Communication Infrastructure Corporation

Technical Paper

Millimeter-Wave Radios in Backhaul Networks

Millimeter-wave radio has numerous uses in the public and private sectors, and it's suitable for indoor and outdoor applications.

Introduction

Recently, millimeter-wave (MMW) radio has attracted a great deal of interest from academia, industry, and global standardization bodies due to its ability to provide multi-gigabit rates required in transmission links for emerging broadband wireless networks. Wireless broadband access is attractive to operators because of its low construction cost, quick deployment, and flexibility in providing access to different services.

In October 2003 the Federal Communications Commission (FCC) established new MMW radio services along with its allocation, band plan, service rules, and technical standards to promote private sector development and use of the spectrum in the licensed 71-76 GHz, 81-86 GHz, and 92-95 GHz bands ("E" bands.) This paper describes E-band allocation and millimeter-wave propagation, including engineering data useful for MMW link design, as well as limits and constraints on link configurations. We also discuss the 60 GHz unlicensed spectrum.

Millimeter-Wave Radio Applications

Millimeter-wave radios have numerous indoor and outdoor applications that include such sectors as residential, business, public (libraries, etc.), and commercial (cafes, hotels, etc.). MMW is suitable for in-home applications like audio/video transmission, desktop connections, and portable devices. In addition, it can be used for outdoor point-to-point applications. Judging by the interest shown by many leading companies, applications can be divided into the following categories:

Point-to-Multipoint

- High-definition video streaming
- File transfer
- Wireless gigabit Ethernet
- Wireless docking station and desktop point-to-multipoint connections
- Wireless ad hoc networks

Point-to-Point

- Wireless backhaul for 3G and 4G mobile communications
- Campus applications
- Video relay of uncompressed HDTV

The Unlicensed 60 GHz Band

The 60 GHz band has been allocated worldwide for unlicensed wireless communications systems. In 2001 the FCC set aside a continuous block of 7 GHz of spectrum (57-64 GHz) for wireless communications. All uses are permitted except for radar. The major commercial benefit is that users don't need an FCC license to operate equipment in this spectrum. In addition to the high-data rates the spectrum allows, energy propagation in the 60 GHz band has unique characteristics that add other benefits, such as excellent immunity to interference, high security, and the reuse of frequency.

The FCC does not require users of the 60 GHz band to have a license. In addition, the frequency is immune to certain types of interference and allows for high data rates.

Regulatory organizations in United States, Japan, Canada, and Australia have already set frequency bands and regulations for 60 GHz operation, while in Korea and Europe intense efforts are currently underway. Table 1 summarizes the issued and proposed frequency allocations and main specifications for 60 GHz radio regulation in six countries.

Region	Unlicensed Bandwidth (GHz)	Tx Power	EIRP	Max. Antenna Gain
USA	7 GHz (57-64)	500 mW (max)	40 dBm (av) 43 dBm (max)	NS
Canada	7 GHz (57-64)	500 mW (max)	40 dBm (av) 43 dBm (max)	NS
Japan	7 GHz (59-66) max 2.5 GHz	10 mW (max)	NS	47 dBi
Australia	3.5 GHz (59.4-62.9)	10 mW (max)	150 W (max)	NS
Korea	7 GHz (57-64)	10 mW (max)	TBD	TBD
Europe	9 GHz (57-66) min 500 MHz	20 mW (max)	57 dBm (max)	37 dBi

Table 1: Technical Specification for the 60 GHz Band

Check with the FCC for the current status of ET Docket No. 07-113, which proposes changes to unlicensed transmitters operating in the 57-64 GHz frequency range.

On June 1, 2007, the FCC released ET Docket No. 07-113, a proposal to amend the requirements in Part 15 of the FCC rules applicable to unlicensed transmitters operating in the 57-64 GHz frequency range. Specifically, the proposal would increase the fundamental radiated emission limit for unlicensed 60 GHz transmitters with very high gain antennas, specify the emission limit as an equivalent isotropically radiated power (EIRP) level, and eliminate the requirement for an identification for 60 GHz transmitters. The proposal would increase the current average EIRP level from 40 dBm to a new level of 82 dBm minus 2 dB for every dB that antenna gain is below 51 dBi. The peak power EIRP level would increase from 43 dBm to a new level of 85 dBm minus 2 dB for every dB that the antenna gain is below 51 dBi. These increases would be limited to 60 GHz transmitters located outdoors or those located indoors with emissions directed outdoors, e.g., through a window. The changes would allow longer communication ranges for unlicensed point-to-point 60 GHz broadband digital systems and thereby extend their ability to supply ultra high-speed broadband service to office buildings and other commercial facilities. The proposal is still under discussion and had not been implemented as of this printing.

Oxygen Absorption and the 60 GHz Band

For many years the intelligence community has used point-to-point wireless systems operating at 60 GHz for high security communications; the military for satellite-to-satellite communications. Their interest in this band results from a phenomenon of nature: Oxygen molecules (O_2) absorb electromagnetic energy at 60 GHz. Figure 1 shows the gaseous attenuation for both oxygen and water vapor absorption as a function of range, over and above the free-space loss. The resonances for frequencies below 100 GHz occur at 24 GHz for water vapor and 60 GHz for oxygen. Absorption occurs to a much higher degree at 60 GHz than at the lower frequencies typically used for wireless communications.

Because oxygen molecules absorb electromagnetic energy in the 60 GHz frequency, the band is perfect for security applications. In addition, it allows for more 60 GHz links to operate in the same geographic area than links with longer ranges.

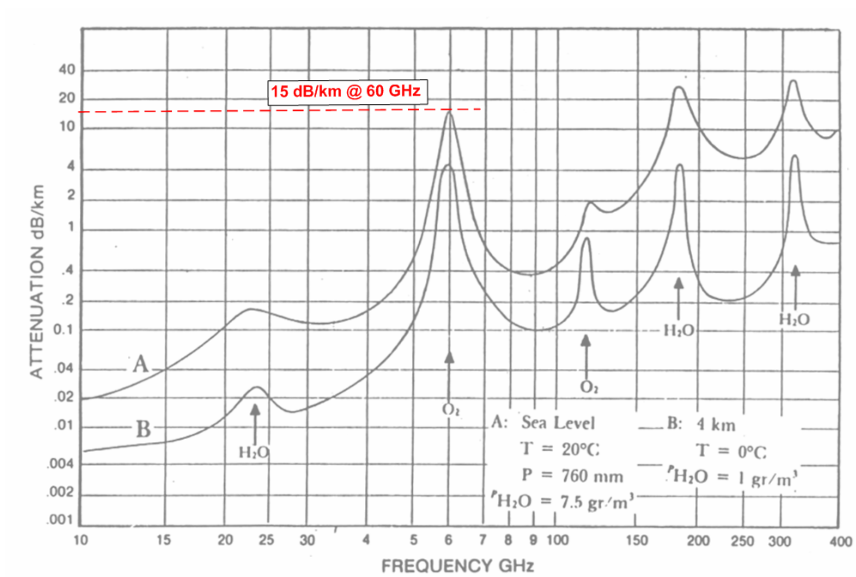

Figure 1: Gaseous Absorption at 60 GH

Absorption attenuates (weakens) 60 GHz signals over distances, so that signals cannot travel far beyond their intended recipient. For this reason, 60 GHz is an excellent choice for covert satellite-to-satellite communications because the Earth's atmosphere acts like a shield preventing Earth-based eavesdropping. Because of the rich legacy of applications in this band, a wide variety of components and subassemblies for 60 GHz products are available today. Another advantage of O_2 absorption is that radiation from one particular 60 GHz radio link is quickly reduced to a level that will not interfere with other 60 GHz links operating in the same vicinity. This reduction enables higher "frequency reuse," e.g., the ability for more 60 GHz links to operate in the same geographic area than links with longer ranges.

Oxygen absorption is not the main limiting factor of link range in the 60 GHz frequency. Instead, MMW radios are more limited by the amount and rate of rainfall in any given region.

The question is whether O_2 absorption is the main limiting factor of the link range. It does affect the range with the resulting benefits described above; however, link distances of millimeter-wave radios are limited primarily by rain. Users of MMW radios typically want the links to provide robust communication capability, such as the "five nines" availability (99.999% of the time) demanded by most carriers. In this application, the rainfall rates where the microwave links are used will typically be more of a limiting factor than O_2 absorption. In other words, the maximum operating link distance is a function of the level of availability desired (99.999% or 99.99%) and rainfall rates in the geographic area of intended use. Link distance increases as level of availability and rainfall rates decrease. Rainfall statistics are so well known for locations around the globe that range and availability can be accurately predicted.

In moderate rainfall regions, the attenuation due to rain is about twice the oxygen attenuation. In heavy rainfall regions, the attenuation is more than three times the oxygen attenuation. Therefore, in designing a 60 GHz link to provide robust communication capability, rain attenuation is actually a larger factor than O_2 absorption, although both must be considered.

In 2003 the FCC opened 13 GHz of spectrum at frequencies much higher than previously available commercially. The 71-76 GHz and 81-86 GHz frequencies allow full duplex transmission, enough bandwidth to transmit a gigabit of data with the simplest modulation schemes. More spectrally efficient modulations could allow full duplex data rates of 10 Gbps.

The 70, 80, and 90 GHz Bands

In 2003 the FCC opened up 13 GHz of spectrum at frequencies much higher than had been previously available commercially. The spectrum provides the means for economical broadband connectivity for the first time at true gigabit data rates and beyond. In 2005 the Commission for European Post and Telecommunications (CEPT) released a European-wide frequency channel plan for fixed service systems in these bands. The following year, the European Technical Standards Institute (ETSI) released specifications covering these bands.

Of particular interest is the 10 GHz of bandwidth between 70 and 80 GHz. Designed to coexist, the 71-76 GHz and 81-86 GHz allocations allow 5 GHz of full duplex transmission bandwidth, enough to transmit a gigabit of data even with the simplest modulation schemes. With more spectrally efficient modulations, full duplex data rates of 10 Gbps (OC-192, STM-64 or 10 GigE) can be achieved.

The FCC has allocated the E-band spectrum (71-76, 81-86, and 92-95 GHz) for shared government and non-government use for short-range line-of-sight radios. The spectrum is available for non-exclusive nationwide licensing and will allow more users within a geographic area to share the bandwidth. So-called pencil-beam antennas make this possible.

Regarding the E-band spectrum, the FCC's approach is to allow nonexclusive nationwide licensing with site-by-site coordination but without extensive FCC action. This is made possible by using the "pencil beam" concept of operation, in which stringent requirements are placed on the antenna radiation pattern of at least 50 dBi gain and no more than a 0.6-degree half-power beamwidth (see Table 2). The three spectrum segments of the E-band (71-76, 81-86, and 92-95 GHz) have been allocated as a shared non-federal and federal government service for short-range line-of-sight radios. E-band is as yet the highest frequency spectrum allocated to licensed operation, and it contains sufficient space for digital transmission speeds comparable to optical communication systems (1.25-5 Gbps). Furthermore, under the licensing rules, a large number of users within a small geographic area will be able to share the E-band allocation.

Region	Bandwidth (GHz)	Tx Power	EIRP	Max. Antenna Gain
USA	1.25 GHz (71-76 & 81-86)	NS	55 dBW (max)	50 dBi (min) 0.6° (-3 dB points)

Table 2: Technical Specs for E-Band in the USA

Other than the pencil-beam antenna concept to allow for a high spatial reuse of frequencies, there are few restrictions imposed on manufacturers of E-band equipment. Thus, it's likely that technological developments will make using E-band—and perhaps still higher frequency bands—practical and more efficient. Several radios have appeared on the market that use the 71-76 and 81-86 GHz bands as a paired channel. At present they have a fixed transmission speed of 1.25 Gbps full duplex, and their intended applications are for high-speed wireless local area networks, broadband access systems for the Internet, and point-to-point communications. Each E-band licensee is assigned the totality of the spectrum in the 71-76, 81-86, and 92-95 GHz bands. The first two bands can be used as a paired channel, i.e., each transceiver transmits in only one of the bands and receives in only the other. The 92-95 GHz band is intended for indoor applications only, so it will not be discussed here.

MMW radio links fail most often due to inappropriately applied rain data for micro-climate areas.

Millimeter-Wave Link Engineering

Many millimeter-wave links fail to perform properly because rain rates are not adequately applied or are not appropriately assessed for a micro-climate area. For example, Town A has an average of 48 in. of rain/year. Just 10 miles away, Town B gets 23 in. of rain/year. (Average rainfall is the mean monthly precipitation, including rain, snow, hail, etc.). Thus, planning for a link in Town A may not be the same as for Town B even though they are in the same region.

Rain intensity plays a greater role in link design than total amount of rain.

The ITU-R recommendation used for estimating long-term statistics of rain attenuation is considered to be valid in all parts of the world for frequencies up to 40 GHz and path lengths up to 60 km.

Of course, the total amount of rain is not as important as the intensity of the rainfall (the rain rate in mm/h), which also must be carefully assessed. Many cities have micro-climates where temperature and rain rates differ significantly from one area to another. Although important in the design of all microwave links in the 10-38 GHz band, exact rain rate data (as shown in Figure 2) becomes absolutely critical when designing links in even higher millimeter-wave bands. The ITU-R recommendation used for estimating long-term statistics of rain attenuation is considered to be valid in all parts of the world for frequencies up to 40 GHz and path lengths up to 60 km.

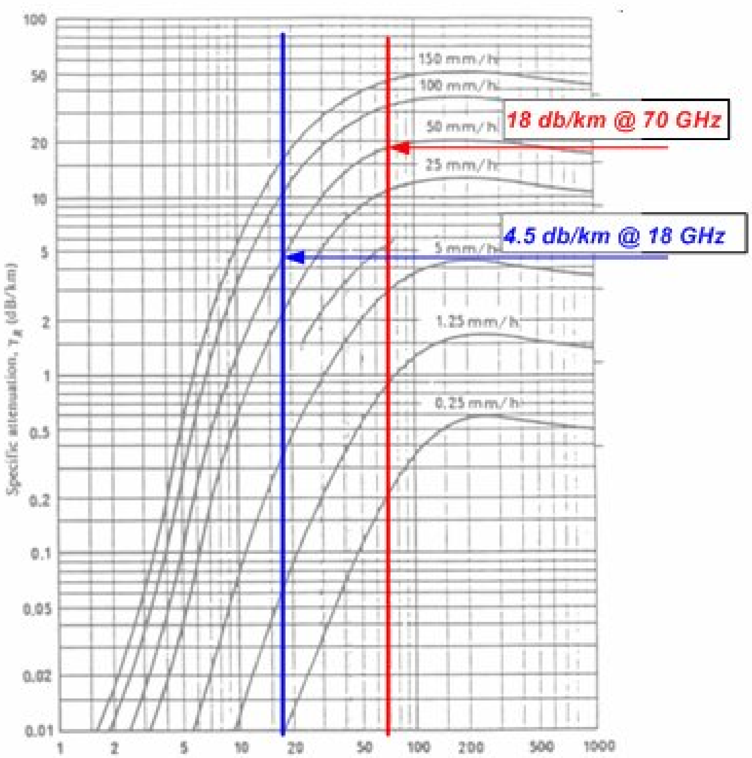

Figure 2: Rain Attenuation Curves

Most likely, certain modifications of the existing models may be required to extend their validity to MMW links. Some preliminary long-term measurements on a 0.5-mile link performed in the early 2000s show a significant deviation from the ITU-R recommendations. Measured attenuation was typically 1-5 dB higher than the calculated one based on the ITU recommendation. Further, it appeared that the lower rain rates caused a larger difference in results than the higher rain rates for the particular percentage of time. Table 3 shows results of millimeter-wave link engineering for the typical unlicensed 60 GHz and licensed 70 GHz link.

Today's digital radios use the threshold degradation method of interference analysis.

A simple formula is used for estimating the maximum allowed deflection for a microwave transmission antenna.

Installation challenges include making sure an antenna and its mounting structure have a deflection of 0.5° or better and finding installation technicians with experience aligning a pencil-beam antenna.

		Maximum Hop Length (Miles) for Rain Regions in the USA [Crane 1996]		
Frequency	**Availability**	**A**	**D-2**	**E**
60 GHz	99.999 %	0.48	0.32	0.26
	99.995 %	0.55	0.39	0.33
	99.990 %	0.59	0.44	0.36
70 GHz	99.999 %	1.4	0.68	0.53
	99.995 %	1.95	0.93	0.68
	99.990 %	2.3	1.12	0.78

Table 3: Millimeter-Wave Path Lengths

Interference

All the digital radios today use the threshold degradation method of interference analysis. Existing links shall be protected to a usual threshold-to-interference ratio (T/I) of 1.0 dB of degradation to the static threshold of the protected receiver. Any new link shall not decrease a previous link's desired-to-undesired (D/U) signal ratio below a minimum of 36 dB unless the earlier link's licensee agrees to accept a lower D/U (see FCC 03-248 for more information).

Antenna Deflection Limitations and Installation Challenges

The typical limitation in twist/sway for the tower and antenna structure corresponds to a maximum 10 dB signal attenuation due to antenna misalignment. A simple formula for estimating the maximum allowed deflection (α) in degrees for a microwave transmission antenna is:

$$\alpha_{-10dB} = \frac{18}{f \cdot D}$$

Where: D=antenna diameter [m]
f =frequency [GHz]

For example, if we assume a 2-ft. dish at 60 GHz, the maximum deflection of the antenna and the structure should be 0.5°. For the 70 and 80 GHz bands, the value should be even smaller. Installation challenges are twofold: 1) to ensure that the antenna, together with the mounting structure, has a deflection of 0.5° or better; and 2) the people installing it should have sufficient experience and/or training in aligning a pencil-wide beam antenna. The unlicensed band of 60 GHz has different installation requirements than the usual 2.4, 5.8, and even new 24 GHz unlicensed bands.

Because of their low power, MMW radio systems do not pose radiation harm to the general public.

Safety of the Millimeter-Wave System

Because MMW systems have low power levels, millimeter-wave systems do not penetrate the human body. High frequency emissions such as 60 GHz are absorbed by moisture in the human body and thus cannot penetrate beyond the outer layers of skin. As a result, exposure to 60 GHz is similar to exposure to sunlight but at 1/10,000 of the energy. Low frequency emissions penetrate, and may even pass completely through, the human body, while the minimal penetration of 60 GHz energy sets it apart from the debate that currently surrounds the safety of other RF communication systems. At MMW frequencies, RF is generally absorbed at the skin layer, but eye damage is a health concern. In consultation with four health-related agencies, the FCC has adopted exposure limits as follows: For the general public, accepted exposure levels in the 1.5-100 GHz band is 1 mW/cm^2 averaged over 30 minutes. The occupational/controlled exposure in the same band is 5 mW/cm^2 averaged over 6 minutes.

The FCC and NTIA Licensing Process

The FCC ruling also permits a simplified licensing scheme for millimeter-wave radios, allowing cheap and fast allocations to prospective users: You can apply for a 10-year license, get accepted, and pay for it in less than 30 minutes for only a few hundred dollars. The FCC will issue an unlimited number of non-exclusive nationwide licenses to non-federal government entities in the 12.9 GHz of spectrum allocated for commercial use. These licenses will serve as a prerequisite for registering individual point-to-point links. The 71-95 GHz bands are allocated on a shared basis with federal government users. Therefore, in order to operate a link under its non-exclusive nationwide license, licensee will have to:

Licensing MMW radios is simple and inexpensive: A 10-year license costs a few hundred dollars and only takes about a half-hour to apply for.

- Coordinate with the National Telecommunications and Information Administration (NTIA) with respect to federal government operations.
- Register as an approved link with a third party Database Manager.

On September 29, 2004, the Wireless Telecommunications Bureau (WTB) appointed Comsearch, Frequency Finder, and Micronet Communications as independent Database Managers responsible for the design and management of the third-party 71-95 GHz bands Link Registration System (LRS). Proposed links must be coordinated with NTIA. NTIA has developed an automated coordination mechanism that can determine whether a given non-federal government link has any potential conflict with federal government users. A proposed link entered into NTIA's automated system will result in either a "green light" or a "yellow light" based on the proposed parameters.

Proposed MMW links must be coordinated with the NTIA and registered with a third-party Database Manager.

If the proposed link receives a green light, that link will be protected for 60 days in NTIA's system. If registration has not been completed through the LRS after 60 days, the link must be resubmitted through NTIA's automated system for coordination with federal government operations. If the proposed link receives a yellow light, users will need to file Form 601 and Schedule M with the FCC for further coordination with NTIA through the existing Interdepartment Radio Advisory Committee (IRAC) process. When IRAC clears a proposed link, the FCC will send the licensee a letter confirming that the IRAC coordination has been completed. Database Managers will also be notified through ULS nightly batch files so that they can complete the link registration.

To summarize, a filing with the FCC will be required for links that:

- Receive a yellow light from NTIA's automated system.
- Require environmental assessment.
- Require coordination because of a radio quiet zone.
- Are subject to international coordination requirements.

Licensees have 12 months from the date their link is registered to begin operations.

Licensees must begin operation of a link within 12 months from the date that the link is registered through the LRS. While licensees need not file a notification of construction completion, it is their responsibility to notify a Database Manager to withdraw unconstructed links from the LRS. In turn, the Database Manager must then remove a link from the LRS if the link remains unconstructed after 12 months. Further, the interference protection date will be rendered invalid for any registered link that does not comply with the 12-month construction requirement.

Licensees must meet the loading requirements of 47 C.F.R. § 101.141. If they don't, the database will be modified to limit coordination rights to the loaded spectrum, and the licensee will lose protection rights on any spectrum that has not been loaded. Currently, there are no international agreements between the United States, Mexico, and Canada with regard to the 71-76 GHz, 81-86 GHz, and 92-95 GHz bands. However, as a general rule, wireless operations must not cause harmful interference across international borders. (See FCC Public Notice DA 05-311, Feb 03, 2005, for more information on the registration process in these bands.)

Despite some issues and technical challenges, MMW radios are promising candidates for multi-gigabit rates in point-to-multipoint and point-to-point applications.

Conclusion

The huge unlicensed bandwidth, coupled with higher allowable transmission power and advances in integrated circuit technology, have made millimeter wave radios promising candidates for multi-gigabit rates in point-to-multipoint and point-to-point applications. A number of open issues and technical challenges have yet to be fully addressed. In particular, propagation and implementation issues require further optimization and research in order to obtain a truly efficient and low-cost millimeter-wave communication system.

About Communication Infrastructure Corporation®

CIC is a leading provider of infrastructure engineering and development services for the wireless telecommunications industry, specializing in the design and deployment of wireless backhaul solutions. We offer site development, microwave/RF engineering, installation, maintenance, and AWS relocation solutions for the efficient design and deployment of both large- and small-scale networks. Our expert team of 100+ professionals employs the latest appropriate technologies, the highest quality service, and the most up-to-date knowledge to meet the demands of wireless carriers.

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