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Optimization of capacity in non-Gaussian noise models with and without fading channels for sustainable communication systems

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Abstract

The highest rate at which information may be reliably sent via a communication link is known as its capacity. In the case of non-Gaussian noise, the capacity of the channel depends on the specific characteristics of the noise, which can cause severe errors and reduce the reliability of communication systems over a fading channel. The Gaussian mixture impulsive noise model (GMINM), which is a more general and flexible non-Gaussian model for impulsive noise, has been compared in this paper with the Middleton Class-A impulsive noise model (MCAINM) in terms of derived channel capacity normalized by channel bandwidth (C/BW) with and without Rayleigh fading (Rf) channels. It also investigated the trade-off between complexity and accuracy in modeling the impulsive noise using two simplified Middleton Class-A impulsive noise models based on derived C/BW. The derived C/BW of these models under various conditions, such as different signal-to-noise ratios and impulsive noise parameters and models, have been performed and evaluated using two different scenarios: the exact method and the semi-analytical method. When the impulsive noise parameters α and A are both near 0 in GMINM and MCAINM, respectively, the capacity of the impulsive noise channel is found to be equivalent to that of the Gaussian channel sustainable, as shown by the findings based on Monte-Carlo simulations. We have shown that when the impulsive noise decreases, the capacity increases in all models; however, the capacity of Gaussian noise is higher than the capacity of non-Gaussian noise, which in turn is higher than the capacity of non-Gaussian noise over the Rf channel overall values of SNR in dB. Moreover, multi-channel configuration introduces spatial diversity and multiplexing gains that have been proposed to sustainably optimize the ergodic capacity for the challenge case when the channel state information (CSI) is unknown at the transmitter in non-Gaussian noise over Rf channel. In today's rapidly evolving world, sustainable communication systems play a crucial role in ensuring efficient and responsible utilization of resources. As the demand for wireless communication continues to rise, it becomes imperative to optimize the capacity of communication channels, especially in scenarios involving non-Gaussian noise models and fading channels.

Keywords: Non-Gaussian Noise Models, sustainability of Capacity, Optimization, Sustainable Communication Systems, Efficiency, Reliability.

1. Introduction

In recent times, one of the issues that has attracted the attention of researchers and industry professionals is source transmission over wireless networks. To this end, many works done in this area have proposed ideas related to cross-layer design techniques [1] with the aim of improving the physical, link, and network layers through a collaborative optimization framework. More so, some researchers have shown theoretic interest in contrasting source and channel diversity under different channel sustainable characteristics [2], as well as the evaluation of source fidelity across a multipath channel [3]. A communication system's capacity can be described as the highest amount of and sustainability information that can be dependably transmitted over the channel. There is a wide range of variables that influence a communication system's capacity. These variables include the kind of modulation scheme, the bandwidth of the channel, the coding scheme, and noise characteristics. Typically, if the state of the channel is known [4] or unknown [5], the capacity of the communication system is calculated for channels that have been affected by Additive White Gaussian Noise (AWGN), while other sources of noise, like human activity, industrial noise [6], and network interference [7], are not given attention (or impulse noise). Impulsive noise is a short bust of interference that occurs at a high amplitude, interfering with the communication channels. This kind of noise disrupts the transmitted signal. The capacity of a communication channel refers to the maximum rate at which the transmission of reliable information can be performed over the channel without error. The usual way of measuring it is in bits per second (bps) or by using a similar unit of measurement. The channel capacity can be significantly affected by impulsive noise in the channel of communication. More so, errors can be introduced to the received signal by impulsive noise, which in turn causes the performance of the communication system to degrade. In other words, the performance of a communication channel is reduced by impulsive noise. When a channel of communication is exposed to impulsive noise, the capacity of such channel will be determined by characteristics of the noise like duration, statistical properties, and amplitude [8, 9]. In the presence of impulsive noise, which is characterized by short bursts of high-energy interference, significant reduction can occur in a communication system's capacity. The transmission of data can be negatively affected by the errors caused by impulsive noise, thereby, degrading the quality of the communication system. MCAINM (Middleton Class-A Impulsive Noise Model) is a type of impulsive noise that may be present in communication systems [10]. This kind of noise is usually recognized by a heavy-tailed probability distribution, implying that there is a greater possibility that it could produce large amplitude noise as compared to other kinds of noise. The channel capacity of a communication channel which is exposed to MCAINM, can be determined through the use of Markov chain [11]. Upon completion of simulations with various values for the parameters that characterize the GMINM, and simplified MCAINIM models MCAINM, it was found that the channel's capacity was equivalent to that of AWGN channel for $A \geq 10$. In comparison with a channel that is characterized by additive white Gaussian noise (AWGN), an increase occurs in the capacity while the impulsiveness of noise reduces. The MCAINM is the main source of errors and, therefore, leads in the underperforming of communication systems. The effect of the non-partialness can be measured through the calculation of the systems' average output in the case of MCAINM. That of the average capacity can be conceived as a quantity of the average signal level, measured in the process of communication, per time unit. On the other hand, the MCAINM efficiency in compromising the mean capacity in similar to the system has SNR (signal-to-noise radio) depend on the system modulation, and the magnitude of impulsive noise as well [10;12]. Experts have come up with a huge array of redesigning effects to deal with unwanted noises that may interfere with communication systems like adaptive filtering, error correction algorithms, and techniques that are used in signal processing. Feedback mechanism and adaptive modulation techniques used in these systems result in their reliability and the improved average capacity [13]. Today communication approach integrated into the community makes it possible to relay data, even though it passes through long routes. Conversely, though the dependence on wireless communication has acted as a double-edged sword, and presented concerns over energy consumption, electromagnetic pollution, and resource depleted. To achieve this, slow production and communication system have received attention to look into the conscientious balance of technological advancement with environmental responsibility. Capacity analysis, conceptual and basic element of communication theory, serves as key component of designing efficient and sustainable communication transmission systems. The application of capacity analysis in scenarios involving non-Gaussian noise models and fading channels holds significant promise for sustainable communication systems. The application of capacity analysis in scenarios involving non-Gaussian noise models and fading channels holds significant promise for sustainable communication systems:

1. Energy-Efficient Resource Allocation: The communication systems that analyze channel capacity in non-Gaussian noise environments is given a power to allocate resources as optimal as possible, hence energy saving is achieved while maintaining desired quality of service [14].

2. Green Wireless Networks: Peripheral capacity analysis is a vital attribute of energy-efficient wireless networks that helps to reduce the excess of energy during communication challenges [15].

3. IoT and Sensor Networks: Due to this the IoT technologies are more effective when these communication links are more efficient. This enables the design of protocols that wirelessly communicate and thus prolong devices' life time and reduce the rate of their battery replacements turning them "greener [16]".

4. Renewable Energy Integration: The efficient utilization of renewable sources of energy for communication network development infers the system integrity and release from the crutches of the non-renewable energy sources [17].

This research aims at improving the channel capacity mostly in the scenario where the noise is modeled as non-Gaussian and channel fading is present, exploring the role of communication signals in maintaining the sustainability of the communication systems. Making use of the capacity analysis that employs non-Gaussian noise models and channels with variation schemes is the first milestone towards the target of maintaining sustainability in modern communication network. Communications systems are able to balance resource utilization by giving priority to utilization while handling electronic interference, and energy efficiency.

2. Impulsive noise model types

2.1. Capacity of impulsive noise channel

In the scenario in the case of impulsive noise has detected during SC transmission, the received signals can be stated in matrix form as **y = x + i**. Here, **y** denotes the received signal, **x** denotes the modulated signal utilizing binary phase shift keying (BPSK) modulation, and **i** denotes the impulsive noise, which represents different impulsive noise models in this paper. In the presence of certain presumptions, the computation of the channel capacity can be made in an approachable manner by modeling a time-varying channel as a Markov chain, it is much simpler to do so when the sender and the receiver are aware of the current state of the channel. Let's call this number Cm, which stands for the AWGN channel's capacity in state m. We get the mean channel capacity C by using a shared time contention, which gives us the value [18]. The AWGN channel has a capacity normalized by the BW in bits per second per Hertz (bps/Hz) can be calculated by the Shannon Capacity formula [12, 18]:

$$\frac{C}{B} = log_2\left(1 + \frac{S}{N}\right)\ [bps/Hz]. \qquad (1)$$

Where B, S, and N denote the bandwidth, the total signal power, and the total noise power over the bandwidth in state m. The ratio of $\frac{S}{N}$ denotes the Signal-to-Noise Ratio (SNR), which is the ratio of signal power to noise power at the receiver in linear scale. Moreover, $S = E_S = E_b$ in the case of BPSK modulation and $N = 2\sigma^2$. In [2, 13, 19, 20], the probability density function (PDF) in the time domain of the first model, named the Gaussian mixture impulsive noise model (GMINM), is given as

$$p_i(i_n) = (1 - \alpha)\mathcal{N}(i_n, 0, \sigma_w^2) + \alpha\mathcal{N}\left(i_n, 0, \sigma_w^2 + \sigma_i^2\right) \qquad (2)$$

Where α is the impulsive occurrence probability, σ_w^2 and σ_i^2 are the additive gaussian noise and IN variances, respectively, and $\Gamma = \frac{\sigma_i^2}{\sigma_w^2}$ is the impulsive to Gaussian noise power ratio. Therefore, in this case, based on (1), the average capacity normalized by channel bandwidth (C/BW) can be derived as

$$\frac{C}{BW} = (1-\alpha)log_2\left(1+\frac{E_s}{2\sigma_w^2}\right) + \alpha\, log_2\left(1+\frac{E_s}{2(\sigma_w^2+\sigma_i^2)}\right) \quad (3)$$

In the second model, named Middelton's class A's model (MCAINM), the probability density functions (PDFs) in the time domain are expressed as

$$p_i(i_n) = \sum_{\ell=0}^{L-1} \frac{e^{-A}A^{\ell}}{\ell!} \mathcal{N}\left(i_n, 0, \sigma_\ell^2\right) \quad (4)$$

Where σ_ℓ^2 is the variance of ℓ-th weighted impulsive noise from $0 \leq L < \infty$ and $\sigma_\ell^2 = \sigma_w^2(1+\frac{\ell}{A\rho})$ which is related with the simultaneous emission from ℓ noise sources that participate to the IN. A indicate the average number of impulses during time of interference, the Gaussian-to-impulsive noise power ratio is denoted by $\rho = \frac{\sigma_w^2}{\sigma_i^2}$. The average C/BW can be expressed as [10, 21].

$$\frac{C}{BW} = \sum_{\ell=0}^{L-1} \frac{e^{-A}A^{\ell}}{\ell!} log_2\,(1+\frac{E_s}{2\sigma_\ell^2}) \quad (5)$$

Spaulding and Middleton [22] offer an expression for an approximation of the MCAINM model using a mixed model of two Gaussian PDFs. Therefore, the third model, named simplified Middelton's class A's model (S1MCAINM), has the sum of two PDFs with zero mean but differing variances expressed as

$$p_i(i_n) = \frac{e^{-A}}{\sqrt{2\pi}\sigma_w} e^{-\frac{{i_n}^2}{2\sigma_w^2}} + \frac{(1-e^{-A})}{\sqrt{2\pi}\zeta}\; e^{-\frac{{i_n}^2}{2\zeta^2}} \quad (6)$$

where $\zeta^2 = \sigma_w^2\,(1+\frac{1}{A\rho})$. Therefore, the average C/BW can be derived as,

$$\frac{C}{BW} = e^{-A}log_2\left(1+\frac{E_s}{2\sigma_w^2}\right) + (1-e^{-A})log_2\left(1+\frac{E_s}{2\zeta^2}\right) \quad (7)$$

In the MCAINM model, approximating two states is possible if the impulse noise parameter A is small enough for ℓ = 0 and ℓ = 1 where P(ℓ = 0) = 1 − P(ℓ = 1) = 1 − A, with variable variances σ_w^2 and, ζ^2, respectively. Therefore, the fourth model, named second simplified Middelton's class A's model (S2MCAINM) has a PDF shown in [23].

$$p_i(i_n) = \frac{(1-A)}{\sqrt{2\pi}\sigma_w} e^{\frac{-{i_n}^2}{2\sigma_w^2}} + \frac{A}{\sqrt{2\pi}\zeta}\; e^{\frac{-{i_n}^2}{2\zeta^2}} \quad (8)$$

Where $\zeta^2 = \sigma_w^2\,(1+\frac{1}{A\rho}) = \sigma_w^2 + \frac{\sigma_i^2}{A}$. The average C/BW can be derived as follows:

$$\frac{C}{BW} = (1-A)log_2\left(1+\frac{E_s}{2\sigma_w^2}\right) + A\, log_2\left(1+\frac{E_s}{2\zeta^2}\right) \quad (9)$$

2.2. Capacity of impulsive noise over Rayleigh fading channel

Rayleigh fading is a kind of fading that occurs in wireless communication due to the random fluctuation of magnitude and phase of the received signal as a result of multipath propagation. In the case of an Rf channel, the SNR differs over time because of the effect of fading. Given this situation, the channel capacity is measured as the average capacity over all potential fading states. This kind of capacity is referred to as ergodic capacity.

If the accurate channel capacity becomes computationally difficult or unachievable, the use the semi-analytical channel capacity is employed. Thus, the use of semi-analytical method is used because the exact computation suffers the problem of high complexity. Also, the semi-analytical method can be deployed in the estimation of the ergodic capacity of a BPSK system over a Rf channel.

$$\left(\frac{C}{B}\right)_{avg} = \frac{1}{N}\sum_{k=0}^{N-1} log_2\left(1 + E\left\{\frac{S|h_k|^2}{N}\right\}\right) \ [bps/Hz]. \quad (10)$$

Where $\left(\frac{C}{B}\right)_{avg}$ and $E\left\{\frac{S}{N}\right\}$ are the Ergodic capacity normalized by the BW in bits per second (bps/Hz) and the expectation of the SNR over all possible fading states. The ergodic capacity can be computed based on Fig. 1 for the switch, which selects from a range of AWGN over Rf channels whose SNR, $\gamma_k = E\left\{\frac{S|h_k|^2}{2\sigma_w^2}\right\}$, $0 \le \gamma < \infty$, where $|h|^2$ is the power channel gain, follows an exponential distribution. If the switch is flipped between positions during each symbol period with equal probabilities, it may use a fixed channel encoder and achieve our maximum data rate.

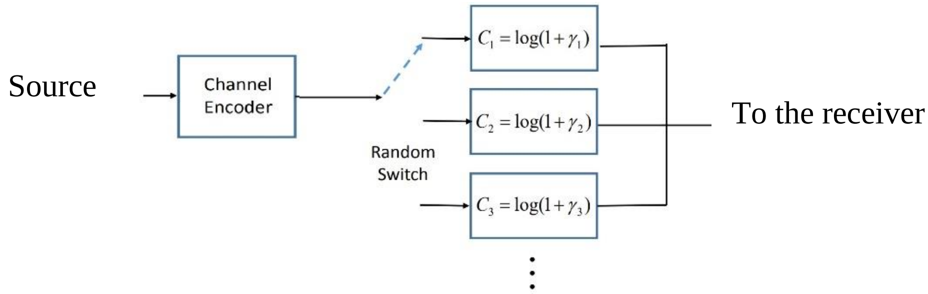

Figure 1. Fading channel capacity

Therefore, the average capacity normalized by the BW of the GMINM over the Rf channel can be derived as

$$\frac{C}{BW} = \frac{1}{N}\sum_{k=0}^{N-1}\left\{ (1-\alpha)log_2\left(1 + \frac{E_s|h_k|^2}{2\sigma_w^2}\right) + \alpha\ log_2(1 + \frac{E_S|h_k|^2}{2(\sigma_w^2 + \sigma_i^2)}) \right\} \quad (11)$$

On the other hand, the exact average capacity normalized by the channel BW can be derived as

$$\frac{C}{BW} = \int_0^\infty (1-\alpha)\log(1+\gamma_1)\,p(\gamma_1)d\gamma_1 + \int_0^\infty \alpha\log(1+\gamma_2)\,p(\gamma_2)d\gamma_2$$

$$= \frac{1}{\ln(2)}\left[(1-\alpha)e^{\frac{1}{\overline{\gamma_1}}}E_1\left(\frac{1}{\overline{\gamma_1}}\right) + \alpha\ e^{\frac{1}{\overline{\gamma_2}}}E_1\left(\frac{1}{\overline{\gamma_2}}\right)\right] \quad (12)$$

Where $\overline{\gamma_1} = \frac{E_S}{2\sigma_w^2}$, $\overline{\gamma_2} = \frac{E_S}{2(\sigma_w^2+\sigma_i^2)}$ and $E_1(x) = \int_x^\infty \frac{e^{-t}}{t}dt$ is the Exponential integral function. The $E_1(x)$ function can be computed in MATLAB as E=expint(x).

Moreover, the average capacity normalized by BW of MCAINM over the Rf channel using the semi-analytical method can be derived as

$$\frac{C}{BW} = \frac{1}{N}\sum_{k=0}^{N-1}\left\{\sum_{\ell=0}^{L-1}\frac{e^{-A}A^\ell}{\ell!}log_2\,(1 + \frac{E_s|h_k|^2}{2\sigma_\ell^2})\right\} \quad (13)$$

However, the average capacity normalized by the channel BW can be obtained as follows:

$$\frac{C}{BW} = \int_0^\infty \sum_{\ell=0}^{L-1} \frac{e^{-A}A^\ell}{\ell!} log_2\,(1+\gamma)\,p(\gamma)d\gamma = \frac{1}{\ln(2)} \sum_{\ell=0}^{L-1} \frac{e^{-A}A^\ell}{\ell!} e^{\frac{1}{\bar{\gamma}}} E_1\left(\frac{1}{\bar{\gamma}}\right) \quad (14)$$

Where $\bar{\gamma} = \frac{E_s}{2\sigma_\ell^2}$. Exponential functions can result in large values that exceed the representable range of floating-point numbers. To prevent this, we can use the logarithmic function to transform the computation into a logarithmic form, which can be more numerically stable and prevent overflow issues. Then, we use the exponential function again for the final result. Therefore, Eq. (14) can be rewritten in this form as

$$\frac{C}{BW} = \sum_{\ell=0}^{L-1} e^{\left(log\left(\frac{e^{-A}A^\ell}{\ln(2)\ell!}\right)+\frac{1}{\bar{\gamma}}+log\left(E_1\left(\frac{1}{\bar{\gamma}}\right)\right)\right)} \quad (15)$$

Furthermore, the S1MCAINM average capacity normalized by BW using the semi-analytical method may be derived as

$$\frac{C}{BW} = \frac{1}{N}\sum_{k=0}^{N-1}\left\{e^{-A}\,log_2\left(1+\frac{E_s|h_k|^2}{2\sigma_w^2}\right) + (1-e^{-A})log_2(1+\frac{E_s|h_k|^2}{2\xi^2})\right\} \quad (16)$$

However, the average capacity normalized by the channel BW can be calculated as follows:

$$\frac{C}{BW} = \int_0^\infty e^{-A}\log(1+\gamma_1)\,p(\gamma_1)d\gamma_1 + \int_0^\infty (1-e^{-A})\log(1+\gamma_2)\,p(\gamma_2)d\gamma_2$$
$$= \frac{1}{\ln(2)}\left[e^{-A}\,e^{\frac{1}{\overline{\gamma_1}}}E_1\left(\frac{1}{\overline{\gamma_1}}\right) + (1-e^{-A})\,e^{\frac{1}{\overline{\gamma_2}}}E_1\left(\frac{1}{\overline{\gamma_2}}\right)\right] \quad (17)$$

Where $\overline{\gamma_1} = \frac{E_s}{2\sigma_w^2}$, $\overline{\gamma_2} = \frac{E_S}{2\xi^2}$

The average capacity, which is normalized by BW in the S2MCAINM using the semi-analytical method, can be derived as follows:

$$\frac{C}{BW} = \frac{1}{N}\sum_{k=0}^{N-1}\left\{(1-A)log_2\left(1+\frac{E_s|h_k|^2}{2\sigma_w^2}\right) + A\,log_2(1+\frac{E_s|h_k|^2}{2\zeta^2})\right\} \quad (18)$$

As an alternative, the average capacity normalized by the channel BW can be calculated as

$$\frac{C}{BW} = \int_0^\infty (1-A)\log(1+\gamma_1)\,p(\gamma_1)d\gamma_1 + \int_0^\infty A\log(1+\gamma_2)\,p(\gamma_2)d\gamma_2$$
$$= \frac{1}{\ln(2)}\left[(1-A)\,e^{\frac{1}{\overline{\gamma_1}}}E_1\left(\frac{1}{\overline{\gamma_1}}\right) + A\,e^{\frac{1}{\overline{\gamma_2}}}E_1\left(\frac{1}{\overline{\gamma_2}}\right)\right] \quad (19)$$

Where $\overline{\gamma_1} = \frac{E_s}{2\sigma_w^2}$, $\overline{\gamma_2} = \frac{E_S}{2\xi^2}$

2.3. Optimized the capacity using multiple antennas system

Multiple-Input Multiple-Output systems are a basic technology in the field of wireless communication. They use multiple antennas at both the sending and receiving ends to improve data rates, reliability, and the system's overall performance. The primary objective of a Multiple communication system is to optimize the channel capacity in channels contaminated by impulsive noise, which denotes the highest attainable data transmission rate over the wireless channel. The scenario in which the Channel State Information (CSI) is not available at the transmitter is commonly referred to as an open-loop MIMO-GMINM, or MIMO-MCAIN system. The optimization of channel capacity in an open-loop MIMO-GMINM, or MIMO-MCAIN system encompasses several methodologies, including Spatial Multiplexing, Precoding, Water-Filling Power Allocation, and Diversity Techniques. In this case, the channel capacity is known as the ergodic capacity of the random multi-channels and can be computed as [24]:

$$\mathrm{C} = \mathrm{E}\left[\log_2 \det\left[\mathrm{I}_{\mathrm{N_R}} + \frac{\mathrm{SNR}}{\mathrm{N_T}}\,\mathrm{HH^H}\right]\right] \tag{20}$$

Therefore, the optimized ergodic capacity normalized by the BW of the GMINM over the Rf channel can be derived as

$$\frac{C}{BW} = (1-\alpha)E\left[\log_2 \det\left[\mathrm{I}_{\mathrm{N_R}} + \frac{E_s}{2\sigma_w^2 \mathrm{N_T}}\,\mathrm{HH^H}\right]\right] + \alpha\, E\left[\log_2 \det\left[\mathrm{I}_{\mathrm{N_R}} + \frac{E_s}{2(\sigma_w^2+\sigma_i^2)\mathrm{N_T}}\,\mathrm{HH^H}\right]\right] \tag{21}$$

Moreover, the optimized ergodic capacity normalized by BW of MCAINM over the Rf channel can be derived as

$$\frac{C}{BW} = \sum_{\ell=0}^{L-1} \frac{e^{-A}A^{\ell}}{\ell!} E\left[\log_2 \det\left[\mathrm{I}_{\mathrm{N_R}} + \frac{E_s}{2\sigma_\ell^2 \mathrm{N_T}}\,\mathrm{HH^H}\right]\right] \tag{22}$$

Furthermore, the S1MCAINM optimized ergodic capacity normalized by BW can be derived as

$$\frac{C}{BW} = e^{-A}E\left[\log_2 \det\left[\mathrm{I}_{\mathrm{N_R}} + \frac{E_s}{2\sigma_w^2 \mathrm{N_T}}\,\mathrm{HH^H}\right]\right] + (1-e^{-A})\, E\left[\log_2 \det\left[\mathrm{I}_{\mathrm{N_R}} + \frac{E_s}{2\xi^2 \mathrm{N_T}}\,\mathrm{HH^H}\right]\right] \tag{23}$$

Finally, the optimized ergodic capacity, which is normalized by BW in the S2MCAINM can be derived as follows:

$$\frac{C}{BW} = (1-A)E\left[\log_2 \det\left[\mathrm{I}_{\mathrm{N_R}} + \frac{E_s}{2\sigma_w^2 \mathrm{N_T}}\,\mathrm{HH^H}\right]\right] + A\, E\left[\log_2 \det\left[\mathrm{I}_{\mathrm{N_R}} + \frac{E_s}{2\zeta^2 \mathrm{N_T}}\,\mathrm{HH^H}\right]\right] \tag{24}$$

3. Simulation Results

In this section, several figures show the average channel capacity normalized by the BW for the analytically derived formulas using Monte-Carlo computer simulations for different impulsive noise models such as the GMINM, MCAINM, S1MCAINM, and S2MCAINM for BPSK modulation with and without RF channel. The results are due to the effort of adapting the parameters from different impulsive noise models, e.g. α, Γ for GMINM, A, the maximum value of l and ρ for the models MCAINM, S1MCAINM and S2MCAINM, etc. The channel capacity sustainability has been simulated as a function of ISI with respect to the BW for α ∈ [0.01, 0.1, 0.3] which are scenarios where the impulsive noise occurrence probability is low α =0.01, medium α = 0.1, and severe α = 0.3 and for Γ=10, The impulsive noise should have the same impact among the models following moderate comparison to other models. Therefore, A's value has to be computed based on its connected network and compatibility level to α as $A = -\log(1-\alpha)$ and $\rho = \frac{1}{\Gamma}$ where L=100 in this paper. The information theory and communication systems specify the channel capacity to be an SNR - and BW - normalized. Correlation between channel capacity and S/N (signal-to-noise) ratio is one of the essential indicators of communication systems' efficiency and performance level. This part delves into the result analysis, in which we will examine the relationship between SNR and the BW-normalized channel capacity as yielded by the experimental results. Wide array of impulsive noise models were applied to the simulation with the impulsive noises being different. The obtained results displayed that the SNR values were within the range of 0 to 30dB, and the analyses of the BW-normalized symbol rate and channel capacity was conducted. Our simulation results for channel capacity normalized with BW/SNR are shown in Figures 2-4. Low S/N ratio level is seen to cause the system and channel capacity performance as well as the overall channel capacity to degrade. On the other hand, higher SNR, resulted in increased channel capacity, showing that higher SNR increases the capacity sustainability for information transmission. This finding of the study can be attributed to the notion that higher values of SNR results in higher and better channel capacity, because higher SNR means that the signal will be higher than the noise. This in turn, enhances communication performance, meaning that, communication will be flawless and free of interference. The increase in SNR can drive the channel capacity to its theoretical limit, which is referred to as the Shannon capacity, which denotes the maximum rate of reliable information transmitted via a communication channel for each SNR value in dB. The experimental results revealed that the impulsive noise has a damaging effect on the capacity of the channel. The concept of impulsive noise is described as an abrupt noise that is disruptive to the communication signals. The results showed that an increase in the occurrence of impulsive noise resulted in decreased channel capacity. This can be attributed to the fact that the impulsive noise causes distortions and errors in the received signal. More so, the experimental results revealed that there was normality in the relationship between impulsive noise and channel capacity by the BW is nonlinear. On the other hand, lesser occurrence of impulsive noise resulted in low impact on the capacity of the channel. Nevertheless, higher impulsive noise resulted in significant degradation of channel capacity. This in turn results in reduced communication performance. Moreover, the capacity normalized by the BW in the presence of an impulsive noise channel without an Rf channel will always be higher than that of the Rf channel for the same SNR value, as the Rf channel introduces additional losses due to fading. This can be attributed to the fact that the average BER has an impact on capacity of impulsive noise over the RF channel, and the average BER, is in turn affected by the magnitude of channel fading. When the fading results is higher in average BER, the capacity of the channel decreases, indicating that there is a limitation to the capacity that can potentially be achieved irrespective of how high the SNR versus impulsive noise over the Rf channel is. Additionally, priority was given to a plethora of impulse noise models, as well as their effects on channel capacitance were analyzed. The total applicability of the four models for low α values was brought to play in this work. The results showed that there were variances in the high vales of α for the different impulse noise models. In terms of the simplification models (S1MCAINM and S2MCAINM), there was a shift from the original results, and this was expected due to the fact that the two aforementioned models are the original versions of the MCAINM model, which produces accurate results with a very large value of L. This finding highlights the significance of channel capacity normalized by the BW as a performance metric in communication systems and underscores the importance of optimizing SNR to achieve efficient and reliable communication. Through the study findings, valued insights regarding the relationship between channel capacity normalized by the BW and SNR versus impulsive noise over Rf channel, has been gained. Thus, it can be concluded that, noise environment, especially impulsive noise must be taken into consideration so that the performance of communication systems can be optimized.

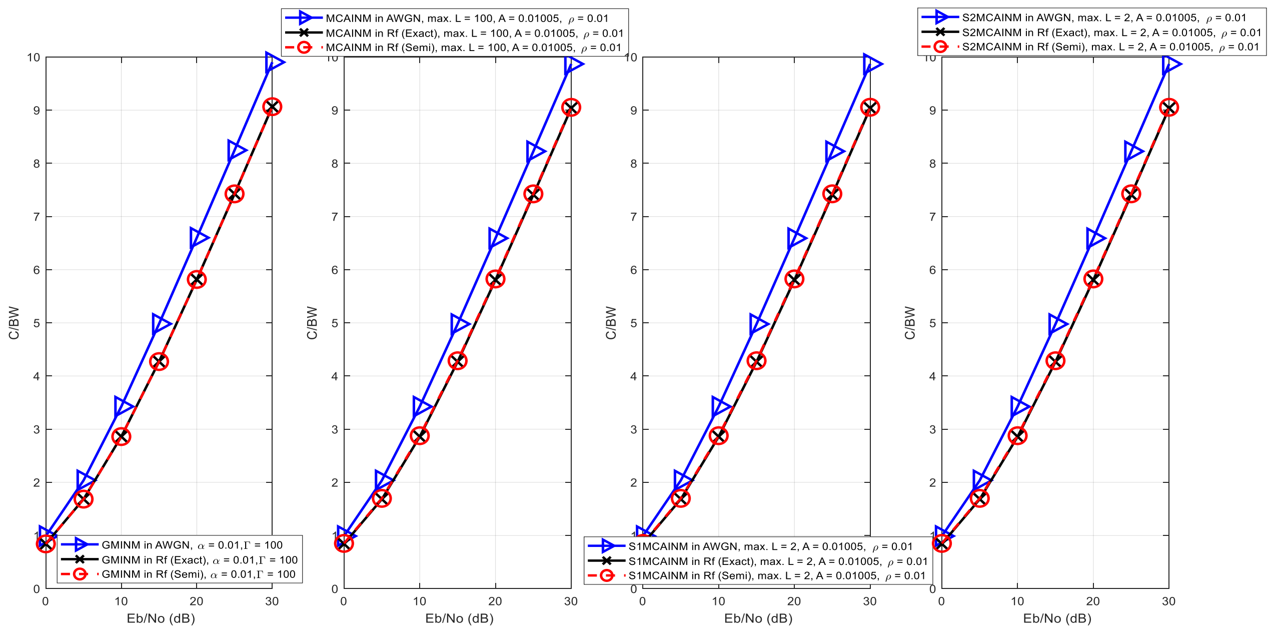

Figure 2. Channel capacity normalized by the BW for $\alpha =\ 0.01$ and $\Gamma = 100$

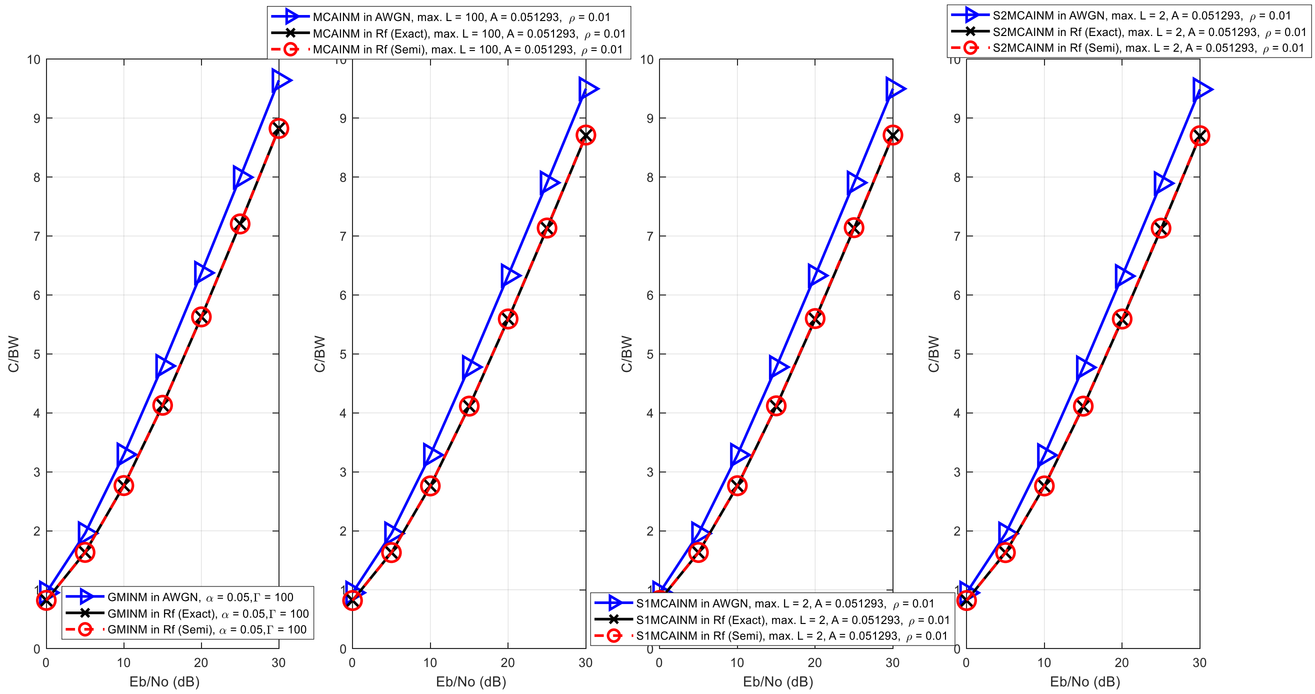

Figure 3. Channel capacity normalized by the BW for $\alpha = \ 0.05$ and $\Gamma = 100$

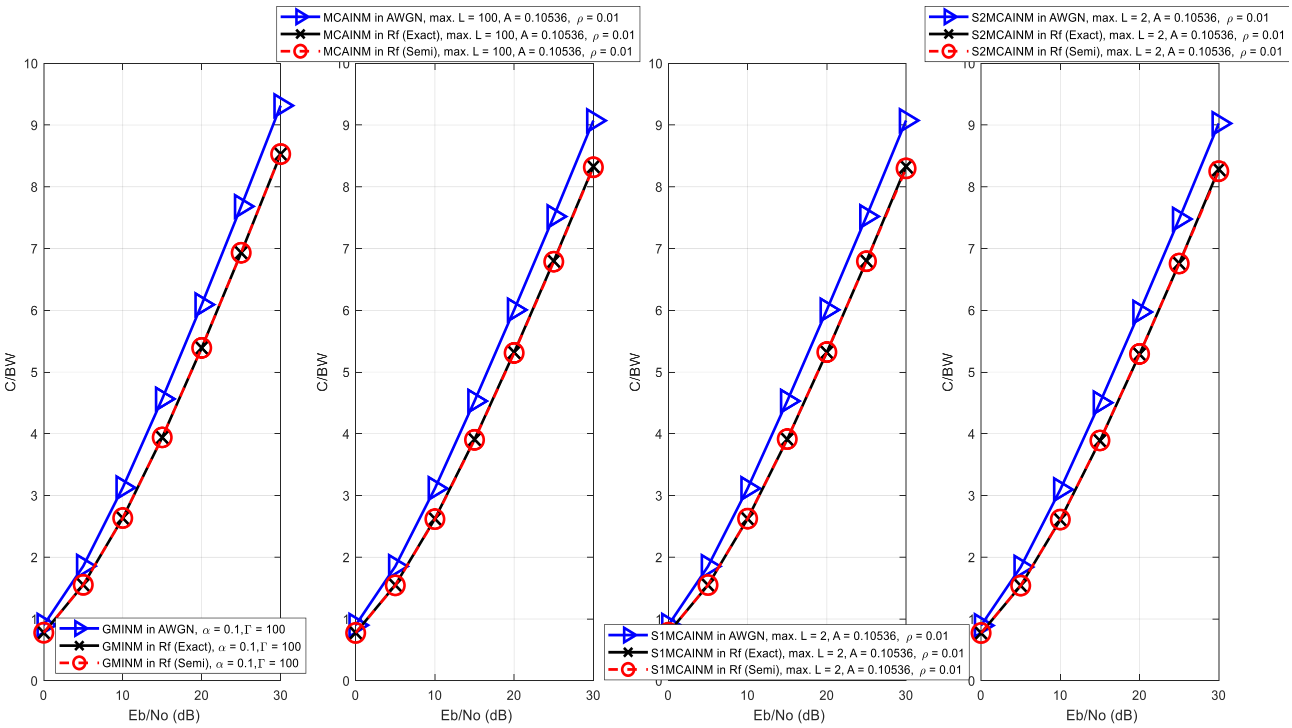

Figure 4. Channel capacity normalized by the BW for $\alpha = \ 0.1$ and $\Gamma = 100$

Figs. 5-6 show the channel capacity normalized by the BW for $\alpha = \ 0.1$ when $\sigma_i^2 = 10\ \sigma_w^2$ which means $\Gamma = 10$ in GMINM and $\rho = 0.1$ in MCAINM and for $\sigma_i^2 = 1000\ \sigma_w^2$ which means $\Gamma = 1000$ in GMINM and $\rho = 0.001$ in MCAINM. Thus, altering the variance of impulsive noise translates into the average magnitude of the noise signal fluctuations. The variance of impulsive noise refers to the average magnitude of how the noise signal fluctuates. Based on the results of the simulation, higher levels of impulsive noise may lead to increased levels of distortion and errors in the transmitted signal, which may in turn cause the reduction of the entire channel capacity.

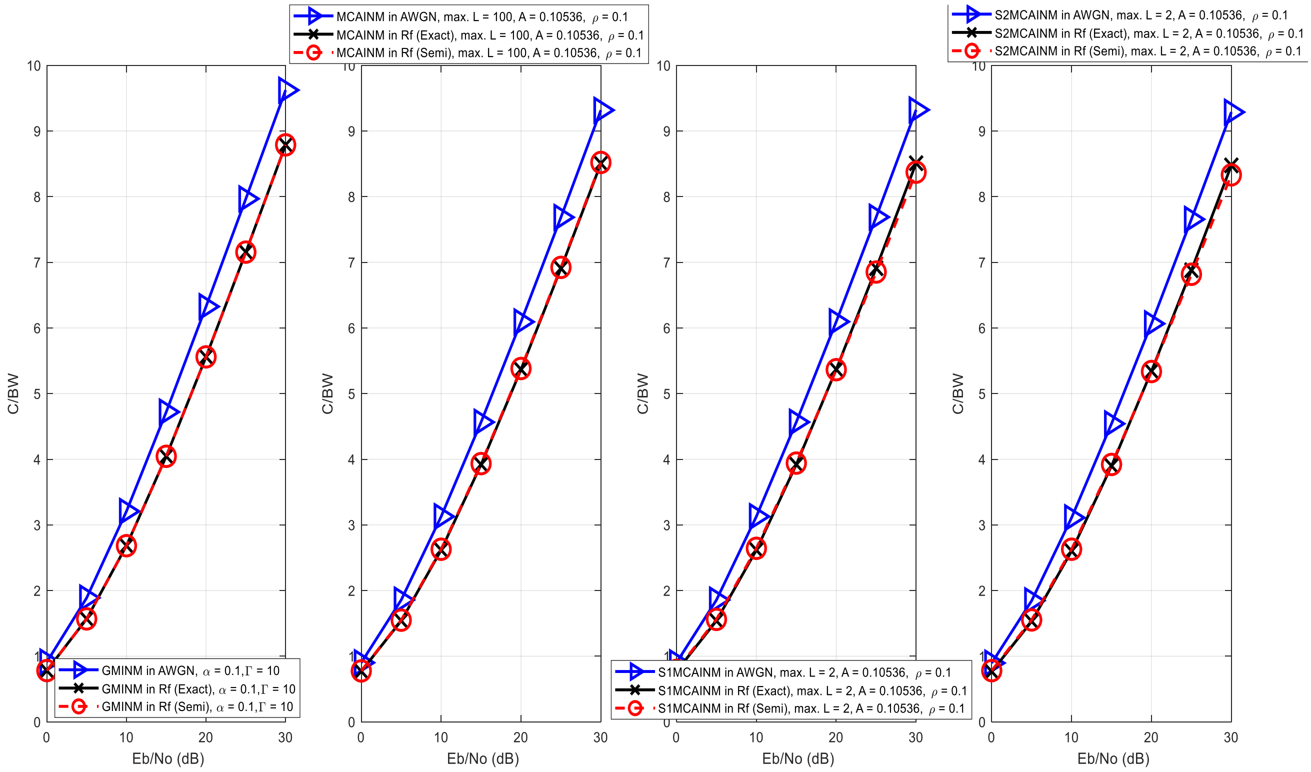

Figure 5. Channel capacity normalized by the BW for $\alpha =\ 0.1$ and $\Gamma = 10$

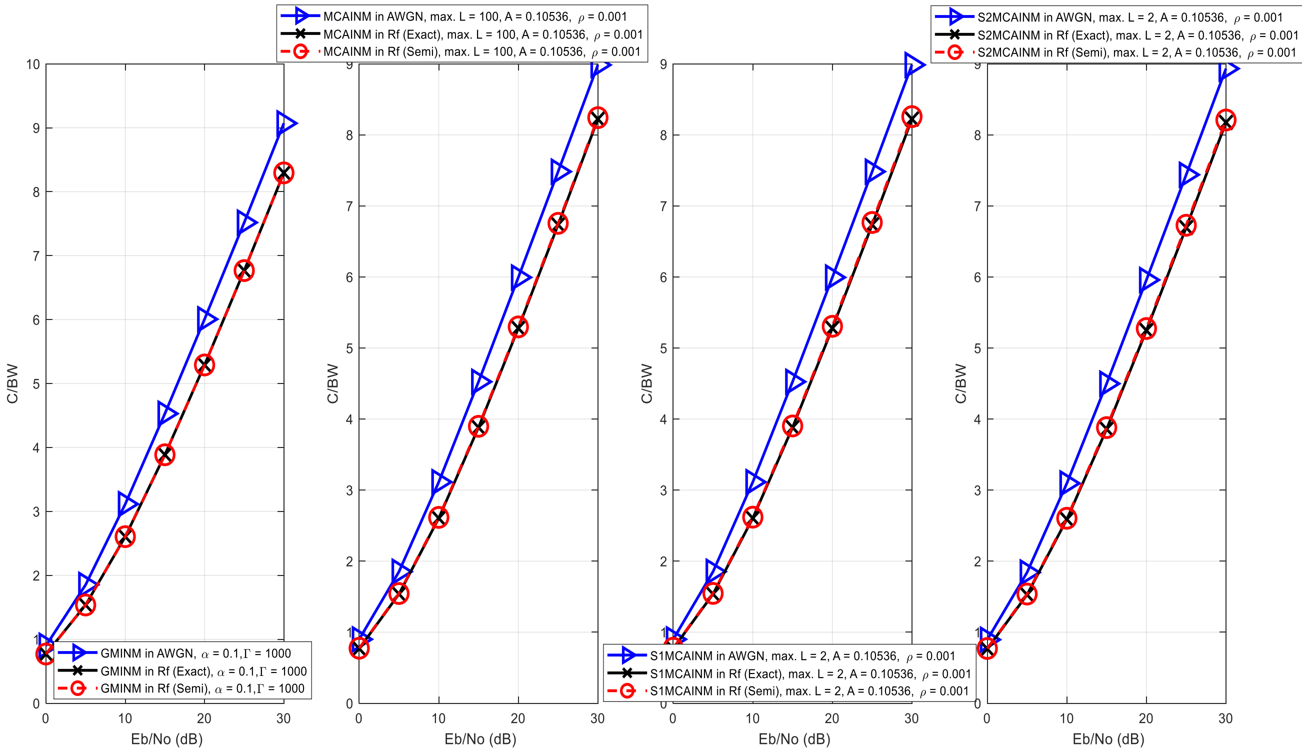

Figure 6. Channel capacity normalized by the BW for $\alpha =\ 0.1$ and $\Gamma = 1000$.

Fig. 7 shows the optimized ergodic capacity normalized by the BW for GMINM, MCAINM, S1MCAINM and S2MCAINM systems when (NR, NT) = (1, 1), (2, 2), and (4, 4), respectively, for α = 0.01 when σ_i^2=100 σ_w^2 which means Γ=100 in GMINM and ρ=0.01 in MCAINM. Based on the results of the simulation, the ergodic capacities normalized by the BW are improved for all models when the number of antennas increases in the transmitter and receiver.

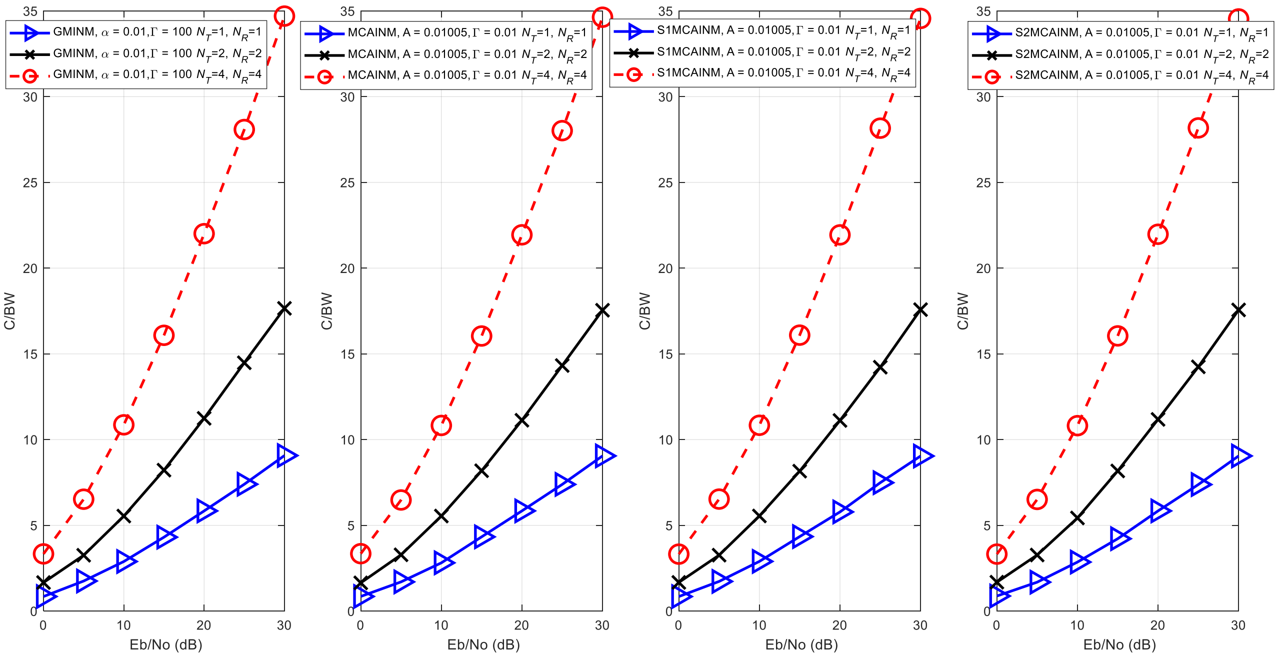

Figure 7. Optimized ergodic capacity normalized by the BW for GMINM, MCAINM, S1MCAINM and S2MCAINM systems for $\alpha = \ 0.01$ and $\Gamma = 100$

4. Conclusion

The channel capacity, which is normalized by the BW channel sustainability, may be determined by many factors like impulsive noise, signal-to-noise ratio, and Rayleigh fading. When the sustainability capacity of the channel is higher, higher data rates are allowed, and the performance of the communication will be improved based on the results of the simulation, signal-to-noise ratio is a critical factor that influences the reliability and quality of communication sustainability. When the SNR is higher, the communication performance is better, because there is less interruption from noise. In this work, the impact of impulsive noise modulated by various impulsive noise models, like sustainability of GMINM, MCAINM, S1MCAINM, and S2MCAINM on the performance of communication systems is examined. These models describe the statistical characteristics of impulsive noise, which can significantly degrade the performance of communication systems sustainability, especially in channels with a severe occurrence of impulses. The simulation results show that the occurrence and ratio of the impulsive noise to the Gaussian noise reduce the channel capacity because they introduce errors in the received signal, which can lower the achievable data rate, especially in the Rf channel compared to the AWGN channel. The higher the amplitude and duration of the impulsive noise bursts, the more severe the degradation in channel capacity. Impulsive noise can cause errors in the detection of the transmitted bits, leading to a decrease in the achievable data rate and overall system performance. The interplay between channel capacity, SNR, impulsive noise, and Rf in communication systems is complex and requires different impulsive noise mitigation methods for improved channel capacity and reliable and efficient communication performance. Therefore, the utilization of the multi-channels configuration introduces spatial diversity and multiplexing advantages and has enhanced the ergodic capacity in scenarios where the channel state information (CSI) remains unknown at the transmitter. The study has proven the validity of the simplified models used in impulsive noise modeling compared to the original Middleton Class-A model for impulsive noise modeling. In addition, the simulation results show the phenomenon of fading channels in wireless communication due to random variations in amplitude and phase that degrade the capacity of the wireless communication systems. In conclusion, while capacity in non-Gaussian noise models with and without fading channels is not directly related to sustainability, optimizing the capacity can indirectly contribute to sustainability by improving the efficiency and reliability of the communication network. Incorporating the insights from impulsive noise modeling and channel capacity analysis can significantly contribute to the sustainability of communication systems. By understanding the interplay between impulsive noise models, channel capacity, and multi-channel configurations, practitioners and researchers can devise strategies to mitigate the impact of non-Gaussian noise and enhance the reliability, efficiency, and overall sustainability of communication networks in various real-world scenarios.

Declaration of Competing Interest

The authors declare that they have no any known financial or non-financial competing interests in any material discussed in this paper.

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