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An optimal fuzzy control medium access in wireless body area networks

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ABSTRACT

Wireless body area network (WBAN) collects significant signals of human body or environment information for health monitoring or professional services. But normal medium access protocols can hardly make a balance and ensure enough reliability of a network because there are specific features and service quality in WBAN applications. Contention access or fixed allocation of bandwidth cannot meet all nodes' requirements and may cause collisions and delay. Especially in emergency medical situations, some data must be transmitted immediately for accurate diagnosis and decision. The dropping of critical messages could possibly create life threatening results. In order to improve the reliability and efficiency of data transmission in WBAN, this paper proposes a fuzzy control medium access (FCMA) mechanism based on input parameters for performance gains. It controls the contention window in contention access period (CAP) and slots allocation in contention free period (CFP) according to nodes' status. Through simulation analysis, the improved performance of throughput, latency, and packets breakdown is demonstrated by efficient usage of bandwidth and avoidance of collision.

1. Introduction

A wireless body area network (WBAN) is a novel system which uses low power, tiny wireless sensors to continuously gather physiological, behavioral or other health related values and then forward them to professionals [1,2]. Various significant signals of human body or environment information such as Blood Pressure, Electro Cardiogram (ECG), Heart Rate, and Temperature are measured in applications.

WBAN is accepted in some innovative and significant utilization such as healthcare, sports, entertainment and military because it can provide convenient and economical services with invasive or non-invasive mini gadgets [3–5]. However special concerns and requirements in some applications hinder the wide spread of using. For example traffic rate of different sensors may range from very low to very high in a network. Beside that in critical or emergency medical status, highest reliability and immediate responses to some sensors are required. The dropping of critical signals could eventually lead to life threatening consequences. These special features distinguish WBAN from conventional wireless sensor networks (WSN) and induce many new issues in utilization [6]. Therefore effective and feasible solutions should be considered in different situations, such as: flexible data rate, various priority and capacity of channel, which may be constrains in existed protocols. Generally there are two main wireless medium access mechanisms: one is based on slots contention such as CSAM/CA and the other is contention free based on slots assignment. For contention mechanism the collision probability exponentially goes up along with the number of nodes. While fixed slots assignment mechanism is difficult to make a balance for diverse traffic load and priorities, appropriate medium access schemes are very necessary to solve some limitations and obtain better performance.

Recently a wealth of research papers is inspired to propose coordination or optimization method on medium access control (MAC) for a more reliable and efficient communication. Park derived an adaptive algorithm to formalize the power consumption while guaranteeing reliability and delay constraints [7]. Zhang used application specific control channels in MAC to provide priority Guarantee [8]. Sanli and Cam proposed a practical coverage and rate allocation protocol to exploit this dependency in realistic environments [9].

In this paper a novel optimal fuzzy control medium access scheme is proposed. With input values and fuzzy rules an adaptive solution is applied to improve throughput, reduce collision, provide efficient usage of bandwidth and guarantee high reliability

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of multi-level services. The performance of the scheme is evaluated with simulations in Castalia-3.2.

For the remaining part of this paper, Section 2 explains the fuzzy logic system and basic components. Section 3 briefly introduces 802.15.4 Protocol. Section 4 explains the structure of optimal control model for medium access. Section 5 explains the performance. Section 6 shows the results of the evaluation and Section 7 makes conclusions.

2. Fuzzy logic control

Fuzzy logic is an extension of classic logic to provide a simple way for a definite conclusion based on vague, ambiguous or imprecise input information [10]. A fuzzy logic system (FLS) maps crisp inputs into crisp outputs based on rules. The crisp numbers would be acquired in defuzzification at the output. For example, this number represents a control action in control system, while in a signal processing, a number could be related to the prediction or a financial forecast. A fuzzy system handles input linguistic variables to produce output linguistic variables and can be constructed of basic components: Fuzzification, Rule Based, inference Engine and Defuzzification as shown in Fig. 1. Once the rules have been established, a FLS can be viewed as a mapping from inputs to outputs.

Fuzzification transfers system inputs (crisp inputs) space to fuzzy sets in a defined universe. The membership function is associated to each system input: $F = fuzzifier(x_i)$, where x_i represents a crisp input value, F is a fuzzy set and fuzzifier represents a fuzzification operator. Rule Base: A fuzzy rule is a conditional statement with the following form: if x is A then y is B, where x and y are linguistic variables, A and B are linguistic values represented by fuzzy sets defined on the universe X and Y. A fuzzy rule has multiple parts, which can be combined by "and" or "or" operators.

Inference engine: The inference engine uses the knowledge and the fuzzy inputs to make inference by a reasoning method. All fuzzy rules will be activated and are combined together.

Defuzzification: It reconverts the fuzzy output values, deriving from the inference mechanism, into crisp values.

A fuzzy logic system is widely used in many areas such as digital image processing, pattern recognition, and medical service. Boulkroune proposed an adaptive fuzzy tracking control for a class of MIMO systems [11]. Wang proposed a fuzzy decentralized control approach for a class of uncertain stochastic nonlinear large-scale system [12]. Kazemian presented Neuro-Fuzzy applications to MPEG-4 video transmission in ZigBee [13]. Ling proposed a genetic algorithm based fuzzy reasoning model to recognize the presence of hypoglycemia [14]. Tong proposed Observer-based fuzzy adaptive robust control of nonlinear systems [15]. Chan developed a traffic flow predictor based on the architecture of fuzzy neural networks [16]. Also there are some researchers use fuzzy logic in wireless medium access control. For example: Liu and Hsu proposed a Protocol for multi channel WLANs with a simple fuzzy controller to tune the size of MACl backoff window [17]. Wallace proposed Fuzzy Logic Optimization of MAC Parameters and Sleeping Duty-Cycles in Wireless Sensor Networks [18]. Using fuzzy logic model in medium access is proposed by above papers but they mostly focus on the possibility of collisions without considering nodes' working status. It is not enough for CAP and CFP access in WBAN.

3. Overview of IEEE 802.15.4 protocol

The novel fuzzy control medium access (FCMA) mechanism is proposed based on IEEE 802.15.4 MAC protocol. The IEEE 802.15.4 standard specifies the physical layer and the MAC layer for low-rate Wireless Personal Area Networks (WPANs) [19]. The standard defines a beacon-enabled modality, which uses a slotted Carrier sense multiple accesses with collision avoidance (CSMA/CA) and the optional Guaranteed Time Slot (GTS) allocation mechanism. IEEE 802.15.4 supports low rate wireless personal area networks working in beacon mode by superframes. The superframe beacons are transmitted periodically by the coordinator and are used to synchronize the attached devices. aBaseSuperframeDuration is a variable to define the minimum duration of the superframe and the actual superframe size is a multiple of it. A coordinator regularly forwards the beacon frames in each beacon interval and communicates with sampling sensors in duplex during active period, named the superframe duration (SD). After this period system goes into the low-power status as inactive period.

The structure of the superframe is determined by two parameters, the beacon order BO and the superframe order SO, which determine the length of the superframe and its active period, respectively. The range of the superframe and the range of its active period can be defined as Eqs. (1) and (2):

$$BI = aBaseSuperframeDuration \times 2^{BO} \quad (1)$$

$$BI = aBaseSuperframeDuration \times 2^{SO} \quad (2)$$

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

The superframe consists three components: a beacon, a contention access period (CAP), and a contention free period (CFP). The beacon is transmitted in Slot 0 without CSMA/CA, and the CAP starts immediately after the beacon. The CFP, if presents, commences after the CAP to the end of the active period. Any allocated GTSs should be located within the CFP. All frames in the CAP shall use a slotted CSMA/CA mechanism to access the channel. MAC command frames shall always be transmitted in the CAP. The CFP will start on a slot boundary immediately following the CAP, and it will finish before the end of the active period. If any GTSs have been allocated by the coordinator, they will be located within the CFP and occupy contiguous slots. The CFP duration will increase or decrease depending on the total length of GTSs.

IEEE802.15.4 is used in short-range wireless systems but it has several limitations such as statical bandwidth utilization, random back off period, and data length in the application. The standard is

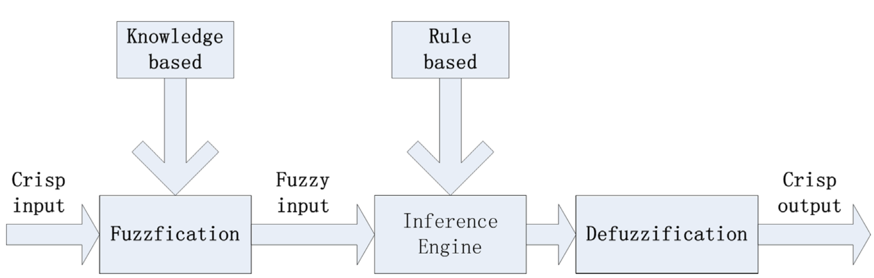

Fig. 1. Basic fuzzy system.