Towards the Development of Cross Layer Approach for Energy Efficiency and Mobile Wireless Body Area Networks

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Abstract—**Medium Access Control (MAC) protocols play a significant role in maximizing the lifetime of Wireless Body Area Network (WBAN) by controlling the dominant sources of energy waste, i.e., collision, idle listening, overhearing, and control packet overhead. Considerable research efforts are devoted to develop an energy efficient MAC protocol for WBAN. For this purpose, researchers have conducted a comprehensive study of the well- know low-power MAC protocols including WiseMAC , SMAC, IEEE 802.15.4 and PB-TDMA , and concluded that none of these protocols accommodate the heterogeneous traffic requirements of WBAN. Most of them were unable to satisfy the stringent Quality of Service (QoS) requirements. We are working to extend the current work towards a complete and sophisticated WBAN system, which can be practically deployed in hospitals and healthcare centers. We propose prototype development to achieve energy efficiency and high throughput at different frequency band, a cross layer approach together with MAC protocol (at the PHY layer) for Medical Implant Communication Systems (MICS), Ultra-wide and Wireless Medical Telemetry System (WMTS) frequency bands in order to support a variety of medical and Consumer Electronics (CE) applications.**

Keywords-WBAN, Health Monitoring, MAC, Energy Efficiency

I. INTRODUCTION TO WBAN

The rapid technological growth in physiological sensors, low power integrated circuits and wireless communication has enabled a new generation of wireless sensor networks. These wireless sensors networks are suitable for different applications i.e. traffic monitoring, plant monitoring in agriculture, infrastructure monitoring and health monitoring. However our work is related to Wireless sensor technology for health monitoring applications called WBAN (Wireless body area network). WBAN is a rich interdisciplinary area that revolutionizes health care system by allowing inexpensive, continuous and ambulatory health monitoring with real time updates of medical record via Internet. A number of intelligent physiological sensors can be integrated into a wearable wireless body area network, which can be used for computer assisted rehabilitation and even early detection of medical conditions. Though there is some limited research going on in this area, but its applications are not practically implemented in hospitals or other health care centers. Its only limited to laboratories. Making WBAN practical for hospitals is a challenging task, which is still not achieved. Our aim is to design a flexible prototype that could be practically implemented in hospitals.

As mentioned earlier, our aim is to develop a flexible and proactive prototype, which could be practically implemented in hospitals. Traditionally holter monitors have been used to gather data for offline processing, which is not suitable for real time applications. A health-monitoring device using PAN (personal area network) has been integrated into user's clothing [1]. However this type of system limits the patient's normal activity. A WBAN prototype for computer assisted physical rehabilitation applications has been developed by [2]. He actually focused on general system architecture and described an activity sensor called "ActiS-Activity Sensor" which is based on a standard wireless sensor platform and a custom sensor board with a one-channel bio amplifier and two accelerometers [3]. The ActiS when using ECG (Electrocardiogram) as a bio amplifier will monitor heart activity and position of upper trunk. While by using EEG (Electroencephalography) as a bio amplifier, the same Actis can be used to monitor brain electrical activity. The ActiS is specifically developed for WBAN. Therefore we will use ActiS as a wireless sensor platform during our research. In order to understand the concept more precisely, please consider the following diagram, which is the best example of a complete Wearable WBAN [2].

This research was supported by Najran University, Kingdom of Saudi Arabia under the grant number NU 14/12

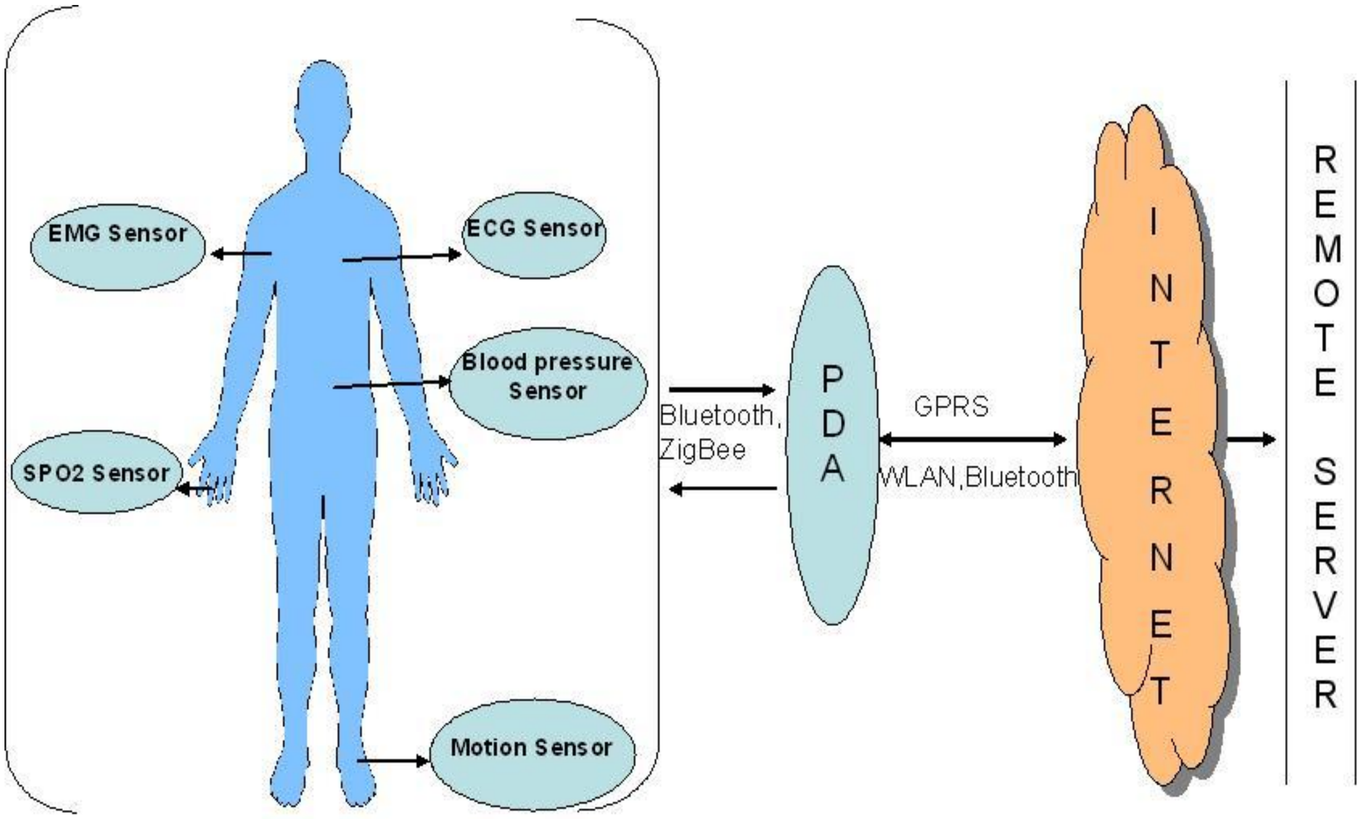

Figure: 1 WBAN System for Continuous Health Monitoring

Figure 1 indicates three-tier architecture of Wearable WBAN developed at Department of Electrical and Computer Engineering, University of Alabama in Huntsville. The lowest level contains a set of physiological sensors called tier 1. The second level is the personal server i.e. Internet enable PDA or home computer called tier 2.

The third level called tier 3 contains a network of remote health care servers. Each level is very complex to implement. This diagram is only given in the paper [2] as very good example of a complete WBAN system. But they actually focused on lowest level i.e. development of hardware for various physiological sensors. Hence the second and third level is still a big issue to deal with.

Current healthcare systems are facing new challenges due to the rate of growth of the elderly population (persons 65 years old and over) and limited financial resources. According to the US Bureau of the Census, the number of old people (65-84 years old) is predicted to double from 35 million to 70 million by 2025. This trend shows that the world elderly population will double from 375 million in 1990 to 761 million in 2025. Furthermore, overall healthcare expenditure in the US was $1.8 trillion in 2004, and this number is projected to be triple by 2020, or 20% of the US Gross Domestic Product (GDP). The impending health crisis attracts researchers, industrialists, and economists toward optimal and quick health solutions. The non-intrusive and ambulatory health monitoring of patient's vital signs with real time updates of medical records via the internet provides economical solutions to the challenges that health care systems face. Wireless Body Area Networks (WBANs) provide innovative solutions to the aforementioned problems. They are used for ambulatory health monitoring of a patient for a long period of time with real-time updates to the physician. WBAN devices work autonomously and can search a suitable network including Wireless Local Area Network (WLAN), Worldwide Interoperability for Microwave Access (WiMAX), or internet to reliably transmit data to a remote server. Possible applications include diagnoses and treatment of many diseases including myocardial infarction, gastrointestinal tract, cancer detection, asthma, diabetes, and other health diseases. Non-medical applications include monitoring forgotten things, establishing a social network, monitoring of athletes, and in some cases assessing soldier fatigue and battle readiness.

II. Energy Efficient MAC protocols for WBAN

The MAC layer is a broad research area and many researchers have done research work in the new area of low power and wireless sensor networks[7][8][10]. It is one of the main/central protocol stack which provides the basis of achieving Quality of Service (QoS) in wireless networks.

One fundamental task of the MAC protocol is to avoid collision so that two interfering nodes do not transmit at the same time.[6]. Other tasks includes preventing simultaneous transmissions while preserving maximum throughput ,minimum latency and maximum energy efficiency. Various MAC protocols developed for voice and data communication networks are TDMA, CDMA and contention based protocols (also called as duty cycling protocols) but are not suited for WBANs for following reasons.

- The TDMA schemes are not good for WBANs as it requires high quality of synchronization and sensitivity as a clock drift may lead to disastrous results. It also requires the nodes to form real communication clusters like Bluetooth and LEACH.
- The sleeping mechanisms of contention based protocols require considerable overhead to keep neighboring nodes synchronized.
- A physiological fluctuation may trigger many sensors at the same time.
- The CSMA/CA protocol are not reliable solution in multi-piconets.[9]
- Since in WBANs most of the traffic is inter-related CSMA(contention based) are not suitable for them. [11]
- The TDMA protocols require dynamic slot assignment and real clusters formation is difficult and these protocols do not support scalability.

So the MAC protocol for WBANs must focus on reducing unnecessary energy expenditure and reliability of the data. [5]. A energy efficient wireless MAC protocol is a protocol that minimizes idle listening (waiting for a potential packet to arrive) and overhearing (receiving a packet not belonging to the node) which are major source of energy waste, while minimizing collisions.

CICADA:

(Cascading information retrieval information by controlling access with distributed slot-Assignment) is a low energy protocol designed for wireless, multi-hop mobile body area network which sets up network tree in distributed manner. The spanning tree approach uses the MAC packets to determine presence/absence of next-hop guaranteeing collision free access to the medium and route data towards the sink.[4]

In this the cross layer approach the control-cycle is for sending information from sink to the node and the data-cycle is for transmitting data from the node to the sink. This movement of control information from sinks to nodes and data from the nodes to the sink takes care overhearing, idle listening and collisions. Since all slots are assigned a node knows when to sleep and when to send.

WiseMAC:

It focuses on low traffic, WiseMac is based on preamble sampling where a node regularly samples or polls the medium for a very brief time to check whether a packet needs to be received. With power save protocol of ***IEEE.804.15.4*** ZigBee standard Wise Mac can provide a significantly a low power consumption for the same delay. Wise MAC protocol is for downlink of infrastructure, transmitting data from access point to the node. Wise Mac is an asynchronous protocol relying on low power listening. [4].

But its subjected the receiver waits for the full period until the preamble is finished and overhearing [5]. The latency is also bounded to preamble length. It cannot adopt to changing traffic patterns as it focuses on low- traffic

X-MAC:

Variations of Wise-MAC such as X-MAC use strobe sequence of short packages for fast shutdown and response. This short preamble overcomes excess latency at each hop. Since the energy consumption is proportional to number of nodes(receivers) within the range. Hence, the energy usage is dependent on density as well as traffic load. The drawback of overhearing is overcome in X-Mac as it incorporates the receivers address and hence the non-target receivers can go back to sleep. Each and every short packet contains the receivers ID The nodes can wake up more often to while maintaining a low duty cycle.

At first X-Mac node transmits an extended preamble and when the receivers awakes to sample the medium, if a preamble exists, it keeps awake until the whole preamble. If it’s not the target goes back to sleep. In X-Mac, the strobe of small pauses makes the transmitting node receive the acknowledgement from the target node and eventually sends the data packet.

If more than one transmitter is sending to the same target, the second transmitter backs-off and waits for one transmission to complete. The target node keeps awake after receiving the first transmission in case other transmitters waiting to send.

S-MAC:

The variation combines scheduling and channel polling to coordinate sleeping among neighboring nodes to avoid idle listening. The nodes wake-up periodically to perform the functions of receiving and transmitting data and then go back to sleep, turning off its radio. The local synchronization of schedules is done at the beginning of awake period through broadcast. Transmitting is done during the awake period, communicating with its neighbors sending any messages queued during the sleeping part, once the transmission starts it does not stop until completed. But the nodes are awake during the entire awake period even if they are not transceiving data.

S-Mac nodes are deployed in ad-hoc fashion and communicate as peers not as single base station. Synchronization is done periodically using SYNC packet.
S-Mac protocol tries to reduce wastage of energy from all sources energy inefficiencies

T-MAC:
T-Mac(Time Out) improves on S-Mac by making the nodes listen to the channel for short-duration after synchronization phase, during which time if does not find data the node goes back to sleep. It uses 1/5th of the energy used by S-MAC. If a node sends route to send (RTS) and does not receive (Clear To Send) then send RTS twice again and goes back to sleep and the T-Mac suffers from sleeping problems. Instead of using a fixed-length mechanism T-Mac uses a time-out mechanism to determine the end of active period.

A Very Low Power MAC Protocol:
Mechanism was proposed for a BSN, which exploited the traffic patterns of the BSNs to accommodate the entire traffic classification. We further introduced a Bridging function that integrated all the BNs working on different PHYs into a complete BSN. The proposed wakeup mechanism backed by the Bridging function provided a complete solution towards power-efficient and reliable communication in a BSN. A detailed comparison is given in the table-1 below [12-21]:

Table 1: Implant node Comparison of MAC Protocols

Protocols	Advantages	Disadvantages	Energy Efficiency Mechanism
Okundu MAC	Minimize time slot collision, reduce idle listening and overhearing	Only 8 slave nodes can be communicated to Master Node	Wake up Fall back Time (WFT)
MedMAC	Energy waste due to collision is reduced	Do not support high data rate applications	Wake up Fall back Time (WFT)
Low Duty Cycle	Collision problem is reduced, allows patients' monitoring	Not suitable for dynamic type of networks	TDMA, concept of Guard Time
Ta-MAC	Accommodates normal, emergency and on-demand traffic, energy efficient, reasonable delay	Not suitable for dynamic Topologies	Central coordination according to traffic patterns of the nodes
S-MAC	High latency and time synchronization overhead may be prevented due to sleep schedules	Overhearing and collisions may occur If a node is not the listening node	Scheduled based, organized in slots and operation based on schedules
H-MAC	Improves BSN's energy efficiency and reduces extra energy cost	Does not support sporadic events and posses slow spectral/band width efficiency	Heartbeat Rhythm information is used for synchronization
T-MAC	Packets are sent in burst and with low latency which collectively gives better result under variable load	The nodes go back to sleep too early	Have slots and operation is based on schedules
B-MAC	Improves packet transmission hence saves energy	Uses CSMA/CA in the uplink frame of CAP period, which is not a reliable scheme	TDMA, Bandwidth mechanism
DTDMA	Reduce packet dropping rate, less energy consumption	Does not support emergency and on-demand traffic	TDMA based, use of slotted aloha in CAP field

WiseMaC	Organized randomly, is based on listening and adaptive to traffic load		Good for high traffic applications, not suitable for low duty in-body/on body nodes

III. Research Design

Let us first explain the multi tier architecture being given in Figure 1. Different sensors are integrated at different points i.e. ECG for heart monitoring, SpO2 for oxygen saturation and motion sensor on ankle etc. These sensors continuously monitor their corresponding organs and send the data to a personal server (internet enabled PDA or home computer) using zigbee protocol. The data being received by PDA or home computer is sent to remote health care servers. This enables remote health care servers to continuously update the patient information in databases. GPRS technology assists us in finding the correct location of a patient.

E. Jovanov [2] has partially worked on the lowest level i.e. introducing ActiS as a very good platform for the integration of different bio amplifiers. His work reduces some of the complexity at the lowest level. But the problem of monitoring continuous data and sending it to PDA is a very complex issue. Moreover, at the lowest level, zigbee protocol is used, but from PDA to remote health care system, zigbee is not a valid protocol. Therefore the PDA must have a capability of receiving data using zigbee protocol and sending it to remote health care servers using Bluetooth or some other Internet protocols. Furthermore, the remote health care servers are expected to receive large amount of data. So we also need different data mining techniques that could help us in managing this large amount of data. Theoretically it's very easy to explain the architecture of WBAN but practically it's like a hard nut to crack.

As WBAN is an interdisciplinary area which requires assistance of Medical and Computer Science experts. Fig 1 shows a sketch of a complete Wearable WBAN. The work should be distributed among three different departments. Medical department could be very helpful in providing technical information about various physiological sensors. Our lab should work on the lowest level i.e. integration of physiological sensors using BSN platform. Moreover our task includes getting continues data from each organ, process it at sensor level BSN, and send it to an internet enable PDA or mobile using zigbee or UWB. The PDA will forward the received data to health care servers via Internet. The third level requires assistance of computer experts i.e. sending data from PDA or mobile to health care servers via internet. How to treat this large amount of data is the task of computer experts. They are supposed to develop a database that could receive this large amount of data directly from PDA and could store it accordingly. Likewise data entered into health care servers provide support for data mining and knowledge discovery relevant to specific conditions and patient categories. Hence different data mining techniques are required that could find various patterns (related to patient's record) in these databases.

Our design work focuses on the development of low-power MAC/routing protocol for WBAN. We have extended the current work towards a complete and sophisticated WBAN system, which can be practically deployed in hospitals and healthcare centres. The proposed TaMAC protocol will be improved (at the PHY layer) for Medical Implant Communication Systems (MICS), Ultra-wide and Wireless Medical Telemetry System (WMTS) frequency bands in order to support a variety of medical and Consumer Electronics (CE) applications. To achieve higher throughput and minimum delay at different frequency band, a cross layer approach together with the TaMAC protocol (PHY and MAC) will be adapted. Apart from PHY and MAC layers, Network layer is becoming increasingly important. My plan is to consider the Network layer for WBAN and to develop a cooperative routing protocol for multi-hop WBANs.

Currently, not many routing protocols for WBANs exist. Protocols specifically designed for WBANs like AnyBody [22] and CICADA [23] do resolve some of the issues that are typically encountered in WBANs, however there is still a lot of work to do. Existing routing protocols are either well suited for mobility but highly energy inefficient from a sensor point of view, or they do not support fast mobility. Based on my preliminary results on routing for WBANs, I believe there is still a large hurdle to be overcome to completely start using WBANs. My aim is to extend my preliminary results and to overcome the complex trade-off between energy efficiency and fast routing in mobile WBAN.

The aim of my research is to successfully implement low-power MAC and routing protocols on real WBAN systems. After the prototypes are developed, the next step will be to introduce them to the hospitals and healthcare systems in Canada. Although there are many applications of WBAN in healthcare sector and many of them are currently in use, the detection of epileptic seizure has not be investigated, perhaps due to the complexity of random patterns in the brain. In application point of view, I will consider cooperative communication strategies in the WBAN system that will predict the epileptic seizure in advance and will allow the patient to take care of him/her self. Different wearable and implantable sensors will be used to achieve this goal. If required, a patient tracking mechanism can be integrated into the system to locate a patient during medical emergency.

IV. Conclusion

Our study focuses on the energy efficient MAC protocol for WBAN. We have studied various existing MAC protocols in the context of energy efficiency for WBAN and envisaged that a TDMA based could satisfy the energy efficiency requirement for WBAN including heterogeneous traffic and correlation. In future, we will use this study to design a novel low power MAC protocol for WBAN with low energy consumption.

In our design, we have proposed a feasible and cross layer MAC prototype for Wearable WBAN system, which could reduce the power consumption and hence the quality of life. Since I will work on the development of cross-layer protocols at PHY, MAC, and Network layer, we believe the new cross-layer protocol will provide innovative solutions to many problems that are not easy to be solved using a single layer protocol. Additionally, this research will open a new way (in academia) of using cross-layer concept for the first time in WBAN and hence will attract many researchers to this area. The target WBAN system will use the cross-layer protocol and will provide ambulatory health monitoring of patients and alerting them in emergency case. In addition to predicting epileptic and other life-threatening events, this system will provide smart health care services, remote diagnostic and telemedicine services, smart nursing homes, emergency communication and patient's data maintenance.

ACKNOLEDGMENT

This research was supported by Najran University, Kingdom of Saudi Arabia under the grant number NU 14/12.

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