Towards Key Issues of Disaster Aid based on Wireless Body Area Networks

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Abstract

With recent advances in wireless communication and low-power miniaturized biomedical sensor and semiconductor technologies, wireless body area networks (WBAN) has become an integral part of the disaster aid system. Wearable vital sign sensors can track patients' status and location, thus enhancing disaster rescue efficiency. In the past few years, most of the literatures in the area of disaster aid system based on WBAN have focused on issues concerning wireless sensor design, sensor miniaturization, energy efficiency and communication protocols. In this paper, we will give an overview of disaster aid, discuss about the types of network communication as well as outline related issues. We will emphasize on analyzing six key issues in employing the disaster aid system. Finally, we will also highlight some of the challenges that still need to be addressed in the future in order to help the disaster aid system be truly and widely accepted by the public.

Keywords: wireless body area networks, disaster aid, emergency response, cloud data storage, wireless sensor networks

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1. Introduction

A mass casualty incident (MCI) is often caused by natural disasters such as an earthquake, tsunami, volcanic eruption, fire hazard or terrorist attacks. For example, the Great Sichuan Earthquake has caused 69,180 known deaths and 374,176 casualties according to the official report in China [1]. The Chinese government and non-governmental organizations (NGO) had dispatched a number of medical workers to carry out rescues, and many rescue teams from South Korea, Japan, Singapore, Russia and Taiwan arrived at the disaster area and took part in the rescue effort, but still more responders were needed. The same thing happened in Japan where, according to the report of Japanese National Police Agency, 15,870 deaths and 6,114 casualties were reported in the 2011 Tōhoku earthquake and tsunami [2]. These disasters have caused massive casualties and have involved various types of responders or doctors. Unfortunately, compared with the large number of patients, responders, especially those who were experienced in rescuing were in very short supply at the disaster scene. The responders were thus required to take care of the patients with limited resources under the intense pressure of limited time [3].

Traditionally, if a MCI happens, the emergency response process is separated into three stages, namely the triage, treatment, and transportation. The rapid and accurate triage of the patients is important. A frequently-used method is the Simple Triage and Rapid Treatment (START) developed in 1983 by the staff members of the Hoag Hospital [4] and Newport Beach Fire Department [5] located in California. The responders that arrive first perform triage by attaching a paper tag that is either green, yellow, red or black. The patients are labeled with one of the four colored triage tags, which indicates the severity of the injury. Those with red tags are considered to be in a life-threatening condition and need immediate medical attention; the yellow ones are those in a less severe condition than red ones and can wait up to one hour before receiving medical attention ; the green ones are those who are the least severely injured; the black ones are those who are either deceased or mortally wounded, and are expected to die in spite of immediate medical attention [6].

Once casualties have been triaged, they can then be moved on to the appropriate treatment areas. These treatment areas will be within walking distance and will be staffed by an appropriate number of properly certified medical and supporting personnel. Upon arrival at the treatment area, the secondary triage allows for in-depth reassessments, and the patients' injuries are given initial treatment to stabilize their conditions until they can be released (in the case of green-tag casualties), transported for further treatment (in the case of red-tag and yellow-tag casualties), or transported to the morgue (in the case of black-tag casualties). After triage and treatment have been carried out, the final stage in the pre-hospital management of a is the transportation of the injured and the ill to a hospital for more definitive care [3, 7].

There are a few drawbacks in the traditional process. They are as follows [8]:

(a) *Insufficient information*: In such an urgent environment, the responders have little time to record the vital signs and chief complaints in detail, which would cause reading the tags later to be difficult. At the same time, as the paper tag has limited room for recording essential information, there is only little effective feedback for the medical personnel. In addition, four categories is also not able to ensure sufficient triages.

(b) *Discontinuous monitoring*: If transportation to a hospital is delayed, the responder must reassess the patients every 5 to 15 minutes. Considering the large number of patients, the task cannot be completed effectively. Vital signs such as blood pressure, blood glucose, pulse oximetry and respiration rate, cannot be notified promptly, which will lead to unnecessary deterioration of the patients' conditions.

(c) *Inability to track location of patient*: Patients who can move freely often depart from the disaster site without authorization from the commander of the emergency medical service (EMS). When patients contaminated with hazardous materials (e.g. cholera) depart before they have been decontaminated, public facilities and receiving hospitals will run into the risk of secondary exposure. Therefore, accurately tracking of the patients' location should be carried out continuously.

(d) *Lack of telemedicine*: Shortage of medical personnel at the disaster site has been a problem for a long time, and doctors who are far away from the site cannot participate in the rescue effort. The patients' physiological status cannot be shared to other doctors, and video conferencing or other collaborative tools cannot be employed, thereby resulting in some patients having to go without receiving help for a long period of time.

To resolve some of these challenges, studies on the disaster aid system for mass casualties have been launched in several research institutes such as the Sensor Network Laboratory of Harvard University [9] and Johns Hopkits University Applied Physics Laboratory [8]. Wireless body area networks (WBAN), which includes body sensors and wireless communication, have been introduced into the aid system.

CodeBlue, developed by Prof. Matt Welsh et al. of Harvard University, is a wireless infrastructure intended for deployment in emergency medical care which integrates low-power devices, wireless vital sign sensors, PDAs as well as PC-class systems. CodeBlue can enhance the responders' ability in assessing patients at the scene, thereby ensuring the seamless transfer of data among reponders, facilitating efficient allocation of hospital resources as well as supporting reliable, ad hoc data delivery, a flexible naming and discovery scheme as well as a decentralized security model [10]. Prof. Matt Welsh et al. have developed a range of wireless medical sensors based on the popular TinyOS "mote" hardware platform. A wireless pulse oximeter and wireless two-lead EKG are the first two sensors developed by his lab. The details will be shown in Section 3.1.

The Advanced Health and Disaster Aid Network (AID-N) has been presented by T. Gao et al. based on CodeBlue, which relieves responders from the burden of manually recording vital signs on hardcopy pre-hospital care reports. The AID-N electronic triage tag operates under very low power constraints. Furthermore, the development of a lightweight triage tag, a portable BP mote, a lightweight EKG mote as well as the results from a disaster drill are described in detail. The current methodologies in emergency response are prone to error and are burdensome. The AID-N triage system allows for the rapid gathering of vital signs and location data as well as the pervasive real-time transmission of these data to a central server. The ubiquitous collection of vital sign information and location allows one to better understand what has exactly occurred during a MCI and to plan efficiently for such an event. See details of location-tracking employed by MoteTrack in Section 3.3.

Compared with the traditional process methods of MCIs, the disaster aid system based on WBAN boasts the following advantages:

(a) *Automatic data collection and sharing*: Wireless sensors are used to collect physiological data of patients automatically, which can then be forwarded to a data server through the communication infrastructure. Other medical workers can access the data server through the Internet or 4G cellular network and diagnose remotely.

(b) *Mobility and flexibility*: WBAN users are able to move around freely, which is made feasible by advancements in lightweight, small-size, ultra-low-power and intelligent wearable monitoring sensors [11]. The medical workers and authorized users can acquire patient data via PDA, loptop, PC, or mobile handheld. It is more convinient to select an appropriate device based on the need of the disaster site.

(c) *Accurate location*: By using a GPS receiver and an indoor location sensor to track the patients in an outdoor or indoor environment, the responder is able to locate patients in an emergency situation accurately. The EMS commander can then plan the rescue effort efficiently.

(d) *Effectiveness and efficiency*: The signals provided by the body sensors can be effectively processed to obtain reliable and accurate physiological estimations [12, 13]. If the physiological estimation exceeds the threshold, the system will sound a warning so that the responder can cope with the sudden deterioration of certain patients immediately.

From what have been discussed above, most incidents are marked by a relatively sudden and dramatic event that causes a surge in a number of patients. Emergency response should cover a wide range of incidents of various degrees of severity. The disaster aid system based on WBAN can enhance the information collection capability for responders and help the commander to make more effective decisions in order to plan a rescue. In order to provide a better understanding of this emerging domain, we propose to give an overview of the disaster aid system, discuss the types of network communication, and review related issues and challenges.

The remainder of this paper is organized as follows: We discuss the architecture of WBAN-based disaster aid system in Section 2. In Section 3, we review key issues of disaster aid or emergency response such as biomedical sensors, multi-MAC bridging, location technologies, data storage, and middleware. Section 4 outlines some problems that need to be resolved in the future, and Section 5 concludes this paper.

2. Architecture of WBAN-based Disaster Aid System

WBAN is implemented with single hop star topology where the network coordinator wakes the sensor node up for data transmission. The wireless sensor nodes collect information of a body, relay it through the coordinator and store the biological information on the data center through the communication infrastructure. Fig. 1 illustrates the general architecture of a WBAN-based disaster aid system.

There are three tiers of communication infrastructures: (1) local connectivity, e.g. WBAN for communication and data collection, an indoor/outdoor localization technology; (2) backbone connectivity where the physiological data of the patients are transferred to the cloud storage system normally through 4G cellular network. If the public communications infrastructure has been destroyed by the disaster, the local wireless hub and temporary data center will be used as backup; (3) and Internet connectivity where responders, doctors and EMS officers can access the cloud storage server and share data of patients through the Internet.

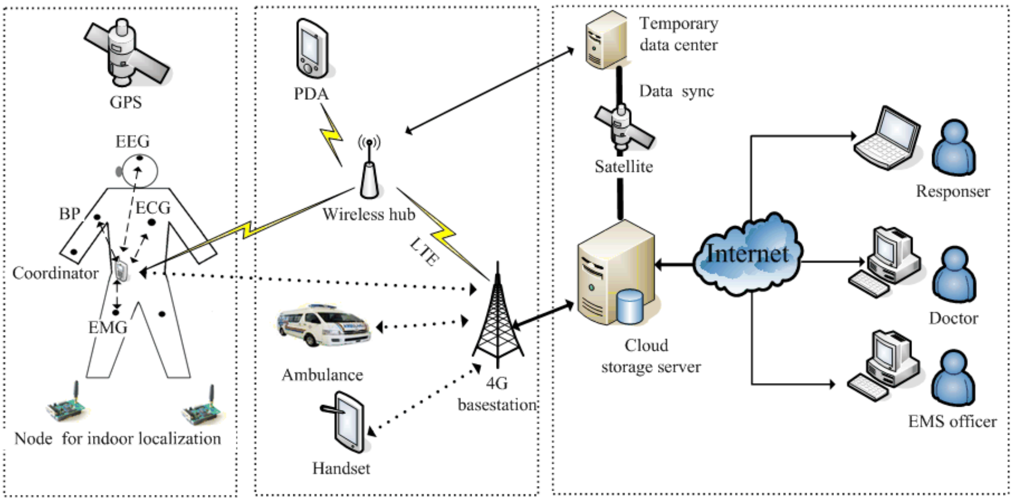

Fig. 1. Architecture of WBAN-based disaster aid system.

The communication protocols of the disaster aid system are complex. In local connectivity, the WBAN or ad hoc network employs different MAC protocols to save energy comsumption. Different bands are also employed in order to accommodate the internal and external environments of the body. In the LTE cellular network, Frequency Division Duplexing (FDD) and Time Division Duplexing (TDD) are the standards of 4G, whereas the Multiple Input Multiple Output (MIMO) technique is used to increase the communication bands, and certain control protocols manage the channel allocation. For Satellite Communication, the communication between satellite and ground basestation uses the 1G-10G electromagnetic wave, and the Internet is upgraded from IPv4 to IPv6. Table 1 shows the communication protocols for WBAN-based disaster aid.

Table 1. Communication protocols for disaster aid system

Network Layer	WBAN or Ad Hoc	LTE cellular network	Satellite Communication	Internet network
Physical	ISM, MICS, UWB	FDD, TDD (OFDMA, MIMO,SC-FDMA)	Electromagnetic wave	Twisted Pair, Fiber
MAC	CSMA, TDMA, Slotted ALOHA, BTMA, MACAW, FPRP, or a combination of both	HARQ	CFDAMA, RRAA, D-RRAA, MF-TDMA	CSMA-CD
Router (Control protocols for LTE)	OLSR, TBRPF, DSR, AODV, ABR, ZRP, SHARP, MP-DSP, ADMR	RLC, PDCP,RRC	TLSR, MLSR, SGRP, DRP-BM, SDRP, THRA, TDRP, T-ARP	RIPng, OSPFv3, IS-ISv6, BGP4+

2.1 Local Connectivity

The local connectivity can be further sub-categorized as: (1) communications between the body sensor and coordinator; (2) communications between the coordinator and wireless hub/LTE basestation; (3) wireless indoor localization network and outdoor GPS localization.

Due to the high accuracy and real-time nature of the physiological data collected from the patients as well as their location information, the design of local connectivity is critical.

Several body sensors and one coordinator are to be organized into logical sets, referred to as WBAN, and coordinated by their respective coordinator for medium access, as illustrated in **Fig. 2**. There should be only one coordinator in a WBAN, whereas the number of sensors in a BAN is to ranges from 0 to 3m. In a one-hop star WBAN, frame exchanges are to occur directly between the sensor and the coordinator of the WBAN [14]. The coordinator is responsible for collecting patients' data and relay it to the backbone network.

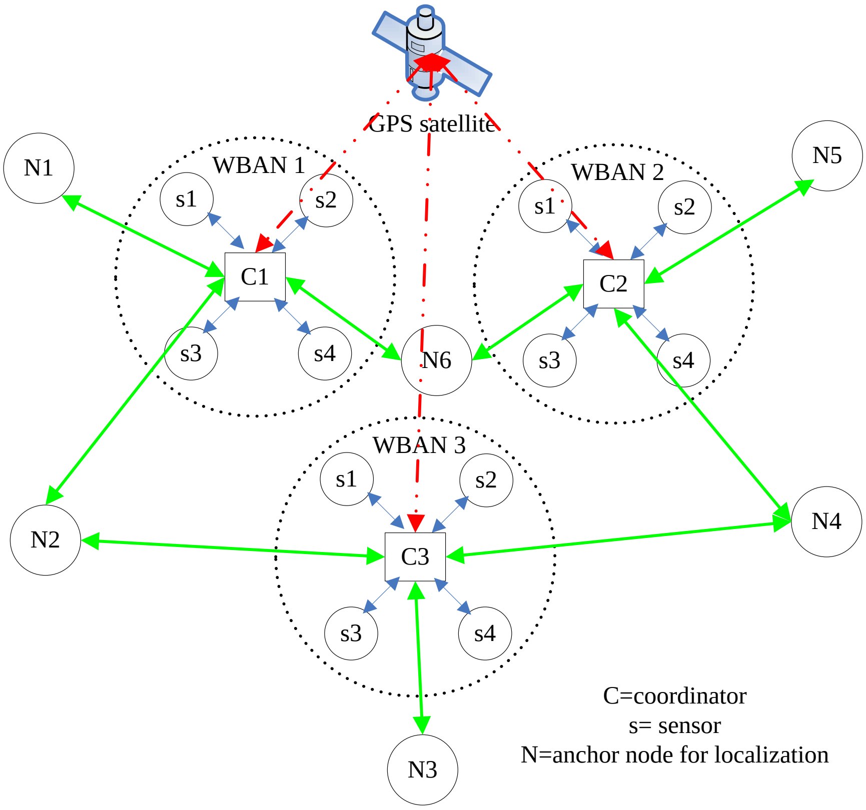

Fig. 2. Local connectivity topology

In most of the outdoor circumstances, we can track our own latitude and longitude through the GPS receiver [15]. In an indoor environment, however, it is up to the coordinator to identify its location in wireless localization network, referred to as indoor localization [16]. The coordinator is a mobile node whose location varies. Anchor nodes are motionless and pre-established, which provide the reference for mobile nodes. The coordinator sends and receives the localization frame and calculates its own location by a localization algorithm such as Angle of Arrival (AOA), Time of Arrival (TOA), Time Difference of Arrival (TDOA), Received Signal Strength Indication (RSSI), Time of Flight (TOF) and Symmetrical Double Sided Two Way Ranging (SDS-TWR). Localizational range and accuracy depend on the emission power, localization algorithm and modulation method of the wireless node. 2D localization and 1m-3m positioning accuracy are required for a disaster aid system.

The coordinator sends location information and physiology data of patients to hubs or LTE basestations, which then relay them to the cloud storage server.

2.2 Backbone Connectivity

The physiological data, location, pictures or videos of patients are transferred to the cloud storage server through the backbone network. In order to ensure the validity and realtime of the patients' data, the backbone networks should achieve high throughput and low average queuing delay. We have divided the paradigms of backbone communication into two categories, ie. the public infrastructure-based network and the backup ad hoc-based wireless network architecture.

Usually, due to the virtually ubiquitous coverage of cellular network, the disaster aid system chooses the 3G or 4G cellular network as its backbone transmission network. The 3G network technology HSPA+, according to the latest Universal Mobile Telecommunications System (UMTS), is theoritically able to provide a peak data rate of up to 56 Mbps in the downlink (28 Mbps in existing services) and 22 Mbps in the uplink [17]. A 4G cellular system, according to International Mobile Telecommunications Advanced (IMT-Advanced), has a peak data rate of up to approximately 100 Mbps for high mobility such as mobile access, and up to approximately 1 Gbps for low mobility such as roaming/local wireless access [18]. From the bandwidth perspective, both communication networks can meet the requirement of transmitting a patient’s basic physiological data. With regards to the transmition of pictures or videos of patients, however, 4G is superior to 3G. The responder can record a video of the patients and be sent to the remote doctor or through video conference so that the doctor can administer treatment directly from 4G cellular network. Thus, the 4G cellular network based on LTE technology is the best choice.

LTE network, used to support WBAN traffic, boasts the advantages of reliable delivery and being free of delay. But cellular networks are optimized for a large number of mobile devices, of which only a small portion are active at any given time and most of the data traffic flows in the downlink direction; the disaster aid network has a large number of small body area networks comprising a coordinator and several body sensors that are always active, and a major portion of the traffic flows in the uplink direction. There are serious challenges that need to be overcome in the 4G cellular network before they can be used for disaster aid. Prof. Min Chen has made some suggestions with regards to these challenges in the MTC project. To enable the LTE architecture to deal with MTC traffic, he presented a new method that extends the EPC of LTE to support MTC using the MTC facilitator (MTCF).

A rescue cannot rely solely on the public communication infrastructure. It may be fully or largely destroyed by the disaster, be non-existent as in the case in many rural areas, or be saturated by public safety users, the press and others [19]. Therefore, building a temporary wireless communication network equipped with high bandwidth wireless hubs is necessary. In [20], the goal of the researchers at Virginia Tech's Center for Wireless Telecommunications is to provide a 120Mbps wireless backbone network through a hub. In demonstrations of the early prototype, off-the-shelf networking equipment modems, up/down converters and 28-GHz radios were used. Once the public communication was interrupted, the data will be transfered and redirected seamlessly to the temporary data center through the hub.

2.3 Internet Connectivity

Unlike the local connectivity and backbone connectivity, the third tier communication is able to use the Internet, and is thus aptly called Internet connectivity. The authorized medical personnel (e.g. doctor, nurse, responder, medical reseacher) can access a patient's medical information remotely using the Internet.

A cloud storage server is an important component as it maintains the patient's profile and medical history. Using the physiological data and videos acquired from cloud storage, the commander of EMS is able to schedule the medical facilities such as ambulances more conveniently and effectively; the doctors can participate in rescue activities remotely because automatic diagnosis and notification is made possible with data mining technology. Users can access the storage server through the PC, PDA, mobile phone and tablet PC, etc. In order to adapt to the heterogeneous network application, an unified interface-based middleware is necessary.

In addition, data synchronization between the temporary data center and cloud storage server is also an important component. In the event that the basic public communication infrastructure was destroyed, satellite synchronization is a good option. Apart from transmission delay, it has advantages over other communication methods, such as a wide coverage, supporting l55Mbps bandwidth, rapid deployment and low cost, etc.

3. Key Issues of Disaster Aid System

Several key issues must be addressed in order to enable the deployment and adoption of WBAN for disaster aid. On the hardware level, wireless body sensors must be small, thin, non-invasive and wearable [21]. On the MAC level, designing an appropriate MAC protocols to ensure higher network capacity, energy efficiency [22, 23] and adequate quality of service (QOS) is imperative [24, 25]. A new challenge that has emerged in MAC layer is in getting the sensors to interact with each other, as different sensors operate on different frequency bands. On the network level, due to the cellular network's wide coverage, employing it as a backbone network is convenient for disaster aid, but handling WBAN traffic with a cellular network is not adequate. Therefore, we should find a new method to resolve this, as discussed in section 2. On the application level, innovative architectures should be implemented for disaster aid, and large volumes of data storage and data mining should be taken into account. In this section, we will discuss six key issues: body sensors, MAC bridging, localization technologies, client application for smartphones, cloud data storage and middleware.

3.1 Body Sensors

A body sensor node consists mainly of two parts: the physiological signal sensor(s) and the radio platform to which multiple body sensors can be connected. The general function of body sensors is to collect analog signals that correspond to the human physiological condition. Such an analog signal can be acquired by the corresponding radio-equipped board where it is digitized. The digital signal is then forwarded by the coordinator to and store in the data center. Based on these body signals, an accurate diagnosis can be obtained to administer correctly and timely treatments for the patients. As a data source of the WBAN-based disaster aid system, the design of wireless medical sensor is critial and should satisfy the main requirements such as wearability, reliability, security and interoperability [26, 27].

Disaster aid network is different from an ordinary health care system. An ordinary health care system collects only one or two physiological signs according to the patient's condition, but the disaster aid wireless sensor network monitor vital signs such as heart rate, blood pressure, core temperature, ECG, oxygen saturation and respiration [28-30]. In order to employ available body sensors conveniently, we have conducted a detailed survey.

(a) *Blood pressure sensor*: The blood pressure (BP) sensor is a non-invasive sensor designed to measure systolic and diastolic human blood pressures. The BP sensor automatically inflates an upper arm cuff at customizable time intervals to acquire BP readings and transmit the data over the coordinator to the data center. The BP sensor, developed by Johns Hopkins University Applied Physics Laboratory [8] based on the NIBP module from SunTech Medical, acquired a reading every 5 minutes. The device operates for 10 hours on a four-cell battery pack of 9V lithium batteries, and delivers a pluse rate with an accuracy of ± 3 beats per minute and pressure with an accuracy of ±3mmHg [31].

(b) *CO_2 gas sensor*: It measures gaseous carbon dioxide levels to monitor changes in CO_2 levels as well as oxygen concentration during human respiration. In [32], a wireless passive carbon nanotube-based gas sensor was introduced by Keat Ghee Ong et. al.. Multiwall carbon nanotubes (MWNTs) are used to acquire remotely the detection data of carbon dioxide, oxygen and ammonia based on the measured changes in MWNT permittivity and conductivity with gas exposure.

(c) *ECG sensor*: ECG is a graphic record of the heart's electrical activity. Healthcare providers use it to help diagnose a heart disease [33]. In order to obtain an ECG signal, several electrodes are attached at specific sites on the skin, and the potential differences between these electrodes are measured [34].

(d) *Humidity and temperature sensor*: They are used for measuring the temperature of the human body or the temperature and humidity of the immediate environment around a person. In [35], the authors have designed a wireless temperature and humidity sensor.

(e) *Pulse Oximetry sensor*: It measures the oxygen saturation and heart rate of a patient using a non-invasive probe. The SpO_2 sensor board developed by Smiths Medical has a high accuracy when being used in ambulances [36]. It operates with an SpO_2 accuracy of ±2% variation and heart rate accuracy of ±2 bpm according to the manufacturer's specifications. This sensor board was chosen for the AID-N project.

(f) *Camera sensor*: Complementary metal-oxide-semiconductor (CMOS) active-pixel sensors such as OV9650 can be embedded in a handset (PDA, cellphone). Video recordings have been used to treat Parkinson's disease [37]. The clinical expert examines the video recordings and provides clinicals cores representing the severity of the tremor, dyskinesia and bradykinesia.

The vital signs monitoring sensor node benefits from the development of wireless communication technologies. This is evident in that the miniaturization and energy efficiency of embedded computing area have improved significantly. The sensor node is becoming increasingly smaller. Acceptance of a disaster aid system is determined primarily by wearability, ease to use, energy efficiency, accuracy of physiological sign and security [38]. In the design or selection of a sensor, current challenges should be taken into account.

Usually, body sensor use a RF PHY layer, but several reseachers have investigated the possibility to transfer electronic data by capacitive and galvanic coupling, also called body-coupled communication (BBC). These radios work at low frequencies (ranging from 10kHZ to 10MHZ), use the human body as the communication channel. It is viewed as more reliable and energy efficient and RF communication. We believe BBC is an interesting approch for improving energy-efficiency of the PHY layer in WBAN.

3.2 MAC Bridging for Multi-PHYs and Cross-Layer Optimization

Like traditional wireless sensor network, the sensor nodes of WBAN are extremely low-power [39] and have limited communication range [40]. There are some common challenges, such as Quality of Service (QoS) [41], scalability and wearability, which we have discussed in

[42-46]. In the wireless disaster aid network, however, a new challenge appears. The in-body sensor nodes work on the Medical Implant Communication Service (MICS) band, and out-body nodes operate on Unlicensed Industrial, Scientific and Medical (ISM) [47]. The localization communication operate on ultra wide band (UWB) or ISM band. **Table 2** shows the typical settings of WBAN devices.

Table 2. Sensor nodes band requirements [48].

Device	**Frequency Band**	**Data Rate**	**MAC**	**Power** Supply	**Application**
Out-Body	ISM bands	Up to 10Mbps	CSMA, TDMA or combination of both	High or Moderate Battery	Medical monitoring
In-Body	MICS band	Up to 500Kbps	CSMA, Slotted ALOHA, TDMA or a combination of all	Limited Battery	Medical monitoring
Localization	ISM/UWB bands	Up to 10Mbps	CSMA, TDMA or combination of both	High Battery	Localization or communication with wireless hub

The problem is that these nodes operate on different frequency bands or multiple physical layers, which have impact on the interaction of the nodes. The MICS band transmission range is limited to 2-3m, which cannot be employed by localization module. A bridging method was presented by Prof. Sana Ullah in [48], which uses a single MAC to support Multi-PHYs. In his design scheme, it is the bridging function that establishes logical connections between the different nodes working on different PHYs. The coordinator implementing the bridging function must have two or more different PHY interfaces. The necessary information from all the PHYs are recorded into a table called the bridging table. This table contains all the information regarding the BAN, including information related to the PHY (MICS, ISM, or UWB) . The protocol stack of the bridging function is given in Fig. 3 [48]. The bridge can collect or disseminate data from or to in-body/out-body nodes. As can be seen in the figure, the bridge has two PHY interfaces using the MICS and ISM band respectively, and can adapt the settings of both PHYs independently.

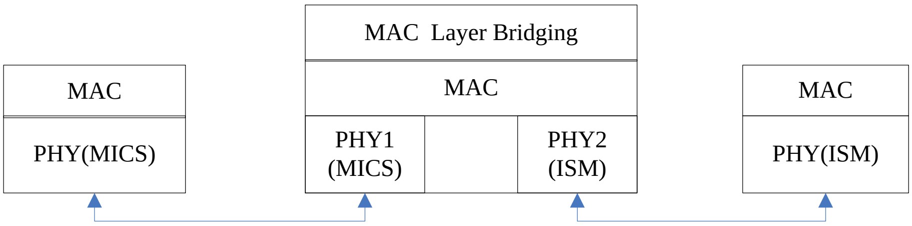

Fig. 3. Bridging method

The good performance of bridging method is validated by the Monte Carlo simulations, but this method also increases the node's energy consumption. Therefore, the coordinator employs the bridging in MAC Layer while other sensor nodes communicate with the coordinator only.

Meanwhile, the coordinator must be equipped with a large-capacity battery which ensures sufficient power supply in order to process communication and localization tasks.

The development of suitable WBAN technology is still a relatively new research area with many inherent challenges. Cross-layer protocols design is one of challenges, which has the potential to deliver greater efficiencies than traditional layered protocol stack [49].

Generally, cross-layer schemes can be divided into loosely coupled and tightly coupled designs. Loosely coupled protocol designs focus on adapting the parameters available at the lower layer to opimize the performance at a higher layer. In the tightly coupled approch to cross-layer design, the different layers are optimized together to form one complet solution to an optimization problem. Performance gains for tightly coupled designs should be greater than loosely coupled as they do not incur the same stack communication overhead, however this may be at the expense of protocol transparency and maintenance. A summary of relevant cross-layer is shown in **Table 3** [50].

Table 3. Low power cross-layer protocols

Layer	**Protocol**	**Protocol Summary**
MAC and Physical	Channel Adaptive Energy Management (CAEM)	CAEM allows a node to dynamically adjust the data throughput according to quality of the link, the deliver performance gains of up to 30% compared to traditional protocols.
Network and MAC	Sleep Collect and Send Protocol (SCSP)	Dynamically calculates node sleep and data receive periods depending on traffic levels. MAC layer provides the list of neighbor nodes to the network layer, which in turn provides multiple forwarding choices to it. Switches between active and sleep periods by dynamically adapting modes depending on traffic levels. Uses a simple routing protocol that doesn't need route maintenance or discovery. Extends the network lifetime and connectivity in comparison with 802.15.4.
Transport and MAC, Physical	QoS Adaptive Cross-layer Congestion control	Incorporates an adaptive cross-layer mechanism to control congestion for real and non-real time data flow to support QoS guarantees at the application layer. Priority given to real time data for delay and available link capacity. Scheme links the QoS requirements at the application layer and packet waiting time, collision resolution, and packet transmission time metrics at the MAC layer.
Application and MAC, Physical	Correlation-based Collaborative MAC (CC-MAC)	Cross-layer solution incorporating the application and MAC layers. Exploits the spatial correlation between nodes to reduce energy consumption without compromising reliability at the sink. Delivers improved performance over S-MAC and T-MAC in terms of energy efficiency, packet drop rate, and latency.
Tightly Coupled (Multi-layer Cross-Layer schemes)	Cross-layer Module (XLM)	Replaces the entire layered architecture by a single protocol where the objective is reliable communication with minimal energy consumption, adaptive communication, and local congestion avoidance. Each node has the freedom to decide on participating in communication. XLM outperforms the traditional layered protocol stack in terms of performance and implementation complexity.

3.3 Localization

Localization plays an important role in the disaster aid system. If an incident commander could track the location of multiple rescuers and patients inside or outside of a building from the command post, such capabilities would greatly improve rescue operations at the disaster site. The job of outdoor localization is to equip sensor node with GPS receiver. GPS is the most widely used satellite-based positioning system that offers maximum coverage. The GPS can achieve an accuracy of about 3m [51]. In an indoor environment, however, we should find other methods to acquire location information. We know that the communication between receivers and satellites is impossible in a non-line-of-sight (NLOS) environment. There are various obstacles, for example walls and human beings, which lead to multi-path effects [44]. Some interferences and noises from other wireless networks such as WIFI or electrical radiating equipment, such as microwave ovens, degrade the accuracy of location. Irregular building geometry and the density of water vapor in the air leads to reflection and extreme path loss. Thus, indoor localization is more complex.

Some articles have given overviews of several technologies used to build up an indoor localization system [52]. Some use dedicated RFID tags and readers[53-55] while others use existing WLAN networks [56], infrared, ultrasonic, Bluetooth, UWB or magnetic signals. We have conducted a survey of existing localization system which may be deployed in a disaster aid system.

(a) *MASCAL*

MASCAL uses a prototype WiFi-based indoor geolocation system from Awarepoint Corporation in La Jolla, CA. This system utilizes existing wireless infrastructure and has three components: 802.11b RFID tags, fixed transceivers that measure ambient 802.11b signal strength, and a central geolocation server that computes location [57]. The localization tags measure ambient 802.11b signal strength and broadcast this data back to the location server periodically. The localization algorithm compares the tag data with the reference topology, effectively triangulating the location of the tag to within a theoretical resolution of approximately10 feet. The performance of WiFi positioning has been obtained from studies in indoor environments with a very high AP density [58].

(b) *MoteTrack*

MoteTrack is a robust, decentralized approach to Zigbee-based localization developed by Harvard University [59] which has been chosen for CodeBlue and AID-N projects. Location tracking is based on empirical measurements of radio signals from multiple transmitters using an algorithm similar to RADAR [60]. The accuracy of MoteTrack can achieve 2-3 m in a building equipped with 20 beacon nodes distributed over one floor. MoteTrack does not rely on any back-end server, and employs a dynamic radio signature distance metric that adapts to loss of information, partial failures of the beacon infrastructure and perturbations taking these measures enhance the robustness of the system.

(c) *Nanotron Find*

The Nanotron Find localization platform is a high throughput Real Time Location System (RTLS) developed by Nanotron Technologies. Its PHY employed the Chirp Spread Spectrum (CSS) technology based on the unlicensed 2.4 GHz ISM band. It can void the NLOS influence effectively and tolerate multipath effect to maintain a 1-m localization precision [61]. It is a full-function RTLS system equipped with nanoANQ or nanoANQ XT RTLS anchors, Nanotron’s Location Server (nanoLES) and nanoTAG that covers about 500 sqm indoors and 5,000 sqm outdoors. With the help of additional anchors or tags, the system can be expanded.

For example, the development toolbox provides 8 nanoANQ RTLS anchors that cover an area of 500 sqm or more. Twenty nanoTAG tags with a configurable blink rate exhibit a system throughput of 200 location readings per second. The deployment of Nanotron Find RTLS in emergency environments is able to track patients, staff and assets as well as provide many benefits to both patients and responders.

(d) *Ubisense*

Ubisense 7000 serial is an in-building UWB radio-based tracking system developed by Ubisense [62] which can determine the positions of people and objects to an accuracy of tens of centimeters using small tags attached to objects. They are carried by personnel, and a network of receivers that are placed around buildings. UWB is well-suited to the in-building at an emergency site [63] because of its non-line-of-sight nature, 3D position, modest infrastructure requirements and high tracking accuracy [64]. A well-designed UWB tracking system is low-power (thus low maintenance), and the fundamental technology is simple and low-cost.

The function of localization not only track the target location, but also supports many fundamental network services, including network routing, coverage, topology control, boundary detection, clustering, etc. Most routing protocols for multi-hop wireless networks utilize physical locations to construct forwarding tables and deliver message to the node closer to the destination in each hop [65]. Acoording to the location information, the topology of entire network is easy to build. Topology control utilize location to adjust network parameter, energy consumption and interference can be effectively reduced.

3.4 Client Application of Smart Handheld Devices

Smart handheld devices such as mobile phones, tablet PCs and iPads can easily access the data center through the LTE cellular network. Usually, these devices use platforms that allow the development of custom applications in the iOS, Android or Windows Mobile development environment. Using off-the-shelf smartphones or tablet PCs enables us to save development time and utilize existing features such as high resolution display, high definition video, 4G communication module and audio [38].

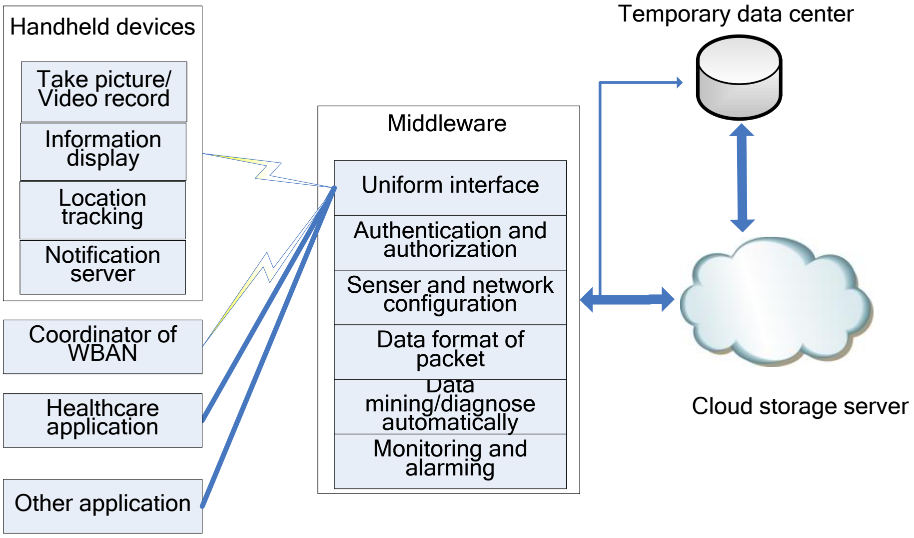

Fig. 4. Framework of application for handheld devices portion

The client-end application based on the smartphone platform should satisfy disaster aid requirements such as information display, location tracking, notification server and video recording. See the section on the framework of software for handheld devices in Fig. 4.

The application based on handleheld devices acquires data from a cloud storage server. The data includes name, sex, picture, blood pressure, oxygen saturation, heart rate, core body temperature, humidity, and temperature around the patient and location. The application should display these information correctly. The application will then mark the location of the patient on the map or on the geographic information system (GIS) according to the location of the patients and rescuer [66]. If the patient's life is in jeopardy, accurate location will help the responder or doctor administer treatment quickly. The photo-taking function can supplement the patient's medical profile. The video recording function is necessary for telemedicine as the doctor is then able know the severity condition of the patient remotely. Due to the shortage of medical personnel, telemedicine can improve the efficiency of the rescue. The notification server is critical in the disaster aid system. If the patient’s condition suddenly worsens and his or her life is in danger, the aid system is required to make a diagnosis automatically and notify the nearby doctor or other medical person promptly. After having received the notification, the application should sound a warning. The doctor can then attend to the emergency quickly according to the physiological data and location.

3.5 Cloud Data Storage Server

Normally, every hospital has a private data server that stores the patient’s profile, medical history and personal medical information. Storing extremely large volumes of data in a local data server is expensive. A local data storage device has many drawbacks, such as a limitied shelf-life, the need for back-up and recovery systems, the need for a physical space that requires specific environmental conditions, the need for personnel to manage it, as well as the consumption of a considerable amount of energy for both powering and cooling. Furthermore, the data server is installed in different hospitals in isolation, and data cannot be shared among one another. Since the data formats and access interfaces are different, interoperation between heterogeneous systems is not possible. If an emergency occurs, the data is not able to synchronize with the disaster data center immediately.

Table 4. Commercial cloud storage services provided by Amazon, Microsoft and Google

Vendor	Instance storage	Object storage	Block storage	Semi-structured data storage	Relational Database storage	Distributed File System
Amazon	EC2	S3	EBS	SimpleDB	RDS	N/A
Microsoft	Azure VM	Azure Blob	Azure drive	Azure table	SQL Azure	N/A
Google	N/A	Google Storage for Developers	N/A	BigTable	N/A	Google File System

To resolve the data storage problem, we can build a data center for every medical institution. With the development of the cloud data storage technology, this problem had been solved perfectly. Cloud data storage has lots of advantages in processing large volumetric data, such as affordability, reliability, and scalability [67]. In [68], offload computing and remote storage can save energy for the coordinator and handleset.

The cloud providers can be classified as commercial and academic. In terms of service quality and maintenance, the commercial provider is a better choice for disaster aid. **Table 4** shows different types of commercial storage services provided by three major vendors: Amazon [69-71], Microsoft [72] and Google [73].

Cloud data storage, however, has several major drawbacks, some of which include performance issues, availability and incompatible interfaces. Cloud data storage performance is limited by bandwidth. The availability of cloud data storage relies on the network connectivity between the coordinator and the cloud data storage provider. Network connectivity can be affected by any number of issues, including global network disruptions, solar flares, severed underground cables and satellite damage. The quality and bandwidth of a network is key to solving these problems. The cloud data storage should be equipped with at least more than just 3Gbps bandwidth through the optical fiber. The 4G cellular network can ease the burden of backbone communication. Moderate communication line redundancy is also indispensable for disaster aid system. Uniform interface is necessary, and that will be discussed in Section 3.6.

Furthermore, the storage system should synchronize patient's data between a temporary data center and cloud data storage server in a timely manner. If the public communication infrastructure is destroyed in disaster field, the coordinator would turn to transfer patient’s data to the temporary data center. The data redirection would result in the patient's medical history and other data in the cloud storage server being out of sync with the temporary data center. This would affect the treatment of the patient or telemedicine. Therefore, maintaining data synchronization is very important for disaster aid.

3.6 Middleware

In disaster aid system, a corresponding middleware layer is needed to integrate seamlessly with other systems [74]. As shown in **Fig. 4**, the middleware consists of the following modules:

(a) *Uniform interface*: The middleware is designed to be neutral to programming languages as well as provide a standard SOAP and REST interface or other web service interfaces. The other systems can access the data expediently.

(b) *Authentication and authorization*: Authentication is the process of verifying that you are who you claim to be. On the other hand, authorization is the process of checking the permissions that an authenticated user has to access certain data. This module allows you to set up users and passwords as well as the access levels for each user (view, add, delete, change).

(c) *Sensor and network configuration*: This module enables the user to define the WBAN, register a sensor or change its configuration, delete a sensor, and define variables such as sampling rate, frequency range, operation mode and time to save data, etc. If the public communication infrastructure was destroyed, the wireless hub should be configured automatically by the middleware.

(d) *Format of data packet*: The other healthcare systems need to communicate with the disaster aid system, but how do we know the meaning of the packet content? This heterogeneity represents the main challenge for enabling interactions because objects can provide different information in different formats that can be used for different purposes. To solve this problem, we are exploring semantic web technologies such as XML applied to interactions. XML has certain advantages over other web technologies [75], such as simplicity, openness, extensibility, and facilitating the comparison and aggregation of data, etc. XML is an almost universally supported way of exchanging documents and data across applications and platforms. The example of data packet is as shown in Fig. 5.

```
<?xml version="1.0"?>
<Patients>
  <patient name="maly" id="363101198450664323" sex="female">
    <temperature type="outside"> 26 </temperature>
    <temperature type="body"> 36.5 </temperature>
    <humidity> 10 </humidity>
    <CO2> 10 </CO2>
    <ECG>
      HR:122BPM.8120 PR:136MS.321 QRS:96MS.54 QT/QTC:305/435
      MSP/QRS/T:77/61/61 RV5/SV1:2.64/0.56MV RV5+SV1:3.20MV
    </ECG>
    <oxygensaturation> 90 </oxygensaturation>
    <heartrate> 64.1 </heartrate>
  </patient>
</Patients>
```

Fig. 5. XML example with information about patient

(e) *Data mining and automatic diagnosis*: After employing WBAN for emergency response, our capability in collecting data from biosensors have been improving. This explosive growth in physiological data has generated an urgent need for new techniques and tools that can intelligently and automatically transform the processed data into useful information and knowledge. For example, the heart rate of a normal adult is 60~100. If the heart rate is less than 60, we can determine that he is ill. The same cannot be said, however, of a specific adult such as an athlete. Data mining, also referred to as knowledge discovery, can extract a suitable heart rate of his own from his medical history. Automatic diagnosis refers to a data mining module that determines or identifies a possible disease or disorder automatically.

(f) *Monitoring and alarming*: In case of abnormalities, the system sends alarms to pre-defined subscribers (e.g. doctor, nurse, patient's relatives, patient and network administrator, etc.) based on pre-defined attributes (e.g. predefined threshold), which is the result of data mining. Abnormal patient data triggers the system to send an alarm to the previously-registered subscribers concerned. There are three levels of alarm: light, normal and serious. If the doctor receives a serious alarm, he should treat the patient immediately. The critical sensor status can also cause an alarm. Biomedical sensor errors may occur due to complete device malfunction or interference. In a harsh real-time medical environment, such errors are not acceptable as they may result in resource mismanagement (e.g. taking up staff time) or the covering up of a serious medical symptom. The system provides a mean of monitoring multiple sensors of the same type (e.g., two pulse sensors) within a WBAN. A tolerance level is built in. However, if this tolerance level has been exceeded, a sensor failure or error alarm will be triggered.

4. Discussion

Though a disaster aid system based on WBAN leverages on the effect of rescue operations, problems still exist that would affect the usability. The most significant open issue is the communication QoS in relation to the entire aid system. In the WBAN and ad hoc networks, the communication bands are different between in-body and out-body. The data relay through the router protocols will increase the stack size in the coordinator and power consumption. The MAC bridging method can cope with two bands, but if there are three radio bands, we will seek other methods to cope with such a situation. The MAC cross-layer optimizing technique is deemed to be an alternative. In a specific WBAN-based disaster aid application, we can introduce the router technique into the MAC layer and build a router table in the MAC layer according to the network ID, band, channel and other information; the data from the ISM band sensor node can relay directely to the UWB bands sensor node depending on the router table in the MAC layer. Employing the cross-layer optimizing technique can help to decrease power comsumption and delay and enhance the communication quality of WBAN. In an LTE 4G cellular network, the coordinator sends the data collected from the ECG sensor to the LTE basestation every second, and the traffic flows in the uplink direction. The large amount of coordinators connected in parallel also cause serious delays in network occasionally. Extending the architecture of the LTE protocol stack helps to accommodate the uplink traffic. In our future effort, some methods will be addressed in order to enhance the communication Qos.

The second most significant concern is indoor and outdoor cooperative localization. For the indoor positioning system, location information of the target (patients or doctors) is relative to the anchor nodes' location. It has its own coordinate system, which is different from the geodetic coordinate system. Due to the lack of latitude and longitude, there is difficulty in displaying information on the map or GIS based on the location acquired from the indoor positioning system, which will affect target tracking. The target's location information should be transformed into latitudes and longitudes, while the indoor and outdoor location information should combined harmoniously. The cooperative positioning method should thus be addressed so that it can cope with indoor and outdoor localization.

Furthermore, time synchronization and calibration of sensors for distributed data collection are problems that exist in a disaster aid system. In reality, due to the limitations of clock generating oscillators, the clock offset and clock drift will corrupt the accuracy of time synchronization. Tight synchronization is needed for measuring the delay between a sensor and a coordinator, which involve two clocks. Also, the synchroniztion signal can be affected by interference from other signals, noise and multipath propagation. A feasible scheme should take this into account.

Due to the unreliable power supply, battery charging becomes very difficult. Low-power design and its methods of controlling are still one of the important factors to consider in wireless network design, as well as one of the key factors to the success of sensor-based products. At present, progress has been made in low-power design, such as the trade-off between high performance and power. However, as for achieving the desired effect, there is still a long way to go. Since a coodinator needs to relay physiological data and consumes a great deal of energy, energy-efficient design is of greater importance. Energy-efficient design is still an issue that we would like to resolve in the future.

5. Conclusions

Disaster aid system based on WBAN promises to revolutionize the next generation in emergency response. From network connectivity aspect, we have presented the architecture of a WBAN-based disaster aid system. We have also discussed several key issues in detail that are relevant to disaster aid, as well as their advantages and disadvantages. Through this system, the commander and doctor can monitor patients' condition continuously and make a better plan for rescue operations subsequently. In addition, accurate location information further improves rescue efficiency. Large volumes of data storage and data mining enhance the reliability of automatic diagnosis. The biosensor of disaster aid system brings out a new set of challenges, such as wearability, ease of use and the accuracy of physiology sign, which are highlighted in this article. Despite advances in wireless communication, embedded integrated circuit and cloud computing, there are many challenges that still need to be addressed, especially on energy efficiency design as well as the middleware design of a successful application.

References

[1] *Sichuan earthquake*. Available: http://en.wikipedia.org/wiki/2008_Sichuan_earthquake
[2] *Tōhoku earthquake and tsunami*. Available: http://en.wikipedia.org/wiki/2011_T%C5%8Dhoku_earthquake_and_tsunami
[3] *Mass-casualty incident*. Available: http://en.wikipedia.org/wiki/Mass-casualty_incident
[4] *Welcome to Hoag Hospital*. Available: http://www.hoaghospital.org/
[5] *City of Newport Beach, CA - Fire and Lifeguard Safety*. Available: http://www.newportbeachca.gov/index.aspx?page=58
[6] *Simple triage and rapid treatment*. Available: http://en.wikipedia.org/wiki/Simple_triage_and_rapid_treatment
[7] E. C. Kyriacou, C. S. Pattichis, and M. S. Pattichis, "An overview of recent health care support systems for eEmergency and mHealth applications," in *Proc. of Annual Int. Conf. of the IEEE Engineering in Medicine and Biology Society*, pp. 1246-1249, 2009. Article (CrossRef Link).
[8] G. Tia, T. Massey, L. Selavo, *et al.*, "The Advanced Health and Disaster Aid Network: A Light-Weight Wireless Medical System for Triage," *Biomedical Circuits and Systems, IEEE Transactions on*, vol. 1, pp. 203-216, 2007. Article (CrossRef Link).
[9] *CodeBlue: Wireless Sensors for Medical Care*. Available: http://fiji.eecs.harvard.edu/CodeBlue
[10] M. David, F. Thaddeus, W. Matt, *et al.*, "CodeBlue: An ad hoc sensor network infrastructure for emergency medical care," in *Proc. of Mobisys 2004 Workshop on Applications of Mobile Embedded Systems (WAMES 2004)*, pp. 12-14, 2004. Article (CrossRef Link).
[11] *Body Sensor Networks*. Available: http://ubimon.doc.ic.ac.uk/bsn/m621.html
[12] M. Chen, S. Gonzalez, A. Vasilakos, *et al.*, "Body Area Networks: A Survey," *Mobile Networks and Applications*, vol. 16, pp. 171-193, 2011. Article (CrossRef Link).
[13] S. Ullah, H. Higgins, S. Islam, *et al.*, "On PHY and MAC performance in body sensor networks," *EURASIP Journal on Wireless Communications and Networking*, pp. 479-512, 2009. Article (CrossRef Link).
[14] "IEEE Standard for Local and metropolitan area networks - Part 15.6: Wireless Body Area Networks," *IEEE Std 802.15.6-2012*, pp. 1-271, 2012. Article (CrossRef Link).
[15] D. Braginsky and D. Estrin, "Rumor routing algorthim for sensor networks," in *Proc. of the 1st ACM Int. workshop on Wireless sensor networks and applications*, pp. 22-31, 2002. Article (CrossRef Link).
[16] B. Archana, A. Vijay, and P. Sai, "Sensor Networks: An Overview," *Potentials, IEEE*, vol. 22, pp. 20-23, 2002. Article (CrossRef Link).
[17] K. Johansson, J. Bergman, D. Gerstenberger, *et al.*, "Multi-Carrier HSPA Evolution," in

Proc. of IEEE 69th Vehicular Technology Conf. , pp. 1-5, 2009. Article (CrossRef Link).

[18] S. Parkvall, E. Dahlman, A. Furuskar, *et al.*, "LTE-Advanced - Evolving LTE towards IMT-Advanced," in *Proc. of IEEE 68th Vehicular Technology Conf.*, pp. 1-5, 2008. Article (CrossRef Link).

[19] D. Zhang, J. Wan, X. Liang, *et al.*, "A taxonomy of agent technologies for ubiquitous computing environments," *KSII Transactions on Internet and Information Systems*, vol. 6, pp. 547-565, Feb. 2012. Article (CrossRef Link).

[20] F. M. Scott and W. B. Charles, "Rapidly-deployable broadband wireless networks for disaster and emergency response," in *Proc. of the 1st IEEE Workshop on Disaster Recovery Networks (DIREN 2002)*, 2002. Article (CrossRef Link).

[21] J. Emil, R. Dejan, P. John, *et al.*, "Patient Monitoring Using Personal Area Networks of Wireless Intelligent Sensors," *Biomedical Sciences Instrumentation*, vol. 37, pp. 373-378, 2001. Article (CrossRef Link)

[22] M. Chen, S. Gonzalez, Y. Zhang, and V. Leung, "Multi-Agent Itinerary Planning for Wireless Sensor Networks," *Quality of Service in Heterogeneous Networks*, vol. 22, pp 584-597, 2009. Article (CrossRef Link).

[23] S. Ullah and K. S. Kwak, "An Ultra Low-power and Traffic-adaptive Medium Access Control Protocol for Wireless Body Area Network," *J. Med. Syst.*, vol. 36, pp. 1021-1030, 2012. Article (CrossRef Link).

[24] M. Chen, C. F. Lai, and H. Wang, "Mobile multimedia sensor networks: architecture and routing," *EURASIP Journal on Wireless Communications and Networking*, vol. 2011, pp. 1-9, 2011. Article (CrossRef Link).

[25] M. Chen, V. Leung, S. Mao, *et al.*, "Directional geographical routing for real-time video communications in wireless sensor networks," *Computer Communications*, vol. 30, pp. 3368-3383, 2007. Article (CrossRef Link).

[26] A. Milenkovi, "Wireless sensor networks for personal health monitoring : issues and an implementation," *Computer Communications*, vol. 29, pp. 2521-2533, 2006. Article (CrossRef Link).

[27] E. Jovanov, J. Price, D. Raskovic, *et al.*, "Wireless Personal Area Networks in Telemedical Environment," in *Proc. of 3rd Int. Conf. on Information technology in Biomedicine ITAB-ITIS*, pp. 22-27, 2000. Article (CrossRef Link).

[28] C. Baozhi, J. P. Varkey, D. Pompili, *et al.*, "Patient vital signs monitoring using Wireless Body Area Networks," in *Proc. of the 2010 IEEE 36th Annual Northeast Bioengineering Conf.*, pp. 1-2, 2010. Article (CrossRef Link).

[29] E. Jovanov, A. Milenkovic, C. Otto, *et al.*, "A wireless body area network of intelligent motion sensors for computer assisted physical rehabilitation," *Journal of NeuroEngineering and Rehabilitation*, vol. 2, pp. 1-10, 2005. Article (CrossRef Link).

[30] T. Gao, D. Greenspan, M. Welsh, *et al.*, "Vital signs monitoring and patient tracking over a wireless network," in *Proc. of the 27th Annual Int. Conf. of the Engineering in Medicine and Biology Society*, pp. 102-105, 2005. Article (CrossRef Link).

[31] A. Georgiades, A. Sherwood, E. C. Gullette, *et al.*, "Effects of exercise and weight loss on mental stress-induced cardiovascular responses in individuals with high blood pressure," *Hypertension*, vol. 36, pp. 171-176, 2000. Article (CrossRef Link).

[32] K. G. Ong, K. Zeng, and C. A. GRIMES, "A wireless, passive carbon nanotube-based gas sensor," *Sensors Journal, IEEE*, vol. 2, pp. 82-88, 2002. Article (CrossRef Link).

[33] T. Martin, E. Jovanov, and D. Raskovic, "Issues in Wearable Computing for Medical Monitoring Applications: A Case Study of a Wearable ECG Monitoring Device," in *Proc. of the 4th IEEE Int. Symposium on Wearable Computers*, pp. 43-49, 2000. Article (CrossRef Link).

[34] J. Welch, F. Guilak, and S. Baker, "A Wireless ECG Smart Sensor for Broad Application in Life Threatening Event Detection," in *Proc. of the 26th Annual Int. Conf. of the IEEE Engineering in Medicine and Biology Society*, pp. 3447-3449, 2004. Article (CrossRef Link).

[35] A. D. DeHennis and K. D. WISE, "A wireless microsystem for the remote sensing of pressure, temperature, and relative humidity," *Journal of Microelectromechanical Systems*, vol. 14, pp. 12-22, 2005. Article (CrossRef Link).

[36] T. Polk, W. Walker, A. Hande, *et al.*, "Wireless telemetry for oxygen saturation measurements," in *Proc. of IEEE Biomedical Circuits and Systems Conference*, pp. 174-177, 2006. Article (CrossRef Link).

[37] S. Patel, K. Lorincz, R. Hughes, *et al.*, "Monitoring motor fluctuations in patients with Parkinson's disease using wearable sensors," *IEEE Transactions on Information Technology in Biomedicine*, vol. 13, pp. 864-873, 2009. Article (CrossRef Link).

[38] E. Jovanov and A. Milenkovic, "Body Area Networks for Ubiquitous Healthcare Applications: Opportunities and Challenges," *Journal of Medical Systems*, vol. 35, pp. 1245-1254, 2011. Article (CrossRef Link).

[39] U. Sana, I. Member, K. Pervez, *et al.*, "On The Development of Low-power MAC Protocol for WBANs," *Lecture Notes in Engineering and Computer Science*, vol. 2174, pp. 310-314, 2009. Article (CrossRef Link).

[40] S. Ullah, B. Shen, S. M. Riazul Islam, *et al.*, "A Study of MAC Protocols for WBANs," *Sensors*, vol. 10, pp. 128-145, 2009. Article (CrossRef Link).

[41] A. Thapa and S. Shin, "QoS Provisioning in Wireless Body Area Networks: A Review on MAC Aspects," *KSII Transactions on Internet and Information Systems*, vol. 6, pp. 1267-1285, May 2012. Article (CrossRef Link).

[42] M. Chen, S. Gonzalez, and V. C. M. Leung, "Applications and design issues for mobile agents in wireless sensor networks," *Wireless Communications, IEEE*, vol. 14, pp. 20-26, 2007. Article (CrossRef Link).

[43] M. Chen, L. T. Yang, T. Kwon, *et al.*, "Itinerary Planning for Energy-Efficient Agent Communications in Wireless Sensor Networks," *IEEE Transactions on Vehicular Technology*, vol. 60, pp. 3290-3299, 2011. Article (CrossRef Link).

[44] H. Suo, J. Wan, L. Huang, *et al.*, "Issues and Challenges of Wireless Sensor Networks Localization in Emerging Applications," in *Proc. of 2012 Int. Conf. on Computer Science and Electronics Engineering*, pp. 447-451, 2012. Article (CrossRef Link).

[45] J. Wan, H. Yan, H. Suo, *et al.*, "Advances in Cyber-Physical Systems Research," *KSII Transactions on Internet and Information Systems*, vol. 5, pp. 1891-1908, 2011. Article (CrossRef Link).

[46] M. Chen, J. Wan, and F. Li, "Machine-to-Machine Communications: architectures, standards, and applications," *KSII Transactions on Internet and Information Systems*, vol. 6, pp. 480-497, 2012. Article (CrossRef Link).

[47] A. Kailas and M. A. Ingram, "Wireless Aspects of Telehealth," *Wireless Personnal Communications*, vol. 51, pp. 673-686, 2009. Article (CrossRef Link).

[48] S. Ullah, P. Khan, N. Ullah, *et al.*, "MAC-Bridging for Multi-PHYs Communication in BAN," *Sensors*, vol. 10, pp. 9919-9934, 2010. Article (CrossRef Link).

[49] M. Chen, V. Leung, S. Mao, *et al.*, "Cross-layer and path priority scheduling based real-time video communications over wireless sensor networks," pp. 2873-2877, 2008.

[50] M. Chen, V. Leung, S. Mao, and T. Kwon, "Receiver-oriented load- balancing and reliable routing in wireless sensor networks," *Wireless Communications and Mobile Computing*, vol. 9, no. 3, pp. 405-416, Mar 2009. Article (CrossRef Link).

[51] C. Barrios and Y. Motai, "Improving Estimation of Vehicle's Trajectory Using the Latest

Global Positioning System With Kalman Filtering," Instrumentation and Measurement, IEEE Transactions on, vol. 60, pp. 3747-3755, 2011. Article (CrossRef Link).

[52] J. Hightower and G. Borriello, "Location Systems for Ubiquitous Computing," *Computer*, vol. 34, pp. 57-66, 2001. Article (CrossRef Link).

[53] F. Zhu, Z. Wei, B. Hu, *et al.*, "Analysis of indoor positioning approaches based on active RFID," in *Proc. of the 5th Int. Conf. on Wireless communications, networking and mobile computing*, pp. 5182-5185, 2009. Article (CrossRef Link).

[54] M. Chen, S. Gonzalez, V. Leung, *et al.*, "A 2G-RFID-based e-healthcare system," *Wireless Communications, IEEE*, vol. 17, pp. 37-43, 2010. Article (CrossRef Link).

[55] M. Chen, S. González, Q. Zhang, *et al.*, "Software agent-based intelligence for code-centric RFID systems," *IEEE Intelligent Systems*, vol. 25, pp. 12-19, 2010. Article (CrossRef Link).

[56] G. Sachin, "Infrastructure-based Location Estimation in WLAN Networks," in *Proc. of IEEE Wireless Communications and Networking Conf. (WCNC)*, pp. 465-470, 2004. Article (CrossRef Link).

[57] E. A. Fry and L. A. Lenert, "MASCAL: RFID tracking of patients, staff and equipment to enhance hospital response to mass casualty events," in *Proc. of AMIA Annual Symposium*, pp. 261-265, 2005. Article (CrossRef Link).

[58] P. A. Zandbergen, "Accuracy of iPhone Locations: A Comparison of Assisted GPS, WiFi and Cellular Positioning," *Transactions in GIS*, vol. 13, pp. 5-25, 2009. Article (CrossRef Link).

[59] K. Lorincz and M. Welsh, "MoteTrack: A Robust, Decentralized Approach to RF-Based Location Tracking," in *Location- and Context-Awareness*. vol. 3479, T. Strang and C. Linnhoff-Popien, Eds., ed: Springer Berlin Heidelberg, 2005, pp. 63-82. Article (CrossRef Link).

[60] B. Paramvir and N. P. Venkata, "RADAR: An In-Building RF-based User Location and Tracking System," in *Proc. of the 19th Annual Joint Conf. of the IEEE Computer and Communictions Societies*, pp. 775-784, 2000. Article (CrossRef Link).

[61] *nanotron find*. Available: http://www.nanotron.com/EN/PR_find.php

[62] *ubisense*. Available: http://www.ubisense.net/

[63] R. Hill, J. Al-Muhtadi, R. Campbell, *et al.*, "A Middleware Architecture for Securing Ubiquitous Computing Cyber Infrastructures," *IEEE Distributed Systems Online*, vol. 5, p. 1, 2004. Article (CrossRef Link).

[64] M. R. Mahfouz, C. zhang, B. C. Merkl, *et al.*, "Investigation of High-Accuracy Indoor 3-D Positioning Using UWB Technology," *IEEE Transactions on Microwave Theory and Techniques*, vol. 56, pp. 1316-1330, June 2008. Article (CrossRef Link).

[65] M. Chen, V. C. M. Leung, S. Mao, *et al.*, "Hybrid Geographic Routing for Flexible Energy—Delay Tradeoff," *Vehicular Technology, IEEE Transactions on*, vol. 58, pp. 4976-4988, 2009. Article (CrossRef Link).

[66] S. L. McLafferty, "GIS and health care," *Annual review of public health*, vol. 24, pp. 25-42, 2003. Article (CrossRef Link).

[67] B. P. Rimal, E. Choi, and I. Lumb, "A Taxonomy and Survey of Cloud Computing Systems," in *Proc. of the 2009 5th Int. Joint Conference on INC, IMS and IDC*, pp. 44-51, 2009. Article (CrossRef Link).

[68] K. Kumar and Y.-H. Lu, "Cloud computing for mobile users: can offloading computation save energy?," *Computer*, vol. 43, pp. 51-56, April 2010. Article (CrossRef Link).

[69] *Amazon RDS*. Available: http://aws.amazon.com/rds/

[70] *Amazon S3*. Available: http://aws.amazon.com/s3/

[71] *Amazon EBS*. Available: http://aws.amazon.com/ebs/

[72] *Windows Azure Platform*. Available: http://www.microsoft.com/windowsazure

[73] K. Shvachko, H. Kuang, S. Radia, *et al.*, "The Hadoop Distributed File System," in *Proc. of the 2010 IEEE 26th Symposium on Mass Storage Systems and Technologies (MSST)*, pp. 1-10, 2010. Article (CrossRef Link).

[74] M. Abousharkh and H. Mouftah, "A SOA-based middleware for WBAN," in *Proc. of 2011 IEEE Int. Workshop on Medical Measurements and Applications (MeMeA)*, pp. 257-260, 2011. Article (CrossRef Link).

[75] *XML Benefits*. Available: http://www.softwareag.com/xml/about/xml_ben.htm

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