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Chapter 9

Mobile Functional Optical Brain Spectroscopy over Wireless Mobile Networks Using Near-Infrared Light Sensors

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Additional information is available at the end of the chapter

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1. Introduction

The purpose of this research is to determine the feasibility of providing quality medical data with an acceptable time duration (event-to-action: in real time or near real time) using full mobility in everyday environments using a system that utilizes heterogenic nodes and a near-infrared light sensor designed to monitor brain function in humans. Multiple wireless networks employing different protocols are used for data transmission to provide new freedom to conduct tests in real environments outside a lab. Measurements of changes in the concentration of oxyhemoglobin (HbO_2) and deoxyhemoglobin (Hb) in the real-life environment may lead to better understanding of tissue pathologies.

A fully mobile functional brain Spectroscopy system was developed in this research to allow the possibility of testing subjects to be monitored in their real environments. The developed application introduces a model (four-node-model) to build fully mobile medical applications that support quality medical data and acceptable time duration (event-to-action time) for medical purposes.

The system introduces a newly created application level protocol to increase data quality and reduce event-to-action time duration. Moreover a new algorithm was created to minimize data loss. Finally a mathematical model was created to calculate the acceptable event-to-action time for particular physiological data based on the number of nodes and the type of nodes that data will go through.

To test this hypothesis, communication software was developed to allow for the collection of physiological data from a mobile near-infrared sensor via a mobile telephone. This system was then used to track changes in concentrations of HbO_2 and Hb during various activities

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and send data to a computer at a monitoring site using the protocol and algorithm created. The resulting data's accuracy was compared with other methods where the medical data collection was local to the test subject and observer.

Data was captured using a wireless near-infrared light sensor (Node 1: Client), transmitted to a mobile phone (Node 2: Mobile Server) using Bluetooth. The mobile phone sent the data to a central server (Node 3: Central Server). Finally the data was displayed on a monitoring station (Node 4: Monitoring Client).

Large amounts of data and small amounts of data can be captured from the biological tissues for different purposes in different situations. The amount of data, the type of data, the type of tissues, and the event-to-action requirements can effect the quality of captured data. Three data types were tested in this research: three biological events to ensure enough sample scenarios to test the hypothesis. The first data type was the effect of cigarette smoke on the human brain five minutes of smoking. The second data type was the effect of breathing on the human brain during a two–minute time period. The third data type was the response of a Canine when presented with its favourite toy one minute after detecting explosives. The responses from the activities can be inferred from the changes in concentration of HbO_2 and Hb. The data types used in this research have a direct relationship with the acceptable time duration of event-to-action and a direct relationship with the acceptable data quality that has been gathered. As a result, this has a direct effect on the packet size that is needed to be transmitted and on the acceptable time of transition.

2. Related work

2.1. Heterogenic networks

Networks – whether infrastructure based or non-infrastructure based – play an important role in our lives [1]. Wired networks, such as the Internet, provide us with global data access, while wireless networks, such as the Global Standard for Mobile Communications (GSM), give us mobility. Non-infrastructure-based networks (ad-hoc networks), such as Bluetooth networks, give us the freedom to communicate at no cost over short ranges [2].

Bluetooth devices utilize the unlicensed frequency of 2.4 GHz that offers a 10 to 100 meter range and a data transfer rate of up to 1 MBps [3]. Bluetooth technology offers point-to-point and point-to-multiple-points communication [4]. It performs communication through a protocol stack divided into hardware and software layers [5]. Bluetooth standards were created to provide guidelines to device manufacturers to facilitate interoperability between devices from different vendors. Moreover, Bluetooth standards specify profiles that determine the usage of the device and the services offered by it [6]. Standardization, low cost, minimum hardware, low power requirements, and the free use of unlicensed bandwidth all contribute to the wide spread use of Bluetooth devices [7].

GSM is widely used in more than 200 countries around the world, having an estimated subscriber base of over two billion users [8]. Roaming is one of the value-added features

introduced by the GSM standard. This capability allows mobile users to travel the world and still be able to use their phones to connect with local operators. The introduction of data communication has also helped GSM standards to become more and more popular. GSM networks currently offer wide varieties of services, ranging from basic voice services to more advanced capabilities, such as allowing Internet access.

GSM's many features make it possible to use this type of network to assist in the monitoring of people's physiological parameters in everyday life regardless of their location [9]. GSM networks use different frequencies for upload and download links, which offer various data transfer rates between the network and the device. The data transfer rates can reach up to 9.6 KBps, which allows the networks to offer basic data services to their users [10]. The introduction of General Packet Radio Services (GPRS) – data services to GSM networks – has made it possible to run more varieties of applications than ever before at lower costs and faster speeds [11]. GPRS was added to the traditional GSM network to allow network operators to offer better data communications. GPRS is a packet-switched communication method where the communication channel can be employed by other users, unlike other data communication methods such as circuit switched data. With GPRS download rates reaching 236 KBps and upload transfers reaching up to 118 KBps, GPRS offers enhanced speed over the traditional GSM network [12].

2.2. Sensor networks

Several types of sensors have been created and used to monitor different object functions [13]. These sensors have been used in a variety of fields: health, medicine, manufacturing, telecommunications, security, and the natural environment [14, 15].

Often some sensors can communicate with each other directly or indirectly to form sensor networks [16]. Currently there are wide varieties of sensor networks used in different facilities to perform different monitoring tasks with different subjects: humans, machines, products, and workers [17]. Monitoring people, machines or products within a physical location does not necessarily require full mobility or full wireless connectivity since everything is in close proximity.

Some applications require variable degrees of wireless support or mobility support or a combination of both. For example, full wireless support is required when monitoring habitat without disturbing the surrounding environment for an extended period of time [18]. Monitoring people while they are on the move is an example where full wireless mobility support is required.

Each application has its own requirements and some technologies currently support these applications to some level. On the other hand, monitoring human brain using full mobility to collect medical data is a challenge and the current technology does not fully support it.

Sensor networks differ in their technical capabilities and implementation (hardware, software, communication protocols, algorithms, etc). Currently, available sensors and sensor networks support long-range and short-range communication (433 MHz-5.9 GHz) [19].

Some health care sensor networks combine short- and long-range communications to monitor patients [20]. They utilize mobile phone networks and Bluetooth networks together to achieve better coverage [21]. Wireless networks have wide variations of data transfer rates. Some have a low transfer rate (Spike, 35 KBps) and others have a high transfer rate (WLAN, IEE 802.11a, 54 000 KBps). Transfer rate requirements are highly dependent on the type of application. Some applications require a high transfer rate [22] because they generate large amounts of data that must be dealt with quickly. Sensor networks remain an active research area with focus on different components: networks, sensors, data acquisition, protocols, performance [23].

2.3. Protocols

Transmission Control Protocol (TCP) protocol is a reliable protocol used in communication when a reliable connection is required [24]. It allows two hosts to communicate and exchange data streams and guarantees the data delivery [25]. Data packets are delivered in the same order they were sent. In contrast, User Datagram Protocol (UDP) does not provide guaranteed delivery and does not guarantee packet ordering [26]. Selecting which protocol to choose for a particular application mainly depends on the application requirements. These protocols have proven their value and made their way into Bluetooth and GSM networks.

Bluetooth networks support both TCP and UDP communications [27]. Applications running on the Bluetooth networks can use any of these protocols to send and receive data. The most common way to send TCP and UDP packets over Bluetooth is using Bluetooth Radio Frequency Communications (RFCOMM) [28]. RFCOMM is a transport protocol that provides RS-232 serial port emulation. Bluetooth Serial Port Profile (SPP) is based on this protocol [29].

GSM networks are similar to Bluetooth networks and wired local area networks (LANs). They support TCP and UDP communication protocols [30]. Since wireless networks support the same communication protocol as wired LANs, applications running on wireless networks can communicate and exchange data with the applications running on wired LANs.

Application level protocols are created to support specific applications. These protocols can run on top of either TCP or UDP protocols. The protocol in this research is an example of such protocols. MDTP is a packet-oriented protocol created to support data exchange between heterogenic nodes. MDTP is a protocol created in this research to allow global communication between sensors, mobile data devices, and stationed servers over Bluetooth and GSM networks.

2.4. Functional Optical Brain Spectroscopy

Functional Optical Brain Spectroscopy using Near-infrared Light (fNIRS) has been used as a method to conduct functional brain analysis. fNIRS is a method that uses the reflection of

infrared light to observe changes in the concentration of HbO_2 and Hb in the blood, and can provide a similar result to Functional magnetic resonance imaging (fMRI) [31]. fNIRS takes advantage of the absorption and scattering of near-infrared light to provide information about brain activities [32]. For a long time, it was thought that it was only possible to collect information from the superficial layers of tissue (e.g., microscopy) due to light scattering. However, about 25 years ago, it was discovered that functional information could be obtained from brain tissue using light shone at the scalp and detected from the scalp. This discovery motivated the development of diffuse optics as a method for brain monitoring. This method has different names: Near-infrared Spectroscopy (NIRS), Diffuse Optical Tomography, and/or Near-infrared Imaging (NIRI). Today, several types of NIRS devices have been built to image brain functions. These devices differ in their capabilities, designs, and costs [33, 34].

The NIRS devices can be classified into three main types: Continuous Wave Spectroscopy (CWS), Time-resolved Spectroscopy (TRS), and Frequency Domain Spectroscopy (FDS). The CWS device consists of a continuous light source, which transmits light waves with constant amplitude, and a detector that locates the attenuated incident light after it passes through the tissues. The TRS device transmits short incidents of light pulses into tissues and measures the light after it passes through the tissues. On the other hand, the FDS device transmits a sinusoidal modulated light wave into the tissue [33].

Each of these types of NIRS devices has limitations and strengths [35]. CWS has the advantage of low cost; however, with CWS it is difficult to distinguish contributions of absorption and scattering to the light attenuation. FDS, on the other hand, is known for its good spatial resolution, penetration depth, and accurate separation of absorption and scattering effects. Nevertheless, FDS is significantly more expensive than CWS. As for TRS, although theoretically it can provide a better spatial resolution than FDS, it has a lower signal-to-noise ratio. Since TRS requires short pulsed lasers and photon counting detection, it is the most expensive type of the NIRS instrumentation. Despite the advancements in NIRS technology, NIRS still has limitations, such as the short path length and the artefacts' movements during measurements.

NIRS relies on a simple principle: light in the range of near-infrared light emitted on the organ of interest passes through the different layers above the organ. When it passes through the tissues, light photons go through physical interactions, such as scattering and absorption that lead to a loss of energy in the emitted light. When the remaining light exits the organ, it is measured by a detector.

Near-infrared light, in the range of 700-900 nm, can travel relatively deep into body tissues. It is also worth mentioning that such light can easily travel through soft tissues and bones, such as those of neonates and infants. Therefore, it is suitable to use near-infrared devices to monitor brain activities or other oxygen-dependent organs in this category of humans [36].

Absorption and scattering are the main physical processes effecting the transmission of light photons in tissues. Light photon absorption and scattering causes the light intensity to

decrease. Both absorption and scattering are wavelength dependent. The amount of absorbed light photons is also impacted by the concentration of blood HbO_2 and Hb in tissues that vary in time, reflecting physiological changes in tissues' optical properties [31].

When light photons travel through tissues, they are scattered several times before finally reaching the receiver. Scattering increases light's optical path length, causing photons to spend more time in tissues that in turn affects the tissues' absorption characteristics. NIRS measures the optical properties of HbO_2 and Hb concentrations in near-infrared light. The effects of the changes in concentration levels of HbO_2 and Hb in the blood stream on light absorption can be described by the Beer-Lambert's Law. A Modified Beer-Lambert Law can be used to predict the amount of blood chromophoers (HbO_2 and Hb) in tissues [34].

3. Hardware architecture

This system, developed for this research, consists of three main hardware components The first component is a Bluetooth wireless sensor (built by Arquatis GmbH, Rieden, Switzerland), which is the data acquisition device The second component is a PDA and is the main controller for the measurement process and the data communication bridge between the sensor and the central computer. The third component is a central computer (Server, or Host Computer, or PC) that stores the data for later analysis. Figure 1 displays the system's architecture.

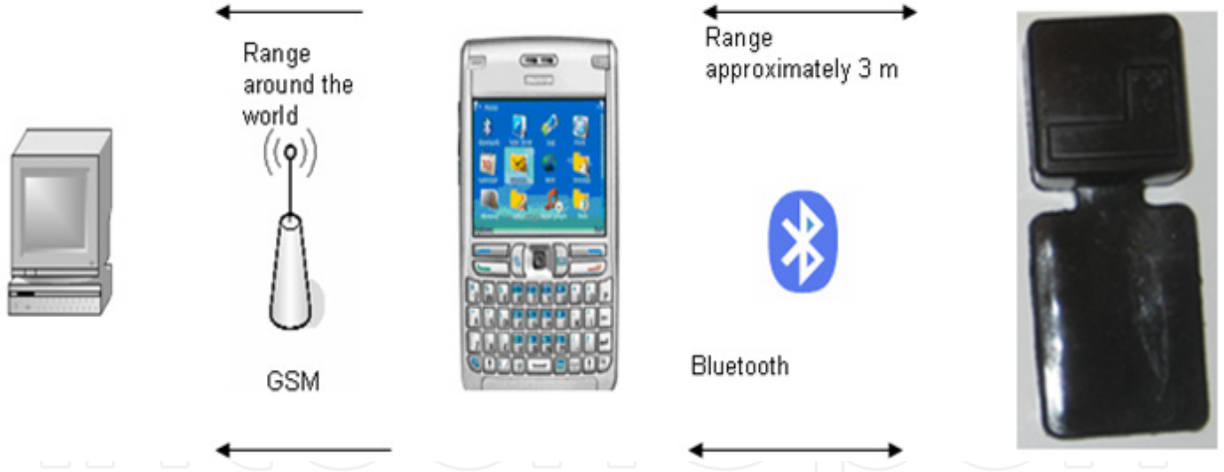


Figure 1. Hardware Architecture

3.1. The sensor

The sensor is a wireless near-infrared imaging sensor developed by Arquatis GmbH, Rieden Switzerland (Figures 2).The sensor quantifies changes in the concentration of HbO2 and Hb in tissues and sends information to a computer using wireless Bluetooth technology. The sensor has the following components: four light sources; each light source has two LEDs (Light Emitting Diodes) emitting at 730 and 830 nm. It has four light detectors (PIN silicon photodiodes) with a sampling rate of 100 HZ. An analog LED controller controls the emitted

light. A microcontroller has an analog/digital (A/D) controller to manage the light intensity signal detection and the conversion of the signal into data. The accuracy of the A/D is 12 bits. The Bluetooth transceiver sends and receives data between the sensor and the Bluetooth networks within a range of 3 m. The sensor requires a power supply and uses a 3.7 volt rechargeable lithium-ion battery that can last up to 3 hours. The sensor's total weight is about (40 grams); its dimensions are (90 x 34 x 20 mm). To achieve better measurements, the sensor components are mounted on a rigid-flexible printed circuit board (PCB).

3.2. The Mobile Phone (PDA)

The personal digital assistance (PDA) device is a commercially available cell phone with data access capabilities, Bluetooth communication support, and Java support. The mobile phone used in this project is a Nokia E62 smart phone that runs Symbian operating system (Figure 3). It has extensive features and capabilities, however not all are necessary to run the developed system. It supports the following Bluetooth profiles SPP. The developed system uses only the SSP profile to carry out the communication between the sensor and the mobile phone. The developed system uses mobile information device profile (MIDP) v2.0, connected limited device configuration (CLDC) 1.1, and the optional Java package for Bluetooth (JSR 82).

The phone has single ARM 9 CPU with clock rate of 233 MHZ. The available memory allows the system to acquire and save data for at least 8 continuous hours; it has 80 MB by default. The battery can last up to 5.5 hours when the system is in full use.



Figure 2. Wireless Sensor



Figure 3. Mobile Phone (PDA)

3.3. The host PC (Server)

The host PC is a regular desktop personal computer with 2 GB RAM and dual core Intel processor.

4. Software

4.1. Software components

Java portability allows it to run on a wide range of operating systems and devices. Sun Microsystems realized that one size does not fit all; it grouped Java into three main editions, each targeted at a specific range of devices. Java Enterprise Edition (J2EE) is targeted for enterprise servers to create large scalable applications. Java Standard Edition (J2SE) is targeted for desktop applications. Java Micro Edition (J2ME) is targeted for small devices with limited hardware capabilities. J2ME was used to build the mobile phone application and J2SE and J2EE was used to build the server application. The sensor application was built using C language.

Eclipse and Netbeans are among the most popular integrated development environments (IDE) used to build and debug Java applications. Both IDE's are used in this research.

4.2. Software architecture

The system software architecture (Figure 4) has three major layers: a data acquisition layer (DAL), a control layer (CL), and a data storage layer (DSL). The DAL software component in the sensor controls data acquisition and packet transmission. It is composed of a set of programs that implement the data communication protocol, the RFCOMM Bluetooth protocol, and the sensor's low-level controls. The second layer (CL) resides on the PDA and acts as the central control unit for the application. The majority of the system components reside in this

layer. The third layer (DSL) is mainly used to accept connections from the PDA and store the received data packets in the server for later analysis. The PDA creates a persistent connection with the sensor and with the PC during the duration of the measurements. The system is designed to support a wide range of measurements and acquisition activities. Several types of tests can be performed using the system without the need to modify the programs. Most of the components are designed to be configuration-driven. The system architecture provides high interoperability between heterogeneous hardware and software.

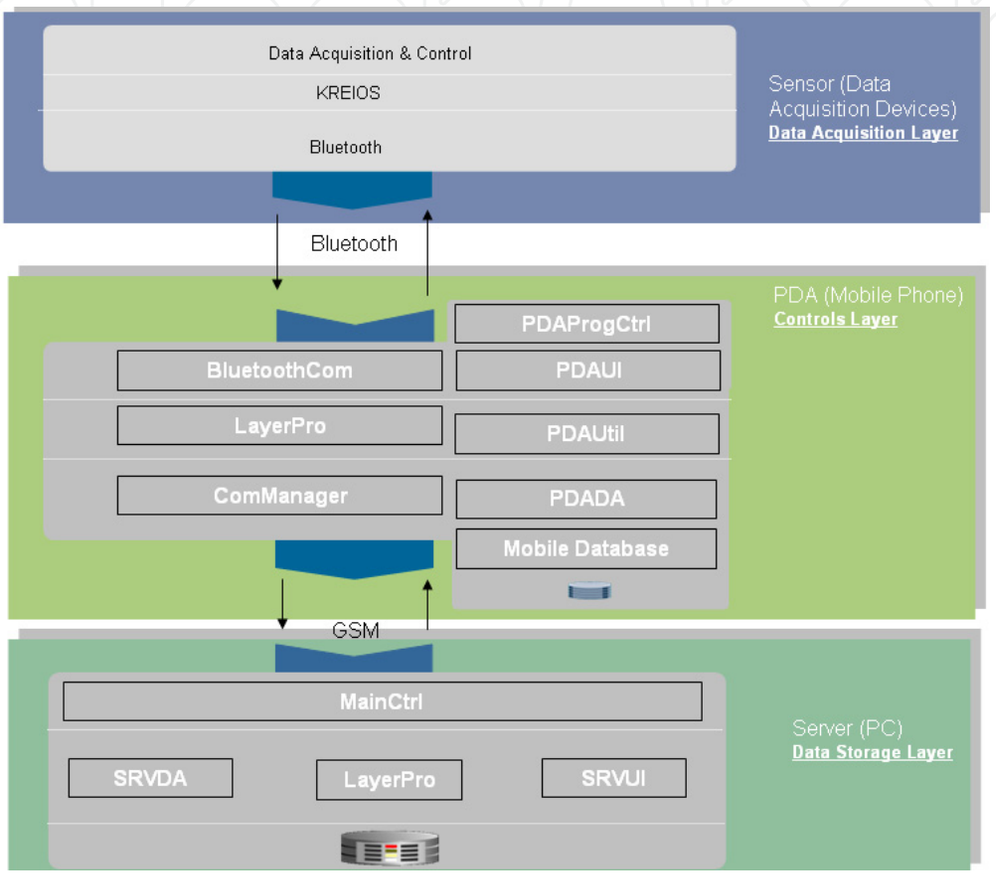


Figure 4. The System Software Architecture

4.3. Overall system component interaction

The overall system interaction is depicted in the sequence diagram in Figure 5. The sequence diagram shows the steps and the sequences of the steps in relation to time.

The system administrator starts the server. The sensor is carried by a test subject. The test subject fixes the sensor on a test area and starts the measurement process from the PDA software. The sensor emits light directly in the test area and starts the data collection. The sensor transmits the data back to the PDA. The PDA receives the data packet and forwards it to the server and at the same time the PDA will save a local copy to the file system. The server receives the data packet and displays the data on the screen at the same time it saves the packet in the server's local file system. Once the test is completed, the data is extracted and analyzed.

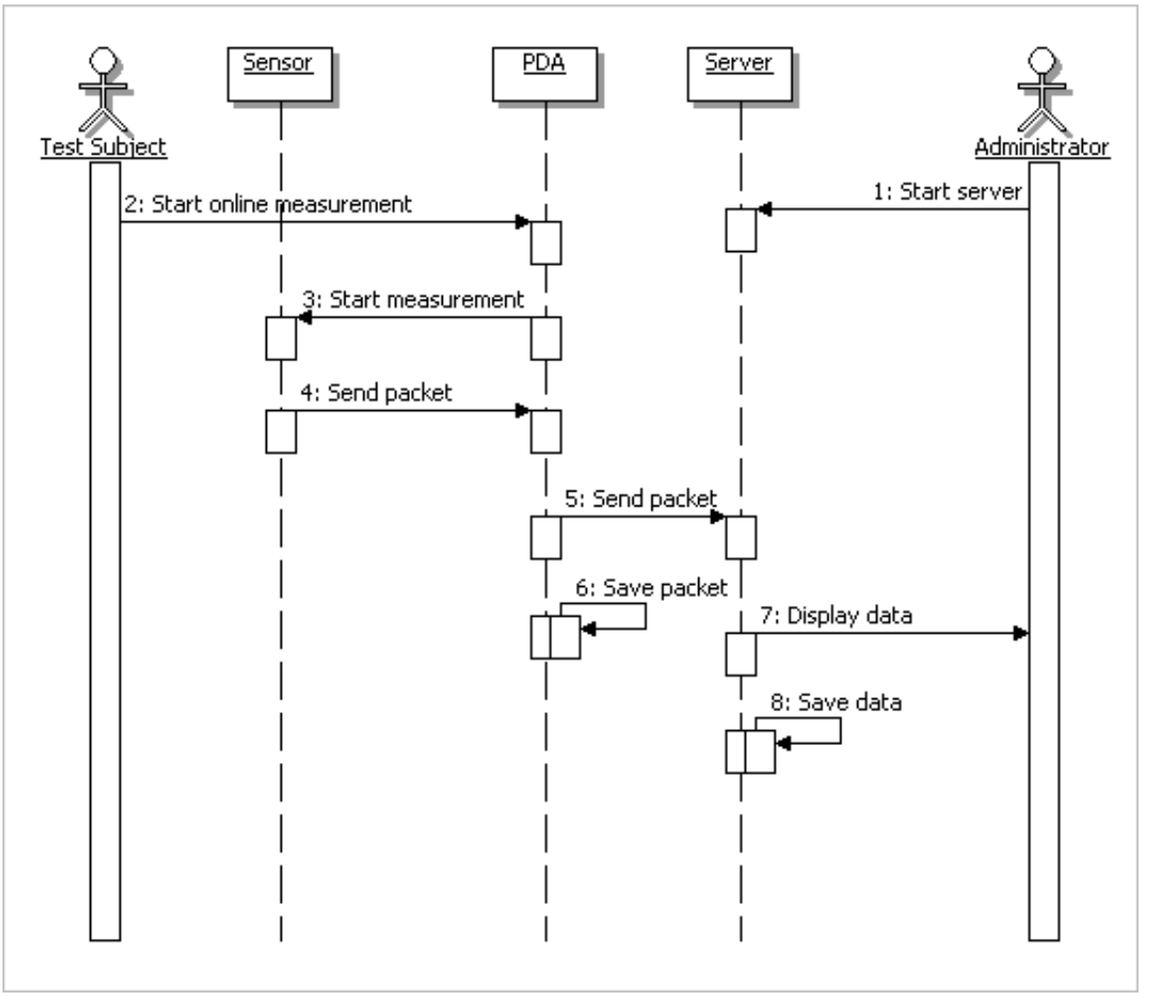


Figure 5. The Overall System Sequence Diagram

5. Four-node model

The four-node model (Figure 6) depicts the minimum necessary devices and networks required to support an affordable and practical solution to monitor biological tissues with an acceptable event-to-action time duration. In the proposed model, in order to support real near-time (event-to-action) mobility monitoring of biological tissues, a minimum four types of device and three types of networks are required.

The first node (Node 1) is a wireless sensor closely attached to the body that supports short-range communication. The sensor can be a device that implements any data collection approach (near-infrared, ECG, etc.). The purpose of this node (the sensor) is to closely monitor specific biological data in the body. Multiple sensors can be attached to the body to collect more specialized data from different type of tissues. The sensor can have different frequencies used to sample data from tissues. The system built to test this model used a sensor with 100 Hz sample rate and data accuracy of 12 bits.

The second node (Node 2) is a data buffer and a long-range data communication device (a Cell phone support data communication). The purpose of this node is to act as a data buffer

for the data collected from the sensor. This node can also act as a network speed regulator between the sensor and the wide area network (WAN). The node implements a data integrity algorithm to minimize data losses due to data transmission over multiple networks. When integrating networks with different throughputs, data loss can occur due to capacity problems. The amount of captured data from the sensor sometimes cannot be sent fast enough to the central server; this node can prepare the data and store it to be forwarded to the central server. Finally this node adjusts its receiving speed based on the sensor transition speed.

Node 1 and Node 2 provide full mobility support in this model. These two nodes can be used in several scenarios. For example, in one scenario a doctor can monitor patients in their real environment (work, home, etc). Today most people carry cell phones that can be used as Node 2. The monitored subject can move freely while carrying a light weight sensor. Depending on the data type that needs to be monitored, the subject can carry a specific type of sensor that is capable of collecting the required data type. In this scenario the data can be transmitted to a central location or stay in local storage. The data is transmitted or downloaded at a later time when the event-to-action time duration is not critical.

In another scenario, doctors can carry their own communication device and their own sensors. While administrating to patients either in their clinic or in the hospital, they can collect data from their patients. The data ist stored and the doctor can analyze the collected data at a later time when the event-to-action time duration is not critical.

The third node (Node 3) is a central server that acts as a communication and long-term storage node. Node 2 communicates with Node 3 over any type of long-range network. In the implemented application in this research, a combination GSM network and the internet were used to test the four-node model.

During the communication between Node 2 and Node 3 a special consideration, based on the number of networks that are involved in the transmission process, is required. If a public infrastructure is used to transmit data, control over the priority of the transferred medical data over these networks is not guaranteed. The lack of control over the priority can cause delay or data accuracy issues.

This dependency can make the medical data less useful. The data might become less useful due to the two reasons discovered in this research: event-to-action time duration and data accuracy. These issues can be addressed by introducing a combination of a new protocol and a new algorithm that can make public networks appropriate to transfer medical data with acceptable event-to-action time durations and acceptable data accuracy. Later this article will explain briefly the proposed protocol and the proposed algorithm.

The fourth node (Node 4) is a monitoring device that is used to observe the monitored subject remotely. This node can be stationary or mobile. If the node is a stationary device then a wired network can be used to transmit data from the central server (Node 3). If the node is a mobile device, a combination of wireless and wired networks can be used to transmit the data.

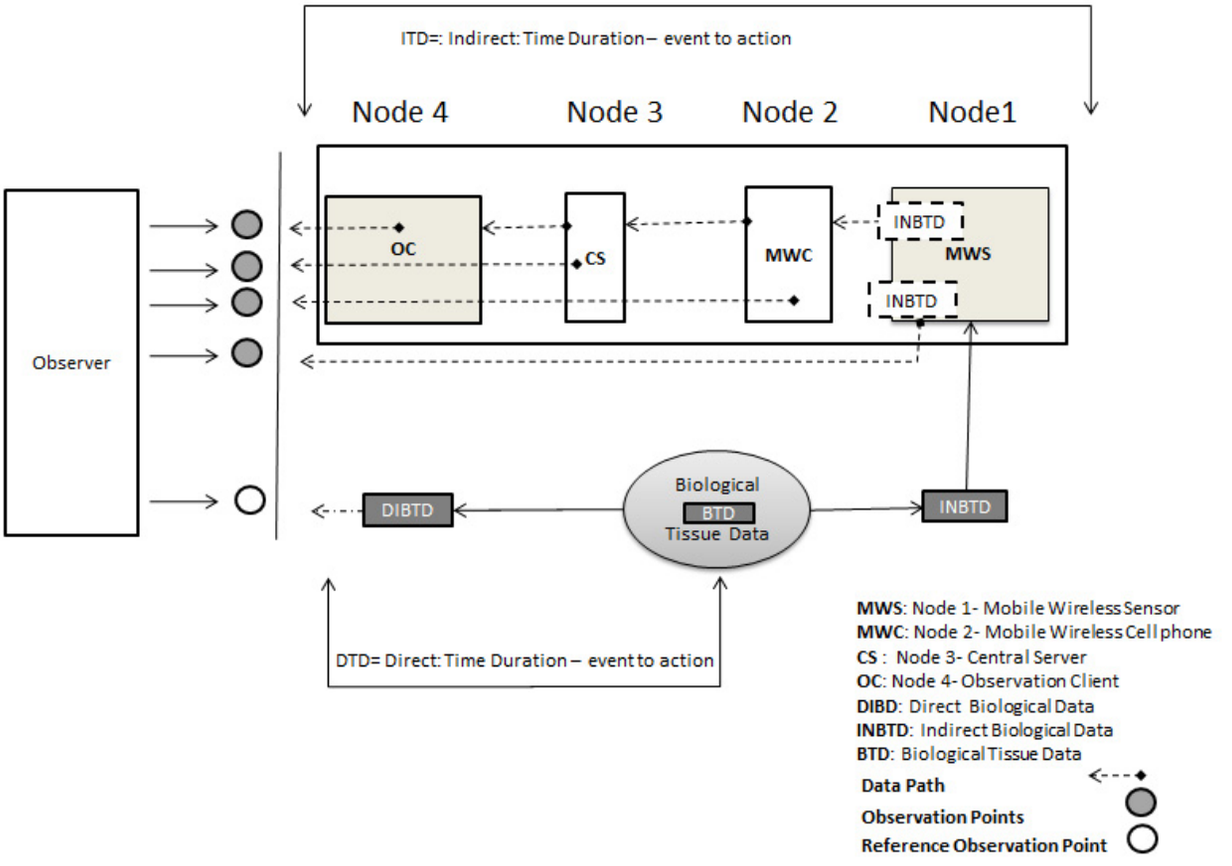


Figure 6. Four-Node Model

These four nodes are the minimum required nodes necessary to support full mobility to monitor biological tissues in near real time (acceptable event-to-action time durations with acceptable data accuracy) for most medical data types. To support this model, three network types are required: short-range wireless network; long-range wireless network; and wired network. Finally three types of protocols are required: protocol to transmit data over the short-range wireless network; protocol to transmit the data over the long-range wireless network; and finally a protocol to transmit the data over the wired network. One of the enhancements this research contributes is eliminating the need for three different protocols to transmit the data over these networks. This contribution enhances the event-to-action time duration and data accuracy. One more contribution of this research is, due to eliminating the need for multiple protocols, an algorithm can take into account the speed and data priority difference between the different networks.

6. Medical data

6.1. Data types

Large number of data types can be gathered from biological tissues for medical purposes. The data type that can be used for medical purposes varies based on the organ that is being monitored, the parameter being collected and the event-to-action time duration required. In

this research the focus was on the brain as an organ, the amount of blood oxygenation as a parameter and the event-to-action time duration after a specific activity.

We monitored one data type – HbO_2 and Hb concentrations in the brain during three activities. Two activities dealt with the human brain and one activity dealt with the Canine brain. The HbO_2 and Hb concentrations were observed in human brain during breathing and during smoking. The HbO_2 and Hb concentrations were observed in the Canine brain after an explosion detection exercise.

The time duration required to observe the changes in the data was recorded during the above mentioned activities.

The first experiment was designed to generate observer data during human breathing over 120 seconds. The observed time duration during the experiment indicated that over the time duration of 20 seconds, we can see that each breath holding trial had a clear measured impact on the HbO_2 and Hb concentrations. From the experiment we can infer that an acceptable event-to-action time duration when monitoring breathing is 20 seconds. Based on this timing, the generated data were 2,000 (20 seconds x sensor sample rate is 100 Hz) state changes in HbO_2 and Hb concentrations during one breath. The experiment lasted for 120 seconds. The total amount of data during this experiment was (120 X 100) 12,000 state changes.

The second experiment was designed to gather data during 900 seconds when a human smoked a real cigarette (complete cigarette). The observed time duration during the experiment indicated that over the time duration of 100 seconds, we can see that each inhalation of cigarette substances (nicotine and other chemicals) had a clear measured impact on the HbO_2 and Hb concentrations. From the experiment we can infer that an acceptable event-to-action time duration when monitoring a human smoking is 100 seconds. Based on this time, the generated data were 10,000 (100 seconds x sensor sample rate is 100 Hz) state changes in HbO_2 and Hb concentrations during one inhalation of cigarette substances. The experiment lasted for 900 seconds. The total amount of data during this experiment was (900 x 100) 90,000 state changes.

The third experiment was designed to gather data after rewarding a Canine for detecting an explosive substance over a duration of 180 seconds. The observed time duration during the experiment indicated that over the time duration of 20 seconds, we can see that the effect of detecting an explosive substance had an impact on the HbO_2 and Hb concentrations but was not clear. From the experiment we can infer that an acceptable event-to-action time duration when monitoring explosives discovery is 20 seconds. Based on this timing the generated data were 2,000 (20 seconds x sensor sample rate is 100 Hz) state changes in HbO_2 and Hb concentrations during one detection of explosive substances. The experiment lasted for 120 seconds. The total amount of data during this experiment was (180 x 100) 18,000 state changes.

6.2. Data observation points

Medical personnel can observe biological changes through four observation points in the four-node model. The first observation point is the output data from the sensor (Node 1).

The second observation point is the output data from the cell phone (Node 2). The third observation point is the central server (Node 3). The last observation point is the observation client (Node 4). At each observation point data was examined to validate data accuracy and event-to-action time duration.

In order to validate the collected data accuracy and timing requirements using this model, a reference observation point was used. The reference observation point is data collected using an fMRI system.

6.3. Data transmission path

Speed and throughput of networks and nodes that are involved in transmitting data need to be able to transmit data with a speed that can meet the timing requirements. Otherwise, the data might be less useful to provide acceptable event-to-action time duration results. At the same time, networks and nodes need to ensure no data loss during transition. Data loss during transmission can compromise data quality, which in turn may make data less useful.

Data captured by Node 1 goes through a specific path to reach Node 4. The data is passed from Node 1 to Node 2 that ensures the integrity of the transmitted data over the heterogenic networks. When data arrives at Node 3, data is checked for integrity. Once the data integrity is complete, data is passed to Node 4. In case of data integrity issues, Node 3 requests a retransmission of data from Node 2. Node 2 resends the data and goes through the same process again.

In typical situations, the longer the path the more time is taken to transmit data and the more likely data integrity can be compromised. The proposed protocol and the proposed algorithm can reduce the effect of data path length effect.

7. Data integrity and event-to-action time duration

During data transmission over heterogenic networks and heterogenic nodes, data accuracy might be compromised due to network load or node processing speed. The time duration to transfer data from Node 1 to Node 4 might not be enough to meet the required event-to-action time duration of the monitored biological data. In order to overcome the above two challenges, the research proposed an algorithm and a protocol to enhance the data accuracy and the event-to-action time duration of.

7.1. The protocol: Medical Data Transfer Protocol (MDTP)

MDTP (Figure 7) is a binary application layer protocol for using heterogenic networks to transfer medical data. The protocol encapsulates biological data along with some data integrity identifiers that identify the medical data that is being transferred. The protocol consists of a small number of transactions and is stateless. It has three transactions: open, send, close. The protocol is bi-directional. Each participant node needs to establish a connection. The source node establishes a connection (Seed Connection). The target node establishes, in return,

another connection back to the source node. The two connections make up a session with a full handshake. The two connections are required to complete the handshake and request data in cases of data loss. The target node can use this connection to ask Node 1 to resend the missed data using this connection. Once the session is established, the source node starts sending data with a sequence number identifying the sent packet. When data reaches an end, the source node sends a close transaction to terminate the session. The target node also sends a close transaction to the source node to complete the session termination.

The size of the data packet is small and has a variable length. The length of the packet depends on the medical data type that is to be sent and the sensor type. The packet consists of two parts: head and tail. The head is of fixed size; the tail is variable based on the data type. The variable length helps the protocol to transmit the data within acceptable event-to-action time durations for the specific data type.

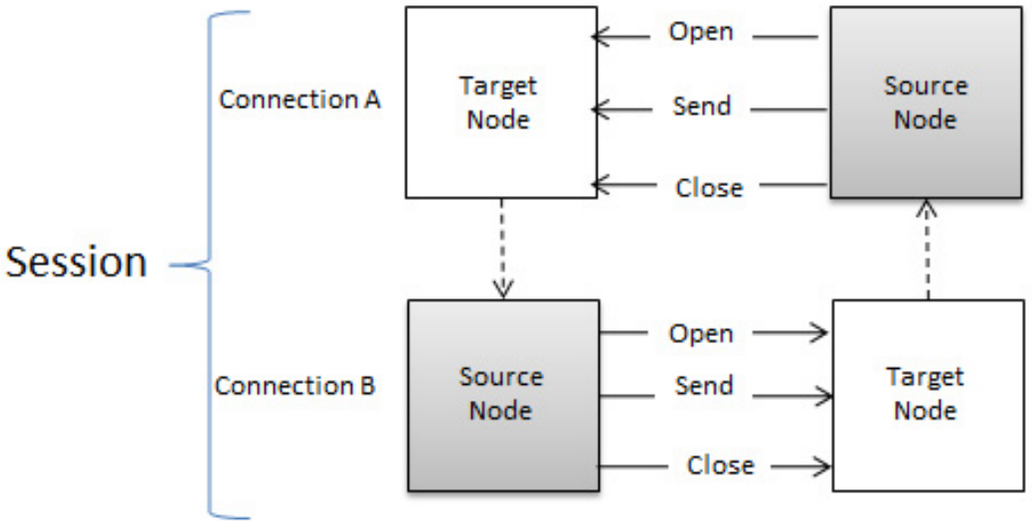


Figure 7. MDTP

7.2. Data Integrity Algorithm (DIA)

To ensure data integrity the data is validated at each node. The algorithm (Figure 8) validates the sequence number of each packet. If the data is valid, the protocol sends the data to the next node, otherwise the target node asks the source node to resend the data using the second connection. The algorithm on the target node tries to merge data after it ensures the correct sequence of packet has been received. Based on data type, the algorithm tries to reconcile the received packet or simply ignores any missed packets. Any packets losing medical data, such as changes in HbO_2 and Hb concentrations during detection of explosive substances, can make the data less useful. In this case the timing requirement for such state changes is not critical, but the data integrity is more important. On the other hand, a data packet loss during monitoring changes in HbO2 and Hb concentrations while smoking is not critical and neither is data accuracy. In this case, the changes occur over a longer time period and the algorithm can establish a pattern even if data loss occurs. In the case of monitoring changes in HbO_2 and Hb concentrations during breathing, the time

requirements and the data accuracy is different. Even if a packet is lost, the observer still can infer the changes. Finally there might be a case where data integrity and event-to-action time duration is short and important. In this case the algorithm might be less useful.

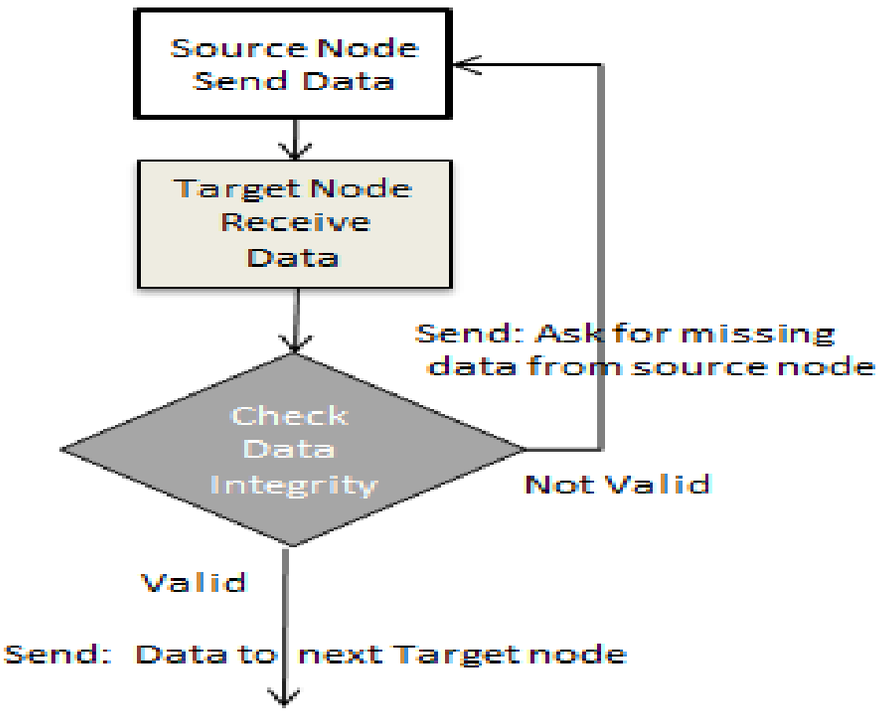


Figure 8. DIA

7.3. Event-to-action time duration

It is important to understand the event-to-action time duration and the data integrity requirements when monitoring HbO_2 and Hb concentrations during a specific activity. Based on the requirements, the proposed model, algorithm, and protocol can be useful or less useful.

In this research in order to validate the event-to-action time duration, we use the following formula to calculate time duration.

$$ITD \leq DTD$$

ITD: Indirect Time Duration – event to action
DTD: Direct Time Duration – event to action

$$ITD = \sum_{0}^{N} Tn$$

$$n \in N$$

N: Set of nodes data pass through
T_n: Processing and transfer time for node n

8. Experiment and results

The proposed model was designed to support a wide range of measurement and activities. We wanted to verify the model using an actual experiment. In order to achieve this goal, we conducted several tests inside and outside a lab environment. HbO_2 and Hb concentration changes in brain and tissue were collected under different circumstances. Figure 9 shows the event-to-action time duration during breathing. The result (Figure 4) was compared with a lab method [37] and was similar. At the start of the transmission we found there was a shift, but after the transmission stabilized the data went back to a synchronous state.

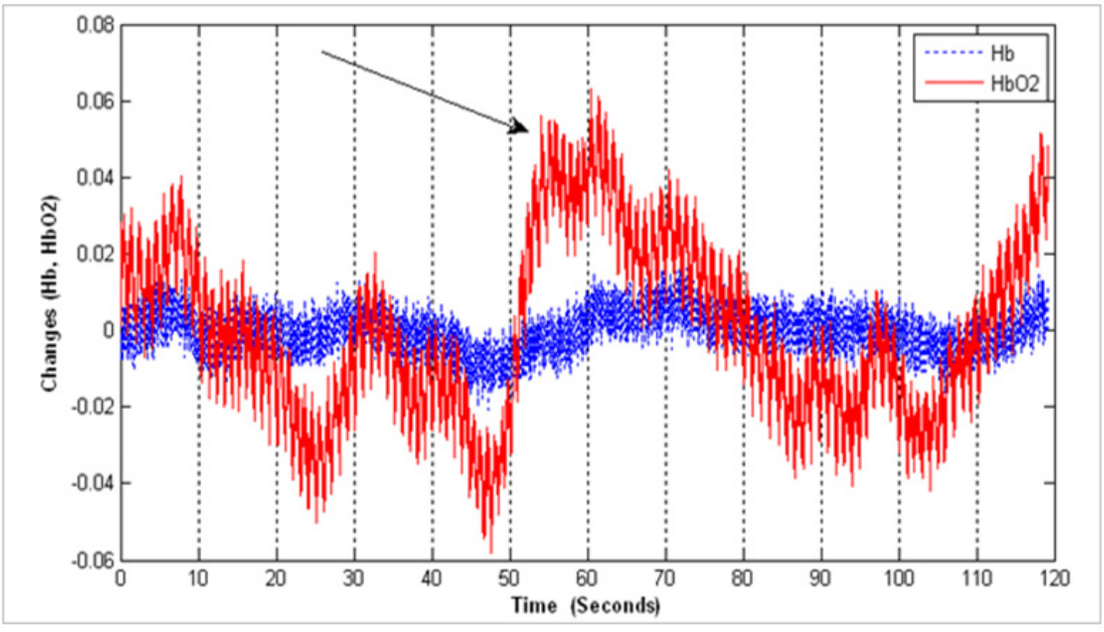


Figure 9. Time Duration and HB, HbO_2 Concentration Changes During Breathing

9. Conclusions and future work

The need to deal with different biological data that has variable timing requirements led to the introduction of a new algorithm that can be used to provide acceptable data quality. Sending and exchanging data over multiple nodes with acceptable quality and time durations (event-to-action) requires a protocol that can ensure these requirements met despite the lack of control over these heterogenic nodes. Medical Data Transfer Protocol (MDTP) was introduced to address this challenge.

The specific aims of this research were: create a model that can be used to represent the minimum node to build a fully mobile medical system that uses heterogenic nodes to monitor human physiological data in near-real time; provide quality medical data; transmit data within acceptable time durations (event-to-action). As a result this model might also allow health care providers to take effective action within acceptable time frames when possible. Moreover this may lead to a better understanding of tissue pathologies. The main aims of the project were achieved. The results have shown that it is possible to utilize

heterogenic networks and near-infrared technologies to collect useful medical data. The proposed model was initially tested on a system to monitor HbO_2 and Hb concentrations in the human brain and tissues with acceptable event-to-action time durations. Further work will be required to ensure that the system provides better event-to-action time durations for changes that have shorter time duration requirements.

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