Department of Computer Science  
MSc Project Proposal

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**Second Reader (Representing the HoD):**

**Field of Research:** Wireless Sensor Networks

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Date:

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**Signatures**

We confirm that the above candidate presented a seminar on [ ] in the Department on the subject of this research proposal and we recommend that the proposal be approved

**Supervisor(s):**

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Smart Networking using RFID tag-based Sensor Networks

Project Description

Wireless sensor networks (WSNs) are envisioned to consist of many small devices (nodes) that can sense the environment and communicate data to a base station which is generally attached to a gateway node. The gateway node either further processes the data (to produce meaningful results) or forwards the data to an external network.

This family of wireless networks are currently deployed in:

1. Military applications to achieve Battlefield surveillance, Enemy tracking, etc.
2. Civil applications to support Habitat monitoring, Environment observation and forecast systems, Health and differing commercial applications such as Medical monitoring, home security, Machine failure diagnosis, Chemical/biological detection and Animal or plant monitoring.

Their vast and differing range of applications has revealed that designs of WSNs are fairly application dependent. However there are intrinsic characteristics that are sustained throughout the various applications that need to be addressed. Some of the more significant characteristics are:

1. Fault Tolerance: In this case nodes may run out of energy, get damaged, or communication between two nodes may be interrupted. These events occur frequently in sensor networks and it becomes important that the network can tolerate such faults, [(1 p. 8)].
2. Lifetime: In many scenarios, nodes will have to rely on a limited supply of energy (using batteries). Replacing these batteries in the field is normally impractical, and a WSN must operate for a given mission time, or as long as possible. Hence, lifetime (or energy expenditure) becomes an important factor to consider in WSNs design, [(1 p. 8)].

The RFID technology uses radio waves to identify people and assets in real-time to get information on their location and status. RFID has developed from a next generation of bar codes technology removing the need for active scanning into a well established technology with standardized protocols and mature commercial applications.

A typical hybrid sensor/RFID networking scenario consists of proactive Habitat monitoring system where a system of RFID tags stuck on objects in a given environment is used as the first mile to a WSN that collects the information on the status of these objects in real-time. This may be applied for example in “Elderly Healthcare” to control the amount of medicine the elderly require and assist them in taking the accurate amount of medicine. These sensors and readers are networked to collect data which are used to show and control in, real time, the activity of the objects located in some specific regions of the controlled environment using the Internet. A similar scenario may be deployed in disaster situations where fire-fighters may be using a RFID tag-based sensor network of cameras and other sensors to make the commander aware of the conditions in the field and help direct the operations to maximize the use of forces while preserving the life of his responders using the Internet.

Wireless systems in general have, for a while now, been shifting towards a more software-based and flexible hardware architecture (software defined radio (SDR)), which is giving them a wider range of
capabilities in the form of awareness and more intelligent operation. A cell phone is a simple example which indicates the progress made from a fixed radio to an adaptive aware one. Cognitive systems are considered as the next evolution of such devices. Cognitive radio technology uses real-time knowledge of its environment to adapt its behaviour dynamically with the intent to enhance its operation. The kind of information gathered from the environment includes (but not limited to), [2]:

1. Information about the physical environment (e.g. interference)
2. Radio Frequency channel
3. Radio resources
4. User/application requirements

In general, a cognitive system can be thought of as a system that can make informed decisions and operate without the need for human intervention.

The objective of this project is to build a cognitive WSN that is capable of adjusting its operation based on the current conditions of the environment, whilst maintaining the operational requirements of the system. The implications or expected outcome of this project is to verify that such a system enhances network performance in terms of throughput, fault tolerance (when considering interference) and energy, which are important characteristics of a wireless sensor network. The final output will be a simple application that makes use of this cognitive radio along with RFID tags.

### Research Question

Both RFID and Sensor networks rely on the 802.15.4 [3] and ZigBee [4] for wireless communication in collocating network environments where 802.15.4 is used to provide low power, low rate, and small range operations while 802.11 devices are used for their high bandwidth, long range communication capabilities. While the 802.15.4 is used to support the physical and MAC layer communication, ZigBee is used by the upper layers to achieve other wireless communication services. Both research and practice have revealed that sensor and RFID devices running the 802.15.4 on their MAC layer may be competing with Wi-Fi enabled 802.11 and Bluetooth devices on the 2.4 GHz ISM (free frequency) band. Furthermore various proprietary devices communicating using similar protocols are emerging from niche applications into commodity products that add to this competition by sharing the same ISM frequency bands. There are several issues related to frequency management in both wireless networks and collocating wireless environments. Based on this my research will concentrate on:

1. **Interference detection.** Here various strategies that are used for interference detection will be reviewed and compared for their suitability in WSN. In particular techniques such as RSSI (received signal strength indicator) and LQI (link quality indicator) will be looked at. This is an important step in the project since only if the detection protocol is reliable and efficient can appropriate measures be taken to avoid interference.

2. **Interference Mitigation.** Building upon the knowledge of different protocol characteristics, we will propose interference avoidance schemes that may improve the performance of sensing activities in environments where these protocols are competing for frequency in the ISM band. These include Wi-Fi, Bluetooth and 802.15.4 protocols.
In particular, we will make use of one of the techniques reviewed during the work on interference detection. The data gathered by the detection technique will be piggy-backed on existing routing protocols, and will be used to help improve the performance of the system, based on the sensed environment. Essentially three approaches, to improve system performance, will be utilized here:

I. Intra-network channel allocation: In this scheme we will study the effect of allocating separate channels to different types of information (humidity, temperature, luminosity, etc.) or different user queries.

II. Interference avoidance through channel management: This scheme will look at avoiding interference while handling multiple accesses to a single channel from various nodes. Techniques such as adjusting transmission times and adjusting data rates may be considered.

III. Cognitive routing: Here a routing technique will be adopted to avoid interference. In this case if a preferred route has a high level of interference then an alternative route will be determined and utilized.

3. Cognitive WSN configuration: In this study multi-objective based algorithms, such as genetic algorithms and game theory, will be considered to develop a system that is capable of sensing the current condition of its environment and then reacting to it appropriately. This basically means that the system should be capable of adjusting its operating parameters so as to optimize its performance for that environment.

The contribution that this project will make is the development of a robust cognitive system that is suitable for wireless sensor networks. During this development there will be a review of interference detection and avoidance techniques. This project will also provide valuable insight into the difficulties related to developing such a system.

Related Work

This section presents some of the work done in the areas of interference mitigation, efficient routing and cognitive systems.

Interference mitigation through channel manipulation: In this area of work a number of papers were reviewed in particular [5], [6] and [7]. Here I present papers that are most relevant to my work

In, [8], an interference detection protocol is developed which is based on the author’s following experimental observation:

i) When a strong link (with a high packet delivery ratio) exists between two communicating nodes, the interference range is smaller than the communicating range.
ii) When there is a weak leak (with low packet delivery ratio) between two communicating nodes than the interference range is actually larger than the communication range.
Using this, the authors [8] assert that information on communication range is not sufficient enough to design real collision free media access control protocols. To solve this problem, the authors [8], introduce two protocols namely; RID (Radio Interference Detection) and its variation RID-B. The RID protocol bases its functionality on the transmission of a high power detection packet (HD packet) and a normal power detection packet (ND packet). RID operates by first transmitting an HD packet to an intended receiver, once that is delivered it immediately follows it up with a ND packet. The authors [8], call this the HD-ND sequence. The receiver uses the HD-ND packet to estimate the transmitter’s interference strength. The HD packet is used to identify the transmitter to the receiver, once this is done; the receiver then uses the power level of the ND packet (that is to be received) to estimate the transmitter’s capability of causing interference. After this HD-ND detection process, each node then shares its interference information among its neighbourhood, and then uses this information to estimate all collision cases within the system. RID-B on the other hand is light weight version of RID that simply put, stores less information about the interference capability of a transmitter (i.e. does not record the power level of the ND packet) and does not accommodate for multiple transmitters. The authors [8], test these protocols using a simulator (GlomoSim) and in combination with the TDMA protocol. The results obtained show that TDMA that uses RID has a 100% packet delivery ratio, while the traditional TDMA has a 60% packet loss ratio, under heavy load.

[9], introduce a useful technique for congestion sharing amongst nodes whose transmissions may potentially interfere with each other. The algorithm is called the Interference Fair Rate Control (IFRC) and it ultimately provides fair and efficient use, of the bandwidth available, to all nodes.

The algorithm works by controlling the rate at which all nodes transmit information based on the congestion level of the network. The idea here is that if a node “A” in the network is congested with traffic (i.e. it has problems transmitting) then the best manner to mitigate the problem is by reducing the rate at which data is transmitted on to the network by all nodes that can interfere with the node “A’s” transmission. Doing this will provide more time to node “A” for transmitting the data that it has queued up, and reduces the amount of data that will be sent to node “A”. This effectively reduces interference and improves system throughput.

The author detects congestion in the network by measuring the queue length at each node. The reason being, that if a node “A” has problems transmitting data successfully then it is most probably due to some form of interference, the result of this may lead to node “A” having an ever extending queue, since nodes that use node “A” as an intermediate hop to its destination will continue sending their data as they are unaware of node “A’s” difficulty in transmitting data. Thus, the author mitigates this problem by applying a threshold on the queue length. Once the queue length has passed a predefined threshold value the algorithm dictates that the rate of transmission for both the congested node and all its possible interferers need to reduce by half. This will provide more time for the node to drain the queue. This mechanism has an added benefit that it ensures that during congestion there is no single node that dominates the channel and thus unfairly prevents other nodes from transmitting data (i.e. intra-network interference).

There are, fundamentally, three stages to this algorithm:

1. Detection of congestion
2. Congestion sharing
3. Rate adoption.

Detection of congestion as mentioned previously is done by monitoring the queue length of every node in the network to check if it has passed a specified threshold value. Once it does then the data rate of the node (along with interferers) is reduced until the queue has fallen below a separately
specified threshold. After which the data rates start for concerned nodes start incrementing at a previously determined rate.

Congestion sharing, simply specifies which nodes will have to help “share the congestion” by reducing their data rates. The nodes that get affected are:

a) The node itself
b) All nodes that are a neighbour to the affected node (incl. children and parent nodes).
c) All the nodes that are a neighbour to the parent nodes, and the children of those neighbour nodes.

Rate Adoption looks at altering the rate based on the congestion level. That is once the queue length of a node has passed the threshold, then all nodes mentioned above (congestion sharing nodes) have to half their data rates. Once the congestion has subsided (i.e. queue length has fallen below the threshold) then the data rates of all nodes can expand incrementally.

Experimental results provided by the author are promising. They show fair distribution of congestion amongst interfering nodes while allowing spatially non-interfering nodes to transmit data at normal rates. The result essentially shows that there is high system throughput though it comes at the cost of degrading the performance of individual nodes.

**Efficient routing**: Following is a discussion on research papers that introduce routing techniques that are viable for sensor networks. Such papers provide a good guideline on how to develop the routing protocol required for this research. A number of papers were reviewed such as [ (10 pp. 819-829)]. The most relevant to my work are presented.

[ (11)] Introduce a power aware routing protocol that based on the AODV reactive routing protocol. The objective behind developing the protocol was to prolong the lifetime of the sensor network by extending the life time of the sensor nodes. The protocol works by considering the battery life of a node before subjecting the node as an intermediary in the route construction process. The AODV protocol works by having the sending node broadcast a route request packet (RReq), amongst the nodes to receive this request; which ever node re-broadcasts this packet back to the sender first becomes part of the complete route to the destination. The authors [ (11)], assert that while this mechanism is simple and fast, it can be wasteful in terms of energy consumption, since there will be multiple nodes that are re-broadcasting the request packet which are not going to become part of the route. The authors [ (11)], try to solve this problem with their protocol by introducing a timer for when each of the nodes, that receive this RReq packet, should re-broadcast the packet back to the sender. The timing mechanism is based on the battery level of a node, and is designed such that the lower the battery life the higher the timer should be. Thus, in this design the node with the highest battery life responds first to the RReq packet and re-broadcasts the packet back to the sender. When it re-broadcasts the packet the other neighbouring nodes (which initially received the RReq packet) catches the broadcast and is made aware that a response has already been made, and thus it terminates its own timer and does not take further part in the process. This essentially saves the network from wasting energy and hence allows the network to prolong its lifetime. The authors [ (11)], then goes on to introduce the idea of forwarders into the design of his protocol. Forwarders are basically nodes which have a higher battery capacity then the normal sensor nodes. In [ (11)], it is explained, that the reason for bringing in this type of node is due to the fact that certain sensor nodes (especially those close to a base station or a sink) may be repeatedly called upon for routing traffic which would firstly prevent it from conducting its primary objective of sensing, and secondly would quickly deplete its power level. Thus, the authors [ (11)] make use of forwarders that need to be placed into strategic
positions such that on average when a sensor wishes to transmit information the forwarder is within range of receiving the RReq packet. Since, predominantly, the forwarder will have more battery life it’ll be selected over other nodes to take part in routing events. Once again this process is intended to increase the network life. Tests were performed using a simulator (QualNet) where the performance of the AODV protocol, timer AODV protocol with no forwarders and 2 sets of timer AODV protocol with forwarders (one set with 8 and the other with 16). The results obtained generally showed that timer AODV protocol with forwarders outperformed the rest in terms of throughput and energy consumption, while the timer AODV protocol outperformed the AODV protocol under the same evaluation parameters.

[ (12)], discuss a routing mechanism which tries to optimise power usage during transmissions while maintaining a certain level of quality-of-service. The algorithm makes use of the link gain between two communicating nodes (link gain is the ratio of the power level when a receiving node is collecting data over the power level when a sending node is transmitting data) and the noise level (white noise) that exists at a node. This information is sent to a sink node which then feeds the data to a power-cost function which the authors, themselves, have developed. The power-cost function is then used to determine the optimal route from any source to destination based on the path which has the least interference (from white noise) and spends the least amount of power in transmissions. The power-cost function also determines the optimal power that each node should use in a particular route. Now, the authors stress that in order to maintain reliability in the transmissions (i.e. to ensure a high success probability in transmissions) there should be a minimum transmitting power level (or threshold) that a node should not fall behind. The authors use the frame error probability in order to determine the threshold for transmission. The frame error probability (FEP) represents the average percentage of frames that get corrupted with errors during a transmission between two nodes. Thus, the FEP is used as a constraint in the power-cost function. The idea here is, that to provide a level of quality of service for a route, the system (using the power cost function) must operate with a constraint that a certain degree of end-to-end frame error probability should be met. The end-to-end probability FEP is simply the product of all the FEPs in the links from source to destination node. The entire processes works in the following manner; a source node broadcasts a route discovery request (RDREQ) packet to all its neighbours while also requiring to establish one session with the sink node (i.e. even after a route to the target node is found, nodes should continue broadcasting the RDREQ packet until it reaches the sink node). When a node receives the RDREQ packet it appends its link gain, white noise level, and maximum transmission power onto the packet before re-broadcasting. All the RDREQ packets (that have travelled along various paths) end up at the sink node. The sink node then uses the set of information (link gain, white noise level, transmission power) gathered by each RDREQ packet and applies it to the power-cost function. After this operation the sink node will select a single route with the least power consumption. The sink node then sends out a route reply (RREP) packet which includes a list of all the intermediate nodes and their optimal transmission powers for that route. The authors conducted their experiments through simulation, and they compared their results with that of a heuristic method used by a MATLAB tool. Their results proved to be consistent with that of the heuristic method. On average, between two nodes at a distance of 0.5m apart, a transmission power of 1.138mW is used. The authors set out their experiment by laying out a set of nodes in a topology whereby there were multiple routes from source to sink. In their experiment the sink was made to be the destination node. The results showed that their algorithm picked the most power efficient route which, as it turns out, was not the shortest path. The authors reason that while the shortest path is widely adopted in wired networks, it may not be suitable for wireless networks where the priority tends towards network lifetime more than any other constraint.
Cognitive channel modelling – In this research area, algorithms that allow for the development of a cognitive system will be reviewed and implemented. Generally, such systems tend to be complex as there are many parameters to consider, and the algorithms used need to be capable of satisfying multiple objectives. The parameters (involved in the decision making process) can range from transmission power, bandwidth, network lifetime required, frequency/channel selection etc. The work completed previously will be incorporated into this system to help enhance its performance. Several papers were reviewed [(13), (2), (14)], following is a discussion of the most relevant.

[(15)], discuss a cognitive radio system that was built for multi-carrier transceivers. The system developed by the authors make use of a genetic algorithm (GA), which is designed to select the optimal transmission parameters by scoring a subset of parameters and evolving them until the optimal value is reached for a given goal. In [(15)], it is explained that the objective of the work is to analyse the performance of the GA algorithm as well as to explore, in detail, the set of fitness functions that are available for the algorithm. The authors [(15)], further find that the accuracy of the decisions made by the GA depends on the quality and quantity of inputs made to the system. Thus it becomes important to have the right set of parameters for modelling the environment as well as for modelling the radio system. In this work, the environment parameters selected were; the bit error rate, signal to noise ratio, and the noise power. The transmission (or radio) parameters selected were; the raw transmission power, modulation type, and the modulation index (total number of symbols in a constellation). The work of the GA then becomes to tweak these parameters (or a subset of these parameters) to obtain maximal performance based on the fitness objectives. The fitness objectives in this case were to; minimize the bit error rate, maximize throughput, and minimize power consumption. The fitness objectives are ranked based on a weighted, aggregate sum, and thus the primary objective of the system (which is based on the current goal of the system) can be chosen by adjusting the weights. Experiments were carried out in a simulated framework with various scenarios (i.e. with differing primary objectives making use of different subsets of the parameters listed earlier) under multi-carrier and single carrier systems. The multi-carrier system was modelled using 64 subcarriers. The results showed that the fitness functions steer the evolution of the GA in the correct direction to optimise the given objectives for each scenario. In each scenario the final decision of the GA provided a parameter set that put more emphasis on the primary objective while still balancing the two secondary objectives.

[(16)], discusses the development of a cognitive system that considers channel selection as well as power allocation. The emphasis in this paper was placed on control of transmission power, since it can reduce the overall energy consumption in the network. In their system the cognitive radio senses the environment by sending probes which measure the available channels for local interference temperature, based on this information it selects the best channels for transmission and determines the optimal transmission power for each of those channels. Subsequent probes are done just before transmission on a selected (single) channel to, again, check the interference level as well as the link quality (based on bit error rate (BER), and signal to interference ratio (SIR)). Accordingly, adjustments are made by varying the data rate or by switching to different frequency channel. To handle the operation just described the authors decided to make use of a game theoretic formulation whereby the adaptive channel allocation and power control problem are modelled as a potential game. Now, game theory is especially suited for modelling interactive decision processes in which every participant acts to try and optimise its own behaviour. Specifically, game theory follows the notion of a game and has three primary components:
1. A finite set of players. In this case it is the number of nodes in the network
2. An action space. This represents the set of actions that a node can perform.
3. A set of utility functions that quantify the player’s preferences over the game’s possible outcomes. The outcomes are determined by the actions chosen by all the players in the game.

As mentioned earlier, players act in their own self interest, whereby the actions they select are done in such a way that it increases the number returned from their utility function. The end result of the game is that all players reach a stage whereby none of them can perform an act (independently) which can result in the improvement of its own performance. This is known as the Nash Equilibrium (steady state), and for the distributed algorithms that bring the system to this stage, this is known as the convergence property of the algorithm. This is the desired steady state that a system looks for since it means that all nodes of a network are working together in a unified manner. In the case, for the authors of [ (16)], the players are the nodes of the network; the action set is the channel selection, and transmission power adjustment; and the utility functions are based on the transmission power and channel. This process will eventually bring their system to a steady state (Nash Equilibrium) where the link throughput is optimised and a fair spectrum sharing over the network is established.

Experiments were conducted through simulation, a set of 20 nodes were randomly distributed within a 1000m x 1000m square area. The experiments were carried out in 5 scenarios:

1. CA_NPC: Channel Allocation, No Power Control
2. PC NCA: Power Control, No Channel Allocation
3. CPC NCA: Constraint Power Control, No Channel Allocation
4. JCAPC: Joint Channel Allocation with Power Control
5. JCACPC Joint Channel Allocation with Constraint Power Control

Performance evaluation was based on average throughput per node and total transmission power used in the network. In terms of throughput, results show that CA_NPC, JCAPC and JCACPC have similar performances but easily out-perform the rest. In particular JCAPC showed very little variation in throughput per user, which indicates that the system had reached an efficient steady state in that scenario. As for the total transmission power, results show that JCAPC and JCACPC used a fixed of amount of power regardless of the maximum transmission power allowed on the radio, whereas the rest of the scenarios showed a linear property where the total transmission was dependent on the max transmission power allowed. Again this result shows how game theory managed to get the system in a state whereby all nodes collaborate and provide an efficient and fair working system overall.

**Methodology**

Here I will describe the process that will be undertaken to evaluate each of the research questions.

**Interference Detection:** Work related to this area will begin by comparing two differing interference detection protocols and that exist on the Sunspots. The protocols will be evaluated against each other on a hardware test bed in an indoor- controlled scenario. The protocols will be tested for their sensitivity to interference from external network devices (most probably being Bluetooth and 802.11 devices). The experiments will also include observing the effect on their sensitivity by varying parameters such as number of nodes, distance of interferer from two communicating nodes, and transmitting power of the interferer.
The experiment will be conducted within an indoor-managed environment so as to control the interference levels introduced and to effectively analyse the results obtained. The protocol with the best performance will then be reused for the interference mitigation stage.

**Interference Mitigation:** For this research area interference avoidance schemes based on routing and channel management will be implemented. The idea here, being, that channel management schemes will be used until the interference has reached a level whereby useful communication cannot be conducted. In such a case discovering a new route takes precedence for ensuring continuous communication. The channel management and cognitive routing protocol will be evaluated based on energy efficiency and throughput. This combination will be taken forward for the development of the cognitive WSN configuration.

Experiments will be carried out in two scenarios; managed-indoor and unmanaged-indoor. The managed-indoor experiment will be conducted in a manner whereby interferers (i.e. this can be a Bluetooth device or an 802.11 device) will be introduced into the environment. The reason for doing it in this way is so that we can isolate the observances as being the result of introducing the interferers. Once testing has been completed in the indoor managed environment the system will be tested in an unmanaged-indoor environment. The unmanaged-indoor experiments will test how the system performs in a dynamic (uncontrolled) environment.

**Cognitive WSN configuration:** For this research area algorithms which allow a radio system to automatically adjust its operational parameters based on the environment will be implemented. Such algorithms generally make use of artificial intelligence (AI) techniques as well as being capable of handling multiple objectives. The algorithm will make use of the techniques developed in the previous stages of this research. A “cognitive” based algorithm will be implemented and tested to observe its ability to adapt to a dynamic environment with changing primary objectives. Examples of what the objective of the system may include are: minimizing bit error rates, maximizing throughput, and minimizing power transmission.

Once again experiments will be carried out in a managed indoor scenario (where changing conditions in the environment will be controlled) and an unmanaged indoor scenario. In the managed indoor scenario tests will be conducted to observe the effect of adjusting interference levels, distance between nodes, number of nodes, and topology. An example of how the cognitive system is expected to operate is if in the case where the system detects little or no interference we expect the system to then adjust itself so as to increase its data transmission rates and improve on throughput, but later if it detects high interference we expect the system to reduce its transmission rate so as to minimize the number of corrupted packets being transmitted, doing this also has the effect of reducing wastage of battery power.

In the unmanaged scenario the cognitive system will be tried against the original sunspot to test if the cognitive system provides better performance in terms of throughput and network lifetime.
Work Detail

Risks

1. Not enough physical sensor nodes to properly test and evaluate the system. A manner in which to counteract this is to make use of simulation programs. The sunspots come with its own emulation environment, but if that is not sufficient other programs such as Qualnet (17) or Desmo-J (18) exist.

2. May require additional hardware to help improve the system in interference detection. May also require a more powerful transceiver in order to make use of multiple bands for transmission. These devices may be built and acquired from the engineering department. Since this will be dependent on an external source it can be a huge risk as it could affect the progress of the project. If it takes too long then research will continue with existing hardware.

3. Taking too long to implement a certain section of the project.
   
   a. If it’s related to implementation of a particular technique based on any of the three stages of the project; then the option is either to reduce the number of implementations that we have planned thus shifting from 2 algorithms to a single algorithm. The comparison will then be based on the sunspot original implementation and my implementation. This will allow more time for development, and won’t affect the project duration.

   b. If a particular stage of the project is taking too long to develop then either an extension on the project will be required (if it’s considered that the overall research will contribute significantly to the research community) or a reduction in the scope of the project so as to finish the project within time.

   c. If the reduction of the scope of the project puts us in the position where the research question cannot be answered then a revision of the research question may be required.
Timeline

**August – November (2009):** Implementation of algorithms related to interference detection as well as testing and evaluation. Research paper based on this by the end of November.

More detailed brake down: 2 months for development of algorithms, 1.5 months for testing and evaluation, plus time for any adjustments that may be required to help improve the system. Last two weeks to write the research paper. Throughout this period preliminary work on the methodology, testing and evaluation chapters will be prepared.

**December (2009) – March (2010):** Implementation of the interference avoidance protocols as well as testing and evaluation. Research paper by end of March.

More detailed brake down: 2 months for development of algorithms, 1.5 months for testing and evaluation, plus time for any adjustments that may be required to help improve the system. Last two weeks to write the research paper. Throughout this period preliminary work on the methodology, testing and evaluation chapters will be prepared.

**April – July (2010):** Implementation of a cognitive WSN, as well as testing and evaluation. Research paper by end of July.

More detailed brake down: 2 months for development of algorithms, 1.5 months for testing and evaluation, plus time for any adjustments that may be required to help improve the system. Last two weeks to write the research paper. Throughout this period preliminary work on the methodology, testing and evaluation chapters will be prepared.

**August – October (2010):** Completing the overall thesis, including background chapter and reworking the main body of the methodology, testing and evaluation chapters.

Resources required

1. In terms of equipment, I will need WiSpy (19) product. The interference detection mechanism used in the WiSpy will be evaluated along side other implemented protocols.

2. May require a network simulator program in order to test the algorithms under high density which may not be possible under practical conditions.

3. Sunspot sensor nodes. This will be the device in which all the implemented programs will run and be tested on.

4. Netbeans IDE 6.5. This will be the development environment under which the algorithms will be implemented. Main reason for this being that the sunspots are compatible to Java.
Deliverables

1. 3 Research papers
2. A cognitive routing protocol.
3. A Final cognitive WSN which has an enhanced interference detection and avoidance scheme.
4. A sample application which makes use of RFID tags.
5. Final thesis.

Milestones:

1. Mid November an evaluation of interference detection protocols.
2. End November a research paper documenting the results and evaluation
3. Mid March a system which makes use of an enhanced/improved interference avoidance scheme.
4. End March a research paper documenting the results and evaluation.
5. Mid July a Cognitive Radio System. Possibly an application with RFID Tags.
6. End July Research paper documenting the results and evaluation.
7. October Final thesis.

**Evaluation of Research results**

This has already been described in the methodology section. The evaluation of the experiments will be based on factors that are relevant to successful deployments of WSN which, in particular, revolve around energy efficiency.

**Interference Detection:** Here the protocols will be evaluated based on their sensitivity to the exposure of varying levels of interference. The protocol which provides a reasonable performance (i.e. sensitivity) but expends less energy will be preferred.

**Interference Mitigation:** This will be evaluated based on throughput and energy (power) expenditure. The protocols implemented will be expected to provide reasonable throughput while expending minimal energy. Reasonable throughput will be considered as anything that is higher or equal to the throughput of the original sunspot under the same conditions.

**Cognitive WSN Configuration:** Experiments carried out on this stage will have the system adjusting its objective based on the environment. Thus the system is expected to respond in an appropriate manner based on observed characteristics of the environment. For example if there is little to no interference in the environment then the system is expected to increase its transmission power so as to
increase the data rates and improve the system throughput, this though will be subject to the amount of energy available in individual sensor nodes.

**Anticipated Outcomes**

**Interference Detection:** In this stage we expect to find a protocol (i.e. out of the protocols implemented) that is capable of detecting interference while expending minimum energy.

**Interference Mitigation:** In this stage we plan to make use of interference avoidance techniques that considers channel sharing and re-routing. We hope to implement algorithms that outperform the current implementation on the sunspot, while still maintaining reasonable energy consumption and throughput.

**Cognitive WSN Configuration:** Here we plan to build a cognitive WSN that makes use of the algorithms developed in the previous stages. We expect that the system will be able to adjust its operational parameters based on the current conditions. We also expect that such a system will outperform the original sunspot in terms of throughput and network lifetime.

**Major software artefacts:**

1. **Cognitive Routing Protocol**
   a. Characteristics/features: Dynamically selecting a path, from a set of possible paths, from a source to a target node based on the perceived levels of interference.

   b. Design Challenges:


      ii. Having to test interference and congestion effects with minimal nodes.

      iii. Determining the threshold for interference which will determine when re-routing will need to take place.

      iv. Modelling the interference levels on the separate links

2. A protocol stack that allows for a cognitive WSN
   a. characteristics/key features: Makes use of a multi-objective algorithm that automatically selects the appropriate operational parameters and interference avoidance techniques based on the current environment

   b. Design challenges:

      i. Selecting the most appropriate techniques (out of a handful that are available) for implementing in the cognitive WSN.

      ii. Determining the multiple objectives that should steer the system to perform optimally.

iv. If spectrum sharing is considered then designing a more powerful antenna may be necessary.

v. Getting the Cognitive WSN to communicate with the RFID system.

**Key Success factors**

1. The interference aware and avoid algorithm performs better and is more efficient (or at least on par in both cases) than the native technique used on the Sunspot.

2. The development of a cognitive routing protocol.

3. The Development of a cognitive WSN that can adjust its operational parameters based on environment.
Bibliography


