

# Survey Paper: Medical Applications of Wireless Networks

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## Abstract:

With recent developments in the wireless networks field, new and innovative medical applications based on this technology are being developed in the research as well as commercial sectors. This trend has just started and we predict wireless networks are going to become an integral part of medical solutions due to its benefits in cutting down healthcare costs and increasing accessibility for patients as well as healthcare professionals. In this survey paper we give some background on applications of wireless networks in the medical field and discuss the issues and challenges. We have also tried to identify some of the standards in use. Another contribution due to this paper is the identification of innovative medical applications of wireless networks developed or currently being developed in the research and business sectors. In the end we also talk about the future trends in this field.

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Keywords: *medical applications survey, medical applications, wireless networks, sensor networks, wireless applications, wireless homecare, smarthomes, WBAN, patient management, CodeBlue, wireless medical solutions, Washington University in St. Louis*

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## 1. Introduction

Wireless networks technology has been consistently improving with time and increasingly finding its way into all aspects of our daily lives. Medical applications is a field where technologies such as Wireless Networking have a promising future. In the healthcare field, access and cost saving are two of the hottest issues these days. Wireless Technologies have something to contribute towards helping with both of these issues.

The healthcare system is continuously getting more complex around the world but especially in the United States. Up to 98,000 patients die each year as a result of preventable medical errors [[Vawdrey03](#)]. These are errors that could have been avoided. The sad story is that physicians and clinicians most of the time provide patient care without knowing history of prescriptions and medical procedures, resulting both wasteful duplication and sketchy clinical decisions that do not take into account critical data related to patient health. Wireless technology offers tools that can help with such situations. These tools can help give caregivers real-time access to accurate patient data, clinical histories, treatments, medications, tests, lab results, insurance information and etc.

With all this discussion of wireless applications, healthcare providers such as hospitals, insurance agencies and the government are becoming interested in investing in this area. Cost saving is one of the main factors because medical errors by doctors brings in law suits. Patient and hospital management can be very expensive too.

In this survey paper we will be talking about applications of wireless networks in the Medical field. We will start out with some discussion on issues and challenges in the medical field. Then we will talk about some of the wireless technologies currently in use. Afterwards, we will present example applications of wireless networks in the research and commercial sectors. In the end we will talk about future trends and end with a summary.

### 1.1 Why Wireless Networks for Medical Applications

Due to advances in the wireless networks field, new and innovative applications are being thought of in medical as well as healthcare field. In the medical field applications ranging from equipment management to patient management are being developed. Efficiency among hospital staff is increased by using some of these newly available applications and tools. In the healthcare field, issues such as long-term patient care, support for elderly people and smart homes are being discussed in the realm of wireless networks. There is also research being done on creating teletrauma systems [[Chu04](#)] using the wireless channel. This will potentially allow trauma specialist to be virtually on patients bed sides while they are being moved to the trauma center. In the near future homes can be designed that take care of patients or people with disabilities without the presence of a healthcare provider. A patient who is located remotely can be cared for remotely by communicating his/her status in realtime to caregivers. Another issue that concerns the healthcare field is the

very large number of expensive medical devices that are incompatible with each other. Tedious routines are involved in translating results from one machine to another. With Wireless Technology this compatibility issue can be reduced.

Another hot issue in the wireless networks field is implantable devices. These devices can be implanted on normal day to day wearables [Malan04]. Wireless sensor implanted inside patient's body have their own significant benefits [Timmons04], [Scanlon03]. Patients can wear sensors that monitor vital signs and report them in realtime to their doctor. This helps towards the issue of access because now the patient doesn't need to be around the hospital all the time. This improves access and quality of healthcare for patients and saves money for care providers.

## 1.2 Who Benefits?

Whenever a new technology or tool is introduced to public use, the first question is how will it help me or what can it do for me? Here we discuss who benefits from applications of wireless networks in the healthcare field.

We hear in the news everyday that there is a shortage of specialized doctors or nurses around the country. One of the benefits of these applications is that they increase doctors' and nurses' efficiency. Now they can care for more patients than before. Their work is also improved and made easier by having access to accurate data on patients in real-time.

For patients whose health is on the line the benefits are even greater. They have increased access to specialized doctors. They don't have to stick around the hospital any longer. This ease in mobility allows them to do their own work while still under the doctor's care. Safety is another issue that is helped here because the rate of mistakes can significantly be decreased. Also, patients can be picky when making changes in their daily lives when signing up for a treatment. With Wireless Technologies, their healthcare can be less intrusive, for example in the case of wearable sensors [Malan04]. They don't have to show up to the hospital for a blood pressure check. It can be done while they are working through wearing wireless sensors that transmit this information in realtime to their doctors.

As mentioned earlier, negligent mistakes by doctors and nurses costs hospitals, insurance companies and the government a large sum of money each year. These costs can be reduced by reducing the number of mistakes. Efficient and secure data handling and resource management is another area where wireless networks can help. Deploying huge machines around the hospital can be very expensive and time consuming. With Wireless Technology interfaces can be designed such that access to the machines can be provided from anywhere in the hospital. This allows for rapid and flexible deployment. By increasing the doctors' and nurses' efficiency, hospitals can provide care for more patients and increase their profits.

So far, we gave a basic introduction of how wireless networks can help in the healthcare field. We talked about the benefits from these applications. We also talked about how it can help with two of the main issues in the healthcare field which are access and cost. Next we will be talking about issues and challenges that are involved in bringing this technology to the healthcare field.

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## 2. Challenges and Issues

With new technologies new applications and solutions finding their way into different fields comes challenges and issues that didn't either exist before or are worsened. The medical field has the most strict quality and assurance requirements. Because patients' sensitive information and their well being is at stake, new challenges arise on how to tackle these issues. In this section we will be talking about the many challenges that are faced when deploying new wireless networks based solutions in the medical field.

Some of the challenges faced when deploying Wireless network-based solutions include engineering issues, social issues and patients well-being issues. An implementation related challenge is interoperability among various devices. For example wireless devices are developed by different companies which follow different standards and in some cases no standards. Therefore making sure that all these devices work together and work reliability can be a challenge. For example different wireless medical devices working at different frequencies. One cannot assume that a device that works once will always work. In the medical field, strict guarantees are needed because a patients well being may depend on it.

In applications where there are realtime requirements, it can be challenging when guaranteeing realtime service. Wireless devices can behave differently at different times and locations due to natural and unnatural issues. Power requirements and power availability maybe in different situations. Some devices may fail during operation. Guaranteeing a a seamless service during bandwidth jitters and handling total disconnection can be challenging.

As mentioned earlier, reliability is one of the most important issues in medical applications. Hospitals will not be willing to use a wireless device or application that can not guarantee reliability due to the fear of lawsuits and other costs in the case of failure.

For patients one of most important issue is how their daily life be affected less by using these new applications. Thus, designing applications that can be useful while unobtrusive is another challenge for wireless networks based application/solution developers.

Since most wireless networks based devices are battery operated, one of the major challenges for developers is the issue of power limitations. Sometimes they have to guarantee that the device will work for a year or two without changing the battery [Culpepper04]. This could include devices such as heart pacemakers [Culpepper04]. The developers have to design better scheduling algorithms and power management schemes to deal with these power issues. Also we know that wireless channels are slower than wired. Developing applications/devices that can deal with traffic congestion and other performance issues, is a major challenge.

Some main issues that arise due to the use of wireless networks devices include security, privacy and the learning curve for new technologies. Ensuring patients information security can be a major issue when deploying these applications. Privacy of user data over wireless channels can be another major issue. wireless networks based medical devices can be very limited in terms of power availability and processing strength. Thus ensuring privacy without using complex encryption algorithms can be a big issue for developers of medical devices. With the new technologies taking hold in our daily lives, new users can find it challenging to use these new devices to the fullest. Thus it can be an issue and a challenge for developers to create some of the best solutions without forcing the users to make unnecessary of effort just to learn how to use them.

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### 3. Wireless Networks Technologies in Use

Due to accessibility and mobility requirements wireless is the preferred medium in medical applications. Due to limited mobility, most of the expensive and large machines that have been around for a long time are not

being used to their fullest. Wireless technologies are being developed to give new interfaces to these machines and make them interact with any new machines and procedures required in medical field.

### 3.1 Wireless Technologies in Use - Current and Past

In this section we will talk about some recent and past wireless networks based technologies used in the area of medical applications.

#### 3.1.1 WBAN (Wireless Body Area Network)

Recent advances in sensors, lower powered integrated circuits and wireless networks have brought ideas in developing low powered physiological sensor platforms that can be integrated in Body Area Networks (BANS). These sensor networks have extremely low power requirements which make them fit for integrating them in day to day wearables [Malan04]. In the medical application field, these unobtrusive devices can be attached to patients bodies to collect vital health information such as ECG, Blood pressure etc [JovanovMar05]. When used inside hospitals BANS can be used to monitor patients in critical conditions. Outside the hospital, i.e. homecare, patients' vital signs can be collected and transmitted over the internet to their doctors and nurses in realtime. Besides medical applications, BANS are also finding use in fashion and defense fields.

#### 3.1.2 RFID (Radio Frequency Identification)

Radio Frequency Identification (RFID) technology is a hot topic these days both in terms of its potential benefits and misuses [RFID]. RFID tags are used in hospitals to keep track of equipment. They can also be planted on patients as well as doctors to know at at time where they are. RFID are extremely low powered radio devices that don't need any battery power and thus have potential uses in storage areas. Other potential uses are in monitoring hospital supply stocks. Hospitals can manage their resources properly and know in real-time the status of their supplies.

#### 3.1.3 WPAN (Wireless Personal Area Network)

WPANS [ChevrollierJuly05], [Golmie05], [Golmie04] using 802.15.4 or Bluetooth have potential uses in the medical fields. These are short range networks that can be deployed for example, within a patients room. Nurses are able to monitor patients in realtime without having to visit them frequently. This saves them time and give them the opportunity to take care of more patients. Other uses of WPANs are in interfacing multiple expensive and large devices within the hospital. Data from one device can be forwarded directly from one machine to another without doctors wasting time by transferring this information by hand. Bluetooth is also a good technology for short range communication, for example, in home healthcare.

#### 3.1.4 Sensor Networks

Sensor Networks technologies such as Zigbee [ChevrollierJuly05] are being combined with WBANS [JovanovMar05] to form smaller scale networks that can be placed on human clothing (or other objects) and provide unobtrusive access to their health information. Sensor Networks are also increasingly being used in natural sciences for example in monitoring wild life or other natural phenomenon. Due to lower power requirements they can be deployed for a long period of time. Due to limited range, they are deployed in large numbers and thus form a distributed network covering a large portion of space. A good example of an application of sensor networks in the medical field is the CodeBlue project [Malan04] being developed at Harvard. Other experimental applications include forest fire detection and path tracking using adhoc sensor networks [Fok04]. Since sensors networks devices are very cheap, they can be deployed anywhere in large

numbers. Some of the wireless sensor networks based devices are very sophisticated. They operate on their own operating system called the TinyOS. Therefore they can be programmed over the air, making their management very easy.

### 3.1.5 GPRS/UMTS

GPRS and UMTS wireless technologies have also found their uses in the area of medical applications. An application called MobiHealth, which we will discuss in a later section, had been designed by using BANs with GPRS/UMTS for internet connectivity.

### 3.1.6 Wireless LAN (802.11)

Most hospitals, universities and corporate offices these days provide wireless LAN access. Some benefits include untethered access to the internet. Hospitals can use the wireless LAN channels to transfer patient data around the hospital. Communication between medical devices is also made possible using this wireless channel.

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## 4. Standards

Although the area of wireless networks for medical applications is largely without standards due to companies developing products based on their own standards, there do exist some standards and we have listed a few below. Recently there are increasing demands for creating strict standards, especially for pacemakers, which are being used by a large number of heart patients across America.

- IEEE Standards Medical Device Communications / Health Informatics Standards Subscription
  - ISO/IEEE Health informatics - Point-of-care medical device communication
  - IEEE Standard for Medical Device Communications-Transport Profile
- Mobile Health Care Alliance
  - Setting standards for mobile health information systems
- Medical Implant Communications Service in the 402-405 MHz band
  - High-speed, ultra-low power, non-voice transmissions to and from implanted medical devices such as cardiac pacemakers and defibrillators.

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## 5. Research Applications

In this section we will talk about some special applications that have been developed or are currently being developed in the research community for the purpose of healthcare improvements. Some these medical applications have impacts in daily social life, while others have pure medical benefits.

### 5.1 CodeBlue

CodeBlue is a sensor networks based medical research project being developed at Harvard. Specific goals for

this project include pre-hospital care and in-hospital emergency care, stroke patient rehabilitation and disaster response. Research from this project has potentials for resuscitative care, real-time triage decisions and long term patient observations.

This project has hardware as well as software parts. Some devices and software produced in the project include

- Wireless Vital Sign Sensors
- Wireless two-lead EKG [[Jones04](#)]
- Accelerometer, gyroscope and electromyogram (EMG) sensor for monitoring patients with strokes
- CodeBlue Software Platform

The following are images of a few of the devices developed in this project.



Figure 1: Wireless Pulse Oximeter sensor [[Malan04](#)]



Figure 2: The Harvard "Pluto" mote, designed to be small and wearable [[Malan04](#)]

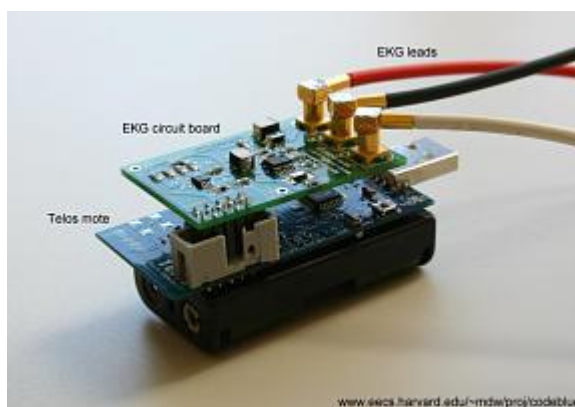


Figure 3: Wireless two-lead EKG [[Malan04](#)]

## 5.2 MobiHealth

Mobihealth is a project based on a European initiative to create a generic platform for home healthcare using BAN-based sensors and wireless telephony technology. They are using GPRS/UMTS wireless communication technology for transferring data. Some of the capabilities include measurement and transmission of vital signs and other biosignals. In this project they developed a Body Area Network (BAN) and a service platform for patients and healthcare professionals.

Some benefits of the devices created in this project include:

- Light-weight sensor system worn on the body
- Increases mobility and out of hospital care and monitoring
- Low interruption to daily life

Some of the challenges faced include:

- Low bandwidth with GPRS/UMTS
- Power requirements
- Security and reliability

### **5.3 Wireless Physiological Sensors for Ambulatory and Implantable Applications**

In this project, they are developing wireless sensor technology for ambulatory and implantable human psycho-physiological applications [[JovanovSept05](#)]. Some of the devices developed here are for monitoring the functioning of the heart, monitoring prosthetic joints for a very long period of time and monitoring other vital signs. They focus on wearable and in particular implantable or subcutaneous biosensors which will provide significant advantages over more conventional methods. Besides these devices and mechanisms, their work also can allow doctors and care givers to have to remote access to useful information about the patient that is collected through these devices. The subcutaneous design is unique and perfected here. This will allow it to be used in other research projects as well.

The main aims of this project include

- Wireless communication
- Biosensors
- Biomaterial technologies
- Physiological modeling
- Electronics packaging

### **5.4 Project Connect**

The Connect project is basically focusing on creating solutions to help people with disabilities in their day to day life. They are trying to create a distributed wireless communication infrastructure that allows for individual customization of portable devices such as a PDA. Initially the project relied on GPRS for communication between the PDA devices and the central server. The main aim of the project is to enable people with disabilities to customize their wireless devices i.e PDA to keep schedules for them, give them important reminders and allow them to communicate with their caregivers through any of the sever possible ways provided. Therefore this system adapts to the user's needs.

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## **6. Industry Applications**

Wireless technology for medical applications is still relatively new but there are companies who see the potential demand in the future. In this section we will talk about some wireless networks based medical solutions/applications that are available commercially. These include the following:



- LifeSync Wireless ECG System
- Airborne(TM) Embedded Wireless Device Server Modules and Radios
- ecgAnywhere
- LifeSource Products
- HealthTrax

## 6.1 LifeSync Wireless ECG System

LifeSync Wireless ECG System is a basic ECG device that operates using Bluetooth wireless technology. It can collect patient ECG and respiratory data and transmit using two-way radios. The main goal with this device is that it will provide a more mobile interface to existing ECG monitors in Hospital. The device can be placed anywhere with the results shown in conventional monitors. One of the advantages with using this device is that it includes continuous monitoring in a mobile environment and also that they are designed to interface with existing medical devices. This will somewhat reduce the reluctance of hospitals to phase out old but expensive machines. These devices can provide a more efficient and modern standard interface to such expensive machines.

## 6.2 Airborne(TM) Embedded Wireless Device Server Modules and Radios

Airborne(TM) modules are an answer to integrating old machinery with latest wireless technology. Instead of phasing old but still useful and functioning medical devices, these interface modules will allow hospitals and clinics to make them useful and last much longer. One of the main drawbacks of using the heavy and expensive machines in hospitals is that once placed in a room, they belong to the room and the room belongs to them. These interface modules will allow hospitals to reduce wiring and incompatibility issues because machines will start communicating over the air. Currently the wireless technology used with these modules is the basic 802.11b WLAN.

Some benefits of the Airborne(TM) modules are:

- Remote monitoring
- Ease in sharing data between doctors and hospitals
- Can be remotely controlled or control other devices
- Data is available in a continuous and real-time fashion
- Can be combined with other protocols to create new medical applications

## 6.3 ecgAnywhere

ecgAnywhere is a electrocardiograph recorder, that records and transmits ECG data to a central data warehouse. This device can be used by healthcare professionals to monitor patients outside of the hospital. The device collects useful data and sends it over the internet via a PC, PDA or other wireless devices.

Some potential uses include

- Diagnostic and long term evaluation
- Drug evaluation
- Mass screening
- Homecare remote monitoring

## 6.4 LifeSource Products

LifeSource [[LifeSource](#)] company designs products such as monitoring devices for telemedicine. They design

both wired and wireless (Bluetooth) interfaced products.

Some Applications include

- Remote Blood Pressure monitoring
- Remote weight monitoring
  - Digitally IDs each weight reading with date-time stamp
  - Transmits weight reading to a central server using access points i.e. PC or PDA or other device
- Available in Wired and Bluetooth versions

Some sample devices offered

blood pressure monitor

Figure 4: Blood Pressure Monitor [[LifeSource](#)]

weight scale

Figure 5: Personal Scales for Telemonitoring [[LifeSource](#)]

## 6.5 HealthTrax

HealthTrax is a tracking system with potential uses in hospitals. It uses RFID tags attached to medical devices, patients etc. It can significantly reduce costs in equipment and patient management. One innovative application of this system can be a real-time inventory management system, where to the hospital know at any moment the status of its supplies. They can order supplies when desired, or automatically as the stock goes down. Some systems like these are used in shopping market management, where shelves automatically send alerts when emptied.

Some benefits of using the HealthTrax system include:

- Patients who are on strict medicine schedule can be tracked and given medicine in time.
- Doctors or nurses can be located around the hospital more efficiently.
- Medical devices can be profiled in the system and replaced or fixed when needed.

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## 7. Future Trends

Although wireless technology in the field of medical applications is still relatively new, commercial products are being developed by several companies to solve wide ranging problems. In some cases these new applications are design purely purely social health benefits i.e. reducing interference to daily life when dealing with long term patient care. In this section we will talk about the trends in wireless networks use in medical applications by giving a few examples of what's to come.

Some of these applications include:

- Patient Homecare
- Context-Sensitive Medicine
- iRevive

## 7.1 Patient Homecare

Patient Homecare is a new area in the use of wireless networks for medical applications [[Fishky03](#)]. Homecare has a central role in the emerging medical applications of wireless technology [[Stankovic05](#)]. Remote monitoring of patients and the elderly inside their homes will significantly reduce costs for caregivers and also provide a non-intrusive lifestyle for its users [[Fishky03](#)].

Some Applications include:

- Medicine intake tracking
- Remote ECG collecting and monitoring
- Remote blood pressure and weight monitoring
- Wearable sensors as part of a BAN to monitor vital signs and other biosignals.
- Monitoring and control of devices remotely

Some benefits of using wireless networks based technologies in Homecare include:

- Non-invasive monitoring
- Cost saving and efficient method of care
- Ease of communication between care givers and patients

As we are talking about trends in the wireless networks for medical applications field, some potentially useful applications in the homecare sector include:

- In-home assistance
- Smart nursing homes
- Clinical trial and research augmentation
- Control of home appliances
- Emergency communication
- Medical data lookup
- Memory enhancement

## 7.2 Context-Sensitive Medicine

By using Active RFID-tags, management of resources becomes more intelligent. For example machines needing servicing can automatically inform the technician. Patient care can be scheduled and reminders will be sent out exactly when something needs to be done. The location of equipment, doctors, patient etc. inside a hospital can be tracked in real-time. This allows the patients to move around freely. It also allows doctors and nurses to tend to more patients. Besides potential uses in the medical field, Context-Sensitive technology have military uses as well. Keeping track of military equipment is an important issue.

Wireless technology employed

- Active-RFID
  - Send signals indication location etc.
- Radianc Indoor Positioning Solution (IPS)
- WLAN

Some potential applications of Context-Sensitive Medicine include:

- WorkFlow
- Equipment Tracking

- Patient Location
- Patient Information Retrieval During Emergencies [[Vajirkar03](#)]
- Single-Use Location Tag

The following figure describes a basic architecture based on the Context-Sensitive Medicine platform. An Active RFID-tag is attached an object (equipment, patient, doctor etc.). This tag continuously sends out updates over the wireless channel to a wireless receiver which is in communication with a central server in the hospital. The server can then take action or forward that information to other mobile devices or email accounts of people in charge.

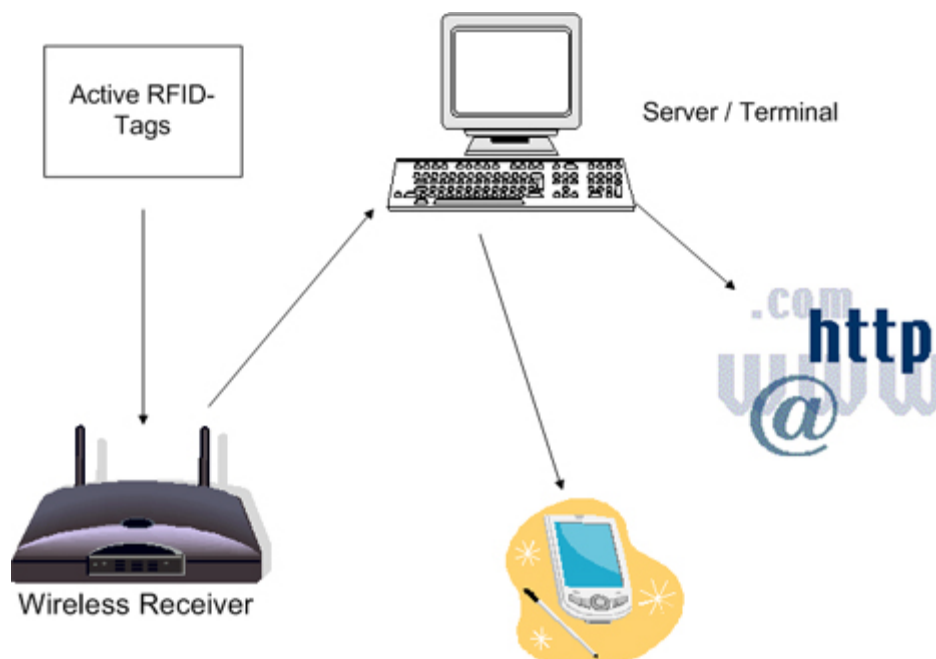


Figure 6: Architecture of a sample system based on Contentext-Sensitive Medicine idea

### 7.3 iRevive

iRevive is commercial project that is based on the CodeBlue research project from Harvard. It provides mobile device synchronization with a central database server. These mobile devices can capture vital signs information in real-time and store using VitalDust technology (CodeBlue) [[Shnayder05](#)] or send them to a central server.

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## Summary

Wireless networks for Medical Applications is becoming a hot topic in the industry. With its potential uses in the medical and home healthcare fields, wireless networks have an important contribution in improving lives of patients. Besides bringing comfort to patients, there are large commercial benefits in the area of reducing costs and improving equipment and patient management.

In this survey paper, we discussed the benefits of using wireless networks for medical applications. We talked

about how these new technologies can be used to potentially reduce costs for hospitals, government and insurance companies. With wireless networks-based medical technologies, applications can be designed to be less intrusive in patients' daily lives.

All applications based on scientific methods have a development lifecycle. This is normally starting out with a research project and moving onto commercialization. Lessons learned here are applied when designing newer applications in the future. We talked about current and past research projects. We also brought in some commercial applications that are currently available in the market. Some of these products are very innovative and have chances of succeeding. With all new technologies, there are chances of failures and success. Some of the projects that we talked (i.e CodeBlue) about are long term project and parts of them have already made the transition to commercialization. Homecare is an area where wireless networks for Medical Applications have the most potential. Smarthome based technologies are being designed which will eventually care for our elderly and patient who need long term care.

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## List of Acronyms

**UMTS** - Universal Mobile Telecommunications System

**GPRS** - General Packet Radio Service

**WBAN** - Wireless Body Area Network

**BAN** - Body Area Network

**WPAN** - Wireless Personal Area Network

**RFID** - Radio Frequency Identification

**ECG/EKG** - Electrocardiogram

**EMG** - Electromyogram

**IPS** - Indoor Positioning Solution

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Note: This paper is available on-line at <http://www.cse.wustl.edu/~jain/>