Energy Efficient Communication Techniques for Wireless Sensor Networks

Bhavnesh Jaint, S.Indu, Neeta Pandey

Abstract: In wireless sensor networks (WSN), energy efficiency is of critical concern as the sensor nodes are powered by limited battery capacity. The choice of a modulation scheme and error control code plays an important role in determining the energy consumption of WSN. This paper analyses the performance of error control codes and various modulation schemes for WSN. The analysis reveals that the energy consumption in WSN can be decreased by a suitable choice of modulation scheme and error control codes. Our simulation results show that by using BPSK modulation with Reed Solomon (RS) code saves 48 % energy in WSN at an internode distance of 60 meters in comparison to higher order modulation schemes.

Index Terms: Energy Efficiency,Error Control Codes Modulation Scheme, Wireless Sensor Networks,

I. INTRODUCTION

A WSN consists of autonomoussensorsthat keeps a track onnatural environmental conditions, liketemperature, vibration, motion, level of pollutants etc., and communicate with each other the data viaa network to a sink. A basic communication system using modulation and error control coding is shown in Fig.1. Here, the information source is a sensor which measures the data (e.g. temperature, light, humidity etc.). This data is encoded using an error control code (linear or convolution codes). Finally, data is transmitted using a suitable modulation scheme e.g.ASK, FSK, PSK. At the receiver, the reverse process at the transmitter is performed to receive the data. The energy consumption of a WSN node depend s on the distance between receving node and transmitting node , choice of Bit Error Rate (BER), modulation techinques and error control code (ECC). S. Chouhan et al. [1]have investigated node energy variations based on used ECC and modulation parameters. Additive white Gaussian noise (AWGN) channel is considered for energy-optimal node design for the nodes. S. Cui, et al. [2] have studied transmission energy, circuit energy, transmission time, and constellation size for both uncoded and coded M-QAM and M-FSK and corresponding tradeoffs. Multi-level (M-ary) modulation and. binary modulation schemesare compred by A.Y. Wang, et.al. [3]. It is found that energy efficiency of former is better than the later one for the case with shortstart-up time and smaller RF output power. A. Ghaida et al. [5] have considered fading environments and addressed energy efficiency ofadaptive error correction in WSN.

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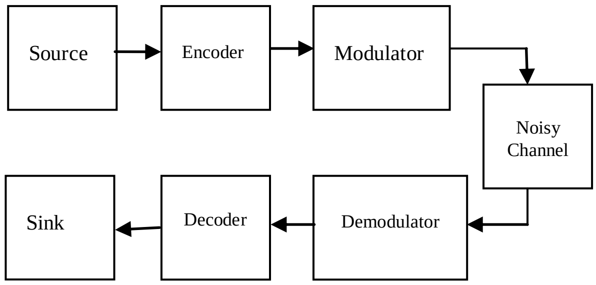

Fig. 1 Modulation & Error Control Codes in a Communication System.

H. Sharma et al. [6] have analyzed three modulations schemes viz. ASK, BPSK and OQPSK for WSN. H. Sharma et al. [4] have alsoanalyzed different error control codes. Hamming code(HC), convolutional code(CC), Goley code(GC) and Reed Solomon (RS) code show coding gain of 0.4 dB, 3.1 dB, 1.4dB and 2.4dB over uncoded data transmission.Though the CChas highest gain, its bit error rate i.e. BER ≈ (10^{-1}– 10^{0}) is higher than RS codes.Here an optimal selection of ECC and modulation scheme for WSNenergy efficient nodes is presented.In [17] authors presented the BERperformance of BPSK in AWGN by considering block codes and CC. All the codes are compared in the basis of BER and energy per bit to noise ratio. In [18] a survey on various methods of howECC techniques in WSNs is presented. And also, analysis energy models for finding energy efficiency of ECCs in WSN.

The work is organized in six sections.Section I provides an introduction to WSN. Section II provides an overview of digital modulation schemes, and Section III provides an overview of error control codes. Section IV gives the sensor node energy model and simulation results are placed in Section V. Finally, Section VI provides the conclusion.

II. DIGITAL MODULATION SCHEMES:

The digital modulation schemes involve switching or keying the amplitude, frequency or phase of the carrier as per bits of the digital message. Many digital modulation schemes for the transmission of digital data are available [7] in literature and are as follows

- Amplitude Shift Keying (ASK)
- Frequency Shift Keying (FSK)
- Phase Shift Keying (PSK)
- Quadrature Amplitude Modulation (QAM)

Selection of a modulation scheme for an application is not always straightforward. Following are some preferable requirements from a digital transmission system [8].

The very high data rate, minimum transmission bandwidth, minimum BER, minimum transmission power, minimum interference, cost-complexity should be less.

III. ERROR CONTROL CODING TECHNIQUES:

Coding techniques are used to add security to the message by encrypting the message bits with some extra bits at the transmitter end. These bits are referred to as redundancy bits. The receiver can perform error detection usingredundancy. Generally, the error control methods are classified into two types [7]:

(i) Error detection with retransmission.

(ii) Forward error correction.

In the former type, the error is first detected and a request is subsequently sent to the transmitter for resending (ARQ) data. The later type relies on correcting data using proper coding techniques at the receiver end.The various types of error control coding techniques [9] are Hamming Code, Goley Code, Reed Solomon Code, Convolution Code, BCH code.

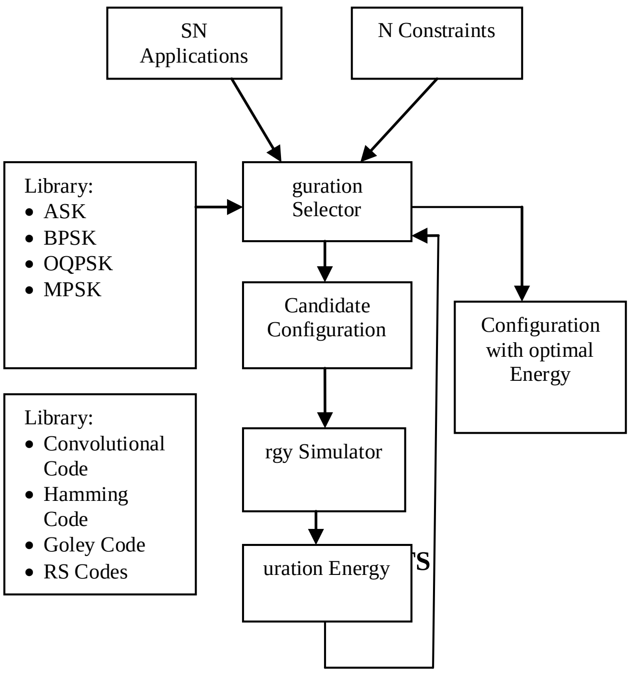

Fig. 2 Framework for finding optimal ECC-Modulation[4]

A.Reed Solomon (RS) Codes

The RS codes [10] are nonbinary cyclic codes with m bit symbols (where m>2). An RS (n,k) code on m-bit symbol exists for all n and k for which

$0 < k < n < 2m + 2 \ldots (1)$

where k denotes the encoded, a number of message symbols and n is the of codeword length. The standard equation for defining the RS (n, k) code with an error correcting capability of t bits is:

$(n, k) = (2m - 1, 2m - 1 - 2t) \ldots (2)$

For example, if m=3, & t=1, the value of (n,k) is RS (7,5) codes. The RS codes are block-based error correcting codes (non-binary BCH codes) with various applications in digital communications and storage. An RS code is defined in the following form:

$\boldsymbol{RS(n,k)}$ with $\boldsymbol{s}$-bit symbols.

It implies that the encoder requires k data symbols of $s$bits each. Further parity symbols are added to make a n symbol codeword. There are $(\boldsymbol{n},\boldsymbol{k})$parity symbols of bits each. An RS decoder can correct up to t symbols that contain errors in a codeword, where $\boldsymbol{2t} = (\boldsymbol{n},\boldsymbol{k})$.

Fig 3 shows a typical RS codeword. The following RS code encoder differs from a binary encoder as it operates on multiple bits rather than individual bits. Specifically, a$RS(n,k)$code is used to encode m −bit symbol into blocks consisting of $n = 2m - 1$, where $m \geq 1$.

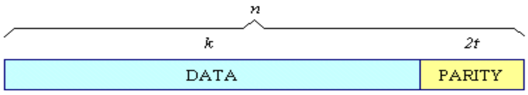

Fig. 3 Adding 2t parity(redundant) bits with(k) data bits in RS code

Thus, the encoding scheme expands an initial message block of k symbols to n symbols before transmission by adding $n - k$ redundant bits.

As $RS(n - k)$ code with error correcting capability $t$has the following parameters as shown in Table 1.

Table 1.Reed Solomon (RS) Codes Parameters

Block Length	$\boldsymbol{n = 2m - 1}$symbols
Message Size	$\boldsymbol{k}$symbols
Error Correcting Capability (Parity Check Size)	$\boldsymbol{n - k = 2t}$ symbols
Minimum distance	$\boldsymbol{d_{min} = 2t + 1}$ symbols

Various coderates are provided by RS code that can be chosen to optimize performance. One more reason for RS code being widely applicableis efficient decoding techniques are available.

IV. SENSOR NODE ENERGY MODEL AND ENERGY ANALYSIS

The factors on which energy consumption of a sensor node depends are Internodes distance(d), chosenBER, modulationtechniques, and ECCs[11].Fig. 2 shows the WSN design space exploration methodology for designing an energy-efficient networkwith various design parameters. The design space parameters are driven by WSN application and associated constraints. The deployment range is guided by specified application with the parameters such as area under surveillance, number of nodes to be deployed, network topology for efficiency and minimum power consumptionand the channel conditions.The minimum QoSto be maintained and Signal to noise ration (SNR)is the constraints to be maintained.Numerous optionsare provided bythe library to the configuration selector for compression techniques,channel coding techniques, modulation schemes and processor model.A particular configuration decided by the configuration selector based on above inputs. Energy consumption calculated by an energy simulator for chosen configuration.Feedback of energy consumption pattern helps the configuration to repeat the optimal energy isobtained.

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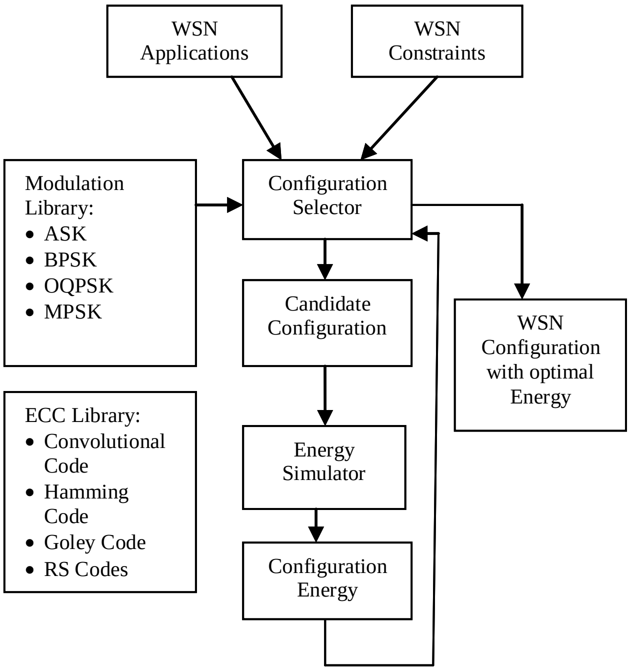
Fig. 4 The power consumption of a Sensor Node in various modes of operation



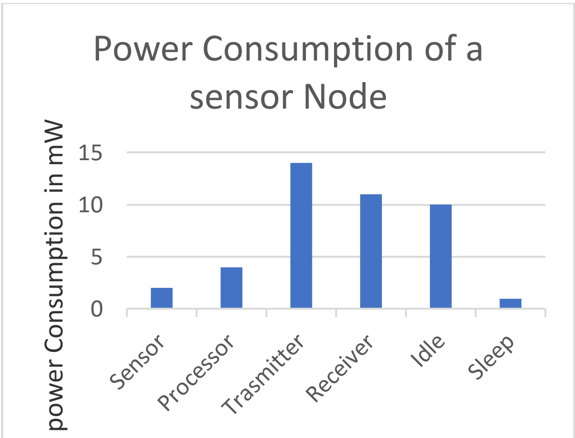


Figure 4 depicts the power consumption of various subsystems in a typical WSN node and modes of operation namely Transmit, receive, idle and sleep mode. [14],[15],[16]. From here, it is noted that communication subsystem (Transmit-Receive mode) consumes maximumpower as compared to other subsystems or modes of operation in the sensor node. For MICAz mote platform sensor node the energy consumed in Transmit mode is 25.4 mA, receive mode15.1 mA, idle mode 3.2 mA and sleep mode consumes 27 µA.

A.Radio Energy Model (Radio EM):

The components which contribute to the variation in energy consumption of a radio energy model are energy consumed in signal transmitting and energy consumed by radio circuit [14] [16].

On transmitting L bits, the radio energy per bit can be written as [12],

$$E = \frac{P_{on}T_{on}+P_{sp}T_{sp}+P_{tr}T_{tr}}{L} \quad \dots (3)$$

where, $P_i$and $T_i$correspond to power consumed in transceiver and mode duration and $i = on, sp, tr$fortransceiver on, sleep, and transmitmodes. Thesummation of signal transmit power $P_{sig}$and circuit power consumption P_{ckt_tot} is the power consumption in radio during ON mode.Thus, the radio energy consumption is

$$E_{radio} = \frac{(P_{sig}+P_{ckt\_tot})T_{on}}{L} \quad \dots\dots (4)$$

B.Transceiver Circuit Energy Model:

Total Circuit power consumption (P_{ckt_tot}) depends on power consumed in power amplifier (PA) power (P_{PA}) and other transceiver circuit elements power (P_{ckt}) namely digital to analog converter (DAC, low pass and band pass filters (LPF and BPF), frequency synthesizer (FS) and low noise and intermediate frequency amplifiers (LNA and IFA).

$$P_{ckt\_tot} = P_{PA} + P_{ckt} \quad \dots\dots (5)$$

$$P_{ckt} = P_{DAC}+2P_{LPF}+2P_{FS}+2P_{BPF}+P_{LNA}+P_{IFA}+P_{ADC} \quad \dots\dots\dots\dots (6)$$

C.Transmit Single Energy Model:

The transmitted power required for sending L bits is given by

$$E_{radio} = \frac{\left((1+\alpha)P_{sig}+P_{ckt}\right)T_{on}}{L} \dots\dots\dots\dots (7)$$

Signal power required in the free space can be obtained with Friis transmission equation [13]

$$P_{sig} = \left(\frac{4\pi}{\lambda}\right)^2 d^n \frac{P_r}{G_t G_r} \dots\dots\dots\dots (8)$$

where, $P_r$is the receiver power;$d$and λ correspond to distance between transmitter and receiver, and wavelength of the transmitted signal.$G_t$and $G_r$are the transmitter and receiverantenna gains and exponent$n$denotesthe path loss. The received power is

$$P_r = SNR_{uncoded} bB \frac{N_0}{2} NF \quad \dots\dots (9)$$

Here, $SNR_{uncoded}$ denotes the SNR ratio for transmitting uncoded data, $b$denotes number of bits per modulation symbol, Bdenotes bandwidth, noise spectral density is $N_0/2$ for the AWGN channel, and receiver noise figureisNF.

D.Computation Energy Model(CompEM):

The total computation energy per bit is

$$E_{comp} = \frac{E_{enc}+E_{dec}}{L} \quad \dots\dots (10)$$

where $E_{enc}$is encoder and $E_{dec}$is decoder computation energy. The final node energy per information bit for the coded system is the summation of $E_{radio}$and E_{comp}

E.Final node Energy Equation:

Ina coded system, the Energy of node per bit is the summation of radio energy and computation energy. It is denoted by$E_{node_coded}$and calculated by using Eq. (4), (6), (7) and (10)

$$E_{node\_coded} = \frac{(1+\alpha)P_{sig}T_{on}+P_{ckt}T_{on}\frac{N}{K}+LE_{comp}\frac{N}{K}}{L} \quad ..... (11)$$

where, K is the number of message bits and N representstotal number of encoded bits.

V.SIMULATION RESULTS:

Three modulation schemes i.e. ASK, BPSK and OQPSK were evaluated in Qulanet network simulator as shown in table 2 and Fig. 5

Table 2. Simulation parameters

Parameters	**Values**
No. of WSN nodes	12
Deployment Scenario	Home Automation
Radio Type	802.15.4 Radio
Transmission Power(dBm)	15.0
Gainof Antenna (dB)	0.0
Efficiencyof Antenna(dB)	0.8
Mismatch Loss of Antenna (dB)	0.3
Cable loss ofAntenna (dB)	0.0
Antenna Connection Loss(dB)	0.2
Antenna radiation	Omnidirectional
Temperature	290.0 K

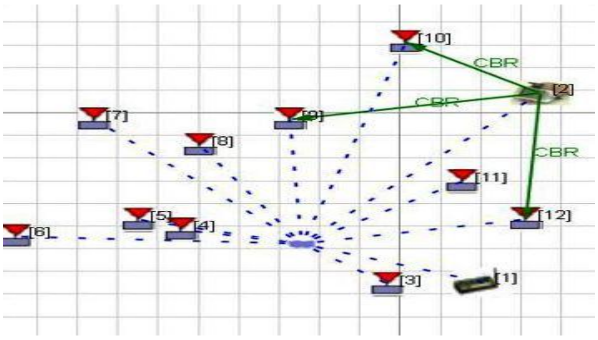


Fig. 5 WSN nodes in Home Automation Scenario of Qualnet Network Simulator

From Table 3, it is seen that the ASK is consuming the smallest power in all three modes as compared to BPSK & OQPSK (uncoded data transmission). But as we know that the Noise has a high effect on ASK modulated data packets therefore unwillingly, we have to leave the ASK from our choice for WSN and to choose the second smallest energy consumption modulation scheme i.e. OQPSK for WSNs.

Table 3. Simulation Results for Energy Consumed in 12 Sensor Nodes:

Exp. No.	**Modulation Scheme**	**Transmit Mode (mJ)**	**Receive Mode (mJ)**	**Sleep Mode (mJ)**	**Idle Mode (mJ)**	**Total Energy (mJ)**
1	ASK	0.0712	0.203	0	10.739	11.013
2	BPSK	0.3745	1.254	0	10.487	12.115
3	OQPSK	0.0725	0.215	0	10.736	11.023

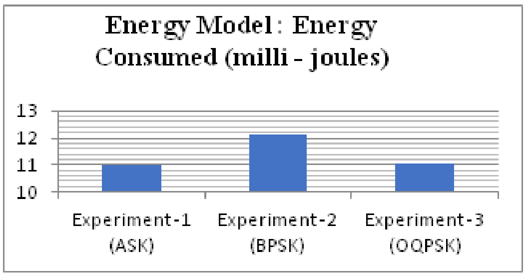


Fig. 6 Total Energy Consumed (mJ) using ASK, BPSK & OQPSK Modulations

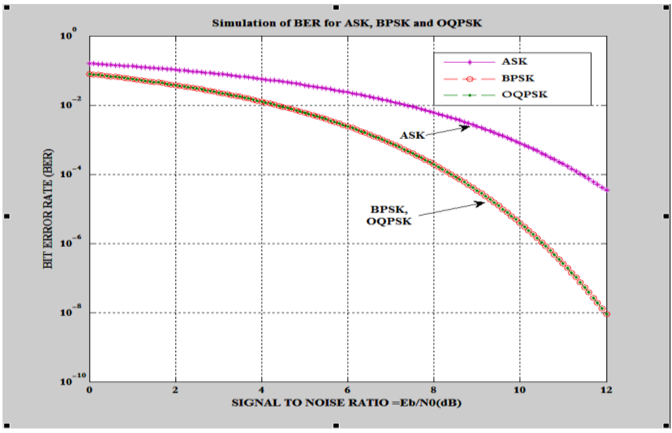


Fig. 7 Plot of differet modulation schemes (ASK, BPSK and OQPSK) versus SNR

For error control codes with modulation schemes, the simulation is performed in MATLAB simulator. The obtained simulation results have been shown in table 3 and figure 5.

Table 4. MATLAB Simulation Results for RS (N=63) code with t=2 & t=4:

Distance (d)	BPSK	Node EnergyE_1 per data bit(μJ) at t=2	Node EnergyE_2 per data bit(μJ) at t=4	Node Energy saving (μJ) E_3= E_1 – E_2	Node energy saving (%)= (E_3/E_1) X100
30	2	5.38	2.79	2.60	47%
60	2	5.41	2.81	2.60	48% (max.)
90	2	5.42	2.85	2.57	47%
120	2	5.52	2.92	2.60	47%
150	2	5.54	3.20	2.34	42%
180	2	5.75	3.40	2.35	40%

From these simulated results of Table 3, we find at distance (d) =60m an optimal ECC-modulation pair RS (N=63) code with t=4 & BPSK modulations schemes gives 48% energy savings.

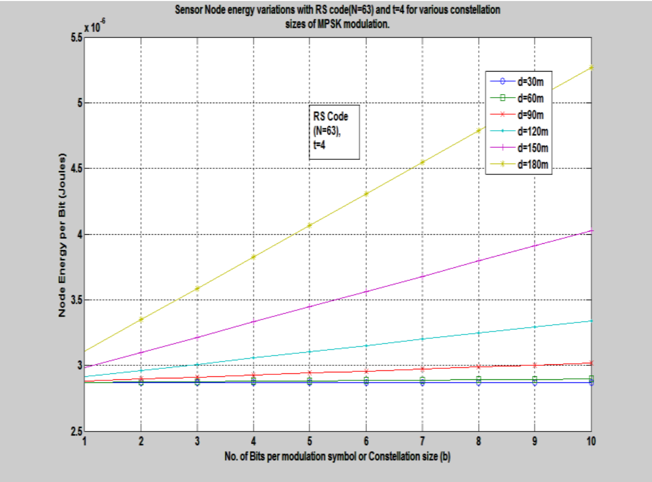


Fig. 8 Sensor Node energy variations with respect to distances at t =4.

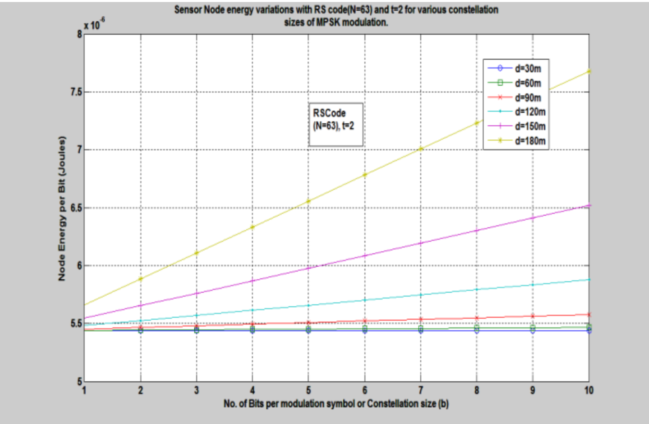


Fig. 9 Sensor Node energy variations with respect to distances at t =2.

The Figs. 8 and 9 show WSN node energy variations using RS codes with BPSK at N=63 and error correcting capability (t=4 and t=2) for various distances respectively

VI. CONCLUSION:

A methodology for the energy consumption of sensor nodes has been discussed in this paperand evaluation is done on the basis of various ECCs. A home automation scenario is considered for evaluation. The simulation results show that in sensor node with Reed-Solomon codes and BPSK modulation consume the optimal energy in certain operating conditions. We find at distance (d) =60m an optimal ECC-modulation pair RS (N=63) code with t=4 & BPSK modulations schemes gives 48% energy savings.

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