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OVERVIEW OF MILLIMETER WAVE COMMUNICATION

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ABSTRACT - This paper presents the overview of the millimeter wave communication for 5G cellular systems. The millimeter wave that involves the frequencies from around 30 GHz to 300 GHz is one among the most valid competitors for 5G technology. The worldwide transfer speed insufficiency for wireless carriers leads to the development of millimeter wave communication. Millimeter wave frequencies supports larger transmission capacity assignments that provides the higher information rate. The current status of the worldwide regulations and standards for 60 GHz band are explained in this paper. To improve the signal strength, the directional antenna is used, which guarantees the signal delivery if there exists the line of sight path between the transmitter and receiver.

KEYWORDS: Millimeter Wave, 5G, Complementary Metal Oxide Semiconductor(CMOS) technology ,Radio-Over-Fiber technology (ROF), Direct Intensity Modulation, Multi-Mode Fiber (MMF), Mach-Zehnder Modulator (MZM) ,Optical Heterodyning, Carrier-to-Noise Ratio (CNR).

1. INTRODUCTION

Millimeter wave occupies the electromagnetic spectrum that spans between30 GHz to 300 GHz which corresponds to wavelengths from 10 mm to 1 mm. Millimeter wave can be used for high speed wireless broadband communications. Millimeter wave technology is a next generation wireless technology that can provide up to multi-Gbps wireless connectivity for short distances between electronic devices[1]. The data rate is expected to be 40-100 times faster than today's wireless LAN technologies that can transmit an entire DVD's data in roughly 15 seconds. This will be like having leading-edge wire line connectivity without worrying about cable connections. The chip sets including antenna will become small and affordable. It allows to transmit signals wirelessly using a 60-GHzband carrier frequency. This frequency range is almost 1,000 times higher than those used for FM radio. In addition, reliable digital data transmission at multi-Gbps data rates cannot be achieved without sophisticated coding techniques. Therefore, the digital data need to be encoded and decoded appropriately at multi-Gbps data rates, such that efficient and robust transmission can be achieved. The rapid increase of mobile data and the use of smart phones are creating unprecedented challenges for wireless service providers to overcome a global bandwidth shortage. The communication in millimeter wave frequency ranges are shown in Figure 1. Millimeter wave is an undeveloped band of spectrum, which can be used in a broad range of products and services such as high speed networks and point to point communications. Despite millimeter wave technology has been known for many decades, the millimeter wave systems have mainly been deployed for military applications. With the advances of process technologies and low-cost integration solutions, millimeter wave technology has started to gain a great deal of momentum from academia, industry and standardization body. The development of Complementary Metal Oxide Semiconductor technology, with low cost and low power consumption, has enabled the use of the millimeter wave spectrum for the wireless communications, including the provisioning of Quality of Service (QOS) sensitive applications. Millimeter wave communications in the 60 GHz band are considered as one of the key technologies for enabling multi-gigabit wireless transmission. The 60 GHz huge bandwidth offers many benefits in terms of the capacity and flexibility [2].Due to the mobile traffic, 5G cellular network increases the system rate 1000 times higher than the current systems in 10 years. Several studies are investigated to integrate millimeter wave access into the current cellular networks as a multiband heterogeneous network which exploits the ultra-wide band aspect of the millimeter wave band communication.The growth of mobile data and usage of advanced mobile phone technologies is making a dare for wireless service providers to overcome a bandwidth shortage problem. So that

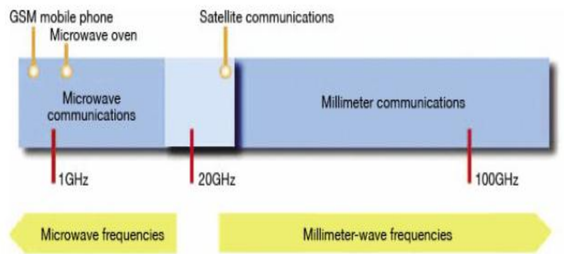

Figure 1: Communication in Millimeter wave frequencies

use of the millimeter wave frequencies ranges raised [3], [4]. It is required to bring increased information rates, enhanced scope, limit and lessened idleness, to take care of the steadily increasing demand and authorize new applications.

2. WHY 60 GHZ?

Throughout the world approximately 5–7 GHz bandwidth is available over the 60 GHz millimeter-wave band. This bandwidth makes use of multi-gigabits for wireless transmission purpose. Moreover, this voluntarily available, pre-approved spectrum allocation discards the regulation contrasts. This probability is very hopeful, while taking into account the narrow delay of UWB. In addition to the large spectrum allocation, the 60 GHz millimeter-wave channel shows the higher path loss than the lower microwave bands. Also that, the atmospheric oxygen (O2) absorption and rain interference are known to raise attenuation by 10–15 dB/km beyond 2 km. The propagation properties of indoor 60 GHz channel reduce interference to other systems and increases the frequency reuse factors and space efficiency [5]. The high signal attenuation can strictly trap the physical range of a network that would enable the most secure wireless communications. Due to the short wavelength of about 5 mm, an antenna or other RF components of 60 GHz frequency can be implemented in a smaller size than other microwave band systems. Thus, we can reduce mobile or portable wireless communication devices of 60 GHz millimeter-wave-based WPAN. The use of high frequency signals such as millimeter wave frequency bands is one of the most promising potential 5G technologies. The millimeter wave frequency band allocates more bandwidth to deliver faster, higher quality video and the multimedia contents. To increase the connectivity and speed, some other researchers seek to enable a single mobile device to connect to multiple wireless networks simultaneously. By the use of directional transmission between the base station and the mobile station, the energy efficiency is getting improved by millimeter wave technology. Due to the direct transmission the signal interference is reduced and there is a reduction in energy usage. For a given transmission energy level,it is possible to send the data at higher data rates when the direct link is established and the interference is suppressed. Consequently, the throughput per unit area increases and hence the energy efficiency is also improved. In such an analysis, it is important to consider the possible increase in hardware energy consumption due to higher operating frequencies. Because of the growth in the number of users and devices, energy efficiency is considered as one of the important standard.

3. WORLDWIDEREGULATIONS AND STANDARDIZATION

The worldwide regulations and standardization efforts for 60 GHz band are revised and the frequency allocations used in number of countries such as North America, Japan, Australia, Korea, Europe are discussed in this section. The summary of issues and future frequency allocation and the provisions for the radio regulations in the number of countries are given in Figure 2.

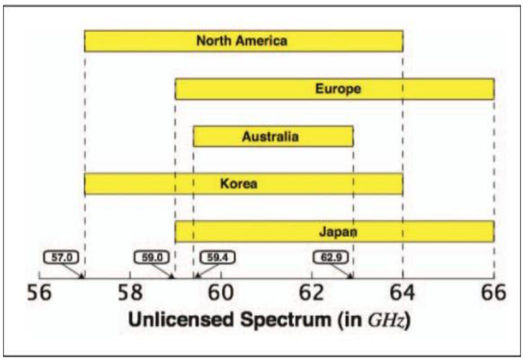

Figure 2: International Unlicensed Spectrum around 60 GHz [6]

3.1 60 GHZ regulations in North America

The United States of Federal Communication Commission's (FCC) allocated the 7 GHz bandwidth in the unlicensed 54-66 GHz band, used in the year of 2000. FCC rules allow emission with average power density of 9 μW/cm^2 and maximum power density of 18 μW/cm^2 both are at 3 meters. The average Equivalent Isotropic Radiated Power [EIRP] and maximum EIRP is 40 dBm and 43 dBm respectively. 500mW is the maximum transmit power [6].

3.2 60 GHz regulations in Japan

The Ministry of Public management Home affairs, posts and Telecommunications (MPHPT) of Japan issued 60 GHz radio regulations for unlicensed utilization in 59-66 GHZ band in the year of 2001. The maximum transmission power in unlicensed use is limited to the 10dbm with the maximum antenna gain 47dBi [7].

3.3 60 GHz regulations in Australia

The Australian Communication and Media Authority (ACMA) has taken a similar step to adjust the 60 GHz band in the year of 2005 June [8]. But, for unlicensed use only the 3.5 GHz bandwidth is allocated that is, from 59.4 to 62.9 GHz. The maximum transmit power used is 10mW and maximum EIRP is 150 W.

3.4 60 GHz regulations in Korea

The millimeter wave Frequency Study Group (MFSG) was created under the Korean Promotion Association. The unlicensed bandwidth used by the MFSG is 7 GHz. The maximum transmitted power used is 10 mW.

3.5 60 GHZ regulations in Europe

The European Conference of postal and Telecommunications Administrations (CEPT) and the European telecommunication Standards Institute (ETSI) is providing the unlicensed frequency with 9 GHZ bandwidth. The maximum transmitted power is 20 mW with the maximum EIRP of 57 dB.

4. GENERATION OF MILLIMETER WAVE TECHNIQUES

Millimeter wave generation in the optical domain is the key technique to enable wireless communication in the wireless band. Optical fiber is the standard medium for millimeter-waves transmission due to its low loss, low cost and wide bandwidth. The resultant technology is called Radio-over-Fiber technology (ROF). Radio-over-Fiber in millimeter wave band is the hopeful technology to meet challenges of next generation communication systems.

4.1 Millimeter wave signal generation by direct intensity modulation

The direct intensity modulation uses a millimeter wave carrier source to directly modulate a high speed LASER and then the millimeter wave signal can be improved at photodiode by direct detection. The method of direct intensity modulation is shown in Figure3.The directly modulated Distributed Feedback Back (DFB) lasers are used to transmit high data-rate Orthogonal Frequency Division Multiplexing (OFDM) video signals over 1- km Multi-Mode Fiber (MMF) [9].

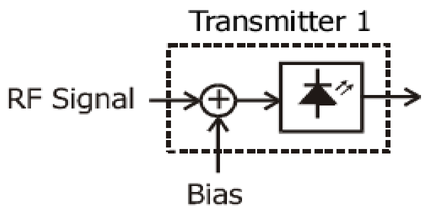

Figure 3: Direct Intensity Modulation [10]

The direct intensity modulation method is possible only when the operating RF frequencies are lower than the modulation cut-off frequency of the laser diode used. The highest cut-off frequency of laser is 40 GHz [10]. Most of the existing lasers have modulation frequencies of about 10 GHz or less. Even though this method is efficient but is not appropriate to mm-wave bands as the bandwidth of modulating signal is limited by the modulation bandwidth of laser. For generating high frequencies, the modulating signal should also be at high frequency. This is not possible due to limited Bandwidth. For the fibre transmission of higher frequencies such as millimeter-wave signals, the optical external modulation is used instead of direct intensity modulation.

4.2 Millimeter wave generation by external modulation

In this method, the laser operates in Continuous Wave (CW) mode. To modulate the intensity of light an external modulator such as Mach-Zehnder Modulator (MZM) or Electro Absorption Modulator (EAM) is used. Even though the configuration is simple, it has some disadvantages like fibre dispersion effects, high insertion loss and distortion due to the intrinsic nonlinearity of the modulators [11]. The phenomenon of external intensity modulation using MZM is shown in Figure 4.

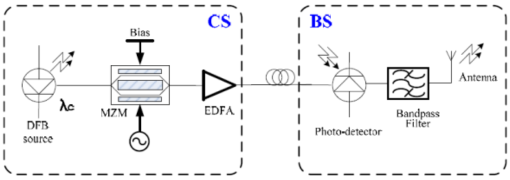

Figure 4: External Intensity Modulation using MZM [11]

A single DFB laser source is used together with a MZM. By biasing the MZM at Vπ, the half-wave voltage of MZM, the optical carrier at centre wavelength will be suppressed. The beat of upper and lower 1st side-modes will generate the required mm-wave signal with frequency twice to that of the mm-wave signal applied to MZM. Another approach uses Fabry Perot filter to select the two second order optical sidebands. An optical modulator with a maximum operating frequency of 15GHz can generate a millimeter wave signal up to 60 GHz. This system was complex and costly as it relies on the optical filter to select two optical sidebands and generate tunable millimeter wave signals.

4.3 Millimeter wave generation by up-down conversion

In this method, instead of RF band signal, Intermediate Frequency (IF) band signal is transported over optical fiber and the IF-to-RF band up conversion is accomplished at the Base Station (BS) level [12]. The electrical frequency conversion between the IF-band and millimeter wave requires frequency mixers and a millimeter local oscillator which leads to the increase in additional cost to the BS. The advantage of this technique is that it occupies small amount of bandwidth and is almost free from the dispersion effect. The respective configuration is shown in Figure 5.

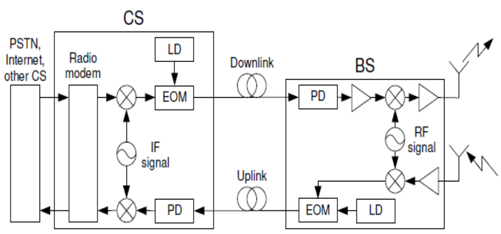

Figure 5: ROF link configurations for External Optical Modulator (EOM), IF modulated signal [12]

4.4 Millimeter wave generation by Optical heterodyning

In this method, two or more optical signals are simultaneously transmitted and are heterodyned in the receiver. The high frequencies are generated using optical heterodyning which are limited only by the photo detector bandwidth. The advantage of heterodyning is the higher link gain and higher Carrier-to-Noise Ratio (CNR). Remote heterodyning has the advantage of chromatic dispersion. The drawback of heterodyning is the laser phase noise due to the uncorrelated phases of the two optical signals. The phase sensitivity can be reduced using Optical Phase Locked Loop (OPLL) and Optical Injection Locking (OLL). By employing optical heterodyning techniques, 40 GHz millimeter wave signals have been obtained [13].

5. CHALLANGES

In spite of the capability of millimeter wave cellular systems, the various key difficulties for understanding the perception of cell is organized and explained as follows.

5.1 Directional communication and range

Friis' transmission law [14] states that the free space omnidirectional path loss increases with the square of the frequency. The small wavelength provides the proportionally larger antenna gain for the same size of antenna. Thus, the high frequency of millimeter wave signal doesn't themselves results in the free space. The propagation loss and the directional transmission are used and antenna area is also stable.

5.2 Shadowing

The millimeter wave signs are remarkably too vulnerable for example, materials like brick attenuates the signal that results in 40–80 dB and the human body also attenuates that result in 20–35-dB loss. The rain and the humidity fades are the common challenges of long-extend millimeter wave backhaul links which are not a problem with cell frameworks mentioned in Figure 6.

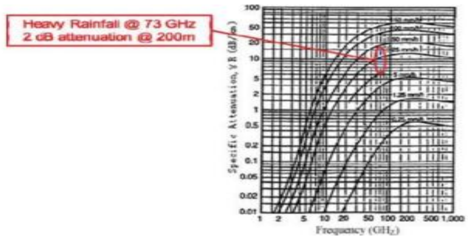

Figure 6: Rain attenuation in dB/Km through frequency at several rain fall rates

6. MERITS OF THE MILLIMETER WAVE COMMUNICATION

Millimeter wave larger bandwidth is able to provide higher transmission rate, capability of spread spectrum and is more immune to interference. Extremely high frequencies allow multiple short distance usages at the similar frequency without interfering each other but it requires the narrow beam width. For the same size of the antenna, when the frequency is increased, the beam width is decreased.

7. DEMERITS OF THE MILLIMETER WAVE COMMUNICATION

For reducing the size of the component higher cost is required. There is a significant attenuation occurs at higher frequencies. Hence the millimeter waves cannot be used for longer distance applications. There are interferences with oxygen and rain at higher frequencies. Therefore, further research is going on to reduce this.

8. APPLICATIONS OF MILLIMETER WAVE COMMUNICATION

8.1 Small Scale Access

The Small Scale Access is used in the macro cells and provide the solution for the capacity improvement in the 5G cellular network. For the higher bandwidth the millimeter wave communication can able to offer the gigabit rates.The communication over Small Scale Access is shown in Figure 7.

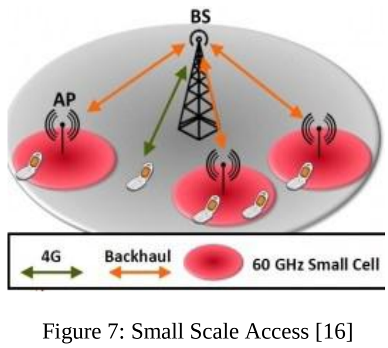

Figure 7: Small Scale Access [16]

8.2 Wireless backhaul

In wireless backhaul the 60 GHZ and E band gives the numerous Gbps data rate and can be a hopeful backhaul solution for the small cell [15]. The E band backhaul, provides the high speed transmission between the small cell base stations or between base station and gateway.

8.3 Millimeter wave propagation

In millimeter wave propagation the characteristics are in millimeter wave and the bands are below the 4 GHz. The distance achieved is very small and the signals are not reflected in the wall and any other objects. Typically the millimeter wave propagation is used in the outdoor ranges between the 200-300 meters.

9. CONCLUSION AND FUTURE SCOPE

With the potential to provide higher capacity over current communication systems, millimeter wave communications become a hopeful candidate for the 5G mobile communication networks. Despite of its huge potentials to achieve multi gigabit wireless communications, 60GHz radio has a sequence of technical challenges that have been determined before its full deployment .We also summarize the potential applications of millimeter wave communications in the 5G network that includes the small cell access, the millimeter wave propagation and the wireless backhaul.

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