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ICRTEC 2023

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TABLE OF CONTENTS

Principal
A.J. Institute of Engineering & Technology
Mangaluru - 575 006

42	P Samyuktha, Srinivas D and Himabindu T	Grid-connected solar power generating systems with superior power quality controlled using PBT	ICRTEC2023-42
44	Himabindu T, Chaitanya G and Srinivas D	SCIG Based Wind Energy Conversion System Fed DC Micro Grid Using DTC	ICRTEC2023-44
48	Ramya S and Jayasri B S	A Review on the analysis of Behavioral pattern of Students during pandemic COVID-19	ICRTEC2023-48
49	Akhil V M, Pavan Pundalik Mangaji, Rahul N Murthy, Rakesh D, Shridatta Hegde and Sukesh V Devadiga	Gear Fault Diagnosis Using SVM Based on Empirical Mode Decomposition	ICRTEC2023-49
52	Ankitha A Nayak and Shashank Shetty	A Systematic Analysis on Task Scheduling Algorithms for Resource Allocation of Virtual Machines on Cloud Computing Environments	ICRTEC2023-52
55	M Prathiksha, Priyanka R Badiger, Varshini Thangaraj, D A Varshini, Sahana Srikanth and Sanjeev Gurugopinath	A Survey on Machine Learning Techniques for Multimodal Biomedical Signal Processing	ICRTEC2023-55
57	Harjeevan Singh	Designing a Hybrid Optical Fiber/FSO System For Last Mile Users Under Tropical Weather Conditions	ICRTEC2023-57
58	Lakshmi B S, Rekha K S	A Survey Paper on Blockchain Technology with supply-chain management in Charity donation System	ICRTEC2023-58
59	Ranjan Mahapatra, Gnane Satapathi, Pradeep Kumar, ,Akshith N Shetty, Shashwath Shettigar, Abhinav J P, B Shivalal Patro, Diika Satapathy	Design and analysis of microstrip patch antenna	ICRTEC2023-59
60	Arjun Chakkrapani, Preethaa Jansirani	Efficient FPGA Implementation of Phase Shift Keying	ICRTEC2023-60
61	Lokesh B S and Narasimha Kaulgud	A review on analysis of transport layer security in open quantum safe cryptographic algorithm	ICRTEC2023-61
64	Bhushan K Munoli, K Abheeshta Jain, Prem Kumar, , Aditya Ram P S and Ashwini	Human Voice Analysis to Determine Age and Gender	ICRTEC2023-64
65	Ranjan Mahapatra, N S V Shet, Gnane Satapathi, B Shivalal Patro and Dipika Satapathy	Analysis of Modulation schemes Using Rayleigh and AWGN channel for wireless sensor nodes in Internet of Things	ICRTEC2023-65

Principal
A.J. Institute of Engineering & Technology
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72	Rajesh Kannan S, Ezhilarasi P, Rajagopalan VG, Sushanth Krishnamithran, HRamakrishnan H, Harish Kumar Balaji	INTEGRATED AI BASED SMART WEARABLE ASSISTIVE DEVICE FOR VISUALLY AND HEARING-IMPAIRED PEOPLE	ICRTEC2023-72
74	Ananya H P, Shreya K Magadum, Swathi S and Anitha S Prasad	Real Time tomato plant leaf disease detection using convolutional neural network	ICRTEC2023-74
75	P A Anshad , Niteesh M Gowda, Vijaykumar Kandakur and Anitha S Prasad	Forest Fire Detection Using nRF24L01 Wireless Sensor Network And Prediction by Machine Learning Model	ICRTEC2023-75
78	S Kannan, Prabakaran D, Dhenesh Kumar S, Sivaram S	A DEEP LEARNING-BASED CONVOLUTION NEURAL NETWORKS TO FORECAST WIND ENERGY	ICRTEC2023-78
80	Ashish sharma and Rinku Garg	New Technology for Harnessing Energy: Future of Hydrogen	ICRTEC2023-80
82	Mohan V S, Abhay Gowda G, Rekha R Nair, Kishore S and Tina Babu	Face Mask detection using Mask R-CNN to control the spread of Covid-19	ICRTEC2023-82
83	Raye Haarika, Tina Babu, Rekha R Nair and Rajesh T. M	Breast Cancer Prediction using Feature Selection and Classification with XGBoost	ICRTEC2023-83
86	Shreya G Abhyankar, Shashank S Bharadwaj, G Shobha Rani, Pruthvi G Karigiri, Sahana Srikanth and Sanjeev Gurugopinath	A Survey on Music Genre Classification Using Multimodal Information Processing and Retrieval	ICRTEC2023-86
87	Niranjan L, Manjunath V Gudur, Parthasarathy P, Pradeep Kumar Mallaiah, Mahesh B Neelagar and Sreekantha B	IoT-based safety system for swimming pools to avoid sinking of individuals	ICRTEC2023-87
91	Fida Fareesha, Chanadanashree Y K, Gowthami V, Remya Jayachandran, and Shaeen Kalathil	Real-Time Artificial Mood-tracking and Health-monitoring System (RAMAHS) for people with mental illness and their Caregivers	ICRTEC2023-91
92	Nilakshee Rajule, Mithra Venkatesan, Radhika Menon, Anju Kulkarni	Mobility Prediction in Cellular Networks: A Survey	ICRTEC2023-92
93	Nandini B M and Narasimha Kaulgud	Wavelet-based method for enhancing the visibility of hazy images using Color Attenuation Prior	ICRTEC2023-93
94	Darshan Babu K S, G Adarsh, Karan K ,Shylesh Kumar P B, Rupesh S, and Remya Jayachandran	A Novel scheme for IoT based Real Time Monitoring of Biodiesel Quality	ICRTEC2023-94
95	Amith Bharadwaj , Ananya Kashyap, Gurusatwik Bhatta, Remya Jayachandran and Rajalekshmi Kishore	A Survey on Terahertz Devices-A cutting edge Technology	ICRTEC2023-95

96	Rajalekshmi Kishore and Sanjeev Gurugopinath	Energy-Efficient Ant Colony Task Assignment Based Spectrum Sensing for Cognitive Radios	ICRTEC2023-96
97	Fuhad Muhammed, Sayana Tomes, Manu Elappila and Shamanth Nagaraju	Automated Contactless Continuous Temperature Monitoring System for Pandemic Disease Controlling Infrastructures	ICRTEC2023-97
105	Manjunath V Gudur, Saravanan M, Parthasarathy P, Niranjan L, Mahesh B Neelagar and Sreekantha B	Machine Learning based Routing approach and Resource Management in Vehicular Adhoc Networks	ICRTEC2023-105
106	Parthasarathy P, H N Shree Harsha, Manjunath V Gudur, Niranjan L, Mahesh B Neelagar and Sreekantha B	A novel optimization approach using multi-objective PSO incorporated with SEPIC and buck-boost converters for renewable energy sources	ICRTEC2023-106
107	Sharzeel Saleem, Jeba Shiney O and Pratikshit Vashishta	Binary Classification of Human Emotion using EEG and LTSM	ICRTEC2023-107
113	Sanjay Tippannavar, Yashwanth S D, Chandrashekar Murthy B N, Madhusudhan M P, Puneeth K M, , and Vinay Prasad M S	Comparative Analysis and Development of an Efficient Management System for a Photo-Voltaic Module	ICRTEC2023-113
114	Sanjay S Tippannavar, Puneeth K M, Yashwanth S D, Madhusudhan M P, Chandrashekar Murthy B N and Vinay Prasad M S	EVAS – Emergency Vehicle Alert System using LoRa for automobiles	ICRTEC2023-114
115	Sanjay S Tippannavar, Vijay Mishra, Yashwanth S D, Rishitha Gowda, Sathvik H R and Ajay M	Smart Transformer – An Analysis of Recent Technologies for Monitoring Transformer	ICRTEC2023-115
118	Alakesh Sharma, Jeba Shiney O	An Analysis on the Techniques for Water Quality Prediction from Remotely Sensed data	ICRTEC2023-118
122	Anita Patrot , Harish H, Shambbavi B, Geetha P L,Sahana	NBA GAME PREDICTION USING MACHINE LEARNING ALGORITHM	ICRTEC2023-122
126	Ramyateja Singamshetty, Sangani Sruthi, Kodati Chandhana, Sreedhar Kollem,and Rajendra Prasad Ch	Brain Tumor Detection Using the Inception Deep Learning Technique	ICRTEC2023-126
129	Shashi Gupta, V. Suresh Kumar, Alex Khang, Bramah Hazela, Nivethitha T and Bhadrappa Haralayya	Detection of Lung Tumor using an efficient Quadratic Discriminant Analysis Model	ICRTEC2023-129
130	Shashi Gupta, Surabhi Saxena, Alex Khang, Bramah Hazela, Chandra Kumar Dixit and Bhadrappa Haralayya	Detection of Number Plate in Vehicles using Deep Learning based Image Labeler Model	ICRTEC2023-130

131	Shashi Gupta, Ahmed Alemran, Prabhdeep Singh, Alex Khang, Chandra Kumar Dixit and Bhadrappa Haralayya	Image Segmentation on Gabor Filtered images using Projective Transformation	ICRTEC2023-131
132	Shashi Gupta, Waseem Ahmad, Dimitrios A. Karras, Alex Khang, Chandra Kumar Dixit and Bhadrappa Haralayya	Solving Roulette Wheel Selection Method using Swarm Intelligence for Trajectory Planning of Intelligent Systems	ICRTEC2023-132
136	Adi Surya Suwardi Ansyah, Miftahol Arifin, Muhammad Bahauddin Alfan, Matthew Vieri Suriawan, Nadhif Haikal Farhansyah, Ary Mazharuddin Shiddiqi, Hudan Studiawan	MQTT Broker Performance Comparison between AWS, Microsoft Azure and Google Cloud Platform	ICRTEC2023-136
140	Sangeetha D P, Sabitha R, Shirisha J and Balaji A	Investigating and Checking the Javelin Athlete’s Movement Parameters Using Smart WSN	ICRTEC2023-140
141	Sivakumar T, Sashi Rekha K, Vikram N and Maruthu Kannan B	Misbehavior Node Detection using Hamming Residue Mechanism in Clustering WSN	ICRTEC2023-141
144	Kishore Sonti V J K, Sundari G, Bernatin T and Sahaya Anselin Nisha A	Ecological Observing using Sensor and IoT to Protect the Global Warming in WSN	ICRTEC2023-144
146	Sanjay S Tippannavar, Yashwanth S D and Puneeth K M	SDR – Self Driving Car Implemented using Reinforcement Learning & Behavioural Cloning	ICRTEC2023-146
148	Bansilal Bairwa, Madan Murari , Mahammadgaous Sahapur, Kavya M.R, Md.Firdosh Khan	Drive Cycle Based Speed Control of BLDC Motor Using Pulse Width Modulation	ICRTEC2023-148
150	Akula Shravya Sri,Bobbili Varshith Reddy,Kanuri Balakrishna,Vollala Akshitha, Sreedhar Kollem and Ch Rajendra Prasad	Detection of MRI Brain Tumor Using Customized deep learning method Via Web App	ICRTEC2023-150
151	Insha Yaqoob Sheikh	Efficient Novel Binary to Gray Code Converter Using Coulombic Interaction on Quantum Dot Cellular Automata	ICRTEC2023-151
153	Anka Rao Mogili, Sreenivasulu. J, Prudhvi Sai Bojanapalli	Sliding Mode Controller with Disturbance Estimator for Fuzzy Logic Controller fed PMSM Drives	ICRTEC2023-153
154	Naveen Kumar Peelam, Kiranmayi.R, Nagabhushanam. K, Swathi.N	Wind Turbine Integrated Generator Rectifier System with Fuzzy Logic Controller based on MPPT	ICRTEC2023-154

155	Mallapu Vijaya kumar, Maruthi Kudadala	a novel fuzzy logic controller topology for grid connected pv system by dc voltage droop control	ICRTEC2023-155
158	Bansilal Bairwa, ShriHarinayaka P, Sagar B S, Ashwini Kumari P	Temperature Dependent Capacity Fade Prediction of Electric Vehicles Batteries	ICRTEC2023-158
159	Sathya K and Guruswamy K P	Performance Analysis for LLC Resonant Converter in Electric Vehicle Applications	ICRTEC2023-159
161	Bansilal Bairwa, Manohar K A, Mallikarjun M Magadum, Keerthi S, R Chitrashree	Modeling of Low Cost Battery Charge Controller for Stationary to Mobile Applications	ICRTEC2023-161
162	Shubham Subhas Borkar, Guruswamy K.P	Performance Analysis of Half-Bridge LC Resonant Converter for UPS Battery Charging Application.	ICRTEC2023-162
166	Vanditha M, Surendra R Hegde, Snehith K, Anitha S Prasad and Eshwari A Madappa	Agricultural Supply Chain Management System using Blockchain	ICRTEC2023-166
169	Geetha Rani E, Roshan Jose S, Joel Thomas Chacko , Joshua Paul C , Jeanette Krizelda K	Peer-to-Peer File Streaming Using Web Sockets Protocol	ICRTEC2023-169
175	M. Venkata Subbarao, G. Challa Ram, D. Ramesh Varma	Performance Analysis of Pistachio Species Classification using Support Vector Machine and Ensemble Classifiers	ICRTEC2023-175
176	Rajini H, Bansilal Bairwa , Arpita Banik, Surineni Jagadeesh	Development of ON Road Charging System for Electric Vehicle Applications	ICRTEC2023-176
179	A.Ravi, Gnanasree Dupaguntla, Devi Krishna Tadepalli	Image Denoising Using Feature Map Based Convolutional Neural Networks	ICRTEC2023-179
180	Nanditha Krishna, Padma C.R., Surabhi A.S, Saritha Pal, Aishwarya Prabhu, Sahana P	A review on VARIBRACE - A wearable therapeutic device	ICRTEC2023-180
182	Yashavanth T R, Suresh M	Performance Analysis of Multimodal Biometric System Using LBP and PCA	ICRTEC2023-182
184	Shashidhar R, Sanjay Tippannavar, Sushma B S and P Shukla	Smart Electric Wheelchair for disabled and paralyzed person using Attention Values on Arduino	ICRTEC2023-184
187	Rakheeba Taseen, Haseeba Yaseen, Niranjan L,Gadige Radha, Mahesh B Neelagar and Shwetha N	An Innovative Method for Energy Intensive Routing and Transmission Network Positioning in Integrated Wireless Detector Networks	ICRTEC2023-187

190	Armend Salihu, Halil Snope, Artan Luma, Jaumin Ajdari	Comparison of time complexity growth for different methods/algorithms for rectangular determinant calculations	ICRTEC2023-190
198	Harish S.V and Archana N.V	A Distributed Cluster Based Protocol to Extend Lifetime using Fitness Function algorithm in Wireless Sensor Networks	ICRTEC2023-198
199	J Suneetha, Niranjan L, Husna Tabassum, Swamy Goud, Rakheeba Taseen and Mahesh B Neelagar	A Wireless Detector Network for Three-Dimensional Positioning Using Artificial Neural Networks	ICRTEC2023-199
204	Susandhika m, Shirly Edward A	M/S. The National Institute of Engineering	ICRTEC2023-204
212	I. Evangeline Felicia, V. Gomathi and E. Isac Paulraj	Two-Port UWB-MIMO Antenna Design with Improved Isolation for WiMAX and X-Band Applications	ICRTEC2023-212
213	Sanjay S Tippannavar, Yashwanth S D, Chandrashekar Murthy B N and Praveen Kumar M S	IoT enabled Smart Car with V2X Enhanced Comunication and Safety Alert system	ICRTEC2023-213
215	H.N.Srinivasa Nayaka , Shankar Nalinakshan,M.S. Ganesh Prasad , Vikram Y and Appalabathula Venkatesh	Design and Implementation of Electrical system in H-Gantry automation for Double Disc Front Brake	ICRTEC2023-215

2023 International Conference on Recent Trends in Electronics and Communication (ICRTEC)

Analysis of Modulation schemes Using Rayleigh and AWGN channel for wireless sensor nodes in Internet of Things

Ranjan Kumar Mahapatra
Department of ECE
A J Institute of Engineering & Technology
Mangalore, India
mahapatra.ranjankumar@gmail.com

N S V Shet
Department of ECE
NITK, Surathkal
Mangalore, India
shekar_shet@yahoo.com

Gnane S Satapathi
Department of ECE
A J Institute of Engineering & Technology
Mangalore, India
gnaneswar.24@gmail.com

B Shivalal Patro
School of Electronics Engineering
KIIT Deemed to be University
Bhubaneswar, India
bspatro@ieee.org

Dipika Satapathy
Department of IT
Modern Institute of Technology & Management
Bhubaneswar, India
dipika.satapathy@gmail.com

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***Abstract*—Constraints of energy in a wireless sensor network has become a critical issue as almost all the nodes are battery driven. Hence energy is limited. Hence optimization of energy is a critical factor for the sensor node's lifetime. Here we have considered the asymmetric method of communication that uses different modulation schemes with error correcting codes for uplink and down-link communication. We evaluate and compare two extensively used error correcting codes, Hamming and Reed-Solomon (RS) codes, together with well-known modulation schemes, including QAM, M-FSK, M-PSK, and BPSK. This paper makes use of the relation between Signal to noise ratio (SNR) and bits per symbol towards modelling and analysis purposes.**

I. INTRODUCTION

Concern regarding global warming has increased manifold. Hence there has been a lot of attention on the energy saving schemes. In a wireless sensor network, energy efficient schemes play an important role where energy efficiency affects the sensor node lifetime in a direct way. In general, the power source can not be replaced in a deployed sensor network. Hence power conservation is the most important and critical factor to be considered in the wireless sensor network. we can find so many stringent energy consumption constraints in wireless sensor networks [1], [2]. This motivated us to have a comprehensive study of energy efficient modulation schemes. In several works of literature, BPSK seemed to be mostly used modulation scheme as compared to others. In this paper, an investigation has been done with BPSK and other modulation schemes. Bit Error Rate (BER) is the most crucial factor in wireless communication but BER needs to be as low as possible. In most scenarios, communication between sensor nodes and Base Station (BS) happens in a noisy environment with fading.

The fidelity of the Internet of Things (IoT) has become crucial as the number of things keeps on increasing in the Internet of Things. Sensor nodes [3] play an important and crucial role in IoT. In narrow-band IoT, fewer subcarriers, as well as modulation techniques with the lowest order such as Binary Phase Shift Keying (BPSK), are used. Hence the investigation of BPSK with other modulation techniques is essential which is presented in this work.

This study still covers analysis of different modulation techniques for Rayleigh fading and Gaussian Noise channels. The structure of this article is as follows. Section II describes related work. The background is described in Section III. The System Performance Analysis and Evaluation is presented in Section IV. The conclusion is depicted in Section V.

II. RELATED WORK:

Recent literature has emphasized addressing the energy aware (resource constrained) networks. The main problem that needs to be focused on is energy savings and management. Many authors have focused on providing some solutions in this aspect. Analysis for power consumption mostly comprises two parameters such as transmitted power and the power that is consumed by the circuit. This section explains the use of popular digital modulation techniques such as BPSK, M-ary QAM, and FSK for significant energy saving in wireless sensor networks.

In the paper [4], transmission time, as well as constellation size for M-ary QAM and FSK, is compared to 10 meters

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which concluded in the higher energy efficiency of M-QAM. The paper [5] explains how capacity and SNR in M-QAM are related which concluded with the result of minimum energy between the nodes. Authors in [6] have derived the expressions in exact and generic form for bit error rate in the M-ary QAM constellation. Paper [7] presents the modulation schemes towards minimum energy consumption. For analysis purposes, authors have considered the consumption of the signal power as well as the circuit power.

Authors in [8], have depicted the detailed sensor network architecture. In this paper, the authors summarized the solutions that are covered in the sections on the relevant protocol stack layers. They also highlighted unresolved research difficulties with the goal of igniting fresh interest and advancements in the area. The paper [9] provides the analysis for non-coherent MFSK with AWGN channel. Paper [10], represents the performance of RS code over Bose Chaudhuri Hocquenghem (BCH) code. On the processor based on implementation, energy for RS codes is calculated.

III. BACKGROUND

A. *Error initiating Mechanism in communication*

Most of the time, the thermal motion of the electrons which leads to front end noise in the receiver, is the cause of the error. When signal energy E_{signal} per noise power density $NP_{Density}$ decreases, the number of errors observed per unit time increases. When where E_{signal} is Signal Energy and $NP_{Density}$ is Noise Power Density.

Most of the time the generated noise at the front end is Additive White Gaussian Noise f(AWGN), as it affects the signal in an additive manner. Random fluctuations in received signal strength lead to the occurrence of the error introduced. The reduction in received signal strength can be due to several factors such as:

- Long range of communication
- Path Loss
- Receiver position is in a shadow zone
- Multipath

B. *System Model*

Fig. 1 shows the topology [11] of a sensor network. The system taken into consideration comprised of:

Sensor helps to receive the physical parameter at the transmitter section to process it to digital form with the help of an analog to the digital filter. A local oscillator produces a carrier signal which carries the information. The signal needs to be amplified and the impedance matching network helps in matching the impedance of the path to the impedance of the transmitting antenna.

In the receiver section, the reverse process is followed once the transmitted signal arrives at the receiver. Most sensor nowadays integrates the RF transceiver, ADC and DAC, processors, amplifiers, etc in a single small chip comparable to a coin powered by small batteries. Hence energy needs are conserved. Three modes of operation were considered:

- ON State: For Information Transmission and reception
- Transition State: The temporary state that acts between On and Sleep state which sets up the frequency Synthesizer of the local oscillator.
- Sleep state: Saves energy

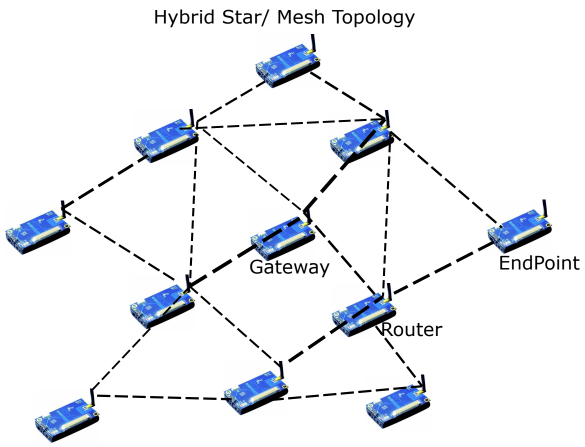

Fig. 1. Topology of sensor network considered for this work

$$\mathrm{E_{Radio}} = \frac{\mathrm{P_{ON}T_{ON} + P_{transition}T_{transition} + P_{sleep}T_{sleep}}}{\mathrm{L}} \tag{1}$$

where P_{ON}, $P_{transition}$, P_{sleep} are the power consumed for different states respectively. T_{ON}, $T_{transition}$, T_{sleep} are time duration of transceiver on, transition and sleep states respectively. L is the information bit length for transmission.

Because of the low leakage current assumption for CMOS, power consumption during sleep is likely to be close to nil. Additionally, since the transition length is shorter than the ON-state duration, i.e. the energy during the transitory state is assumed to be negligible.

$$P_{sleep}T_{sleep} \quad << \quad P_{ON}T_{ON} \tag{2}$$

$$P_{transition}T_{transition} \quad << \quad P_{ON}T_{ON} \tag{3}$$

Hence equation (1) reduces to

$$\mathrm{E_{Radio}} = \frac{\mathrm{P_{ON}T_{ON}}}{\mathrm{L}} \tag{4}$$

As P_{ON} comprises of transmitted signal power (P_{signal}), power consumed due to power amplifier (P_{pa}) and total power consumed by the circuit element $(P_{circuit})$, equation(4) can be written as:

$$\mathrm{E_{Radio}} = \frac{\mathrm{(P_{signal} + P_{pa} + P_{circuit})T_{ON}}}{\mathrm{L}} \tag{5}$$

In general, the efficiency of the power amplifier is given as:

$$\eta_{pa} = \frac{RFoutputpower}{DCinputpower} \tag{6}$$

Also the relation between power consumption in power amplifier P_{pa} and the signal power P_{signal} is :

$$\mathrm{P_{pa}} = \beta \times \mathrm{P_{signal}} \tag{7}$$

where β is a constant.
Hence the equation(5) can be re-written as :

$$\begin{aligned} \mathrm{E_{Radio}} &= \frac{\{\mathrm{P_{signal}} + (\beta \times \mathrm{P_{signal}}) + \mathrm{P_{circuit}}\}\mathrm{T_{ON}}}{\mathrm{L}} \\ &= \frac{\{(1+\beta)\mathrm{P_{signal}} + \mathrm{P_{circuit}}\}\mathrm{T_{ON}}}{\mathrm{L}} \end{aligned} \quad (8)$$

As the medium is free space and Line of Sight is assumed to exist between transmitter and receiver, so required signal power is expressed by the Friis transmission equation [12]

$$P_{signal} = \frac{P_r}{G_t G_r} \frac{(4\pi)^2}{\lambda^2} r^n \quad (9)$$

where P_r is the received power; G_t, G_r are the gain of the T_x and R_x respectively; λ is the wavelength; r is the distance between transmitter and receiver antenna; n is the path loss exponent [13] which ranges from 2 to 4.
The Signal to Noise Ratio(SNR) for uncoded(uc) transmitting data is given as:

$$SNR_{uc} = \frac{P_r \times \gamma}{M \times BW \times NF} \frac{1}{\frac{N_0}{2}} \quad (10)$$

where M is the number of bits per symbol; BW is the bandwidth; $\frac{N_0}{2}$ is the noise spectral density for additive white gaussian noise channel; γ is the code gain and NF is the noise figure for the receiver.

$$\text{Noise Figure (NF)} = 10 \log \text{Noise factor (N)} \quad (11)$$

The Signal to Noise Ratio(SNR) for coded(c) transmitting data is given as:

$$SNR_c = \frac{P_r}{M \times BW \times NF} \frac{1}{\frac{N_0}{2}} \quad (12)$$

where M is the number of bits per symbol; BW is the bandwidth; $\frac{N_0}{2}$ is the noise spectral density for additive white gaussian noise channel and NF is the noise figure for the receiver.
Suppose we are transmitting $'k'$ information bits and $'n'$ are the respective encoded bits for k info bits, then code rate(CR) is calculated to be $\frac{k}{n}$. Hence

$$\mathrm{E_{Radio_c}} = \frac{\frac{(1+\beta)\mathrm{P_{signal}T_{ON}}}{\mathrm{L}} + \dots}{\frac{P_{circuit}T_{ON} \times CR + LE_{comp} \times CR}{L}} \quad (13)$$

Similarly for the uncoded system:

$$\mathrm{E_{Radio_{uc}}} = \frac{(1+\beta)\mathrm{P_{signal}T_{ON}} + \mathrm{P_{circuit}T_{ON}}}{\mathrm{L}} \quad (14)$$

Expression for Information Rate(IR) with T_{ON} is given by

$$IR = \frac{\mathrm{L}}{\frac{\mathrm{T_{ON}}}{\mathrm{T_S}}} \Rightarrow T_{ON} = \frac{LT_S}{IR} \quad (15)$$

where Ts denotes time spent to transmit one symbol.

IV. SYSTEM PERFORMANCE ANALYSIS AND EVALUATION

A. *Analysis of RS codes with BPSK in AWGN channel*

Reed-Solomon Codes as error correcting codes remain the most understood codes whereas in the recent literature survey. Despite of several theoretical applications, it has much more impact on practical real-time applications such as wireless communication.

Performance analysis of Reed-Solomon codes(RS) in Fig. 2 and Fig.3. Fig. 4 shows the Performance analysis of Reed-Solomon codes (RS) with Binary PSK. Fig. 5 shows the Performance analysis of Hamming Codes).

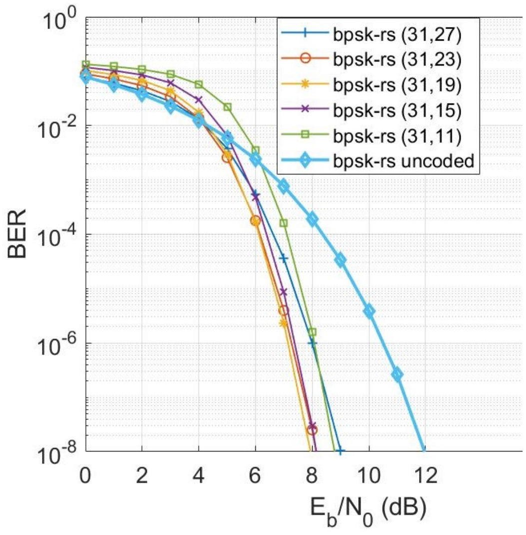

Fig. 2. Analysis of RS(31,k) codes with BPSK

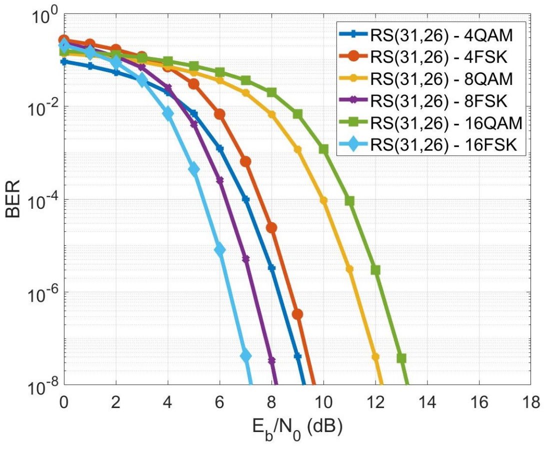

Fig. 3. Analysis of various RS(31,26) codes with M-QAM and M-FSK

B. *Performance Evaluation in fading condition*

The fade is dependent upon the signal variation in time and on the received envelope amplitude distribution. In most of the scenarios, Rayleigh fading is considered due to reflection and

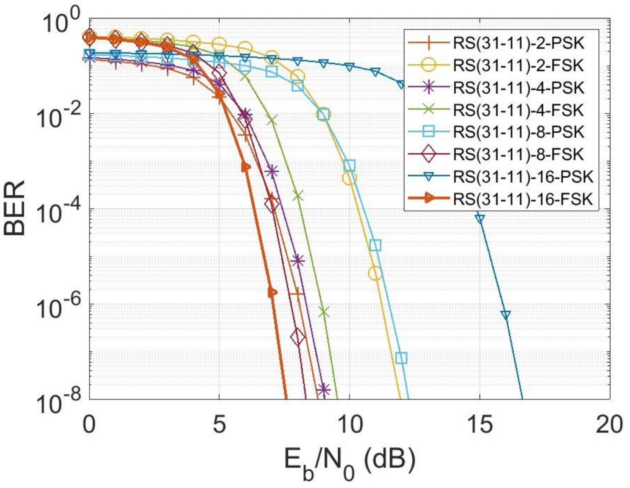

Fig. 4. Analysis of various RS(31,11) codes with M-PSK and M-FSK

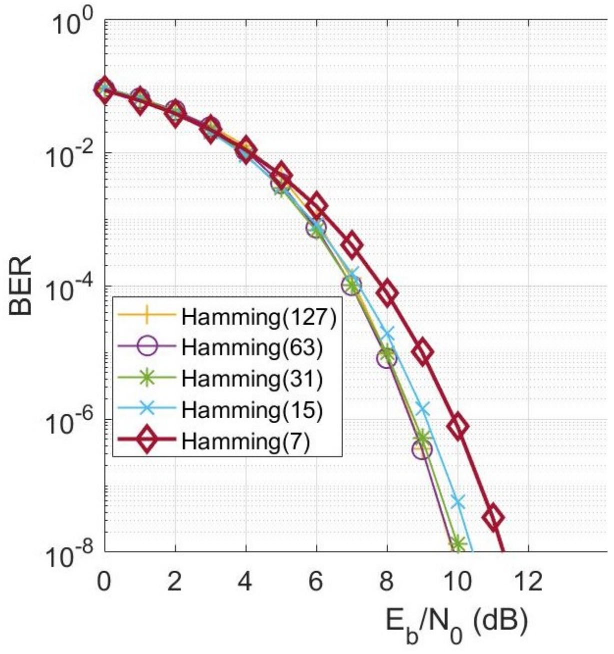

Fig. 5. Analysis of various Hamming codes with BPSK

scattering of the signal. The envelope of the received signal can be calculated as:

$$x_r(t) = Rl(t) \times T_x(t) \times n_{Gaussian}(t) \tag{16}$$

where $x_r(t)$ is Received signal, Rl(t) is Rayleigh component, $n_{Gaussian}(t)$ is added Gaussian noise representation. Analysis of RS codes in AWGN with Rayleigh is presented in Fig. 6. Bit error rate performance for the different signal constellations is presented in Fig. 7

V. CONCLUSION

This paper presents the analysis of block codes with various modulation schemes in AWGN channels. Here for a fixed modulation type, we have obtained the SNR for coded and uncoded transmitting data. From the simulation, it is found that RS codes perform better than Hamming codes.

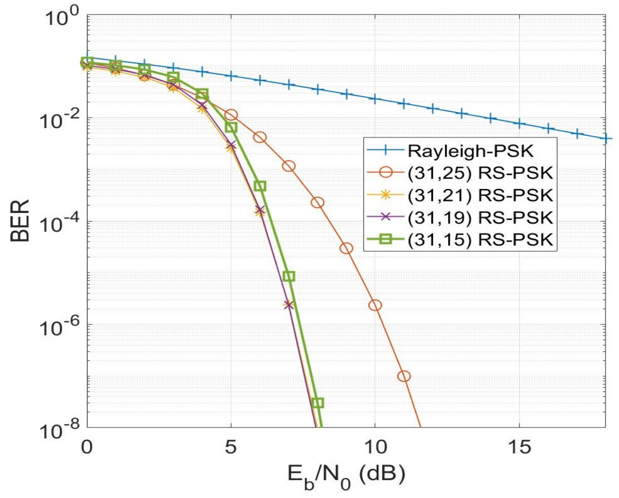

Fig. 6. Performance of various RS codes with Rayleigh channel

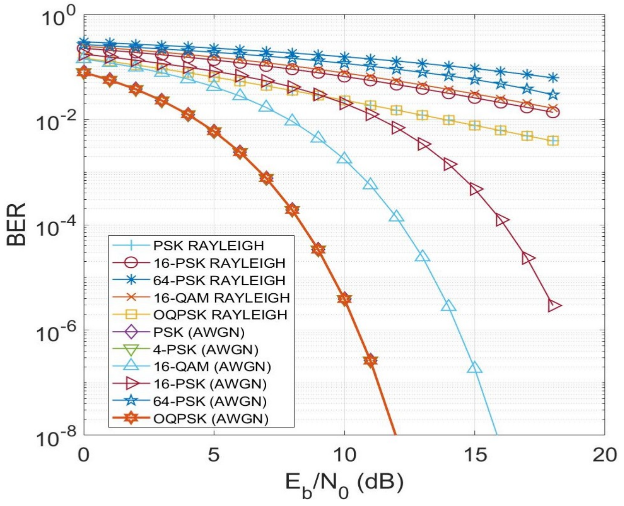

Fig. 7. Bit error rate performance for different signal constellation

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