

Towards a Scalability Model for Wireless Mesh Networks

Shree Om, Carlos Rey-Moreno, William D. Tucker

Department of Computer Science, University of the Western Cape,
Private Bag X17, Bellville 7535 South Africa

{som, crey-moreno, btucker}@uwc.ac.za

Abstract— Zenzeleni mesh network is a wireless ad-hoc mesh network that provides voice services using public analogue telephones to the Mankosi community in the Eastern Cape Province. We would like to improve on the network infrastructure by upgrading the mesh routers and introducing low-end smartphones onto the network; and offer both data and voice over Internet protocol services. However, before deploying resources, it is imperative to identify the maximum number of mesh nodes, clients and simultaneous voice over internet protocol calls that can be supported by the mesh network while maintaining acceptable quality of service levels. Absence of such data might lead to financial risk and time depletion when setting up an optimal network. Bolstering the claim are investigations that report drop in quality levels as network density and hop count escalate. As current investigations mostly yield capacity models to predict per-node throughput with increasing hop count, we propose experiments to devise a scalability model to quantify scalability of mesh networks in this paper. We recommend experimental implementations at simulation level in Network Simulator-3 moving on to testbeds built using WiBed, and then finally take results to the field.

Keywords— Limited Range Communications, Ad-hoc, Planning issues, Simulation for Management Support.

I. INTRODUCTION

Zenzeleni mesh network (ZMN) is a community-driven, self-organized, decentralized and bottom-up mesh network deployed and operational in the Mankosi administrative area of the Eastern Cape Province, South Africa [1]. For the most part, the ZMN is managed and run by the local community, attracting revenue by charging mobile phones with excess solar power and also for breakout calls. The principle customer premises equipment for the network is an off-the-self router named Mesh Potato (MP) with an analogue telephony adapter. When an ordinary phone is connected to an MP and a call is made, the MP uses Asterisk to relay the phone call to another MP establishing automatic connection. This process continues until the destination is reached. So far, the ZMN allows calls to be made for free locally among 12 MP version 1 (MP01) units existing in the community with additional support for breakout calls via a gateway to landlines and mobile phones outside the network at a cost lower than that of the telecommunication operators [2]. Fig. 1 depicts the current network.

The next stage of the project considers an upgrade of the network by substituting the routers used with a newer version of the Mesh Potato, MP02, a router with more processing capacity and the possibility to connect an additional WiFi radio. We expect the upgrade to be able to offer data and VoIP services to low-end Wi-Fi-enabled smartphones. These devices would connect to the network in infrastructure mode, as the Mesh Potato allows the single radio to be multiplexed

for both ad-hoc and infrastructure modes simultaneously. This will make for a much more complicated network, although the mobile devices will not act as mesh nodes, but rather as WiFi clients. It is well known that wireless mesh network (WMN) performance degrades in terms of packet loss, delay and jitter as the number of clients and hops increase [3][4][5][6]. Hence, the community-driven initiative could suffer a costly mistake if the field network is upgraded without prior research and testing of network performance. A major step forward would be the ability to quantify the performance of the mesh network in advance of actual hardware upgrades in the field. To do so, this paper describes steps towards a model to find the minimum number of routers that are required to handle the traffic from a given number of client devices while maintaining acceptable quality of service (QoS) levels i.e., packet loss, delay and jitter for voice over Internet protocol (VoIP) calls. The paper proposes a framework to arrive at such a model and in turn a successful upgrade of the network.

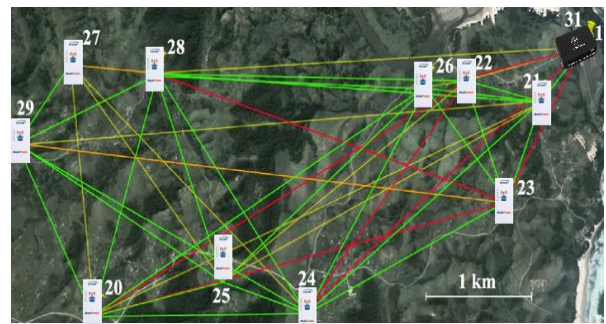


Figure 1: Current Zenzeleni mesh network with MP01s [2]

II. RELATED WORK

Attempts have been made to devise mathematical models to estimate per-node and network throughput capacity of wireless ad-hoc networks. Gupta and Kumar have presented two theoretical models; 1) $\lambda(n) = W/\sqrt{n}$ for arbitrary traffic pattern and 2) $\lambda(n) = W/\sqrt{n \log n}$ for random traffic pattern, where n is the number of nodes, W is the baseline throughput per single hop in Kbps and $\lambda(n)$ is the throughput capacity per node, to determine per node throughput capacity based on an extensive study of throughput degradation due to hop count in packet-based ad-hoc networks with single radios [7]. Further evaluation of models of Gupta and Kumar showed throughput decayed at the rate of $\lambda(n) = W/n^{1.68}$ [8]. Johnson compared Gupta et al.'s model [8] against their throughput results obtained from the outdoor mesh network and predicted the throughput decay to be $\lambda_{Pebbles}(n) = W/n^{1.62}$ [3].

After reviewing work on scalability and capacity models of WMNs, it appears that the proposed mechanisms do not present any clear indication of the maximum number of single radio mesh nodes, clients and simultaneous VoIP calls that can

be supported while maintaining acceptable QoS levels and none for BATMAN-adv using WMNs. In addition, the models presented to estimate change in throughput as the hop count rises do not present any evidence of any attempt at quantification of scalability which would be an ideal step forward. We agree with the conclusion of Johnson [3] that further analysis is necessary to understand the performance of mesh networks under severe load conditions.

III. PROPOSED DIRECTION

We would like to learn how to determine a scalability model for the Zenzeleni mesh network. A logical experiment system has been adopted i.e., to begin in a simulator and test the findings in a testbed before taking results to the field. The simulator chosen for the objectives of this research is Network Simulator-3 (NS-3) because when compared to the next best alternative, OMNET++, NS-3 uses lower memory, is more efficient on computation time and scalability, provides the suitable libraries, good emulation support, excellent documentation and user support [9][10][11][12]. In addition, NS-3 supports Direct Code Execution (DCE), which is a framework to execute existing implementations of user space and kernel space network protocols or applications without source code changes [13]. Using DCE, the routing protocol used in the Zenzeleni network, Better Approach to Mobile Ad-hoc Networking (BATMAN-adv), would be simulated. In order to facilitate quick and cost-efficient acquisition, deployment, and management of testbeds based on 802.11 for experimentation with wireless technology, WiBed testbed platform is being considered [14].

As a result, we aim to achieve the following:

1. Build and debug the BATMAN-adv network, used by Zenzeleni mesh network as a simulation model in NS-3.
2. Send realistic voice packets between clients to confirm correctness of the model.
3. Gradually increment number of simultaneous calls by increasing WiFi clients and simultaneously collecting performance results for throughput, packet loss ratio, delay and jitter with each increment.
4. Alter source and destination clients to observe change in performance results as distance changes.
5. Define a pattern of change in performance as call volume increases over different hops using simulation results.
6. Establish a formula to calculate the maximum number of WiFi clients a mesh node can efficiently support.
7. Evolve the formula to include the maximum number of WiFi clients that can be efficiently supported.
8. Test the formula by comparing results with simulation varying mesh nodes and clients and make adjustments.
9. Change simulation model in (1) by adding a second radio to mesh nodes for communication. The mesh nodes will have a 5 GHz radio for ad-hoc mode and 2.4 GHz radio for infrastructure mode, instead of utilizing a single radio.
10. Using simulation parameters of (3) and (4), simulate the model built in (9) and collect performance results.
11. Compare performance results of the single radio mesh node network with dual radio mesh node network.
12. Modify formula from (8) to suit the model built in (9).
13. Build testbed based on WiBed platform using MP02s and smartphones.

14. Replicate simulation parameters on live testbed and compare performance results.
15. Test scalability formula obtained in (8) and (9) for live testbed and make adjustments.

At the completion of experiments, the researchers will have a formula which, given the number of mesh nodes and clients, will yield a coefficient that will help predict the number of simultaneous calls that could be efficiently supported by the Zenzeleni mesh network. Hence, the scalability formula will predict the optimal combination of mesh nodes and WiFi clients for an efficient VoIP mesh network, and allow us to successfully upgrade the Zenzeleni network. It is hoped that other mesh network projects might use our formula to scale their own networks.

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Shree Om received MSc in Computer Information Systems from University of Botswana and BSc in Computer Engineering from University of South Alabama. He is currently pursuing PhD in Computer Science with the University of the Western Cape (UWC). His research interests are in mesh networking.