Wireless Aspects of Broadband Access

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Abstract **-- Access to data is no longer a luxury. The demand for access to large volumes of data is driving industry to find ways to assure real-time, high quality delivery at affordable cost. In this paper we examine some of the aspects of wireless broadband data access.**

I. INTRODUCTION

The continued high rate of fiber backbone installation growth in this country, and in the world at large, is fueling the demand for access to data by both industrial and commercial users. While fiber networks and fiber and cable sub-networks provide high quality access for much of the user population, there are areas where data delivery through cable or fiber is economically precluded. In areas of low population density, at the outskirts of a city, the potential user base may not support an investment in installed fiber or cable even if clear rights-of-way are present. In some areas of the inner city, even though the population of potential users is high, the age and/or topography of the city infrastructure may make installation so expensive as to preclude the use of cable or fiber. In these areas, wireless access solutions can be very competitive. Also, wireless solutions, once authorized, can be rapidly deployed and as the market grows can validate the economics of the marketplace to support the eventual installation of cable or fiber. In this paper we discuss some of the issues affecting the affordable delivery of broadband data over wireless links.

II. THE TRANSMISSION ENVIRONMENT

Wireless access comes in two carrier flavors, millimeter-wave and optical free-space wireless. Carrier frequencies for millimeter-wave solutions range from 3GHz to 100GHz and operating bands allocated at these frequencies are up to 1GHz wide. Split into 6MHz channels and using contemporary modulation schemes, data bandwidths of 10 megabits-per-second and greater can be offered to individual users. The optical solution carriers, typically measured in units of wavelength, operate at 700 to 1600 nanometers; equivalent frequencies are 430,000GHz to 190,000GHz. Obviously, at these optical wavelengths, there is the potential for delivery of data at rates up to several gigabits-per-second.

Free-space optical solutions also have a dramatic advantage in the focussing of narrow beams of radiation. Beamwidth is related to aperture diameter by $BW \approx \lambda/D$, where λ is the carrier wavelength and D is the aperture diameter. For a given aperture diameter and perfect manufacturing techniques, an optical free-space beam-width could be one six-thousandth that of a millimeter wave beam. This advantage can be realized in lower radiated power, longer distances or higher energy per bit (and thus lower BER) while supporting the potentially higher data rates of the optical solution. But free-space optical solutions also have a dramatic disadvantage in that the presence of fog on the link severely curtails performance. Fig. 1 shows that the link margin of a 3-kilometer optical link may drop by over 35dB in the presence of thin fog. Even haze on the link may cause a 15dB impact. Heavier fogs render an optical link inoperable at all but very short ranges.

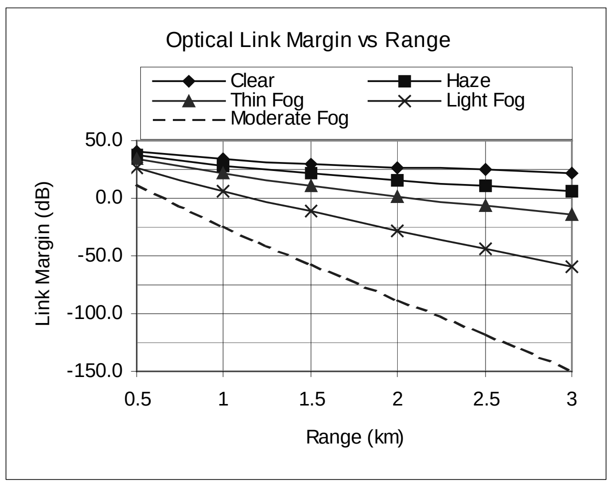

Fig. 1 Fog is a deterrent to free space optical links

Millimeter wave links see little degradation from fog, but are impacted by heavy rain. In rain region K, a 75GHz, horizontally polarized 3.5-kilometer link needs 38.5dB of link margin to provide 99.97% availability. A vertically polarized link over the same distance needs 35.6dB of margin. Fig. 2 shows, at several millimeter wave frequencies, the link margin required to achieve 99.97% availability over a 3.5-kilometer distance for both vertical and horizontal polarizations. In addition to rain issues, allocations for normal atmospheric losses must be made. These losses vary as functions of frequency and are dominated by the effects of water vapor and oxygen

0-7803-6540-2/01/$10.00 (C) 2001 IEEE

molecules. They have major impact at frequencies near 60GHz and above 150GHz but elsewhere are less than 1dB per kilometer [1].

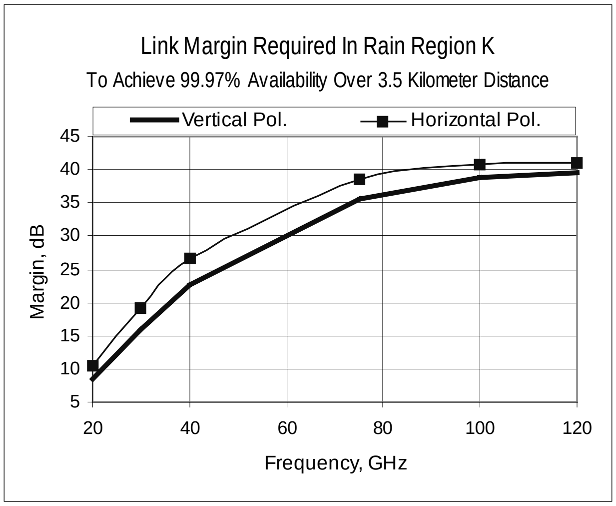

Fig. 2 Rain is a major driver for millimeter wave links

The antennas and transmitters of millimeter wave solutions can be sized, at reasonable cost, to overcome both the rain and atmospheric losses over distances to 5 kilometers. Thus millimeter waves become the preferred delivery medium for wireless broadband access.

III. Millimeter-wave antennas

Antennas for millimeter wave solutions can provide relatively high gain with relatively small surface areas. Fig. 3 shows, as a function of frequency, the antenna aperture area needed to achieve gains of 35dB and 40dB assuming 70 percent aperture efficiency. A 5-inch by 10-inch aperture (50 square inches) can provide 35dB of gain at 30GHz and over 40dB of gain at 60GHz. According to link budgets developed at Motorola, the downlink effective isotropic radiated power (EIRP; antenna gain times radiated power) needed for delivery of a 1.2Gbps information rate is 38dBW for horizontal polarization and 35.1dBW for vertical polarization. This assumes the rain environment of Fig. 2, QPSK modulation, strong coding and a subscriber terminal with a 0.3-meter dish antenna and a 3dB device noise figure. The required EIRP can be achieved with an antenna aperture of 100 square inches and a 1-Watt power amplifier. If the aperture is an array with multiple columns of radiating elements, the amplifier function can be distributed over the columns, reducing the power per device. Further, if the array antenna is fed by a Rotman lens or some other type of multi-beam feed network, the single aperture can form multiple orthogonal beams covering an angular sector of over 90 degrees. Thus, a small number of apertures can provide all of the high-gain beams needed to support a broadband cellular hub. Alternatively, one or two antennas can support a single node of a mesh network.

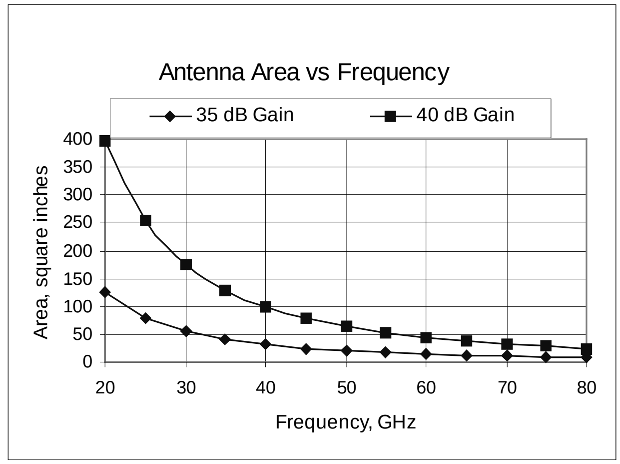

Fig. 3 Antenna aperture areas needed to achieve 35dB and 40dB gain. (70% aperture efficiency assumed)

IV. Network issues

Most network questions are the same for all broadband access mechanisms, wireless or not. End-user services drive protocol choices and application topologies regardless of the physical layer. Also, there is a substantial fixed infrastructure behind any access network. This infrastructure includes the core network, which supports applications, and the backhaul network, which bridges the distance between the core and the access network. Backhaul is often wired, but in some designs may include point-to-point wireless links. The approach to coverage distinguishes the various design options among access networks. Wireless access networks can be characterized by a cellular design or a mesh design.

A cellular wireless network topology achieves coverage of a service area by establishing hubs, whose location and range are strategically chosen for optimal coverage of a subset of the terminals in a region, balancing resource capacity against service demand. Each hub communicates with tens or hundreds of user terminals in a point-to-multipoint (PMP) arrangement. User terminals do not communicate directly with one another; all information flows through one or more hubs. Hubs are connection points between the access network and the backhaul network. Fig. 4 shows a typical cellular network with fiber-ring backhaul.

Because the location itself is often the most expensive part of a cellular hub, and because lower complexity and cost are generally desirable in user terminals, cellular system design allocates significantly higher complexity to the hub. For example, the hub transmitter is usually more powerful, and the hub receiver more sensitive, than the corresponding user terminal components. The hub also takes on most of the complexity in resolving the multiple-access protocol inherent in PMP systems. The cost of a hub's concentrated functionality is both justified and bounded by averaging it over the number of user terminals the hub supports.

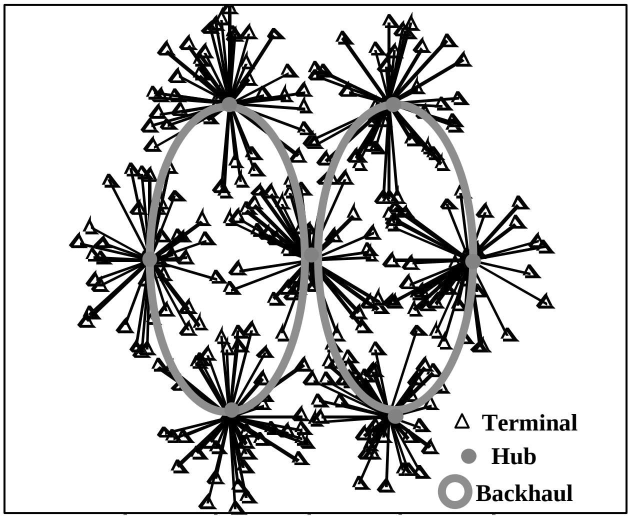

Fig. 4 Cellular network coverage

The cellular approach has evolved into a high art through its application to mobile personal communication services (PCS), in support of the ubiquitous cellphone and 2-way pager. System planning is well understood, and many tools are available. Therefore, most broadband wireless systems have adopted the cellular approach as well, extending the tools to address shorter ranges and higher link speeds as necessary. Many wireless equipment vendors offer such systems using millimeter-wave technology; optical cellular systems have begun to emerge as well.

Where a cellular network attempts to minimize the terminal complexity by concentrating functionality in the hubs, a mesh network attempts to eliminate the hubs altogether by distributing functionality among more complicated user terminals. Each terminal connects to two or more peers, supporting its user’s service and at the same time providing a portion of the access network for other users. The user service for some terminals is the backhaul network, thus providing a gateway function connecting the mesh access network to the rest of the world. Fig. 5 shows a typical mesh network with fiber-ring backhaul.

In a mesh whose terminals are designed with the same link range as a typical cell, the mesh is able to extend access over a larger area than the cell. Because cell size is inversely related to user density such that over a wide range of densities most terminals are closer to their nearest neighbors than to the hub, mesh terminals are instead designed with a significantly shorter range than cellular equipment. This in turn allows each link to support the higher data rates required to participate in the access network on behalf of other terminals.

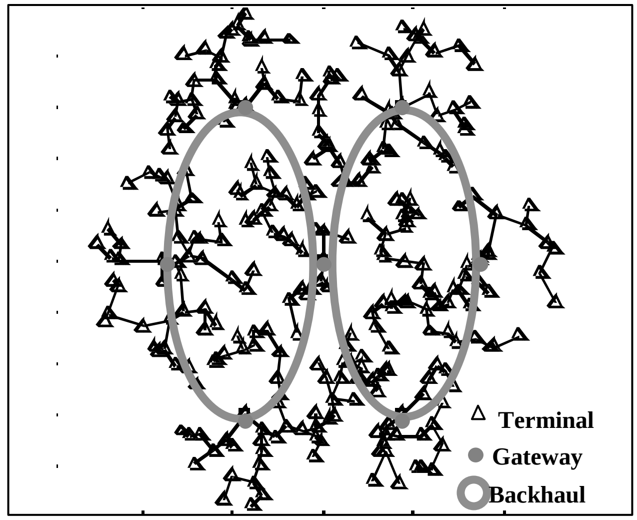

Fig. 5 Mesh network coverage

The mesh approach to wireless access networks is not as well developed as the cellular approach. Where a cell embodies its complexity in the hub, a mesh's complexity appears in the arrangement of links and routes, choices that depend on service mix and user location. Without the stabilizing effect of hub-focused traffic flow, the specific topology of a particular mesh access network can change as users join and leave the network. Tools to design and manage this dynamic behavior are not yet broadly available, as compared to cellular planning tools. Broadband wireless mesh access systems, including both millimeter-wave and optical versions, are available mainly from startup companies today.

In addition to the cellular and mesh network models, several hybrid models are conceivable, which blur the distinction between access and backhaul networks. In one known example, small-footprint cellular hubs serve mobile terminals, and these hubs are interconnected by a fixed wireless mesh forming part of the backhaul network. As tools for constructing wireless mesh networks mature, more such hybrids are likely to appear.

V. System cost

A very important aspect of any broadband access solution is the cost of system installation. For a wireless solution, the high cost area is in the hubs. It has been estimated that in current systems eighty percent of the cost of a hub is in the gallium-arsenide (GaAs) chips of the transmitter and receiver and in the silicon chips of the digital processors that make up the core of the hub. Motorola and others are working to increase silicon and GaAs integration techniques, thus enabling smaller, faster, and lower-cost wireless systems.

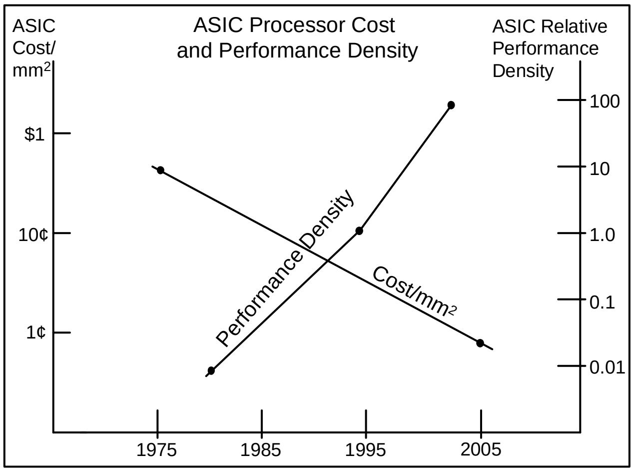

Fig. 6 Moore's Law reduces ASIC processor cost by 100 times per decade

Fig. 6 indicates trends for ASIC processors. In the past twenty years silicon wafer diameters have increased 9 times in size, from 100mm to 300mm in diameter. During the same time frame, transistor density increases of over 500 times (5 micron to less than 0.2 micron features) have enabled ASIC processor density improvement of over 10,000 times. With increased density, increased clock rates and thus increased processor throughput have been achieved. The resulting decreased cost of processing (by over 100,000) has enabled "smart" radio back-ends (the processor part). Two-way radios, cell-phones, and hubs all benefit from these smarter, cheaper processors.

Similar improvements are now occurring for the radio front-end via advances in GaAs MMIC technology indicated in Fig. 7. GaAs wafer areas are increasing at a rate of four times per decade (100mm to 200mm diameter), and GaAs feature sizes of 0.15 micron now facilitate high performance millimeter-wave (30GHz) low-noise amplifiers (LNA) and power amps. As the feature size of typical MMIC foundry processes continues to drop below 0.15 micron, GaAs MMIC operating frequencies are extending beyond 30GHz to the 60-100GHz region.

Network design interacts with component costs to affect total system cost. As noted above, hubs dominate system cost in a cellular design due to their high density of high-speed processors and high-power RF components. In contrast, the reduced link range required in a mesh design generally affords an advantage over the equivalent cellular network by reducing the cost of the wireless components.

In addition to the wireless resources, computation capacity for routing and management must be added to the mesh terminal. However, these functions, and their cost, are incremental to the computation already present in user terminals, such as is needed for security, service management, and applications. For some wireless technologies (including everything above 20GHz today) the short-range advantage is sufficiently large that a mesh terminal with two to four links can have a lower cost than a single-link PMP terminal.

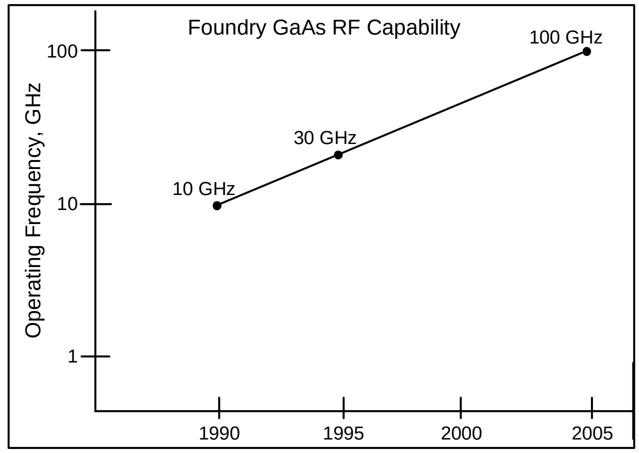

Fig. 7 Foundry GaAs Capability will reach 100GHz by 2005

To characterize fully the comparison between wireless system design options and wired systems, it is necessary to average each cost element over the planned user population. In addition to the technological factors discussed here, this complex calculation must consider regulatory factors such as license costs, operational factors such as installation and site/facility costs, market factors such as financing costs and optimum pricing to users, and many others. Since these variables are always changing and are different for every service area, it is likely that several approaches will succeed over the long term.

VI. Conclusion

Wireless solutions are, and will continue to be, essential and viable elements of the global broadband system portfolio.

Acknowledgement

The authors wish to thank Ken Peterson and Doug Tomren for their assistance in presenting data on the effects of rain and fog, and Doug Reed for his depictions of the links in cellular and mesh networks.

References

[1] CCIR Report 719-1 Attenuation by Atmospheric Gases. CCIR XV Plenary Assembly, Geneva 1982, Vol. V.