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A green and reliable communication modeling for industrial internet of things

Anfeng Liu[a], Qi Zhang[a], Zhetao Li[b,*], Young-june Choi[c], Jie Li[d], Nobuyoshi Komuro[e]

[a] School of Information Science and Engineering, Central South University, ChangSha, 410083, China
[b] College of Information Engineering, Xiangtan University, Xiangtan, 411105, China
[c] Department of Softwarwe, Ajou University, Suwon, 443749, South Korea
[d] Faculty of Engineering, Information and Systems, University of Tsukuba, Tsukuba, 305-8573, Japan
[e] Graduate School of Advanced Integration Science, Chiba University, Chiba, 263–8522 Japan

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ABSTRACT

Green and reliable communication has great significance for Industrial Internet of Things. Unfortunately, because of the loss nature, achieving reliable transmission is challenging. In this paper, a novel hybrid transmission protocol (HTP) is proposed to maximize lifetime while the reliability is still guaranteed. The proposed protocol adopts Send-Wait automatic Repeat-Request protocol in hotspot areas to reduce the energy consumption and network coding based redundant transmission approach with adaptive redundancy level in non-hotspot areas to guarantee the reliability. The proposed protocol could improve the lifetime and shorten the delay on the premise of ensuring the reliability. Comparing with Send-Wait automatic Repeat-Request protocol, it can improve lifetime by 15%–30% under the same reliability and improve the reliability by 12%–45% under the same lifetime. Comparing with network coding based redundant transmission approach, the lifetime has increased by more than one time under the same reliability.

1. Introduction

Industrial wireless sensor networks are of important component of Industrial Internet of Things that integrating the physical systems with sensing, computing, and actuation exhibit new capabilities with unprecedented dependability and efficiency [1–5]. It makes the smart factory real [6,7]. For the sensor nodes in these applications, sense the environmental data and transfer them to sink node is one of the important features. Due to the characteristics of the wireless networks, there are noise and error during data transmission, which leads to data lost [8–10]. The sensor networks depend on the sensory data to take action, if data reliability is not high, it may lead to decision-making mistakes [10–12]. Thus the packet delivery reliability becomes a prominent challenge in industrial WSNs [10–16]. Due to their inherent characteristics of resource-constrained, for data collection, Green (energy efficiency) communication is another vital issue since replacing or recharging the batteries of sensor nodes is extremely difficult [8–10,24]. Summarily, green (energy efficiency) communication, the delay and data reliability (the probability of data packets successfully received by receiver) are regarded as the major concerns

* Corresponding author.
E-mail address: liztchina@gmail.com (Z. Li).

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in the design of industrial wireless sensor networks [10,17]. Many studies show that there is a trade-off among the delay, energy efficiency and reliability [10,13].

There have been some strategies to guarantee the reliability of data transmission, such as Send-Wait automatic Repeat-Request (SW-ARQ) protocol [10,13]. With SW-ARQ protocol, the sender transmits one packet each time and waits for an ACK or a timeout before its next transmission [10,13]. The advantages of this protocol are easy-to-use and energy-saving. But the disadvantage of it is the delay. Especially in the network with poor link quality, multiple retransmissions may lead to long delay. Another strategy which called network coding based redundant transmission (NCRT) approach [18] is to encode the data packets and transmit them with some redundancy levels. The delay of it is short, but the energy consumption is large, so the network lifetime of this method is short.

For industrial applications, they also require the protocol can improve the data transmission reliability, keep a longer network lifetime and reduce the delay. But to the best of our knowledge, there have not a method that can optimize the network performance simultaneously. The application of WSNs is more and more widely, especially in industrial production, a data transmission strategy that can achieve high-reliability, low-latency and long lifetime is urgently needed.

In this paper, combining the advantages of SW-ARQ protocol and NCRT approach, we proposed a new method which called hybrid transmission protocol (HTP) to maximize lifetime with reliability guarantees for wireless sensor networks. The main contributions of our study are as follows:

The HTP approach which we proposed adopts SW-ARQ protocol in hotspot areas (the areas near sink) and NCRT approach in non-hotspot areas (the areas far to sink), which can prolong lifetime as well as reduce end-to-end delay. In the areas near the sink, we adopt SW-ARQ protocol to save energy as much as possible. In the areas far to sink, we make full use of the rest energy to improve the network reliability and shorten the delay. On the whole, HTP approach can overcome the shortcomings of the other two methods. It can achieve low-latency, high-reliability and long lifetime in the network. It can also change the phenomenon of unbalanced energy consumption in WSNs. Through our extensive studies, comparing with the other two kinds of method, the performance of HTP is improved greatly.

The rest of this paper is organized as follows: In Section 2, the related works are reviewed. The system model is described in Section 3. In Section 4, a novel hybrid transmission protocol (HTP) is proposed. The HTP's performance analysis is provided in Section 5. Section 6 is experimental results and comparison. We conclude in Section 7.

2. Related work

Because the reliability, delay and network lifetime are all important performance for wireless sensor networks, so there has been a tremendous amount of research about them [1–7]. In this section, we review some current related research and divide them into two categories: one is improve the network reliability only by using data transmission method, the other one is cross-layer optimization.

(1) Cross-layer optimization is the method while optimizing at multiple levels. Such methods mainly optimize MAC layer and transport layer simultaneously. The principle of such methods is: there are strong correlations between data transmission reliability and sending power of the node. Generally speaking, if we improve the sending power of the node, the SNR also improves, so that the probability of successfully receiving packets for the receiver improved, and the data transmission reliability improved. This method requests the hardware of nodes can provide different transmit power, so it couldn't be used in some networks. Also, the energy consumption of this method is big and the lifetime is short. There are a lot of studies belong to this category, Ref. [19] proposed a method which adopts different transmit power to reduce the bit error rate (BER) and delay in adaptive MPSK-based wireless sensor networks. We can also see some related research in Ref. [20,21].

(2) The reliability and delay guaranteed mechanism in data transport layer. Because the cross-layer optimization method has higher requirement for the networks, and it also requires to optimization in the transport layer. Therefore, many studies still research at the transport layer. Such studies can be divided into following categories:

(a) Retransmissions-based reliability and delay guaranteed mechanism. In this method, for each sender node, it sends the packets to the destination node one time, then waiting the receiver returns an ACK to ensure the packets are received. If the sender receives an ACK within the expected time, it continues to send next packet. Otherwise, the packets would be sent by the sender the second time. Repeated the above process again and again, until the sender receives an ACK or the retransmission times exceed the predetermined maximize retransmission times. The advantages of it are that, it is simple and has low requirement for the system, it can be adopted in all kinds of networks, and the network lifetime of it is high. But the disadvantage of it is the long delivery delay, especially in a low link quality network. While the retransmission mechanism has several transformations: (1) Go-Back-N (GBN) protocol (2) Selective repeat (SR) [9,11–13]. All the retransmission protocols can operate in hop-by-hop (HBH) or end-to-end (E2E) mode [11,13].

(b) Multi-path transmission. It belongs to redundant transmission. In Ref. [22], it divides redundant transmission methods into following categories: (1) Multi-path data transmission mode. It means the same data packets can reach sink through multiple routing and as long as one route reaching is ok. (2) Multi-copy data transmission mode. This method is similar to the above retransmission mechanism. It sends the same packets in the same link several times. But it doesn't need to wait the return of ACK. For these methods, the advantages of it are the reliability can be guaranteed

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