Medical Body Area Network, Architectural Design and Challenges: A Survey

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Abstract. Medical body area network is a human-centric application of wireless sensor network which has recently gained much significance. The application includes both wearable and implantable sensors for continuous monitoring of patients in hospitals, old houses or at any remote location. These sensor nodes in medical body area network possess all the characteristics of nodes in wireless sensor network. In this paper a survey of medical wireless body area network, its architectural design issues and challenges have been discussed.

Keywords: Wireless sensor network, medical body area network: architectural design, reliability, energy efficiency and routing.

1 Introduction

Body area network is a subcategory of wireless sensor network for monitoring physiological conditions around human and animal body. It has many human-targeted applications such as sports, entertainment and healthcare etc. Medical body area network keeps track of patients' vital signs in hospitals, in homes and even when patients are mobile through continuous real-time monitoring to provide healthcare services to them. For better understanding of technology, first we will introduce wireless sensor network then body area network and its healthcare applications.

Wireless Sensor network is composed of thickly inhabited tiny sensors which interact with the environment by sensing or monitoring it and pass their data to a base station for further processing and controlling actions. It has a wide variety of applications [1] including but not limited to industry, agriculture, habitat, forest and environmental monitoring, home and office automation, healthcare and medicine, urban sensor network and energy management etc. It can also be used in the application areas of security, defense, military and disaster monitoring. Its healthcare applications [2] include home-based care, hospital or clinical monitoring, management of disaster relief and medical facility, sports health etc.

Sensor nodes in wireless sensor network are small in size and memory, low cost, low power, and equipped with low processing and computing power. These nodes are of two types i.e. source node which monitors the environment and sink

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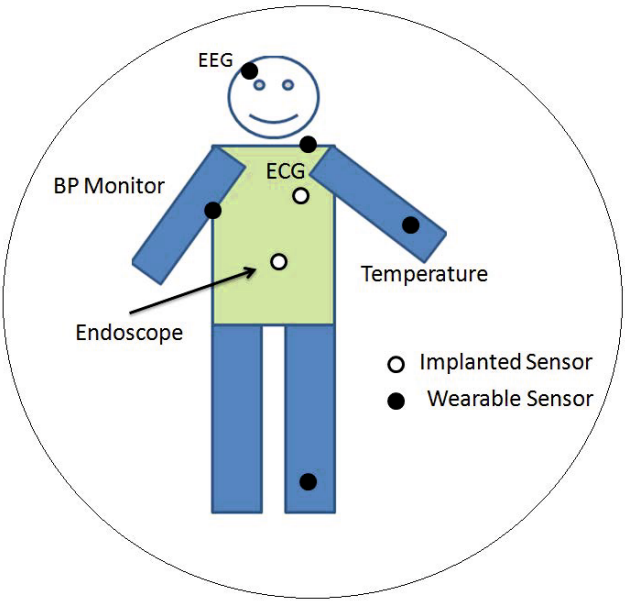

Fig. 1. Placement of sensor nodes on human body

which collects the information from the source and sends to base station. These nodes can be mobile depending on the nature of the application. In temperature monitoring application nodes are usually static and some applications like flood forecasting, transportation monitoring etc contain mobile nodes. Mobility can be categorized as sensor mobility, sink mobility and event mobility. Sensor nodes can be mobile to monitor a region or sense a phenomenon. For sink mobility it might be possible that a sink node is not a part of wireless sensor network e.g. PDA or laptop which remain mobile. The event can also be mobile. E.g. water in a river. There is a data centric communication in wireless sensor network which can be either in single-hop or multi-hop fashion [3]. Single hop communication supported in Bluetooth based wireless sensor network uses star like topology. In multi-hop communication relay nodes are involved which cooperatively pass on data to sink node. It is supported in ZigBee based wireless sensor network. Communication models used in wireless sensor network are periodic, event driven and query driven. In periodic data communication, sensor node periodically senses and sends data to the sink node e.g. monitoring weather, temperature etc. In a query based communication sensor nodes only transmit data when they receive any request from the sink node. In an event driven communication, sensor nodes only become active when a certain event occurs e.g. rise in temperature to threshold level etc.

Medical body area network slightly differs from other applications of wireless sensor network. Placement of sensor nodes on human body is shown in Fig. 1. Both internal and external sensors [4] are used for monitoring patient's vital signs. Internal sensors are ingestible or implanted devices e.g. core body

temperature sensor. External sensors are wearable or detachable electrical signaling devices e.g. pulse OXIMETER, ECG, EEG sensors etc. Sensor nodes in medical body area network possess all characteristics of wireless sensor network and are of two types i.e. source and sink which can be static or mobile. For example in ICU rooms patients are static and in emergency rooms patients can be mobile where they are waiting for a checkup. Communication model used in medical body area network mainly depends on the patient's condition. Similarly sensor nodes in the network can communicate with each other either in single hop or multi-hop manner. Topology is usually known and communication is hybrid because some patients need continuous monitoring and some non critical patients need only periodic or query based reporting. In medical body area network information is identity centric [5] because data comes from different sensors which belong to different patients.

There are already very well known and comprehensive surveys on body area network (e.g., [6],[7],[8],[9],[10]) which focus on challenges and open research areas such as topology issues, MAC and physical layer issues and routing challenges etc. These surveys are generic and give a broader overview of body area network. We surveyed body area network to highlight research challenges specific to patient monitoring applications. Different telemetry systems are used in hospitals for patient monitoring such as In Vivo medical telemetry systems, Philips IntelliVue telemetry system, GE healthcare telemetry system etc. In these telemetry systems monitoring devices are attached to transceivers via wires on the cost of patient comfort. These transceivers transmit the patient data to receiving devices which further forward this data to base station where it will be accessible to doctors or caretakers. These telemetry systems are very costly and also involve wiring to some extent. Developing countries have limited resources and are very deficient in education and healthcare facilities. People in developing countries are very prone to diseases due to poor living conditions and food quality. Patient monitoring using wireless sensors would become a very cost-effective system for developing countries. These systems also provide ease of mobility to patients along with continuous and real time monitoring of their vital signs. Medical body area network is facing many research challenges related to architecture, energy efficiency reliability, MAC, network and physical layer issues. In our survey we focused on research challenges of reliability, energy efficiency and routing in medical body area network. We also highlight some applications of body area network for patient monitoring and architectural designs and its related issues.

We have organized the rest of our paper as follows: Section 2 covers some application examples of medical body area network for patient monitoring. Section 3 presents the functional architecture and section 4 presents challenges in medical body area network which includes the reliability, energy efficiency and routing. Section 5 includes the recommendations for overcoming the challenges in medical body area network. In section 6 we emphasize research and technology related challenges of medical body area network in developing countries. We present the conclusions in Section 7 followed by reference listing.

2 Medical Body Area Network

Many systems have been proposed for remote or hospital monitoring of patients. One example is SMART (Scalable Medical Alert Response Technology) a hospital monitoring system proposed by Dorothy et al. [11] which integrates wireless patient monitoring, geographical-positioning, signal processing, targeted alerting, and also wireless interfaces for doctors and caretakers. It is implemented in waiting or emergency rooms for monitoring of the patients who are sitting there and waiting for a checkup and medical aid. Similarly Jeonggil et al. [12] presented a network model MEDiSN for emergency detection using wireless sensor network. MEDiSN is developed for hospital and disaster monitoring. In this model relay points are used to carry and pass on the data in multi-hop fashion. Octav et al. [13] discuss the shortcomings of MEDiSN and conclude that the sensing reliability of body area network has been ignored in MEDiSN which is more critical as compared to network reliability in body area network. This paper represents the deployment of wireless clinical monitoring system for monitoring of pulse rate and oxygen saturation rate of patients. Sharma et al. [14] presented a prototype for remote monitoring of medical vital signs of a patient i.e. ECG, breathing rate and body temperature. This paper presented the implementation of body area network in beacon mode in which network coordinator wakes up the sensor nodes to sense and transmit the data to base station.

The first step towards medical body area network is to design an efficient, cost effective and robust architectural design. There are many distinct features of the medical body area network architecture which makes it unique from other wireless sensor network applications. Limited numbers of sensors are strategically located on human body to sense different types of data. In the following sections we will discuss some architecture of body area network and their design issues.

3 Functional Architecture

A basic functional architecture of the medical body area is shown in Fig. 2 in which patient's data is transmitting to the base station via relay node from where authorized doctors can access it for taking the necessary actions. Relay node also sends the data to monitoring or nursing room and triggers alarms here if any patient's condition goes critical. A data driven architecture of the medical body area network is proposed by Yuan-Jen et al. [15] which divides the network into two parts. In the first part communication is between sensor nodes and database and in the second part between the database and user interface. The sensor node senses data in periodic or event driven environment but transmission will be demand based. Users have no direct control and they update or acquire information from the sensor nodes via web applications. In paper [16] authors presented the comparison between 1-hop star and 2-hop extended star architectures and concluded that not any architecture fits the environment. They gave some guidelines to effectively design body area network. Similarly Yu Ge et al. [17] investigated the impact of single hop star and multi-hop architecture designs and concluded

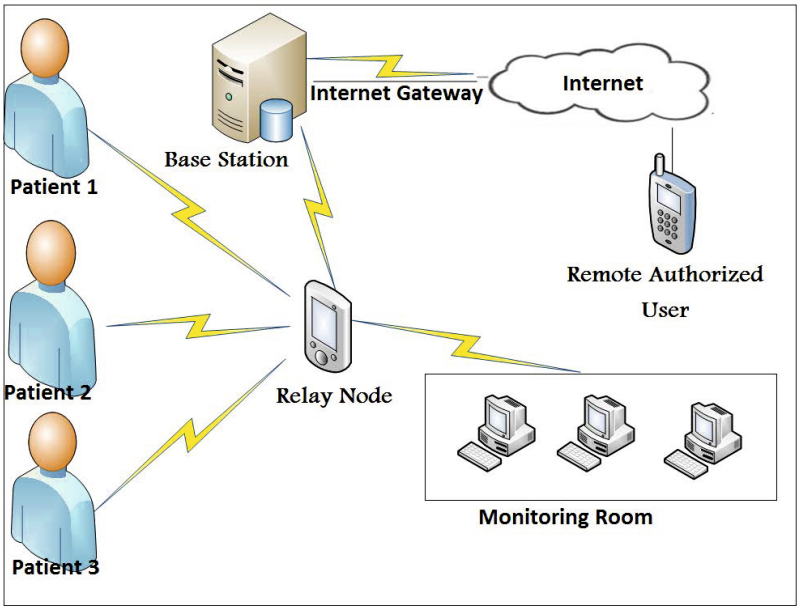

Fig. 2. Functional Architecture of Medical Body Area Network

that for reliable transmission of data multi-hop network architecture is efficient as compared to star architecture. Maha et al. [18] proposed a service oriented design for middle ware in body area network for continuous monitoring in care rooms or in old houses which also allow small scale mobility to patients. Sun et al. [19] presented architecture for medical body area network where different types of data are collected from patients. Network coordinator merges the data and sends it to the data centre or monitoring system.

There are many challenging requirements to be considered by designers while designing architecture of the medical body area network. For example appropriate placement of sensor nodes and relay nodes to reduce the interference so they can efficiently communicate with each other. To decide the number of sink nodes and their selection is a quite difficult task. The gateway provides connectivity to body area network towards other networks and internet. It is another challenge that which gateway approach should be used for body area network i.e. single gateway or multiple gateway approach. Architecture should be designed in a way they it should be robust and have the capability to resume from failures within very short time. Network failure of one unit could not affect the functionality of the other network. Besides architectural issues medical body area is facing critical research challenges such as energy efficiency, reliability and routing which should be addressed carefully. In the following section we will discuss these issues briefly.

4 Challenges

Due to limited power supply of nodes and critical nature of patient's data both energy efficiency and reliability have become very crucial issues. Routing is important in a way that it should consume minimum network resources. Following subsections present some related work of energy efficiency, reliability and routing in medical body area.

4.1 Energy Efficiency

Reason for sensor nodes being limited in power resources is their inexpensive nature and small size. Many protocols are introduced for power saving in medical body area network. Omeni et al. [20] proposed a MAC protocol for medical body area network which achieves energy efficiency simply avoiding collisions in the network by using an algorithm called clear channel assessment which is based on listen-before-transmit. HyungTae et al. [21] proposed an energy efficient MAC scheme in which a coordinator node controls the medium access by periodically sending beacon packets in order to synchronize the time slots among sensor nodes. Moshaddique et al. [22] proposed energy efficient MAC protocol which uses additional radio circuit to wake up the nodes. Using TDMA with wake up signal reduces the chance of collision and also increases the sleep time of nodes with acceptable packet delay. Sensor devices used in medical body area network can be broadly classified as wearable and implantable devices. To accommodate all types of devices in a single network is also a big challenge. In this context Timmons and Scanlon presented a medical MAC protocol named MedMAC [23] for energy efficiency and adaptability of channel access in medical body area. It uses TDMA for periodic data and also contains support for emergency data. An adaptive guard band algorithm is used to maintain the synchronization between nodes during their sleep.

Energy efficiency is a very important requirement of medical body area but it is still facing many research challenges. Algorithms for improving energy efficiency can cause unacceptable reliability issues, delays, latency for example duty cycles to avoid overhearing or idle listening. Turning radios on/off in sleep scheduling mechanisms consumes maximum energy. Both energy efficiency and reliability are controversial issues and we will have to draw a balance line of tradeoff between them. Techniques for ensuring reliability such as redundant data, retransmissions or acknowledgments utilize more network resources. In the following section we will discuss reliability then we will have a clear picture of these issues.

4.2 Reliability

Reliability in the detection and reporting of event is very critical because the patient's data is very sensitive in body area network. Other than network reliability sensor and software reliability is also a very important requirement. Software which maintains network devices, patients data and alarm systems should be

robust to failure and available all the time. Octav et al. [24] proposed a mechanism named DRAP to cope with the patients mobility in clinical monitoring using wireless sensor network for achieving first hop reliability on the cost of energy efficiency. A cooperative network coding scheme is proposed in [25] in which network coding and cooperative communication are combined for many to many network configurations which reduces the probability of packet loss and increases network throughput. This scheme also avoids the single point of failure. Increasing number of nodes decreases the performance of the network because single transceiver devices cannot handle the growing traffic in the network. Ivanov et al. [26] proposed an approach to solve this problem by introducing multiple channels at MAC layer along with multi-hop cooperative communication between medical and environmental sensors. Sampangi et al. [27] proposed a scheme to reduce the network delay and packet loss by introducing multiple intermediate sinks. This scheme also reduced the contention between the sensor nodes for single sink node. Octav et al [13] highlighted the deficiency of MEDiSN [12] and proposed oversampling to ensure sensing reliability. They also used an alarm system to inform if any sensing device disconnected from the system. Similarly MedMAC [23] which accommodates multiple types of sensors in the network for energy efficiency and adaptability of channel access is also ensuring the node reliability. Dongheui et al. [28] proposed a two level communication scheme to provide reliable data transmission in medical body area network. In proposed scheme different RF bands are used for communication of sensor nodes to gateway and from gateway to base station. They also developed software and hardware platforms to support this two level scheme which is composed of sensor nodes, gateway and data server. The software platform composed of network protocols, kernel and application layer. Stepan et al. [29] proposed virtual grouping medical body area network for quality of data and it's analysis. They also introduced a new parameter called quality of health monitoring to take feedback from the doctors on data quality.

The reliability mechanisms cause more energy consumption which reduces the network's lifetime. For ensuring sensing reliability using oversampling cause more energy consumption due to multiple transmissions. It also causes redundancy and overburdens the sink nodes to receive and handle the increasing amount of data. In case of network or hardware failure how will it resume, how much time it will take to resume and what type of the backup should be available are also challenges for reliability. Reliability and energy efficiency are important factors but routing is also attention-demanding in medical body area network. Medical body area network requires a routing protocol which provides reliable and energy efficient end to end data delivery.

4.3 Routing

A routing protocol for healthcare application of wireless sensor network must have support for both periodic and event driven data. Support for periodic data is necessary to continuously monitor the data and event driven data for reporting the vital signs of patient to the doctor is necessary for in time treatment of

patients. Routing protocols in healthcare monitoring can be categorized [30] as (1) periodic sampling, (2) event-driven monitoring and (3) hybrid monitoring. LEACH is a proactive protocol in which nodes periodically send their data to base station. TEEN is another cluster based algorithm which is reactive protocol for event driven monitoring. APTEEN is a hybrid protocol developed to merge the properties of both LEACH and TEEN protocols. Many sensors in the body area network monitor same observation region and have the same type of information. A routing scheme has been proposed [31] which selectively collects information from the nodes to reduce burden on the sink node by reducing transmissions in the network. Ababneh et al. [32] proposed energy-balanced rate allocation and routing protocol in medical body area network for load balancing and efficient rate allocation to nodes. EBRAR protocol builds a routing path on the basis of residual energy of nodes. Energy-balanced rate allocation and routing protocol force the packet to route through a path with nodes of higher energy towards the sink node. In this way it protects the nodes having lower residual energy. The proposed algorithm not only conserves the bandwidth of the system but also allows the nodes to transmit the data more intelligently and equally divides the burden of data transmission. C-AODV [33] is a routing algorithm for monitoring system which is based on cooperative communication among the nodes to obtain good performance tradeoff between the energy efficiency and reliability in the network. Hello message is sent to neighboring nodes for the purpose of acquiring informing about the node's queue length. On the basis of congestion in queue length the nodes take the decision of selecting a next hop for required destination. Quwaider et al. [34] proposed routing algorithm for location based store-and-forwarding of packet with frequent postural partitioning which provides the better routing delay performance. In order to reduce the electromagnetic interference from wireless sesnsor network in healthcare applications Quang et al. [35] proposed an adaptive and distributed routing protocol called EMI-aware routing protocol (EMIR). The algorithm assigns a positional value to each node. On the basis of this calculated value the traffic is diverted from the nodes with high electromagnetic interference or which are located far away from the gateway. Security is also an important feature in the medical body area network. Security concerns and threats can cause patients to suffer dangerous conditions or even death. Xiaohui et al. [36] proposed a routing protocol called distributed prediction based secure and reliable routing framework which provides reliability and prevention against the data injection attacks e.g. denial-of-service attack etc.

Routing is first step which will be performed in body area network. Sensing and transmission of data come next to it. All the steps involving in routing process such as neighbor discovery, maintenance of routing tables and path discovery and path maintenance all are resource consuming process. Reactive routing protocols cause delay in communication while proactive protocols cause so much utilization of network resources. Selection of appropriate routing protocols which should be reliable and energy efficient is still a question mark in research and needs to be addressed carefully.

5 Recommendations

Reliability is the most important requirement and critical issue in medical body area network. In star topology there is a single point of failure and it can cover only a small area. Nodes which are located at a long distance from the cluster head require a larger transmission range. Multi hop communication is a good option for ensuring communication reliability. For sensor reliability alarms should be introduced if devices disconnected from the network and there should be some mechanism to check the reliability of sensing data. For software reliability there should be back-up in case if the software fails. All the network devices which have a direct electricity supply should have backup energy resources so that network should be available all the time if an electrical failure occurs.

In the body area network energy efficiency and reliability are especially critical at first hop where there is communication between sensors and relay nodes. Sensors have limited power supply and can also be mobile while relay nodes are intelligent devices and are rich in resources i.e. power supply, processing and computing power etc. We can divide the network into two parts. At the first hop there is need of high reliability and energy efficiency and we can focus on this part. In the second part there will be communication between relay nodes and gateway to send the data to the base station over wired or wireless channel. Energy efficiency is not a big problem because the devices are having rich resources. Here we can focus on reliable data transmission and solving the interference problem.

The medical monitoring application involves transmission of vital signs of patients to the central base station. The main requirement in medical body area network is transmission of data so routing in the network should not be resource and bandwidth hungry. Building and maintenance of reliable routes should be efficient enough so that we can save energy in the routing and use it in communication of vital signs. At some points in the network we need proactive routing schemes and sometime we need reactive routing. The proactive routing scheme is more energy consuming and has larger overhead. We have to efficiently select the routing scheme in order to achieve energy efficiency but not on the cost of reliability in the network.

6 Challenges for Developing Countries

Medical body area network is very helpful and cost effective assisted living application. Developing countries can use this technology to improve the healthcare facilities for their people. Besides technology related issues medical body area network can face some extra challenges while introducing in developing countries. Implementation of this technology should be cost effective. Training of medical staff to use this system is an important task. There might be a possibility that users will be reluctant to use new technology. There are some issues specifically related to requirement of market research. User-friendliness,

cost effectiveness, interoperability and compatibility of the medical body area network are key challenges for gaining market placement in developing countries. Many questions can arise for market placement that who will be expected buyer of this system? Who will be liable for damages and malfunctioning of system? What will be an acceptable cost for both customers and stakeholders? Who will be the owner of patients data in hospitals? Who will be able to access the data of the medical body area network? All these points should also be considered for implementing this technology in developing countries.

7 Conclusion

In this paper we have discussed the common properties of wireless sensor network and presented a survey of its health related applications. We have surveyed of medical body area network and discussed its implementation in hospital for clinical monitoring and disaster relief. We also discussed architectural design and challenges of body area network. While discussing the challenges in body area networks applications in healthcare we have touched upon reliability, energy efficiency and routing as these are the issues of great interest. There is a tradeoff between reliability and energy efficiency. There is a need to develop an efficient communication protocol which achieves both reliability and energy efficiency at an acceptable tradeoff level. We also discussed the benefits of introducing medical body area network in developing countries and challenges regarding this context.

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