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Cross-Layer Fuzzy Reasoning-Based Back off Framework for Wireless body area networks (WBANs)

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Abstract

Wireless body area networks (WBANs) are an emerging technology that can transmit data from smart, low-power sensor hubs placed on, around, or even inside a person. There will be one key node, or facilitator, in the heart of each WBAN. A smartphone or even more impressive device collects biometric data from the sensors and actuators. The engineering behind WBANs can be roughly divided into two categories: sensors and facilitators. In order to convey the patient's vital signs to the medical clinic's clinical team, WBAN acts as an interface between the patient and the outside clinical wellbeing framework. By reducing the need for conventional strings and links, WBAN may facilitate the creation of medical equipment in settings where the patient's connection to medical devices does not need to be restored. It has remarkable promise for monitoring chronically ill patients round-the-clock for extended periods. In addition, mobile staff and server-based clever programming computations have access to entire, real-time patient data for the purposes of screening patients and making preliminary decisions. WBAN is responsible for relaying fundamental clinical data and signaling emergencies, such as the failure of a vital organ. In order to transfer data, WBANs, like other remote systems, rely on a shared correspondence channel between multiple hubs. To enhance arrangement reliability, we suggested the Cross-Layer Fuzzy Reasoning-Based Backoff Framework (CLFB), which takes into account factors like Parcel Delivery Ratio (PDR) and crash rate. Their effectiveness and suitability can affect the system's dependability and execution by determining when a hub can access the channel and mediating any conflicts between competing hubs.

Keywords: WBAN, MAC, CLFB, Fuzzy logic, Backoff

1. Introduction

The commonly used IEEE 802.15.4 in WBANs [1, 2] has been evaluated previously, and the results have shown that the standard's efficiency can be limited in terms of reliability (as measured by packet delivery ratio; PDR) and performance (as measured by throughput; 3, 4, 5, 6). Eventually, consistent quality will be a crucial requirement. To provide patients with trustworthy clinical care, for instance, human services checking applications require solid correspondence.

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Since WBANs are used to send clinical information and sign emergencies like key organ disappointments, in the worst-case scenario, a failure in communication might lead to death if no one saw the impending danger. As a result of this realization, some exciting new research has been directed at raising the bar for PDR. The purpose of this section is, as intended, to raise the bar for consistency in the existing norm. IEEE 802.15.4 has a number of problems, including inconsistent quality and poor throughput. WBANs need to be able to support sensors with a high transmission rate, like ECG sensors, in order to be useful for social insurance checking applications. To increase system dependability and performance, Chen et al. [7] developed a delicate registration approach for such applications. Mouzehkeshetal also oversaw a complementary comparative study. To enhance the dependability and performance of IEEE 802.15.4 systems, we propose Dynamic Postponed Medium Access Control (D2MAC) [8]. Improving reliability and performance is important, but not if it means significantly increasing the delivery time. In reality, the standard package delay ought to be reduced to a reasonable minimum. This need makes perfect sense in medical settings, where fortunate synchronicity is very desirable.

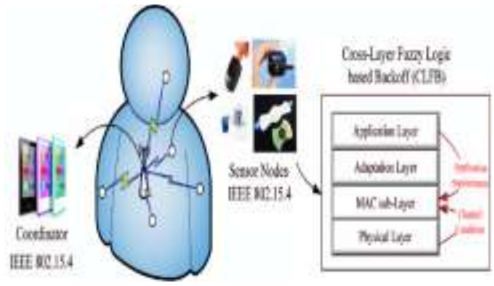


Fig 1. Architecture of WBAN using CLFB

An additional carrier sensing (ACS) approach [9] has been proposed to use the third Channel Clear Assessment (CCA) to eliminate unnecessary time presented by the moved backoff period and so reduce the system delay. To implement the CA part of Carrier Sense Multiple Access with Collision Avoidance (CSMA/CA), an arbitrary backoff delay is introduced before the channel is surveyed using bearer detection. In particular, the largest backoff delay will grow at an exponential rate while the channel is deemed to be in use. IEEE 802.15.4 CSMA/CA transmits blind to the current channel state. Instead of adjusting the backoff delay based on the current state of the channel, it simply starts over. Since the channel is still being used, the impact rate may increase, resulting in lower throughput. This Fig. 1 backoff delay is balanced in a progressive fashion using a different cross-layer strategy than the typical way. Our lighthearted justification structure for the change has widespread support. We have also directed a manual process to adjust nebulous rules to make them more practical for use in social insurance programs. This paper's remaining contents are organized as follows: A backoff estimate based on the cross-layer fluffy reasoning is proposed in Section 2. In Section 3, we show you how to set up your FLC manually. Reproduction procedures and outcomes are depicted in Section 4.

2. Existing work

3. Numerous studies have demonstrated the poor quality of remote channels near the human body and the consequent high rate of route misfortune [10]. The main concerns, particularly in applications for medical services, are transmission failures, decreased dependability, and subpar performance, all of which can be a result of WBANs' poor channel conditions [11]. IEEE 802.15.4 also does not take into account application-specific requirements, such as the frequency of channel access, when adjusting the backoff delay. Furthermore, IEEE 802.15.4 will continuously construct BE without regard to whether or not the channel is currently being used. According to the process described, each hub will always begin the backoff procedure anew for each new transmission, regardless of any differences between transmissions or between the needs of different applications or late channel conditions. As a result, hubs might not adjust the backoff delay quickly enough, which would substantially increase the crash rate in WBANs. As required, there is a yin and yang effect on reliability and channel utilization. To address this problem, we introduced Cross-Layer Fuzzy Logic Based Backoff (CLFB) [11] that allows the backoff delay to be tuned by adjusting the Backoff Exponent (BE) based on a number of factors, including the state of the channel and the needs of the application. If fuzzyEnable is set to true, CLFB will be used to determine the backoff delay. Additionally, IEEE 802.15.4's open CSMA/CA standard will be widely adopted. CLFB employs an FLC to dynamically tune BE in response to changing late-system conditions and specific application requirements.

Proposed system

Figure 2 shows that the FLC in CLFB takes into account two informational elements, such as NBRate and datarate. In addition, fuzzyBE is the result. Our FLC will use an inferencing framework based on the standard Mamdani fluffy framework [12].

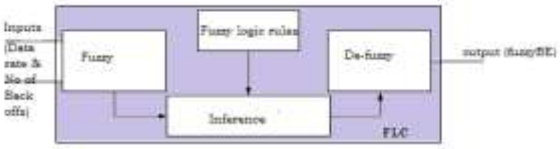


Fig 2. FLCinCLFB

Uncertainty in the Inputs and Outputs In CLFB, NBRate is the initial value for the FLC. When the channel is being used, the NB value will rise, and this is how the NBRate is calculated. A transmission failure will occur when there are more than two Mac Max Backoffs. As a result, the NB penalty must be significantly higher than the maximum backoffs. Since NB provides an immediate record of the channel's status in the recent past, NBRate rapidly increases once the channel's health declines. In a similar vein, as the channel's condition improves, the value goes down. Our FLC classifies the NBRate as low, medium, medium-high, and high. A key related study [8] suggests using no more than four fuzzy levels as input to a fuzzy system, so we make the decision to implement this maximum. We will investigate the potential advantages of adopting more fine-grained fuzzy levels, despite the fact that this is not always a technical limitation. NBRate will include a penalty in its computation. In particular, our approach implements the penalty to clearly distinguish between failures during CCAs and a complete transmission failure when a transmission attempt fails because NB exceeds Max Backoffs. Six NBs is obviously more than the maximum NB value during any CCA and hence represents the punishment. With this penalty system in place, the NB rate can be anywhere from 0 to 6. Our FLC in CLFB takes data rate as its second input variable. As it affects the equilibrium of the channel condition and the waiting time, it is an important variable. We opted to standardize the data rate so that it would function with a wider variety of network configurations. Upon joining the WBAN, a sensor node will report its application data rate to the coordinator, who will use this information to calculate the total possible data rate for all sensors in the network. After determining the maximum data rate, the coordinator will share that information with everyone on the network. Each sensor node will adjust its own data rate to fall somewhere between 1 and 100. Using normalized data rates may help maximize available network throughput. Low, medium, medium-high, and high are the four distinct fuzzy levels into which the normalized rate is further divided. Our FLC yields a fuzzy BE as an output. In order to achieve a reasonable cost-to-accuracy ratio, we break fuzzy BE down into four distinct fuzzy levels: B1, B2, B3, and B4. Our FLC uses the center-of-mass metric to defuzzify fuzzy BE and generate an accurate value.

Fuzzy Logic Rules

There are 16 distinct rule antecedents4 fuzzy levels of NBRate 4 fuzzy levels of knowledge rate in this investigation. Consequently, our FLC in CLFB comprises 16 distinct fuzzy rules. Each rule conforms to the fundamental structure depicted in Figure 3.

.	**Data Rate**			
NB	**Low**	**Medium**	**Medium High**	**High**
Low	B1	B1	B1	B2
Medium	B2	B2	B2	B3

Medium High	B3	B3	B3	B4
High	B4	B4	B4	B4

Fig 3. Fuzzy Logic Rules

Changing the fundamental parameters defining membership functions is one of the most common ways to tune them. Two tuning parameters, namely and, are regarded for this purpose. In actuality, it regulates the contraction and expansion of the membership function, whereas it shifts the membership function to the left and right. The objective of tuning is to adjust the two parameters so as to improve the WBAN's dependability and performance. In this study, there are three stages to the tuning procedure. They are listed below.

Adjusting the output membership functions: Since the output membership functions have a greater impact on the efficacy of FLC, they are adjusted first. While modifying the output membership functions, the input membership functions are held constant. Adjusting a membership function begins with adjusting the parameter. After each modification, thirty independent evaluations are conducted to confirm its utility, i.e., improvement of IEEE 802.15's reliability and performance. After three local adjustments, we will then regulate using a standardized procedure. After modifying and separately, we have an accurate approximation of and. Then, we use them to ascertain the values through a series of random local searches. This method is utilized for all B1, B2, B3, and B4 membership operations.

Tuning the input membership functions: In order to investigate suitable parameters for the input membership function and further enhance the performance of FLC, the input membership functions are tuned, while the output membership functions remain unaltered. The tuning of and for each membership function essentially follows the procedure described in Step 1.

Tuning both the input and output membership functions: the previous two stages used a greedy search strategy to determine the optimal settings for each membership function. During this final stage, an area search is performed to simultaneously tune the input and output membership functions in order to improve FLC performance. By following this procedure, the admissible membership functions for each fuzzy level of each input and output variable are finally determined.

4. Results

During a star-based WBAN with a single WBAN coordinator, our simulation is about to come to an end. The number of sensors will rise from two to nine in order to assess network conditions under various traffic pressures. Due to the six different categories of medical sensors and the range of data rates, the simulation scenarios examined in this research are heterogeneous. Although they only make up a small portion of all medical sensors now on the market, these sensors are the ones that simulation studies employ the most frequently [13]. Each simulation scenario is reviewed 30 times separately to ensure accurate results. The averages from these simulation sessions will be included in the simulation results.

A WBAN coordinator is located in the center of a 2 m2 area where all body sensors are distributed at random. For ease of use, sensor nodes are started with a battery of equal capacity, or 5500 mAh. Our simulation takes advantage of the important and widely accessible 2.4 GHz upper waveband of the IEEE 802.15.4 standard, with a standardized rate of 250 Kb/s and a maximum payload size of 102 bytes. The scenarios that our simulation takes into account are dependent on the 2.44 GHz waveband, which is appropriate for body-to-body communication under two conceivable conditions, namely line-of-sight (LoS) propagation and non-line-of-sight (NLoS) propagation. We employed the log-normal shadowing model [14] to build a simulation environment that closely resembles actual communication circumstances. Existing research indicates that the log-normal shadowing model, as opposed to the typical Rayleigh and Ricean distributions, can better reflect the smallscale fading in WBANs. The trail loss exponent, which is located along the front of the physical body, is close to 3. This configuration is the result of trial and error. In our simulated WBAN, we discovered that employing it always provides an accurate indication of channel status.

The results of the simulation are presented in this subsection. The following measures are used to evaluate the network's dependability and performance:

- Packet Delivery Ratio (PDR): This is the proportion of sent to received data packets, as seen below:

PDR = Total Number of Packets Sent by All Sensor Nodes Total Number of Packets Received by the Coordinator

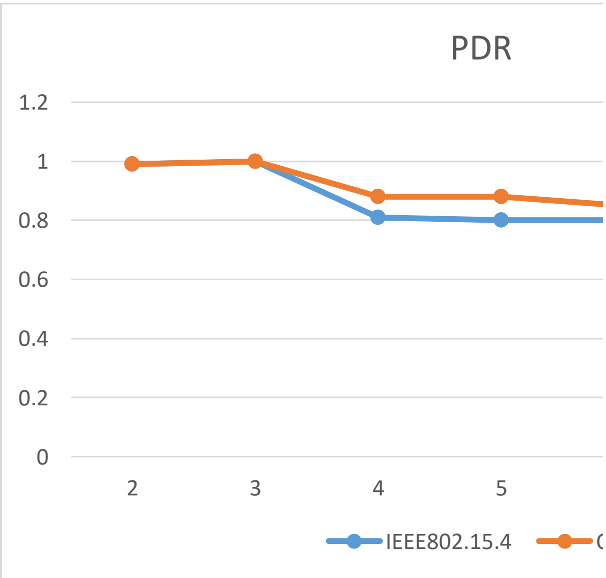
The collision rate is the average number of data packet collisions experienced through a channel.

The typical number of knowledge frames that may be successfully supplied over a channel at the MAC sub-layer is known as the "MAC throughput." The average time it takes a knowledge packet to get to the coordinator is called the packet's end-to-end latency. When data frames enter the MAC sub-layer, the packet delay is first measured.

Packet Delivery Ratio and Collision Rate

In this study, PDR and the number of collisions are used to investigate the dependability of WBAN when using CLFB. Table 1 contrasts the PDR attained by CLFB with four rival algorithms, namely IEEE 802.15.4, ACS [15], D2MAC [16], and another rival algorithm [17], which will be referred to as "NB-Step" for the purposes of our discussion. As depicted in Table 3.3, PDR is almost 100%, and there are no statistically significant differences between the different algorithms when there are two or three nodes in the network. PDR starts to stray as the number of nodes increases. For instance, the PDR for the algorithms will be 0.63 (IEEE 802.15.4) and 0.63 (CLFB), respectively, when there are nine nodes. The t-test is used to show that CLFB is statistically more trustworthy (i.e., has a higher PDR) than IEEE 802.15.4 and can greatly increase communication reliability.

Table 1. PDR of IEEE 802.15.4 and CLFB



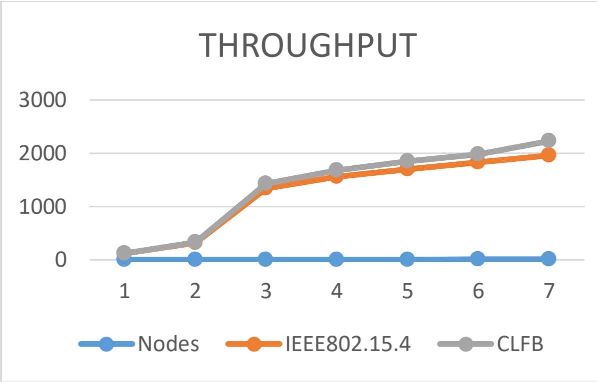
In contrast to IEEE 802.15.4, a larger PDR than CLFB can be achieved. This occurs as a result of the noticeably longer backoffs they impose on CSMA and CA. The outcome is a significant increase in packet latency. Unlike these two rival methods, CLFB has the ability to keep the delay just outside the limits determined by IEEE 802.15.4. It can still attain a higher PDR in the interim.

PDR is examined first, and then the collision rate is added. In general, the PDR will dramatically diminish as the number of nodes rises. This is frequently brought on by the network's rising collision rate, as illustrated in Table 1. In terms of statistics, the simulation demonstrates that CLFB can perform noticeably better than IEEE802.15.4. On the other hand, no collisions are frequently seen while simulating just two nodes. Even though the findings demonstrate that steps reduced collisions, they drastically increased the delay. We discovered that CLFB's significant advantage over competing technologies is due to its capacity to reduce collisions without appreciably lengthening IEEE 802.15.4 communication delays.

MAC Throughput

The network's performance is shown in Table 2 in terms of MAC throughput. When there are only two sensor nodes in the network, the CLFB protocol statistically beats IEEE 802.15.4 and ACS, according to the T-test. In the meantime, statistically speaking, CLFB performs similarly to D2MAC and NB-step when the network includes nine nodes. However, the simulation findings demonstrate that D2MAC and NB-step throughputs frequently beat CLFB. That occurs as a result of them greatly lengthening the backoff duration in order to prevent more crashes. Long backoff delays, however, might not be preferred for applications that are time-sensitive.

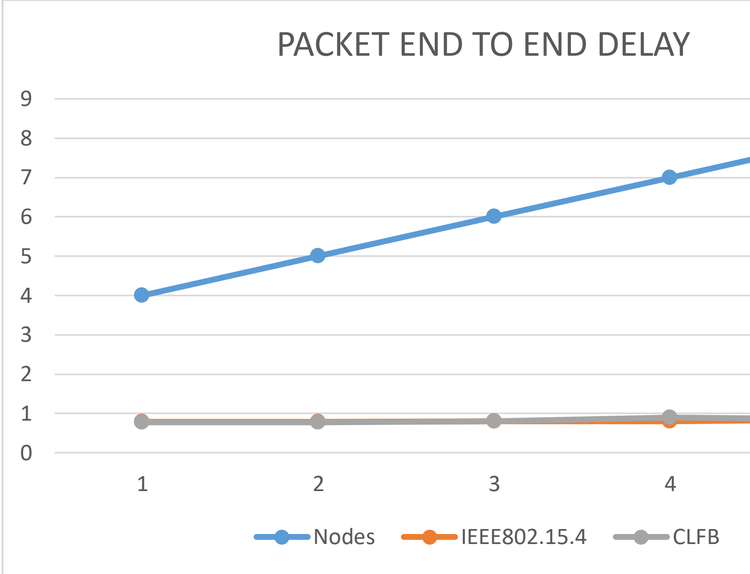
Table 21. Throughput of IEEE 802.15.4 and CLFB



Packet end-to-end delay

As we already said, Table 3's simulation results demonstrate that this technique introduces much higher network delays than other techniques. For instance, our t-test analysis shows that CLFB can achieve much shorter latency. In actuality, CLFB's delay is statistically equivalent to that of IEEE 802.15.4 Packet latency.

Table 3. IEEE 802.15.4 and CLFB packet end-to-end delays



Conclusion

To improve network reliability, namely Packet Delivery Ratio (PDR) and collision rate, we presented the Cross-Layer Fuzzy Logic-Based Backoff System (CLFB). We also wanted to increase WBAN throughput without significantly increasing packet latency. We developed CLFB to provide the Backoff Exponent (BE) by taking into account both the channel state and, consequently, the application rate. WBANs now have higher levels of adaptability thanks to this design. In order to improve the effectiveness of CLFB's fuzzy membership functions, we also presented a manual method for doing so. We successfully improved the suitability of this IEEE standard for numerous WBAN-based applications by incorporating our CLFB into the IEEE 802.15.4 MAC sub-layer. Additionally, this integration doesn't significantly alter IEEE 802.15.4's fundamental structure. Backward compatibility is thus guaranteed. The outcomes clearly show that our CLFB improved the performance and reliability of the network. According to the initial standard, the packet latency was kept at a reasonable level in the interim period.

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