PERFORMANCE STUDY OF WIRELESS BODY AREA NETWORK IN MEDICAL ENVIRONMENT

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Abstract

The advanced developments in sensors and wireless communications devices have enabled the design of miniature, cost-effective, and smart physiological sensor nodes. One of the approaches in developing wearable health monitoring systems is the emerging of wireless body area network (WBAN). IEEE 802.15.4 provides low power, low data rate wireless standard in relation to medical sensor body area networks. In the current study, the star network topology of 802.15.4 standard at 2.4 GHz had been considered for body area network (BAN) configured in beacon mode. The main consideration is in the total data bits received by all the nodes at the coordinator and flight times of a data packet reaching its destination. In this paper we discussed on wireless technologies that can be used for medical applications and how they perform in a healthcare environment. The low-rate Wireless Personnel Area Network (WPAN) is being used to evaluate its suitability in medical application.

1. Introduction

Nowadays, most wireless technology is focusing on increasing high data throughput. A set of applications such as industrial, agricultural, vehicular, residential and medical required simple wireless connectivity, relaxed throughput, very low power, short distances and low cost. The IEEE 802.15.4 standard was specifically design to support low power with low data rate networks where latency and bit rate are not so critical. This is a response to the rapid usage growth in this area [1]. IEEE 802.15.4 would go beyond the current state of the art where a 403MHz medical implant communication services (MICS) is used for implant-to-controller, point-to-point communication without networking support [2]. The study and research are focuses in the analysis of IEEE 802.15.4 standard configured as a star network where the coordinating device which are external to the body. The performance of data transmission between nodes to Personal Area Network (PAN) coordinator is observed.

IEEE 802.15.4 working group is defined at lower layers of protocol stack, which are MAC and physical layer (PHY). IEEE 802.15.4 is a simple packet data protocol for lightweight wireless networks and it channel access is via Carrier Sense Multiple Access with Collision Avoidance (CSMA/CA) with optional time slotting. The physical layer defines three medium-dependent wireless raw data rates covering three different frequency bands. The frequency bands are 20, 40, and 250 kbit/s using the 868-868.8, 902-928 and 2400-2483.5 MHz frequency bands. In these respective frequency bands, there are one, ten and sixteen channels at these particular rates.

2. Background

The low rate WPAN supports two types of topologies. They can perform a star topology which is the nodes can only talk to the coordinator or in a peer-to-peer topology where network nodes able to route the data. Several peer-to-peer networks can work together to form a mesh or cluster tree topologies. In this paper, a star network topology is considered. With the star topology there are two communication methods, which are beacon mode and non-beacon mode. In beacon mode, communication is controlled by the network coordinator, which transmits beacons for device synchronization and network association control. The network coordinator defines the start and end of a super frame by transmitting a periodic beacon. The length of the beacon period and hence the duty cycle of the system can be defined by the user between certain limits as specified in the standard [3].

In non-beacon mode, a network node can send data to the coordinator, by using CSMA/CA if required. To receive the data
from the coordinator the node must power up and poll the coordinator. The advantage of non-beacon mode is that the node's receiver does not have to regularly power-up to receive the beacon. The disadvantage is that the nodes must wake up to receive the beacon and the coordinator cannot communicate at anytime with the node but must wait to be invited by the node to communicate.

Figure 1 Superframe structure with GTSs

Figure 1 illustrates the structure of the superframe uses by IEEE 802.15.4. A superframe begins with beacon frames sent periodically by the coordinator at an interval that can ranges from 15ms to 245s. There are both active and inactive periods in the superframe. The coordinator communicates with the nodes only during the active period and enters a low power mode during the inactive period. The macBeaconOrder (BO) decides the length of the Beacon Interval (BI) and the parameter macSuperframeOrder (SO) describe the length of the active portion of the superframe. The BI and baseSuperframe duration can be calculated as below:

\[ BI = BSfD \times 2^{BO} \text{ symbols} \tag{1} \]

\[ BSfD = BSD \times N_{Sf} \tag{2} \]

where

- BI = Beacon Interval
- BSfD = Base Superframe Duration
- BSD = Base Slot Duration = 60 symbols
- \( N_{Sf} \) = Number of Superframe Slots = 16

The active portion of each superframe is divided into 16 equal time slots and consists of 3 parts; the beacon, a Contention Access Period (CAP) and a Collision Free Period (CFP). Each guaranteed time slots (GTS) consists of some integer multiple of CFP slots where;

\[ 1 \leq SO \leq 15 \tag{3} \]
\[ 1 \leq BO \leq 15 \tag{4} \]

1. The CFP is only present if GTS are allocated by the PAN coordinator to some of the devices

3. Data transmission

There can be three different types of possible data transmission, which are transmission from a device to the coordinator, transmission from the coordinator to the device and transmission between any two devices. In a star topology only the first two transmission techniques are possible. Transmission between any two devices is not supported, where as in a peer-to-peer network all the three types of transmissions are possible.

Figure 2 Transmission between device to coordinator

The process shown in Figure 2 is transmission between devices to coordinator [3]. The operation starts when device listens for the beacon. On finding the beacon, device will synchronizes the superframe structure. This process will acknowledge the device of the beginning and end time of the CAP. Then the device will have to compete with its peers for a share of the channel. The device will transmit the data to the coordinator when it is permitted.

4. Medical Environment

In the experiment, the WBAN is set to have 3 number of nodes on the body with area is set to 10m x 10 m. CBR packets will be operating in this architecture. For this simulation, the medical data rate is reference to [4] and it is shown in table 2. The parameters for simulation result in figure 3, 4, 5 and 6 are summarized in the table1:

<table>
<thead>
<tr>
<th>Table 1: Traffic parameters</th>
</tr>
</thead>
<tbody>
<tr>
<td>Parameter</td>
</tr>
<tr>
<td>Traffic Type</td>
</tr>
<tr>
<td>Number of Nodes*</td>
</tr>
<tr>
<td>Number of Coordinator</td>
</tr>
<tr>
<td>Mode Movement</td>
</tr>
<tr>
<td>Traffic Direction</td>
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<tr>
<td>Packet Size</td>
</tr>
</tbody>
</table>

*Applications to the nodes is defined in table 2
Table 2: Physical and Application parameters

<table>
<thead>
<tr>
<th>Applications</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>ECG bit rates (node1)</td>
<td>600 bit/s</td>
</tr>
<tr>
<td>Blood Pressure (node2)</td>
<td>0.3 bit/s</td>
</tr>
<tr>
<td>Video (node 3)</td>
<td>8 bit/s</td>
</tr>
</tbody>
</table>

5. WPAN performance

The network throughput is a measurement of the amount of data transmitted from the source to the destination in a unit period of time (second). The throughput of a node is measured by counting the total number of data packets successfully received at the node, and computing the number of bits received, which is divided by the total simulation runtime [5] that gives;

\[ tp = \frac{Rbits}{sim\_time} \]  

where

- \( tp \) = throughput
- \( Rbits \) = total data bits received
- \( sim\_time \) = simulation runtime

The simulation model used a star network topology where routing mechanism has been disabled. This is because the standard does not support routing of data among the peers. Therefore, the maximum number of hops for any data packet before reaching the destination node can be only one [5]. The average delay is calculated by taking the average of delays for every data packet transmitted.

\[ D[E] = \frac{TD}{Rpkts} \]  

where

- \( D[E] \) = Average Delay
- \( TD \) = Total Delay
- \( Rpkts \) = Total number of received Packets

6. Results and discussions

We analyze the performance of WPAN in beacon enabled with star environment as the beacon order varies from 0 to 8. The result is shown in figure 3 where more collisions had been observed in the low beacon order compared to high beacon order.

![Average Delay vs Beacon](image)

Figure 3 Delay increases with increasing of beacon

Figure 3 also shows that low beacon causes high average delay in data transmission from devices to coordinator. Therefore, more transactions are likely to be delayed until the beginning of the next frame. Because beacon is in enabled mode, transmission of a frame using slotted CSMA/CA is required to be complete before the end of the CAP. This means that slotted CSMA/CA can no longer work effectively if the beacon is small.

![Throughput vs Beacon](image)

Figure 4 Collisions reduces by increases beacon.

Next we analyze the throughput performance in WPAN with varied beacon order. The result is shown in figure 4 where CAP allows each beacon to send almost the same amount of data to a coordinator. It also shown that when the beacon is small, the amount of data received at coordinator is also small which will cause collision, while the throughput increases by the increasing the number of beacon.
The packet size is assumed to be 70 bytes for CBR traffic as shown in figure 5. By setting the packet size to 70 bytes, the throughput is almost 900 bit per second. This is because according to table2 the ECG sensor transmits 600 bits per second data rates from devices to coordinator while blood pressure transmits almost 0.3 bits per second. Therefore, assumption of packet size 70 bytes is reasonable to allow data transmits for all three devices to coordinator.

The relationship between throughput and area topology (meter), average delay and area topology (meter) are also analyzed. Figure 6 a) shown that by increasing the area within coordinator and devices will cause the throughput to decline tremendously after 15 meters square. This is because there are probabilities that the MAC packets are loss due to the interference of other devices such as collisions. However, the average delay will increased when the node gets further away from the coordinator as shown in Figure 6 b). Thus, we can conclude that the suitable maximum range for medical environment is to operate within 15-meter square from the coordinator.

Figure 6 Throughput and delays differences across area in a) and b)

Figure 7 shows the affect when we add more nodes on the body area. Effectively when there are fewer frames waiting in MAC queue lead to the lower average delays as observed in the graph. It is observed that the offered loads on the WPAN will reach its maximum with just four devices. Adding another device to the network will result overload the capacity of WPAN. By increase the number of nodes to seven in 10x10 meter area will cause the throughput to drops to 0.922% due to interference of devices such as collisions.

Figure 7 Throughput compared to number of devices

7. Conclusions

Wireless Personnel Area Network (WPAN) is a new wireless short-range communication technology. WPAN targets low data rate, low power consumption and low cost wireless networking, and it offers device level wireless connectivity. This paper focused on the performance analysis of WPAN. It estimates possible working conditions of the technology for medical applications.
The results indicated that the technology can be successfully used for low data rate application with the factors that effect the performances of wireless body area network are the size of packet size, the number of beacon that being used, topology area and number of devices on the body. It has been observed that more collisions will happened at the beginning of a superframe, especially a low beacon order. The packet size is set to 70 byte to achieve desired output and the distance should be less than 15 meter square for IEEE 802.15.4 operating at a good condition in hospital room/medical environment. Increasing the number of nodes to seven in 10x10 meter area will drops the throughput to 0.922% due to interference of devices such as collisions.

This paper has presented the performance analysis of data transmission in WBAN using WPAN technology. However, there are several WPAN features that can be implement and test. For the propose future works is to compare three different data transmission methods which is direct, indirect and guaranteed time slot in wireless body area network.

8. References