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Article

Channel Model for CM-3 Scenario Over Generalized Distribution Under Various Window Functions

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Abstract: In terms of fundamental research and technology development level, Wireless Body Area Network (WBAN) is a well-established paradigm of wireless system. However, like any wireless system, channel modeling of WBAN is one of the most challenging research eras. Also, literature suggests Channel Model-3, termed as CM-3 scenario based on the positioning of the Nano antenna, is one of the most useful deployment scenarios of WBAN. Further, arrival time and the number of arrivals, which plays an important role in the CM-3 scenario of WBAN, are modeled using the Poisson distribution. However, in Poisson distribution the variance and mean are equal and the probability of success is kept fixed. Hence, the versatility of the channel model based Poisson distribution is limited due to limited parameters. On the other hand, Negative Binomial (NB) distribution with extra parameters is a more general distribution. Therefore, this manuscript employs Negative Binomial distribution to present a more general channel model under the CM-3 scenario. In addition, effects of different windowing techniques, such as Bartlett and Gaussian window, on the channel model are analyzed under both, Poisson distribution and Negative Binomial distributions.

***Keywords*:** negative binomial (NB) distribution, wireless body area network (WBAN), channel model (CM), channel impulse response (CIR), body centric communication (BCC)

1. Introduction

Evolution in the field of Nanotechnology has given a new vertical shift to the existing Body Area Network (BAN). This paradigm shift may be termed as Nano Enabled Body Area Network (NE-BAN), the essential use cases of which includes diseases detection and therapy among the others [1]. In particular, NE-BAN is a Nanotechnology based short-range network developed to establish communication links in the vicinity of the human body. The focus of NE-BAN is within the human body and its immediate surroundings. However, links in NE-BAN are established with the help of wearable Nano devices and/or Nano sensors implanted in the human body. NE-BAN is capable of transmitting continuous information that includes vital physiological data to remote areas for healthcare monitoring or for the assistance of people with disabilities [1]. The NE-BAN is also able to accomplish different complex tasks with the help of a variety of Nano-devices [2,3]. Catheterization and endoscope of delicate tissues of the body such as the spinal cord, human eye or gastrointestinal are few among them [2]. It is worthwhile to mention Graphene and Carbon Nanotubes (CNTs) are the basic building blocks of the NE-BAN at THz and sub THz band [4–6].

Further, in NE-BAN, like in any wireless system, channel or wireless medium through which communication takes place is always an open end and may cause different impairments such as fading,

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interference, and noise. In NE-BAN, a total four channel model for seven possible scenarios (listed below in Table 1) [7] have been proposed by IEEE-802.15. Channel Models-3 (CM-3) is one of them. Out of CM-1 to CM-4, CM-3 is the most important as it is based on wearable Nano devices used for various observations of different bodily functions. Also, a number of channel models for CM-3 scenarios has been presented by different authors in literature. It is most important to mention that arrival time and the number of arrivals plays a ubiquitous role in the CM-3 scenario of WBAN [7]. In particular, for dynamic scenarios consideration of arrival time and the number of arrival is essential [8–12]. According to [8] the position of Tx/Rx and the movement of objects are factors in channel modeling. Authors in [9] present an optical channel model for medical WBAN considering both local and global mobility of the patient. Also, [10] and [11] respectively present the effect of Rician K-factor and running/walking on path loss. Whereas, authors in [12] present users mobility along with position and orientation of Tx/Rx.

Table 1. Possible Scenarios of NEBAN

Channel Model	Description	Scenario
CM(1)	Implant to Implant	S-1
CM(2)	Implant to Body Surface	S-2
CM(2)	Implant to External	S-3
CM(3)	Body Surface to Body Surface (LOS)	S-4
CM(3)	Body Surface to Body Surface (NLOS)	S-5
CM(4)	Body Surface to External (LOS)	S-6
CM(4)	Body Surface to External (NLOS)	S-7

However, as per our best knowledge in literature, Poisson distribution is used to find the arrival time and the number of arrivals in the channel model of CM-3 scenario. But, in Poisson distribution, the mean and variance are assumed to be equal and the probability of success is kept fixed. This, in turn, limits the versatility of the channel model based on Poisson distribution. On the other hand, Negative Binomial (NB) distribution is a generalization of Poisson distribution with extra parameters. In particular, NB distribution includes a variable number of trials and is suitable to model a scenario with rare, moderate and high occurrences of the events. Whereas, in case of Poisson distribution, the number of trials are fixed with only rare occurrences of the event [10]. Therefore, in this manuscript Negative Binomial (NB) distribution is used in place of Poisson distribution to represent arrival time and the number of arrivals. In addition windowing techniques such as Bartlett and Gaussian windows are used to analyze the channel model under CM-3 scenario. It is noteworthy to mention that without loss of generality, in this manuscript only LOS of CM-3 scenario, which is basically S-4 scenario, is considered for numerical simulation.

Further, the major contributions of this research are as follows.

- Presents a system model for NE-BAN under the CM-3 model in which Nano antennas are placed on the body surface.
- Negative Binomial (NB) distribution is proposed as a generalization of Poisson distribution to represent arrival time and the number of arrivals.
- Bartlett and Gaussian windows are used to analyze the CIR under both distributions using different physical parameters.

Further, the manuscript is organized as follows. Introduction is presented in section 1. Detailed related work is presented in section 2. Brief of the presented system model is presented in section 3. Whereas, section 4 presents numerical discussion. Finally, section 5 concludes the manuscript.

2. Related Research

There are ample literatures in which location of Tx/Rx and dynamics of patient/object have been considered [8–20]. In addition, most of them include arrival time and the number of arrivals in the respective model of channel for WBAN.

It is observed that the position of Tx/Rx and the movement of objects, where they are placed, are key factors influencing the dynamic behavior of the channel model [8]. Authors in [8] present effect of different sensors and hubs on data transmission and receptions to ensure faithfulness of WAN in tracking and data delivery. Authors in [9] present OCM for medical WBAN employing a set of medical sensors and a node. CIR is proposed under 3-dimensional deployment considering both local and global mobility of the patient. Various first order and second order metrics are presented.

Also, authors in [10,11] present the effect of dynamic behavior of different objects on the channel modeling. In [10] authors have utilized the Rician K factor to characterize path loss and multipath of dynamic channel models. Whereas, authors in [11] present the effect of running and walking on path loss considering location of Tx/Rx at waist to chest, waist to knee, waist to wrist and waist to head. Authors in [12] present OCM considering users mobility along with position and orientation of Tx/Rx. Also, authors in [13–15] present an analysis of UWB-BAN considering different aspects of the channel for WBAN. Authors in [13] have addressed Quality of Service (QoS) by employing decomposable codes. Whereas, [14] have analyzed transmission failure ratio and energy efficiency under Super-Orthogonal Convolutional Codes (SOCC). And authors in [15] present performance to cost analysis for WBAN. Further, Authors in [16], present the outage probability of the Cognitive Relay Network in presence of interference under Amplify and Forward (AF) relay. It is noteworthy to mention that a dynamic scenario is considered in which a single Secondary User-Destination (SU-D) is mobile at a high vehicular speed. Whereas, the Secondary User-Source (SU-S) and Secondary User-Relay (SU-R) are kept fixed. It is noteworthy to mention that Rayleigh fading channel and Nakagami-m fading channel are employed for stationary and dynamic nods respectively. Various parameters such as location of Primary Users (PU), speed of SU, number of relays and severity of the fading channels have been included in the analysis. In sequence [17] presents various performance measures over κ-μ fading channel, which shows better fit to measured data, for outdoor scenarios. It is very important to mention that authors in [17] employ Fluctuating Multiple Relay (FMR) in contrast to normal relay employed in [17].

It is noteworthy to mention that recently, literature has presented Optical Channel Models (OCM) towards development of Optical WBAN. There is a plethora of literature focusing on OCM for WBAN. Authors in [18,19] present Channel Impulse Response (CIR) for indoor static channel models. Whereas, authors in [20] consider time varying OCM to present CIR taking different dynamics into consideration and suggest that Rayleigh and Gamma distributions are suitable distributions under LOS and diffuse components respectively. Authors in [21] presents OCM considering users mobility along with position and orientation of Tx/Rx as uniform distribution. Whereas, the body of the patient was considered as a rectangular deployment. Recently, authors have proposed Monte Carlo Ray-Tracing (MCRT) approach to model OCM considering extra WBAN channel characterizations [22].

CM-3 for Body surface communication, be it Line of Sight (LOS) or be it Non-Line of Sight (NLOS), in the frequency band 400, 600, 900 MHz & UWB is presented in [7]. Path loss under the CM-3 scenario is modeled using Log-normal distribution [23]. It is depicted from [7] that Rayleigh distribution is not appropriate to the model of multipath propagation under UWB due to the existence of a large number of multipath components. Further, it is suggested that to overcome the limitations Log-normal and non-Rayleigh distribution can be used. Authors in [24] demonstrated that Nakagami distribution is equally applicable as Log-normal distribution in [7] for modeling. Also, measurements in [24] appeal to the requirement of diverse channel modeling to represent fading and time of arrival of multipath components in the case of UWB and narrowband. It is shown in [25] that for the modeling of multipath under UWB the Rayleigh distribution is not appropriate due to the existence of a large number of multipath components. Further, it has been suggested that to overcome the limitations Log-normal distribution and non-Rayleigh fading may be used. Rayleigh, Normal, Lognormal, Rician, Nakagami-M Weibull, Gamma and Kappa-Mu distributions are found suitable in WBAN [26–31]. Also, the authors in [27] suggest that the Log-normal distribution gives the best fit to the measured data. In [32], it is mentioned that the Finite Integration Technique (FTT) emerges as a promising technique for the realistic modeling of on-off body communication channels. In [33], the effect of the frequency band, body size and the environment on the path loss are studied. In [34], CIR under different kinds of room volumetric conditions is evaluated using the discrete binomial, negative binomial and Poisson distributions to represent the statistical delay [35]. Further, it is observed that the Negative Binomial distribution comes out to be the most suitable distribution among them. In [36,37], Negative Binomial distribution is used to represent the total excess delays. Data loss due to channel impairment is studied in [38] and the IKA algorithm is proposed to overcome the impairments. The authors in [39] discourse that the unimodal, like Lognormal and Gamma distribution, does not suitably represent the real scenario well and propose the Lognormal mixture distribution as an alternative.

Finally, in [23], amplitude, arrival time, the phase between the two antennas and the number of arrival paths are used to represent the Power Delay Profile (PDP) of the UWB system. However, it is noted that arrival time and the number of arrivals both are modeled using a Poisson distribution which may not appropriately represent a real scenario. This is so, as in Poisson distribution the mean and variance are assumed to be equal and the probability of success is kept fixed. Further, in [23], Hamming window is used for side lobe suppression, which only has the side lobe suppression of 41dB. In contrast, this paper replaces Poisson distribution with Negative Binomial distribution, used to model the path arrival time and the number of arrivals. Negative Binomial distribution not only introduces probability of success as an extra parameter but removes the constraint on mean and variance as well. In other words, Negative Binomial distribution provides not only generalization over Poisson distribution but includes one extra parameter as the probability of success. Further, as mentioned above the Hamming window provides side lobe suppression up to 41 dB which is not suitable for various applications as more is side lobe suppression, higher is the detection of more multipath components [23]. So, this paper applies Gaussian Window and Bartlett Window for better side lobe suppression.

3. System and Channel Model

In the CM-3 scenario which is body surface to body surface communication, the transmitter, as well as receiver antennas, are located on the surface of the body, at most 2 cm above the human skin. In the CM-3 scenario, both LOS and NLOS are possible as shown in Figure 1. The link between 'A' and 'B' is a LOS while that between 'B' and 'C' is an NLOS communication. Output power is set to a maximum of 25 µW ERP. While, according to FCC & ITU-R, the output power is set to a maximum of 25 µW EIRP, which is ≈ 2.2 dB lower than the ERP level [21]. However, without loss of generality, in this manuscript only LOS of CM-3 scenario, which is basically S-4 scenario, is considered for numerical simulation.

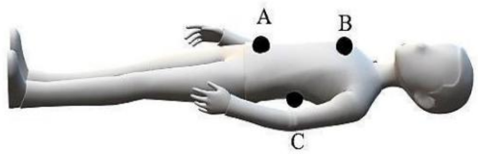

Figure 1. Model for showing antenna positions in the CM-3 scenario

Various parameters used for simulation are listed in the numerical section. However, setup for measurement includes the following apparatus/device. Vector Network Analyzer (VNA) over GHz frequency band, SDR Transmitter of frequency range: 100 MHz – 6 GHz and maximum bandwidth of 56 MHz, spectrum analyzer of frequency range: 15 – 2700 MHz and 4850 – 6100MHz, Ultra Wideband Band (UWB) Antennas and SMA Cables.

The Power Delay Profile (PDP) is modeled as [23]

$$h(t) = \sum_{l}^{L-1} \left(e^{j\phi_l} \delta(t - t_l) a_l \right) \tag{1}$$

where, a_l , t_l, and L denotes (each for l[th] path) the path amplitude, path arrival time and the number of arrival paths respectively. Also, ϕ_l denotes the phase of l[th] path which is modeled by a uniform distribution for $[0,2\pi)$ and $\delta(t)$ denotes the Dirac delta function. The path amplitude is given by exponential decay factor D with Rician factor γ_0

$$10\log_{10} |a_l|^2 = \begin{cases} 0, & l = 0 \\ 10\log_{10} e^{\frac{-t_l}{D}} + S + \gamma_0, & l \neq 0 \end{cases} \tag{2}$$

where, S is a statistical term modeled by log-normal distribution. It is noticeable that the arrival time and number of arrival [(6) and (7) in [23] are modeled by Poisson distribution. On the other hand, in [36,37], Negative Binomial distribution turns out to be the best out of Poisson, Binomial and Negative Binomial distribution for statistical delay modeling. So, in this paper, we replace Poisson distribution with Negative Binomial distribution to model arrival time and the number of arrivals. The probability mass function of Negative Binomial distribution is given by [40]

$$P(r,p) = \begin{cases} \dfrac{r+x+1}{x} p^r (1-p)^r, & r : Z \\ \dfrac{\Gamma(r+x)}{\Gamma(x)\Gamma(r+x)} p^r (1-p)^r, & r : R \end{cases} \tag{3}$$

where, r is the number of success and p is the probability of r success. Also, r could be an integer or real numbers. In (3), for $r : Z$ (integers), the upper equation is valid and for $r : R$ (real number), the lower equation is valid and $\Gamma(.)$ denotes the Gamma function given as

$$\Gamma(x) = \int_0^\infty t^{x-1} e^{-t} dt \tag{4}$$

Finally, it is noteworthy to mention that in [21], Hamming window having side lobe suppression of 41 dB is used to model the CIR under the CM-3 scenario. In contrast, this paper presents the CIR of CM-3 scenarios under different window functions such as Gaussian window [Eq. 5.22, 41] and Bartlett window [Eq. 3.4, 41] given by Eq. (5) and Eq. (6) respectively.

$$W(t) = e^{-\frac{1}{2}\left(\alpha \frac{2t}{\tau}\right)}, \quad 0 \le |t| \le \frac{\tau}{2} \tag{5}$$

where, α is the shaping parameter and τ is the window length or duration.

$$W(t) = \begin{cases} 1 - \frac{|t|}{\tau}, & |t| \le \tau \\ 0, & \text{elsewhere} \end{cases} \tag{6}$$

where, τ is the window length or duration.

4. Numerical Results

This section discusses the simulated results of the proposed work i.e., CIR for NE-BAN system under the CM-3 scenario using MATLAB-14. The CIR is simulated for which the arrival time and number of arrival both are modeled by Poisson distribution and Negative Binomial distribution. Also, CIR is analyzed under different window functions such as using Hamming, Gaussian and Bartlett windows. It is noteworthy to mention that we have also taken Poisson distribution with different window techniques. However, as in every simulation input data is random and therefore numerical comparison is not possible. Even so, presented numerical analysis shows the versatility of the proposed Negative Binomial distribution and different windows such as the Hamming, Gaussian and Bartlett window.

Table 2 shows the list of parameters used for simulation [23].

Table 2. List of parameters used in the simulation

Channel paths	100
Number of arrival paths	20
Standard deviation of amplitude	5.94 dB
Decay factor	61.3 ns
Rice factor	−3.3 dB
Time difference of neighboring path	6.18 ns
Sampling interval	5.0125 ns

Figure 2 shows the graph of amplitude vs the number of channel paths for CIR under the CM-3 scenario, CIR described in [21] is reproduced in Figure 2, in which path arrival time (t_l) and the number of arrival paths (L) both are modeled using Poisson distribution.

However, Poisson distribution in [21] is used for the modeling of arrival time and number of arrival for CIR analysis, which does not satisfy the practical scenario. It is so because in Poisson distribution the mean and variance are assumed to be equal while keeping the probability of success as small as possible with a large number of trials [42].

Whereas, the number of arrival and probability of success in Negative Binomial distribution makes it not only generalized but also make it suitable for real scenarios. This is so because NB distribution includes an additional parameter and the Poisson distribution is deduced from NB distribution as a special case of it. Keeping the above fact in mind, CIR is analyzed using Negative Binomial distribution in Figure 3, which includes both the number of arrival paths and path arrival time. The number of arrival paths and probability of success (probability of arrival path) is taken as 30 and 0.04 respectively in Figure 3.

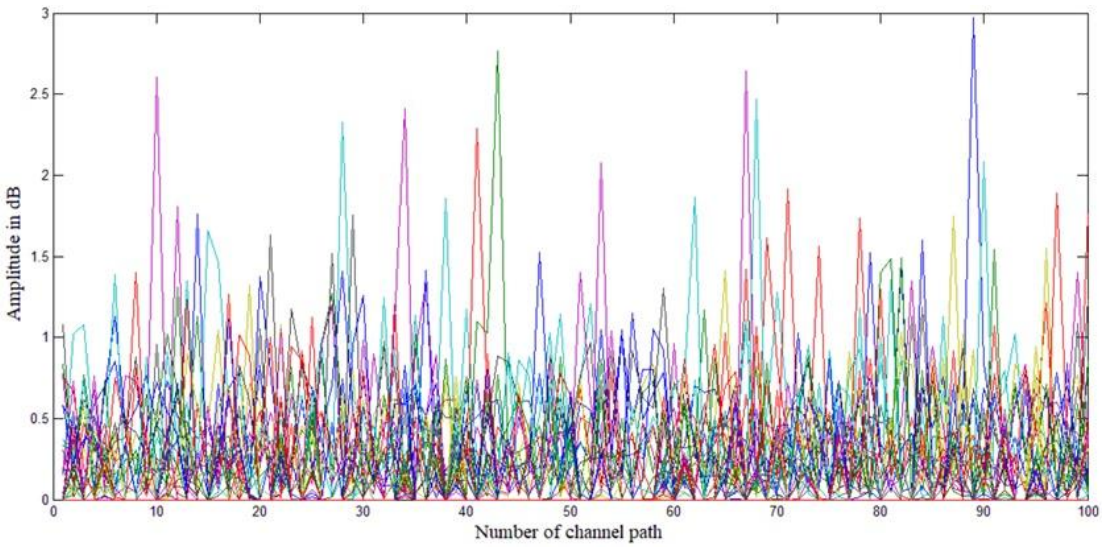

Figure 2. CIR for CM-3 scenario as a function of the number of channel paths considering Poisson distribution

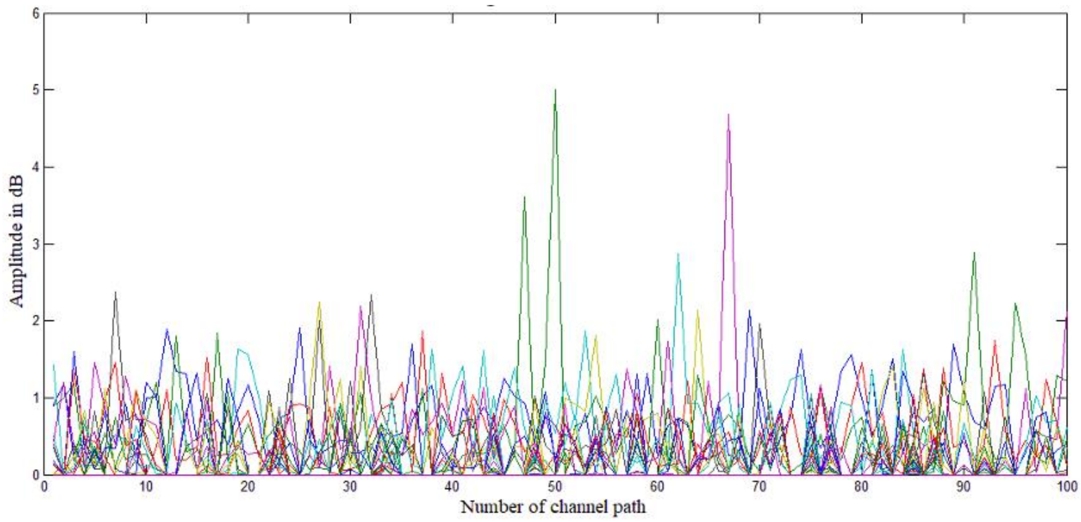

Figure 3. CIR for CM-3 scenario as a function of the number of channel paths considering Negative Binomial Distribution

In Figure 4, the CIR under Negative Binomial distribution is analyzed for the different probability of success such as 0.9, 0.1 and 0.03 with a fixed number of arrival paths as 20.2. With the inclusion of probability of success in Negative Binomial distribution, the model became more realistic. It is also observed that with the decrease in the probability of success the overall amplitude of the Impulse responses decreases. This justifies the theoretical background.

The classical hamming window provides 41 dB sidelobe suppression which is less compared to the sidelobe suppression achieved by other windows like Blackman, Bohman, Gaussian, Bartlett window. Sidelobes play an important role in any communication system, as larger sidelobes result in lower amplitude/density of information contained in the signal. Hence, it is necessary to reduce the sidelobes as much as possible. Thus, in this research work different window functions namely, the Gaussian window and the Bartlett window are employed in the CIR analysis of the CM-3 scenario. From Figure 5 and Figure 6, it is observed that for given sets of parameters Gaussian and Bartlett window function produces better results than Hamming window function.

First of all, from Figure 2 (CIR under Hamming window in case of Poisson distribution) and Figure 5 (CIR under Gaussian window in case of Poisson distribution), it is clear that the Gaussian window outperforms over Hamming window in terms of the amplitude of the CIR. Likewise, from Figure 2 and Figure 6, the Bartlett window also outperforms over Hamming window in terms of the amplitude of the CIR.

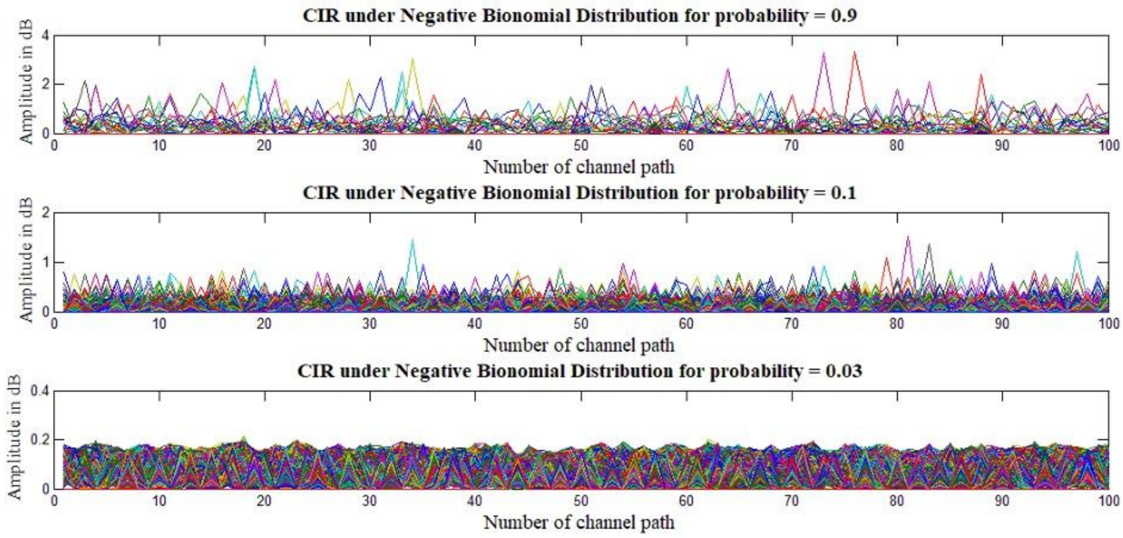

Figure 4. CIR for CM-3 scenario considering Negative Binomial for the different probability of success

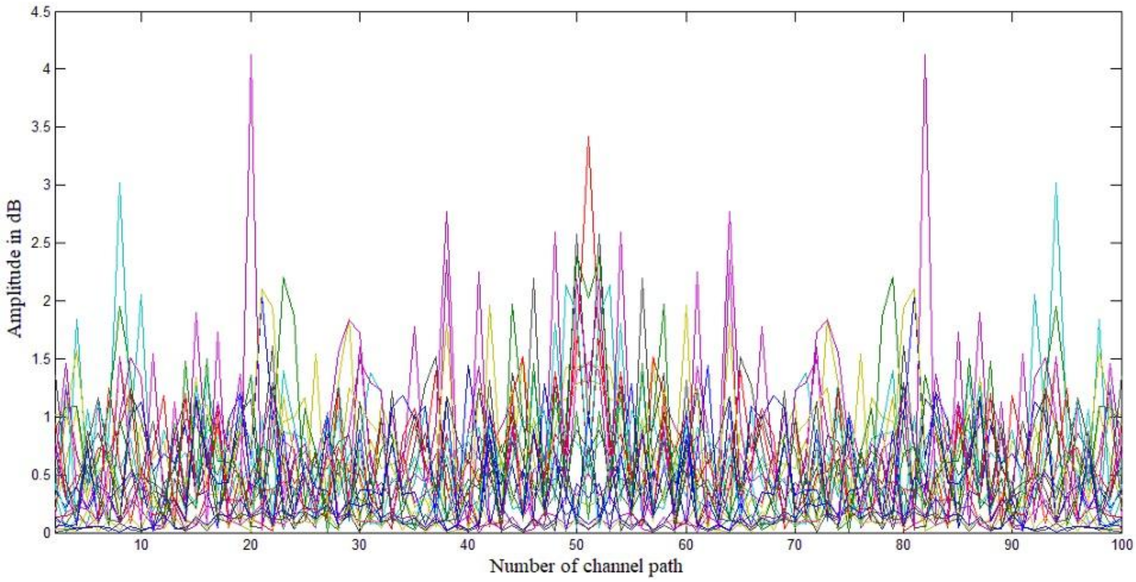

Figure 5. CIR under Poisson Distribution for Gaussian window function

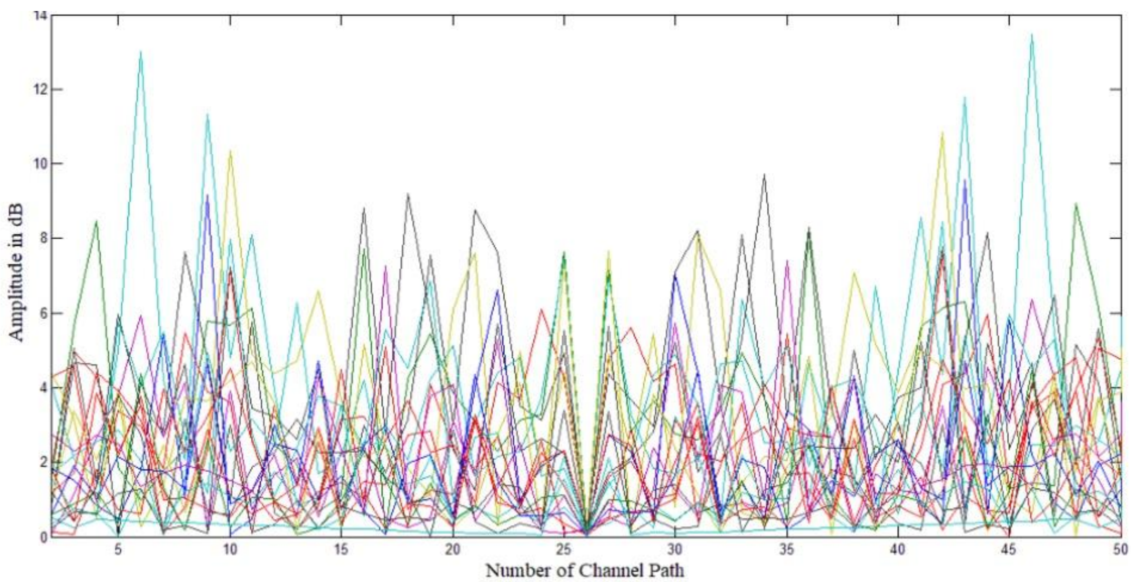

Figure 6. CIR under Poisson distribution for Bartlett window function

CIR analysis under Bartlett and Gaussian window is presented in Figure 7 and Figure 8 respectively for the case of NB distribution. From Figure 3, Figure 7, and Figure 8 the following observations are made. First, in the case of NB distribution too, for a fixed probability of success, both the Gaussian window and Bartlett window outperform over the Hamming window. Second, in the case of NB distribution, for a fixed probability of success Bartlett window is the best choice among the Gaussian window and Hamming window.

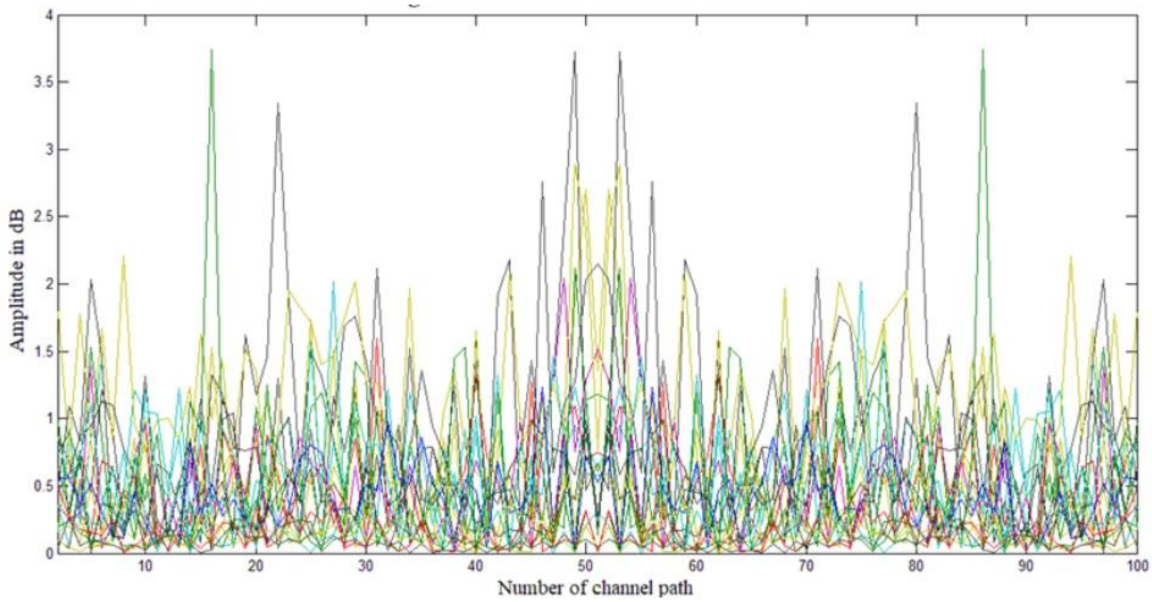

Figure 7. CIR under Negative Binomial Distribution for Gaussian window function

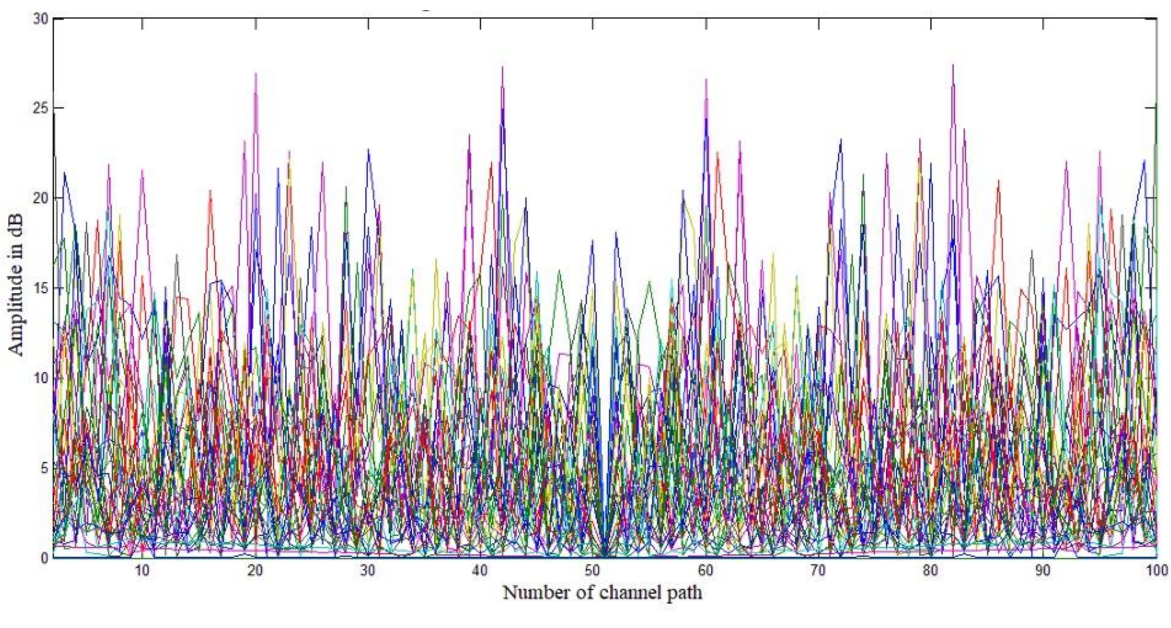

Figure 8. CIR under Negative Binomial Distribution for Bartlett window function

From Table 3, following may be observed that Bartlett windows outperform over all the windows under consideration. For given distribution and window parameters as probability of success increases, the average value of CIR increases. For Poisson distribution with a given set of parameters Gaussian window outperforms Hamming window function.

Table 3. Comparison Table with Numerical Quantification

Type of Distribution	Type of Window	Probability of Success	Average Value of CIR (dB)
Poisson	Hamming	0.04	0.682
Negative Binomial	Hamming	0.9	1.12
Negative Binomial	Hamming	0.1	0.89
Negative Binomial	Hamming	0.03	0.16
Poisson	Gaussian	0.04	1.37
Negative Binomial	Gaussian	0.04	1.35
Negative Binomial	Bartlett	0.04	14.29

5. Conclusions

Channel model of the Nano Enabled BAN under the S-7 scenario of CM-3 deployment was carried out in this research work. More general distribution has been used to represent the number of arrival paths and path arrival time to analyze the CIR for the scenario under consideration. In particular, Negative binomial distribution, with an extra parameter, has been utilized to overcome the shortcomings of Poisson distribution. Also, the effect of different window functions was presented. It was observed that in either Poisson distribution or negative binomial distribution the Gaussian window outperformed the Hamming window whereas the Bartlett window outperformed the Gaussian window. The most appealing insight that can be drawn from the presented result includes; for fixed window function probability of success is the most important parameter for CIR. Whereas, for a given probability of success window function plays a key role for CIR. However, the effect of window function on CIR is very much dominating. Even Though, sufficiently large set of experiments data have been used in numerical analysis. However, a more sophisticated experimental set up may be used for better efficacy. On the other hand, application of different window functions in the fractional Fourier domain to find optimal fractional order can be the future scope of the work.

Conflict of Interest

There is no conflict of interest for this study.

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