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Efficiency Comparison of Different Modulation Scheme for 5G Application Using Simulation Approach

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***Abstract*—** The aim of this research is to investigate performance metrics such as bit-error-rate (BER), throughput, spectral efficiency, peak-to-average power ratio (PAPR) and one-way latency for the different modulation scheme used in a 5G wireless network. The Quadrature Phase Shift Keying (QPSK), 16QAM (16-Quadrature Amplitude Modulation), 64QAM and 256QAM were studied for signal to noise ratio (SNR) ranging from -10dB to 20dB at intervals of 5dB. It was experimentally demonstrated through MATLAB simulation that the efficiency of the 5G network in various aspects depends on the modulation coding scheme (MCS) used. The QPSK MCS exhibited the best performance in BER with 0 bps at all SNRs, throughput of 100%, PAPR of 3dB and one-latency of 1.75ms. However, it suffered a major drawback in spectral efficiency because of the small modulation order. The 256QAM might be the choicest of all considering its number of bits per symbol mapping when the SNR is around 10 to 15dB. However, it performs very poorly when the signal to noise ratio is low, largely due to the reduced hamming distance between the symbols, making it prone to Inter Symbol Interference (ISI). At the worst SNR of -10dB, 256QAM has a BER of 0.5008bps, 0% throughput, maximum PAPR of 7dB and latency of 5.25ms with a block error probability of 1. The 64QAM modulation scheme exhibits a good compromise at a reasonable SNR of 5dB. It has a BER of 0.0, achieves a throughput of 100% and a spectral efficiency of 0.0295 bps/Hz.

***Keywords*—**Modulation, fifth generation, performance, bit-error-rate, throughput, spectral efficiency, peak-to-average power ratio, one-way latency.

I. Introduction

The fifth-generation mobile communication system is aimed at building an economic, convenient and reliable interaction of information for humans. The increased use of wearable devices, the emergence of different types of mobile terminals and growing demands for inter-operability of the wireless system necessitated the inclusion of various features in the 5G mobile network.

In Figure 1, 5G mobile broadband properties can be illustrated distinctively by the three corners of a triangle as shown. Namely: enhanced mobile broadband (eMBB), ultra-reliable low-latency communication (URLLC), and massive IoT (also known as massive machine type communications, mMTC). This enhances transmission speed, fewer/reduced interruptions, and connection of a large number of sensors and devices.

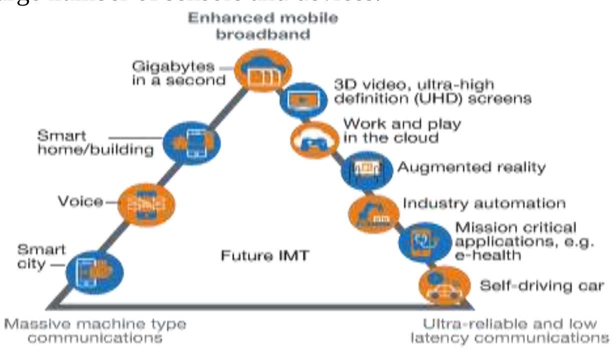

Figure 1:Usage Scenarios of IMT for 2020 and Beyond

There is an inter-twined relationship between 5G application scenarios and daily human activities. Under different use cases, wireless communication will exhibit different characteristics. In the transport system, the high mobility feature of wireless communication will be important, especially in high-speed train; ultra-high traffic volume density and connections will characterize a crowded and dense area like marketplaces and stadiums [1].

Baseband modulation is an integral part of any wireless communication system due to the effect it has on the error rate, spectral efficiency and energy efficiency. In baseband modulation, a group of bits are mapped into a set of complex valued symbols by modifying the amplitude and phase 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:

$$log_2M = N \#(1)$$

Where M and N are the modulation order and number of bits respectively.

There are some key requirements in a 5G cellular system which are dependent on the expected features. It will have to allow for a large data rate which can partly be accomplished through 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 an 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]. 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 ms. This will enhance more robust real-time applications used in ultra-reliable and low latency communication [7].

I.I Contribution statement

This research paper will experimentally determine how the major requirements highlighted above varies with the baseband modulation scheme used. Also, it will be demonstrated using empirical values that justifies 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.

Rest of the paper is organized as follows, Section I contains the introduction to baseband modulation in 5G, expected performance and applications. Section II contains related work on effect of modulation scheme in a wireless network. Section III briefly describes the methods used in modelling important parts of the 5G network and mathematical relations used in determining the performance efficiency of key indicators. Section IV discusses the simulation results obtained from MATLAB extensively and their adaptability to various 5G deployment scenarios. Section V concludes the research paper, states the assumptions and limitations of this work with future recommendations.

II. RELATED WORK

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 a 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 subframe.* 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 scheme [9].

The four modulation schemes been used in the 5G wireless network are: QPSK, 16QAM, 64QAM and 256QAM. These modulation techniques all have their own 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 a greatly impact 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 in the power consumed by the wireless system [10].

In 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 the efficiency. This modified QAM combines the frequency shift keying (FSK) and QAM to improve on the overall channel capacity and also mitigating 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.

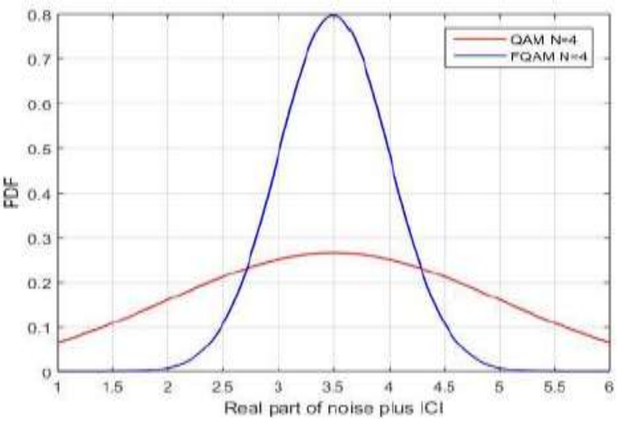

Figure 2:The relationship between real part of ICI and PDF [11].

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 [11].

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 serve several single antenna users at the same time making the number of transmitting antennae to be usually greater than receiving antenna. 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 is one of such methods that can be used for channel estimation to improve the performance of 5G wireless network [12].

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 compatible with traditional multiple access techniques [13].

III. METHODOLOGY

III.I 5G link model

A downlink model with 8 transmitting antennae and 2 receiving antennae was examined in MATLAB version 2019. Out of the subcarrier spacing (SCS) available in 5G, 30KHz is selected for simulation amidst 15, 30, 60, 120KHz SCS mode.

In the transport channel as depicted in Figure 3, message bits are grouped as transport block and appended with a fixed size check bit using generator polynomials in a process known as cyclic redundancy check. The CRC appended bits are then broken into layers depending on the size of the transport block. The resulting code blocks are channel coded using low density parity check (LDPC) technique. After channel coding, the code blocks are rate matched either by interleaving or puncturing, to utilize maximally the available resources on the resource grid. The layers of code blocks are then concatenated to form the codeword as shown in Figure 3. The Packet Data Units (PDUs) from the transport channel are delivered to the physical layer through the Physical Downlink Shared Channel.

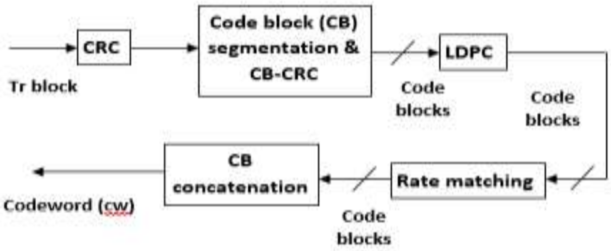

Figure 3: DL-SCH Processing Chain

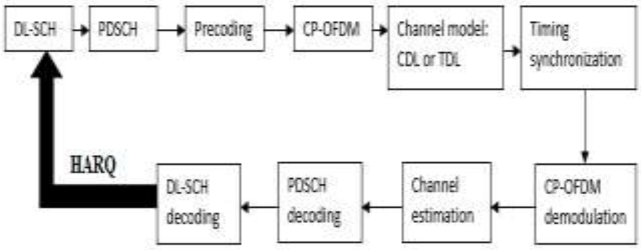

Figure 4:Downlink Structure for Link Model

In Figure 4, the codewords sent to the physical layer undergoes symbol mapping/modulation based on the required constellation size. The mapped symbol undergoes precoding for the purpose of maximizing received signal to a particular antenna while reducing interference with other antennae. Multiple beams are weighted by using the precoding matrix to achieve this.

The pre-coded symbols then undergo orthogonal frequency division multiplexing (OFDM) and a cyclic prefix is appended to the symbols which are now orthogonal. The symbols are transmitted over a frequency selective channel with additive white gaussian noise.

For the simulated model, the timing synchronization is assumed to be perfect. In the following, the theoretical and mathematical framework for the relevant part of the model is briefly reviewed.

III.II Model Resource Grid

The resource grid describes how the available bandwidth was shared between symbols. A total number of N_{frames} frames of 2 were transmitted each with a duration of 10ms, $N_{subframes,f}$ subframes of 10 and $N_{slots,s}$ slots per subframe of 2 for a SCS of 30kHz. 14 OFDM symbols make up a slot in 5G numerology standard.

$$N_{OFDM,F} = N_{frames} \times N_{subframes,f}$$
$$\ldots \times N_{slots,s} \times N_{symbols,sl} \#(2)$$
$$N_{OFDM,F} = 2 \times 10 \times 2 \times 14$$
$$N_{OFDM,F} = 560\ OFDM\ symbols$$

In 5G New Radio (NR), a resource block contains 12 subcarriers. Simulation using 72 resource blocks gives:

$$N_{subcarriers} = 72 \times 12 = 864\ subcarriers$$

The synchronization signals, reference signals, broadcast channel and physical channel are assigned to distinct symbols in the time domain at a range of frequencies.
All 14 symbols in the slot are allocated to various channels as listed below:

The physical downlink shared channel (PDSCH) occupies unutilized symbols and subcarriers in the resource grid while PDSCH-Demodulation Reference Signal (DMRS) occupies all subcarriers in symbol 3.

Symbol 4 to 7 and 8 to 11 carries a combination of the synchronization signal block (SSB) and physical broadcasting channel (PBCH). A block consists of SSB and PBCH. Summarily, the SSB is made up of 240 subcarriers and 4 symbols. The resource allocation of the model is shown in Figure 5.

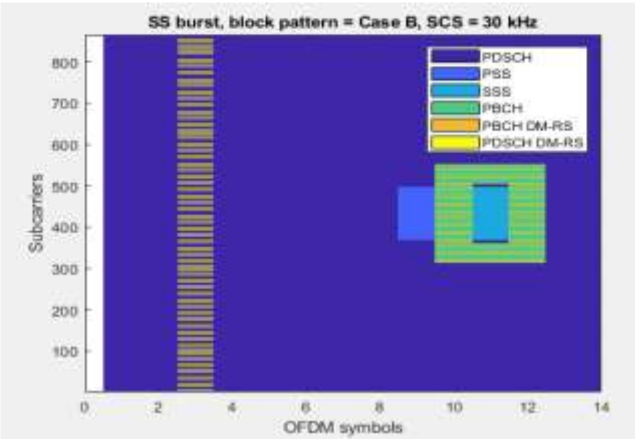

Figure 5: Simulated Resource Block Allocation

SS block appeared on the 8th symbol of the 14 symbols in a slot transmission. This meets the requirement of [0 1 0 1] for the SS burst block pattern. At the 4th symbol, the SS block is not transmitted as it is turned off in the transmission scheme. In the simulation, a new SS burst is transmitted after 20 successive HARQ process. Each HARQ process, transmits 14 symbols (i.e., 1 slot) at time with a duration of 0.5ms. For 20 successive HARQ processes, the total time duration is 20×0.5ms=10ms, which is the SSB periodicity.

III.III Propagation Channel

The multipath fading channel used in the simulation consists of 24 paths each modelled with a finite-impulse-response (FIR) filter. The channel impulse response is illustrated in Figure 6 below and represented by equation (3).

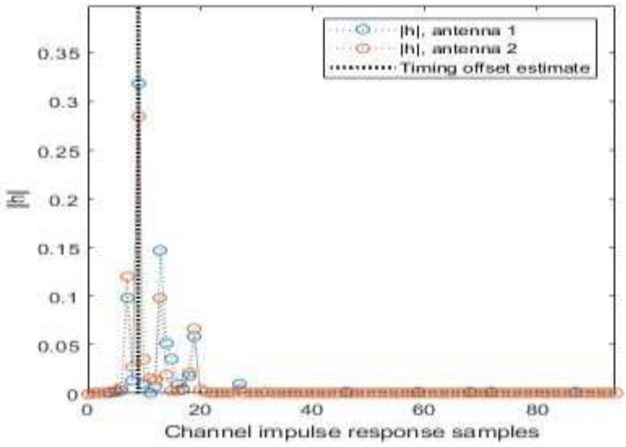

Figure 6: Channel Impulse Response

$$h(t,\tau) = \sum_{i=1}^{N} c_i(t)\delta(\tau - \tau_i) \quad \#(3)$$

$where\ N\ is\ the\ number\ of\ coefficients,$
τ_i are the delay values

In the modelling of the multipath fading channel with impulse response shown in Figure 6, *The 95 samples obtained are a combination of the effect of 24 linear finite-impulse-response (FIR) filter,* shown in equation (4) and (5)

$$y_i = \sum_{n=-N_1}^{N_2} s_{i-n} g_n \ \#(4)$$

$$g_n = \sum_{k=1}^{K} a_k sinc[\tau_k f_s - n],\ -N_1 \le n \le N_2 \ \#(5)$$

$$sampling\ rate, f_s = N_{FFT} \times SCS$$
$$= 1024 \times 30\ kHz = 30.72\ MHz\ .$$

The sampling rate of $30.72\ MHz$ in discrete time environment used in model and simulation translates to a subcarrier spacing, $\Delta f\ of\ 30\ kHz$ in the analog domain

$total\ number\ of\ paths, K = 24$
$a_k\ is\ the\ complex\ path\ gains$
$\tau_k\ is\ the\ path\ delays$

g_n sums up the total 24 FIR path filters used to model the frequency selective multipath fading channel.

III.IV Performance Metrics

The underlisted performance metrics were examined and implemented for the 5G model.

III.IV.I Bit Error Rate (BER)

It is the probability that a transmitted bit is incorrectly received as a result of noise, which is the number of errored bits divided by the total number of transmitted bits. This is measured by comparing the pseudorandom bits generated at the source using MATLAB random generator $randi$ with decoded bits at the receiver.

$$BER = \frac{NErr}{NBits}(bps)\ \#(6)$$

III.IV.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.

$$\eta = \frac{R_c N \zeta_g \log_2(\mathcal{M})}{T_s} \left(\frac{b}{s}\right) \#(7)$$

Where R_c is the code rate, N is the number of subcarriers, $\zeta_g \leq 1$ is inefficiency due to possible guard bands, $\mathcal{M}$ is the cardinality of modulation and T_s is the sampling time

III.IV.III Spectral Efficiency

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

$$\xi_{eff} = \frac{\eta}{BW}\left(\frac{bps}{Hz}\right) \quad \#(8)$$

Where BW is the bandwidth

III.IV.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,

$$F'(x) = 1 - \Pr[\mathrm{X} \leq \mathrm{x}] \ \#(9)$$

For continuously distributed samples,

$$F'(x) = 1 - \int_{-\infty}^{x} f(\mu) d\mu \ \#(10)$$

For discrete samples,

$$F'(x) = 1 - \sum_{i=0}^{x} f(i) \ \#(11)$$

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

III.IV.V One-way latency

The one-way latency is expressed in terms of error probability, p of the first Hybrid Automatic Repeat Request (HARQ) transmission. Mathematically written as:

$$L = \left(\frac{1}{2} + p\right)(t_{eNB} + t_{UE} + 2TTI) \ \#(12)$$

The error probability, p can also be referred to as the block error ratio (BLER). t_{eNB} and t_{UE} represents the processing time of the base station and mobile equipment respectively. The TTI is the transmission time interval [14].

In 5G NR numerology, for a SCS of 30kHz used in the simulation, the OFDM symbol and CP duration are $33.3\mu s$ and $2.41\mu s$ respectively. This translates to an overall CP-OFDM duration of $35.71\mu s$. Utilizing 1 slot for a transmission time interval, TTI for 14 symbols, the duration is $(14 \times 35.71\mu s) = 0.5ms$.

IV. Results and Discussion

After the modelling, evaluation and simulation of the 5G link, the performance metric as indicated in the objectives were obtained against the variation of the signal-to-noise ratio from -10dB to 20dB for the selected modulation scheme of QPSK, 16-QAM, 64-QAM, 256-QAM. The outcome of this variation, its impact and application are discussed in this paper.

IV.I bit error rate

The results of the link model as shown in Table 1 and Figure 7 shows QPSK provides the best link performance in terms of immunity to noise.

Table 1: Simulation Results of BER

SNR (dB)	QPSK (bps)	16QAM (bps)	64QAM (bps)	256QAM (bps)
-10.000	0.000	0.4981	0.5004	0.5008
-5.000	0.000	0.1334	0.4982	0.5005
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	0.0621
15.000	0.000	0.0000	0.0000	0.0000
20.000	0.000	0.0000	0.0000	00000

Form the plot shown in Figure 7, an increase in constellation size, increased the BER significantly. The 256QAM have the lowest immunity to noise and might not be suitable for transmission in a noisy channel.

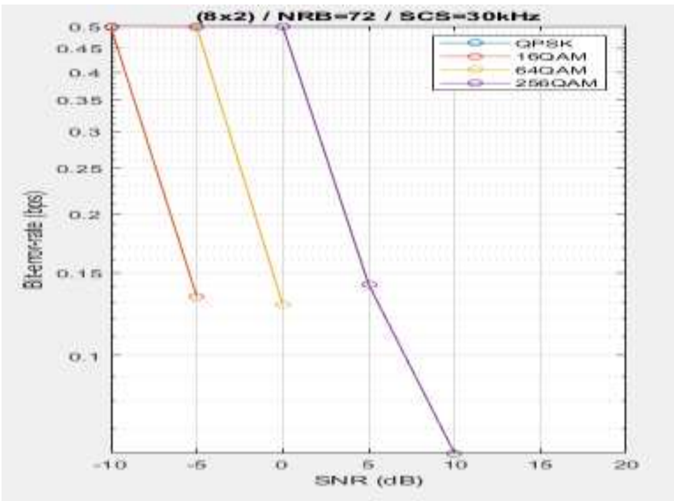

Figure 7: Bit Error Rate Performance for QPSK, 16QAM, 64QAM and 256QAM

It can be deduced that an increase in constellation size means a reduction of the distance between mapped symbols, this increases the chances of inter-symbol interference (ISI), and made worse by a noisy channel.

At the lowest SNR of -10dB used in simulation for QPSK, all bits were transmitted successfully without degradation. Apart from the various techniques adopted in the 5G wireless communication to reduce error, the high immunity to noise of the QPSK can also be linked to the low code rate of $^{193}/_{1024}$. The code rate of $^{193}/_{1024}$ signifies coding 193 bits of useful information with 1024 bits, making the forward error correction scheme very effective. Hence over a noisy channel like poor atmospheric condition, 5G can be better deployed using the QPSK symbol mapping or modulation scheme.
However, at SNR of 15dB, all mapped symbols are transmitted without errors as obatined in the 5G link model.

IV.II Throughput
The results from the simulation shown in Table 2, puts 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 inhibited by the increase in SNR.

Table 2: 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

An accumulation of all the retransmissions due to failed initial transmission can affect the time of arrival of all required information bits at the receiver. It also increases significantly power consumption, computational power and the throughput. At a threshold of 15dB, all modulation scheme measured up to an equal performance of 100% throughput. This is well illustrated in Figure 8 shown below.

The 5G ultra reliable and low latency communication (URLLC) needs to attain a ‘close to perfect’ reception rate of up to 99.999% while maintaining the latency at a reasonable rate with short length sensor data. The number of retransmissions should be considerably low and an extremely low BER less than 10^{-7}. These requirements make the QPSK modulation scheme suitable in this scenario as it guarantees a reliable and less error prone, information exchange between the transceiver. This scenario is targeted at V2X communications, smart grid, process automation etc.

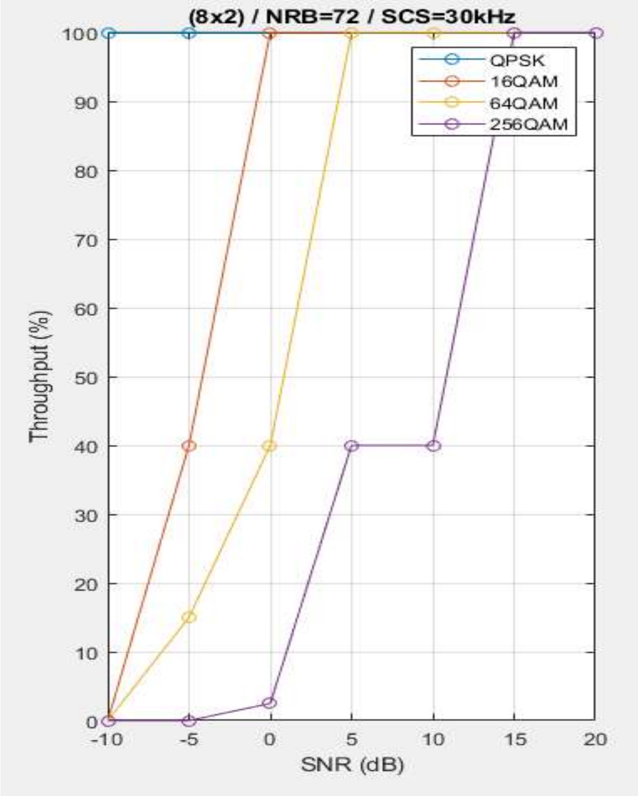

Figure 8: Throughput Performance for QPSK, 16QAM, 64QAM and 256QAM

IV.III Spectral Efficiency
In previous section, QPSK seems to excel in immunity to noise. However, there is a lot of bandwidth wastage in QPSK modulation scheme as shown in the code rate, where 1024 bits is used to represent the useful information bit. This incurs a lot of overhead in transmitting payload data over a channel.

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 frequency band.* This reduces the overhead incurred during transmission by a factor of 15. The 256QAM is also characterized by high data rate because of its constellation size. Hence, making it suitable in enhance mobile broadband (eMBB) deployment scenarios applicable to virtual and augmented reality, ultra-high definition (UHD) video, cloud computing etc.

Table 3: 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

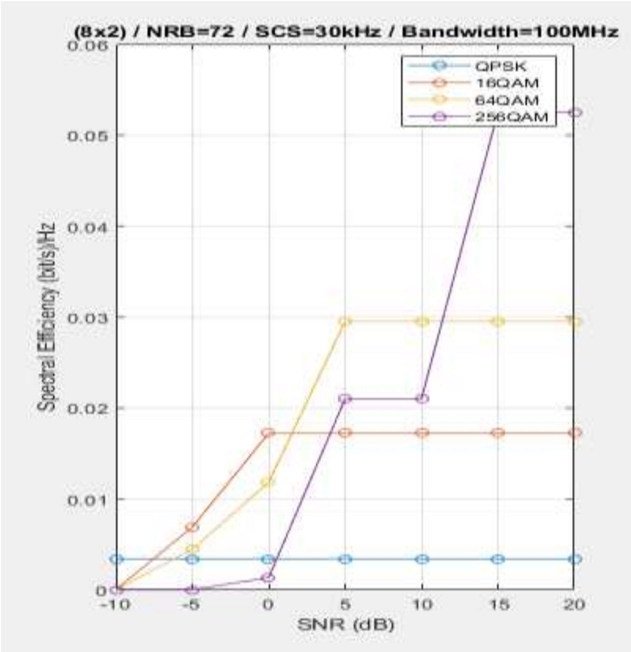

Figure 9: Spectral Efficiency Performance of QPSK, 16QAM, 64QAM and 256QAM

IV.IV Peak to Average Power Ratio

The CCDF curve shown from Figure 10 to Figure 13 depicts the percentage of time spent by a signal above a specific power level which is expressed in dB relative to the average power. It can otherwise be described as a plot of probability against the relative power level. This plot was obtained for the 8 transmitting antenna, each with similar characteristics. The QPSK CCDF curve as shown in Figure 10 has a lower deviation from the peak to average ratio at 3dB, while as we go further by increasing the modulation order, the CCDF curve shifts further to the right indicating a stressed signal.

A modulation scheme with large deviation has the tendency of placing undue power consumption on the power amplifiers and can affect the performance of the power amplifier considerably.

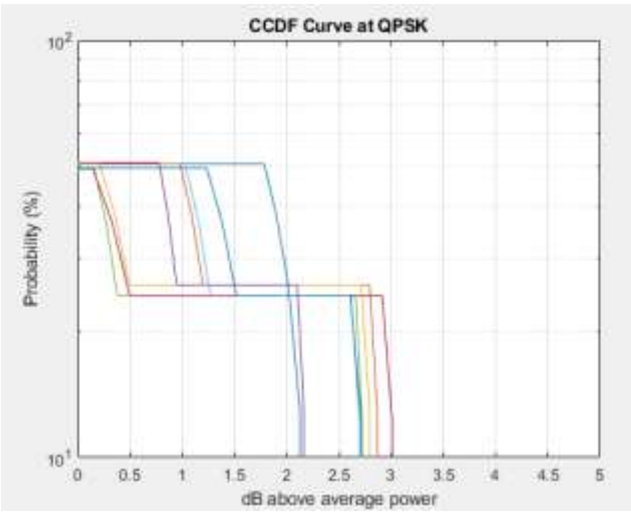

Figure 10: PAPR for QPSK

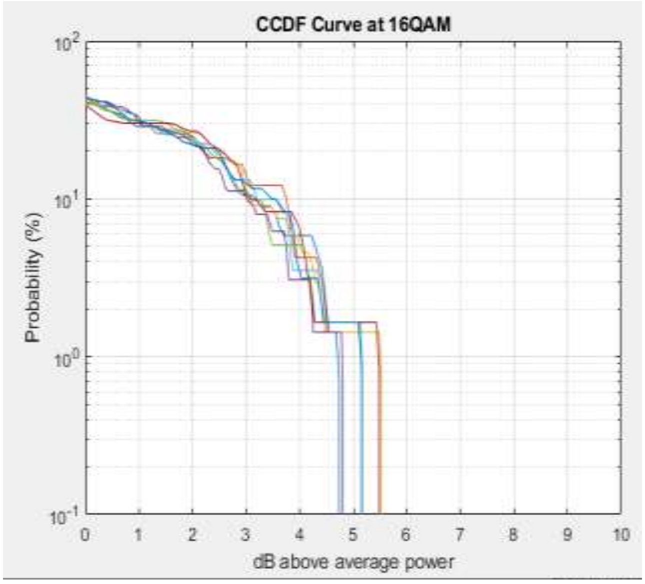

Figure 11: PAPR for 16QAM

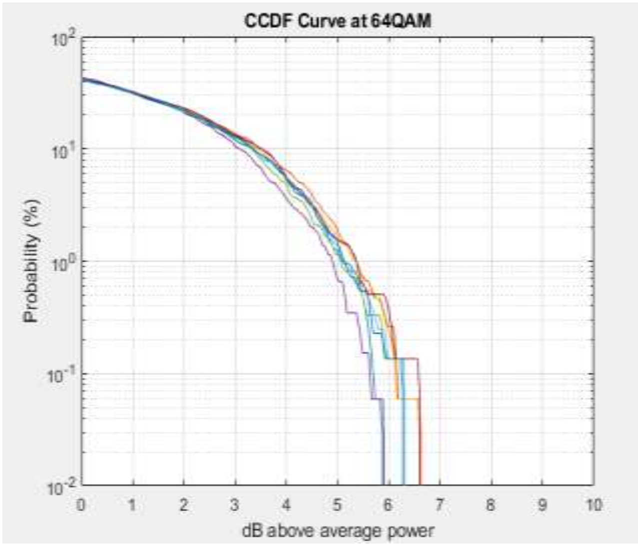

Figure 12: PAPR for 64QAM

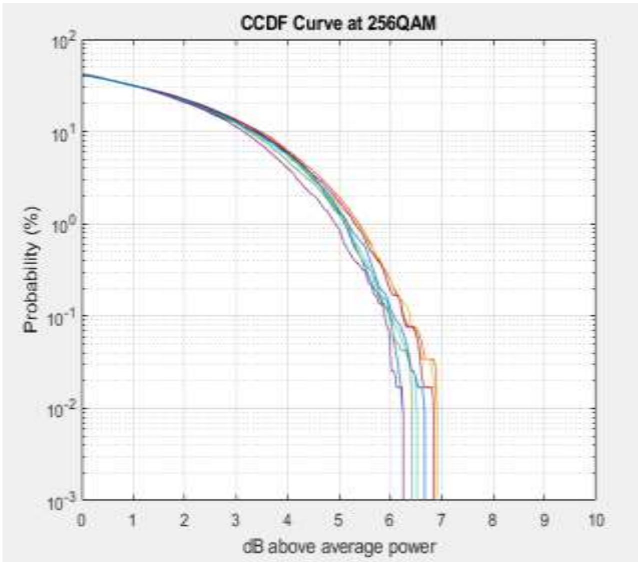

Figure 13: PAPR for 256QAM

A high PAPR also have 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 5G wireless network as it entails the interconnection of a large number of sensors and machine 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.

However, network performance is multifaceted and parameters cannot be determined using one criterion only. Designers will need to evaluate the requirement to be met and select the optimum modulation technique that will give the desired performance.

IV.V One-way latency

The simulation results as obtained in Table 4 depicts a reduction in the latency with increasing SNR.

Table 4: Simulation Results for Block Error Rate

SNR (dB)	**QPSK**		**16QAM**		**64QAM**		**256QAM**	
	p	L (ms)	p	L (ms)	p	L (ms)	p	L (ms)
-10	0	1.75	1.0	5.25	1.00	5.25	1.00	5.25
-5	0	1.75	0.6	3.85	0.85	4.73	1.00	5.25
0	0	1.75	0.0	1.75	0.60	3.85	0.98	5.16
5	0	1.75	0.0	1.75	0.00	1.75	0.60	3.85
10	0	1.75	0.0	1.75	0.00	1.75	0.60	3.85
15	0	1.75	0.0	1.75	0.00	1.75	0.00	1.75
20	0	1.75	0.0	1.75	0.00	1.75	0.00	1.75

Assume a processing delay of 1.5ms and 1ms for t_{eNB} *and* t_{UE} respectively, the one-way latency, $L = \left(\frac{1}{2}+p\right)(t_{eNB}+t_{UE}+2TTI)$ can be expressed as:

$$L = \left(\frac{1}{2}+p\right)\big(1.5+1+2(0.5)\big)ms$$

$$\Rightarrow L = 3.5(0.5+p)\ ms \ \#(11)$$

Where p is the error probability or block error ratio.

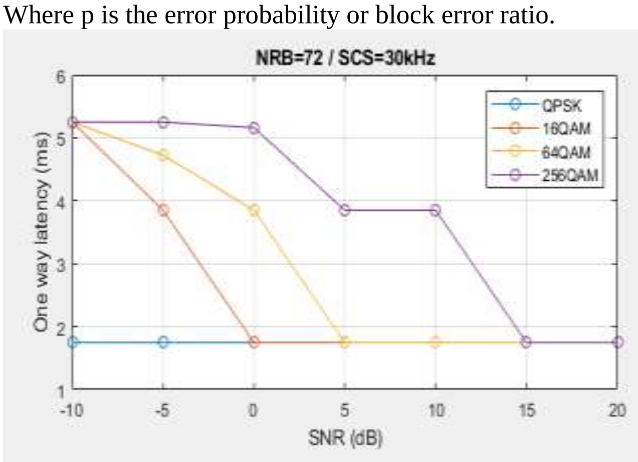

Figure 14: One-way Latency Comparison for QPSK, 16QAM, 64QAM and 256QAM

This effect on latency is largely due to the incremental redundancy- hybrid automatic repeat request (IR-HARQ) technique that was adopted in the 5G model. An errored block causes the receiver to send a no-acknowledgement (NACK) to the transmitter, the transmitter consequently resends the same information from the copy stored but in a different block using a different redundancy version.

The repetitive retransmission increases at lower SNR and higher modulation order. When the number of retransmissions increases due to error in the transport block, it lowers the latency. At zero error probability, the system has a one-way latency of 1.75ms which is the lowest but with a BLER of 100%, it can be concluded that there were no successful transmissions. The table and figure obtained in Table 4 and Figure 14 respectively for the latency was to relate how the number of HARQ retransmission can adversely affect the overall latency of the 5G wireless network.

Where the information to be transmitted is small and need for very low latency, the QPSK stands out as the most preferred modulation scheme to be adopted.

IV.VI 5G Deployment scenario

The 5G wireless network is designed to provides users with various services apart from having a better user experience. Various standards for IMT-2020 as specified for 5G and the summary of the relevance of different performance metric to the deployment scenarios are summarised pictorially in Figure 15 below.

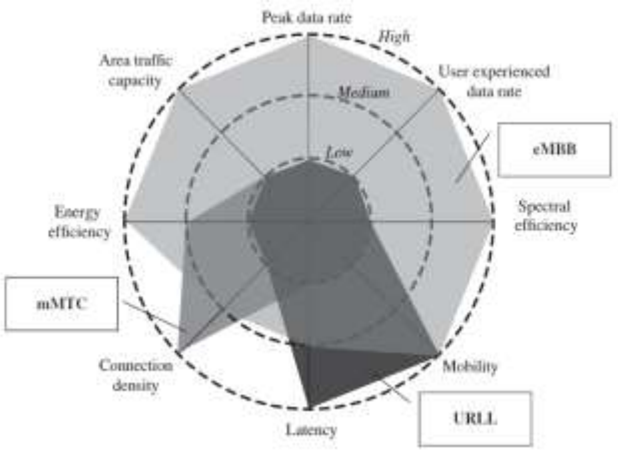

Figure 15: 5G Prioritized Requirement for Different Deployment

From the simulation results obtained, the 64QAM modulation scheme exhibits a good compromise between the three use cases highlighted above. At a reasonable SNR of 5dB, it has a BER of 0.0, achieves a throughput of 100% and a spectral efficiency of 0.0295 bps/Hz. The modulation technique next to 64QAM with a higher spectral efficiency of 0.0525 bps/Hz is the 256QAM but at a SNR of 15dB giving 64QAM an edge in immunity to noise compared to 256QAM.

Both 64QAM and 256QAM has a PAPR ranging between 6dB to 7dB on all the receiving antennae, hence provides little or no basis for comparison with respect to the PAPR as both exhibits nearly the same characteristics from the CCDF curve in Figure 13.

V. CONCLUSION AND FUTURE SCOPE

The Quadrature Phase Shift Keying modulation coding scheme exhibited the best performance at the poorest SNR of -15dB used in the simulation. It has a BER of 0.0bps, throughput of 100%, one way latency of 1.75ms. The major disadvantage is the poor bandwidth utilization at a spectral efficiency of 0.0034 bps/Hz which is very small compared to 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 a SNR of 20dB, the 256QAM with a spectral efficiency of 0.0525bps/Hz will transmit larger amount of information, thereby reducing cost and also delivering at 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 on the performance of OFDM but there is another proposed waveform like the pulse shaping technique. It can be adopted and the system studied to observe behavioural changes.

In addition, the 5G system level model can be simulated to measure the overall system latency and 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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