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Classification of Measurement in Two-Tier Urban Man

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Abstract: Multihop wireless mesh networks can provide Internet access over a wide area with minimal infrastructure expenditure. In this work, we investigate key issues involved in deploying such networks including individual link characteristics, multihop application layer performance, and network-wide reliability and throughput. We perform extensive measurements in a two-tier urban scenario to characterize the propagation environment and correlate received signal strength with application layer throughput. Further, we measure competing, multihop flow traffic matrices to empirically define achievable throughputs of fully backlogged, rate limited, and web-emulated traffic. We find that while fully backlogged flows produce starving nodes, rate-controlling flows to a fixed value yields fairness and high aggregate throughput. Likewise, transmission gaps occurring in statistically multiplexed web traffic, even under high offered load, remove starvation and yield high performance.

Keywords: network, multihoop, transmission MAN

I. INTRODUCTION

Mesh networks provide high-bandwidth wireless access over large coverage areas with substantially reduced deployment cost as compared to fiber or wire line alternatives. In a mesh network, fixed (i.e., non-mobile) mesh nodes are deployed throughout an area with a small fraction of the nodes featuring wired backhaul connections. The remaining wireless mesh nodes form a multihop wireless backbone to the nearest wired entry point.

Virtually unlimited applications exist for the use of mesh networks, from traffic control, transportation, and parking system inter-connectivity (the original motivation for the Philadelphia wireless project), to Internet connectivity or building automation within a multi-story business or home or a grid of heat sensors that prevent forest fires. The most prominent of these, of course, is providing high speed Internet access to communities and metropolitan areas. Although we focus here on the deployment of a two-tier mesh access network, our results are of merit for the deployment of any type of mesh solution. In a two-tier mesh network, an access tier provides a wireless connection between clients and mesh nodes, and a backhaul tier forwards traffic among mesh nodes.

In contrast, wireless technology provides an economically viable solution for low cost deployment of broadband networks. Yet, even wireless architectures must inevitably connect to the wire line Internet via costly backhaul, averaging $750/month for T1 1.5 Mb/sec access and $10,500 for T3 45 Mb/sec access. Consequently, we seek to minimize the number of wire line entries from the wireless access network to the backbone Internet.

Under these constraints, we utilize two-tier urban mesh access network architecture similar to the network. By using off-the-shelf components in our deployment, we leverage the economies-of-scale that have driven the costs of IEEE 802.11 components to a price point that is feasible for low-income communities. Moreover, we aggregate all traffic to a single wire line backhaul point and use directional antennae to form long-haul links as needed.

TFA-Wireless Business Model

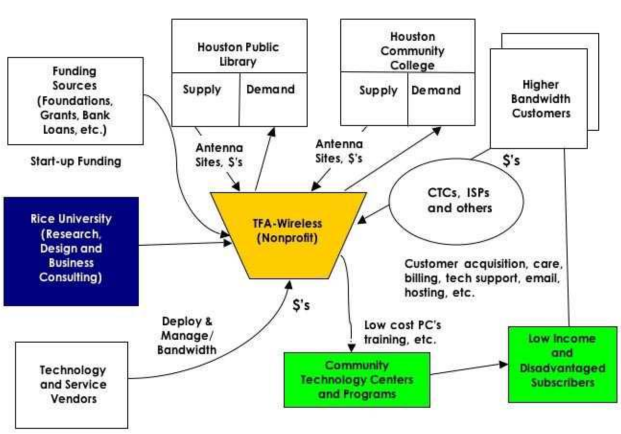

Fig 1 TFA's self-sustaining business model to offer free wireless Internet to low income users

II. TWO-TIER ARCHITECTURE

In our measurement study and network deployment, we employ two-tier network architecture as illustrated in Fig. 1. The access tier connects the client wireless device (e.g., a wireless laptop in a home or a wireless Ethernet bridge) to a mesh node. The backhaul tier interconnects the mesh nodes to forward traffic to and from wire line Internet entry points. Thus, the network provides coverage to all users within range of the mesh nodes. In our single-radio deployment, both tiers are realized via the same radio and channel, and we employ traffic management techniques (rate limiting) to ensure proper division of resources between access and backhaul.

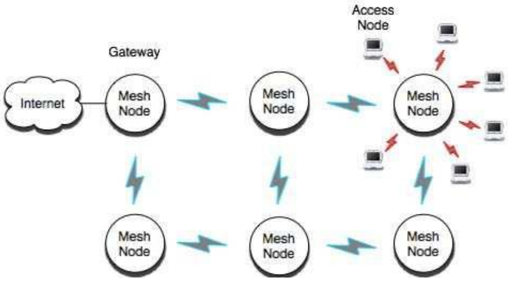

Fig 2 A two-tier networks consist of infrastructure nodes which forward packets and client nodes which only originate or source traffic.

We quickly found that penetration into the homes would be problematic for average (nominal powered) wireless devices. Thus, the client nodes within our network employ Ingenious/Senao CB-3 Ethernet bridges which have 200 mW transmission power and 3 dBi external unidirectional antennas.

III. LINK MEASUREMENTS

In this chapter, we present the results of our measurements of single-link performance of mesh nodes in our neighbourhood. The measurements represent both access and backhaul links and include received signal strength and throughput over a range of distances. We match our data to theoretical models to find a path loss exponent and shadowing standard deviation so that we can accurately determine the range and reliability of the mesh links. As there are no accepted theoretical models for throughput, we introduce an empirical mapping between signal power and achievable throughput.

The multiplicative effects of the wireless channel are divided into three categories: path loss, shadowing, and multipath fading. In this work, we focus on path loss and shadowing because they are the most measurable and predictable effects. Multipath fading produces dramatic variations in signal power, but the variations happen on such small scales of time and space that predicting them is prohibitively complex.

Path loss describes the attenuation experienced by a wireless signal as a function of distance. Extensive prior empirical modelling indicates that signal power decays exponentially with distance according to a path loss exponent that is particular.

Access Link Measurements

The following measurements characterize access links between clients (residences) and mesh nodes. The mesh node antennas are mounted at 10 meters while client nodes are fixed at a height of 1 meter. For a single fixed backbone node installation, we measure throughput and signal strength with the access node at many representative locations in the surrounding neighbourhood. We use iperf traffic generator to create a fully backlogged UDP flow by connecting a laptop to the access node via Ethernet. We record signal strength measurements provided by the wireless interface in the mesh node.

IV. RESULTS

Fig. 3 depicts signal strength measurements as a function of link distance. Using a set of 138 measurements, we calculate an empirical path loss exponent and shadowing standard deviation. The figure shows the theoretical path loss curve and curves representing 1 and 2 standard deviations around the mean due to shadowing.

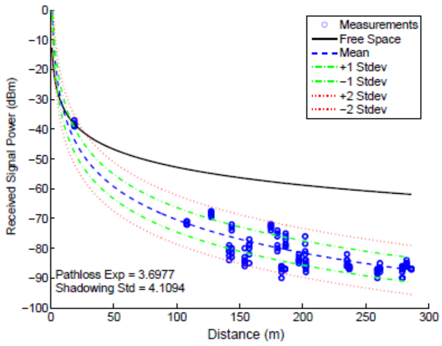

Fig 3 Empirical data and theoretical predictions for signal power received from an access node at 1 meter with a low gain antenna from a transmitter at 10 meters having a 15 dBi antenna.

V. EXPERIMENTAL SET-UP

We construct a parking lot traffic matrix consisting of five wireless nodes contending for bandwidth in a single branch of the backhaul tree. We perform the experiments outdoors in the same physical environment as the measurements using our mesh node hardware. To reduce the physical size of the parking lot, we opt for low gain (3 dBi) unidirectional antennas mounted at approximately 2 meters. We space the mesh nodes to achieve target signal strength of −75 dBm which is typical of a link between deployed mesh nodes. We perform each experimental trial at fixed locations, spaced approximately 100 meters apart. We illustrate the topology with every traffic flow of the parking lot experiments. In each test, we ensure that each mesh node will route data to its nearest neighbour only. That is, no node will send traffic directly to nodes that are two nodes away in the chain. There is one wired gateway mesh node for the topology. We use iperf sessions on the gateway and each of the nodes to generate TCP traffic for test intervals of 120 seconds.
Independently, we run iperf server-client applications from each node to its nearest with a fully backlogged queue to find the single hop link capacities. The physical layer rate is set to 11 Mbps on the wireless interface to remove auto rate fallback effects. We find that the effective link capacity between nodes is 4 Mbps on each link along the chain.

UDP vs. TCP Falloff

In both the upload and download case, the throughput falloff is not as pronounced for UDP traffic as TCP traffic. The reasons for this are twofold. Primarily, the additive increase, multiplicative decrease nature of TCP ensures that it will be sending below peak bandwidth most of the time. In contrast, our UDP experiments transmit traffic at the peak rate for the duration of the experiment regardless of packet loss. Additionally, TCP consumes bandwidth for acknowledgments in the reverse direction.

VI. CONCLUSIONS

In this work, we develop a measurement driven deployment strategy for a two tier urban mesh access network. With our link measurements, we parameterize the wireless channel and correlate channel effects with throughput performance. We then generate a probabilistic model for link throughput and reliability as a function of distance. We find that our backhaul links will be the bottleneck within our urban mesh deployment. Broadly, we find that elevated or backhaul nodes within an urban residential environment receive greater shadowing and multipath effects despite having less path loss than nodes at the ground level. In our multihop throughput experiments, we parameterize the multihop throughput distribution of competing, multihop flows. We find that in the fully backlogged parking lot scenario, simulations have less extreme spatial bias than CSMA hardware in an identical scenario. Further, we find that rate-control mechanisms and web traffic eliminate starvation and yield high performance. For our deployment, we find that we can expect mesh nodes support up to 35 simultaneous web users fairly with the ability to burst beyond this with reasonable fairness characteristics.

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