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The E-Band as Future Candidate for Next Generation Networks

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***Abstract* - Millimeter-wave (mm-Wave) frequencies between 30 and 300 GHz are a new frontier for cellular communication and this band is considered as the potential candidate for high speed communication services in 4 and 5G networks due to its huge bandwidth.This paper discuss the potential applications of mm-Wave communications in the 4 and 5G networks, including the small cell access, the cellular access, and the wireless backhaul. However, mm-Wave does come with its challenges. Some of most prominent issues like rain attenuation and directivity of beam of antenna.**

***Index Terms* – mm-Wave , E-band ,FSO, Pencil Beam ,FCC .**

I. INTRODUCTION

With a 5th generation technology that is expected to be commercially launched during this year or next year, the new generation will offers 1000 times of current capacity and supports smart devices more than 100 times the current cellular networks. And of all data transfer rates that services requiring a high transmission rate, such as video streaming ,IPTV ,etc.[1].

Increased distribution of small cells produces a huge backhaul traffic in the core network, which decisively becomes an important, but somewhat less addressed bottleneck in the system. Using the fiber cable in dense small cell backhaul would result in prohibitively high cost and practical difficulty in deployment [2].

Wireless backhaul may offer an acceptable and cost-reduction solution. However, traditional microwave frequency bands, e.g., sub-5 GHz, may be limited in achievable gains due to the existing spectrum shortness. Despite emerging mechanisms to enhance spectrum efficiency it remains difficult to achieve data rates exceeding 1 Gbps or even 10 Gbps. Therefore, it is hard to meet the rapid increase of 5G traffic demands in such relatively low frequency bands.

Also for coverage issue the traditional broadband spectrum need to be more suitable for increased data rate demand even in 4G not to mention the upcoming 5G services .Here comes the need for old/new spectrum technique as an evolved solution and available resources that will reduces the cost of both Radio Frequency (RF) resources and the fiber cable installation .

The radio-frequency covering the range 30 to 300 GHz is known as millimeter-Wave frequency or very high-frequency. The mm-Wave frequency has drew a lot of attention due to multi-gigabit communication services including high definition multimedia interface, uncompressed high definition video streaming, high-speed internet, wireless gigabit Ethernet, and close-range automotive radar sensor [3].

Till last few years there was a huge "gap" between fiber and other wireless systems . Fig.1 shows the major higher capacity wireless technologies that available now, and how they fit together to produce the current broadband wireless landscape . For many years, optical fibers stayed the only way to realize medium and long distance communications at the diffuse GigE networking interface speed, but the cost of installing and maintaining made its accessibility limited to just a few numbers of users ,only two can reach fiber-like gigabit per second speeds.

These are both of the Free Space Optical systems (FSO) and 60 GHz system limited in distance of just a few hundred yards, significantly limiting their effectiveness as part of wide area networks. There numerous longer distance wireless alternatives, but these are limited in data rate to around 100 Mbps or so.

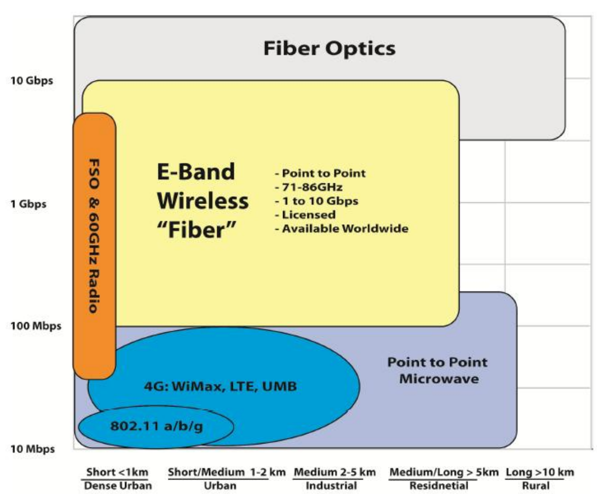

Fig. 1. The major higher capacity wireless technologies.

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For these reasons, the Federal Communications Commission (FCC) and many other regulators around the world have opened up the e-band 71-76 GHz and 81-86 GHz frequency bands. The availability of this spectrum enables fiber-like gigabit per second and up interconnection speeds, multiple mile transmission distance systems, and products with significantly lower cost and improved economics over buried fiber.

II THE MM-WAVE

The current 4th generation (4G) systems including Long Term Evolution (LTE) and mobile Worldwide Interoperability for Microwave Access (WiMAX) already use advanced technologies such as Orthogonal Frequency Division Multiplexing (OFDM), Multiple Input Multiple Output (MIMO), multi-user diversity, link adaptation, turbo code, etc, to achieve the most spectral efficiencies close to theoretical limits in terms of bits per second per Hertz per cell [4]. With limitations for future spectral efficiency improvement, another possibility to increase capacity per geographic area is to install many smaller cells such as femtocells and heterogeneous networks. Anyway, because the capacity can only grow linearly with the number of cells, small cells alone will not be able to meet the increased capacity required to met the increases in mobile data traffic. As the mobile data demand grows, the sub 3 GHz spectrum is becoming increasingly crowded. On the other side , a huge amount of spectrum in the 3 to 300 GHz range remains underutilized. The 3 to 30 GHz spectrum is generally referred to as Super High Frequency (SHF) band, while 30 to 300 GHz is referred to as Extremely High Frequency (EHF) or millimeter- Wave band.

Since radio waves in the SHF and EHF bands share similar propagation characteristics, we refer to 30 to 300 GHz spectrum collectively as millimeter-wave bands with wavelengths ranging from 10 to 100 mm.

A. History Of mm-Wave.

May be the reader thought this term (mm-Wave) could be new in the world of wireless communication, the history of mm-Wave technology goes back to the 1890's when J.C. Bose was experimenting with mm-Wave signals at just about the time when his colleagues at that time like Marconi were inventing radio communications. Following Bose's research, mm-wave technology remained within the limits of university and government laboratories for almost half a century.

The technology started so see its early applications in Radio Astronomy in the 1960's, followed by applications in the military in the 70's. In the 80's, the development of mm-Wave integrated circuits created opportunities for vast manufacturing of mm-Wave products for commercial applications. In the beginning of 90's, the existing automotive collision avoidance radar at 77 GHz marked the first consumer oriented use of mm-Wave frequencies above 40 GHz. In 1995, the FCC opened the spectrum between 59 and 64 GHz for unlicensed wireless communication, resulting in the development of availability of broadband communication and radar equipment for commercial application.

On October 16, 2003 the FCC announced that the 71–76 GHz, 81–86 GHz, and 92–95 GHz frequency bands collectively referred as E-band had become available to very high-speed data communication including point-to-point wireless local area networks, mobile backhaul, and broadband Internet access. A total of 12.9 GHz bandwidth is available in the E-band as shown in Fig. 2, with a narrow 100 MHz exclusion band at 94.0–94.1 GHz. Highly directional beam signal characteristics in E-band permit systems in these bands to be engineered in close proximity to one another without causing interference. Therefore, the FCC and regulators in other countries have introduced “light licensing” schemes for managing this band. These innovative licenses keep the advantages of full interference protection.

B. mm-Wave Allocation Frequency.

mm-Wave frequencies usually refer to the frequency range from 30GHz to 300GHz, the wavelength of which is between 10 mm to 100 mm. There are many Motivational points for desire to use E-Band frequencies in radio links:

1) The radio spectrum at mm-Wave frequencies is still rather undeveloped, and more bandwidth is available at these frequencies.
2) The same RF can be reused again at closest distances because of higher attenuation in free space and through walls.
3) The inherited security and privacy is much better at mm-Wave frequencies because of the limited range and the relatively narrow beam widths that can be achieved.
4) The physical size of antennas at mm-Wave frequencies becomes too small that it becomes practical to build complex antenna arrays.

Figure 2 shows the mm-wave band allocation in the United States. There is 5GHz bandwidth available at the 60GHz band (59–64GHz) for Industrial, Scientific and Medical (ISM) unlicensed applications. The 24GHz band (22–29GHz) band and 77GHz band (76–77GHz) are currently assigned to automotive radar. Fixed point-to-point communication links can use 71–76GHz, 81–86GHz and 92–96GHz that need a license in the USA from The FCC [5].

C. Mm-Wave Products

The mm-Wave frequency bands offer many new products and services, for example:-

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1) The huge bandwidth at 60GHz can gives unlicensed short-range high-speed links for Wireless Personal Area Network (WPAN) (802.15.3c) and short-range super Wireless Fidelity (Wi-Fi) (802.11ad) which providing data throughput speeds up to 7 Gbps for wireless high definition video streaming (Wireless HD.

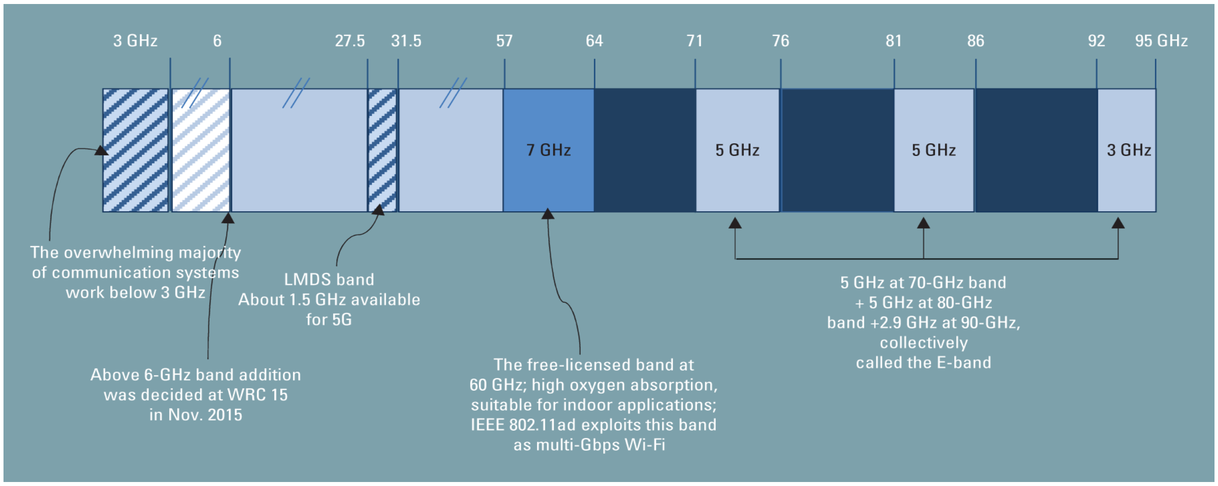

Fig. 2. mm-Wave Spectrum.

2) The 77GHz band is convenient for automotive long-range (100m) Autonomous Cruise Control (ACC) radar. The high carrier frequency allows small size antennas to have a small beam width and therefore a better angular resolution.
3) The 24GHz band can be used in automotive short-range radar, since the large bandwidth at 24GHz offers sufficient small distance resolution nearly 5cm.
4) The large bandwidth at 71–76GHz, 81–86GHz and 92–95GHz can provide licensed high-speed links with data throughput up to 10Gbps.
5) The natural thermal emission of objects in the 35GHz and 94GHz bands allows passive imaging to construct an image.

D. mm-Wave Applications.

The mm-Wave offer many applications that will be more efficient such as:-

1) Small Cell Sites.

High density of small cells has been suggested to get the 10,000 times increase in network capacity by 2030 [6,7,8]. mm-Wave small cells are able to provide the multi-gigabit rates, and wideband multimedia applications such as live streaming of both compressed and uncompressed High Definition TeleVision (HDTV), high-speed data transfer between devices, such as cameras, pads, smart phones, and personal computers, wireless gaming can be also supported , and wireless gigabit Ethernet .

2) Cellular Access sites.

The huge bandwidth in the mm-Wave bands supports the usage of mm-Wave communications in the 4G and 5G cellular access sites , The mm-Wave cellular networks have the possibility for huge coverage and capacity as long as the infrastructure is densely installed.

3) Wireless Backhaul.

With small cells densely deployed in the next generation of cellular systems (4G and 5G), it is expansively to connect the Base Stations (BSs) to the other BSs and to the network via fiber optics backhaul [9]. In other side, high speed wireless backhaul is better as cost-efficient, flexible, and easier to install. With large bandwidth available, wireless backhaul in mm-Wave bands, such as the 60 GHz band and E-band (71–76 GHz and 81–86 GHz), gives several-Gbps data rates and can be a promotes backhaul solution for small cells. As shown in Fig. 3, the E-band backhaul provides the high speed transmission between the small cell base stations (BSs) or between BSs and the gateway. And few of mm-Wave applications are illustrates in Table(1).

TABLE 1
APPLICATIONS OF MM-WAVE COMMUNICATIONS

No	Frequency Band (GHz)	Scenario	Application
1	60	indoor Office	Internet Access
2	60	WPAN	transmission between devices flows with QoS requirements
3	60	WLANS	uplink channel access
4	28,38.71-76,81-86,92-95	urban street	access and backhaul
5	60	WPAN	HD video
6	60,70	indoor	multimedia

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III THE 60 GHz BAND.

The unlicensed 60 GHz frequency band has more bandwidth available than all of other unlicensed bands together. Even for the smallest allocation, there is more than 3 GHz of bandwidth available, and most regions around the world allow use of at least 7 GHz. In comparison, the 5 GHz unlicensed band has about 500 MHz of total valid bandwidth, and the 2.4 GHz band has less than 85 MHz of bandwidth in most regions. The additional bandwidth increases the channel capacity, but is not enough to enable high-speed communications for practical applications. Exchange operational systems that can use the wide bandwidth at low cost are necessary.

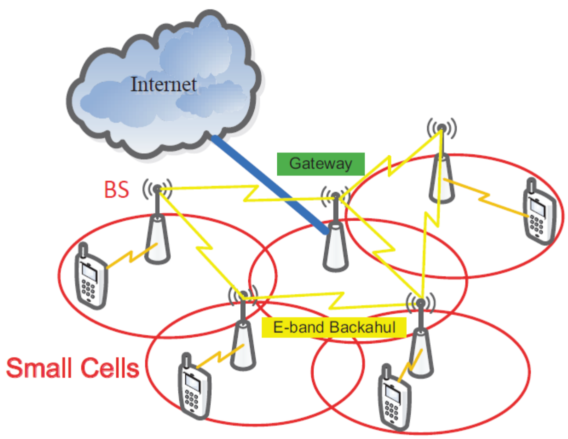

Fig. 3. E-band backhaul for small cells densely deployed [9].

A specific challenge for 60 GHz is get rid off the path loss from transmitter to receiver. The Friis equation is used to compute this effect:

$$P_r = \frac{P_t.G_t.G_r.\lambda^2}{(4\pi.R)^2}$$

Where is P_r is the received power, P_t is the transmitted power, G_t is the transmitter antenna gain, G_r is the receiver antenna gain, λ is the wavelength, and R is the range from transmitter to receiver.

A. *The 60 GHz Band Standardization .*

Due to the great possibilities of mm-Wave communications, many international organizations have emerged for the standardization, including European Computer Manufacturer's Association (ECMA) [10], Institute of Electrical and Electronics Engineers (IEEE) 802.15.3 Task Group 3c (TG3c) [11], IEEE 802.11ad standardization task group [12], the WirelessHD consortium [13], and the Wireless Gigabit Alliance (WiGig) [14]. two standards, IEEE 802.11ad and IEEE 802.15.3c,will be reviewed here briefly .

1) IEEE 802.11ad.

In an effort to provide capacity requirements a very high frequency Wireless Local Area Network (WLAN) modification has been proposed (IEEE 802.11ad). IEEE 802.11ad, also referred to as Wireless Gigabit (WiGig), operates in the globally unlicensed 60 GHz band and offers channel bandwidths nearly 100 times as wide as 802.11n. The higher bandwidth Paves to multi-Gbps throughput .

IEEE 802.11ad specifies the physical layer and MAC layer in 60GHz band to support multi-gigabit wireless applications including instant wireless sync, wireless display of High Definition (HD) streams, wireless computing, and internet access [11]. In the physical layer, two operating modes are defined, the OFDM mode for high data rate applications , and the single carrier (SC) mode for low power and low complexity implementation. In IEEE 802.11ad, a Basic Service Set (BSS) consists of a designated device, called Access Point (AP), and N non-AP Devices (DEVs). AP provides the basic timing for the BSS, and coordinates medium access in the BSS to coordinates the traffic requests from the DEVs.

2) IEEE 802.15.3c

IEEE 802.15.3c specifies the physical layer and MAC layer for indoor Wireless Personal Access Networks (WPANs) (also referred to as the Piconet) contains of several wireless Nodes (WNs) and a single PicoNet Controller (PNC). The PNC provides network synchronization and coordinates the transmission in the Piconet. In IEEE 802.15.3c, network time is divided into a sequence of super frames, each of it consists of three portions: the Beacon Period (BP), the Contention Access Period (CAP), and the Channel Time Allocation Period (CTAP). During BP, the network synchronization and control messages are broadcasted from the PNC. CAP is for devices to send transmission requests to the PNC by the Carrier-Sense Multiple Access with Collision Avoidance (CSMA/CA) access method, and CTAP is for data transmissions among devices. During CTAP, Time Division Multi-Access (TDMA) is applied, and each time slot is scheduled to a specific flow.

B. *Oxygen Absorption and the 60 GHz Band*

For several years the intelligence authorities had been use P2P wireless systems operating at 60 GHz for high security communications such as the military satellite-to satellite communications. Their concerns in this band comes from a phenomenon of nature, Oxygen atoms (O2) absorb electromagnetic energy at 60 GHz. Fig. 4, shows the gaseous attenuation for both oxygen and water vapor absorption as a function of range, over and above the free-

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space loss. The resonances for frequencies below 100 GHz happens 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.

Absorption attenuates 60 GHz signals over distances, so that signals cannot pass far beyond their target. For this reason, 60 GHz is a perfect choice for hidden satellite-to-satellite communications because the Earth's atmosphere acts like a shield preventing Earth-based eavesdropping. Because of the huge number of applications in this band, a wide variety of components and subassemblies for 60 GHz products are available today

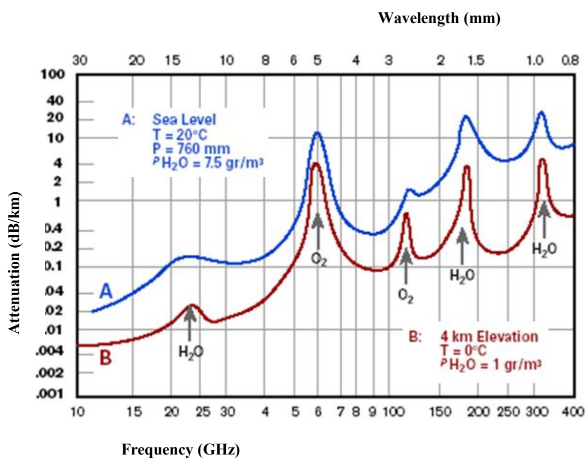

Fig 4: Gaseous Absorption at 60 GH.

Another benefit of O2 absorption is that radiation from one particular 60 GHz antenna is quickly decreased to a level that will not interfere with other 60 GHz links operating in the same area. This reduction enables higher frequency reuse, for example, the ability for more 60 GHz links to operate in the same geographic area than links with longer ranges [15].

C. Advantages of 60 GHz Band [16]

There is many advantages of this band such as :-

1) Large spectrum.
2) Small Antenna Separation:
3) Easy Beamforming.
4) Low Interference.
5) Directional Antennas.
6) Inherent security.
7) Higher power transmission.

D. Disadvantages of 60 GHz Band [17]

There is a few disadvantages like large attenuation, directional deafness ,easily blocked.

IV THE 71-76 , 81-86 AND 92-95 GHz E-BAND FREQUENCIES.

In 2003 the FCC opened up 13 GHz of spectrum at frequencies much higher than had been available commercially before . This spectrum provides the means for economical broadband connectivity for the first time at true gigabit data rates and more.

Some of interest frequencies is the 10 GHz of bandwidth between 70 and 80 GHz. Designed to be exist, 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 via Optical Carrier interfaces (OC-192, STM-64 or 10 GigE) can be achieved.

This is will be possible by using the pencil beam as concept of operation, in which high level requirements are placed on the antenna radiation pattern of at least 50 dBi gain and no more than a 0.6-degree |Half Power Beam Width (HPBW) , in Fig .5 a comparison between the mm-Wave beam (pencil beam) and MicroWave (MW) beam.

The three spectrum segments of the E-band (71-76, 81-86, and 92-95 GHz) have been 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).

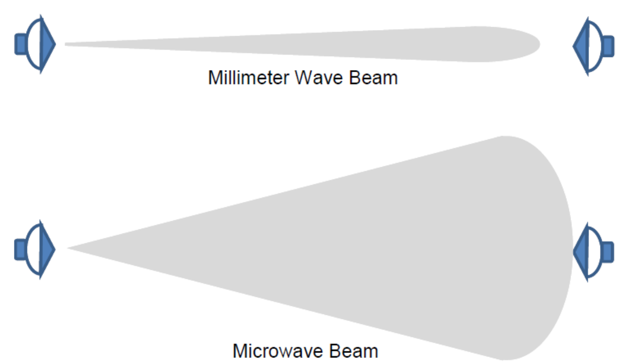

Fig. 5. Millimeter Wave Beam (Pencil Beam) vs MW Beam.

A. E-band Wireless Benefits.

E-band wireless systems offer the most convincing alternative to fiber optics system. Of all the high capacity wireless technologies, the E-band systems offer numerous benefits including:-

1) Highest data rates : E-band offers the highest data rates of any available wireless technology, with systems available that offer 1 Gbps and above through full-duplex throughput.

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2) Guaranteed data rates : On the reverse of WiFi, WiMAX and other broad coverage technologies that has system performance depends strongly on the radio frequency environment, number of users, distance from Base Station (BS) and even installation quality, E-band systems guarantee data throughput performance, even under poor transmission conditions.

3) Guaranteed interference protection : Since the E-band is a licensed technology, all links has to be registered with national wireless regulators and coordinated with other links in the area. This gives links full interference protection from other nearby wireless sources.

4) Long distance transmissions : With the exception of lower data rate and more complex Microwave systems, the E-band wireless offers the longest transmission distances of the higher capacity wireless systems. Under any environmental condition, a 1 Gbps E-band system can transmit many times further than similar data rate 60 GHz

V THE CHALLENGES OF MM-WAVE TECHNOLOGY

Even with the available bandwidth in the E-band is more than 50 times the entire cellular spectrum, radio signals in the E-band are more adversely affected by environmental factors [18]. The characteristics of E-band signals and systems can be summarized as follows:-

1) Due to the higher carrier frequencies, the antennas are need to be more directional, making E-band systems mainly convenient for line-of-sight (LOS) applications.

2) Rain and obstacles: Rain attenuation will form natural limits on link distances. As shown in fig.6, mm-Wave transmissions can experience significant rain attenuations during the rain [19]. “Heavy” rainfall at the rate of 25 mm/hour cause just over 10 dB/km attenuation at e-band frequencies. This increases to 30 dB/km for 100 mm/hour (which is not often present in Libya weather) tropical rain. These values of attenuation are used in link planning to determine the maximum link length allowed to overcome rain events.

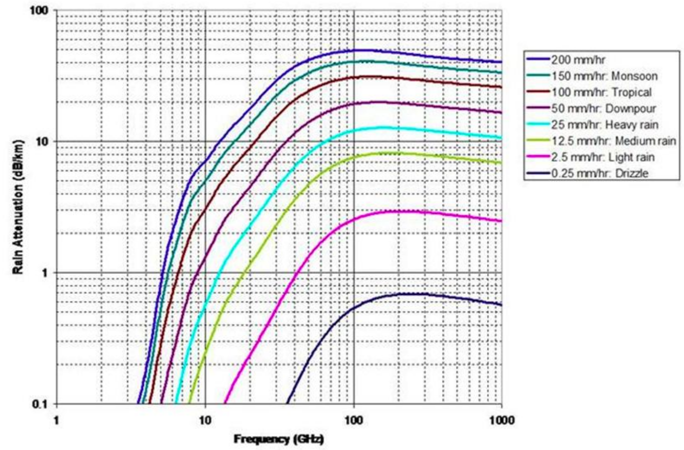

Fig. 6. Rain attenuation at microwave and mm-Wave frequencies.

VI CONCLUTION

The mm-Wave technology is a promised technology that will improve the overall performance of the network to met the increased requirements of data rates in 4 and 5G systems . With the cost and geographical limitations of Fiber optics systems , the E-band systems will be The most appropriate alternative for both coverage cells and transmission backhaul .And even through the heavy rain which is not common in the Libya’s weather this technique will be more suitable and gives a significant flexibility for the growing networks .

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