An Analysis of the Requirements for Efficient Protocols in WBAN

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***Abstract*—Wireless Body Area Networks (WBAN) plays a major role in the advancement of technology, particularly for diagnosising the many life threatening diseases as well as providing real-time health monitoring. The objective of this paper is to study and analyze the problems of protocols in WBAN to provide the requirements related to health care in a medical environment. The protocols need to be energy efficient and reliable as well. To date, several metrics, such as channel utilization and energy efficiencies are defined. This research provides a clear outlook on the types of routing protocols and the problems related to the losses and distribution of data in a medical environment, thus meeting energy efficiency, low delay and reliability.**

***Index Terms*—Healthcare. Wireless Body Area Network (WBAN), WBAN protocols, Wireless Communication and Mobile Computing.**

I. Introduction

WBAN is a wireless network of wearable computing devices that may be either embedded inside the body and implants, or surface-mounted on the body in a fixed position. There are several WBAN with specific MAC protocols, which can be immediately sub-divided into single hop protocols and multi-hop protocols. This study concerns about the multi-hop aware protocols, particularly the protocols that are optimized for multi-hop topologies. The single hop topology has used in the design of a single hop topology. The Heartbeat driven MAC (H-MAC) [1], is an interesting example as it uses the heartbeat to synchronize nodes. The protocol is typically designed for WBANs. In this case, a preamble based TDMA MAC protocol, called PB-MAC is proposed [2], considering that the traffic adaptation is impossible, Some data rates are also impossible with this protocol, even though it supports heterogeneous data rates,. The IEEE 802.15.4 is normally the preferred choice, although there are some other protocols that have been developed,

In a study by Nabi et al., (2010), several multi-hop protocols were found to be in existence [3]; thus, they have proposed a three-level network topology, represented by a. Monitoring Station that communicates with a few Master Nodes. These Master Nodes will then communicate with the Sensor Nodes [4]. They proposed the use of gossiping to distribute information throughout a network with dynamic topology. They also claimed that delay limits due to the gossiping approach cannot be strictly guaranteed by the protocol [5]. Besides IEEE 802.15.4, a few WSN protocols are utilised in the WBAN research. Considering their dynamic nature, ad hoc network protocols could also be regarded as a viable candidate in WBAN protocols. However, the network size and the battery capacity are much smaller in WBANs. Another aspect that makes their application to WBANs unfeasible is that the ad hoc network protocols are dependant on always-on radios..

II. WBAN Specific Routing Protocols

Absorption of radiation and heating effects on human body are of significant importance, when considering wireless transmission around and on the body [6]. A model for the bio effect which is caused by bio sensors on human body, and which are compatible either in near-field or far-field communication, using the Specific Absorption Rate (SAR) has been proposed in [7]. They elucidate that the bio effects caused by radio frequency radiation are very much related to the incident power density, network traffic and tissue characteristics. A guideline for designing a WBAN derived based on observations is either the normalized bio effect metric or Coefficient-of-Absorption-and-Bioeffects (CAB).

Bio effects can be reduced through power scheduling and traffic control algorithms. This is further evidenced by a price-based rate allocation algorithm. Besides, there is another approach to balance the communication over the sensor nodes. It is administered by using TARA, LTR and ALTR. Thermal Aware Routing Algorithm (TARA) routes data away from areas of high temperature, which is also termed as hot spots [8] due to data communications processing. For immediate calculation of the temperature increase, the authors have defined the Temperature Increase Potential (TIP), which is based on the SAR.

Every node monitors the neighbor packet counts, and then calculates the power consumption and communication radiation, before deriving the present temperature of the neighbors. Once the temperature of a neighboring node is above a certain threshold limit, (i.e., the node is beginning to become a hot spot); the packets will be withdrawn and later rerouted through alternate pathways and will not be forwarded to the node. The algorithm results in the distribution of a better temperature over all the nodes in the network. Temperature is the only factor that TARA considers as a metric. Therefore, it suffers from a low network lifetime, high ratio of dropped packets and low reliability. These implicating factors are problematic for WBAN.

Least Temperature Routing (LTR) and Adaptive Least Temperature Routing (ALTR) [9] are the improvements of TARA. Contrary to TARA, LTR always chooses the neighboring node which shows the lowest temperature reading to be the next hop for routing. A predefined maximum hop count is used to maintain the network bandwidth. The packet will be discarded when the number of hops exceeds the maximum hop count. Maintenance of a list in the packet with the recently visited nodes enables the avoidance of loops. Therefore, when the coolest neighbor is available in the list, the packet will be forwarded to the second coolest neighbor that is not in the list. ALTR is the same as LTR. The only difference is that when the packets exceed the maximum hop count, it can use the shortest hop routing to take the packet to the destination as quickly as possible. Both the LTR and ALTR suffer from the same problem, alike TARA. Routing in terms of energy efficiency, reliability or delay is not optimized. Due to excess hop count nearly half of the generated packet in larger sensor networks are dropped [9]. This leads to a low packet delivery ratio and energy wastage besides increasing the temperature in the network. LTR can be categorized as a greedy algorithm that is not optimized at the global level. The simulations in [8] illustrate further that TARA, LTR and ALTR have a shorter lifetime than the shortest path routing, and this is a consequence of rerouting the packets.

Least Total Route Temperature (LTRT) is a smart combination of a LTR and the shortest routing pathway [10]. Temperature routes are selected by LTRT instead of only taking the next hop into consideration. With the use of Dijkstra's algorithm, the node temperatures are converted into graph weights, and simultaneously, minimum temperature routes are also obtained. Within a predefined time interval the node's temperature increases by 1unit upon receiving a packet and decreases by 1 unit when no packet is received. LTRT experiences a lower hop count per packet. When the number of packets dropped is low, the rise in temperature is also low. The main disadvantage of LTRT is that a node needs to identify the temperature of all the nodes in the network. This study investigates neither the overhead of obtaining the data nor the energy consumption. Generally, temperature routing can be considered as a specific case of weight-based routing that produces promising results, but it is difficult to guarantee in terms of issues relevant to reliability and energy efficiency [5].

III. Relating To Wireless Sensor Networks

Similar to the relevant MAC protocols, good candidates for WBANS include several routing protocols for sensors and ad hoc networks. It is important to highlight that the WSN protocols focus on networks of a larger scale. On the other hand, ad hoc network routing protocols assume nodes with a larger battery and are always on the radio, thus enabling routing protocol overheads to be larger [5]. The most important difference between WBAN node and WSN node is that there is a need for reliable communication in each WBAN node in contrary to the WSN node, which has a redundant character. This is a typical scenario in the medical application of weapons, where only a single sensor per vital parameter is used. Furthermore, the scale of WBANS is very small in comparison to a typical large scale deployment of WSNs. Another difference is that in a WBAN, up to twenty nodes are expected to be deployed on a single person, whereas the WSN protocols are mostly designed for hundreds of nodes and are deployed in areas of hundreds of meters in diameter.

Many studies have been conducted towards achieving energy efficient routing in ad hoc networks and WSNs [10]. However, inadequacy in terms of the proposed solutions for WBANs has been discovered. For example, WSNs maximal throughput and minimal routing overhead are found to be more crucial than the minimal energy consumption. Another fact to be highlighted is that the energy efficient ad hoc network protocols only attempt to find routes that minimize energy consumption in the terminals of network with small energy resources. Consequently, this results in the neglecting of parameters such as the amount of operations, which encompass measurements, data processing, access to memory and energy required to transmit and receive a useful bit over the wireless link. A worse condition will be when the loss of a sensor is not considered to be problematic.

The number of devices worn by a patient in a WBAN should be less. This is to provide better patient comfort. Most protocols for WSNs only consider networks with homogeneous sensors, which is an incorrect assumption. This is because each of the various devices in a WBAN, comes with their different required data rate. In many cases, the network is assumed to be static. In contrast, it has been pointed out that a WBAN has heterogeneous mobile devices accompanied by stringent real-time requirements. This is due to the sensor-actuator communication. Mobility in sensor networks is considered on a scale of meters or tens of meters. These kinds of movements of tens of centimeters can result in the mobility of WBANs.

In short, it cannot be denied that there are intrinsic differences between WBAN and WSN despite the challenges faced by both are similar in many ways. This issue indeed requires special attention [5].

IV. The Challenges In The Development Of MAC Protocols

Several challenges in the development of MAC protocols for WBANs are identified. Firstly, the urge for multi-hop WBAN protocols is motivated. This leads to challenges in developing a multi-hop WBAN MAC protocol, which needs to be reliable and energy efficient. Therefore, a TDMA WBAN protocol which supports multi-hop WBAN topologies has to be developed. Finally, while remaining in an energy efficient mode, the mobile WBAN nodes have to be supported. Presently, work on multi-hop TDMA protocols for WBANs is deemed limited. Support for its mobility is also found to be almost non-existent.

The following are the main research contributions presented in this study. Firstly, this study includes the exploration on the field of multi-hop WBAN-MAC protocols. The challenges are then identified. Following these, two protocols namely WASP and CICADA are proposed. Both of these protocols are the first multi-hop TDMA protocols for WBANs. CICADA is analyzed for further extension; thus, leading to a protocol which is energy efficient and reliable. This is followed by an analysis on the impact of topologies on WBANs, thus leading to the need for a more cooperative approach. Next, it involves an analysis of the difficulties in supporting mobile nodes in WBANs and the proposal for the LIMB protocols which would support mobile nodes. Three variants are firstly taken into consideration and are then analyzed. They are then, further extended with the notion of improving reliability and energy efficiency.

The preliminary analysis of the WASP protocol and its concepts have been published in [11], the CICADA protocol and its extensions in [12, 13]. The impact of topologies has been researched in [14] and further extended in [15]. [16] and [17] have presented the initial research behind the LIMB protocols, and currently the protocol extensions are under submission. The ideas presented in Section II, which include specifically the initial ideas behind the WASP and CICADA protocols, were formulated and implemented synergically by Dr. Benoît Latré at the University of Ghent. This was devised in the scope of the Flemish IBBT project IM3 [18] and the Flemish FWO project FWOBAN. The PhD thesis of Dr. Latré [19] conveys an introduction and analysis of the protocols. These will be further investigated in this work. The topology analysis has been developed in close collaboration with Prof. Wout Joseph and Ir. Elisabeth Reusens who are members of the WiCa research group [20].

V. TDMA Protocols

Most TDMA based protocols which have been researched before are not really applicable to the envisioned case of dynamic WBANs, even though the number of these protocols is very high. Studies on a combination of multi-hop scheduling with dynamic rates are indeed rare. A well known example includes Packet Reservation Multiple Access (PRMA) system. In this system, several nodes compete for the empty slots. Once a node has successfully reserved the slot, it would be able to maintain its reservation for as long as it uses the slot. While competition implied as a delayed variable, a more prominent problem arises from the probabilities of packet loss in wireless links. Besides, when not all of the nodes are in a multi-hop topology hear transmissions of a given node, performance will decrease.

In circumstances when both multi-hop scheduling and dynamic rates are supported by protocols, the focus is mostly on always-on radios. However, this is not feasible in WBANs. Despite the fact that Delay Tolerant Networks show interesting distributed properties as well as providing a solution [21] , their main area of application is networks where there is tolerance of delay. This is not in sync with the typical WBAN case. [22] recommends a directional, TDMA based MAC protocol. The authors have used directional antennas, in an attempt to avoid the complexity of guaranteeing conflict-free access to slots. Although the TDMA scheme could be simplified via this procedure, the hard proven fact is that applying directional antennas on a moving body poses difficulties.

VI. Multi-HP WBAN Protocols

CSMA is normally used, in comparison to TDMA, for medium access in ad hoc networks. Despite this fact, scheduling medium access to the typical dynamic links in ad hoc networks is comparable to the situation in a WBAN. Nevertheless, there are a number of important differences. Ad hoc networks consume a larger source of energy, typically a laptop battery or even wall power. Additionally, the radios are always assumed to be on. This implies that the nodes can easily exploit the retrieved data even though the data is not immediately applicable to the network protocols.

WSNs could be a good match to WBANs as they are typically optimized to achieve high energy efficiency. A serious mismatch between the requirements of WBANs and WSNs is that WSNs are usually not dynamic networks. They are rather static and are specifically tailored towards very low data rates. On top of that, WSNs are normally deployed with a high number of redundant nodes.

WASP is a slotted protocol that utilizes a spanning tree for routing and medium access coordination. Every node in the tree conveys to its children regarding the slot that they can send their data, using a special message (a WASP-scheme). This WASP-scheme which is unique for each and every node is constructed in the node which conveys the scheme [23]. A prominent property of WASP is its dual usage scheme which exploits the broadcast nature of wireless links. The schemes are utilized by the node which assigns slots to its children besides requesting resources from its parent for these children. In this way, the protocol's overhead is minimized as each scheme is deployed by the parent and children of the sending node. By listening to the WASP-schemes appearing from its parent node (one level up in the tree) and from its children (i.e., a level lower in the tree), every information that the node needs to generate the scheme can be obtained. Consequently, a distribution method [5] is used to divide the time slots.

VII. Future Work

The field of WBAN research is progressing rapidly, geared by the economic and demographic evolution. Nevertheless, the results of real life protocol trials assist greatly in the advancement of WBAN's field of research in general and specifically in the performance analysis of protocols in mobile WBANs.

VIII. CONCLUSION

This paper presents reliable and energy efficient protocols for Wireless Body Area Networks. The study does not cover all types of protocols. The research context of WBANs is explained, together with the work related. This study focuses on the WBANs challenges in supporting specified topologies which have been identified. Since the research in WBAN is new, there are many challenges in the development of MAC protocols for WBAN.

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