

Performance of a Hybrid ARQ Scheme in CDMA Wireless Sensor Network

U. Datta

Member, IEEE, Dept. of E&I, CSIR-CMERI, Durgapur, India
uma_datta58@yahoo.in

D. Bharath Kumar

Dept. of ECE, N.I.T Durgapur, Durgapur, India
dbr_773@yahoo.com

Amit Kumar Ball

Dept. of E&I, CSIR-CMERI, Durgapur, India
amit.ball@yahoo.com

S. Kundu

Member, IEEE, Dept. of ECE, N.I.T Durgapur, Durgapur, India
sumitkundu@yahoo.com

Abstract

The paper evaluates the energy level performance of CDMA wireless sensor networks (WSN) with a new error control strategy using BCH coding following hybrid ARQ. The performance of the proposed scheme is compared with simple ARQ using CRC and with an existing HARQ-I employing BCH code when applied to CDMA based WSN in terms of energy consumption for successful transmission of fixed length packet. Two kinds of interference namely multiple access interference (MAI) and node interference (NI) are considered. Packet error rate (PER) and energy required for successful delivery of information to a sink considering single hop communication is estimated. The effects of several network parameters such as node density, correlation amongst interferers, power control error (pce) on PER, average number of retransmissions, energy consumption for successful reception of a packet at sink are investigated and energy efficiency in a single hop transmission are estimated and compared for different error control strategies. Analytical results are verified through simulations.

Keywords: HARQ, BCH coding, Wireless CDMA Sensor Network (WCSN), Correlation.

1. Introduction

A sensor network is composed of a large number of sensor nodes that are densely deployed in region of interest to monitor the local information [1]. The information gathered by these nodes is forwarded to the sink, as shown in Fig.1, to allow the end users to access the data. Despite the diversity of applications, the following requirements are true for all of them: low power, low cost, and long lifetime of the entire network [2]-[3]. These nodes are battery powered, have limited memory and processing power, and form a randomly connected adhoc network. Energy constraints are the driving factors in the design of wireless sensor networks,

which require low power consumption and energy efficient communication protocols. To handle a large number of nodes, where number of nodes simultaneously and asynchronously access a channel, CDMA is a good choice as a MAC protocol. CDMA has been advocated for WSN in [4], [5] where distribution of interference power in randomly distributed nodes is discussed. Interference shadowed by same obstacles tends to be correlated and correlation has significant impact on SIR [6]. In a CDMA environment as quality of a radio link depends upon the signal to interference ratio (SIR), it is an important metric for performance evaluation in MAI/NI constraint environment.

In wireless sensor networks, sensor nodes demand simple and facile error control schemes to make the system less complex. Automatic repeat request (ARQ) and forward error correction (FEC) are the key error control strategies in wireless sensor networks. In [7], the performance of CDMA wireless sensor network is assessed using ARQ scheme with CRC. The usefulness of ARQ in sensor network environments is limited by the additional retransmission energy cost. Forward error correction (FEC) systems, however, do have some drawbacks. The energy requirement is quite high as compared to ARQ due to transmission and reception of additional bits and decoding energy associated with FEC scheme. Another approach to minimize energy is through the use of hybrid ARQ scheme which incorporate both retransmission and FEC. Proper combination of ARQ and FEC may be investigated for minimization of energy [8]. Hybrid ARQ (HARQ) is a promising approach to mitigate error control in energy constrained wireless sensor network. The analysis in [9] enables a comprehensive comparison of FEC, ARQ and HARQ schemes in WSN, where node interferences were not considered. A low-power hybrid ARQ scheme is proposed in [10] to improve energy efficiency without considering node interferences. BCH code is used in our work as the energy efficiency of BCH code outperforms any other channel codes due to its low encoding and decoding energy consumption [11].

In this paper, we evaluate the energy consumption for successful delivery of a data packet in single hop from source to sink in CDMA based WSN. A new hybrid –ARQ scheme using BCH coding is proposed for error correction. Appropriate modeling of MAI and NI considering imperfect power control is done. Correlation amongst interferers is incorporated in our analysis. More precisely, our contributions are as follows:

- Proposing a new hybrid ARQ scheme using BCH coding.
- Evaluation of average energy for successful transfer of data packet in single hop utilizing proposed scheme.
- Evaluation of average energy for successful transfer of data packet in single hop using an existing HARQ-type 1, (HARQ-I) and simple ARQ schemes when applied to similar scenario of WSN and comparison with the proposed scheme.
- Estimation of energy efficiency for each scheme.
- Analyzing impact of network parameters such as node density, correlation amongst interferers, pce on energy consumptions.

The remainder of the paper is organized as follows: Section 2 presents the interference and system model. Simulation model is described in section 3. Results are discussed in section 4. Finally we conclude in section 5.

2. Interference and System Model

A CDMA based wireless sensor network considering single hop communication is shown in Fig.1. The sink s is receiving information from the source/relay node d . Since only the nodes located within one hop layer i.e. within receiving radius (r_R) of the sink can directly communicate with the sink, the concurrent nodes that are sending their information to the sink within area πr_R^2 would bring about the MAI. On the other hand, the node k is sending information to its own destination node k' (it can be any sensor except the sink). Due to the interference range of the receiver, here it is sink, the transmitting signal power generated by the node k might be sensed at the sink. In Fig.1, node j can be regarded as MAI and node k as NI. To obtain the interference power distribution at sink, we use the assumptions and definitions following [4],[7].

- Sensor nodes are uniformly distributed over a sensor field with omni-directional antennas of same gain with a minimum distance r_0 . The receiving and interference distance are r_R and r_I respectively. Typically $r_I \approx 2r_R$
- Imperfect power control is assumed.
- As all information is received by the sink, nodes causing MAI are more than NI

2.1. Estimation of Interference Power

Following [4],[7] The mean value of the collected interference power η' from an interfering node to the desired receiver (i.e. sink) is given by

$$\eta' = \eta \cdot e^{\left(m_{s_{21}} + \frac{\sigma_{s_{21}}^2}{2}\right)} \cdot e^{-\left(m_{s_{11}} + \frac{\sigma_{s_{11}}^2}{2}\right)} \cdot e^{\left(m_{R_{11}} + \frac{\sigma_{R_{11}}^2}{2}\right)} \quad (1)$$

η can be found out as in [4] as:

$$\eta = \frac{4P_R \left(r_R^{\alpha+2} - r_0^{\alpha+2}\right) \left(r_I^{\alpha-2} - r_0^{\alpha-2}\right)}{\left(\alpha^2 - 4\right) r_0^{\alpha-2} r_I^{\alpha-2} \left(r_I^2 - r_0^2\right) \left(r_R^2 - r_0^2\right)} = \gamma P_R \quad (2)$$

Where P_R is the received power, $m_{s_{11}}$, $m_{R_{11}}$ are the mean and $\sigma_{s_{11}}$, $\sigma_{R_{11}}$ are the standard deviation of shadowing and pce for the path kk' . α is the path loss exponent $2 < \alpha < 6$ and $m_{s_{21}}$, $\sigma_{s_{21}}$ are the mean and standard deviation of shadowing of the path between the nodes k and s .

The expected number of nodes within the interference range of the receiver is [4]

$$b = \rho \pi r_I^2 \quad (3)$$

Where ρ is the node density. Activity factors determine the number of active nodes at any instant in the two layers contributing MAI and NI, a fraction of b as given in (3).

2.2. Estimation of Average BER

Total interference power due to NI and MAI

$$I = P_{NI} + P_{MAI} = \eta \sum_{i=1}^{t1} e^{Z_i} + P_R \sum_{i=1}^{t2} e^{R_i} \quad (4)$$

Where t1 and t2 are the number of nodes causing NI and MAI respectively. Approximating the summation (I) by an equivalent log normal distributions,

$$I = P_R e^{\Phi} = \eta \sum_{i=1}^{t1} e^{Z_i} + P_R \sum_{i=1}^{t2} e^{R_i} \quad (5)$$

Applying Wilkinson's approach [6], the mean m_{Φ} , and the standard deviation σ_{Φ} of Φ in (5) are estimated. By matching the first and second moment of I , (u_1 and u_2), m_{Φ} and σ_{Φ} are represented as:

$$m_{\Phi} = 2 \ln (u_1/P_R) - \frac{1}{2} \ln (u_2/P_R^2) \quad (6)$$

$$\sigma_{\Phi}^2 = \ln (u_2/P_R^2) - 2 \ln (u_1/P_R) \quad (7)$$

For simplicity all interferers are assumed to have identical statistics. With direct sequence BPSK of spreading bandwidth W and for constant received signal power levels, the probability of error under the Gaussian approximation is:

$$P_e = Q\left(\sqrt{2 \frac{E_b}{\chi}}\right) = Q\left(\sqrt{\frac{2P_R e^R / R_b}{I/W}}\right) = Q\left(\sqrt{\frac{2P_R e^R / R_b}{P_R e^{\Phi} / W}}\right) = Q(e^{\psi}) \quad (8)$$

Following [12], the mean probability of error at any hop can be approximated by

$$\bar{P}_e = \frac{2}{3} Q(e^{m_{\psi}}) + \frac{1}{6} Q(e^{m_{\psi} + \sqrt{3}\sigma_{\psi}}) + \frac{1}{6} Q(e^{m_{\psi} - \sqrt{3}\sigma_{\psi}}) \quad (9)$$

Where,

$$m_{\psi} = E(\psi) = \frac{1}{2} [\ln(2 \cdot pg) - m_{\Phi}] \quad (10)$$

$$\sigma_{\psi}^2 = \text{var}(\psi) = \frac{1}{4} (\sigma_R^2 + \sigma_{\Phi}^2) \quad (11)$$

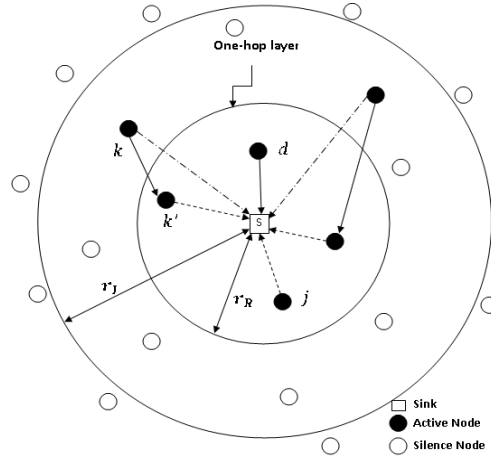


Figure 1. Interference Model at the Sink

A received packet is not accepted whenever any of the bits of a packet is received with error. Different error control mechanisms, such as ARQ, HARQ-1, and a new proposed scheme are considered. Performances of error control schemes are compared in terms of energy consumption for successful delivery of packet in single hop communication.

2.3. Analysis for Energy Efficiency of Error Control Schemes

Automatic Repeat Request (ARQ): First we consider a simple ARQ, where the received packet is checked by CRC decoding, followed by retransmission in case of erroneous data. Here we consider stop and wait ARQ with CRC-4. Let ℓ_{payload} be the length of message and ℓ_{CRC} be the length of packet to be transmitted after encoding with CRC. Assuming that ACK/NACK packet (ℓ_{ACK} bits/packet) is received without any error, the packet error rate of ARQ is given by

$$\text{PER}_{\text{CRC}} = 1 - (1 - \overline{p_e})^{\ell_{\text{CRC}}} \tag{12}$$

Where $\ell_{\text{CRC}} = (\partial + \ell_{\text{payload}} + \beta_1)$ is the size of the packet, ∂ , ℓ_{payload} , and β_1 are the length of the header, payload and frame check sequence respectively as shown in Fig. 2.

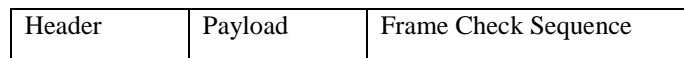


Figure 2. MAC Frame Format of DATA in 802.15.4 [13]

Let c be the number of retransmissions for successful delivery of packets. The probability of success at the c th transmission [14]:

$$P_{\text{CRC}}[c] = (1 - \text{PER}_{\text{CRC}}) \cdot (\text{PER}_{\text{CRC}})^{c-1} \tag{13}$$

Average number of retransmissions

$$(\bar{N})_{\text{CRC}} = \sum_{c=1}^{\infty} P_{\text{CRC}}[c] \cdot c = 1/(1 - \text{PER}_{\text{CRC}}) \quad (14)$$

Assuming energy consumption for CRC decoding is insignificant as compared with transmission and reception, energy consumed per packet at each transmission is attributed to the energy spent in the communication for both forward transmission, reception of data packet $E_{\text{CRC}}^{\text{pkt}}$ and reverse transmission, reception of ACK/NACK E^{ack} [15], where

$$E_{\text{CRC}}^{\text{pkt}} = (P_t + P_R) \cdot \ell_{\text{CRC}} / R_b \quad (15)$$

$$E^{\text{ack}} = (P_t + P_R) \cdot \ell_{\text{ACK}} / R_b \quad (16)$$

R_b is the data rate, P_t is the mean transmitted power as in [7]. Energy consumed for a single loop of transmission and reception,

$$E_{\text{CRC}}^{\text{total}} = E_{\text{CRC}}^{\text{pkt}} + E^{\text{ack}} \quad (17)$$

Energy consumed by the message, i.e. the payload, in single transmission, i.e. the effective energy

$$E^{\text{eff}} = (P_t + P_R) \cdot \ell_{\text{payload}} / R_b \quad (18)$$

Average energy for successful reception of message is expressed as

$$E_{\text{CRC}}^{\text{avg}} = (\bar{N})_{\text{CRC}} \cdot E_{\text{CRC}}^{\text{total}} \quad (19)$$

Energy efficiency of the system using ARQ scheme with CRC-4 is expressed by the relation [11]:

$$\xi_{\text{CRC}} = \frac{E^{\text{eff}}}{E_{\text{CRC}}^{\text{avg}}} (1 - \text{PER}_{\text{CRC}}) \quad (20)$$

Hybrid ARQ (HARQ): Forward error correction (FEC) can correct a few bits depending on error correcting capability. FEC codes incur communication overhead in terms of transmission and reception of additional redundant bits as well as additional energy spent in decoding packets. Hybrid ARQ schemes aim to exploit the advantages of both ARQ and FEC schemes. We consider two schemes using hybrid ARQ, where complexity of transmission protocols are less than hybrid ARQ type 2 (HARQ-II). First HARQ-I scheme, as described in [8] is analyzed. Further, one new scheme is proposed and its' performance is compared with other schemes in terms of energy consumption for successful delivery of a fixed length packet.

In HARQ-I scheme as in [8], each fixed length packet consists of header and message, is first encoded with parity bit. The encoded data is again encoded in next level using BCH code of one bit correction capability. The receiver discards erroneous packets (when errors remain after BCH decoding), sends a retransmission request to the transmitter and asks for an

entirely new retransmission. Retransmissions take place at the same code rate until the packet is correctly decoded. The data flow graph for HARQ –I is presented in Fig. 3.

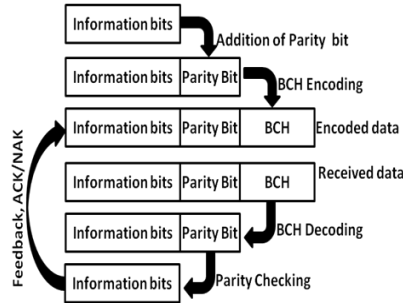


Figure 3. Data Flow Graph for HARQ-I Scheme

Energy required for decoding a BCH code (n, k, t) is expressed by [11]:

$$E_{dec} = I_{proc} \cdot V_{proc} \cdot (2nt + 2t^2) \cdot 3 \cdot \left\lceil \frac{m}{8} \right\rceil \cdot t_{cycle} \quad (21)$$

Where I_{proc} is the current for processor, V_{proc} is the supply voltage, t_{cycle} is one cycle duration of processor and $m = \log_2 n + 1$ [16]. The packet error rate (PER) for the scheme as in [11] is:

$$PER_{P-BCH} = 1 - \sum_{i=0}^t \binom{\ell_{P-BCH}}{i} \cdot p_e^i \cdot (1 - p_e)^{\ell_{P-BCH} - i} \quad (22)$$

Where $\ell_{P-BCH} = (\partial + \ell_{payload} + \beta_2)$ is the number of bits/packet to be transmitted and is the sum of header length ∂ , length of frame check sequence β_2 (consists of Parity and BCH code), and length of payload $\ell_{payload}$.

Let 'c' be the number of retransmissions using this scheme for successful delivery of packets. The probability of success at c-th transmission:

$$P_{P-BCH}[c] = (1 - PER_{P-BCH}) \cdot (PER_{P-BCH})^{c-1} \quad (23)$$

Average number of retransmissions for successful reception of a packet

$$(\bar{N})_{P-BCH} = \sum_{c=1}^{\infty} P_{P-BCH}[c] \cdot c = 1 / (1 - PER_{P-BCH}) \quad (24)$$

The energy consumed per packet at each forward transmission and reception is given by

$$E_{P-BCH}^{pkt} = (P_t + P_R) \ell_{P-BCH} / R_b + E_{dec} \quad (25)$$

Total energy consumed per packet at each transmission loop

$$E_{P-BCH}^{total} = E_{P-BCH}^{pkt} + E^{ack} \quad (26)$$

Average energy required for successful delivery of packet

$$E_{P-BCH}^{avg} = (\bar{N})_{P-BCH} \cdot E_{P-BCH}^{total} \quad (27)$$

The expression for energy efficiency of the scheme using HARQ-I, as in [11], is defined as:

$$\xi_{P-BCH} = \frac{E^{eff}}{E_{P-BCH}^{avg}} (1 - PER_{P-BCH}) \quad (28)$$

Proposed Hybrid ARQ: In the proposed scheme, each packet of length $\partial + \ell_{payload}$ is first encoded with parity bit. The encoded data is then encoded in next level using BCH code to correct one bit followed by another CRC-4 encoding on the BCH encoded data, forming a packet of $\ell_{P-BCH-CRC} = (\partial + \ell_{payload} + \beta_3)$ bits. The receiver first checks the transmitted packet by CRC-4 decoding. In case of no error, the receiver extracts the data directly without BCH decoding. In case of erroneous data, the receiver performs the BCH decoding. The receiver discards erroneous packets (when errors remain after BCH decoding), sends a retransmission request to the transmitter and asks for an entirely new retransmission at the same code rate until the packet is correctly received. The data flow graph of the proposed scheme using HARQ is presented in Fig.4.

The packet error rate of the proposed scheme on which retransmission depends is expressed by:

$$PER_{P-BCH-CRC} = PER_{P-BCH} \cdot P_H \quad (29)$$

Where PER_{P-BCH} is expressed by (22) and

$$P_H = 1 - (1 - p_e)^{\ell_{P-BCH-CRC}} \quad (30)$$

Let 'c' be the number of retransmissions for successful delivery of packets. The probability of success at c-th transmission:

$$P_{P-BCH-CRC} [c] = (1 - PER_{P-BCH-CRC}) \cdot (PER_{P-BCH-CRC})^{c-1} \quad (31)$$

Average number of retransmissions for successful delivery of a packet

$$(\bar{N})_{P-BCH-CRC} = \sum_{c=1}^{\infty} P_{P-BCH-CRC} [c] \cdot c = 1 / (1 - PER_{P-BCH-CRC}) \quad (32)$$

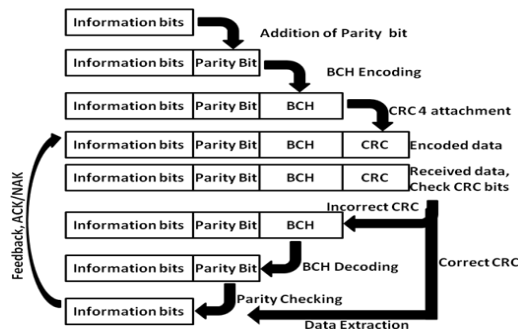


Figure 4. Data flow graph for the proposed HARQ scheme

The energy consumed per packet at each transmission loop without considering decoding energy is expressed by:

$$E_{P-BCH-CRC}^{total} = E_{P-BCH-CRC}^{pkt} + E^{ack} \quad (33)$$

$$\text{Where, } E_{P-BCH-CRC}^{pkt} = (P_t + P_R) \cdot \ell_{P-BCH-CRC} / R_b \quad (34)$$

As requirement of decoding energy E_{dec} depends on the packet error rate of the received packet (P_H) before decoding, average energy consumption for successful delivery of message

$$E_{P-BCH-CRC}^{avg} = (\bar{N})_{P-BCH-CRC} \cdot (E_{P-BCH-CRC}^{total} + P_H \cdot E_{dec}) \quad (35)$$

Where P_H is expressed by (30).

The expression for energy efficiency of the proposed HARQ scheme is:

$$\xi_{P-BCH-CRC} = \frac{E^{eff}}{E_{P-BCH-CRC}^{avg}} (1 - PER_{P-BCH}) \quad (36)$$

3. Simulation Model

The simulation model is developed in MATLAB for validation of analytical results on PER, average number of retransmissions, average energy for successful delivery of message and energy efficiency using different error control techniques. MAI and NI in presence of correlated interferers, is incorporated in the simulation model. The steps of simulation are presented below.

- 1 Gaussian random variables are generated for the desired signal (S), using desired variance (σ_R^2) and with the expression $S = P_R e^R$.
- 2 Different interference powers due to MAI and NI are generated randomly using Gaussian distribution for different node densities, and with desired correlation amongst interferers using Cholesky factorization of the correlation co-efficient matrix. Total interference power (I) due to MAI and NI are evaluated at the receiving node using (5), followed by the generation of signal to interference ratio (SIR).
- 3 For simulation of PER and average number of retransmissions for successful delivery of message of fixed length, a packet is generated with random data bits +1 or -1, which indicates message bits of fixed length.
- 4 Single parity bit, encoding bits for one bit correction of message using BCH coding and CRC-4 encoding for combination of message with encoded bits of one bit correction using BCH coding are generated respectively for simple ARQ, HARQ-I and HARQ-proposed respectively.
- 5 In case of ARQ, message bits along with CRC-4 encoding bits are transmitted, whereas in case of HARQ-I, message bits with encoding bits for one bit

correction and in case of HARQ-proposed, message bits followed by one parity bit, encoding bits for one bit correction and CRC-4 encoding bits are transmitted.

- 6 A Gaussian noise sample is generated with variance $\sigma_g^2 = 1/(2 \cdot pg \cdot SIR)$ and added to each transmitted bit, where SIR is found following steps mentioned in 1-2, pg is the processing gain. The noise samples are added with the transmitted bits and received at the receiver.

The received bit is first detected as +1 or -1 after comparing with a threshold of zero. Assuming CRC-4 bits are received correctly, in case of ARQ, received bits are decoded by CRC-4 decoder and checked with the transmitted bits.

In case of HARQ-I, received bits are decoded by BCH decoder for one bit correction and checked with the transmitted bits.

In case of HARQ-proposed, received bits are first decoded by CRC-4 decoder followed by comparison with transmitted bits. In case of no error, no need of BCH decoding, directly message is extracted from the received signal. In case of any error, BCH decoder for one bit correction followed by checking of single parity bit is carried out and checked with the transmitted bits.

For all cases, if error occurs, counters are used for subsequent evaluation of PER and average number of retransmissions.

4. Results and Discussions

Following parameters are used in analysis and simulation as shown in Table 1. Mean of all shadowing and pce components are considered to be zero.

Table 1. Parameters Used in Analysis and Simulation

Parameter	Value
Node density (nodes/m ²)	0.016, 0.024, 0.032, 0.04, 0.048
NI interferers at sink (t1)	4, 6, 8, 10, 12
MAI interferers at sink (t2)	8, 12, 16, 20, 24
Receiving distance of receiver (rR)	20 m
Min. dist. between two nodes (r ₀)	1 m
Spread bandwidth	5MHz
Transmission rate (R _b)	20.0kbps
Constant receive power (P _R)	1.0e-07w
Path loss parameter (α)	3
Stand. deviation of Shadowing (σ _s)	3 dB
Correlation amongst interferers	0.0, 0.6
Power control error	0.5dB, 1.0dB
Packet length after BCH encoding	127 bits for 1 bit correction
Number of ACK/NACK bits	2

Fig.5, 6, 7 and 8 show the variation of PER, average number of retransmission, average energy requirement for successful delivery of a packet and energy efficiency with node densities using different error control schemes. It is expected HARQ with BCH code will have better PER than simple ARQ, which is also seen in Fig.5, where PER using ARQ and HARQ-I is shown. This improvement of PER is valid for both HARQ schemes i.e. HARQ-I and HARQ-proposed. Due to improve PER, number of retransmission for successful delivery of a message is also less using BCH coding [Fig 6]. Average energy consumption for successful delivery of a message is seen to be less for the proposed HARQ scheme as

compared to the existing HARQ-I scheme. It is seen that HARQ-I is not energy efficient in low interference condition, i.e. when node density is low. This is due to additional decoding energy for each transmission, which may not be required at all. In case of proposed scheme [(HARQ)_{P-BCH-CRC}], Fig.7 shows that at low node densities, average energy consumption for successful delivery of message using the proposed HARQ scheme is low as compared to an existing HARQ-I scheme, [(HARQ)_{P-BCH}], as described in [8] and resembles almost similarly as that of ARQ with CRC scheme [(ARQ)_{CRC}]. This is due to the fact that (HARQ)_{P-BCH-CRC} scheme may or may not use BCH decoding energy at the last retransmission of packet. At low node density region, as the interference is low, the number of retransmission is low. In this condition, omission of decoding energy seems to play a vital role in reduction of total energy consumption for successful delivery of a packet. At high node density region, with increasing interference, PER, and the number of retransmission is significantly higher in simple ARQ scheme as compared with both HARQ schemes using BCH coding. Thus energy consumption of ARQ increases and its' energy efficiency decreases more rapidly as compared with other HARQ schemes [Fig. 7, Fig. 8].

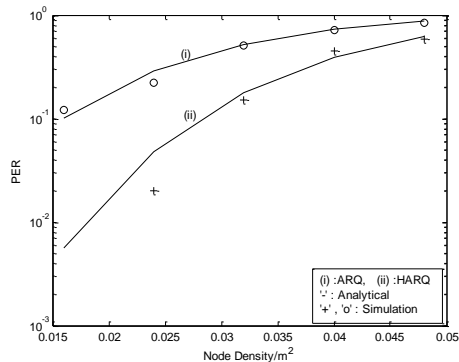


Figure 5. Variation of PER with node densities using different error control schemes i.e. ARQ with CRC -4(ARQ)_{CRC}, existing HARQ-I with parity bit, BCH code (HARQ-I)_{P-BCH}. Power control error (pce)=0.5dB, correlation between interferers (r)=0.0, message length=119 bits, and the standard deviation of shadowing =3dB remain same in all cases.

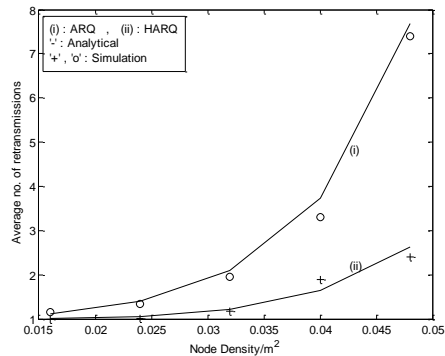


Figure 6. Variation of average number of retransmissions with node densities using different error control schemes i.e. ARQ with CRC -4(ARQ)_{CRC}, existing HARQ-I with parity bit, BCH code (HARQ-I)_{P-BCH}. Power control error (pce)=0.5dB, correlation between interferers (r)=0.0, message length=119 bits, and the standard deviation of shadowing =3dB remain same in all cases.

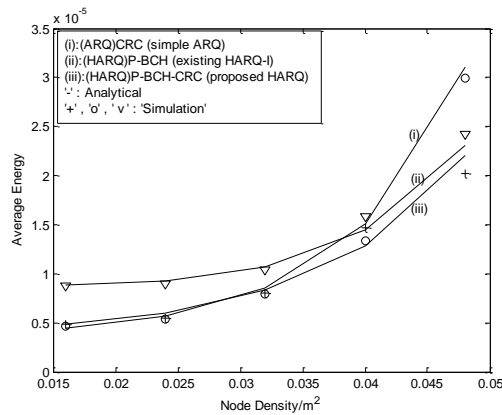


Figure 7. Variation of average energy consumption for successful reception of information with node densities using different error control schemes i.e. ARQ with CRC -4(ARQ)CRC, existing HARQ-I with parity bit, BCH code (HARQ-I)P-BCH, and the proposed HARQ with parity bit, BCH coding and appended by another CRC-4 (HARQ-I)P-BCH-CRC. Power control error (pce)=0.5dB, correlation between interferers (r)=0.0, message length=119 bits, and the standard deviation of shadowing =3dB remain same in all cases.

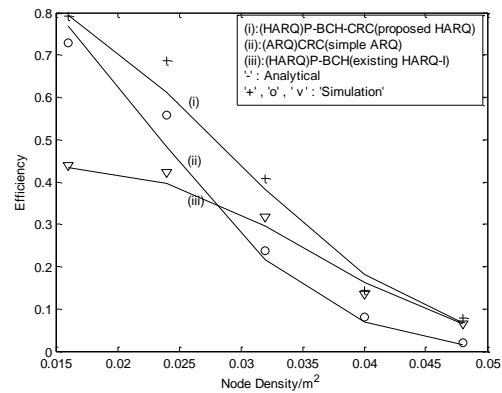


Figure 8. Variation of energy efficiency with node densities using different error control schemes i.e. ARQ with CRC -4(ARQ)CRC, existing HARQ-I with parity bit, BCH code (HARQ-I)P-BCH, and the proposed HARQ with parity bit, BCH coding and appended by another CRC-4 (HARQ-I)P-BCH-CRC. Power control error (pce)=0.5dB, correlation between interferers (r)=0.0, message length=119 bits, and the standard deviation of shadowing =3dB remain same in all cases.

Impact of correlation amongst interferers (r) on average consumption of energy for successful transmission of a packet using different error control schemes is shown in Fig. 9. It is observed that energy consumption increases with increase in correlation. This is due to the fact that BER degrades with increase in correlation [7], which results in increase in average number of retransmission for successful reception of a packet. At a fixed node density, increase of average energy consumption with increase in (r) is highest for simple ARQ scheme, (ARQ)_{CRC}, as compared to proposed HARQ. At node density equal to 0.040

nodes/m², increasing (r) from 0.0 to 0.6 leads to 58% increase in energy consumption in case of simple ARQ (curve i and iii), while 36% increase in energy consumption are seen for proposed scheme (curve ii and iv).

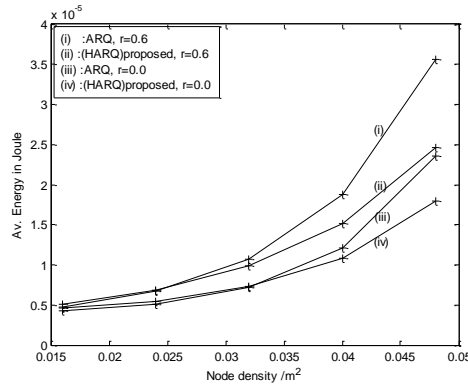


Figure 9. Variation of average energy consumption for successful reception of a message with node densities and with different correlation amongst interferers using different error control schemes; pce=0.5dB remain same in all cases.

Impact of power control error on average consumption of energy for successful transmission of a packet using different error control schemes is shown in Fig. 10. It is observed that energy consumption increases with increase in pce. This is due to the fact that BER degrades with increase pce [7], which results in increase in average number of retransmission. At a fixed node density, increase of average energy consumption with increase in pce is seen to be the highest for simple ARQ scheme (curve i and ii), as compared to proposed HARQ (curve iii and iv).

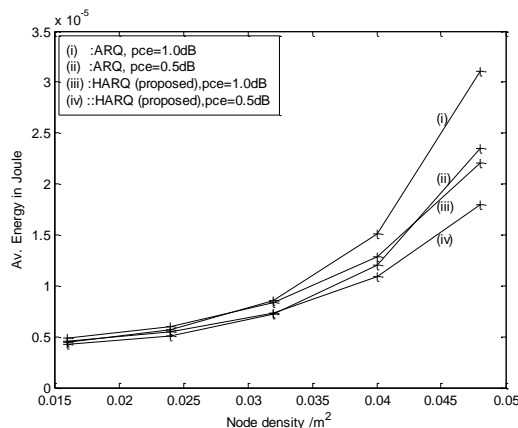


Figure 10. Variation of average energy consumption for successful reception of a message with node densities and with different pce using different error control schemes; r=0.0 remain same in all cases.

5. Conclusion

Cross layer strategy appears as the key issue to optimize the performance of energy constraint CDMA wireless sensor networks, which helps to achieve quality of service targets required by the future applications. The use of error correcting code can allow a system to operate at a lower error rate than an uncoded system. But the choice of error control scheme is very important for an energy constraint wireless sensor network. Hence hybrid ARQ is a promising choice. A new hybrid ARQ scheme is proposed and its performance in terms of energy consumption is evaluated for single hop data transmission in a CDMA based WSN. The proposed scheme is found to be more energy efficient with respect to an existing HARQ-I scheme for wide range of node densities. It outperforms simple ARQ scheme with CRC at higher node density region, while at low node density region, both the schemes show almost similar performance. Average energy consumption for successful transmission of packet increases with increase in correlation amongst interferers (r) and pce. Node density, correlation amongst interferers, and pce have higher impact on energy consumption for simple ARQ scheme as compared to present hybrid schemes. The proposed scheme seems to be a better choice considering higher energy efficiency with lower complexity in transmission.

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Authors



Uma Datta received her B.Tech. degree in Electronics and Communication Engineering in 1980 from Institute of Radio Physics and Electronics, Kolkata, India and M.Tech. degree in Industrial Electrical Systems from NIT, Durgapur, India in 1994 respectively. She has been working as a scientist in the department of Electronics and Instrumentation in Central Mechanical Engineering Research Institute (a National Laboratory under Council of Scientific and Industrial Research), Durgapur since 1981 and is currently a Senior Principal Scientist there. Her research interests include Control System for Machine Automation, Wireless Ad Hoc and sensor networks, and Energy Harvesting System to extend Lifetime of Sensor Network. As of today, she is associated with a number of government and private sponsor projects and has published thirty three (33) research papers in various journals and conferences. She is a member of IEEE (Communication Society) and is a reviewer of several IEEE conference papers.



Bharat Reddy Devireddy received B.Tech in Electronics & Communication Engg from Jahwarlal Neheru Technical University (JNTU), India in 2008. He has obtained Master of Technology (M.Tech) from National Institute of Technology (NIT), Durgapur, India specializing in Telecommunication Engineering in 2011. His areas of interests are in AdHoc and Wireless Sensor Networks.



Amit Kumar Ball received his B.Sc in Computer Science (Hons.) from The University of Burdwan in 2008 and M.Sc in Computer Science from Visva-Bharati, Santiniketan, India in 2010 and now working as a Project Assistant in the department of Electronics and Instrumentation in Central Mechanical Engineering Research Institute (a National Laboratory under Council of Scientific and Industrial Research), Durgapur. His research interests are in different Error Control Coding in Wireless Communication and Image Processing.



Sumit Kundu received his B.E. (Hons.) degree in Electronics and Communication Engineering in 1991 from NIT, Durgapur, India and M.Tech. degree in Telecommunication Systems Engineering and Ph.D. in Wireless Communication Engineering from IIT Kharagpur, India, respectively. He has been a faculty in the department of ECE, National Institute of Technology, Durgapur since 1995 and is currently an Associate Professor there. His research interests include radio resource management in wireless networks, Wireless Ad Hoc and sensor networks, and Cognitive Radio Networks. As of today, he has published hundred (100) research papers in various journals and conferences. He is a member of IEEE (Communication Society) and is a reviewer of several IEEE journals.