Evaluation of Scalability Issue of 802.15.4 MAC for Body Area Networks

Pradnya H. Ghare, A. G. Kothari, and A. G. Keskar

***Abstract*—Recent advances in wireless technology have led to the development of wireless body area networks (WBAN), where a set of communicating devices are located around the human body. These networks have stringent technical requirements and to suite these requirements proper communication standard is required. Out of the available communication standards, IEEE 802.15.4 seems to be the suitable candidate for BAN. In this paper we have verified the suitability of 802.15.4 standard particularly scalability of MAC for single as well as multiple BAN in terms of throughput, power consumption and delay . The results show that non beacon mode gives best results but at the expense of power consumption. The beacon mode with GTS is suitable for low data rates but with increased data rate the performance of 802.15.4 get worsened and the throughput started deteriorating. Finally this paper suggests for improvement in the MAC layer particularly the superframe structure of existing IEEE 802.15.4 standard.**

***Index Terms*—CAP, CFP , IEEE802.15.4 , WBAN, WPAN**

I. Introduction

According to the Department of Health and Human Services, the elderly segment of the population (65+) will continue to grow significantly in the future and there is a need to have some healthcare units to look after these people. Due to recent developments in wireless, radio frequency identification (RFID), biosensors and networking a new field of research has come into existence to satisfy the above need. This new field namely body area networks consist of on body or implantable sensors with the capability to remotely monitor a large population and sending the information wirelessly to healthservice providers. In near future WBAN will be able to provide efficient healthcare services to common man and help in ongoing clinical research. For these body area networks a standardization committee namely IEEE 802.15.6 WBAN task group (TG) have been evolved [1]. Relative to the technology of WPAN, WBAN provides closer interconnection (2-5 meters) with more strict technical requirements such as the high reliability, extreme power efficiency and security, especially the safety for human body. To suite these technical requirements a proper communication standard is required. IEEE 802.15.4 is a low-rate low-power WPAN suitable for sensor n/w applications. The adaptation of this technology to operate in and around the human body, connected via a WBAN can be tested. In this paper, our objective is to evaluate the IEEE 802.15.4 standard for WBAN applications and thereby analyze scalability issue in MAC. This paper evaluates these results by considering single BAN as well as multiple BAN scenarios.

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A. Related Work

Many researchers are working on finding a suitable communication standard for medical BAN. As 802.15.4 seems to be a suitable candidate for medical BAN, researchers have presented their contribution for evaluating performance of 802.15.4. In [2], the IEEE 802.15.4 MAC prototype was implemented and the performance evaluations were provided, focusing on the beacon-enabled mode without considering the beaconless mode. Reference [3] presented a mathematical analysis of the IEEE 802.15.4 performance in relation to medical sensor body area networks only considering the power consumption issue, i.e., the lifetime of the network. Reference [4,5] analyzed the slotted CSMA-CA scheme of IEEE 802.15.4 with the unique metric of throughput. In [6], other than the throughput, the energy consumption was also analyzed. Reference [7] evaluated the IEEE 802.15.4 performance via several sets of practical experiments without considering the latency. In this paper we are evaluating the performance of IEEE 802.15.4 for single as well as multiple BAN for low as well as high data rate. The parameters such as throughput, jitter, delay and power consumption have been analyzed. The rest of this paper is organized as follows. Section II gives an overview of BAN. Section III describes briefly the IEEE 802.15.4 MAC protocol. The simulation results are presented in Section IV. Section V offers a final discussion and concludes the paper by a brief outlook on future work.

II. Overview of BAN

Body Area Network (BAN), as far as the class of communication is concerned, have been derived from the concept of wireless local area network (WLAN). As in [9] the term BAN was first coined at Massachuats Institute of Technology & Science, USA during the year 2002 by the researchers. The BAN connected sensors continuously measure and transmit vital constants, audio, images or positioning information to health service providers and brokers. This way the BAN facilitates remote monitoring of patients' vital signs and therefore enables proactive disease prevention and management by continuous monitoring of patients' health condition 'anytime and everywhere'. BANs can be classified as external BAN and implant BAN. As in [9] BAN has certain distinct features.

BAN for medical applications have variable data rates based on the various medical applications.

Following table gives data rates for various medical applications

TABLE I: BAN DRAFT SPECIFICATIONS [9]

Distance	2 m standard 5 m special use
Network Density	2 - 4 nets / m^2
Network Size	Max: 100 devices / network
Power Consumption	~1 mW / Mbps
Latency (end to end)	10 ms
Network setup time	< 1 sec (Per device setup time excludes network initialization)
Frequency band	Regulatory and/or medical authorities approved communication bands for in and around human body

TABLE II: DATA RATES FOR MEDICAL APPLICATIONS [9]

Application	Data rate
ECG	192 kbps(6kbps/lead, 32 leads)
EEG	86.4 kbps (3.6 kbps/lead, 24 leads)
Drug Delivery	<16 kbps
Deep brain simulations	<320 kbps
Heart Rate	0.05 kbps
Blood Pressure	0.05 kbps
Body Temperature	0.05 kbps

As in [10] – [12] WBAN MAC Major Issues are:

1) Heterogeneous Traffic: Normal, On-demand, and Emergency traffic
2) Interoperability: Multiple frequency bands and correspondingly multiple PHY techniques
3) Scalability: Variable data rate (Kbps ~ Mbps) and variable number of devices
4) Energy saving: Different periods of wake up and sleep.

The BAN elements are BAN Network Coordinator (BNC) and BAN Node (BN) Devices.

The BNC can support normal, emergency, and on demand traffics, it should maintain the traffic-based wake-up table. It should calculate its own wakeup pattern based on the BN's wakeup patterns. It should maintain the traffic-based wake-up table; The BNs are operating on limited power and support a default normal wakeup state. Wake-up and sleep states are according to traffic-based wake-up table.

Alternatively BN wake-ups are upon receiving an 'on demand' request from a BNC or BN wakes-up by itself to handle emergency events.

III. OVERVIEW OF 802.15.4

As in [13], 802.15.4 is a low power, low data rate standard suitable for medical applications. The range of communication is about 10-30 meters. It has three frequency bands available. Out of that 2.4 GHz band having 16 channels and bit rate of 240 kbps seems to be suitable for medical BAN applications. The IEEE 802.15.4 MAC can operate in two modes:

A. Beacon-Enabled and Beaconless

In the beacon-enabled mode, the PAN coordinator broadcasts a periodic beacon containing information about the PAN. The period between two consecutive beacons defines a superframe structure. A superframe is always initiated by the beacon, while the remainder may be used for data communication by means of random access, and form the so called CAP (contention Access period). The beacon contains information related to the PAN identification, synchronization, and superframe structure.

In this case, two types of data transfers exist:

1) Transfer from a device to the coordinator - a device willing to transfer data to the coordinator uses slotted CSMA-CA.

The coordinator may confirm the successful data reception with an optional acknowledgment following the data frame.

2) Transfer from the coordinator to a device - when the coordinator has data pending for a device, it announces so in the beacon. The interested device adopts slotted CSMA-CA to send a request to the coordinator, indicating that it is ready to receive the data. When the coordinator receives the data request message, it selects a free slot and sends data using slotted CSMA-CA as well.

In order to support time critical data applications, the PAN coordinator can reserve one or more slots that are assigned to devices running such applications without need for contention with other devices. Such slots are referred to as GTSs, and they form the CFP of the superframe. Note that CFP (contention frees period) can not operate independently and is always integrated with CAP. An example of the superframe with CAP, CFP and inactive period is shown in Fig. 1 [2].

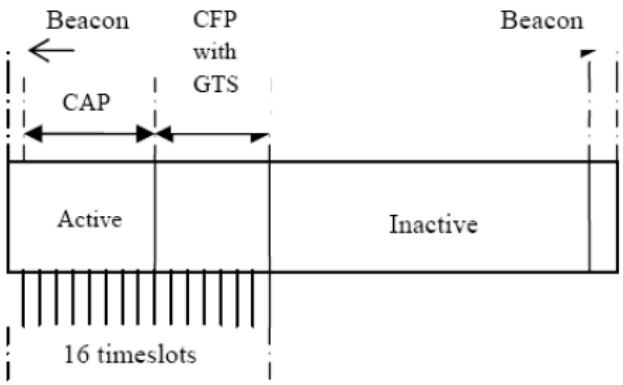

Fig. 1. IEEE 802.15.4 superframe structure

In the nonbeacon-enabled mode there is no explicit synchronization provided by the PAN coordinator. Since there is no superframe defined in the nonbeacon-enabled mode and no slot synchronization is available, no GTS can be reserved and only random access is adopted for medium sharing.

The CSMA-CA algorithm shall be used before the transmission of data or MAC command frames transmitted within the CAP. For the transmission of beacon frames, acknowledgements, or data frames transmitted in the CFP, the CSMA-CA algorithm shall not be used. Thus it can be

seen that totally there are three types of channel access mechanism for IEEE 802.15.4 MAC, i.e., unslotted CSMA-CA, slotted CSMA-CA, and slotted CSMA-CA integrated with GTS. The first scheme is working in the beaconless mode and the remaining two schemes are both working in the beacon enabled mode.

IV. Results and Discussion

In this paper, simulations based on Qualnet 5.0 are made by modeling the IEEE 802.15.4 network closely and carefully , including beacon, superframe, CAP and CFP etc.

A. Scenario 1: Low data rate application for single BAN

Here a single BAN consisting of one BAN coordinator (BC) and several sensor nodes (SNs) is considered. Here single BAN refers to one patient. And the effect of increase in number of leads on performance metrices has been shown.

A. Simulation Setup

Simulation time : 10 min.
Phy. Layer : IEEE 802.15.4
MAC layer: IEEE802.15.4
Beacon order : 4
Data rate : 100 bps/ lead
Superframe Order : 3(Duty cycle= 50%), 4(Duty cycle = 100%)

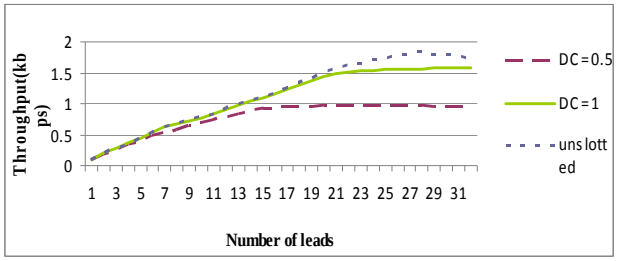

Fig. 2a. Throughput vs. no. of leads

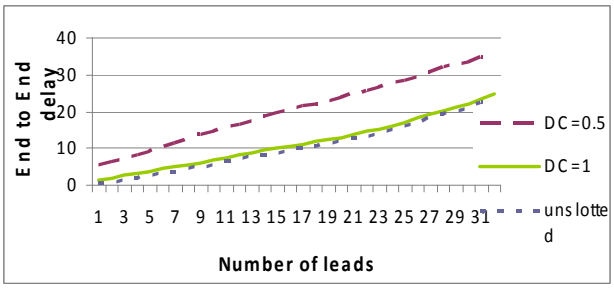

Fig. 2b. Delay (ms) vs. no. of leads

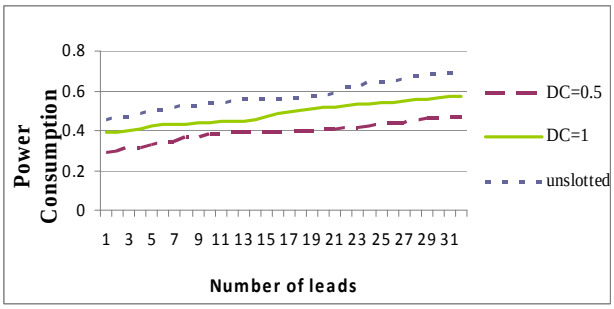

Fig. 2c. Power consumption (mw) vs. no. of leads

As shown in Fig 2a the throughput obtained for the various modes of 802.15.4 appears to be deteriorating with increase in number of leads. This feature is due to the fact that in 802.15.4 CAP, every lead has to compete with other leads when it has to send data using slotted CSMA-CA mechanism for beacon mode and unslotted CSMA-CA for non beacon mode. Gradually as the number of leads increased, more time was required to get access to the channel resulting in reduction in throughput as indicated in Fig 2a and larger delays as indicated in Fig. 2b. Thus with increase in no. of leads throughput decreases and delay increases. Unslotted mode gave better performance for throughput; delay compared to other duty cycle cases. But, in case of power consumption, unslotted had the highest value. This can be attributed to the fact that the node has to be awake for a longer time period. In case of different duty cycles, the higher duty cycle gave better results for throughput, delay at the expense of higher power consumption. Lower duty cycle resulted in lesser power consumption because of the lesser duration of the active period in the superframe. Thus from the graphs it can be seen that, 100 percent duty cycle provides the best answer to the scalability issue but at the expense of slightly larger delays (than non-beacon mode) and slightly larger power consumption (than lower duty cycles).

B. Scenario 2: Low data rate application for multiple BANs.

In this scenario, the no.of persons are increased and its effect on the performance metrics was observed.

B. Simulation Setup

Simulation time: 10 min.
Data rate: 12 kbps/ person (12 sensors with 1kbps/sensor)
Superframe Order: DC= 0.75, DC = 1, unslotted
Simulation results:

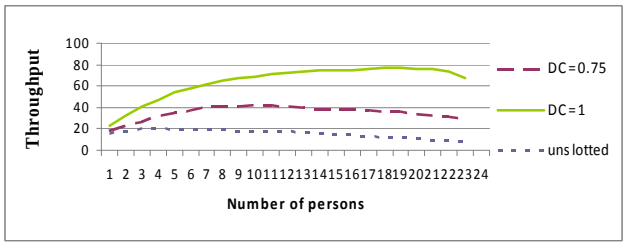

Fig. 3a. Throughput vs. no. of leads

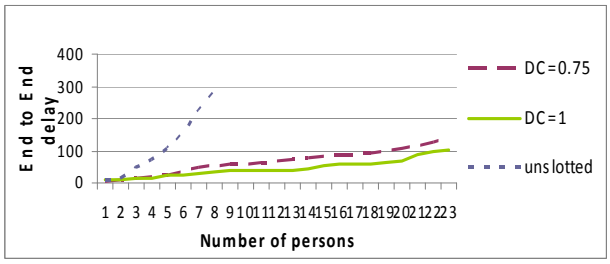

Fig. 3b. Delay (ms) vs. no. of leads

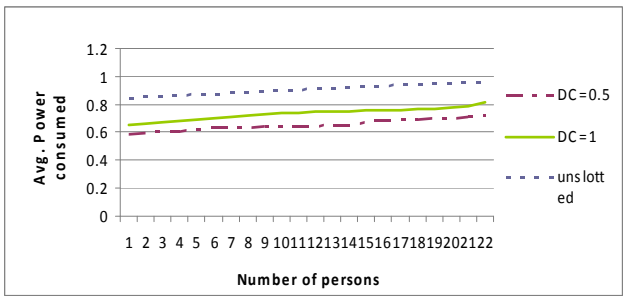

Fig. 3c. Power consumption vs. no. of leads

As shown in Fig. 3, the nonbeacon mode(unslotted) case gives best results for QoS requirements upto 12 persons. But after 12 person's throughput decreases drastically. Also delay increases exponentially after 12 persons. Also power consumption has highest value for nonbeacon mode. For duty cycle case, higher duty cycle gives better results compared to lower ones at the expense of higher power consumption.

V. Conclusions and Future Work

This paper studied the suitability of IEEE 802.15.4 for WBAN by varying the no. of leads and by varying the no.of persons. From the various scenarios studied in this paper it can be concluded that for low data rate applications 802.15.4 provides a limited answer to scalability issue in its beacon mode at the expense of degradation of QoS parameters and slightly increased power consumption.

Also for large no. of persons, both beacon as well as nonbeacon mode is highly unsuitable because of significant degradation of QoS parameters. Hence for all types of BAN applications, CAP of IEEE 802.15.4 is not suitable. In the future, it is required to design the novel MAC for a WBAN, which can be achieved by modifying the superframe structure of IEEE 802.15.4. Here we propose that based on the medical application all data transfer should be done in the CFP only. This will minimize the power consumption.

Other than that, coexistence between BANs, coexistence between BAN and other wireless technologies, and coexistence of BAN in medical environments (EMC/EMI) are the issues to be addressed.

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