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The changing usage of a mature campus-wide wireless network

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ABSTRACT

Wireless Local Area Networks (WLANs) are now commonplace on many academic and corporate campuses. As "Wi-Fi" technology becomes ubiquitous, it is increasingly important to understand trends in the usage of these networks. This paper analyzes an extensive network trace from a mature 802.11 WLAN, including more than 550 access points and 7000 users over seventeen weeks. We employ several measurement techniques, including syslog messages, telephone records, SNMP polling and tcpdump packet captures. This is the largest WLAN study to date, and the first to look at a mature WLAN. We compare this trace to a trace taken after the network's initial deployment two years prior.

We found that the applications used on the WLAN changed dramatically, with significant increases in peer-to-peer and streaming multimedia traffic. Despite the introduction of a Voice over IP (VoIP) system that includes wireless handsets, our study indicates that VoIP has been used little on the wireless network thus far, and most VoIP calls are made on the wired network.

We saw greater heterogeneity in the types of clients used, with more embedded wireless devices such as PDAs and mobile VoIP clients. We define a new metric for mobility, the "session diameter". We use this metric to show that embedded devices have different mobility characteristics than laptops, and travel further and roam to more access points. Overall, users were surprisingly non-mobile, with half remaining close to home about 98% of the time.

1. Introduction

Wireless Local Area Networks (WLANs) have become commonplace, especially on university and corporate campuses, and increasingly in public "Wi-Fi hotspots" as well. Most modern laptops are equipped with an IEEE 802.11 wireless network adapter, but wireless devices are rapidly diversifying to include PDAs, printers, audio players, and more. These new devices lead to changes in the way that WLANs are used. For instance, we might expect a wireless PDA to have different usage patterns than a wireless printer; a PDA might be more mobile as its user traverses a WLAN-enabled campus, whereas the printer may remain in one place to serve wireless clients.

The growing popularity of WLANs encourages the development of new applications, which may also exhibit new usage characteristics. Real-time multimedia applications, for example, have quality-of-service (QoS) requirements that may be difficult to fulfill in a shared-medium WLAN. Some of these new applications and devices may emerge simultaneously; for instance many wireless PDAs are equipped with streaming audio or video software. Understanding the usage, and trends in usage, of these new devices and applications is important for providers who deploy and manage WLANs, for designers who develop

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new high-throughput and multimedia-friendly wireless networking standards, and for software developers who create new wireless and location-aware applications.

In this paper, we study a large trace of network activity in a mature production wireless LAN. At the time, DartmouthCollege had 802.11b coverage for three years in and around nearly every building on campus. We collected extensive traces from the entire network throughout the Fall and Winter terms of 2003/2004.

Our study extends previous work in two ways. First, this is the largest study to date, with over 7000 unique wireless cards observed over 17 weeks. Second, we examine trends in behavior of a mature WLAN, and examine geographic mobility within a large WLAN. We compare this 2003/2004 trace to our earlier trace from Fall 2001, taken shortly after the initial installation of our campus WLAN. We found that the workload had changed significantly since 2001, and was significantly different than in other previous studies. We saw new embedded wireless devices, and new applications such as peer-to-peer file sharing and streaming multimedia.

The main difference between this paper and the original MobiCom conference version of this paper [12] is the additional data analysis in this version. In particular, we extend our analysis of application usage by considering usage at home and non-home locations in Section 6. We have also improved our method for detecting peer-to-peer file sharing applications, which has led to different results in Section 5.

We next describe the environment of our study, and then detail our methodology in Section 3. In Section 4, we compare the most interesting characteristics of the data to those taken from an earlier study. Section 5 examines three particular applications in detail: peer-to-peer file sharing, streaming media, and voice over IP. In Section 6, we analyze some of the mobility characteristics of the new devices and applications that we observed. Section 7 discusses related work, and Section 8 draws conclusions and lists recommendations for WLAN developers and deployers.

2. The test environment

The Dartmouth College campus has over 190 buildings on 200 acres. In 2001, Dartmouth installed 476 Cisco 802.11b access points (APs) to cover most of the campus. Since then, APs have been added to increase coverage and to cover new construction, and at the time of this study, there were 566 APs. The compact nature of the campus means that the range of indoor APs covers most outdoor areas.

All APs share the same SSID, allowing wireless clients to roam seamlessly between APs. On the other hand, a building's APs are connected to the building's existing subnet. The 188 buildings with wireless coverage span 115 subnets, so roaming clients may be forced to obtain new IP addresses. (During our study, Dartmouth began to move its WLAN to a small set of separate VLANs, reducing the number of subnets.)

Dartmouth College has about 5500 students and 1200 faculty, and during our study there were approximately 3300 undergraduates on campus. Students are required to own a computer, and most purchase a computer through the campus computer store. Wireless laptops increasingly dominate those purchases, making up 45% of the total in 2000, 70% in 2001, 88% in 2002, and 97% in 2003. Assuming that students obtaining computers elsewhere choose laptops in the same proportion, we estimate that over 75% of the undergraduates owned laptops at the time of our study. In 2008, at the time of this writing, the number is close to 100%.

2.1. Voice over IP

In the summer of 2003 Dartmouth began to migrate its telephone system from a traditional analog Private Branch Exchange (PBX) to a Voice over IP (VoIP) system. A new Cisco VoIP system included a "CallManager" call processing server, which served to connect callers and callees, and bridge to the PBX and the local telephone company. A second, independent VoIP system by Vocera [28] served wearable voice-controlled Wi-Fi badges; its server connected Vocera callers to other Vocera users, and bridged to the PBX, CallManager, and telephone company. Note that only our internal telephone network has migrated to IP; all off-campus calls route to the telephone company and beyond, and these other telephony providers may not use VoIP.

The VoIP roll-out was still underway during this study. At the time of our study only approximately 500 licenses (for Cisco's SoftPhone) had been issued. Vocera devices were available for rent at subsidized rates. Wired and wireless Cisco VoIP phones were also available, along with a VoIP client for wireless PocketPCs.

2.2. Client devices

Since most students own laptops, we expected most of the devices on our WLAN to be Windows or Macintosh laptops. As the WLAN has matured and a larger variety of client devices has become available, however, we also expected to see more non-laptop devices on the network.

To determine the types of devices in use, we used the OS fingerprinting tool p0f [21] on our tcpdump traces (see Section 3 for details of our collection infrastructure) to identify the operating systems used by a given device. p0f uses differences in TCP/IP stacks and implementation flaws (e.g., timestamp values, initial window sizes, ACK values and TCP options), to derive an OS signature by scanning packet traces, much as nmap [9] and TBIT [22] do. We chose p0f for its extensive list of OS signatures.

For each card (MAC address) seen in our syslog and SNMP traces, we ran p0f on all of its TCP flows recorded by our sniffers. If all guesses for a card were the same OS (ignoring version numbers), then we assigned that OS to the card. If all guesses could run on the same CPU (e.g., Linux and Windows both run on x86), then we assumed that card was a dual-boot machine.[1] We left the card as "unidentified" if p0f guessed OSes that ran on different CPUs,

[1] We assume that these cards represent dual-boot laptops. They could be cards that have been inserted in different machines. This distinction, however, does not affect our analysis.