128-QAM Based *mm*-Wave Communication (5G) Architecture

Abdullah Al-Mamun Bulbul[1,2*], Md. Tariq Hasan[2], Faysal Iqbal[3], Md. Bellal Hossain[2]
[1]Dept. of Electronics and Telecommunication Engineering, Bangabandhu Sheikh Mujibur Rahman Science and Technology University, Gopalganj, Bangladesh,
[2]Electronics and Communication Engineering Discipline, Khulna University, Bangladesh,
[3]Dept. of Electrical and Electronics Engineering, Bangladesh Army University of Engineering & Technology, Bangladesh,
[*]corresponding author: bulbulmamun@yahoo.com, bulbul@bsmrstu.edu.bd

Abstract – *Demand for bandwidth can never be fulfilled with any definite amount. Population is growing at a high speed which also causes an increase in the demand for bandwidth. Currently available bands ranging up-to 10 GHz is at the edge of saturation. So a newer and unutilized bandwidth is mandatory for the fulfillment of the increasing bandwidth demand. The millimeter wave band which is fully unused, offers a wide range of bandwidth (30 GHz ~ 300 GHz). A slight part of this band, the E-band, has been used in the design of the 5G network proposed in this paper. Single-carrier frequency-division multiple access (SC-FDMA) and orthogonal frequency-division multiple access (OFDMA) have been proposed for the uplink and downlink multiple access respectively. The use of SC-FDMA in the uplink ensures low power consumption at mobile station due to its inherent low PAPR characteristics as evident from simulation results. A Rayleigh fading channel that highlights the real-life environments comprised of non-line-of-sight (NLoS) paths between transmitter and receiver is used as the propagation environment along with different losses at sea level ($T = 0^\circ C$, $P = 760$ mm Hg, $H_2O = 1$ gm/m^3). 128-quadrature amplitude modulation (QAM) has been used as the principle modulation technique. This modulation approach ensures enhanced data rate of approximately 9 Gbps. Adaptive beam-forming antenna has been used in the proposed network as it possesses the capability to steer the main radiation in the anticipated direction while filters out the unwanted signals from neighboring users communicating at nearby frequencies without the physical movement of the antenna. The use of this type of antenna ensures an increased coverage of about 2 km for the proposed network.*

Keywords: *E-band, OFDMA, SC-FDMA, 128-QAM, 5G.*

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I. Introduction

With an ever-growing volume of smart mobile devices, the increase of mobile data traffic is a compelling reality. A 1000-fold increase in system capacity is expected within the year of 2020 [1]. Due to the limited available spectrum in the microwave band, the existing mobile networks will fail to support the traffic demand. Furthermore, to enable envisioned varieties in mobile services like ultra-high-definition (UHD) video or 3D live program streaming, IoT services, augmented reality, cloud support and etc. in upcoming mobile networks and devices, new challenging requirements, e.g., in terms of throughputs, latencies and reliability, will be imposed for an entire system design [2]. The millimeter wave (mm-wave) is anticipated as the most suitable option which will be able to fulfill the bandwidth requirement for the next-generation wireless communication [3]-[5]. But the mm-wave suffers from severe propagation loss and atmospheric absorption loss, which degrades the signal quality and limits the coverage area. Due to their short range of few hundred meters, mm-waves follow the line of sight (LoS), so this wave propagation can be interrupted by objects like trees, walls and buildings. For these reasons, mm-waves may be used for high-bandwidth point-to-point communication links at short range.

Existing mm-wave communication systems can afford 2.1 Gbps maximum data service [6] and can ensure only about 200 meters coverage [1],[7]. From the wide available mm-wave band, 71 ~ 76 GHz and 81 ~ 86 GHz (known as E-band) is chosen to design the proposed network since this band suffers from less propagation loss if compared to the other mm-wave bands. Orthogonal frequency-division multiple access (OFDMA) provides the most competent use of radio spectrum by permitting overlapping orthogonal channels and multi-user diversity. This orthogonal channels are resistant to interference and frequency selective fading. Both the single-carrier frequency-division multiple access (SC-FDMA) and OFDMA possess comparable structure and performance [8]. But SC-FDMA provides an additive advantage of the low peak to average power ratio (PAPR) compared to OFDMA [8]. Low PAPR defines energy efficiency at the mobile terminal (MT). For the described reasons SC-FDMA and OFDMA have been chosen as the multiple-access technique for the MT terminal and base station (BS) respectively. In order to achieve energy efficiency and enhance the coverage area, the proposed 5G network is comprised of adaptive MIMO antennas.

In this article, the mm-wave band and mm-wave communication systems are first investigated. The limitations of currently proposed 5G communication networks have been discussed. Then the mm-wave network for 5G communication is proposed which is followed by the simulation results of the network and a brief discussion of envisioned future works.

II. Literature Review

To mitigate the high demand for new bandwidth, the radio network planners and designers have concentrated their attention to the higher stage of frequency spectrum in search of greater capacity [9]. Outdoor measurements to evaluate the practicability of mm-wave systems have been examined at frequencies of 5 GHz, 28 GHz, 38 GHz and 60 GHz [1],[7],[10]. As predicted in [5], a large portion of mm-wave band suffers from severe atmospheric absorption. The 60 GHz band faces acute O_2 absorption loss of approximately 15 dB/km of attenuation along with the other free space losses [11]. But this loss is expressively lower above 70 GHz and again this loss rises after 100 GHz [11]. Hence, the frequency band from 70 GHz to 100 GHz is on available window with lower atmospheric absorption loss making it a perfect candidate for long distance wireless transmission. In particular, the international telecommunication union (ITU) has released the E-band [12]. E-band is allowed more transmit power than the 60 GHz band as it is licensed by the federal communications commission (FCC). The 10 GHz bandwidth of this band is about fifty times the total mobile bandwidth presently in use.

Despite the potential offerings and services at mm-wave band, huge amount of obligations exists in designing a communication network using mm-wave. High carrier frequency and large bandwidth gives birth to a number of technical obligations and complexities in implementing circuit elements and antennas for mm-wave networks [3]. At mm-band, power amplifiers suffer from serious nonlinear distortion caused by high signal power and equivalent isotropic radiated power (EIRP). Besides, integrated circuit (IC) designing upsurges phase noise and IQ imbalance [13]. Several researches have been carried out on ICs for operating at mm-band. A phased-array antenna solution has been carried out for communicating at 28 GHz in [14] which is expected to provide near-spherical coverage. The antennas operating at mm-band frequencies have become so smaller in physical size that it becomes possible to accumulate antenna arrays on printed-circuit board or chip.

Rappaport *et al.* [1] proposed an mm-wave communication network using 28 GHz and 38 GHz. The channel has been modeled by the statistical spatial channel model (SSCM) and an MIMO antenna is proposed as the transmitting antenna, expected to provide a coverage of 200 m only. No multiplexing and modulation techniques have been mentioned and the data rate of the network is not taken into account. An mm-wave network using a massive MIMO is proposed in [15] where data rate of up to 10 Gbps is expected. But no multiplexing and modulation technique have been mentioned and coverage is not specified. An mm-wave network using a massive MIMO antenna and 64 QAM at 28 GHz is proposed in [16]. Data rate up to 1 Gbps and 200 m coverage is expected. But no multiplexing technique is mentioned in that paper. Another mm-wave network using massive MIMO antenna, QAM modulation and OFDM multiplexing technique is proposed in [17]. Though the network is assumed to provide a coverage area greater than 200 m, MT suffers from high power consumption and the data rate is not specified. In [18], an mm-wave network utilizing 7° beam-width antennas at 38 GHz and 60 GHz is proposed. Up to 265m coverage is expected in that paper. But modulation technique, multiplexing approach, power consumption at MT and data rate are not taken into account.

Due to low atmospheric absorption loss at E-band, this band is chosen for the proposed 5G network. Besides the utilization of adaptive MIMO antennas is one of the best techniques that reduces channel attenuation and interference in mm-wave networks [19]. To reduce interference, achieve high directivity and mitigate poor coverage problems, an adaptive beam-forming antenna is proposed in this report. SC-FDMA and OFDMA are proposed as the multiple access technique at Uplink and Downlink terminal, respectively. Also, it is expected that the use of 128-QAM modulation technique will increase the data rate of the designed network.

III. Network Configuration

The E-band is being utilized to design the network. The network has been simulated using MATLAB *v*.2015a. The overall network design has been summarized in Fig. 1.

The 71-76 and 81-86 GHz band has been chosen as the uplink frequency and the downlink frequency respectively. SC-FDMA has been chosen as the multiple-access technique to design the uplink due to its low PAPR. Because low PAPR ensures power efficiency at the MT [8]. 128-QAM is selected as the modulation technique to increase the capacity of the designed network. The network has also been simulated for QPSK and 16-QAM. An adaptive beam-forming antenna has been used in the proposed mm-wave network of this paper as it is a prominent candidate [20]. This type of antenna has been used due to its efficient detection and estimation of signal of interest at the output of an array by removing interference and least-square spatial filtering. In this type of antenna, optimal value for the beamforming weights are computed using I/O array statistics [21]. This implies the name adaptive, making it distinguishable from conventional beamforming antennas. The antenna has been designed and simulation results has been carried out using the least-mean-square (LMS) algorithm for 32 antenna elements with λ/2 elements spacing. This algorithm updates the optimum value of the weights through minimizing the difference between wanted and true signal [22].

The wireless channel environment has been modelled as Rayleigh fading channel. Rayleigh fading is more efficient in examining practical scenario compared to Rician fading channel as it inspects worse case environment where there exists no LoS paths between transmitter and receiver.

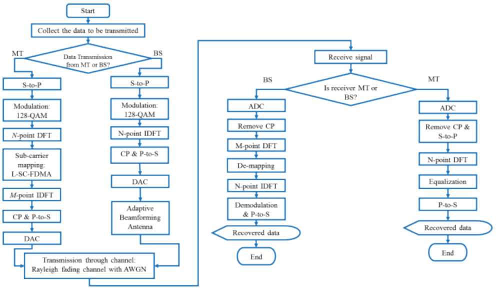

Fig. 1. Designed *mm*-wave network's architectural flow chart

Free-space loss (FSL) has been calculated using subsequent equation 1 [23]:

$$Loss_{FSL} = [92.4 + 20\log_{10} f + 20\log_{10} R]dB \quad (1)$$

Here, frequency, f is expressed in Gigahertz and distance, R is in kilometer. According to [24], the atmospheric gaseous absorption loss, $Loss_{AGL}$, at sea level (T = 0 ˚C, P = 760 mm Hg, H_2O = 1 gm/m^3) is 0.125 dB/km for E-band. Foliage losses are significant in the mm-wave band. The amount of foliage loss is estimated as a function of the depth (D in meters) of foliage transversed by using equation 2 [25]:

$$Loss_{FL} = 1.589 \times f^{0.3} \times D^{0.6} dB \quad (2)$$

Rain absorption loss, $Loss_{Rain}$, for a signal in the 81–86 GHz band is 0.29 dB/km on average for rainfall of 0.25mm/h [26]. The total path loss of the design has been projected using the following equation 3.

$$Loss_{Total} = Loss_{FSL} + Loss_{AGL} + Loss_{FL} + Loss_{Rain} \quad (3)$$

The transmitted signal is received by the MT. The received signal level (RSL) at the MT is estimated by the following equation 4:

$$RSL = [P_{TX} + G_{TX} + G_R - Loss_{Total}]dBm \quad (4)$$

IV. Numerical Results

The simulation results of the proposed 5G network has been analyzed. A discussion has been made on the results to verify the network's capability of reducing the energy consumption in addition to high data rate services.

A. Study on the Effect of Path Loss

A free-space loss comparison of different bands at mm-wave frequencies is made. With increase in frequency, free-space loss gradually increases as evident from Fig. 2.

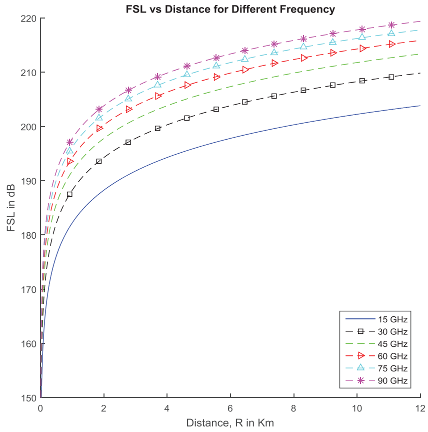

Fig. 2. FSL comparison among different bands of mm-wave

But the atmospheric gaseous absorption loss is lower at E-band. This loss is about 0.125, 4.5 and 0.127 dB/km at E-band, 60 GHz and 100 GHz respectively. For this reason total path loss is lower at E-band than in the 60 GHz band as found in Fig. 3.

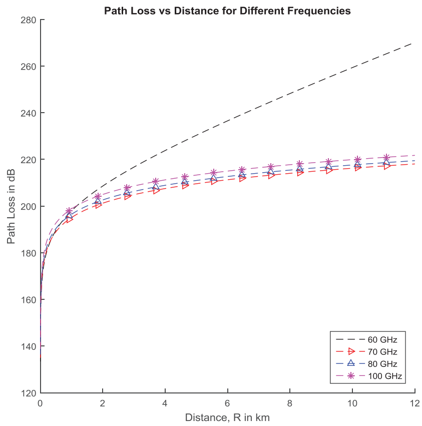

Fig. 3. Overall Path-Loss comparison for different mm-wave bands

B. Comparison of PAPR

Fig. 4 represents a PAPR comparison between uplink and downlink for different types of modulation (QPSK, 16-QAM & 128-QAM). The PAPR is high in the downlink (OFDMA) compared to the uplink (SC-FDMA). High PAPR indicates the presence of a non-uniform or spiky power spectrum. This in turn indicates the higher power consumption in downlink transmission from the BS compared to uplink transmission from the MT.

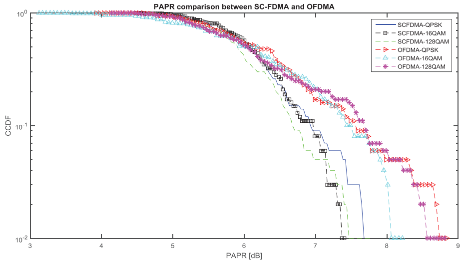

Fig. 4. PAPR comparison between uplink and downlink

C. BER Performance

Fig. 5 represents a bit error rate (BER) comparison between uplink (SC-FDMA) and downlink (OFDMA) for different types of modulation. The numbers of bits per symbol are 2, 4 and 7 in QPSK, 16-QAM and 128-QAM respectively. As apparent from Fig. 5, BER increases with increase in bits per symbol. But the compensation for the increased BER is the increase in data rate due to the use of 128-QAM as the principal modulation in this network.

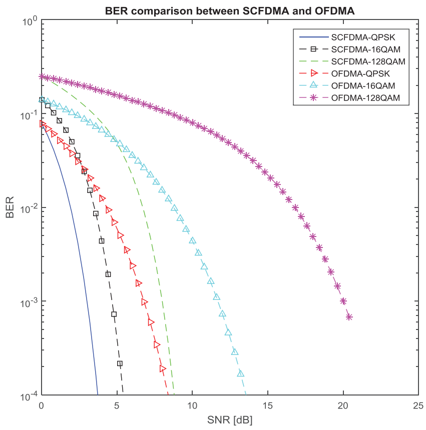

Fig. 5. BER comparison between uplink and downlink

D. Investigation of RSL

Fig. 6 represents an RSL comparison between uplink (SC-FDMA) and downlink (OFDMA) for different types of modulation. The received signal level is high in the downlink (OFDMA). As this signal is received by the MT, so the amount of required amplification decreases at the MT and thereby the power consumption is reduced. In Fig. 6, the RSL at 2 km distance from the BS is –80 dBm using 128-QAM, which denotes a good signal level at the MT. In the uplink, the RSL at 2 km distance from the MT is –100 dBm using 128-QAM, which represents a moderate signal level.

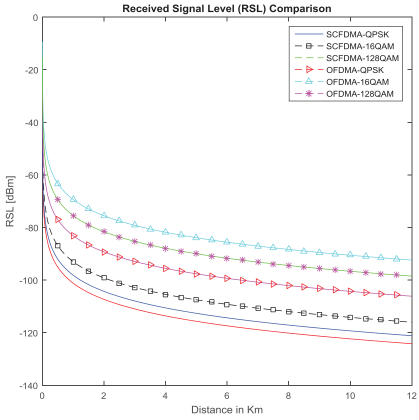

Fig. 6. RSL comparison between uplink and downlink

E. Capacity of the System

Fig. 7 represents a capacity comparison of the 3 different types of modulation: QPSK, 16-QAM and 128-QAM as a function of bandwidth. The Shannon's capacity theorem [27] has been used to estimate the network capacity. For all types of modulation, the increase in bandwidth increases the capacity. But this increase in capacity is much higher for 128-QAM than for the other two types. In Fig. 7, the capacity of 128-QAM is about 9.2 Giga bits per second (Gbps) and 9.7 Gbps for bandwidths of 5 GHz and 10 GHz respectively which is much higher compared to the proposed network in [28] that employs 16-QAM. This is the evidence of the high capacity of this designed mm-wave communication network.

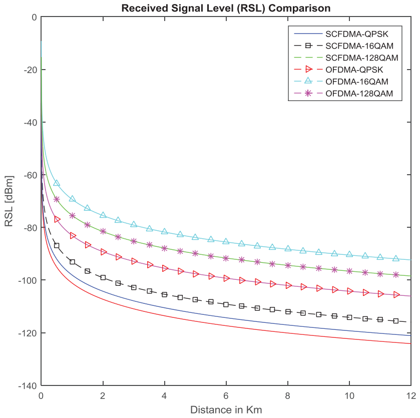

Fig. 7. Capacity comparison among different types of modulation with varying bandwidth

The contributions of the designed network have been summarized in Table 1.

TABLE I
COMPARATIVE RESULTS

Comparison Field	Present Network	Proposed Network
Symbol Rate	2.5 Gbps (max)	9.2 Gbps (max)
Coverage	200 m	About 2 km
Energy Consumption at MT	High	Low
RSL at 2 kilometers	≥ −107 dBm	≤ −100 dBm

V. Future Work

In this proposed network, the energy efficiency at the MT is only minimized. But a high power-consumption problem arising at BSs resulting from high PAPR needs to be reduced. Besides the 5G network will have to coincide with the other networks like 2G, 3G and 4G as heterogeneous environment. In future, the performance of the proposed work in such heterogeneous environment will be investigated.

VI. Conclusion

The overall path loss in E-band for the proposed network is quite low if compared to the other mm-wave bands as found in Fig. 3. OFDMA were used in the downlink communication for efficient spectrum utilization and SC-FDMA were used in the uplink to reduce the power consumption at MT. These objectives were assured as per the simulation result as evident in Fig. 4. Moreover, OFDMA and SC-FDMA provide enhanced system capacity. Meanwhile, 128-QAM outperforms the QPSK and 16-QAM and comes up with the highest data rate of about 9.2 Gbps. Adaptive beamforming antenna implemented using LMS algorithm efficiently performs beam-steering in the desired direction which in turn ensures high coverage area of about 2 km while existing network can cover only few hundreds of meters. Overall simulation results suggest that the proposed mm-wave network will be the most appealing candidate for the next-generation 5G network.

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