MOFBAN: a Lightweight Modular Framework for Body Area Networks

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Abstract. The increasing use of wireless networks, the constant miniaturization of electrical devices and the growing interest for remote health monitoring has led to the development of wireless on-body networks or WBANs. The research on communication in this type of network is still at it's infancy. The first communication protocols are being proposed, but a general architecture that can be used to integrate the protocols easily is still lacking. However, such an architecture could trigger the development of new protocols and ease the use of WBANs. In this paper, we present a lightweight modular framework for body area networks (MOFBAN). A modular structure is used which allows for a higher flexibility and improved energy efficiency. The paper first investigates the challenges and requirements needed for sending messages in a WBAN. Further, we discuss how this framework can be used when designing new protocols by defining the different components of the framework.

1 Introduction

Recent advancements in electronics have enabled the development of small and intelligent (bio) medical sensors which can be worn on or implanted in the human body. However, the use of wires to extract data is becoming too cumbersome due to the multitude of sensors. As a solution, the sensors placed on and inside the body are equipped with a wireless interface which enables an easier application [1]. Doing so, a patient is no longer compelled to stay in a hospital. The health care is becoming mobile. This is referred to as m-health [2]. For this purpose, a new type of network is defined: a wireless on-body network or a Wireless Body Area Network (WBAN) [3,4]. This type of network communicates wirelessly and consists of several small and mobile devices close to, attached to or implanted into the human body. Interaction with the user or other persons is usually handled by a personal device, e.g. a PDA or a smartphone which acts as a sink. Generally speaking, one can distinguish two types of devices: sensors and actuators. The sensors are used to measure certain parameters of the human body, either externally or internally. Examples include measuring the heartbeat, body temperature or recording a prolonged ECG. The actuators or actors on the other hand take some specific actions according to the data they receive from the sensors or through interaction with the user, e.g. an actuator equipped with a built-in reservoir and pump for administering the correct dose of insulin to diabetics based on the measurements of glucose level. These systems reduce the enormous costs of patients in hospitals as monitoring can occur real-time and over a longer period of time, even at home [5].

Only emerging in recent years, the concept of a Wireless Body Area Network can be seen as fairly new. The main research nowadays focuses on the development of new radio interfaces and sensors. The devices are becoming tinier, even less than 1 cm^3 [6] and the energy consumption is decreasing [7]. The IEEE 802.15 Working Group has recently started a Study Group for WBANs [8]. Current implementations of WBANs generally assume a star topology where the sensors or actuators are directly communicating with the personal device. However, recent studies have spoken out for the use of multi hop routing in wireless on-body networks where intermediate sensors may be used as relay devices in order to reach the personal device [9,10]. The main reasons for using such an approach are to increase the reliability and connectivity of the network, the high path loss experienced around the body [11,12] and to even further lower the energy consumption.

The development of new network protocols especially designed for body area networks has been considered in a lesser degree. Nevertheless, the creation of protocols which are adapted and optimized to the specific requirements of WBANs, can even further lower the energy consumption while other requirements, e.g. reliability and delay, are still satisfied. In order to boost the development of such protocols, we propose a lightweight framework for a system architecture usable in body area networks called MOFBAN or MOdular Framework for Body Area Networks. This framework will allow for an easy integration of existing and newly developed protocols and optimizes the energy-efficiency by using its modular structure. It further provides a uniform interface for application and radio designers.

The remainder of this paper is as follows. Section 2 gives an overview of current work in the field of Body Area Networks where we will focus on existing networking protocols for body area networks. The specific characteristics and properties will be discussed in Section 3. Section 4 discusses the modular framework of the proposed protocol. The modules are described in Section 5. In Section 6, the communication in the framework is discussed. And finally, Section 7 offers directions for future research and Section 8 concludes the paper.

2 Related Work

Protocols for WBAN can be divided in *intra-body communication* and *extra-body communication*, see Figure 1. The former controls the information handling between the sensors or actuators and the personal device [13], the latter ensures communication between the personal device and an external network

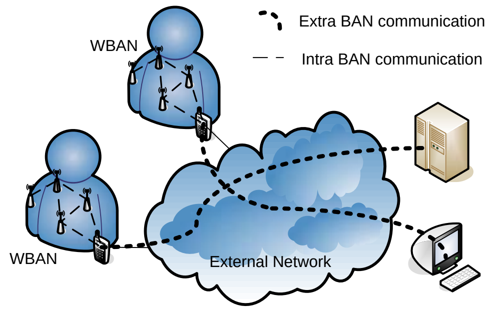

Fig. 1. Example of intra-body and extra-body communication in a WBAN

[7,14,15,16]. Doing so, the medical data of the patient at home can be consulted by a doctor.

This paper deals with intra-body communication. Developing efficient routing protocols in WBANs is a non trivial task because of the specific characteristics of a wireless environment. First of all, the available bandwidth is limited, shared and can vary due to fading, noise and interference, so the protocol's amount of control information should be limited. Secondly, the nodes that form the network can be very heterogeneous in terms of available energy or computing power. A lot of research has already been performed in the area of sensor networks [17]. These protocols can not be used in a intra-body network as is as these protocols are mainly developed for large networks whereas the WBAN only has a limited number of devices. Besides, sensor networks assume one-way-communication between the sensor and the sink and more reliability is wanted in WBANs. In current implementations, these networks consider a star topology where the sensors are directly (and of course wirelessly) connected to a personal device [18]. Hence, the routing aspects of these protocols are very minimal as only direct communication is to be contemplated.

The strict separation of the protocol stack has proved to be a good solution for wired networks, but is not suitable for wireless networks [19]. Hence, a cross-layer approach is considered as the way to go in developing protocols for wireless networks and sensor networks. By using a cross layer architecture, optimization can be done at several layers at once, it is possible to achieve a global optimization and conflicting optimizations between different layers can avoided. Hence, most recent protocols have opted for a more holistic view using a cross layer approach [20]. A special type of cross layer is the modular approach [21]. This allows for a rich interaction between the building blocks of the protocol, but requires a total new approach which changes the very way protocols are organized. Another approach of a modular sensor network, is to make the sensor nodes themselves modular in hardware. This is done in mPlatform [22], that uses a collection of stackable hardware modules that share a well defined common interface.

Table 1. Examples of medical WBAN applications [23,24]

Application	Data Rate	Bandwidth	Accuracy	Reliability
ECG (12 leads)	144 kbps	100-1000 Hz	12 bits	10^{-10}
EMG	320 kbps	0-10,000 Hz	16 bits	10^{-10}
EEG (12 leads)	43.2 kbps	0-150 Hz	12 bits	10^{-10}
Blood saturation	16 bps	0-1 Hz	8 bits	10^{-10}
Glucose mon.	1600 bps	0-50 Hz	16 bits	10^{-10}
Temperature	120 bps	0-1 Hz	8 bits	10^{-10}
Motion sensor	35 kbps	0-500 Hz	12 bits	10^{-3}
Audio	1 Mbps	–	–	10^{-5}
Voice	50-100 kbps	–	–	10^{-3}

3 Properties of a WBAN

Many different types of sensors and actuators are used in a BAN. The main use of all these devices is to be found in the area of health applications. In this view a BAN can be utilized to provide interfaces for the disabled, for diagnostics, for drug administration in hospitals, for telemonitoring of human physiological data, as aid for rehabilitation, etc. The devices are worn on the body and therefore should be made as tiny as possible. Consequently, limited space will be available for energy supply. In order to minimize the energy consumption, one can use an extremely low transmit power. Energy scavenging can be used, but this will only deliver small amounts of energy [25].

An important property is that the data consist of medical information. Hence, a high reliability and low delay is required. It is crucial that messages with monitoring information are received by the health care professionals. The reliability can be considered either end to end or on a per link base. Examples of reliability include the guaranteed delivery of data, in-order-delivery, ... Besides, the delivery of the messages should be in reasonable time.

Different types of delivery can be distinguished: *continuous* (data or control information is sent continuously or periodically with small intervals), *demand driven* (data is only sent when needed), *event driven* (data is sent whenever an event occurs, i.e. if a threshold is crossed) or *hybrid* (a combination of the types above). Most applications will have continuous data transmission.

A small overview of health care applications in a BAN can be found in Table 1. The data rate is calculated by means of the sampling rate, the range and the desired accuracy of the measurements [23,24]. The sampling rate is twice the required bandwidth. The number of bits required per measurement is calculated through the range and accuracy:

$$\text{Data rate} \; = \; \text{nr of bits} \cdot 2 \cdot (f_{max} \; - \; f_{min}) \qquad (1)$$

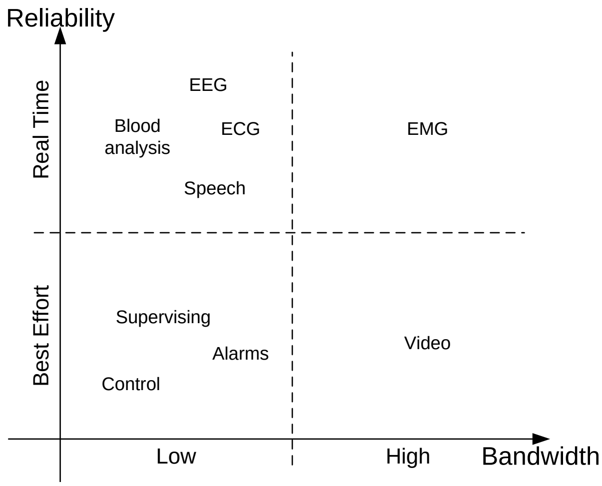

Fig. 2. Traffic analysis in a WBAN.

Looking at Table 1 and the visualization of Fig. 2, we can group the applications into 4 categories:

- Low data rate and low reliability
- Low data rate and high reliability
- High data rate and low reliability
- High data rate and high reliability

It is clear that the traffic in a WBAN is quite heterogeneous and newly developed protocols should be capable of coping with this heterogeneity in mind.

In most cases, a WBAN will be set up in a hospital by medical staff, not by network engineers. Consequently, the network should be capable of configuring itself automatically, i.e. self-organizing should be supported. Whenever a node is put on the body and turned on, it joins the network and the routes are set up without any external intervention. When a route fails, a back up path should be set up. The self organizing aspect also includes the problem of addressing the nodes. They can use a preconfigured address given at manufacturing time (e.g. the MAC-address) or an address given at set up time by the network itself. Further, the network should be quickly reconfigurable, i.e. for adding new services.

Another important issue is the network security. The data gathered by the sensors is highly confidential and private. Special efforts such as encryption, key establishment, authentication, . . . are needed.

From the analysis above, it is clear that we have a set of different requirements for supporting communication in a BAN. In order to ease the development of new and robust applications, a framework and new protocols are needed. These should consider the energy efficiency, reliability, the delay, the different QoS-levels and data rates, the ease of use of the system and the security. In the following, we present a framework especially designed for body area networks that will take care of these requirements.

4 Modular Framework

In this section, we present MOFBAN, a lightweight MOdular Framework for Body Area Networks. The framework uses a modular design instead of the normal layered approach. This means that all the functionalities needed are implemented as software modules [21]. The use of modules allows for a more flexible solution as some functionalities can be changed, added or removed more easily, simply by altering the corresponding module. These modules can be used and altered more easily compared to a general cross layer approach where all the functionalities are implemented in one layer.

Developing protocols in a modular way requires a new approach in designing network protocols. In a layered design, the interfaces between the protocols residing on different layers are well-defined, i.e. in the TCP/IP stack. This is no longer the case in a modular framework. One has to make sure the modules are called in the appropriate order and that the exchange of parameters between the modules is standardized. In MOFBAN, the interaction between the different modules is handled by a controller module that is responsible for addressing the appropriate function at the right time. The controller module further acts as a general access to a storage space or data bank for the parameters that can be used in the network.

An example of the MOFBAN framework can be found in Figure 3. The most important element of the framework is the middle part. It contains the different modules which implement the desired functionalities and holds the controller module. Further, two interfaces are provided. At the top, the application interface eases the use of the framework for application designers. The application layer is handled separately in order to facilitate the use of different applications (such as sensing, video,. . .) and the addition of extra services/applications. It is necessary to define a sort of generic interface between applications and the framework (see section 6). At the bottom, the physical interface provides a uniform access to the physical layer. The framework has a simple architecture and the use of modules avoids the duplication of functionality, making the framework lightweight.

In a Body Area Network, two types of devices can be defined: a sensor/ actuator node and the personal device. In these two types, the MOFBAN framework is implemented.

– The *Sensor/Actuator nodes* are the regular nodes in the network. The specific use of the node is determined by the application designer who uses the application interface to activate the required functions. A node can be a ECG-sensor or an actuator. Another example is that the node can be used as a relay device. These devices are merely used for relaying data, not for

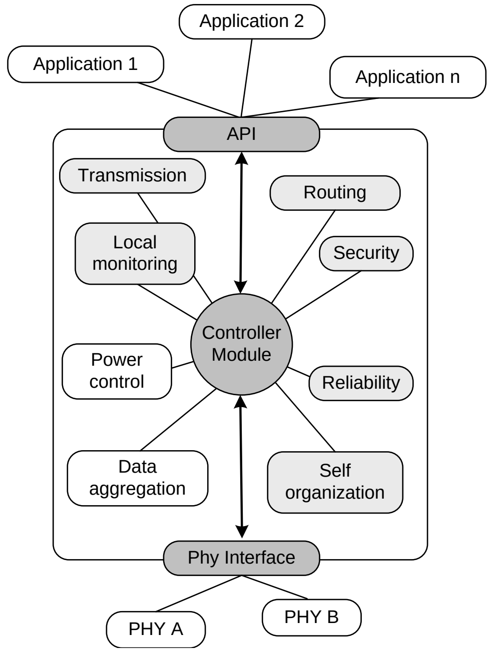

Fig. 3. The modular framework for BAN or MOFBAN

sensing. The question of which modules needs to be used is determined by the application designer. The sensor nodes can have different implementations between themselves. Doing so, the network can support the different requirement of heterogeneity of the network.

- The *Personal device* acts as a gateway between the BAN and other networks. Therefore, the personal device needs to support the normal IP-stack. It is an IP-capable device and it takes care of the conversion between the modular protocol stack and the layered OSI protocol stack. This device generally has two or more physical interfaces: one to connect with the WBAN and the other to connect with an external network. It further has a larger energy supply and more computation power.

5 Modules

The modules of MOFBAN take care of the networking functionality in general, such as routing, medium access, reliability, self organization,... Three types of modules can be distinguished: the *controller* module and the *required* and *optional* modules. The required modules are essential to have a proper working BAN and implement the basic networking functionalities. When a more functional BAN is needed, i.e. a BAN supporting a certain level of reliability, security or power control, extra optional modules are added. It is up to the user of the network, i.e. the application designer, to define what is needed.

5.1 Controller Module

The controller module is the most important module. It is responsible for handling the correct functioning of the framework and handles all incoming requests from the physical and application layer. It consists of two major parts: a scheduler that calls the other modules at the appropriate time and a passage to the database that acts as a data-repository accessible by the other modules.

It is of utmost importance to keep the information between the different modules consistent. This is regulated by the controller module. It defines the interaction or communication process between the modules. For this purpose the controller module uses an additional database module. If a module wants to access or pass information, this is communicated to the controller that gets or stores the information in the database. The controller module is responsible for solving and controlling interdependencies between different modules. A uniform data structure is used by all the modules.

The controller is responsible for calling the appropriate module. This can occur packet-based or periodically. When a packet is received by the framework, the controller intercepts it. The data part is removed and temporally stored in the database. Based on the header information, the correct module is activated by the scheduler. When the module has finished, it passes the control back to the scheduler which activates the next module. The controller also holds several timers. Upon expiration of a timer, the appropriate module is activated.

5.2 Required Modules

The required modules are essential to have a proper working WBAN. In the following, an overview of the required modules is given:

- The *Information Module* stores all the information from the network and the modules. It is the database of the controller. The controller module acts as a gateway to the database and controls the access.
- The *Transmission Module* regulates the transmitting of data on the medium and handles the channel access to the medium. The implementation in this required module is very basic: a simple CSMA with collision avoidance.
- The *Routing Module* is responsible for setting up a path toward the personal device or other destinations. This can be done using a weight function, number of hops, ... The routing module provides the next hop to the transmission module via the controller module. It can use information about the network, e.g. from the QoS module or from the information module. Different implementations can be made for this module. If a new protocol is used, a new routing module can be added easily. Even multiple routing modules can exist in the same node. It is the responsibility of the controller to activate the correct routing module.

- The *Local Monitoring Module* monitors the network parameters such as the link quality, received signal strength, remaining battery power of the node, the number of neighbors, . . . Stated otherwise, this module retrieves the information of the physical layer and other layers that needs to be shared among the other modules. The information is stored in the information module.
- The *Self Organization Module* is responsible for the automatic set up of the network and for maintaining the network. It is activated by the controller module when the node starts up and at certain periods of time.

5.3 Optional Modules

The second type of modules are the optional ones. These modules are used to enhance the functionality of the network. Some examples to illustrate the realm of possibilities:

- The *Advanced Transmission Module* introduces a more sophisticated channel access where slots are used.
- The *ACK-Module* is used for sending acknowledgments. It stores a copy of the packet sent and a timer is started in the controller. If no ACK is received when the timer expire, the transmission module is activated by the scheduler. The module is also activated when a packet is received and it is required to send an ACK.
- The *Security and Privacy Module* has as primary goal to authenticate devices in order to protect the Body Area Network from intruders. The second goal is to protect the privacy of sensitive information, i.e. medical data, by encrypting the data and/or encrypting the links between the authenticated devices. In order to obtain this, a private key can be exchanged.
- The *Power Control Module* acts on the transmission power of a node. This can be useful for limiting the number of neighbors and thus influencing the interference between nodes, or for lowering the power consumption and thus lengthen the lifetime of the node. This module not only considers the power control of each node individually, but can also look at the whole (or a large area) of the network. The module needs to work closely with the routing module. The routing module can ask to this module to alter the transmission power (and doing so the network topology) if no appropriate route to the destination can be found.
- The *Reliability Module* can be regarded as an extended version of the transmission module. It adds error control, better retransmission, priority queuing, . . . Stated otherwise, this module is responsible for providing QoS and guaranteed delivery. If wanted, one can define multiple modules that each take care of a QoS aspect.
- The *Data Aggregation Module* can be considered as an extension of the routing protocol. The data received by other nodes is aggregated prior to send them further to the personal device. Doing so, fewer transmissions are needed and the aggregated data can consist of fewer bits. Thus, the energy efficiency is increased.

– The *Local Data Processing* module adds the possibility to perform local data processing or in network processing.

6 Communication

When developing a framework, it is important to define how the communication in the framework should take place. This communication can be either within or between the framework and the application or physical layer or between nodes themselves. In this section, we will briefly describe how the communication is handled in MOFBAN.

The modules in the framework need to communicate with each other. This communication mostly is nothing more than passing parameters to a module or invoking another one. In the framework, this is handled by the controller. The module sends the parameters to the controller which stores it in the information module. By using the controller as gatekeeper to the database, data conflicts between modules can be avoided.

The interaction between the framework and the application interface is provided via a sort of API, usable by the application designers. The API eases the application development as the designers do not need to be aware of the underlying network characteristics. It allows the designers to adjust settings such as the required level of security, the maximum desired delay, the bitrate needed by the application,... The application interface also allows the application designer to select the modules needed in order to meet the characteristics of the network/application. The API informs the controller module which modules needs to be included in the framework.

The properties of the physical layer largely depend on the design of the hardware. In order to have a common interface usable by the framework, a mapping between the proprietary characteristics of the hardware and the more generic properties used by the framework is provided. Examples of such information are bit error rate (BER), path loss, received signal strength, ... Every time a packet has been received, additional transmission information can be communicated to the framework through the interface. The controller module receives this information and stores it in the information module.

A last type of communication can be found between similar modules located at different nodes. For this purpose, the packet header is used. As the framework is modular, i.e. modules can be added, removed or changed, the packet header should be capable of handling the modularity. This can be done by using a modular header structure. Each module can add an extension to the header. When a packet is received by a node, the header is analyzed by the controller module. The controller puts the data of the header in the database, determines which modules need to be activated, starts the first one and passes the required arguments to the module.

7 Future work

The framework presented in this paper serves as a preliminary proposal for a fully flexible modular architecture for WBANs. Various requirements considered in section 3 are covered, such as coping with heterogeneity, flexibility, ease-of-use, energy efficiency, . . . However, several improvements can still be made.

In a first step, we need to properly validate the framework and investigate thoroughly the impact of the framework on the overall performance of the network. The overhead introduced by MOFBAN should be examined. We believe that this overhead will be minimal due to the avoidance of duplication and the use of the central database. Further we will use the framework to test existing protocols for WBANS such as CICADA [13]. Based on the analysis, we will propose further improvements to have a more energy efficient solution. In a last phase, we envision to put the framework to test in a real-life testbed.

In the communication part, we have introduced the concept of the modular header structure. This structure is beneficial for reducing the overhead between nodes as data can be shared better and no redundant or duplicate data is sent over the network. Future research will specify the use of modular header structure and analyze its performance.

8 Conclusion

In this paper we have proposed a framework that supports the communication protocols in on-body networks. It is designed in such a way that it is more transparent for the application designer. The functionality of the framework is easily adaptable and expandable. This is made possible by the use of modules. Other resulting advantages are:

- Duplication of functionality is avoided and a simple structure is used. The framework can be regarded as being lightweight.
- Heterogeneity and QoS are well supported by using different implementations of the routing module or reliability module.
- Easy to add functionality by simply plugging in a new module in the framework.
- Quickly reconfigurable through the application interface.

Further, we have discussed the communication in the framework. The interaction between the modules is handled by the controller module and information is stored in a common database. Conflicts in the database are avoided by using the controller as gatekeeper. The controller module also takes care of the communication between modules, with the applications and physical layer en between the nodes. It further is responsible for activating the appropriate module at the correct time by using the scheduler. The controller module can be considered as the key element of MOFBAN.

Finally, we are convinced that MOFBAN will proof to be a starting point for the development of new protocols for communication in a WBAN. It will ease the development of new applications and trigger the use of WBANs.

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