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**Abstract**

In recent years Wireless Mesh Networks have been deployed and grown in popularity in many metropolitan areas. The deployment of such networks has allowed clients to gain access to publicly available broadband networks. The implementation of wireless mesh networks requires that backhaul services (traditionally carried by wired networks) be maintained via wireless mesh points. Because of their structure, wireless mesh networks provide an excellent means for targeting a large group of end users or simply to relay data. This may be achieved by means of broadcasting or more specifically multicasting. The lack of standards and support for multicasting over wireless mesh networks makes this area very challenging as well as providing much scope for improvement.

**Keywords:** Multicast, Routing, Wireless Mesh Network, Shortest Path Tree

## 1    Introduction

In the following paragraphs we set out to describe the work being carried out as part of a PhD research thesis in Wireless Mesh Networks (WMNs). The focus of this work is Multicast Routing over WMNs and the optimisation of routing by adapting well established techniques as well as developing new ones. The area of research concerning multicast routing over WMNs is considered to be in its infancy which leaves us with much scope for development. Currently there is no support for multicast routing over WMNs in the existing IEEE 802.11 standard, however, at present the IEEE 802.11s standard is being developed to allow interoperability between heterogeneous mesh network devices. In the Internet Engineering Task Force (IETF), the Mobile Ad Hoc Network (MANET) work group has standardised many multihop routing protocols such as Ad Hoc On Demand Distance Vector Routing (AODV), Dynamic Source Routing (DSR), and Optimised Link State Routing (OLSR). These routing protocols are mainly developed for the deployment of unicast traffic and take into consideration mobility but do not directly address multicasting [1]. Furthermore, multicasting over WMNs does not support RTS/CTS nor does it support ACKs due to the high probability of collisions at the transmitter and can therefore be classed as an unreliable service [2]. It is our intention to outline the existing challenges of multicast routing over WMNs, describe how we intend to make enhancements to routing and path selection techniques and show how we will implement and validate these techniques.

## 2    Problem Description

This section presents the source of the problem to be solved and why it is being addressed. We also provide some technical detail and background as well as presenting current research and proposals as to why the problem has not yet been fully addressed.

### 2.1    Problem being addressed

When developing multicast trees in WMNs, Shortest Path Trees (SPT) are seen to be more advantageous than Minimum Number of Transmissions (MNT) or Minimum Steiner Trees (MST) [5]. SPTs by their nature will have a minimum delay. However, these tend to assume a fixed transmission

rate based on the maximum available physical layer (PHY) rate (e.g. 11Mbps for 802.11b networks). In reality, the transmission rate is based on Packet Error Rate (PER) which is related to the signal strength (which in turn is related to the distance between nodes), resource utilisation and channel error model. In shortest path tree algorithms the path is created by finding the most direct route from source to destination. Hence, these algorithms tend to use long links resulting in lower rates. In addition to this, many multicast routing algorithms assume a link cost of one and hence ignore link metrics which may have a significant impact on performance.

## 2.2    Significance of the problem

Existing multicast routing protocols are often tailored for wired networks. Wireless multicast routing is still in its infancy and existing solutions often make too simplistic assumptions about the underlying radio environment. Thus there is a need to tailor the multicast routing protocols for wireless networks in order to allow for their efficient operation. The problem of finding optimum multicast trees in a wireless environment has significant impact on the performance of wireless mesh networks, the main reasons for which are outlined as follows:

- Such optimal multicast trees may not allow the realisation of sophisticated multimedia platforms (which require multicasting) in a wireless environment, where resources are scarce.
- Such optimal multicast trees conserve resources for other data connections.
- Algorithms needed to create and maintain such trees need to be lightweight to allow for deployment on low cost hardware which is typically used to build mesh nodes.

Multicast trees transmit at the lowest available rate on a given path. Low rate path links can cause congestion or bottle-necks in the multicast tree. The outcome of this can result in a multicast network with poor performance. Multicasting can be divided into 3 main groups; One-to-Many, Many-to-Many and Many-to-One. In developing shortest path trees we also encounter One-to-One paths. Our research focuses mainly on the improvement of One-to-One and One-to-Many paths. Examples of multicast usage can be seen in distributed audio/video, multicast based "television", push media (e.g. news headlines, weather reports, sports), multicast group announcements (e.g. network time, public keys), monitoring (e.g. stock prices, sensors, security) or file distribution.
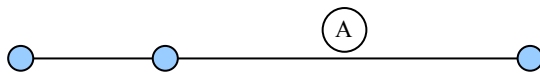


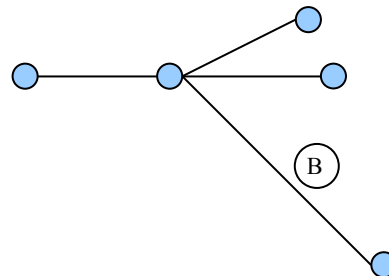**Figure 1**. Point-to-point connection.          **Figure 2**. Point-to-multipoint connection.

In Figure 1 and 2 above we illustrate examples of point-to-point and point-to-multipoint trees. It can be seen in both cases (in the links marked A and B) that if the link rate is dependent on the distance then bottle necks will occur in the tree. In the first figure link A is the longer path and will therefore result in a lower link rate. In the second figure link B has the longest path from the branch point. Because each node will transmit only once, the transmission rate to each of the branch nodes will be determined by link B.

## 2.3    Current state of existing research

There has been much research carried out in addressing multicast trees in wired networks. However, this does not necessarily translate directly over to Wireless Mesh Networks (WMNs). The problem of finding minimum cost trees based on Minimum Steiner trees has been shown to be NP-Complete [3]. Minimum Steiner trees are shown to be complex to implement and may not result in a minimum cost tree when used in a WMN [4]. In [4], Ruiz et al use minimum number of transmissions as a link cost

metric and demonstrate that the problem of finding a MNT tree in a WMN is also NP-Complete. In [2] the authors acknowledge the fact that design goals in WMNs have shifted from maintaining connectivity to providing sufficient throughput. The authors use techniques taken from unicast routing and adapt them for multicasting and provide a comprehensive performance study. In [5] the author describes the main aspects of SPTs and MCTs. In this paper the author gives a very detailed analysis of a performance test between SPTs, MSTs and MNTs. The paper focuses on performance metrics (whilst partially neglecting link costs) and concludes that SPTs out-perform MSTs and MNTs. Each progression has made minor improvements or detailed observations in performance. Although there has been much research in this area and the problem has been addressed, it is still at a very early stage and as such, there is still vast room for improvement.

# 3    Goal Statement

In the following sections we set out to describe our research hypothesis. We also indicate how we intend to solve this problem and by what means.

## 3.1    Research goals

Our intention is to optimise a multicast Shortest Path Tree (SPT) path selection algorithm, by ensuring a SPT with maximum transmission rates. We also intend to develop an algorithm that is aware of the link costs such as contention, transmission time and signal strength. Our end result will also determine the minimum number of nodes required to maximise space efficiently over a given area. Thus we aim to design a multicast tree construction method which will use the wireless medium in efficient way.

## 3.2    Artefacts, tools, theories and methods

We will make use of the Dijkstra Shortest Path Algorithm [6] to develop shortest path multicast trees. We will implement our network using a custom made simulated network model developed in the Perl programming language. Our plan is to develop a simulator which takes into account wireless aspects of the operating environment and as such will allow us to design a multicast routing algorithm aware of the radio environment. Paths will be created in a randomly generated topology after which we will identify "key points" along a path which are to be considered for optimising. We will use a feed back mechanism to introduce additional supplementary nodes to optimise the path. Link metrics for each topology will be given a weighted link cost and the best path will be selected.

## 3.3    How will goals be reached?

The goal is to tailor a multicast routing algorithm for a wireless medium. To achieve this we plan to take into account various features of the wireless environment, such as transmission rate selection, contention or utilisation of the wireless spectrum. For example, by identifying the key points between nodes, i.e. point-to-point low transmission rate link and point-to-multipoint with one or more low transmission rate links, we can identify bottle necks in each path in the overall tree. We will also evaluate the network topology by taking into consideration the impact of neighbouring nodes. This will allows us to develop an algorithm which uses link cost metrics determined by neighbouring nodes. Using simulated networks we can verify if our method is successful. We will introduce a set of scenarios to determine how the network performs under certain conditions.

# 4    Method

In this section we give an overview of how we will conduct our research. We give details of assumptions made and the main characteristics of our model. We then explain how we intend to verify our results by use of physical experiments and comparison of results.

## 4.1    Procedural set-up

Our simulation will consist of an abstract simulated network model. The model will be fully developed using Perl programming language and all results will be logged and graphed using Gnuplot. We will also use the GD library to display the topological information. The model will have the following characteristics.

- The nodes will be placed in a 2D plane of specified dimensions (small, medium and large).

- We will specify the total number of nodes available for each simulation. The number of nodes utilised for the first pass of each simulation will be fixed in advance. After which we will log the number of additional nodes used from the total available in the second pass.
- We will allow for various node placement patterns to simulate different deployment scenarios
- Each node will be allowed to transmit a given packet only once (this is to conform to current 802.11 MAC broadcasting methods).
- The transmission rate for a point-to-multipoint is dependent on the lowest available PHY rate of an IEEE 802.11b network.
- We will use Dijkstras Shortest Path Algorithm to calculate the minimum path. Link cost metrics used (but not limited to), will be distance, transmission time, hop count, and interference.
- Performance metrics measured will be (but not limited to), average path delay, average throughput, average path length, number of forwarding nodes, number of nodes used.
- The model will identify point-to-point low link rate paths and point-to-multipoint low link rate paths.
- Use a feed back mechanism to introduce new nodes to the same network on a second pass and measure performance metrics.

## 4.2 Validation strategy

Once simulation has been successfully completed we will begin testing on a hardware based wireless mesh network in a laboratory. This test bed will consist of 25 Dell PCs running Linux OS and configured as wireless mesh nodes. Each node will be equipped with a Netgear WG311T wireless PCI card. To eliminate interference and to control attenuation between nodes in the lab, each node will be connected via RF cabling. Various topologies can be configured by using multiport power dividers, directional attenuators and a selection of in-line coupled attenuators. It will be possible to refine our simulation set-up based on feedback from the results of our experimental setup.

## 4.3 Proof of validation

Once computer simulation has been refined to a satisfactory degree we will replicate our results on the hardware based test bed. Because the simulation is an abstract model it will have certain limitations. However, by implementing our techniques using hardware we will be able to draw a comparison to our results. We would expect the hardware results to compare favourably to the simulated results and show an improvement in network performance.

## Acknowledgements

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