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On the design of coding framework for energy efficient and reliable multi-hop sensor networks

Imad Ez-zazi*, Mounir Arioua, Ahmed El Oualkadi

Laboratory of Information and Communication Technologies (LabTIC), National School of Applied Sciences, Abdelmalek Essaadi University, Tangier, BP 1818, Morocco

Abstract

Energy efficiency and reliability are the key requirements for wireless sensor network (WSN), as sensor nodes are expected to be stand-alone for a long time and communication to be successfully carried out. Communication is the most energy consuming process in WSN, especially in lossy environment. In multi-hop WSN, packets are more susceptible to transmission errors which worsens the communication reliability and energy consumption. Therefore, coding schemes are mandatory to cover the channel impairments and save the transmission energy. In this work, we propose an adaptive coding (AC) scheme that can be adapted with the channel state and inter-node distances in order to decode and correct the packets or request for retransmissions. The proposed scheme has proved to be energy efficient and adaptive compared to Automatic Repeat reQuest (ARQ) and Forward Error Correction (FEC) schemes.

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Keywords:
Wireless sensor network, Multi-hop network, Energy efficiency, Reliability, FEC, ARQ

1. Introduction

Energy efficiency and communication reliability are the most important issues in Wireless Sensor Network (WSN). This emergent technology has attracted significant attention in recent years in many applications [1]. WSN is composed of numerous sensor nodes dispersed autonomously in specific area of interest to gather a physical parameter or monitor environmental conditions [2]. Typically, nodes are powered by small and limited batteries which replacement is difficult and expensive in hostile environment. Thus, nodes are expected to be stand-alone and able to run for many months or even years without batteries recharging or replacement [3]. Therefore, reducing energy consumption in order to prolong network lifetime is the most crucial challenge for WSN [4].

* Corresponding author. Tel.: +212-668-554-440 ; fax: +212-593-393-744.
E-mail address: ezzazi@ieee.org

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Noise, interference and multipath fading are often present in wireless channel which make the transmission errors unpredictable in WSN[5]. These channel impairments are particularly major in harsh environment which result in packet loss and delayed receiving. However, transmission process is the most energy consuming among other node processing. In this case, each transmission failure will cost more energy for retransmission until successful receiving. Although increasing the transmission energy results in successful and reliable transmission, it profoundly affects the sensor nodes energy and the network lifetime. Therefore, designing optimal WSN implies taking into consideration both the transmission energy and transmission reliability, by providing reliable communication with minimum required energy[6]. Error control coding (ECC) has been widely known as a key of error encountering in wireless channel[7]. FEC and ARQ schemes are the main strategies of ECC, where the former consists of detecting and correcting the errors based on some included redundancy at the transmitter, while the later is based on detection of errors and retransmissions of packets[8]. In energy constrained technology such as WSN, using adaptive and low power ECC techniques is primordial requirement due to the limit processing and energy capacity.

In the last years, the energy efficiency problem has gained greater attention and many algorithms and protocols have been proposed for the sake of extending the network lifespan[3]. However, most of these works have been focused on routing protocols, multiple access architectures, aggregation and compression approaches[9,10]. In fact, several works which address the problem of coding schemes have been concentrated on end-to-end communication without taking into account the network architecture[7]. For instance, Low Density Parity Check (LDPC) codes have been proven to be efficient in terms of reliability and energy in single hop WSN[11]. Results presented in[12] show that using Reed Solomon (RS) codes with short codeword length in WSN saves about 50% of energy. However, the decoding process worsens the energy consumption in multi-hop network, where coding and decoding are used in each node. In this case, a few papers have been interested in the optimization of coding techniques in multi-hop network design. In[13], a low power decode and forward approach is proposed for multi-hop WSN, where a Viterbi decoding of convolutional codes is implemented in intermediate nodes while the iterative decoding algorithm of Turbo codes is applied at the base station. An adaptive coding approach for multi-hop WSN, in which strong and soft FEC schemes are adaptively adopted according to the distance and channel condition is suggested in[14]. This paper presents an adaptive coding scheme based on FEC and ARQ in multi-hop WSN for effective trade-off between reliability and energy efficiency.

The rest of the paper is organized as follows. The system model with propagation and energy models is presented in Section 2. In Section 3, the error control coding approaches including ARQ, FEC and proposed scheme are discussed. The obtained simulation results are analyzed and discussed in Section 4. Section 5 concludes the paper.

2. System model

A multi-hop WSN with N sensor nodes is considered in this work. Figure 1 shows a system model of the multi-hop sensor network. Each source node S transmits its sensed data through $N - S = R$ intermediate nodes that are relays of the subsequent S nodes. According to the distance, source nodes decide which relay node to be communicated with in the next hop. If the distance between source node and the base station (BS) is the minimum, direct communication turns out to be the adequate choice.

2.1. Propagation model

Many radio propagation models known for wireless communications predict the signal-strength loss with distance. The free space and multipath propagation models are widely used in WSN[14]. In the free space model, communications between the transmitter and receiver are clear line-of-sight in which reflecting surfaces and effect of the earth surface are solely absent. The multipath propagation is as result of different signal paths between the transmitter and receiver. These paths are the major detriment to signal propagation by giving rise to interference, distortion of the signal and loss of data. For both free space and multipath propagation, the received power decreases as the distance between the transmitter and receiver increases[15]. In this work, both the free space model and the two-ray ground model are used, depending on the distance between the transmitter and receiver. If the inter-node distance (distance between transmitter and receiver) is less than a crossover distance (d_{cr}), the Friss free space model is used (d^2 attenuation). Otherwise ($d > d_{cr}$), the two-ray ground propagation model is considered (d^4 attenuation).