E-BAND WIRELESS TECHNOLOGY OVERVIEW

EXECUTIVE SUMMARY

The 71-76 and 81-86 GHz bands (widely known as "e-band") are permitted worldwide for ultra-high capacity point-to-point communications. E-band wireless systems are available that offer full-duplex Gigabit Ethernet connectivity at data rates of 1 Gbps and higher in cost effective radio architectures, with carrier class availability at distances of a mile and beyond.

The significance of the e-band frequencies cannot be overstated. The 10 GHz of spectrum available represents by far the most ever allocated by the FCC at any one time, representing 50-times the bandwidth of the entire cellular spectrum. With 5 GHz of bandwidth available per channel, gigabit and greater data rates can easily be accommodated with reasonably simple radio architectures. With propagation characteristics comparable to 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.

This paper explores the technology behind e–band wireless, and demonstrates how it enables the fastest commercial radios available today.

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A BRIEF HISTORY OF THE E-BAND

The 71-76 GHz and 81-86 GHz e-band allocations for fixed services were established by the International Telecommunication Union (ITU) almost 30 years ago at the 1979 WARC-79 World Radio communication Conference. However not much commercial interest was shown in the bands until the late 90's, when the FCC's Office of Engineering and Technology published a study on the use of the millimeter-wave bands [1]. This report concluded that "*System designers can take advantage of the propagation properties manifested at millimeter wave frequencies to develop radio service applications. The windows in the spectrum are particularly applicable for systems requiring all weather operation … or for short range point-to-point systems*."

At the 2000 WRC-00 World Radio communication Conference, ITU delegates discussed enabling High Density Fixed Services at high frequencies. Around this time, several events were converging that caused interest in e-band wireless. Firstly, device technology had advanced to the point where components operating in the millimeter-wave frequencies could be commercially fabricated. Secondly, congestion in the widely used microwave bands (6 to 38 GHz) meant designers had to start considering alterative frequency bands. Finally, with a vision for multi-megabit and even gigabit per second speeds required by newer generation communication and multimedia services, new paradigms for wireless transmission were needed.

Following petition by the wireless industry, the FCC released a Notice of Proposed Rulemaking in 2002 [2] that resulted in the opening of the bands under existing Part 101 fixed service point-to-point rules in 2003 [3]. A novel "light licensing" scheme was introduced in 2005 and the first commercial e-band radios were installed soon after.

The wireless regulators in Europe quickly followed the US lead. In 2005, the European Conference for Postal and Telecommunications Administrations (CEPT) released a European-wide band plan similar to the US [4]. In 2006, the European Telecommunications Standards Institute (ETSI) released technical rules for equipment operating in the 71-76 and 81-86 GHz bands [5]. These were consistent with European EU rules to allow e-band wireless equipment to be commercially used in Europe.

Many parts of the world have now followed the US and European lead, and opened up the e-band frequencies for high capacity point-to-point wireless, enabling gigabit-speed transmission in the millimeter-wave bands.

THE E-BAND FREQUENCY ALLOCATION

The e-band frequency allocation consists of the two unchannelized bands of 71-76 GHz and 81-86 GHz, as shown in figure 1.

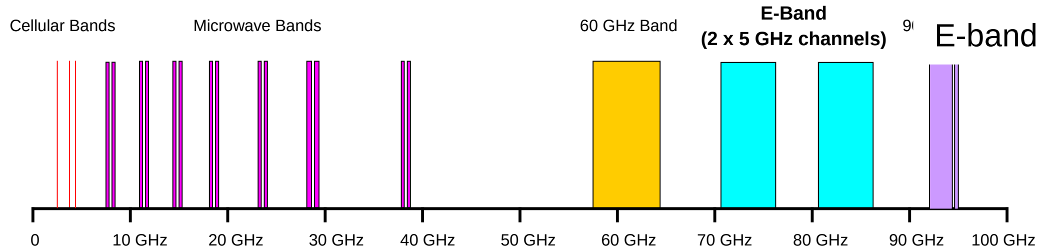


Figure 1: Significant USA frequency allocations.

This allocation is significant for two main reasons. Firstly, the combined 10 GHz of spectrum is significantly larger than any other frequency allocation. Together this is over 50-times larger than the entire spectrum allocated in the USA for all generations, technologies and flavors of cellular services, and much larger than all the widely used microwave communication bands. The availability of such a large swath of spectrum enables a whole new generation of wireless transmission to be realized.

Secondly, the e-band allocation, divided into two paired 5 GHz channels, is not further partitioned, as is the case in the lower frequency microwave bands.

In the USA, the FCC slices each common carrier microwave band into channels of no more than 50 MHz. This channel size ultimately limits the amount of data that can be squeezed into the channel. With 5 GHz channels at e-band, 100-times the size of even the largest microwave band, and larger than the wide 60 GHz and 90 GHz allocations, significantly more data can be carried by each signal. The e-band spectrum allocation is enough to transmit a gigabit of data (1 Gbps or GigE) with simple modulation schemes such as BPSK.

With more spectrally efficient modulations, full duplex data rates of 10 Gbps (OC-192, STM-64 or 10GigE) can be realized. Since there is not the need to compress the data into small frequency channels, systems can be realized with relatively simple architectures. Radio equipment can take advantage of low order modulation modems, non-linear power amplifiers, low cost diplexers, direct conversion receivers, and many more relatively non-complex wireless building blocks, reducing system cost and complexity, whilst increasing reliability and overall radio performance.

E-BAND WIRELESS PROPAGATION

Wireless propagation at e-band frequencies is well understood. Characteristics are only slightly different to those at the widely used lower frequency microwave bands, enabling transmission distances of many miles to be realized.

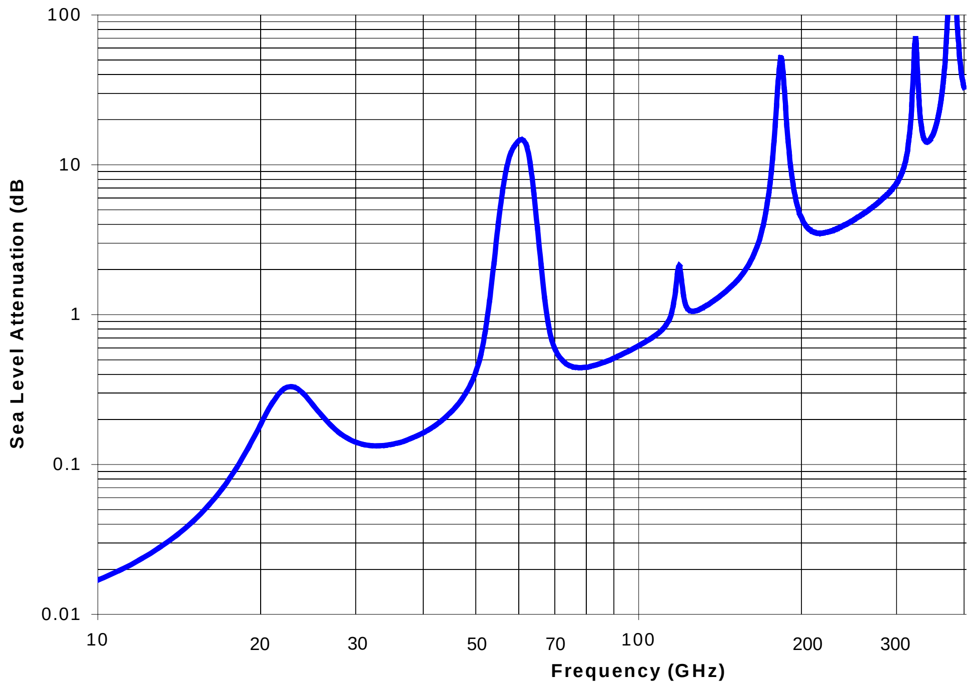


Figure 2: Atmospheric and molecular absorption.

The atmospheric attenuation of radio waves varies significantly with frequency. Its variability has been well characterized [6] and is shown in figure 2. At the microwave frequency bands of up to 38 GHz, the attenuation due to the atmosphere at sea level is low at 0.3 dB/km or less. A small peak is seen at 23 GHz, followed by a large peak at 60 GHz, corresponding to absorption by water vapor and oxygen molecules respectively. This effect at 60 GHz in particular, where absorption increases to 15 dB/km, significantly limits radio transmission distance at this frequency.

Above 100 GHz, numerous other molecular absorption effects occur, limiting the effectiveness of radio transmissions. A clear atmospheric window can be seen in the spectrum from around 70 GHz to 100 GHz. In this area, low atmospheric attenuation around 0.5 dB/km occurs, close to that of the popular microwave frequencies, and very favorable for radio transmission. For this reason, e-band wireless systems can transmit high data rate signal over many miles under clear conditions.

WEATHER AND OTHER EFFECTS AT E-BAND

The physical properties of high frequency radio transmission in the presence of various weather conditions are well understood. With proven models of worldwide weather characteristics allowing link fading to be understood, link distances of several miles over most of the globe can confidently be realized.

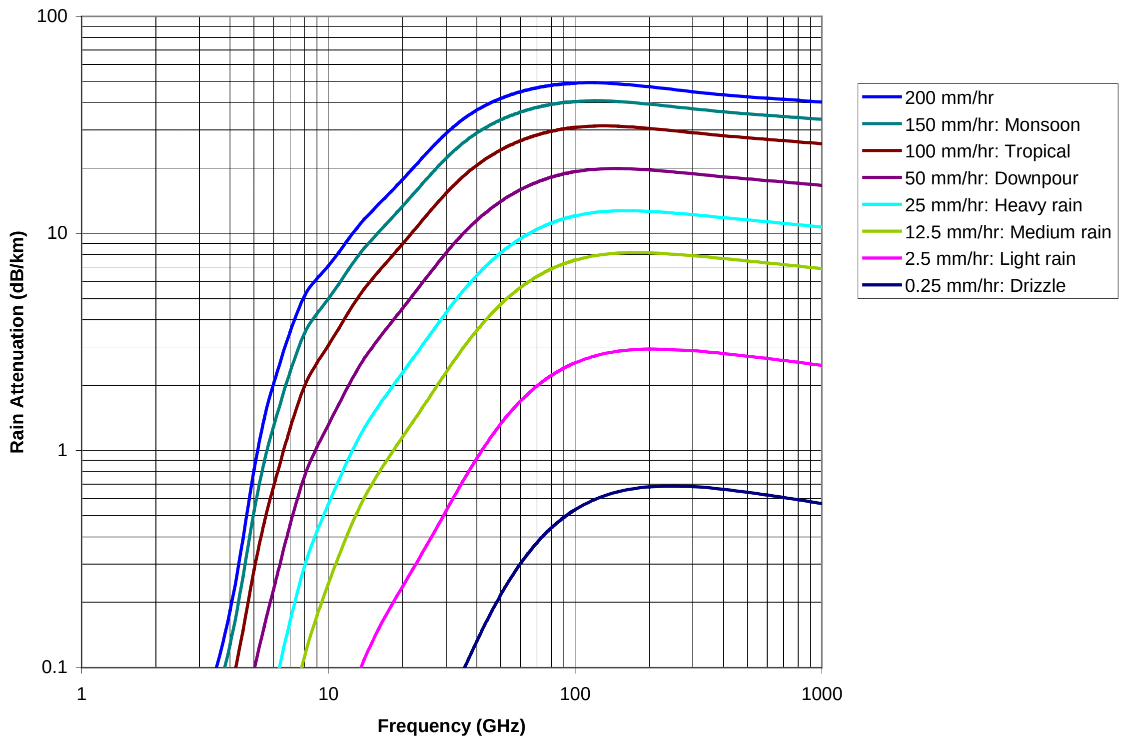
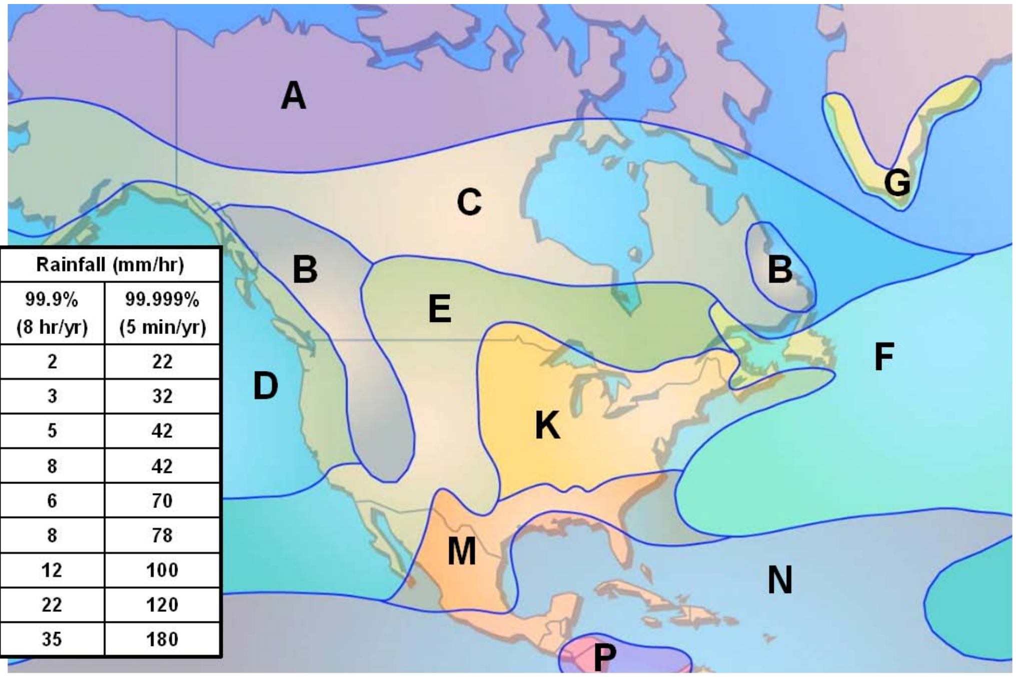


Figure 3: Rain attenuation at microwave and millimeter-wave frequencies.

RAIN

As with any radio transmission above about 10 GHz, rain attenuation will place natural limits on link distances. As shown in figure 3, millimeter-wave transmissions can experience significant rain attenuations in the presence of rain [7]. "Heavy" rainfall at the rate of 25 mm/hour (1" per hour) yields just over 10 dB/km attenuation at e-band frequencies. This increases to 30 dB/km for 100 mm/hour (4" per hour) "tropical" rain. These values of attenuation are used in link planning to determine the maximum link length allowed to overcome rain events.

Global rain patterns have been studied and characterized over many years. The ITU and other bodies publish models derived from decades of rain data from around the world [8]. Models are available to predict rain intensities and annual rainfall at those intensities, to enable link designers to engineer radio links to overcome even the worst weather, or to yield acceptable levels of rain outage on longer links. Figure 4 shows the ITU rain data for North America.



ITU Rain Region	Rainfall (mm/hr)	
	99.9% (8 hr/yr)	99.999% (5 min/yr)
A	2	22
B	3	32
C	5	42
D	8	42
E	6	70
F	8	78
K	12	100
M	22	120
N	35	180

Figure 4: ITU rain statistics for North America.

Example: Consider New York City in ITU rain zone K. For 99.9% of the time, rainfall is less than 12 mm/hr (i.e. rainfall exceeds 12 mm/hr for only 8 hours per year). For 99.999% of the time, rainfall is less than 100 mm/hr (i.e. rainfall exceeds 100 mm/hr for only 5 minutes per year).

FOG AND CLOUDS

One benefit of e-band wireless is that it is essentially unaffected by fog and clouds. Thick fog with a visibility of 50 m (150 foot) has a density of about 0.1 g/m^3, which yields an almost negligible attenuation of 0.4 dB/km at e-band frequencies [9]. This almost absence of attenuation is due to the fog and cloud particles being so much smaller than the wavelength of the e-band radio signal (roughly 4 mm or one-sixth of an inch). As such, minimal scattering from the fog and cloud's tiny water particles occurs.

Contrast this situation to free space optical (FSO) systems, a high data rate alternative to e-band wireless. Since an FSO optical signal has a wavelength of the same order of magnitude as the small fog and cloud particles, attenuations of order 200 dB/km can be experienced with heavy fog in the FSO transmission path.

AIRBORNE DUST, SAND AND OTHER SMALL PARTICLES

Similar to fog and clouds, e-band wireless signals are not scattered from particles of much less than 4 mm in the transmission path. This property makes any small airborne particle essentially invisible to e-band wireless systems.

TECHNICAL ATTRIBUTES OF E-BAND WIRELESS

There are a number of additional physical and regulatory-enabled technical characteristics that add to the attractiveness of e-band as useful spectrum for wireless communications.

Firstly, the gain of an antenna increases with frequency. Thus it is possible to realize large gains from relatively small antennas at e-band frequencies. Figure 5 shows the variation in gain for a 1 ft (30 cm) parabolic antenna. At the popular 18 GHz common carrier band, such an antenna has about 32.5 dBi of gain. At e-band, an equivalent size antenna has 44 to 45 dBi of gain. This equates to an extra 24 dB or so of system gain per link – a significant number when one considers that just an additional 6 dB of system gain allows a link to be doubled in length. Therefore, under ideal conditions, a 24 dB improvement in link margin equates to a four-fold improvement in link distance. An alternative comparison is that a 4 ft antenna at 18 GHz has the same gain as a 1ft antenna at e-band, with obvious reduced cost, ease of installation and planning & zoning benefits.

Secondly, the FCC permits e-band radios to operate with up to 3W of output power. This is significantly higher than available at other millimeter-wave bands (for example, 25 dB higher than the 10 mW limit at 60 GHz). Also the 5 GHz wide e-band channels enable the radio to pass high data rate signals with only low level modulation schemes (for example, FSK or BPSK modulation can easily allow 2 Gbps data rates in the 5GHz channels). The output power in an e-band system is relatively high as the low-order modulation scheme places minimum linearity requirements on the transmitter's power amplifier (PA) and so the PA can be run close to its maximum rated output power. A high data rate SDH microwave radio (incidentally offering less than one-sixth the data rate of an e-band radio) has to use 128 or higher modulation to compress the data in the small megahertz wide channel. Here power amplifier linearity is of utmost importance, and amplifiers have to be backed off significantly, throttling back output power to many dBs below rated outputs.

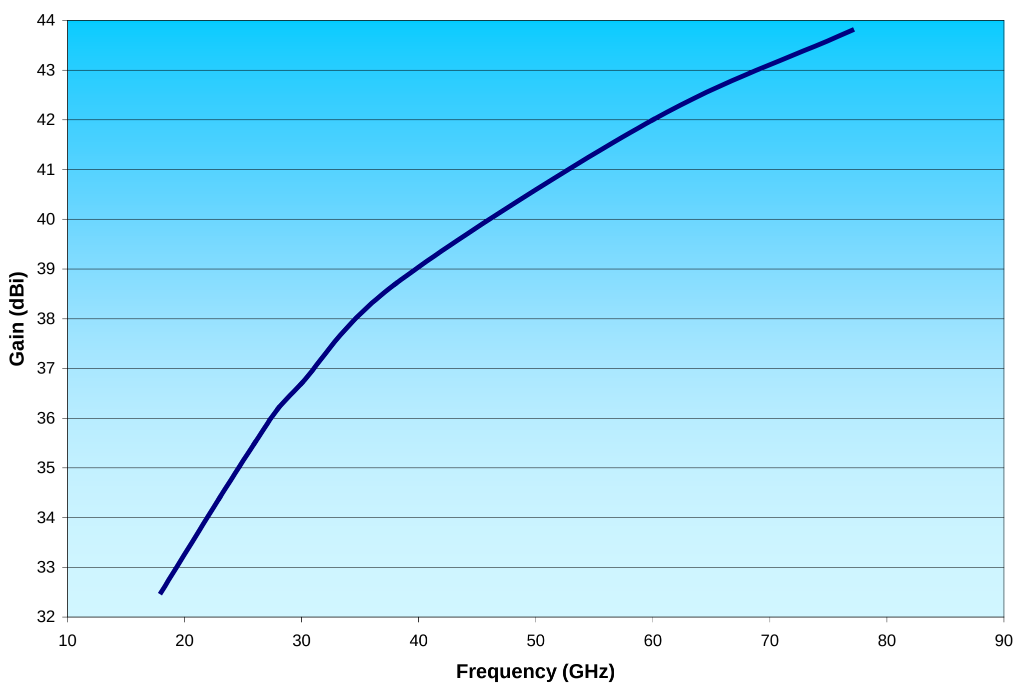


Figure 5: The effect of frequency on antenna gain for a 1ft (30 cm) parabolic antenna.

Together, this high output power and high antenna gain allows e-band radios to operate with very high radiated power (EIRP) and hence overcome the higher rain fading seen at higher frequencies, enabling system performances that are equivalent to the widely used microwave point-to-point radios.

THE PERFORMANCE OF COMMERCIALLY AVAILABLE E-BAND WIRELESS SYSTEMS

Figure 6 shows a photograph of the E-Link 1000 G1 radio from E-Band Communications Corporation. This product utilizes leading-edge RF MMIC technology to provide best-in-class link performance for gigabit and multi-gigabit throughputs at e-band frequencies. Licensing GaAs device technology from Northrop Grumman, the product reduces the e-band chipset complexity through integration, leading to an industry leading output power and improved system reliability through reduced component count.

Figure 6: The E-Link 1000 G1 E-Band radio.

To demonstrate how this technology works in practice, figure 7 shows the performance of the E-Link 1000 G1 radio for various rain regions across the globe. It can be seen that in a city such as New York (rain region K), a 2 mile link can provide 99.99% weather availability, with an estimated down time of 50 minutes per year. For a drier climate such as Las Vegas, even a 10 mile link will be robust enough to achieve better than 99.9% weather availability.

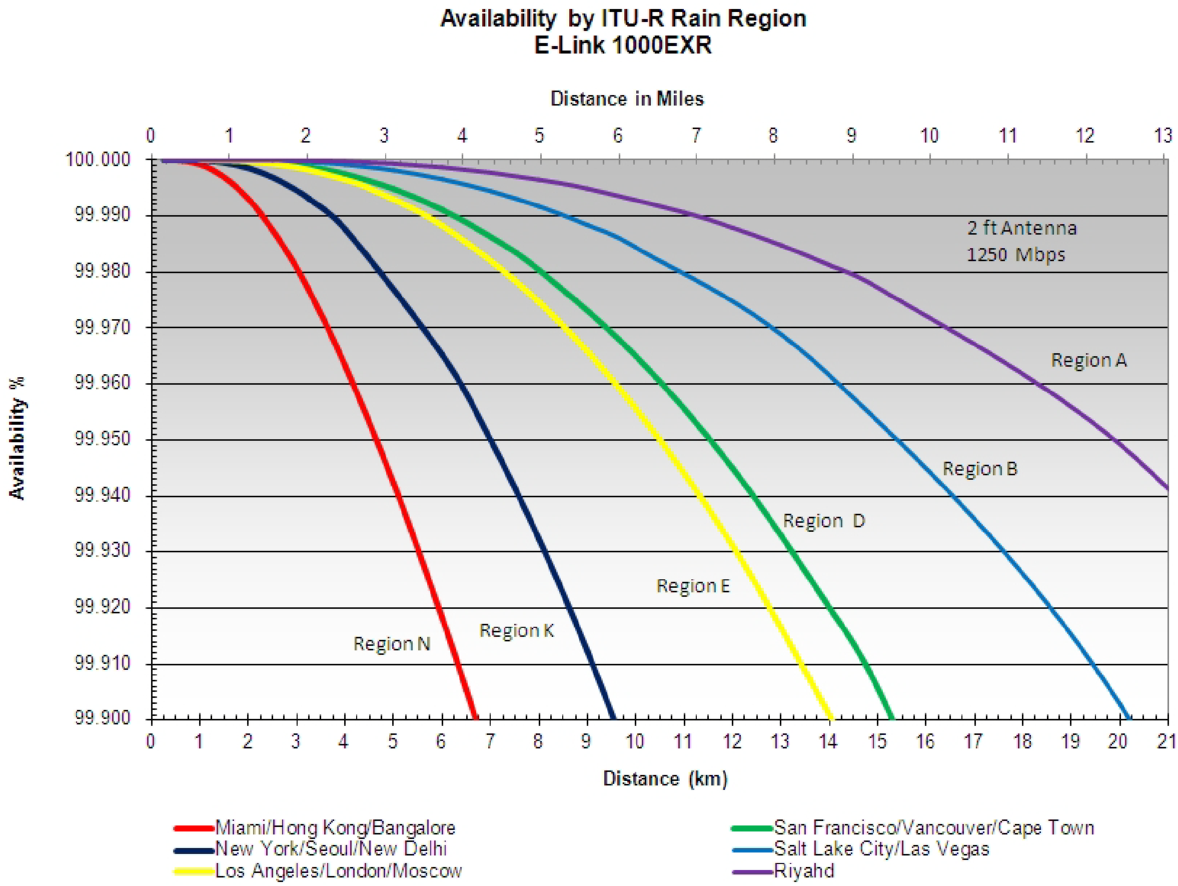


Figure 7: E-Link 1000EXR E-Band radio distance and available by ITU rain regions

SUMMARY

The 71-76 and 81-86 GHz e-band frequencies are globally available for ultra high capacity point-to-point communications, providing Gigabit Ethernet data rates of 1 Gbps and beyond. Cost effective radio architectures have been realized that enable carrier class availability at distances of a mile and further.

This paper introduces the technology behind such radios. The e-band spectrum offers the widest bandwidth radio spectrum available today, enabling the fastest radio products commercially offered. Favorable propagation conditions, almost equivalent to the widely used microwave bands, enable robust links to be engineered that can provide all weather carrier-class transmission over several miles.

The E-Link 1000EXR radio from Aviat Networks is available today and can be engineered to provide reliable service on paths in excess of 2 miles (3.2 km) in cities such as New York City. Significantly longer links can be reliably achieved in cities with drier climates.

References

[1] FCC Bulletin 70, "*Millimeter Wave Propagation: Spectrum Management Implications*," July 1997.
[2] FCC Notice of Proposed Rule Making 02-180, "Allocations and Service Rules for the 71-76 GHz, 81-86 GHz, and 92-95 GHz Bands," June, 2002.
[3] FCC Report and Order 03-248, "Allocations and Service Rules for the 71-76 GHz, 81-86 GHz, and 92-95 GHz Bands," November, 2003; and FCC Memorandum Opinion and Order 05-45, March, 2005.
[4] ECC Recommendation (05)07, "Radio frequency channel arrangements for fixed service systems operating in the bands 71-76 GHz and 81-86 GHz", October 2005.
[5] ETSI TS 102 524, "Fixed Radio Systems; Point-to-Point equipment; Radio equipment and antennas for use in Point-to-Point Millimetre Wave applications in the Fixed Services (mmwFS) frequency bands 71 GHz to 76 GHz and 81 GHz to 86 GHz," July 2006.
[6] ITU-R P.676-6, "Attenuation by atmospheric gases," 2005.
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[8] ITU-R P.837-4, "Characteristics of precipitation for propagation modeling," 2003.
[9] ITU-R P.840-3, "Attenuation due to clouds and fog," 1999.