An Efficient Forward Error Correction Scheme for Wireless Sensor Network

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Abstract

The two basic methods to recover erroneous packets in any network are Automatic Repeat Request (ARQ), and Forward Error Correction (FEC). The lifetime of any wireless sensor network depends directly on the efficient use of its power resources. Power is primarily consumed during wireless transmission and reception. As energy conservation is a major issue of concern in WSN, repeat transmission is not an option and FEC would be preferred over ARQ. One such FEC scheme is (16, 8) quasi cyclic code, which can be used to correct up to 2 Bit Errors and to detect 3 Bit Errors. However, when more than 2 errors occur, retransmission of data is required. In this work, an efficient FEC scheme for WSN’s has been developed to avoid retransmission which not only saves energy but also extends its functionality and enables it to handle “BURST ERRORS”. The Proposed Error Correction Scheme is effective for correcting Burst Errors of even 8 bits.

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1. Introduction

A Wireless Sensor Networks (WSN) can be defined as a network of devices, denoted as nodes, capable of sensing the environment and communicating the information gathered from the monitored field through wireless links. The data is forwarded to a sink that can use it locally or is connected to other networks through a gateway. The movement generally uses multiple hops. The nodes can be stationary or moving. They can or cannot be aware of their location. They can be homogeneous or heterogeneous.

The main design concern for any applications of wireless sensor networks is the limited energy supply, limited computation capability and communication range of sensor nodes as compared with other computing and communicating devices [1], [4]. Lifetime of wireless sensor network depends on lifetime of battery of individual sensor nodes. The nodes play a dual role as data sender and data router in a multi-hop WSN. Aggressive energy management techniques are used to fulfill the main design goals of WSNs which is to carry out data communication while trying to prolong the lifetime of the network and prevent connectivity degradation. One way to conserve the energy in WSNs is to avoid retransmission due to error as far as possible and instead use efficient error control scheme for error correction.

Forward error correction (FEC) also called channel coding is a system of error control for data transmission, whereby the sender adds systematically generated redundant data to its messages, also known as an error-correcting code. The carefully designed redundancy allows the receiver to detect and correct a limited number of errors occurring anywhere in the message without the need to ask the sender for
additional data. FEC gives the receiver an ability to correct errors without needing a reverse channel to request retransmission of data, but this advantage is at the cost of a fixed higher forward channel bandwidth. FEC is therefore applied in situations where retransmissions are relatively costly, or impossible such as when broadcasting to multiple receivers. In particular, FEC information is usually added to mass storage devices to enable recovery of corrupted data. The maximum fractions of errors or of missing bits that can be corrected are determined by the design of the FEC code, so different forward error correcting codes are suitable for different conditions.

The purpose of this paper is to establish a common channel coding standard for bandwidth efficient spacecraft and ground systems communications. The need for bandwidth efficiency has prompted the creation of an alternate coding standard which can enhance the performance and increase efficiency in communications. This alternate coding standard enhances the efficiency thus increasing the life of the nodes of the Wireless Sensor networks. In order to ensure that data is transmitted securely over the network without any loss during the transmission processes for the verification of the data such as retransmission have to be carried out which are generally time-consuming as well as energy-consuming. Thus using this alternate common channel coding standard these disadvantages can be eliminated.

The new Error Correction scheme has a wide scope and can be implemented for communication channels in the applications of Wireless Sensor nodes like Broadcasting, Environmental monitoring, logistics, positioning and tracking, healthcare monitoring. The new common channel coding implements the quasi cyclic code which obviates the need to request for the retransmission of the data which helps in reducing the energy consumption to a great extent.

Rest of the paper is organized as follows. Section 2 discusses the present error correction scheme. Section 3 introduces proposed error correction scheme. Section 4 compares proposed scheme with old scheme. Section 5 details the advantages of proposed scheme. Section 6 gives the limitation of proposed scheme. Finally, Section 7 concludes this paper.

2. The Present Error Correction Scheme

At present, a systematic (16, 8) quasi-cyclic code that can correct 2-bit errors, as well as detect 3-bit errors is in practice. A quasi-cyclic code is defined as the code wherein a cyclic shift of n₀ digits always produces another code word. Thus, encoding of the message can be done serially using linear feedback shift registers, or in parallel if low latency is required. The implementation checks for and corrects single and double bit errors. If any error is detected, a signal is sent to the higher layer that an error has occurred. The syndrome value is represented by 8-bits. This implies that there are a total of 256 possible syndromes. Of these, the zero syndrome is used when there are no errors in the received message, 16 are used by single-correctable errors, and 120 by double-correctable errors.

The generator matrix G and the parity matrix H is given by

\[ G = [I_8 \ C] = \begin{bmatrix} 1 & 0 & 0 & 0 & 0 & 0 & 0 & 1 & 1 & 0 & 1 & 0 & 1 & 0 & 1 & 0 \\ 0 & 1 & 0 & 0 & 0 & 0 & 0 & 1 & 1 & 0 & 1 & 0 & 1 & 0 & 1 & 0 \\ 0 & 0 & 1 & 0 & 0 & 0 & 1 & 0 & 1 & 1 & 0 & 1 & 0 & 1 & 0 & 1 \\ 0 & 0 & 0 & 1 & 0 & 0 & 1 & 0 & 1 & 1 & 0 & 1 & 0 & 1 & 0 & 1 \\ 0 & 0 & 0 & 0 & 1 & 0 & 1 & 1 & 1 & 0 & 1 & 0 & 1 & 0 & 1 & 0 \\ 0 & 0 & 0 & 0 & 0 & 1 & 1 & 1 & 0 & 1 & 0 & 1 & 0 & 1 & 0 & 1 \\
\end{bmatrix} \]

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

It is to be noted that the minimum Hamming distance between any two rows is 5.

An example of how data is encoded, and how received message can be corrected is shown below.

Let the message being sent be 0100 0010. The encoded message is therefore

\[ [0 \ 1 \ 0 \ 0 \ 0 \ 0 \ 1 \ 0] = \begin{bmatrix} 0 & 1 & 0 & 0 & 0 & 0 & 1 & 1 & 0 & 1 & 0 & 1 & 0 & 1 & 0 & 1 \\ 0 & 1 & 0 & 0 & 0 & 0 & 1 & 1 & 0 & 1 & 0 & 1 & 0 & 1 & 0 & 1 \\ 0 & 0 & 1 & 0 & 0 & 0 & 1 & 0 & 1 & 1 & 0 & 1 & 0 & 1 & 0 & 1 \\ 0 & 0 & 1 & 0 & 0 & 0 & 1 & 0 & 1 & 1 & 0 & 1 & 0 & 1 & 0 & 1 \\ 0 & 0 & 1 & 0 & 0 & 0 & 1 & 1 & 1 & 0 & 1 & 0 & 1 & 0 & 1 & 0 \\ 0 & 0 & 1 & 0 & 0 & 0 & 1 & 1 & 1 & 0 & 1 & 0 & 1 & 0 & 1 & 0 \\
\end{bmatrix} \]

It is assumed that the second and third bits are inverted due to noise in the wireless channel. Then, the received message is 0010 0010 1001 1100. Multiplying the received message by the transpose of the parity matrix H,
3. Proposed Forward Error correction Scheme

3.1. Module Description

The proposed scheme consists of three modules

Encoding
- Creation of Generator matrix from the Binary matrix and Identity matrix
- Generation of Parity matrix by concatenating the identity matrix and the transpose of binary matrix
- Conversion of Data word into Code word by multiplication

Transmission
- The code word is transmitted in a Column-wise fashion. This is also called as the column major transmission, i.e Transmission starts from the last element of the last row and the last column and proceeds in a cyclic way along the Column major

Decoding
- The Code word received at the receiver’s end is decoded into the data word and the syndrome is compared with the predefined table values of the syndrome for error detection

3.2. Algorithm

1. Divide data into 8-bit fragments and Encode each of the data byte using (16,8) quasi cyclic code.
2. Group the encoded code words into groups of 4 code words and transmit the code words in column major, such that the mapping of bits in retransmission medium to code words is as follows, the bits at positions p=4n,4n+1,4n+2,4n+3 where n=0 to 15 to codeword1,codeword2,codeword3,codeword4 respectively and the data bit positions in particular code words are at (15-n)
3. Decode the received code words using (16,8) quasi cyclic code decoding scheme.

FRAGMENTATION (k)
- Let fragmented data word be D

QUASI_CYCLIC_CODE (generator, parity)

ENCODING (dataword)
- Generator matrix=concatenation(identitymatrix[k],binarymatrix[k*r(parity)])
- Parity matrix=concatenation((binarymatrix)^T,identitymatrix[k])
- Multiply D with generator to get codeword

TRANSMISSION(codeword)
- Transmission along column major

DECODING(codeword)
- Data word= Codeword * (Generator)^-1

3.3. Energy Analysis

Power Consumption in Original Scheme
Energy of converting dataword into Codeword =E1(D,C), Energy of Transmission over a distance d = E1(T1,d)
Total Energy = E1= E1(D,C)+E1(T,d)
In new scheme
Group of 4 codewords are sent
Energy of converting dataword into codeword =E2(D,C)=4*E1(T,d)
Energy of storage = E2s ≈ 0
Energy of converting from Row Major to Column Major = E2(r,c)
Energy of transmission E2(T,d) = E1(T,d)
Total Energy = E2(D,C) + E2s + E2(r,c) + E2(T,d)
The transmission of data according to new encoding scheme is shown below

<table>
<thead>
<tr>
<th>Cw1</th>
<th>Cw2</th>
<th>Cw3</th>
<th>Cw4</th>
</tr>
</thead>
<tbody>
<tr>
<td>0 0 0 0</td>
<td>1 1 1 1</td>
<td>0 1 1 1</td>
<td>0 1 0 0</td>
</tr>
<tr>
<td>0 0 0 0</td>
<td>0 1 1 1</td>
<td>0 0 1 1</td>
<td>0 1 1 1</td>
</tr>
<tr>
<td>0 0 0 0</td>
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<td>0 1 1 1</td>
<td>0 0 1 1</td>
<td>0 1 1 1</td>
</tr>
</tbody>
</table>

Data in transmission channel is generated by getting it column wise from the above matrix started from column 0
0 0 0 0 0 0 0 0 0 0 1 0 0 1 0 0 1 1 0 1 0 0 0 1 1 1 0 1 0 1 1 1 0 1 1 1 1 1 0 0 0 0 0 0 0 0 0 0 0

During transmission, there may be burst error like below
0 0 0 0 1 0 0 0 0 1 0 1 1 0 1 1 0 0 1 1 0 1 1 0 1 1 0 1 1 0 1 1 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0

As it is known that the errors of length up to 2 bits can be corrected, the above errors in code words are successfully corrected and accepted. Hence the burden of retransmission is reduced.

4. comparison of proposed scheme with old

4.1. Comparison of Energy consumptions

In case of Burst Error, in original scheme the received codeword is rejected and the receiver asks for retransmission. Assuming that when 4 code words are sent, burst error occurs in one of them, Then energy consumed
E1= E1(D,C) + 5E1(T1,d) -- (1)
Whereas, in the new scheme the Burst Error can be corrected. Therefore, Total Energy consumed = E2(D,C) + E2s + E2(r,c) + E2(T,d) --(2)
Comparing the equations (1) and (2), E1-E2 = E1(T, d)-E2s - E2(r, c) ≈ E1(T, d)
Hence the energy saved is almost equivalent to E1 (T, d)
In some Radio Chips used in Sensor Nodes, the Energy consumed for transmitting one bit over a distance of 100m is equivalent to energy consumed by it to process 3000 instructions.
In the case of Original Algorithm, if more than 2 bit error occurs then Retransmission becomes necessary Extra Overhead
Energy Consumed = Energy required to process 16*3000= 48000 instructions
Table 1. Comparison of old and new scheme

<table>
<thead>
<tr>
<th>Sl</th>
<th>Old Scheme</th>
<th>New Scheme</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Transmission of the data word takes place in a horizontal manner</td>
<td>Transmission of the data word takes place in a vertical manner</td>
</tr>
<tr>
<td>2</td>
<td>Effective only for correcting Burst Errors of size less than or equal to 2 bit</td>
<td>Effective for correcting Burst Errors of even 2 or more bits</td>
</tr>
<tr>
<td>3</td>
<td>When the Burst Error is of more than 2 bit, the received codeword is rejected</td>
<td>Even when the Burst error is of more than 2 bit, the error is detected as it is distributed across the data word</td>
</tr>
<tr>
<td>4</td>
<td>Retransmission of the codeword becomes necessary when there is a burst error</td>
<td>Burden of Retransmission is reduced or rather avoided</td>
</tr>
<tr>
<td>5</td>
<td>Efficiency is less because of the Retransmission of the code word</td>
<td>Efficiency is comparatively more as Retransmission is reduced or rather avoided</td>
</tr>
</tbody>
</table>

5. Advantages of New Scheme

The proposed scheme has following advantages over the old scheme. (i) It can correct burst error of length up to 8 bit. (ii) In original scheme if an inversion of bit occurs during transmission, it will be located in a particular codeword, (iii) Whereas in new scheme if an inversion occurs it may be located in any one of the four code words because in every 4 bits in transmission medium, there is a bit from each of the 4 code words, (iv) The possibility of particular code word being affected by noise is reduced to ¼. For example, From pre-calculated measurements it is clear that most of the errors occurring are either 2 bit or single bit. So the number of affected data bits in 64-bits is less than 8. In the best case and worst cases,

- The error distribution over 4 code words may be less than 3 bits
- It achieves the performance of (16,8) quasi cyclic code and it also guarantees the correction of burst error.
- Supposing that 8 inversions are present, when two code words get more than 2 errors, retransmission of 2 code words has to be done.
- Even if there are 3 inversions in a block of 16-bit, it might be possible for other blocks either to have a maximum of 5 errors or to not have any error. In this case the errors are corrected and the code word is retransmitted

6. Limitations of Proposed Scheme

If the error occurs more than twice at only 4n positions or 4n+1, or 4n+2 or 4n+3, it implies that the corresponding code would contain more than 2 errors. Hence it becomes essential to retransmit that code word again. When more than 8 errors are present in a block of 64-bit then retransmission of at least one codeword has to be performed.

7. Conclusion

A common channel coding standard is developed for the transmission of data using the nodes of Wireless Sensor networks which have a wide range of applications such as in weather and environmental monitoring, healthcare, positioning and tracking, spacecraft and ground system communications. This new coding standard obviates the need for the retransmission of the data which is generally a time-consuming and energy-consuming process and sometimes an impossible process too in the case of applications such as Broadcasting to multiple nodes. The newly proposed error correction scheme implements the Forward Error Correction (FEC). This in contrast to the Automatic Repeat Request (ARQ) and consumes lesser energy. As the power is scarce for wireless transmission and reception in the wireless sensor nodes the FEC is preferred over the ARQ.

The Forward Error correction implements a (16-8) quasi cyclic code. As per the Original Error Correction Scheme the Transmission of the data word takes place in a horizontal manner. The Original Error Correction Scheme is effective only for correcting Burst Errors of size less than or equal to 2 bit. When the Burst Error is of more than 2 bit, the received codeword is rejected. Retransmission of the codeword becomes necessary when there is a burst error. Hence in order to overcome these drawbacks a
new error correction scheme is proposed. As per the Newly Proposed Error Correction Scheme the transmission of the data word takes place in a vertical manner. The Proposed Error Correction Scheme is effective for correcting Burst Errors of even 2 or more bits. Even when the Burst error is of more than 2 bit, the error is detected as it is distributed across the data word. Burden of Retransmission is reduced or rather avoided in this case. Efficiency is comparatively more because the energy expended for the retransmission in the case of the original correction scheme is saved when the new proposed error correction scheme is implemented.

References

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