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Applications of Wireless Sensor Networks in Medical Health Care

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Abstract— The purpose of this paper is to provide a snapshot of the current developments and future direction of research on Wireless sensor networks (WSN) for continuous and efficient health care monitoring. Coming along with the urgent development of the wireless technology, wireless devices have invaded the medical areas with the wide range of capabilities. Not only improving the quality of life of patients and doctors, wireless technology enables clinicians to monitor patients remotely and give them timely health information reminders anywhere anytime. We are emphasizing on the advantages that WSN has over wired alternatives and portable devices such as heart rate and blood pressure monitors. With the advent of WSN technologies, the time consuming jobs are terminated and patients are liberated from instrumentations. The recent enhancements in WSN has introduced a new field, wireless body area networks(WBAN), which aims to improve different aspects of our lives using vesture and non-vesture sensor devices. Different academic researches and projects based on WSN are summed up to let the readers know what the future of WSN in health care holds. The paper presents a variety of emerging applications and new-age projects of WSN in countries like US and UK. It also throws some light on the use of this technology in future in the developing countries. We conclude by providing a global overview of the real time implementation of WSN in the healthcare sector of developed countries and compare the progress to that in developing countries like India.

Keywords— Wireless Sensor Network, Body Area Network, Healthcare, Emplaced, Implantable, IEEE 802.15, Zigbee, MEMS Technology

I. INTRODUCTION

Medical technology has come a long way over the last several decades. Starting with the invention of microscope, it kept advancing to evolve technologies like endoscopes, x-ray machines, CT scanners, ultrasound imaging, magnetic resonance imaging ,pacemakers, defibrillators, BP machines, Ultrasound ,nuclear medicine, the heart-lung machine, kidney dialysis, Transplants, artificial hip joints, brain-computer interface chips, etc [1][2] .Traditionally, the sensors for these instruments were attached to the patient by wires; the patient sequentially becomes bed-bound, and the results are recorded in a medical chart. In addition, whenever patient needed to move, all monitoring device had to be disconnected and then reconnected later.

With the further progress in technology, computers became ubiquitous in healthcare system by making the storage and data-handling, a less tedious job. Patients with their families started finding specialists via the Internet. This was when the world got the first glimpse of what devices and networks can do.

The evolution included sensors and finally led onto the wireless networks of communication which help patients in keeping touch with their health care providers. Wireless systems like Radio Frequency Identification (RFID) have contributed a lot to the healthcare sector. But, RFID involves sensing items and conveyances only when they pass very near to the occasional interrogator. What happened with the sensors in between remained vague thus making hospitals adopt Real Time Locating Systems (RTLS) also known as the second generation active RFID, where interrogators sense location in 3D without being nearby. Recently, Reva Systems Corporation in US has deployed RTLS equipment at the new Roy and Patricia Disney Family Cancer Center in Burbank, California, USA [3].

The need to eliminate the flaws in these conventional systems brings WSN into picture. This is a Third Generation Active RFID, a self-healing self-organizing mesh network, each of the nodes deployed, being able to sense not just locate. WSN includes an exquisite technology namely Wireless Body Area Networks (WBAN) which leverages wireless communications protocols that allow for low-powered sensors to communicate with one another. The following sections explain as to why and how the roll-out of WSN in health care monitoring is profusely occurring.

II. WHAT IS WSN?

It is a dense collection of tiny sensor motes deployed in a region of interest to gather information about a specific phenomenon for later analysis. WSNs allow distributed and collaborative control of various physical and environmental events. Each such sensor network node has typically several parts: a radio transceiver with an internal antenna or connection to an external antenna, a microcontroller, an electronic circuit for interfacing with the sensors and an energy source, usually a battery or an embedded form of energy harvesting. But each such sensor employed in the network

should be designed such that they have a small effect on what is measured.A sensor node is like a small computer that is capable of performing some processing, gathering sensory information and communicating with other connected nodes in the network. The functionality of both transmitter and receiver are combined into a single device known as a transceiver. The operational states are transmit, receive, idle, and sleep. Radio frequency-based communication is the most relevant that fits most of the WSN applications. Though Sensor nodes often make use of ISM band, they also make use of the UWB band and Zigbee as per the IEEE 802.15 standard. WSNs tend to use license-free communication frequencies: 173, 433, 868, 915 MHz and 2.4 GHz [4-6].

A microcontroller is often used in the sensor nodes rather than FPGAs and ASICs because of its low cost, flexibility to connect to other devices, ease of programming, and low power consumption. Batteries, both rechargeable and non-rechargeable, are the main source of power supply for sensor nodes. When it comes to software, Real time operating systems such as eCos (embedded configurable operating system) or uC/OS (Microcontroller Operating System), TinyOS, LiteOS and Contiki are used. The topologies for WSN are star, cluster and multi-hop networks.WSNs are meant to be deployed in large numbers in various environments, including remote and hostile regions, where ad hoc communications play a key role. Operating in ad-hoc mode allows all wireless devices within range of each other to discover and communicate in peer-to-peer fashion without involving central access points and human intervention.

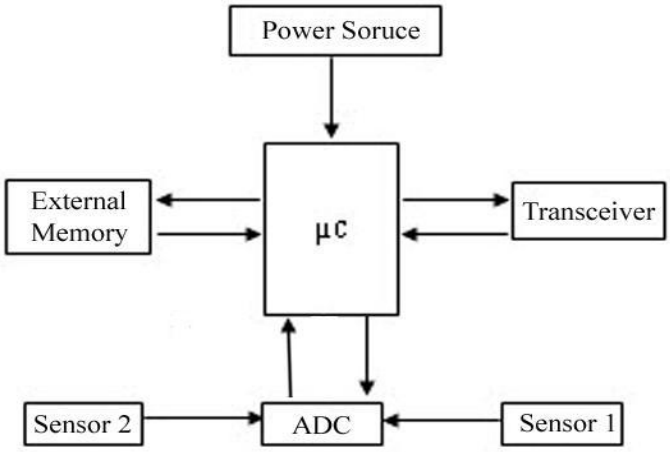

Fig.1-Sensor Node Architecture

III. WHY WSN?

Having seen what WSN actually is, we now provide insight as to why WSN is preferred over the other technologies.

A. Portability and Unobtrusiveness

With a number of advantages over wired alternatives, including: ease of use, reduced risk of infection, reduced risk of failure, reduced patient discomfort, enhanced mobility and low cost of care delivery, wireless applications bring forth exciting applications to provide healthcare at the patient's ease.

B. Reduces cables and cabling costs

The risk of unexpected connection problems with the wires is eliminated.The cabling cost is more in all the wired equipments and devices of the medical field. The cost of integration, maintenance as well as the cabling weight induces constraints that can be more costly than the price of cabling alone. WSN reduces the cost of the entire system and is more effective.

C. Miniaturized sensors

Using MEMS Technology, the size of a sensor node can be brought down to that of a grain of dust. And because of this available flexibility in size, remote areas that had earlier been inaccessible to wired instruments are now at reach. The average price per node will drop from $9 in 2011 per piece to $5 per piece in 2021 making it cost effective as well [3].

D. Real-time measurement

In emergency situations, real-time health parameter is crucial. According to the American Heart Association, treatment of a patient experiencing ventricular fibrillation within the first 12 minutes of cardiac arrest brings a survival rate of 48%-75%. The survival rate drops to 2%-4% after 12 minutes have gone. Thus with continuous and pervasive monitoring, medical emergencies can be detected sooner [7].

E. Simpler Storage Techniques

Since information can now be accessed through a centralized monitor or PDA's , the liability of spotting transcription errors in medical charts is ruled out. Databases of patients that can be built up by continuous medical monitoring will be accessed and updated as and when required. As a result, the amount of paper works required and the duplication of patient record will be dropped down. It has been proved that manual recording of patient information accounts for 40% of the total patient care time for each active bed [8].

F. Reconfiguration and self-organization

Its ability to cope with node and communication failures and the provision for mobility of nodes make WSNs highly desirable for implementation at the hospitals. It can accommodate new devices at any time and go through physical partitions at the same time.

G. Long lasting

When energy harvesting using ambient energy sources, Ad hoc networks, and Zigbee protocols are used then the sensor node life is boosted up to around 2-3 years, thus proving to have an edge over other technologies[5].

IV. HOW IS WSN APPLIED IN HEALTHCARE ?

WBAN is an ubiquitous and affordable healthcare technique which is used for fitness monitoring .The concept of this system is to place unobtrusive wireless sensors on a person's body to form a wireless network which can communicate the patient's health status with base station connected to the monitoring PC.

The system consists of four parts:

(1)WBSN includes four sensors which are responsible for collecting the physiological signals from patient.

(2)WMHRN (Wireless Multi-Hop Relay Node), consist of a number of wireless relay nodes which is in charge of forwarding the health data to the base station.

(3)BS (Base Station) which receives the relayed data and sends it to the PC.

(4)Graphical User Interface (GUI) which is responsible for storing, analyzing and presenting the received data in graphical and text format, and also sending an SMS to the healthcare provider or patient's family in emergency conditions through the GPRS or GSM modem. A similar system is explained in [9].

The network is silent until any detection is done. At that point the network node that needs a connection broadcasts a request for connection. Other nodes forward this message, and record the node that they heard it from, creating an explosion of temporary routes back to the needy node. The advantage is that it creates no extra traffic for communication along existing links. Also, distance vector routing is simple, and doesn't require much memory or calculation.

There is no specific standard for WBAN but it generally work on ZigBee when less bit rate required, for higher data rate requirement it works on either IEEE 802.15.3a or IEEE 802.11 a/b/g. There is broad range of possible devices which can connect through a single WBAN provided the total system load is less than 500 kbps. Many patients can be monitored through a single healthcare advanced monitor which can handle five similar type of WBAN network but the total traffic per patient should be less than 10 kbps [6].

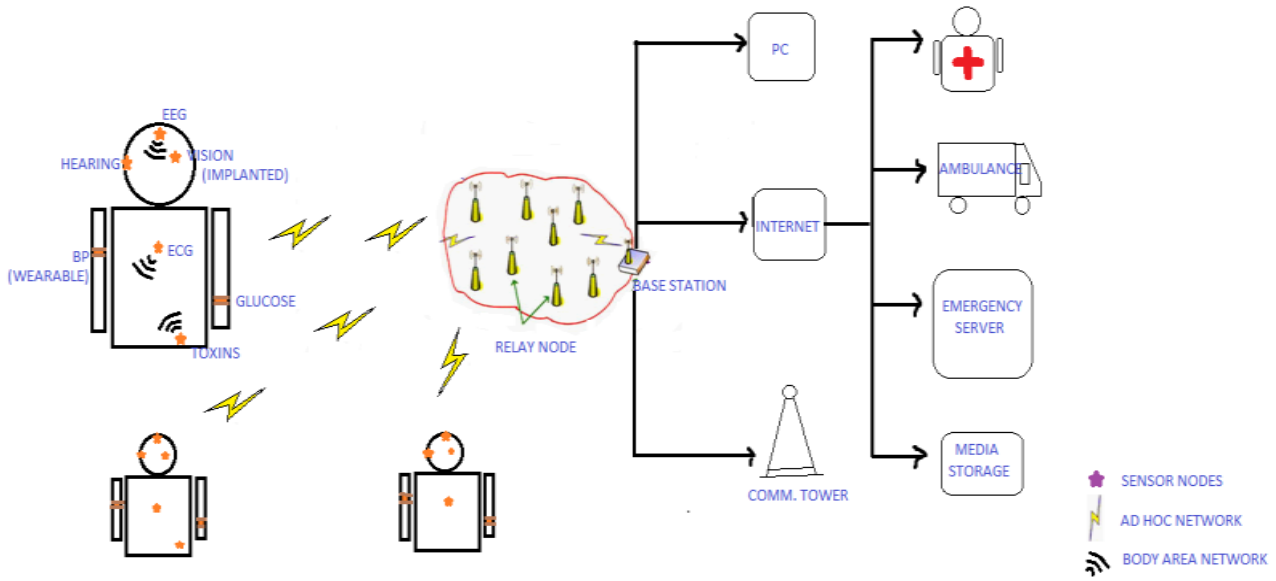

Fig.2-Architecture of WSN for healthcare

V. WIRELESS SENSOR PLATFORMS

There are variety of architectures and models being proposed for WSN implementation in healthcare. In [10]a secure and efficient (i.e., communication and computation) data collection and distribution process for WBANs. Another framework addresses the communication challenges of Nanonetworks and presents the architecture of Green Wireless Body Area Nano-network (GBAN) as a collection of nano-devices [11]. These architectures may deploy different kinds of nodes. The nodes depending on the kind of application needed come in different forms like Wearable, Implanted and Emplaced

A.WEARBLE

1)Pulse Oximeter :

A pulse oximeter is a medical device that indirectly measures the oxygen saturation levels in an individual's blood .A wearable PPG (photoplethysmographic) biosensor in the form of a ring has been developed. have designed a pulse oximeter that integrates a BCI micro power oximeter with a Mica2 or MicaZ wireless sensor platform[12-14].

2)Electrocardiography (ECG):
An ECG sensor is supported by a Mica2 mote hardware platform. The sensor utilizes two electrodes to produce a single ECG signal. This sensor is another node in the CodeBlue medical sensor network platform [12-14].

3)Smart Shirt :
It is made up of conducting fabrics acting as electrodes to capture the electrocardiogram and acceleration signals., which are then transferred to an ad hoc network using the IEEE 802.15.4 communication standards[5][15].

4)Wrist Watch :
A wrist watch alert system targets high risk patients and measures the pulse rate, skin temperature and blood pressure. It uses a CPU operating at 8MHz with 10KB RAM with a radio range of 100m (protocol: IEEE 802.15.4/Zigbee) [16].

B.IMPLANTABLE
1)Glucose Monitoring
Continuous monitoring was enabled by placing an implantable sensor covered with a multilayered membrane in the subcutaneous tissue of the abdomen. Glucose levels were determined every 30 s and radio transmission of the glucose data occurred every 5 minutes.

2)Neural Stimulators
Implantable neural stimulators send electrical impulses into the brain or spinal cord for the treatment of Parkinson's disease, intractable epilepsy and chronic pain [17].

3)Artificial Retina
Patients with no vision or visually impaired can see at a reasonable level by using retina prosthesis chips implanted within a human eye.

4)Swallowable pills
WBAN nodes can be even embedded into capsuled pills. A model has been developed to maintain the best possible video quality while ensuring security and energy efficiency in Swallowable Capsule Based WBANs[18]

C.EMPLACED
1)Smart chair
This sensor device is deployed in the environment (rooms, hallways etc) to support sensing and monitoring, of temperature, humidity, motion and acoustic. It detects vital signs and measures heart rate to give cardiac output. The sensor network interfaces to multiple body networks, seamlessly managing reported data and patient presence information.

2)Pressure sensitive bed.
Physical rehabilitation is an important process for patients recovering after surgery. A framework has been designed to monitor on-bed range of motion exercises that allows physical therapists to evaluate patient adherence to set exercise programs. Using a dense pressure sensitive bed sheet, a sequence of pressure maps are produced and analyzed using manifold learning techniques [20].

3)Motion sensors
A low-cost sensor module that is capable of detecting motion and ambient light levels has been adapted. The module has a simple one-button and LED user interface for testing and diagnostics. It is interfaced to a MicaZ wireless sensor node that processes the sensor data and forwards the information through the wireless network. A set of such modules is used to track human presence in every room of the simulated smart health hospitals [19].

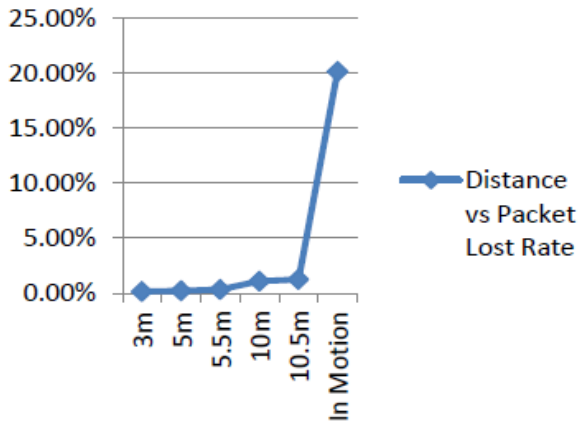

Fig.3-Loss Rate graph for the in-house patient

VI. RELATED WORK

The stress of this paper presents short overview of medical applications based on WSNs, being developed in large research sectors. Here, some projects with different medical interests are mentioned.

A. UbiMon project

UbiMon (ubiquitous monitoring environment for wearable and implantable sensors) is the architecture for distributed mobile monitoring, developed at Imperial College London. The system aims at detecting life threatening abnormalities beforehand by integrating wearable and implantable sensors into the Body Sensor Network (BSN).This framework provides pervasive monitoring of patients under their natural physiological states.

B. Satire project

Satire (software architecture for smart attire) is a wearable personal monitoring service, developed through cooperation between University of Illinois and University of Virginia. They deploy an off-the-shelf wearable monitoring platform for sensing and storing data without explicit maintenance required from the user [21].

C. Alarm-Net project

Alarm-Net is a wireless sensor network for assisted-living and residential monitoring being developed on University of Virginia. It integrates physiological sensors in a scalable, heterogeneous architecture [4]. The focus of this network is to provide smart environment and to secure patients' monitoring on daily basis.

D. Code-Blue

CodeBlue is a project undertaken by the Harvard sensor networks lab. It is being used by the AID-N project at Johns Hopkins Applied Physics Laboratory, which is investigating a range of technologies for disaster response. In addition to the hardware platform, scalable software is also developed. CodeBlue is designed to provide routing, naming, discovery, and security for wireless medical sensors, PDAs, PCs etc. The AID-N wireless sensors (which run the CodeBlue software) include an electronic "triage tag" with pulse oximeter, LCD display, and LEDs indicating patient status; a packaged version of our two-led EKG mote, and a wireless blood pressure cuff [16][23].

VII. GLOBAL OVERVIEW

This section gives a brief idea about the progress of WSN from a global and commercial viewpoint. Ever since WSN was born, researchers have been exploring its potentiality and this has led us straight to its application in the most crucial and promising sector of all:Healthcare. Various projects and devices have come to life as some of the countries have begun adopting this new technology, thus broadening the scope of WSN in healthcare monitoring. Here we try to give a clear picture by making a comparative analysis between the current WSN status in developed countries and developing countries with special reference to India.

A] WSNs have a lot of potential capability to provide diverse services to human by monitoring things scattered in real world and hence they are envisioned one of the core enabling technologies for ubiquitous health care monitoring. First Generation RFID has been around for about 60 years, RTLS for about 12 years and WBAN, in fully functional form, is only now becoming available. However, it has the potential to become multibillion dollar business which will grow rapidly from $0.45 billion in 2012 to $2 billion in 2022 [3].

Total WSN market US$ million is given in the following fig.4 from the years 2011 to 2014.

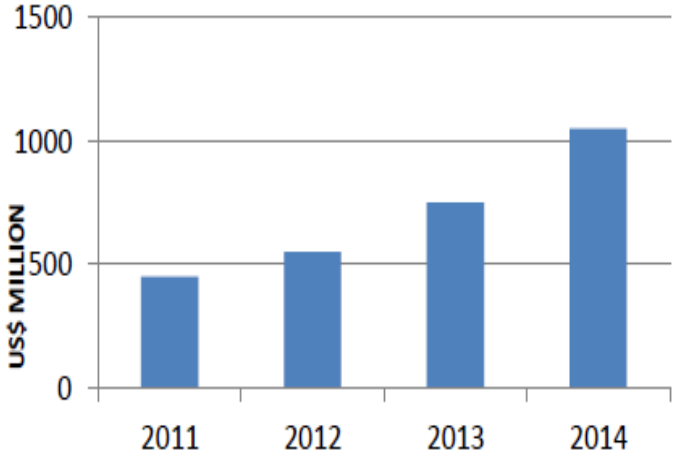

Fig.4-WSN market growth

B] The main WSN players and their location by country are given in fig.5. From the fig, we can clearly state that India has negligible contribution towards the development and promotion of WSN[3].

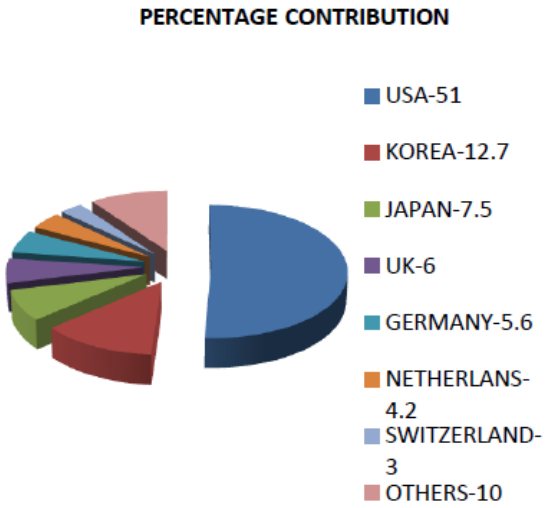

Fig.5-Global Share

C] REAL TIME IMPLEMENTATIONS

1) Healthcare in Germany:

Healthcare in Germany is a particularly active user. For instance, up to 30,000 blood and tissue samples arrive daily for examination at the Medical Care Center, headquartered in Monchengladbach, Germany. The medical samples are transported from various physicians' offices, hospitals and other laboratories in approximately 600 special transport containers. Particular attention must be paid to shipping as temperature fluctuations can cause the transported samples to be unusable. As a result, the Medical Care Center laboratory deployed a WSN that simplifies existing processes and provides a reliable quality assurance tool. An alarm system forwards an electronic error message to the supervising personnel [22]. Bamberg Hospital are monitoring both blood and patients with a full WSN system installed by a Fraunhofer institute. It gives the location of blood and matches it to the patient in these hospitals. The batteries last 2.5 years, which is quite good for WSN, yet far from ideal.

2) Healthcare in UK.

A wireless digital plaster that monitors vital signs is being tested on patients and volunteers at Imperial College London. News.com reports of a company,Toumaz Technology, that has begun clinical trials of a disposable body worn monitoring device it has developed that allows for the monitoring of body temperature, heart rate, and respiration of patients in a continuous fashion.

3) Healthcare in Japan

Verification testing of Japan's first medical body area network ,Fujitsu Clinic in Kawasaki, Japan announced on April 12,2013 that it has successfully completed the first verification test in Japan for a medical body area network (mBAN). The verification test was conducted conforming to IEEE 802. 15.6 standards and using a prototype device with a frequency band reserved for medical applications (400MHz. It was part of a study project commissioned by Japan's Ministry of Internal Affairs and Communications titled, "Studies on advanced frequency application technologies for 400MHz-band medical telemeters."[24]

4) Healthcare in Netherlands

Dutch researchers have proposed the idea of a wireless body area network, where your organs are each given an IP address and can communicate with each other. The body area network, or BAN, would include sensors that monitor each organ's health, and could connect to a mobile phone. For example, it could alert the emergency services if your heart stops, or call a doctor if a diabetic's blood sugar levels reach a certain level. Warnings can also be displayed on the phone's screen, or it could ring or buzz.

5) Healthcare in India

India's leading systems integrator ICEGEIN has deployed Ekahau RTLS at Apollo Hospital Chennai. The hospital tracks patients having various tests done as part of their annual check-up, in order to better utilize hospital resources and shorten patient wait times. Each day the hospital offers annual comprehensive health checks for 200 patients, which require them to visit a number of departments - such as cardiology, imaging and the laboratory. Because these patients move from one place to another frequently during the process, it is hard to monitor which department is busy and which one has no wait, or whether a patient is in the right place at the right time. The system solves this [22].

D] QUALCOMM'S ULTRALOW PEANUT POWER TECHNOLOGY

Qualcomm has been particularly active in addressing this aspect, coming up with new algorithms last year which are now included in an ultralow power network called Peanut, a dedicated low power network designed especially for WBANs. It

stands as a potential challenger to Bluetooth and ZigBee in the home, industrial and even body monitoring markets. The firm said Peanut could be used over distances from a few inches to the length of a room. It requires fractions of a mill watt of power but moves data at high speed like a few Mbps for data, voice and video. [25].

E] WHO RANKINGS

There are 1,80,000 hospitals worldwide. China leads the list with 69,105, followedby India with 15,067, Russia with 11,200, Japan with 9413 and USA at no. 10 with 6097 hospitals[26]. A developing country like India in spite of standing second in the ranking list of countries with the maximum hospitals , comes at no. 112 in the Health ranking report by WHO whereas Japan is ranked 10 ,UK ranked 18 and USA is ranked 37[27]. This is a definite indication of the lack of effective and indigenous techniques for maintaining the required levels of health quality in the home country.

VIII. CONCLUSION

a] Wireless BSN technology is emerging as a significant element of next generation healthcare services.Fig.4 indicates the total WSN market growth from 2011-2014. The average rise per annum is calculated to be 44.4%. The market has grown by 22.2% in the year 2011 followed by a rise of 44.4% in the year 2012. It is estimated that 2014 will witness a market growth of around 66.6%.This observation clearly shows the emergence of WSN as a technology that will soon rule the global market.

b] From Fig.5, it has been observed that the developed countries namely USA, Korea, Japan, UK have given the major share of contribution while that of India is dismal. A small country like Netherlands has been reported to spend a good portion of its GDP on health sector. If the Indian government raises it's funding by a considerable amount, then it will enable WSN to take roots and thus boost up the health quality of the people.

c] From the brief overview of the real time implementation of WBAN in Germany, UK, Japan and Netherlands, we can conclude that India lags behind because the second generation RTLS itself is in its infancy stage. So it will be long before India sees the revolution that WSN can bring about, unless some indigenous methods are quickly adopted.

d] For developing countries like India, it is suggested to use new embedded and intelligent processors like 8 bit PIC controllers such as PIC16F193X family of microcontrollers featuring microchips enhanced midrange 8 bit core MCUs-PIC16F1934,PIC16LF1934,PIC16F1936,PIC16LF1936,PIC16F1937 and PIC16LF1937.These microcontrollers are strongly recommended because they have low power requirement, in the range of few nano-watts and also provide a cost effective solution for real time implementation of WSN.

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