MEASUREMENT STUDY ON 5G NSA ARCHITECTURE OVER FADING CHANNEL

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ABSTRACT

The 5G NR network with the Non-Standalone (NSA) architecture aims to advance with regard to throughput. When compared to fourth-generation mobile communication (4G LTE), the 5G has a higher data exchange capability through the gNB and the UE (User Equipment). For evaluation and optimization, it is necessary to carry out practical studies on the behaviour of the system in different environmental conditions, subject to attenuation processes, such as large-scale fading (Shading) and small-scale fading (Multipath propagation). This work has analysed the effect of the MCS (Modulation and Coding Scheme) variation on Throughput/BLER for, initially, a channel degraded by default AWGN, then the analysis extends to the multipath fading effect, which emulates more realistically a mobile communication network. The analysis confirmed the need for robust decision process algorithms in terms of MCS switching to maintain adequate data rates according to the requirement of each scenario with specific QoS (Quality of service), considering both 64 QAM and 256 QAM. The throughput degradation effect was more evident in higher-order modulations due to the higher probability of error inherent in the symbol arrangement. This study can be a key for understanding and developing huge modulation and coding schemes for fifth generation communications.

KEYWORDS

5G, NSA, Fading, MCS, Throughput, Modulation, Coding scheme, BLER, Signal-Noise Ratio.

1. INTRODUCTION

The exchange of data at high transmission rates is a fundamental requirement of today's mobile networks [1], [2], encompassing ultra-high resolution video streaming, online gaming, among other services that require high demand for both downlink and uplink. The fifth-generation mobile technology, 5G New Radio (5G NR), has been widely implemented around the world to meet new requirements, naturally imposed by the advancement of telecommunications services. 5G emerges as the foundation for Enhanced Mobile Broadband (eMBB), Massive Machine-Type Communication (mMTC) and Ultra Reliable Low Latency Communication (URLLC) scenarios [3]. The initial implementation of the fifth generation network has been established initially following the NSA (Non-Standalone) architecture, which makes use of the LTE network as an interface for connecting 5G devices, adding greater throughput potential to the network [4]. This solution aims to save time and reduce costs for operators, since the entire LTE architecture already deployed serves as the core for the New Radio system. Fig. 1 illustrates the 5G Non-standalone (5G NSA) connection.

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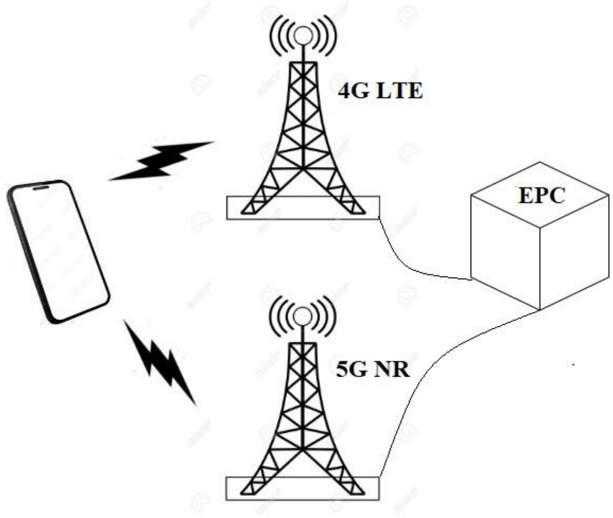


Figure 1. NSA Architecture

As standardized by the 3GPP (3rd Generation Partnership Project), in this type of configuration, the device (User Equipment) connects to both the LTE and NR networks, in the so-called Dual Connectivity (DC), in order to improve the total network coverage and increase the data rate. This mechanism is accomplished through the carry aggregation (CA) technique, in which two or more frequency bands are allocated on a single data channel to improve the network capacity. When Dual Connectivity is realized by joining an LTE band (sub 6 GHz) and an NR FR2 band (mmWave band), transmission rates can reach Multi-Gbps, combining the coverage power of the LTE band (lower frequency) and the high bandwidth capability FR2 (up to 400 MHz) [5], [6].

A more realistic analysis of a mobile wireless communication system is given by considering the Fading effect, which characterizes attenuations in the power level received by the mobile device as a consequence of the temporal variation inherent to mobility, causing harmful effects to the data transmission rate (throughput) due to the increase in block error rate (BLER) [7]. This work analyses the performance of a 5G NSA network under the effect of multi-path fading, characterized by an urban propagation scenario, varying basic parameters such as SNR levels and modulation and coding schemes (MCS). The data are obtained from measurements in a professional 5G laboratory, that provides a controlled environment, which certifies and validates the analysis.

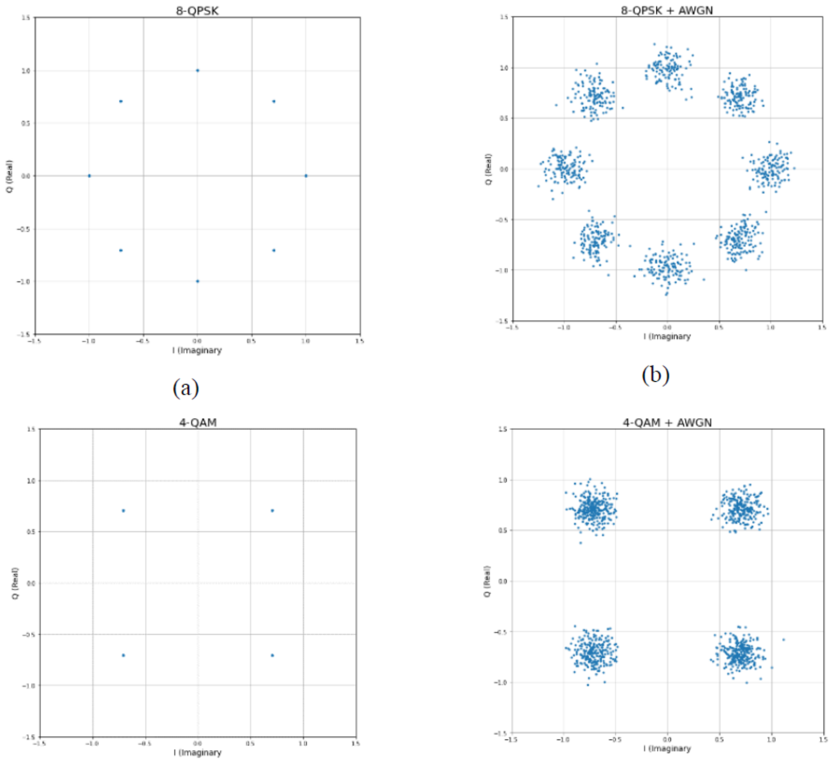
The work continues with the following division: Section II makes a brief theoretical discussion about AWGN and Fading and the effect on data transmission. Section III presents the lab setup and the measurement methodology. The collected data is analysed, compared and discussed in Section IV. Section V provides concluding discussions and perspectives on future work.

2. WIRELESS COMMUNICATION AND FADING CHANNELS

In wireless and mobile electromagnetic communication, the transmitted signal suffers several external interferences as it propagates through the medium. A basic and constant effect is the noise addition, which is well modelled using the AWGN model, which adds noise equally to all frequency components of the signal, simulating various random processes seen in nature. Another mechanism that is part of the propagation of electromagnetic waves is Fading, which considers the effect of multiple path copies of the originally transmitted signal [8].

2.1. AWGN Channel

The AWGN is a basic model of thermal noise that occurs naturally as the signal travels through the air. Its addition causes uncertainties in decision-making of digital signal demodulation. It is considered *white* because it equally affects the signal in its band (flat power spectral density). It is *Gaussian*, because its samples have a Gaussian distribution. Figure 2 compares the constellations of a random 1000-bit stream sent by 8-QPSK and 4-QAM modulated signals, showing the results with the presence of AWGN (Fig.2 (b) and (d) The simulations were performed using Python language.



(a) (b)

(c) (d)

Figure 2. Constellations under AWGN

When analysing figures 2(b) and 2(d), it can be seen that the uncertainty in the bit detection decision is increased as noise is added to the transmitted signal. High power of additive white Gaussian noise compromise data exchange, leading to low throughput efficiency. This situation can be minimized by increasing the transmission power or by using lower-order modulations, which have a greater spacing between the elements of their constellation, facilitating the correct bits demodulation.

2.2. Fading Channel

The receiver obtains and demodulates multiple copies of the signal sent by the transmitter. This process occurs by reason of the complexity of the propagation environment, which is time-varying and with the presence of several reflective and diffracting objects. Such copies can be received with relative time delays and with different spatial orientations (arrival angles at the receiver) and amplitudes. As a consequence, there will be random modulations in frequency, due to the Doppler Effect of each signal variant, time dispersion caused by the multipath propagation components and rapid variations (fluctuations) of the intensity of the final received signal, as this is the result of constructive and destructive combinations of copies [9], as illustrated in Fig. 3.

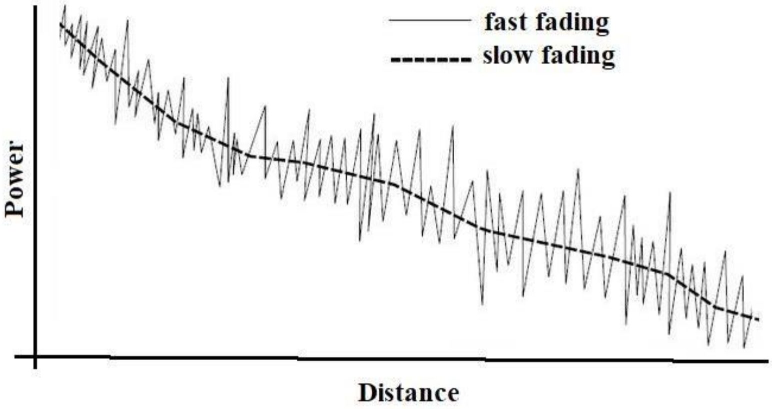


Figure 3. Fading effect

In the literature, statistical approaches are found that aim to model the fading effect on the channel according to propagation scenario. For mobile communications, the most adopted model is the Rayleigh model, applied to estimate propagation from multipath, when there is no direct line of sight (LOS) between transmitter and receiver. In this case, the response of the channel g on the multipath effect considering L paths is given according to Equation 1.

$$g = \sum_{i=1}^{L} \sqrt{\alpha_i}\, e^{\frac{-j2\pi(d_i - d)}{\lambda}} \tag{1}$$

Where α is the channel gain of path *i* and the exponential term refers to the phase shift of each path. When L is large, a statistical model must be implemented, because of the random channel gains and phase shifts. As the variables of Equation 1 are independent and identically distributed, a Gaussian distribution is a good approximation, according to the Central Limit Theorem, as shown in Equation 2.

$$g \approx N_c(0, \beta) \tag{2}$$

The *N* term indicates a complex distribution with mean equal to zero and variance β. The absolute value |g| has a Rayleigh distribution. The Rayleigh fading model can be applied to analyse radio propagation with a statistical basis. It operates best under conditions when there is no dominant signal (direct line of sight between transmitter and receiver). In many instances, mobile phones being used in a dense urban environment fall into this category.

3. SETUP AND MEASUREMENT METHODOLOGY

3.1. Setup

The Anritsu Measurement Setup used in this work makes it possible analysis with actual parameters standardized by 3GPP. By varying specific system variables, important KPIs (Key Performance Indicators) of the 5G can be verified [10]. The Anritsu module MT8000A builds and controls the 5G network and emulates the Fading effect over the NR, supported by a Server loaded with many fading profiles (3GPP standard). As a NSA architecture is been considered for this study, the 4G base stations and EPC (Evolved Packet Core) are controlled by a second MT8000A module. The RTD (Rapid Test Design) software is the graphic interface where the campaigns are developed and executed. The setup design is illustrated in Fig. 4.

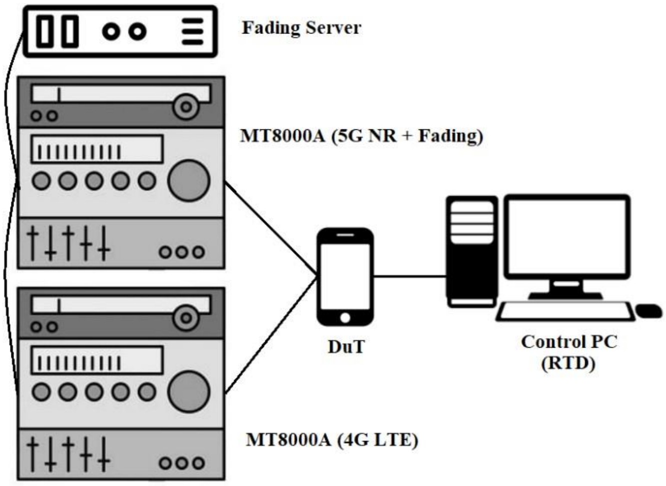


Figure 4. Measurement Setup

3.2. Methodology

In order to obtain samples, a measurement methodology consisting of a volume of data collected for statistical validation [11], then the treatment of such data is done. In this context, measurement campaigns were carried out, considering a NSA architecture. 5G NR supports QPSK, 16-QAM, 64-QAM and 256-QAM modulations, for this study, the last two are considered due to greater throughput capabilities. The campaign was defined in LTE band 1 (2100 MHz) with 20 MHz bandwidth and the n78 5G band (3500 MHz), considering 64/256-QAM modulation. The objective was to analyse the MCS variation effect in the 5G NR cell over throughput, with 100 MHz bandwidth, 30 kHz subcarrier spacing, 273 RBs (Resources Blocks) allocated and with a SISO scheme. Table I summarizes the parameters analysed in this article.

TABLE I. Campaign Parameters

Parameter	Value
Architecture	NSA
NR band/bandwidth	band n78 (3500 MHz)/100 MHz
LTE band/bandwidth	band 1 (2100 MHz)/20 MHz 11
LTE MCS	(64-QAM/fixed)
Resource Blocks	273
Modulation	64/256-QAM SISO
Transmission Mode	(1x1)
Fading profile	Suburban (static)

Data was collected according to the received power variation (SNR), from a bad quality channel (12 dB) to a good one (30 dB).

4. RESULTS ANALYSIS

Based on the measurement campaigns and the data obtained, it is possible to determine some analysis on the throughput metrics. There is a range of received power according to the network configurations, the objective is to measure how Throughput/BLER behave with the channel degradation, which can be used for estimating a threshold for specific QoS (Quality of Service).

Block Error Rate (BLER) is defined as the number of erroneous received blocks divided by the total number of blocks that was transmitted. The target BLER is typically about 10 percent for many application scenarios. If the BLER is larger than 10 percent (due to signal losses or interferences), the MCS must be switched to a lower value, providing a reliability communication, by making the BLER value stable (equal to or less than 10 per cent, in accordance with the application requirements).

The MCS is related to modulation and coding scheme. Digital modulation specifies how many bits can be transmitted in a symbol, which is defined as Resource Element (RE) and MCS defines how many useful bits can be transmitted per Resource Element. The higher order is the modulation, the more data is able to be transmitted, in the other hand, higher order modulation increases the probability of error. However, a Coding scheme is implemented according to the channel conditions, by adding redundant bits on data stream to enable error detection. A trade-off is that there is less useful bits in the transmitted blocks.

There are about 32 MCS Indexes (0 to 31). MCS Index 29,30 and 31 are reserved and used for re-transmission. The 3GPP Specification 38.214 has given three tables for MCS: 64-QAM Table, 256-QAM Table and Low Spectral Efficiency (Low SE) 64-QAM Table. The gNB instructs the UE to select a specific MCS table using a combination of RRC and Physical layer signalling.

64-QAM table may be used when gNB or UE does not support 256 QAM or in poor radio condition, where 256-QAM table is not decoded successfully. The 256-QAM table is allocated in good radio conditions. A specific table (Low SE 64-QAM) is used considering the Ultra reliable and Low-latency communications (URLLC) category, when applications need reliable data transfer, by reducing coding rate (increasing channel coding redundancy).

For this article, the campaigns were carried out considering the 256-QAM Table, which has 28 (0 to 27) defined indexes.

4.1. Analysis for AWGN Channel

First analysis is considered by applying the AWGN effect to the signal, emulating many random processes that occur in nature, such as the constant thermal noise, which is added to the signal in the propagation phenomenon by the motion of charged particles in conducted media. The AWGN effect is a good reference for the next section (Section B), where Fading will be introduced in the transmitted signal. Table II presents the statistical metrics related to measurements of Block error rate (BLER), MCS and SNR for campaigns with 64-QAM and 256-QAM modulations.

TABLE II. BLER *versus* MCS under AWGN

64-QAM		
MCS	BLER (SNR 15 dB)	BLER (SNR 25 dB)
11	0%	0%
15	20%	0%
19	50%	4%
256-QAM		
MCS	BLER (SNR 15 dB)	BLER (SNR 25 dB)
20	50%	3%
24	65%	32%
27	70%	50%

From Table II we can see that a higher order modulation produces higher BLER, mainly when a bad channel condition is considered. Note that a lower order modulation (64-QAM), due to the greater spacing between symbols, it provides a lower block error rate when compared to a higher order modulation (256-QAM), assuming similar channel qualities. This expected effect is better illustrated in Figure 5, which considers Throughput capability values (%) according to SNR variation for 64-QAM modulation.

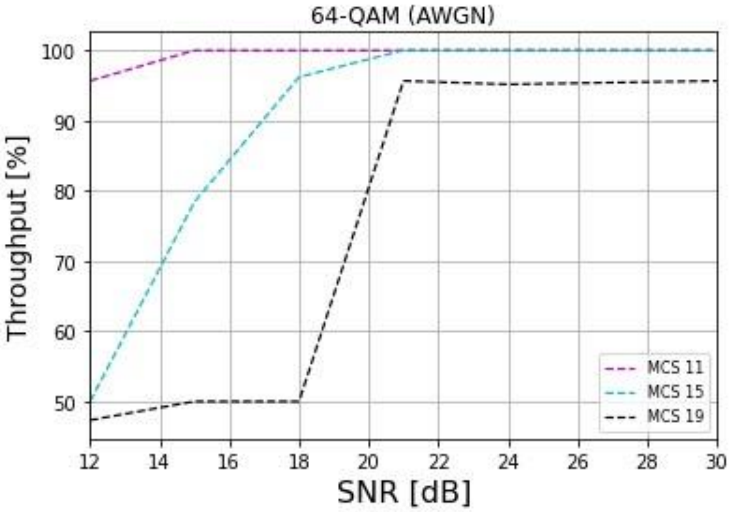


Figure 5. Throughput efficiency for 64-QAM (AWGN)

Note that throughput efficiency is directly related to the channel condition and the MCS index for the downlink. In this case, considering a low MCS (MCS 11), even under severe channel noise conditions, a throughput rate of more than 95 % can be achieved. The better the quality of channel, the less redundant bits need to be add for avoiding error detection.

As the SNR value increases, the probability of error reduces. Therefore, in good SNR conditions, a higher-order modulation can be scheduled for the user, increasing the throughput data rate.

Figure 6 shows the throughput behaviour for a 5G NSA network operating in 256-QAM modulation over an AWGN channel.

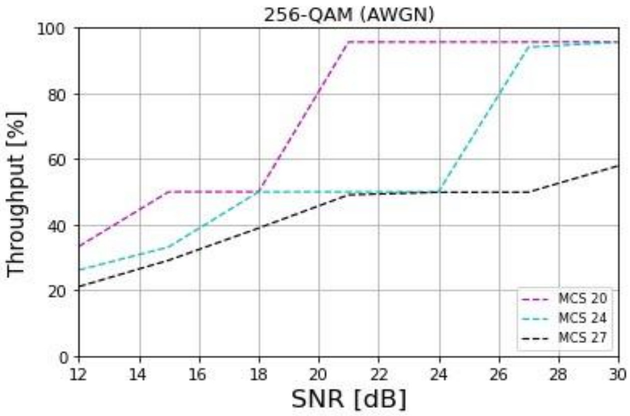


Figure 6. Throughput efficiency for 256-QAM (AWGN)

By analysing Fig.5 and Fig. 6, it can be noticed that the 256-QAM modulation, even providing a better throughput rate, is more susceptible to errors, when compared to the 64-QAM modulation scheme. For 256-QAM, even with good channel condition (SNR > 25), the MCS 27 is unable to deliver an acceptable BLER value (approximately 40%, in this case), which means that the coding scheme must be more robust, by allocating more redundant bits on the data stream to improve the throughput efficiency.

Next section the Fading effect will be studied over a 5G NSA network. The throughput response is analysed over the MCS variation.

4.2. Analysis for Fading Channel

The addition of Fading on the transmitted signal increases the error probability due to the small scale power oscillations. This causes poor performance in a communication system because it can result in a loss of signal power without reducing the noise power. This signal loss can be over a part of or all of the signal bandwidth. This can cause problems such as phase distortions and inter symbol interference in data transmission. The consequence is a higher BLER compared with the analysis made in Section A. This section shows the strong degradation over the signal considering an suburban fading profile.

Table III presents the campaign results for a 5G signal weakened for fading losses for 64QAM/256-QAM modulations and variable coding scheme (MCS).

TABLE III. BLER *versus* MCS under AWGN + Fading

64-QAM		
MCS	BLER (SNR 15 dB)	BLER (SNR 25 dB)
11	7.5%	0%
15	50%	1%
19	53.5%	24%

256-QAM		
MCS	BLER (SNR 15 dB)	BLER (SNR 25 dB)
20	61%	20%
24	70%	50%
27	77.5%	50.5%

By observing Table III it is clear the degradation of the transmission compared to the results presented in Table II, where only the AWGN was assumed.

Figure 7 shows the throughput rate efficiency over the fading channel for the 64-QAM modulation. While in the AWGN case (Figure 5). with SNR equal to 21 dB the 10 per cent BLER criteria was achieved, when fading was added the criteria is achieved only for about SNR around 30 dB. These values make clear the strong effect of fading over the signal propagation.

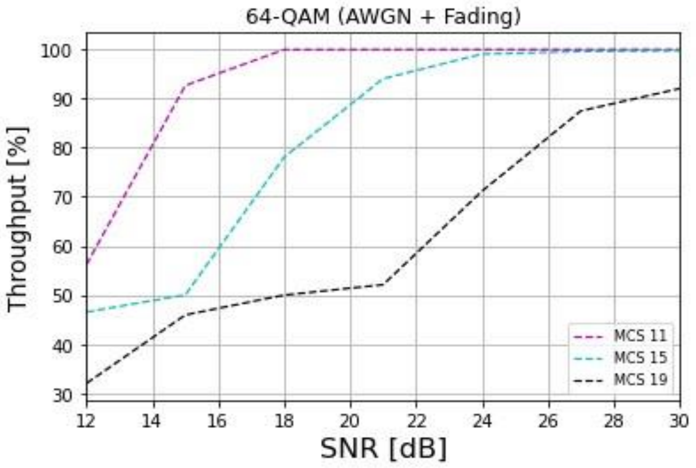


Figure 7. Throughput efficiency for 64-QAM (AWGN + Fading)

Similar to what was done in Section 4.1, campaign results for a higher-order modulation were analysed. The MCS variation comparison is illustrated in Figure 8. Because of its dense bits arrangement, the 256-QAM modulation over the considered fading must operate in very good SNR for providing an adequate BLER. Thus, for achieving a more efficient throughput, the MCS must be switched for a lower value regarding an acceptable BLER, according to the required QoS.

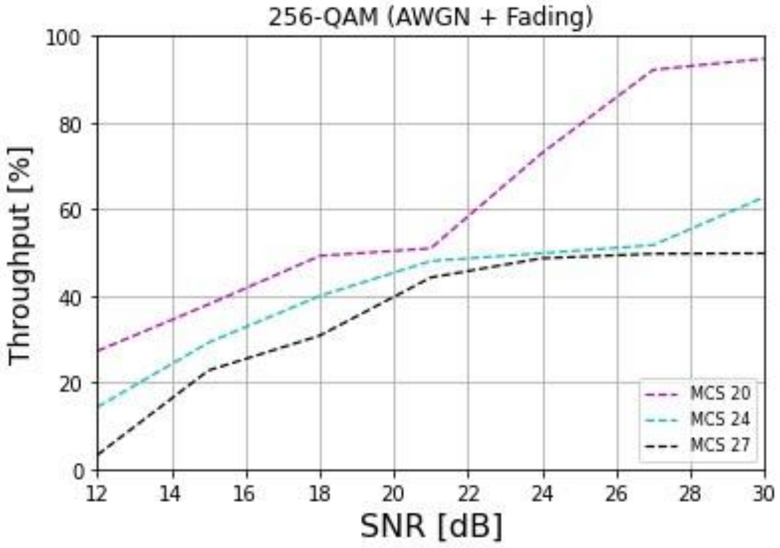


Figure 8. Throughput efficiency for 256-QAM (AWGN + Fading)

5. CONCLUSIONS

The present work aimed to study laboratory measurements about the influence of modulation and coding scheme over the throughput of an 5G NSA network, considering a theoretical scenario, with the effect of AWGN, and further analysis, in which effect of fading was added to the signal. A great difference was observed in the degradation of the signal even in good condition for the reception. Therefore, an efficient and well-modelled dynamically MCS switching is necessary for the better functioning of the network. Although generally, a BLER of 10\% or less is a target, certain conditions can show good functionality under higher values. It has been observed that users in good radio conditions or with high traffic utilization perform better with lower BLER Targets. Nevertheless, users in poor radio conditions or with small packets can perform satisfactorily with higher BLER. To deal with that, new MCS allocation models must be developed to meet specific throughput demands, according to each scenario.

In conclusion, for future work, other frequency bands in 5G, including the FR2 Band (mmWave band) will be studied in order to understand the behaviour of the network under fading and how strategies can be applied to optimize the system, such as the implementation of MIMO (Multiple Input Multiple Output) and proposals of MCS allocation algorithms according to specific applications.

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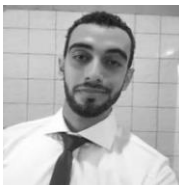

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