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Energy Efficient Quasi Cyclic FEC for Wireless Sensor Networks

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Abstract: Wireless sensor network (WSN) is a collection of battery operated sensor devices with lossy nature. Achieving reliability in data transmission in WSN is a big challenge. Forward error control (FEC) and Automatic Repeat request (ARQ) are the error control mechanisms used for increasing the reliability of data transmission. Since, WSN is a power constraint environment, the error control mechanism implemented in the sensor nodes should consume less energy. In this paper, we propose optimal quasi cyclic FEC scheme in WSN for detection and correction of burst errors. In ARQ, retransmission of corrupted data is highly time consuming whereas the proposed quasi cyclic code handles the burst errors effectively, which are very common in bulk data transmission. Quasi cyclic codes are known for their minimum distances among linear codes. In the proposed work, optimal binary quasi cyclic code is adopted for the first time for error correction in WSN with column wise transmission. The inference is that quasi cyclic FEC is effective in terms of energy efficiency compared to other FEC codes and ARQ schemes. It also improves the network lifetime by reducing the retransmission.

Keywords: Quasi cyclic codes, Forward error correction, Energy efficiency

1 Introduction

Wireless sensor network (WSN) is a network of hundreds of low power sensor nodes dispersed in inaccessible areas like forests, mines, underwater, air, battle fields, etc. Sensor nodes are very small in size with limited power resource. These nodes are capable of sensing various parameters from the environment wherein they are deployed as shown in Fig.1. The gathered information from the monitored field is transmitted wirelessly to the sink or base station by multi hops. Wireless Sensor networks are expected to have longer network life time through efficient use of the power required for various operations. Due to its power constraints and lossy nature [1], reliable data transmission is a paramount challenge in varying channel conditions. Moreover, sensor nodes act as data senders, data routers or forwarders in the multihop scenario until the sensed data reaches the sink node. Reliability is provided by means of error control mechanisms like FEC, ARQ and Hybrid ARQ (HARQ). Based on the requirement of the application, any of the above mentioned error control strategies can be chosen to overcome the problem of transmission errors. But energy efficient error control technique is very much essential for energy constrained WSN.

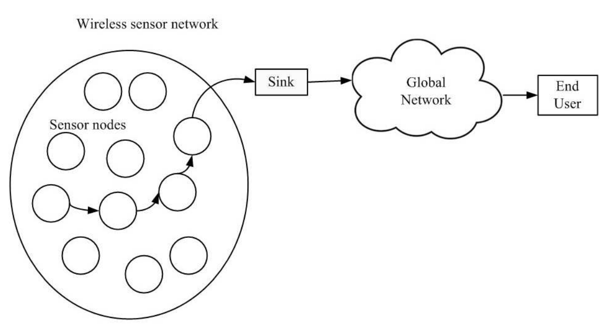

Fig. 1: Wireless Sensor Network

Many FEC, ARQ and HARQ schemes have been discussed in the literature. Several energy efficient error control techniques have been proposed for the improvement of the lifetime of the WSN nodes [5,6,9,10]. In FEC, redundant bits are added with original information depending upon the type of error correcting code chosen. These bits help the receiver to identify and correct the errors. The probability of error with the received data packets depends upon the channel

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condition. There is also an increase in overheads due to the redundancy added to the transmitted data packets. At the same time, the amount of energy spent to decode the received message will also be more. FEC is preferred over ARQ schemes when retransmission are impossible or more costly. Use of specific forward error correcting codes depends on application requirements of wireless sensor networks. Powerful codes provide better performance even in poor channel conditions at the cost of battery power.

In this paper, optimal binary quasi cyclic code based FEC is attempted for the first time for error correction in power constrained wireless sensor network. This coding scheme improves the life time of the sensor nodes by reducing or eliminating the need for retransmission.

The rest of paper is organized as follows. Section II deals with related works. System model and quasi cyclic FEC are presented in section III, performance evaluation of the proposed scheme is discussed in section IV. Section V presents conclusion and future work.

2 Related Work

Error control schemes are often applied to data transmission over wireless links. Kan Yu et.al proposed the Adaptive Forward error correction Scheme for Wireless sensor networks [2]. Here the sensor nodes are deployed with inbuilt FEC codes. The FEC codes are identified with different numbers. Based on the channel quality found suitable, FEC code is chosen for encoding. Packet delivery ratio and throughput are increased and energy consumption is also reduced when compared to the conventional static FEC code usage. Link quality metric is not justified in this paper. Y.Sankarasubramaniam et.al proposed an optimal packet size for data transmission with error control coding in energy stringent wireless sensor networks [3]. BCH codes are considered for error correction in this paper. Energy efficient optimal packet size is suggested for WSN. Burst error correction is not addressed in this work. Exhaustive comparisons of BCH codes with other codes were not presented.

Osjkar Eriksson et.al proposed Hybrid ARQ Adaptive FEC (HAF) scheme based on BCH codes using Channel state Information [5]. Tradeoffs between FEC and retransmission scenarios for industrial applications are discussed in this paper. They have proved that HAF provides improved performance in terms of energy efficiency and latency, when compared to conventional ARQ schemes. The authors have not considered the Channel state information to choose the error control scheme that has to be employed. Zhen Tian et.al analyzed the energy efficiency of error control schemes in wireless sensor networks [6]. Here the energy efficiency of optimum FEC scheme BCH is compared with ARQ schemes on the basis of size of the packet and communication distance. The authors conclude that FEC outperforms ARQ for a certain packet size and communication distance. Analysis proves that energy efficiency of ARQ schemes remains the same for any number of retransmission times and energy efficiency is independent of retransmission attempts.

Ghaida A. AL-Suhail et.al developed an analytical model to determine the energy efficiency of Adaptive Error Correction Code in fading environments in wireless sensor networks [7]. In this work, the authors have proposed an adaptive error control with an idea that, BCH forward error correcting code increases the throughput and ARQ increases the reliability of the data transmission. Based on received signal strength, channel state information is sent with the acknowledgement to the sender as a feedback. This enables adaptive choice for the transmitter between FEC and ARQ for data transmission for target communication distance and packet length with maximal energy efficiency.

Mehmet C. Vuran et.al presented the cross layer analysis of error control in wireless sensor networks [11]. Evaluation of the performance of FEC, ARQ and HARQ was done with hop length extension between the nodes and transmission power control by considering the effect of MAC. Here BCH and RS codes are used as FEC codes. They consider broadcast wireless channel model and multi-hop structure of WSN for analytical modelling. Results prove FEC and HARQ having improved performance in terms of latency, energy efficiency and end-to-end packet error rate.

Nabli Ali Alrajeh et.al studied the different techniques used for error correction in wireless sensor networks [12]. Selection of optimum error correcting code in WSN depends on the requirement of the application. Suitable error correcting codes are identified on the basis of its performance and energy consumption. Various implementation strategies of error control techniques used in WSN were studied in this paper. Energy efficiency of different error control coding schemes is evaluated on the basis of decoding energy per bit as optimization criterion. They showed that stronger error control codes perform well at the cost of utilizing more energy. But simpler error control codes are more energy efficient though with poor performance. It is also suggested that stronger error control codes can be adopted for end to end error control strategy and simpler error control codes for node to node error control strategy. No specific error control coding is considered in this paper.

Sonali Chouhan et.al analyzed the energy consumption of sensor node by considering error correcting code and modulation schemes [23]. Energy efficient combination of Reed Solomon (RS) codes with different error correcting capability and modulation schemes with different constellation size is studied in this paper. The authors reported, RS codes (63,59,5) with Binary Phase Shift Keying (BPSK) modulation scheme as optimum energy efficient pair in wireless sensor networks.

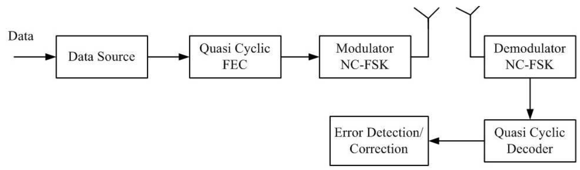

Fig. 2: Proposed Quasic cyclic coding system in wireless sensor network

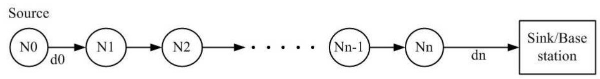

Fig. 3: Multihop linear array sensor network model

JH Kleinschmidt proposed a simulation model to analyze the energy efficiency of ARQ retransmission strategy and BCH codes in WSN using IEEE 802.15.4 standard in Rayleigh fading channel [25]. Network performance is evaluated for different channel conditions with different packet sizes for multihop scenario. Results have demonstrated the suitability of cyclic redundancy check for good channel conditions and few hops transmission. For more hops and low values of Signal to Noise Ratio, ARQ and BCH is energy efficient. BCH codes have better energy efficiency for longer packets when compared to ARQ.

To complement the existing work, we propose an appropriate quasi cyclic code to encode the data and transmit the code word in column wise for mitigating the burst errors. Quasi cyclic code avoids the need for retransmission and in turn reduces the energy consumption to a greater level.

3 Proposed System model

In the proposed model, the sensed data is encoded using a quasi-cyclic code before transmission as shown in Fig. 2. Proposed quasi cyclic code is an alternative to standard channel coding for applications like terrestrial communication systems and space crafts. Once the data is encoded and modulated by Non Coherent Frequency Shift keying, it is transmitted wirelessly. It takes multiple hops to reach the base station as shown in Fig.3. N_0 is the source node while all other intermediate nodes are assumed to be arranged in linear manner with di as the distance between nodes. Here the functions of the intermediate nodes are to receive and forward the coded data until it reach the base station.

3.1 Wireless Link Model

In this work we consider a log-normal shadowing path loss channel model [4], where the transmitted signal undergoes path loss, shadowing and multipath fading effects before reaching the base station or sink. Considering all these effects, the average received signal power $P_r(d)$ at a distance d from the transmitter is expressed as

$$P_r(d) = P_{tr} - P_{d0} - 10\beta log(\frac{d}{d_0}) + X_\sigma \qquad (1)$$

where P_{tr} is the transmitted power, β is path loss exponent and it is set as 3.5. P_{d0} is the path loss at reference distance d_0 and X_σ is the shadow fading component. The signal to noise ratio at the receiver is given by

$$\gamma(dB) = P_r(d) - P_n \qquad (2)$$

where P_n is the noise power represented by [17]

$$P_n = (F+1)kTB \qquad (3)$$

where F is noise figure, k is Boltzmann?s constant, T is temperature in kelvin and B is signal bandwidth.

3.2 Error rate

Non-coherent Frequency Shift Keying (NC-FSK) modulation is considered on the basis of the IEEE 802.15.4 standard at 2.4GHz band [16]. For multihop sensor networks with Rayleigh slow fading channel with average signal to noise ratio $\bar{\gamma}$, probability of error P_b of FSK modulation scheme is

$$P_b = \frac{1}{2+\bar{\gamma}} \qquad (4)$$

Packet error rate (PER) for the error control scheme is calculated on the basis of the bit error rate. PER of single transmission of packet with length of n bits and error correcting capability t is given by

$$1 - PER = \sum_{j=0}^{t} \binom{n}{j} (P_b)^j (1-P_b)^{n-j} \qquad (5)$$

3.3 Energy Efficient Calculations

The transmission energy efficiency η of WSNs depends on both energy consumption of the system and reliability of communication, which is defined as [6]

$$\eta = \eta_e r = \frac{E_{effi}}{E_{total}}(1-PER) \qquad (6)$$

where η_e denotes the energy throughput, which is the ratio of energy consumption of payload E_{effi} to the total energy consumption E_{total} and $r = (1-PER)$ is the packet acceptance rate which accounts for data reliability.

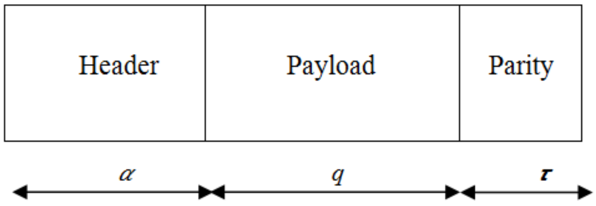

Fig. 4: Data Link Layer Packet Format in IEEE 802.15.4

3.4 Energy Consumption Characteristics of FEC

Focus is made on the data link layer protocols in sensor networks with unique error control strategy. The analysis is based on Mica2 sensor node [12] with ATmega128L processor [13] and CC1000 radio module [14]. Data link packet format is depicted in Fig. 4. Hop by hop error control is employed in data link layer using quasi cyclic code. Energy spent by the source to encode the sensed data is negligible when compared to the transmission of encoded bits and decoding the received code word. Energy consumed to transmit and receive one information bit is given as [11]:

$$E_{bit} = E_t + E_r + E_d \tag{7}$$

where E_t the energy consumed for transmission of a single bit and E_r is energy consumed for reception of bit and E_d is energy spent for decoding a single bit.

The energy spent on transmission and reception can be represented as

$$E_t = \frac{(P_t + P_0)\frac{n}{R} + P_{st}T_{st}}{q} \tag{8}$$

$$E_r = \frac{P_r(\frac{n}{R}) + P_{sr}T_{sr}}{q} \tag{9}$$

where P_0 is the output transmit power, $P_{st/sr}$ is the start-up power consumed in the transmitter/receiver, Tst/sr is the start-up time of transmitter/receiver, q is the size of the payload in bits, R is the data rate in kbps and $n = \alpha + q + \tau$, is the total length of the data packet in bits. Here α is size of the header in bits, τ is the number of parity bits and $q + \alpha$ is the length of the message. The energy consumed for decoding the information bit [15] is estimated as

$$E_d = \frac{P_{tot}}{R} \tag{10}$$

$$P_{tot} = CV_{dd}^2 + I_{leak}V_{dd} \tag{11}$$

where C is the total switched capacitance, V_{dd} is supply voltage and I_{leak} is the leakage current of the CMOS logic of the decoder architecture considered.

Equation (7) can be written as follows,

$$E_{bit} = S_1 + S_1\frac{(\alpha+\tau)}{q} + \frac{S_2 + E_d}{q} \tag{12}$$

where S_1 and S_2 are the constants of radio transceiver and can be represented as

$$S_1 = \frac{(P_t + P_0) + P_r}{R} \tag{13}$$

$$S_2 = P_{st}T_{st} + P_{sr}T_{sr} \tag{14}$$

Now using transceiver constants S_1 and S_2 energy efficiency equation (6) can be rewritten as

$$\eta = \frac{S_1 q}{S_1(\alpha + k + \tau) + S_2 + E_d}(1 - PER) \tag{15}$$

Quasi cyclic codes in the form of (n,k) have been used, where n is the total length of packet with parity bits. Here $n = \alpha + k + \tau$ and k is the length of the message which is given as $k = q + \alpha$. Values n and k can be changed based on the requirement of application. Also the energy efficiency is the function of error correcting capability t and total length of the packet n.

3.5 Quasi Cyclic Error Correcting Code

Quasi cyclic codes belong to a subclass of cyclic codes that are highly promising when compared to other standard codes [19]. Quasi cyclic code is defined as, a linear block code C of length $n = mp$ over finite filed F_q. It is also known as quasi-cyclic code of index p, if for every codeword $c \in C$ there exists a number p such that codeword obtained by p cyclic shifts is also a codeword in C.

$$c = (c_0 \ldots c_{n-1}) \in C \Rightarrow c' = (c_{n-p}, \ldots, c_0, \ldots, c_{n-p-1}) \in C$$

The index p is defined as the smallest number of cyclic shifts where the code is invariant. Quasi cyclic codes are generally derived from cyclic codes. That is cyclic codes with $p = 1$ are quasi cyclic code. In other words a code is said to be quasi cyclic code (n,k,d) if the cyclic shift of a code word by p positions also produces another code word with a code rate of $1/p$. For example, the binary (6,3) code with generator matrix

$$G = \begin{bmatrix} 1\;1\;0\;1\;0\;0 \\ 0\;0\;1\;1\;0\;1 \\ 0\;1\;0\;0\;1\;1 \end{bmatrix}$$

is a quasi-cyclic code with $p = 2$. For ease of understanding, in the above generator matrix, the shifts are represented as blocks,

$$G = \begin{bmatrix} 11\;01\;00 \\ 00\;11\;01 \\ 01\;00\;11 \end{bmatrix}$$

The generator matrix G gives so called 1-generator (6,3) code over F_2 with $p = 2$ and $m = 3$, and the generator vector (11 01 00). These quasi-cyclic codes very well meet the Shannon lower bound with small redundancy and larger minimum distance between code words [20, 21]. A majority of quasi cyclic codes are majority logic decodable, which is very simple and fast in terms of decoding. So the decoding complexity of quasi cyclic codes is quite manageable.

The importance of choosing quasi cyclic code lies in the establishment of an alternate channel coding standard for communication systems with improved performance and efficient bandwidth usage. Life time of the sensors nodes in WSN is increased by employing quasi cyclic codes with reduced energy consumption.

The best quasi cyclic codes are identified with code rates of $1/p$ and $(p-1)/p$ through the use of linear integer programming and its extension. For example, if we consider quasi cyclic code (16,8,5) with code rate of $1/2$ and minimum distance of 5, the length of the code word is 16, length of the message is 8 bit and the error correcting capability is $t = 2$, with cyclic shift of 2 bit positions.

Error Correcting Methodology

1. Sensed data is fragmented into groups of 8 bits. The message vector is multiplied with the generator matrix to get the code word. Using $(16,8)$ quasi cyclic code, the entire fragmented data is converted into a code word. Quasi cyclic code $(16,8)$ can detect 3 bit errors and capable of correcting 2 bit errors. 8 bit syndrome representation is used here.
2. Four such code words are grouped and transmitted to the receiver column wise rather than the conventional row wise transmission as depicted in Fig.5. The first bits of all the four code words are transmitted to start with, followed by second bit and so on.
3. The bits at position $p = 4n, 4n+1, 4n+2, 4n+3$, are mapped from retransmission medium to code words (cw) as $cw1$, $cw2$, $cw3$ and $cw4$ respectively and $n = 0$ to 15. This is the result of column wise transmission. The data bits are positioned at $(15-n)$ in the code word.
4. At the receiver side, received code word is multiplied with inverse of generator matrix and the resultant is compared with predefined syndrome to check for errors.

   Let us consider, the generator matrix G given by

$$G = \left[I_8 \; C\right] = \begin{bmatrix} 1&0&0&0&0&0&0&0&0&1&1&0&1&0&1&0 \\ 0&1&0&0&0&0&0&0&0&0&1&1&0&1&0&1 \\ 0&0&1&0&0&0&0&0&1&0&0&1&1&0&1&0 \\ 0&0&0&1&0&0&0&0&0&1&0&0&1&1&0&1 \\ 0&0&0&0&1&0&0&0&1&0&1&0&0&1&1&0 \\ 0&0&0&0&0&1&0&0&0&1&0&1&0&0&1&1 \\ 0&0&0&0&0&0&1&0&0&1&0&1&0&0&1&1 \\ 0&0&0&0&0&0&0&1&1&0&1&0&1&0&0&0 \end{bmatrix}$$

And the parity matrix H is represented by

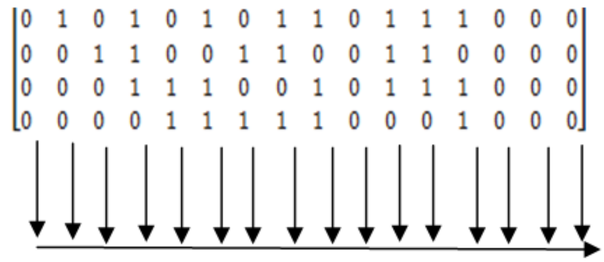

Fig. 5: Column wise transmission of codewords

$$H = \left[C^T \; I_8\right] = \begin{bmatrix} 0&0&1&0&1&0&0&1&1&0&0&0&0&0&0&0 \\ 1&0&0&1&0&1&1&0&0&1&0&0&0&0&0&0 \\ 1&1&0&0&1&0&0&1&0&0&1&0&0&0&0&0 \\ 0&1&1&0&0&1&1&0&0&0&0&1&0&0&0&0 \\ 1&0&1&1&0&0&0&1&0&0&0&0&1&0&0&0 \\ 0&1&0&1&1&0&0&0&0&0&0&0&0&1&0&0 \\ 1&0&1&0&1&1&1&0&0&0&0&0&0&0&1&0 \\ 0&1&0&1&0&1&1&0&0&0&0&0&0&0&0&1 \end{bmatrix}$$

The message to be sent is assumed as 01000010. Then the encoded message will be

$$\begin{bmatrix} 0&1&0&0&0&0&1&0 \end{bmatrix} \begin{bmatrix} 1&0&0&0&0&0&0&0&0&1&1&0&1&0&1&0 \\ 0&1&0&0&0&0&0&0&0&0&1&1&0&1&0&1 \\ 0&0&1&0&0&0&0&0&1&0&0&1&1&0&1&0 \\ 0&0&0&1&0&0&0&0&0&1&0&0&1&1&0&1 \\ 0&0&0&0&1&0&0&0&1&0&1&0&0&1&1&0 \\ 0&0&0&0&0&1&0&0&0&1&0&1&0&0&1&1 \\ 0&0&0&0&0&0&1&0&0&1&0&1&0&0&1&1 \\ 0&0&0&0&0&0&0&1&1&0&1&0&1&0&0&0 \end{bmatrix}$$

$$= \begin{bmatrix} 0&1&0&0&0&0&1&0&0&1&1&0&0&1&1&0 \end{bmatrix}$$

(a) Some of the bits of the above code word may be corrupted during transmission due to noise and reach the receiver with error. Errors may occur at different positions or as a bunch of consecutive bits in the received code word.

(b) Error may be located at any one of the four code words, because of column wise transmission; in every 4 bit transmission, there is a bit from each code word. The possibility of a code word affected by noise is reduced to one fourth, as a result.

(c) Even burst error can be detected and corrected at the receiver side. The received code word is compared with the syndrome table and burst errors are easily identified.

(d) Retransmission is avoided, if the burst error occurring in the received code word is less than or equal to 8, with the proposed column wise transmission. As depicted in Fig. 5, 64 bits are transmitted as 4 code words, with each code word carrying 16 bits. The proposed quasi cyclic code is capable of correcting a 2 bit error in each code word. For 4 code words it can correct up to 8 bit each. So, the proposed error correction code $(16,8)$ is capable of correcting burst errors of up to 8 bits.

4 Simulation Results

In this section, the performance of the proposed scheme is evaluated analytically using MATLAB simulation tool. The performance is evaluated in terms of energy efficiency for packet length optimization and compared with the ARQ schemes available in the literature. Various radio parameters settings used for the simulation are depicted in Table. I. This section deals with the energy efficiency analysis of quasi cyclic code. Data communication between sensors in wireless sensor networks can be made energy efficient by choosing suitable error correcting codes. We considered quasi cyclic codes with majority logic decoding technique at every intermediate node. It is assumed that nodes are deployed in a linear manner as shown in Fig. 3.

Table 1: Radio Parameters Setting

Symbol	Parameters	
	Name	**Value**
B	Bandwidth	30KHz
F	Noise Figure	13dB
Pn	Noise power	-105dBm
$\alpha+\tau$	Size of MHR and FCS	11 bytes
K	size of payload	Variable
P_{d0}	pathloss at reference point	55dB
P_t	Transmitting power	0dBm
R	Data rate	250kbps
S_1	Transceiver constant 1	$1.85\mu J/bit$
S_2	Transceiver constant 2	$24.86\mu J$

The possible achievements in terms of performance analysis are investigated with the use of a binary quasi cyclic code. Energy efficiency (η) is expressed as a function of packet length and error correcting capability (t). Irrespective of the code rate, for every error correcting capability (t) of the quasi cyclic code, there must be unique highest energy efficiency value, with an optimal packet size. Without loss of generality, the variables q and n can be changed for ease of analysis. Fig. 6 illustrates the energy efficiency for different packet length and error correcting capability t for bit error rate of $P_b = 10^{-4}$. Here P_b is chosen based on maximum attainable energy efficiency and increased payload length. Energy efficiency η is evaluated, for different values of error correcting capability t and for a range of packet length. It is inferred from the plot that, with the use of quasi cyclic code energy efficiency improved significantly as much as

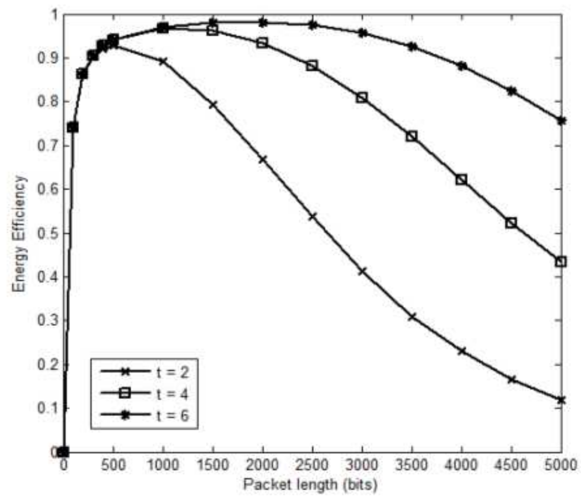

Fig. 6: Energy efficiency (η) for different packet length for quasi cylic codes with t = 2,4,6.

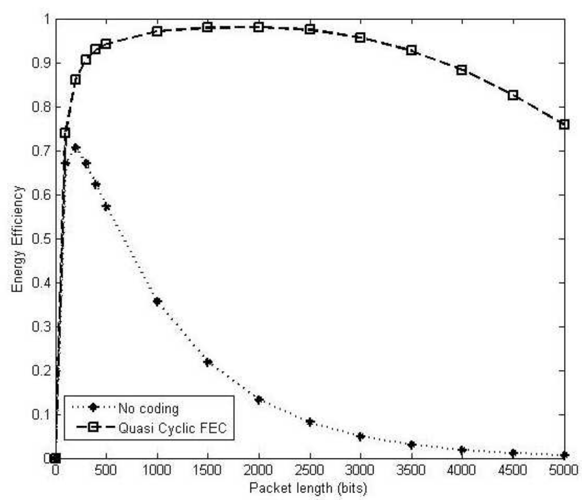

Fig. 7: Comparison Energy Efficiency (η) for Quasi cyclic FEC code and ARQ

27%. When t increases, energy efficiency also increases for a specific packet length. For example, 98 percent efficiency is achieved for a packet length of 1900 bits at $t = 6$. At the same time, the efficiency is sustained for a wide range of packet length. It is assumed that the above results holds true for independent bit errors.

Fig. 7 shows the comparison between Energy expenditure for quasi cyclic FEC code and without any FEC. Improvements in energy efficiency are quiet significant in quasi cyclic code FEC compared to that of the no coding case, $(t = 0)$.

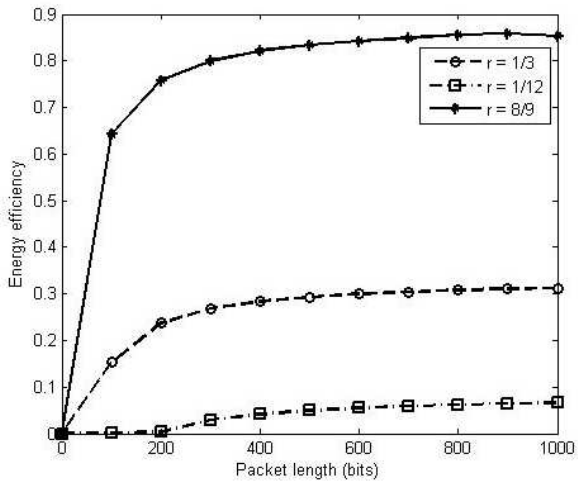

Fig. 8: Energy Efficiency (η) for code rates r = 1/3,1/12 and 8/9 as function of packet length for t = 4

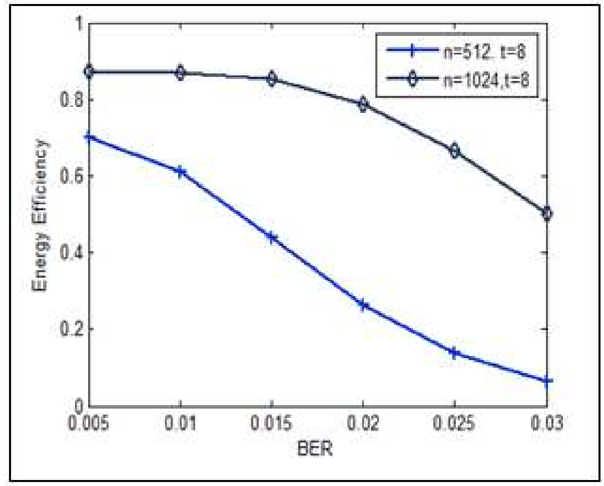

Fig. 9: Energy Efficiency (η) versus Bit error rate for packet length 512, 1024 bits

Retransmission of raw data requires feedback channel with latency that too for hop by hop packet transfer scenario. Code rate of the quasi cyclic code also limits the efficiency of the maximum energy. We have analysed the energy efficiency behaviour for various packet lengths for error correcting capability $t = 4$. Code rates $1/3$, $1/12$ and $8/9$ of quasi cyclic code are considered for the same. Results shown in Fig. 8 depict, energy is effectively utilized for the packet transmission using code rate $8/9$. With code rates $1/3$ and $1/12$ the efficiency is very less for the same packet length considered. Higher code rates like $8/9$ outperforms when compared to medium code rates like $1/3$ and low code rate $1/12$. A higher code rate enables error recovery. Its energy efficiency performance is increased with increasing packet length. The error recovery is unlimited for lower code rates at the cost of energy efficiency with a large number of redundant bits. In quasi cyclic code, the greater the value of p in $1/p$ case, the smaller the energy efficiency. It implies that quasi cyclic codes with code rate $1/2$ or $8/9$ or $13/12$ etc. in the form of $(p-1)/p$ is more efficient in terms of energy for optimum packet size.

Under burst error conditions the energy efficiency of quasi cyclic code depends mainly on bit error rate and the size of the error. Fig.9 shows the energy efficiency as a function of the bit error rate for packets of different size and length. FEC increases with decreasing bit error probability. However the lowest energy expenditure is achieved for greater error correcting probability with a greater packet size. It is seen that for error correcting capability $t = 8$ with packet length $n = 1024$ outperforms compared to $n = 512$ case. An eight bit error correcting binary quasi cyclic code improves the energy efficiency as much as 27% with optimum packet size.

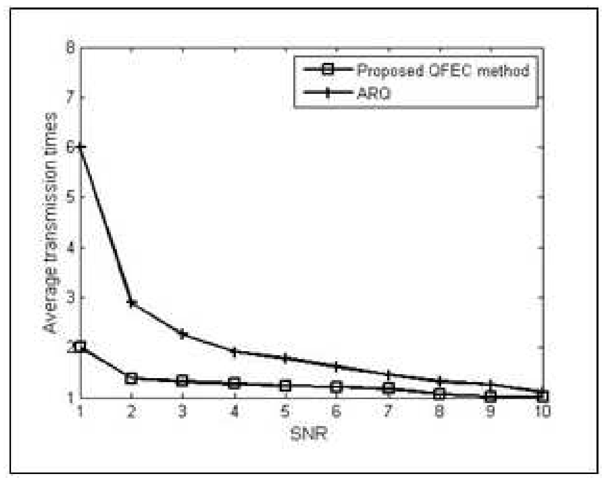

Fig. 10: Average transmission times vs SNR

Fig. 10 shows the relationship between average transmission times and SNR for the proposed Quasi-cyclic FEC method in comparison with that of ARQ method where no coding technique is utilized for error correction. Column wise transmission of code word matrix encoded by (16,8) quasi-cyclic code is considered for the evaluation. The proposed code facilitates the receiver with higher decoding probability and it also guarantees the correction of burst error. Average number of transmission times required by proposed method is 2, when the channel conditions are poor. If there are less than 2 errors in each code word of (16,8) quasi cyclic code, then the message bits are decoded correctly in the first transmission itself. For SNR range of up to 6dB, ARQ method needs at least two retransmission times to receive the correct message in the codeword.

The energy consumption of the proposed quasi cyclic code with column major transmission has to be evaluated.

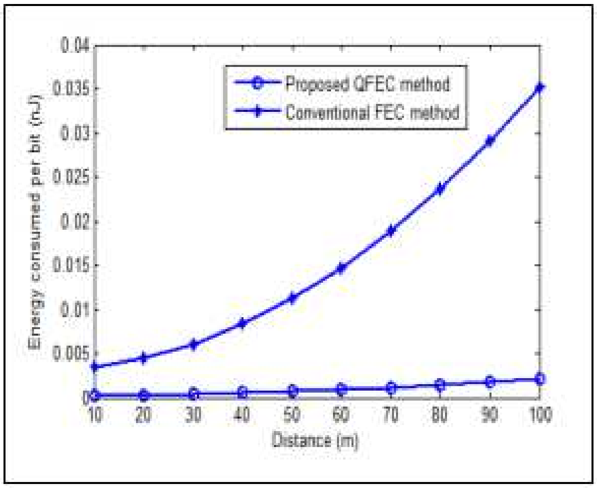

Fig. 11: Energy consumed per bit(nJ) versus distance (m)

As per the FEC model mentioned in section III, the occurrence of a burst error is assumed when four code words are sent. In the conventional row wise transmission, received code word is rejected. Retransmission is a must, when the burst error size is greater than 2. In proposed column wise transmission, energy saved is equivalent to energy of transmitting the encoded code word over a distance to destination. CC1000 radio model of sensor node is considered for evaluation.

In CC1000, energy consumed for transmission one bit over various communication distances is calculated based on the number of instructions required to process it. Fig.11 shows the increase in energy consumed to transmit one bit by the proposed column wise transmission of quasi cyclic encoded data with the distance. Energy spent on transmitting one bit by conventional row wise transmission method is very high when compared to the proposed one.

Fig. 12 illustrates the comparison between the burst error correcting capability of the row wise transmission method and the proposed column wise transmission method for quasi cyclic codes. Quasi cyclic codes $(16,8),(12,4),(60,30)$ are identified as some of the best quasi cyclic codes [19] with comparison made through their use. Greater (n,k) codes are capable of detecting and correcting larger burst error of size of error. Quasi cyclic code $(60,30)$ corrects 20 bit size burst error in the proposed method and 5 bit size burst error in the conventional method whereas $(12,4)$ corrects 12 bit size burst error in the proposed method and 3 bit size error in the conventional method. So the proposed column wise

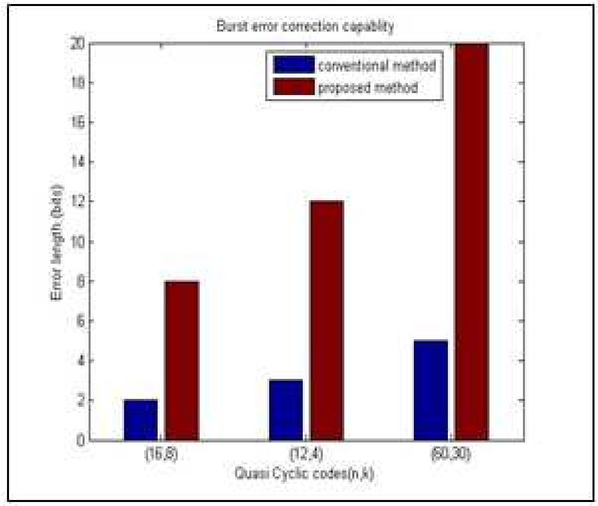

Fig. 12: Burst error length (bits) vs different quasi cyclic codes (n,k)

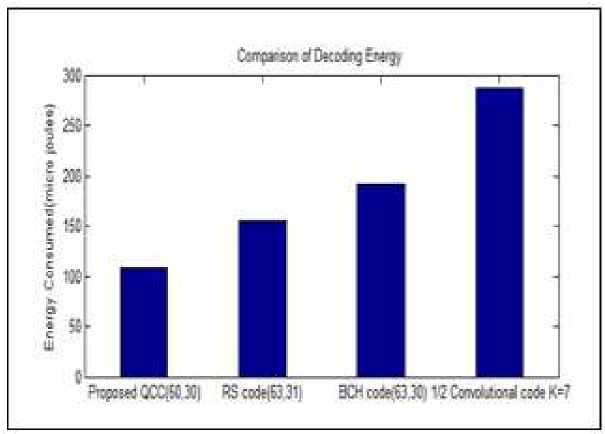

Fig. 13: Comparison of decoding energy

transmission method detects and corrects larger burst errors compared to row wise transmission method.

Decoding energy consumption of the proposed quasi cyclic code is compared with other error correcting codes. Decoding energy varies depending on the decoding methods and the number of operations involved in the decoding. Quasi cyclic code $(60,30)$ is compared with RS code $(63,31)$, BCH code $(63,30)$ and $1/2$ rate convolution code of length K=7 as shown in Fig.13. In terms of error correction capability as well as energy consumption for decoding, quasi cyclic code $(60,30)$ corrects 5 bit errors with 20% lesser energy than all other codes.

5 Conclusion

This paper discusses the energy efficiency of quasi cyclic code in power constrained wireless sensor networks as an optimization measure. We analysed the performance of quasi cyclic code FEC with different packet size and bit error probability. Simulation results show quasi cyclic codes as the best choice for sensor networks. Fixed packet size is also suggested in this paper for reducing transmission and retransmission overhead and to manage the operating cost. Column wise transmission of code word mitigates the problem of burst errors and eliminates the problem of retransmission. Choosing most appropriate packet size is the best way to overlook the energy cost and also to minimize the overhead.

Energy saving is ensured by adopting the column major transmission of code word. Larger size burst error recovery is facilitated. The work for the future can involve the extension of energy analysis taking into consideration parameters like communication distances, number of hops and transmission power control.

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