

# A Review on Requirement of Wireless Sensor Network in Healthcare Applications

Mohit Kumar<sup>1</sup>, Neeraj Kumar Parashar<sup>2</sup>

Assistant Professor

Department of Computer Application

Shekhawati Institute of Technology, Sikar,

*mohitkumar.usit@gmail.com, neerajparashar333@gmail.com*

**Abstract:** An assortment of uses depend on Wireless AdHoc and Sensor Networks (WASN) which has pulled in individuals from a wide number of regions demonstrating its utility extents from protection to farming, climate gauging to pre-fiasco discovery, geography to mineralogy, catastrophe alleviation frameworks to medicinal care, vehicle following to territory checking, and a considerable measure many. In the field of therapeutic sciences the uses of WASN are new however have left an incredible effect on the psyches of the two analysts and specialists. Medicinal determination and test examination like observing the patients, detecting exceptional and basic indications physically and rationally should be possible utilizing sensor systems for the therapeutic care. The potential restorative utilizations of WASN are 'Constant, nonstop patient observing', 'Home checking for interminable and elderly patients', 'Gathering of long haul databases of clinical information'. Alternate applications can be giving therapeutic supervision to individuals in remote zones and for detecting vast mischances, fires, fear based oppressor assaults and remote crucial sign checking facilitating the activity of specialists. In this paper we have attempted to make an overview of all the conceivable utilizations of WASN in the field of therapeutic Sciences.

**Keywords:** Medical Sciences, disaster relief system, WASN, sensors, Vital Dust.

\*\*\*\*\*

## I. Introduction

It has been observed that the medical care [1] has been greatly influenced by Wireless technologies and Sensor networks. They are bringing about dramatic improvements in the quality of healthcare by allowing patients unprecedented mobility while providing healthcare professionals by allowing easy access to patient data.

With the help of wireless, wearable vital sign sensors, collecting detailed real-time data on physiological status can be greatly simplified. However, the medical care sensor network systems needs to be checked upon the existing sensor network to bridge the gap between two. Medical sensor networks must support multicast routing topologies, node mobility, a wide range of data rates and high degrees of reliability, and security must be supported by both. The concept of CodeBlue, a combined hardware and software platform has been described by Victor and Konard in [1] based on their experience. This network provides protocols for device discovery and multichip routing and a simple query interface that is tailored for medical monitoring.

Over the last decade, there has been a radical shift from wired to wireless medical devices becoming a need for the speeding lifestyle and to improve patient care. It plays an integral role in helping its customers bring these new products to market and then manufacture them. The healthcare has one of the most mobile workforces with an incredible dependency on collaborative communication. One can quickly conclude that wireless technology is a must have in all acute patient care environments by coupling the highly mobile and communicative nature with the need to be consistently connected to backend clinical systems.

Dr. Eric Topol a leading cardiologist says we'll soon use our smartphones to monitor our vital signs and chronic

conditions [2]. At TEDMED, he highlights several of the most important wireless devices in medicine's future all helping to keep more of us out of hospital beds.

Doctors are using mobile devices frequently at an alarming pace to the workplace which they are seeking to use in patient care. This unrestricted practice of such devices could expose private patient information as well as place an unacceptable burden on the network and IT resources. These devices potentially share a network environment with critical hospital wired and wireless devices including location tracking systems, telemetry, and biomed devices with their independent needs for security, quality of service, data access, and bandwidth. On the other hand IT organizations provide the flexible resources required to manage a comprehensive BYOD strategy while maintain costs, control, and security, the guests could be easily log on to the network, without disturbing the bandwidth.

The remainder of the paper is organized as follows. Section II gives the requirements for a medical sensor network design. In Section III, we discuss about the hardware and technical challenges in Medical sensor networks. Section IV tells about the standards used in wireless medical applications. Section V describes the possible locations of medical sensor networks. Section VI and VII introduces the current and forthcoming technologies in Medical Sciences. Finally, section VIII, concludes the paper.

## II. Wireless Medical Devices Challenges

Wireless technologies are more prone to failures and hence need to keep in mind all the problems before hand. The challenges with wireless medical devices can be as follows:

- A. Interoperability: Wireless systems will have to ensure faultless data transfer across standards such as Bluetooth, ZigBee etc. to promote information exchange, plug and play device interaction. Further, the systems will have to be scalable ensuring efficient migration across networks and offering uninterrupted connectivity.
- B. System devices: The sensors used will have to be low on complexity, small in form factor, light in weight, power efficient, easy to use and reconfigurable. The storage devices need to facilitate remote storage and viewing of patient data as well as access to external processing and analysis tools via the Internet.
- C. System and device-level security: Considerable effort would be required to make secure and accurate transmission. It will have to be ensured that the patient "secure" data is only derived from each patient's dedicated system and is not mixed up with other patient's data.
- D. Invasion of privacy: People might consider the wireless medical technology as a potential threat to freedom, if the applications go beyond "secure" medical usage. Social acceptance will be the key to this technology finding a wider application.
- E. Sensor validation: persistent sensing devices are subject to inherent communication and hardware constraints including unreliable wired/wireless network links, interference and limited power reserves. This may result in incorrect datasets being transmitted back to the end user. It is of the great importance especially within a healthcare domain that all sensor readings are validated. This helps to reduce false alarm generation and to identify possible weaknesses within the hardware and software design.
- F. Data consistency: Data residing on multiple mobile devices and wireless patient notes need to be collected and analyzed in a seamless fashion. Within body area networks, vital patient datasets may be fragmented over a number of nodes and across a number of networked PCs or Laptops. If a medical practitioner's mobile device does not contain all known information then the quality of patient care may degrade [12].
- G. Interference: The wireless link used for body sensors should reduce the interference and increase the coexistence of sensor node devices with other network devices available in the environment. This is especially important for large scale implementation of WBAN systems.

Besides hardware-centric challenges, the following human-centric challenges should be addressed for practical BAN development. These include-

**Obliged Deployment:** The WBAN should be wearable, lightweight and non meddling. It ought not change or burden the client's every day exercises. The innovation

ought to at least be straightforward to the client i.e., it ought to play out its checking assignments without the client acknowledging it

**Cost:** Today's shoppers expect minimal effort wellbeing checking arrangements which give high usefulness. WBAN usage should be fetched upgraded to claim contrasting options to wellbeing cognizant purchasers.

**Consistent Monitoring:** Users may require diverse levels of checking, for instance those in danger of cardiovascular ischemia may need their WBANs to work continually, while others in danger of falls may just need WBANs to screen them while they are strolling or moving. The level of checking impacts the measure of vitality required and the life cycle of the BAN before the vitality source is exhausted..

**Consistent Performance:** The performance of the WBAN should be consistent. Sensor measurements should be accurate and calibrated even when the WBAN is switched off and switched on again. The wireless links should be robust and work under various user environments.

### III. Basic Requirements of the wireless medical services

The prerequisites for a medicinal sensor arrange configuration depend enormously on the particular application and sending condition. A sensor organize intended for specially appointed and a body territory arrange sending in a crisis circumstance has altogether different necessities than one sent for all time in a healing center. The last can make utilization of settled, fueled door hubs which gives access to a wired system framework. In any case, the general attributes we can distinguish that about all restorative sensor systems would share are as per the following.

1. Node's Hardware: Sensor hub requires new equipment outlines for specific restorative applications relying upon the specific application and sending situation.
2. Wearable sensor stages: Medical applications sensors should be little, lightweight, and wearable as they should be in contact with body of the patient.
3. Reliable interchanges: For therapeutic applications extraordinary accentuation is set on information accessibility. Albeit irregular parcel misfortune because of obstruction might be adequate, tenacious bundle misfortune (because of blockage or hub portability) would be hazardous. Contingent upon the sensors being used, testing rates may go anyplace from under 1 Hz to 1000 Hz or more, put substantial requests on the remote channel.
4. Multiple recipients: Data from a given patient will normally be gotten by different specialists or medical attendants watching over the patient. This proposes the system layer should bolster multicast semantics.

5. Device versatility: Doctors, patients and parental figures are altogether portable, requiring that the correspondence layer adjust quickly to changes in interface quality. A multi bounce directing convention being used ought to rapidly discover new courses when a specialist moves from space to room amid rounds.
6. Security: Other than the undeniable security contemplations with delicate patient information, United States law orders that therapeutic gadgets meet the protection necessities of the 1996 Health Insurance Portability and Accountability Act (HIPAA). Every single late work on private-key and open key cryptography plans for sensor systems might be connected here, yet should be incorporated into a proper confirmation and approval structure.

#### IV. Wireless Medical applications aspects

##### WPAN

WPANs utilizing Zigbee or Bluetooth guidelines are picking up in ubiquity, with remote bits accessible from industry. Various physiological checking frameworks in light of the bits have been proposed and sent in genuine clinical settings. Notwithstanding tolerant observing these frameworks can be utilized for persistent following in circumstances where area data is fundamental, for example, mass loss incidents. Started with Ericsson's Bluetooth Project in 1994, Bluetooth innovation is viewed as a Wireless Personal Area Network (WPAN). Bluetooth works in frequencies running from 2402 to 2480MHz with direct transmission capacity of 1MHz in US. The information rate is characterized at 720 kbps per client. Time division multiplexing strategy partitions the direct in to 625 small scale second openings, 1600 times RF bouncing for every second. Working in one of three transmission mode, from 1-3 which have transmission yield powers are 20dBm, 4dBm and 0dbm with run from 100m to 10m individually, Bluetooth is an innovation intended for link substitution and short separation impromptu network. A Bluetooth arrange, a supposed piconet can be framed by an ace, up to 8 dynamic slaves and up to 255 stopped slaves. Upon association foundation, a slave synchronizes recurrence jumping and its clock to the ace's and afterward sits tight for the surveying from ace to transmit. Another innovation utilizing as a part of WPANs is Zigbee, a purported IEEE 802.15.4. The standard is a ultra-low power, low-information rate which is utilized for checking and controlling applications. Gadgets utilizing Zigbee has under 1% life time in dynamic status. In the majority of the life, the gadgets are in rest mode to spare gadget's energy. With numerous preferences including low-control utilization, little size, basic convention, wide similarity, et cetera, WPAN is connected to numerous therapeutic applications including telemedicine framework, unavoidable and nonstop patients checking and remote coordinated restorative gadgets. As another case for utilization of Bluetooth, remote electroencephalograms (EEG) utilize Bluetooth remote interface to exchange EEG to PDAs. Numerous different utilizations of Bluetooth and

Zigbee in medicinal application will be talked about in the later segments

##### WBAN

A body-integratable system, supposed WBAN, can be framed by incorporating these gadgets. WBAN with sensors devouring amazingly low power is utilized to screen patients in basic conditions inside healing facility. Outside the healing center, the system can transmit patients' indispensable signs to their doctors over web in realtime. WBAN ordinarily utilizes Zigbee, or UWB standard. One of numerous utilizations of WBAN in medicinal area is PC helped physical recovery. Canny sensors wearing by patients transmit essential signs to individual server, which is running on a PDA, PC or 3 G cellphone. Successively, the information is transmitted from individual server to servers of the medicinal services framework, for example, climate gauge, therapeutic database or crisis server over Internet.

##### 2.2 WLAN

The first and most seasoned remote innovation utilized as a part of medicinal application is remote neighborhood (WLAN). The models of WLAN were 3 of 12 initially presented in 1997, to be specific IEEE 802.11. The limits of IEEE 802.11 guidelines advanced from 1-2Mbps in the underlying form to 54Mbps in IEEE 802.11a and IEEE 802.11b. IEEE 802.11a has a scope of 100 feet and 802.11b has scope of 350feet outside and 150 feet indoor. Numerous expansions of 802.11 were discharged, including 802.11g, included 2003 with limits of 54Mbps transmission chipping away at 2.4GHz band at scope of 350ft outside and 150 feet inside; 802.11n with higher throughput of up to 200Mbps; 802.11i, included 2004 with upgraded security; and 802.11s included for Mesh Network. These days, WLAN are given in nearly US healing facilities. By utilizing this transmission media, correspondence between offices inside healing facilities, from clinic to doctor's facility can be made on the fly. Patient's information is effectively exchanged around the healing center. WLAN are broadly utilized as a part of telemedicine, medicinal services information transmission, and numerous different applications

##### BLUETOOTH BENEFITS

Bluetooth is the latest remote convention in the medicinal space. As a low-control, point-to-point convention with an acknowledged worldwide standard, Bluetooth empowers expanded patient versatility and gives human services experts less demanding access to understanding information. These specially appointed systems, called piconets, can possibly make the consistent coordination of all key medicinal hardware in doctor's facility rooms and at home conceivable. Understanding protection can without much of a stretch be outlined into items, since Bluetooth underpins numerous security highlights, including watchword insurance and encryption.

A decent case of an item that Bluetooth makes conceivable is a remote electrocardiogram. Every patient lead can be outlined as a different battery-fueled Bluetooth gadget that

speaks with a battery-controlled Bluetooth-empowered patient screen. That patient screen, which additionally speaks with the healing center's 802.11b system, constantly, sends the electrocardiogram information to the system. In the mean time, the specialist can screen this information from anyplace in the clinic utilizing his handheld PDA, accordingly finishing the whole electrocardiogram checking process without a solitary wire.

### I. Location of a wireless network in a health care system

#### Body area network (BAN):

Wireless body area network (WBAN) or body sensor network (BSN) are terms used to describe the application of wearable computing devices [2] [30] [31]. This will enable wireless communication between several miniaturized body sensor units (BSU) and a single body central unit (BCU) worn at the human body.<sup>[4][5]</sup> The development of WBAN technology started around 1995 by considering wireless personal area network (WPAN) technologies for communications on, near and around the human body. Later around 2001, this application of WPAN has been named as body area network (BAN) to represent the communications on, in and near the body only. A WBAN system can use WPAN wireless technologies as gateways to reach longer ranges.

#### Medical-Grade Network (MGN):

It is important to reflect on the point that the term Medical-Grade Network (MGN) generates a great deal of discussion, as it should. Given the fact that there are no formal network-specific standards or metrics that can be applied to determine what constitutes an MGN, the reader should understand that the best known industry practices when applied properly can achieve what Cisco terms an MGN. Such network architectures often comprise the set of attributes as defined in the proceeding section, but what makes an MGN different than other network architectures are the use of biomedical devices, federal regulations and the criticality of systems involved in life safety.

Additionally, over time technologies change, the underlying techniques used to achieve these standards will therefore also change. The network architect and engineering teams responsible for the deployment of medical networks (wired or wireless) must consider the attributes and concerns described above in order to provide the best possible service available with the current state of technology and therefore resulting in what is considered a Cisco MGN. Cisco MGN provides numerous services like location based services, patient monitoring, voice recognition, and so on.

### II. Developed medical applications of WSN

#### Quatech Airboune (TM) and AirbourneDirect (TM):

Airborne modules are a powerful technique to incorporate old machines, which don't have remote correspondence

ability, with present day remote human services framework. The interface modules permit the old machines last more. Airborne modules enable these machines to have remote correspondence, diminish wiring and make it perfect with current system. Quatech Airborne and AirborneDirect bolster 802.11b/g are: Airborne(TM) 802.11b/g implanted Wireless Device Server Module, Airborne(TM) 802.11b/g inserted Wireless Ethernet Bridge Module, AirborneDirect(TM) 802.11b/g outside Wireless Device Server, and AirborneDirect(TM) 802.11b/g outer Wireless Ethernet Bridge.

#### CIMIT:

CIMIT is a middle leading examination so as to enhance persistent care [CIMIT]. CIMIT groups have delivered genuinely novel, practical social insurance arrangements, huge numbers of them are organized sensor arrangements, remote observing, and following frameworks. These novel arrangements will be actualized in genuine sooner rather than later from healing facility to home. CIMIT groups have been outlining and developing "Working Room of the Future, a completely working room in which novel, incorporated advances and new procedures are presented, assessed, and enhanced, and through which patients move with far more prominent solace, speed and security".

The accompanying are pictures of few of the gadgets created or are right now being produced by CIMIT teams. CIMIT is a demonstrated and effective model for starting and quickening translational restorative research in the space of gadgets, methodology, and clinical frameworks designing.

CIMIT mission is to enhance persistent care by encouraging joint effort among researchers, designers and clinicians to catalyze the disclosure, improvement and usage of imaginative advances, stressing negligibly obtrusive methodologies

CIMIT originators made another worldview in translational research, a model for development associating the clinical and scholastic research groups: a system of researchers in medication, science, science, arithmetic, building, material science and industry, each with an energy to reach past customary research and convey progressive results.

#### Life Star vital signs monitoring Systems:

Life begin checking frameworks is a mix of numerous estimating gadgets and remote advances [Lifestar] [20]. The testing comes about are transmitted by means of Bluetooth innovation to the LifeStar handheld gadget. Clients' data can be utilized immediately on the handheld gadgets or transmitted again to the LifeStar Network, where the information is put away.

#### The wireless B.O.HM Center:

Like LifeStar framework, The Wireless B.O.H.M. Focus is utilized for self-observing and administration of crucial signs by patients [19]. The framework comprises of five

medicinal services gadgets incorporated Bluetooth and cell interchanges. The Wireless B.O.H.M Center can be utilized to screen 5 patients' imperative signs all the while, including heart rate, body temperature, blood glucose levels, muscle versus fat and 1-Lead ECG.

#### **CodeBlue:**

A consolidated equipment and programming stage for therapeutic sensor systems, called CodeBlue. CodeBlue gives conventions to gadget disclosure and distribute/buy in multihop directing, and additionally a basic inquiry interface that is custom fitted for medicinal observing. We have built up a few restorative sensors in view of the well known MicaZ and Telos bit outlines, including a heartbeat oximeter, EKG and movement action sensor. We additionally depict another, scaled down sensor bit intended for restorative utilize

### **III. Forthcoming Medical applications of WSN**

#### **Piping Wireless into the Home**

Other than conveying computerized information, optical strands can likewise transmit radio signs for remote correspondence. Purported "radio-over-fiber" innovation has been utilized to give access to radio no man's lands, however new research is investigating utilizing this innovation to communicate remote nearer to home.

#### **Remote Intelligent Drug Delivery System (RIDDS)**

Advances in remote sensor organizing have opened up new open doors in social insurance frameworks [23]. The future will see the mix of the wealth of existing specific therapeutic innovation with inescapable, remote systems. They will exist together with the introduced framework, enlarging information gathering and continuous reaction. Cases of regions in which future restorative frameworks can profit the most from remote sensor systems are in-home help, brilliant nursing homes, and clinical trial and research expansion. With the appearance of customized medication, propels in diagnostics and the scaling down of sensors and control frameworks for conveying drugs consequently. The coming innovation, the Remote Intelligent Drug Delivery System (RIDDS) may soon be embedded under the skin, evacuating the bother of manual medication conveyance. Inbuilt sensors of RIDDS gadget should screen biomarkers of a patient's manifestations, beat rate, or blood oxygen levels, for example. They could alter medicine recurrence or levels as vital construct either in light of direct patient perception or sensor yields. In any case, one part of RIDDS arrangement that is yet to be tended to is security.

#### *Your Wireless Router Could Save Lives in an Emergency*

The specialists have now built up the idea of a crisis mode for remote switches of the sort found in numerous workplaces and homes [24]. This crisis mode enables people on call and advantaged clients to associate with the Internet

from workstations and different gadgets without plan of action to the cell phone network. Immanuel Schweizer and Kamill Panitzek working in Max Mühlhäuser's lab have long-standing background in crisis organizing. Already, they analyzed open access remote systems in various metropolitan territories on various mainlands. These switches, as well, could give a specific level of fallback network for specialists on call. Be that as it may, their new approach is considerably more capable and would even work in medium-sized towns. With a specific end goal to exhibit this, the creators gathered information utilizing a purported war-driving application on the Android open stage. Combined with GPS information, information from this application enabled them to pinpoint remote switches in urban situations, without defying any protection norms. Their investigation of the information in this run of the mill urban area uncovered that people on call could guide into the web inside a 30-meter hover from practically any situation around the local area. Network with their companions and back to their partners at home office and somewhere else could be guaranteed.

#### **Wireless medical devices security concerns**

The developing utilization of remote innovation joined with the multifaceted nature of a large number of restorative gadgets has raised worries about how ensured they are against data security chances that could influence their wellbeing and adequacy [26]. Remote restorative gadgets are possibly helpless against being remotely controlled by programmers and should go under more prominent government oversight, as per a Government Accountability Office report.

That was the focal determination of a report issued today from the Government Accountably Office that approached the Food and Drug Administration, the office inside the Department of Health and Human Services (HHS) that is in charge of guaranteeing the wellbeing of medicinal gadgets, for example, implantable cardio-defibrillators or insulin pumps, to fix the security necessities of therapeutic gadgets.

From the GAO: "Medicinal gadgets may have a few such vulnerabilities that make them powerless to unexpected and purposeful dangers, including untested programming and firmware and restricted battery life. Data security dangers coming about because of specific dangers and vulnerabilities could influence the wellbeing and adequacy of medicinal gadgets. These dangers incorporate unapproved changes of gadget settings coming about because of an absence of proper access controls. Government authorities and specialists noticed that endeavors to moderate data security dangers should be adjusted with the potential unfriendly impacts such endeavors could have on gadgets' execution, including constraining battery life." "Even the human body is helpless against assault from PC programmers," Representative Anna Eshoo, a Democrat from California, said in an announcement. "Implantable medicinal gadgets have brought about enormous health advantages for the patients who utilize them, yet the exhibited security dangers

require a recharged accentuation by the FDA and producers to distinguish, assess and plug the conceivably uncommon however genuine security gaps that exist in these gadgets."

The write about medicinal gadget wellbeing was started after PC security scientists discovered unsafe vulnerabilities in insulin pumps. Diabetics depend on the pumps, which are worn beside the skin, to administer insulin, a lifesaving hormone. Two scientists Jay Radcliffe and Barnaby Jack, who worked independently - exhibited approaches to control the remote abilities on gadgets made by Minneapolis-based Medtronic Inc. to remotely assume control over the pumps and administer deadly dosages of insulin.

A prior investigation, in 2008, from a consortium of scholastics found that at a well known pacemaker-defibrillator could be reconstructed to convey savage shocks. While data security is a best need for any association, medicinal services suppliers must be particularly persistent in ensuring classified patient information. Notwithstanding the advancing risk postured by programmers and different interlopers, government directions, for example, the U.S. Medical coverage Portability and Accountability Act (HIPAA), build up security prerequisites for ensured wellbeing data (PHI).

System based applications have changed practically every industry, and human services is no exemption. Arrangements that enable access to electronic restorative records (EMRs), medicinal administration frameworks, imaging, biomedical data, material administration, understanding bookkeeping, conceding data, and online cases entries are getting to be typical in remote, wired, and portable situations.

Since the general system security is just as solid as its weakest connection, suppliers should be as sure as conceivable that WLANs are giving an indistinguishable level of access control and protection from wired LANs. Rather than a wired LAN, in which a physical association controls access to the system, WLANs communicate information through the air. Unique security contemplations ought to be made to meet the necessities put forward by US and universal administrative bodies and associations including HIPAA, HITRUST, Data Security Standards (DSS) and PIPEDA

#### Smart Homecare

In [25] researchers propose remote sensor organize design for brilliant homecare that has the fundamental components of every one without bounds therapeutic applications, to be specific:

- Integration with existing therapeutic practices and innovation,
- Real-time, long haul, remote checking,
- Miniature, wearable sensors, and

- Assistance to the elderly and constant patients.

It broadens medicinal services from the conventional center or doctor's facility setting to the patient's home, empowering telecare without the restrictive expenses of retrofitting existing abodes..

#### IV. Conclusion

This paper displays an underlying investigation into the difficulties of equipment and programming outline for therapeutic sensor systems. We trust that low-control remote sensors have the potential for gigantic effect in numerous therapeutic applications. We have endeavored to make a study of all the conceivable utilizations of WASN in the different fields of therapeutic Sciences. CodeBlue and other a few undertakings are right now being produced through a few dynamic joint efforts with nearby healing centers keeping in mind the end goal to encourage specialists and patients. In coming future Wireless sensor systems will cover the vast majority of the area of medicinal science.

#### REFERENCES

- [1] "St. Louis Hospital Tests Wireless System That Monitors Vital Signs", iHealthBeat, August 2011
- [2] Lin Yao,1 Bing Liu,1 GuoweiWu,1 Kai Yao,2 and JiaWang1 "A Biometric Key Establishment Protocol for Body Area Networks" International Journal of Distributed Sensor Networks Volume 2011, Article ID 282986, 10 pages doi:10.1155/2011/282986
- [3] J. A. Stankovic, Q. Cao, T. Doan, L. Fang, Z. He, R. Kiran, S. Lin, S. Son, R. Stoleru, A. Wood "Wireless Sensor Networks for In-Home Healthcare: Potential and Challenges"
- [4] R. Dor, G. Hackmann, Z. Yang, C. Lu, Y. Chen, M. Kollef and T.C. Bailey, "Experiences with an End-To-End Wireless Clinical Monitoring System", Wireless Health (WH'12), October 2012.
- [5] Y. Mao, W. Chen, Y. Chen, C. Lu, M. Kollef and T.C. Bailey, "An Integrated Data Mining Approach to Real-time Clinical Monitoring and Deterioration Warning", ACM SIGKDD International Conference on Knowledge Discovery and Data Mining (KDD'12), August 2012.
- [6] Y. Mao, Y. Chen, G. Hackmann, M. Chen, C. Lu, M. Kollef and T.C. Bailey, "Early Deterioration Warning for Hospitalized Patients by Mining Clinical Data", International Journal of Knowledge Discovery in Bioinformatics, 2(3):1-20, 2012.
- [7] Y. Mao, Y. Chen, G. Hackmann, M. Chen, C. Lu, M. Kollef and T.C. Bailey, "Medical Data Mining for Early Deterioration Warning in General Hospital Wards", ICDM Workshop on Biological Data Mining and its Applications in Healthcare (BioDM'11), December 2011.
- [8] G. Hackmann, M. Chen, O. Chipara, C. Lu, Y. Chen, M. Kollef and T.C. Bailey, "Toward a Two-Tier Clinical Warning System for Hospitalized Patients", American Medical Informatics Association Annual Symposium (AMIA'11), October 2011.
- [9] O. Chipara, C. Lu, T.C. Bailey and G.-C. Roman, "Reliable Clinical Monitoring using Wireless Sensor Networks: Experience in a Step-down Hospital Unit",

- ACM Conference on Embedded Networked Sensor Systems (SenSys'10), November 2010.
- [10] J. Ko, C. Lu, M.B. Srivastava, J.A. Stankovic, A. Terzis and M. Welsh, "Wireless Sensor Networks for Healthcare", Proceedings of IEEE, 98(11): 1947 - 1960, November 2010.
- [11] "Toward a Two-Tier Clinical Warning System for Hospitalized Patients", American Medical Informatics Association
- [12] O. Chipara, C. Brooks, S. Bhattacharya, C. Lu, R.D. Chamberlain, G.-C. Roman, and T.C. Bailey, "Reliable Real-time Clinical Monitoring Using Sensor Network Technology", American Medical Informatics Association (AMIA) Annual Symposium, November 2009.
- [13] Annual Symposium (AMIA'11), October 2011.
- [14] "Reliable Clinical Monitoring using Wireless Sensor Networks: Experience in a Step-down Hospital Unit", ACM Conference on Embedded Networked Sensor Systems (SenSys'10), November 2010.
- [15] "Toward Wireless Clinical Monitoring in General Hospital Units", PRECISE Seminar, University of Pennsylvania, October 2010.
- [16] "Wireless Sensors Relay Medical Insight to Patients and Caregivers, IEEE Signal Processing Magazine", 29(3): 8-12, May 2012.
- [17] Victor Shnayder, Borrong Chen, Konrad Lorincz, Thaddeus R. F. FulfordJones, and Matt Welsh "Sensor Networks for Medical Care
- [18] "Mesh Network Monitors Patients in Virtual ICU", British Journal of Healthcare Computing, August 2011.
- [19] "Hospital Tests Wireless Patient Monitoring", UPI, August 2011.
- [20] "Clinical Warning System Could Change Healthcare", Nurse.com, August 2011.
- [21] Ibrahim Noorzaie, "Survey Paper: Medical Applications of Wireless Networks
- [22] "Wireless Network in Hospital Monitors Vital Signs", Washington University News Release, August 2011.
- [23] Jeonggil Ko, Jong Hyun Lim, Yin Chen, Razvan Musaloiu-E., Andreas Terzis and Gerald M. Masson "MEDiSN: Medical Emergency Detection in Sensor Networks" ACM Transactions on Embedded Computing Systems
- [24] ScienceDaily (Dec. 14, 2009)
- [25] ScienceDaily (Feb. 6, 2009)
- [26] ScienceDaily (Aug. 20, 2012)
- [27] "Washington University Researchers Seek to Bring Mobility to ICU Patients", RFID Journal, August 2011.
- [28] ScienceDaily (Aug. 24, 2011)
- [29] ScienceDaily (Apr. 6, 2010)
- [30] ScienceDaily (Oct. 11, 2010)
- [31] Lai, D. , Begg, R.K. and Palaniswami, M. eds, Healthcare Sensor Networks: Challenges towards practical implementation, ISBN 978-1-4398-2181-7, 2011
- [32] Garcia P., "A Methodology for the Deployment of Sensor Networks", IEEE Transactions On Knowledge And Data Engineering, vol. 11, no. 4, December 2011.
- [33] O. Chipara, G.Hackmann, C. Lu, W. Smart and G.-C. Roman, "Practical Modeling and Prediction of Radio Coverage in Indoor Sensor Networks", ACM/IEEE International Conference on Information Processing in Sensor Networks (IPSN'10), April 2010