

Wireless Communications Technology in Telehealth Systems

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Abstract—Telehealth is an inter-disciplinary area and is basically the delivery of health and medical information and services over large and small distances using electronic information and communication technologies. Broadband wireless services available today, along with more powerful and convenient handheld devices, will enable a transformational change in health management and healthcare with the introduction of real-time monitoring and timely responses to a wide array of patient needs. Further, a network of low-cost sensors and wireless systems help in creating constantly vigilant and pervasive monitoring capability at home and at work. This paper addresses recent efforts in this growing field, including standards, system architectures, and lower layer protocols for body area networks. The paper also suggests the use of cooperative transmission-based strategies for such wireless topologies.

Index Terms—Routing for body area networks, telehealth, wireless communications, telemedicine, cooperative transmission.

I. INTRODUCTION

Telehealth is a fast-growing inter-disciplinary area, in which electronic information and communication technology is used to deliver health and medical information and services over large and small distances. Telehealth includes telemedicine, which offers empowerment, a better quality of life, and a reduced cost of care for patients with chronic disease, such as cardiovascular disease, diabetes, chronic respiratory diseases, and cancer [1]. However, telehealth also includes applications for healthy people, who want to maintain or improve their health.

The application of wireless communications is already quite common in hospital and emergency settings [3]. Some examples of medical equipments include heart, blood pressure and respiration monitors [2]. In addition, emergency medical service companies are, or will be, important users of telemetry and other wireless technology [3]. In vehicles, telemedicine equipment can be as simple as a cell phone or a laptop computer with two-way videoconferencing capabilities. More sophisticated vehicles offer mounted video cameras that the hospital emergency physician can pan and zoom remotely [4].

Another very common form of telemedicine that has generated a lot of interest in the networking community is remote patient monitoring [5], which facilitates an improved quality of life for the patient by enabling the measurements to be made anywhere there is a phone connection, and by reducing the need for routine trips to the clinic. While such systems have demonstrated positive outcomes, e.g. in terms of reduced

number of trips to the emergency room [2], wireless monitoring promises further improvements by providing continuous monitoring, patient mobility, and improving patient compliance with frequent and better quality measurements. This paper reviews some of the remote monitoring architectures in use today as well as some that have been proposed. The paper also reviews the standards and routing schemes that have been proposed for body networks, and suggests the use of cooperative transmission for such wireless network architectures.

II. REMOTE MONITORING ARCHITECTURES

Patient monitoring can be classified into two categories, namely “On-body” monitoring and “In-body” monitoring. On-body monitoring refers to sensors that are strategically placed on or near the skin, while the in-body monitoring refers to implanted sensors. Wireless transmission in both categories is characterized by extremely low peak power and low duty cycle, to extend the life of the batteries. For implants, low power and duty cycle also enable the body to safely dissipate the heat generated by the transmission. The transmissions must also be reliable and not cause excessive interference to other applications in the same band.

Several standards already in use or being considered for use for wireless remote monitoring are listed in Table I. All the standards except the first have been considered for on-body BANs. The IEEE 802.15 family of standards address the wireless personal area network (WPAN). The IEEE 802.15.4 physical and link layer standard was initiated to “investigate a low data rate solution with multi-month to multi-year battery life and very low complexity” and to operate in an unlicensed, international frequency band [8]. IEEE 802.15.4 underlies Zigbee, a popular open industry standard that provides high-level functionality concerned with network structure, message routing and security. IEEE 802.15.4a is an amendment to IEEE 802.15.4, ratified in 2007, that provides an alternative low-data-rate physical layer; its aim is to provide “communications and high precision ranging/location capability (1 meter accuracy and better), high aggregate throughput, and ultra low power; as well as adding scalability to data rates, longer range, and lower power consumption and cost” [9]. The IEEE 802.15 Task Group 6 (802.15.6) is developing a communication standard (not shown in Table I) “optimized for low power devices and operation on, in or around the human body (but not limited to humans) to serve a variety of

applications including medical, consumer electronics personal entertainment and other” [10], however, there is little information available about this developing standard at the time of this writing.

In 2000, the FCC established the Wireless Medical Telemetry Service (WMTS) [11] [14] [16], which designates the bands 608-614 MHz, 1395-1400 MHz and 1427-1432 MHz (a total of 16 MHz), for medical telemetry [13]. Land-mobile radios and television are not allowed to operate on these frequencies, making this band safe from these sources of RF interference [14].

According to the FCC website, “WMTS equipment may be used only within a health care facility. The FCC currently does not allow home use of WMTS equipment because of a concern that temporary use of such equipment at many dispersed locations would make it difficult to coordinate the operating frequencies, resulting in harmful interference. The FCC has indicated, however, that it may revisit the issue of home use of WMTS equipment in the future if experience suggests that home use can be effectively coordinated to avoid interference. The same interference concerns that led the FCC to exclude WMTS equipment from home-use also led it to prohibit the use of WMTS equipment in vehicles, including ambulances. It would be difficult to ensure that WMTS equipment operated in ambulances or other vehicles would not interfere with other WMTS equipment operating on the same or adjacent frequencies at fixed sites in hospitals and health care facilities within the area passed by the ambulance” [12].

The WMTS band suffers from several limitations, primarily low bandwidth and adjacent channel interference [11]. The largest band is only 6 MHz, and the adjacent channel interference makes it effectively smaller [11]. The two main advantages are (1) support is simplified because of band exclusivity, and (2) customers are less likely to change because they have to change out all the equipment [15]. Because of these pros and cons, hospital monitoring vendors are split on the use of WMTS and 802.11 [15].

Most papers about implanted wireless transmitters assume the medical implant communications service (MICS) standard, which is defined for the 402-405 MHz band, although there are exceptions such as [23], which considers IEEE 802.15.4, [22], which considers MICS and the 2.4 GHz band, and [46], which considers MICS, 868 MHz, and 2.4GHz bands.

A. On-body Patient Monitoring

A typical hierarchical architecture for patient monitoring system is shown in Fig. 1 [5]. The lowest level encompasses a set of wearable or on-body physiological sensors (such as ECG sensors, tilt sensors, motion sensors, etc.), which together form a BAN; the second level is the personal server; and the third level encompasses a network of remote health care servers. The information is relayed from the BAN to a personal server, which could be an internet-enabled PDA or a 3G cell phone. This personal server acts as the gateway to the internet and provides the human-computer interface

and communicates with the remote server(s). The last hop is to the accessing client, which could be the medical doctors, caregivers, physicians, etc. While phone or the PDA is a convenient device for connecting to the internet, the main disadvantage is that the phone or the PDA is a single point of failure, and redundancy is desirable for critical applications [15].

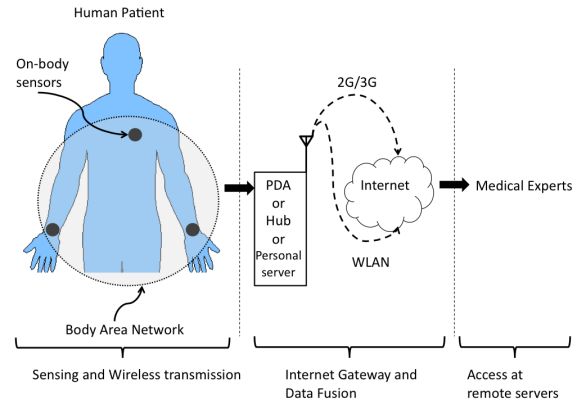


Fig. 1. Typical generic architecture for remote patient monitoring.

Some specific examples are the sleep management system [28] and the biofeedback system for posture correction [29]. In both systems, multiple sensors are connected by wire to a communication module, which communicates wirelessly to a gateway module. The gateway connects to the internet via WiFi or GPRS [28], and for the close-loop system in [29], the user gets audio biofeedback from the PDA via the headphones.

B. Monitoring with Implants

For chronically ill patients requiring frequent updates of health parameters, implanted wireless biosensors can provide increased convenience (e.g. no cleaning and re-application), more mobility, and no embarrassment because of visible devices. From a medical viewpoint, implanted sensors provide more precise measurements and continuous patient compliance [30]. Cardiac treatment (e.g. pacemakers and implanted cardioverter defibrillators (ICDs)) make up the largest segment of the implant medical telemetry market [36], however other applications include implants include insulin pumps [33], glucose monitoring [37], and blood pressure monitoring [38].

Early pacemakers and ICDs transmitted at 175 kHz over a few centimeters of range between the pacemaker device under the collarbone to a reader/programmer held against the skin over the implanted device [39]. More recent models communicate in the MICS band with a bedside unit or cellphone [41].

While several research groups have simulated wireless networks comprising multiple implants [42], [23], [65], there are no such networks in practice, to the best knowledge of the authors. One reason why multi-implant networks may not happen very soon is that surgeons do not like to make multiple incisions, which take more time and increase the patient’s vulnerability to infection [43].

TABLE I
CURRENT STANDARDS FOR ON-BODY SENSORS AND IMPLANTS IN THE HUMAN BODY

Standard	PHY Layer	Band of Operation	Cited in
MICS[7]	4-FSK/2-FSK	402–405 MHz	[22]
IEEE 802.15.4 [18]	DSSS, BPSK/DSSS, O-QPSK/CSS	868(Europe)/915(US)/2.4 GHz	[23]
IEEE 802.15.4a UWB [19]	BPM-BPSK with spreading	250–750 KHz/3.1–5 GHz/6–10.6 GHz	[24]
UWB [20]	PPM	3.1–10.6 GHz	[25]
WMTS[21]	IEEE 802.11x-based (e.g. PSK, OFDM)	608–14/1395–1400/1427–32 MHz	[26]
IEEE 802.11a/b/g [15]	PSK, DSSS, OFDM	2.4 GHz	[11]

C. Propagation Models

The wireless channels for BANs can be classified into around the body (“around”), within the body (“in-in”), and from inside to outside of the body (“in-out”) channel models. Wireless channels are usually characterized by path loss, which depends only the distance between the transmitter and receiver, shadowing, which is a random variation in received power caused by obstructions, and multipath fading, which is a random variation in received power caused by sometimes constructive and sometimes destructive vector combination of the electric fields of reflected and refracted paths. From [44]–[47], striking disparities in the attenuations for different frequency bands and between the “in-in” and “around” channels are observed. A more comprehensive review of propagation models can be found in [48].

III. BODY AREA NETWORK MAC AND ROUTING SCHEMES

Communication between the wireless body area network (WBAN) sensors and the hub or PDA is an example of the classic “reach-back problem,” in which a cluster of radios communicates with a distant destination [59]. In general, if every sensor can transmit directly (i.e. in a single hop) to the hub, then the network can have the star topology, shown for a WBAN in Fig. 2 (a). However, a single sensor cannot always communicate directly to the hub because of the energy and power constrained nature of the sensors, and because of the multipath fading and shadowing discussed above. Multi-hop routing, shown in Fig. 2 (b), is a traditional wireless communication approach to this problem. Here, the goal is to pass the message to the node that is in the “best” position (metrics will be discussed below) to transmit to the hub device. An alternative, and relatively new, physical layer approach is cooperative transmission, in which at least one radio assists another in the transmission of a single message. Below, we give a brief review of these approaches.

A. Single hop

For the star topology, a design challenge is the Medium Access Control (MAC) protocol, which decides which radio will have access to the hub at any given point in time, in any given channel. For routine transmissions, the hub under the MICS standard must “Listen Before Talk (LBT),” “to minimize harmful interference to other equipment or services,

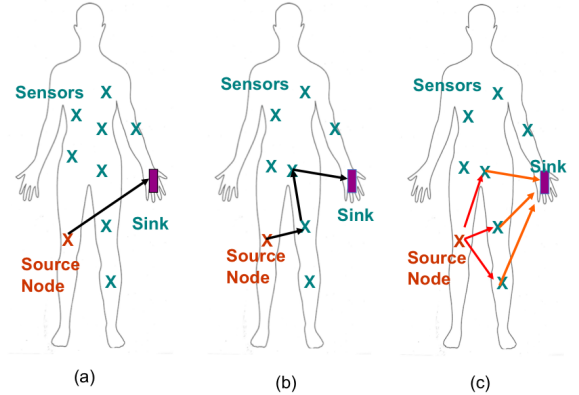


Fig. 2. (a) Single hop routing, (b) Multi-hop routing, (c) Cooperative routing.

reduce the potential for disturbance to this equipment from ambient sources or other medical device users in the band and provide a high degree of link reliability in the interest of the patient” [7]. If there is a emergency “medical implant event,” then a sensor is allowed under MICS to transmit a short message without LBT [7].

Very recently, researchers have realized that the timing of the routine WBAN sensor reports is quite predictable, changing only when a new device joins the network or when a previously networked device leaves the network [62] [63]. Therefore, a scheme such as Carrier Sense Multiple Access/Collision Avoidance (CSMA/CA), which is used in the 802.11 (“WiFi”) MAC, wastes energy resolving contention for the channel each time a message is sent. Researchers have devised ways for the sensors to figure out, among themselves, a Time-Division Multiple Access (TDMA) protocol, that enables the sensors to make their reports in an orderly and efficient sequence [62] [63].

B. Multi-hop

The multi-hop approach routes the message along a sequence of short hops or links to one node that is in a favorable location to transmit to the hub. Each transmission along the route is intended only for the next node along the route, and the desired signal for each receiver along the route is that transmitted by the previous node on the route. This strategy requires less transmit power compared to the single-hop routing schemes. Most of the work on routing in the literature

today treats large networks comprising more than 50 nodes, and covering much larger distances (e.g. 100 m), typically requiring many hops between a source and destination [49]. Therefore, many of these schemes do not apply to the small WBAN network.

One class of multihop routing algorithms that do apply are the cluster-based algorithms: LEACH [50], PEGASIS [51], and HIT [52]. In a large network, the cluster-based algorithms start by partitioning the network into clusters; for WBANs, it is possible that there is only one cluster. Within a cluster, LEACH elects a cluster head (CH) that will transmit to the hub; all other nodes in the cluster transmit to the CH. CHs are re-elected over time so that different nodes can share the burden of being a CH. PEGASIS also elects a CH, but forms a multi-hop chain that leads to the CH. As the message is passed along the chain, data fusion (i.e. local data processing to reduce the number of bits transmitted) takes place. HIT is similar to PEGASIS, but has multiple routes to the CH. [17] proposes rotation of the CH to avoid tissue heating.

Braem et al [53] carefully craft a tree-spanning protocol for the WBAN that also includes the MAC function, with emphasis on delay. [53] assumes levels, parents, and children are all determined beforehand and that a node's range includes only its parent, its children and nearby siblings. The protocol is distributed; a node computes its "WASP scheme," or MAC schedule, based on its parents WASP scheme and on the demands of its siblings and children. Ren et al. [54] take a formal optimization approach to jointly optimize MAC and congestion control. The metrics considered are latency, throughput, fairness and energy efficiency. [55] and [56] also propose an additional metric based on bioeffects (body heating).

C. Cooperative Transmission for Body Area Networks

Cooperative transmission (CT) is another approach to the reach-back problem. CT differs from conventional multi-hop in that a receiver combines versions of the same message from multiple transmitters [57], [58]. When two or more nodes transmit the same message to a given destination through orthogonal channels that fade independently, the benefit is realized because chance that all the both links fade at the same time is small; therefore, the fade margin can be reduced while still maintaining the same packet error rate. The amount of power reduction is called the diversity gain.

To get the diversity gain from cooperative transmission, the cooperating nodes, which would be the skin patch sensor nodes or implanted sensor nodes, must have sufficient separation in space to ensure that their links to the hub have uncorrelated fading. For indoor scenarios, because of the rich scattering, a separation of only a half wavelength of the carrier (e.g. 6 cm at 2.4 GHz, the WiFi frequency) should be sufficient for skin-patch nodes[61]. The same separation is also good for in outdoor pico-cellular and micro-cellular environments, where there are lots of walls and objects in the environment [61]. To the best knowledge of the authors, no measurements have been

performed to determine the required separation of implanted sensors to ensure uncorrelated fading to the hub device.

A cooperative transmission technique that requires low overhead is the Opportunistic Large Array (OLA) approach of [59]. In an OLA, nodes behave without coordination between each other, but they naturally fire at approximately the same time in response to energy received from a single source or another OLA [59]. All the transmissions within an OLA are repeats of the same waveform, therefore the signal received from an OLA has the same model as a multipath channel. As long as the receiver, such as a RAKE receiver, can tolerate the effective delay and Doppler spreads of the received signal and extract the diversity, decoding can proceed normally. The large number of nodes participating in an OLA offers array gain and reduces the per-node transmit power, which in turn, reduces heating effects in implants.

IV. CONCLUSIONS

The Telehealth field is currently an extremely active interdisciplinary research area. The research includes modeling physical, link, and network layer protocol development, and the creation of new applications for healthy and sick people. An IEEE Task Group is working on a new ultra-low power body area network (BAN) standard, which will enable more applications. New MAC protocols and cooperative transmission techniques aim to increase reliability and reduce energy consumption. The engineers computer scientists are clearly intrigued by the topic; however, more communication between engineers and doctors will be necessary before BANs, and particularly implanted BANs, can become practical.

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