Multigigabit wireless technology at 70 GHz, 80 GHz and 90 GHz

This article introduces a wireless technology that supports the fastest radios available today. Operating at the FCC-approved 70 GHz and 80 GHz bands, commercially available products offer full-duplex data rates in excess of 1 Gbps in cost-effective, reliable architectures, with carrier class 99.999% weather availability at distances of one mile or more. Cost-effective pricing is transforming business models for backhaul and access connectivity providers.

By Jonathan Wells

In October 2003, the Federal Communications Commission (FCC) issued an historic ruling that 13 GHz of previously unused spectrum at 71 GHz to 76 GHz, 81 GHz to 86 GHz and 92 GHz to 95 GHz was available for high-density fixed wireless services in the United States. For the first time, true gigabit-speed wireless communications with carrier-class performances over distances of a mile or more became realizable. New markets for fiber replacement or extension, point-to-point wireless local area networks and broadband Internet access at gigabit data rates and beyond have been opened. Then-FCC Chairman Michael Powell heralded the ruling as opening a "new frontier" in commercial services and products for the American people.

The significance of the 70 GHz, 80 GHz and 90 GHz allocations cannot be overstated. Collectively referred to as E-band, these three allocations are the highest ever licensed by the FCC. Together, the 13 GHz of spectrum increases the amount of FCC-approved frequency bands by 20% and represents 50 times the bandwidth of the entire cellular spectrum. With 5 GHz of bandwidth available at 70 GHz and 80 GHz and 3 GHz at 90 GHz, gigabit and greater data rates can easily be accommodated with reasonably simple radio architectures. With propagation characteristics being only slightly worse than those at the widely used microwave bands, and well-characterized weather characteristics allowing rain fade to be understood, link distances of several miles can confidently be realized. The FCC ruling also permits a novel licensing scheme, allowing cheap and fast allocations to prospective users.

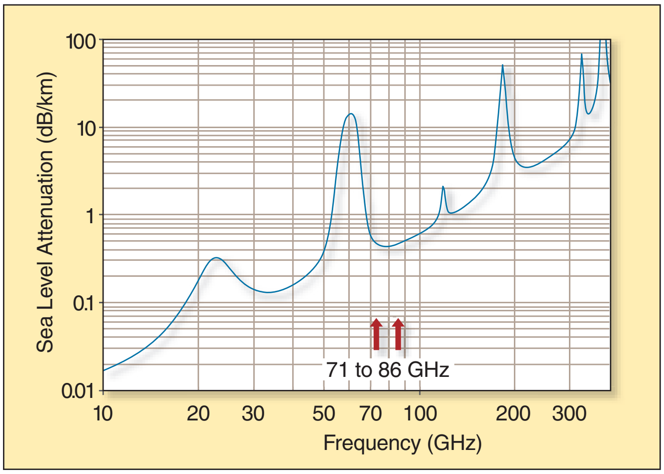

Figure 1. Atmospheric and molecular absorption.

This paper explores the significance of the 70 GHz, 80 GHz and 90 GHz bands, showing how the allocations are fundamentally reshaping high data rate transmission applications and business models.

The market: high availability gigabit connectivity at one mile

In the United States, there are 750,000 commercial buildings with 20 or more occupants. Such premises need high data rate capacity, requiring or demanding DS-3 (45 Mbps) connectivity or higher. However, 95% of these building have no fiber connection, and have to rely on leasing wired circuits from the incumbent or alternative telephony providers (ILECs or CLECs). Such costs can run to $3,000 a month or more. Despite this demand, 75% of these commercial building are within one mile of a fiber connection, yet cannot be connected because of the huge infrastructure cost of laying fiber (up to $250,000 per mile in urban environments, and prohibited in many of the largest U.S. cities). Fiber to commercial building connectivity figures in Europe is far worse at less than 1%.

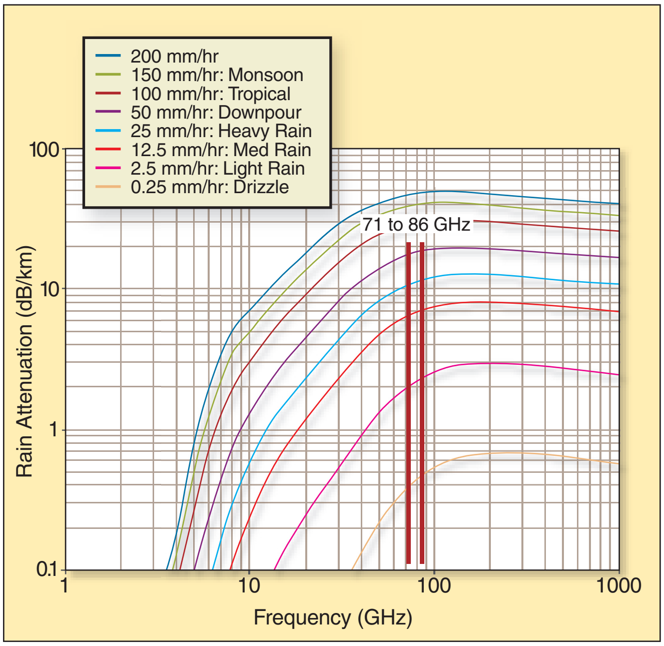

Figure 2. Rain attenuation at microwave and millimeter-wave frequencies.

There is, therefore, a huge, unserved need for short-haul wireless connectivity in the last mile.

Commercial 70/80 GHz systems are priced at such levels that payback against trenching fiber is a few months, and against leasing capacity is much less than one year. This pricing makes the economics of gigabit connectivity attractive.

Many high data rate applications can be satisfied with such a cost-effective technology:

- CLEC and ILEC fiber extensions and replacements;
- IP and SONET backhaul;
- gigabit wireless LANs and private networks;
- fiber backup for access/technology diversity;
- machine to machine connectivity for storage area networks;
- Redundancy, portability and security for homeland defense;
- 3G cellular or WiMAX backhaul for dense urban networks; and
- portable and temporary links for high-definition video or HDTV transport.

Not to be overlooked is the huge military and government potential, with many agencies experienced in employing millimeter-wave systems for covert operations. Very high data rate network security and redundancy applications, as well as portability and ease of deployment, make E-band communications ideal for military purposes.

Why 70 GHz, 80 GHz and 90 GHz?

Of the three frequency bands opened up, the 70 GHz and 80 GHz bands are widely viewed to hold the most interest.

Designed to co-exist, the 71 GHz to 76 GHz and 81 GHz to 86 GHz allocations allow 5 GHz of full-duplex transmission bandwidth; enough to transmit a gigabit of data (1 Gbps or GigE) even with the simplest modulation schemes. With more spectrally efficient modulations, full-duplex data rates of 10 Gbps (OC-192, STM-64 or 10GigE) can be reached. With direct data conversion and low-cost diplexers, relatively simple and thus cost efficient and high reliability radio architectures can be realized.

The 92 GHz to 95 GHz allocation on the other hand is far more difficult to work with. Segmented into unequal portions and separated by a narrow 100 MHz exclusion band at 94.0 GHz to 94.1 GHz, the frequency allocations forces lower data throughputs and more complicated filtering schemes, both a deterrent to low-cost commercial use.

Transmission distances at 70 GHz and 80 GHz can be many miles. Under clear air conditions, atmospheric attenuation varies significantly with frequency[1] as shown in Figure 1. At conventional microwave frequencies (up to 38 GHz), atmospheric attenuation is reasonably low at a few tenths of a dB/km. A large peak is seen at around 60 GHz where absorption by oxygen molecules seriously limits radio transmission distances. After this peak, however, a large window opens up where attenuation drops back to ½ dB/km—not much worse than at the popular microwave frequencies. Above 100 GHz, atmospheric attenuation generally worsens and there are numerous molecular effects (O_2 and H_2O absorption at higher frequencies). It can be seen that the spectrum from around 70 GHz to 100 GHz exhibits low atmospheric attenuation and is, therefore, suitable for wireless transmission.

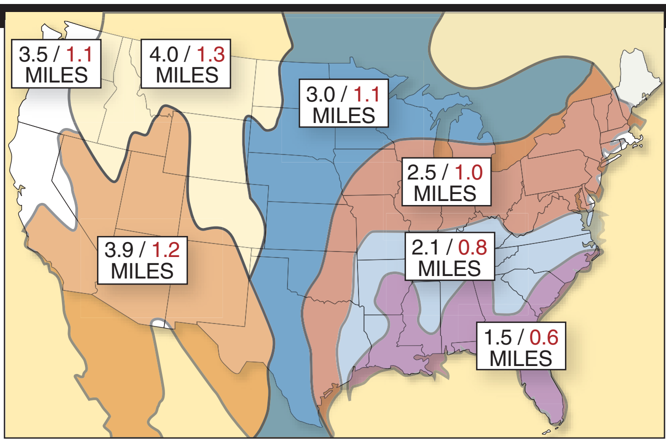

Figure 3. Link distances for 99.9% and 99.999% weather availability for commercial 70/80 GHz equipment.

Practical link distances at 70 GHz and 80 GHz

As with all high-frequency radio propagation, rain attenuation will place practical limits on link distances. E-band transmissions can experience large attenuation when in the presence of rain,[2] as shown in Figure 2. Fortunately, the most intense rain tends to fall in limited parts of the world; mainly the equatorial countries. In the United States, maximum rainfalls experienced tend to be no more than four inches/hour (100 mm/hr), yielding 30 dB/km attenuation, and generally occur only at that intensity in short bursts. Such severe weather tends to form in small, dense clusters within a larger, lower intensity rain cloud, and is usually associated with a severe weather event that moves quickly across the link. Therefore, rain outages tend to be short and are only problematic on longer-distance transmissions.

The International Telecommunications Union (ITU) and other bodies have collected decades of rain data from around the world, so rainfall characteristics are well-understood.[3] With such information, it is easy to engineer radio links to overcome even the worst weather or to predict the levels of weather outage on longer links. Data for the United States shows that currently available 70/80 GHz commercial equipment[4] can achieve gigabit per second connectivity with 99.999% weather availability (equivalent to only five minutes of weather outage per year) more than 80% of the country with links of one mile or more. For a lower 99.9% availability, distances of three miles can be routinely achieved (Figure 3). When configured in a ring, effective distances double for the same availability due to the dense, clustering nature of heavy rain and the diversity that the ring configuration provides.

One strong benefit of E-band wireless is that it is unaffected by many other transmission deteriorations. Thick fog, for example, at a density of 0.1 g/m3 (about 50 m visibility) has just 0.4 dB/km attenuation at 70/80 GHz[5], compared to more than 225 dB/km at visible wavelengths (close to where free space optics systems operate),[6] E-band wireless is similarly unaffected by dust, sand, snow and other transmission path impairments.

Competition: alternative high data rate technologies

Besides E-band wireless, there are only limited technologies capable of supporting high data rate connectivity.

1. *Fiber-optic cable.* Fiber-optic cable offers the widest bandwidth of any practical transmission technology, allowing very high data rates to be transmitted over long distances. Thousands of miles of fiber are available worldwide, however, local access remains limited and access can be difficult or impossible due to substantial and often prohibitive up-front costs associated with digging trenches and laying terrestrial fiber. Long delays are frequent, due not only to the physical work but also due to obstacles caused by environmental impacts and legal implications of the project. For this reason, many cities around the world now prohibit fiber trenching because of

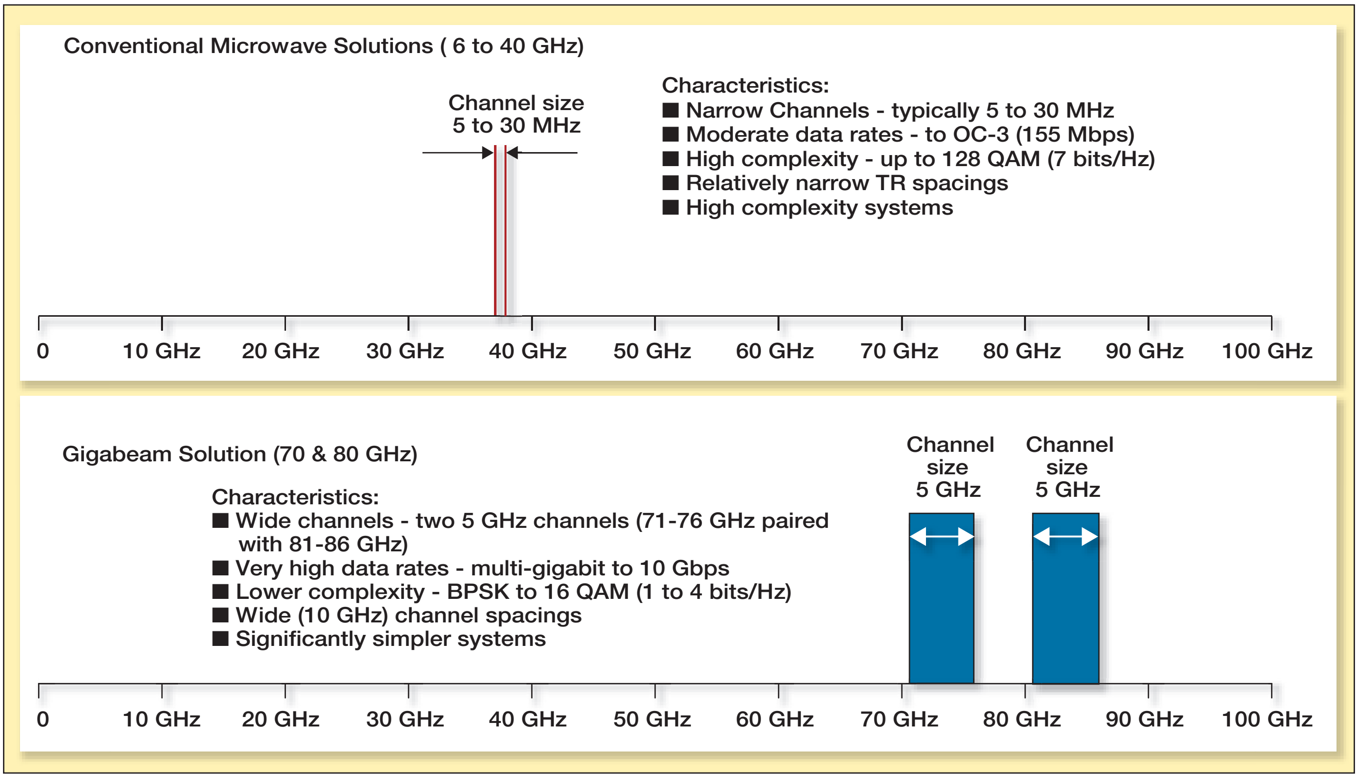

Figure 4. Comparison of a high data rate microwave radio to a 70/80 GHz solution.

Figure 5. Photographs of GigaBeam's WiFiber G-1.25 gigabit per second wireless radio connected to a two-foot antenna.

city disruption concerns and risks to architecturally significant or historic buildings and relics.

2. *Microwave wireless.* Fixed wireless radios can support high data rates—full-duplex 100 Mbps (100BaseT Ethernet) or 155 Mbps (OC-3 or STM-1 SONET/SDH)—at the frequencies of 6 GHz to 40 GHz. At these bands, radios have to compress the data into narrow channels of no more than 50 MHz and typically 30 MHz or below. Thus, highly complex system architectures employing modulation schemes up to 128 QAM are employed. Such highly complex systems result in high product costs, yet still limit practical data rates to 155 Mbps or 311 Mbps in the largest channels. A visual comparison of such microwave solutions to a 70/80 GHz approach is shown in Figure 4.

3. *60 GHz wireless.* In the United States, FCC rules allocate sufficient bandwidth at 60 GHz to allow data rates of 1 Gbps to be achieved. However, limited power requirements, coupled with the poor propagation characteristics due to high atmospheric absorption by oxygen molecules, limits link distances to less than half a mile, and for carrier-class performance (99.999% availability) to little more than 400 yards. Furthermore, the FCC also categorizes 60 GHz spectrum as license- free, requiring no legal approval or coordination for deployments and thus no protection against interference, either accidental or intentional. The license-free nature of this band significantly increases the potential for interference, especially in densely populated metropolitan areas.

4. *Free space optics.* Free space optic (FSO) technologies employ a laser technology to transmit data to photodiode receivers. Very high data rates of 1 Gigabit per second and beyond can be achieved. Transmissions are drastically affected by fog, where atmospheric absorption can exceed 225 dB/km,[6] resulting in carrier-class 99.999% availability for distances of only a few hundred yards in coastal or fog-prone areas. Because of this serious limitation, some FSO equipment vendors have been bundling their equipment with more robust microwave technology radio links to compensate for this weakness.

FSO systems employ complex and costly architectures to overcome the many physics and technology issues of optical transmission. Multiple transmitter lasers are used to minimize blockages of the narrow optical paths by birds, snow, sand, dust or flying debris. Active tracking mounts are used to maintain the precise laser alignment as towers sway or buildings move. Complex cooling systems are required to keep lasers cool and extend lifetimes. Filters are required to minimize optical scintillation effects and deteriorating performance during direct sunlight during sunrise and sunset hours.

Summary

A comparison of all the available high data rate transmission technologies key performance drivers are shown in Table 1.

Wireless solution

GigaBeam's founders petitioned the FCC for release of the

	70/80 GHz	Buried Fiber	Microwave Radio	60 GHz Radio	Free Space Optics
Data Rates	1 Gbps	Virtually Unlimited	To 311 Mbps	1 Gbps	1 Gbps
Typical Link Distances (99.999% Availability)	1 Mile	Virtually Unlimited	3 Miles	400 Yards	200 Yards
Relative Product Complexity	Low	Low	High	Low	High
Relative Cost of Installation and Ownership	Low	High	Low	Low	Low
Installation Time	Hours	Months	Hours	Hours	Hours
Regulatory Protection	Yes	Yes	Usually	No	No

Table I. Comparison of high data rate transmission technologies.

70 GHz, 80 GHz and 90 GHz bands and drove the rules to manage these frequencies.

GigaBeam's WiFiber G-series communications family provides systems operators with an ultrahigh data rate, low-cost alternative to metropolitan fiber lines. Introduced in 2005, the WiFiber G-1.25 wireless solution offers a full 1.25 Gbps/GigE capacity payload, with high availability, carrier-class transmission (99.999% availability) at distances of a mile or more (Figure 3). The WiFiber wireless-based network solution offers true fiber-like performance and quality of service, together with an integrated SNMP agent, allowing seamless monitoring and control by the user's own management software or network operations center. A photograph of the WiFiber G-1.25 radio and a typical installation can be seen in Figure 5. This radio has become the de facto wireless solution for ultrahigh data rate wireless transmissions.

Conclusion

Commercially available equipment can provide fiber-like performance at a fraction of the cost of laying fiber or leasing capacity. Equipment is commercially available with full-duplex data rates in excess of 1 Gbps in cost-effective, reliable architectures, with carrier class 99.999% availability at distances of one mile or more. Several other technologies exist to provide gigabit services, but 70/80 GHz wireless is the only solution that offers carrier-class reliability at any significant distance at a cost that can transform backhaul and access business models. RFD

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2 . ITU-R P.838-3, "Specific Attenuation Model for Rain for Use in Prediction Methods," 2005.

3. ITU-R P.837-4, "Characteristics of Precipitation for Propagation Modeling," 2003.

4. For example, see www.gigabeam.com.

5. ITU-R P.840-3, "Attenuation Due to Clouds and Fog," 1999.

6. S. Bloom, PhD, "The Physics of Free-Space Optics," available at www.freespaceoptics.com.

ABOUT THE AUTHOR

Jonathan Wells is director of product management for GigaBeam Corp., a provider of gigabit wireless access solutions that operate in the licensed 71 GHz to 76 GHz and 81 GHz to 86 GHz E-band radio spectrum. Wells has a Ph.D. in millimeter-wave electronics for work on novel 94 GHz and 183 GHz receivers and an MBA with specialization in strategic R&D management. He is a senior member of the IEEE and is active on the WCA's above 60 GHz spectrum development committee. Wells has held a variety of technical and managerial roles in a number of countries around the world. He can be contacted at jonathan.wells@gigabeam.com.