Computers and Electrical Engineering 000 (2017) 1–15

Contents lists available at ScienceDirect

Computers and Electrical Engineering

journal homepage: www.elsevier.com/locate/compeleceng

Pre-channel scheduling and Priority-based reservation in medium access control for industrial wireless sensor network applications☆

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ARTICLE INFO

Article history:
Received 8 November 2016
Revised 26 April 2017
Accepted 8 May 2017
Available online xxx

Keywords:
Data fusion
Industrial Wireless Sensor Network (IWSN)
Packet classification
Reservation-based MAC
Slot scheduling

ABSTRACT

Numerous technical advancements and the pervasive controlling schemes in the Industrial Wireless Sensor Network (IWSN) with the capability of interoperability among the nodes facilitate the reliable communication. With the increase of participating sensors size, the memory and energy consumption reduce the lifetime adversely. To alleviate these issues, this paper creates an energy efficient data management and routing architecture based on the data fusion techniques in IEEE 802.15.4. The data classification through proposed Multi-Stage Classification (MSC) prior to priority assignment techniques makes the immediate decision regarding the controlling actions. The split up of data using Reservation-based Medium Access Control (RMAC) raises the resource allocation requests according to the data type. The built up of the relationship between the number of slots and the data arrival enhances the resource utilization performance for each slot. The guarantee of transfer of immediate transmission with the priority supports the critical conditions with high energy efficiency.

1. Introduction

With the numerous deployment of tiny and intelligence sensor devices, the application of IoT is extended to support the real-time applications drastically. The operational constraints (resource utilization, reliability) are diverse in nature like the controlling of one will affect the other parameter. Hence, the monitoring and maintenance of the sensor devices in a unified manner are the challenging task in Industrial Wireless Sensor Network (IWSN) applications. The important issue to achieve the reliable communication among the sensor nodes is the target coverage problem. Besides, the uses of feedback control loops in the industrial environment highly impose the end-to-end delay during data transmission among the devices in the IWSN. Due to the inheritance of broadcast characteristics, the wireless medium is opened to the either authorized or unauthorized users (eavesdropping attacks). The challenging issue with the real-time reliable communication is to meet latency requirements for the feedback control loop. The multi-hop communication governed by the industry standard called IEEE 802.15.4 increases the communication delay under dynamic challenges in channel conditions.

☆ Reviews processed and recommended for publication to the Editor-in-Chief by Associate Editor Dr. M. H. Rehmani.

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http://dx.doi.org/10.1016/j.compeleceng.2017.05.010
0045-7906/

The reliability enhancement depends on the scheduling of slots, requests, frequency hopping, mesh-star routing and the redundancy routing. Sensor Nodes (SN), Relay Nodes (RN) and the Base Stations (BS) are the major parts of the IWSN. The deployment of RNs on single connected environment ensures the connectivity between the sensor nodes and the decision-making the unit. But, the failure in RN under the harshest environments breaks the functionality of the network and disconnects the data forwarding link to the base stations. Resource constraints, rescheduling and the routing ordered slot assigning raises the challenges in slot scheduling. The extension of IWSN into the cognitive models is the active research area nowadays. The design principles of Cognitive Radio Network (CRN) models [1,2] reveal the communication protocols highlight the challenges in node deployment, strategies, clustering issues in detail. The spectrum utilization is the major issue in the CRN formulation that makes the spectrum sensing as the essential mechanism that induce serious threat to sense the spectrum effectively. The security threats [3] observed in the CRN communication were incumbent emulation and the sensing data falsification. The availing of large bandwidth through the channel bonding algorithm [4,5] reduces the contiguous channels effectively. The governing of the Medium Access Control (MAC) layer plays the major role in QoS provisioning in IWSN. But, the lack of priority leads to difficulty in decision making regarding the control parameters.

The design of hybrid MAC considers the allocation of sensor node requests in contention periods and the contention free period to meet the diverse demands for different nodes. But, the traffic information in the superframe structure increases the overhead that will deteriorate the performance in IWSN. The standard IEEE 802.15.4 contains two modes such as non-beacon and beacon enabled modes in MAC. In the first mode, each node sends their data by using the Carrier Sense Multiple Access/Collision Avoidance (CSMA/CA). The clustering-based adaptive routing and data gathering algorithm [6] addresses the issues in transmission and gathers the real-time big data to analyze the risk in the industrial operations. The extension of data gathering is to perform the fault diagnosis with low energy consumption and high network lifetime in industrial applications. Many routing algorithms contribute towards the network lifetime improvement such as Low Energy Adaptive Clustering Hierarchy (LEACH) [7] combines the energy-efficient-based clustering and media access for data aggregation. The self-configuring capability of large number of nodes and algorithms for even distribution of energy support the lifetime improvement. The major disadvantage of LEACH is additional energy overhead due to the transmission of location and residual energy of each node to the decision making unit. Alternatively, the Hybrid Energy-Efficient Distributed (HEED) [8] periodically selects the Cluster Head (CH) on the basis of the residual energy and proximity to the neighbors. Low-message overhead and the preservation of connectivity are the major observations in HEED protocol. The neighborhood information-based cluster formation caused the uneven energy overheads. The data from the multiple sensors are combined to enhance the accuracy of measurement that initiates the fusion techniques. The detailed study of the protocols implemented on IWSN highlights the challenges as follows: assurance of limited resource usage, satisfying of Quality of Service (QoS) requirements, minimum data redundancy, scalability and security constraints. The major contributions of the proposed work are listed as follows:

- The core node selection based on the High-Priority Indication Space (HPIC) super frame mitigates the overlapping in channels and monitors the operations (transmission and reception of data) performed by the nodes. In traditional method [9], the trade-off between the energy efficiency, throughput and the delay is the major limiting factor due to the multi-domain constraints of the sensor devices. The introduction of parallel data fusion techniques with the priority assignment scheme provides the trade-off between those parameters.
- The employment of Multi-Stage Classification (MSC) before the priority assignment serves as the base for immediate decision making regarding the normal and isolate data.
- The data classification (normal and emergency) facilitates the reservation of slots improves the throughput performance with less time and energy consumption.

The paper organized as follows: The detailed description about the related works on energy-delay aware routing protocols in IWSN is discussed in Section 2. The implementation process of Multi-Stage Classification (MSC) on Reservation-based MAC layer is described in Section 3. The comparative analysis of the proposed approach with existing delay-aware routing protocols provided in Section 4. Finally, the conclusions about the application of proposed work on various communication scenarios presented in Section 5.

2. Related work

2.1. IWSN scenario

A unified management of wireless sensor devices requires the industrial authorities with the capabilities of provisioning the network infrastructure support to IWSN applications. Distributed and dynamic topology of WSN introduced the special requirements for routing protocols. Pantazis et al. [10] provided the survey of energy-efficient routing protocols based on four major schemes such as network model, communication model, topology and reliable routing. The major categories of the protocols are investigated to balance the energy level. Akhtar [11] described the survey of potential renewable energy resources with the characteristics of WSN, battery recharging techniques and the applications of WSN with the challenges and future scope. The incorporation of WSN in an urban environment was investigated in [12]. The limitations of the IWSN applications are energy-conservation during the data gathering by Hybrid Rapid Response Routing (HRRR). With these gathering requirements and the additional features of TinyOS [13] offered the operational flexibility.

Please cite this article as: K. R. et al., Pre-channel scheduling and Priority-based reservation in medium access control for industrial wireless sensor network applications, Computers and Electrical Engineering (2017), http://dx.doi.org/10.1016/j.compeleceng.2017.05.010