# SIMULATION APPROACH TO EVALUATE 5G MODULATION TECHNIQUE PERFORMANCES

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**ABSTRACT**

The main objectives of this article is to evaluate the performance of different modulation schemes in a 5G communication based on parameters like Bit Error Rate (BER), Peak to Average Power Ratio (PAPR),One-way delay, Spectral efficiency, through-put. The effectiveness of the 5G network in different areas was experimentally proved using various tools for simulation in MATLAB. The Quadrature Phase Shift Keying (QPSK), 16-QAM (16-Quadrature Amplitude Modulation), 64-QAM, and 256-QAM were investigated at the signal to noise ratios (SNR) ranging from -10dB to 20dB at 5dB intervals. The QPSK modulation technique provide the greatest performance with respect to BER, PARP, throughput and latency at the expense of spectral efficiency significantly due to modulation order. For moderate to high SNR, 256QAM shows great results but performance degrades with falling Signal to Noise Ratio and susceptibility to Inter Symbol Interference rises due to the shorter hamming distance. At the lowest SNR of -10dB, 256QA Modulation Technique shows possibly worst numbers – Bit Error Rate of 0.5006bps, almost 0% throughput with a maximum PAP ratio of 8dB, and One-way latency of 5.23ms. Finally, the 64QA modulation technique provides a balanced figures as far as Bit Error Rate, Throughput, Spectral Efficiency and other evaluating parameters are considered with respect to Signal to Noise Ratio of 5dB.

Keywords—Fifth-Generation (5G), Modulation, Signal to Noise Ratio, Bit-Error-Rate, Throughput, Spectral Efficiency, Peak-To-Average Power Ratio, One-Way Latency, QPSK, QAM.

## INTRODUCTION

With anticipation and prospective market trackers globally, Intense research and development of the Fifth-Generation Mobile Communications System (popularly known as 5G) has been launched with greatest enhancement of Next generation mobile communication systems in the 2020s. The properties of 5G mobile network are illustrated in Figure 1, by the corners of a triangle. Namely: enhanced mobile broadband (eMBB), ultra-reliable low-latency communication (URLLC), and massive IoT (also known as massive machine type communications, mMTC). Which includes improved transmission speed, fewer/reduced interruptions, and the connection of a large number of sensors and devices. Figure 2, provides overview of 5G usage scenarios, traffic models and various parameters as per IMT-2020.

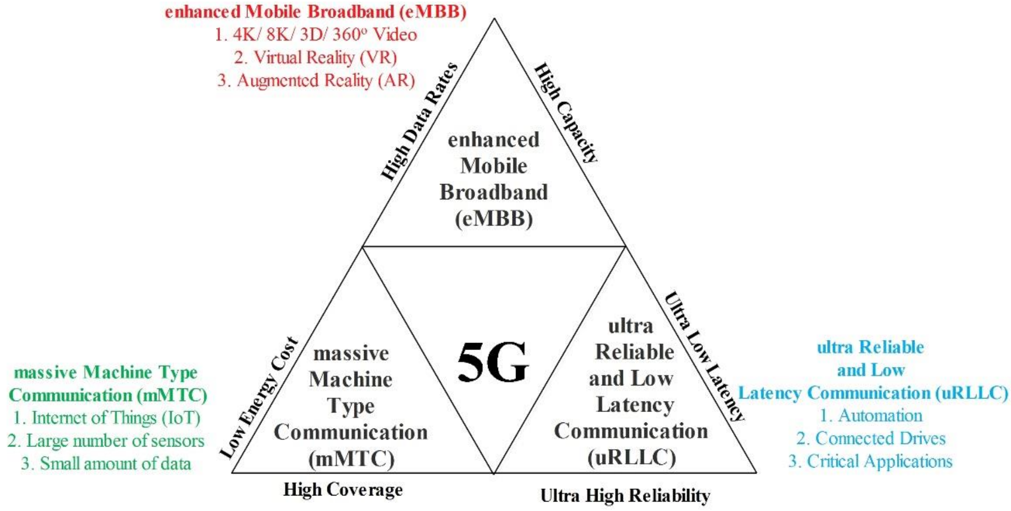


*Figure 1 Properties of 5G mobile network as per IMT-2020.*

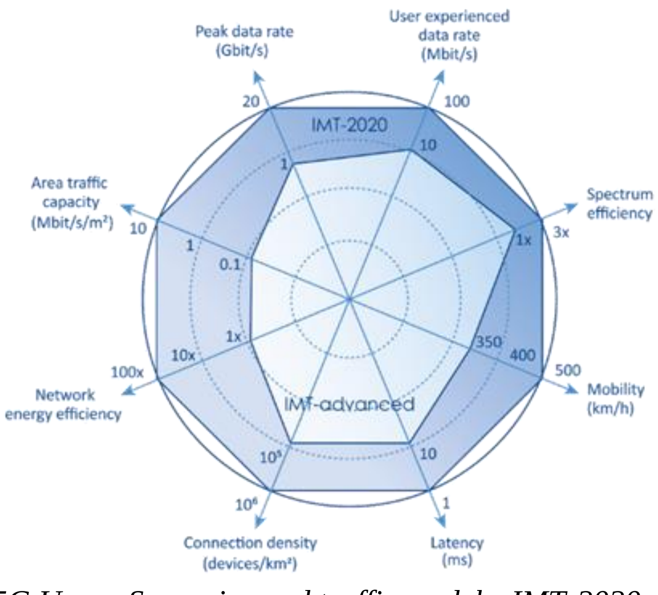


*Figure 2 5G Usage Scenarios and traffic models, IMT-2020 and Beyond.*

The fifth generation of mobile technology promises to be the fastest, reliable and most efficient technology to date delivered and it can turn human way of life drastically. Under different circumstances like geography, operating requirements, wireless communication provides different characteristics. For instance, in public transport system, the high mobility, fidelity features are vital, especially in high-speed trains; ultra-high traffic volume density and connections will characterize crowded and dense areas like marketplaces and stadiums [1]. Usually, Baseband modulation is a fundamental part of wireless communication system due to the effect it has on the BER, communication efficiency and power consumption feature. In baseband modulation, a group of bits is mapped to form a symbols by modifying the amplitude and phase characteristics of the signal. The number of symbols is dependent on the modulation scheme and determines the modulation order. Mathematically, the relationship between the constellation size and the number of bits per symbol is denoted as:

$$M=2^N \quad \text{...Equation – 1}$$

Where, M – denotes modulation order or constellation size based on modulation scheme and N – denotes the number of bits used to form symbols.

The high speed is a premier requirement of 5G network which can be achieved through a flexible modulation scheme and coding rate depending on the channel status. To increase the overall system capacity, small cells are to be adopted hence the need for more advancement in mm-wave communications [2], [3]. Mm-wave is applicable in short-range cellular communications which implies the availability of line-of-sight links, low Doppler effect, large bandwidths, and a stable environment for propagation. Simple modulation formats are more likely to be used at these high frequencies and large bandwidths [4]. There is a proposed massive interconnection of devices in the nearest future with the advent of the Internet of Things (IoT) [5], [6]. The huge number of devices will be transmitting short messages over the network which is likely to place a great burden on the network in power consumption and synchronization due to the massive signaling that will be going on. The 5G wireless system is expected to demonstrate low- latency targeted at a roundtrip delay of 1. This will enhance more robust real-time applications used in ultra-reliable and low latency communication [7].

In this article we will determine how the IMT 2020 requirements varies with the change in modulation scheme. Also, it will be demonstrated using empirical values that justify the fact that: Though, a modulation scheme might improve on one or more of the key performance indicators to be met by the 5G wireless network, but the same scheme might suffer some drawbacks when other performance metrics are considered. There is therefore a need to determine the most suitable modulation scheme for different scenarios of the 5G wireless technology use cases. The rest of the article is followed by related work on the effect of modulation schemes in a wireless network, discussion on models used to evaluate performance of 5G network, simulation results and finally concluding remarks with future scope.

## LITERATURE SURVEY

For different modulation techniques, the bit error rate (BER) for different levels of signal-to-noise ratio (SNR) for an LTE wireless system in an urban setting can be determined quantitatively. The comparative analysis for low-level correlation of Multiple Input, Multiple Output (MIMO) depicts a relatively low BER and a better BER at 10 MHz bandwidth for the LTE system [8]. There are various ways of improving the performance of wireless communication systems. Apart from the use of Adaptive Modulation and Coding in increasing network capacity or data rates, different channel estimation techniques can be used to improve the throughput of an LTE network. Considering the following channel estimation: Ideal Channel Estimation, Interpolation, averaging over each slot, and averaging over each sub frame. It can be deduced that in terms of BER performance, the ideal channel estimation topped the list followed by interpolation, averaging over each slot, and lastly averaging over each sub-frame. An upgrade to this work is to experimentally determine how the performance of the 5G wireless system can be improved by adapting different modulation schemes [9]. The four modulation schemes that have been used in the 5G wireless network are QPSK, 16QAM, 64QAM, and 256QAM. These modulation techniques all have their unique applications and relevance. The QPSK is characterized by a constant envelope while the QAM has a varying envelope. The envelope of the modulated signal can have greatly impacted the efficiency of the power amplifiers (PAs) used. When the envelope is non-varying, nonlinear PA is suitable but if the envelope is varying, then a linear amplification is needed. The inefficiency of the power amplifier is further worsened when the variation is high due to the increased PAPR of the signal modulated. The overall characteristic of the PA is therefore a determinant of the power consumed by the wireless system [10]. In a 5G system, there is a need for connectivity with high data rates, and more complex smaller cells to improve the overall efficiency. A modified QAM can also be used to improve efficiency. This modified QAM combines the frequency shift keying (FSK) and QAM to improve the overall channel capacity and also mitigate against Inter-Carrier Interference (ICI) at the cell edge. This modified QAM is called FQAM. The modulation scheme of the interfering signal determines the allocation of the ICI. Assigning ICI in a Quadrature Amplitude Modulated interfering signal takes the form of a Gaussian distribution especially when useful subcarriers are used up. In terms of channel capacity, the worst-case representation of additive noise in a wireless network is the Gaussian distribution. In scenarios where the interfering signal is FSK modulated, the ICI exhibits a high deviation from the Gaussian curve as shown in Figure 2.

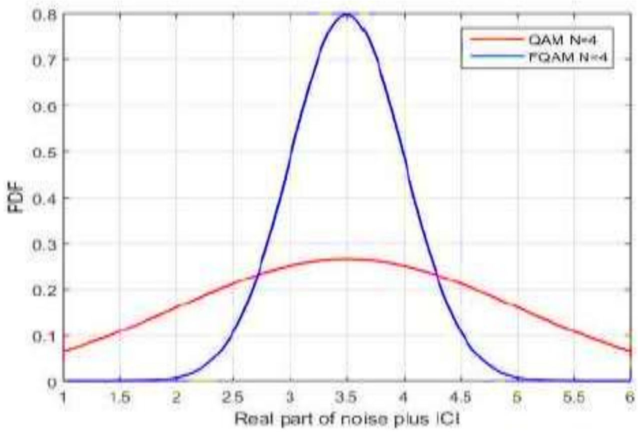


*Figure 3 The relationship between real part of ICI and FDF.*

In terms of BER and frame error rate (FER), the FQAM exhibits better performance than the QAM in terms of reduced interference. FQAM outshines QAM because FQAM has a better SNR per frequency component and allocates all power on a single active frequency component. On the other hand, power is assigned to the entire active frequency components in QAM [10]. Massive MIMO is one of the topologies proposed for 5G wireless communication to meet demand. The huge system is outfitted with a vast array of antennas at the base station that serves several single-antenna users at the same time making the number of transmitting antennae to be usually greater than receiving antennae. The benefits of massive MIMO may be realized if Channel State Information (CSI) is available at the base station and the downlink channels are characterized by orthogonality. The QR decomposition recursive least squares are one of such methods that can be used for channel estimation to improve the performance of the 5G wireless network [12]. A coordinated multi-point (CoMP) transmission approach can be employed in downlink multi-cell Non-Orthogonal Multiple Access (NOMA) systems while the distributed power allocation at each cell is taken into account. CoMP transmission is employed to provide consumers with good reception from several cells, while each cell uses NOMA for resource allocation separately. It increases power to the weak recipient, effectively utilizes the spectrum, and is compatible with traditional multiple access techniques [13].

## METHODOLOGY

### *5G link model*

MATLAB version 2019 is used to examine a downlink model with 8 transmitting antennae and 2 receiving antennae. Amongst the 15, 30, 60, 120KHz subcarrier spacing (SCS), 30KHz is selected for experimental simulation. As shown in Figure 4, Codes are gerated by adding successive blocks which are generated by grouping message bits and CRC bits are added as overhead. These PDUs are then delivered to the physical layer.

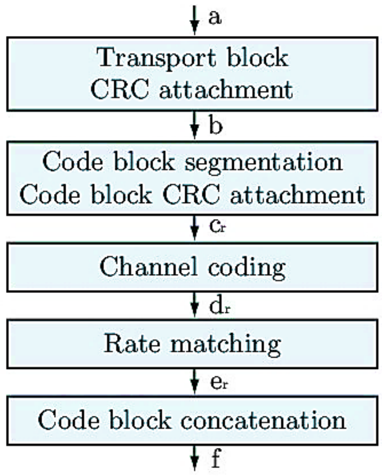


*Figure 4 DL-SCH Processing Channel.*

At physical layer modulation and mapping is carried out. The pre-coded symbols are then prefixed by CRC code before undergoing orthogonal frequency division multiplexing (OFDM). These symbols are then transmitted over channel with white Gaussian Noise. For the model, the timing synchronization is assumed to be ideal.

### *Propagation Channel*

For simulation purpose 24 multipath fading channel used each modelled with a finite-impulse-response (FIR) filter. The channel response is given by Equation (2) and shown in Figure 5 below.

$$h(t,\tau) = \sum_{i=1}^{N} c_i(t)\delta(\tau - \tau_i)$$

$where\ N\ is\ the\ number\ of\ coefficients,$
$\tau_i$ are the delay values ... Equation – 2

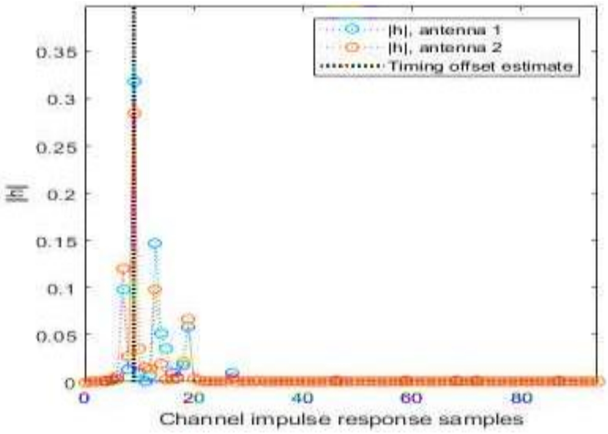


*Figure 5 Channel Impulse Response.*

In the modeling of the multipath fading channel with impulse response shown in Figure 5, The 95 samples obtained are a combination of the effect of 24 linear finite- impulse response (FIR) filters, shown in equations (3) and (4).

$$y_i = \sum_{n=-N_1}^{N_2} s_{i-n} g_n$$

... Equation – 3

$$g_n = \sum_{k=1}^{K} a_k sinc[\tau_k f_s - n], \ -N_1 \leq n \leq N_2$$

... Equation – 4

$$sampling\ rate, f_s = \ N_{FFT} \times SCS$$

$$= 1024 \times 30\ kHz = 30.72\ MHz\ .$$

The sampling rate of 30.72 MHz in discrete-time environment used in the model and simulation translates to a subcarrier spacing, Δf of 30Khz in the analog domain sums up the total number of K=24 $a_k$ is the complex path gain $\tau_k$ is the path delays $g_n$ sums up the total 24 FIR path filters used to model the frequency-selective multipath fading channel.

***Performance Metrics***

The performance metrics listed below are examined in the model.

i. *Bit Error Rate (BER)*

It is the measure of probability that a transmitted bit is received incorrectly because of noise, this is measured by comparing the pseudorandom bits generated at the source using MATLAB random generator with decoded bits at the receiver.

$$BER = \frac{NErr}{NBits}(bps)$$ ... Equation – 5

*ii. Throughput*

The throughput is the rate of successfully delivered data over a communication network measured in bps. For every network channel, there is a maximum amount of data that can be transmitted successfully which is dependent on the channel's bandwidth.

$$\eta = \frac{R_c N \zeta_g \log_2(\mathcal{M})}{T_s}\left(\frac{b}{s}\right)$$ ... Equation – 6

Where Rc is the code rate, N is the number of subcarriers, tg <1 is inefficiency due to possible guard bands, M is the cardinality of modulation and Ts is the sampling time.

*iii. Spectral Efficiency*

It is the rate of successfully transmitting data over a given bandwidth. Given a band's limited frequency, it defines how efficiently the frequency band can be utilized. It is proportional to the throughput and has a simple mathematical relationship.

$$\xi_{eff} = \frac{\eta}{BW}\left(\frac{bps}{Hz}\right)$$ ... Equation – 7

**Where BW is the bandwidth*

*iv. Peak-to-Average Power Ratio*

The complementary cumulative distribution function is the statistical tool used to determine the probability that a variable X or a distribution function of X, takes on a value greater than x. Mathematically,

$$F'(x) = 1 - \Pr[X \leq x]$$ ... Equation – 8

*For continuously distributed samples,*

$$F'(x) = 1 - \int_{-\infty}^{x} f(\mu)d\mu$$ ... Equation – 9

*For discrete samples,*

$$F'(x) = 1 - \sum_{i=0}^{x} f(i)$$ ... Equation – 10

In a Matlab simulation environment, the object function computes the probability that the input signal's instantaneous power is at a specific level above its average power. The technique is useful in accurately describing the peak-to-average-power ratio, a study that is relevant in the choice of power amplifiers used in transmission and the overall energy efficiency of the system.

**RESULT**

Evaluating the modelling and simulation results, the performance metrics are obtained against the variation of the SNR from -10dB to 20dB for the selected modulation scheme. The outcome of this variation, its impact and application are discussed in this paper.

*i. Bit Error* Rate

The results of the link model as shown in Table 1 and Figure 6 shows QPSK provides the best link performance in terms of immunity to noise

TABLE I. SIMULATION RESULTS FOR BIT ERROR RATE (BER)

| *SNR (dB)* | *QPSK (bps)* | *16QAM (bps)* | *64QAM (bps)* | *256QAM (bps)* |
|---|---|---|---|---|
| **10.000** | 0.000 | 0.4982 | 0.5003 | 0.5007 |
| **-5.000** | 0.000 | 0.1334 | 0.4979 | 0.5006 |
| **0.000** | 0.000 | 0.0000 | 0.1284 | 0.5007 |
| **5.000** | 0.000 | 0.0000 | 0.0000 | 0.1418 |
| **10.000** | 0.000 | 0.0000 | 0.0000 | 0.0620 |
| **15.000** | 0.000 | 0.0000 | 0.0000 | 0.0000 |
| **20.000** | 0.000 | 0.0000 | 0.0000 | 00000 |

From the plot shown in Figure 6, an increase in constellation size increased the BER significantly. The 256QAM has the lowest immunity to noise and might not be suitable for transmission in a noisy channel.

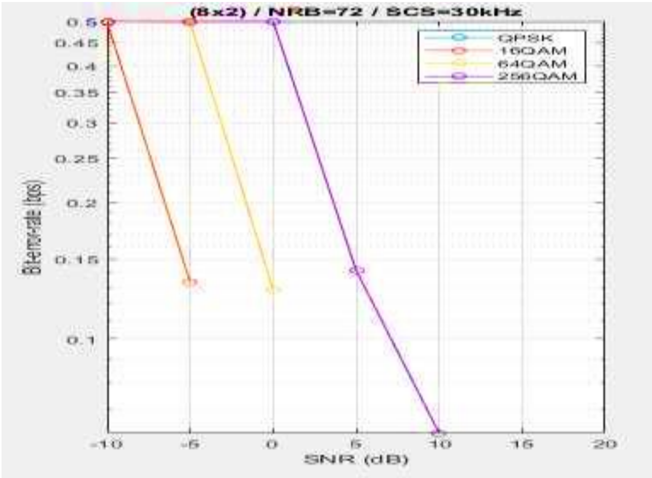


*Figure 6 Bit Error Rate Performance for QPSK, 16QAM, 64QAM and 256QAM.*

*ii.* *Throug*hput

The results from the simulation shown in Table 2, put the QPSK modulation technique above others. All 40 HARQ processes were successful, no retransmission was required. On the contrary, the number of retransmissions increases as simulation goes from QPSK to 256QAM although it was inhabited by the increase in SNR.

TABLE II. SIMULATION RESULTS OF THROUGHPUT

| *SNR (dB)* | *QPSK (%)* | *16QAM (%)* | *64QAM (%)* | *256QAM (%)* |
|---|---|---|---|---|
| **-10.000** | 100.0 | 0.0 | 0.0 | 0.0 |
| **-5.000** | 100.0 | 40.0 | 15.0 | 0.0 |
| **0.000** | 100.0 | 100.0 | 40.0 | 2.5 |
| **5.000** | 100.0 | 100.0 | 100.0 | 40.0 |
| **10.000** | 100.0 | 100.0 | 100.0 | 40.0 |
| **15.000** | 100.0 | 100.0 | 100.0 | 100.0 |
| **20.000** | 100.0 | 100.0 | 100.0 | 100.0 |

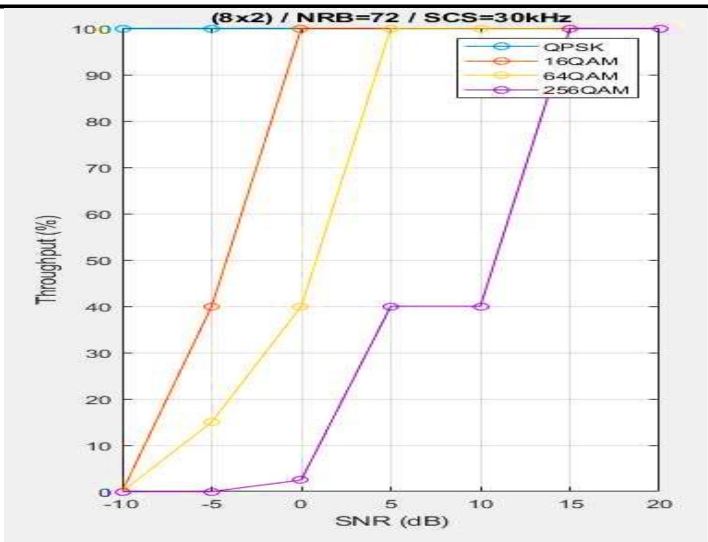


*Figure 7 Throughput Performance for QPSK, 16QAM, 64QAM and 256QAM.*

*iii. Spectral E*fficiency

In Table 3, QPSK is only able to transmit at a maximum rate of 34 bps for every 10kHz of bandwidth irrespective of the signal-to-noise ratio. On the contrary, with 256QAM, transmission can be done at 525bps for every 10kHz of the frequency band. This reduces the overhead incurred during transmission by a factor of 15. The 256QAM is also characterized by a high data rate because of its constellation size. Hence, making it suitable for enhancing mobile broadband (eMBB) deployment scenarios applicable to virtual and augmented reality, ultra-high definition (UHD) video, cloud computing, etc.

TABLE III. SIMULATION RESULTS OF SPECTRAL EFFICIENCY

| ***SNR (dB)*** | ***QPSK (bit/s/Hz)*** | ***16QAM (bit/s/Hz)*** | ***64QAM (bit/s/Hz)*** | ***256QAM (bit/s/Hz)*** |
|---|---|---|---|---|
| **-10.00** | 0.0034 | 0.0000 | 0.0000 | 0.0000 |
| **-5.000** | 0.0034 | 0.0069 | 0.0044 | 0.0000 |
| **0.000** | 0.0034 | 0.0172 | 0.0118 | 0.0013 |
| **5.000** | 0.0034 | 0.0172 | 0.0295 | 0.0210 |
| **10.000** | 0.0034 | 0.0172 | 0.0295 | 0.0210 |
| **15.000** | 0.0034 | 0.0172 | 0.0295 | 0.0525 |
| **20.000** | 0.0034 | 0.0172 | 0.0295 | 0.0525 |

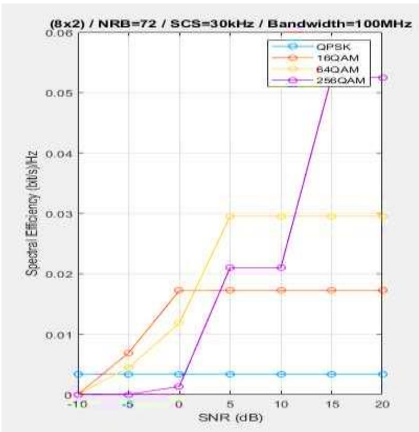


*Figure 8 Spectral Efficiency Performance of QPSK, 16QAM, 64QAM, and 256QAM.*

*iv. Peak to Average* Power Ratio

The CCDF curve shown in Figure 9 to Figure 12 depicts the percentage of time spent by a signal above a specific power level which is expressed in dB relative to the average power.

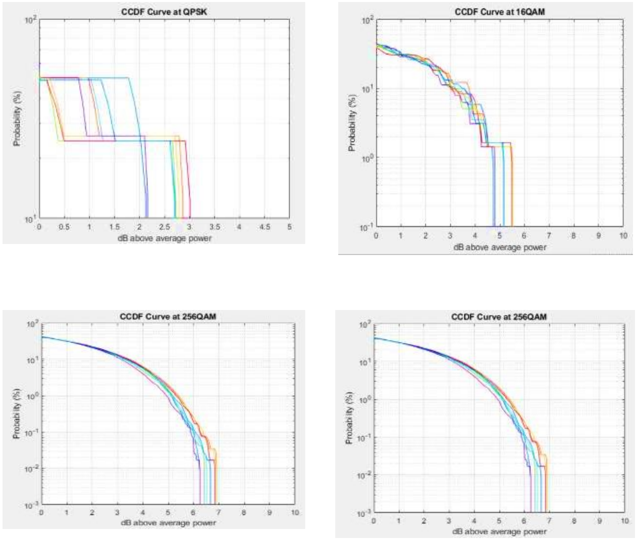


*Figure 9 PARP for various modulation schemes.*

A high PAPR also has a direct impact on the power consumption of PAs and consequently on the overall energy efficiency of the wireless network. Increased power consumption constitutes a drawback to massive machine-type communication (mMTC) in a 5G wireless network as it entails the interconnection of a large number of sensors and machines whose power consumption must be kept at a minimal level. In deploying mMTC, the QPSK might want to be the most preferred when considering PAPR only. Also, in mMTC, the required message size is not large which established further the appropriateness of adopting the QPSK symbol mapping as far as the device density and size of the transport block is of major concern.

## CONCLUSION AND FUTURE SCOPE

The Quadrature Phase Shift Keying modulation coding scheme provided the best performance at the poorest SNR of -15dB used in the simulation. It has a BER of 0.0bps, a throughput of 100%, one-way latency of 1.75ms. The major disadvantage is the poor bandwidth utilization at spectral efficiency of 0.0034 bps/Hz which is very small compared to a higher-order modulation scheme. It will definitely cost more in finance when QPSK is adopted in sending the same amount of information considering only the factors discussed above. Where there is a guarantee that the communication link is very good at an SNR of 20dB, the 256QAM with spectral efficiency of 0.0525bps/Hz will transmit a larger amount of information, thereby reducing cost and also delivering at the same latency of 1.75ms with QPSK. In this study, the OFDM waveform was used but poses a challenge of out-of-band emission. Although other signal processing techniques were applied to improve the performance of OFDM there is another proposed waveform like the pulse shaping technique. It can be adopted and the system studied to observe behavioral changes. In addition, the 5G system-level model can be simulated to measure the overall system latency and the effect of other network parameters on the performance of the network.

Also, different channel estimate also exists when SNR and baseband modulation was varied in the 5G model, further study can be carried out to see how dependent channel capacity is on these duo parameters.

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