

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.

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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 burst 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 MCAINM 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 presence of MCAINM can have a significant impact on the performance of communication systems. The impact of the noise can be measured by calculating the system's average capacity when subjected to MCAINM. The average capacity can be described as a measure of the average amount of information that can be reliably transmitted over the communication channel per unit of time. Nevertheless, the exactness of MCAINM's impact on the average capacity is dependent on numerous factors like the system's signal-to-noise ratio (SNR), the modulation scheme that is used, and the magnitude of the impulsive noise [10, 12]. Experts have designed a wide range of techniques for the mitigation of the impact of impulsive noise on communication systems including adaptive filtering, error correction, and techniques deployed in signal processing. Through the use of these techniques, the communication system can be improved in terms of robustness and increased average capacity [13]. Communication systems have become an integral part of modern society, enabling seamless exchange of information across vast distances. However, the increasing reliance on wireless communication has led to concerns about energy consumption, electromagnetic pollution, and resource depletion. As a result, sustainable communication systems have gained traction, aiming to strike a balance between technological advancement and environmental responsibility. Capacity analysis, a fundamental concept in

communication theory, plays a pivotal role in designing efficient and sustainable communication networks. 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:** By understanding channel capacity in non-Gaussian noise environments, communication systems can allocate resources optimally, reducing energy consumption while maintaining desired quality of service [14].
2. **Green Wireless Networks:** Capacity analysis in fading channels aids in the development of energy-efficient wireless networks, ensuring minimal power usage during challenging propagation conditions [15].
3. **IoT and Sensor Networks:** Sustainable deployment of Internet of Things (IoT) devices and sensor networks requires efficient communication strategies. Capacity analysis helps in designing communication protocols that prolong device lifespan and reduce the need for frequent battery replacements [16].
4. **Renewable Energy Integration:** Sustainable communication systems can facilitate the integration of renewable energy sources into the communication infrastructure, allowing for efficient power management and reducing dependence on non-renewable resources [17].

The purpose of this research is to optimize the capacity of communication channels, especially in scenarios involving non-Gaussian noise models and fading channels and analyze their importance for the improvement of sustainable communication systems. The application of capacity analysis in communication systems operating under non-Gaussian noise models and fading channels is a crucial step towards achieving sustainability in modern wireless networks. By optimizing resource allocation, adapting to channel fluctuations, and enhancing energy efficiency, communication systems can contribute to a more environmentally responsible and resource-efficient future.

2. Impulsive noise model types

2.1. Capacity of impulsive noise channel

In the scenario where impulsive noise is detected during SC transmission, the received signals can be expressed in matrix form as $\mathbf{y} = \mathbf{x} + \mathbf{i}$. Here, \mathbf{y} denotes the received signal, \mathbf{x} denotes the modulated signal utilizing binary phase shift keying (BPSK) modulation, and \mathbf{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 C_m , 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]:

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

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

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

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

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

Where σ_ℓ^2 is the variance of ℓ -th weighted impulsive noise from $0 \leq L < \infty$ and $\sigma_\ell^2 = \sigma_w^2 \left(1 + \frac{\ell}{A\rho} \right)$ 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].

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

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 Middleton'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 $\zeta^2 = \sigma_w^2 \left(1 + \frac{1}{A\rho} \right)$. 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 $\ell = 0$ and $\ell = 1$ where $P(\ell = 0) = 1 - P(\ell = 1) = 1 - A$, with variable variances σ_w^2 and, ζ^2 , respectively. Therefore, the fourth model, named second simplified Middleton'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 $\zeta^2 = \sigma_w^2 \left(1 + \frac{1}{A\rho} \right) = \sigma_w^2 + \frac{\sigma_i^2}{A}$. 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.

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

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, $\gamma_k = E \left\{ \frac{S|h_k|^2}{2\sigma_w^2} \right\}$, $0 \leq \gamma < \infty$, 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.

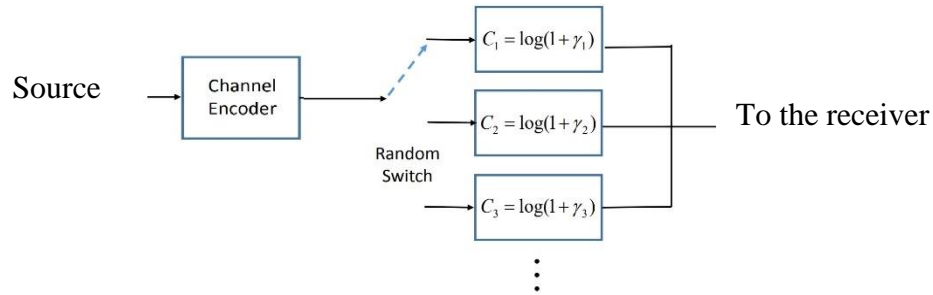


Figure 1. Fading channel capacity

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

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

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

$$\begin{aligned} \frac{C}{BW} &= \int_0^\infty (1 - \alpha) \log(1 + \gamma_1) p(\gamma_1) d\gamma_1 + \int_0^\infty \alpha \log(1 + \gamma_2) p(\gamma_2) d\gamma_2 \\ &= \frac{1}{\ln(2)} \left[(1 - \alpha) e^{\frac{1}{\bar{\gamma}_1}} E_1 \left(\frac{1}{\bar{\gamma}_1} \right) + \alpha e^{\frac{1}{\bar{\gamma}_2}} E_1 \left(\frac{1}{\bar{\gamma}_2} \right) \right] \end{aligned} \quad (12)$$

Where $\bar{\gamma}_1 = \frac{E_S}{2\sigma_w^2}$, $\bar{\gamma}_2 = \frac{E_S}{2(\sigma_w^2 + \sigma_i^2)}$ 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

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

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 $\bar{\gamma} = \frac{E_s}{2\sigma_w^2}$. 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 SIMCAINM average capacity normalized by BW using the semi-analytical method may be derived as

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

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

$$\begin{aligned} \frac{C}{BW} &= \int_0^{\infty} e^{-A} \log(1 + \gamma_1) p(\gamma_1) d\gamma_1 + \int_0^{\infty} (1 - e^{-A}) \log(1 + \gamma_2) p(\gamma_2) d\gamma_2 \\ &= \frac{1}{\ln(2)} \left[e^{-A} e^{\frac{1}{\bar{\gamma}_1}} E_1\left(\frac{1}{\bar{\gamma}_1}\right) + (1 - e^{-A}) e^{\frac{1}{\bar{\gamma}_2}} E_1\left(\frac{1}{\bar{\gamma}_2}\right) \right] \quad (17) \end{aligned}$$

Where $\bar{\gamma}_1 = \frac{E_s}{2\sigma_w^2}$, $\bar{\gamma}_2 = \frac{E_s}{2\xi^2}$

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

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

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

$$\begin{aligned} \frac{C}{BW} &= \int_0^{\infty} (1 - A) \log(1 + \gamma_1) p(\gamma_1) d\gamma_1 + \int_0^{\infty} A \log(1 + \gamma_2) p(\gamma_2) d\gamma_2 \\ &= \frac{1}{\ln(2)} \left[(1 - A) e^{\frac{1}{\bar{\gamma}_1}} E_1\left(\frac{1}{\bar{\gamma}_1}\right) + A e^{\frac{1}{\bar{\gamma}_2}} E_1\left(\frac{1}{\bar{\gamma}_2}\right) \right] \quad (19) \end{aligned}$$

Where $\bar{\gamma}_1 = \frac{E_s}{2\sigma_w^2}$, $\bar{\gamma}_2 = \frac{E_s}{2\xi^2}$

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]:

$$C = E \left[\log_2 \det \left[I_{N_R} + \frac{\text{SNR}}{N_T} \text{HH}^H \right] \right] \quad (20)$$

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

$$\begin{aligned} \frac{C}{BW} &= (1 - \alpha) E \left[\log_2 \det \left[I_{N_R} + \frac{E_s}{2\sigma_w^2 N_T} \text{HH}^H \right] \right] \\ &+ \alpha E \left[\log_2 \det \left[I_{N_R} + \frac{E_s}{2(\sigma_w^2 + \sigma_i^2) N_T} \text{HH}^H \right] \right] \end{aligned} \quad (21)$$

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

$$\frac{C}{BW} = \sum_{\ell=0}^{L-1} \frac{e^{-A} A^\ell}{\ell!} E \left[\log_2 \det \left[I_{N_R} + \frac{E_s}{2\sigma_\ell^2 N_T} \text{HH}^H \right] \right] \quad (22)$$

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

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

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

$$\frac{C}{BW} = (1 - A) E \left[\log_2 \det \left[I_{N_R} + \frac{E_s}{2\sigma_w^2 N_T} \text{HH}^H \right] \right] + A E \left[\log_2 \det \left[I_{N_R} + \frac{E_s}{2\xi^2 N_T} \text{HH}^H \right] \right] \quad (24)$$

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 outcomes have been achieved by adjusting the parameters of the impulsive noise models, such as α , Γ for GMINM, A , the maximum value of ℓ and ρ for the models MCAINM, S1MCAINM, and S2MCAINM. The channel capacity sustainability normalized by the BW has been simulated for various values of impulsive occurrence probability α where $\alpha = [0.01, 0.1, 0.3]$ represents different scenarios of impulsive noise, beginning from low impulsive noise occurrence when $\alpha = 0.01$, to severe impulsive noise when $\alpha = 0.3$ and for two values of $\Gamma = 10, 100$ and 1000 which means the impulsive noise power is 10, 100 and 1000 times greater than the Gaussian noise power. In moderate comparison to other models, the impulsive noise should have the same effect in all models. Therefore, the value of A should be computed in relation to α as $A = -\log(1 - \alpha)$ and $\rho = \frac{1}{\Gamma}$ where $L=100$ in this paper. The normalization of the channel capacity by the BW and the signal-to-noise ratio (SNR) are key parameters in information theory and communication systems. A key element in determining the efficiency and performance of communication systems is the correlation between channel capacity and signal-to-noise ratio. In this section, the results of the simulation are discussed, highlighting the correlation between SNR and the normalization of channel capacity by BW based on the study findings. The use of a wide range of impulsive noise models was employed for the simulations, and different impulsive noises were applied. The results showed that SNR values within the range of 0 to 30dB were achieved, and analysis of the corresponding channel capacity normalized by the BW was presented. The simulation results for the channel capacity normalized by the BW and SNR are presented in Figures 2-4. The simulation results showed that, at low SNR levels, the performance of the system and sustainability of channel capacity were significantly influenced in a

negative manner. 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.

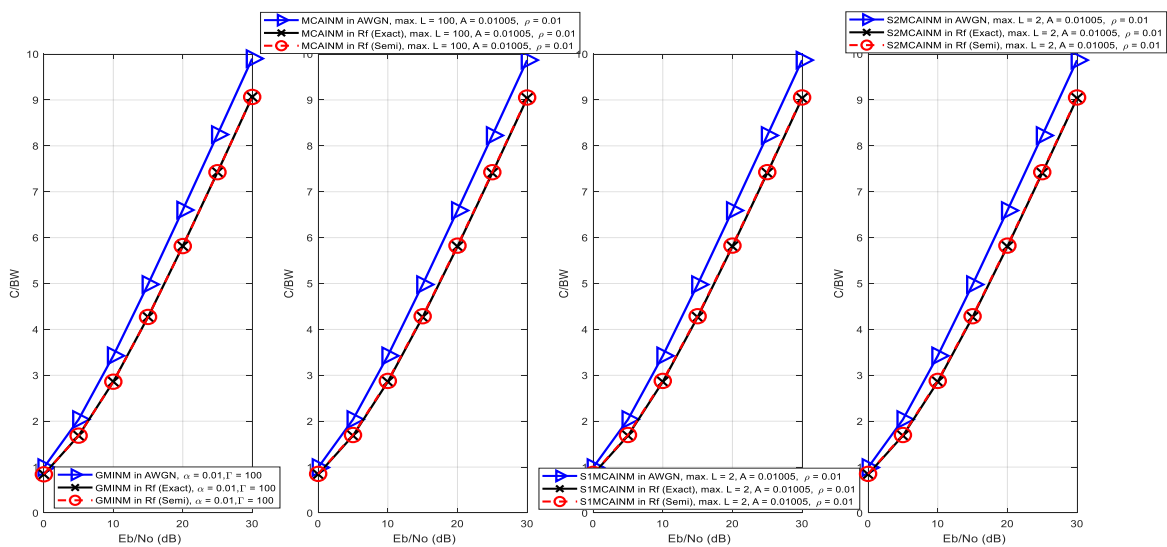


Figure 2. Channel capacity normalized by the BW for $\alpha = 0.01$ and $\Gamma = 100$

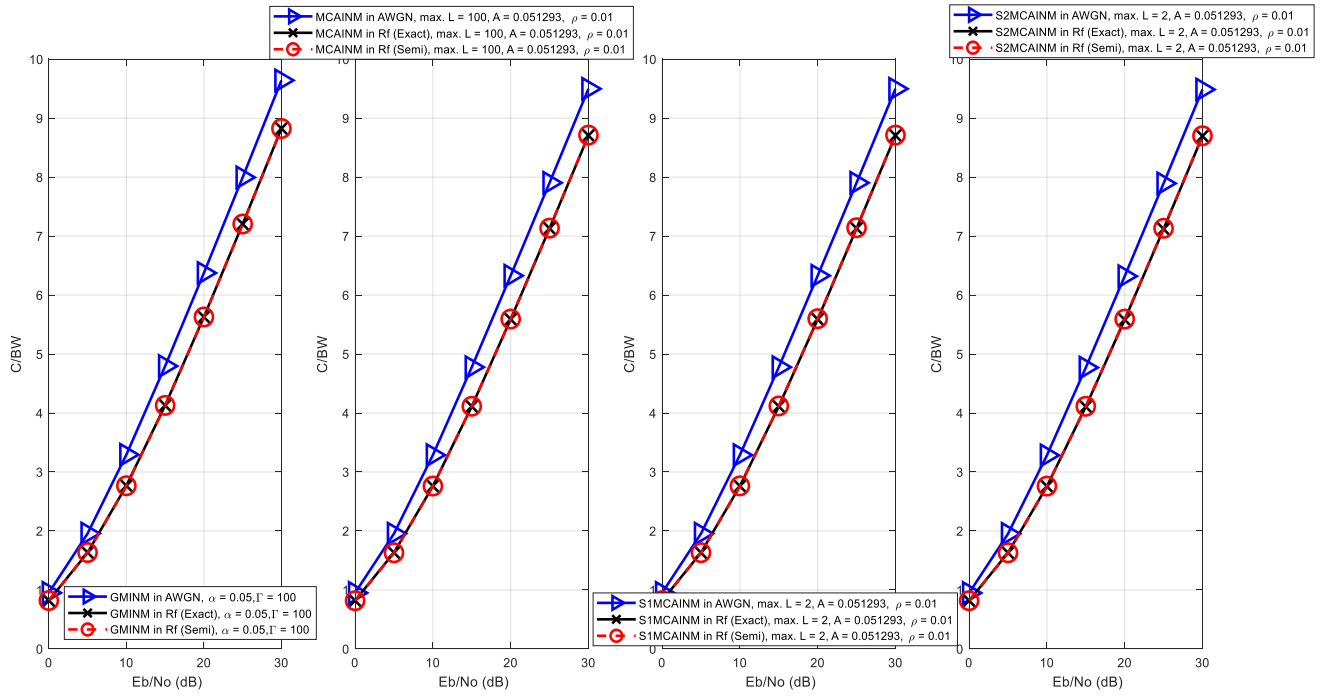


Figure 3. Channel capacity normalized by the BW for $\alpha = 0.05$ and $\Gamma = 100$

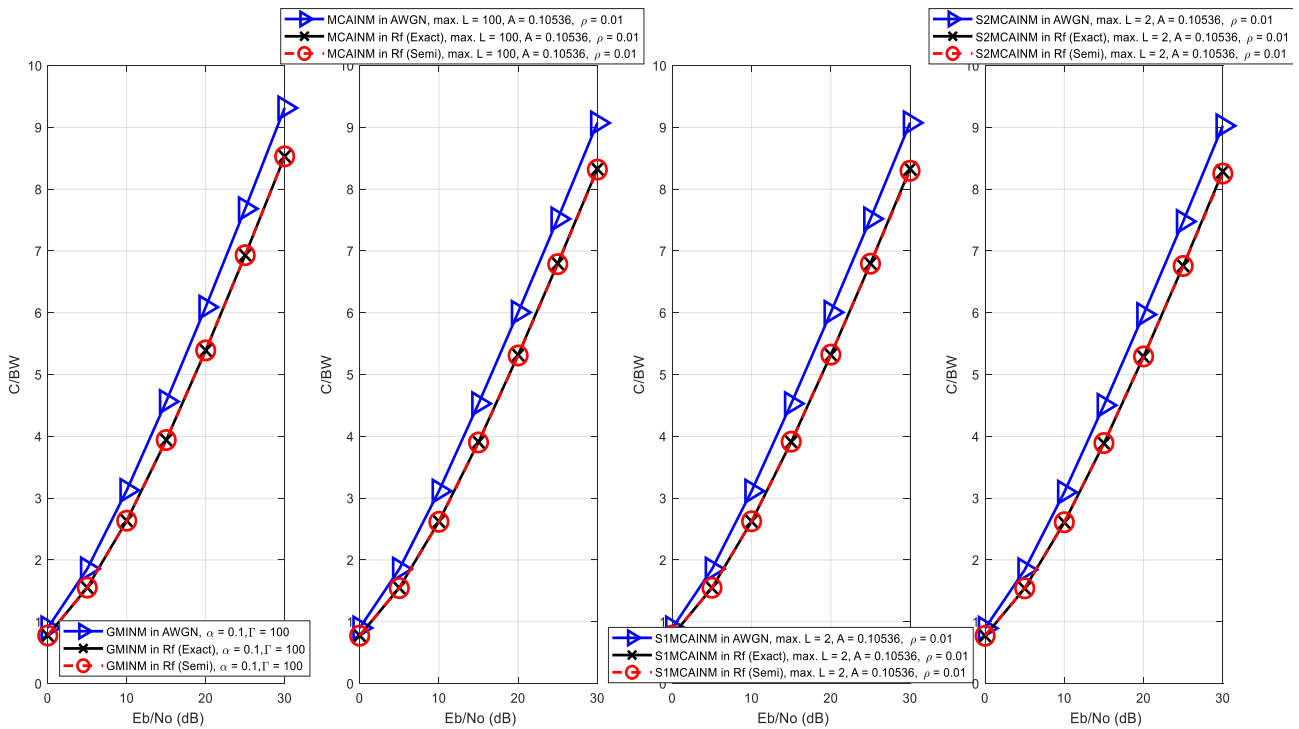


Figure 4. Channel capacity normalized by the BW for $\alpha = 0.1$ and $\Gamma = 100$

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.

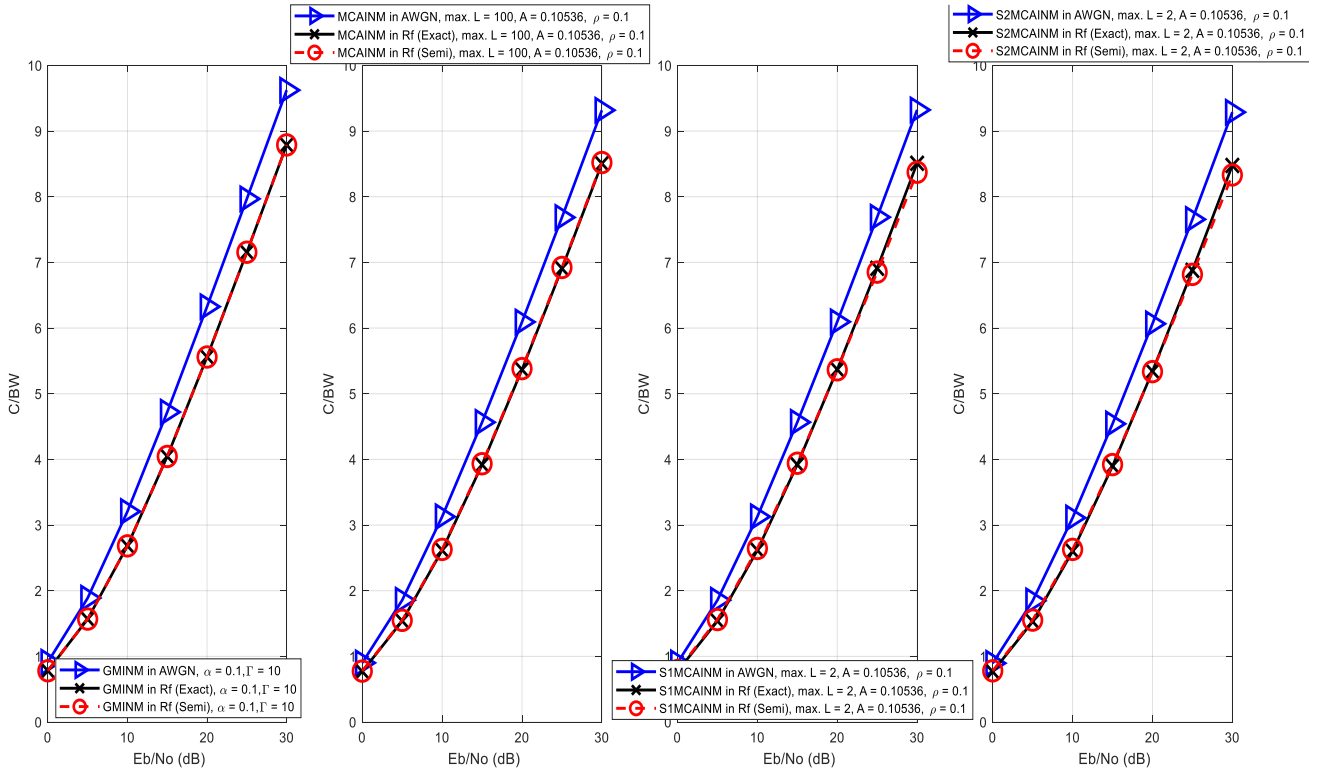


Figure 5. Channel capacity normalized by the BW for $\alpha = 0.1$ and $\Gamma = 10$

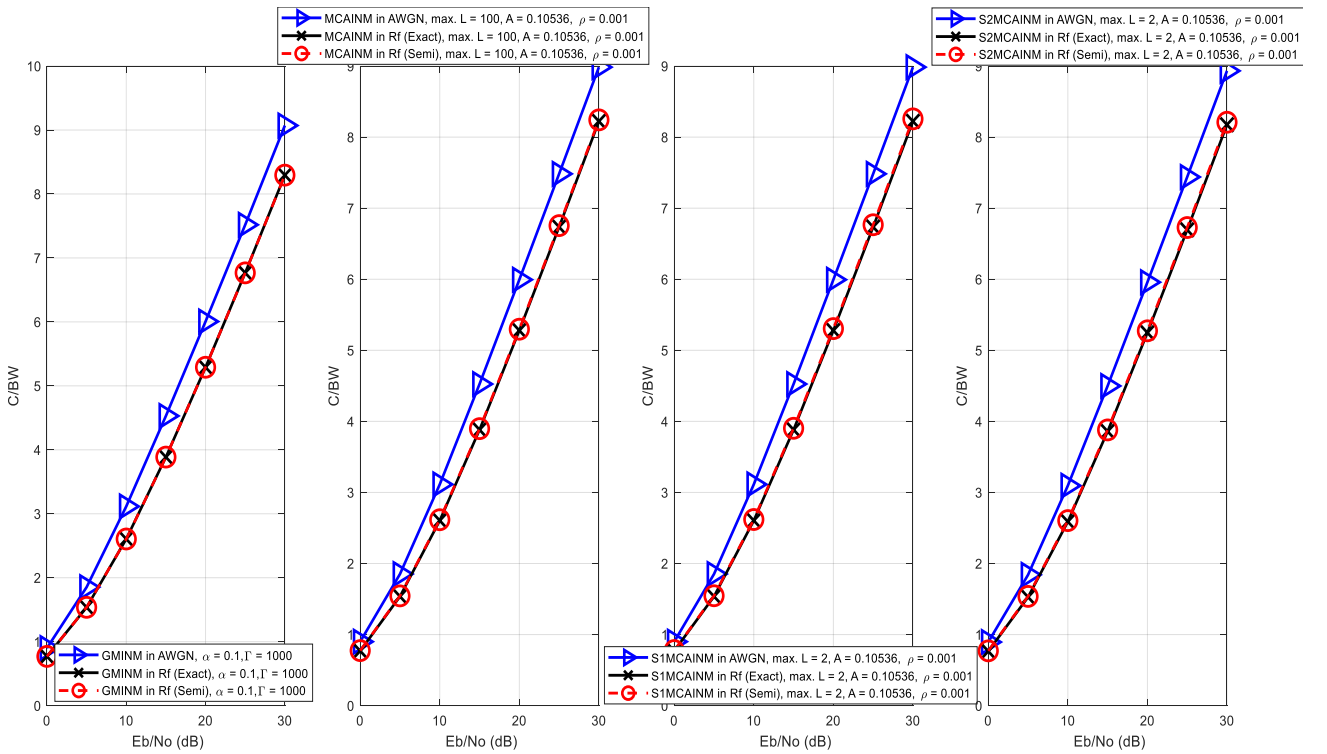


Figure 6. Channel capacity normalized by the BW for $\alpha = 0.1$ and $\Gamma = 1000$.

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 $\alpha = 0.01$ when $\sigma_t^2=100 \sigma_w^2$ which means $\Gamma=100$ in GMINM and $\rho=0.01$ 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.

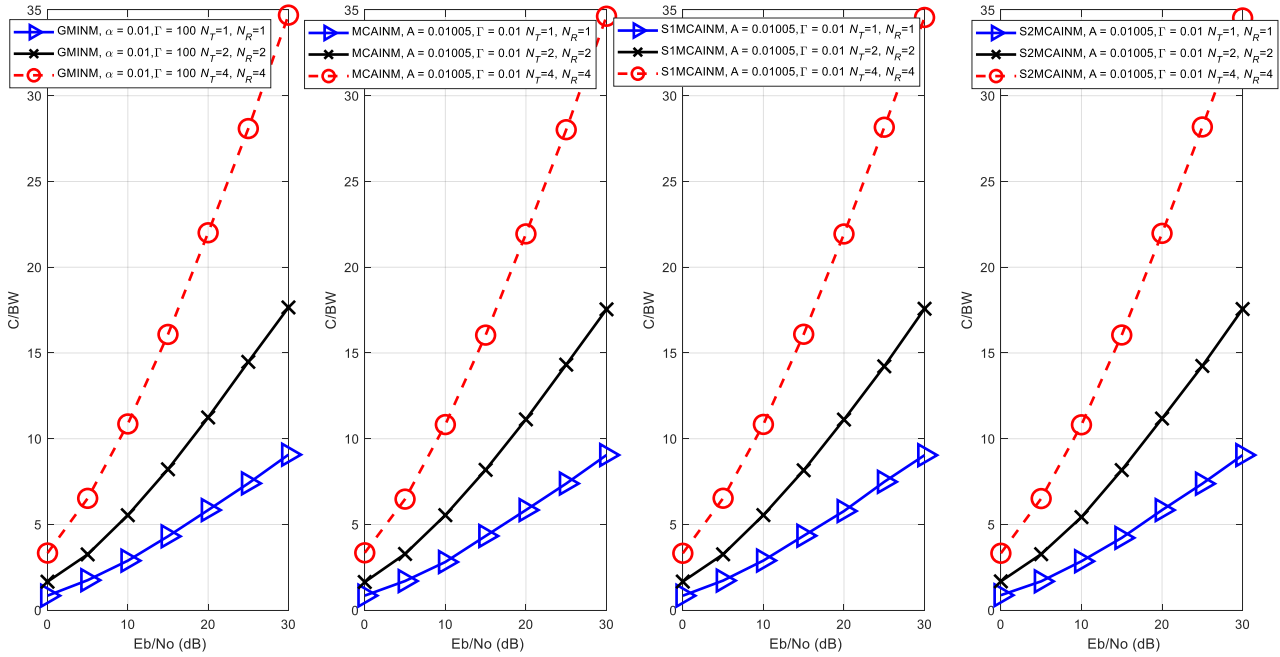


Figure 7. Optimized ergodic capacity normalized by the BW for GMINM, MCAINM, S1MCAINM and S2MCAINM systems for $\alpha = 0.01$ and $\Gamma = 100$

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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References

- [1] H. Hamlili, S. Kameche, and A. Abdelmalek, "A survey on impulsive noise models removal techniques based on adaptive filter in ECG signal," in *2018 International Conference on Electronics, Control, Optimization and Computer Science (ICECOCS)*, 2018: IEEE, pp. 1-6.
- [2] M. Ghosh, "Analysis of the effect of impulse noise on multicarrier and single carrier QAM systems," *IEEE Transactions on Communications*, vol. 44, no. 2, pp. 145-147, 1996.
- [3] L. Clavier, G. W. Peters, F. Septier, and I. Nevat, "Impulsive noise modeling and robust receiver design," *EURASIP Journal on Wireless Communications and Networking*, vol. 2021, no. 1, pp. 1-30, 2021.
- [4] U. Ashraf and G. R. Begh, "Effect of Impulsive Noise on IRS-Aided Communication Systems," *IEEE Transactions on Vehicular Technology*, vol. 72, no. 1, pp. 648-653, 2022.
- [5] C. D. Charalambous, S. Z. Denic, and S. M. Djouadi, "Robust capacity of a Gaussian noise channel with channel and noise uncertainty," in *Proceedings of the 2005, American Control Conference, 2005.*, 2005: IEEE, pp. 1829-1834.
- [6] D. Middleton, "Statistical-physical models of electromagnetic interference," *IEEE transactions on Electromagnetic Compatibility*, no. 3, pp. 106-127, 1977.
- [7] H. Kanemoto, S. Miyamoto, and N. Morinaga, "Statistical model of microwave oven interference and optimum reception," in *ICC'98. 1998 IEEE International Conference on Communications. Conference Record. Affiliated with SUPERCOMM'98 (Cat. No. 98CH36220)*, 1998, vol. 3: IEEE, pp. 1660-1664.
- [8] D. Umehara, H. Yamaguchi, and Y. Morihira, "Turbo decoding over impulsive noise channel," in *Proceedings of the 8th International Symposium on Power Line Communications and Its Applications (ISPLC'04)*, 2004, pp. 51-56.
- [9] N. Andreadou and F.-N. Pavlidou, "PLC channel: Impulsive noise modelling and its performance evaluation under different array coding schemes," *IEEE Transactions on Power Delivery*, vol. 24, no. 2, pp. 585-595, 2009.
- [10] K. Wiklundh, P. Stenumgaard, and H. Tullberg, "Channel capacity of Middleton's class A interference channel," *Electronics letters*, vol. 45, no. 24, pp. 1227-1229, 2009.
- [11] N. Meskin and K. Khorasani, "Fault detection and isolation of discrete-time Markovian jump linear systems with application to a network of multi-agent systems having imperfect communication channels," *Automatica*, vol. 45, no. 9, pp. 2032-2040, 2009.
- [12] C. E. Shannon, "A mathematical theory of communication," *The Bell system technical journal*, vol. 27, no. 3, pp. 379-423, 1948.
- [13] Y. Ma, P. So, and E. Gunawan, "Performance analysis of OFDM systems for broadband power line communications under impulsive noise and multipath effects," *IEEE transactions on power delivery*, vol. 20, no. 2, pp. 674-682, 2005.
- [14] J. Chen, Y. Xie, X. Mu, J. Jia, Y. Liu, and X. Wang, "Energy efficient resource allocation for IRS assisted CoMP systems," *IEEE Transactions on Wireless Communications*, vol. 21, no. 7, pp. 5688-5702, 2022.
- [15] B. Memić, A. H. Džubur, and E. Avdagić-Golub, "Green IoT: sustainability environment and technologies," *Science, Engineering and Technology*, vol. 2, no. 1, pp. 24-29, 2022.

- [16] G. V. Gurram, N. C. Shariff, and R. L. Biradar, "A secure energy aware meta-heuristic routing protocol (SEAMHR) for sustainable IoT-wireless sensor network (WSN)," *Theoretical Computer Science*, vol. 930, pp. 63-76, 2022.
- [17] P. A. Østergaard, N. Duic, Y. Noorollahi, H. Mikulcic, and S. Kalogirou, "Sustainable development using renewable energy technology," vol. 146, ed: Elsevier, 2020, pp. 2430-2437.
- [18] A. J. Goldsmith and P. P. Varaiya, "Capacity of fading channels with channel side information," *IEEE transactions on information theory*, vol. 43, no. 6, pp. 1986-1992, 1997.
- [19] G. A. Al-Rubaye, C. C. Tsimenidis, and M. Johnston, "Low-density parity check coded orthogonal frequency division multiplexing for PLC in non-Gaussian noise using LLRs derived from effective noise probability density functions," *IET Communications*, vol. 11, no. 16, pp. 2425-2432, 2017.
- [20] G. A. Al-Rubaye, C. C. Tsimenidis, and M. Johnston, "Non-binary LDPC coded OFDM in impulsive power line channels," in *2015 23rd European Signal Processing Conference (EUSIPCO)*, 2015: IEEE, pp. 1431-1435.
- [21] G. A. Al-Rubaye, C. C. Tsimenidis, and M. Johnston, "Performance evaluation of T-COFDM under combined noise in PLC with log-normal channel gain using exact derived noise distributions," *IET Communications*, vol. 13, no. 6, pp. 766-775, 2019.
- [22] A. Spaulding and D. Middleton, "Optimum reception in an impulsive interference environment-Part I: Coherent detection," *IEEE Transactions on Communications*, vol. 25, no. 9, pp. 910-923, 1977.
- [23] H. C. Ferreira, L. Lampe, J. Newbury, and T. G. Swart, *Power line communications: theory and applications for narrowband and broadband communications over power lines*. John Wiley & Sons, 2011.
- [24] K. D. Rao, *Channel coding techniques for wireless communications*. Springer, 2015.

