

Letter to the Editor

Evaluation of Implant Communication with Polarisation and Unslotted CSMA/CA Protocol in Wireless Body Area Networks

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The performance of the implant inside a human body with polarisation, distance, and different power settings at the base-station is presented. In addition, the unslotted CSMA/CA protocol is studied for a heterogeneous WBAN.

1. Introduction

In [1], authors show that the implant's effective radiated power (ERP) and receive signal strength indication (RSSI) are affected by the depth inside a human body. Neither the polarisation of the implant nor the effect(s) of the implant's distance (from the base station) and the power settings (at the base station) on the RSSI is considered. With regards to the MAC part, the authors of [1] discourage the use of the CSMA/CA protocol for WBAN due to unreliable clear channel assessment (CCA) in the medical implant communication service (MICS) band. There is no discussion on the MAC performance of the CSMA/CA protocol for WBAN. In this letter, we extend the results of [1] by considering the effects of the implant's polarisation, distance, and the power settings (at the base station) on the ERP and RSSI. We further analyze the behavior of the CSMA/CA protocol for WBAN. For the performance analysis of the CSMA/CA protocol, we consider the unslotted CSMA/CA protocol used in a nonbeacon IEEE 802.15.4 mode [2].

2. Vertical and Horizontal Polarisation of the Implant

A body phantom defined in [3] is used to analyze the effects of depth and polarisation on the signal level. The

environment is an anechoic chamber that includes a screened room. The interior walls of the room have sound-absorbent cones to minimize any reflections from the walls or the floor that could distort the results. The body phantom is mounted on a wooden stand (nonconductive). The MICS base station dipole antenna is mounted on a stand. To calculate ERP from the implant, all combinations of the implant and test antenna polarisation are considered, that is, vertical-vertical (V-V), horizontal-vertical (H-V), vertical-horizontal (V-H), and horizontal-horizontal (H-H) polarisation. The V-V polarisation of the implant is the case when the long side of the box and the antenna are vertical. The V-H polarisation is when the box is vertical and the antenna is horizontal. The H-V polarisation is when the box is horizontal and the antenna is vertical. The H-H polarisation is when both the box and the antenna are horizontal. The ERP is calculated from the received signal power and the antenna characteristics. Figure 1(a) shows the signal dependency on polarisation and depths. For the V-V polarisation, the ERP increases from 1 cm depth to a maximum between 2 cm and 7 cm, and then decreases, while for the H-H polarisation, the ERP is minimum for all depths [4]. To measure the RSSI from the implant, the Zarlink ZL70101 has the RSSI function that gives a relative measure of the signal level detected. The implant receives and measures a continuous wave signal transmitted by the base station. The implant

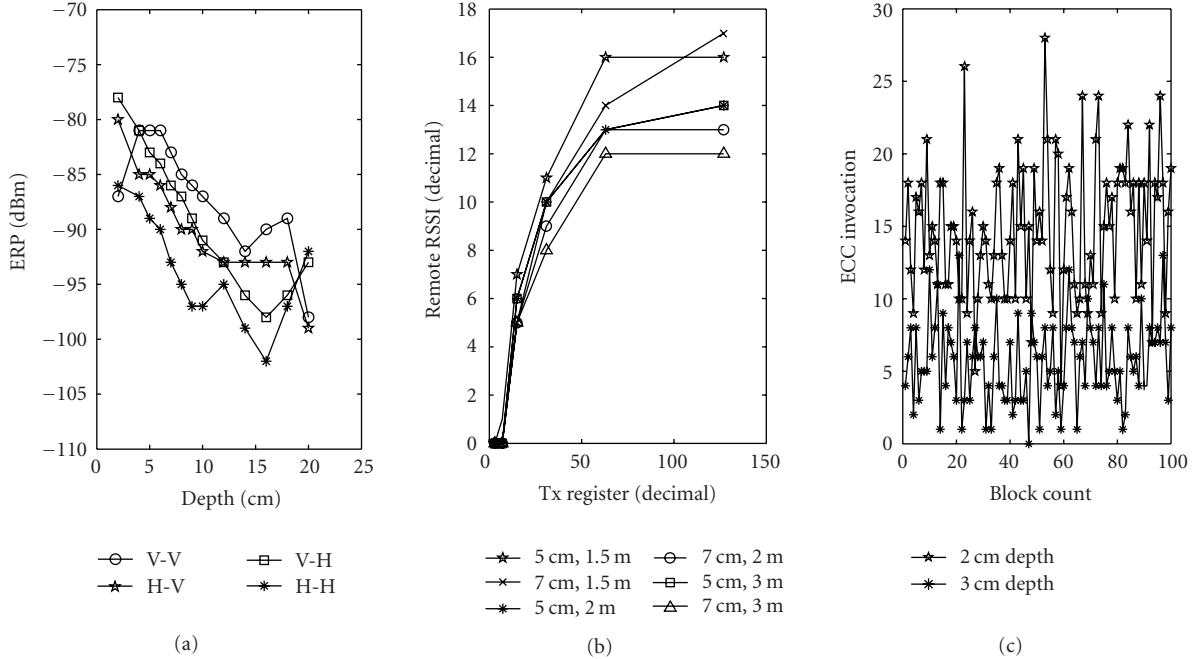


FIGURE 1: (a): ERP versus Depth, (b): RSSI versus Base station power (in decimal), (c): ECC invocation versus 100 blocks of data.

transmits the RSSI value to the base station after 30 seconds session. In [1], the RSSI is calculated for 15 decimal power at the base station with a distance from the implant (body phantom) to the base station equal to 3 m. We analyze the RSSI of the implant by changing the distance between the implant and the base station as well as by changing the power settings at the base station. Figure 1(b) shows the RSSI as a function of different power settings. It can be seen that there is a significant increase in the RSSI by decreasing the distance between the body phantom and the base station and/or by increasing the power settings at the base station. For example, the RSSI of the implant at 7 cm depth increases by decreasing the distance between the implant and the base station to 1.5 m but when the distance is increased to 3 m, the RSSI of the implant decreases for the same depth. Optimization of the ERP and the RSSI is essential but not always enough to maintain reliable data transfer. Therefore, the ECC must be employed to recover corrupted data. In [1], the authors present the average ECC invocation as a function of the implant's depth. It is shown that the infrequent ECC invocation means better link quality, which is achieved at 3 cm depth. This result is further validated by sending 100 blocks of data at 2 cm and 3 cm depths. The ECC is invoked whenever there is error in the transmission. Figure 1(c) shows that the ECC invocation for each block of data is fewer for the implant at 3 cm depth, which is in line with the results presented in [1].

3. The Unslotted CSMA/CA Protocol for WBAN

We consider the unslotted CSMA/CA protocol used in the nonbeacon IEEE 802.15.4 mode. This protocol uses two variables, that is, NB and BE. The NB is the number of back-

off periods permitted before declaring the channel access failure and is initialized to zero before each new transmission attempt. The BE is the back-off exponent and has a range between 0 and 5. This defines the number of back-off periods a device must wait before transmission. The waiting time is randomly generated in the range of $(0, 2^{\text{BE}} - 1)$ back-off periods. The default value of the BE is 3. Further details are given in [2].

Initially the BE is set to $\text{macMinBE} = 3$. The worst channel access time is given by

$$T_{\text{BACK-OFF}} = T_{\text{IB}} + T_{\text{CCA}} = (2^3 - 1) \times T_{\text{UB}} + T_{\text{CCA}} = 7 \times 320 \mu\text{s} + 128 \mu\text{s} = 2.368 \text{ ms}, \quad (1)$$

where T_{IB} is the *InitialBackoffPeriod*, T_{UB} is the *aUnitBack-offPeriod*, and T_{CCA} is the CCA detection time. According to the IEEE 802.15.4 standard, the values of T_{UB} and T_{CCA} are 8 and 20 symbols (1 symbol = 16 μs).

In order to calculate the total frame transmission time T_{FRAME} , the IEEE 802.15.4 frame format given in Figure 2(a) is considered. The T_{FRAME} is given by

$$T_{\text{FRAME}} = (x + H_{\text{PHY}}) \times \frac{8}{250} \times 10^3 = 4.256 \text{ ms}, \quad (2)$$

where x represents the *aMaxPHYPacketSize*, which is 127 bytes, and H_{PHY} is the PHY header as shown in Figure 2(a).

Now the total data transmission time T_{DATA} including the overhead is

$$T_{\text{DATA}} = T_{\text{BACK-OFF}} + T_{\text{FRAME}} + T_{\text{TURN}} + T_{\text{ACK}}. \quad (3)$$

T_{TURN} and T_{ACK} represent the turn-around time and the acknowledge (ACK) transmission time and are equal to 0.192 ms and 0.352 ms, respectively.

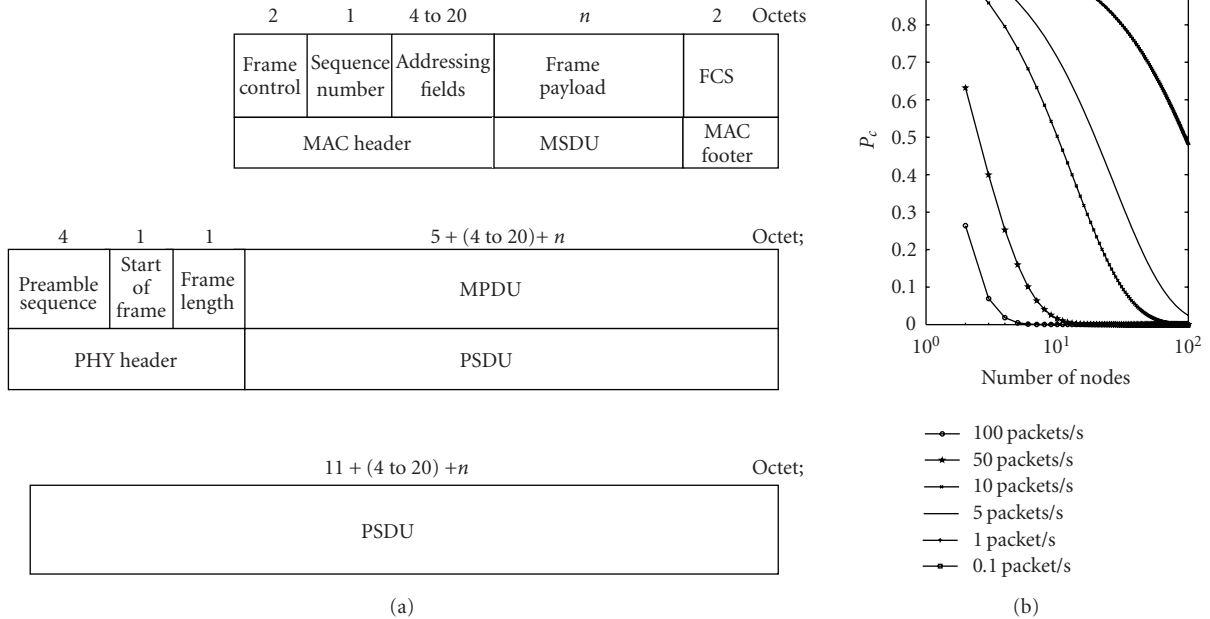


FIGURE 2: (a) IEEE 802.15.4 frame structure, (b) clear channel probability versus number of nodes.

We consider n nodes in WBAN and each node generates heterogeneous traffic (packets) by BAN day, BAN hour, BAN minute, and BAN second. Nodes generating traffic by BAN day are called low-traffic nodes while nodes generating traffic by BAN second are called high-traffic nodes. In other words, low-traffic/high-traffic nodes wake up x times per BAN day/second. We are interested to find out the key parameter P_C which is the probability that the channel is clear or available for transmission. For n nodes, the P_C is given by

$$P_C = (1 - P_B)^{n-1}, \quad (4)$$

where P_B is the probability of the busy channel and is equal to

$$P_B = \frac{T_{\text{DATA}} \times E(\delta) \times (n-1) \times (1 - P_L) \times W_f}{\Gamma}, \quad (5)$$

where Γ corresponds to BAN day/hour/minute/second, P_L is the packet loss probability, W_f is the wake up frequency (number of times the node wakes up per Γ), and $E(\delta)$ represents the average number of packets that should be served in a busy period of the M/G/1 queuing system [5] and is equal to $E(\delta) = 1/(1 - \rho)$, where $\rho = (D' + T_{\text{FRAME}} + T_{\text{TURN}} + T_{\text{ACK}})$ is the average service time. D' is the delay of the packet residing in the queue just before transmission. According to [5], the value of D' can be calculated as

$$D' = \sum_{i=0}^k P_B^i (1 - P_B) \left\{ \sum_{j=0}^i \frac{2^{\text{BE}} - 1}{2} \times T_{\text{UB}} + (i+1) \times T_{\text{CCA}} \right\} + P_B^{k+1} \left\{ \sum_{j=0}^k \frac{2^{\text{BE}} - 1}{2} \times T_{\text{UB}} + (k+1) \times T_{\text{CCA}} \right\}. \quad (6)$$

For nodes that generate traffic (10 packets) by BAN day/hour the $P_C \geq 0.9$ for $n = 100$, and by BAN minute the $P_C > 0.8$ for $n = 100$. These results are obvious since all types of the CSMA/CA (slotted and unslotted) protocols perform well for low-traffic nodes. However, in WBAN, there are a number of nodes that generate traffic (considerable amount of packets) by BAN second which affects the performance of the unslotted CSMA/CA protocol as given in Figure 2(b). It can be seen that for the nodes generating 100 packets/sec, the P_C is almost zero for $n > 6$. Furthermore, most of the traffic in WBAN is correlated, for example, if a patient is suffering from fever, the temperature, blood pressure, and the respiration sensors are triggered simultaneously [6]. These changes may also affect the oxygen saturation level (SpO2) in the blood. These kinds of physiological parameters increase the traffic correlation. A single physiological fluctuation triggers many sensors at the same time, thus generates huge amount of traffic which cannot be accommodated by the unslotted CSMA/CA protocol due to low P_C .

4. Discussion

In this letter, we concluded that the performance of the implant is not only affected by the increasing depth inside a human body but also by polarisation, distance, and different power settings at the base station. In addition to the unreliable CCA problems, we further concluded that the unslotted CSMA/CA protocol is unable to satisfy the average WBAN traffic requirements including the traffic heterogeneity and correlation requirements.

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