The Economics of the Wireless Local Loop

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4.0 Wireless technology in the *National Information Infrastructure* (NII)

Wireless telecommunications is receiving a lot of attention these days. Some would say an inordinate amount. Why? After all, wireless telecommunications has been around for a very long time, and by now nearly everyone knows about the convenience of cordless and mobile telephones. The key to what is going on lies in the fact that, for the first time ever, wireless technology is progressing to the point that it will not only be convenient to use, but will be affordable for the mass market of American consumers.

Due to the obvious advantage of portability, it is a given that wireless telecommunications will be very successful with consumers. However, any meaningful discussion of the role that wireless communications might play in the grand scheme of things cannot occur in a vacuum. While it is a foregone conclusion that the convenience inherent to portable wireless telecommunications assures that it will always be an integral part of the telecommunications business, the real public policy issue for governments around the world is whether or not wireless technology will be an important part of the public network infrastructure for the 21st century. This raises some obvious questions: 1) can wireless technology meet the service demands placed on a modern network infrastructure?; 2) can this be done at a cost lower than those for wired alternatives?; and 3) if the answer to questions 1 and 2 are yes, then what could (or should) the government do to stimulate investment in a public wireless network infrastructure?

One critical roadblock to obtaining a market based answer to these questions has been the government's historical policy of compartmentalizing wireless network operators by restricting the use of their particular slice of spectrum to one specific type of service(s) and expressly prohibiting entry into the market for traditional telephone services. Finally, however, the *Federal Communications Commission* (FCC) has adopted a new "flexible use" philosophy, and is considering allowing wireless network operators into the market for tradtional telephone services. This is a huge step in the right direction, but is only a beginning. As of this writing the FCC has not removed this barrier to entry, but they are considering it.[1] This chapter begins an investigation of the potential for wireless technology to augment or even replace the traditional wired telecommunications network infrastructure.

The Clinton Administration's characterization of the NII provides the context for the discussion of wireless technology herein. But the Administration has said very little about what the form or substance of that infrastructure would be. For example, will the NII use wireline or wireless technology, or some combination of the two? Will it be digital, analog or both? Will it be capable of "narrowband" voice and data services applications, or will it support multimedia and "broadband" services such as TV or even video telephony? The answers to these questions are simply not addressed in the current version of the Administration's vision of the NII. Therefore, each of these possibilities will have to be considered.

There are some aspects of the future NII which are clearer. There are three basic pillars of the Administration's vision of the NII as an advanced network infrastructure: 1) investment for infrastructure will be privately funded; 2) services will be widely available and accessible to the public (i.e., "affordable"); and 3) the various networks comprising the NII will be compatible or standardized.

Given these principals, what current or future wireless network systems are likely candidates for the NII? Since virtually every household in America already has affordable access to analog broadcast radio, television and cordless telephone service, the NII must represent more. Maybe the NII is best described in terms of new digital television, interactive television, new digital voice and data mobile telephone systems, satellite radio paging and messaging systems?

Such questions must be answered before any meaningful progress can be made in deciding what characteristics make wireless systems candidates for use in the NII. The key is to narrow the field of likely candidates without eliminating the possibility of novel systems that may not even be on the drawing board yet? The way to do this is to focus on the generic role and capabilities of the technology itself, rather than analyzing specific wireless network systems or trying to guess the uses to which the technology will ultimately be put.

For analytical convenience it is useful to view wireless technology as potentially playing a role in three major aspects of the physical NII: 1) consumer terminal devices or cordless "handsets"; 2) the over-the-air transmission network; and 3) the interconnection, or*wireless access*, arrangement connecting a consumer terminal or private network to the nationwide public network infrastructure.

Wireless access, the focus of this chapter, implies the use of a handset and is, therefore, the term that best captures the essence of the role of wireless technology in the NII; it represents the wireless counterpart of the all important on/off ramps to the information superhighway. Of much less importance for the NII is the role of wireless transmission for internodal transport--the "open road" part of the information superhighway. Besides representing only a small fraction of the total cost of an advanced network infrastructure, experts agree that there will be many private industry players and much investment flowing into this segment of the NII using a mix of routing and transmission technologies.

The great potential for wireless telecommunications in the NII is obvious once one considers the basic economics of supply and demand. On the demand side, the raw convenience offered by truly portable, personal and private telecommunications in the everyday activities of all Americans makes it an unambiguous winner in the market place. On the supply side, wireless telecommunications technology is progressing to the point where it meets or exceeds the cost performance and quality characteristics of wireline alternatives for traditional telecommunication services.

4.1 What exactly is "wireless" telecommunications?

The answer to this question is invariably a matter of scope and context. Broadly speaking, the term "wireless" simply refers to telecommunications which does not involve a tether. But this definition is too broad to be meaningful in the context of the NII which places certain minimum requirements on infrastructure network technology (e.g., that it feature capacity and cost characteristics that make it publicly accessible to, and affordable for, most Americans).

Many popular forms of electronic communication already rely on wireless technology but would not be suitable for the NII. Mass market demand for wireless communications has been rapidly expanding for decades, but has generally been limited to use in the immediate household area (e.g., broadcast and satellite TV, radio, and cordless phones). In most cases, non-interactive wireless "networks" using truly portable wireless media have been featured (e.g., PCs and diskettes, video tapes and VCRs, and compact discs and CD players).

Wireless telecommunications in the context of the NII is different. The technology must support two-way real time (i.e., interactive) digital telecommunications. In common parlance, it simply means a *phone without wires*; but, technically, that's what a cordless phone is. So, to be more precise, the wireless phone of the future would be connected via a digital wireless interface to the *public switched telephone network* (PSTN). Just where that point of interconnection would be is one of the most critical, yet fluid, issues being considered by would-be wireless network operators.

Thus, wireless refers to the ability to engage in real time, private, two-way voice and data communications at a distance without the use of wires.

Note that the issue of whether or not wireless systems may support only narrrowband voice and data services or include multimedia and broadband services (e.g., video telephony) is not pre-supposed, nor should it be at this early stage. Any requirement that the future NII include broadband service will depend partly on the government's public policy objective and partly on the costs of achieving it--the latter being the focus of the discussion which follows.

4.2 Portability aspects of wireless access

On the demand side of the wireless market, the convenience aspect of portability poses a substantial inherent advantage over wireline service. Holding constant the quality and price of wireless transmissions, the combination of portability and reliability will be paramount in determining winners and losers in the market place. However, supply side considerations dictate that portability itself is a matter of degree and is directly related to wireless system cost. From a wireless network operator's perspective, meeting consumer demand for a wide range of service capabilities and portability features is potentially very costly.

It is one thing to say that a given consumer application of wireless telecommunications is "portable," but quite another to claim that it is possible to use a portable phone *anywhere*, *anytime*, to call *anyone*. These are the all important three "A"s of portability. The availability of portability anytime is a given, the ability to call anyone is not and will depend on the connectivity of wireless and wireline networks. Portability anywhere is yet another matter.

Anywhere means that a telephone handset will work at home or in the office, or while walking or driving. More formally, there are three possible modes associated with calling anywhere: 1) using wireless access while at the home base station location; 2) moving about (e.g., walking) at a distance from the home base station in a given home base station area; and 3) roaming (e.g., driving) at a distance from the home base station area. The economics of wireless access systems critically depends on the relative costs and demand for each of the three modes of portability. The overall cost of building wireless access systems varies dramatically as portability is expanded from modes 1 thru 3.

These "modes" of portability should not be confused with popular lingo in the cellular phone business today which characterizes as "multi-mode" those "smart" handsets which are capable of changing frequencies. In the lingo of wireless marketing, so-called "dual-mode" handsets are contemplated for switching between paging and cellular service, home area and roaming, or for switching between different types of new digital cellular systems. For example, Nextel is introducing a triple-mode phone capable of performing dispatch, paging, and cellular functions.

To place the three portability modes in context, the stationary or "fixed" wireless mode is akin to using a cordless telephone in the home, office (including wireless *local area networks* (LANs), and wireless *private branch exchanges* (PBXs)), or at another base station location (e.g., shopping mall, airport, bus and train terminal). This mode of operation is the least expensive to provide.

The second portable mode for wireless access, moving about in a given geographic area at a limited distance from the "home" base unit (e.g., walking, driving in town), requires that base station unit(s) provide continuous coverage throughout the local geographic area. Personal/portable phones, pagers, two-way radios, and car phones will work in such situations, whether using radio, cellular, broadcast, or satellite technology. This mode of operation is considerably more expensive to provide than the fixed location mode above, but much less expensive to provide than complete portability.

The third portable mode works even when driving fast in a car potentially far away from home base. Mobile cellular systems are one example of this at work, but satellite-based systems would work as well. This mode of operation is the most costly, so would-be wireless system operators must carefully evaluate the value to consumers of this type of system relative to other more limited systems to assure that the substantially increased costs associated with offering "fast hand-off" mobile capability and "roaming" service capability is worth it.

A single multi-mode handset may potentially function on one or more wireless systems simultaneously for all three modes of portability, providing a full range of portable narrowband voice and digital data services. In addition, all three modes could support a host of other digital services including non-real time messaging (e.g., paging and locator services, data, computing, and fax services) and other transaction services (e.g., "smart-card" debit/credit financial services, electronic databases, information services). There are other more exotic portable applications as well, such as satellite "briefcase" phones (actually a portable earth station) for communicating from isolated and remote locations, air-to-ground phones, and ship-to-shore phones. However, none of these niche market applications is important for the mass market contemplated in the NII which connotes a publicly available infrastructure.

One of the most crucial decisions which prospective wireless network operators face is the tradeoff of consumer demand for the added convenience of multi-mode operation versus the additional cost of providing the sophisticated hybrid network hardware, electronics and handsets necessary to make it all work. Through the use of sophisticated network electronics, digital signal processors, and intelligent control software, any of the three modes of portability may be used in conjunction with one another in hybrid wireless network systems via interconnection arrangements and so-called "overlay" networks used to combine features of different wireless systems.

The network design and cost structure of these systems will be examined in more detail later within this chapter. But first, a basic description of known wireless access alternatives and service capabilities will be discussed.

4.3 Wireless access alternatives

There are many wireless network alternatives. Four major categories of wireless systems which will be discussed below include cellular radio, non-cellular radio, broadcast, and satellite. Within each of these categories there are any number of alternative methods for network access, transmission and routing functions. The basic technical and economic aspects of the most popular wireless access systems, and their acronyms, are briefly described as follows:

1. Cellular--any given geographic market area is segmented into "cells", each with its own radio base station. This arrangement is often cost effective relative to non-cellular arrangements because it allows for the possibility that different users could share the same radio frequencies within a given cell, and allows for re-use of the same frequency spectrum in different cells across the entire geographic coverage area. Depending on network system design criteria, a network operator may utilize relatively large cells ("macrocell"), relatively smaller ones ("microcell"), or even smaller ones yet ("picocell"). All other things being equal, smaller individual cell areas allow for higher system traffic

capacity, but the overall system cost is higher due to the larger number of network nodes (antennae sites) per total system coverage area.[2] Current generation mobile cellular systems use macrocells, and future ones will use microcells or picocells (e.g., *personal communication network or system* (PCN/PCS)).[3]

There are three primary modes of operation for cellular networks, *frequency division multiple access* (FDMA), *time division multiple access* (TDMA), and *code division multiple access* (CDMA), all of which refer to the method by which network operators provide, and individual users access, a particular communications channel. The relative costs and performance of these three access methods will be discussed in the next section. FDMA and TDMA are well known technologies that work. CDMA systems have yet to be deployed and that has given TDMA digital systems a huge head start in the market. However, some major industry players are betting that CDMA is imminent and could even become the predominant technological chioce for digital wireless access systems.[4]

Even within a given cell area, system capacity and unit cost performance may be improved through "sectorization" of the cell into smaller geographic coverage areas via the use of directional antennae and variable powering schemes for handsets and/or base stations to reduce interference. Cell sectorization comes at a cost, but is usually a less expensive method of adding system capacity compared to adding entirely new cells or splitting the older, larger cells into newer, relatively smaller, cells.

2. Non-cellular--this wireless access system is conceptually similar to traditional analog radio networks with a single radio station transmitter serving a given geographic area (e.g., mobile phones, taxi dispatch, emergency services). Such systems typically feature very limited capacity compared to cellular systems, but may be less expensive to develop and operate depending on the type of service being offered (e.g., dispatch and paging services). By using the same methods for frequency sharing as cellular systems (i.e., FDMA, TDMA, CDMA), and "sectorization" of the radio coverage area, it has become possible to dramatically improve system capacity and performance. The leading applications for this technology are called *specialized mobile radio* (SMR) and *enhanced SMR* (ESMR). It is possible to expand the capacity of these systems by migrating to a cellular or "cellular-type" network structure and setting up many relatively low power radio signal repeater sites that may re-use the same frequencies as other such sites within the same geographic coverage area.

From a network service perspective it is not yet clear whether the cost of migrating an existing SMR system toward a cellular structure is a less expensive proposition than building and operating a digital cellular network, even assuming that the service quality of the former could equal the latter.

3. Broadcast radio--traditionally used for one-way analog video and audio service, broadcast radio is being reborn using digital technology to expand system capacity and allow for two-way transmissions. Digital signal processing and compression of video signals have dramatically improved channel capacity and functionality of broadcast

systems ultimately providing for two-way interactive communications including basic telephone services. The most popular systems being considered for the NII are two-way "wireless cable" systems called *multipoint and local multichannel distribution systems* (MMDS and LDMS). There are a number of other system designs featuring more limited capacity, geographic coverage, and functionality including some which are single-channel broadcast systems (e.g., *single master antenna television* (SMATV), *interactive television* (ITV), *low power television* (LPTV)).

The economics of migrating one-way broadcast networks toward two-way digital service capability is unclear as it is in the very early stages of development. To date, it appears that, for a relatively small incremental investment in network electronics, such systems will soon be able to support a digital narrowband upstream data channel for limited consumer interactivity for such services as "pay per view" video, "near video on demand", and, ultimately, "virtual VCR" video service. Most of the consumer cost of subscribing to interactive television services will be for sophisticated electronics to perform the required signal decoder and memory functions in the television "set top" boxes. Voice and video telephony are another matter, however, and the incremental network investments required to provide these services over traditional broadcast networks may be substantial. Whether or not it will prove to be cost effective to upgrade digital radio broadcasting systems to provide for interactive multimedia service, the FCC has at least started to remove a major regulatory barrier to entry into this market, but only for LMDS systems not MMDS. In July 1995 the FCC issued rules which allow LDMS operators to provide services that compete with the fixed wired local service of local telephone companies. The wording of the applicable provision effectively limits LMDS operators to providing basic voice services. It does not permit LMDS operators to provide other enhanced telecommunications services, but it is certainly an important step in that direction.

4. Satellite--these wireless systems rely on orbital satellite transmissions as opposed to terrestrial or "land-based" wireless alternatives. The most popular systems being considered for possible application in the NII are *low earth orbit* (LEOs), *medium earth orbit* (MEOs), and *geosynchronous earth orbit* (GEOs) satellites using high frequency (e.g., Ku and Ka band) radio frequency spectrum. So many new digital satellite systems have been announced that it is difficult to sort out the similarities and the differences.[5]

GEOs have historically dominated the scene for satellite telecommunications for both two-way telephone service and for one-way broadcasting services using C-band radio frequency spectrum. Because of their high orbital altitude (36,000 km), and correspondingly slow orbit period (24 hours), GEO telecommunication systems may achieve effective global coverage with only three satellites. Traditional GEO systems use relatively low frequencies, and therefore require lower operating power levels. Such low powered, low frequency systems required system users to install rather unwieldy (and unsightly) large signal receiver dishes. The first applications of this technology for telephony were made by the traditional C-band public satellite telecommunication network systems such as COMSAT, INTELSAT, and, more recently, PANAMSAT.

The newer GEO systems use higher power levels and frequency bands (Ku and Ka band) to provide one and two-way video and data communications. These satellite systems support popular data networks called *very small aperture terminal* (VSAT) telecommunications systems which use small, unobtrusive and relatively inexpensive signal receiver dishes.

Using the same high frequency bands, new digital GEO systems providing *direct broadcast satellite* (DBS) services are being deployed to provide digital video broadcasting direct to the home. As in the case of traditional land-based broadcasting systems, new digital signal processing techniques will continually expand the capacity and functionality of many types of satellite broadcast systems, ultimately allowing for two-way voice and data transmission. The FCC's flexible use spectrum policies may be extended to allow DBS networks of the future (or, for that matter, any other broadcast satellite networks) to provide two-way voice and data services. One persistent problem faced by GEO broadcast video and data systems wishing to migrate toward two-way voice service capability is the inherent transmission delay time associated with geosynchronous orbit "uplink" and "downlink" which causes annoying echo and cross-talk in voice telephone calls.[6] While such problems have always existed with traditional C-band long distance telephone systems, consumers will be less willing to tolerate it when good substitutes are available for global transmissions like trans-oceanic cables.

LEOs and MEOs are low-flying satellites which reduce considerably the problems of signal delay in GEO systems, making them more acceptable for voice services.[7] Such systems require that more satellites be launched and maintained or replaced. Whereas GEO systems may achieve effective global coverage with only a few satellites, MEO systems require 10-15 satellites with an orbit altitude of 10,000 km and orbit period of 6-12 hours. LEO systems require more than 48 satellites at an altitude of only 700 km and orbit periods of about 1.5 hours.[8] One proposed LEO system, Teledesic, uses hundreds of satellites. In the near future (pending final approval from the FCC), new global and domestic *mobile satellite systems* (MSSs) using the higher frequency Ku and Ka bands will begin providing two-way voice and data services. These systems are being planned and financed by many major communications companies. Pending other FCC decisions regarding spectrum allocation, still other future satellite systems are targeting not only mobile but also otherwise fixed telecommunication service markets which could ultimately compete directly with traditional wired voice and data telephone networks.

Given the level of business activity that is already occurring, it is safe to say that all of the four categories of wireless services discussed above will be players in some portion of the NII. Some of them, perhaps even most of them, will be only very small players. The relative cost and service advantages of each will dictate which ones ultimately become viable for mass market deployment.

4.4 Functionality of wireless

There is considerable dispute within the telecommunications industry as to the service "functionality" of wireless access. In other words: what functionalities are possible using wireless access (e.g., analog/digital switching and transmission, narrowband and broadband signal speeds, circuit and packet switching and transmission, routing, network control), over what types of networks (e.g., cellular, SMR, broadcast, satellite), to provide what range of services (voice, video, text, data), capable of satisfying what types of end user applications? The answer to this series of questions is: all of the above. It is simply a matter of network cost and the cost and availability of RF spectrum.

The functionality of wireless transmission is potentially universal, just as it is for wireline transmission, with one obvious benefit on both the supply and demand side of the market equation--it is portable ("untethered"), and does not require costly installation because there are no physical transmission cables or wires. The actual functionality of wireless access (as opposed to wireline access) is directly related to the government's willingness to provide sufficient usable frequency spectrum so as not to limit its capacity, and, in turn, its service capabilities. The more relevant questions then become: in light of what we know or can forecast about the government's spectrum allocation policies, what functionalities will various types of wireless access systems be able to provide, and what types could be cost effectively provided vis a vis wireline alternatives?

Among the technical improvements in digital telecommunications technology, advances in wireless signal processing techniques to enhance network functions such as, access, routing, transmission, control, message encoding and encryption, will continue to improve system functionality and performance. It is already known that any of the four types of wireless access either can now, or will soon be able to, utilize digital technology to perform both circuit and packet network functions capable of providing two-way voice and data telecommunications. However, some of the wireless network alternatives have a huge head start (for example cellular mobile service started back in 1984), while others have just begun to be developed or have yet to be conceived (for example local lightwave telecommunications using so-called "photonic phones" are on the horizon).

The following section on wireless access network cost structures and cost estimates includes underlying assumptions regarding the amount of frequency spectrum available to each individual network operator in a given stylized geographic area and will therefore indirectly address the issue of system functionality. Of course, it is very dangerous at this early stage of technology development and deployment to presuppose the functional uses to which wireless access systems will be put, especially in business markets with highly specialized applications and system requirements.

It remains to be seen whether or not portable wireless access systems will be capable of providing for two-way or interactive real-time video telephony. Some of the systems could potentially do so, but only at a significant incremental cost above narrowband digital service. Most experts agree that such cost is at least high enough to preclude it from being universally available to the mass market of *plain old telephone service* (POTS) subscribers, making it ineligible for the NII. What's more, from a practical perspective, it is not likely that most people will be watching TV while on the move using digital wrist watches or pocket phones. It is most likely that people will be stationary when participating in activities involving broadband telecomunications.

Upgrading a two-way narrowband voice and data cellular telecommunication system for broadband telephony or "bandwidth-on-demand" service requires enormous capacity additions and financial investments to current, and even planned, systems. Expansion of capacity in wireless systems, especially those capable of handling both mobile and fixed services, implies additional expenses for support structure and scarce public rights-of-way (e.g., light poles and rooftops) for additional antennas, transceivers and associated electronics; whereas, for wireline systems, broadband capacity expansion can generally be accomplished by adding digital processing equipment within the existing support structure and rights of way.

Picture a fixed fiber optic or coaxial cable phone connection from a subscriber location to a network node which, in turn, is connected to a fiber-optic backbone network. Compare that to expanding capacity on wireless connections requiring "line of sight" connections in a mobile environment. Once the initial network system is constructed, it is generally less expensive to expand capacity on the fixed wireline network connections which do not require line of sight. Frequency spectrum limitations of wireless systems notwithstanding, the additional electronics and new cell sites required to significantly expand wireless network system capacity is relatively expensive compared to similar incremental capacity expansion of an existing wireline network system.

Unless there are radical and, as yet, unanticipated, advances in both wireless access technology and the FCC's spectrum allocations, the future vision of integrated broadband access offering end-user bandwidth-on-demand type service will likely be reserved to the province of wireline technology.

Rather than thinking of integrated bandwidth-on-demand service as an extension of next-generation narrowband cellular systems, it is much more likely that wireless technology, should it become the vehicle for the information "super pipe" of the future, will develop as an extension of next generation digital broadcast and satellite systems, such as two-way MMDS, LMDS and DBS systems. Like wireline systems, these wireless systems are primarily designed to serve fixed service demand. Therefore, line of sight and support structures are only significant issues for the initial deployment of the network, not for capacity additions to serve increased demand for bandwidth. Still, the additional costs associated with electronics for providing two-way bandwidth-on-demand service, combined with existing limitations on frequency allocations effectively make this scenario an unlikely alternative to the wireline solution.

While there is no doubt that the specific areas of the frequency spectrum which are, or will be, assigned to digital wireless access systems of all types will be nominally capable of providing multimedia and broadband telecommunications (including video telephony), the significant issue is the bandwidth of the particular slice of spectrum licensed to any one network operator, which may easily be less than that required to support mass market multimedia and broadband services featuring simultaneous (and random) access by network subscribers. Given the relatively small slice of spectrum which the FCC has licensed to individual wireless PCS network operators (no more than 40 MHz in a geographic market area), it is clear that these operators are not going to be in the multimedia or broadband business for the mass market.

This is not necessarily true, however, in the case of satellite and other broadcast radio network systems, which may be licensed with sufficient spectrum to provide for any type of digital multimedia service including broadband video telephony. While technological advances on these types of wireless access systems will eventually make it possible to provide an integrated bandwidth-on-demand service capability, it is not probable that scenario will ever be realized for the mass market unless the FCC allocates even more frequency spectrum to this industry segment.

4.4.1 Frequency spectrum and wireless system functionality

Cost and service characteristics inherent to a given wireless access system notwithstanding, all types of wireless access facilities require radio frequency spectrum to function. The potential for success depends on the FCC's procedures governing the allocation and licensing of spectrum. Allocation refers to the amount of spectrum and the specific uses to which it may be applied. Licensing refers to the FCC's assignment of the exclusive rights to use a portion of the allocated spectrum to a company in a particular geographic area. Usually this right to use the spectrum is granted subject to provisions specifying the types of services which may be provided, and stating that it is granted only for a temporary (but not always specified) time period. Thus, quite apart from the issue of technical cost and service advantages inherent to any particular technology or network design, the scales of competitive advantage may be tipped in favor of one type of wireless access system or another depending on FCC spectrum policy.

The FCC is in the process of implementing an entirely different regime of flexible spectrum allocations and market-based licensing procedures (i.e., auctions), while "grandfathering" its past non-market-based decisions.[9] Beginning with the spectrum allocations and licenses for PCS services, the FCC has allowed licensees to provide whatever services they wish (except broadcast and point-to-point microwave services). This new flexible use policy, which the FCC has adopted as a pillar of its new market-based spectrum allocation policies for the future, should be expanded to include other portions of the radio frequency spectrum. For example, if broadcasters were allowed to use (or offer to others for use) their spectrum endowments under current and future licenses, then such spectrum could possibly serve as a platform for two-way digital telephony in the NII.[10]

Specifically, in the future environment, traditional analog broadcast video channels may be digitally compressed resulting in dramatic increases in spectrum efficiency to support many more channels per unit of radio bandwidth, including upstream voice and data channels. This would argue for the FCC to expand its flexible use policies so that broadcasters and wireless cable systems may become full players in the NII by providing two-way digital voice and data services.[11] Once the FCC's service restrictions are removed from current broadcast spectrum licenses, the playing field among competing wireless access alternatives is leveled to the point where the least-cost network systems could emerge to compete with the wireline systems of cablecos and telcos.

Expanding the FCC's flexible use policies puts a very complex twist into any analysis of potential winners and losers in the market for wireless access alternatives. But this is a market risk which must be accepted by the wireless players as they vie for market position. That is not to say that the FCC should be empowered to randomly, and without notice, be able to change its spectrum policies with the effect of devaluing existing, or future, licenses. This would create tremendous uncertainty among prospective wireless system network operators and could seriously dilute the value of (and the monetary bids for), new spectrum licenses. What it does mean is that the FCC must make clear its long term intentions regarding spectrum policy: that it will gradually and deliberately expand both the spectrum allocations and the flexible use rules.

In any event, the FCC's spectrum policies going forward must try to balance the business risk associated with investing in new communication networks with the interests of consumers seeking more market choices and lower costs. The FCC should generally opt for those policy options which favor the latter over the former. The old spectrum policies did as much to protect the business interests of competitors as it did to promote the interests of consumers. The new policies are pointed in the direction of reversing this situation and should be aggressively pursued.

For purposes of the technical analysis to follow, to the extent possible, the impact of FCC spectrum allocation policy *on any given* wireless access alternative will be considered neutral as among alternatives within the four categories of technologies listed above.

However, *between and among* wireless access alternatives this assumption is problematic for two reasons. First, the total bandwidth allocated within any geographic area between competing wireless access systems will potentially affect the per unit costs of providing service, and, in turn, could dictate winners and losers in the market place. Second, regardless of the absolute amount of spectrum associated with a given license, the old service restrictions, which were conditional with the granting of the license, severely limit the market opportunities available for any type of wireless system, and, in turn, may be enough to dictate winners and losers in the market place. If the FCC is serious about extending its new flexible use policies beyond those for the relatively narrow PCS bands, they should begin the process as soon as possible so as to allow all types of wireless access systems to achieve their full potential in the NII.

Invariably, spectrum allocation rules for a given technology/service type will, in practice, directly affect its relative cost performance. The primary reason is that the total amount of spectrum allocated to a wireless service, or that portion granted to one licensee, (e.g., 30 MHz out of 200 MHz total allocation), along with its corresponding underlying network/technology (e.g., PCS/TDMA), and exactly where in the range of electromagnetic spectrum (e.g., 1.8-2.0 GHz) that particular allocation lies, in large part determines the cost, performance, and market viability of a given wireless access system. A full discussion of such issues is beyond the scope of this analysis, but the implications of known spectrum licensing rules for wireless system economics will be evident in the cost and service evaluations to follow.

The implication of the FCC's current spectrum policy for new digital wireless access systems is that, while these systems can fare well in the NII (as a narrowband service platform in the case of PCS or as a one-way broadband service platform in the case of wireless cable), they will not fare well if the vision of the NII includes broadband telephony. The reason is that when the FCC licenses spectrum, it has traditionally done so with very strict spectrum usage limitations. For example, when the FCC allocated SMR spectrum, it issued licenses to individual applicants with a very strict proviso that it only be used for local radio dispatch services. Recently, that restriction has been relaxed to allow for provision of new two-way narrowband telephony.

The same practice is true, but somewhat less so, under the new flexible use rules that the FCC is applying to its recent spectrum allocations for PCS services. While a licensee is allowed to use the PCS spectrum for any service it wants (except broadcast and point-to-point microwave service), it is assigned so little spectrum that there is still an implied or effective service limitation. By limiting any given service provider to 40 MHz of PCS spectrum in a given geographic area, the FCC is effectively precluding them from mass market broadband service applications like video telephony. In other words, if very many system subscribers chose at any point in time to access multimedia and broadband telephone services, the system capacity would quickly exhaust leaving no room for other users to sign on.

Thus, under the FCC's current spectrum policy, the market for two-way broadband services will be the province of wireline access alternatives, primarily fiber optic and coaxial cable, perhaps in conjunction with satellite and other land-based broadcast networks. The irony of this may be that the FCC, in the name of promoting digital wireless technology, has simply not allowed for wireless access to be the technology of choice in the race to develop a fully integrated broadband network system, leaving the winner's circle to wireline access alternatives. However, this is not a criticism of the current Administration or the FCC, both of which favor changing the rules to liberalize spectrum usage restrictions. Indeed, the current policy has been constrained by historical practices which can only be gradually changed over time. The past restrictive spectrum use policies were not a serious problem in the days when digital radio services were non-existent or nascent and the public demand for spectrum was relatively low. Nevertheless, it remains important for the government to aggressively pursue the new policy direction toward flexible use so that the NII may develop unencumbered by obsolete spectrum policies.

In any event, it still remains to be seen if, in the very long run, the market for a wireline information "super pipe" to the home will ever become financially viable in the presence of cheaper, non-integrated alternatives, including digital wireless access and digital broadcasting systems.

4.4.2 The cost of frequency spectrum

Since 1993, the FCC has raised about $9 billion from auctions of radio frequency spectrum for new digital services. The first auctions were for relatively low valued spectrum for interactive television and regional and national paging services. Since then, interactive TV has gone nowhere as a service while paging has grown very rapidly. The early auctions only generated about $2 billion, compared to frequency spectrum auctions for PCS which concluded on March 19, 1995 and generated about $7 billion. The top bidders were established companies with deep pockets including, in the top three, the telco-cableco consortium called Wireless Co ($2.1B--Sprint, TCI, Cox, and Comcast), AT&T ($1.8B), and PCS Primeco ($1.1B--AirTouch, Bell Atlantic, NYNEX, USWest). In response to the future development of digital television broadcasting, the FCC is considering extending the auctions to new (or even existing) broadcast frequency spectrum. If it does, it could bring in another $100 billion dollars in bid revenues.[12]

The up-front cost of purchasing the rights to use the radio frequency spectrum, either via FCC auction or by purchasing it from an incumbent, is substantial. This situation causes many bidders to complain that auctions, rather than posing a market opportunity, are actually a barrier to entry. However, bidding merely implies that there is a perceived financial payoff from owning the license, and that perceived benefit is at least as high as the bid price. Thus, the cost of the license for the rights to use a slice of RF spectrum is very straightforward for a prospective system operator to incorporate into a business case analysis. It simply represents a (potentially huge) start-up cost which is amortized over the system life or other planning horizon. Presumably, there is also a (potentially huge) salvage value of spectrum rights as well. The overall effect may be just like having money in the bank. Indeed, spectrum itself can be banked; just like oil in the ground and fallow land held for future use, there is latent value inherent to some types of stored assets and spectrum happens to be one of them.

As an up-front, fixed cost, once incurred, spectrum cost has little real impact on future competitive market outcomes. In a financial model, spectrum license fees are simply rents assigned at the outset to either the government or incumbent private interests, depending on which has the spectrum rights. Therefore, any would-be market entrant must offset this amount against the *net present value* (NPV) of cash flows from network operations.

This is not to say that the start-up costs of spectrum cannot be so substantial as to give a would-be wireless access operator serious pause to enter the market. Only that, no matter what the up-front cost of spectrum, an incumbent or entrant firm will make a bid for it unless there is simply no profit to be made by entering the wireless access business. In that case no one would come forward to bid for spectrum and the government would have to re-evaluate its spectrum allocation and licensing policies.

There is also the risk of overbidding for an FCC license, especially if the FCC does not guarantee that additional spectrum would not be allocated in the future, thereby diluting the value of a license purchased today. However, this is hardly a legitimate complaint against the government's auction. In a world of uncertainty, the risk of overbidding is always there.

This is a very important point because there are many who believe that the auctioning of spectrum would discourage market entry, or otherwise distort market outcomes, due to the apparent asymmetry of requiring new wireless access network operators to purchase spectrum when incumbent firms (or, for that matter, future entrants) may be endowed with "free" spectrum. This would be true except that incumbents, too, have an opportunity cost and market value associated with their own spectrum endowments. Therefore, the spectrum auction fees are really just a one-time assignment of the rents associated with spectrum rights to the government instead of the private sector. The net effect on market entry and network operations of either the new wireless network operators or the incumbents should be neutral, with one important caveat -- that either is free to compete with the other if they choose to and are willing to pay for the privilege.[13]

This is a non-trivial caveat. If the government were to regulate and limit the uses to which spectrum could be put, then there is the possibility that competitive market outcomes would be precluded and that monopoly quasi-rents associated with spectrum rights would exist. In the case of wireless access for PCS services, the government has followed the advice of economists and has not restricted the uses to which the new spectrum allocated for wireless access could be put.[14] In turn, the government has not precluded incumbent cellular operators, previously endowed with spectrum via so-called "set asides" of half of the spectrum to PSTN operators and the other half, via lottery, allocated to non-PSTN operators, from using it for new wireless access services.

The FCC's flexible use policy for spectrum allocated to PCS is totally new and represents a true sea change in spectrum licensing policy.[15] However, the FCC still retains strict rules limiting how the vast majority of licensed RF spectrum is used. For example, broadcast spectrum cannot be used for non-broadcast services, and spectrum allocated to wireless telecommunications cannot be used for broadcast services or point-to-point microwave services.

Critical to business case analysis of wireless access operators is the uncertainty and risk associated with changing FCC spectrum allocation policies, and whether or not more total spectrum will be assigned to wireless telecommunications. For example, in the future, the FCC could, in further pursuit of its new flexible-use rules, allow UHF spectrum, which lies adjacent to cellular spectrum, to be used for wireless telecommunications. Or the FCC could allow wireless cable spectrum, which lies adjacent to PCS spectrum, to be used for telephony. This would represent a veritable flood of additional spectrum into a competitive wireless telecommunications market, diluting the value of the licenses of the early licensees.[16]

In pursuit of its objective to allocate spectrum for use by wireless service entrepreneurs and innovators, Congress has ordered that another 200 MHz of RF spectrum below 5 GHz be reassigned from government to private sector use. While the process of reallocation of all 200 MHz may take up to 15 years, the FCC has since requested that the government immediately specify and transfer 50 MHz to be allocated for unlicensed private wireless telecommunication services and has invited comment on who should be able to use it.[17]

4.5 Mass market demand and supply

When considering the market efficiency or desirability of various technologies for the NII, it does not really matter what the *ex-ante* market supply conditions are if *ex-post* market acceptance never materializes. Successful market entry will hinge on issues of service choice, quality, convenience and low prices. The market cannot be ignored when developing government technology and competition policy. Successful market entry into the wireless access business will require that a system feature portability, that it is interconnected to those not on the local system, and that its (quality adjusted) price is affordable.

The costs of making a call on wireless networks is, and will, for some time to come, continue to be more expensive than wireline network calling, partly because it actually costs more to provide the service and partly because there is a willingness to pay a premium for the convenience of portability. The clearest evidence of this for the mass market is the explosive growth of cordless telephone units in spite of their relatively high price - on average about four times that for a wired telephone. The cost of usage is the same for both, so this is a good metric for evaluating the value to consumers of portability, at least for fixed-base-station service.

While it may cost only a dollar to make a cellular phone call from a car, that same call from a remote location or a cruise ship can easily cost ten times that. Of course, part of the reason is the lack of alternatives in captive markets, just like pricing food services in a ballpark, but part is also due to underlying costs of providing the service. Communicating while "on the move" has always cost more than standing still. Calling long distance has always cost more than calling locally, and so on. Even when considering using a satellite service, which, due to the nature of the technology tends to be distance insensitive, there are still significant issues of the technology and cost of transporting the call to the exact location of the called party, who may be on the move.

It is obvious that consumers accessing the NII would like their portable phones to work in all three portability modes providing a full range of services. But not if the price is too high. There is always the option of having two or three different phones and putting up with the hassle of having to remember to always have the right phone in the right place. Many Americans already have a cordless and cellular phone in addition to their normal wireline service and inexpensive pagers are now rapidly being added to the mix.

Nevertheless, there is a huge debate raging among experts on the demand side of the wireless future as to whether or not people will continue to buy so many different phones and at what price, even if each one is relatively cheap compared to a triple-mode phone. Indeed, as cellular phone operators have discovered, the price which consumers face for handsets, as well as the cost of making a call, is an important determinant of mass market demand. Regardless of one's conviction that many consumers will pay a premium to avoid the hassle of owning more than one phone for each mode of operation, the mass market will remain very price sensitive. Therefore, to assure a high level of residential demand and mass market penetration the incremental cost to consumers for handsets featuring multi-mode operation had better be somewhere close to the total cost of owning different handsets. Consumers today seem to be able to put up with the hassle of owning a separate pager, cell phone, and *cordless telephone* (CT) unit without too much complaint.

Residential local phone calls are provided "free" almost everywhere in the U.S.. Only a few states charge for local PSTN calls and even then the charge is quite low at 1-2 cents per minute. This means that whatever the costs of providing for local phone calls, the telephone companies recover it from the monthly charges on other services, especially business phone lines, or from long distance services. This fact makes it very difficult, if not impossible, for independent wireless network operators to enter and compete in the mass market for local telephony because it is hard to compete against a zero price for usage when there is no source for subsidizing such entry (e.g., toll calling revenues). This sets the mass market entry price "bogey" for wireless companies to be in the range of monthly charges that incumbent wireline telephone companies charge for local service, which currently runs about $18 per month per household nationwide.

This also helps to explain why interconnecting carriers, especially long distance companies interested in becoming the beneficiary of their own payments to local telcos, are at the forefront of those clamoring to get into the wireless access business. For example, AT&T's takeover of McCaw cellular allows for the possibility that McCaw customers will be saving on payment of subsidies associated with their calls using AT&T, which, in turn, saves by reducing the amount it must pay out to the local telephone companies for access to the PSTN.

Cable television companies are the next most logical entrant into the market for local telephony as they see their use of wireless access as a two-way voice and data channel which allows them potentially to become a full service multi-media communications provider. Cable companies and other independent wireless network operators however, face the daunting prospect of paying high prices for interconnection to the telco's PSTN facilities to guarantee nationwide service capability to their subscribers. No wireless access system can become a viable market player unless ubiquitous call terminations anywhere in the country can be achieved. Current local telco interconnection charges are very high at an average $.07 per minute. This is so high as to be the single highest non-network operating expense of potential wireless access service providers.[18]

The FCC has often stated that it believes that wireless access services are the best hope for introducing competition into local telephone service markets. If this is to be the case, then Federal and State regulators need to level the playing field of market entry by reducing toll and interconnection charges and business service cross subsidies by deregulating the local and toll charges of incumbent wireline carriers.[19] If this is not possible, then the Administration and the FCC had better plan on seeing some very familiar faces on the wireless scene as incumbent suppliers jockey for position to bypass one another (or even themselves) using the new wireless network alternatives to save on paying cross subsidies.

Unfortunately, the new telecommunications law is not very much help in this regard. While the new law does contain suggestions for reforming PSTN access charges, it also recommends that all service providers interconnecting to the PSTN (which, by definition, includes new wireless network operators) share in the burden of cross subsidizing the ongoing costs of funding the universal availability of advanced wired networks. In years past, this cost burden was largely borne by long distance service providers in the form of PSTN access charges. Now it may be applied to wireless operators as well. This would be sure to substantially increase the costs of interconnection for wireless network operators. On a more positive note, the new telecommunications law does eliminate requirements for *commercial mobile radio service* (CMRS) providers, which encompasses all cellular carriers, to provide so-called "equal access" to their systems. This allows for cellular carriers to join together in exclusive dealing and interconnnection arrangements with long distance service providers or others, increasing the opportunities for cellular carriers to bypass the networks and local access charges of traditional local exchange carriers. However, for terminating cellular calls to wired public network subscribers, it will always be difficult to bypass the high access charges of local telephone companies.

For now and the foreseeable future, local telephone companies cross subsidize a portion of the costs of providing basic local exchange service from profits on business services and access charges paid by interconnecting toll carriers. This artificially raises the price of interconnection to the public telephone network for toll carriers and lowers it for the interconnected local networks. Eliminating all or a portion of the artificial cost burden this places on interconnecting toll carriers, and, in turn, the cost benefit it confers on local telephone companies, will cause interconnection charges among local telephone companies to rise and this will dramatically reduce barriers to entry in markets for local access and transport services.

While it is entirely possible that, under deregulation, the same telephone companies and cable television companies would eventually dominate the new wireless markets anyway, it would be preferred for the FCC to allow entry on an equal footing to new entrants if, as the FCC has stated more than once, its new wireless policy is to "let a thousand flowers bloom."

4.6 Cost structure of wireless communications

The conceptual model of a wireless access network system is simple. Just like all radio communication systems, wireless access is fundamentally a "line of sight" technology. The basic characteristics of wireless network systems are illustrated in the stylized network in figure 4.1. This simple generic system includes the essential aspects of all digital land-based systems now being considered for the NII, some of which are up and running in actual test market applications and most of which are still in the prototype testing or development phase.

Figure 4.1 Basic characteristics of wireless access system.

Wireless access systems in the NII will be "open" networks allowing for public access on demand for both call originations and terminations (assuming system capacity and spectrum utilization is engineered to meet demand in a given market area). This is not to say that the handsets or other consumer terminal devices which are required to access the wireless network are themselves "open." While most wireless access system network operators in the NII will need to conform to generic *network network interface* (NNI) requirements, this is not necessarily the case for the *user network interface* (UNI) connecting user terminals to the network. Many local wireless network operators, especially very large ones, may use proprietary signaling protocols for transmissions between handsets and base stations depending on the particular choice of technology and network control software.

In figure 4.1, a base station tower is connected to a subscriber's handset for two-way digital transmission. This connection may or may not pass through other network node points between the tower location and the handset depending on the type of wireless access system. Each base station is potentially also connected to another base station tower in the network or through a network switching center which is itself connected to the PSTN so that calls from the subscriber handset can terminate anywhere. The Mobile Switching Center or MSC is a primary network node which represents the control point of the wireless access system. The MSC is the "brains" of the network and performs complex network operation and control functions, including, in cellular systems, call hand-off. For roaming functions and other future intelligent network functions (e.g., call waiting, three way calling), the MSC communicates via a packet data link with a *home location register* (HLR--not shown in figure 4.1). The HLR is a computerized database which keeps track of the locations of mobile units and performs other functions yet to be determined.

The counterpart of the MSC in analog systems is the *mobile telephone switching office* (MTSO) which serves as the network host node for existing mobile cellular systems in North America (*advanced mobile phone service* (AMPS)). In a network system, the MSC node will be interconnected, usually by high-capacity wireline or point-to-point microwave radio trunks, to the PSTN. In certain types of single coverage area wireless access systems (e.g., SMR), the MSC node location may also serve as a *base station* (BS) connected via RF links directly to subscriber handsets. In cellular network systems, the

MSC serves as a digital host network controller connected via microwave or fiber optic links to one or more BSs, also called *base station systems* (BSSs). Figure 4.2 illustrates a BSS. A *base station controller* (BSC) is the host node of a BSS. The BSC performs basic network functions such as channel allocation, link supervision, transmitted power level control and transmission of network signaling information. The BSC serves remote nodes called *base transceiver stations* (BTS). In cellular systems, the BSC could be connected to BTSs via either wireline or wireless trunk connections.

Figure 4.2 Base station.

Conceptually, newer land-based wireless access systems are no different from the way an old-fashioned Mobile Telephone System (MTS) works. But this is where the similarities end. The poor signal quality, lack of privacy, small coverage area, short distance and congestion typical of old analog two-way radio systems would never have developed into full mass market penetration because nearly every household already has ready access to a regular phone line to obtain high quality telephone service.

To overcome the list of problems with traditional analog two-way radio services, digital wireless access systems are immensely more complex. Through the use of sophisticated microelectronics, digital wireless access systems are potentially able to meet or even exceed current wireline network quality and reliability for voice and data services. There are now several wireless network systems contending for prominence in the NII featuring unique network design characteristics and cost structures.

4.7 Wireless access network characteristics and costs
This section describes the basic network design for the four types of digital wireless access systems described briefly in the first section: a. cellular, b. non-cellular, c. wireless cable and, d. satellite.

4.7.1 Cellular
This category of digital wireless access systems includes all types of cellular configurations regardless of the size of the individual radio cell (macrocell, microcell, picocell, etc.). For purposes of discussion, digital *cordless telephone* (CT) technology will also be discussed even if it does not conform to the cellular radio model because it is likely to be used in conjunction with some cellular systems. The basic wireless access network described in figure 4.1 and discussed earlier featured all of the basic building blocks of digital cellular networks. The primary distinction between different cellular network configurations is the size and structure of the cells and, in turn, corresponding differences in system signaling, handset power levels, channelization schemes, co-channel interference and reuse factors.

Digital AMPS (AMPS-D)
Digital signal processing techniques will ultimately allow for substantial capacity gains over AMPS. In the US, the purpose of first generation digital cellular systems is primarily for upgrading analog AMPS systems to expand network capacity. This is not true in other

developed countries where digital cellular systems are separate from older analog mobile systems, or in less developed countries where analog systems were never deployed.

AMPS utilizes *frequency division multiple access* (FDMA) techniques and AMPS-D systems use the more efficient *time division multiple access* (TDMA) techniques. To allow for a smooth migration of subscribers from old to new technology AMPS-D systems are designed to operate in "dual mode" with current AMPS systems (i.e., using a portion of the same 25 MHz spectrum licensed to AMPS operators). Now that the FCC has allocated an additional 120 MHz of radio spectrum to PCS there will soon be new TDMA network operators on the scene.

Just as in the application of time division multiplexing in the PSTN, digital radio TDMA techniques allow AMPS operators to expand capacity by sharing the same communication channel among users. Digitally enhanced versions of AMPS (e.g., Narrowband AMPS or NAMPS) provide an effective short term method of expanding the capacity of AMPS cellular systems and provide a bridge to deployment of fully digital systems.[20] Under the IS-54 North American TDMA standard, NAMPS uses the same bandwidth per carrier channel as AMPS (30 kHz), but by allowing three users to share it, the bandwidth per voice channel is only 10 kHz (20 kHz duplex) instead of the full 30 kHz (60 kHz duplex), for a three to one capacity gain

Tables 4.1, 4.2, and 4.3, taken from Uddenfeldt (1991), are valuable for gaining a basic understanding of some distinguishing characteristics of leading alternative digital cellular systems. Table 4.1 provides a comparison of digital cellular standards for European, American, and Japanese systems. Table 4.2 compares them to the capacity of current North American AMPS systems. Table4.3 provides the basic distinguishing characteristics of macrocell, microcell, and picocell systems.

Table 4.1
Comparison of digital cellular standards for European, American and Japanese systems

	GSM	ADC	JDC
Access method	TDMA	TDMA	TDMA
Carrier spacing	200 kHz	30 kHz	25 kHz
Users per carrier	8 (16)	3	3
Voice bit rate	13 kb/s (6.5 kb/s)	8 kb/s	8 kb/s
Total bit rate	270 kb/s	48 kb/s	42 kb/s
Diversity methods	- Interleaving - Frequency	- Interleaving	- Interleaving - Antenna

	hopping		diversity
Bandwidth per voice channel	25 kHz (12.5 kHz)	10 kHz	8.3 kHz
Required C/I	9 dB	16 dB	13 dB

Notes: GSM - European Standard
ADC - North American Standard
JDC - Japanese Standard

Table 4.2
Comparison of capacities of European, American, Japanese and current North American AMPS systems

	Analog AMPS (ref)	GSM Full rate	GSM Half rate	ADC	JCD
Total bandwidth (B_t) in Mhz	25	25	25	25	25
Bandwidth per voice channel (B_c) in kHz	30	25	12.5	10	8.33
Number of voice channels (B_t/B_c)	833	1000	2000	2500	3000
Re-use factor (N)	7	3	3	7	4
Voice channels per site (M)	119	333	666	357	750
Erlang per sq. km (3 km site - site distance)	12	40	84	41	91
Capacity gain	1.0(ref)	3.4	7.1	3.5	7.6

Table4.3
Basic distinguishing characteristics of macrocell, microcell, and picocell systems

	Macrocells	Microcells	Picocells
Bandwidth allocation	11.34 MHz	1.26 MHz	1.26 MHz

	(11134 channels)	(126 channels)	(126 channels)
Channel allocation	Fixed	Adaptive	Adaptive
Transmit peak power per voice channel	6 Watt	0.6 Watt	0.03 Watt
Antenna configuration per site	120^0 sector	Omni	Omni
Erlangs per site	148	6	2
Site - site distance	3 km (hexagonal)	0.3 km (rectangular)	0.06 km (rectangular)
Erlang per sp. km and Mhz	1.6	52	2300/floor
Erlang per sq. km	18.2	66	3000/floor

In the current macrocell environment, the capacity of a cellular system is normally determined by calculating the number of simultaneous users M per base station cell site for a given amount of RF spectrum, B(t). The system capacity therefore is: M=1/N [B(t)/B(c)], where B(c) is the equivalent bandwidth of a voice channel and N is the RF reuse factor. Table 4.2 shows that current generation digital cellular systems using TDMA offer 3-8 times the capacity of AMPS systems without adding new cell sites or resorting to microcell deployment. AMPS-D is at the low end of the range.

Lee (1993) has also estimated the capacity gains when comparing new digital cellular systems with AMPS. Using a fixed amount of spectrum for a radio carrier channel (1.25 MHz), AMPS FDMA systems feature a capacity of 6 radio channels per cell, while TDMA features a capacity of 31 channels (5 x FDMA). Code Division Multiple Access (CDMA) techniques, which are relatively new in commercial applications, offer system capacities of 120 channels (20 x FDMA).[21]

The per subscriber capital costs of current AMPS systems is about $700-$1000.[22] The per subscriber capital costs of AMPS-D systems (TDMA) is much lower at about $300-$500.[23]

Global System for Mobile communications (GSM)

The earliest and most prevalent global standard for digital cellular service is the European GSM (TDMA) standard. GSM, like North American cellular radio telephone systems, operate in two distinct frequency bands which the government has allocated to cellular mobile (900 MHz) and PCS services (1800 Mhz GSM and 1900 Mhz U.S.). For obvious reasons, it is important that these two systems may interwork with one another and GSM has proven that they can. Many GSM systems are already operating or are in the deployment phase throughout the world. The newer version 1800 Mhz GSM systems are called DCS 1800.

GSM TDMA techniques can achieve considerable capacity gains over AMPS (about 7 to 1, see table 4.2). While the US has already adopted the interim IS-54 (TDMA) standard for AMPS-D, it is still possible for new US wireless access network operators, or incumbents for that matter, to adopt GSM techniques.[24] Indeed, large GSM system equipment vendors (e.g., Ericsson) will be targeting U.S. markets to compete with North American standards. In allocating cellular spectrum for PCS, the FCC has left wide open the choice of wireless access scheme. Carrier channels in GSM have considerably more bandwidth than those in AMPS-D, and therefore may handle more voice channels per carrier. But, the real advantage of GSM's wider carrier channel bandwidth (200 Khz) may be the migration from supporting voice to multimedia and high speed data services. The per subscriber costs of GSM systems are in the range of those found for AMPS-D.

To expand the capacity of digital macrocell networks like AMPS-D and GSM, antenna diversity and cell sectorization techniques may be employed. For example, the transceivers and associated omnidirectional antennae at BTS cell sites may be reconfigured by employing directional antennae to split the cell into sectors, like slices of a pie. In addition, altering the power output to distinguish handsets according to near/far conditions is another technique which may be used to gain capacity within the cell area. In this case, the cell is split into concentric zones based on distance from the antenna location, rather than like slices of a pie.[25] It is also possible for cellular system operators to adjust cell sizes and cell coverage areas using combinations of directional antennas and powering schemes.[26]

Increasing capacity to handle increased demand in wireless access systems often simply involves the placement of more transceivers on an existing BTS tower. For example, assume that service begins by placing a single omnidirectional antenna on a tower serving a single carrier radio channel. In a GSM system, a single radio channel is time multiplexed into 8 virtual channels, 7 of which may be accessed by subscribers, and one of which is reserved for network functions. To increase capacity, a BTS cell may be split into three sectors by placing additional transceivers on the tower and employing directional antennae, each serving one carrier channel, like a pie sliced into thirds; this situation may be characterized as a 1x1x1 antenna configuration (i.e., one antenna facing each direction). When capacity at that BTS site needs to be expanded further, additional directional antennae may be placed on the same tower and may be added for the particular cell sector needing capacity relief (e.g., 1x2x1, 2x2x1, etc., up to a 3x3x3), or when there are no more carrier channels available.

There are other methods of increasing system capacity while holding constant the available RF spectrum. Digital signal processing techniques may be used for adaptive channel allocation and lowering the bit rate for digital voice coding.[27] Incremental changes in per subscriber or per minute system costs associated with the adoption of these types of innovations in voice coding are not yet available.

GSM Evolution

By now, GSM systems have moved beyond their initial Phase of deployment in order to add new functionality and services. As new system capacity constraints were experienced and in order to save on system expansion costs, GSM systems turned to half rate (8 Kb) voice coding schemes to achieva a nominal 2 to 1 gain in the number of subscribers the system can support. This decision however involves a trade off in voice quality, esecially when calls are made between two cellular subscribers, each with half rate digital voice coding. This is also problematic if GSM is to evolve toward a universal wireless service for the mass market and as a potential substitute (or at least not too inferior complement) for fixed wired telephone service operating with voice channels of 64Kb/s each (even though high quality voice does not require that much bandwidth) and with digital cordless systems offering 32 Kb voice channels. New GSM *enhanced full rate* (EFR) voice coders operating at about 13 Kb increase voice quality and still fit within the 16 Kb full rate GSM voice channel. This EFR coder may also be used in the U.S.'s 1900 Mhz systems.

Other new GSM network services on the horizon include conferencing and related group calling services, enhanced and intelligent network services such as call forwarding and call blocking, packet data and even high speed data services.[28] Compared to fixed wired networks, the use of enhanced and intelligent network services features and functions in cellular radio networks presents some very special problems for the core network system which always has the difficult task of keeping track of where subscribers are located to preserve the integrity of individual messages and connections across cells or even neighboring systems. This would call for substantial expansion of the functionality of the HLR which may be viewed as the future wireless counterpart of the *network control point* (NCP) component of the traditional *intelligent network* (IN) used used to provide network routing and number translations for the public telephone network.[29] GSM network designers are also considering ways to allow GSM and advanced digital cordless systems like DECT to work together. Similarly, an effective interface to allow interworking between GSM systems and new digital global satellite systems is being investigated.

One very attractive future GSM system development involves globalization. As more and more countries adopt the technology, extended inter-country roaming becomes possible. A standardized *subscriber identity module* (SIM), an electronic card which would plug in to a cellular handset, could provide the necessary functions required for system compatability, fraud protection, and billing accuracy across totally different cellular systems.

Macrocell mobile systems and PCS

The beauty of cell sectoring in celluar radio systems is that, using essentially the same type of network equipment, the cost of increasing individual cell capacity may grow incrementally over time as demand grows. Even in a microcell environment, it is possible to employ cell sectoring schemes to increase capacity and transmission quality.

The use of cell sectorization techniques in a macrocell environment to improve RF reuse in a given market area has the same effect, but at less cost, as implementing microcells. By "piggybacking" early PCS service demand on the macrocell network, mobile system operators believe that they can compete against the capacity and performance of new microcell wireless access systems. In fact, this has been the pronouncement of most major cellular operators in the US, who contend that they have a significant head start and market advantage over new microcell PCS operators. Some of these pronouncements are suspect, because the FCC has restricted incumbent cellular network operators to acquiring a total of 15 MHz of PCS spectrum per market area.[30] This places incumbents at a competitive disadvantage to other new PCS operators which are allowed a total of 120 MHz (40 MHz each) per market area. Thus, it behooves existing operators to announce early-on their intention to compete in the PCS market in order to gain customers and to signal new entrants of their intentions to compete using their existing cellular system and RF endowments.

Once the demand for PCS grows to the capacity limitations in the sectored macrocell environment, the mobile network operator still has the opportunity to split the coverage area into smaller cells. This further expands system capacity and begins to mimic the network design of the microcell system operator. This should give microcell network operators pause if they believe that their choice of technology is somehow unique in serving the market for PCS. In fact, recent research suggests that both TDMA and CDMA may be cost effectively applied in a macrocell environment until such time as capacity constraints require adopting a microcell system structure.[31]

Other things equal (e.g., system demand), it is always more expensive to deploy microcells than macrocell systems because this means incurring more radio tower sites and associated transceiver equipment costs. Microcell systems require the placement of many more nodes (BTSs) per coverage area, and, to the extent that such placements may be delayed by macrocell network system operators without sacrificing tapping into the early PCS market potential, it behooves mobile network operators to squeeze as much capacity out of their macrocell network as possible. If PCS service demand were to skyrocket however, mobile operators will have to worry about system capacity shortages.

CDMA

CDMA macrocell cellular systems may use essentially the same architecture as that for TDMA, AMPS-D, and GSM systems. The primary difference is the considerable gain in system capacity by reducing the spectrum reuse factor from 7 to 1. The gain in spectrum efficiency (i.e., system capacity) for a given radio coverage area and fixed amount of radio spectrum is inversely related to the numerical value of the spectrum reuse factor. In CDMA "spread spectrum" systems, the bandwidth of the radio carrier channel is much greater and is shared among many more subscribers in the same cell. Cell sectoring techniques are also used to expand capacity in CDMA systems.

CDMA macrocell systems are not yet deployed and there are a number of possibilities for channelization schemes. Qualcomm, a major supplier of CDMA systems, has proposed a 1.25 MHz carrier channel bandwidth which can accommodate 25 voice channels. With cell sectoring (3 sectors per BTS) CDMA carrier channels have a capacity of 75 voice channels. For urban CDMA systems employing this sectored cell network configuration with over 50,000 subscribers, McGarty reports a per subscriber capital cost of about $350.[32] The per subscriber costs for urban systems are sensitive to subscriber density within a cell and the size of the coverage area. Holding constant the total radio coverage area, the per subscriber system costs increase rapidly for subscriber levels below 50,000 and could easily be 2 to 3 times the $350 number for very low penetration (e.g., 10,000 subscribers). The per subscriber costs slowly decrease as demand expands beyond 50,000 subscribers but flattens out very quickly. The same would be expected to be true for TDMA and even AMPS-D cellular systems.

PCS microcell

Microcell TDMA and CDMA wireless access systems use fundamentally similar radio technology compared to their macrocell counterparts, but with reduced cell sizes (e.g., 3 km radius, vs. .3 km radius). Reed (1992) studied microcell PCS network costs and reported the per subscriber capital cost to be about $500 for both TDMA and CDMA systems.[33] Interestingly McGarty (1994) reports fairly similar per subscriber costs (considering the rough level of the analysis) for large urban macrocell systems using either CDMA ($373) and TDMA (GSM) ($453).[34] As mentioned previously, these per subscriber system cost estimates are derived from static calculations of total construction costs, including start-up, divided by a target level of subscribers (e.g., 50,000). Using a different approach, once the initial system is built and operational, the estimated incremental capacity cost per minute for growth in network usage multiplied times the average system usage per subscriber (180 minutes per month), yields a TDMA per subscriber cost of about $200.[35]

In a mobile environment assuming fast hand-off capability, the implication from the available data is that microcell network structures have no inherent unit cost advantages over macrocell ones and that a network operator should delay the conversion from macrocells to microcells until capacity constraints require it. However, this reactive mode of operations could backfire if the early microcell system operator is better positioned to fill (unanticipated) PCS demand. It is also possible that if, in the near future, it is perceived by the macrocell system operator that capacity constraints in the macrocell system will create the need to reduce cell sizes, then squeezing as much capacity out of a macrocell system design before converting to microcells to relieve capacity may actually end up raising the total long run cost of operations. This would be especially so if the costs incurred for macrocell system capacity expansion were non-recoverable before being forced to eventually convert to microcells to improve capacity to levels required by rising demand.

Expense factors in cellular networks

There exists a wide range of estimates of marketing and operating expenses associated with new digital cellular wireless access systems.[36] Since the fundamental operations among competing carriers for stand-alone cellular systems are homogeneous (e.g., system administration, service provisioning, repair and maintenance, etc.), the on-going expenses for network operations are likely to be similar, or at least this is a reasonable assumption. Since competing carriers operate in the same markets to attract the same customers, marketing expenses could also be expected to be similar across carriers in the same market area. In the case of incumbent cellular carriers, especially vertically integrated ones, there may be some economies of scale and scope from reduced interconnection, operating and marketing costs. However, there is little to be gained at this early stage in comparing expense estimates since it is not likely to be the determining factor *ex-ante* in selecting one type of network system over another.

Cordless Telephone (CT) technology
"Mobile multimedia" is the ultimate concept in digital cordless technology. The international vision of this concept has been called *universal mobile telecommunications system* (UMTS) and in the U. S. it is referred to as *future public land mobile telecommunication system* (FPLMTS). In 1992, the *World Administrative Radio Conference* (WARC) assigned 230 Mhz of spectrum around the 2000 Mhz radio frequency band to UMTS. It reamins to be seen if this is enough bandwidth to ever support a true mass market wireless multimedia network infrastructure. It is likely not and more bandwidth in higher frequency bands will likelyt be needed.

The goal of UMTS is to provide high quality high speed servvices with unlimited mobility and global coverage. Needless to say, achieving this concept will take a lot of work in the research and development community and there will no doubt be some serious setbacks. But, it is a valuable goal from a social infrastructure perspective and a useful vision to keep in mind for guiding wireless technology developments. UMTS is based on a *personal telephone number* (PTN). A PTN is like a PIN number that will be able to follow an individual wherever they go and whatever terminal they are use. International standards bodies are investigating how to keep track of incoming and outgoing calls in this new environment so that network and equipment standards may be developed. The reason that cordless telephone service, which is normally associated with a very limited and fixed coverage area, may be the key to starting to design a cost effective global mobile system is that most people most of the time are in fact close to home or their workplace. Recent polls in the U.S., known to be one of the most, if not the most, mobile society in the world, indicate that 90 percent of the time that individuals are out of their office are either within the same building or nearby. In order to achieve global coverage, UMTS may be interconnected with emerging global digital satellite networks. Many proposals to launch satellite personal comunication networks exist and these may represent the forerunner of the satellite portion of the global UMTS system.[37]

Compared to cellular service, CT technology generally features very low power, slow (or no) hand-off, and a limited base station coverage area. For very short distances from a base station unit, CT handsets may handle the network control functions which, in cellular roaming modes, would have been handled within the network. For example, a CT handset should be capable of automatic selection of an open channel from those available at the base station, the way some cordless phones already do today.

For obvious reasons, most telephone usage occurs while at home or in an otherwise stationary situation (e.g., office, shopping mall). This simple fact of life is what allows CT technology, which costs a lot less than a stand-alone cellular system, to become a potential market winner. The market for digital cordless phones in 1994 alone was $1B and doubled in 1995 to $2B and it is estimated to grow to $32B by the year 2000.

The network and handset costs associated with fast hand-off and roaming features offered in a mobile environment are very high compared to CT systems offering only fixed location or slow hand-off capability. However, such supply-side cost advantages may mean very little in terms of market success if consumers truly desire, and are willing to pay for, the added convenience of total portability in a mobile environment.

The US has no significant players planning to deploy CT technology except in conjunction with other plans for wireless infrastructure. CT's role in the NII will be as a complementary service offered in conjunction with, or interconnected to, other wireless networks; or as a cheap substitute for more expensive wireless network systems for those consumers that either do not want, or cannot afford, such access. Thus, CT network systems will not be examined herein except for their role in conjunction with other modes for wireless communications.

It is not that there will not be a demand for this service. Indeed the explosion in the demand for cordless handsets in American households makes that a given. In fact, we should be anticipating the day when infrared light is used in addition to, or as a substitute for, current CT radio frequencies in the home; using photonic phone technology, the numerous remote control devices for televisions and stereos could double as portable phones, pagers, and intercoms - as the futurists have put it, "We'll be watching our phones and answering the TV".

Around the globe, CT technology is beginning to be deployed in various forms, notably the UK, Japan, and soon in Canada. Compared to these countries, there is much less excitement and anticipation in the US regarding the deployment of advanced public CT networks among consumers or major players in the wireless access industry. The US has adopted no standard for advanced CT technology. Still, to maximize both the functionality and capacity of planned wireless access systems, US cellular carriers are considering CT technology for near-base-station communications. GTE's proposed TELEGO wireless network system is one early example. TELEGO is touted as a fully functional portable phone service which switches to fixed location CT mode when in the home base station area and switches back to "on the move" mode when outside the home base area and to mobile roaming mode when driving a vehicle far from the home base area.

The question of whether or not there is a market for CT type networks depends on the nature of demand. In particular, is the mass market characterized by a very dense and not very mobile population, both in terms of the speed of movement (slow) and the proximity of subscribers (close) to the base station? If the majority of the urban population tend to congregate in very limited areas (e.g., downtown rail/subway stations) and are not very mobile (usually on foot or on a bicycle), then CT networks may be the best market alternative among wireless access systems. Many Asian countries (among others) meet these criteria and they are likely to be early adopters of this technology.

Even in the US, there are potential mass market applications for advanced forms of CT technology, especially those which may become a good substitute for digital wired phone service, even in rural areas. For example, a standard has been specified for a *personal access communications system* (PACS) suitable for PCS and fixed wireless loop applications.[38] WACS employs a very low power microcell TDMA technology featuring a relatively low cost infrastructure capable of providing high quality digital service. However, no vendor in the US is actively pursuing deployment of such a system because the FCC has not licensed suitable spectrum for this purpose. Even with sufficient spectrum, in order for CT systems to be financially viable in rural applications high power levels would be required thereby increasing the coverage area of a single antennae site. The FCC's power restrictions associated with spectrum licenses (to avoid interference), often designed with dense urban areas in mind, becomes a limiting factor for the market viability of rural CT systems.

The network cost of CT technology deployment can range from nearly zero, in the case of the vastly popular household units, to very expensive, depending on the sophistication of the technology, power level, distance capability, functionality of the handset (e.g., paging, intercom), and the number and spatial distribution of base station locations and remote nodes. Advancements in the technology include increasing the practical operating distance between the base station unit and handset and increasing the number and locations of base station units and remote electronics (e.g., signal repeaters and amplifiers, and trunks). The CT mode of operation is relatively cheap to provide compared to mobile radio service and is almost strictly a function of the number of base station units, sub-units and electronics. The handsets are small and relatively inexpensive because they may operate on very low power. Capital costs associated with a CT network for trunking and interconnection are minimized because the phones only work near a base station and because relatively unsophisticated "plug in" connections to the PSTN may be used. As in any other portable communications network system, there are the usual operating costs including marketing, sales, network operations, administration, billing, etc.

Cell sizes for CT technology are very small (e.g., 100-500 meters radius). There are many versions of CT technology. The first generation Cordless Telephones (CT1) were simple single base station phones on a single fixed radio frequency connected to the PSTN. Beginning in 1985, the *Conference of European Posts and Telecommunications* (CEPT) initiated a standard for second generation cordless digital systems called Cordless

Telephone 2 service (CT2--also called Telepoint). This is the first cordless technology to use digital voice coding (FDMA) and multiple base stations in a limited coverage area. CT2 functions like a normal cordless phone in non-Telepoint mode. When away from the home base, CT2 allows for only originating calls. CT2+, a second generation standard, allows for slow hand-off between cells. Telepoint was introduced in the U.K. with much fanfare in 1988 and dubbed "the poor man's mobile phone". By now, most CT2 service providers have given up and are being displaced in favor of newer digital cellular systems.

Also in 1988, CEPT decided on a new cordless system operating at a different frequency. Introduced in 1992, the new system was called *digital european cordless telephone* (DECT--European standard) and CT3 (Ericsson), a third generation CT technology which employs TDMA GSM techniques allowing for send and receive capability and adaptive channel allocation. Compared to CT2 phones, DECT doubled the transmission range (up to 300m outdoors) and permitted handoff between base stations. DECT, like CT2, uses 32 kb/s voice channels, but DECT may allow for combining channels for high speed data services. While DECT does allow for hand off and complete coverage in the area where the system is located, its geographical coverage area is usually restricted to a campus environment. The system design makes it an expensive proposition to cover a very wide area and still allow for roaming. The very popular worldwide standard for TDMA cellular networks, GSM, is basically the same as the European CT standard, DECT. The DECT standard defines compliant protocols for interworking with both ISDN and GSM.[39] Such compatibility promotes the deployment of the technologies as they may grow in tandem due to network compatibility and interconnection.

Early applications of public CT network technology were championed in the UK. Mercury has already launched the first PCN system (dubbed One-2-One) which now competes in certain market segments with macrocell mobile carriers. The consumer markets served by these two types of network access systems may not overlap as much as one might think. So far, the demand for the CT alternative in the UK has not substantially slowed the demand growth in cellular systems. In just two years, Mercury has signed up over 300,000 subscribers, two-thirds of whom never used a cellphone.[40]

In Japan, DDI has introduced the *personal handy phone* (PHP) which, due to widespread deployment of base station units, will feature wide area coverage and two-way capability, but will not allow for mobile communications due to lack of fast hand-off capability.[41] In Canada, the government has adopted a CT2+ technology standard, allocated spectrum and licensed several CT networks (e.g., Popfone, Telezone, Personacom).

4.7.2 SMR

SMR systems are the only wireless access technology being considered for the NII which is based on the traditional (non-cellular) model of two-way mobile radio. SMR systems use RF frequencies located adjacent to mobile cellular service frequencies, but when the FCC allocated them, they were single (paired) channel frequencies intended for high power, single antenna, large coverage areas for two-way radio and dispatch type services.

Beginning in 1987, Fleetcall (now Nextel) and others began purchasing and aggregating thousands of SMR frequencies in cities throughout America to achieve scale economies. With the help of FCC rulings allowing for different radio system configurations, Nextel was authorized in 1991 to construct digital radio networks using SMR frequencies. Today there are a handful of players that have pieced together coast-to-coast service capability.

With the assistance of *Motorola's integrated radio system* (MIRS) technology, the enhanced version of SMR (ESMR) relies on the same advances in digital signal processing that has opened up the future for all of the land-based wireless access companies. In ESMR systems, the old familiar scratchy and haphazard transmissions of taxi and emergency dispatch systems will be digitally enhanced to the point where they may compete with newer cellular systems.

ESMR systems using MIRS technology operate in a TDMA "cellular-like" environment. Such systems may expand the capacity of a single SMR radio channel six-fold allowing ESMR wireless access systems to have enough capacity to compete for the customers of cellular network systems. However, as is the case with current cellular networks, the capacity of ESMR systems for serving mass market demand may still become limited if PCS demand takes off.

The ESMR system cost per subscriber for wireless access is very difficult to estimate because some of the system infrastructure is already in place for existing lines of business, including dispatch and radio paging services. Suffice it to say that it is reasonable to assume that the per subscriber costs of upgrading SMR systems to ESMR using MIRS is lower than the system start-up and build-out costs of PCS competitors, and is probably less than digital cellular upgrade costs on shared AMPS/AMPS-D systems.

Because of the historical use of SMR radio frequencies for two-way radio dispatch and paging-type services and the installed base of subscribers to those services, ESMR wireless access system handsets will be among the first to offer multi-mode service. In fact, because ESMR systems will be built in market areas where a radio network infrastructure was already in place, they will be bringing the service to market potentially 2 to 5 years ahead of PCS systems, which cannot even begin the network build out until some time in 1996. This could represent a huge marketing and service advantage. However, as is often the case with being the first to trial a new technology, ESMR is having early service problems. As one ESMR business customer in Los Angeles put it, calls on the network "sound like you're underwater."[42]

4.7.3 Wireless cable systems (MMDS/LMDS)

Originally planned as a wireless broadcast alternative to cable television service, wireless cable systems are potentially capable of two-way digital access services in the NII.

Originally, the FCC allocated spectrum (2.596-2.644 GHz) for the new wireless cable services. Thirteen video channels called *multipoint distribution service* (MDS) and *multichannel multipoint distribution service* (MMDS) were allocated for use by licensees. Additional spectrum (20 channels) using frequencies originally set aside for educational programming has been made available to MMDS operators so that a total of 33 channels could be offered. The FCC has since set aside certain RF spectrum for "response bands" for upstream signaling for interactive video services.

More recently the FCC has proposed allocating another 2 GHz in the 27.5-29.5 GHz band to a new service dubbed LMDS for uses similar to MMDS, but has not yet granted standard operating licenses. Recently, FCC has announced plans to allocate and auction more spectrum for this service in the 6 GHz band.

Both MMDS and LMDS systems plan to use digital technology to increase broadcast channel capacity and to provide for limited two-way interactive service. If the FCC allows it under its new flexible use policy, wireless cable systems could use two-way digital channels for telephony.

The basic cost structure of wireless cable technology is illustrated in figure 4.3. The systems will consist of a head end for combining video signals from terrestrial network and satellite feeds for transmission directly to subscribers. Subscribers to wireless cable systems receive the signals using a small antenna and signal downconverter and television set top box for channel selection.

Figure 4.3 Basic cost structure of wireless cable network.

The primary distinguishing characteristic of wireless cable systems' cost structure is their substantial up front fixed and getting started costs, and, in turn, the low incremental capital cost of adding subscribers. Most all of the incremental investment associated with subscriber additions is *customer premises equipment* (CPE), including the installation of the receiving antenna, signal downconverter, and television set top box. For this reason, such systems are especially well suited for high density urban applications. Due to line of sight requirements for clear television reception, wireless cable systems will have area coverage problems when adverse weather, terrain, and man made interference factors are present.

As with any video delivery system, wireless cable networks' use of digital technology is brand new. Significant advances in the network application of digital signal processing and compression techniques to support video on demand and interactive services are still largely on the drawing board. However it is a forgone conclusion that digital signal processing technology will be applied and that two-way capability will eventually be a reality. Since the original purpose of these wireless access systems was to provide for television service at fixed locations, the portability aspects associated with roaming have not been investigated. If roaming capability is ever to be in the cards for these systems, it will likely have to come from interconnection to other mobile systems which are interconnected to the PSTN.

While industry observers have mixed opinions regarding the ultimate capability of wireless cable systems to provide wireless access services as part of the NII, it is generally agreed that they will be a potentially significant player in the digital video business. Therefore wireless cable systems may be used by subscribers as a platform for broadband service in conjunction with other narrowband wireless access networks (e.g., PCS) to provide for a totally wireless mass market service platform in the NII.[43] Relative advantages of digital wireless cable systems include the rapid deployment feature of the technology and its ability to fill in the gaps for areas not otherwise served by wireline alternatives. Wireless cable's relative disadvantage is bad weather and terrain (especially trees), both of which can adversely affect the quality of the signal.

System upgrades and costs

Due to the very large coverage area from a single antenna site (e.g., 3,000+ sq. mi., 30 mi. radius) and the high subscriber densities offered by urban areas, the fixed network capital costs on a per subscriber basis for wireless cable (MMDS) systems are very competitive, lower than that for traditional wired cable systems. Average per subscriber system costs are about $500.[44] Variable cost for existing analog wireless cable systems are the dominant cost factor at about $350-$450 per subscriber, about half of which is CPE and half installation.[45] People's Choice TV in Tucson reports an incremental per subscriber system capital cost of $525 -- $380 of which is fully reusable if a subscriber discontinues service.[46]

On the near term horizon is the digitization of wireless cable signals which will allow for video compression and a dramatic increase in channel capacity (250 channels) and system functionality (e.g., video on demand, near video on demand). The system costs on a per subscriber basis will remain steady in a digital environment, although the cost of set top boxes will rise somewhat at first, but the increased system capacity will cause the per channel cost to fall dramatically. The price of digital signal converter boxes (by late 1996) is estimated to be about $300-350.[47]

Upgrading a wireless cable system which already has digital broadcast video capability to provide two-way digital wireless access service capability should not be too difficult, but very little hard data is available on the cost of doing so. One of the main reasons for this is that the FCC has not licensed the spectrum for telephony. Assuming that network operators are already planning to digitize their networks and use digital compression technology to expand channel capacity, the incremental fixed network costs to provide digital wireless access for two-way telephone services on a wireless cable system should be low. All that is required is that a portion of the broadcast radio links be assigned to upstream signal carriage. There may also be a network cost incurred to aggregate upstream traffic in a cellular-like or sectored environment similar to the way other narrowband wireless access systems plan to backhaul subscriber traffic. For example, wireless cable operators might employ remote antennae sites and signal repeater/amplifier stations for traffic aggregation allowing for shared use of upstream channels. In order to conserve broadcasting spectrum and make efficient use of that portion of the total available spectrum (about 200 MHz) band which must be dedicated to upstream communications channels, MMDS systems could employ the same shared access techniques used in PCS systems such as CDMA. Another possibility is the use of wireless LAN access techniques. As in all of the other wireless access systems, wireless cable systems could team up with local wireline network providers (telcos, cable television companies , etc.) for backhauling and terminating upstream traffic originating on the wireless system.

The variable per subscriber cost required to upgrade a wireless cable customer for two-way digital service however will not be nearly as low as the costs required for the network portion of the system, but, in any event, should not be any higher than that which a wired cableco would have to incur since both require sophisticated set top boxes to separate, combine, modulate and demodulate the incoming and outgoing signals. A set top "transverter" unit (a combination radio signal transceiver, codec, and up/down signal frequency converter) would be required to make the system work on a customer premises. Network equipment manufacturers have not yet announced the availability of digital equipment for wireless cable applications and therefore reliable cost data for upgrading the systems for digital wireless access service are not available.

LMDS systems differ from MMDS in network design and operation. Operating in a very high frequency band, the LMDS head end location will only be capable of serving a much smaller coverage area compared to MMDS due to the higher frequency signal propagation. Serving an entire city, metropolitan area, or remote locations, will require the system head end to feed signals to remote signal repeater/amplifier antennae sites designed for smaller coverage areas in a cellular design. To date, the FCC has issued only one license for LMDS service, to CellularVision, which operates a single experimental system in New York, but which plans to license its technology for many more systems throughout the US CellularVision's provisional license provides it with over 5 times the nominal spectrum available for use by an MMDS operator confusing sentence/clarify meaning. This obviously is an advantage as long as the costs required to cover an entire metropolitan area in a cellular arrangement are low enough to compete with single-tower two-way cable systems. The costs of these systems should still be lower than wired cable, since, like MMDS systems, the cost of laying cables and maintaining the wired system with all of its signal amplifiers is avoided.

LMDS cells sizes will vary, but may be as large as 12 miles radius (for very flat areas with no trees and dry climate) or as small as 1 mile radius or even less in areas with varied terrain like large urban centers. CellularVision claims its transmitter provides excellent service for a coverage area of 48 sq. mi. (4 mi. radius). Thus to serve a major city of say, 1000 to 2000 sq. mi., would require 20-40 transmitter sites.[48] LMDS technology has the capability and, if the FCC licenses it, the available spectrum, to provide two-way services including video telephony.

LMDS system capital costs per subscriber will be somewhat higher than for MMDS systems and will depend on the number of cells and remote transmitters required. In time, the costs of production CPE (e.g., antenna, downconverter, set top box) will likely be the same as for MMDS. The same is probably true for the cost of upgrading subscribers for two-way telephony using digital signal "transverters" located on the subscribers premises.

But for the greater spectrum bandwidth allocated to LMDS service, these systems face many of the same problems of MMDS operators in establishing two-way mobile and roaming services and would probably have to consider interconnection with another mobile system operator to become a full-service wireless communications company.

One example of a prototype LMDS video system using today's technology and subscriber equipment with cell sizes of 1-3 mi. radius (urban), estimates network system investment costs at about $40 per home passed, and for larger cells requiring repeater/amplifier nodes (e.g., 12 mi. radius suburban system) the cost is about $110 per home passed. On a per subscriber basis, the cost would be much higher depending on the penetration rate assumed. Associated CPE costs are estimated at about $700. Adding two-way narrowband telephone service adds substantially to these costs. The system capital costs per subscriber quadruples to about $200 and associated CPE costs are about $1,200. Both the network equipment and CPE costs should fall dramatically once manufacturers begin to provide production quantities. In a production mode, it has been estimated that equipment costs will fall such that a two-way LMDS system may be installed for about $700 per subscriber.

4.7.4 Satellite

Due to high up-front investment costs and the wide area coverage, the cost structure of satellite network systems is similar to that for wireless cable systems. The greater signal coverage area of the satellite system compared to land-based wireless systems make the potential per subscriber costs of satellite network systems very competitive. As with wireless cable systems, most of the variable cost per home passed or per subscriber will be for CPE. There are many types of new high powered, high frequency satellite networks and services on the horizon including LEOs, MEOs and GEOs. The FCC licenses providers of *mobile satellite systems* (MSS) operating in the 1.5-2.5 GHz band. Already the FCC has approved five licenses for so-called "Big LEO" systems.

The initial applications of the technology will be in niche markets for locator services, mobile roaming and remote telecommunications, where it eventually could dominate the scene. While it is technically possible that MSS networks may be used as a mass market substitute for fixed wired access, this seems very unlikely in developed countries with nearly universal access already available. While not a substitute for land-based wired networks, new digital satellite systems will potentially become important complements providing for worldwide connectivity. Many systems will offer dual-mode handsets capable of using either the satellite or interconnected land-based systems, whichever offers the most convenient or lower-priced service.

In addition to proposed digital satellite systems offering voice and data services, due to desirable cost characteristics it is anticipated that Direct Broadcast Satellite networks will be the dominant technology for distributing broadcast video signals worldwide for use by other land-based video distribution networks or directly to end users themselves, especially in remote locations or in locations not otherwise served by terrestrial networks. But this is not the only possibility. Assuming that the FCC continues to liberalize the uses to which spectrum may be put, DBS systems may be able to profitably expand into the two-way telephony business.

Table 4.4 provides a summary of proposed MSS systems.[49] From table 4.4 it is clear that major players are vying for a share of the MSS service market. Within the satellite services market, so-called small LEOs operating at lower frequencies will primarily serve niche markets for data and locator services (e.g., global positioning), while big LEO operators (e.g., Iridium, Globalstar, Teledesic) will target the market for worldwide two-way mobile voice and data services, including rural and remote locations and less developed countries.

Table 4.4
Proposed MSS systems

Organization	Investors	Cost to build	Service	Description
Iridium, Inc. Washington, D.C.	Includes Motorola, Sprint, STET, Bell Canada Enterprises and Daina Denden	$3.4 billion (include. launch)	1998	66 LEO satellites to link handheld wireless phones with global reach
Odyssey	TRW, Teleglobe	$2.5 billion	1998	12 MEO satellites
Inmarsat London	Inmarsat, a treaty based "co-op" of telecom operators from 73 countries or a privatized In-marsat spin-off	$2.6 billion	2000	"Inmarsat-P" system still undefined but leaning toward 12 MEO satellites to link handheld wireless terminals
American Mobil Satellite Corp., Reston, VA	Includes Hughes McCaw Cellular Mtel and Singapore Telecom	$1.2 billion	1994	3 GEO satellites will link handheld phones in North America
Ellipsat International, Inc.	Includes Mobil Communications	$700 million	1997	16 elliptically orbiting LEO satellites for

Washington, D.C.	Holdings, Inc., Fairchild Space & Defense, and Israeli Aircraft Ltd.			service to handheld terminals
Globalstar Palo Alto, CA	Includes Loral, Qualcomm, Alcatel Deutsche, Aero-space, Air Touch, Vodafone and Dacom	$1.8 billion	1998	48 LEO satellites to provide worldwide voice, data, paging and facsimile
Teledesic Kirkland, WA	Includes Craig McCaw Develop-ment Co. and William Gates	$6.3 billion	2001	840 LEO satellites to provide global coverage for broadband data, video and voice service

Motorola, a major player in wireless network equipment and consumer terminals, is the driving force behind the Iridium LEO system and will be in a good position to link up to other ground-based wireless access systems or the PSTN whenever complementary joint service opportunities arise. However, at a pre-announced price of $3 per minute, it is clear that Iridium is not a mass market substitute for land-based wireless access service in the NII. The Iridium handset itself is very expensive at an estimated $3,000.[50] Planned for service in 1998, the Iridium system includes about 66 LEO satellites orbiting about 500 miles above the earth and operating in the 1.5-2.5 GHz band, at a launch cost of $13M each. Motorola's Iridium system is unique in that it will utilize satellite-to-satellite links to transit traffic between user locations, thereby bypassing terrestrial networks in transiting countries. Iridium will even be able to transmit direct to user handsets, but will usually make use of its domestic "gateway" cellular providers' terrestrial network for call terminations or originations.

Most other proposed systems have somewhat less ambitious plans than Iridium and plan to utilize the existing facilities of terrestrial carriers. For example, Globalstar's LEO system is planning to augment land-based wireless access systems using 48 satellites and 200 earth station gateways. Globalstar's handset costs are estimated at $700.[51] American Mobile Satellite Corporation, a GEO system, plans to operate a relatively inexpensive system of dual-mode satellite/cellular mobile service covering only North America and has announced target prices which are among the lowest. Based on the early price announcements, many MSS firms will be much more price competitive than Iridium. Target per minute usage charges for these MSS systems range anywhere from about $.25 to $2.00. Competition should force these prices to come closer together, probably somewhere in the middle of these estimates. Handset prices will also vary at first, but competition should also force some convergence.

Among planned MEO systems, Inmarsat, the international satellite consortium providing telecommunications service for shipping and airlines, has announced the introduction of a new personal satellite phone service called Inmarsat-P, available in the 1998-2000 time frame. Odyssey, a satellite system backed by TRW and Teleglobe, recently announced a two-way global MEO network consisting of 12 satellites orbiting about 6000 miles above the earth. This system would also plan to compete for mass market telephony services as well as niche market applications.

The Teledesic network backed by McCaw and Microsoft is an even more ambitious technological effort than Iridium. Operating in the very high frequency Ka band (20-30 GHz), these birds would be capable of providing global coverage for 2-way broadband services including video telephony and multi-media. Such projects are hugely expensive however, and, while the potential telecommunications capabilities and applications of these "superbirds" is very impressive, it is also still very experimental.

There have recently been even more global satellite systems announced besides those listed in table 4.4. Spaceway, a new all-digital satellite system proposal before the FCC made by the Hughes Communications division of General Motors is a MEO Ka band wireless access system. The proposed system, consisting of 17 satellites, would be designed to provide bandwidth-on-demand for all types of narrowband and broadband telecommunications services in competition with land-based alternatives. A novel feature of this system which allows for spectrum reuse is that an individual satellite will use transponder "spot beams," to segment the very large signal coverage area (or "footprint") normally provided by geosynchronous orbit birds. Subscribers would be connected with so-called *ultra small aperture terminals* (USAT) measuring only 66 cm across and costing less than $1,000.

With so many grandiose announcements from so many deep-pocket investors it is safe to assume that some, perhaps most, of these global satellite communications systems will eventually become operational (though some industry consolidation is likely). The investment community views the future as risky and attracting external financing has not been easy. Two of the leading contenders in the race to deploy satellite systems, Globalstar and Iridium, have both failed recently to attract investor interest in recent bond offerings, even at fairly high coupon rates.[52]

In addition to approximately 320 communication satellites already operating, satellite networks providing a wide variety of services will become a ubiquitous public infrastructure. Pelton (1994) provides estimates of revenues for global satellite service markets, which are forecast to more than triple by the year 2002. Nevertheless, even after considering the pronouncements of the major industry players, satellite services will be relegated to serving niche market applications and therefore, their role in the American NII will be limited. Perhaps the greatest potential for the new global satellite systems would be to take advantage of their relative cost performance and coverage capability to provide for modern digital telecommunications service in rural, remote, or otherwise undeveloped parts of the world.

4.8 Evaluating network costs

Comparing the economics of various alternatives for wireless access systems requires an examination of the time path of the expenditure stream and compared that to the anticipated revenues. The focus herein is on that portion of the expenditure stream which reflects the capital costs of building a wireless access network system. These costs come in several different flavors: 1) so-called first costs, or the total installed costs of the initial wireless access system upon activation; 2) build-out costs, or the costs incurred over time to expand the system coverage area to its long term target; and, 3) system growth and maturation costs or the variable costs which result from rising system usage. In the case of existing wireless access systems, there is also a difference in the costs to upgrade or otherwise modernize the system to handle new service capabilities compared to the costs associated with building a system from scratch.

The third item, the variable costs of operating the system to handle increased demand, is actually the most critical since it is the determining factor for a company's long term operating cash flow or price/cost margins. Of course, that assumes that the up-front fixed (e.g., start-up) costs of building a particular network system are not so much higher than other competing systems that the project would never get off the ground. But this is not likely when comparing alternative system costs on a per subscriber basis for a large scale urban market, in which case the high up-front fixed costs are spread over so many demand units that the average fixed cost represents a very small portion of the average total cost (the sum of average fixed and variable costs).

The goal of economic analysis is to identify and design the wireless access system which achieves the lowest investment in network facilities for a given demand level (assuming that the level of service quality is a competitive one). This usually means that, for a given market area, a network design is selected which provides area coverage for the least amount of network facilities. The network is engineered in accordance with technical network parameters (e.g., RF spectrum bandwidth, radio carrier channel size, user channel size, co-channel interference factors, frequency reuse patterns, etc.) corresponding to a particular technology (e.g., TDMA/CDMA) and network architecture (e.g., macrocell/microcell). Depending on the market area (e.g., city) to be studied, a geographic terrain and climate is assumed (e.g., flat, hilly, rainy, dry), along with assumed levels and distributions of man made RF interference factors (e.g., traffic patterns and loads, buildings). A subscriber density must also be assumed (e.g., subscribers per sq. kilometer and calls or call attempts per hour).

Based on the size of the radio coverage area, the network start-up or initial construction phase includes investments in the core network hardware and software represented by the MSC and the associated trunk network connecting to the initial number of BSs deployed. BSTs are placed to prevent unacceptable signal fading and signal propagation associated with geographic topology (e.g., lakes, rivers, hills, valleys, trees) and other physical RF barriers (e.g., buildings, tunnels, bridges). There are any number of problems associated with the lack of line of sight for the RF signals between the base stations and handsets, and considerable engineering discretion is used in solving them in any specific instance. For example, when a large building or other structure blocks a given radio transmission path, the problem may be handled by placing an extra radio antenna on top of a building or along a section of street to go around it, or even under the building by transferring the signal to underground wireline facilities.[53]

Once the network system operating parameters and assumptions are developed for any given market area and the network is engineered, the vendor equipment can be sized and priced to estimate the initial or "first cost" for building the network. First cost is also called the *engineered, furnished, and installed* (EF&I) system cost and represents the total cost of "turning up" a network system. By assuming an initial market penetration rate, the relative cost per subscriber for different wireless access systems of similar service capability and service quality may be determined.

In the case of satellite networks, the EF&I costs of satellite development and launch dominate the first costs of the system (or transponder lease costs), followed by earth station siting and construction costs. By their very nature, the initial capacities of satellite systems are huge. During the build-out phase for satellite systems, the per subscriber system costs fall even more rapidly then those experienced by land-based systems because average costs for satellite networks are more sensitive to the scale of operations. In most metropolitan land-based wireless access systems, the per subscriber system costs level out relatively early compared to satellite systems (e.g., 50K vs. 1M subscribers). This makes it imperative for satellite operators to sign up as many subscribers as possible through advance marketing programs. This is the opposite of the situation for most land-based systems, which are often more concerned with keeping up with demand early in market roll outs. In both land-based and satellite-based wireless access systems, once system build out is reached the variable capital cost of adding individual subscriber connections is quite low.

A further evaluation of the EF&I costs of different wireless access systems may be made by holding constant the total available RF spectrum and the size of the service coverage area (using the same assumed levels of terrain and man-made interference factors) and then systematically varying the subscriber density. This will reveal how different systems (e.g., CDMA/TDMA, macrocell/microcell, ESMR) perform for dense urban applications versus less dense suburban and rural applications.

The analysis can become considerably more complex by combining different wireless access technologies in all or certain portions of the radio coverage area (e.g., wireless multi-mode systems using both CT, and cellular technology). Furthermore, due to advances in digital signal coding and compression techniques, directional antennae placement, and sophisticated variable powering of handset-to-base-station signal strength to account for near/far conditions, the capacities of most wireless access systems are constantly being improved usually resulting in reduced per subscriber system costs. The different combinations of the various methods which are available to simultaneously increase system capacity and lower unit costs makes it hard to distinguish definitively which type of wireless access system can achieve the highest capacity and lowest cost per unit of available RF spectrum. Different types of wireless access systems have different methods of channel access and utilization, different power levels, frequency reuse patterns and co-channel interference factors, all of which affect the overall economics of system construction.

In another stage of the cost analysis, by systematically increasing the available spectrum per coverage area, there is the possibility for increased channel spacing and less concern about controlling co-channel interference which adds to system costs. It is useful to examine the trend in cost per demand unit for increments in available spectrum, including an examination of the resultant per subscriber costs for increasing levels of subscriber density and penetration with and without the possibility for increasing the available spectrum.

The entire study process would yield an evaluation of the relative cost and efficiency of spectrum use at various levels of system utilization. While such an approach in the abstract would clearly be preferred before the FCC decided on its spectrum allocation and licensing scheme, it can not happen that way in practice because the performance characteristics of the technology itself are so fluid. It is simply not possible to wait for the "right" wireless access method to come along before licensing spectrum since no one really knows what the "right" one is. For example, several years from now, further advancements in so-called "spread spectrum" and broadband wireless access techniques (e.g., CDMA) may reveal that the FCC's current spectrum licensing scheme of 30 MHz blocks and 10 MHz blocks, up to a total allowed 40 MHz per market area, may not have been enough to maximize efficient bandwidth utilization.[54]

4.9 Economics of wireless access

The engineering and capital budgeting analysis for prospective wireless access systems involves considerable effort and numerous assumptions about some very young technologies, all in the presence of uncertain future demand. The competitive environment and the FCC's continuing spectrum auctions have raised the stakes considerably for would-be wireless access network providers to decide now which technology to select for a market rollout. Consequently, detailed and specific engineering and financial analyses being performed in the industry are being held close to the vest. However, based on publicly available data (including that from investment houses in their efforts to calculate prospective market penetration rates and net cash flows to establish valuation benchmarks for the investor community) indications are that the state of the art in engineering economics and financial modeling of network systems is not very far along.

There are several reasons for this. First, as stated, there is a "cart before the horse" problem with the FCC setting spectrum allocations and licensing schemes before the technology of digital wireless access has progressed to the point that there is a clear indication of how much spectrum should be allocated to narrowband and broadband wireless access services. The fact that the technology is so fluid, coupled with the deadline for spectrum auction bids, puts a tremendous amount of pressure on industry players to commit now to a given wireless access technology and network architecture so that financial modeling can precede the spectrum auction awards.

Consequently, prospective wireless access system operators have had to contract with one or another equipment manufacturers to obtain bid prices for the new, (and, in some cases, untested) technology in advance of the development of production equipment. This has led most major players to set their stakes in the ground based on one preferred technology and/or equipment vendor, rendering moot the issue of analyzing the costs of alternative systems.

While it is still possible to pursue financial analysis to evaluate the relative costs of different network configurations within a chosen technology, it occurs in a much more limited context than a full evaluation across technologies. Given the FCC's announced spectrum policy, coupled with the fact that a technology choice must be made relatively quickly, the industry's network models and financial analyses are being conducted in a rather unsystematic fashion.

In the economic and financial phase of the analysis, the network engineering design is now ready for application to a dynamic capital budgeting plan in a business case setting. Once the static cost of initial construction is combined with an analysis of the incremental costs of the system build out over time, a dynamic picture of the stream of expenditures associated with a given wireless access system is sufficiently developed to make an informed decision about committing investment dollars to the construction program.

The initial system costs for wireless access network construction for land-based systems is dominated by the investment in siting and constructing the network nodes, especially the MSCs and BSCs, related hardware and software, and the trunk network required to aggregate and "backhaul" subscriber usage to the BSC and MSC. After initial system construction, the cost drivers associated with system growth during build out are the addition of transceivers (e.g., BTSs) and trunking facilities to expand system coverage and capacity incrementally.

Once build out has occurred and the system has matured, operating and marketing expense factors dominate. Usage-based interconnection charges paid to the PSTN operator will likely be a significant cost driver during both the growth and the maturation phase. Bypassing the local telco network (for example by interconnecting to a competitive access provider or long distance carrier) may be a way for a wireless carrier to avoid paying the high rates for PSTN access on the originating end of a call, but it is not so easy on the terminating end of a call where there is no way of knowing where the calls are going to terminate *ex-ante* on the PSTN.

The expenditure streams associated with the three primary phases of wireless access development (start up, build out, and maturation) can be estimated according to the time path of forecasted demand. The demand forecast is based on pricing assumptions. Since it is so difficult to forecast market penetration rates over time and total demand levels at any future point in time -- especially in what is arguably going to be a highly contentious market due to the number of participants -- sensitivity analysis to account for forecasting error is crucial. Sensitivity analysis involves randomly changing the initial demand assumptions over a range of possible values to be able to judge the potential for forecasting error to affect prospective cash flows.

Returning to the dynamics of system costs, it is interesting to note that when initial construction and build out of AMPS cellular systems began in 1984 the per subscriber costs were very high at first at $2,000-$3,000, and fell rapidly thereafter, levelizing at about $700-$1000 per subscriber with very little marketing expenses. After only ten years of being in existence, competition for customers has become fierce with the marketing expense per new subscriber now being almost equal to the total amount of current capital costs per subscriber, about $700 (making the total cost of a new subscriber about $1,400). Thus, even before the AMPS market has matured (it is still growing), the nature of the business has already been transformed from one of simply keeping up with demand to one of actually vying for demand.[55]

AMPS subscribership growth is still rapidly expanding (51% last year). But system capacities, many of which have been increased through the use of FDMA/TDMA techniques and the partitioning of cells into sectors, are generally able to handle the rising demand with little additional capital cost. This has created some very high cash operating margins from the base of cellular subscribers. This cellular experience buoys the financial outlook for future wireless access systems which are actively seeking investment dollars to build new networks.

Since new digital wireless access networks have the same fundamental cost structure as AMPS-D or GSM digital cellular systems (see figure 4.1), the per subscriber costs of new ESMR, macro and microcellular systems are expected to track along a similar time path as system construction and build out occurs, although at a different level depending on the specific features and costs of different types of wireless access systems.

4.10 Critique of the approach

The financial modeling of wireless access systems to date has focused almost entirely on static calculations of per subscriber capital costs of the stand-alone wireless network. There would appear to be at least two areas of network and financial modeling that could use substantial improvement: 1) the common assumption that all subscribers (and their associated network costs) are alike; and 2) the lack of consideration of shared trunking alternatives, including wireline network interconnection. These need to be addressed to fully evaluate the prospects of wireless alternatives.

Regarding the first point about static calculations of per subscriber average costs, there needs to be more emphasis on dynamic process models based on the pattern and level of network usage, not on an "average" subscriber. A model based on usage would better describe the underlying network engineering relationships between network components and how they vary with growth in usage. There is at least one such model, but it has not yet been applied to actual data in the US.[56]

In other words, the network model should be able to answer the basic question: As peak network usage grows, what is the incremental cost of handling that growth for each major network component (e.g., BSC, BTS, trunking, etc.)? In contrast, current models focus on a different, but related, question: as subscribers are added to the network system, what is the average cost per subscriber? The answer to the latter question may be useful, but much less instructive than the former.

The efficiency of a wireless access system to handle demand growth is best measured by incremental capacity costs caused by network usage, not the average cost per subscriber. Once a wireless access network system is built, the primary cost drivers are the additional network facilities required whenever system capacity is strained by additional usage. For any given cell site, certain system components will exhaust due to capacity constraints, causing the placement of additional antennas, transceivers, and associated trunking facilities. When cell sites themselves exhaust, cell coverage areas are reduced to expand frequency reuse causing new cells sites to be placed. It is expensive to equip entirely new cell sites. This explains the dynamic cost structure of wireless access systems.

Existing network and financial models are static and tend only to focus on spectrum and network capital costs per subscriber, or per population (in the industry jargon "per pop") for discreet levels of market penetration. Thus, the focus is on primarily fixed and sunk costs of system start up. In reality, on-going network cost drivers, which are important for determining operating cash flows, are based on two primary considerations not usually reflected in existing cost models. The incremental cost of expanding area coverage, and the incremental cost of usage. The per subscriber and per minute costs of the latter are quite different and distinct from the former; it is the time and spatial distribution of the frequency of call attempts and the calls themselves during busy periods that cause costs to be incurred. For example, the MSC is a computer that controls network usage, assigns frequencies, adjusts power levels, and controls call hand-off. In the case of calls from or to roaming units (meaning away from the home base station area), there is more work involved to complete calls because the MSC must interact with a network database and intelligent network system, which may or may not be located at the MSC site. The remote transceiver sites similarly must transmit calls between the handsets and the BSC using subscriber radio channels and trunking facilities.

All of the major components of wireless access systems have an operating capacity that is sensitive only to peak period usage; it is the exhaust of the available capacity which defines the trigger point for incurring additional network investments necessary to relieve that exhaust. Thus, it would be useful to view the cost of the total network and its major components as varying with usage levels. Contrast this to the common approach of current network models that assume an average usage level (in industry jargon, erlangs per subscriber), and then assume that as subscribers are added, network usage increases exactly in proportion to the existing base of subscribers. In addition, the assumed amount of usage per subscriber is a small fraction of that used in standard wireline models of thetelephone companiesand is usually based on what is known about mobile cellular subscriber usage.

This is somewhat unrealistic. What is known from the mobile cellular experience is that early subscribers tend to be heavy users of the service because they value it more and are willing to pay high prices and can afford higher total phone bills. Later subscribers joining the system during system build out, value the service less, are willing to pay less, use it less, and tend to roam less. Since all network costs are usage sensitive and since different users have different usage patterns, this cannot be reflected in the type of broad averages assumed in current studies. A richer analysis would build costs from the bottom up by taking usage and roaming costs and assigning them to types of users. User demographics (e.g., high use/low use, roaming/not roaming, moving fast/moving slow) naturally varies from one market area to another or even within market areas by BTS location. Models based on actual usage characteristics would be better able to reflect the impacts on system capacity and costs from adding subscribers and/or calls. Hence, to the extent that there is a difference between usage and subscription rates, the former should be tied to the demand forecast which drives the economic cost model in a business case.

Furthermore, the use of an average historical usage rate per mobile system subscriber would not be expected to be representative of the actual usage one would eventually expect from an average wireless access system subscriber. Wireless access will be cheaper to use and more versatile than mobile access and therefore per subscriber usage will be higher. Wireless access is suitable for all modes of portability. It is therefore more useful and convenient in both portable and stationary situations compared to cellular mobile service. Eventually wireless access is going to become a substitute for fixed wireline telephone service. This would call for assumptions of higher usage levels than those being assumed in current cellular models, but somewhat lower than monthly network usage levels associated with flat rate local telephone service. The reason is that wireless access systems will offer more features and similar quality, but lower prices and more convenience than mobile cellular systems.

In fact, it is entirely possible, if not probable, that eventually wireless usage levels per subscriber would actually grow to levels higher than that associated with current local telephone service. The reason is that the added convenience of communicating anywhere, anytime, with anyone, would increase the overall propensity to communicate. It is well known that telephone usage begets more usage -- how many times do you play telephone tag or need to follow-up on a call? That is some time away however if wireless access network operators plan to charge for usage and do not offer flat rate options like local telephone companies. Consumers like flat rate options for local phone service and have experienced many decades of satisfaction with it. Flat rate wireless pricing may already be getting started; the first digital PCN operator (Mercury--UK) has a zero usage price in off-peak periods.[57]

To summarize the point, the focus of current cost models on per subscriber capital costs requires a host of somewhat unnecessary assumptions. Fundamentally, the primary cost drivers of a wireless access system are based on usage. Changing the modeling approach to capture and reflect the costs of increasing capacity incrementally on the network system would yield a much more realistic operating scenario for capital budgeting and business case analysis. In this costing approach, a clearer picture of the cash flow from wireless system operations is developed. Increasing demand for wireless access and usage, or both at once, translates into an increase in certain portions of the engineered capacity of the system (e.g., advancing the placement of BTSs, expanding capacity of traffic aggregation and trunk and backhaul facilities), and increases revenues incrementally as well.

Another area for improvement in wireless access system models is to model explicitly the cost of PSTN network interconnection and shared trunking arrangements. The cost of PSTN interconnection could be incurred per minute or per interconnecting trunk and should be included in any financial analysis since it will be, in most cases, an unavoidable incremental cost of usage growth, whether for call originations or terminations. This raises an important strategic issue for wireless network modeling. If a wireless access system operator must incur interconnection costs to the PSTN, why not plan to interconnect at the most convenient and cost-minimizing way? Very little explicit modeling of local PSTN joint service arrangements has occurred to date, but could be an important source of cost savings to new network operators.

A primary driver of incremental cost for wireless access systems involves aggregating and trunking traffic among remote radio nodes (BTSs/BSCs) and between those nodes and the central nodes (MSCs). There are also the network control functions which may require trunking to and from a centralize database. Instead of the standard assumption of a stand-alone wireless access network system, including trunking facilities, why not consider as a strategic alternative the sharing of network facilities owned by incumbent wireline carrier networks, like telephone companies and cable television companies ? Interconnecting to, and leasing capacity on, the ubiquitous intelligent networks employed by PSTN operators or other *competitive access providers* (CAPs) has the potential to reduce substantially investment costs in stand-alone facilities of the wireless access network.

4.11 Public policy for wireless networks in the NII

A number of public policy implications flow from the preceding discussion and analysis in key areas: NII market structure and spectrum allocation, network compatibility standards, interconnection and access pricing, common carriage and universal service.

4.12 Market structure and spectrum allocation

The Administration's stated objective for the NII is to have a competitive market as the vehicle to drive investment in the telecom sector. The FCC has certainly followed suit by allocating RF spectrum to foster at least three major players in the market for so-called "broadband" PCS wireless access services. This is in addition to new and expanded allocations to true wireless broadband service providers such as wireless cable and satellite systems.

Whether intended or not, the FCC's spectrum allocations of up to 40 MHz for individual licensees of PCS services effectively preclude them from the two-way broadband services market. If wireless is to someday serve the mass market for multi-media or video telephony, it will have to come from wireless cable and satellite service providers or some combination of these and other land-based systems, perhaps coupled with in-home wireless systems using unlicensed spectrum (e.g., infrared). As wireless technology progresses and as the government can be convinced to let go of more of the fallow frequency spectrum, the role of wireless access may be expanded considerably over that already planned with PCS networks.

The FCC can facilitate this process by extending its new-found "flexible use" policies beyond the relatively small amount of PCS spectrum to a much wider range of spectrum encompassing existing licensed bands, starting with those broadcast frequencies that appear to have greatest potential for two-way service in a digital environment (e.g., wireless cable) and those which are underutilized (e.g., UHF TV). Revisiting the reasonableness of old licenses and the old spectrum endowments could not only bring more money into the government coffers, it would also expand competition and investment in the NII. In adopting its flexible use rules for PCS and allocating unlicensed spectrum at no cost to new service providers, the FCC has begun to move down the right path. Hopefully it will continue the journey.

4.13 Network compatibility standards, interconnection and access pricing

Critical to the success of the NII and the role of local wireless access services within it is the ability to offer convenient nationwide calling capability. Wireless access systems could someday provide the ability to call *anyone*, *anywhere*, *anytime*. Similar to what has already occurred for narrowband ISDN standards, national and international coordination of network compatibility is crucial to the success of a technology and a public infrastructure. Rules for governing both the wireless network interface and user network interface to the PSTN must be agreed upon by the industry players. The government's role is to establish a fair process to see to it that the industry sets a reasonable standard in a reasonable period of time. It is the voluntary nature of standard setting and the compliance process that will minimize the risk of adopting an inferior standard or having no standard at all.

Pricing for network interconnection and access to the PSTN must be nondiscriminatory and competitively neutral. During the transition to full competition in all aspects of the PSTN, regulations regarding cost-based, nondiscriminatory tariffs for PSTN interconnection is essential to assuring a level playing field for entrants and incumbents alike. If such rules are developed and enforced, then there is no reason to restrict in any way competition between incumbents and entrants. The FCC's licensing of wireless PCS and broadcast spectrum allocations are biased against incumbent operators so that direct competition for local telephone service and television will develop. This should be a temporary measure until nondiscriminatory pricing rules for PSTN access and interconnection are adopted. Otherwise, legitimate economies of scope from technological integration of network operators in the NII may be unduly delayed or foregone altogether, to the ultimate detriment of consumers.

The cost of new wireless technology is primarily driven by the portability demands of the calling party and secondarily by the requirements of locating the called party wherever they are. This means that the success and the cost of achieving portability critically depends on network interconnection. Even when the called party is not on the move, wireless network interconnection to the PSTN is critical to successful call completion.

Since new wireless access systems are predominately competitive local operations providing services to the public for random call originations, it will be very difficult to successfully avoid paying for call terminations on the PSTN because it simply cannot be known where the calls are going to end up. Bypassing the local PSTN operators for call terminations to avoid paying network access charges has always been problematic, even for major national long distance companies. It will be a very long time before the various competitive wireless access companies will be able to successfully piece together national bypass arrangements on both the originating and terminating portions of calls. This situation would require that most Americans use wireless access and that there is very close service coordination among what are ostensibly competing local companies. While some national wireless consortiums with national spectrum licenses will claim to be able to provide "seamless" national service, there will invariably be a need for local interconnection for some (probably most) calls.

Depending on future regulatory rules concerning pricing for interconnection, PSTN access charges are potentially very substantial. The imperative of the Administration's NII policy--that wireless or other private networks interconnect or are otherwise compatible with one another and the PSTN--is well founded. The cost and price of that interconnection within the context of the NII has yet to be directly addressed. If the government truly wants to solve the interconnection problem for new wireless access operators, it will require some creative plans to gradually reduce the PSTN interconnection tariffs. A system of cost-based rates for PSTN interconnection will substantially improve the financial prospects of new competitive wireless access networks, and, at the same time, will level the playing field between incumbent localtelephone companiesand new entrants. The transition to non-discriminatory cost-based PSTN interconnection charges will not be easy because it involves reforming the current system of cross-subsidies to basic local exchange services, but the process must begin soon to eliminate artificial barriers to entry to new technologies like digital wireless access.

The most obvious economic solution to achieving both a competitive market for local telephone service and low cost interconnection would simply be for the government to quit regulating local market entry and, at the same time, deregulate rates. This would start a very desirable chain reaction in the market which would begin to solve both the problem of how to increase local telephone competition and lower PSTN interconnection costs. Basic local phone rates would rise to at least a cost compensatory level (perhaps capped by regulators at that point), thereby attracting more local market entry, which in turn would stimulate bypass and competition for local interconnection, thereby keeping its cost down as well. At that point, the main issue remaining for the government to achieve the vision of the NII is how to protect universal and affordable access to the new competitive infrastructure.

4.14 Common carriage and universal service

The goals set for the NII hinge on principles of common carriage and universal service. Normally, the FCC forbears from regulating private radio networks, instead treating them as private "contract" carriers. However, common carriage is implied for new wireless access network operators because of the FCC's rapid network build out requirement for area coverage in accordance with the terms of the license to use the spectrum. What remains somewhat more problematic from a policy perspective is the lack of a related universal service requirement. In other words, even if new wireless access networks provide the area coverage required as a condition of their license, there is still no obligation to provide service to everyone or to provide it at regulated prices. Indeed, the FCC's own new flexible use policies provide new wireless system operators the freedom to use their system capacity for services targeted to only businesses or other lucrative niche markets within the coverage area, thereby totally ignoring the mass market of residential subscribers. In such situations, a sort of red-lining could occur due to private market incentives to discriminate in the name of profit opportunity rather than any conscious avoidance of serving certain neighborhoods.

Universal nondiscriminatory access to the PSTN is part and parcel of the tradition of regulated common carriers in the US. On the other hand, private contract carriers like cable television companiesand wireless systems have neither the obligation nor the inclination to provide service in very thin rural and remote locales. The available cost data indicates that the financial health of both wired and wireless access systems is strongly and directly related to subscriber density. This is not true for satellite systems, however, which depend more on total system demand without particular regard to where the demand is coming from. Thus, satellite systems of the future may be well suited to provide universal coverage in rural and remote areas because they do not feature the very high subscriber connection costs that land-based network systems do. Within the context of the NII, it remains a matter of public policy as to whether or not the level of service via two-way digital satellite systems for rural and remote areas is acceptable and comparable to the level of service provided by land-based urban systems.

In light of this and the fact that the NII policy generally prefers private market solutions to public assistance programs, perhaps the FCC should consider a rural area policy that provides certain benefits to those network operators willing to serve remote and rural subscribers that otherwise would not be able to obtain access to the NII without a government subsidy.

In the case of telephone companies serving rural areas, the FCC typically relaxes rules restricting PSTN operators to allow them to provide wireless services within their monopoly local service areas by granting them waivers to use spectrum normally reserved for competitive entrants or to use spectrum normally reserved for other uses, but which lie fallow in rural areas.

If the current state of cellular mobile service in rural areas is any indication, the Commission may need to do more. This could be done, for example by extending spectrum rights to regional licensees serving metropolitan areas to encourage them to extend their coverage area, perhaps in conjunction with the rural PSTN operator using toll connect trunks back to the urban center. Beyond allocating more spectrum to rural radio services, the FCC could tailor its system powering restrictions to meet the needs of rural operators. Radio system interference is less likely in rural areas than in dense urban areas. An increase in the allowed power levels of rural radio systems will increase the coverage area per antenna site thereby improving the financial viability of rural wireless systems.

Barring success with such policies, as a last resort, the government may choose to subsidize PSTN network upgrades in rural areas under a related NII initiative.

4.15 The politics of the NII

The important message for public policy is that, until the service requirements of the universal NII have been specified, the question as to which is preferred, wireline or wireless access service, cannot be answered. If, as many believe, the NII only contemplates socially efficient access to narrowband digital voice and data services, then digital wireless technology is preferred for dedicated subscriber connections to the wireline intercity PSTN. The fact that wireless access costs are lower notwithstanding, the real bonus for the consuming public from this scenario is portability.

If however, access to broadband service, especially bandwidth-on-demand type access service, must be added to the narrowband service mix for the NII, then wireline access technology is likely to be the winner in the race for preeminence in the future NII.

There is an interesting irony which flows out of this conclusion: acting in their own business interests, wireless access network providers of all types, narrowband and broadband (e.g., wireless cable and satellite services), would not want to back a definition of service for the NII that included broadband capability. If they did, the long-term winner in the race to be the infrastructure network provider is likely to be wireline access.

By promoting a narrowband access infrastructure, narrowband wireless network operators would be the least cost alternative, and digital wireless broadcast networks would also be the least cost alternative for the traditional (huge) niche market for one-way video service.

Thus, if the social cost of infrastructure is the issue for the NII, and if policy makers envision bandwidth-on-demand as a long term infrastructure imperative, integrated two-way broadband services are best provided by wireline operators (e.g., cable television companiesand telcos). In this scenario, even though the role of wireless access services in the NII is not a dominant one, the indisputable convenience aspects of portability coupled with the affordability of new wireless technology will assure that the mass market will still be served by the interconnected adjunct networks of wireless access operators.

This conclusion leads to another interesting twist for the public policy stance of the wireless industry regarding the NII. By voluntarily opting out of the government NII juggernaut, wireless network system operators may actually be selecting the right path. After all, the NII concept implies government interference in such critical areas of universal service and so-called "carrier of last resort" obligations, common carrier regulations for pricing, standards and network interconnection; none of which apply to private contract carriers, which is what many new wireless carriers are planning to be. Since wireless technology has inherent cost and market advantages (e.g., portability, convenience) over its wireline counterpart, its importance in future consumer markets is virtually assured and there may be relatively little to be gained by the wireless industry becoming one of the tools of the federal government's regulatory competition policy in the NII. New digital wireless carriers also run the risk of encountering burdensome state regulation if they are similarly used by state governments as a tool to bring competition to the market for local telephone service.

The bottom line for wireless technology, whether preferred by policy makers for the NII or not, is that it will be around and it will develop and thrive in the mass market. Considering this inescapable conclusion, and considering that the private sector tends to be very distrustful of government involvement in a an otherwise competitive business, wireless network operators of all stripes might consider it a blessing that they are not tagged as the vehicle for driving onto the public information superhighway.