Energy Efficiency Analysis of Adaptive Error Correction in Wireless Sensor Networks

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Abstract

In this paper, we develop an analytical energy efficiency model using adaptive error correction code (AECC) in wireless sensor networks in fading environments. To adapt energy efficiency of sensor node to channel variations, the packet length is tuned at the data link layer. In this model, we consider the error control of Bose-Chaudhuri-Hochquengh (BCH) coding for NC-FSK receiver node using AECC scheme and compare it to one of non-AECC. The analysis is based on Mica2 sensor node where a look-up table of distance vs. adaptive correction code is installed in the node sender. Depending on channel state variation via the ACK feedback, the sender can adjust the adequate BCH code required for the next transmission. The numerical results show that the AECC scheme can significantly improve the energy efficiency for the long link distance and under various packet lengths over Rayleigh fading channel.

Keywords: *BCH Coding, Adaptive Coding, Energy Efficiency, Fading Channels, Wireless Sensor networks.*

1. Introduction

The emergence of wireless sensor networks (WSNs) has currently become increased with wide-ranging applications from health, home, and environmental to military, space and commercial. They are a special case of ad-hoc wireless networks where the constraints on resources are especially tight [1], WSNs are composed of nodes typically powered by batteries, for which replacement or recharging is very difficult. With finite energy, a finite amount of information can only be transmitted. Therefore, minimizing the energy consumption for data transmission becomes one of important design considerations for WSN in most application scenarios. Moreover, the channel fading has also a great effect on the reliability of data transmission and energy consumption in WSN. As a result, the design of energy efficient strategies to prolong lifetime or minimize the energy consumption is still of utmost and critical importance issue in WSN design [2][3]. Wireless sensor networks require simple and facile error control schemes because of the low complexity request of sensor nodes. Automatic repeat request (ARQ) and forward error correction (FEC) are the key error control strategies in wireless sensor networks. There have been some studies that consider the energy efficiency of error control techniques in sensor networks.

In [4], an optimization metric of energy efficiency is proposed. This model exactly describes the energy efficiency in sensor networks and many subsequent researches [5][6][7] are based on this model. For example, the authors in [4] examine the energy efficiency of ARQ and they indicate that retransmission strategy of ARQ cannot improve the energy efficiency in sensor networks. Nevertheless, this conclusion is not accurate or comprehensive. In [8], energy efficiency of FEC is studied. They reveal that the energy efficiency of BCH code outperforms any other channel codes due to its low encoding and decoding energy consumption. Accordingly, BCH code is used in our work. Although the basic ARQ protocols provide error control capabilities, they have several drawbacks. In order to overcome the drawbacks, a hybrid scheme consisting of the combination of ARQ and FEC were used and is referred to as hybrid ARQ. The FEC subsystem increases the system throughput by correcting most of the frequently occurring error bits in the transmitted packets. When a detectable but not correctable error is being realized, an ARQ retransmission is requested thus increasing the system reliability. As a result, the combination of FEC and ARQ scheme provides higher reliability than a system operating only with FEC, and higher throughputs than a system operating only with ARQ. In this paper, the mathematical analysis for energy efficiency of HARQ is presented. The result of our analysis reveals that there is an optimum error correction capability with the largest energy efficiency for a target communication distance and packet size.

The rest of this paper is organized as follows: System Model is given in Section 2. In Section 3, the proposed approach is addressed. In Section 4, we present our simulations and results. Finally, the paper is concluded in Section 5.

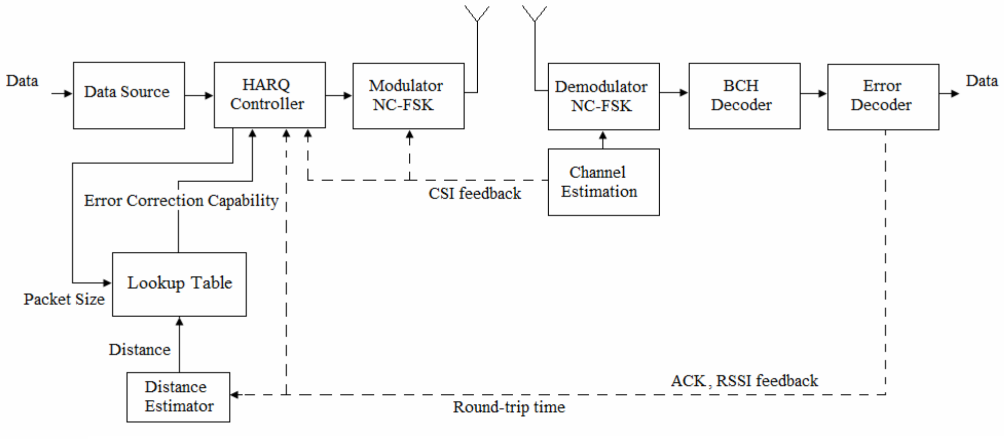


Fig. 1 Proposed Adaptive Error Correction Coding System in Wireless Sensor Network

2. Proposed System Model

In this paper, we consider the sender of wireless sensor with adaptive error correction capability as shown in Fig. 1. At the sender, the optimum error correction capability (t) chooses from Look-up Table depending on the packet size and the distance between neighbouring sensors to achieve the best energy efficiency. Where the packet size varies based on BER in an inverse relationship. ARQ controller and BCH controller of HARQ are both considered to provide error protection on the transmitted data. BCH controller is responsible for adding channel coding to packet at the physical layer; and if the BCH decoder at the receiver fails in correcting the bit errors in the packet then ARQ controller retransmits the entire packet after timeout expired, if t=0 then only ARQ subsystem of HARQ system is to be activated; otherwise HARQ is activated. Received signal strength indicator (RSSI) is a measurement of the power present in a received radio signal. At the sender, when ACK packet is received, the value of RSSI feedback is used to estimate the distance between neighbouring sensors. At the first transmission, initially minimum packet size (511 bits) is sent with error correction bits (t) equals 2 bits. For more illustration, Fig. 2 explains the events sequence between the sender and receiver. Figure 3 summaries the details of the mechanism based on the ACK feedback to adapt the required error correction to the next packet transmission. This feedback refers to RSSI indicator.

2.1 Channel Estimation

We first estimate the raw channel bit error rate (BER) for typical wireless sensor networks. The probability of bit error is evaluated under a non-coherent FSK modulated Rayleigh fading channel model in wireless sensor networks, is defined as follows [4]:

$$P_{b,NC-FS} = \frac{1}{2+SNR} \quad (1)$$

$$SNR(dB)=77\text{-}10\beta\log(d) \quad (2)$$

where β is the path loss exponent. (Assume a typical β = 3.5).

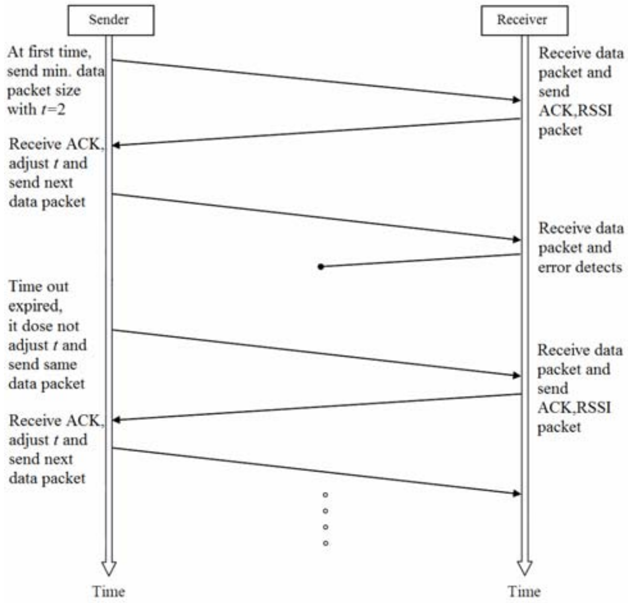
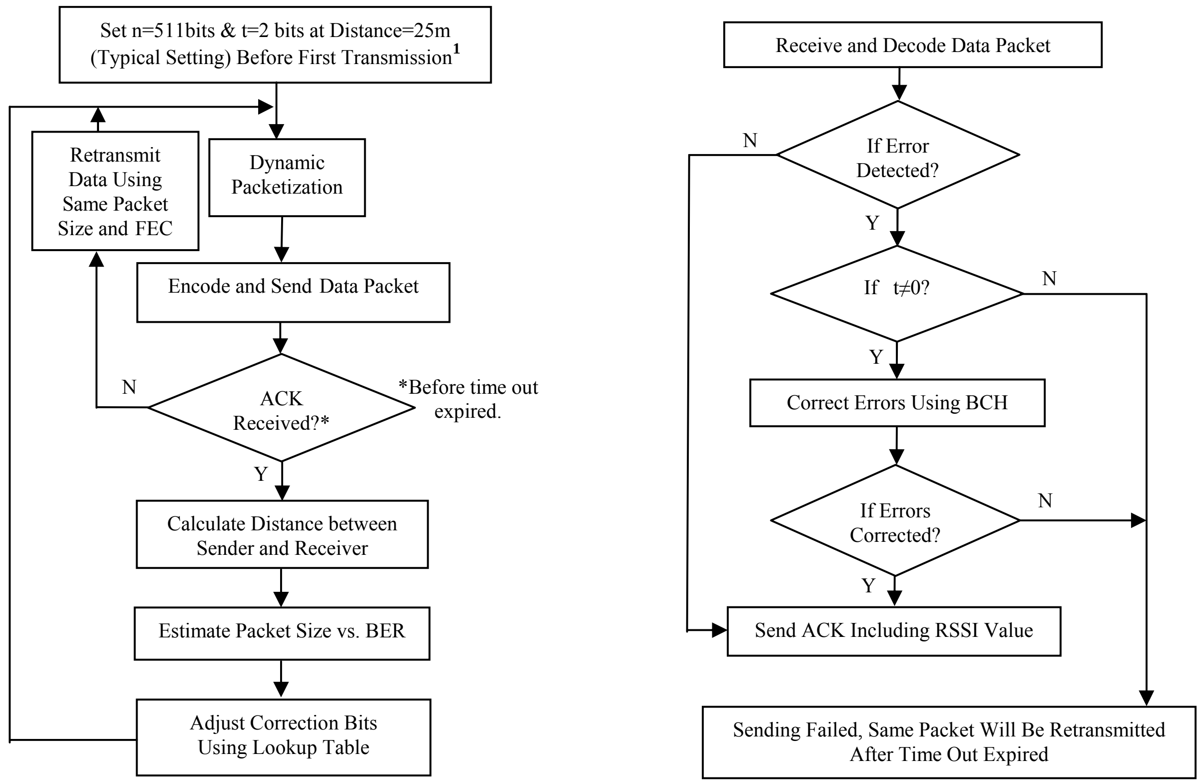


Fig. 2 Timing Diagram



(a) (b)

Fig. 3 Proposed Adaptive Error Coding System in Wireless Sensor Network (a) Sender node (b) Receiver node

According to the receiver implementation, signal-to-noise ratio (*SNR*) depends on the neighbor distance *d* between sensor nodes. The path loss is the average propagation loss as a function of the distance *d* on the order of β.

2.2 Optimization Metric

The energy efficiency η is a suitable metric that captures the energy and reliability constraints, which is defined as [4]:

$$\eta = \eta_e . R = \frac{E_{eff}}{E_{total}} (1 - PER) \tag{3}$$

where η_e is the energy throughput, R= (1 - PER) is the packet acceptance rate, which accounts for data reliability, and E_{eff}/ E_{total} denotes the energy throughput. Therefore, the energy efficiency η represents the useful fraction of the total energy expenditure in a communication link between neighbouring sensors.

[1] - Assume ED and FEC are added to each packet prior to transmission

3. Adaptive Error Control Analysis

The energy efficiency analysis is based on Mica2 sensor node [9] with ATmega128L processor [10] and CC1000 radio module [11]. Energy consumption of HARQ can be expressed as:

$$E_{HARQ} = E_{tran} + E_{re} + E_{dec} \tag{4}$$

where encoding energy is considered to be negligibly small value [4] and E_{dec} is the decoding energy. For a t error correction binary BCH code the decoding energy E_{dec} can be expressed as [12]:

$$E_{dec} = I_{proc} V_{proc} \left(2nt + 2t^2\right) \left(\frac{m}{8}\right) 3t_{cycle} \tag{5}$$

where I_{proc} is the current for processor, V_{proc} is the supply voltage, t_{cycle} is one cycle duration of processor, n is the total data packet size and m = $\log_2 n$ +1 [13]. And the expression for the energy efficiency of HARQ defined as:

$$\eta = \frac{(I_{tr}+I_{re})V_{radio}T_{tr}(n-\alpha-\tau)}{(I_{tr}+I_{re})V_{radio}T_{tr}N+E_{dec}} \times R \quad (6)$$

where I_{tr} , I_{re} , V_{radio} are the transmit current, receive current and the supply voltage for CC1000, T_{tr} = $1/R_{radio}$ is the time consumed to transmit 1 bit by CC1000, α sum of header and frame check sequence (FCS) size, $\tau = m * t$, $N = n + l_{ACK+RSSI}$ and R is packet reliability:

$$R = \sum_{i=0}^{t} \binom{N}{i} p_b^i (1-p_b)^{N-i} \quad (7)$$

Eq. (6) is a bounded function with $0 < \eta < 1$ and its values vary along the error correcting capability t which is always an integer, length of the packet and distance between communication pairs. For ARQ, energy efficiency is independent of retransmission attempts and is unchangeable with the number of retransmission [14].

4. Simulation Results

4.1 System Settings

Parameters settings are based on the Mica 2 series WSNs platform of Crossbow Company, which are given by Table1.

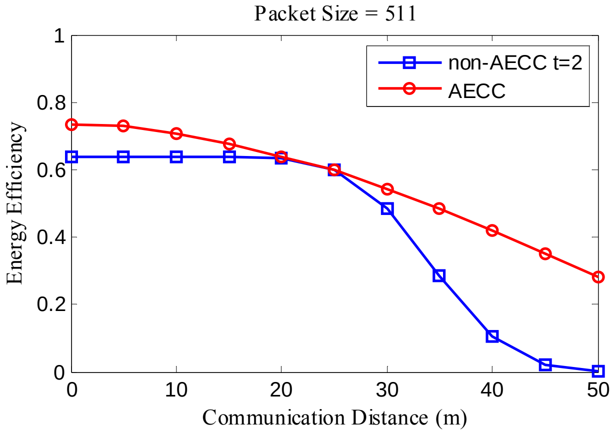
Table 1: Parameter Settings

Symbol	Parameters	
	Definition	***Quantity***
α	Sum of header and FCS size	11 bytes
$l_{ACK+RSSI}$	Packet length of ACK and RSSI	9 bytes
V_{radio}	Supply voltage for radio	3V
V_{proc}	Supply voltage for processor	5V
I_{proc}	Current for processor	8mA
t_{cycle}	One cycle duration of processor	250ns
I_{tr}	Transmit current	8.5mA
I_{re}	Receive current	7mA
R_{radio}	Data rate	38.4kbaud

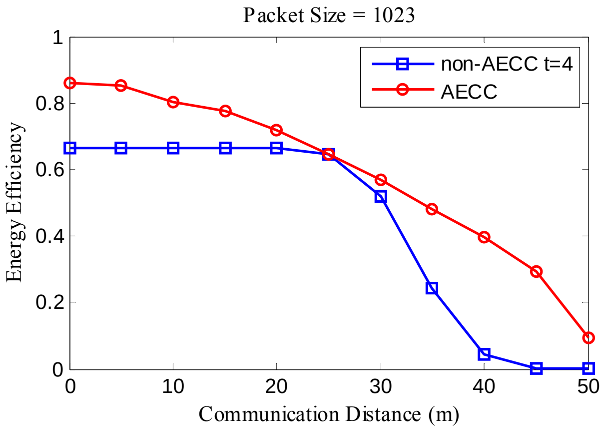
4.2 Performance Evaluation

In this section, the AECC scheme was compared with one of non-AECC, in terms of energy efficiency based on different communication distances and data packet size using HARQ error control over Rayleigh fading channel. The interval of the distances in simulation is 5 meter because of the location error in WSNs. The energy efficiency of two types of error control scheme is all sharply reducing with increasing of communication distance. Energy efficiency of AECC scheme decreases to some degree, but the performance of this scheme is maintained relatively well with increasing of communication distance for various packet size.

In Fig. 4(a), (b), (c) and (d) the energy efficiency of AEEC and non-AECC schemes were compared over 50m communication distance and packet size of 511, 1023, 2047 and 4095 bits, respectively. For non-AECC scheme each packet size has error correction capability t of constant value independent on variation of communication distance. It is clearly noticed that the energy efficiency of AECC scheme is better than that of non-AECC, so AECC is the optimal error control scheme.



(a)



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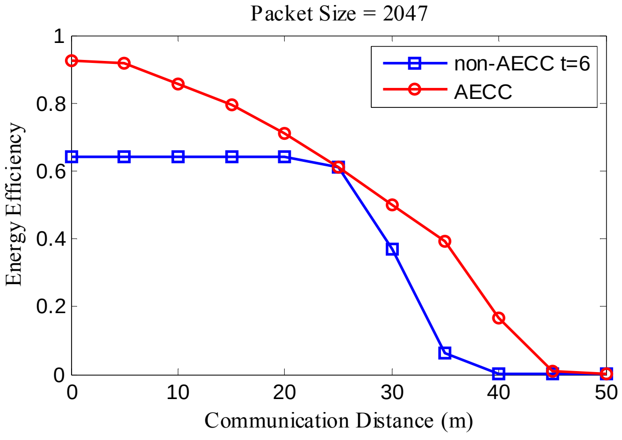
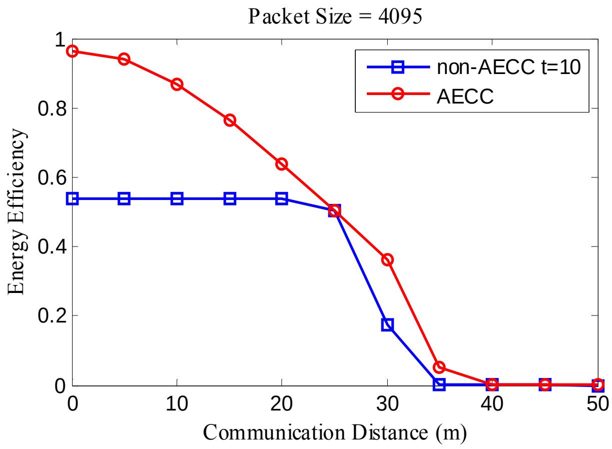


(c)



(d)

Fig. 4 Energy efficiency of AECC and non-AECC for different packet sizes and communication distance

5. Conclusion

In this paper, energy efficiency of error control schemes in wireless sensor networks is discussed. The maximal energy efficiency of HARQ technique can be achieved by adaptation of error correction capability for a target communication distance and packet size. Moreover, AECC is compared with non-AECC scheme in terms of energy efficiency based on different communication distances and packet lengths.

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