I-BATMAN
an interference aware routing protocol for
Smart Wireless Mesh Networks

Project Proposal

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1. Project description

The aim of the project is to design and implement a wireless mesh routing protocol which modifies the routing decisions of a node based on the analysis of its spectrum environment. The project builds upon the state of the art wireless models which have been enabled by the advances in wireless technology. Our project has a specific focus on the implementation of cognitive routing in the emerging multi-radio multi-channel mesh networks of the future. The main tasks involved in this project are:

i. Designing of cognitive nodes that learn about the interference in their environment. Quantifying this interference using appropriate models and designing a routing metric based on this.

ii. Designing and implementing a cognitive routing protocol in which the spectrum information gathered from the nodes’ environment is piggybacked on the existing protocol called BATMAN (*Better Approach to Mobile Ad Hoc Networking*). We refer to the resulting protocol as *Interference-aware BATMAN* (I-BATMAN).

To clarify for the purposes of this proposal, please note that a *channel* is an assigned frequency range which a radio may use for data transmission; a collection of *channels* is termed a *frequency spectrum* (or when the context is clear, simply *spectrum*). *Channel capacity* is the upper bound on reliable throughput available to a node transmitting over a channel. When we use the term ‘spectrum environment’ we mean ‘the busyness (great or small) of the channel the node is transmitting over, and of other channels’.

In addition, to clarify the usage of words like 'learning' and 'cognitive', we propose their usage in the same way that has been used in the area of cognitive radio. The convention found in the literature follows the Oxford English Dictionary (OED) which defines cognitive as pertaining to the action of *cognition*, and *cognition* as *knowing* including *sensing*, *perception* and *conception*. Therefore the ability of a network to sense its environment and make decisions on that information is reasonably labeled as being cognitive. In this proposal the use of the word 'learning' is used synonymously with 'sensing'.


Problem statement

Wireless Mesh Networks (WMN) are an emerging significant new technology envisaged to extend Internet access and other networking services in personal, corporate, rural, and metropolitan areas. The popularity of WMN is due in part to its low upfront costs, rapid deployability, and suitability for hard-to-wire buildings and terrain. The key feature of mesh networks which differentiates it from other types of networking is the multi-hop relaying of packets across wireless links for communication between the participating nodes.

The type of mesh network architecture being considered is known as infrastructure mesh (see [1] for the classifications of mesh network architectures) in which the end-user devices such as PDAs, laptops do not participate in the packet relay. Instead, routers form a mesh of self-configuring, self-healing links among themselves. Currently, much effort is expended on the IEEE 802.11 medium access control (MAC) layer to fully exploit novel physical (PHY) layer techniques. Nevertheless, in multi-hop scenarios where the quality of the links is constantly changing, performance depends on the routing protocol to properly choose optimal routes [2].

This project attempts to address routing in next generation wireless mesh networks. Our approach consists of designing and implementing smart nodes capable of sensing their spectrum environment upon which routing decisions would be made; with the objective of achieving a cognitive routing protocol. The information about the spectrum environment is piggybacked over existing routing protocols such as BATMAN. In other words the routing metric assimilates this information and uses it to determine the properties of routes from which new routing decisions can be made- thereby optimizing the overall routing process. In order to realize a cognitive routing protocol, the following research questions will need to be addressed:

2.1 What is the most efficient approach?

One of the main problems facing wireless mesh networks is the reduction in total channel capacity due to interference between multiple simultaneous transmissions as explained in [3]. Sensing and packet transmission cannot be done simultaneously by nodes with a single radio interface. Cognitive nodes have to stop transmitting while sensing, which may decrease spectrum efficiency. We will investigate the use of multiple coordinated wireless network cards tuned to
non-overlapping frequency channels proposed in[3] which optimize channel capacity by allowing nodes to receive and transmit simultaneously.

2.2 What is the most appropriate spectrum sensing model?
Once information about the radio spectrum has been gathered there needs to be a way to logically quantify this information. In the case of exploiting spectrum holes (white spaces) various models could be employed - however since that is not our focus these most probably won’t provide us with the characterization we need. In the case of quantifying the interference, models like Physical (SINR), Protocol or COIM could be used. The task here is choosing the model based on its complexity - excessive complexity could induce serious computation overhead (like SINR [10]) which is something we wish to avoid. Therefore the most appropriate model is not overly complex, but at the same time does not compromise on necessary detail which would result in low utility and dubious metrics. We may have to start with an overly simplified approach before we attempt to improve on this by finding a suitable choice of model. We may even find that re-working and adapting some models will be necessary.

2.3 Can the information about interference be used to influence the routing process?
In traditional routing protocols, the routing process was influenced (for example) by asking which routes had the least hop count to a destination. In a similar way we ask whether the routing protocol can consider sending packets over links with low levels of interference as an added way of ensuring better overall throughput, and less delay.

2.4 How can cognition be used to improve the routing process?
The goal of any routing protocol is to determine the best path. Cognition at the PHY/MAC layer can be used to determine the path with the least amount of interference - in other words, a better path. However, we need to either come up with a scheme of sharing this information among the nodes without increasing overhead traffic, or, in the spirit of the BATMAN protocol, restrict this information to only the node itself to assist in its routing decisions. Furthermore, we need to balance the tasks of sensing and routing to avoid incurring excessive processing costs. That is to say, improving the quality of routing through sensing should not overly affect other aspects of networking such that there might be worse performance.
3. Procedures and methods

As stated above, the project’s main tasks are the design of cognitive nodes capable of sensing their spectrum environment and the design and implementation of a cognitive routing protocol. The following provides detail of how we will attempt to do this.

3.1 Development environment & Implementation strategy

The implementation will be done using the following software, hardware and configurations:

- **Software** - The protocol, written in C, will be run on a ‘light’ version of Ubuntu Linux. This is because our project builds upon an existing protocol (BATMAN) which was originally written in C. We will also need Linux’s wireless tools and a suitable spectrum analyzer software - which will be hacked to meet our needs.

- **Hardware** - We will use ALIX system Boards, in particular the alix2d13 boards which we have sourced. On these, the ‘light’ version of Ubuntu will be installed and regular network interface cards will be will be connected. Initial testing of the node’s cognizance will be done using these regular wireless network interface cards because they are easily obtainable off the shelf. We will require GSM/GPRS modems with AT commands which will allow a node to act as a gateway. We will also possibly need sensor motes with GPRS, these could be used to sense the physical environment (heat, light etc) and route meaningful information to the gateway.

- **Testbed configuration** - The mesh testbed could have several different configurations. Following the layout in [5], a nxn array of nodes most likely will be set up with Ethernet ports for sending measurement data back to the server so that it does not interfere with the tests. Furthermore we will need to test different configurations of the network interface cards (NIC’s) to determine the best setting for the wireless grid. These setting include power level range, protocol modes, and sending rates. We will take care to set up the test bed so that it does not interfere with University wireless networks, this can be achieved either by testing off of University premises, or by using a different frequency band.
3.2 Design features

(a) Cognitive nodes

The nodes comprising the Smart Wireless Mesh Network (SWMN) will consist of the following key features:

- **Detection** - The nodes will be able to sense the congestion in the channel (interference).
- **Interference Aware Mitigation** - Move the operation of the network away from the zones of interference- performed by ‘routing decisions’ at the Network Layer.
- **Operation** - The core operation of the nodes will be to use the information about their spectrum environment to optimize the routing process. We expect to develop a routing protocol that will build on a routing metric and send packets over links with the least amount of interference, in other words, over links that have optimum channel capacity.

(b) System model and basic routing algorithm

The **System model** is a graph representation of the network, composed of vertices and edges. The basic **routing algorithm**, the classification of one hop neighbours and all other aspects of the BATMAN routing objective will be represented in this way. (see [5] for a complete description of the System model for BATMAN).

(c) Routing objective

Building upon the routing objectives of BATMAN which is to maximize the probability of delivering a message, our routing protocol will compare the links in terms of the levels of interference and attempt to route packets via the link with the least amount of interference.

3.3 Expected challenges

The project is largely implementation based. We will need to secure enough smart boards to set up a prototype SWMN. There is the risk of sourcing poorly documented hardware which could potentially complicate the task of implementation. In addition, the project requires us to learn a host of new material which includes:

- Cognitive Radio Technology - there are various models in use for analysing the radio spectrum, some far more complex than others, we will take care to avoid unnecessary
complexity. A current state of the art interference model like COIM which is simpler may be of better use for the scope of this project.

- Routing Protocols - such as BATMAN, how they work, and how they are implemented.
- Programming language - for example C.
- Physics - we will need to thoroughly ground ourselves in some of the physics behind radio communications when configuring our testbed.

There is a risk of not knowing the complexities involved and how much time is required for a particular task. Therefore, to avoid slipping behind schedule, deliberate effort will be made to stay ahead of the project plan.

3.4 Performance testing

A prototype wireless mesh network will be set up and the performance of I-BATMAN will be compared with the original BATMAN. We are going to borrow the methods used in [5] to compare BATMAN with OLSR to get the measurements summarized in Table 1. In addition, we wish to analyse both the CPU load and the memory consumption as a further way of quantifying the overall improvement or degradation due to introducing cognition.

Table 1: comparing the performance of I-BATMAN with BATMAN, adapted from [5].

<table>
<thead>
<tr>
<th>Routing protocol</th>
<th>Forward hop count</th>
<th>Symmetric links (%)</th>
<th>Seconds per route</th>
<th>Packet loss (%)</th>
<th>Delay (ms)</th>
<th>Throughput (kbps)</th>
<th>No link (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>I-BATMAN</td>
<td></td>
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<tr>
<td>BATMAN</td>
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</table>

4. Ethical, professional and legal issues

The project will not require ethics clearance since it does not involve user based testing. There may be policy issues associated with wireless communication in certain frequency bands. However, all our experiments will be done within the 2.4 GHz/5.8 GHz ISM bands which is licence free.
Regarding intellectual property rights, the outcome of this project will be released under the open source license so that other researchers can benefit from the research findings.

## 5. Related work

A survey carried out on wireless mesh networks revealed that although cognitive radio technologies are still in their infancy, they are expected to be the future platform for wireless networks due to their dynamic control capability. These advanced wireless radio technologies all require a revolutionary design in higher-layer protocols, especially MAC and routing protocols [1]. The effect of introducing the cognitive principle in the logic of wireless networks with a focus on routing has been investigated. The results show that multi-user interference awareness as provided by the cognitive functions may improve network performance [6].

Recently, several protocols that vary communication parameters based on spectrum awareness and incorporate cognition in the routing metric have been proposed to improve wireless mesh routing. These include Spectrum Aware Mesh Routing protocol (SAMER) which exploits the available spectrum opportunistically and attempts to balance between long-term route stability and short-term opportunistic performance [7]. The SAMER network model assumes the presence of a control channel used by nodes to contend for spectrum access. But, according to [8] nodes in multi-hop, single transceiver cognitive radio networks which use the IEEE 802.11 DCF as the MAC protocol cannot provide a synchronization mechanism by tuning to a common channel at a specific time and so, routing in this network scenario should not be control channel based. For this reason, Multi-hop Single-transceiver CRN Routing Protocol (MSCRP) is proposed, which is not control channel based. MSCR is a spectrum aware routing protocol in which nodes initiate a route discovery procedure by broadcasting a Route Request (RREQ), which piggybacks the available channel information.

Other related works include, Opportunistic Service Differentiation Routing Protocol (OSDRP) for the dynamic cognitive radio networks [9]. Unlike all the other routing protocols considered so far, OSDRP is a cross-layer routing protocol which addresses a situation where the average available duration of the communication channel might be much shorter than the communication time.
6. Anticipated outcomes

6.1 System & Major design challenges

At the end of the project we expect to implement a Smart Wireless Mesh Network (SWMN) using Alix Boards. The SWMN will consist of “smart” nodes with a cognitive routing protocol.

The major challenge of this project will be the design of smart nodes. We will need to experiment extensively with spectrum sensing models, we will need to design a routing metric (or re-purpose an existing one), incorporate this metric into the BATMAN protocol and evaluate various radio configurations such as power range, protocol modes and sending rates [5].

6.2 Expected impact

Wireless mesh networks (WMN) suffer many challenges such as packet loss, low throughput and delays. This is due to either internal interference from other users or from external interference sources such as microwaves and Bluetooth devices operating in the same ISM band [10]. Optimizing the routing process by considering interference in the routing metrics would lead to improved performance. Furthermore, WMN are envisaged to extend Internet access to rural areas. Findings from this project could lead to increased ‘connectivity’ via WMN due to the optimization of interference free channel use.

The other benefit from this research would be the report on the cognitive radio capabilities which may be applied in several other communication contexts other than routing.

6.3 Key success factors

The project builds on top of the BATMAN protocol. BATMAN was developed in response to the shortcomings of OLSR [5]. Therefore our expected protocol which we are calling Interference-aware BATMAN (I-BATMAN) will be evaluated in comparison with the original BATMAN on the following terms summarized in table 1. I-BATMAN will be considered successful if it performs better than the original BATMAN.
7. Project plan

7.1 Risks

The following section describes the risks associated with this project as well as the mitigation strategy put in place.

(a) Failure to meet deadlines

If key milestones are not met on time, it could lead to the whole project slipping behind schedule.

Severity: high

Likelihood: medium

Mitigation: progress monitoring will be done weekly to compare actual team performance against the set targets. The primary objective is to ensure that the project is completed within the scheduled time. Regular meetings with the supervisor will help ensure that the project stays on course. If we fail to meet a deadline, extra effort will be put in to catch up with the set targets.

(b) Equipment failure

The project involves the implementation of wireless mesh network nodes using Alix Boards fitted with radios. These are pieces of electronic equipment that can fail at anytime. The lack of equipment could result in delays in the implementation and testing.

Severity: high

Likelihood: medium

Mitigation: we will try to acquire equipment that is of good quality. The plan is to implement a 4 x 4 wireless grid. In case of severe equipment constraints, the mesh size can be scaled down without any significant consequences since the core focus of the test is not on scalability.

(c) Team member unavailability
A member of the group may be unavailable due to illness or some other unforeseen circumstances. This could result in delays in the overall project delivery or work overload for the member carrying on with the work.

Severity: high

Likelihood: low

Mitigation: The project has been divided up into two main tasks. The tasks are interrelated but, they are sufficiently split up to enable one group member to carry on with the project in the event that the other becomes unavailable.

(d) Scope of the project

Due to the newness of this area of research, there is a risk of underestimating the complexity of tasks and therefore not being able to complete them in time.

Severity: high

Likelihood: medium

Mitigation: if the amount of work involved turns out to be unmanageable, the scope of the project can be scaled down as might be the case if a team member were to be unavailable. If the project is completed ahead of time, there are several enhancements that could be added.

7.2 Time line

See the Gantt chart in figure 1.

7.3 Resources required

<table>
<thead>
<tr>
<th>Software</th>
<th>Hardware</th>
</tr>
</thead>
<tbody>
<tr>
<td>Linux wireless tools.</td>
<td>ALIX System Boards</td>
</tr>
<tr>
<td>Wind River Software</td>
<td>GSM/GPRS modems with AT command support</td>
</tr>
<tr>
<td>Spectrum Analyzer software.</td>
<td>Sensor motes with GPRS.</td>
</tr>
</tbody>
</table>
7.4 Deliverables
See table 2 for the deliverables for the project.

7.5 Milestones
See table 3 for the project milestones.

7.6 Work allocation
The project consists of two main tasks and the work has been split up as follows:

Richard Maliwatu. *Cognitive nodes*: design of a next generation of mesh network node that may learn from their environment and broadcast that information to their neighbours in order to allow the mesh network to optimize its routing performance based on informed decision.

Dominic C. Follett-Smith. *Cognitive routing*: design and implement next generation routing models which include cognition based on the information learned from the nodes’ environment and piggy back that information to the existing protocols such as BATMAN.
### Table 2: project deliverables

<table>
<thead>
<tr>
<th>Deliverable</th>
<th>Date</th>
</tr>
</thead>
<tbody>
<tr>
<td>Project proposal</td>
<td>21 May</td>
</tr>
<tr>
<td>Prototype: initial feasibility demonstration</td>
<td>15 June</td>
</tr>
<tr>
<td>Background/ Theory chapter</td>
<td>29 July</td>
</tr>
<tr>
<td>Design Chapter</td>
<td>29 August</td>
</tr>
<tr>
<td>First implementation</td>
<td>19 September</td>
</tr>
<tr>
<td>Final implementation</td>
<td>28 September</td>
</tr>
<tr>
<td>Chapters on implementation and testing</td>
<td>03 October</td>
</tr>
<tr>
<td>Outline of complete report</td>
<td>10 October</td>
</tr>
<tr>
<td>First complete draft of report</td>
<td>24 October</td>
</tr>
<tr>
<td>Final report handin</td>
<td>31 October</td>
</tr>
<tr>
<td>Poster</td>
<td>03 November</td>
</tr>
<tr>
<td>Project web page</td>
<td>07 November</td>
</tr>
<tr>
<td>Individual reflection paper</td>
<td>11 November</td>
</tr>
</tbody>
</table>
Table 3: project milestones

<table>
<thead>
<tr>
<th>Milestone</th>
<th>Due date</th>
</tr>
</thead>
<tbody>
<tr>
<td>Project Proposal</td>
<td>21 May</td>
</tr>
<tr>
<td>Presentation of project proposal</td>
<td>24 May</td>
</tr>
<tr>
<td>Revised proposal finalized</td>
<td>11 June</td>
</tr>
<tr>
<td>Project web presence (including proposal, timeline, plan)</td>
<td>12 June</td>
</tr>
<tr>
<td>Prototype: Initial Feasibility Demonstration</td>
<td>13 June</td>
</tr>
<tr>
<td>Background chapter done</td>
<td>29 July</td>
</tr>
<tr>
<td>Design chapter done</td>
<td>29 August</td>
</tr>
<tr>
<td>First implementation/experiment/performance testing with write up</td>
<td>19 September</td>
</tr>
<tr>
<td>Final implementation and performance testing with write up</td>
<td>28 September</td>
</tr>
<tr>
<td>Final implementation (optimization) and coding complete</td>
<td>03 October</td>
</tr>
<tr>
<td>Chapters on implementation and performance testing</td>
<td>03 October</td>
</tr>
<tr>
<td>Report outline: chapter and major section headings with 1-2 sentences</td>
<td>10 October</td>
</tr>
<tr>
<td>Final complete report draft</td>
<td>24 October</td>
</tr>
<tr>
<td>Report final handin</td>
<td>31 October</td>
</tr>
<tr>
<td>Poster due</td>
<td>03 November</td>
</tr>
<tr>
<td>Final Project web page</td>
<td>07 November</td>
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<tr>
<td>Individual reflection paper</td>
<td>11 November</td>
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<tr>
<td>Final project presentation</td>
<td>17-18 November</td>
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</tbody>
</table>

Figure 1: project plan details (overleaf)
References


