TFA: A Large Scale Urban Mesh Network for Social and Network Research

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ABSTRACT

We have deployed a large-scale multi-tier wireless network in one of Houston's most economically disadvantaged neighborhoods. The network serves two objectives: empowering under-resourced communities with access to technology, education and work-at-home tools, and providing an unprecedented platform for research of wireless communication technologies. In this paper, we present the joint societal objectives of the network, its technical and economical properties, the obtained research results, and future research challenges.

Categories and Subject Descriptors

C.2.1 [**Computer-Communication Networks**]: Network Architecture and Design-*Wireless Communication*

General Terms

Measurement, Performance, Reliability, Experimentation

Keywords

Mesh Networks, Under Resourced Communities, Programmable

1. INTRODUCTION

Rice University and Technology for All have partnered since September 2004 to architect, build and operate Internet access for one of Houston's most economically disadvantaged neighborhoods. To this end, we deployed the TFA wireless network serving more than 4,000 clients in a $4km^2$ area (see Figure 1). We also provided wireless-enabled computers, inexpensive 802.11 devices and smart phones to a subset of users for their free network access. The network serves both as a model for empowering low-income communities, and an unprecedented research platform that is fully observable and programmable, and has a real user population.

The paper is organized as follows: Section 2 presents societal objectives of the TFA network, Section 3 presents the current design of the network, Section 4 shows crucial research results obtained in the TFA network, while Section 5 describes planned evolution of the network.

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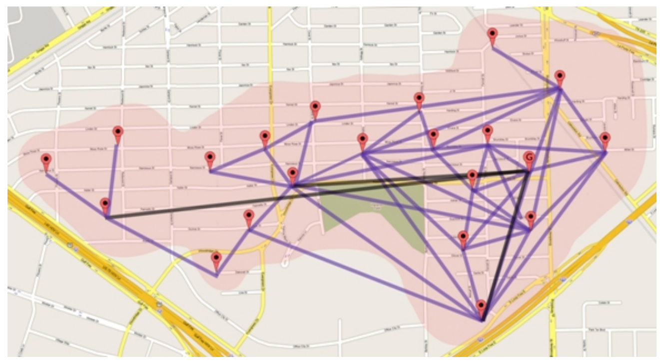

Figure 1: TFA network coverage map

2. SOCIETAL OBJECTIVES

In many homes across the United States, families have access to a wide spectrum of technologies enabling education, communication, search for employment, news, or entertainment. However, low-income communities cannot generally access such technology, thus not being able to exploit its offered opportunities. To address this problem, Rice University and non-profit organization Technology for All [1] partnered to reduce this digital divide in one of the most economically disadvantaged neighborhoods of Houston. In this neighborhood, per-capita income is approximately one-third the national average and 36.7% of children (under the age of 18) are living below the poverty line, according to the 2000 U. S. Census. Moreover, there is significant lack of education indicated by 64.2% of adults being without a high school diploma or GED equivalent[1].

As shown by a recent study [2], the access to technology resourced and the Internet can improve graduation rate, provide a community with better employment opportunities and subsequently result in economic improvement. A partner in our project, Technology For All, has developed several programs to enable users to benefit from the home Internet access. One of the programs is called "Learn and Earn," where students are encouraged to complete a course and community service in order for them to earn a refurbished desktop or laptop. The program "TFA-JobTech", initially funded by the U. S. Department of Commerce Technology Opportunity Program [3], enables livable-wage jobs in the homes of neighborhood residents via document conversion

[1]Houston Independent School District, July 2003

and coding performed via the Internet[2]. We have has also established a relationship with Houston Community College[3] that hosts one of the network nodes to provide online learning and student assistance programs. This extends classroom walls to the neighborhoods around the college.

In addition to these organized programs, having an Internet access offers benefits in itself. There is numerous evidence that the residents worked towards improving their own education or applied for employment on-line. Moreover, prior to the network deployment many homes did not have any land line service. To this end, the TFA network also provided users with personal benefits, providing them with email and free Internet telephony to communicate with their extended families often living abroad via communication.

3. TECHNICAL OBJECTIVES

Design Choices. The TFA network is designed to meet two technical objectives: pervasive Internet access at Megabits-per-second speeds, and sustainable deployment and operating costs for low-income demographics. This precluded deployment of a new wireline infrastructure with associated costs estimated to $200,000 per linear mile [4]. In contrast, we resorted to the wireless technology of low-cost of broadband networks. Yet, even these networks require a wired gateway connectivity to the Internet, costing on the average $750/month for T1 1.5 Mb/sec access and $10,500 for T3 45 Mb/sec access[4]. Consequently, our current deployment and its planned extensions aim to minimize the number of wireline entries that bridge the wireless access network to the Internet backbone. Under these constraints, we utilize a multi-hop wireless access network architecture as outlined in [5], employing a single gateway location.

The TFA-Wireless business plan has established a sustainable business model for providing broadband connectivity to residents of the neighborhood. The model works by charging competitive market rates to customers needing higher bandwidth and commercial service levels while providing free lower bandwidth service (128kbps) to low-income customers that have Houston Public Library cards.

Network Architecture. The TFA network features a multi-tier architecture. First, the access tier serves as a connection point for clients to access points (APs) that provide coverage in the neighborhood. Second, a backhaul tier wirelessly interconnects the network APs, primarily to forward client traffic from and towards the wired gateways. Finally, a capacity injection tier distributes capacity across the network. In particular, a single AP is connected to a 100 Mbps fiber gateway, whose capacity is further distributed through directional links to 3 APs. Those radios operate on separate channels, thus preventing any interference from other backhaul links.

Each TFA node is a PC-compatible computer employing a VIA EPIA Mini-ITX motherboard with a VIA C3 1GHz x86 processor and 512 MB of RAM. The storage is a 4GB DiskOnChip solid-state hard drive that offers robustness to mechanical impacts in field deployments. Moreover, this storage solution enables deployment of inexpensive node cooling. For communication, each node employs a variety of models of IEEE 802.11 high-power (200mW) PCMCIA wireless cards for omni directional coverage, and Ubiquiti SR5 cards for capacity-injection coverage over 5 GHz dedicated directional links. Our longest 5 GHz link is 1.8 km long. The node computers are stored in the NEMA 4 weatherproof enclosures that further connect to a variety of high-gain horizontally omni-directional or highly-directional antennas. To this end, we respect FCC regulations for the omni-directional coverage, such that the transmission power of our cards attenuated by the cable and connector losses is 15 dBi. Most of the ante nnas are elevated to 10 m masts in order to enable clear line-of-sight communication through a dense foliage in the area. At the gateway location we elevate antennas to a 30 m tower, resulting in a larger coverage area and better connectivity to other nodes.

In terms of software, the TFA network runs on a Linux kernel and an customized open-source mesh networking software originally developed by LocustWorld. The software platform supports wireless routing that directs traffic of wireless clients through the backhaul to the Internet. It also enables IPSec-based authentication of devices and clients ensuring that no rogue devices can misuse or associate to the network. Finally, we developed custom management software that informs the network manager about the network load, number of active clients, node failures, etc.

Finally, we note that the open-source nature of this network enables development and experimentation with custom protocols up to the basic functionality provided by the deployed hardware. Moreover, the memory capacity of individual nodes is sufficient to store days-long fine-grained data of network-wide measurements.

Network Topology. The current area covered by the network is $4km^2$. Our central location is at the TFA office building where we keep the central gateway and end-nodes of all capacity-injecting directional links. Other nodes are dispersed thought the neighborhood: in private houses, two public schools, Houston Community College (HCC), local YMCA center, and a local public library. All nodes have at least an omni-directional antenna providing a 225-275 meters radius of coverage. This distance constraint along with the performance-decreasing properties of multi-hop wireless communication led to the deployment of the capacity-injecting tier of directional links. The directional links connect the gateway location with the YMCA building, the HCC building and the local library. Currently, the network consists of 21 mesh nodes.

4. RESEARCH RESULTS

Our completed projects focused on the critical aspects of successful communication between wireless clients and wireless infrastructure. We present three crucial outcomes. First, our study of commonly occurring inter-link interference [6] showed that even a low-rate management and control traffic can produce disproportionally large degradation in data throughput. We identified that this results from data packets on forwarding links losing physical layer capture to the overhead packets on non-forwarding links, yielding in an order of magnitude larger degradation in data-throughput as compared to the interfering overhead rate. Next, our research on wireless routing [7] showed that the widely-employed, on-demand route selection inherently yields poor and long-lived routes due to decisions based on incomplete information. We showed that such incomplete routing information results from the actions of basic mechanisms of

[2]http://www.techforall.org/tfa jobtech.html
[3]http://www.hccs.edu/portal/site/hccs
[4]http://www.pathfinderbandwidth.com, May 2005

wireless overhead reduction. To this end, we devised a routing paradigm that exploits historical information in order to maintain the overhead efficiency while still making near-optimal selections. Finally, our client-based research [8] showed that current network interfaces employ policies that result in long outage durations, even when clients are always in range of at least one access point. To counter this, we designed and evaluated a family of outage-preventing client-driven handoff techniques. Employing channel quality measurements, long-term AP quality scores, or knowledge about hand-off time scales, our policies enable balancing of the instantaneously best associations against performance penalties incurred from spurious handoffs due to channel fluctuations and marginally improved associations.

5. FUTURE RESEARCH

Extensibility and Research Challenges. Our platform provides synergy of wide-ranging research issues on platforms ranging from widely-available hardware to fully custom FPGA designs. In a collaborative project of Rice University, Princeton University and the Methodist Hospital, we plan to extend TFA network to a Societally-driven Programmable At-Scale Wireless Network (SPAWN). The main objective of this network would be to enable disruptive system designs unconstrained by any existing standards. It enables research projects in the areas of wireless resource consumption, wireless access, and network health sensing. We will focus on following key elements for a development of such network:

1. SPAWN node would enable clean-slate programmability at any layer while simultaneously achieving throughputs required for urban deployments. The node will be a first-of-its-kind programmable wide-band platform able to access up to to 100 times more spectrum than any currently available research platform.
2. SPAWN scope would provide distributed signal, packet, and system monitoring across vast spectral, spatial, and temporal scales for both clients and infrastructure nodes. This would be a unique network-scale monitoring tool.
3. SPAWN net would enable fully-observable at-scale experiments with disruptive protocol designs driven by unique applications and traffic types. If would enable access for both specialized SPAWN devices, custom wireless health sensing devices, and widely-available 802.11 client devices).

The research on SPAWN architecture will be 3-pronged societally-driven research:

1. Green wireless would address energy architectures by analyzing SPAWNscope data to account for system-wide resource consumption.
2. Wireless for underserved communities would address low-cost wireless architectures and flexible spectrum access protocols and their specific utilization patterns by under-resource communities.
3. Wireless health sensing would study capabilities of continuous wireless health monitoring and processing of its data.

This strong interdisciplinary work will develop new research methods and yield core results for applications of wireless health sensing. It would benefit under-resourced communities and schools. The data sets collected by SPAWN-scope would be anonymized and made publicly available to serve as a unique resource for the research community. All SPAWNnode and SPAWNscope would be open-source. SPAWNnodes could be made commercially available to the research community. SPAWN workshops, data sets, and open-source code and platforms would promote community-wide efforts.

6. REFERENCES

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