# Experimental Characterisation of Data Aggregation in BANs with a Walking Subject

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## ABSTRACT

This paper deals with the implementation of a Wireless Body Area Network, where sensor devices, are deployed on a body and report the measured data to a final receiver. A novel Medium Access Control protocol, inspired by those defined by the IEEE 802.15.4 and 802.15.6 standards, is presented and a data aggregation strategy is proposed to reduce packets losses and energy consumption. The latter opportunistically exploits the body movements performed when the human subject is walking: transmissions are inhibited when no connectivity between transmitter and receiver is present and aggregated data is transmitted when visibility is gained. Results are achieved through experimental measurements made on the field, by implementing the proposed solution on the Texas Instruments CC2530 platform. Results show the benefit of applying such a data aggregation strategy. This work has been performed in the framework of the FP7 Integrated Project, WiserBAN (Smart miniature low-power wireless microsystem for Body Area Networks).

## Categories and Subject Descriptors

C.2 [**Computer-Communications networks**]: Network Architecture and Design, Network Protocols—*wireless communication, network communications, network protocols.*

## General Terms

Wireless Body Area Networks, Data Aggregation, Medium Access Control.

## Keywords

CSMA/CA, Slotted ALOHA, Report Loss Rate, Delay



## 1. INTRODUCTION

Scientific interest in the field of the Wireless Body Area Networks (WBAN) has increased significantly in recent years thanks to the advances in microelectronics and wireless communications. Among the possible applications for WBANs there is the so called ubiquitous healthcare: the ability to gather data on almost any physiological characteristic and transmit them to the medical personnel to diagnose health problems [3].

The current standards for short-range communications of low to moderate data rates, such as IEEE 802.15.4 [6] and Bluetooth Low Energy, are not capable of meeting all the WBAN requirements [4]. Several WBAN protocol proposals can be found in the literature, as well as studies of applicability of existing Wireless Sensor Network protocols to WBAN scenarios, see for example [7]. In particular, [7] consider the IEEE 802.15.4 standard as reference, [3] mainly focus on reducing devices duty-cycle to save energy, while [4] proposes a Time Division Multiple Access (TDMA)-based Medium Access Control (MAC) protocol. Finally [5] proposes a routing protocol, exploiting data aggregation to reduce energy consumption.

The WiserBAN project (Smart miniature low-power wireless microsystem for Body Area Networks) is an FP7 European Project aiming at creating an ultra-miniature and ultra low-power radio frequency microsystem for WBANs. The proposed MAC protocol, presented in this paper, will address the need of satisfying very different application requirements, in terms of reliability, delay and energy consumption.

This paper presents the results obtained through a measurement campaign performed within WiserBAN focusing on the MAC performance. The reference scenario considered is composed of four devices located on a body and transmitting data to the Coordinator of the network (see Fig.1). Experiments were performed on a walking subject. A query-based application has been accounted for: the Coordinator periodically sends queries and, upon reception of the query, nodes reply with a packet. One packet per query is generated and packets should be correctly received before the generation of the subsequent query.

A data aggregation strategy has been proposed and tested,

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in order to save energy, while reducing the number of packets lost during transmissions, at expenses of larger delays.

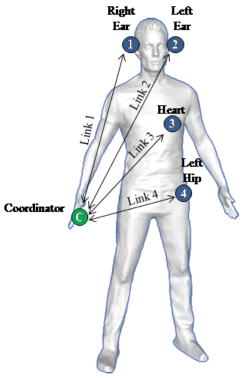


**Figure 1: Experimental scenario.**

## 2. THE MAC PROTOCOL

The access to the radio channel is managed by the Coordinator of the network, by the establishment of a superframe (SF), defined as the period of time between two consecutive beacon packets, which represent the queries of our application.

The active portion of the SF is divided into the following parts: i) Beacon portion, reserved for the transmission of the beacon by the Coordinator; ii) Contention Access Period (CAP), where the access to the channel is managed through a contention-based protocol. Depending of the application requirements, in fact, one of the two following possible solutions will be used in the CAP portion: the Carrier Sense Multiple Access with Collision Avoidance (CSMA/CA) defined in the IEEE 802.15.4 standard [6], or the Slotted ALOHA (SA) defined in the IEEE 802.15.6 [2].

Experimental measurements have been performed to compare the latter solutions. Performance have been evaluated in terms of Report Loss Rate (RLR), defined as the ratio between the number of reports lost and the number of reports generated. In the case of data aggregation more reports are included into the payload of a data packet, whereas in case of no aggregation a data packet contains only one report. Packets can be lost due to connectivity (i.e., the power received by a given receiver is lower than the receiver sensitivity), MAC collisions, or the end of the SF. The RLR is averaged among the RLR achieved by the different nodes in the network.

## 3. THE DATA AGGREGATION STRATEGY

To decrease the energy consumption and the RLR a data aggregation strategy has been implemented. In our scenario, a certain number of retransmissions in the same SF are allowed; however, if a packet is lost due to connectivity issues, mainly caused by the shadowing effect of the body, performing retransmissions immediately after the transmission is useless, since the channel will be most probably in the same conditions owing to slow movements of the subject. Moreover, all the energy spent for retransmitting the packet is wasted. Assuming that the person wearing the devices is walking [1], in fact, the body movement generates an alternation of situations in which nodes are in visibility and in which nodes are shadowed by the body. This is mainly due by the typical arm movement performed during the walk, in case the Coordinator is held in the hand. Therefore, it is possible to take advantage of the movement and avoiding packets transmissions during period during which there is a lack of visibility and aggregated data transmission when the visibility between nodes is gained.

Based on the above intuition, the following data aggregation strategy has been implemented. When a device does not receive the ACK from the Coordinator, instead of retransmitting the packet in the same SF, it will wait for a given number of SFs, during which it will only store the generated data, without transmitting them. After a given number of SFs, the node will try to transmit a single packet, containing the lost data plus all the data generated and not transmitted, in an aggregated packet. We denoted as $N$ the number of reports aggregated in case of packet loss. Therefore, once a packet is lost, the node will only store data for the following $N-2$ SFs and at the $(N-1)-th$ SF after the loss it will transmit a packet with a payload containing the $N$ aggregated reports. $N$ is limited by the MAC Protocol Data Unit (MPDU) maximum size. This mechanism is depicted in Fig. 2.

It will be shown in Sec. 5 there exists an optimum value of $N$ minimizing the RLR. The presence of an optimal value can be motivated as follows: when $N$ is too small, there is still correlation between the channel condition experienced by the transmission and the one experienced by the retransmission; when $N$ is too large, the size of the transmitted packet becomes very large, therefore collisions may occur (i.e., the channel condition is uncorrelated and no connectivity issues could be present, but MAC collisions may occur). The optimum is reached when a trade-off is found.

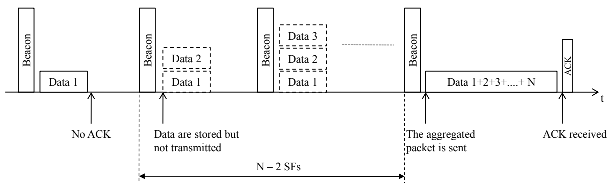


**Figure 2: Example of the data aggregation strategy.**

## 4. THE EXPERIMENTAL PLATFORM

In order to evaluate the MAC layer performance for the proposed WBAN, a benchmark platform has been realized using the Texas Instruments CC2530 development kit [1]. The core of each node is the CC2530: an IEEE 802.15.4 compliant System-on-Chip (SoC). We refer to [1] for details about the SoC.

The query-based traffic model is implemented as follows: at the beginning of every SF, each node generates one packet to be transmitted toward the Coordinator. Packets generated by nodes have all the same size. If a node does not succeed in sending correctly its packet to the Coordinator by the end of the current SF, the packet is considered as lost. A

[1]How to detect the fact that the subject is walking is out of the scope of this paper. However we note that observation of RSSI over time will easily bring to such detection.

maximum number of three retransmissions is allowed. 10000 packets per transmitter are sent in the experiments.

Experiments were performed by locating five CC2530 devices on a human subject in the positions shown in Fig.1. Acquisitions were performed in an indoor environment, a room of 7 x 7 meters, while the human subject performed several walking cycles keeping a distance of 2 meters from on of the walls. As for the packet sizes, we set the beacon size equal to 20 bytes, whereas we vary the data packets size. Numerical results in terms of RLR were achieved by averaging over 10000 packets generated by each end-device and transmitted towards the Coordinator. As far as the CSMA/CA protocol, we set the MAC parameters at the default values.Finally, according to the WiserBAN project specifications we set the transmit power equal to $-22dBm$.

# 5. NUMERICAL RESULTS

Fig. 3 shows the RLR as a function of the packet payload for the different links. As expected the best link is the one connecting the Coordinator and the right ear, while the worst link is that connecting the Coordinator with the left ear. This is because of the shadowing effect introduced by the subject's head. Links 3 and 4 have intermediate performance because the propagation is shadowed by the human body roughly for half of the duration of the experiment, by reason of the typical oscillating movement of the arm during walking. The SA protocol has been implemented for the

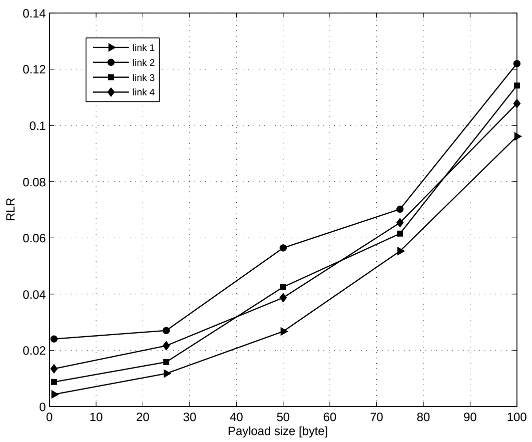


**Figure 3: RLR for different links.**

CC2530: the SF is divided into slots and once a node has a packet to be transmitted (i.e., after the reception of the beacon), it will transmit in the current slot with a probability $CP$ (contention probability). $CP$ ranges in the interval $[CP_{min}, CP_{max}] = [1/8, 1/4]$. The SA slot duration has been set as follows: each slot should contain the packet transmission, the ACK transmission one *TurnAroundTime* (the time needed by the transceiver to switch from transmission to reception state) and a guard time.

The comparison of the results achieved in the case of CSMA/CA and SA is reported in Fig. 4. As expected, SA performs worse in terms of RLR. This can be explained considering that sensing is not performed in SA, so collisions cannot be avoided; moreover, increasing the payload size makes the number of available slots in the SF to decrease, leading to less chances to access the channel.

For the data aggregation measurements we evaluate the optimal value of $N$ to be set. This optimum is shown in Fig. 5 in the case of payload size equal to 1 byte. As can be seen the optimum value is equal to 30 aggregated packets, which means approximatively that the duration of the inactivity period for the radio transceiver is 900 $ms$, when accounting for the SF duration.

Fig. 6 shows the RLR as function of the payload size when three retransmissions are allowed and when not, and in the case of using the data aggregation strategy described in Section 3. In the latter case, three retransmissions of the aggregated packet are allowed.

It can be easily seen that the data aggregation strategy performs better in terms of RLR with respect to the other cases; moreover it is more energy efficient. In fact, thanks to aggregation, nodes can save energy, assuming that they switch off the radio during all the SFs where they just have to store information data. To this end, Fig. 7 shows the average energy consumption per SF for a CC2530 based node. The straight line is the average energy consumption per SF for a node when no aggregation strategy is used; it is computed using as $E_{no\_aggr} = V_{DD} \cdot I_{on} \cdot T_{SF} = 3V \cdot 20.5mA \cdot 31.72ms = 1.89mJ$ assuming that the transceiver is always on during the SF, draining $I_{on}$ [1] ,$V_{DD}$ is the supply voltage and $T_{SF}$ is the SF duration. The energy spent by the node performing aggregation is calculated using Eq. (1) and considering the following: while performing aggregation, the node just receives beacons, draining $I_{on}$, and keeps the transceiver off during the rest of the SF, draining $I_{idle} = 6.5mA$ [1].

$$E_{aggr} = [N_{active} \cdot E_{no\_aggr} + N_{inactive}(I_{idle} \cdot T_{CAP} + I_{on} \cdot T_{beacon}) \cdot V_{DD}]/(N_{active} + N_{inactive}) \quad (1)$$

Where $N_{active}$ and $N_{inactive}$ are obtained from the experiments and represent the number of SFs during which the node is not performing aggregation, and during which is performing aggregation respectively. $T_{beacon} = 640\mu s$ is the beacon reception time and $T_{CAP}$ is the CAP duration; note that $T_{beacon} + T_{CAP} = T_{SF}$. The difference between the two curves is not very large, since according to our protocol, nodes perform data aggregation only when a report is lost, that is not for all the duration of the experiment. This is done to avoid the increasing of the average delay. In case the requirements of the application in terms of latency are not stringent, the aggregation procedure could be implemented to a larger extent, bringing to better performance in terms of both, RLR and energy consumption.

# 6. CONCLUSIONS

This paper shows the results of an experimental campaign performed within of the WiserBAN project. Different MAC protocol solutions have been compared, and a data aggregation strategy has been proposed. Results show that, in case the application requirements are very stringent, in terms of reliability, CSMA/CA is the best solution, while SA could be used when the application requires very low energy consumption. Results also show the benefits in terms of RLR and energy consumption, achievable when data aggregation is used.

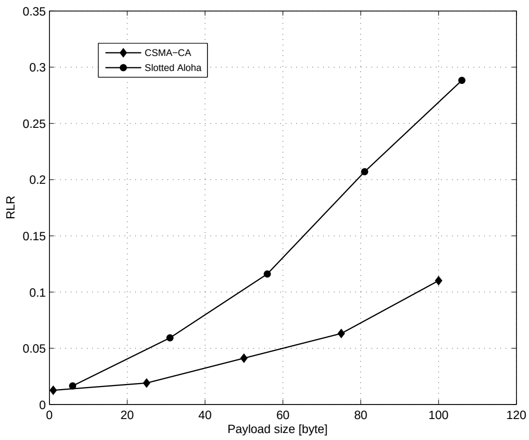


**Figure 4: Average RLR in the case of SA and CSMA/CA.**

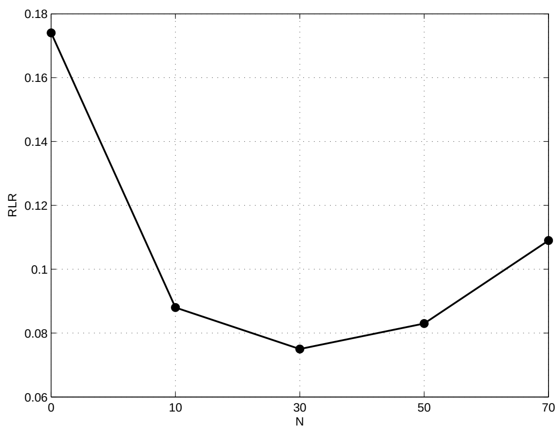


**Figure 5: Optimal value of $N$.**

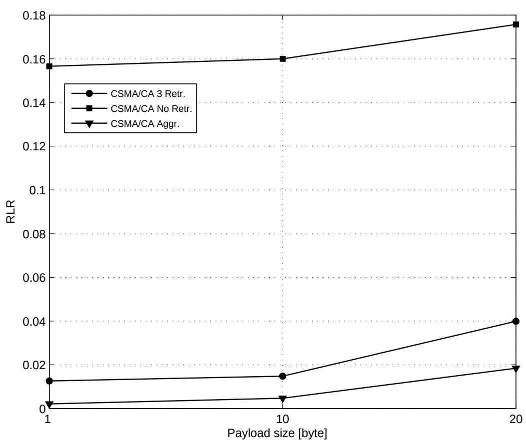


**Figure 6: RLR varying the payload size.**

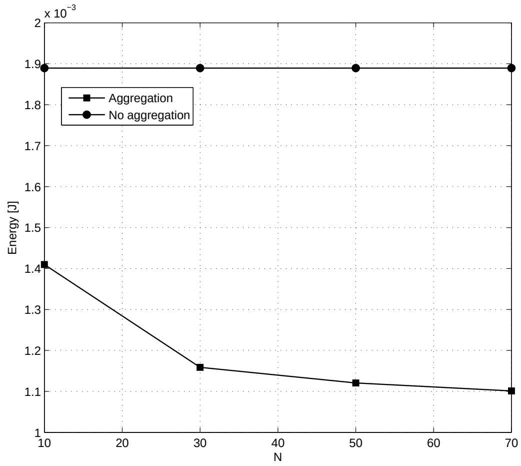


**Figure 7: Average energy consumption per SF.**

# 7. ACKNOWLEDGMENTS

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