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A reliable medium access mechanism based on priorities for Wireless Body Sensor Networks

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Abstract—**Wireless body sensor networks (WBSN) provide health related information for monitoring or professional analysis by collecting various signals of human body or environment information with sensors. But different data acquired in many applications have different transmission requirements. The dropping of life-critical messages could possibly create life threatening results if the network is not reliable. To improve the reliability this paper proposes a novel reliable medium access mechanism (RMAM) which guarantees transmission of data with different priorities in less delay and energy consumption. The mechanism is designed and evaluated by Castalia. The improved performances of latency, packets breakdown and energy consumption are analyzed and depicted with comparison.**

I. INTRODUCTION

A wireless body sensor network (WBSN) is a system that uses some low power, tiny wireless sensors to continuously gather physiological, behavioural or other health related parameters and then forward them to professionals for monitoring or analysis [1].

WBSN is widely applied in many fields such as healthcare, sports, entertainment and military through invasive or non-invasive mini gadgets. However special concerns, and requirements encountered in applications hinder the wide spread usage in specific areas. For example: various data for different healthy or medical purposes have different frequency and transmission requirements. Non critical signs or non-real-time messages only require to be delivered with the best effort, while critical vital signs, or real-time messages should be transmitted with least delay, and they should avoid collision or missing. Particularly for people in some vital or emergency medical status, highest level of reliability, shortest transmission latency and immediate response are very essential. The missing of life-critical signals may eventually lead to life threatening disasters if patients are in urgent treatments. These special features distinguish WBSN from conventional wireless sensor networks (WSN) in capability and induce many new issues in the process of utilization. Effective and feasible schemes of flexible bandwidth request are required to solve constrains of limited capabilities in traditional design.

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To guarantee reliability of diverse data transmission, in recent years, a wealth of research papers are inspired to propose coordination or optimization method on PHY or MAC layers to realize a more reliable and efficient communication environment. Pangun Park derives an adaptive algorithm to formalize the power consumption while guaranteeing reliability and delay constraints in the packet transmission[2]. Yan Zhang uses application specific control channels in MAC to provide priority Guarantee [3]. H. Ozgur Sanli and Hasan Çam proposes a practical coverage and rate allocation protocol to exploit the dependency in realistic environments[4]. Those protocols consider more of the power consumption and efficiency of transmission in BSN while the influence of priority is paid less attention in applications of health care or monitoring. In fact appropriate priority assignment and bandwidth scheduling schemes are very significant to guarantee the reliability in utilizations.

In this paper a novel scheme dynamically changes the superframe pattern based on 802.15.4 protocol to schedule channel according to priorities of nodes. The system's performances of this method are evaluated with simulations by Castalia-3.2. For the remaining part of this paper, Part 2 briefly introduces 802.15.4 protocol. Part 3 explains the structure of reliable medium access mechanism (RMAM) system. Part 4 explains the proposed medium access mechanism. Part 5 shows the results of the performance evaluation and Part 6 makes a conclusion.

II. OVERVIEW OF IEEE 802.15.4

The IEEE 802.15.4 protocol defines the physical layer and the MAC layer for low-rate Wireless Personal Area Networks (WPANs)[5]. The standard specifies two channel access models: (1) a beacon-enabled model, which utilizes a slotted carrier sense multiple accesses with collision avoidance (CSMA/CA) and the optional Guaranteed Time Slot (GTS) allocation scheme; (2) a simpler un-slotted CSMA/CA without beacons. We choose the beacon enabled mode because a star topology with a coordinator is widely accepted in WBSN. The coordinator regularly forwards the beacon frames in each beacon interval (BI). The coordinator and sampling sensors communicate in duplex during active period, named the superframe duration SD. The structure of the superframe constituted with BI and SD is determined by two parameters, the beacon order BO and the superframe order SO. The range of BI and SD can be defined in (1) and (2).

$$BI = aBaseSupeframeDuration \times 2^{BO} \tag{1}$$

$$SD = aBaseSupeframeDuration \times 2^{SO} \tag{2}$$

Where $0 \le SO \le BO \le 14$.

A BaseSuperframeDuration is defined by number of symbols when SO is equal to 0 in initial assignment. In addition, the superframe is divided into 16 equally sized slots. The superframe consists of three components: a beacon, a contention access period (CAP), and a contention free period (CFP). The beacon is transmitted in Slot 0 without CSMA, and the CAP start immediately after the beacon. The CFP, if present, follows the CAP. All frames transmitted in the CAP use a slotted CSMA-CA mechanism to access the channel. MAC command frames are transferred in the CAP. If any GTSs have been assigned they are allocated in the CFP and capture continuous slots. The CFP duration will increase or decrease according to the whole length of calculated GTSs.

IEEE802.15.4 has several limitations such as statically bandwidth utilization of the messages, data length and back off time in applications. The standard is not flexible to adjust because BO and SO are defined at initiation. The system cannot modify configuration in run period therefore it is unable to deal with changing requirements of messages. Under some situations, fixed setting will lead to the wastage of energy and slots. Also, the size of GTS is no more than seven slots in the CFP because a minimum size of CAP is eight slots to guarantee MAC commands' delivery. So CFP can accommodate only a few real time messages at high data rate. If nodes require large bandwidth to send high priority data, they won't be allocated enough bandwidth. Then they have to wait for long time and would eventually cause data loss. In order to overcome theses disadvantages in general IEEE 802.15.4 some modifications are considered in our mechanism to achieve automatically reconfiguration of superframe structure.

III. THE STRUCTURE OF RMAM MODEL

According to specific circumstances in WBSN the configuration of RMAM is operated by the coordinator, which is in charge of receiving data from other nodes, analyzing, setting priorities, allocating bandwidth and transferring data to the service centre. When abnormal or emergency data are detected, the coordinator changes initial priorities and allocates bandwidth to adapt to new circumstances. Then some sensors change data transmission rates to ensure high priority with high reliability. The system is divided into three logical function modules: Information collection module, priority assignment module and bandwidth allocation module.

A. Information collection module

The information collection module includes nodes which collect environmental, biological and runtime information, such as blood pressure, body temperature, heart rate, environment temperature and so on. The sampling frequencies of biomedical sensors usually are no more than 300 Hz since biological signals oscillate at low frequencies. But if a large array of sensors are used, e.g., Electroencephalography (EEG) 192-channel recording, the data rate will increase up to hundreds of kilobits per second. These sensors should be classified by critical or non critical nodes with original priorities in different applications. Data acquired by a variety of sensors go through wireless channel to the coordinator in WBSN.

B. Priority assignment module

A priority assignment module is executed by the coordinator. It receives data, analyses and assigns priority. Some data are very critical under certain situations and should be ensured with high end-to-end reliable transmission and lower delivery delay. However non critical data are not time urgent and real time transmission is not necessary for them. So normal data can be transferred at low rate while abnormal or emergency data should be transferred with high rate. In our mechanism data are classified into four types: non real- time data, normal real-time data, abnormal data, and emergency data with priorities as 1,2,3,4 respectively. So the priority of a node which transfers non real time data possibly would be 1, 3 or 4 depending on the sampling data. While the priority of a node collecting real time data would be 2, 3 and 4. Each sensor has a weight β to avoid collision when maximum bandwidth cannot meet the requirements. When sensors with transient abnormal data go back to normal status, the priority decreases to its original configuration.

C. Bandwidth allocation module

The priorities of sensors are defined to indicate services and bandwidth requirements of the BSN. The mechanism of bandwidth adjustment is tailored on IEEE802.15.4 protocol due to its widely application in WBSN. Emergency data node, issued by the MAC frame, shall be tagged as EN04; normal non real time data nodes are tagged as NNRN01; normal real time data nodes are tagged as NRN02; abnormal data nodes are tagged as AN03. Normal non real time data nodes use slotted CAP and real time data nodes use GTS to transmit messages. When abnormalities and emergency information are detected, GTS will be calculated to allocate enough bandwidth for requirements of reliability. Then coordinator sends commands to sensors so they can alter the rate according to a new bandwidth configuration.

IV. A RELIABLE MEDIUM ACCESS MECHANISM

The proposed RMAM is designed base on IEEE 802.15.4 MAC standards with some changes. The system operates on 2.4 GHz RF band with a star topology. A slotted (CSMA/CA) mechanism is used to access the channel for non real time data during the CAP. In the CFP, the dedicated bandwidth is used for time critical data. All non-real time messages should be periodically dispatched in CAP period. Other real time information transmitted in GTSs allocated by coordinator with priority value. From a point of view, the GTS allocation is similar to a time division multiple access mechanism. A reserved bandwidth is previously granted for given data. Adaptive parameters of the super frame will be assigned by the determined amount of time slots. Therefore scheduling slots is implemented to ensure data reliability in our proposed method from two aspects: GTS allocation and CAP back off mechanism.

A. GTS allocation

To solve restrictions of IEEE 802.15.4, in our proposed scheme superframe slots vary accordingly to priority assignment module. The Superframe Duration (SD) of this protocol is adjusted by the amount of slots according to priorities. So it can acquire better bandwidth utilization, energy saving and high reliability. The equations of modified BI and SD are listed in (3) and (4):

$$BI = aBaseSlotDuration \times (BO + NumSlot) \quad (3)$$

$$SD = aBaseSlotDuration \times NumSlot \quad (4)$$

NumSlot is determined by the sum of each node's required slots on the basis of data rates for different priorities. BO should be determined by (5):

$$1 \le BO + NumSlot \le 2^{14} \quad (5)$$

If required slots exceed the maximum we allocate bandwidth by nodes' weight β in (6):

$$W_i = W_u \times (\beta_i / \sum_{i=1}^{n} \beta_i) \quad (6)$$

W_i is the bandwidth allocated for the i_{th} node, W_u is the bandwidth utilized for GTS .

B. CAP access mechanism

The CAP shall be executed when the nodes want to send normal non real time data. Nodes that operate in beacon enable mode must utilize the slotted CSMA-CA access mechanism. In this algorithm, each node with non real time data uses different binary exponential back-off (BE) by given weight. The higher is the weight, the shorter is the back off time. High-weight nodes access with higher probability in CSMA.

C. Example analysis

Now we explain the allocation scheme in detail with an example: There are 5 nodes assumed to transfer data in a network. Node 1 forwards normal real time data, node 2 forwards emergency data and node 3 forwards abnormal real time data .Node 4 and 5 forward non real time data. Therefore node 1, 2 and 3 use GTSs in CFP while node 4 and 5 use CAP. When required slots for these nodes are 5, 13, 9, 3 and 3 respectively, the total number of required slots are 33 and 27 slots are for GTS. In standard IEEE 802.15.4 the number of GTS is limited to 7 and it cannot satisfy the requirement of nodes. Some nodes have to wait for another cycle to complete transmission, which will cause latency of critical information and even bring life-threaten result. While in RMAM mechanism the increase and decrease of slots number can be dynamically adjusted in superframe configuration so it would achieve maximum bandwidth utilization and minimum latency to guarantee high reliability.

V. PERFORMANCE ANALYSIS AND SIMULATION

A. Latency

It is extremely important of WBSN to transmit critical data in short time so that data should be received within minimum latency. Usually latency can be given by (7):

$$Latency = QLatency + Tx_{Time} = 16 \times SlotDuration \times \left\lceil \frac{N}{7} \right\rceil + \frac{P}{R} \quad (7)$$

Where P is the packet size and R is data bit rate. Therefore latency increases linearly with the amount of nodes and it is terrible for emergency data with waiting a long queuing. If emergency data are allocated enough slots in a super frame with RMAM so they can be transferred without queuing latency (QLatency) to guarantee transmission in shortest duration.

B. Energy consumption

The energy expenditures are different from various communication techniques. The transmission power is set by a transmitter and the energy in our system is the model in reference [6] and can be defined by

$$E(R) = P_l t_l + P_{tx} \times \frac{f}{R} \quad (8)$$

where P_l is consumed power in the period listening, t_l is time in the period of listening and P_{tx} is power in the period of transmitting. So it is simple to count the network's energy expenditure at various rates. If this system is working under general IEEE802.15.4 protocol, t_l is depending on the time of CSMA. While in RMAM if slots are well allocated the listening period could be reduced to save energy.

C. Packet breakdown

The packet breakdown rate is associate with packet arrival rate λ and beacon interval BI. These parameters decide how long, on the average, a frame will have to wait for its opportunity to transmist and be possible to be dropped as new frames arrive. According to reference[7], packet breakdown can be defined in (9):

$$P_{breakdown} = P_{d0} + (1 - P_{d0}) \times \sum_{i=1}^{n} d_i . \quad \textbf{(9)}$$

$$P_{d0} = 1 - (\lambda B_I e^{-\lambda B_I} / 1 - e^{-\lambda B_I}) , \; P_{di} = (1 - P_{d0}) P_e^i (1 - e^{-\lambda B_I}) e^{-(i-1)\lambda B_I}$$

Where $e^{-(i-1)\lambda B_I}$ represents no arrivals in the previous i-1 superframes and $1 - e^{-\lambda B_I}$ represents at least one arrival in superframe i. Also $(1 - P_{d0})$ is the probability that the packet is not fail in the first superframe. In general IEEE 802.15.4 the probability failure is associated with the waiting time and collision while in RMAM this probability can be reduced due to well allocated slots.

D. Simulation results

We tested RMAM by Castalia Simulator. For the simulation, we use 6 nodes of a star topology, in which one node is a coordinator and other 5 nodes are sampling sensors. The sensor nodes adopt CC2420 radios for a simulation time of 600 seconds with 3 repetitions. Table I explains the specifications of nodes. By this simulation model, we compare general IEEE802.15.4 protocol with RMAM and present the performance parameters like latency, energy consumption and packet breakdown with the bandwidth allocation for priority devices.

TABLE I. SPECIFICATION OF NODES

Nodes	Node1	Node2	Node3	Node4	Node5
Priority scope	2,3,4	2,3,4	2,3,4	1,3,4	1,3,4
Initial priority	2	2	2	1	1
weight β	0.2	0.3	0.2	0.2	0.1

Figure 1 shows the comparison of latency. It seems the new mechanism performs better. The energy expenditure of each node is depicted in figure 2. We also see that RMAM is more energy efficient while node 2 expends higher energy according to the traffic requirement. Figure 3and 4 show the packets breakdown as a fraction of 1. The portion of failed packets is high especially when a node is at maximum rate while in the new method the ratio decreased sharply because it gets enough bandwidth.

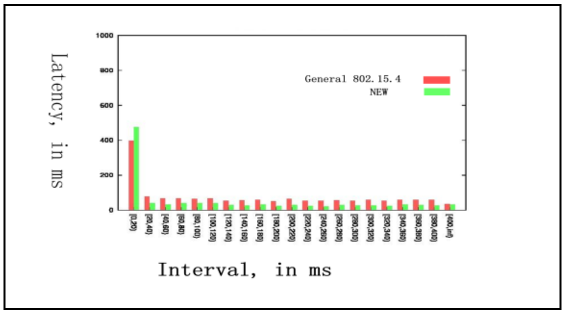

Figure 1. The latency comparison

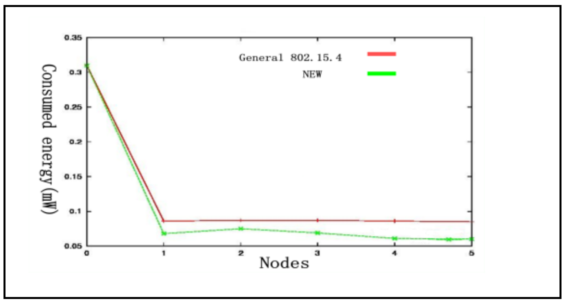

Figure 2. Energy expenditure of each node

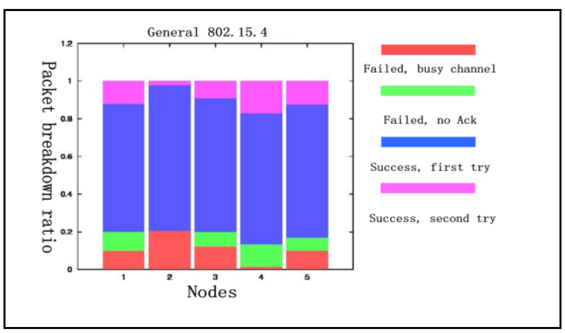

Figure 3. Packet breakdowns in 802.15.4

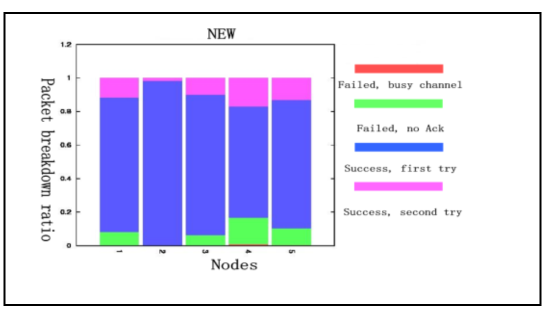

Figure 4. Packet breakdowns in NEW mechanism

From results showed in above figures, we can generally know the RMAM performs better compared with general model because it makes a more efficient usage of the wireless medium and reduces collisions at high data rate.

VI. Conclusion

The object of this paper is to propose a priority based MAC protocol that meets the requirements of WBSN such as: real-time transmission, collision avoidance, adaptation, minimal end to end delays, and low packet breakdown by considerable utilization of bandwidth. This mechanism introduces dynamic Superframe reconfiguration in bandwidth allocation with priorities to transfer signals. The validity is demonstrated by Castalia and results show it significantly decreases delay and reaches a considerably high packet delivery ratio in the entire network as compared to the general IEEE 802.15.4 model. In the future more characteristics of physical and application layers should be considered for better performances and reliability.

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