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Congestion Control in Implementing Multi Coding Schemes for Energy Optimisation in Wireless Sensor Networks

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ABSTRACT

Hybrid ARQ (HARQ) has been identified as one of the most common optimal error control protocols. However, due to the complexity of the existing error codes, the use of HARQ in WSN can be viewed as energy-consuming, if it were not implemented properly. Multi coding as an extension to the HARQ protocol can be a promising method for improving a network plagued by high error rates. However, in implementing the error correcting codes for the better error rates, one may increase the overhead in terms of computational redundancies added to the transmitted bits, especially in a highly condensed network. This can lead to further degradation of the remaining energy and fluctuations in the Bit Error Rates (BER). Based on a previous study, other aspects must be considered to indicate the congestions present, rather than solely be dependent on the Signal to Noise Ratio (SNR). This paper proposes a congestion control based on the node density variation to control the congestion caused by different levels of numbers of nodes deployed, as well as the complexity of error correcting codes which were used in the network. We collected the BER values, as well as the remaining energy and latency, to study the optimal error correcting codes which varied with the codeword length, and the respective error correcting capabilities which suited the defined congested environments. Based on our results, our proposed multi coding assignment can adapt to the sudden changes in the channel condition, as well as improve the performance in terms of optimising the error rates, and the remaining energy across different types of channel conditions.

Keywords: Channel adaptation, channel estimation, error control protocol, multi coding scheme, wireless sensor networks

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INTRODUCTION

The technology of Wireless Sensor Network (WSN) has evolved from transmitting smaller data, to massive data, and has progressively moved to highly condensed traffic. The existing architecture of WSN may not be able to tolerate the advancement of this technology, which will lead to intolerable higher error rates in a congested area. Multi-coding schemes are seen to be able to increase energy-efficiency (Ali et al., 2012), and reduce the overhead associated with single-coding schemes, by assigning different error correcting codes having its optimal performances corresponding to the specific channel condition (Razali et al., 2017). Compared to the single-coding schemes, these error correction schemes do not adapt to the changes in channel conditions.

Theoretically, in low Signal-to-Noise Ratio (SNR), the Bit Error Rate (BER) will be high. As the SNR increases, the BER will drop significantly. On the other hand, implementing single-coding schemes with high error correcting capabilities during high SNR would be a waste of energy when the low error correcting capability codes is sufficient to address errors. The high usage of error correcting capability, t, of the desired error correcting codes, can degrade the lifetime due to the high decoding energy, and the increase in the transmitted bits, especially when the WSN is highly resource-constrained (Kavitha & Sridharan, 2013). Implementing single-coding schemes with low error correcting capability codes during low SNR may not be enough to correct high levels of BER errors.

In a uniform node distribution, there may be negligible node interferences, as nodes are localised uniformly with one another. However, implementing non-uniform node distributions may lead to a rise in different levels of node interferences. This interference rises due to the different levels of node densities (Celaya-Echarri et al., 2018) which is caused by the high number of nodes localised in a particularly small area. These nodes may be located too close with one another, in a manner which allows many nodes to interfere with the transmission range of other nodes. This will lead to significant interferences. In addition, such interferences can cause intolerably high BER, high packet drops, and collisions. If the multi-coding schemes are wrongly assigned in this high node density condition, it will further push the network to accumulate much higher unacceptable BER.

RELATED WORKS

In the paper by Datta and Kundu (2014), the authors implemented a Hybrid Automatic Repeat Request (HARQ) with the Bose, Chaudhuri, and Hocquenghem (BCH) code. The authors also tested the HARQ-BCH across different node densities and message lengths. They stated that the BER was high in low hop count conditions. Previous works have also demonstrated the high usage of error correcting capabilities of the error correcting codes using more energy as the appended bits increased with the increase in error correcting capability. Theoretically, in the low SNR condition, the BER is considered high, due to the lower boost of signal power compared to a network with much higher SNR. Thus, there is a need to use higher error correcting capabilities with adequate codeword lengths. However, in a condition where the SNR is high, the use of high error correcting capabilities may not be as efficient, because the BER is already low. Considering the non-uniform node deployment of practical WSN, there is a need to design a method which can adapt to these changing channel conditions, and as well as the changing in node deployment.

The work from Ali et al. (2012) proposed the multi-coding schemes in the network with Network Master (NM) sensors and sinks. They applied BCH codes with two different rates between the sensor and the NM, and between the NM and the sink. Based on their results, multi-coding schemes have a good effect on the network's lifetime when the low rate BCH codes such as (511, 148) are used at the sensor node, and the high rate BCH such as the (511, 484), is used at the NM. These findings can be seen as proof that multi-coding can be more energy-efficient as compared to single-coding schemes.

Our previous research implemented the use of low overhead error corrections based on the HARQ process, in which we incorporated the use of SNR classifications to classify the link quality which denoted the network condition of our predefined Coded Division Multiple Access (CDMA) WSN architecture. The SNR classification was proposed to support the network condition, which would always change over time, considering aspects such as mobility and traffic loads. The reflection, refraction and noise link conditions can be concerning matters which contribute to the non-constant SNR. Based on our previous research, we proposed the implementation of different error correcting capabilities, as well as variations in the codeword length for different SNR ranges, and denoted that the SNR range should be between 5 dB to 50 dB. We highlighted a method to enhance the performance of the CDMA WSN using the modified HARQ process, in which we enabled the module to transmit power and multi coding schemes to comply with the changes in the network conditions. The changing of the network conditions denotes the changes in the SNR values, in which, the network might migrate from a good reception towards a bad reception, or vice versa, due to fading effects. For instance, our research selected a range of error correcting capability, t, between 2 to 7, with the codeword length, n, in the range of 31 to 127 bits. This is meant to support the fact that, by using higher error correcting capabilities and codeword lengths, it would be impractical for WSN functionality due to the increase in complexity and appended bits.

This research studied the effects of error correcting codes on the performance of the proposed SNR classification algorithm (Razali et al., 2017) towards congestion control by implementing the aspects of node density. This research also proposed an extension of the SNR classification algorithm to detect the changes in the node density levels, provided that the node density was able to indicate the congestion levels, as the number of nodes increased due to scalability, or changes in the position of the nodes. This paper presents simulation results of the listed BCH and Reed Solomon (RS) error correcting codes and assigns the most optimal error correcting codes with its respective error correcting capability for the defined type of congestion. Last but not least, this paper also presents the results of the proposed method compared to existing processes without the adaptation of channel conditions and congestion control.

METHODS

Overview of Node Density-based Congestion Control

Figure 1 shows the process flow of the proposed congestion control for a previous SNR classification system. Compared to the existing method utilising HARQ, the data was encoded with an error detection scheme, for example, Cyclic Redundancy Check (CRC), and subsequently encoded further with error correcting codes such as BCH or RS. The

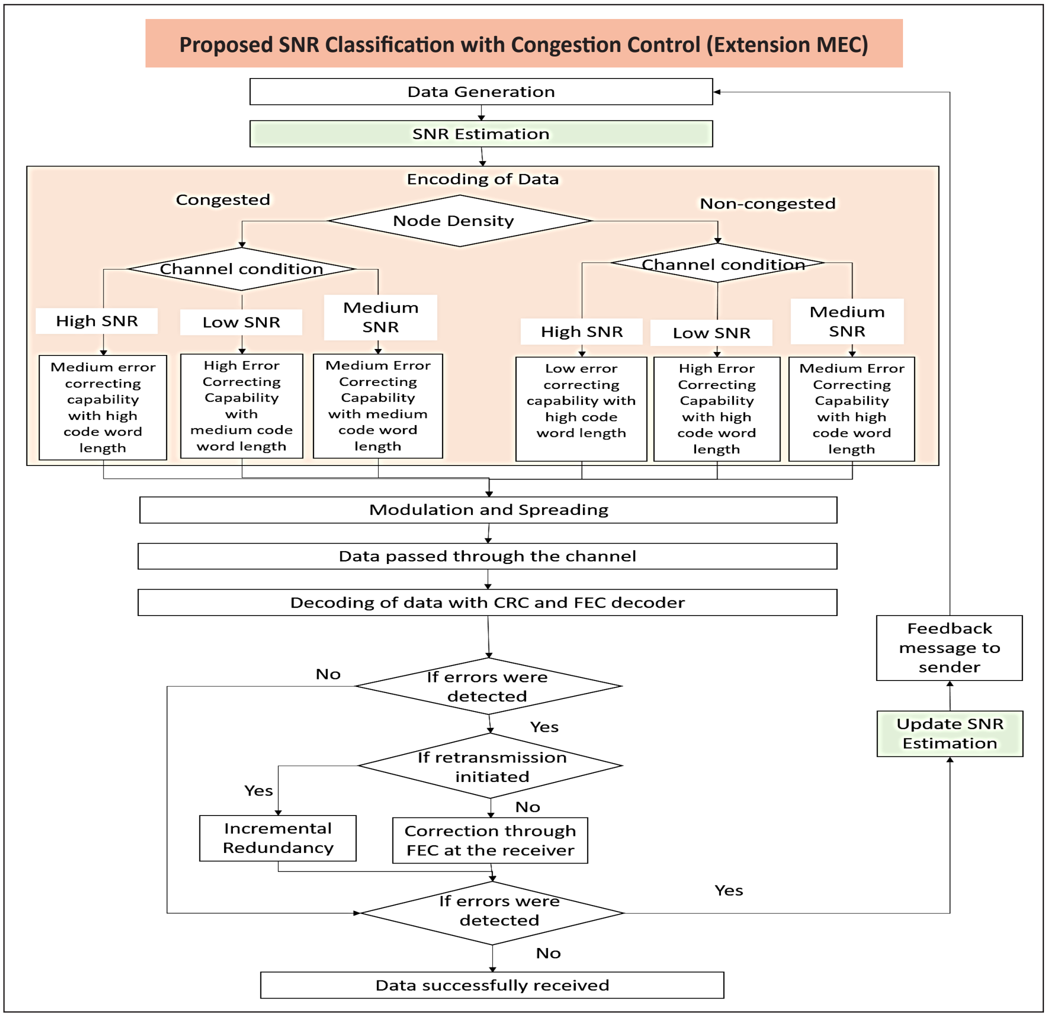

Figure 1. The process flow of the proposed Congestion Control for SNR classification

existing process uses single coding schemes regardless of the changes in the channel conditions or the congestions present. Based on other previous studies, SNR was not able to accurately determine the network conditions or link these congestions (Qin et al., 2013). Thus, there is a need to add other aspects to determine these congestions as the number of nodes starts to increase. According to the work by Chitlange and Deshpande (2015), when the number of nodes increases at a certain point above the acceptable threshold of the network, the throughputs seem to degrade due to fact that the network has started to congest. They also observed that there was a slight increase in the throughput when the node density increased initially, because of the increase in the routing performance. For instance, as the node density reached 45, the Packet Delivery Ratio (PDR) and throughputs started to decrease, which indicated congestion. In a small monitoring area, a large number of nodes deployed in a non-random distribution could lead to a rise in different levels of node densities in one monitoring area. Condensed networks are caused by the placement of nodes which are too close to each other, which can lead to performance degradation.

The length of the codewords is equally substantial when it comes to the error correcting capability. It adds to the congestion control, to ensure that the errors are not being increased by the implementation of long codewords when there is no need for it. From the Figure 2, high codewords are denoted by longer codeword lengths of 127, or more. Medium codeword lengths are denoted by the shorter codeword length of 63 and below. The idea of implementing different error correction schemes has been adapted to the channel conditions, as well as different levels of node densities to optimise the energy efficiency of the sensors with the error rates in the network. Both factors are equally essential, as a degradation of any one of them, would degrade the performance of the other.

Our multi-coding scheme was previously proposed (Razali et al., 2016; Razali et al., 2017) and comprised SNR classification classes to a different assignment of error correction schemes. We used BCH and RS codes that varied in codeword length, n, and error correcting capability, t. The error correction schemes assigned to each of these classes were based on their optimal performance obtained through means of simulation. The SNR classification also aided with SNR estimation using a Kalman Filter, to estimate the benchmark SNR for the error correcting module. This helped to encode the proper error correcting codes to the un-coded binary data. In this research, we studied the effects of adding the congestion control based on node density variation as an extension to the proposed multi-coding scheme mentioned above.

Problem Formulation

We tested the network with node increments of 4, 16, 32, 48, 64 and 80. The expression of the node density was calculated from the predefined number of nodes denoted by the Equation 1 as follows:

$$Node\ Density = \frac{(N * \pi * \ R^2)}{A} \tag{1}$$

Where, *N* is defined as the number of nodes, *R* is the transmission range, and *A* is the area of minoring. We classified the node density, which is denoted as Nd, in the variation of three different levels of congestion, such that EC denoted a condition which had extremely high congestion (Nd of more than 27.9253). MC denoted a medium congestion condition ($16.7552 \leq \text{Nd} \leq 22.3402$), and NC denoted a non-congested network (Nd less than 11.1701). For this paper, we managed to test two types of node density-based congestions, between 5.4851 and 22.3402. We considered the use of a low error correcting capability, t, such that $1 \leq t \leq 5$, as a much higher error correcting capability appended a higher number of redundancies in the transmitted bits. The codeword length was kept between n=63 and n=127 to suit the low overhead CDMA WSN environment.

Formula Derivation for Performance Analysis

In this paper, we present several equations which have been used, or derived for measurements throughout the experiments. The measurement models comprise formula to calculate Bit Error Rates, the network's remaining energy, and latency.

The expression of BER for BPSK in Rayleigh Fading is illustrated in Equation 2 below (Weber et al., 2007). The Rayleigh Fading was considered to address the multipath environment of urban areas. Radio systems in established urban outdoor locations are subject to these fadings, due to the attenuation of signals when there is no line of sight (Bensky, 2019).

$$BER = \ ½ \left[1 - \frac{\sqrt{\frac{E_b}{N_0}}}{\frac{E_b}{N_0} + 1} \right] \tag{2}$$

Eb/N0 is defined as the Energy per bit to noise power spectral density ratio. Eb/N0 is also known as the normalized SNR. In relation to the SNR, Eb/N0 can be explained by the following Equation 3:

$$\text{SNR} = (Eb * br\ )/(\ \text{N0} * B) \tag{3}$$

Eb is the received energy per bit, NO is the noise power, *br* is the Bit Rate, and *B* is denoted as the bandwidth (Viswanathan & Mathuranathan, 2017). We also derived the received signal power that followed the free space path loss, collaborating the path loss exponent and the distance between the transmitter and the receiver. The equation for the received signal power was also aided with the Additive White Gaussian Noise (AWGN). We also took the Rayleigh Fading into consideration as shown in Equation 4.

$$Y = h(x) + n \tag{4}$$

Where, *h* denotes the channel gain, while *x* is the transmitted data, and *n* is the noise. Channel gain, *h* captured the effects of the Rayleigh fading, in which the channel gain, *h* can be formulated again as shown in Equation 5:

$$Y = h\left[d\hat{}\left(\frac{-\alpha}{2}\right)\right] \tag{5}$$

Where, α, is the path loss exponent denoted as $2 \le \alpha \le 6$. The value of the path loss exponent corresponds to the urban area cellular radio, which has a value of 3.5 (Miranda et al., 2013), while, *d* was defined as the distance between the transmitter and the receiver (in meters). The minimum energy was expressed as *E* as shown in Equation 6, in which each transmitted bit consumed 1 unit of energy, and received bit consumed 0.75 units of energy according to (Kleinschmidt et al., 2005; Kleinschmidt et al., 2009):

$$E = H\,(N\_packet\,)(N\_bits + \ N\_bits\ \ (0.75)) \tag{6}$$

Where, H is the number of hops, *N_packet* is the number of packets, and *N_bits* is the total number of bits, which includes the header and payload. Thus, the equation for energy consumed in the transmission for CRC-32 and Error correcting codes can be rewritten as shown in Equation 7 below:

$$E\_ECC = (H)(N\_packet)\,[N\_bits + \ (N\_bits\,)(0.75)] + \ E\_DEC \tag{7}$$

The decoding process imitated both the RS and BCH decoding processes with the narrow-sense generator polynomial. The decoding energy can be calculated as shown in Equation 8:

$$E\_DEC\ = (2nt + 2t\hat{}2\,)(E\_addition + \ E\_multiplication\,) \tag{8}$$

Where, n is the block length for the corresponding error correcting codes, and t is the error correcting capability. In addition to that, *E_addition* + *E_multiplication* corresponds to the energy consumed in the addition and multiplication of error correcting codes. The network latency, *d_network* is measured according to Equation 9 shown as follows:

$$d\_network = d\_proc + d\_queue + d\_trans + d\_prop \quad (9)$$

Where, *d_proc* is the processing time which is usually negligible (Ross & Kurose, 2000). *d_queue* is the queuing time, which is denoted in Equation 10, *d_trans* is the transmission time, which is denoted in Equation 11 and *d_prop* is the propagation time, denoted in Equation 12. The queuing time, *d_queue* is defined as time that a packet spends in a queue at a node, while waiting for other packets to be transmitted, and is calculated as follows:

$$d\_queue = (d\_trans)(l\_queue) \quad (10)$$

Where, *d_trans* is the transmission time and *l_queue* is the length of the queue. The equation below shows illustrates a means to measure the transmission delay, which is defined as the time required to put an entire packet into a communication media.

$$d\_trans = l\_bits / R\_trans \quad (11)$$

Where, *l_bits* is the length of bits, and *R_trans* is the transmission rate in the unit of bits per time. The following equation denotes the propagation delay, *d_prop*:

$$d\_prop = D\_node/s \quad (12)$$

Where, *D_node* is the distance from sender to receiver, while *s* is the propagation speed of the media.

Simulation Parameter

Table 1 below shows the parameters defined for the simulation model and the error correcting codes with its defined code length, n, and the information length, k, as well as the error correcting capability, t. We did not test the error correcting capability which exceeded t>10, as the nature of the WSN was unsuited to support such high complexity of codes.

We defined the noise as an Additive White Gaussian Noise (AWGN) with a Binary phase-shift keying (BPSK) modulation. The data was generated in a random binary of 10,000 bits for every transmission. We also added the path loss exponent to the BER calculation as shown in the equations above. The payload bits and header bits followed the existing architecture, such that this culminated in 128 bits and 256 bits, respectively.

We generated the CRC-30 polynomial after encoding the un-coded data, with either BCH or RS codes, corresponding to the SNR for that time period. We set the default number of generated bits at 10,000 bits. However, the transmitted bits varied according to the chosen error correcting codes, as different error correcting codes appended different redundancies that resulted in a different number of transmitted bits per given time. The BCH and RS codeword lengths were tested as shown in Table 2.

Table 1
The parameters defined for the simulation of CDMA WSN

Parameter	Value
Min. dist. between two nodes	10 m
Noise	AWGN
Modulation	BPSK
Monitoring area (meter^2)	300 m x 300 m
Path loss parameter (α)	3.5
Payload, Header	128,256 bits
Error Detection	CRC-32
Error Correction	BCH and RS (from the range of codeword length from 63 to 127 and error correcting capability from 1 to 7)
Number of Nodes	16,64 (Node density of 5.5851 and 22.3402)
Number of Bits (bits)	10000

Table 2
Error Correcting Codes tested with its respective codeword length and error correcting capability

Error Correcting Codes	n	k	Error Correcting Capabilities, t
BCH	63	57	1
	63	51	2
	63	45	3
	63	39	4
	63	36	5
	63	30	6
	63	24	7
	127	120	1
	127	113	2
	127	106	3
	127	99	4
	127	92	5
	127	85	6
	127	78	7
RS	63	59	2
	63	57	3
	63	55	4
	63	53	5
	63	51	6
	63	49	7
	127	123	2
	127	121	3
	127	119	4
	127	117	5
	127	115	6
	127	113	7

RESULTS AND DISCUSSION

Pilot Study Results

In this study, we have tabulated the tested error correction codes in Table 2, that would optimise the BER and remaining energy across two different node density variations. From the table, we assumed that the number of nodes below 32 nodes (Nd < 11.1701) was denoted as node densities less than 11.1701, which indicated that the network was not congested. Thus, for the network which has 16 nodes, the calculated node density was 5.5851, and denoted that the network was not congested. For this type of node density, we used a low error correcting capability and low redundancy code to optimise between BER and the remaining energy.

Table 3
The proposed optimal error correcting codes with its defined (n, k) and error correcting capability for 16 nodes

No. of Nodes	Node Density	SNR Range	ECC	n	k	Total transmitted bits for one node
16	5.5851	48.512~52.512	RS t=3	127	121	10545
		43.512~47.512	RS t=5	127	117	10926
		38.512~42.512	BCH t=3	127	106	12069
		33.514~37.512	BCH t=4	127	99	12958
		28.512~32.512	BCH t=5	127	92	13847

As the SNR increased, a much lower error correcting capability was used to lower the amount of the appended bits transmitted through the channel (Table 3). This is because, theoretically, as SNR increases, the BER will drop, indicating that the link's quality has improved.

Thus, there is no need for higher error correcting capability codes if the medium capability is enough to reduce the BER. The network is assumed to start getting congested when there are more than 32 nodes in one given area, which is based on an experiment by (Chitlange & Deshpande, 2015). For extremely congested conditions, we have chosen the codeword length of 63 which denotes that the node density is 22.3402 for the moderate, to the highest error correction mode, as the codeword length of 63 for the BCH codes appended much higher redundancies as compared to the codeword length of 127.

However, the increase in the codeword length also increased the energy consumption. Even though it was seen that the higher codeword length of 127 appended lower redundancies, as the total number of transmitted bits was slightly less than the codeword length of 63, the results from previous studies showed than higher codeword length uses higher energy. Thus, we suggest that for the CDMA WSN, the use of the codeword length from 63 to 127 is preferable, as opposed to higher codeword lengths of more than 255 bits. This is because it increases the complexity, and adds more encoding and decoding overhead.

Table 4
The proposed optimal error correcting codes with its defined (n, k) and error correcting capability for 64 nodes

No. of Nodes	Node Density	SNR Range	ECC	n	k	Total transmitted bits for one node
64	22.3402	27.440~31.440	BCH t=1	127	120	10672
		22.440~26.440	BCH t=2	127	113	11307
		17.440~21.440	BCH t=3	63	45	14053
		12.440~16.440	BCH t=4	63	39	16195
		7.440~11.440	BCH t=5	63	36	17518

Table 4 and Table 5 show the remaining energy and latencies obtained from the simulation of CDMA WSN using the parameters in Table 1, and the predefined (n, k) with error correcting capabilities as stated in Table 2. By implementing higher codeword lengths, the energy consumption might increase beyond the limits of the WSN usage. Based on our tests, the codes which used n=127 had lower appended bits than the codes which used n=63. Despite the fact that the codes which used n=127 had lower redundancies, the remaining energy was much lower than the codes which used n=63. As seen in Table 4, the use of codes n=127 might not be necessary when the node density was sufficiently high.

Table 5
Remaining Energy and Latency for 16 nodes network

No. of Nodes	Node Density	Error Correcting Codes	n	k	Total transmitted bits	Remaining Energy (μJ)	Latency (s)
16	5.5851	BCH	63	57	11092	52693	0.4622
			127	120	10672	18079	0.4447
			63	51	12415	52547	0.5173
			127	113	11307	17735	0.4711
			63	45	14053	52402	0.5855
			127	106	12069	17392	0.5029
			63	39	16195	52256	0.6748
			127	99	12958	17049	0.5399
			63	36	17518	52110	0.7299
			127	92	13847	16706	0.5770
		RS	63	61	10336	52693	0.4307
			63	59	10714	52547	0.4464
			127	123	10418	17735	0.4341
			63	57	11092	52402	0.4622
			127	121	10545	17392	0.4394
			63	55	11470	52256	0.4779
			127	119	10799	17049	0.4500
			63	53	11911	52110	0.4963
			127	117	10926	16706	0.4553

The use of codes n=63 might be able to maintain higher remaining energy, but the error correction might not be able to perform as is intended, compared to that of codes which used n=27. The latency of the network also increased when applying BCH instead of RS codes. The higher the error correcting capability of the codes, the higher the latency was. The high redundancies added to the generated bits might be attributed to the higher number defined bits used for our architecture.

A higher codeword length is preferable for a large number of generated bits, such as 10,000 bits. We observed that for the default generated binary bits of 10,000, the higher codeword length embedded much smaller redundancies compared to the lower codeword lengths. Codeword length of 255 and 511 had reduced redundancies added to the data. However, we also observed that higher degradation of energy cannot be tolerated. Thus, based on the number of appended bits embedded to the transmitted bits, we concluded that the optimal codeword length for 10,000 bits was around 63 to 127 bits.

Figure 2 shows the plot for BER against SNR, with BCH codes that were implemented with increasing correcting capabilities for codeword lengths of 127 bits. From the data collected from the existing schemes, it was seen that the value of BER was already very high during lower SNR and still considered as high even when the SNR increased to 20 dB. Such values were recorded when the distance of 10m between the sender and receiver and the path loss exponent of 3.5 was added to the simulation.

It was observed that BCH codes with 127 bits seemed to be among the optimal codeword lengths with medium added redundancies. BCH (127, 92) recorded the lowest BER for the codeword length of 127 using a higher SNR. The medium SNR was around 11 dB to 15 dB, and BCH (127,113), with a t=2. It recorded the lowest BER. BCH (127,

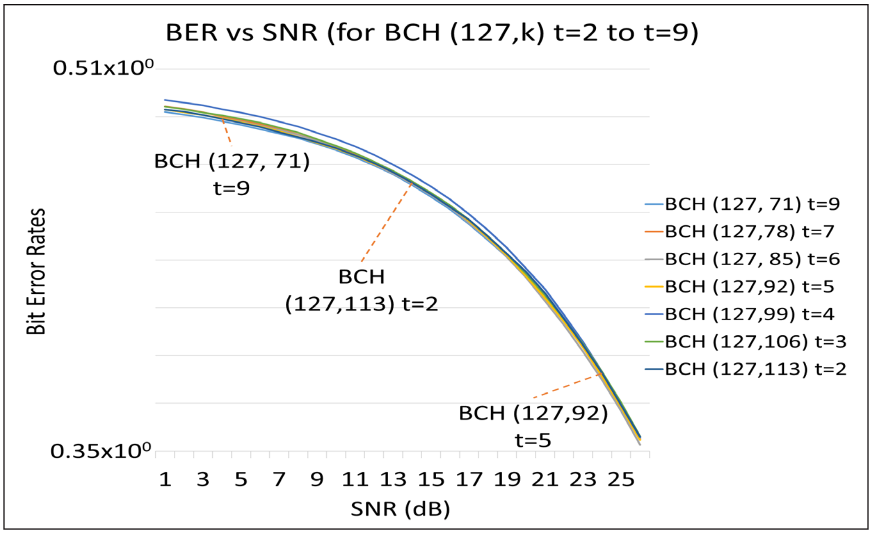

Figure 2. Graph of BER against SNR for the codeword length of 127 with error correcting capabilities from t=2 to t=9

71) had a t=9, and had the lowest BER with the lowest SNR. It was concluded that during the low SNR, it was best to use high error correcting capabilities, but less complex codes.

The BCH with a codeword length of 127 was among the optimal codes used during the non-congested condition. The lower complex codes, or lower codeword lengths with higher redundancies are suggested to be used in a low congested network with low SNRs. The higher codeword lengths with medium or lower redundancies are suggested to be used in a congested network with higher SNRs.

The data was collected using the proposed low error correction schemes (Lowest MEC) and high error correction schemes (Highest MEC), with BCH and RS values obtained from the different error correcting capabilities. The graph in Figure 3 shows the remaining energy corresponding to the number of nodes. We tested a BCH of t=5 (127,92), BCH t=4 (127,99), RS t=5 (127,117) and RS t=4 (127,119) with our optimal Lowest error correction scheme, such that RS T=3 (127,121) and in the Highest error correction scheme BCH T=4 (127,99). The existing error correction BCH t=5, BCH t=4, RS t=5 and RS t=4 had the lowest remaining energy compared to our proposed optimal solution. Our proposed optimal error correction scheme for the Lowest Error Correction Mode for MEC had reached the highest remaining energy of 0.01739 J.

This is because we implemented the moderate error correction scheme as the network does not have high congestion in deploying only 16 nodes. The low congestion network was seen to have lower error rates compared to the higher congested network, which corresponded to the node's interferences. Too powerful an error code, or higher error correcting capabilities might not be necessary to be applied, as the lower error correcting

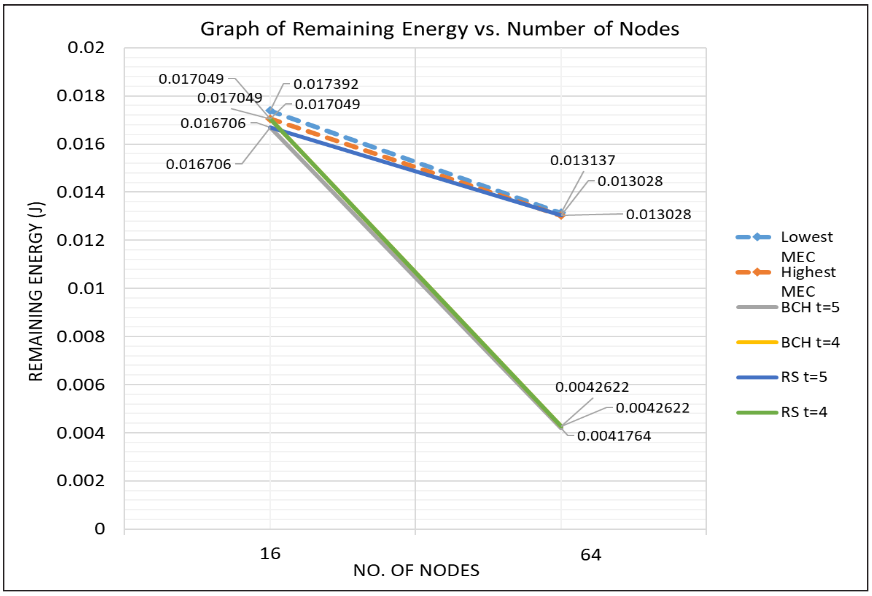

Figure 3. Plot for the remaining energy vs. number of nodes

capability was enough to correct these errors. Too high an error correcting capability, such that t≥10, or codeword lengths, such that n=225 or n=511 (for BCH code) can append high redundancy bits which can degrade the remaining energy of the sensors and render the network inoperative. We can conclude that from this graph, the proposed optimal error correcting schemes had remained at the highest remaining energy values, as compared to other schemes in the increasing network congestion (increasing number of nodes) and can be a promising approach to further maximizing the remaining energy.

The graph in Figure 4 shows the BER against SNR. The network is considered to have low congestion due to the node density value of 5.5851 with 16 nodes. For our Lowest error correction schemes in the low congested network, the network reached the lowest BER value when the SNR increased from 9 to 20, which corresponded to 0.4166 and 0.2554 respectively. The Highest error correction schemes sat between BCH t=5, and RS t=5. Our Lowest MEC for the low congested network outperformed the other error correction schemes, as the low error correcting capability did not append too many redundancy bits which might cause transmitted bits to be lengthy.

The increase in the length of the transmitted data increases the error rates also due to the increase in the use of energy driven by the lengthening of the encoding and decoding processes. Due to the usage of higher error correcting capabilities, the appended bits increase the BER, albeit a little. However, assigning the proper error correction schemes to the extension of the HARQ has a drawback in maintaining the BER with the higher remaining energy. Thus, we do not propose a BER that is too low as a means of achieving higher remaining energy. From the graph in Figure 5, the Highest error correction scheme

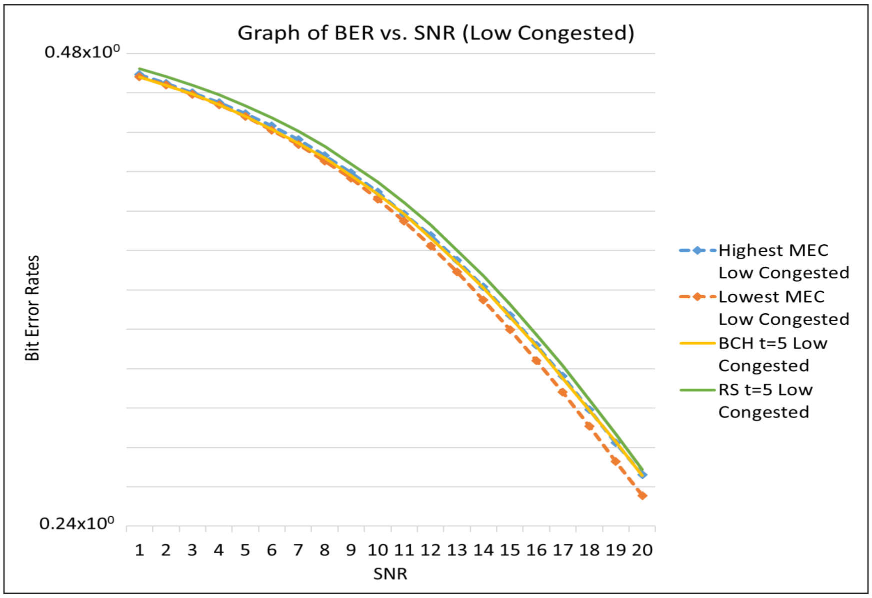

Figure 4. BER vs. SNR (Low congested)

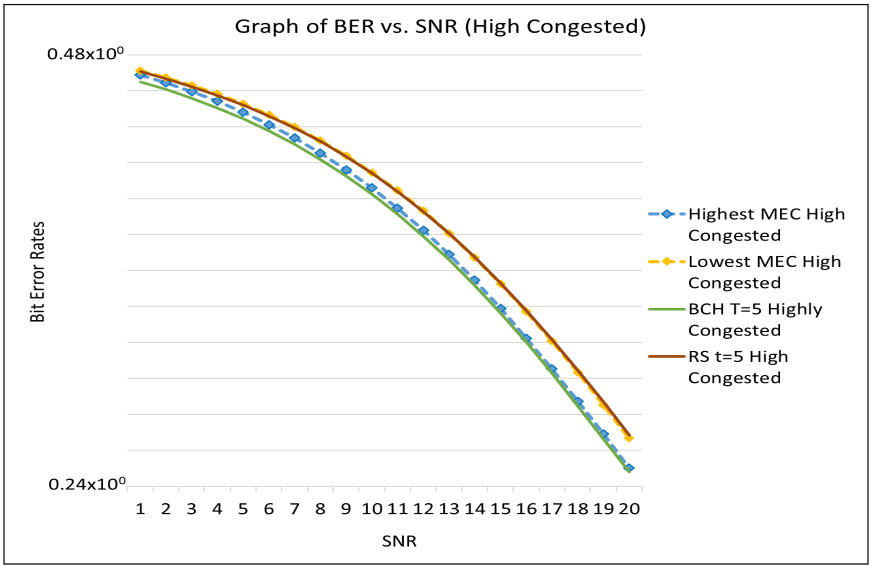

Figure 5. BER vs. SNR (High congested)

achieved the highest remaining energy, compared to other error correction schemes. We conclud that the BER was optimised, as the performance of the BER from the extension of the HARQ and existing BER did not show too much variation.

Figure 5 shows that the graph for BER vs. SNR in the highly congested network was denoted as 64 nodes. Our proposed Highest error correction mode showed that the BER was maintained as the SNR increased. The BER was not seen to reduce too much in relating to the optimized remaining energy. In order to have the remaining energy that outperformed the existing schemes, the medium error correction was assigned. This is to reduce the high energy usage from high error correcting capability so that both remaining energy and BER can be maintained throughout the SNR.

From this graph, the usage of existing BCH t=5 had lowered the BER significantly, which outperformed the MEC in term of BER. However, considering the fact that the optimization of the remaining energy, it was assumed that the higher error correcting capability had degraded the energy performance. Even though the MEC had not outperformed the existing higher error correcting capability of BCH in terms of BER, the MEC optimised the remaining energy in which the remaining energy of MEC as mentioned in Figure 3 are much higher than the existing BCH. The drawbacks of BER with remaining energy make it impossible to boost all aspects at the same time in which these aspects can only be maintained regardless of the channel conditions to ensure the reliability of transmission. A low BER can be achieved by assigning higher error correcting capabilities, but, the use of high error correcting capabilities will be insignificant to the WSN, as the energy usage will be high.

CONCLUSION AND FUTURE WORKS

The proper assignment of error correction in terms of the codeword lengths and error correcting capabilities of the error correcting codes according to different types of congestion is important to reduce excessive decoding and computation errors for correcting codes. The use of too high an error correcting capability in WSN is insignificant, as it increases the appended bits and complexity of the network, that leads to a much higher amount of energy usage. In implementing the multi-coding scheme assignment corresponding to the different channel conditions, the aspects of congestion presented need to be properly studied to avoid excessive latency and degradation of the remaining energy. Link congestion identification and classification can be promising to adequately reduce the energy usage when applying block codes in the network, thereby, optimising the BER and maintaining the remaining energy. For a low error correcting capability, the use of different codeword lengths of error correcting codes (n=127 and n=63) did not show too much impact on the BER, but can impact the remaining energy and latency. Our research demonstrated that certain error correcting codes had achieved the lowest possible BER and remaining energy, but, the drawback was that both aspects cannot be enhanced simultaneously. Our proposed multi-coding scheme seeks to aid the congestion based on our previous SNR classification, and can optimise the network by adapting to the changes in the SNR. For future works, the node deployment plays an important role to ensure that the congestion stabilizes with the corresponding transmission ranges. Higher transmission ranges with many nodes in one region can cause higher interference levels. Thus, the study of the suitable placement of nodes in different environments may contribute toward further lowering of the congestion, and expanding the energy efficiency of the network.

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