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CLPB: vers une approche inter-couches pour une diffusion fiable dans les réseaux WBAN[†]

Wafa Badreddine¹ et Maria Potop-Butucaru²

¹Université de Picardie Jules Verne, MIS Laboratory, Amiens, France

²Sorbonne Université, CNRS, LIP6, F-75005 Paris, France

Le réseau de capteurs corporels sans fil (Wireless Body Area Network (WBAN)) est apparu comme une solution viable en réponse à divers verrous associés aux capteurs filaires couramment utilisés pour surveiller les patients à l'intérieur et à l'extérieur des hôpitaux. Les capteurs placés sur le corps humain collectent et transmettent les paramètres physiologiques et d'autres informations autour du patient. Il existe plusieurs préoccupations dans ce domaine en particulier une communication entre les capteurs fiable et efficace en énergie et en latence qui fait face aux contraintes liées à leur placement sur le corps humain. Dans ce contexte, nous proposons le premier protocole de diffusion inter-couches (Réseau-Liaison de données) dans le réseau de capteurs corporels sans fil - CLPB. Notre protocole surpasse les stratégies de diffusion classiques existantes en termes de la couverture du réseau et du maintien de l'ordre d'envoi des données. Nous évaluons les performances des différents protocoles avec le simulateur OMNET ++ enrichi d'un modèle réaliste de mobilité du corps humain issu d'une récente recherche en informatique biomédicale. Nous étudions la résilience des protocoles de diffusion face à divers taux de transmission et à la mobilité du corps humain. Les stratégies de diffusion existantes ont une baisse drastique des performances à partir d'un taux de transmission supérieur à 11Kb/s tandis que CLPB maintient ses bonnes performances jusqu'à 190Kb/s.

Mots-clefs : Réseau de capteurs corporels sans fil; Protocole inter-couches; Modèle de mobilité du corps humain; Diffusion fiable

1 Introduction

In the healthcare area, WBAN (Wireless Body Area Networks) emerged as a viable solution in response to various disadvantages associated with wired sensors commonly used to monitor patients.

In WBAN tiny devices with low computing power and limited battery life, deployed in/on or around human body, are able to detect and collect physiological characteristics of the human body (EEG (Electroencephalography), ECG (Electrocardiography), SpO₂, etc.), and transmit this information to a collector point (called *Sink*) that will process it, take decisions or alert.

WBANs differ from typical large-scale Wireless Sensor Networks (WSN) in many aspects : the size of the network is limited to a dozen of nodes, in-network mobility follows the body movements and the communication links have a very short range and a quality that varies with the wearer's posture. The transmission power is kept low, which improves devices autonomy and reduces wearers electromagnetic exposition.

Contributions The current work was published in [BP19] and extends in several ways the results in [BCPPB15, BCPP20] where authors evaluate in multi-hop WBAN existing broadcast strategies adapted from Adhoc, DTN (Delay Tolerant Network) and WSN literature and propose new efficient ones. In this paper, we propose the first *Network-MAC cross-layer broadcast protocol, CLBP*, designed for multi-hop communication and resilient to realistic human body mobility. Our protocol exploits the human body mobility model by choosing the most reliable communication paths (i.e paths with the highest success transmission probability) from *Sink* node to all WBAN nodes for each posture. *CLBP* includes a slot assignment mechanism and a light synchronization scheme which improve nodes energy consumption, avoids collisions, reduces idle listening and overhearing.

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2 Broadcast in WBAN

Inspired by the tremendous work in WSN, adhoc networks and DTN, broadcasting in multi-hop networks can be divided into two major categories : *dissemination* (or *flooding*) algorithms which require no particular knowledge of the network, and, *knowledge-based* algorithms which use knowledge of the network mobility to predict spatio-temporal connectivity and use this information to reduce the number of transmissions.

Authors of [BCPPB15, BCPP20] adapted, implemented and compared various broadcasting strategies with different levels of knowledge. The following 7 broadcast strategies were considered in our evaluation and to compare with a cross-layer approach :

- *Flooding* Nodes rebroadcast each received packet as long as its TTL (Time To Live) is greater than 1.
- *Plain flooding* Using sequence number, a received packet is rebroadcasted only once. Other copies are discarded.
- *Pruned Flooding* Each node forwards a received packet to K neighbors, chosen randomly, according to an uniform distribution. We run simulations with different K values.
- *Probabilistic flooding* ($P=0.5$) Nodes decide to broadcast packets according to a constant probability, P . For our simulations, we chose $P = 0.5$.
- *Probabilistic flooding* ($P_{new} = P_{old}/2$) Nodes decide to broadcast according to a probability P that is divided by 2 every time a packet is broadcasted (the initial forwarding probability is set to 1).
- *MBP : Mixed Broadcast Protocol [BCPPB15]* MBP is a mix between the *dissemination-based* and *knowledge-based* approaches.
- *OptFlood : Optimized Flooding [BCPP20]* It builds up on classical flooding, which exhibits excellent performance in terms of network coverage and completion delay, while attempting to keep the number of transmissions and receptions low to preserve energy and channel resources.

3 Channel model

We integrated to our simulator Omnet++ a realistic channel model published in [iNWK⁺15] over the physical layer implementation provided by the Mixim framework. This channel model of an on-body 2.45 GHz channel between 7 nodes, that belong to the same WBAN, using small directional antennas modeled as if they were 1.5cm away from the body. Nodes are assumed to be attached to the human body on the head, chest, upper arm, wrist, navel, thigh, and ankle.

Nodes positions are calculated in 7 postures : walking (walk), walking weakly (weak), running (run), sitting down (sit), wearing a jacket (wear), sleeping (sleep), and lying down (lie). Walk, weak, and run are variations of walking motions. Sit and lie are variations of up-and-down movement. Wear and sleep are relatively irregular postures and movements.

Channel attenuation is calculated between each couple of nodes for each of these postures as the average attenuation (in dB) and the standard deviation (in dBm). The datasets we used to integrate the mobility model are presented in [Bad18].

4 CLPB : Cross Layer Protocol for Broadcast in WBAN

In this section, we introduce our new cross layer broadcast protocol *CLPB*.

CLPB handles both the medium access control and the broadcast process. *CLPB* is a slotted protocol that builds on top of a pruned communication graphs constructed based on the channel model [iNWK⁺15] described in section 3.

In order to include the channel model specificities in the broadcast process, *CLPB* needs a *preprocessing* phase which is only handled at the beginning and only at the *Sink* node level (the node on the chest).

The aim of preprocessing phase is to identify, for each posture and for each node, one or more reliable paths from *Sink* node, i.e paths with the highest success transmission probability.

Then, *Sink* computes a pruned communication graph. Nodes in this graph are the nodes in the network, the edges correspond to the links with success transmission probability greater than 0.5. *Sink* selects a set of *senders*, for each posture, starting from top to down. A sender is a node that represents a link with a

high transmission success probability with a node other than the *Sink*. We suppose that *Sink* node knows in advance the postures of the body (postures detection is out of the scope of our study).

At the end of the preprocessing phase, *Sink* assigns a slot to each sender outputted by the preprocessing phase, then, it broadcasts packets that will carry both data and control information (e.g. slots assignment, synchronization information, etc).

Sink node divides time into *cycles*. A cycle corresponds to a fixed number of time slots i.e. a sequence of time slots equals to the number of senders including *Sink* node.

In a cycle, during its corresponding time slot, each sender forwards data received in the previous time slot or in the previous cycle.

A *sender* includes in packets it forwards : its slot number called **current slot**, the **slots assignment** which is the result of the preprocessing phase and which describes what time slot did the *Sink* assigned to each sender, and **next cycle start** which depends on the transmission rate of the *Sink*.

5 Performance analysis

In this section, we compare flat broadcast strategies published in [BCPPB15, BCPP20] and our new cross-layer protocol *CLPB*. We evaluate protocols' reliability through the percentage of covered nodes and the FIFO order through the percentage of de-sequencing. The FIFO order indicates protocols' capability to preserve the sending order that can be crucial for specific applications as real time patient monitoring. Strategies are stressed with *Sink* transmission rates from 2 to 1000 packets/s[‡].

We use the discrete event simulator Omnet++ and the Mixim framework enriched with the described channel and mobility model in section 3. Above the channel model, we used for the medium access control layer, the IEEE 802.15.4 implementation (2006 version, non-beacon mode).

Each data point is the average of 50 simulations run with different seeds. We used Omnet++ default internal random number generator, i.e. the Mersenne Twister implementation (cMersenneTwister; MT19937) for the uniform distribution, with different initialization seeds for each run, and the normal distribution generator (cNormal) for the signal attenuation.

The transmission power is set at the minimum limit level -55 dBm that ensures a limited energy consumption, reduces wearers electromagnetic exposition and allows an intermittent communication given the channel attenuation and the receiver sensitivity -100 dBm . For *CLPB* protocol, slot duration is set to 5ms (a typical duration used in several references) with a bitrate equal to 1Mb/s .

Figure 1a presents the percentage of covered nodes in function of *Sink* transmission rate.

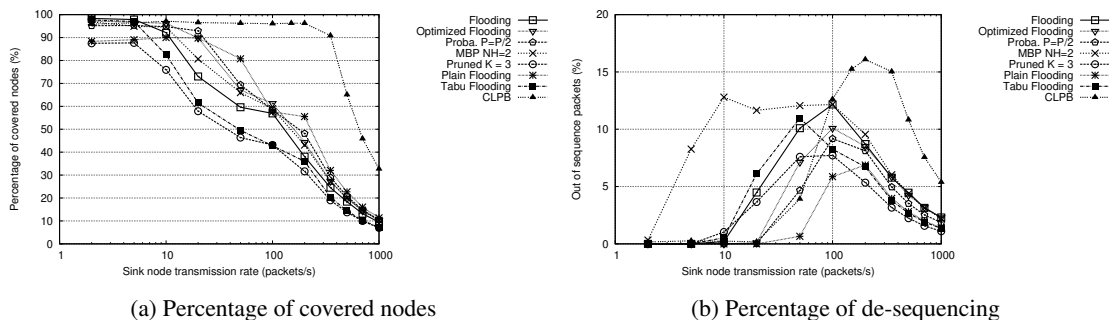


FIGURE 1: Wearing a jacket posture

All flat broadcast strategies behave similarly : going to 1000 packets/s, the percentage of covered nodes almost linearly decreases to reach 10%. At 100 packets/s, only 50% of the network is covered.

CLPB maintains a good percentage, greater than 90%, up to 350 packets/s. Indeed, with 350 packets/s, *Sink* has one packet to send every 2.85ms. In our settings, a cycle lasts 5 time slots with a time slot duration equals to 5ms. At the end of the cycle, *Sink* node has 8 packets waiting in buffer for broadcast. Or, with a

[‡]. More results are available in [Bad18]

bit rate equals to 1Mbs , *Sink* can send up to 5Kbs during its time slot. A packet size is equal to 544 bits then *Sink* can send up to $(5\text{Kbs}/544 \text{ bits})$ packets i.e 9 packets per time slot. Beyond 350 packets/s, performance falls to 30% of covered nodes by 1000 packets/s. Nodes are no more able to broadcast all waiting packets, then new received packets are dropped because buffer is saturated at MAC level.

Figure 1b represents the percentage of de-sequencing in function of *Sink* transmission rate. At the beginning, all strategies present 0% of de-sequencing. At this point, strategies are able to handle more than one packet in the network. Then, from a given rate (depending on the strategy), the percentage increases. Here, based on figure 1a, the percentage of covered nodes decreases due to collisions. Therefore, sequencing is no longer ensured. Finally, the percentage decreases to converge to 0% again due to the fact that few packets are received. *CLPB* reacts as the other strategies and we observe de-sequencing in the received sequence. This is due to the mobility model. That is, unreliable links may occur, thus allowing reception of one of several packets from the broadcasted sequence. The links then disappear and the complete sequence will be received through a more reliable link.

Discussion In figure 1b, we observe that, for flat broadcast strategies, the inflection points of the different curves have the same abscissa. This abscissa corresponds to a transmission rate equals to 100 packets/s which corresponds to the default value of the buffer size at the MAC level. This highlights the hidden impact of the data link layer parameters like MAC buffer size on the performance of the network layer strategies[§]. Our simulation results prove that cross-layering is efficient to offer the best performance. In addition, a precise characterization of the mobility pattern leads to a better efficiency, however acquiring this information has a cost and there is a subtle balance to find between duplicate data packets and control messages. Hence, our protocol takes profit of the data packet to broadcast the control information (e.g. slots assignment, synchronization information, etc) .

6 Conclusion and future works

This paper is, to the best of our knowledge, the first that proposes a MAC-network cross-layer broadcast in WBAN. Our work was motivated by results obtained after an extensive set of simulations where we stressed the existing network layer broadcast strategies [Bad18, BCPPB15, BCPP20] against realistic human body mobility and various transmission rates. With no exception, the existing flat broadcast strategies register a dramatic drop of performance faced to high transmission rates. We therefore, propose a new MAC-Network cross-layer broadcast protocol that exploits the human body mobility. Our protocol maintains its good performance up to 190Kb/s transmission rates. As future work, we intend to extend our study to cross-layer converge-cast protocols. Although, there are several proposals in the WBAN literature, none of them has been stressed with realistic human body mobility model and peaks of transmission rates.

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§. We extend our evaluation to the impact of different MAC buffer sizes on protocols' performance [Bad18]