Biometric Monitoring in Team Sports Using Wireless Ad-Hoc Networking

by

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Declaration

I, the undersigned, declare that this work has not previously been submitted as an exercise for a degree at this, or any other University, and that unless otherwise stated, is my own work.

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Sudden Arrhythmic Death Syndrome (SADS) is a condition that affects people during physical activities such as team sports. It causes erratic rhythms of signals from the brain to the heart, this is known as arrhythmia. We can detect SADS by looking for this arrhythmia while the individual is partaking in physical activities while connected to an Electrocardiography (ECG) device. An ECG device is able to monitor the electrical signals that are sent from the brain to the heart. These devices are used to detect irregularities in these signals during physical stress testing and early detection is necessary to prevent death. However, SADS can occur suddenly which is why a wearable device is needed to continuously monitor biometric signals of the individual.

At present these devices have become wearable due to the recent development of small sensors and embedded devices. This led to such devices being used to monitor biometric data, such as the detection of SADS. Although these devices exist they currently implement a design that requires either relays or a direct communication back to a base station. However, these designs require extra infrastructure and energy usage. Some devices do not send biometric data, rather they write the data to non-volatile storage which is attached to the device and is later analysed. This means real time biometric data cannot be analysed during players physical activities. These designs are inadequate and less adoptable because more cost is associated with high levels of infrastructure and extra power usage causes the devices to increase in size.

In order to create the smallest and most energy efficient device two possible protocols could be used in its development. These are Ad hoc On-Demand Distance Vector (AODV) Routing and a Gossip based protocol. Upon further research it is believed that Gossip protocol would be the most effective for use in team sports. Results from a simulation using Gossip protocol will be evaluated to create a prototype of the device. The results from the prototype can then be fed back into the simulation to create more realistic circumstances and lead to improved development of the device.

This dissertation also presents some future work to enhance the efficacy of Gossip protocol which we have used in the design and implementation.

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Chapter 1

Introduction

Sudden Arrhythmic Death Syndrome (SADS) takes people's lives during team sports, this dissertation will be presenting design decisions and a prototype of a device to prevent this from happening. SADS is a term used to describe sudden death due to cardiac arrest brought on by arrhythmia in the absence of any structural heart disease on a post-mortem [1]. After an unexpected sudden death has occurred it is practice that the coroner would request that a post-mortem be performed. The cardiac pathologist would examine for any abnormalities within the heart, if there is no presence of abnormalities then the death is classed as SADS. There are several reasons for SADS, they branch out into two main categories; cardiomyopathies and channelopathies. The latter cannot be found during a post-mortem as channelopathies is due to fallacious electrical signals sent to the heart which can only be detected when the person is alive. In Ireland, The Mater Foundation statistics state that on average two people every week die of SADS and for all cases of SADS that occur during sport only five have survived the event due to quick thinking of the people around the victim. This dissertation will show with the use of ubiquitous computing and wearable Electrocardiography (ECG) sensors embedded within clothes that we can track biometrics of players during a team game to find if the person is a possible victim of SADS close to real time and provide a view of improving their performance during game play.

We can see pervasive computing being used on public transport, built within our vehicles and now within our wallets. Within public transport there are applications giving real time information of buses and trains due to sensors being placed within the vehicles. This assists citizens on planning their trips by choosing the times more appropriate to their needs, which is being used for the smart cities projects. Within vehicles we can see parking systems built into cars to aid the driver while parking in highly dense areas, some systems go as far as automation of the car parking itself in a parking space. Soon wallets could be a thing of the past as your wallet could be in your phone. The term e-wallet is being used to show that your bank cards, driver's license et cetera, will be within your phone and the use of the information can happen through near field communication to purchase goods or to present your driver's license to a police officer.

Mark Weiser is widely considered to be the father of ubiquitous computing. This vision was that Ubiquitous computing would be post-desktop model of human computer interaction in which information processing has been integrated into everyday objects [2]. Users will be using many computational devices and systems simultaneously, without them being aware that they are doing so. This idea of pervasive computing is slowly being pushed into our everyday lives. We can see that smart devices are being used by people every day; finding their next bus, looking at their exercise statistics after a smart device has been taking sensor readings and even a wrist watch reading blood pressure which then sends the data to a smart phone device. We are living in a world where computer technologies are becoming closer to the user thus giving a different user experience than they had before while using a desktop machine.

Within healthcare, embedded devices that are wearable or that are close to the body can provide huge benefit to the detection of health problems with patients. Doctors will have more data about the day to day state of a patient's health and will be able to accurately diagnose the issues a patient may have. By having such devices monitoring people in this way, doctors may only be giving prevention steps instead of trying to cure the patient.

1.1 Research Problem

One of the main research areas to be addressed will be achieving near-real-time communication of biometric data from each team member to a central monitoring station, while minimising the power consumption, size and weight of the device. Inherently team sport players display patterns when playing their games. Mostly in team sports each player will have a role to carry out and have a position within the game such as a goal keeper, striker or defender. The nature of such team sports show that players move around in patterns and will become close to another player at some point in time during a game. The research will investigate whether the nature of team sports can be exploited to create an ad-hoc network over which biometric data can be transmitted as players come into close proximity in a "gossip" like manner. Finding out how this can be done will allow for such a network to be reliable and fast communication between nodes within the network. Another research point is can an ECG chest strap provide enough biometric data to find arrhythmic patterns that can lead to SADS before it occurs and/or to detect if a person has symptoms? There are two categories that are screened which are cardiomyopathies and channelopathies these both can lead to

SADS. Currently SADS deaths are thought to be due to channelopathies. With channelopathies there are no symptoms between collapses and/or black outs, thus tracking biometric data during sport can give more information to doctors to identify the patients problems just before an incident.

1.2 Motivation

The motivation is to create smaller and cheaper devices so that consumers are more likely to purchase them and so they will be effective for an entire game of their sport. Many team sports are confined to a certain area to play in. This gives motivation that the design can be achieved by exploiting the environment that team sports are played in. When SADS strikes a person while playing a sport there is a very low chance of surviving such an event unless people in the local area have been trained to deal with such events. If there is a way of detecting SADS just before it strikes then a death may not occur during a game. It will be highlighted by a system during the game and action to prevent it can take place. The focus is to prevent these types of deaths happening during sporting events and to detect if a person has SADS symptoms, as they cannot detect themselves what is taking place within their body. If these devices were easily obtained and used by people then many lives can be saved. Therefore the motivation is to have the devices that are easy to setup and can be used by sport clubs and schools around the world.

1.3 Scope and Objectives

The main objective is to make the devices communicate with other devices and exchange data between them. This will lower power usage which will make for smaller devices. There will be fewer infrastructures needed when using the devices e.g. each person's devices will communicate to each other instead of using multiple base stations placed around the pitch. The devices themselves will use each other in order to carry out monitoring. Devices communicating together will make for a cheaper solution. Close to real time monitoring can be viewed on a mobile device; the mobile device will be able to listen to the wireless mesh that has been created by the devices. The monitoring data will be stored on the devices and can be sorted on the mobile device that listens to the wireless mesh. Past monitoring data can also be viewed after a game has been completed. This can also be used to test the real time data and verify that a wireless mesh can give correct and complete data.

A basic example would be if there were three mobile nodes plus a base station and each node can communicate to another node at some point in time. The mobile nodes could be called N1, N2 and N3. N1 sends data to N2 when N2 comes into range. N2 moves out of range but is now within range of N3. N3 receives the data from N2. As N3 is in range of the base station the data can be received and evaluated.

1.4 Desired Outcomes

Within this dissertation we will be showing a device that can monitor real time biometric data. The main aim is to see can we find patterns of arrhythmia to indicate that a person could become a victim of SADS. There are many reasons why SADS occurs;

we will be trying to detect channelopathies as this cannot be found after a person's death, we can only find it when the person is alive. The aim is to try to decrease the death rate within Ireland and also to show if channelopathies are more apparent within SADS deaths. This will be achieved by developing a wearable ECG device that will track biometrics of players during team sports. We will be using pervasive computing in order to tackle SADS. In healthcare, embedded devices can give huge benefit to doctors. Doctors will gain a better understanding of the state of the patient's health and thus be able to accurately diagnose a patient.

The research problem will be near-real-time communication of biometric data from each team member that is being monitored. The biometric data will be sent to a central monitoring station where the data will be analysed. The aim will be minimising the power consumption, size and weight of the device. The way in which we will do this is by exploiting the nature of team sports to carry data between each node within an ad hoc network. Each player will become a node within the wireless ad hoc network and data will be passed in a "gossip" like fashion. We will be able to see if the ECG chest strap will be enough to detect arrhythmic patterns that could lead to SADS while a person is playing their sport.

1.5 Summary

The focus is to create smaller and cheaper devices so that consumers will be more willing to purchase them for their team sports. They can use a smart device to detect SADS occurring to a player. The system will highlight if a player has arrhythmic patterns which could lead to SADS during the game. This will hopefully prevent SADS happening to the player during a sport. Also, the player could be tested for

SADS and present the recorded data to the doctor to allow for diagnosis.

The organisation of this dissertation will be the state of the art within the area of ad hoc wireless networks with the view of low power communication, gossip protocols to exchange data, delay tolerant networks and routing algorithms for ad hoc wireless networks. Next will be the design of a device which will be wearable on a player, ECG chest strap and short range communication technology that will be used. We will then see the implementation of the device and show how the device can be created. We will examine the physical aspects of the device and the technologies that have been chosen for it. We will then evaluate the device in the real world and gather results from testing on a small number of participants during a team sport being played. Further evaluation will be carried out by taking the real world results and feeding them into a network simulator to increase the scale of the evaluation. After both evaluations have been carried out, we will present the conclusions of the project. We will show if team sports could be exploited to create such a wireless network and if a wearable ECG can find arrhythmic patterns to indicate that a person may become a victim of SADS.

Chapter 2

State of the Art

2.1 Introduction

With this chapter we will look at the state of the art within the area of wireless biomedical sensor networks. These sensors are designed to be wearable to allow the biometric monitoring of a person. The device would measure biometric data such as body temperature, muscle movements and heart rate. The data gathered by the device will either be stored on the device and/or sent to another wireless device to monitor biometric data close to real time. This can allow us to monitor a person while they are being active such as during team sports, exercising in the gym and home monitoring.

These designs will have the same type of requirements throughout each design. The common requirements are low energy usage, lightweight and low cost. The device will be running on battery power which is a limited resource, the device must therefore use little power to carry out monitoring and transmitting of the biometric data. These devices can increase their up time by designing energy efficient protocols for routing data and harvesting energy by the movements of people wearing the devices. In the following sections, we will show the state of the art within this area.

2.2 ECG Marathon

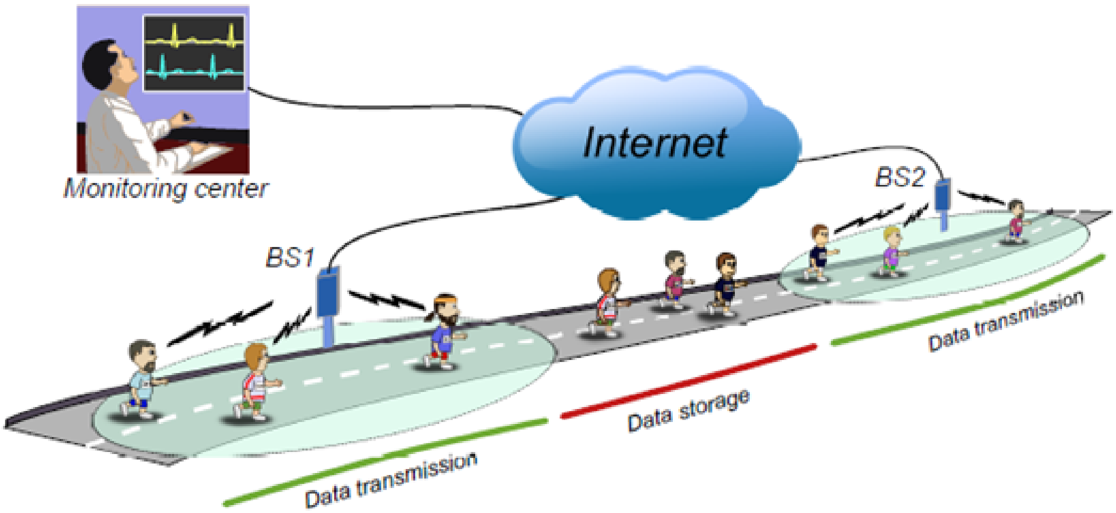

Figure 2.1: ECG Marathon Design

Within [3], they show a design that monitors runners' ECG data during a marathon. The above figure 2.1 shows how they designed the system to carry out the monitoring. Each runner is wearing a device that is taking ECG readings and storing them onto memory. The device also has wireless communication on board; the wireless device in this case was IEEE 802.15.4/ZigBee compliant. The design is to store data on the wearable device until a base station comes into range of the runner. When the runner is in range the device will connect to the base station and then transmit data to the base station until it is out of range again. Once the data is sent to the base station it is then relayed back to a monitoring station via long range wireless communication. Throughout the route of the marathon, base stations were setup at intervals to capture runners' ECG data. This creates a data transmission period in which the runner will be in range along the route.

They carried out field experiments that determined contact duration of mobile nodes to the base station, maximal throughput of data transfers from a single mobile node and a single base station and contention problems between many mobile nodes to a single base station. These areas are their main focus of their experiments and will highlight how much data can be transmitted between mobile nodes and a single base station for a short time span. They carried out the experiments with low power and low data rate devices which provide a short communication range along with slow data speeds for the type of data being sent.

They found that the contact distance between the runners and a single base station was approximately 200 metres. The contact time varied with different runners as some runners were faster than others. The fast runners had an exposed time of 35 seconds while the average speed runners had 60 seconds. This is a short window of time to send the high volume of data that the devices recorded. They found that the throughput of a single mobile node to a base station was 55 data frames a second which turned out to be 50 kbps of application data. This was a very low data rate compared with the wireless device's standard signalling rate of 250 kbps. The low application data rate indicates a problem when many runners are in range of a base station. They found this to be the case in their experiments. They found that when a high number of mobile nodes are in range of the base station contention became an issue in sending the high volumes of data for each runner.

After the experiments they saw that ECG data is very demanding on a network with low data rates. They needed to review the sampling rates that they had set. The volume of data produced per second was 12 kbps during the experiments, the sampling rate needed to be reduced to allow monitoring with low data rate network.

Another point that was considered to reduce the volume of data was to compress the data before sending it to the base station. This would cause an increase in energy usage and the device would need adequate computation power in order to achieve this. They discussed another approach in which the device will analyse the ECG data and if irregular heart rhythm was detected it would send alerts to the base station. This would reduce the amount of data that would be sent which would reduce the contention between the devices.

2.3 ZigBee

ZigBee is based on IEEE 802.15.4 which provides many features to ZigBee which will be discussed in the next section. IEEE 1451.5 ZigBee standard provides a transport layer to allow routing of packets between nodes within the network [4]. Mesh networking is one of the main features of ZigBee, this provides a self-healing network. A self-healing network is a network that can react to changes within the network topology. If nodes move away from each other or a device is broken the network can find new routes to the destination once other nodes are within range. This creates reliability within the network when multiple nodes exist. Another benefit is that increased communication range can be established by the use of the nodes relaying packets throughout a route in order to achieve a greater distance than their predefined communication range. ZigBee is widely used for wireless sensor networks.

2.3.1 IEEE 802.15.4

Institute of Electrical and Electronics Engineers (IEEE) has defined a standard for physical and media access control layers for wireless personal area networks. The standard outlines the goals to achieve low cost, low power and maintain a reliable data communication between wireless devices [5]. The features of this standard include network topologies, low power consumption, data rate of up to 250 kb/s and providing addressing for devices. This standard can be reused as a basis for other protocol stacks. An example of this would be ZigBee sitting on top of the IEEE 802.15.4 layers and providing transport such as mesh networking along with routing protocols.

2.4 Bluetooth

IEEE 802.15.1 defines a standard for Bluetooth technology. Different versions of Bluetooth can have different speeds of communication. The 802.15.1 standard defines a 1Mb/s speed [6]. Bluetooth has been widely adopted with sensor networks and integrated with mobile phones. The high speeds allow applications with large data requirements to achieve transferring of data in a timely manner. The latest Bluetooth versions have been improving the issues around power consumption as previous versions have been shown to use more power than other technologies such as ZigBee. The release of Low Energy Bluetooth has shown that power usage has decreased bringing it closer to the same level as ZigBee [7]. This power improvement will allow more applications to use this device that may not have been able to before due to power consumption.

2.5 Routing Protocols

Within ad-hoc networks, the nodes work together in order to achieve a network. In most wireless networks the nodes will be mobile and move in different locations. The ad-hoc network is required to react to such situations to provide connectivity between the nodes. Connectivity is achieved by nodes using the same routing protocol and follows a series of actions to be able to react and transfer data between nodes within the network. There are many different types of routing protocols which have advantages and disadvantages within different environments. Also some of the routing protocols have been combined together to produce better performance in areas such as energy usage but have trade-offs such as high latency times. In the following sections some of the main ad-hoc routing protocols will be discussed.

2.5.1 Dynamic Source Routing

The Dynamic Source Routing (DSR) protocol allows connectivity between mobile nodes with a wireless ad-hoc network on an as needed basis [8]. A source node that wishes to send a data packet to a destination node will first need to perform a route discovery if the route is unknown. The route discovery process will send what is known as a route request to all nodes within the network. This request then floods all the nodes within the network until the destination has received the route request packet. When a destination node receives the route request, the node will then respond with a route reply. The route reply will be sent to the source node by looking at the header within the route query which will show the route that the query took. The nodes in the network will each have a routing cache. This cache will store all the known routes to a destination. This provides many different routes to a single destination. The protocol detects that routes are invalid when a data packet is not sent successfully through the route. This will cause an error packet that will be sent to the source of the sent data packet. The error packet when sent to nodes will cause their routing cache to be cleared of all routes.

The benefits of this protocol are that many different routes can be used, more routing information can be found and can be improved by sending data packets from all different routes to a single destination. Having the ability to know many different routes to a destination can allow for more reliability within the network. The same data packets can be sent too many different routes which can improve the likelihood that packets will arrive at the destination. This is at the cost of power usage but could be of benefit in quality of service for certain data packets such as an alert of an event.

The drawbacks of this protocol are that route discovery must be redone when a route becomes invalid. This means that all the routes that were stored in the routing cache will be deleted. Generating new routes each time the network topology changes can use a lot of power for a mobile node that has a limited resource. By deleting all the routes in the routing cache the protocol is not going to work very well where mobile nodes have patterns of movement. If only the single invalid route was deleted then it could be more of a benefit to mobile nodes having patterns of movement.

2.5.2 Ad-hoc On-Demand Distance Vector Routing

Ad-hoc On-Demand Distance Vector Routing (AODV) has some of the same characteristics as DSR as it also creates routes on an as needed basis [9]. The route discovery process is the same as DSR in that it floods route request packets throughout the network, although AODV stores its routes in a different manner as DSR. AODV maintains routing tables at each node within the network. Only a single route is selected for each destination node, the route with the shortest path will be added to the routing table. AODV uses sequence numbering to provide a means to detect freshness of routes for different destinations and to prevent routing loops. AODV routes can become expired if the route has not been used for a certain length of time even if the route is still valid. A source node cannot select the route that its data packets can take like DSR allows. Other AODV nodes handle the routing of data packets.

The benefits of this protocol are that a single route to a destination is used, routes used will have the shortest distance to travel and low memory usage is possible as only one route per destination will be stored. Providing a single route can aid mobile nodes that have movement patterns. A commonly used single route will remain in the routing table and never expire as the route is used many times between mobile nodes. Routes that have the shortest distance between source and destination will result in low latency due to fewer hops within the network. This will benefit network speed for data packets being sent throughout the network. Only storing a single route in the routing table reduces the demands of memory and nodes can quickly select the correct route for a data packet.

The drawbacks of the protocol are that the source cannot select a route, cannot send data packets along different routes and less routing information will be generated and stored at nodes. This protocol restricts nodes to sending data packets to a single known route. The source node will not know the route that the data packet will follow as the intermediate nodes will handle the routing of the packets. The protocol reduces the amount of information stored about routes; this does not allow nodes to build up an overall view of the topology. If mobile nodes have random movements with no pattern it can cause route discovery more often within the network.

2.5.3 Destination Sequenced Distance-Vector Routing

Destination Sequenced Distance-Vector (DSDV) Routing is different from AODV and DSR as it is a proactive routing protocol [10]. A proactive routing protocol finds routes once a node in the network has been powered on. All the nodes will participate in finding routes and each node will create a routing table with the destinations. Like AODV these routes will be the shortest distance between source and the destination nodes. In order to achieve connectivity between nodes; each node will transmit their routing table information. This process of exchanging their routing tables is done in two steps. The first step is that a node sends their full routing table to other nodes. This provides sharing of routes with other nodes within the network. After the first step is completed, the second step is to only send routes that are new or have changed. This reduces the amount of traffic generated by the routing protocol to allow for more data packets to be sent throughout the network.

The benefits of this protocol are that routes are generated, maintained and latency is decreased. Having the routes generated and maintained when the devices are powered up reduces the latency time compared to DSR and AODV. DSDV will be able to send data packets through nodes faster as routes have already been discovered unlike DSR and AODV as they need to discover a route first before sending data packets. The protocol may be more suited to mobile nodes having patterns of movements as updates of routes are only needed but if nodes are randomly moving the updating of routes could take more bandwidth compared to AODV and DSR.

The drawbacks are more power usage and time for convergence of the network is needed. More power will be used throughout the life of the network as the nodes will always be communicating route updates. This increases power usage of each node and reduces the time span of a device that is being powered by a battery. Also the first step of exchanging full routing tables will take time for all nodes to receive each others routing tables. There will be a period of time needed for the network to converge; during the network converging nodes will not be able to send data packets. This convergence time will increase when more nodes are added to the network.

2.6 Gossip Protocol

Gossip protocol provides a means of sending data from a source node to a destination node with a probabilistic delivery. Gossip is different to routing protocols as it never creates a route between nodes nor do nodes store routes. Instead the protocol is very simple in that a source node broadcasts its message to anyone that could be in range. If there is no one in range then the packet will be lost. If there are nodes within range of the source node then the other nodes will retransmit the same packet causing a flooding effect. This flooding is how data is passed around to each node within the network. Data packets will even be sent to nodes that are not the desired destination. This type of protocol works very well if nodes are in a confined area. Even if the network is unreliable messages still have a chance to propagate through the network. The concern with this approach is excess flooding of data packets which will have a lot of power usage with limited power resources on devices. The following sections will discuss different types of gossip and show that gossip can be energy efficient.

2.6.1 Types of Gossip

Gossip protocols come in a variety of different forms. Most gossip protocols are tuned and modified for specific applications. Some gossip protocols are suited for unreliable networks and others are used when trying to ensure that all nodes within a reliable network get a piece of information. Some of the factors to gossip nodes are the amount of times the node should send data and to how many nodes. Within the different gossip protocols lies a common core functionality that is used throughout all gossip protocols.

```
while true do
    wait (Δt time units)
    p ← RandomPeer();
    prepare(s);
    send s to p;
    s_p ← receive(·);
    s ← Update(s, s_p);
```

(a) active thread

```
while true do
    s_p ← receive(·);
    prepare(s);
    send s to sender(s_p);
    s ← Update(s, s_p);
```

(b) passive thread

Figure 2.2: Generic Gossip Protocol

A generic gossip protocol is when two threads are executed on every node within the network [11]. Each of the two threads is executed in an infinite loop. Each thread active and passive has a role to carry out in order to gossip a nodes state to another node. Figure 2.2 shows the two threads operations.

The active thread allows communication to a random peer. It will wait for a period of time then select a random peer. When selected it will take the state and send it to the selected peer. The selected peer will then communicate back and the node will then update its own current state. The passive thread waits until a connection has been established by another node. When a node state has been received it will prepare and send its own state to the node and update its own current state.

2.6.2 Energy Efficient Gossip

A gossip protocol called Fuzzy-Gossip is a protocol that is energy aware [12]. Fuzzy-Gossip gets its name by using fuzzy logic. Fuzzy logic is a rule based approach to dynamic behaviour of situations. The rules are set by a human that classifies events or parameters which results with an outcome. This is used alongside gossip to ensure that nodes are sending messages based on their current battery power. The factors that are looked at in this protocol are the distance to the destination and the remaining power on the device. This ensures that a node will select an optimal neighbour node to transmit data. The table below shows the factors and the outcomes.

RE(n) / *D(n)*	**V. Low**	**Low**	**Medium**	**High**	**V. High**
V. Near	Normal	Good	Good	V. Good	V. Good
Near	Bad	Normal	Good	V. Good	V. Good
Medium	V. Bad	Bad	Normal	Good	Good
Far	V. Bad	V. Bad	Bad	Normal	Normal
V. Far	V. Bad	V. Bad	Bad	Bad	Bad

Figure 2.3: Fuzzy Logic Rule Table

We can see if a node is a very far distance to the destination and if the remaining battery level is very low then it would be a very bad choice to select the neighbour in question. This method is a fast way to compute the best energy efficient path to a destination. This protocol will try to allow for the choice of a multi-hop path to the destination which can reduce energy usage which is discussed in the Relaying Section.

2.6.3 Self-Configuring Gossip

Another gossip based protocol is called Gossip3. Gossip3 can be self-configuring, meaning it can adjust to different environments. There are two self-configuring parameters in Gossip3 which are probabilistic based forwarding and a compensation mechanism [13].

The variable for probabilistic forwarding controls a node to forward a packet too many different nodes or to a single node. If more messages are sent to other nodes then there is a higher chance that a packet will get to its destination. Probabilistic forwarding variables can be increased when reliability is required within the network.

The compensation mechanism variable controls how long a packet should remain being forwarded within the network. Depending on the variable a node will listen to the network and check if its sent packet was received to itself. If the node does not detect its packet for a set period of time it will retransmit the packet again to other nodes. This can be different for each node which makes better configuration for a node that is in range of fewer nodes.

2.7 Relaying

In a wireless sensor network, there are many nodes that make up the ad-hoc network. Relaying is a term used to describe data packets being sent to many of the nodes before reaching the destination. This can also be called multi-hop which most routing protocols provide within ad-hoc networks. Using relays can provide some benefits such as increasing communication distance by using many nodes spread out in distance and energy usage can be reduced at each node. Overall energy usage across all the nodes can be reduced as each node will only communicate a short distance reducing power usage. Some can argue that multi-hop does not provide better energy efficiency while others say it can provide better energy usage. In the next sections we will look at the current research within relaying with the aim of increasing energy efficiency.

2.7.1 Types of Relays

There are many different designs of relays. Relays can be a mobile device moving within range of a base station and other mobile devices or a fixed relay node within range of the base station and other mobile nodes. Relays can be used for increasing range of a base station by relaying data packets that are sent by the base station. The relays role is to receive the data packet from the base station and retransmit the packet. This method is known as amplify and forward, the relay node takes a relatively weak signal from the base station and boosts the signal by retransmitting the same packet [14]. In the following paragraphs we will take a look at two common relay systems.

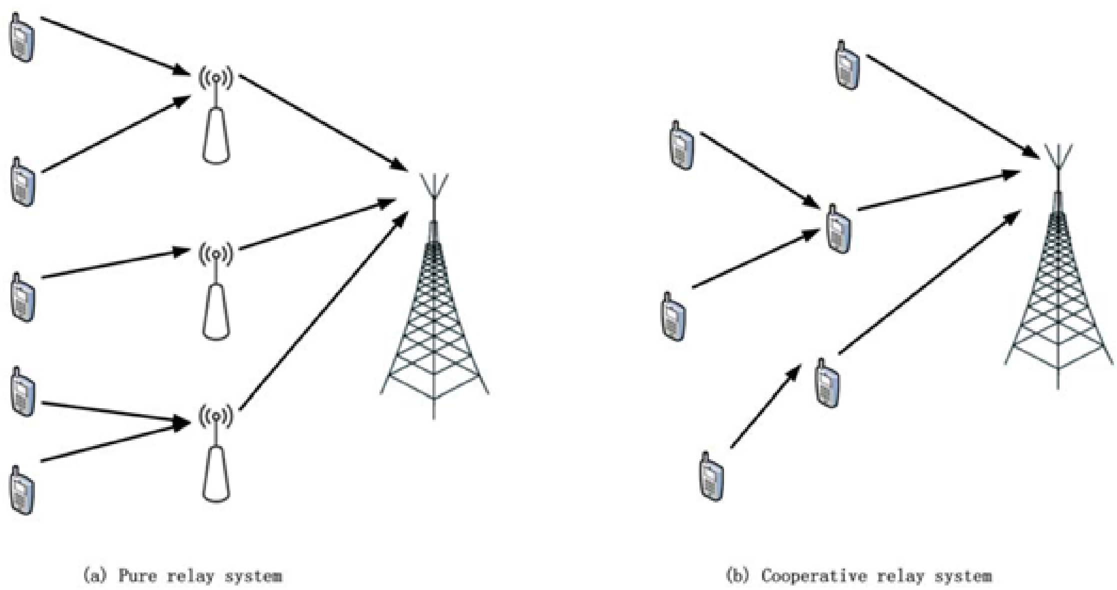

Figure 2.4: Types of Relays Systems

In figure 2.4 we can see pure relay and cooperative relay systems. These two different designs can allow for longer ranges away from a base station. The mobile phone indicates mobile nodes that can move within their environment. We can see within pure relay that there are mobile nodes and three relay stations. These relay stations stay in their position and have a set distance away from the base station. The mobile nodes send their data packets to the relay node which in turn sends the packets to the base station. In cooperative relay we can see a similar type of design but having no fixed relay stations. The mobile nodes act as relays for other mobile nodes. This design also increases range from the furthest mobile nodes to the base station. The cooperative relay increases range at the expense of using the mobile devices limited power resources. Both of these relaying systems can produce another advantage such as energy efficient communications. This is because the communication distance for each device is a set distance away, relaying boosts up the signal which will reduce the need for retransmissions compared to a device communicating directly to the base station. The trade-off with relaying is that it causes increased latency of data packets. One of the main reasons for this is the signal path loss exponent; this will be discussed in the next section.

2.7.2 Energy Efficiency

Research has been carried out to make wireless sensor networks become more energy efficient with the use of multi-hop routing [15,16]. They have found that using multi-hops can reduce the energy used in transmitting. They have looked at long and short range communication such as LTE, WiMAX, Bluetooth and ZigBee. They took propagation loss and path loss exponent into consideration and found that if a device is communicating over a long distance without a relay, there is a higher chance that the receiving side may miss packets due to interference. Therefore the source must retransmit the same packets again in order to deliver them to the receiver. Without using the relay the path loss exponent causes the signal to become weak and therefore is susceptible to noise. With a relay in between the source and the destination it produces a different scenario. The source node to the relay node is half the distance from the source to the base station. This means that the path loss exponent will be halved resulting in a stronger signal at the relay node. With a stronger signal there will be fewer packet losses at the relay node and base station which results in less retransmissions. Comparing a multi-hop approach with a direct communication will show that the multi-hop will lead to significant energy savings.

2.8 Energy Harvesting

Energy harvesting is creating energy within an environment that has external movements or changes and turning it into power that can be used on electronic devices. The aim is to prolong the life of a device with its limited power source. Energy harvesting is usually seen in wireless sensor networks, these types of sensors are meant to run autonomously with no assistance from humans. The sensors can be placed into positions that humans may not be able to reach again, energy harvesting plays a role in ensuring a prolonged life span. Energy can be harvested in many different ways such as solar, movements and temperature differences. Devices can take advantage of their environments and generate small amounts of power.

A type of harvesting is a device taking kinetic energy from human movements and converts it into power that a wearable electronic device can use. These harvesters can be small that can be attached to a person either on a limb, clothing or accessories such as a back pack [17]. Watches have been sold that use this form of generating power, this shows that kinetic energy harvesting has been proven to work well on wearable devices.

Another harvester uses the differences of temperature to create power. These devices can also be used for wearable sensors. Temperature harvesters can come in many forms such as being worn on a wrist or put onto a shirt [18]. A shirt has been created and tested with a hidden harvester and shown to produce a substantial amount of power. The amount of power harvested by this shirt design was during a nine month period it generated more power than the energy stored within a standard alkaline battery. The harvester and a battery are the same size and weight as each other.

2.9 Summary

Current research within biometric monitoring is ever changing and advancing at a considerable rate. This chapter will soon be out of date with new emerging technologies. These technologies will allow for better monitoring of peoples biometric data. This may result in that people will be more aware of their activities that they carry out which will have an effect on their health. Due to low power devices and wireless communication the technologies can easily be used and data tracked by a mobile device or a base station.

Gossip-based protocols are more prevalent and are being used in many different applications. The basis of the protocol can be tuned and modified to best suit each environment that it is exposed to. Some protocols include self-configuration that can be used throughout the life of the network. This provides many advantages such as scaling the network (increasing or decreasing nodes) and providing better energy usage of limited resources.

Most wireless sensor nodes use multi-hop routing in order to achieve longer distance with short range communication devices. Within AODV this is done by selecting the shortest number of hops to a destination node, these results in a lower number of nodes to be used and lower latency times as a result. Fuzzy-Gossip is energy aware in that it takes into consideration the amount of energy remaining and checks the distance to the destination to prevent increased power usage. Many papers state that there is a benefit to multi-hopping, in that it can reduce the amount of power used. This is due to the path loss exponent; if nodes multi-hop the signal will be higher thus fewer packets will be lost during transmission. When the signal is long if devices are trying to communicate long distances it can result in more packet loss causing more power to be used per data bit.

Energy harvesting is being actively researched and can enhance wearable computing. Having a device generate power for wearable devices will allow for more innovative wearable devices. Some devices that we can see today benefit from this type of energy harvesting one of which is watches. They can be worn without needing to maintain the device and can be forgotten about. Other harvesters that can be placed into clothing will solve the problem of power within wearable computing in the future.

Chapter 3

Design

3.1 Introduction

This Chapter proposes an approach for communicating live biometric data from players to a base station in team sports. The requirements, as discussed initially in Chapter 1, are that the system be light-weight, consume little energy and transmit data in a timely manner to facilitate early detection of SADS. Two protocols are considered, the first based on AODV [9] and a second based on a form of Gossip [11]. Requirements and design options are considered in detail in the next section.

3.2 Requirements

There are many requirements that this design must address in order to be able to analyse ECG data close to real time. The design will ensure that ECG data will be sent to a base station in a timely manner. To achieve this, requirements such as wearable, light weight and low power communication need to be achieved in the design.

In the following sections we will consider the aspects of the design and address in detail each of the requirements for the design.

3.2.1 Data Characteristics

ECG data is created from electrical probes that are placed on the skin, near the heart area on the body. These small signals are then amplified to allow detection of electrical signals that are sent to the heart. Many different forms of ECG exist, some of which have three leads and some having a maximum of twelve leads. More leads provide more detailed analysis of the heart signals but some of the twelve leads will be attached to the persons limbs.

We will be looking into having a three lead ECG which allows us to monitor the heart signals. Having a small number of leads will make it more comfortable to wear during physical exercise. Three leads would be adequate to monitor the player and give some insight of his/her condition during their game.

The embedded systems that can currently be purchased off the shelf range in different specifications; an example would be a five lead providing a sampling rate of eight hundred cycles per second. Another example would be the Longfian JAX-209 which provides a three and five leads with a sampling rate of two hundred per second. This type of device is widely used throughout peoples homes.

ECG shields on the market today, such as Olimex EKG shield have a twelve bit value with a sample rate of two hundred per second for each of the channels. If we took a three lead shield for our design this would be a large volume of data that will be gathered during the monitoring of a single person. The amount of bits generated for one second is as follows:

12 bits * 200 samples = 2,400 bits per lead attached

For three leads it would be 7,200 bits per second

With a large volume of ECG data per person, a team of twenty two players will be a large volume of data to wirelessly transmit to a base station in a timely manner. We must consider an adequate data rate to be able to transmit such a volume of data.

3.2.2 Communications

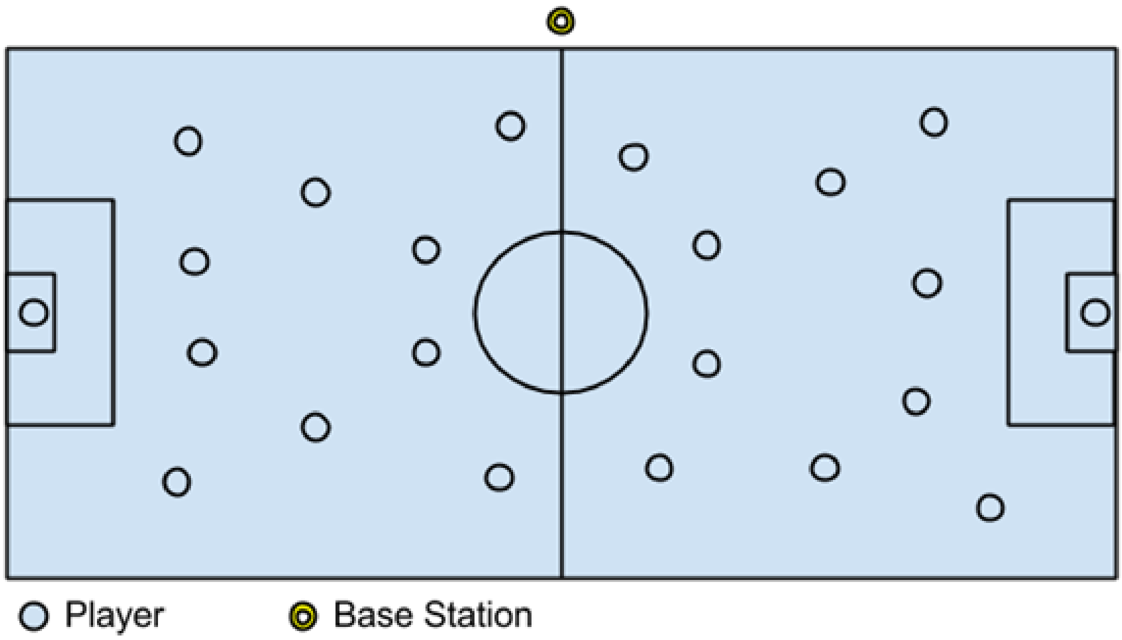

Figure 3.1: Players and Base Station Layout

Figure 3.1 is showing each player having some wireless communication device on their person. The device will allow for sending data to a base station that can analyse the status of each player. The base station can indicate if a player has signs or is at risk of having SADS symptoms throughout their game play. The way the system is designed plays an important role in being able to detect these symptoms. More importantly what data do we send to the base station, do we allow the device to analyse the ECG data and raise alert to the base station or do we send the data straight to the base for it to be analysed?

The on-device analysis will need to have high processing power due to the volume of data. Due to this battery power has to be plentiful on the device. Although this design would be very good it is not feasible as the device needs to be attached to a player. The device will become too large due to the necessary battery power needed for the analysis.

The base station analysis will provide a better design as the base station will have a larger power capacity. If this design moves the analysing to the base station the players devices can be made smaller, lighter and can be attached to the player. This design requires a wireless network that needs to use low amounts of energy with enough bandwidth to handle the data that needs to be sent to the base station.

3.2.3 Timeliness

The design must allow for fast communication back to the base station. Due to the nature of SADS the design must allow for detection of a sudden change in ECG readings. This requires the ECG reading to get from a node to the base station quickly for fast analyses of a players state.

As is the nature of team sports, players are moving around the pitch at different speeds and angles. This causes nodes to come in and out of range of each other and the base station. This can cause an increase in the time it takes to get data packets from a node to the base station. It takes a certain period of time to establish a connection from one node to another.

How we measure this delay is called Latency. Latency in computer networking is the time it takes to send a packet from a source to the destination and return it back to the source. This is known as the round trip time. Some of the key factors to increased latency are propagation times, processing times on a node within the network, a packet being sent through many nodes before reaching its destination and the time it takes to create a route to the destination.

A simple way of communication would be that a node directly communicates straight back to the base station. The expected delays with this type of communication are the propagation time and processing times due to high volumes of data. Direct communication does have drawbacks, such as; nodes need to have long range wireless communication which causes an increase in power. Also, if a team of twenty two players are trying to communicate to a single base station there could be many collisions due to the fact that all nodes may not be in range of each other.

This raises difficulty in media access control as it is hard to handle for the base station. A well-known problem in this area is the hidden node problem. This is when nodes A and B are in range of the base station but nodes A and B are not in range of each other. This creates collisions at the base station as A does not know that B is sending packets or vice versa. The outcome is packet loss within the network and this will increase delays.

Instead of direct communication another approach would be to have multi-hops to the base station. This means we must use other nodes within the network and the packet from the source node will be sent along other nodes until it reaches its destination. In order to achieve this, nodes will communicate together to create routes from source to destination. We can foresee increases in latency with this approach as creating routes where nodes within the network will be moving will take time, such as the case of team sports. Multi-hop will also increase latency due to the fact that each node needs to send its own packets along with other nodes packets.

Creating routes and multi-hops will be the main factors that will cause increase in latency but it may reduce or resolve the hidden node problem. This is because routes will be generated and nodes near the base station will be used to communicate to the base station. This could reduce the collisions by not having all twenty two players going straight to the base station, rather, a small subset of players will be relaying other players data and sending their own data, therefore, reducing the number of nodes talking to the base station.

3.2.4 Wearability

The main requirements for wireless communication for this design are that devices must be wearable and lightweight to allow for attachment of the devices onto the players shirt or body.

Fortunately, over the past few years the size and energy needed to power these devices has decreased, while processing power continues to improve, creating such wearable devices. Nowadays, wearable devices can come in many forms such as watches and chest straps that can be secured around your chest to provide biometric readings.

Electronic textiles can also be used to provide power and connections to wearable computing via fabrics that can be embedded into clothing. This provides computing power within clothing that can be wearable while a person is being active throughout their environment.

Other requirements for wearability are that the attached devices much be able to withstand water or sweat. During team sports, people will be sweating throughout their game and may also receive knocks from other players. The devices must be able to withstand these environments and ensure that ECG readings are being sent back to a base station.

These requirements will be very hard to achieve. In the prototype we will be addressing can a design of a device be put onto a person and wirelessly communicate? Our design for the prototype will not be able to withstand water or knocks and strikes to the devices themselves. Future work on these requirements is needed.

3.2.5 Fixed Infrastructure

The requirements for infrastructure should be kept to a minimum to keep the design as low cost as possible. The only infrastructure that we wish to use in the design is a single base station and each player having wireless communication. This will make the design easy to deploy and allow us to scale in a larger number of players in other team sports.

3.3 Team Sports Environment

3.3.1 Physical Environment

Within team sports there will be many players on the pitch for certain duration of time. Most team sports are played outside in the elements of the weather. We can expect players may be exposed to poor weather conditions. When creating small electronic devices for these environments, devices must be able to withstand the elements and be physically robust enough not to break.

For most team sports players are always in line of sight of each other and are moving around in their positions. In different sports, players will have different positions that they will play in. This can be a concern for our design because some players devices may not be in range for a period of time. Different sports will have different difficulties that the design must overcome.

3.3.2 Soccer

In soccer there are players out on the middle of the pitch and some remain close to one side. For the duration of the game, players will move up and down the length of the pitch depending on who has possession of the ball. The goal keepers on the other hand will always remain close to their goal posts. This could be a problem as players move away from one side of the pitch to the other and the goal keepers may become out of range. This will cause delays in getting ECG data back to the base station. A simple solution to this problem is to increase the range of the goal keepers so that they will be in range to some node within the network.

3.3.3 Rugby

In Rugby the players are often close together or in a line formation. This means we may not have problems like soccer goal keepers and benefit from the players being very close to each other. This could mean that each node within the network could have a smaller communication range therefore using less power. Although other problems exist such as a lot more physical impacts that could cause the devices to break.

3.3.4 Gaelic

In Gaelic we are faced with the same types of problems as Soccer along with other problems. The other problems are that the speed of player during the game is a lot faster. The players will fast approach each side of the pitch. This can cause problems with latency due to the time of creating connections. Creating connections and routes must be done in a timely manner. Also problems exist with the created routes; routes can become more frequently invalid quicker than compared to Soccer.

3.4 Overview of Approaches

Designs have been already made in this area, such as storing ECG data onto the device that a person is using or using direct communication back to a base station. These types of designs can be improved to better allow for close to real time monitoring and achieve better power usage to decrease the size and weight of the devices used. In the following sections we will look into designs that currently address the problem and also show a new approach, benefits and drawbacks.

3.4.1 Adopted Approaches

One approach is to only store the data on a Secure Digital (SD) memory card. This memory is non-volatile meaning it is permanently saved to the card. The device is attached to a player and all data is recorded to the memory card and then later analysed. This approach doesnt give any insight to the players status throughout their exercise therefore it will not allow us to detect SADS.

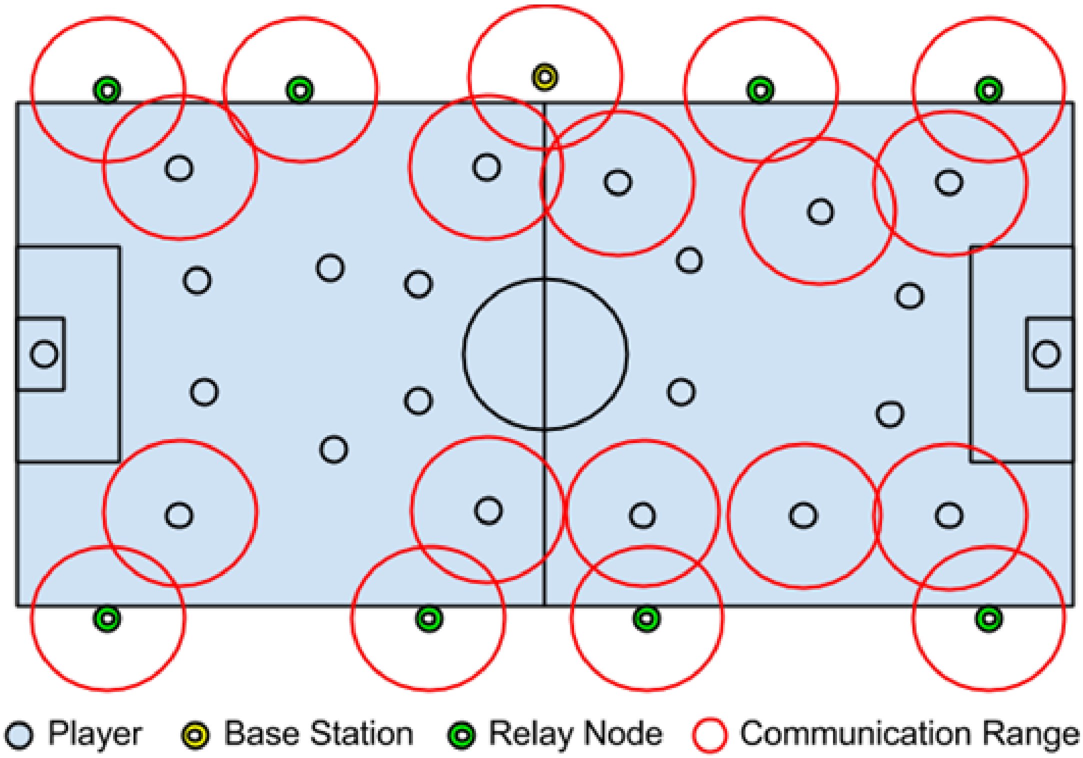

Figure 3.2: Relay Approach

Figure 3.2 we can see how another approach is designed. Many nodes sit next to the side line of the pitch. These nodes are green in colour to show that these are relay nodes and the one base station node is yellow. The other black circles are the players that are on the pitch. Some of them have the red circles to show the communication range of the players devices. Data is sent from the players devices to either a relay node or directly to the base station. If data is sent to a relay, the relay will transmit the data back to the base station.

This design allows the devices to have a small communication range which will reduce power usage on the devices. Another benefit is that large volume of data can be handled due to many base stations being within the area. Network traffic will be spread through the relay nodes to the base station which will reduce congestion.

The main drawbacks to this design are that it requires a lot of infrastructure and nodes on the pitch need to have at least half the width of the pitch communication range. Having more infrastructure increases the cost and the complexity of setting up the system. This type of design could be seen as less adaptable because of cost and complexity. Also the communication range must be wide enough to be able to reach either a relay node or the base station; this will increase the energy usage and the weight of the device.

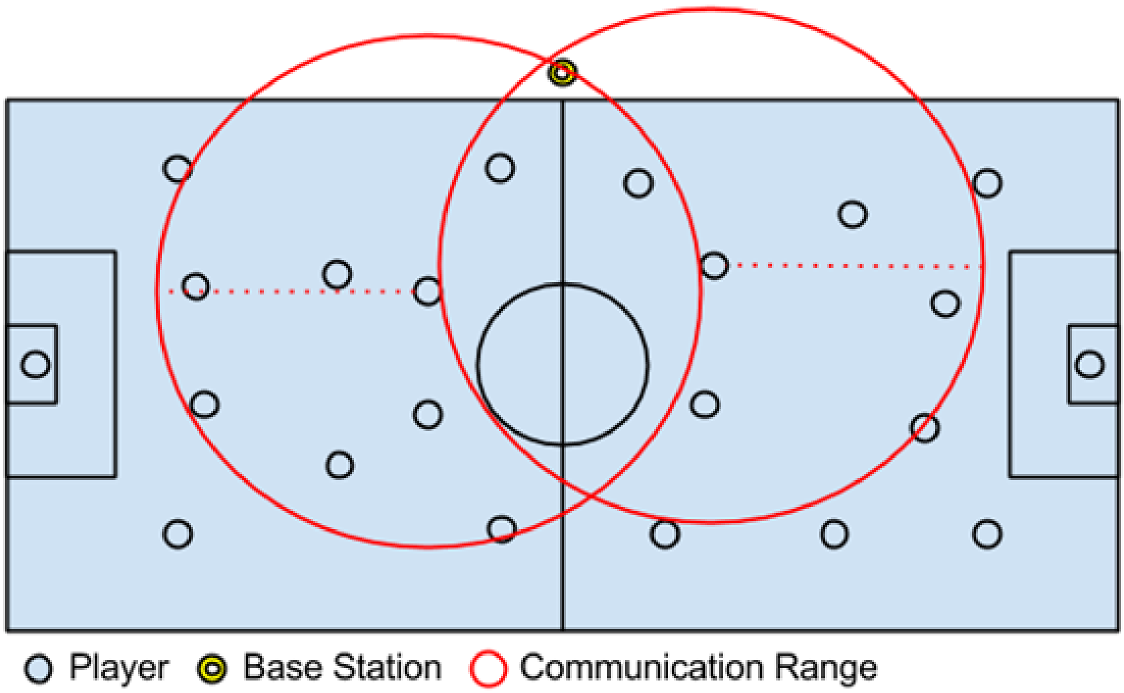

Figure 3.3: Direct Communication Approach

Figure 3.3 shows a different approach to the same problem. In this approach all the nodes communicate straight to the base station. The figure shows only two nodes communicating to the base station. We see that each node must have long range wireless communication to be able to transmit the full length of the pitch. This approach forces the nodes to share the air waves.

Direct communication can have benefits such as little latency to the base station and less collisions due to other nodes in range of each other. There will be little latency from a node to a base station because the propagation delay is very minimal. The network will have fewer collisions because each node will be in range of each other which will fix the hidden node problem. Another benefit is that there are fewer infrastructures needed within the design which will reduce the cost of the design.

There are some drawbacks to this design the main one being each node will need a lot of power to have such a wide communication range. This will make for heavier devices compared with the relay design. Also having one base station could cause congestion problems due to the fact that all twenty two nodes will be sending their data to the base station.

3.4.2 New Approach

In figure 3.4 we can see a different design and in some aspects it is the combination of the two previous approaches. In the figure we keep to a single base station that the nodes need to communicate. The difference is that each node is a relay for other nodes creating what is called a mesh network. This design uses the players pattern of movements to be able to send data back to the base station. The green arrows are showing the pathway where the data is being sent. The furthest node away from the base station is transmitting its data; the other nodes are receiving data and retransmitting the data along with their own data. We can see that this type of pathway will not be valid for a long duration of time so routes will need to be recreated in order to send data back to the base station.

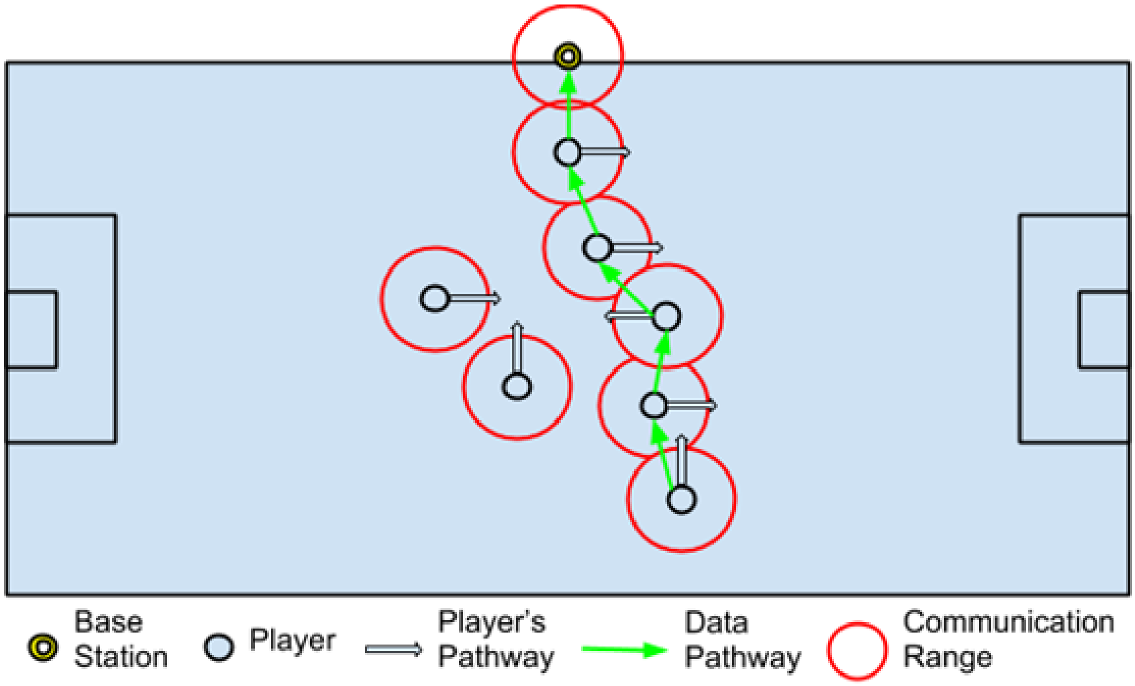

Figure 3.4: New Approach

The benefits of this design are that it requires fewer infrastructures, nodes use less power, it makes for a light weight device and is easy to deploy. The design requires fewer infrastructures because nodes work together to create a self-healing mesh network which is suited to nodes moving in and out of range. Nodes use less power because their communication range can be reduced as other nodes will relay the data back to the base station. Devices can become lighter as less battery power is required because of the shorter communication range. The design is more adaptable for users as the devices can detect each other and generates an ad-hoc network; also if a sport requires more players the network is scalable due to the mesh network. This design takes advantage of players pattern of movements during their game. Another benefit is that the base station will only communicate with nodes that are in range, this reduces the number of nodes communicating to the base station which could reduce congestion.

With this design there can be possible drawbacks that need to be evaluated. Some of these could be the use of the design with certain sports such as Soccer, latency may increase, congestion may increase due to a single route being used to the base station and increased memory usage could be increased for each node. In Soccer the goal keepers will always remain near their goal post. When a team is advancing to score a goal, the goal keeper will remain at his position while other team members move away. This could raise a problem because the goal keeper device may not be in range of any others devices which will cause no data being sent about the goal keepers status. Latency will increase overall because each node will be relaying data back for other nodes, this could be a trade off for communication range. Congestion could increase if a routing protocol selected a single route to a base station. If only one node is selected to communicate all other players data to the base station it will increase congestion, it would be better if a protocol does not select a single route and allows more than one device to communicate to the base station. Each node will need to store its own data along with other node's data thus; each device needs to have a large capacity of memory.

3.4.3 Routing Requirements

The design needs to be able to establish routes even with players moving throughout their game. The network must react to the changing positions of players and provide a means to be able to generate routes back to a base station. This requires fast initialisation of connections between nodes. Also the speed of creating a route to the base station must be done very fast in order to send data back in a timely manner.

If we are using a protocol that creates routes, it is important that a route is created in a short period of time because nodes will be moving in and out of range and a route may become invalid in a short time. We can expect that this could be a potential problem for such a network. If mobile nodes movements cause routes to become invalid frequently, the network will use a lot of power in trying to find a route and more routing packets will be required instead of data packets.

If a protocol is being used to generate routes back the base station, the way in which it selects a path is important. The protocol must be fast in selecting routes and have low overhead in doing so. This can reduce latency and power consummation.

The selected communication protocol must use power in the best possible way meaning that more data packets are sent instead of control packets that manage the network and provides routes. More data packets will make for a better solution and give more data to the base station providing better analyses of ECG data.

3.5 Routing Data

In Chapter two we looked in detail at the state of the art into ad-hoc networks, routing and standards for wireless communication. This section deals with the protocols that will be sending data to the base station. The following sections discuss why the standards and routing protocols have been selected for the design and implementation.

3.5.1 IEEE 802.15.4

IEEE 802.15.4 is a standard that defines a physical and media access control layer for low cost and low powered wireless personal area network. The standard provides a bandwidth rate of 250 kbit per second. Also it was designed to communicate to nearby devices with no infrastructure. More about this standard is in Chapter two.

3.5.2 ZigBee

ZigBee is a specification that allows creating personal area networks by using network protocols. ZigBee uses IEEE 802.15.4 as its lower layers to provide a low cost and low power wireless communication. Currently ZigBee is used in many areas of ubiquitous computing such as home automation and wireless sensor networks. ZigBee provides a self-healing mesh network that is suited for applications that need to be fault tolerant. In Chapter two there is a more detailed description about this specification.

3.5.3 Ad-hoc On-Demand Distance Vector Routing

Built into ZigBee is a networking protocol called Ad-hoc On-Demand Distance Vector Routing (AODV). This protocol is how ZigBee provides the self-healing mesh network. The protocol works by finding a route when a node needs to send data to another node. This feature is very useful when nodes are moving around and new routes are needed. Also, it provides fault tolerance within the network. If for some reason a node has gone down, the protocol can create a new route to the destination. Also, this protocol is distance vector based meaning that it will pick the shortest route back to the base station reducing the number of hops.

Figure 3.5 shows the protocol in our design would be used to create routes from our player nodes back to the base station. It will allow a mesh network allowing other nodes to work together to relay data back to the base station and allow the player nodes to move around within the confined area of the pitch.

```
Node Sending Data To A Destination
Lookup Routing Table For Route
IF NoRouteFound THEN
        Broadcast Route Request With Destination Address
        Listen for Route Reply

        FOR each Route Reply
                IF CurrentRouteNumHops > NewRouteNumHops THEN
                        Add New Route To Routing Table
        ENDFOR
ELSE
        Send Data To Known Route

Other AODV Nodes
Listen for Route Requests
Record node that sent Route Request
IF known route to destination THEN
        Send Route Reply To Route Request Sender
ELSE
        Forward Route Request
```

Figure 3.5: AODV Protocol

3.5.4 Gossip Protocol

Gossip is a different type of protocol in that it does not create routes between two nodes. Instead it is less complex as it only communicates with nodes that are within range of each other. When a node comes into range of another node they will begin to send data to each other. This is done by every node within the network thus causing the propagation of data through the network. Gossip works on probability that if a single node gets a piece of data then potentially it could spread to all nodes within the network at some point in time. There is no guarantee that data will be sent through the network but in the case of our design players move within a confined area and will come into contact at some point in time. We will improve Gossip by making it more energy efficient with the pseudo code shown below.

Gossip Node

```
WHILE true DO
    Listen For Broadcasts (Time Period)
    Broadcast Node Id's and Sequence Numbers
    IF Broadcast Received THEN
        FOREACH Received Sequence Numbers
            IF Received Sequence Number < Stored Sequence Number THEN
                Broadcast Stored Node Id's, Sequence Numbers and All Data
                BREAK
            ELSE IF Received Sequence Numbers > Stored Sequence Numbers THEN
                Do Nothing
        ENDFOR
    ELSE
        Do Nothing
```

Figure 3.6: Gossip Protocol

The above form of Gossip will be used in our design to compare it against AODV. As shown above, this will improve energy efficiency by ensuring that a node has stale data before sending new data to the node. If the node already has fresh data the nodes will not exchange their data as they are already up to date. This gives Gossip better energy performance.

3.6 Approach Summary

The new approach that has been shown above will either use AODV or Gossip. We need to evaluate the design and compare AODV and Gossip to be able to choose the best for the new approach. This can be done by using simulation and prototyping.

Creating a simulation will provide a good insight to see if this approach would work with AODV or Gossip. We will need to select team sports on which to carry out simulations. With the simulation we can check scalability, latency measurements and investigate other team sports. The simulation will require realistic player movements to ensure correct evaluation of each protocol.

Creating a prototype will provide us with real life measurements and be able to see how a device can be attached to a person. The prototype would look into the basics of wearability to ensure that it is feasible. This means the prototype would not be water or shock proof, we will just be looking at whether we can make a wearable device that can transmit ECG data back to a base station. We can then take metrics of experiments and compare them with the simulation. This will give us insight into whether or not the simulation is providing realistic results compared with the prototype.

3.7 Summary

The main challenges in the design is the type of data being produced, timeliness of transmitting data to a base station and making the design wearable so to monitor players during their activities. ECG sensors produce high volumes of data due to their sampling rates. We can reduce the sampling rate to produce less data per device but it is still a substantial amount of data to transmit to a base station in real time. In order to achieve low latency times we must consider the amount of data to transmit through the network. If we want to transmit all ECG data from each node the network will be at full capacity and may be able handle such high volumes. We may need to have a trade-off between the sampling rates versus average latency times. The challenges of having a wearable design maybe a hard to overcome. This is mainly due to sports having harsh elements such as knocks, falls and weather conditions. To overcome these we will need to look further to developing designs which can withstand such treatment.

To create a good design it is important to know what type of different environments a device will be exposed to. This will enhance the design to try ensuring that it will work in different scenarios. Different team sports will have different patterns of movements which can impact on the design in different ways. As discussed in team sports environment section that the goal keepers may not be able to transmit data for periods of time as there may be no other device within range. This time period can be acceptable in the case of soccer as goal keepers are not as active as other players on the pitch thus reducing the chances of SADS occurring. Although, knowing this type of disadvantage could affect another type of application that is using this design.

We have outlined an overview of other approaches to the same problem. The outlined approaches do achieve the goals of transmitting ECG data back to a base station but theyre may exist a better design to improve energy usage to allow for longer duration of monitoring and reducing the size and weight of devices. The new approach tries to provide a better design to reduce power usage and reduce the overall dimensions devices.

The routing requirements for such devices will be challenging to overcome. A gossip based approach could be a better design than trying to create routes when all devices will be moving into different positions. There will be patterns of movements that we can take advantage of but in AODV it could produce a lot of traffic contention between nodes close to the base station as AODV only provides a single route. A single device many always be close to the base station and thus all the nodes traffic will pass through this device onto the base station. Gossip may reduce this as data will not follow a single route, it can be sent from many different paths which may reduce the amount of contention experienced near the base station.

Chapter 4

Implementation

4.1 Introduction

In this chapter we look at implementing the design from chapter three. We aim to develop simulations and a physical prototype to evaluate the proposed design. We will be creating simulations for AODV protocol and the proposed Gossip design. The simulations will allow us to compare and contrast these protocols in situations such as soccer matches.

4.2 Simulation

Implementing a simulation aims at trying to evaluate that the design can be used for different team sports. We aim to take large data sets of players movements from previous team sports and replay them within our simulation. The simulation will be implemented so that we can increase the number of players as well as change other variables such as size of pitch and movements of different sports. This will provide a good insight into the feasibility of the design and allow us to evaluate different routing protocols. In the following sections we show what has been created with the simulation.

4.2.1 Network Simulation Software

There are many different network simulators available on the Internet such as Network Simulator Two (NS2), Network Simulator Three (NS3) and Optimised Network Engineering Tools (OPNET). We looked into each of these simulators to see if they were a good fit for the simulation that we wanted to carry out. We wanted to use software that was open source and did not have cost attached, so OPNET was not selected as it requires the purchase of a license. This left NS2 and NS3 as both are open source. At the time of writing this paper NS3 did not have ZigBee support as the project was starting to port the code from NS2 to NS3. We would have liked to use NS3 but we selected NS2 as it already had the ground work of ZigBee which has been tried and tested in the research community. The NS2 project provides more support as it has been released and used for a long period of time.

NS2 allowed us to implement the design that was discussed in Chapter 3. We were able to have the IEEE 802.15.4 specification along with the routing protocol AODV. This provides an evaluation of the specification that ZigBee devices use and enables us to measure power usage for each node within the simulation. We can provide trace data of movements into the simulation to re-enact previous team sports.

4.2.2 Network Simulator Two

NS2 provides a scripting and a coding language. The coding is done with C++ which allows a person to define their own protocol or a new specification. This allows the creation of a Gossip based protocol within NS2. We defined our own version of Gossip for our design. The scripting language that was used is called Tool Command Language (TCL). This scripting allowed calling objects that were defined by C++. The mapping from TCL objects and C++ objects were one to one. TCL allowed easy changing of parameters within the simulation which otherwise would have to be done in C++. This makes the simulation easy to change either with adding new nodes or changing the wireless ranges of nodes.

NS2 allows modelling of wired and wireless simulations. We will be using only wireless as the design is a wireless network. Nodes in NS2 can be placed within a defined area which is called a scene. Nodes can move around within the scene once the coordinates necessary for movement are provided along with the speed of movement. This can be used to make real simulations of players movements for each of the team sports. As well as this, NS2 provides different models for wireless nodes such as power and radio propagation models which have been used in the simulation.

Input data for each different sport can be a trace file of movements that the simulation can interrupt. This will allow evaluation of each team sport. The output file will be a trace file of all the events that take place during the simulation this includes routing packets, data packets, power usage and other networking data such as addressing.

4.2.3 Implemented Protocols

The simulation was implemented for the design that was described in Chapter 3. The simulation is created to compare AODV and Gossip protocol which allow us to evaluate each in question to select the best protocol for the design.

The implemented scripts have been designed to have a high degree of parameterisation for many aspects of the environment of the players. Parameters such as radio range of a device, speed of nodes during the match and how much energy the node uses while transmitting, receiving or idle state. This allows us to have full control of the environment in which the nodes are exposed to while running each different protocol in such environments.

4.2.4 Simulation Parameters

Within the simulation we can control many different types of parameters. We can set each one and perform a controlled evaluation of each different sport with each protocol which will show which protocol performs better in certain situations. In the following paragraphs we will discuss each parameter that can be changed.

We can set parameters that control the number of nodes and their speed and direction within a pitch. We can also change the size of the pitch that nodes will be in. This provides a means to be able to evaluate patterns of movement that each sport has. We can see if problems exist with the design for different sports such as Soccer. The goal keepers within Soccer may have periods of time where they cannot transmit data back to the base station due to other players being out of range.

There are parameters that can be set for the range of each node on the pitch. This allows evaluating things such as propagation models for radio communication and degrading of radio signals due to distance. The simulation can have radio propagation models to match with the real players environment. We can evaluate a design if it is being used indoor or outdoor by selecting different radio models. An example would be if players are playing outdoors the simulation would use line of sight radio model to accurately represent the environment. Below there is a section called Radio Propagation Models that goes into more detail as to why we have implemented this in the simulation.

We have parameters that are able to track the power usage of each device. We can set the power capacity; transmit power, receiving power and idle power of each device. This will provide evaluation on power usage for each device and see how long each device will last throughout the game. During the evaluation we might see devices close to the base station use more power than those nodes that are far away from the base station.

We can generate different types of traffic and the amount of packets that will be sent through the network. We can change the types of connections such as Transmission Control Protocol (TCP) and User Datagram Protocol (UDP) to each of the nodes. Also we can change the data volumes and packet size that are sent by the nodes to be able to match the same volume of ECG data. This will be very important in our evaluation to see if the design can send the volume of data that is needed to the base station. The simulation measures data volume by duty cycle for a set period of time. An example of this would be for 60 seconds at 50 percent duty cycle the first 30 seconds of the 60 seconds of data will be sent to the base station.

4.2.5 AODV Simulation

The simulation has been implemented to be able to measure metrics such as latency from a node to the base station and find the speed at which a route is created. Along with these metrics we want to able to find how much power is used for each node when AODV is used and how high the duty cycle can be versus the latency time.

We can change parameters such as range of nodes to see if latency decreases due to less hops being taken back to the base station. Also the simulation will give the best communication range for each of the team sports. We may see goal keepers in Soccer need a wider range than other players on the pitch. In a different sport such as Rugby we may evaluate that decreased range will reduce energy usage with an acceptable increase of latency. We can control the amount of data that is being sent to the base station to see where congestion occurs with high volumes of data.

4.2.6 Gossip Simulation

The simulation has been implemented to evaluate Gossip protocol and to out find if data can be transmitted back in a timely manner. Gossip is a different style of communication in that it sends data to any one that is in range. The simulation will allow us to see if this style works for each of the nodes and also measure metrics to compare it against AODV. Due to Gossip being a different style different metrics will be looked at such as the frequencies of updates to the base station rather than latency being more important.

We can foresee that Gossip will increase latency times compared to AODV but the important insight is that data is able to be passed throughout the network. If this is the case the expected outcome could be that energy usage could be less compared with AODV because Gossip does not create routes to the base station. The Gossip simulation will also allow us to see if congestion occurs at some point within the network.

4.2.7 Radio Propagation Models

Within the simulation we needed to select a radio propagation model that we can control each nodes range. Within NS2 there are two main propagation models which are Free Space and Two Ray Ground [19]. The latter provides a more realistic model.

Free Space takes the ideal propagation conditions within line of sight between two wireless nodes. This model does not allow for any signal that is reflected off the environment such as the ground. This is not fully realistic with the environment of team sports.

The Two Ray Ground model has common features such as line of sight between two wireless nodes but it also models the ground reflection between two nodes. For all the simulations this model was selected as it better represented the type of environment of team sports.

4.2.8 Traffic Generator

NS2 has different traffic generator one of which is the constant bit rate [19]. This gives us better control of how much data is sent to the base station. In the simulation constant bit rate was used as duty cycle was a parameter in percentage. For example it sends a certain percentage of data for a set time period. By doing this we are setting how much data is sent through the network, constant bit rate provides the simulation with a set amount of data that is sent at a point in time.

4.2.9 Trace File Analysis

The simulation outputs trace a file that needs to be analysed to know the outcome of the experiment. In order to do this we have developed a tool that goes through each line within the trace file and returns metrics such as latency per node and average latency. We can create scripts for each trace file that we wish to analyse. This will give better evaluation of the results as key metrics for AODV and Gossip will be different. An example of this AODV will have little dropped packets compared to Gossip having many dropped packets due to the way the simulation has been developed. Within NS2 nodes using Gossip protocol are scripted to send data to any device within the simulation, this causes dropped packets within trace file as some nodes may not be in range of the transmitting range. This is expected as nodes will not always be in range of each other. This tool will be used to evaluate both AODV and Gossip protocols.

4.3 Prototype

The prototype was created to evaluate that such a network design can be created. We look at each aspect of the device and outline how a device can monitor a persons biometric readings. In the following sections will look at the developed prototype.

4.3.1 ECG Device

Figure 4.1 shows the ECG board that we used in our prototype. We used leads that connect to both wrists and an ankle for grounding. This device gave us some insight into ECG reading. The device did not produce very accurate readings in our tests, either because we did not tune the amplifier correctly or the device may have been faulty. We did not use any data that was produced from this device rather we generated some sample data that had the sample volume of true ECG data.

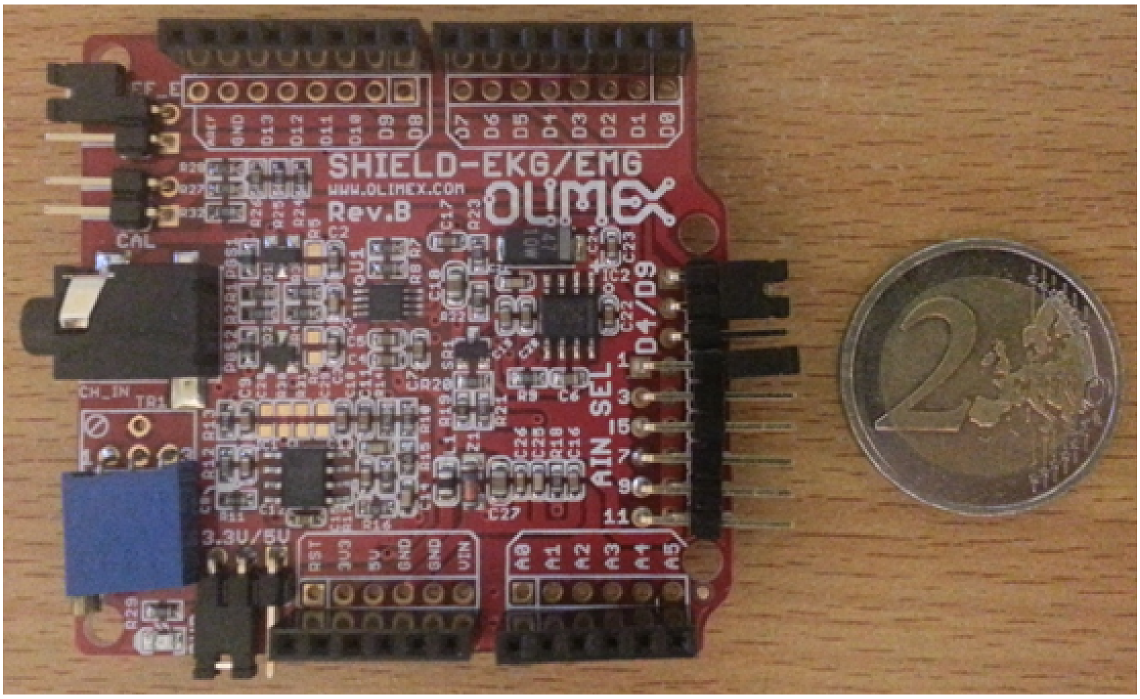

Figure 4.1: ECG Board

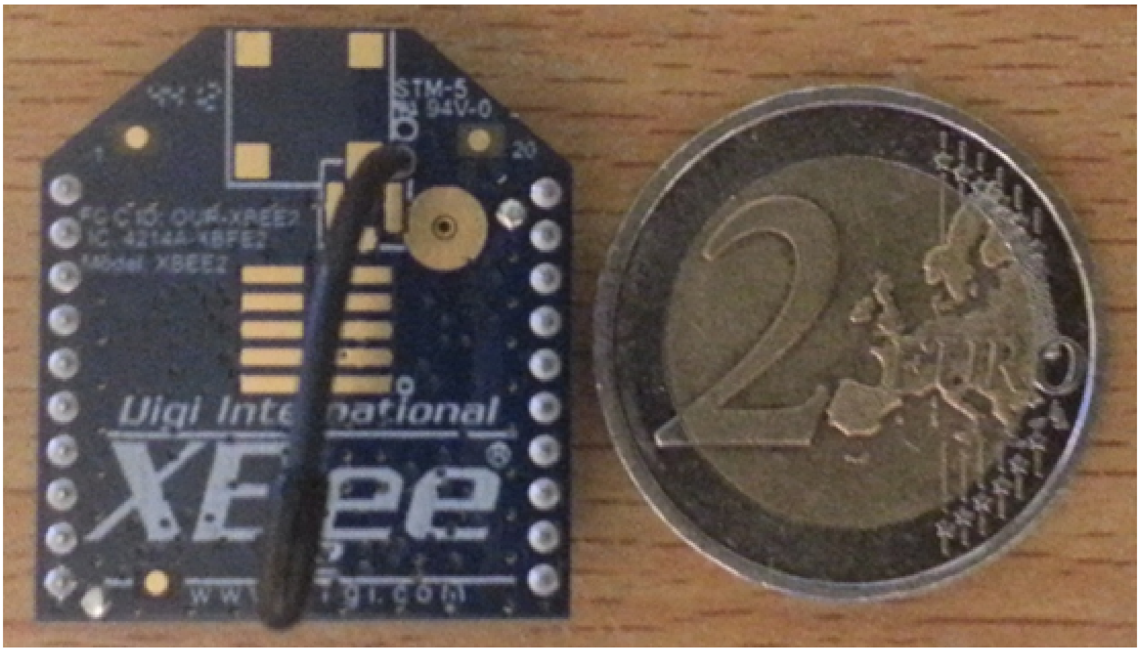

Figure 4.2: ZigBee Device

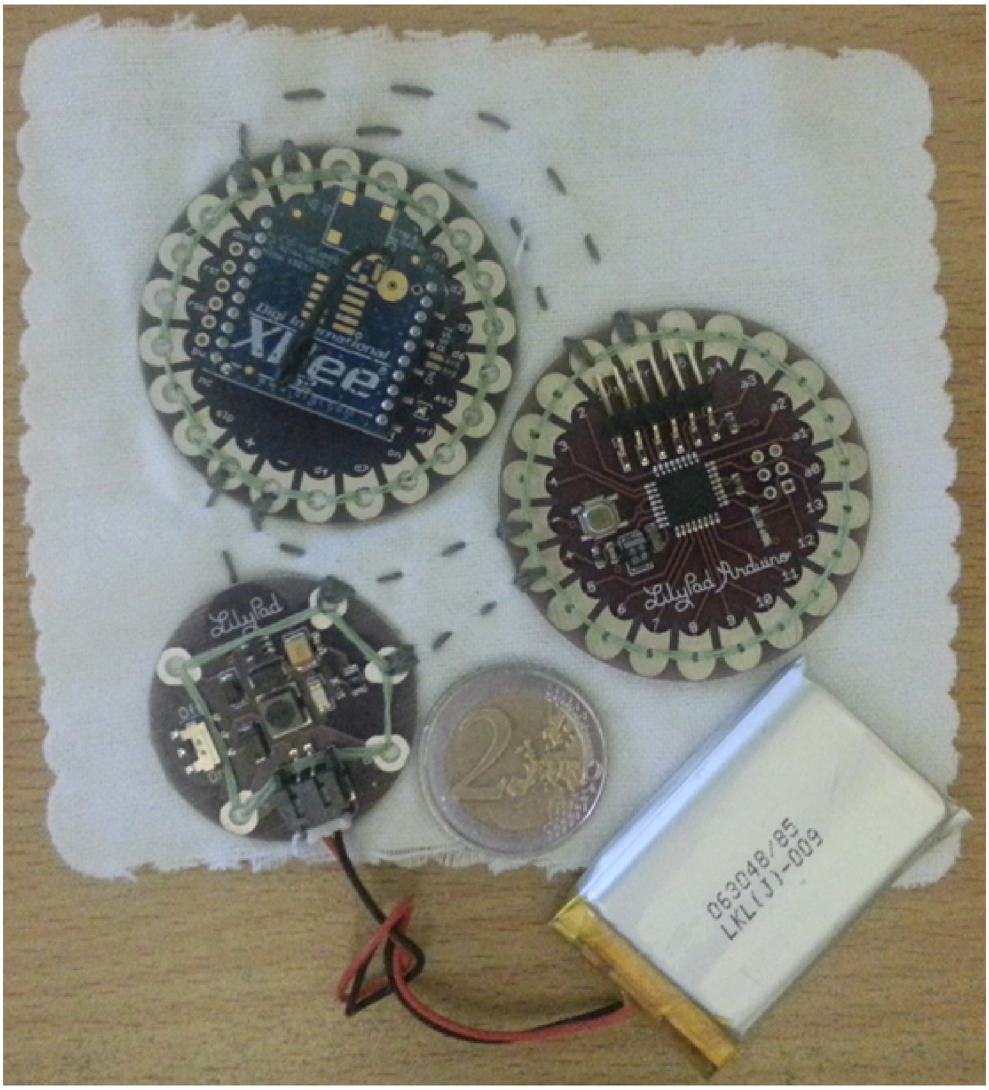

Figure 4.3: The Prototype

4.3.2 On-board Wireless Communication

Figure 4.2 shows a ZigBee device that we used in our prototype. The above version is a series two device which allows mesh networking with other ZigBee devices that are also series two. As you can see these devices are very small, lightweight and are low power devices. For our prototype we chose to have an antenna but there are other versions that have a trace antenna meaning that it is embedded into the chip. If selecting the device again we would go with the trace antenna as it is more slim lined and not as easily caught on clothing.

4.3.3 Wearable Computing

Figure 4.3 shows a prototype that can be attached to a player. We can see that an Arduino LilyPad was used. This allowed the prototype to store ECG readings in memory which is then sent onto the ZigBee device to be transmitted. The lower left chip is the power supply that feeds power to both the ZigBee and LilyPad. The devices get power via conductive thread that has been sown onto the fabric. The heaviest part of the device is the 850mAh battery. Overall the weight of the device is just less than 35 grams.

4.3.4 Prototype Outcome

This prototype was put onto a piece of fabric but when placing on players it would have been sown onto the players clothing. This prototype was to look into a wearable device to see if it was feasible to create and is lightweight enough to be worn. It is feasible but does have issues such as no protecting cover and would be very easy to break during team sports. Another issue is water getting near the device while being powered on. This prototype is suitable for testing the physical design and also allows us to test the new approach which will provide us with realistic metrics of the devices that can be later used in the simulation.

4.4 Realistic Data

When implementing both the simulation and prototype we need realistic data to perform an evaluation. The data needed are players movements and ECG data volumes. In the next sections we discuss this data and how we gathered such data.

4.4.1 Players Movement

Players trace data of movements was hard to locate. We contacted many sports associations trying to find data of previous players movements. We looked for mainly Soccer and Rugby but we received no feedback from the associations.

We needed more than just one trace file for a single match; we needed large data sets for each sport to be able to correctly evaluate the design. Having large data sets will show players patterns of movements through many different games. We needed to evaluate if players patterns would improve overall average latency when evaluating the design.

4.4.2 Gathering Test Data

We created ECG test data by looking into other devices on the market that outlined their specifications of sampling rate along with the number of bits used for each sample. We then calculated the number of bits for each lead attached to the device. This calculation has been discussed in Chapter 3. It shows the volume of data generated for a 3 lead ECG monitoring per second.

As there was no contact back from the sports associations we needed to gather data about team sports. We found a project called RoboCup online which looks at artificial intelligence and robotics. They have two dimensional (2D) and three dimensional (3D) games; 2D is using artificial intelligence to have two teams play Soccer against each other to see which team has better intelligence then the other. In 3D games bring this further by having a small number of robots playing Soccer along with artificial intelligence.

We looked at 2D games that can be viewed on YouTube. The videos are animations of players playing Soccer and visually had the same patterns as real Soccer matches. The duration of these games were on average 10 minutes long and they had many of these games uploaded onto YouTube. We looked at getting the players positions for the 10 minutes and to rewind back the 10 minutes to give us 20 minutes of players movements. This then could be repeated many times to get the time needed for the full duration of a game.

We downloaded the videos from YouTube and developed an OpenCV program that takes each frame within the video and takes all the players positions. The program did this simply by subtracting the background from each frame and only leaving the players left within the picture. Then it records each players position relative to the corners of the pitch. This worked for most of the videos and we recorded trace data for the simulation. There were issues such as players overlapping with one another but this only made the players swap teams. This was not an important detail because we were interested in the patterns of movements without needing to know which node was a certain team.

4.5 Summary

Within this chapter we have outlined that the simulator has been used to create the simulations. The simulator has been used for many different research papers and is a good choice due to wide support on the Internet. We have implemented both protocols AODV and the gossip based protocol discussed in chapter three. Within the simulation scripts we can change many different parameters to reflect the environments that the nodes will encounter. We can also control the amount of traffic that the nodes will produce within the network, this will beneficial when evaluating the protocols. We aim to create realistic movements of players within team sports this can be achieved within the simulation by having trace files of players' movements.

The creation of the prototype showed us that embedded chips are suitable to create such a device. With the prototype we can carry out real evaluations to determine if the simulation is giving realistic results. If the simulation is not providing good results we can adjust the scripts in order to match with real world measurements within the same types of environments. The prototype is not suitable to sew onto clothing as it is fragile but it can be placed into a waist bag to protect it during experiments.

We have developed a way to get trace movements of players as there is a lack of data present in this area. We looked at a project that simulates players playing on a pitch and we were able to extract positions of movements from their videos. This was the only way to get a good amount of data to be able to carry out an in depth evaluation of the design within the soccer environment.

Chapter 5

Evaluation

5.1 Introduction

Within this chapter we will compare AODV and the proposed gossip protocol within the design chapter. The aims of the evaluation are to find which protocol is best suited within the environment of team sports and to see if revisiting the design is required. As gossip based protocols need to be tuned and refined for different scenarios, we can presume that some enhancements can be made to improve aspects of the protocol.

We will be evaluating metrics that can be compared to each protocol. Such metrics are average latency, power usage and frequency of updates to the base station. Within the simulation scripts we can set many different parameters that can change aspects of nodes such as their communication ranges and the volume of data that will be produced for each node. We will carry out experiments for each scenario and show results.

5.2 Simulation

With our created simulations we will be carrying out experiments that will evaluate the design. Each experiment will have a set of parameters which will be highlighted after which a graph of results will be shown. Within the simulation there is a period of settling time required. The graphed results will show the metrics after this period of settling time. Also each experiment has been run with eight different soccer matches movement trace files which will provide realistic movements of nodes.

5.2.1 Experiment One: Duty Cycle vs. Average Latency

This experiment is to evaluate what occurs when increasing the duty cycle, which is the amount of data, collected for each node and is sent to the base station during a time interval of one minute. We carried out three simulations; each simulation had a range set for all nodes and for each game we increased the duty cycle and reran the simulation. Below are the communication ranges we simulated along with their duty cycles.

Table 5.1: Parameters of Experiment One

Parameter Type	Values
Node Communication Range in Metres	25, 40, 100
Node Energy in Joules	50, 50, 50
Duty Cycle in Percentage	10, 20, 30, 40, 50, 60, 70, 80, 90, 100

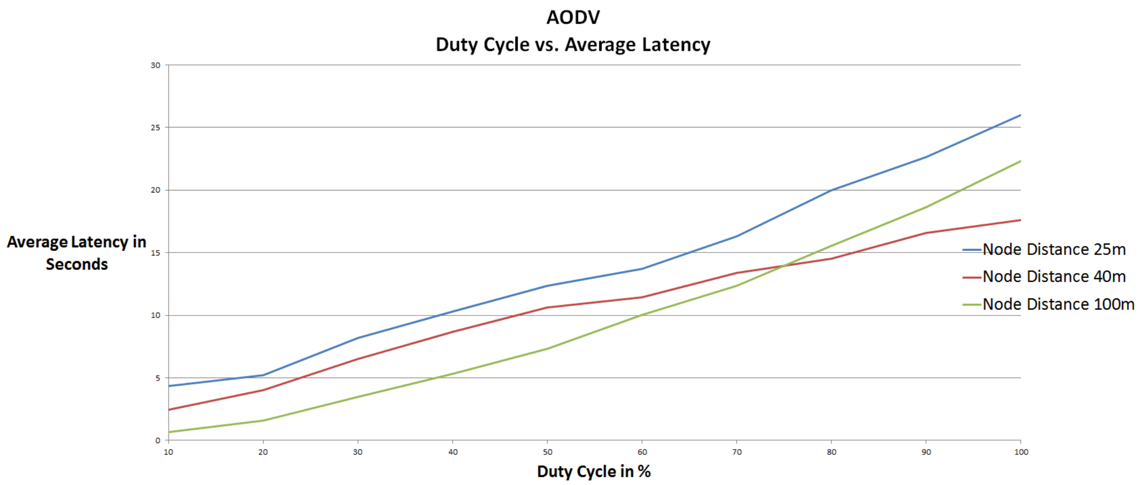

Figure 5.1: Experiment One Results

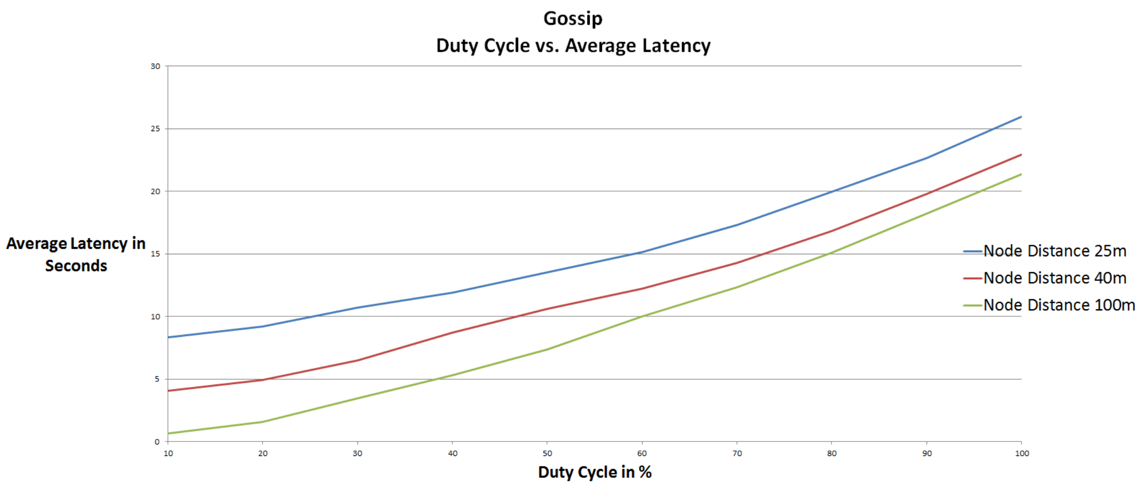

Figure 5.2: Experiment One Results

As we can see in the result an increase in duty cycle causes increase in average latency. When increasing the range of communication we can see reduced latency times as the nodes are able to directly communicate to the base station. When the communication range is low the data packets need to hop from node to node which increases the latency times. In AODV however we can see there is an overlap of node communication distance of 40m and 100m. We believe this is due to contention between all the nodes trying to communicate directly to the base station. With gossip this does not happen, this could be due to other nodes receiving the data and transmitting in an interleaving manner. This interleaving is caused by the offset of times that gossip nodes are transmitting their data.

5.2.2 Experiment Two: Communication Range vs. Average Latency

In this experiment we increase communication range to see the impact of average latency. We also run three different simulations, each simulation will have a different duty cycle to increase the volume of data produced at each node and increase the communication distance for each duty cycle. Below are the communication ranges we simulated along with their duty cycles.

Table 5.2: Parameters of Experiment Two

Parameter Type	Values
Node Communication Range in Metres	25, 30, 35, 40, 50, 60, 70, 80, 90, 100
Node Energy in Joules	50, 50, 50
Duty Cycle in Percentage	10, 50, 100

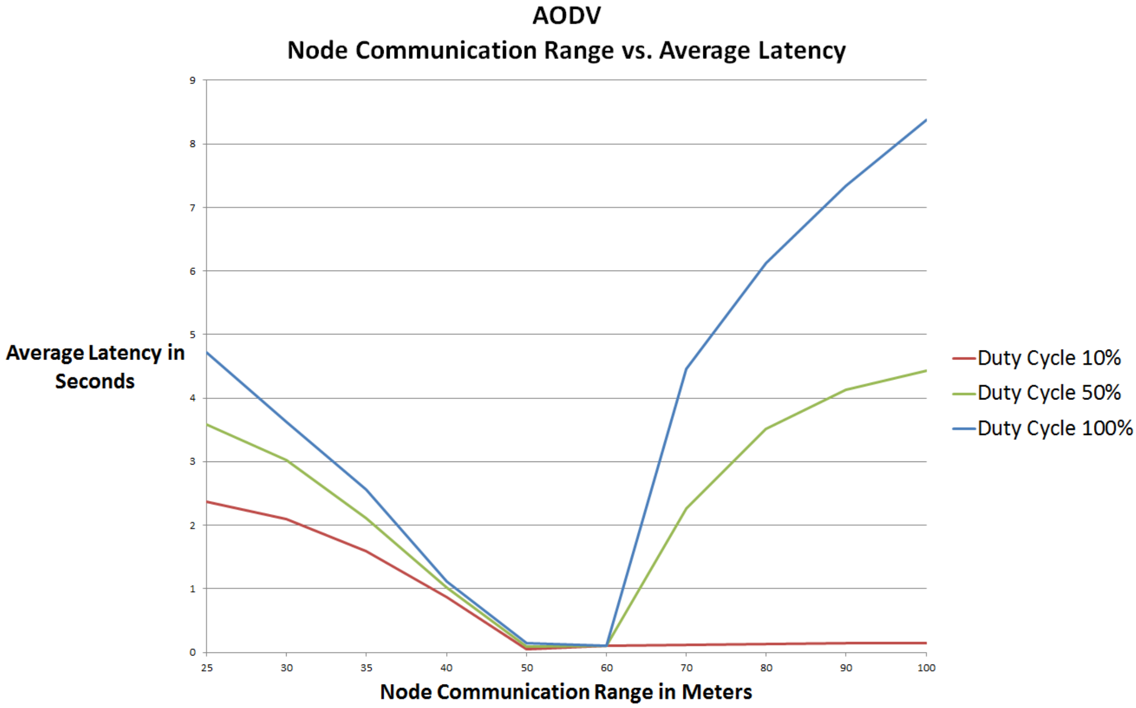

Figure 5.3: Experiment Two Results

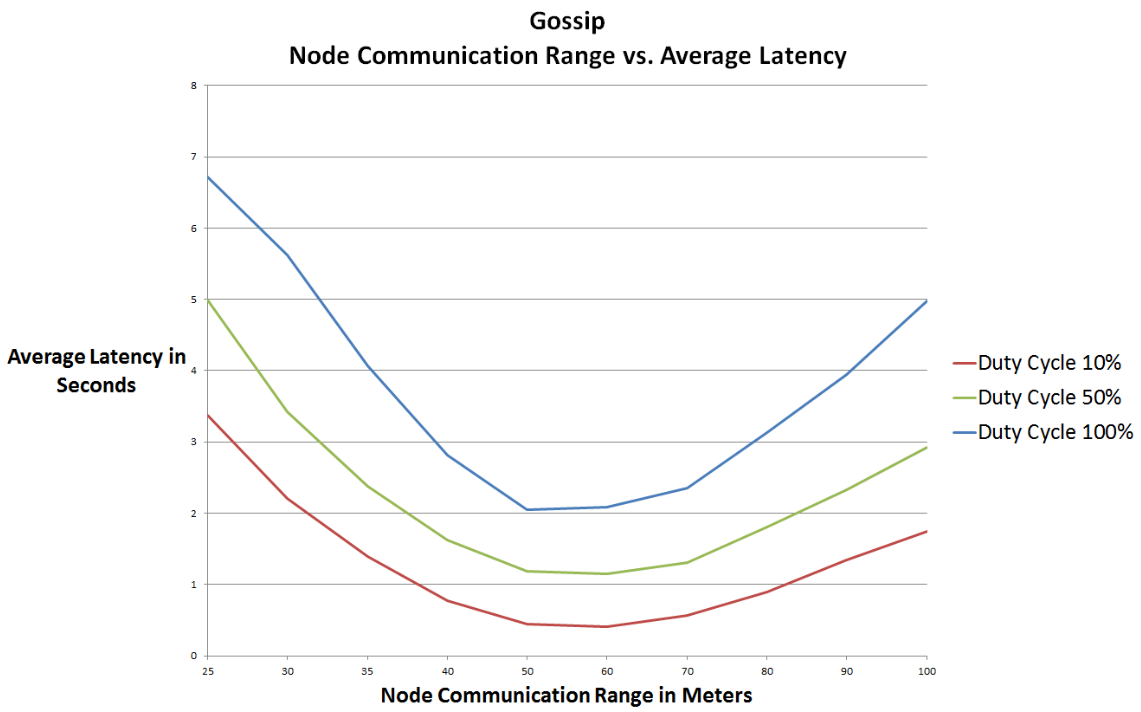

Figure 5.4: Experiment Two Results

We can see in the results when the communication range per node increases the average latency time decreases. We also can see a dip in latency from 40m to 60m. These values produce the lowest latency time for AODV but overall gossip remains to have higher latency times. Within both results we can see an increase after 70m and onward when duty cycles are high. In AODV we can see a major increase of average latency time from 70m to 100m; this is due to contention that is being experienced with high volumes of data. We have seen the contention effect in our first experiment and again in these results. Gossip deals better with this contention as there are multiple routes to the base station. With AODV only one route is selected. Also the interleaving manner of gossip is providing better results when contention is present.

5.2.3 Experiment Three: Communication Range vs. Power Consumption

Within this experiment we looked at communication range and find the average power consumption of nodes. We ran three different simulations for each protocol. We selected three communication ranges and increased duty cycle for each simulation. Below are the values of parameters the simulations used.

Table 5.3: Parameters of Experiment Three

Parameter Type	Values
Node Communication Range in Metres	25, 40, 100
Node Energy in Joules	50, 50, 50
Duty Cycle in Percentage	10, 20, 30, 40, 50, 60, 70, 80, 90, 100

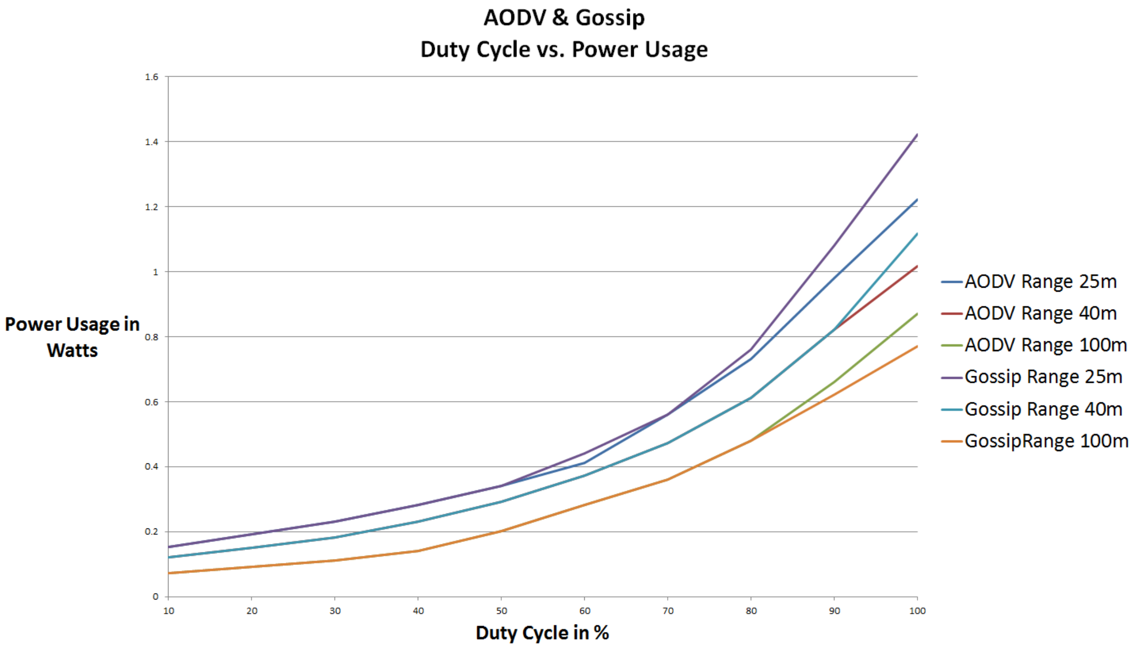

Figure 5.5: Experiment Three Results

As we can see in the results higher duty cycle causes increased power usage. It is clear that when communication range is larger less power is used as the data does not need to reply from node to node. Overall it is better to directly communicate to the base station rather than using many different hops. The reason for this would be that power is used to receive and retransmit data at each relay node. This produces an overall increase in power consumption. Look at the power usage for 40m; we can see that AODV uses more power compared to gossip. This is contributed by AODV needing to generate routes as nodes move around within their environment. When the communication range is smaller we can see that gossip uses more power than AODV, this is due to AODV finding a single path to the base station while gossip is potentially using many different paths.

5.2.4 Experiment Four: Communication Range vs. Power Usage

Within this experiment we looked at communication range and see its effects on power usage with different types of duty cycles. We ran three different simulations; each simulation had different duty cycles and node communication ranges. Below are the parameters that were used in the simulations.

Table 5.4: Parameters of Experiment Four

Parameter Type	Values
Node Communication Range in Metres	25, 30, 35, 40, 50, 60, 70, 80, 90, 100
Node Energy in Joules	50, 50, 50
Duty Cycle in Percentage	10, 50, 100

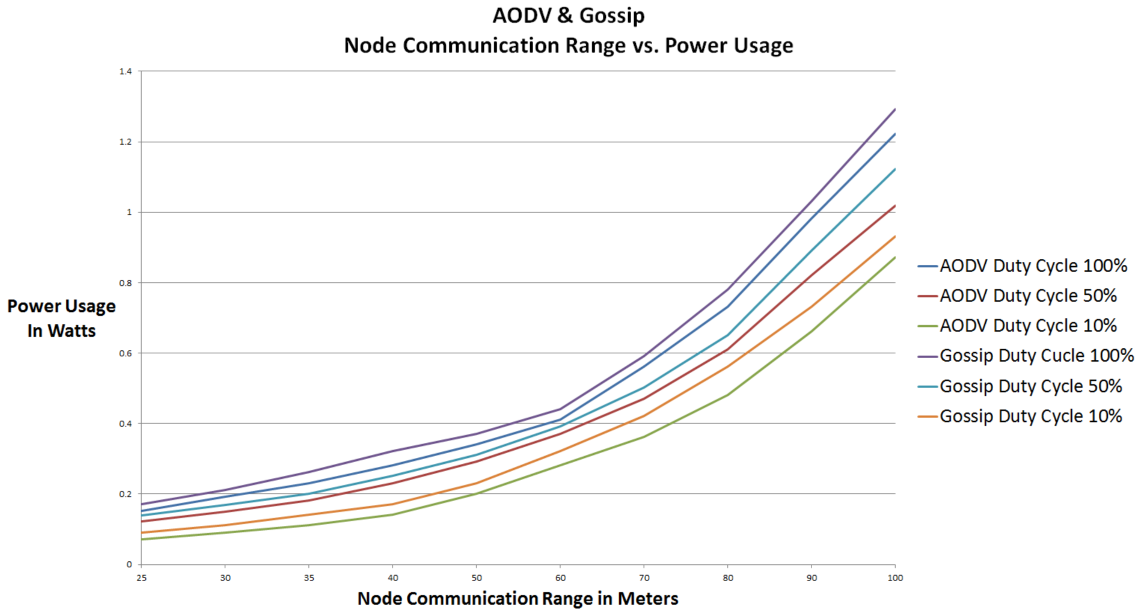

Figure 5.6: Experiment Four Results

We can see in the results that when increasing node communication ranges that more power is used to transmit the data. With less duty cycle less power is used on average between all the nodes. We can see that at 10 percentage duty cycle AODV uses less power than gossip. This is due to a single route being selected to route the data back to the base station. When increasing the duty cycle AODV remains to use less power than gossip as fewer nodes will needed in transmitting data. In the previous experiment we saw that an increase in communication range lowered the overall power consumption again in this experiment we can see increasing the communication range reduces the amount of power used.

5.2.5 Experiment Five: Frequency of Updates

Within this experiment we looked at only a single match to provide the frequency of updates that the base station will reduce within a ten minute period. Duty cycle is a percentage of data taken within one minute. An example of this would be that 10 per cent would be the first 10 seconds of the one minute. As this experiment is measuring the number of updates within 10 minutes the maximum amount of updates can only be 10. Below are the parameters that were used in the simulation.

Table 5.5: Parameters of Experiment Four

Parameter Type	Values
Node Communication Range in Metres	40
Node Energy in Joules	50
Duty Cycle in Percentage	10

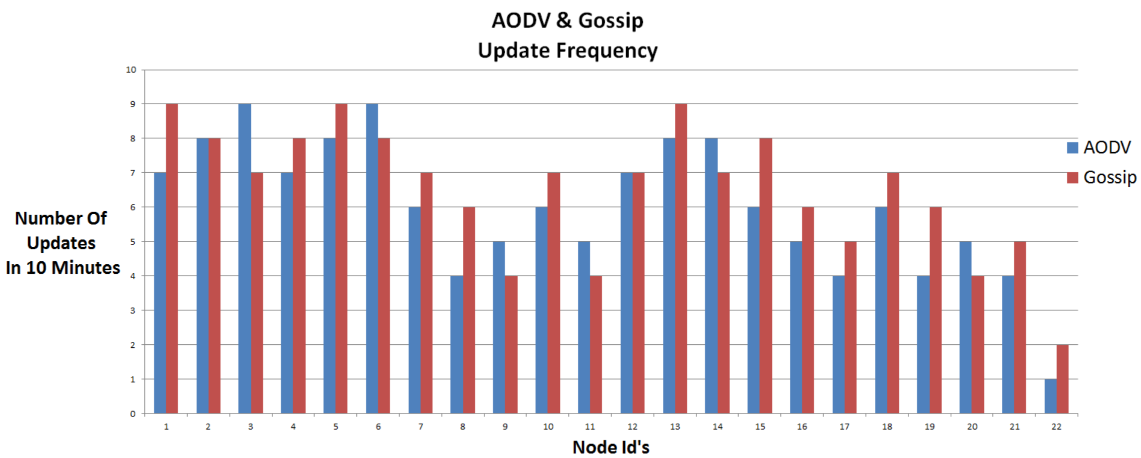

Figure 5.7: Experiment Five Results

As we can see in the results each node was given an identification number. Each of the nodes in the results are only the players, node zero has been taken out as it is the base station. From nodes one to eleven is one team and nodes from twelve to 22 and another team. During visual inspection of the simulation most of the time the teams remained to one side of the pitch as gameplay was one sided. This resulted in node 22, which was a goal keeper, was unable to send updates to the base station. This was expected in the design and to overcome this, the goal keepers communication range needs to increase or detect gameplay moved to the other side of the pitch. Node 11 was able to maintain its updates as there were many other nodes close by to allow relay of the data to the base station.

5.3 Prototype

Evaluations were carried out on the prototype of functionality of the device and not the durability. The first evaluation was that the device could be sewn onto clothing and be able to transmit data between other nodes while being worn on a person. The prototype was light weight enough to be able to not interrupt a person while they were doing physical activities.

We conducted some evaluations of metrics with the prototype. The prototype was running the AODV protocol which could provide us with some metrics. We looked at metrics such as moving the devices in and out of range to find the time it took to connect to another device. Two experiments were carried out. The first experiment is a node connecting to the base station and the second is a node connecting to another node.

5.3.1 Experiment One: Node to Base Station

With this experiment we powered on the base station with an application printing times and displaying no nodes connected, the base station was waiting for a node to connect. We then powered on a single node to connect to the base station. We carried out the experiment 10 times to find the average time it took to establish a connection. The average time was 1.2 seconds to connect to the base station.

5.3.2 Experiment Two: Node Relaying to Base Station

With this experiment we power on the base station again with an application printing times and displaying no nodes connected, the base station was waiting for a node to connect. This time we wanted a node to relay data from another node. We wanted to measure the time to connect to a relay node and send data to the base station. We powered on a node which was just in range of the base station. The base station then showed a single node connected. We then moved away from the base station to ensure that the second node will not be within range. We then powered on the second node and slowly began to move to the first node. When in range of the first node a connection was established and data was sent to the base station. Again this was repeated 10 times to get an average connection time and average latency time of transmitting data.

The results were that it took on average 1.5 seconds to create a connection to the base station through the relay. This was an increased time from the first experiment which was due to connecting to a node and finding a route to the base station. Once the connection was established the data was sent less the point one of a second. The data volume was 200 kilobits in size.

5.4 Summary

We evaluated the design with the use of simulations and a physical prototype. We compared the results of the two protocols to see what outcomes they had within a soccer environment. We saw that gossip protocol uses more power than AODV but AODV has issues with contention when the communication range is increased. Gossip reduces the amount of contention by allowing many different paths to the base station while AODV only provides a single route to the base station. We showed that high duty cycle will increase power usage and cause average latency to increase when using AODV. While latency is increased overall when using gossip it is more predictable when duty cycle is increased. We see that if AODV is used there will be contention issues and as a result fewer updates will occur at the base station. While using gossip we can ensure more updates occur at the base station with a trade-off of power usage.

Chapter 6

Conclusion

Current research enables small devices to be attached to people in order to carry out biometric monitoring. Low power, light weight communication devices allow a device to wirelessly transmit data to other destinations within the network. This enables offloading of analysing data to a node that has larger resources. Some papers have showed that relaying can result in a more energy efficient device. This will allow the devices to last a longer duration and less battery power is needed, therefore the devices can become more light weight. However this dissertation sheds light on the fact that more energy is used when multi-hopping and direct communication will reduce the amount of power used. This can be seen in the experiments section of the evaluation chapter.

We viewed other approaches that already existed which use a lot of infrastructure such as relay nodes. Other approaches also used direct communication which makes devices use more power and causes the devices to have more weight. We created a new approach where we would use fewer infrastructures and allow other nodes to act as relays. The approach would provide better use of power and make for a lighter wearable device. We looked at two different styles of protocols that would give better performance within the environment of team sports. We believe our design can be more finely tuned to enable better performance than other approaches used to date.

In order to test the design we created simulations and a prototype that would allow us to carry out evaluations. The simulation allows us to create realistic movement of players on the pitch. The benefit of the simulation was that we could evaluate different protocols in order to find the optimal solution for different team sports. The prototype showed that devices can be wearable and sewn onto clothing but more work needs to be done in order to protect the device during physical activities.

During our research the sport we focused on was soccer. The two protocols we evaluated were AODV and gossip. We found that gossip was able to handle contention while AODV suffered from it. Overall latency was increased when gossip was being used, AODV gives lower latency times once there was low amount of traffic within the network. We saw that relaying or multi-hop routing did not provide any energy benefits as more energy was used compared to direct communication. More power was used when other nodes were relaying other nodes information back to the base station. We suspected that contention could have arisen at the base station but the levels that we observed were far greater than expected. This is because the volume of data generated by devices was so large in size. We saw that gossip was able to handle contention better than AODV but more power was used as it relies on relaying data. To achieve an optimal design more work needs to be done in refining the gossip protocol.

Overall the work carried out on this project was beneficial as a new approach was created and evaluated. We believe that gossip can provide the necessary requirements within team sports to create a low cost, energy efficient, wearable device that can accurately measure biometric data and aid in the prevention of SADS.

6.1 Future Work

We need to carry out more work to refine gossip protocol for each of the team sports. The operations of the protocol can be reviewed and improved to achieve lower power usage. Further research into AODV needs to be carried out to establish which team sports this protocol will be most suited to. Also we would like to combine gossip and AODV protocols to create a form of hybrid protocol that could possibly be used for many different sports.

Our ultimate goal is to create the wearable devices and carry out field studies in which the devices would be placed on players during training and/or matches. This will gather more realistic network metrics. We can then feed this information back into the simulator to provide more accurate simulations. Upon refining these simulations we will have a better understanding of the requirements needed to create these wearable devices. Hopefully the creation of these devices will be widely adopted by associations to improve training, fitness and prevent SADS in team sports.

Appendix A

Abbreviations

Short Term	**Expanded Term**
SADS	Sudden Arrhythmic Death Syndrome
ECG	Electrocardiography
AODV	Ad-hoc On-Demand Distance Vector
IEEE	Institute of Electrical and Electronics Engineers
DSR	Dynamic Source Routing
DSDV	Destination Sequenced Distance-Vector
SD	Secure Digital
NS2	Network Simulator Two
NS3	Network Simulator Three
OPNET	Optimised Network Engineering Tools
TCL	Tool Command Language
TCP	Transmission Control Protocol
UDP	User Datagram Protocol
2D	Two Dimensional
3D	Three Dimensional

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