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Radiation Signals Transmission over Wireless Multimedia Sensor Networks

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ABSTRACT

Radiation signals from radioisotopes can be utilized to identify information within industrial systems. The radiation exposure is the main challenge of employing these methods. The goal of this work is to reduce radiation exposure by introducing an effective method for transmitting these radiation signals over mobile wireless communications channels. The proposed techniques leverage randomizing data tools and error control mechanisms to improve the transmitted signals performance and quality, even in the presence of noise. The work employs various metrics, such as Bit Error Rate (BER), Number of Lost Packets percentage (NLP), and Throughput (T), to evaluate the error performance of the proposed techniques. Additionally, the quality of the received radiation signals is assessed using the Correlation coefficient (Cr) and Mean Square Error (MSE). Reed Solomon codes are utilized to encode the transmitted packets.The effectiveness of the proposed radiation signal transmission scenarios is investigated through computer simulations, considering mobile terminal different velocities. The experimental results demonstrate the superior performance of the presented transmission scenarios for radiation signals.

1. INTRODUCTION

Applications for radioisotopes in several fields in industry, military, medicine, agriculture, and the environment [1]. The system is exposed to or injected with a radiotracer, and the radiation signals are monitored using a radiation monitoring detector [2]. These signals are utilized to identify the behavior of the system. Examples of industrial applications are; Measurements of residence time distribution (RTD) [3], mixing time, flow rate, and the identification of obstructions or leakage in underground pipelines or the identification of heat exchanger leakage, as well as the scanning of distillation columns using radioactive gamma sources [4]. The main benefits of employing radioisotopes in the industrial field are; the high sensitivity, and the capability of the online detection [5]. These advantages make the radioisotopes can be solve several problems in the industrial system and hence reduce the manufacturing costs and increase the product quality which considered a main objective of Sustainable Development Goals (SDGs) objectives.

Wireless Multimedia Sensor Networks (WMSNs) enable real-time multimedia applications such as; video surveillance, environmental monitoring, and healthcare systems. However, the transmission of radiation signals over WMSNs is challenging due to the sensitivity of these signals to interference, noise, and signal attenuation. Despite these challenges, the development of WMSNs has created new opportunities for real-time surveillance and transmission of radiation signals, which are critical for ensuring the safety of workers and the public in hazardous environments. Early detection of potential hazards is essential for timely response, and WMSNs offer a promising solution for radiation surveillance. However, efficient techniques need to be developed to optimize network performance, including routing, reliable transmission, and low-latency communication, particularly for the high bandwidth requirements of radiation signals.

Because these networks are wireless as shown in figure 1, they are subjected to several security threats, such as eavesdropping, tampering, and denial-of-service

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attacks. It is crucial to ensure the security of WMSNs to safeguard the privacy and the transmitted data integrity. To achieve this goal, numerous security mechanisms, including encryption, authentication, and intrusion detection, have been proposed and implemented in WMSNs. These security measures serve to prevent unauthorized access, detect and respond to attacks, and preserve confidentiality and data integrity.

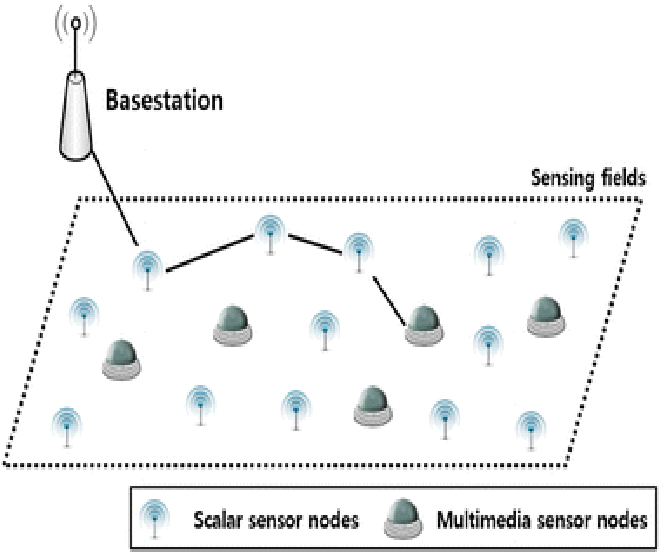


Fig. (1): Wireless multimedia sensor networks

Nevertheless, transmitting radiation signals over these networks can be challenging due to multiple factors. Radiation signals are highly susceptible to interference, noise, and signal attenuation, all of which can adversely impact their transmission quality and dependability. As a consequence, effective techniques must be developed to enhance network performance and ensure dependable transmission.

There are many achieved results related to the WMSN performance and security challenges; (Banerjee et al., 2019) [6] have proposed compression techniques for multimedia data that save energy in Wireless Sensor Networks (WSNs).Their method involves using a curve-fitting technique, which is particularly useful for post-disaster situations, where image capturing of the affected area is necessary. Different categories, requirements, and features of compression are discussed in (Lungisani et all 2022) [7] as shown in figure 2. Meanwhile, (Jan et al., 2019) [8] presented Seamless and Authorized Streaming framework for a hierarchical WSN provides a secure and seamless multimedia streaming experience. Additionally, (Poornima et al., 2020) [9] develop an Online Locally Weighted Projection Regression (OLWPR) technique for anomaly detection in WSNs.

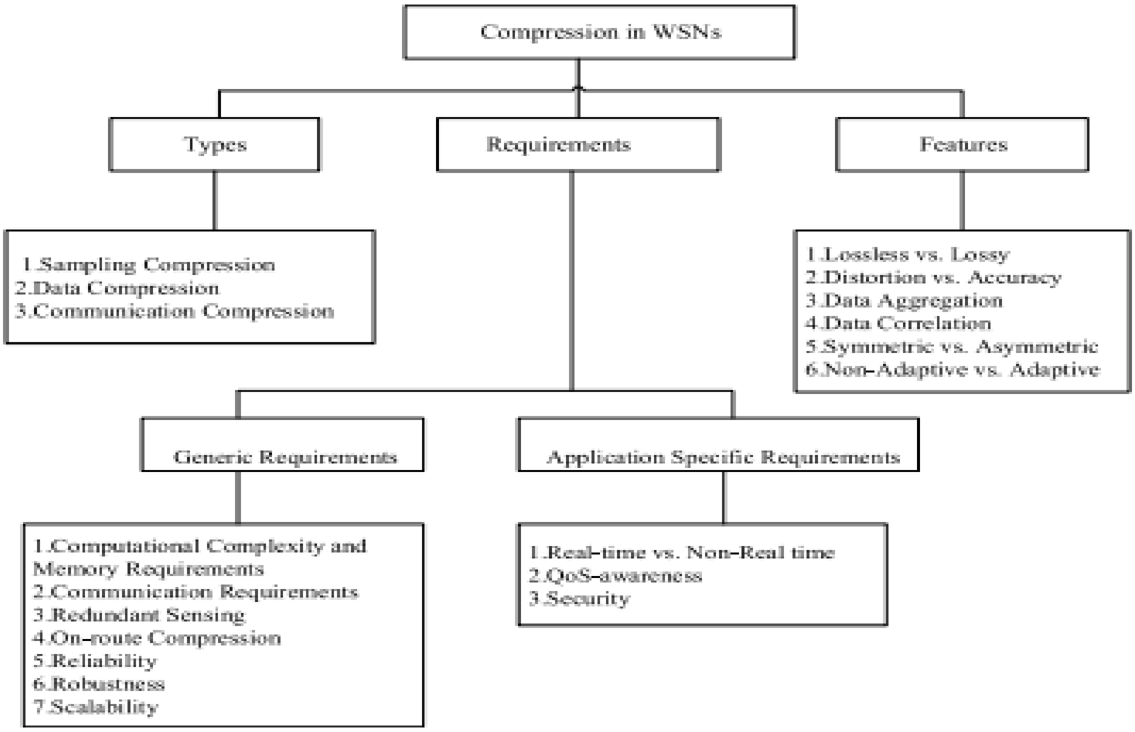


Fig. (2): Compression in WSNs types, requirements, and features summary

In a different study, (Yisa et al., 2021) [10] review literature on security challenges and attacks on underwater wireless sensor networks and possible mitigative solutions. (Dangana et al., 2021) [11] Provide an insight into Narrow-Band IoT (NB-IoT), Industrial IoT (IIoT), and WSN in indoor industrial environments. A significant security-level challenge in WBANs is investigated in [12]. Notably, (Zam et al., 2020) [13]have also made influential contributions to the field of Wireless Sensor Networks.

(Beckman et al., 2018) [14] estimated the Spinus phylogeny using over 45,000 SNPs using analytical methods 4 very contradictory topologies were recovered. In another study, (Stefanescu et al., 2019) [15] proposed a robust sensor network design optimized for detecting radiation sources in urban environments. Meanwhile, (Luo et al., 2019) [16]demonstrated Valosin Containing Protein (VCP) can improve the sensitivity of radiation detection in Esophageal Squamous Cell Carcinoma (ESCC) cell lines, suggesting the VCP potential as a prognostic marker for ESCC treated with radiation therapy. (Turner et al., 2019) [17], reviewed smartphones ability to Ultraviolet (UV) radiation detection and their potential for use in UV research. Despite significant advances in research on the effects of UV radiation on life on Earth, measuring the radiation is still challenged due to dosimeters limitations. (Pushpavanam et al., 2020) [18] Developed a novel colorimetric plasmonic gel Nano-composite for detecting therapeutic radiation levels in electron beam therapy. A demonstrated cost reduction and enabled intelligent data management through IoT using ThingSpeak in environments is discussed in [19]. Additionally, a novel approach to tackling Total Ionizing Dose (TID) effects using machine learning to consume the Field Programmable Gate Arrays (FPGAs) to monitor and replace them before they stop working, rather than relying on expensive radiation-hardened devices is presented in [20]. Other notable contributions to the field are included in [21-24].

This research paper focuses on enhancing the efficiency of transmitting radiation signals through mobile wireless links by improving the signals immunity. The proposed approach involves utilizing randomized encoded packets and employing interleaving techniques along with error control schemes. To enhance the quality of the received radiation signal and reduce the discarded packets number on the communication channel, sophisticated chaotic randomization tools based on the chaotic Baker map are used to randomize the encoded packets. The proposed approach effectiveness is evaluated through computer simulation tests. The research study discusses the different error control strategies that employed the problematic communication channels performance improvement. It also explores different error control strategies, channel situations, and packet lengths. Multiple scenarios are established to achieve better performance and more immune radiation signals.

The rest parts of this paper have been organized as follows: in section 2, the radiation signal data collection has been discussed. Section 3 presents the different techniques of security and wireless performance overview. The proposed model is presented in section 4. In section 5, the simulation experiments are introduced. The research paper contribution has been concluded in section 6.

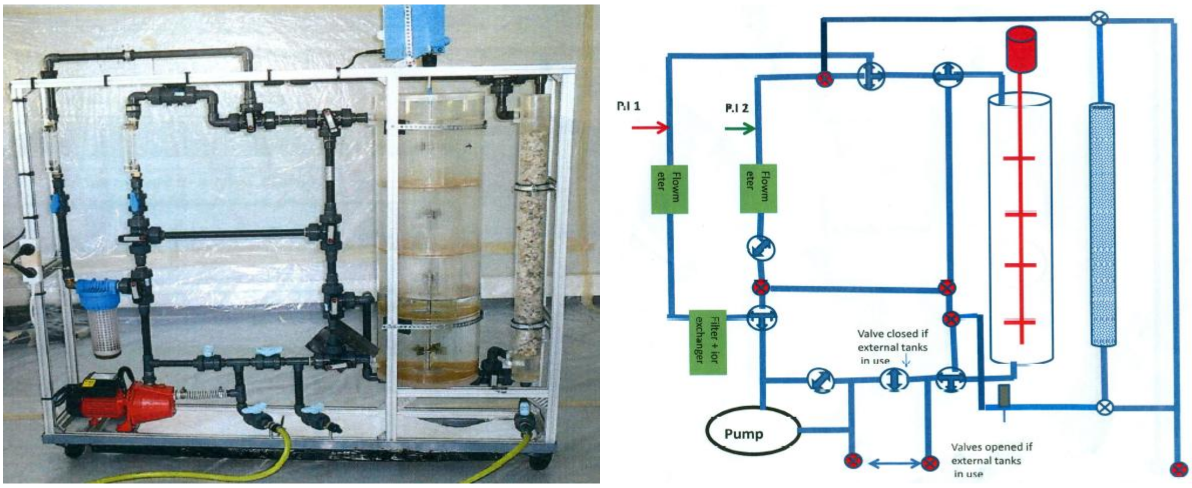
2. RADIATION SIGNAL DATA COLLECTION

A physical model for chemical reactor simulation (PMSCR-MK2) shown in figure 3, has been employed for radiation signals collection.PMSCR-MK2 described with details in (Kasban et al 2016) is two units; the first one is the main circuit, which includes a pump, filter, flow meters, and valve-equipped pipes. The second is the reactor circuit, which includes a plexiglass column to simulate a reactor with four tanks, an impeller, an engine, and mixers connected in series. The materials that enter the tanks are mixed using four mixing paddles. To mix the ingredients entering the system, a motor with a speed controller rotates the paddles.

A USB CRT15 module with CAESAR software is utilized in the tests as a 12-channel DAS to collect the radiation signals from a NaI detector. Ba137m radiotracer narrow pulse is injected into PMSCR-MK2 to conduct the experiments, and the scintillation detector is used to measure the concentration of radiotracer of the system. Cs137/Ba137m generator elutes Ba137m. Ba137m is a short-lived radioisotope that emits gamma rays at 661 keV and has a half-life of 2.6 minutes.

3. THE PROPOSED MODEL OF IMMUNE RADIATION SIGNALS TRANSMISSION

This section presents the suggested model of the radiation signal transmission immune system. The processing stages of radiation signal transmission in the suggested model are depicted in Figure 4. In order to improve the quality of radiation signals transmission and the overall error performance of the mobile wireless communication system.



(a) photo (b) diagram

Fig. (3): PMSCR-MK2 Physical model

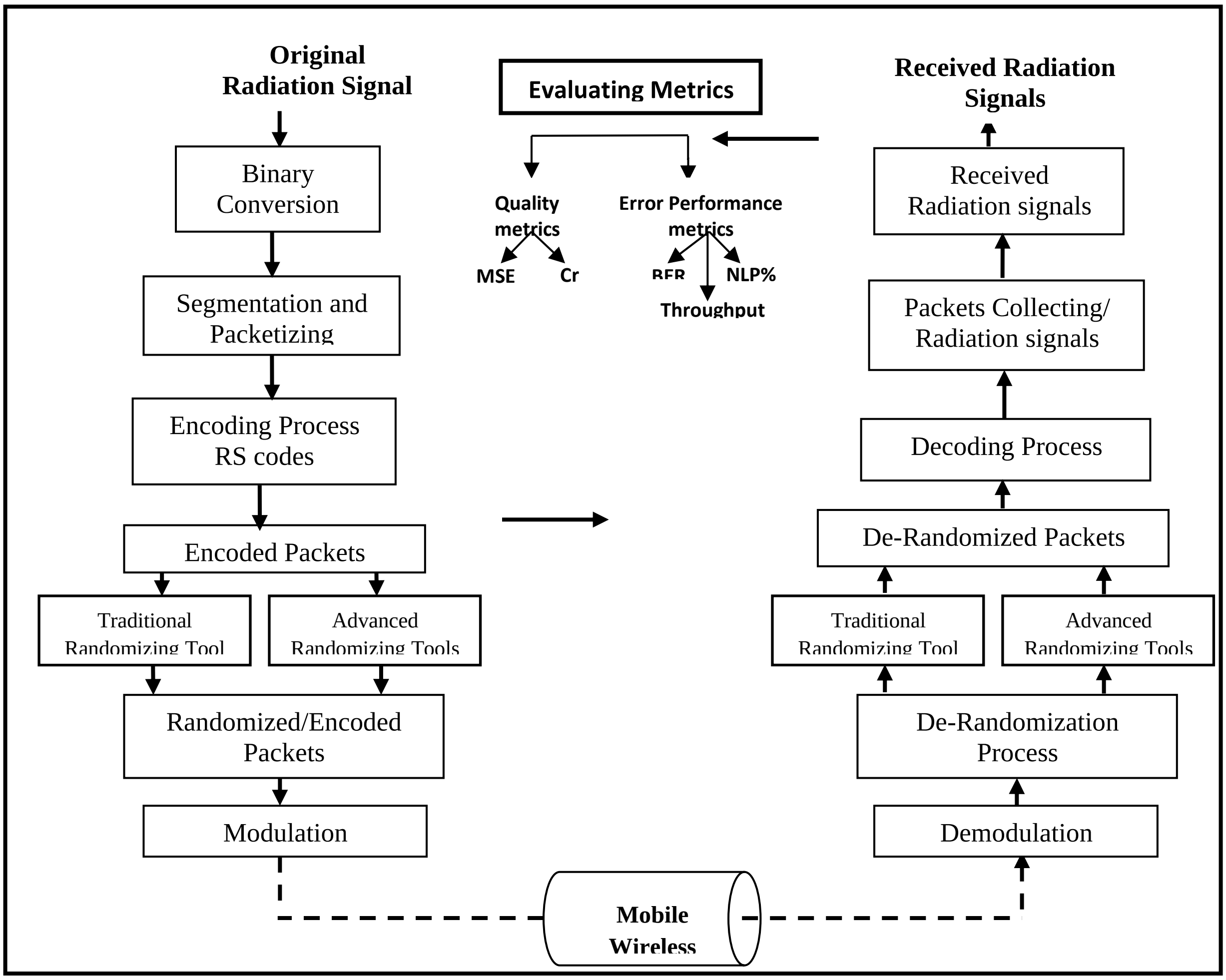


Fig. (4): Radiation signals immune model block diagram.

The suggested model combines pseudo coding and error control systems [25]. The pseudo methods make use of both chaotic tools and the conventional block interleaving technique [26]. The second tool's randomizing procedure is carried out using a secret key that encrypts the sent packets by packet-by-packet behavior. Therefore, the suggested methodology seeks to enhance wireless connection security and error performance simultaneously.

4. EXPERIMENTAL SIMULATION

Sending the radiation signals through the WSN, WMSN or WA/SN is an essential application of object-oriented wireless networks due to the sensitive and harmless effects of radiation on the human body. Therefore, this presented scenario of error performance of radiation signals on the WSN has been studied in this paper. The security of radiation reading is considered also, in this research work by randomizing the transmitted packets by chaos-2D baker map with a variety of secret keys.

Table 1 lists the different parameters and simulation settings. The popular Jakes model is utilized to simulate the mobile wireless communication channel, and MATLAB has been used for computer experiments simulation. Correlation coefficient and MSE metrics have been used to assess the quality of the received radiation signals. BER, NLP, and throughput have been used for error performance.

This section presents the different computerized simulation experiments based on the various parameters as mentioned in Table 1 for evaluating the proposed enhanced error performance and improved secured radiation reading transmission over the WSN. The different performance metrics have been utilized to measure the efficiency of the proposed scenarios. The mobility also is considered in the evaluating process as cleared in the following experiments. Cr, MSE, NLP, PER, and Throughput (T) metrics have been employed to measure the efficiency and effectiveness of the proposed scenarios of radiation reading signals transmission.

MSE and Cr metrics have been displayed in Figure 5. The MSE and Cr of different received radiation signals utilizing the different scenarios and various speeds are given in Figure 4a-d (v1=1& v2=3&v1=10 &v2=20 km/h). As proved from these results, the bad effects of the velocity on the MSE of the received radiation signals can be eliminated by choosing the powerful scenario as seen in the secured encoded randomized packets scenario.

The MSE performance metrics of various transmission scenarios of radiation signals reading concerning the different metrics are shown in Table 2, in which the results show that the transmitted signal quality is improved in case of using the proposed randomization method as a tool to secure the wireless signal besides the error correcting code (ECC) methodology.

Table (1): Simulation Parameters Settings

Parameter	Simulation Values
Packet Size	16384 Bits
Packet Format	Un-coded Packets No error control protection Encoded Packets Interleaved Encoded Packets
FEC:- Error control scheme	Reed-Solomon Codes
Modulation	BPSK modulation
Channel	Mobile Wireless Communications Channel
Channel Modeling	Jakes Model
Mobile Terminal Velocity	$V=v_1=2, v_2=5, v_3=20, v_4=30$ *Km/h*
Signal to Noise Ratio (SNR)	SNR=[0-35 dB]
Randomizing Tool	Block Interleaving based tool Chaotic Interleaving based tool
Secret Keys	Packet-by packet secret key (Optional)
Simulation tool	Matlab-Program 2016
Quality Metrics	Correlation Coefficient (Cr) Mean Square Error (MSE)
Error Performance	Bit Error Rate (BER) Number of Lost packets (NLP)

Table (2): MSE Performance metrics of various transmission scenarios of radiation signals reading with respect to the different metrics

Variations of mobility considered with the various radiation transmission scenarios with respect various metrics

Metrics	Ch. Conditions	No ECC &No Pseudo	ECC & No Pseudo	ECC & Classic Pseudo	ECC & Advanced Pseudo
MSE - v=1km/h	SNR=5dB	0.06463	0.05859	0.05507	0.04719
	SNR=10dB	0.01609	0.02098	0.01919	0.01251
	SNR=15dB	0.00318	0.00461	0.00618	0.00030
	SNR=20dB	0.00014	0.00105	0.00104	0.00075
MSE - v=5km/h	SNR=5dB	0.06498	0.05999	0.06154	0.06227
	SNR=10dB	0.02133	0.02020	0.02025	0.00800
	SNR=15dB	0.00760	0.00688	0.00416	0.00125
	SNR=20dB	0.00174	0.00225	0.00054	0.00029
MSE - v=10km/h	SNR=5dB	0.06694	0.06456	0.06168	0.05710
	SNR=10dB	0.02493	0.02210	0.01300	0.00979
	SNR=15dB	0.00697	0.00708	0.00214	0.00112
	SNR=20dB	0.00231	0.00210	0.00032	0.00073
MSE - v=20km/h	SNR=5dB	0.06791	0.06453	0.05983	0.05722
	SNR=10dB	0.02354	0.02128	0.01205	0.00995
	SNR=15dB	0.00821	0.00668	0.00166	0.00129
	SNR=20dB	0.00232	0.00167	0.00021	0.00532

The quality of received radiation reading signals is discussed in Figure6 and 7 by the MSE and Cr of the received signals. The error performance of the presented scenarios is measured and evaluated by the NLP and BER metrics as discussed in Figure 8.

The NLP and BER of different received radiation signals utilizing the different scenarios and various speeds are shown in Figures 7 and 8 (v1=1 & v2=3 v1=10 & v2=20 km/h). As proved from these results, the bad effects of the velocity on the error performance of the received radiation signals can be decreased by transmitting secured encoded randomized packets scenario.

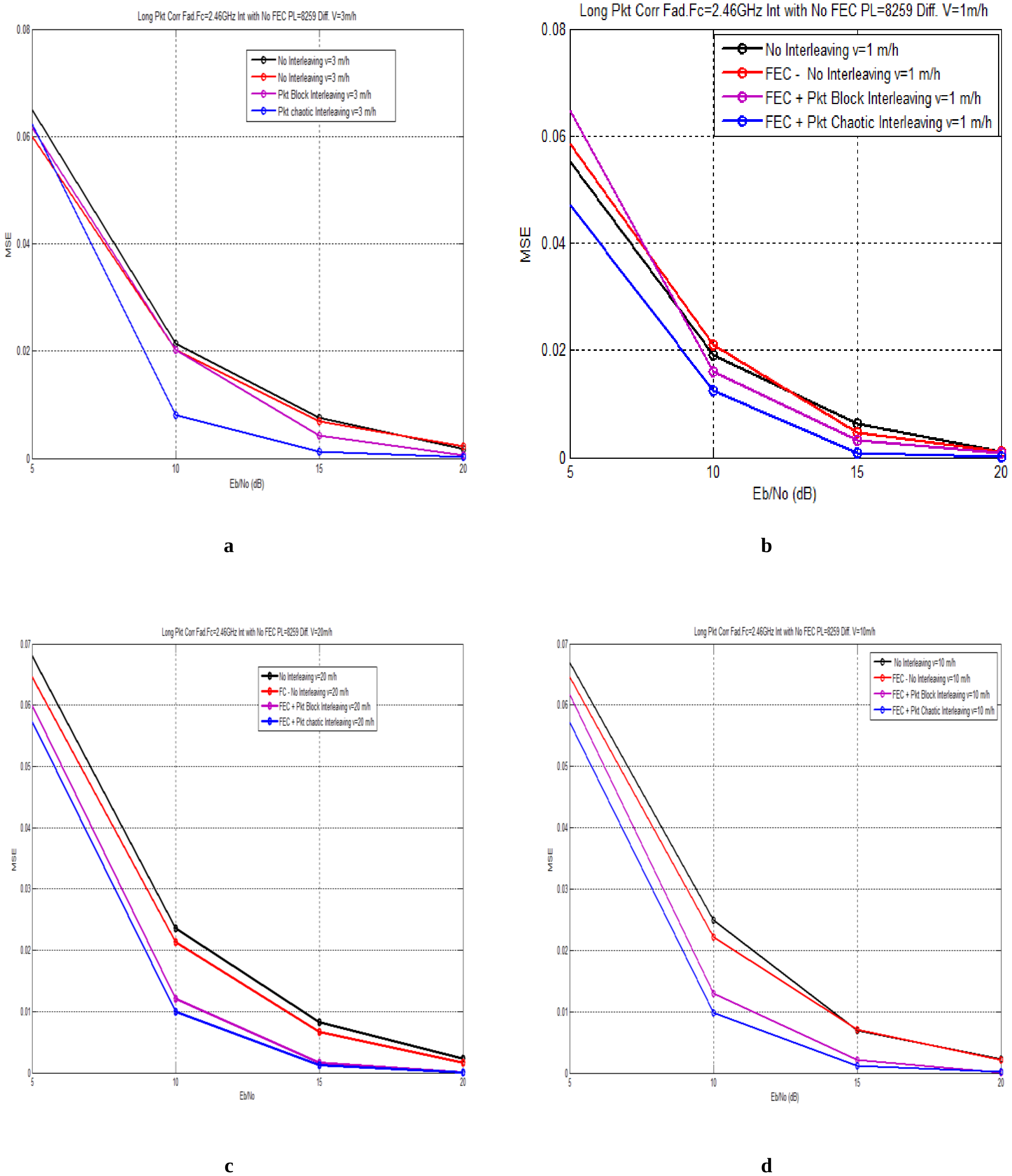
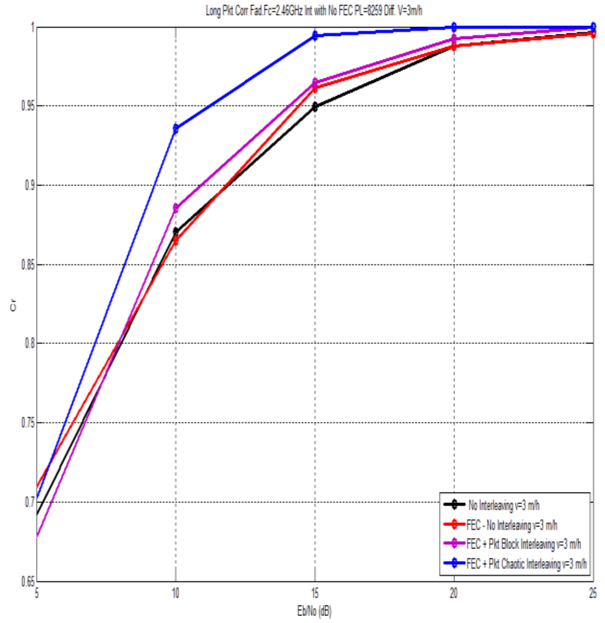


Fig. (5): Received radiation signal with the channel (a- v1=1,b- v1=3, c- v1=10 &d-v2=20 km/h).



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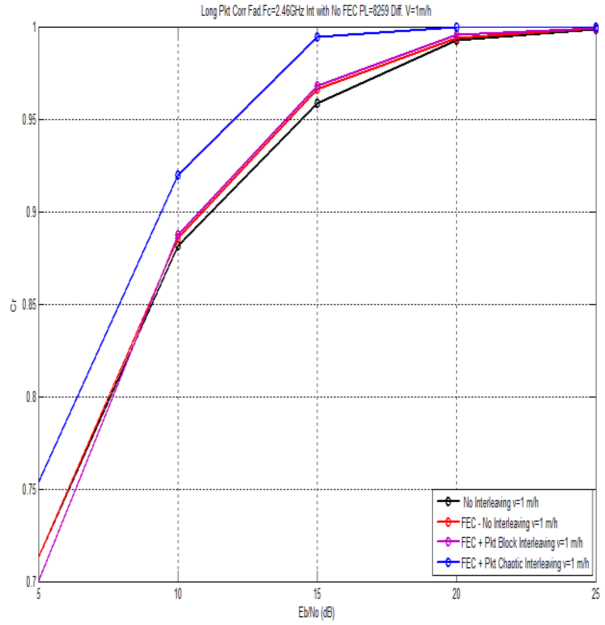

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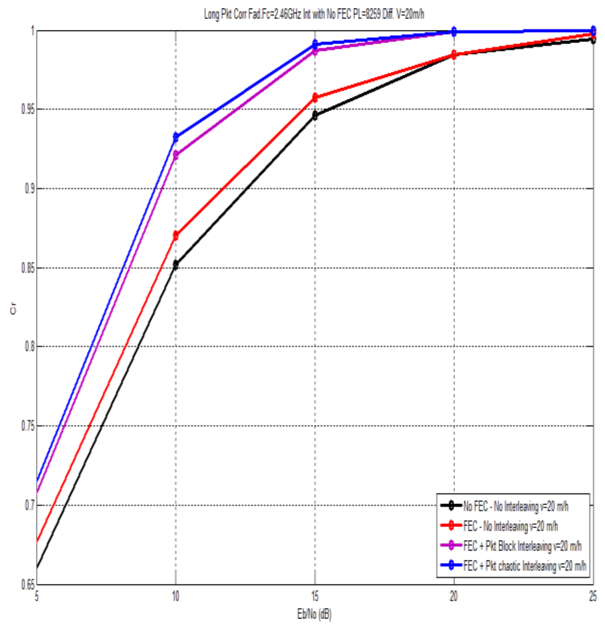

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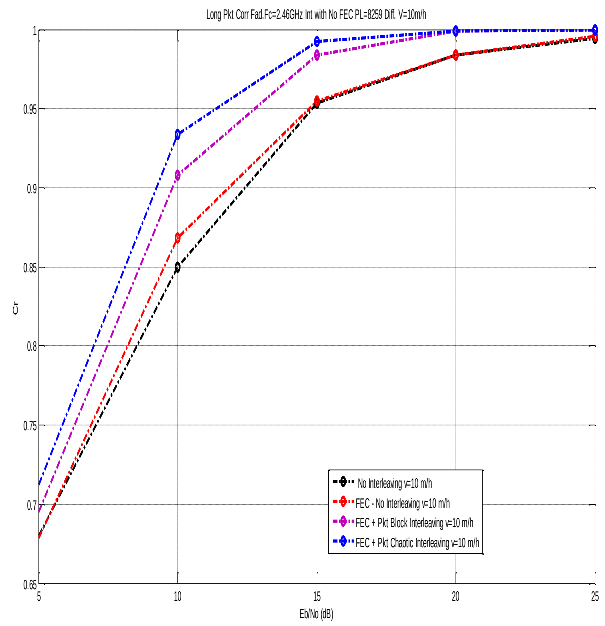
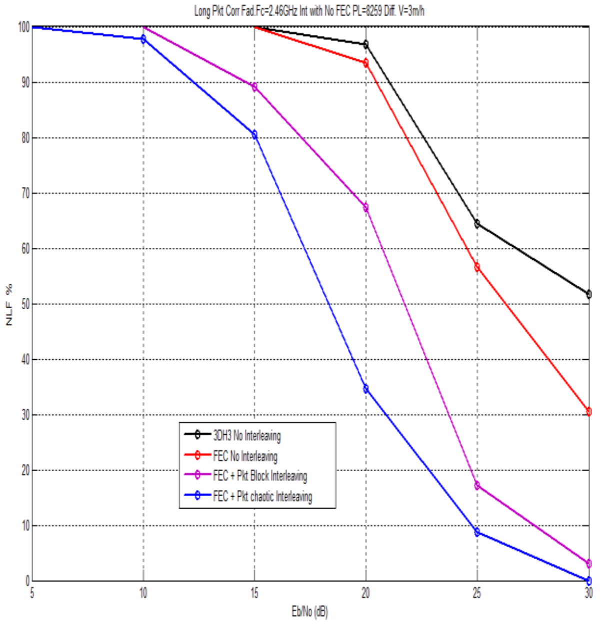


d

Fig. (6): Cr vs. SNR (dB) of Received radiation signal with channel (a- v1=1, b- v1=3, c- v1=10 &d-v2=20 km/h).



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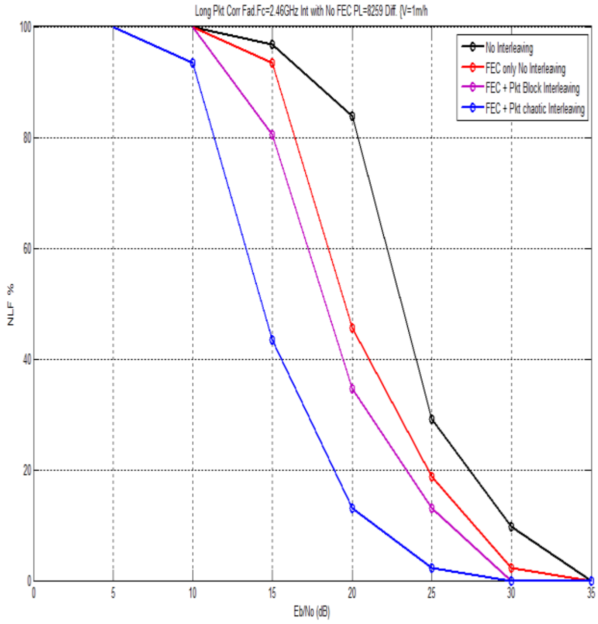

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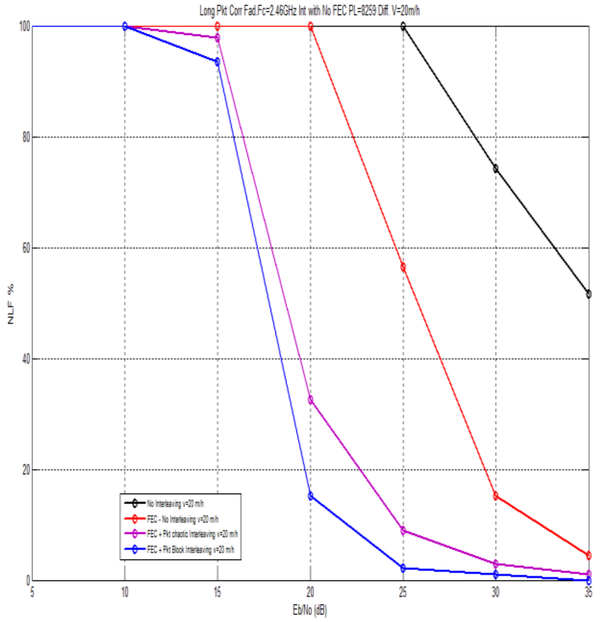

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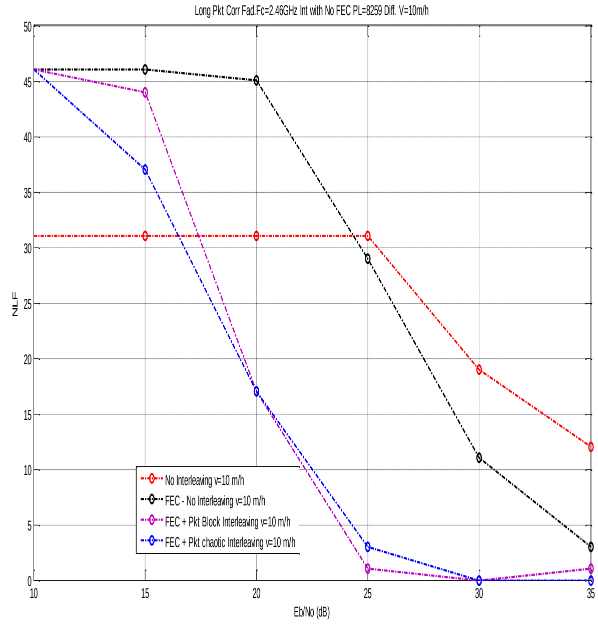

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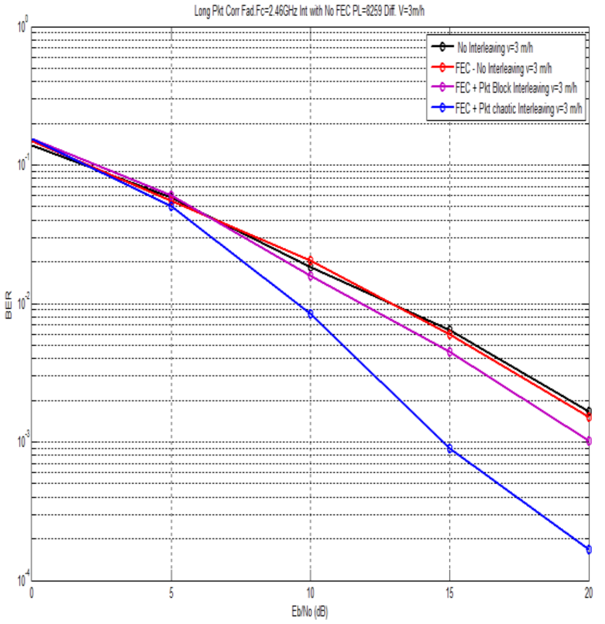
Fig. (7): NLP vs. SNR (dB) of Received radiation signal with channel (a- v1=1, b- v1=3, c- v1=10 &d-v2=20 km/h).



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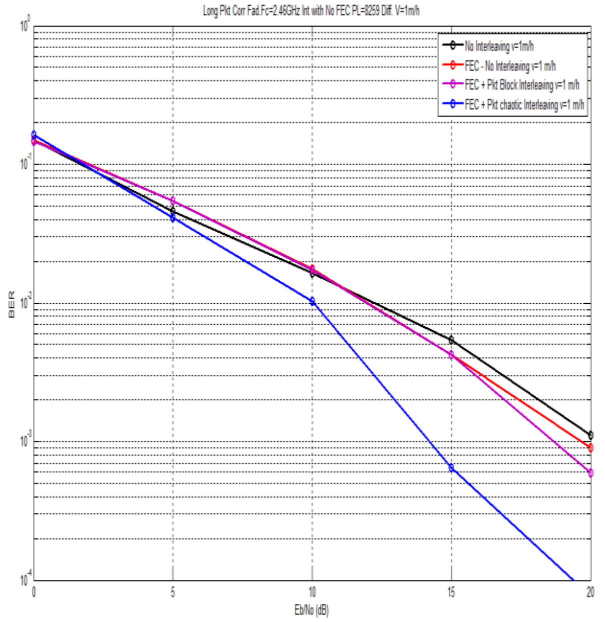

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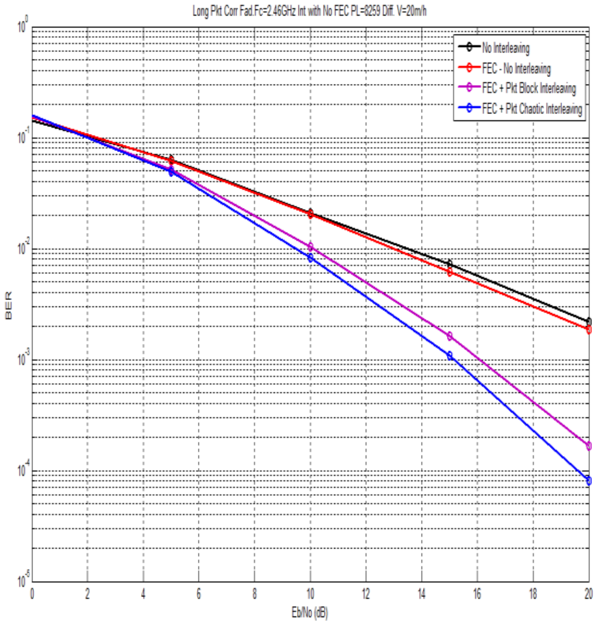

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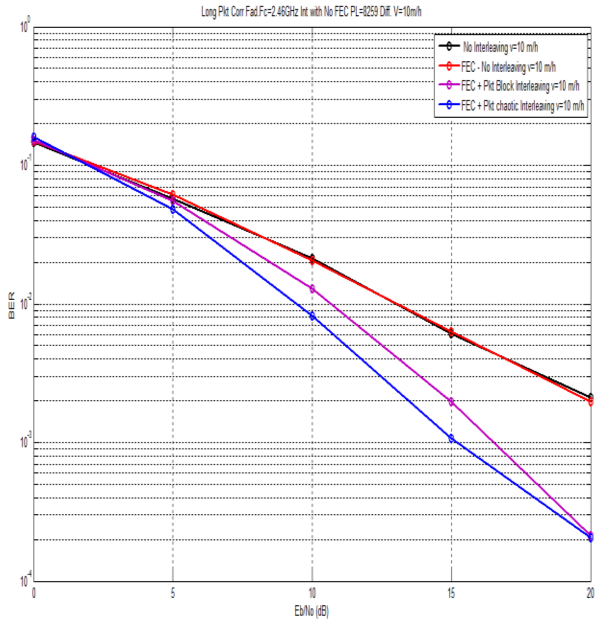

d

Fig. (8): BER vs. SNR (dB) of Received radiation signal with channel (a- v1=1, b- v1=3, c- v1=10, & d-v2=20 km/h).

Comparing the different velocities using the different scenarios of radiation reading signals is considered in this experiment. The results of this experiment used BER vs. SNR, metrics to evaluate the error performance and quality of the radiation signals transmission at different velocities as shown in Tables 3, and 4 respectively. These results prove that the error performance of the transmitted radiation signals is enhanced using the proposed model due to employing the pseudo-schemes with the traditional error control technique for long radiation signal sample transmission over a mobile wireless channel. Also, the bad effects of the velocity on the error performance of the received radiation signals can be decreased by transmitting secured encoded randomized packet scenarios.

The various ECC schemes have been considered in these executed experiments for providing the suitable error performance of radiation signals transmission over the different channel conditions. Also, the complexity is considered due to the ECC schemes. The convolutional codes are known and widely used in the communications systems [27]. There are two error control convolutional codes (Conv. C.) have been utilized to encode the transmitted packets of the radiation signals. The Conv. C. (R=1/2, K3) is the simpler convolutional code with the code rate (R) equals 0.5 and constraint length (K) is 3. The complexity of this ECC is moderate compared to the used RS codes. The performance of this code over the mobile channel is not attractive although the complexity [28].

To clarify the effectively and efficiency of the proposed scenarios based on ECC-pseudo coding merging compared to the higher complex ECC as Conv. C(R=1/2 and K7), the results of these ECCs are tabulated in Table 4. As shown in this Table 4, the lower complex RS merged with pseudo code performs better than the higher complex convolutional codes.

Table (3): BER Performance metrics of various transmission scenarios of radiation signals reading with respect to the different metrics

Variations of mobility considered with the various radiation transmission Scenarios with respect to various metrics					
Metrics	Ch. Conditions	No ECC &No Pseudo	ECC & No Pseudo	ECC & Classic Pseudo	ECC & Advanced Pseudo
BER -v=1Km/h	SNR=5dB	0.04595	0.05437	0.05447	0.04130
	SNR=10dB	0.01629	0.01756	0.01714	0.01018
	SNR=15dB	0.00541	0.00427	0.00426	0.00065
	SNR=20dB	0.00110	0.00090	0.00059	0.00008
BER-v=5Km/h	SNR=5dB	0.05829	0.05505	0.06012	0.05069
	SNR=10dB	0.01847	0.02037	0.01599	0.00844
	SNR=15dB	0.00639	0.00597	0.00446	0.00089
	SNR=20dB	0.00166	0.00151	0.00101	0.00017
BER - v=10Km/h	SNR=5dB	0.05735	0.06142	0.05530	0.04820
	SNR=10dB	0.02134	0.02064	0.01291	0.00819
	SNR=15dB	0.00612	0.00628	0.00196	0.00106
	SNR=20dB	0.00212	0.00196	0.00021	0.00021
BER – v=20Km/h	SNR=5dB	0.25042	0.27010	0.05086	0.04890
	SNR=10dB	0.14066	0.15050	0.01040	0.00820
	SNR=15dB	0.06231	0.06153	0.00163	0.00108
	SNR=20dB	0.02060	0.00186	0.00017	0.00008

Table (4): High mobility error Performance (BER) metrics of various transmission scenarios of radiation signals reading with respect to the different metrics

Variations of high mobility considered with the various radiation transmission scenarios with respect to various metrics and ECC schemes variety with the complexity differentiation

Metrics	Ch. Conditions	No ECC & No Pseudo	ECC & No Pseudo	ECC & Classic Pseudo	ECC & Advanced Pseudo	Conv. C. R=1/2 K3	Conv. C R=1/2 K7
BER – v=45 Km/h	SNR=5dB	0.06155	0.06094	0.05115	0.05127	0.06091	0.05218
	SNR=10dB	0.02229	0.02012	0.00937	0.00925	0.02022	0.00929
	SNR=15dB	0.00708	0.00615	0.00122	0.00133	0.00625	0.00141
	SNR=20dB	0.00216	0.00128	0.00020	0.00009	0.00129	0.00010
BER – v=60 Km/h	SNR=5dB	0.05961	0.05966	0.04919	0.05000	0.060358	0.05010
	SNR=10dB	0.02119	0.01964	0.00900	0.00868	0.02064	0.00871
	SNR=15dB	0.00702	0.00548	0.00121	0.00132	0.00540	0.00212
	SNR=20dB	0.00237	0.00119	0.00012	0.00012	0.00120	0.00020

As cleared from these results, the radiation reading signals can be received in high quality and performs better with good error performance over mobile WSN by transmitting this radiation reading by secured-encoded packets. The used radiation reading have been obtained by practical experiments through real test using radiated material as mentioned in section 2. The presented scenarios of radiation signal transmission provide a secured and reliable link. These secured and reliable links achieve real-time wireless monitoring of radiations in any applications of radiated material and nuclear sites.

Due to the critical and limited resources of WSN and WMSN, the adaptively of ECCs is essential to enhance the life's nodes time and saving the power for the deserving situations. The paper presents varieties scenarios for radiation signals transmission over the WSN with the mobility considerations.

Hence, the presented research point in our paper is important in the practical fields of radiated materials and in highly sensitive nuclear sites. Real-time monitoring of radiation can be useful for saving human life from harmful levels of radiation.

5. CONCLUSION

Reliable and robust mobile WSNs for secured transmission of radiation signals have been presented in this paper. The proposed secured and reliable model of radiation signals has been constructed based on utilizing a chaos-based randomized tool and error control scheme to produce secured-randomized encoded packets. The different computerized-based simulation experiments have been executed to evaluate the proposed model. The results of the experiments reveal the accepted and sufficient quality of the received radiation signals. Also, the error performance of the mobile WSN utilizing the proposed model achieves good error performance. Various metrics have been used to evaluate the quality of received radiation signals and measure the error performance of the mobile WSN. The proposed model of secured/reliable radiation signals is suitable for real-time radiation reading monitoring and helps to enhance the safety of nuclear sites.

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