WiMax Operator’s Manual

Building 802.16 Wireless Networks (Second Edition)

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CHAPTER 2

Architecting the Network to Fit the Business Model

Broadband wireless provides one of many physical-layer options for the operator of a public service network. Furthermore, the different wireless networking technologies themselves exhibit widely varying capabilities for fulfilling the needs and expectations of various customers and enterprises. More than previous wireless standards, 802.16 addresses a multitude of needs for the users of broadband access services, but it is not invariably the best solution for delivering broadband services in every market.

Broadband Fixed Wireless: The Competitive Context

This section strives to answer the question, when is 802.16-based equipment appropriate? It is the first and most crucial question network operators have to ask themselves when considering the broadband wireless option.

At the risk of stating the obvious, I will enumerate the rival competitive access technologies for broadband before discussing their competitive positioning vis-à-vis wireless.

In the metropolitan space, wireless broadband competes with the following:

- T1 and E1 data services over legacy copper where aggregations of ordinary twisted pairs form the physical medium of propagation.
- Data services based on Synchronous Optical Network (SONET) and Synchronous Digital Hierarchy (SDH), running over fiber linkages.
- Frame relay services running over fiber or T1/E1.
- Ethernet data services running over active fiber-optic linkages.
- Ethernet data services running over passive optical networks (PONs).
- IP data services over active fiber.
- Asynchronous Transfer Mode (ATM) services over active fiber.
- ATM over passive fiber.

- Wavelength services over active fiber.
- Ethernet services over hybrid fiber coax.
- Digital subscriber line (DSL); most existing DSL networks contain components based on ATM and Internet Protocol (IP) as well as Ethernet.
- Powerline carriers where AC transmission lines carry packet data.
- Broadband satellite.
- Free-air or free-space optics where laser beams transmit information over an airlink, dispensing with fiber.
- 2.5-generation (2.5G) and 3G mobile data services, including HSDPA.
- Integrated Services Digital Network (ISDN), a nearly obsolete type of medium-speed data service utilizing double pairs of ordinary copper phone lines to transmit data.
- Storage-area networks represent a special case; most use specialized data protocols of which Fibre Channel, which runs over optical fiber, is the most popular.

Of these rivals, several are currently entirely inconsequential. Broadband as opposed to medium-speed satellite services scarcely exists as yet, and powerline carrier services and PONs are scarce as well, though both appear to be gathering impetus. Pure IP and Ethernet metro services over fiber are growing in acceptance, but they are not well established, and ISDN has almost disappeared in the United States, though it lingers abroad. Finally, free-space optics have achieved very little market penetration and do not appear to be poised for rapid growth. Other services mentioned previously—such as wavelength, 3G mobile, direct ATM services over active fiber, and metro Ethernet over active fiber—have some presence in the market but are spottily available and limited in their penetration thus far.

In this context, broadband wireless does not look nearly as bad as detractors would have it. If you consider the whole array of competing access technologies, broadband wireless has achieved more success than most. Still, it faces formidable competitors among the more established technologies, and these are T1/E1 (including fractional and multiple T1/E1), frame relay, DSL, and cable data.

Among the incumbent technologies, cable data and DSL are the leading technologies for residential services, and business-class DSL, T1/E1, and frame relay are the dominant service offerings for small- and medium-sized businesses. The largest enterprises that require large data transfers tend to prefer higher-speed optical services using both packet and circuit protocols.

Circuit-Based Access Technologies

Within the enterprise data service market, T1, fractional T1 (E1 elsewhere in the world), and business-class DSL are the most utilized service offerings, along with frame relay, which is chiefly used to link remote offices and occupies a special niche.

T1 is usually delivered over copper pairs and is characterized by high reliability and availability, reasonable throughputs, 1.5 megabits per second (Mbps), and inherent quality of service. Its limitations are equally significant. T1s cannot burst to higher speeds to meet momentary needs for higher throughputs, and they are difficult to aggregate if the user wants consistently higher throughput speed. T1s are also difficult and expensive to provision, and provisioning times are commonly measured in weeks. Finally, T1 speeds are a poor match for 10 base T Ethernet, and attempts to extend an enterprise Ethernet over a T1 link will noticeably degrade network performance.

Because it is circuit based and reserves bandwidth for each session, T1 offers extremely consistent performance regardless of network loading. Maximum throughput speeds are maintained at all times, and latency, jitter, and error rates are well controlled. Were the bandwidth greater, T1s would be ideal for high-fidelity multimedia, but, as is, 1.5Mbps is marginal in that regard.

T1/E1 is legacy access technology. The basic standards were developed in the 1960s, and the SONET and SDH optical equipment supporting massive T1/E1 deployments dates back 20 years. In terms of performance level, T1/E1 is essentially fixed, a fact that will put it at an increasing disadvantage to newer technologies, including broadband wireless. Also, the infrastructure for these circuit-based access networks is expensive to build, but, since most of it has already been constructed, it is by now fully amortized.

I do not expect a lot of new copper to be built except in developing countries, and so the last-mile access for T1/E1 must be considered a fixed asset at this time. But, somewhat surprisingly, the sales of SONET and SDH equipment for the metro core have been increasing rapidly through the late 1990s and the opening years of this century, and they are not expected to peak until 2007. Therefore, SONET and the T1 service offerings it supports will be around for a long time.

Prices in the past for T1s were more than $1,000 per month, but they have dropped somewhat, and they are now about $300 to $400 in the United States, though prices vary by region and by individual metropolitan market. Compared to newer access technologies, T1 does not appear to represent a bargain, but it is all that is available in many locales. Moreover, the incumbent carriers that provision most T1 connections are in no hurry to see it supplanted because it has become an extremely lucrative cash cow.

Because of the apparently disadvantageous pricing, T1 services may appear to be vulnerable to competition, but thus far they have held their own in the marketplace. Ethernet and IP services, whether wireless or wireline, will probably supplant circuit-based T1 in time, but as long as the incumbent telcos enjoy a near monopoly in the local marketplace and are prepared to ward off competition by extremely aggressive pricing and denial of central office facilities to competitors, the T1 business will survive. I suspect that T1 connections will still account for a considerable percentage of all business data links at the end of this decade.

Frame Relay

Frame relay is a packet-based protocol developed during the early 1990s for use over fiber-optic networks (see Figure 2-1). Frame relay permits reservation of bandwidth and enables tiered service offerings, but it is not capable of supporting quality-of-service (QoS) guarantees for multimedia, as does ATM, or some of the ancillary protocols associated with IP, such as Multiprotocol Label Switching (MPLS), Reservation Protocol (RSVP), and DiffServ. Also, frame relay does not permit momentary bursting to higher throughput rates or self-provisioning. Frame relay is rarely used to deliver multimedia and other applications demanding stringent traffic shaping, and it is never used to deliver residential service. Usually, frame relay is employed to connect multiple remote locations in an enterprise to its headquarters, and connections over thousands of miles are entirely feasible. Frame relay switches or frame relay access devices (FRADs) are usually accessed from an office terminal via a T1 connection, though other physical media may be employed, including wireless broadband. Frame relay transmissions over long distances, commonly referred to collectively as the *frame relay cloud*, invariably travel over fiber and are usually encapsulated within ATM transmissions.

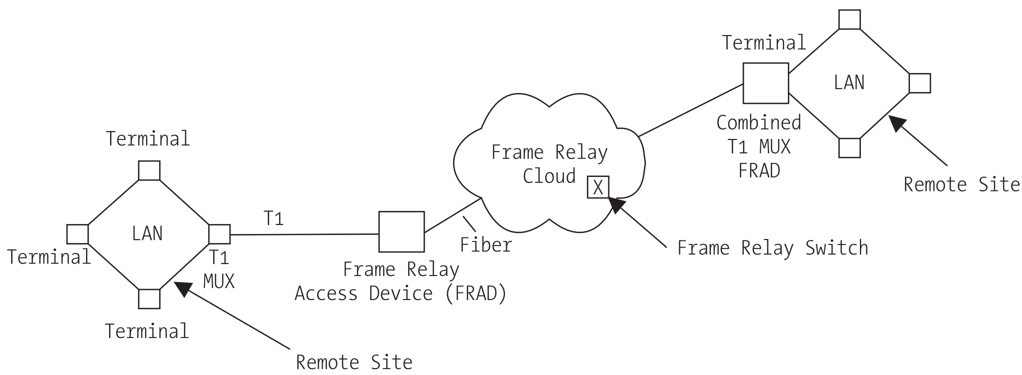

Figure 2-1. *A relay network*

Frame relay services are largely the province of incumbent local phone companies or long-distance service providers. Throughputs vary but are commonly slower than a megabit per second—medium speed rather than high speed. As is the case with T1, frame relay is a legacy technology, standards have not been subject to amendment for years, and not much development work is being done with frame relay devices. The performance of frame relay is not going to improve substantially in all likelihood. Pricing is in the T1 range, with higher prices for higher throughput rates and special value-added services such as Voice-over Frame Relay (VoFR). Also, provisioning of multiple remote locations can be prohibitively expensive with conventional frame relay equipment because the networks do not scale well, and this may limit the popularity of frame relay in the future. Frame relay does not directly compete with wireless broadband in the metro, and thus targeting existing customers for the service makes little sense. Frame relay will continue to lose ground to enhanced metro Ethernet and IP services.

DSL

DSL is arguably the strongest competitor to 802.16 wireless among broadband access technologies. DSL comes in many variants, including asymmetric DSL (ADSL), symmetric DSL (SDSL), G.lite, single-pair high-speed DSL (SHDSL), and very high data rate DSL (VDSL). The distinguishing features of the various substandards are not particularly germane to this discussion and have to do with the speed of the connection and the apportionment of available spectrum upstream and downstream.

DSL utilizes digital signal processing and power amplification to extend the frequency range of ordinary twisted-pair copper lines that were originally designed to carry 56-kilobit voice signals and nothing faster. Aggressive signal processing applied to uncorroded copper can best this nominal limit by orders of magnitude. Commercially available systems can now achieve speeds in excess of 100 kilobits per second over distances of a couple of thousand feet, though the norm for VDSL2, the fastest standards-based DSL technology, is less than 30Mbps over distances exceeding 5,000 feet.

DSL, unlike frame relay, is strictly a physical-layer technology and can be used in tandem with various higher-layer protocols, including circuit digital, Ethernet, ATM, frame relay, IP, and MPEG video, though ATM, IP, and Ethernet are most common today. DSL can support high-quality multimedia if throughput is sufficient and error rates well controlled, but the consistent achievement of high throughput rates is difficult if not impossible in many copper plants.

Plainly put, a DSL network overlay is highly dependent on the condition of the existing copper telephone lines because no one is going to assume the expense of rewiring a phone system—a move to pure fiber would make more sense if that were required. In the presence of corroded copper, both the speed and distance of DSL transmissions are diminished (the best-case distance for moderate-speed transmissions is a little more than 20,000 feet). If the copper plant is compromised, the network operator has no choice but to shorten the distance from the subscribers to the nearest aggregation points known as *digital loop carriers (DLCs)*. And since the latter are expensive to site and construct and require costly fiber-optic backhaul to a central office, they can burden the operator with inordinately high infrastructure costs if they are numerous. Nevertheless, SBC has announced an aggressive VDSL2 build-out.

Assessing the cost competitiveness of DSL vis-à-vis other broadband access technologies is difficult because it is so dependent on contingencies. The pricing structure for a carrier owning the copper lines and central office facilities is entirely different from that of a DSL startup obliged to lease copper as well as equipment space in a telco central office. A DSL network is certainly less expensive than new fiber construction because it leverages existing infrastructure, but it still requires a great deal of new equipment and frequently necessitates installation visits to the customer premises by field technicians.

Despite these limitations, DSL services have been expanding rapidly all over the developed world, with especially extensive deployments in East Asia and the United States. In the United States, DSL has found large and growing markets among small businesses and residential users.

To a limited extent, DSL has been used to deliver video services to homes, but the primary offering is simple Internet access. In neither the residence nor the small enterprise are value-added services yet the norm.

Typical speeds for residential service are in the low hundreds of kilobits and slightly higher in the case of business-class services. Some business-class services also offer service agreements in regard to long-distance transmissions over the Internet.

VDSL and VDSL2, the high-speed variants, have the speed to enable advanced IP and Ethernet business services and high-quality converged residential services and, to that extent, must be regarded as a technology to watch. The distances over which VDSL can operate are relatively short, however, little more than a mile best case, and VDSL networks require extensive builds of deep fiber. Only a fairly small number of such networks exist in the world today, though the technology is finding acceptance in Europe. New low-priced VDSL modems are coming on the market that could speed the acceptance of the service somewhat, but that will not reduce the cost of the deep fiber builds necessary to support it.

DSL is a new rather than a legacy technology, emerging from the laboratory about a decade ago (though not subject to mass deployments until the turn of the century), but already DSL appears to be nearing the limits of its performance potential. Where wireless and optical transmission equipment have achieved orders of magnitude gains in throughput speed over the past ten years, DSL has not improved much on the speeds reported years ago. DSL may not be positioned to compete effectively in the future against other access technologies that have the potential for significant further development.

I think DSL is a transitional technology, one that was developed primarily to allow incumbent telcos to compete in the high-speed access market without having to build completely new infrastructure. I further think broadband wireless, as it continues to improve, will become increasingly competitive with DSL.

Finally, basic DSL technology was developed by Belcore, the research organization serving the regional Bell Operating Companies (RBOCs), and was initially intended to support video services over phone lines, services that would enable the RBOCs to compete with the cable television companies in their core markets. The first serious rollouts of DSL were initiated by independents, however, chief among them Covad, Rhythms, and Northpoint, all of which went bankrupt. Independents owned the actual DSL network elements but were obliged to lease lines and locate DSL aggregators (DSLAMs), switches, and routers in central offices belonging to incumbent telcos, generally RBOCs. Such collocation placed the independents in what was in effect enemy territory and left them vulnerable to delaying tactics and even outright sabotage. Dozens of successful legal actions were launched against RBOCs on just such grounds, but the RBOCs simply paid the fines and watched the independents expire.

The wireless broadband operator should draw two lessons from this. First, do not enter into service agreements with competitors, if possible. Own your own infrastructure, and operate as a true independent. Second, realize that the incumbent telcos are grimly determined to defend their monopoly and will stop at nothing to put you out of business. In the past, wireless has not posed a sufficient threat to RBOCs to arouse their full combativeness, but that will change in the future.

Hybrid Fiber Coax

The final major competitive access technology extant today is hybrid fiber coax, the physical layer utilized by the multichannel systems operators (MSOs), industry jargon for the cable television companies (see Figure 2-2). Hybrid fiber coax consists of a metro core of optical fiber that frequently employs the same SONET equipment favored by the RBOCs along with last-mile runs of coaxial television cable. Each run of cable serves a considerable number of customers—as few as 50 and as many as several thousand. The coaxial cable itself has potential bandwidth of 3 gigahertz, of which less than a gigahertz is used for television programming. Most cable operators allocate less than 20MHz of bandwidth to data. Industry research organization Cable Labs is currently at work on a new standard that is intended to exploit the full potential of coaxial copper and to achieve at least an order of magnitude improvement in data speed. Should low-cost, standards-based equipment appear on the market supporting vastly higher throughputs, then the competitive position of cable will be considerably enhanced. In the past cable operators have proved more than willing to make large investments in their plants to launch new types of services. Wireless broadband operators as well as others embracing competitive access technologies would be well advised to watch their backs in respect to cable. Cable is unlikely to stand still in the midterm.

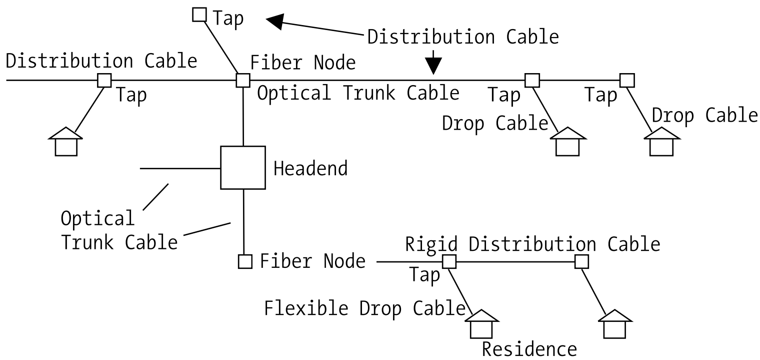

Figure 2-2. *A hybrid fiber coax network*

The speed of a single coax cable far exceeds that of a DSL-enhanced copper pair, but since its capacity is divided among a multitude of subscribers, the speed advantage is manifested to the end user only when the subscriber population on each cable run is small. Cable companies of late have been tending to restrict the number of customers per coaxial cable, but such a strategy is costly and will be pursued only with reluctance and with clear profit-making opportunities in view.

Cable data services aimed at the mass market date back to 1997 in the United States and today account for most of the residential broadband in this country, with DSL ranking a distant second. Unlike the case with DSL, cable data access services are nearly always bundled with video and, increasingly, with cable-based telephone services and video on demand. Cable offers by far the richest service packages for the residential user, and historically the industry has demonstrated a strong commitment to expanding the number of services to cement customer loyalty.

Cable services have historically garnered low customer satisfaction ratings, however, and in truth the actual networks have been characterized by low availability and reliability and poor signal quality. These attributes, it should be noted, are not the consequence of deficiencies in the basic technology but are simply because of the unwillingness of many cable operators to pay for a first-rate plant. Broadband access competitors should not be deceived into thinking that cable systems are consistent underperformers.

MSOs have made some efforts to court business users but have been less successful than DSL providers in signing small businesses. Cable does not pass the majority of business districts, and the cable operators themselves are often not well attuned to the wants and needs of the business customer. Nevertheless, some MSOs have pursued business customers aggressively, and the industry as a whole may place increasing emphasis on this market to the probable detriment of other broadband access technologies. Already several manufacturers have developed platforms for adapting cable networks to serve business users more effectively; these include Jedai, Narad, Advent, Chinook, and Xtend, among others. Cable operators themselves are also beginning to buy the new generation of multiservice switching platforms for the network core that will enable them to offer advanced services based on the Ethernet and IP protocols.

Finally, I should mention *overbuilders*, the competitive local exchange carriers (CLECs) of the cable world. These companies are committed to building the most up-to-date hybrid fiber coax networks, and most of them are actively pursuing business accounts. The ultimate success of the overbuilders is unknowable—they are competing against strongly entrenched incumbents in a period where the capital markets are disinclined to support further ambitious network builds—but in marked distinction to the case with the telco CLECs, the major overbuilders have all managed to survive and to date are holding their own against the cable giants.

Placing cable data access within the context of other competing access technologies is somewhat difficult. Cable could be said to represent the repurposing of legacy technology just as is the case with DSL, but the basic cable plant has been transforming itself so rapidly over the past 15 years that such an interpretation seems less than fully accurate. It is more accurate to say that the hybrid fiber cable plant is an evolving technology that is arguably on the way to having an all-fiber infrastructure in the far future. It may be that local telephone networks will trace a similar evolutionary course—the incumbent local exchanges (ILECs) have been issuing requests for proposals for passive optical networking equipment that would deliver fiber to the curb or fiber to the home—but cable networks lend themselves much more readily to a full conversion to fiber than do telephone networks. My guess is that cable operators will convert more quickly than their telco counterparts. To the extent that this is true, cable emerges as by far the most formidable competitive access technology, and it is one that is likely to preempt broadband wireless in a number of markets. Cable offers potentially superior speed over DSL (and certainly to legacy circuit services); near ubiquity; fairly cost-effective infrastructure; a range of attractive service offerings; and a wealth of experience in network management.

Predicting the course that technological progress will take is difficult, but in the long term, extending into the third and fourth decades of this century, pervasive fiber will establish itself throughout the developed world, packet protocols will be ubiquitous at all levels of the network, and the resulting converged services or full services network will essentially be an evolved cable network. The underlying distinctions between cable and telecommunications networks will vanish, and there will be only one wireline technology.

Wireless Broadband

So where does all this leave wireless broadband?

The singular strength of wireless broadband access technologies is the degree to which they lend themselves to pervasive deployments. At least in the lower frequency ranges, building a wireless network is largely a matter of setting up access points. Subscriber radio modems are destined to decline in price over the course of this decade and will eventually take the form of specialized software present as a standard feature in nearly all mass-market computing platforms, a trend that further supports pervasiveness. Wireless networks will increasingly be characterized by their impermanence and flexibility, and as such they will be complementary to expensive albeit extremely fast fiber-optic linkages.

This book, however, focuses on the present, and current wireless broadband networks are not and cannot be completely pervasive, and subscriber modems are not extremely inexpensive, though they are falling in price. In terms of price and capabilities, wireless broadband is competitive with T1, DSL, and cable; it is better in some respects and inferior and others, and it is highly dependent on accidents of topography as well as local market conditions.

This section first describes how wireless speed and capacity compare with those of the major wireline competitors.

Wireless networks are more akin to cable than to DSL or circuit because they are essentially *shared resource* networks. The same spectrum at least potentially serves every customer within reach of a base station, and the network operator depends entirely on the media access control (MAC) layer of the network to determine how that spectrum is allocated. A network operator could choose to make the entire spectrum available to one customer, but in most cases no single customer is willing to pay a sum sufficient to justify the exclusion of every other party. When a network operator does find a customer who wants to occupy the full spectrum and is willing to pay to do so, the operator will usually link the customer premises with the base station via two highly directional antennas so that the spectrum can be reused in a nearby sector.

How much spectrum the operator has available determines the network's capacity. In the lower microwave region, 100 megahertz (MHz) constitutes a fairly generous allocation, and 30MHz is about the minimum amount necessary to launch any kind of broadband service. You can derive ultimate data throughput rates by utilizing the correct bits-to-hertz ratio. In the lower microwave region, current generation equipment can manage 5 bits per hertz under strong signal conditions, and that number may be expected to rise over time. Thus, the total bandwidth available to most 802.16a operators will allow a throughput of, at most, a few hundred megabits per second—much more than is the case for an individual DSL line or a T1 circuit, but substantially less than can be delivered over hybrid fiber coax. Bear in mind, however, that in a VDSL2 installation, each DSL line can deliver up to 100Mbps, and a network may have thousands of separate lines, so the comparison is not entirely apt. In general, 802.16a is disadvantaged in respect to total throughput as compared to any of the technologies with which it is competing, with the exception of 3G mobile wireless.

Usually, 802.16 radios (which operate in the higher microwave regions) can take advantage of more generous spectral allocations—several hundred megahertz to more than a gigahertz. And where the full bandwidth is used, which it often is, 802.16 radios can vie with fiber. You should understand, however, that the bits-per-hertz ratio is generally poorer for higher-band microwave equipment—often no more than 1 bit per hertz, so the generous bandwidth allocations are to some extent offset by the limitations of the equipment in terms of spectral efficiency. Rather recently, spectrum has been opened above 50GHz in the United States where spectral allocations in the gigahertz are available, and these offer the possibility of truly fiberlike speeds. Then, too, it is not difficult to use such microwave equipment in tandem with free-air optical equipment that is also capable of throughputs of gigabits per second. Thus, aggregate throughputs of 10 gigabits per second (Gbps) could be achieved through an airlink, the equivalent of the OC-192 standard for single wavelength transmissions over fiber.

You must balance these manifest advantages against the poorer availability of the airlink compared to that of fiber. Not a tremendous number of enterprise customers are interested in very high speed and only moderate availability. Usually, customers for high-throughput connections want a very predictable link.

The overall capacity of a broadband wireless network as opposed to the maximum throughput over any individual airlink is largely a function of the number of base stations in the network. The denser the distribution of base stations, the more customers can be accommodated—provided, that is, that the power of individual transmissions is strictly controlled so that transmissions within each individual cell defined by the base station do not spill over into adjacent cells. The situation is almost analogous to cable networks where capacity can be increased by almost any degree simply by building more subheadends and more individual runs of coaxial copper.

The problem, of course, is that base station equipment is expensive, and leased locations on rooftops or the sides of buildings can represent heavy recurrent costs. And unless a base station is equipped with an adaptive array antenna, it cannot remotely compare in capacity with a cable subheadend that can easily accommodate many thousands of users. You should remember that the first use of broadband wireless in the United States was to distribute "wireless cable" television programming over approximately 200MHz of spectrum, a fairly generous allotment. Even so, wireless cable service providers could not compete effectively with conventional cable operators, and most went out of business within a few years.

I should point out that the difficulty in reaching all potential customers is much greater with higher microwave operators covered by 802.16. Any building that is not visible from the base station is not a candidate for service—it is that simple—so the capacity of any individual base station is quite limited. Unfortunately, base station equipment intended to operate at these frequencies is usually far more costly than gear designed for the lower microwave region, so the construction of additional base stations is not undertaken lightly.

Another extremely important limitation on capacity affecting upper microwave operators is the nature of the connection to the individual subscriber. Upper microwave services are invariably aimed at business users. Because of line-of-sight limitations, the operator looks for a lot of potential subscribers within a circumscribed space—a business high-rise is the preferred target. Instead of providing a subscriber terminal to every subscriber—which is a prohibitively expensive proposition because subscriber terminals for these frequencies are nearly as expensive as base station equipment—the operator strives to put a single terminal on the roof and then connect customers scattered through the building via an internal hardwired Ethernet, though a wireless LAN could conceivably be used as well.

Distributing traffic to subscribers may mean putting in an Ethernet switch in an equipment closet or data center, and it will undoubtedly involve negotiations with the building owner, including possibly even recabling part of the building. Successfully concluding negotiations with the owners of all the desirable and accessible buildings is a difficult undertaking, and the network operator is unlikely to be wholly successful there. In contrast, the incumbent telco offering high-speed data services will already have free access to the building—the real estate owner can scarcely deny phone service to tenants and expect to survive—and thus has no need to negotiate or pay anything. Owners can simply offer any services they see fit to any tenant who wants to buy it.

Such real estate issues do not constitute an absolute physical limit on capacity, but in practical terms they do limit the footprint of the wireless network operator in a given metropolitan market. One has only to review the many failures of upper microwave licensees to build successful networks in the United States to realize that despite the ease of installing base stations compared to laying cables, microwave operators do not enjoy a real competitive superiority.

As was the case with throughput, so it is with total network capacity. Whatever the frequency, wireless broadband does not appear to enjoy any clear advantage.

I have already discussed availability and reliability. Wireless will always suffer in comparison to wireline, and wireless networks are apt to experience a multitude of temporary interruptions of service and overall higher bit error rates. In their favor, wireless networks can cope much better with catastrophic events. Though an airlink can be blocked, it cannot be cut, and the network can redirect signals along circuitous paths to reach the subscribers from different directions in the event of strong interference or the destruction of an individual base station. This is not necessarily possible with most equipment available now, but it is within the capabilities of advanced radio frequency (RF) technology today.

In terms of QoS and value-added services, broadband wireless is getting there, but it is generally not on par with the wireline access media. The first generation of 802.16a equipment cannot emulate the cable networks in simultaneously offering video programming, voice telephony, and special business services.

So what is the competitive position of wireless broadband, and where does it have a chance of success?

Many individuals with experience in wireless broadband have concluded that wireless networks should be contemplated only where the leading wireline access technologies such as T1/E1, frame relay, DSL, and cable data are not already established. Each of these access methods is fairly well proven, the argument goes. Moreover, the plant is paid for; that is, the infrastructure is fully amortized. Incumbents offering these services can and will temporarily slash prices to quash competitors, so the wireless operator cannot necessarily compete in price even in such cases where wireless infrastructure can be shown to be much more cost effective.

Still, I am not so pessimistic as to concur with the position that wireless cannot compete against wireline under any circumstances and that it must therefore enter only those markets where there is nothing else. The case for wireless is not nearly so hopeless. A great multitude of business customers, perhaps the majority, is badly underserved by the T1 and business DSL services that prevail in the marketplace today. They are both slow and relatively expensive, and the service providers make little effort to make available value adds such as storage, security provisions, application hosting, virtual private networks (VPNs), conferencing, transparent LAN extensions, self-provisioning, and bandwidth on demand. T1 services, to put the matter bluntly, are a poor value. None of these limitations apply to the wireless broadband networks of today, and the wireless operator can compete against incumbent wireline services simply by offering better and more varied service offerings and by being more responsive to subscriber demands—this despite the fact that wireless equipment lacks the capacity or the availability of wireline networks.

Competing for residential customers is much more difficult. Wireless broadband cannot transmit video as effectively as can cable and cannot ensure the same level of availability for voice as twisted-pair copper, so it lacks a core service offering. All it can provide in the way of competitive services is Internet access and value-added business services. Wireless can, however, afford the user a measure of portability and even mobility, and that may actually be its principal selling point in respect to residential customers. Metricom, the first company to offer public access over unlicensed frequencies, achieved some measure of success by emphasizing portability and later full mobility.

Determining When Broadband Wireless Is Cost Effective

Network operators contemplating a wireless access approach in a given market should consider not only the initial purchase price of the infrastructure but the following factors:

- Total cost of ownership for the wireless components of the network
- Scalability of the networks, both in regard to the absolute number of subscribers who can be served and the marginal costs associated with adding customers

- Subscriber density; the proportion of potential customers who are physically reachable
- Ease and cost of deployment; the speed and availability of the connections
- Types of services that can be supported
- Speed of service provisioning
- Degree to which the network operator will depend on other service providers

Total Cost of Ownership

When the first broadband wireless networks appeared in the late 1990s, proponents liked to emphasize the cost advantage of a wireless solution. If one did not have to lay cable, which was clearly the case with wireless, then one neatly avoided the enormous installation costs associated with digging up the street and encasing the cable in conduit or, in some cases, in concrete channels, as well as the expense of running cable through buildings to the final destination at an Ethernet or ATM switch. Wireless broadband appeared to enjoy a clear and indisputable advantage, and who could possibly suggest otherwise? Several years and hundreds of business failures later I can say only that wireless is less expensive and more cost effective in some individual markets and not in others.

Wireless indeed eliminates cabling in the final connection between the operator-owned network node and the subscriber terminal and in that manner avoids a highly significant cost factor. Cable excavation and installation can run anywhere from a few thousand dollars a mile in rural areas to more than a million dollars in large cities, with median costs running in the tens of thousands of dollars per mile (these figures are based on my own primary research). But such comparisons ignore that two of 802.16’s most formidable competitors, DSL and cable data, commonly use existing cable infrastructure and do not require cable installation. Such is frequently the case with fiber-optic services as well, with fiber operators striving to secure unused “dry fiber” from public utilities or, alternately, running new fiber through existing passageways such as sewers or gas pipes. In most cases, fiber access networks require new builds and are inordinately expensive, but not invariably, and any wireless operator who assumes a competitive advantage over a fiber-based service provider because of cost without any clear evidence to support that assumption may be sadly mistaken.

Another major cost factor that was initially ignored in most cost estimates for broadband installations is the so-called truck roll, industry slang for the professional installation of the subscriber terminal. Except in cases where a connection to a subscriber terminal is already in place waiting to be activated, or where a portable wireless device such as a cell phone is involved, something has to be done to make the connection to the network. Generally in the case of broadband wireless, that something will involve the installation of at least two devices on the subscriber premises: an antenna to transmit and receive signals and a modem on the subscriber’s computer, either external or card based, along with appropriate software.

Because of the vagaries of subscriber terminals, the unfamiliarity of many users with broadband services, and the lower degree of automation in earlier broadband access equipment platforms, most broadband service providers in the past elected to send technicians out to perform the installation and make sure that the service was adequate. Such is still almost invariably the case with very high-speed services offered to large enterprise users.

As broadband operators began to examine their operational expenses, they realized that truck rolls were critically expensive, often running as much as $1,000 per subscriber when all associated expenses were taken into account. Because of the normal problems arising when almost any new, complex, and unfamiliar technology is introduced into a computing environment, many customers required two or more truck rolls, each costing approximately as much as the first.

Obviously this was a serious problem, one that detracted greatly from the profitability of early broadband services. If, for example, a customer in a residential installation was charged $50 per month and had $3,000 of expenses in the installation process, years would be required to recoup expenses, and that was assuming the customer was not induced to try a competing service.

Each kind of broadband service poses its own peculiar installation problems, as it happens. Fiber demands precise trimming and alignment of the optical fibers themselves, DSL requires testing and qualifying every copper pair, and cable requires various nostrums for mitigating electrical noise and interference. With wireless it is primarily positioning and installing the antenna. Wireless may generally be said to pose the greatest installation difficulties, however, at least in terms of the subscriber terminal.

In some cases involving a wireless installation, the installation crew has to survey a number of locations on or in a building before finding one where the signal is sufficiently constant to permit operation of a broadband receiver, and that process can consume an entire workday. Rooftop installations serving several subscribers, which are commonplace in millimeter microwave installations, require the construction of large mountings and extended cable runs back to subscriber terminals and therefore can be very expensive. And, worst of all, the RF environment is dynamic, and an installation that experienced little interference at one time may experience a great deal at some future time—necessitating, you guessed it, another truck roll.

With all current millimeter microwave equipment and first-generation low microwave components, one could expect difficult and costly installations a good deal of the time. Second-generation non-line-of-sight lower microwave equipment, on the other hand, is usually designed to facilitate self-installation and indoor use, eliminating the truck roll in many cases and appearing to confer a decisive advantage on wireless. But unhappily for the wireless operator, cable and DSL have their own second generations, and self-installation of either technology is fast becoming the norm. Furthermore, self-installation normally confers no performance penalty in the case of cable or DSL, but with wireless, this is not the case. With an indoor installation (the easiest type to perform because the user is not obliged to affix mountings on outside walls or roofs), the effective maximum range of the link is much reduced, and the network operator is consequently obliged to build a denser infrastructure of base stations. In some instances this considerable added expense may be offset by the reduction in truck rolls, but not always.

Incidentally, regarding this matter of truck rolls, outsourcing is rarely advisable. Companies that maintain their own crews of technicians can sustain installation costs at a fraction of those charged by contractors—something to think about when planning a rollout. Assembling and training installation crews may be time consuming, but outsourcing may simply be cost prohibitive.

Setting up wireless base stations must be viewed as another major cost factor in building a wireless broadband network. Of course, rival technologies must also set up large network nodes that are the equivalent of broadband wireless base stations, but in the case of cable and DSL these usually already exist, the headend and the central office, respectively. In other words, they do not have to be built from scratch. Furthermore, the capacity of major DSL and cable aggregation nodes is generally much greater than is the case for wireless base stations. A central office in a DSL network can handle thousands of lines, as can a cable subheadend, that is, the termination for the coaxial copper cable connecting the cable customers. Depending on the amount of spectrum available to the wireless operator, an individual base station is more likely to serve hundreds or dozens of subscribers rather than thousands.

Wireless equipment for base stations has come down considerably in price to the point where it is quite cost competitive with cable and DSL equipment, particularly in the lower microwave regions, but equipment may be only a fraction of the total cost of a base station. In very few instances does the network operator own the various locations where the base stations are to be sited. Thus, roof rights and other right-of-way arrangements have to be negotiated with real estate owners, and these are generally recurrent costs. It is difficult to generalize about the cost of such leases, and it is best to map the network and secure all necessary rights of way before going further. If the cost of doing so appears likely to be exorbitant, a wireless network simply may not be feasible within that given market.

Although many details should be considered when estimating total cost of ownership, the way such information is used is fairly straightforward. Operators first have to determine the pricing of services that will make them competitive with other broadband service offerings in the area and then decide if the cost of purchasing, leasing, and maintaining the infrastructure can be borne with the revenues from competitively priced services while leaving something for profits.

How Scalable?

Scalability of the network, the second factor, is no less important than total cost of ownership, because it determines the long-term prospects of the network operator.

In terms of the ability of the central network management software to handle multiple base stations and multitudes of customers, the scalability of 802.16-based networks is not a problem. The real issue is how many base station sites can be secured and what arrangements the operator can make for backhaul. Theoretically, a large network should be more profitable to operate than a small one because central office costs are relatively fixed, as are access costs for an Internet point of presence. Often, however, the network operator will be able to identify only a few buildings with good sales potential and may not be able to sign up more than a few hundred customers. The question then becomes, how does the network scale down? Unless the network operator can upsell the customer on a lot of value-added services and applications, the answer to that question may not be reassuring because the fixed costs of running the network must be amortized among a relatively small number of customers.

Regarding the number of potential customers that are reachable, I have already touched upon this topic. With the new non-line-of-sight equipment for the lower microwave region, most potential customers can now be reached—if they are in range of a base station. With higher-frequency transmissions, the ability to reach buildings remains a problem. The only solution is to utilize a mesh architecture and place routers or switches at each subscriber premises, but no company with the exception of Terabeam is currently making millimeter microwave equipment that can operate in a mesh topology.

Service Delivery and Broadband Wireless

I have also mentioned briefly service offerings. The physical layer of any network is essentially a pipe and should be able to support any type of service or application provided that the raw bandwidth to do so is available. Wireless happens to be unique in that the airlink is intermittent in its capacity, its signal-to-interference ratio, and its susceptibility to fades and interruptions. Such intermittency makes it difficult to deliver certain services, particularly rich multimedia and high-speed, real-time interactive applications.

So what services can wireless 802.16 networks deliver?

Along with basic high-speed Internet access, 802.16 can support the following: VPNs, IP and circuit second-line telephony, telemetry, conferencing, bandwidth on demand and self-provisioning, and storage service networks.

VPNs

VPNs are protected communications going back to a corporate Web site and are demanded by most businesses of any size for employees engaged in telecommuting or remote accessing of corporate data. Several means of enabling VPNs exist. IP/MPLS and Ethernet VPNs form the latest generation of VPN service offerings and can both be managed by the service provider.

IP and Circuit Second-Line Telephony

All 802.16 equipment can support IP telephony, and some can support circuit telephony. Because of the excessive bandwidth demands of circuit telephony and the extremely high cost of traditional class 5 circuit switches, I do not recommend wireless broadband operators offering such legacy services. IP telephony is a different matter because of the much lower cost of the equipment and the high degree of bandwidth efficiency associated with the technology, but you should remember that an airlink cannot ensure the same availability as the copper plant and that radios cannot operate without AC power whereas telephones can. On the other hand, an airlink cannot be cut. Broadband wireless networks are not well suited to offering primary telephone services in markets where such services are already provided over copper, though they may have an application in settings where phone service is otherwise unavailable. If, however, a company chooses to offer such “wireless local loop” services, little network capacity will remain for anything else.

Telemetry

Telemetry is essentially machine-to-machine communication and generally takes the form of remote monitoring. Examples include measuring inventory in vending machines and signaling when restocking is needed, as well as monitoring pipelines for leaks. Wireless is uniquely well suited to telemetry, and it is service that many operators neglect to promote.

Conferencing

Conferencing, particularly videoconferencing, is an application finding increasing acceptance in the enterprise. All 802.16 equipment can support IP-based video and audio conferencing.

Bandwidth on Demand and Self-Provisioning

Bandwidth on demand is a temporary change in the amount of bandwidth or throughput allocated to a subscriber in order to meet an immediate need such as large file transfers or videoconferencing. Self-provisioning allows subscribers to change the terms of their service from a secure Web site without the intervention of a sales agent. Both are more a function of network management than the physical link, and both are possible with 802.16 standards–based equipment. Where bandwidth on demand and self-provisioning have been offered in wireline networks—and they have not been offered by many service providers—they have always proved extremely popular, and I think they are highly desirable service offerings for wireless operators.

Storage Service Networks

Storage is a network application where vital information is off-loaded to remote storage facilities and invoked thereafter, as it is needed.

Subscriber Density

Subscriber density relates pretty directly to system capacity and more directly to how frequently spectrum can be reused. Since frequency reuse is an absolutely key concept to operating any metropolitan wireless network, I will devote some space to the topic in this discussion of subscriber density.

Any given radio frequency can be occupied by only one user within a given propagation path. Two or more users attempting to use the same frequency simultaneously will interfere with one another. To prevent interference the network architect must either assign a single channel to each user or assign recurring time slots to individual users within the same band (combinations of the two approaches are possible as well). The limit of the ability of a given slice of spectrum to carry traffic is reached when every frequency is occupied for every wave cycle.

In practical terms, such a limit can never be reached, but it can be approached through such modulation techniques as Code-Division Multiple Access (CDMA) and orthogonal frequency division multiplexing (OFDM), where individual transmissions are distributed across the entire available spectrum in complex interleavings that leave relatively little spectrum unoccupied for any length of time during periods of heavy network traffic.

Once available spectrum is completely filled, the only way the operator can support more traffic is to employ some means of reusing the spectrum within some restricted area. This is accomplished by two methods: transmitting the signal in a narrow beam by means of a directional antenna and transmitting at low power so that the signal fades to insignificance at distances beyond the terminal for which it is intended.

Directional antennas themselves use two techniques for achieving their directional characteristics: focusing the transmission in a parabolic dish reflector and using complex constructive and destructive interference effects from several omnidirectional monopole antennas to shape a beam. The second type is known as a *phased array* and is far more flexible. Directional antennas ordinarily work only with fixed installations where subscriber terminals do not move in relation to the base station, and thus they impose a limit on mobility or even much portability. They also require careful management because they must continually be realigned as subscribers are added to or dropped from the network.

Directional antennas produce one unfortunate side effect; they extend the reach of the transmitter considerably by concentrating energy along a narrow wave front, and they change the attenuation characteristics of the signal. This means that spill going past the intended subscriber terminal can interfere with distant terminals elsewhere in the network. This can be a real problem in mature networks where the footprint is divided into a series of adjacent cells and the intent is to reuse spectrum from cell to cell (frequencies can rarely be reused within adjacent cells, and wireless networks ordinarily require intervening cells separating those using identical frequencies).

Both parabolic reflector antennas and phased array antennas can be aggregated to produce what are known as *sectorized* antennas—groups of directional antennas distributed on the same vertical axis and dividing the cell defined by the base station into sectors of roughly equal area. Such antennas will permit nearly fourfold increases in spectral efficiency within a cell but will increase interference in adjacent cells by the square of the existing quantity. In other words, they are no panacea, but they may provide the right solution for certain distributions of subscribers.

In the last few years, adaptive phased antenna arrays have been developed where computing engines continually evaluate network conditions and shape the directivity patterns of signals emanating from the array so as to mitigate interference while permitting maximum traffic densities. Alone among directional antennas, adaptive phased arrays can support full mobility in the subscriber terminal.

Adaptive phased array antennas, also known as *smart antennas*, offer other benefits as well, which I will cover in Chapter 4. They constitute what is truly a breakthrough technology that can significantly extend the capabilities of the wireless network and significantly increase both capacity and subscriber density. And yet they have been little employed to date because of the substantial price premiums they have commanded. Prices are beginning to come down, and more companies are entering the field, and within a two- or three-year period such devices will most likely become commonplace. But as of this writing, choices are still limited.

The second technique for achieving high spectral efficiency (using a multitude of low-powered base stations defining *microcells*) will allow the network operator to achieve almost any degree of subscriber density, but at a price. Base stations cost money, and leasing space on which to situate base stations costs more money. The trick in succeeding by subdividing a network into smaller and smaller microcells is determining beforehand how many additional subscribers you are likely to attract. Subscriber growth rarely has a linear relationship with infrastructure growth, and the marginal cost of gaining new customers is apt to increase. Wireless operators seeking customers seldom face an initial situation where the number of customers wanting to be admitted to the network exceeds the amount of network capacity to support them. No broadband wireless operator to date has faced insatiable demand, so network operators should proceed with the utmost caution in building excess network capacity.

Absent adaptive antennas arrays and microcell architectures, the network operators need to deploy fixed antennas carefully based on subscriber growth assumptions for the network and calculate the hard limits of how many subscribers can be allocated how much spectrum. While engineering formulas and design software exist for plotting antenna deployment and directivity for maximum utilization of spectrum within an overall cellular architecture, performing such calculations in the face of uncertainties as to the precise distribution of subscribers at various phases of network expansion is at best an estimate. Chapter 4 discusses such issues in further detail. Here I must emphasize that the first task facing the network operator is to plot the probable distribution of subscribers, with breakdowns as to the relative density of high-value business customers versus basic service subscribers in various locales. Only after that exercise has been completed should infrastructure requirements then be projected.

Local Topography and the Type and Distribution of Man-Made Structures

Of further concern to network operators contemplating a build is not just the density and distribution of potential subscribers but the architecture of the locations where they will be receiving service.

Business parks and high-rises are in many respects the most desirable locations in which to offer service, both because of the abundance of high-value customers and because bandwidth can be aggregated and made available via a single narrow-beam airlink directed to a single rooftop antenna. Distribution to individual subscribers within the complex would then take place through an internal network.

Where such locations are identified, the network operator should secure the right to install an external subscriber terminal prior to designing a base station to serve the building or business park and arrive at an equitable arrangement with the real estate owner to use the internal network. If this cannot be accomplished before the base station is erected, network operators are simply wasting their money.

Subsequent to securing these rights, the network operator should canvass the tenants of the building and determine that an adequate number will subscribe to the service to justify the cost of the installation. The worst thing a network operator can do is embrace the philosophy of "build it and they will come." Countless broadband access providers have failed through just such visionary zeal. Broadband services are a market, not a mission from God. Offer them only where they are truly wanted and where subscribers are willing to support the network.

Multitenant units (MTUs) are the residential equivalent of business parks and high-rises and are subject to many of the same considerations. The difference is that far fewer of them have internal high-speed cabling for distribution of broadband services to the tenants. If an internal network is not present, then the network operator will have to construct it, and that can be extremely expensive and time consuming, especially if coaxial cable is employed.

The problem facing lower microwave wireless operators contemplating MTUs is that they can really compete with DSL only in providing basic high-speed access; they cannot very readily compete with cable in offering video programming because they lack the bandwidth to carry scores or hundreds of channels of video. Millimeter microwave transmissions covered by the 802.16 standard could conceivably serve an MTU market for converged services, but the high cost of the equipment would put the network operator at a competitive disadvantage with cable. In general, MTUs do not comprise an especially favorable market for broadband wireless at this time.

Single-family homes or small businesses located along thoroughfares also constitute a difficult market to serve. Sectoral antennas cannot reapportion spectrum efficiently enough to support high reuse within a broad, low-density suburban setting, so the network operator must restrict throughput to individual subscribers, especially if they are numerous in a given area, in order to preserve scarce spectrum. Microcells provide a partial answer, but since residential users and very small businesses tend to confine themselves to basic service packages, the additional revenues may not justify the outlays.

I do not know of any very successful mass deployment of broadband wireless services to a consumer user population in an urban setting. That is not to say it cannot be done, but the economics of the model do not look favorable with current market conditions and current technology.

A growing phenomenon in the wireless data business is the provision of access services in public spaces by means of *hotspots*, very small radius cells serving casual users. Currently, almost all hotspots utilize 802.11 wireless LAN equipment, not the more expensive 802.16. Although the emerging 802.20 standard may eventually have a place in the hotspot market, I do not see 802.16 equipment being utilized to provide direct services to subscribers. Operators can employ 802.16 links to backhaul hotspot traffic, however.

This brings me to a quite distinct and underappreciated market for wireless services that is presently being met with 802.16 equipment and is undoubtedly accounting for more revenue than any other, namely, backhaul services. *Backhaul* refers to a connection from a base station to a central office, and it is used in mobile as well as fixed-point networks, though far more in the mobile arena. An increasing number of backhaul connections are being made over fiber, but a definite market for wireless backhaul exists and will continue to exist.

Since the subscriber for such services is another service provider, the requirements for the backhaul network are much more stringent than is the case for a network serving enterprise customers, and many startups would not be able to meet such requirements. In any case, wireless backhaul probably represents a declining business. Bear in mind that microwave was formerly the dominant technology for handling long-distance telephone traffic and now has all but disappeared. I predict that fiber backhaul will achieve similar absolute dominance in metropolitan areas.

Speed of Deployment

Ease and speed of deployment, the next consideration facing the prospective network operator, would appear to favor a wireless solution. But this is assuming that negotiations with site owners proceed smoothly. If they do not, the deployment process may become interminable. Securing backhaul may also be a problem, particularly if high-speed wireline links are not in place where they are needed or are priced out of reach. In general, I favor wireless backhaul (transmitting voice and data traffic from a cell to a switch) wherever it is feasible because otherwise the network operator ends up competing with the incumbents on their own turf and, worse, depending on them for facilities.

Independence from Incumbents

This brings me to the final point, the degree to which the wireless network operator can be truly independent from incumbents.

Unlike the DSL service provider, the wireless operator has no reason to collocate in the telco central office. If operators want to provide second-line telephone services, they can buy their own switch, preferably an IP softswitch. They do need a relationship with a long-distance service provider, but that entity need not be a competitor.

Making a Final Determination

Most books about setting up wireless networks deal strictly with logistics. But the network operator should spend an equal or greater amount of time concentrating on the business case and whether a network can in fact be constructed in a given geographical market that sells its services profitably. Going wireless is not just a matter of figuring out how to do it. It is equally a matter of determining why or why not to do it.