Recent Trends in Millimeter Wave Communication

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Abstract –In the world of mobile wireless communication delivery of content with high quality services by taking into consideration available bandwidth, speed, latency, reliability, became very essential in the fulfillment of demand of services for greatly increasing subscribers on the mobile cellular network. Among various solutions one of technology of future is millimeter wave communication. Large spectrum of available bandwidth at very high frequency range 30GHZ to 300GHZ will play a vital role along with other technologies like Massive MIMO, Mobile Cloud, Software Defined Networking, for design and operation of 5G cellular networks. It is best suited for short range line of sight communication. With modification in LTE advanced and hetnets it is possible to achieve coverage, capacity, spectral efficiency, energy efficiency and desired speed up to 1Gbps practically by the use of five channel carrier aggregation and cyclic prefix usage. This review paper basically enlightens opportunities and challenges to exploit available bandwidth using this 5G technology to fulfill the need of customers.

Keywords – bandwidth, latency, services, losses, millimeter wave.

NOMENCLATURE

MIMO: - Multiple Input Multiple Output.
LTE:- Long Term Evolution
LOS:- Line of Sight
Hetnet:- Heterogeneous Network
SDN:- Software Defined Networking
D2D:- Device to device communication
MAC:- Medium Access Control
OFDM: Orthogonal Frequency Division Multiplexing
SINRD:- Substrate Integrated Nonradiative Dielectric
NRD:- Non Radiative Dielectric
BER:- Bit Error Rate
MMIC:- Millimeter Wave Integrated Circuits

1. Introduction

When signal has wavelength 10mm to 1mm and frequency range lying between 30GHZ to 300GHZ the signal is called millimeter wave signal. It has capacity of bandwidth delivery comparable to fiber optics without financial and logical burden of deployment. In 1897 J. C. Bose did first experimentation on millimeter wave signal. Lower portion of microwave wave spectrum is utilized to its maximum limit. 4G LTE has limitation on practicably achievable data rate because of use of two channels. 4G offers maximum bit rate 10 Mbps in outdoor environment and 100Mbps in indoor environment. It is difficult to achieve this in reality in NLOS communication. Channels having frequency greater than 200MHZ are called 5G channels. Those are used to get energy efficiency, spectral efficiency, low latency, high speed data, video information, signaling information, control information etc. Millimeter wave has very high level of penetration loss and small wavelength so most suited for LOS communication. Components, devices, and circuitry using millimeter wave signaling needs research. To serve users present in high density area and to reduce power consumption larger cells are split into smaller cells like micro cells, Pico cells, femto cells. This will reduce transmitter power to greater extent.

B. Iyer, S. Nalbalwar and R. Pawade (Eds.)
ICCASP/ICMMD-2016. Advances in Intelligent Systems Research.
Vol. 137, Pp. 586-591.
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Techniques like wireless HD, wireless GB are used along with Massive MIMO. Now a day's research on millimeter wave components, devices, usage of millimeter wave systems is at peak level and challenges at Physical layer, MAC layer, and Routing layer need to be addressed which is very much essential for 5G to exploit potential of millimeter wave communication. The concept of software defined networking can be used to design architecture, protocols, control mechanism. It is established new method of creating and administering networks [21]. It promotes separation of data plane and control plane. Control plane makes the decision of network forwarding while data plane is used for forwarding data [21]. It is possible to design well-coordinated, fast and cost effective networks. It uses logical centralized software to control the entire network behavior [22]. It also uses log. It improves ability of carrier that may be wired or wireless [20]. It provides flexibility for sharing of bandwidth. On priority requirements of bandwidth are fulfilled. It is directly programmable, centrally managed, configurable, open standard. The IEEE standards used are 802.15.3C and 802.11ad. Challenge is how to reduce impact of environmental parameters on propagation to reduce losses, get channel state information, development of protocols, interference management, deployment of larger arrays, reduction of phase noise, improvement of battery life, reduction of power consumption. Modification or up gradation in hardware as well as software and with use of existing advanced technologies, desired results can be achieved.

2. Key Challenges

Range:-It is limited by transmission losses like free space loss, atmospheric gases, rain, foliage, water vapors, oxygen, scattering, diffraction, sky noise temperature, human body(=35db), cloth, concrete(>35db) interference and millimeter wave signaling systems. In free space loss, the frequency and distance depends upon loss between two isotropic antennas. It is expressed in absolute number by [FCC DC 20554]

$$L_{fsl}= (4\pi\varrho)/ (\lambda)^{2} \quad (1)$$

Foliage loss at millimetre wave frequencies is significant. It may be limiting propagation impairment in some cases. For the case where foliage depth is less than 400meters, the loss is given by [FCC DC 20554]

$$L = 0.2\, f^{0.3} R^{0.6} \text{ db.} \quad (2)$$

L= Foliage loss, F= Frequency in MHZ, R= depth of foliage. The relationship is applicable for frequencies in the range 200MHZ to 95000MHZ. The foliage loss at 40GHZ for a penetration of 10 meters is about 19db. This is clearly not a negligible value. In NLOS path signal may reach to the receiver via reflections from objects in proximity to the receiver or via diffraction or bending. The short wavelength of millimeter wave signal results in low diffraction. Normally the greatest contribution at the receiver is reflected power. Reflections and diffusion are strongly depending on the reflectivity of the reflecting material. Short wavelength i.e. high frequencies cause the reflecting material to appear relatively rougher which results in greater diffusion of the signal and less specular i.e. direct reflection. After converting to units of frequency and putting in db form the equation is given by [FCC DC 20554]

$$L_{fsl} = 92.4 + 20 \log (f) + 20 \log (R) \quad (3)$$

f= frequency in GHZ, R= Loss range between antennas in km. Even for short distances free space loss is quite high. For every octet change in range, the differential equation changes by 6db. Thus for applications of millimeter wave spectrum, only short distance communication link will be supported. In atmospheric gaseous losses when millimeter wave travels through the atmosphere are absorbed by molecules of oxygen, water vapors and other gaseous atmospheric constituents. The losses are greater at certain frequencies coinciding with mechanical resonant frequencies of the gas molecules. For current technology important absorption peak occurs at 24GHZ and 60GHZ. The transmission windows are at about 35GHZ, 94GHZ, 140GHZ, and 220GHZ. It is 0.012db at 28GHZ and 0.016db at 38GHZ for 200 meter respectively [4]. At higher frequencies loss is less. Millimeter wave propagation also affected by rain. Rain drops are roughly the same size as the radio wavelengths and so cause scattering of radio signal. An increase in the rain factor reduces the communication signal availability. It is 7db/km at 28GHZ and falls to 1.4db if cell wounds at 200meter [4].

Sky Noise Temperature

Anything that absorbs electromagnetic energy is a radiator. Constituents of the atmosphere that cause attenuation such as water vapors, oxygen, and rain radiate signal which is noise like. When these signals impinge on the receiver antenna they degrade system performance. An earth station antenna aimed at a satellite at a high elevation angle will pick up sky noise emanating from atmospheric constituents and other sources. This is called sky noise temperature or brightness temperature. For low elevation angles, the dominant noise will be mostly from terrain and will be

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picked up by the antenna side lobes. This phenomenon will also affect suitability of millimeter wave spectrum region for communication applications. The noise entering a receiver from the antenna is commonly referred to as the antenna noise temperature and it includes component of sky noise.

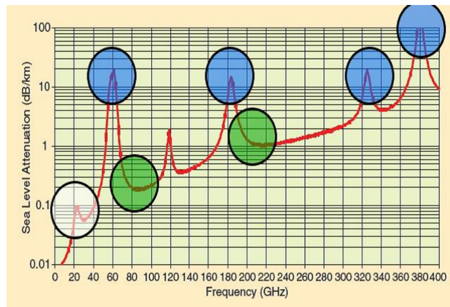

Fig.1. Atmospheric absorption across millimeter wave frequencies in db per kilometer. [4] [5]

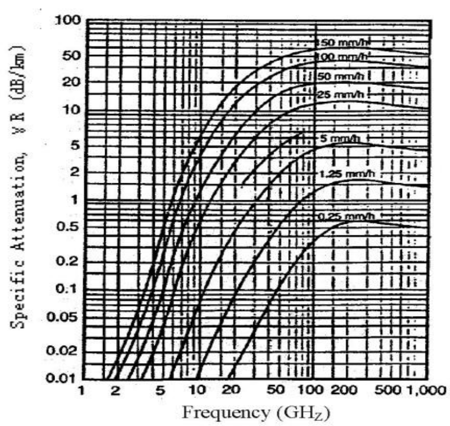

Fig.2. The rain attenuation [4] [5]

3. Data Rate Enhancement

In every generation, evolution of new technologies plays an important role in the data rate enhancement. There is always up gradation in hardware and software tools used. Modification helps to increase capacity, coverage, speed and reduce interference. Using technologies like Massive MIMO with millimeter wave , OFDM for downlink, SC-TDMA for uplink in LTE advanced, Software Defined Networking, Advanced Antenna Technologies, and features like spatial multiplexing, antenna arrays and switching, adaptive beam forming, and knowing channel state information, channel modeling , modified architectures, intensive digital signal processing, interference coordination and management, it's possible to enhance the data rate. Wireless HD and WirelessGB are playing their roles to achieve higher data rates. Techniques like Massive MIMO with millimeter wave signaling, carrier aggregation are very popular now days. In a MIMO system an antenna array is used which uses large number of antenna elements typically ten or hundred at the transmitter and receiver side so called massive [1]. It is evolving technology which has appealed many researchers. Due to its promising capability of greatly improving spectral efficiency, energy efficiency, robustness, and security of the system [2]. It can be of the order of hundred elements or thousand elements. This helps to increase the gain but increases the power consumption and put limitation on the size of the array [10]. As far as other challenges are concerned hardware cost associated with RF elements, and complexity of signal processing resulted from large number of branch signals [10].It uses concept of spatial multiplexing. It depends upon phase coherent signals from all the antennas at the base station. It can improve radiated energy efficiency 100 times and capacity 10 or more [17]. It uses low cost low power components.
It permits substantial decrease in latency on the air interface [17]. It makes the multiple access layers simple. It increases strength against intended interference and jamming. It obtains multiplexing gain of massive point to point MIMO system [17].It eliminates problem due to unfavorable propagation conditions. Orthogonal frequency division

multiplexing and MIMO are used on the downlink channel and single carrier time division multiplexing is used for uplink channel. LTE uses these multiple access techniques to achieve high data rate, improved latency, high coverage area, high spectral efficiency and low cost [6]. Uplink and downlink channels are reciprocal in TDD systems. Precoding is used in downlink and receive combining is used in uplink. Techniques like zero forcing function, Maximum ratio combining, and Minimum mean square error are used to focus each signal on its desired terminal and possibly mitigate interference towards other terminal [6].OFDM has low spectrum efficiency due to strong interference at the cell edge.

This scheme used as digital multicarrier modulation method. It is used to avoid multipath fading on downlink which is problem in UMTS. It uses carrier of 180KHZ. It uses large number of such carriers to carry the data. It has ability to cope up with severe channel conditions. The use of guard band makes it possible to eliminate ISI.It has high peak to average ratio. It is sensitive to frequency offset.It uses 84 transport blocks. These are transmitted in parallel fashion in multiple access scheme like OFDMA in downlink as in LTE [6]. OFDM signal is represented in frequency domain rather than time domain. It is better suited to MIMO. Frequency domain representation of the signal enables easy precoding to match the signal to frequency and phase characteristics of the multipath radio channel [4]. It is sensitive to frequency and phase errors. Doppler shift which causes interference to subcarriers. High peak to average ratio led 3GPP to look different transmission scheme for LTE uplink [4]. Data symbols in the time domain are converted into frequency domain using DFT [5]. In the frequency domain these are mapped to the desired location in overall channel bandwidth before being converted back to time domain using IFFT [5]. It is sometimes called DFT- SOFDM. Finally cyclic prefix is inserted. OFDMA is used to achieve high power spectral efficiency in communication system. SC- FDMA is more power efficient. For a particular value of SNR, BER increases for higher order modulation like 16QAM or 64 QAM [6].

Lower order modulation at receiver like BPSK, QPSK means less data in given bandwidth. Probability of error increases as order of modulation scheme increases[6]. Using CMOS IC technology it is possible to fabricate antenna at nano scale level. Among various fabrication techniques SINRD proved better technique over traditional hybrid integration technique [8]. It suppresses interference. It is suitable for low cost applications at millimeter wave frequencies. MMIC fabricated using NRD guide as a transmission medium has low transmission loss characteristics and does not radiate at curved sections and discontinuities [9]. Directional antennas are used to reduce beamwidth and interference. Thus advanced antenna system is proving better solution than three sector base station antenna system. Beam forming is implemented in two ways. First, antenna switching mechanism approach in which elements of the antenna are made ON or OFF according to the received signal. Second is adaptive array approach where amplitude and phase of each antenna is set independently. Thus we can achieve beams in very large number ideally infinity. It is called adaptive beam forming. Now a days PRS type of antennas can be used for beam forming because of their compact structure and ease of achieving high directivity and simplicity in feeding mechanism [7].

It has two types of admittance surfaces. Metallic grid layer inductive surface and metallic patch layer capacitive surface[3]Antenna array creates null in the direction of strong interference. Highly directional millimeter wave transmission is also not fully secure against the attacker outside the beam. To maintain privacy and security these low level eavesdropping attacks must be reduced. It takes into consideration direction of arrival and signal to interference ratio.

Thus using smartness of antenna technology data rate can be improved. In the scenario of carrier aggregation instead of increasing size of channel more number of channels can be used for further enhancement. Using mobile hetnet, modification in cyclic prefix we can increase energy and spectral efficiency. Radio conditions, type of modulation used, frame formats, network performance also impact bit rate provided. Quadrature amplitude modulation is used in LTE. In excellent radio conditions QAM 64 modulation is used.

Hetnet and Security

The concurrent operation of different classes of base station is known as heterogeneous network. Which provides flexible coverage area. It involves a mix of radio technologies and cell types working together seamlessly. It improves existing macro cell, densify macro network, and add small cells. In hetnet coordination between small cell and macro cell has positive impact on performance of radio network and consequently on overall experience. Next generation wireless networks aiming to achieve extremely high data rates using millimeter wave narrow beams, but a small object in the path enable reflections and allow potential attackers to achieve required signal strength as that of intended receiver which allows eavesdropper to receive signal from outside. Devices like laptop and mobile causes sufficient reflections for eavesdropping which reduces secrecy capacity. Thus highly directional beam with millimetre waves are not that much secure against attacker outside beam. Thus it is essential to reduce these low level attacks by eavesdropper.

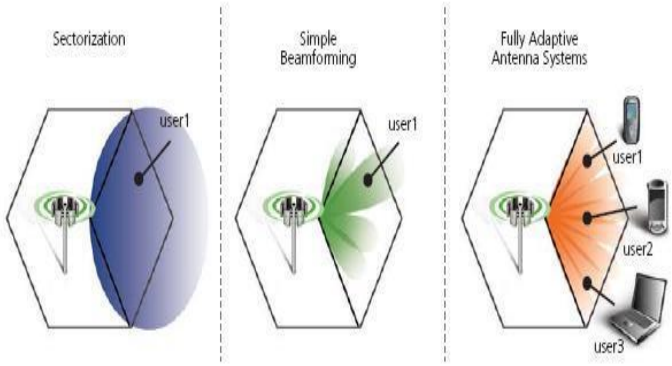

Fig. 3 Beam forming [7]

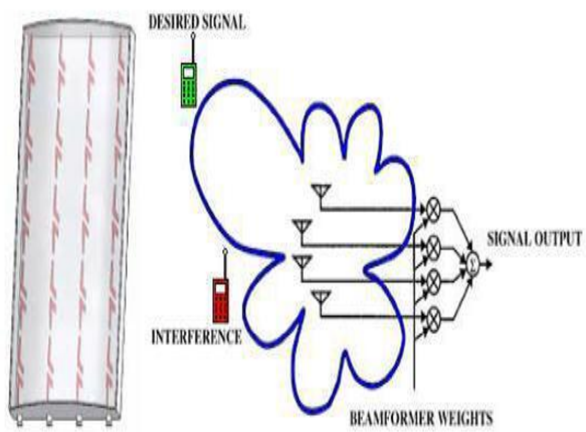

Fig.4 Beam forming [7]

4. Conclusion

Due to limitations to advance LTE, it became essential to exploit unused and unlicensed spectrum of high frequency and high bandwidth to meet very high demand of data rate for very high speed applications in 5G. Capacity enhancement required to accommodate very large number of subscribers approximately 1000 times existing. The technology which can fullfill all the demands of 5G along with other technologies like D2D communication, IOT, Mobile cloud, Massive MIMO, SDN is millimeter wave technology an emerging solution for next generation wireless communication[7]. The technology assures high speed and quality services for line of sight communication with interference management. It is also possible to avail graded quality services for NLOS in near future. Hetnets are also used with millimeter wave signalling to improve capacity and reduction in power consumption by splitting cells.

Acknowledgement

We are grateful to MCOM Technologies, Gurgaon, Delhi, NILIT Aurangabad, Maharashtra and Lokmanya Tilak College of Engineering, Navi Mumbai, Maharashtra.

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