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PERFORMANCE ANALYSIS OF ERROR CONTROL CODES IN WIRELESS SENSOR NETWORKS

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Abstract: Sensor networks are dense wireless networks of small, low-cost sensors, which collect and disseminate environmental data. Wireless sensor networks facilitate monitoring and controlling of physical environments from remote locations with better accuracy. Architectural challenges are posed for designers such as computational power, energy consumption, energy sources, communication channels and sensing capabilities. Embedded Systems provide the computational platform for hardware and software components to interact with the environment and other nodes. In wireless sensor networks, the data transmitted from the sensor nodes are vulnerable to corruption by errors induced by noisy channels and other factors. Hence it is necessary to provide a proper error control scheme to reduce the bit error rate (BER). Due to the stringent energy constraint in sensor networks, it is vital to use energy efficient error control scheme. In this paper, we focus our Study on the performance analysis of various error control codes in terms of their BER performance and power consumption on different platforms.

1. INTRODUCTION

Recent technological improvements have made the deployment of small, inexpensive, low-power, distributed devices, which are capable of local processing and wireless communication, a reality. Such nodes are called as sensor nodes. Each sensor node is capable of only a limited amount of processing. But when coordinated with the information from a large number of other nodes, they have the ability to measure a given physical environment in great detail. Thus, a sensor network can be described as a collection of sensor nodes which co-ordinate to perform some specific action. Unlike traditional networks, sensor networks depend on dense deployment and co-ordination to carry out their tasks. Previously, sensor networks consisted of small number of sensor nodes that were wired to a central processing station [1].

Characteristics and Requirements

In this section we discuss some characteristics and requirements of a sensor node.

i) Energy-efficiency

Sensor node must be energy efficient. Sensor nodes have a limit amount of energy resource that determines their lifetime. Since it is unfeasible to recharge thousands of nodes, each node should be as energy efficient as possible. Hence, energy is the major resource, being the primary metric for analysis.

ii) Low-cost

Sensor node should be cheap. Since this network will have hundreds or thousands of sensor nodes, these devices should be low cost.

iii) Distributed sensing

Using a wireless sensor network, many more data can be collected compared to just one sensor. Even deploying a sensor with great line of sight, it could have obstructions. Thus, distributed sensing provides robustness to environmental obstacles.

iv)Wireless

The sensor node needs to be wireless. In many applications, the environment being monitored does not have installed infrastructure for communications. Thus, the nodes should use wireless communication channels. A node being wireless also enable to install a network by deploying nodes and can be used in many others studies for example liquid flow of materials.

vi)Multi-hop

A sensor node may not reach the base station. The solution is to communicate through multi-hop. Another advantage is that radio signal power is proportional to r4, where r is the distance of communication. Thus, depending on radio parameters as shown in, it can be more energy economic to transmit many short-distance messages than one-long distance message.

vii) Distributed processing

Each sensor node should be able to process local data, using filtering and data fusion algorithms to collect data from environment and aggregate this data, transforming it to information[2].

Applications of WSN

The applications for WSNs are many and varied. They are used in commercial and industrial applications to monitor data that would be difficult or expensive to monitor using wired sensors. They could be deployed in wilderness areas, where they would remain for many years (monitoring some environmental variable) without the need to recharge/replace their power supplies. They could form a perimeter about a property and monitor the progression of intruders (passing information from one node to the next). There are a many uses for WSNs.

Typical applications of WSNs include monitoring, tracking, and controlling. Some of the specific applications are habitat monitoring, object tracking, nuclear reactor controlling, fire detection, traffic monitoring, etc. In a typical application, a WSN is scattered in a region where it is meant to collect data through its sensor nodes[3].

- Environmental monitoring
- Habitat monitoring
- Acoustic detection
- Seismic Detection
- Military surveillance
- Inventory tracking
- Medical monitoring
- Smart spaces
- Process Monitoring

Error Control Codes

Error-control coding is a discipline under the branch of applied mathematics called Information Theory, discovered by Claude Shannon in 1948. Prior to this discovery, conventional wisdom said that channel noise prevented error-free communications. Shannon proved otherwise when he showed that channel noise limits the transmission rate, not the error probability. Shannon showed that every communications channel has a capacity, *C* (measured in bits per second), and as long as the transmission rate, *R* (also in bits per second), is less than *C*, it is possible to design a virtually error-free communications system using error control codes. Shannon's contribution was to prove the existence of such codes[4]. In WSN data is corrupted by errors due to noisy channels and other factors. To detect and correct error control codes are used. The different error correcting codes used in wireless network are ARQ, Block codes, BCH codes, RS codes, Convolutional codes, Turbo codes etc.

Automatic Repeat Request (ARQ)

ARQ is an error control method for data transmission which uses acknowledgments and timeouts to achieve reliable data transmission. An acknowledgment is a message sent by the receiver to the transmitter to indicate that it has correctly received a data frame or packet. A timeout is a reasonable point in time after the sender sends the frame/packet; if the sender does not receive an acknowledgment before the timeout, it usually re-transmits the frame/packet until it receives an acknowledgment or exceeds[6].

Convolutional Codes

With convolutional codes, the incoming bit stream is applied to a *K*-bit long shift register. For each shift of the shift register, *b* new bits are inserted and *n* code bits are delivered, so the code rate is *b/n*. The power of a convolutional code is a function of its constraint length, *K*. Large constraint length codes tend to be more powerful. Unfortunately, with large constraint length comes greater decoder complexity. There are several effective decoding algorithms for convolutional codes, but the most popular is the Viterbi algorithm, discovered by Andrew Viterbi in 1967. Viterbi decoders are now available on single integrated circuits (VLSI) from several manufacturers. Viterbi decoders are impractical for long constraint length codes because decoding complexity increases rapidly with constraint length. For long constraint length codes ($K > 9$), a second decoding algorithm called *sequential decoding* is often used. A third decoding technique, *feedback decoding*, is effective on burst-error channels, but is inferior on random error channels. In general, convolutional codes provide higher coding gain than block codes for the same level of encoder/decoder complexity [4].

Block Codes

The block encoder takes a block of *k* bits and replaces it with a *n*-bit codeword (*n* is bigger than *k*). For a binary code, there are 2*k* possible codewords in the *codebook*. The channel introduces errors and the received word can be any one of 2*n* *n*-bit words of which only 2*k* are valid code words. The job of the decoder is to find the codeword that is closest to the received *n*-bit word [4].

BCH code

In coding theory the BCH codes form a class of parameterised error-correcting codes which have been the subject of much academic attention in the last fifty years. BCH codes were invented in 1959 by Hocquenghem, and independently in 1960 by Bose and Ray-Chaudhuri[1]. The acronym *BCH* comprises the initials of these inventors' names [5].

Reed–Solomon error correction

Reed-Solomon error correction is an error-correcting code that works by oversampling a polynomial constructed from the data. The polynomial is evaluated at several points, and these values are sent or recorded[7].

Turbo Codes

Turbo codes whose name originates from the likening of their operation to a turbo engine use two convolutional codes for error correction. Turbo codes where born in 1993 and the people involved in the research were seeking to come up with codes that could approach the Shannon capacity. Turbo codes have enough randomness to achieve reliable communication at data rates near capacity, yet enough structure to allow practical encoding and decoding algorithms Turbo codes are also known as parallel concatenated convolutional codes (PCCC) because in their implementation two convolutional encoders are used in parallel. Since the encoders are parallel, they act on the same information at the same time rather than one encoder processing information and then passing it on to the second encoder[11].

Minimum Energy Codes

ME codes use a digital modulation scheme On Off Keying Modulation (OOK). In ME-coding scheme, source bits are mapped to constant length codes (ME Codes), which has less number of high-bits in it. Since the OOK transmitter consumes energy only when transmitting a high-bit, mapping to ME-Codes reduces the total energy consumed in RF transmitter. In this paper, we have come up with ME-Coding scheme for sources with unknown statistics and we further propose a new method of code-by-code detection that can detect and correct certain errors in the codeword received. The inferior performance of OOK when compared to other simple modulation schemes is overcome by ME-Coding [8].

2. RELATED WORKS

Various authors are surveyed WSN with respect to different criteria. In [9] the survey on WSN is made with present state of the art WSN architecture giving the protocol stack of WSN, applications, technical issues etc. In [1] also survey about WSN is carried out with respect to applications of WSN, energy and computational constraint and solutions for them is given. In literature many authors have tried to explain energy efficient codes in WSN. [10] Presented performance Analysis of Error Control Codes in Wireless Sensor Networks in terms of their BER performance and power consumption on different platforms. Based on the study and comparison of the three different error control codes, the authors have identified that binary-BCH codes with ASIC implementation are best suitable for wireless sensor networks. In [8] the Minimum Energy (ME) coding scheme for sources with unknown statistics and a new method of code-by-code detection that can detect and correct certain errors in the received codeword is proposed.

3. METHODOLOGY

In this work, we evaluate the power consumption of three different FEC codes, BCH, RS, and convolution codes on different platforms. The implementation on general processors may be inefficient due to the limitation of the compiler and other factors [8]. The code with the least power consumption is identified. All the comparison is based on the assumption of the same error control performance, which is evaluated by the BER test. In the following, we explain the methods used in our study.

Implementation of Codes

Figure 1 illustrates the procedure of encoding and decoding in a communication system, where u is the information word, v is the codeword, v' is the received word and u' is the decoded word. The encoder circuits of linear block codes and convolutional codes have simple hardware and are easy to implement. Some of the issues considered while implementing the decoder circuits are as follows. In binary-BCH and RS codes, the Euclid's

Algorithm (EA) the Berlekamp-Massey Algorithm (BMA) can be used to compute the coefficients of error polynomial.

The information received by the receiver shown in Fig. 1 is quantized before decoding. Depending on the level of quantization, the decoding can be classified into Hard Decision Decoding (HDD) or Soft Decision Decoding (SDD). The HDD is used when the quantization level is two while SDD is used for quantization level greater than two. The SDD performs better than HDD but requires highly complex circuitry. Hence HDD is implemented to minimize the power in the decoder.

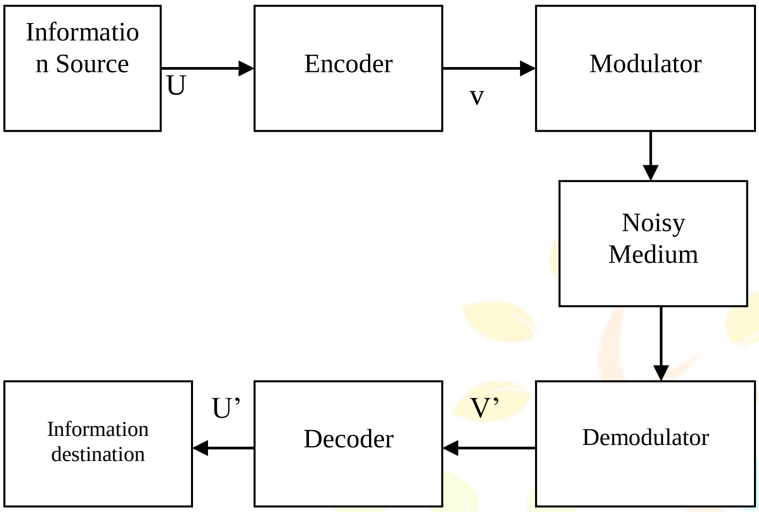

Fig 1. Procedure of Encoding and Decoding in a communication System.

Performance Measure

The next step is to measure the error correcting capability of the implemented codes, which is given by BER, which is obtained by the number of erroneous bits divided by the total number of transmitted bits. BER is affected by several factors including noise in the channel, quantization technique used, code rate *R*, energy per symbol to noise ratio *Es/No* and transmitter power level *Pout*. The *code rate* is given by *R = k/n*, where *k* is the number of bits at the input of the encoder and *n* is the number of bits at the output of the encoder. The BER is shown to be directly proportional to the code rate and inversely proportional to energy per symbol noise ratio and transmitter power level [2]. The encoder encodes the data with code rate *R* and transmits it over the noisy channel. If the transmitter power level *Pout* is unchanged, then the received energy per symbol *E* decreases to *R*E*. Hence, the BER measured at the input of the decoder is larger than the BER of the data transmitted without coding [2]. This increase in BER is overcome by using a decoder that can correct errors. Proper choice of error correction codes will reduce the BER to several orders of magnitude. The difference in BER achieved by using error correction codes to that of uncoded transmission is referred to as *coding gain*. The BER test is performed by simulations on Matlab
following the procedure shown in Fig. 1.

First the information bits are generated using a random number generator. The randomly generated data is then sent to the encoder circuit and encoded into code words, which are transmitted over the noisy channel. Before transmitting, the encoded data is modulated using Phase Shift Keying (BPSK), which is done by mapping 1/0 at the output of the encoder to -1/+1 of an antipodal baseband signal. To evaluate the performance of the error control codes in the noisy channel, an Additive White Gaussian Noise (AWGN) channel is modeled. Adding Gaussian noise to the encoded data is done by generating Gaussian random numbers with desired energy per symbol to noise ratio. The variance *σ2* of additive Gaussian noise which has the power spectrum of *No/2* Watts/Hz is equal to *No/2*. If the energy per symbol *Es* is set to 1, then we have *Es/No = 1/2 σ2* and the standard deviation *σ* is given by *σ = sqrt(1/2(Es/No))*. Hence, the standard deviation *σ* with desired *Es/No* is calculated and used to obtain a Rayleigh random variable *R* as shown in Eq. (1).

*R = sqrt (2*σ2*ln (1/1-U)),* □--------(1)

where *σ2* is the variance of the Rayleigh random variable and *U* is a uniformly distributed random number.

The decoded data is then compared with the corresponding input given to the encoder and the BER is calculated. The BER of the uncoded channel is theoretically calculated using Eq. (2).

*P(e) = ½ *erfc(sqrt(Eb/No) = Q(sqrt(2Eb/No).* (2)

The performance of the coded and uncoded channels is compared based on the calculated BER.

4. PERFORMANCE ANALYSIS OF ERROR CONTROL CODES

In this section, we present and compare the performance of the hamming code, cyclic code, RS codes, and Viterbi codes in terms of their error correction capability in bit error rate (BER).

Fig. 2 compares the BER of hamming codes, cyclic codes, RS codes, Viterbi code, BCH Code, LDPC Code, and Turbo Code. RS code can correct up to *t* errors, where *t* is directly proportional to the number of parity bits (*nk*). Turbo code has the better BER performance in WSN as compared to other Error Control Codes. RS Code has high BER performance among other ECCs. Apart from Turbo codes Convolutional Coding with Viterbi decoding gives good BER performance.

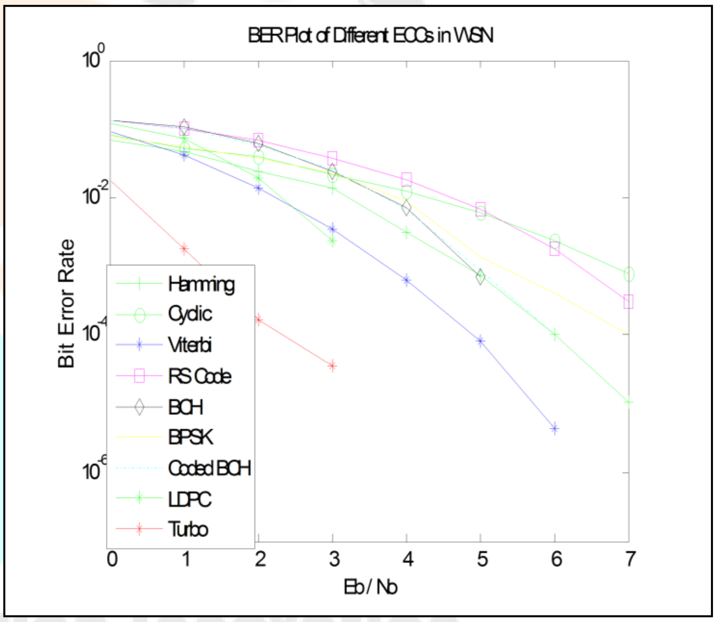

Fig 2 BER Plot for Different ECC in WSN

5. CONCLUSION

Wireless Sensor Network is a new field in wireless communication and researches are going in that field. From fig 2 we can note that Turbo codes provide better performance in WSN with less BER and less energy consumption. Next to Turbo code, Viterbi code is having better performance. RS codes are less efficient than remaining codes in the graph where as cyclic codes are having moderate performance with respect to Bit Error Rate verses Eb/No values. Thus we can conclude that Turbo codes are the Error Control Codes that can give low Bit Error Rate values for low Eb/No values.

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