termed the “Gilder” conjecture, that segmenting bandwidth is not the best means and that using all of the bandwidth amongst all of the users maximizes the public good. This paper considers the “Gilder” Conjecture and demonstrates what can be done with spectrum, independent of auctions under the auspices of implied territorial ownership. The paper presents the most recent theoretical results on optimal spectrum allocation. The paper then proceeds to discuss what is truly achievable in the contest of today’s technology. The paper finally summarizes the financial and policy implications of this radically new approach to spectral utilization and what new options this may open for the regulatory bodies.

1.0 Introduction

Spectrum is a resource that can be given to a set of separate entities and used by each of them for their own economic gain, or it may be viewed, as has been suggested by Gilder and others, as a sharable resource that allows many people to use the resource and to share in its ability to provide new services in a possibly more timely fashion. Recently George Gilder, and the popular press such as the Wall Street Journal, have attached significance to the utilization of spectrum that breaks with the standard paradigm of providing licenses to individuals and purportedly uses technology to facilitate any purveyor of service to offer it via a form of spectrum sharing. The former approach is at the heart of the FCC’s current auction strategy and is called the “selling of beachfront” strategy. The Gilder approach is to keep the Beach open and let technology establish the competitive market. Regrettably, the Gilder suggestion has not yet caught up with the limits of technology, but that has not stopped the policy debate. This paper addresses these issues in some detail, without being overly technical and focusing on the policy implications.

There are two opposing camps that have evolved in the past several years as regards to spectrum allocation. At one extreme is the traditionalists who view spectrum as a finite resource that has value in and of itself, almost independent of its use. These “Traditionalists” then further hold that it is the responsibility of the FCC to divide and allocate spectrum. The Traditionalist school was born in the early age of spectrum allocation wherein radio spectrum was limited by technology to a single user per section of bandwidth. From this technological limitation arose a whole regulatory and business infrastructure. More recently there also arose the process of now auctioning the spectrum so that the value accrue immediately to the public coffers. The policy implications associated with this school are significant. We mention only the one concerning the future evolution of telephony to stimulate thought.

The new school of thought is focused around the concept that spectrum is highly flexible because technology has evolved so greatly that with a bit of extra thought it maybe possible to allow a plethora of uses shared amongst many players and that the control is now not of the spectrum per se but of interfaces or of similar end user technical factors. The most recent proponent of this school of “Innovationists”, that is those seeking to free up the restrictions on spectrum are Gilder in his article of April, 1994. In this writing Gilder uses some of the technological alternatives proposed by Steinbrecher and takes them to and extreme

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[1] Presented at the Telecommunications Policy Research Conference, October, 1994, Solomon’s Island, MD.

in Innovationist thinking. Specifically he proposes that spectrum allocations along traditionalists grounds be abandoned. In 1992, McGarty, in an FCC filing first proposed this concept, in the Telmarc Group request for Pioneer Preference, and further detailed the architecture in June of 1992, which included the detailed integration of the Steinbrecher construct. The McGarty architecture of 1992 anticipated the Gilder construct but due to the limitations of technology at the time and the demands by the FCC for instant solutions, the implementation of the architecture was delayed until late 1993. Even then, the implementation admitted feasibility but not economic implementability for several years.

The Innovationist school assumes that spectrum need not be allocated. It stipulates that users create value by means of their use and that spectrum does not in and of itself have value. The Innovationist school further assumes that the Government from a policy perspective should delimit its involvement in bandwidth allocation and that further that if the Government desires to be compensated for its spectrum it be done so on a value added basis wherein the value is the explicit value of the use of the spectrum. This, the Innovationists would say, taxes or burdens all competitors equally and avoids the problem of the initial monopolists who have significant to loose via competition would not have a predatory influence perforce of their available capital.

In this paper we develop the arguments for the Traditionalists and Innovationist schools, and then analyze how they fit into the current trends in technology. We then discuss the issues of spectral efficiency and show what the optimal usage can provide and what the two differing schools provide separately. We spend a significant amount of effort on architectures for the four possible extremes when we analyze the possibilities divide along the lines of allocated or shred bandwidth, and proprietary of standard interfaces. We believe that these two dimensions, and the resulting four possible architectures provide the policy analysts with four extremes to help guide effective policy development. Finally we present several key policy observations that have been made pursuant to the study of this concept of shared bandwidth.

It is important to note that there have been many others who have raised this issue of shared bandwidth and that this paper is representative of a few of the current views. At the extreme end is a shared view wherein the Government owns and operates all spectrum, as it once did the post office and as it now does the FAA. At the other extreme is the view of the Libertarians that the Government has no useful role, and they use the examples of the Post Office and the FAA. We take no judgmental position on these extremes, but suffice it to say, the structures developed herein may be readily applied to many other constructs. What is important in the policy debate however, is the need to have definitive architectures for what we they develop policy for.

Gilder has postulated several conjectures, which we summarize, and will return to after the analysis. These conjectures are as follows:

(1) Many Users can occupy the same spectrum at one time.[2] ***There exists a well defined set of protocols that allow this and prevent collisions.***[3] ***There further exists a set of workable multiple access/interface technologies that can be interchangeably used.***[4]

Gilder assumes that there is a well developed technology base that can be operationally available and that permits multiple systems to operate simultaneously and that the industry as a whole has agreed to how best to handle the interference problem.

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[2] Gilder, p. 100.

[3] Gilder, p. 112.

[4] Gilder p. 112.

(2) Frequency and modulation/multiple access schemes are utterly unnecessary.[5]

Gilder assumes that worrying about the technical details such as modulation and multiple access is a secondary factor, at best.

(3) Networks can be made open and all of the processing done in software.[6]

Gilder assumes that hardware is de minimis in terms of its interaction with the operations and that all changes and operational issues are handled in software.

(4) Broadband Front Ends replace cell sites in functionality at lower costs.[7]

This conjecture is based upon the Steinbrecher hypothesis, namely that some simple device can replace all of the features and functions of a cell site, such as network management, billing, provisioning, and many other such functions.

(5) It is possible to manufacture spectrum at will.[8] ***Spectrum is abundant.***[9]

This conjecture assumes or posits that spectrum can be "created" de novo from a combination of what is available and the technological "productivity" gains.

(6) Spectrum can be used any way one wants as long as one does not interfere.[10] ***New technology makes hash of the need to auction off exclusive spectrum, spectrum assignment is a technological absurdity.***[11]

The last conjecture is the one that says that given the above five conjectures, spectrum can be used in an almost arbitrary and capricious fashion, allowing the assumed technology to handle the conflicts, and not having to have the FCC handle the conflicts via a spectrum allocation process. The last Gilder conjecture states that technology obviates the needs for spectrum allocation of any form.

2.0 Spectrum Utilization

We shall assume that spectrum is available in blocks of arbitrarily large bandwidth. Let us assume, for example, that there is 100 MHz of bandwidth available. This bandwidth then is to be divided amongst several players who will in turn provide services to end users and thereby create value, provide a set of goods, and obtain an overall economic benefit to all players. The Government, in turn, may seek to obtain a share in the value of the spectrum thus provided in one of many fashions; specifically through a one time or a usage fee base.

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[5] Gilder, p. 104.

[6] Gilder, p. 104.

[7] Gilder, p. 110.

[8] Forbes, p. 27.

[9] Gilder, p. 100.

[10] Gilder, p. 111.

[11] Forbes, p. 27.

The question that we pose is as follows:

"What are the optimal ways to allocate the spectrum so that the consumer is benefited in an optimal fashion and that there is an effective competitive market created that sells the widest variety of services at the lowest possible price?"

This is in a sense a Pareto optimal solution of the spectral allocation problem.

Let us begin by posing a simple problem. We shall use this problem throughout the paper. Specifically:

> ***Given 100 MHz of spectrum, how should we allocate it amongst N users and M service providers to maximize the overall public good for a foreseeable long time horizon. We assume that M and N are unknown.***

This problem begs the question of what is the specific optimization criteria. It also begs the question of who is doing the allocation. Let us first discuss the issue of optimization and then defer the issue of who does the allocation. In many ways we seek the "market" to do the allocation directly, and this may not always be a readily achievable goal.

As to optimization, what is in the maximum public benefit? From the end users perspective the benefit should be optimized if the widest possible variety of service be available, at the highest quality, and at the lowest possible price.

Let us discuss some of the constraining issues that delimit the possibilities. The are:

- Scale Economies: W could take the 100 MHz and divide it equally amongst the M providers. If M is 1,000, then each gets 100 KHz. Let us assume that that is enough spectrum. However, the infrastructure costs, such as billing, sales, customer service, network management and others may have significant scale economies. Each provider will have N/M customers, by assumption, and scale may be reached at some value K which is much greater r than that number. The result is inefficient use of spectrum because of inefficient use of infrastructure, capital as well as operating infrastructure. The market could resolve this by having the small companies get merged into the larger ones, as was the case with cellular. This has been shown to be economically costly to the customer. There are costs of consolidation that drive up the total costs and thus increase the effective inefficiencies.

- Critical Market Size or Customer Base: There is a critical customer base or market size. Marginalizing the market amongst several players may result in a marginalization of the customer base. Whether it is the same service or different services, there may be just too small a total customer base for any one service. Digital Termination Services is an example of where this applies. This was the 10 GHz services that were developed in the early 1980s. There was a market but it was very small.

- Extent of Competition: By definition, a single competitor is a monopolist and as is well known the monopolist has the advantage of a demand curve that is manageable and thus charges a monopoly rent. The duopolist also sees similar manageable demand curves. Cellular and the Local Exchange business are examples of where monopolies and duopolies have stymied innovation and price competitiveness. All one has to do is to look at the Inter Exchange Carrier (IEC) business and see that since 1984 prices have halved and services have exploded. Thus competition has been a dramatic market stimulant.

- Market Confusion: The existence of too may providers of the same or similar service may cause market confusion. The PC market is an example. The confusion in PC software was also a similar example. There is a cost to this confusion and the consumer must bear that costs. However, the gains of competitive pricing often drives down that cost and the et effect is minimal.

- Technology Availability: With many competitors there may be a problem of technology availability or of the manufacturers not being willing to invest in the development of new technology, or that they may not have enough volume to produce for a specific service provider, or that there may not be enough usage of a set of specific service features.

- Interconnectivity: This may be the most significant factor in the development of any new telecommunications technology, the ability to interconnect into the existing set f monopoly local exchange carriers. All new and innovative alternative carriers have had this problem. The LECs have raised various barriers to entry. Such carriers as MFS and Teleport have battled hard and long to achieve mere co-location of their switching equipment. Others, such as Telmarc Telecommunications, have battled to obtain Common Carrier status and eliminate access fees. This factor may be the one barrier that cannot be dealt with other than through regulatory relief. In fact, it is illegal in certain states, such as Virginia and New Jersey to be a Local Exchange Carrier, if you are not the entrenched monopoly player. Clearly there will be major legal and regulatory battles on this front.

- Dominant Market Players: Any market with dominant players and having many others will generally be controlled by the dominant players. The Dominant players may effect the other players through the standards process, raising the cost to compete, through the regulatory process, raising the cost to provide service, and through the legal process raising the cost to litigate and operate. Admittedly, it has been shown, that through long term market forces, with all players being equal at the outset, any market will converge to a small set of stable and competitive players, if the market starts with a asset of dominant players with the ability to delimit the new competitors, then the new entrants will be at significant risk of failure through the power of the dominate players.

These and other factors will determine how the spectrum can be allocated. In the next section we present a discussion of the four canonical architectures.

3.0 Technology Alternatives

We shall consider several extremes of technology alternatives; the current operational AMPs systems, the existing multiple access/dedicated spectrum approach, and the shared access/common protocol approach. The alternatives can be presented by considering the options available to the design from the perspective of ownership of bandwidth and through the common character of the interfaces.

We begin by considering two dimensions that will lead to four architectural alternatives. The two dimensions are:

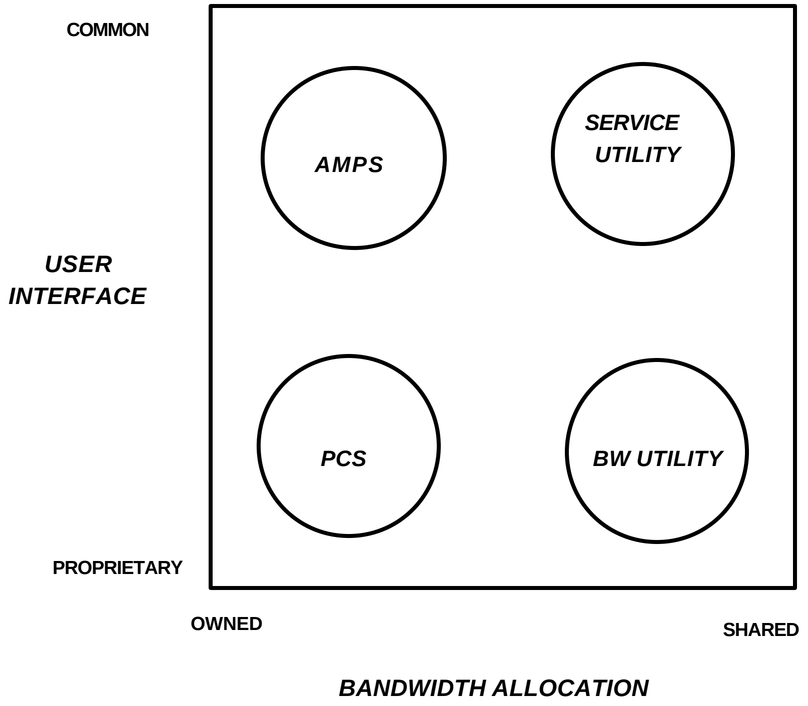
- **User Interfaces**: The user interfaces are also call the air interfaces. They may be a standard, such as AMPs, the current analog standard, or in Europe the GSM standard. They may also be different as in the U.S. digital standards, IS-54 or IS-95, TDMA and CDMA respectively. The issue is whether we accept a single standard or do we allow multiple standards. This is a difficult policy issue. As has been seen in digital cellular, standards can be a way for the entrenched players to keep their control. They also are a means of reflecting a consensus which in may ways is the least common denominator approach. In the GSM case the standard takes another twist ad includes all features and functions and thus is the “kitchen sink” approach to standard making. Standards are long and arduous and frequently the technology is out of date by the time the standard is promulgated. Standards frequently eschew innovation for commonality. However, standards work well in many areas where a minimalist approach is taken. The electrical outlet is a standard. All the electrical utility provides is electrical power ad thus the standard is simply the minimal element in order to get the minimal input to do the most with that input. The question is, can wireless have a minimalist standard?

- **Bandwidth Allocation**: Bandwidth can be allocated by means of segmenting it or by means of common sharing. Segmenting bandwidth is what is done currently in the wireless world. It assumes that each

> owner of the bandwidth is responsible for its use and operations. Shared spectrum, however, has worked in the Part 15 bands, where the limiting factor is power per user. The shared spectrum is at best shared but does not interfere because of a geographical limitation on the user. We take the term shared and extend it to include a broader set of applications. We assume that a set of service providers may be able to share spectrum in some fashion, perhaps by using a ore sophisticated protocol set, as is done in Ethernet LANs, or as may be done in spread spectrum systems, such as CDMA. Broad based spectrum sharing assumes that the technology can utilize the spectrum in the face of interferes. It works because processing has become much more sophisticated and more importantly because the software in the end user terminals now becomes and integral pat of the network. This paradigm shift is the shift towards moving all of the network intelligence to the periphery of the network.

In the following figure we depict the four extremes that can occur. They will be the four extremes that we shall use for policy analysis.

Figure: Positioning of Alternatives



The four alternatives are based upon the division of standard/proprietary interfaces and owned/shared bandwidth. The four have the following characteristics:

AMPs (Standard/Owned): This is the current analog voice and data communications paradigm in the 800 MHz band. There is an AT&T generated standard and the A and B side carriers use the same interface. The providers of the service own the spectrum and they provide whatever they want. There are no other competitors.

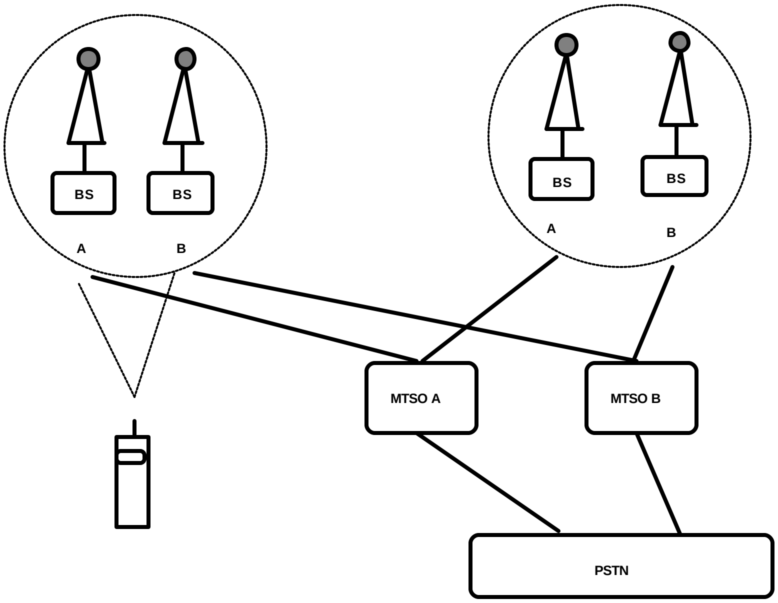
PCS (Proprietary/Owned): This is the proposed PCS system wherein ownership is retained but now any owner can use whatever interface they want. Arguably the analog carriers can do the same and are with TDMA and CDMA applications.

Service Utility (Standard/Shared): This concept assume a shared spectrum but with a common interface. It assumes that all users have agreed on a minimalist version of a common interface. It requires a standards process and an agreement amongst all users. The interface or more appropriately the air interface is the agreed to standard, such as the 802 standards for LANs.

Bandwidth Utility (Proprietary/Shared): This is the version wherein there is no standard and that all frequency is shared. There must be some way to deal with interference, but this may be on a power basis alone. It then assumes that all users will be able to "process" their way out of conflicts. It further assumes that all users receive the same "raw" RF signals from all common receivers and can transmit "raw" RF from each transmitter. It assumes a common set of transmitters and receivers, with appropriate transmitters and receivers, and that the signals are somehow relayed in tact to set of separate processing points. This is the approach that was first articulated by McGarty in May of 1992 and then by Steinbrecher in 1993, and then by Gilder in 1994. The McGarty description depicted both the method as wells as the means and functions of the system architecture.

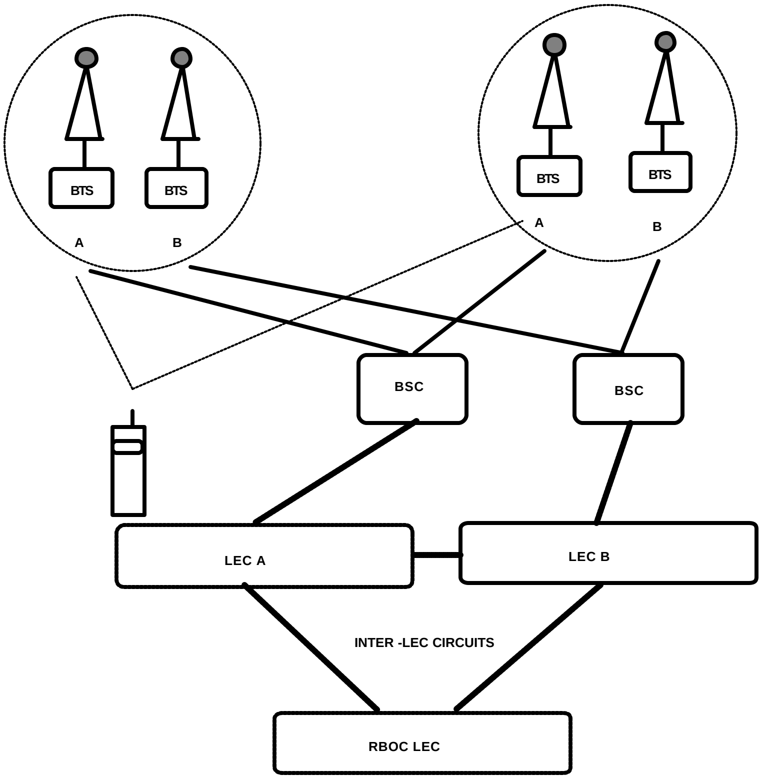
We can now detail the architectures of the four system alternatives. It is important to show how they differ since it is in these differences that the key policy issues will be raised. The first system will be the AMPs design. Recall that the AMPs design was first structured in the late 1960s and reflects the constructs of the telephone system at that time. It is shown in the following figure. In the AMPs design, there are Base Stations whose purpose is to transmit and receive RF energy and to interface with a Mobile Telephone Switching Office, MTSO, and then in turn with the LEC via a Class 5 Central Office. The original and still current concept is to have the same RF or air interfaces and to have the cellular carriers act as wireless line extenders of the monopolist's or RBOCs local exchange. There were never to function as a competitive LEC. This is the essence of the architecture. As a point of further observation, this is also the case with GSM.

Figure: Architecture of AMPs



The next design structure is that of the current PCS architectures. Again there is an assumption of owned bandwidth but now there is no assumed standard interface. Unlike the AMPs design, the PCS design allows for proprietary designs and interfaces by each provider of service. More importantly, the PCS design articulates a system that allows for independent LECs to operate and thus to break the LEC monopoly. However, in this architecture, the air interfaces are different and there is a duplication in the RF infrastructure. There is now a critical difference in the PCS architecture, wherein each PCS carrier may now be a LEC unto itself. The elements are a Base Terminal Station, BTS, which handles all call set up, handling, handoff, and RF. Then is a Base Station Controller, BSC, which is a mini-Class 5 switch that allows the "Onnet” wireless users to communicate as if they were on a separate LEC. Then is the LEC infrastructure which may include its own Class 5 switch.

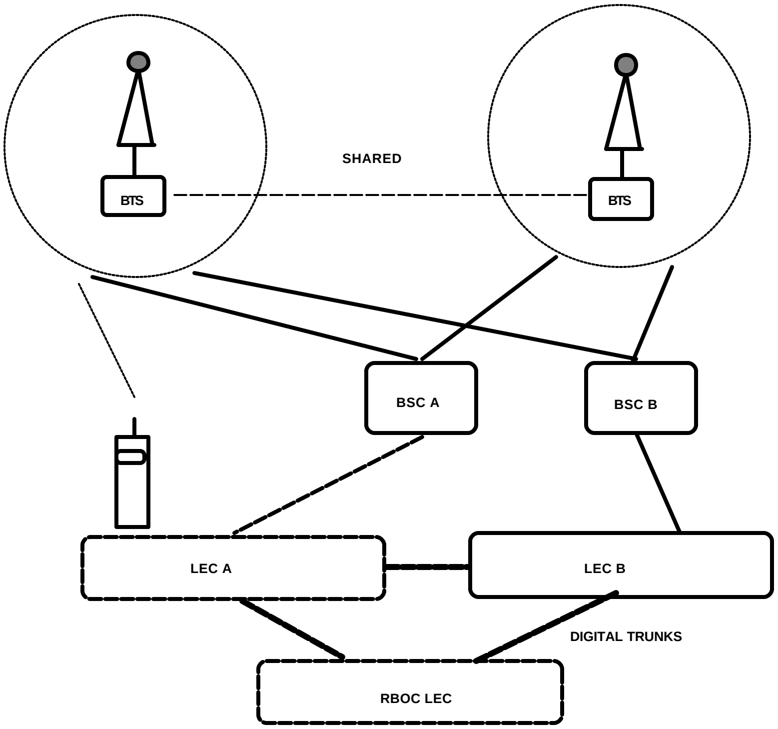
Figure: Architecture of PCS



The Service Utility concept architecture describes a method of providing service whereby the RF infrastructure is further supported by a common standard interface. It is the equivalent of the “intelligent” electrical utility. At its simplest stage, it is nothing more than an electrical outlet for telecommunications. At a more complicated level it is a distributed processing backbone network. Ideally, the intent is to provide a minimalists version of the utility. Namely, the ideal is to provide the various providers with an interface that allows them to connect their value added processing onto the wireless interconnect utility.

In the Service Utility construct, the system has common shared BTS units all operating with the common air interface and all providing a minimalist communications infrastructure. This is akin to having a common shared Ethernet in which the users have common Ethernet boards in their PCs or in this case their wireless units, and wherein the service provider operates a “Server” on the LAN. The value is in the “Server” services and not the LAN transport. This architecture requires agreement amongst all players as to a common interface and the operations and maintenance of that interface. It begs the question as to where the true value in communications truly is. This design can be an all CDMA design using the full 100 MHz of bandwidth.

Figure: Architecture of the Service Utility



The last design assumes that there is a pure “spectral” utility which provides a de minimis access to spectrum remotely to providers and users alike. Namely, it assumes that there exists an entity, whose ownership we shall leave in doubt until latter, who provides to service providers the concept of displaced spectrum. The genesis of the concept is the utilization of the broadband front end developed by DoD researches in the mid-seventies for the purpose of collecting intelligence data and information and them commercialized by Steinbrecher and championed by Gilder. In no case was there an architecture of such a system until that proposed by McGarty in May of 1992 for the Telmarc Group Pioneer Preference filing, at which time both the method as well as the means and function were articulated. The following is a summary of that design architecture.

The Spectrum Utility architecture works as follows. There is a common base of radio towers or sites. There is a transmitter and receiver at each site. The site also has a wideband A/D and D/A converter that allows conversion of 100 MHz of bandwidth with the ability to preserve full 100 dB of dynamic signal range. Thus the inks from the remote RF sensors are at 200 M sample per second times 16 bits per sample, or at 3.2 Gbps. If there are 100 such sensors, there will be 100, 3.2 Gbps links.

Now each service provider has a set of BTS/BSC equivalents, but located at locations other than the RF locations. The RF can now be remoted to the BTS and the BTS sees the RF “as-if” it were in the 3 mi. radius of the supposed cell location. Thus Operator A and Operator B will get the same spectrum from the 100 3.2 Gbps channels. It is thus their responsibility to process this signal.

This then begs the question of how do the different operators share spectrum? What we have developed is a common Physical infrastructure, not a sharable infrastructure. The answer to that may be one of several options; again an agreement on a common air interface standard such as CDMA with different codes, an agreement on power levels such as in the part 15 rules, or an agreement on first come first serve. Namely, we have a layers approach to sharing spectrum in this architecture. Let us discuss this is some detail.

A layered architecture is common in computer communications. In this case, the common structure is the OSI ISO seven layer structure. In our current case we can use the bottom three layers. They are:

Layer 1, Physical Layer: This is the common RF transmit and receive power levels of the cells and of the wireless units.

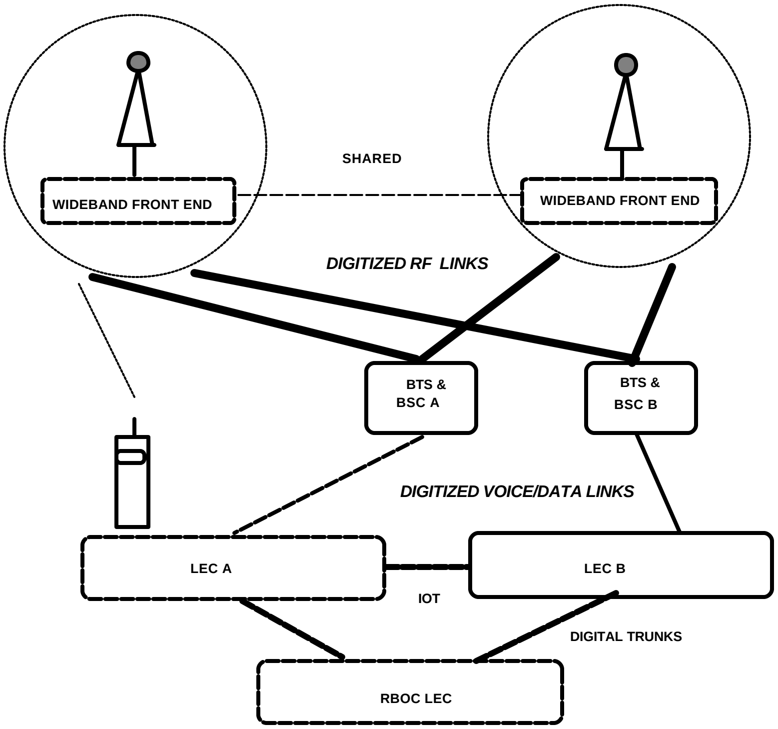
Layer 2, Data Link Layer: This is the layer for common access such as CDMA.

Layer 3, Network Link Layer: This is the layer for protocols to select what user talks and when. This may be a first come first served protocol, a priority protocol, a bidding protocol, or some other protocol.

Thus in this architecture, we may all agree on a common RF, may disagree on a multiple access data link protocol, but agree on a common network layer for protocol management or contention for layer two and layer one resources. Simply put, there is a contention process somewhere in this architecture, its location is where it can be most agreeably made with as little impact on further usage. This is the detail that had been developed by Telmarc Group in 1992. In their writings, it was clear that this was a doable system design but that there were too many issues to be resolved for it to become a PCS standard.

Thus support fell back to the PCS CDMA design. It was this architecture that Gilder has touted as the savior to auctions since spectrum is shared by all and need not be auctioned. Unfortunately, as we have demonstrated, although possible, and in fact developed two years before his suggestion, it is far from implementable at this time.

Figure: Architecture of the Bandwidth Utility



These four architectures will be used as the basis of the development of the policy alternatives. Significantly more detail has been presented on each of these in Telmarc Group FCC filings and these have been made a matter of the public record.

4.0 Spectral Efficiency

There are theoretical limits to spectral utilization and efficiency that must be at the heart of any policy debate. In this section we provide a brief summary overview of the spectral efficiency problem and base it on the classic Shannon Information theory.

The Shannon theory considers channels that have memory and those without memory. The wireless channel is a channel with memory. In particular, the wireless channel has multipath, both specular and diffuse, and it is this multipath signal that is the basis of the fading that occurs on this type of channel. We shall use the Schneider and McGarty theorems (1978) for demonstrating the ultimate capacity of a Wideband multipath channel. This theorem presents the Gallager bounds for channel capacity in a memory channel with a multipath environment. We shall not go into any of the technical detail but only present the overall results.

The question that we pose here is as follows. Having presented a set of architectural alternatives; how efficiently do each of these alternatives use the bandwidth asset as compared to a optimal system. Namely, what is the ultimate capacity of a 100 MHz wireless channel? This latter question was the question posed by Shannon in his now famous information theory papers. The answer to this question has not been analytical fully determined. Many authors have developed bounds on the performance and on the system performance. There are several trends. First, the more bandwidth used by a single carrier the better.

Namely, if there is 100 MHz of bandwidth, then it is better to use all 100 MHz between all the users rather than split it up amongst the users. Second, it is better to use information from all of the users at various power levels rather than try and control all users. Third, CDMA is generally a better operation scheme since it allows easier control over the user allocation, assignment and management. Other than these general observations, there has been a significant amount of theoretical work but no definitive results.

There are theoretical limits to the spectral utilization and efficiency of channels and such matters need to be at the heart of any policy debate. In this section we provide a brief summary overview of the spectral efficiency problem and base it on the classic Shannon information theory.

The theoretical foundations are important because they show which are the intrinsic
sic limitations of the channel irrespective of the technology used. Information theory offers us the possibility to discuss the theoretical optimum, in practice never reachable but which, as technology evolves, we approach. Indeed, current modem technology on telephone wires approaches quite well the theoretically measured capacity of these wires. Successive improvements in technology have there allowed us to utilize the existing wires very efficiently.

The fact that such good performance can be obtained in practice and that the current technology evolved over many years shows that it is moot to ask whether information theoretical results are relevant because current technology may not achieve them. It is important from a policy point of view to understand just how much a resource has to offer, but the exact way in which it will be utilized will almost certainly vary thanks to the resourcefulness of engineers. Thus, we may remove ourselves from the difficult and often contentious debate on particular implementations. Moreover, we need not worry about the obsolescence of current techniques, since any improvements will simply lead us towards the optimum efficiency which we have already determined.

The question which interests us can be posed in broad terms : what are our resources, what limits do we impose upon the manner in which these resources may be utilized and what is the maximum benefit which these resources can yield under our imposed conditions. The three points above can immediately be mapped to the wireless communication problem in the following manner :

- *Resources : how much bandwidth do we allocate. Since the useable spectrum is allocated in finite increments, we may indeed consider spectrum as a limited resource. There are further considerations* *in establishing what type of resource we have. In particular, the quality of the channel will depend strongly on the geography of the location where the communication is taking place.*

- *Conditions for utilization : how much power we can receive. Safety considerations have placed limits on the power that may be sent by a mobile unit. Interference considerations have placed limits on the height of antennas. Conversely, base stations have limits on the amount of power we may transmit. These conditions are set and impose the constraints within which we are required to operate. We do not place*
- *here conditions such as maximum allowable delay for a service and the such, because they are service specific and our discussion is made in abstraction of such considerations.*

- *Benefit from utilization : how many bits/sec may be transmitted with good reliability.*

Although many studies consider the capacity in the number of users that may be fitted in a particular model, such a measure is really an artifact of the current number of bits/sec required for voice channels as found in the telephone. If we are to have variable services which require different rates, how many users can be fitted becomes a moot point, if we do not know which particular services the users will desire. The goal is to provide the maximum overall rate. This does not mean that interference among users is irrelevant. It most certainly is not and it will dictate the effectiveness of different schemes, our need for power control, etc... We shall see, however, how multi-user information theory allows us to state that, for our purposes, the important measure is the total achievable rate while dealing rigorously with the problem of interference.

It may at this point be illuminating to draw a parallel. Since the concept of information superhighway is being lately widely discussed, we take our example from the existing highway system. The resource that we have is a highway. On any highway, we have a finite number of lanes and therefore the lanes are our limited resources. Of course, the use that may be made of these lanes will depend on what their condition is, e.g. the number of potholes. Similarly, the usefulness of spectrum will depend on the fading conditions with which we must contend. The value of these lanes to the consumer will also depend on what points they connect, just as spectrum in a location will depend on e desirability of that location. Such a consideration, however, is outside the scope of this section. The conditions under which we must operate include weight limits on trucks, speed limits, safety requirements for vehicles, ETC...

The weight limit could roughly be compared to the power limit. Finally, what we wish to know is how many pounds per second we can get to go through our highway under all our constraints, i.e. the maximum achievable rate of our highway. Incidentally, this comparison almost immediately gives us a fair manner of pricing, which is the current pricing at tolls : by space occupied (i.e. by axle) and by distance traveled. Having set the framework for problem, we may proceed to consider its solution. In the following section, we concentrate on the reverse link, i.e. the link from the users to the base station or receiving antenna. The receiver must be able to decode the users separately, regardless of the scheme used to transmit. Since we have several users sharing one receiver, this situation is usually referred to as a multiple-acces system.

The problem of determining the maximum rates that users may achieve under given power constraints within a limited bandwidth may be solved using multi-access information theory as established by Liao and Ahlswede ([Lia72], [Ahl]). When we are dealing with a single user, the maximum rate that may be achieved reliably is called the capacity. For the case of several users, we talk about a capacity region, i.e. the set of rates that may be achieved reliably and jointly by all users. For the sake of simplicity, let us consider that the channel, i.e. the behavior of the medium through which the signal that the users send to the base station, is known. We shall subsequently examine the importance of this assumption and how the channel measurement impacts the capacity.

We first consider memoryless channels, i.e. we do not at first worry about the multipath effects on the channel. For the sake of simplicity, let us consider that the channel, i.e. the behavior of the medium through which the signal that the users send to the base station, is known. We shall subsequently examine the importance of these assumptions and how the channel measurement impacts the capacity.

Let us for the sake of simplicity consider that we have just two users. Let R1 be the rate for user 1, R2 be the rate for user 2. Given how the achievable rate region is defined in [Lia72], [Gal85], we have that

$$R_1 + R_2 2 I\left(X_1, X_2; Y\right)$$
$$R_1 2 I\left(X_1; Y \middle| X_2\right)$$
$$R_2 2 I\left(X_2; Y \middle| X_1\right)$$

here I denotes mutual information. In our formulation of the problem, we wish to maximize R1+R2. Let us show how such rates can be computed. We assume that on the channel we must contend with some amount of noise from various sources. Let us for the sake of simplicity assume that there is no fading on the channel, therefore the noise includes all the extraneous nuisances with which we have to contend. The model universally used for such random interference is the Additive White Gaussian Noise (AWGN) model. Figure 1 below shows the superposition of the signals from users 1 through n, the addition of white noise and the received signal Y. The optimal distribution for the Xis, in terms of achievable rates, is Gaussian. We then have the optimal distributions for the Xis, the right-hand terms in the above inequalities can be given by ([Gal85], [Gal])

I (X1, X2;Y) 2 (W/2)ln(1+(S1+S2)/WN0)

I(X1;Y|X2) 2 (W/2)ln(1+S1/WN0)

I(X2;Y|X1) 2 (W/2)ln(1+S2/WN0)

where S1 is the power of user 1, S2 is the power of user 2, N0/2 is the spectral density of the AWGN, W is the bandwidth jointly used by the users, X1 is the (continuous time) input stochastic process of user 1, X2 s the input stochastic process of user 2 and Y is the output stochastic process.

Let us consider how the maximum total rate may be achieved. We consider CDMA, FDMA and TDMA . In the fist case, all users share the whole bandwidth at all time. In the second, users use separate frequencies to transmit. In the last, they transmit in separate time slots. The maximum achievable rates can be attained by transmitting simultaneously over all of the available spectrum two users with random Gaussian signals. Such a mode of operation could be said to be the optimal version of CDMA. Such an optimal operation is theoretical and, of course, does not suggest how one could achieve such optimality.

However, we may note that if we are operating at the corners of the optimality region where the sum of the rates is maximum, we may achieve the desired rate pair by decoding one user first, considering the other as noise, and, having decoded the first user reliably, subtracting its effect and decoding the second user as though the first user were not present. Such interference cancellation in effect shows that if we decode both users successively, we may have a fairly simple manner of achieving the desired boundary of the capacity region. We may actually decode on any point along the line between these two corners, i.e. the line representing the maximum total rate, by having each user send Gaussian signals at two different powers [94]. The fact that under these conditions interference is not harmful was noted in [Car78].

\We may point out that unless we use the results of decoding one user to decode the other, sending both users simultaneously over all the bandwidth is far from optimal. Indeed, the shaded square in figure shows the region of feasible rates in that case. When no knowledge of one user may be used to decode the other user, we are reduced to an interference channel as in [GC80] and Car78].

FDMA and TDMA can achieve optimal total rate. By using FDMA ([Gal85]) or TDMA ([Wyn94]) we may achieve the point shown on figure 2. Such methods have the distinct advantage of allowing simple decoding since the users transmit at different frequencies or in different time slots. A caveat should be included here that TDMA can achieve optimal multi-user capacity only if we consider the power restriction to be an average power restriction rather than an instantaneous one, i.e. the peak power must be allowed to be double the average power for TDMA to achieve optimum rates.

Indeed, we want to give each user the same rate, since each user has the same and does not interfere with other users. Therefore, each user transmits at the maximum possible rate over its assigned frequency band or time slots. We may here point out what happens when the users do not have the same power. The figure above shows the achievable rates for given power. In practice, we usually wish to guarantee users a certain rate but cannot perfectly control power. For instance, we wish to guarantee each user a voice channel but need to contend with power variations.

Figure (x+1) below shows how power can change while maintaining the desired rate R for each user. We may note that whenever we move away from the minimum total power line, we are wasting power. If users are using FDMA or TDMA, each user having the same bandwidth allocated in FDMA or the same number of time slots of given length, having unequal power, we have a suboptimal spectral efficiency. Indeed, it would be better to allocate more bandwidth to the user with the higher achieved power level and less to the one with the lower power level [Han94]. For CDMA, this problem is avoided. Users can overlay their signals and, as long as appropriate interference cancellation or joint decoding can be performed, we have the optimal spectral efficiency available under the user received power constraints.

It would be inaccurate to affirm that CDMA is therefore intrinsically superior to TDMA or FDMA in terms of spectral efficiency. If we specify that time slots and channel bands can be assigned dynamically and rapidly among users according to received power levels, then we may obtain optimal spectral efficiency using TDMA or FDMA. Otherwise, these schemes can only be optimal under perfect power control conditions.

The problem of interference and optimality can now be addressed directly : does interference matter and, if so, how can one deal with it optimally. Interference does matter and we must take it into account. We have just seen that optimal spectral efficiency can only be obtained when we have some knowledge of the behavior of the other users. n the case of TDMA and FDMA, we need to know the specific time slots or bands, respectively, of all the users. We also need to know the relative powers to determine how to assign time or bandwidth optimally. If we do not deal with interference in such an optimal manner, we lose spectral efficiency. In the case of CDMA, we need to decode jointly, therefore we need to know the power levels of all the users sharing the same spectrum and the result of each user's decoding.

Analyzing CDMA is a little more difficult because there are several ways of implementing CDMA. The first remark we may include is that if users are decoded by considering all others as noise, the performance will be limited to be within the shaded area of figure x. Such a scheme is called "naive" CDMA by Wyner in [Wyn94].

The second remark is that if we implement CDMA by taking a signal and multiplying it by a spreading sequence, we are not using fully the degrees of freedom at our disposal in the form of bandwidth and we cannot achieve the desired capacity region. An issue which we have not addressed in the above is the measurement of the channel. We have operated under the simple memoryless assumption, which is not valid in general. If we know the channel perfectly, our analysis closely parallels that of the memoryless case. In general, we need to obtain some information about the channel in order to decode properly. We can obtain a better measurement of the channel if we consider the whole bandwidth at once rather than consider frequency bands independently. Intuitively, what happens at some frequency tells us something about what happens at another frequency.

However, the incremental benefit of having such knowledge decreases with the separation of the frequencies [Jak], [Med94]. Therefore, having one very wide channel versus having a few smaller ones will not appreciably reduce spectral efficiency, as long at these channels are wider than a certain fairly small threshold.

We may now link our discussion to the policy matter at hand : how do different schemes affect spectral efficiency? We shall examine each alternative individually. The AMPS or Standard/Owned alternative can give optimal spectral efficiency. The A and B carrier can each implement an optimal version of CDMA, FDMA or TDMA as discussed above and thus attain maximum spectral efficiency. As long as the standard is optimal, spectral efficiency will be optimized. The PCS or Proprietary/Owned alternative can also yield optimal spectral efficiency. Even though the frequency bands will be smaller, the effect will be inappreciable in terms of channel measurement. Therefore, as long as each owner of bandwidth chooses an optimal scheme, optimal spectral efficiency over the whole of the bandwidth will be preserved.

Thus, an optimal TDMA scheme could be juxtaposed in bandwidth to an optimal FDMA scheme and an optimal CDMA scheme and spectral efficiency would be preserved. We may note that if one owner uses a suboptimal scheme, he/she would have an incentive to change schemes or sell the frequency band to an owner who would use it more efficiently. The Service Utility or Standard/Shared alternative can work as long as there is central processing of the received signal for decoding and dynamic adjustments and as long as the common standard is optimal.

For instance, if FDMA was chosen as the optimal standard but users were allowed to vary in received power without there being re-assignment of bandwidth, then this scheme would be sub-optimal. Therefore, the Service Utility scheme can be optimal as long as there strong centralization and compliance with optimal standards. Finally, the Bandwidth Utility or Proprietary/Shared alternative is intrinsically suboptimal. If we cannot decode other users or assign bandwidth and time slots according to received power, the system will be strongly interference limited. There are theoretical limitations to what can be achieved in the presence of unknown interference.

We cannot get rid of interference of a user transmitting in the same bandwidth as our user when we do not know the coding and decoding of that extraneous user in the same way as when we decode that user also. The table below summarizes these conclusions.

5.0 Financial Models

To effectively compare technological alternatives we must have models for the effective utilization of capital in the two cases. In this section we shall develop these models in summary form. We assume that the system is composed of the following three generic elements;

Base Terminal Stations (BTS): These devices are placed in the field and there are as many BTSs as are need for either coverage or capacity. The first demand is coverage. A BTS may cover X square miles, depending on the power, the modulation, the multiple access, and the capabilities of the wireless end user terminal. For example, in CDMA with PCS, a BTS has three sectors, each sector covers three mile radius or about 33 sq. mi., for a total of 100 sq. mi. per BTS. If there are no customers, then for 1,000 sq. mi., one need approximately 10 BTS. A BTS also serves one or more CDMA channels. If it is a full band CDMA, at 100 MHz, then only one CDMA channel is needed at any time. If it is a narrow band CDMA, then the CDMA channels must be added each time the system load goes beyond the capacity of one link. Namely, in CDMA, a CDMA channel at 1.25 MHz service only 7 instantaneous channels or “trunks”. Thus as the traffic increase, more CDMA channels must be added. Also in any system, trunk interfaces are added as the trunks are added, perforce of traffic growth.

Base Station Controllers (BSC): The BSC provides for the overall coordination and processing of the switched signals. It typically can handle a multiple set of BTSs and a multiple set of trunks. In the current CDMA narrowband system, a BSC handles up to 50 BTSs.

Switches (SW): The switch interfaces with the LECs and the IECs. It is sized based on a fixed component and a component dependent upon the number of trunks. Newer systems use ATM switching which has proven to be more efficient for the packet type voice signals integrated with data in a wireless environment.

The financial models for a narrowband CDMA system is presented below. It assumes that there are 1.25 MHz channels along with a total available spectrum as discussed above, and it assumes that the area covered is 1,000 sq. mi. The results show Capital per subscriber as a function of the total subscriber base. It should be noted that there is significant scale in the lower end.

The following set of sizing are based upon Qualcomm supplied financial numbers but are retail and do not include any volume discounts or other factors. Note that the system capital for the 10 MHz system is about $366 per sub and reaches that at almost 50,000 subs as we have specified. From that point on Capital per sub is all marginal, namely it lacks scale.

Note in the second case, whether we have 30 MHz, we have reduced Capital per subscriber from $366 to $336. This is a $30 per subscriber penalty for only 10 MHz but may be more than set aside by the lower cost of the spectrum.

Table: CDMA (1.25 MHz Channels, 10 MHz Spectrum)

Number of Subscribers	*10,000*	*25,000*	*50,000*	*100,000*	*150,000*	*200,000*	*300,000*
Total Area (sq mi)	*1,000*	*1,000*	*1,000*	*1,000*	*1,000*	*1,000*	*1,000*
No Sectors/BTS	*3*	*3*	*3*	*3*	*3*	*3*	*3*
Total Bandwidth (MHz)	*5*	*5*	*5*	*5*	*5*	*5*	*5*
Bandwidth/CDMA Channel	*1.25*	*1.25*	*1.25*	*1.25*	*1.25*	*1.25*	*1.25*
No CDMA Channels (Max/BTS)	*4*	*4*	*4*	*4*	*4*	*4*	*4*
Capacity/BTS (per CDMA Channel)	*75*	*75*	*75*	*75*	*75*	*75*	*75*
No BTS/BSC	*50*	*50*	*50*	*50*	*50*	*50*	*50*
Erlang Load/Customer	*0.08*	*0.08*	*0.08*	*0.08*	*0.08*	*0.08*	*0.08*
Number of Trunks	*800*	*2,000*	*4,000*	*8,000*	*12,000*	*16,000*	*24,000*
Radius/Cell Cluster	*3*	*3*	*3*	*3*	*3*	*3*	*3*
No Sectors	*36*	*36*	*36*	*36*	*36*	*36*	*36*
No BTS	*13*	*13*	*14*	*27*	*41*	*54*	*81*
No BSC	*1*	*1*	*1*	*1*	*1*	*2*	*2*
No CDMA Channels	*13*	*13*	*14*	*27*	*41*	*54*	*81*
No Trunks	*800*	*2,000*	*4,000*	*8,000*	*12,000*	*16,000*	*24,000*
No CDMA Channels/BTS	*1*	*1*	*1*	*1*	*1*	*1*	*1*
No Trunks/BTS	*61*	*153*	*285*	*296*	*292*	*296*	*296*
No Trunks/BSC	*800*	*2,000*	*4,000*	*8,000*	*12,000*	*8,000*	*12,000*
Maximum Subscribers (000)	*146,250*	*146,250*	*157,500*	*303,750*	*461,250*	*607,500*	*911,250*
Fixed Capital/BTS	*$8*	*$8*	*$8*	*$8*	*$8*	*$8*	*$8*
Capital/Sector/BTS	*$18*	*$18*	*$18*	*$18*	*$18*	*$18*	*$18*
Capital/CDMA Channel/BTS	*$85*	*$85*	*$85*	*$85*	*$85*	*$85*	*$85*
Capital/Trunk/BTS	*$3*	*$3*	*$3*	*$3*	*$3*	*$3*	*$3*
Fixed Capital/BSC	*$700*	*$700*	*$700*	*$700*	*$700*	*$700*	*$700*
Capital/BTS/BSC	*$6*	*$6*	*$6*	*$6*	*$6*	*$6*	*$6*
Capital/Trunk/BSC	*$1*	*$1*	*$1*	*$1*	*$1*	*$1*	*$1*
BTS Capital	*$4,290*	*$7,878*	*$14,028*	*$27,945*	*$41,943*	*$55,890*	*$83,835*
BSC Capital	*$1,578*	*$2,778*	*$4,784*	*$8,862*	*$12,946*	*$17,724*	*$25,886*
Total Capital	*$5,868*	*$10,656*	*$18,812*	*$36,807*	*$54,889*	*$73,614*	*$109,721*
Capital/Sub	*$587*	*$426*	*$376*	*$368*	*$366*	*$368*	*$366*
Efficiency	*7%*	*17%*	*32%*	*33%*	*33%*	*33%*	*33%*

Table: CDMA (1.25 MHz Channels, 30 MHz Spectrum)

Number of Subscribers	*10,000*	*25,000*	*50,000*	*100,000*	*150,000*	*200,000*	*300,000*
Total Area (sq mi)	*1,000*	*1,000*	*1,000*	*1,000*	*1,000*	*1,000*	*1,000*
No Sectors/BTS	*3*	*3*	*3*	*3*	*3*	*3*	*3*
Total Bandwidth (MHz)	*15*	*15*	*15*	*15*	*15*	*15*	*15*
Bandwidth/CDMA Channel	*1.25*	*1.25*	*1.25*	*1.25*	*1.25*	*1.25*	*1.25*
No CDMA Channels (Max/BTS)	*12*	*12*	*12*	*12*	*12*	*12*	*12*
Capacity/BTS (per CDMA Channel)	*75*	*75*	*75*	*75*	*75*	*75*	*75*
No BTS/BSC	*50*	*50*	*50*	*50*	*50*	*50*	*50*
Erlang Load/Customer	*0.08*	*0.08*	*0.08*	*0.08*	*0.08*	*0.08*	*0.08*
Number of Trunks	*800*	*2,000*	*4,000*	*8,000*	*12,000*	*16,000*	*24,000*
Radius/Cell Cluster	*3*	*3*	*3*	*3*	*3*	*3*	*3*
No Sectors	*36*	*36*	*36*	*36*	*36*	*36*	*36*
No BTS	*13*	*13*	*13*	*13*	*14*	*18*	*27*
No BSC	*1*	*1*	*1*	*1*	*1*	*1*	*1*
No CDMA Channels	*13*	*13*	*13*	*13*	*14*	*18*	*27*
No Trunks	*800*	*2,000*	*4,000*	*8,000*	*12,000*	*16,000*	*24,000*
No CDMA Channels/BTS	*1*	*1*	*1*	*1*	*1*	*1*	*1*
No Trunks/BTS	*61*	*153*	*307*	*615*	*857*	*888*	*888*
No Trunks/BSC	*800*	*2,000*	*4,000*	*8,000*	*12,000*	*16,000*	*24,000*
Maximum Subscribers (000)	*438,750*	*438,750*	*438,750*	*438,750*	*472,500*	*607,500*	*911,250*
Fixed Capital/BTS	*$8*	*$8*	*$8*	*$8*	*$8*	*$8*	*$8*
Capital/Sector/BTS	*$18*	*$18*	*$18*	*$18*	*$18*	*$18*	*$18*
Capital/CDMA Channel/BTS	*$85*	*$85*	*$85*	*$85*	*$85*	*$85*	*$85*
Capital/Trunk/BTS	*$3*	*$3*	*$3*	*$3*	*$3*	*$3*	*$3*
Fixed Capital/BSC	*$700*	*$700*	*$700*	*$700*	*$700*	*$700*	*$700*
Capital/BTS/BSC	*$6*	*$6*	*$6*	*$6*	*$6*	*$6*	*$6*
Capital/Trunk/BSC	*$1*	*$1*	*$1*	*$1*	*$1*	*$1*	*$1*
BTS Capital	*$4,290*	*$7,878*	*$13,884*	*$25,896*	*$38,052*	*$50,598*	*$75,897*
BSC Capital	*$1,578*	*$2,778*	*$4,778*	*$8,778*	*$12,784*	*$16,808*	*$24,862*
Total Capital	*$5,868*	*$10,656*	*$18,662*	*$34,674*	*$50,836*	*$67,406*	*$100,759*
Capital/Sub	*$587*	*$426*	*$373*	*$347*	*$339*	*$337*	*$336*
Efficiency	*2%*	*6%*	*11%*	*23%*	*32%*	*33%*	*33%*

CDMA has a larger single cell radius at 0.6 W than does all of the other systems. This is due to the lower E_b / N_o needed for the link. This will have a dramatic effect in achieving the targeted cost per customer number. We shall use the example of CDMA technology to demonstrate how this new technological infrastructure can enable the new market. We shall briefly describe the CDMA system and then proceed to the financial implications of using this new technology. The CDMA system described is that of Qualcomm[12]. Fundamentally the system is characterized in the following fashion:

- *An air interface of a CDMA signal is provided by a cell or cell BTS over the air to the portable. The signal is encoded in a direct sequence CDMA spread spectrum code. Thus a 13 Kbps voice signal is spread, or multiplied by a unique code at the rate of 1.25 Mbps. The codes are orthogonal. Namely, if two or more codes are combined, then if they are multiplied by the desired code, the residual of the other signal appears as a low level noise signal. Thus CDMA is frequently interference limited no random noise limited.*

- *A BSC is used to ensure hand off between other BSCs. The BSC has a capacity that depends upon the Bandwidth, the interference level, the size of the cell and other factors. Typically a BSC has the capacity of 75 trunks per 1.25 MHz of Bandwidth. If a portable is busy 5% of the time then this means a BSC with 375 trunks can handle 6,500 portables. The BSC is a highly intelligent distributed processing node. The CDMA codes assure signal orthogonality and inherently manage the interference. The BSC assures a soft hand-off between the other cells in the grid. In addition, the BSC establishes the relationship between the call and the switch. Namely the BSC passes an intelligent and digitally "packed" set of voice channels.*

- *The BSC hands the switch a DS-3 formatted voice signal, with a SS-7 signaling channel, on a SONET interface, or an ATM formatted signal into an ATM switch. As far as the switch is concerned, the call may have originated from a Class 5 or Class 4 switch. As we have discussed before, the Class 5 LEC functionality is not required. What is required is the Class 4 toll-tandem switching capability. The only need for Class 5 functionality is that needed for billing.*

- *The BTSs are clustered around the BSC. A BTS is used to manage the coverage issue, whereas the BSC is used for the capacity issue. The BTSs are an order of magnitude less expensive than the BSC. The BTSs are interconnected to the BSC via a microwave path, at 40 GHz, or over CATV or a bypass carrier.*

When looked at in this fashion, the use of CDMA dramatically reduces the needs from a LEC environment. All that is needed is the ability to backward access to the Local user, namely a customer of the LEC. Thus the access fee should be reduced.

The financial models for three cases using these models are presented below. The first models is for a narrowband CDMA system. It assumes that there are 1.25 MHz channels along with a total available spectrum as discussed above, and it assumes that the area covered is 1,000 sq. mi. The results show the capital per subscriber as a function of the total subscriber base. It should be noted that there is significant scale in the lower end.

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[12] See the works by Gilhousen for the QUALCOMM approach. Also see the paper by Pickholtz et al for a differing approach to CDMA. The latter approach is Broad Block CDMA compared to mid-Block.

Table: CDMA (1.25 MHz Channels)

Number of Subscribers	*10,000*	*25,000*	*50,000*	*100,000*	*150,000*	*200,000*	*300,000*
Total Area (sq mi)	*1,000*	*1,000*	*1,000*	*1,000*	*1,000*	*1,000*	*1,000*
No Sectors/BTS	*3*	*3*	*3*	*3*	*3*	*3*	*3*
Total Bandwidth (MHz)	*15*	*15*	*15*	*15*	*15*	*15*	*15*
Bandwidth/CDMA Channel	*1.25*	*1.25*	*1.25*	*1.25*	*1.25*	*1.25*	*1.25*
No CDMA Channels (Max/BTS)	*12*	*12*	*12*	*12*	*12*	*12*	*12*
Capacity/BTS (per CDMA Channel)	*75*	*75*	*75*	*75*	*75*	*75*	*75*
No BTS/BSC	*50*	*50*	*50*	*50*	*50*	*50*	*50*
Erlang Load/Customer	*0.08*	*0.08*	*0.08*	*0.08*	*0.08*	*0.08*	*0.08*
Number of Trunks	*800*	*2,000*	*4,000*	*8,000*	*12,000*	*16,000*	*24,000*
Radius/Cell Cluster	*3*	*3*	*3*	*3*	*3*	*3*	*3*
No Sectors	*36*	*36*	*36*	*36*	*36*	*36*	*36*
No BTS	*13*	*13*	*13*	*13*	*14*	*18*	*27*
No BSC	*1*	*1*	*1*	*1*	*1*	*1*	*1*
No CDMA Channels	*13*	*13*	*13*	*13*	*14*	*18*	*27*
No Trunks	*800*	*2,000*	*4,000*	*8,000*	*12,000*	*16,000*	*24,000*
No CDMA Channels/BTS	*1*	*1*	*1*	*1*	*1*	*1*	*1*
No Trunks/BTS	*61*	*153*	*307*	*615*	*857*	*888*	*888*
No Trunks/BSC	*800*	*2,000*	*4,000*	*8,000*	*12,000*	*16,000*	*24,000*
Maximum Subscribers (000)	*158,438*	*158,438*	*158,438*	*158,438*	*183,750*	*303,750*	*683,438*
Fixed Capital/BTS	*$8*	*$8*	*$8*	*$8*	*$8*	*$8*	*$8*
Capital/Sector/BTS	*$18*	*$18*	*$18*	*$18*	*$18*	*$18*	*$18*
Capital/CDMA Channel/BTS	*$85*	*$85*	*$85*	*$85*	*$85*	*$85*	*$85*
Capital/Trunk/BTS	*$3*	*$3*	*$3*	*$3*	*$3*	*$3*	*$3*
Fixed Capital/BSC	*$700*	*$700*	*$700*	*$700*	*$700*	*$700*	*$700*
Capital/BTS/BSC	*$6*	*$6*	*$6*	*$6*	*$6*	*$6*	*$6*
Capital/Trunk/BSC	*$1*	*$1*	*$1*	*$1*	*$1*	*$1*	*$1*
BTS Capital	*$4,290*	*$7,878*	*$13,884*	*$25,896*	*$38,052*	*$50,598*	*$75,897*
BSC Capital	*$1,578*	*$2,778*	*$4,778*	*$8,778*	*$12,784*	*$16,808*	*$24,862*
Total Capital	*$5,868*	*$10,656*	*$18,662*	*$34,674*	*$50,836*	*$67,406*	*$100,759*
Capital/Sub	*$587*	*$426*	*$373*	*$347*	*$339*	*$337*	*$336*
Efficiency	*6%*	*16%*	*32%*	*63%*	*82%*	*66%*	*44%*

The second case is also for CDMA but now for a broadband design. Here we assume a 100 MHz spectrum. We also assume that there is a scale economy by having a signal CDMA channel, however this is mitigated by the fact that this appears as a fixed cost in the early stages. Thus the average capital may be lower at higher penetrations but is higher at lower penetrations. The CDMA of the narrowband variety provides better returns to scale but for a price.

Table: CDMA (100 MHz Channel)

Number of Subscribers	*10,000*	*25,000*	*50,000*	*100,000*	*150,000*	*200,000*	*300,000*
Total Area (sq mi)	*1,000*	*1,000*	*1,000*	*1,000*	*1,000*	*1,000*	*1,000*
No Sectors/BTS	*3*	*3*	*3*	*3*	*3*	*3*	*3*
Total Bandwidth (MHz)	*100*	*100*	*100*	*100*	*100*	*100*	*100*
Bandwidth/CDMA Channel	*100.00*	*100.00*	*100.00*	*100.00*	*100.00*	*100.00*	*100.00*
No CDMA Channels (Max/BTS)	*1*	*1*	*1*	*1*	*1*	*1*	*1*
Capacity/BTS (per CDMA Channel)	*6,000*	*6,000*	*6,000*	*6,000*	*6,000*	*6,000*	*6,000*
No BTS/BSC	*50*	*50*	*50*	*50*	*50*	*50*	*50*
Erlang Load/Customer	*0.08*	*0.08*	*0.08*	*0.08*	*0.08*	*0.08*	*0.08*
Number of Trunks	*800*	*2,000*	*4,000*	*8,000*	*12,000*	*16,000*	*24,000*
Radius/Cell Cluster	*3*	*3*	*3*	*3*	*3*	*3*	*3*
No Sectors	*36*	*36*	*36*	*36*	*36*	*36*	*36*
No BTS	*13*	*13*	*13*	*13*	*13*	*13*	*13*
No BSC	*1*	*1*	*1*	*1*	*1*	*1*	*1*
No CDMA Channels	*13*	*13*	*13*	*13*	*13*	*13*	*13*
No Trunks	*800*	*2,000*	*4,000*	*8,000*	*12,000*	*16,000*	*24,000*
No CDMA Channels/BTS	*1*	*1*	*1*	*1*	*1*	*1*	*1*
No Trunks/BTS	*61*	*153*	*307*	*615*	*923*	*1,230*	*1,846*
No Trunks/BSC	*800*	*2,000*	*4,000*	*8,000*	*12,000*	*16,000*	*24,000*
Maximum Subscribers (000)	*12,675,000*	*12,675,000*	*12,675,000*	*12,675,000*	*12,675,000*	*12,675,000*	*12,675,000*
Fixed Capital/BTS	*$8*	*$8*	*$8*	*$8*	*$8*	*$8*	*$8*
Capital/Sector/BTS	*$18*	*$18*	*$18*	*$18*	*$18*	*$18*	*$18*
Capital/CDMA Channel/BTS	*$760*	*$760*	*$760*	*$760*	*$760*	*$760*	*$760*
Capital/Trunk/BTS	*$3*	*$3*	*$3*	*$3*	*$3*	*$3*	*$3*
Fixed Capital/BSC	*$700*	*$700*	*$700*	*$700*	*$700*	*$700*	*$700*
Capital/BTS/BSC	*$6*	*$6*	*$6*	*$6*	*$6*	*$6*	*$6*
Capital/Trunk/BSC	*$1*	*$1*	*$1*	*$1*	*$1*	*$1*	*$1*
BTS Capital	*$13,068*	*$16,656*	*$22,662*	*$34,674*	*$46,686*	*$58,659*	*$82,683*
BSC Capital	*$1,578*	*$2,778*	*$4,778*	*$8,778*	*$12,778*	*$16,778*	*$24,778*
Total Capital	*$14,646*	*$19,434*	*$27,440*	*$43,452*	*$59,464*	*$75,437*	*$107,461*
Capital/Sub	*$1,465*	*$777*	*$549*	*$435*	*$396*	*$377*	*$358*
Efficiency	*0%*	*0%*	*0%*	*1%*	*1%*	*2%*	*2%*

The third case analyzed is that of comparing capital per subscriber as a function of bandwidth and not of customers. This is shown in the following table. Here we keep the customer count fixed but vary the bandwidth. The variation is complex since it must really reflect fixed and variable costs more effectively.

Table: Comparison of CDMA as Function of Channel Bandwidth

Number of Subscribers	*100,000*	*100,000*	*100,000*	*100,000*	*100,000*	*100,000*	*100,000*
Total Area (sq mi)	*1,000*	*1,000*	*1,000*	*1,000*	*1,000*	*1,000*	*1,000*
No Sectors/BTS	*3*	*3*	*3*	*3*	*3*	*3*	*3*
Total Bandwidth (MHz)	*15*	*15*	*15*	*15*	*15*	*15*	*15*
Bandwidth/CDMA Channel	*1.25*	*1.50*	*5.00*	*7.50*	*10.00*	*12.50*	*15.00*
No CDMA Channels (Max/BTS)	*12*	*10*	*3*	*2*	*2*	*1*	*1*
Capacity/BTS (per CDMA Channel)	*75*	*75*	*75*	*75*	*75*	*75*	*75*
No BTS/BSC	*50*	*50*	*50*	*50*	*50*	*50*	*50*
Erlang Load/Customer	*0.08*	*0.08*	*0.08*	*0.08*	*0.08*	*0.08*	*0.08*
Number of Trunks	*8,000*	*8,000*	*8,000*	*8,000*	*8,000*	*8,000*	*8,000*
Radius/Cell Cluster	*3*	*3*	*3*	*3*	*3*	*3*	*3*
No Sectors	*36*	*36*	*36*	*36*	*36*	*36*	*36*
No BTS	*13*	*13*	*36*	*54*	*72*	*89*	*107*
No BSC	*1*	*1*	*1*	*2*	*2*	*2*	*3*
No CDMA Channels	*13*	*13*	*36*	*54*	*72*	*89*	*107*
No Trunks	*8,000*	*8,000*	*8,000*	*8,000*	*8,000*	*8,000*	*8,000*
No CDMA Channels/BTS	*1*	*1*	*1*	*1*	*1*	*1*	*1*
No Trunks/BTS	*615*	*615*	*222*	*148*	*111*	*89*	*74*
No Trunks/BSC	*8,000*	*8,000*	*8,000*	*4,000*	*4,000*	*4,000*	*2,666*
Maximum Subscribers (000)	*158,438*	*158,438*	*1,215,000*	*2,733,750*	*4,860,000*	*7,425,938*	*10,733,438*
Fixed Capital/BTS	*$8*	*$8*	*$8*	*$8*	*$8*	*$8*	*$8*
Capital/Sector/BTS	*$18*	*$18*	*$18*	*$18*	*$18*	*$18*	*$18*
Capital/CDMA Channel/BTS	*$85*	*$93*	*$170*	*$208*	*$240*	*$269*	*$294*
Capital/Trunk/BTS	*$3*	*$3*	*$3*	*$3*	*$3*	*$3*	*$3*
Fixed Capital/BSC	*$700*	*$700*	*$700*	*$700*	*$700*	*$700*	*$700*
Capital/BTS/BSC	*$6*	*$6*	*$6*	*$6*	*$6*	*$6*	*$6*
Capital/Trunk/BSC	*$1*	*$1*	*$1*	*$1*	*$1*	*$1*	*$1*
BTS Capital	*$25,896*	*$26,001*	*$32,328*	*$38,567*	*$45,750*	*$53,204*	*$61,894*
BSC Capital	*$8,778*	*$8,778*	*$8,916*	*$9,724*	*$9,832*	*$9,934*	*$10,740*
Total Capital	*$34,674*	*$34,779*	*$41,244*	*$48,291*	*$55,582*	*$63,138*	*$72,634*
Capital/Sub	*$347*	*$348*	*$412*	*$483*	*$556*	*$631*	*$726*
Efficiency	*63%*	*63%*	*8%*	*4%*	*2%*	*1%*	*1%*

The results presented in this section lead to the following conclusions on financial implications of the four strategies:

Scale: There is scale in the design but scale may not be efficiently demonstrated in a shared design because of the need for high fixed cost elements. Scale will be a factor but it may be a result of the need for common shared elements. We believe that a development of a financially viable model for the BW utility may lead to dramatically lowered costs for that model. It has been shown by McGarty in prior papers that there is the possibility through the use of the ReRad design and the bandwidth translator to have the capital costs be halved. McGarty initially presented these analyses in late 1992 and they were detailed in the MIT paper of March 1993. There are unfortunately no significant costs available for this design in a fully implemented model.

Marginalization of Capital: The CDMA design of Qualcomm is the only viable design that allows implementation for either a narrowband or wideband implementation as of the date of this paper. Although Omnipoint has proclaimed a design, the authors could not obtain numbers for a public financial analysis nor were there any operations systems as there are with the Qualcomm design. The CDMA capital numbers reduce capital per sub numbers to their marginal capital levels the fastest. The BW Utility architecture numbers have also been analyzed by McGarty in prior publications and these were based upon numbers supplied by Steinbrecher for their ReRad. No Operational system employing the Steinbrecher ReRad implementation are available at this time.

Efficiency of Spectrum Utilization: CDMA is the most efficient users of spectrum that can be found. We define efficiently of use as the ratio of actual spectral filling capacity per Shannon limit. This also allows for the most efficient from a capital point of view also.

6.0 Policy Implications

The policy implications of this analysis are significant. The first approach lends itself to auctions and obtaining economic value to the Government at the initial state. The second approach demonstrates the existence of an allocation procedure based on the current “market” viability of any new service.

The policy issues fall into three general categories; FCC related issues, PUC related issues, and antitrust related issues. We shall focus on these. There are also ancillary issues that relate to the release and applications of new spectrum and the role of Congress in supporting the new spectrum issues. We shall focus on the issues relating to the regulatory policy for shared spectrum. Considerable attention has already been focused on separate owned spectrum and the FCC has already ruled on these issues. The issues of shared spectrum will arise when the FCC and Congress decide on what to do with the newer spectrum to be auctioned, specifically the current DoD spectrum. These issues will help to focus attention on the alternative available.

FCC Issues:

- ***Standards Body***: In the new environment, should the FCC become the standards body. The FCC has attempted to do that in HDTV and it has been successful in many ways but has been a long and drawn out process. Should the FCC encourage standards, should the service providers take the initiative? TDMA and CDMA show that even the service providers cannot converge. Should we abandon standards since technology is changing so fast? These are issues that the FCC must address. The FCC was not a standards body and does not possess the resources to be one. Nor, do the authors suggest it should become one. The suggestions is that the FCC through policy, direct that there be a single standard if the Service Utility approach is chosen. If not, then the FCC has no role.

- ***Tax Collector***: If there is no auction then does the FCC become the tax collector. If the Government policy is to receive remuneration from service providers for use of public spectrum, who sets the rates. An auction is a process for the market setting the rates. A tax is not market driven. Does Congress set rates, is there a service tax, does it apply to all LECs, for example, and should it be a percent of the gross revenues?

- ***Auctioneer***: If spectrum is shared then the auction process is inapplicable since no one operator owns the spectrum. Is the FCC to continue in this role?

- ***Frequency Manager***: If spectrum is shared, what does the FCC say about its use. Are they to control power levels, such as in Part 15. What about enforcement in a shared environment? How are violators detected, controlled, punished, eliminated, etc.? Are these functions of the FCC? If so, under what mandate does the FCC act?

- ***Regulator***: Is the FCC to be a regulator of services, rates, compliance? Is the FCC to replace the PUC for a wireless service or if this is truly a market driven service, should the commission abandon the regulatory role such as was done by the CAB in 1978?

- ***Technology Stimulator***: The FCC can with the new shared spectrum concepts become the technology stimulator and not arbiter. It is argued that the FCC can evolve into a more proactive role as it successfully showed in PCS and stimulate shared services. It can do this through its normal process but by opening a Docket on Shared Services Bands.

- ***Market Arbiter***: Can the FCC play the role of market arbiter as it did in the IEC business by balancing the interests of the new IECs such as MCI and Sprint against AT&T until such time that competitive forces are balanced. This worked very well in the IEC business and it is believed that it can function well in this area.

PUC Issues:

- ***Public Arbiter***: The PUC will still retain its position of public advocate and arbiter. However its control over monopoly players through rate setting will be abandoned. It must become the supporters of full and complete competition.

- ***Local Regulator***: The PUC may regulate local interfaces and interconnects such as with the existing LECs. In its role of competitive arbiter the PUC must insure equal and competitive access by all.

- ***Arbiter of Monopolists***: There are and will still be significant monopolists. We shall argue the issue below. However, we argue that the PUC will have a strong role in continuing to manage the relationship with the dominant monopolist.

General Competitive Issues:

The competitive issues are the most significant in the development of alternative and competitive Local Exchange Services. These system architectures must be accessible to each other. This then leads to the general concept of access and control. Control relates to who “owns” the bandwidth and in turn who “controls” the bandwidth. Access is a key and determining factor in that process. We first begin with a description of access and then discuss in detail some of the antitrust issues.

Access and Interconnect are two separate topics, but highly interrelated. Access is defined as the provision of all systems and services necessary to have one carrier interface with another for the purpose of transferring information, or simply just a voice call. Interconnect is the physical process of connecting the two such carriers. Thus access may embody more elements and to some degree more abstraction than interconnect. Interconnect is simply the physical elements of communications.[13]

In this paper we develop the concept of access because it is through access that competing carriers meet and it is through access that the dominant carrier may have the power to control the nondominant. There are three views of access that are currently in use. These are:

1. ***Access as Externality***: This is the long standing concept of access that is the basis of the current access fee structures. The RBOC contends that it has certain economic externalities of value that it provides any new entrant and that the new entrant brings nothing of value to the table in the process of interconnecting. The RBOC has the responsibility of universal service and furthermore permits the new entrant access to the RBOCs customers, which brings significant value to the new entrant. In fact, RBOCs argue that a new entrant would have no business if the RBOC did not allow it access to “its” customer base. This school of access is the Unilateral school. Commissioner Barrett has stated publicly o several occasions that any new entrant should reimburse the RBOC for the value the RBOC brings to the table. The RBOCs, especially Bell South are strong supporters of this view.

2. ***Access as Bilateralism***: This is the view currently espoused by the Commission in some of its more recent filings. It is also the view of the New York Public Service Commission in the tariff allowing Rochester Telephone and Time Warner Communications to interoprate. It also is the view of Ameritech in its proposed disaggragation approach. Simply stated, Bilateralism says that there are two or more LECs in a market. LEC A will pay LEC B for access or interconnect and LEC B will pay LEC A. It begs the question of what basis the reimbursement will be made, what rate base concept, if any, will be used, and what process will be applied to ensure equity.[14]

3. ***Access as Competitive Leverage***: This concept of access assumes that there is a public policy of free and open competition and that the goal is providing the consumer with the best service at the lowest possible price. It argues that no matter how one attempts to deal with access in the Bilateral approach, abuses are rampant. Thus the only solution in order to achieve some modicum of Pareto optimality from the consumer welfare perspective is to totally eliminate access fees. The Competitive access school say that the price that the consume pays for the service should totally reflect the costs associated with its providers and not with the provider of the service of the person that the individual wants to talk to. For example, my local telephone rate does no change if I desire to talk to someone in Mongolia, even if their rates are much higher due to local inefficiencies. The Competitive Access school says that externalities are public goods, created perforce of the publicly granted monopoly status of the past one hundred years. It states further that Bilateralism is nothing more that an encumbrance that allows the entrenched monopolist to control the growth of new entrants, and is quite simply an artifact of pre-divestiture AT&T operations. The only choice for the Competitive Access school is no access at all and price at cost.

Our arguments relating to Antitrust commence as follows. We assume that we shall use the term PCS in its broadest context and shall expand it to encompass all new wireless services including those provided on a shared access basis. Thus we conclude:

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[13] This division of interconnect and access is due to David Reed of OPP at the FCC.

[14] See the Recent book by Baumol and Sidak, Toward Competition in Local Telephony, MIT Press (Cambridge, MA), 1994. The authors assume Bilateralism and then work from there. They do not event broach the question of what is best for the industry. Their approach is an academic treatise on what are optimal reimbursement mechanisms, rather that what allows competition.

PCS provides, at a minimum, the ability of any new entrant to deliver toll grade quality voice services in a seamless interoperable nation network. This service or product offering is the provision, at a minimum, of voice grade service. It is the same as the service offered by the current Local Exchange Carriers, LEC, and is the same that could be potentially offered by the existing cellular carrier.[15]

This states that PCS is nothing more than "plain old telephone service". It clearly has the potential of providing telephone service at a more competitive price than a wire based service. It is totally cross elastic with a wire based service. Namely, the consumer cannot differentiate with either offering other than possibly through the extra mobility afforded by PCS. In essence, PCS makes wire and wireless telephone service a simple commodity, indistinguishable to the consumer solely on the basis of the technology. The distinguishing feature will most likely be the price and only the price, as it is with all commodities. PCS allows for the commodicization of local exchange service.[16]

PCS, cellular, and wire based local exchange services are indistinguishable from the perspective of the buyer. Therefore, PCS can and should compete with the LEC and the wire based service.

If the intent is to create a competitive alternative to the local loop and, simultaneously, to expand the telecommunications services offered, then PCS offers a significant alternative means to do so. Experimental efforts to date have indicated that the consumer does not necessarily view PCS as a separate service offering. If priced competitively and positioned competitively, the consumer views PCS as a displaceable alternate to the wire based telephone.[17]

The "Market" for PCS is the same as the "Market" for the LEC based services of today. The "Market" for cellular is the same as the PCS "Market".

There is no material or other observable or measurable difference in the offering of PCS and wire based service and the markets for both are the same. The consumer may choose between the two.[18] The definition of the market for PCS will be critical.

PCS enables the commodicization of voice services and establish the possibility for any new entrant to sell the same service to the consumer, with the consumer purchasing the commodicized service solely on the basis of price. PCS allows for the total cross elasticity of supply to the consumer of telephone service.

It is argued that the service offered by the dominant entity or the RBOC LEC is fully displaceable by PCS and that as such competes with the LEC in its primary market.[19]

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[15] In McGarty, 1990 [1], the demonstration is made that the networks as evolved with CS can be constructed in a fully open and distributed fashion. It was in this paper that the concept of commodicization was first presented.

[16] Telmarc Telecommunications NPRM Comments to the FCC, November 8, 1992.

[17] McGarty, 1992 [2]. This paper details the trials in PCS showing the consumer commodicization efforts. Also see Telmarc Quarterly Report, July 1, 1993, which details extensive market research in this area.

[18] The Court, in United States v. E.I. duPont de Nemours & Co. (Cellophane), 351 U.S. 377 (1956), introduced the concept of cross elasticity to determine the market. Although there is no true market measure at this time, extensive market research indicates that there is anticipated to be great cross elasticity as defined by the Court in the aforementioned.

New entrants into the PCS business do not face economies of scale in capital plant that have been faced by prior entrants, thus justifying the prior monopoly position of the LEC. PCS entrants, by means of outsourcing, can also obtain all support and sales services at marginal prices and thus each Local Service Operator, LSO, does not have a scale economy in the operations and sales sides of the business. Thus there are no economies of scale in the PCS business and the justification for any monopoly player is no longer valid on economic principles.

It has been shown that new entrants have the ability to establish capital plant in such a way as to have marginal capital and average capital be almost the same at very small market penetrations, less than 0.5%. Thus there are de minimis scale economies in capital plant. In addition there may be scale in support and operating services, but by outsourcing, and using the economy scope of a third party, such as an ISSC or EDS or CSC (as did NEXTEL), an entrant may purchase such service at the margin. Thus any new entrant may see entry costs all at the margin.[20] This implies that there is no natural monopoly. In fact this implies that competition may be quite significant.

Competition in the PCS market, for voice amongst other services, will be commodicized and the consumer choice will be made on the basis of price, if such is possible. Choice on price for the consumer is Pareto optimal.

With the aforementioned characteristics, the product or service offering will be based upon price. New entrants will compete primarily on price, and their prices will reflect their costs. The consumer welfare is always maximized by maximizing choice while also minimizing price. Price could be so minimized in this market by having full competition and clearing the market on a fully competitive price basis.[21]

Telephone services, as a commodicized entity, do not differ in any way if delivered by a wire or wireless means. The consumer perceives the service as the same in either case. Thus there is complete cross elasticity in a commodicized market. The delivery of telephone service, when differentiated by wire based or wireless, is the same service but sold through a different sales and marketing channel. There is no basic product differentiation between a wire based service and a properly delivered wireless service. The only difference is price as reflected throughout the distribution channel.

The essence of what makes wireless and wire based services different is merely the sales or distribution channel. The sales channel is a different company, although owned by the same holding company. Pac Tel was the only RBOC to publicly recognize this and separate the two entities. The current differential between the two services is price, and this is driven by capital and operation inefficiencies in the analog technology. These will disappear in the digital technologies.

This then leads to the following conclusions on related issues:

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[19] In the decision of Telex v. IBM, the Tenth Circuit Court ruled that IBM had monopolized the market on the basis of the sale of peripheral products that were commodicizable in the terms in which we use herein.

[20] McGarty, 1994 [1], and Telmarc Quarterly Report to the FCC, April 1, 1994.

[21] McGarty, 1993 [2] discusses the competitive aspects of fully competitive markets versus monopoly and duoploy markets. It is shown that in the current monopoly market the price is twice what it could be for telephone service in a competitive market. This fact has been borne out in the IEC market where long distance rates have been halved in the last ten years.

- Means of Production: Access is a means of production and can be critical to the success of any wireless system. Access allows interconnectivity, but it also is broader in terms of assuring the consumer a seamless offering.

- Establishment of Competition: Competition can only exist if the existing monopolists are controlled until entry by other competitors is possible. There are two ways to do this; first by excluding the current monopolists or by opening up spectrum based on market performance rather than spectrum ownership. The "Gilder" proposal is a market performance systems of allocation rather than an auction process which is a financial power means of allocation.

- Barriers to Entry: Access is also a barrier to entry and should be treated as such in an antitrust context. A new architecture must reflect the totality of operational and economic interests that make for a viable and competitive market environment. Thus access in its broadest sense is and essential element to be resolved as regards to any spectrum policy.

7.0 Conclusions

In this paper we have developed alternative architectures for the provision of wireless services. We have introduced the new concepts of the Service Utility and the Bandwidth Utility. The latter is the basis of he Gilder Conjectures. We have demonstrated that the Bandwidth Utility is a viable concept but that it cannot be readily implemented. Malcom Forbes, Jr., the Publisher of Forbes advocated that based upon the Gilder Conjecture that the FCC abandon the auction process. We have demonstrated that such an action is based upon conjectures and assumptions that are groundless, since the technology and interfaces are not available at this time. Conceptually, the Bandwidth utility is an attractive proposition, and has been expressed by the senior author a very viable alternative for the next generation of systems. It will, however, take many years to attain a level of operational capability to effect such a system. Thus it is totally inappropriate to abandon auctions and the FCC's actions are not only timely and correct, but are also the only options available at this time.

This then leads to a review of the six Gilder Conjectures that we discussed. Specifically:

(1) Many Users can occupy the same spectrum at one time. There exists a well defined set of protocols that allow this and prevent collisions. There further exists a set of workable multiple access/interface technologies that can be interchangeably used.

This is essentially a true conjecture with the one exception that at the current time there is no operation hardware or software to implement this. It is not that there will be none, it is that there is none commercially available. Indeed, it is even more difficult, since the multiple access schemes that we have discussed in the shared user scenarios needs further development from a theoretical perspective.

(2) Frequency and modulation/multiple access schemes are utterly unnecessary.

This conjecture has been shown to be untrue. Multiple access is at the heart of any such system, been if it is nothing more than an accepted term of art. Modulation is the only known way to get signals from baseband to RF. Thus there is no way that this conjecture can stand.

(3) Networks can be made open and all of the processing done in software.

This conjecture is quite true. However, one may ask what the tradeoff between hardware and software is in such a system. That is a design tradeoff. Ideally one would like to have as much in software as possible. Economically, that may not be possible.

(4) Broadband Front Ends replace cell sites in functionality at lower costs.

As we have shown, this conjecture is false. I was based upon a misunderstanding of the Steinbrecher technology. Cell sites, as a term of art, assume functionality. That functionality has just been moved from one point to another.

(5) It is possible to manufacture spectrum at will. Spectrum is abundant.

This conjecture assumes that spectrum is infinitely reusable. If viewed in that context, one can get a very high reuse on a national scale but not infinite. This conjecture s probably true in spirit but no in letter.

(6) Spectrum can be used any way one wants as long as one does not interfere. New technology makes hash of the need to auction off exclusive spectrum, spectrum assignment is a technological absurdity.

This is the final and most critical of the Gilder conjectures. The first part is a syllogism. Thus it must be true. The second part is not, and builds on the truth of the first five conjectures. Since the technology is not there, since any agreement on protocols has not been held, since an architecture is not defined, and since contention is a market phenomenon, this conjecture is false also.

We thus argue that the final conjecture, and thus the recommendation, given the current state of technology and the market, is untrue, and thus the FCC's process of spectrum allocation is viable and sustainable. However, if one can address the deficiencies, none being fatal, one can say that the final conjecture can be made true. Thus, in the full extent of technological innovation, Gilder is correct, and the analysis of how to implement this vision should be undertaken.

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