Access and Mobility of Wireless PDA Users

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1 Introduction

As wireless network access proliferates, understanding user behavior and wireless network performance has become crucial as a basis for developing and evaluating new applications, such as context-aware applications, new network infrastructure, such as middleware support for public-area networks, and new wireless communication architectures, such as ad-hoc and multi-hop networking. Over the past few years, there have been a number of wireless workload studies characterizing user behavior and network performance in a variety of settings, including: metropolitan networks [6], university campuses [4], conferences [1], and most recently corporate networks [2]. The goals of these studies have ranged from developing low-level radio signal and error models [3], network installation and maintenance issues [1], and characterizing user workload models, network performance, and mobility of laptop users [4].

We extend previous wireless studies by characterizing the mobility patterns of users of wireless handheld PDAs in a campus wireless network, and evaluate the implications of these mobility patterns on new wireless communication architectures like ad-hoc and multi-hop networks. We use a trace of wireless network availability by 292 freshmen with HP Jornada PDAs over the course of the Fall, 2002, term at U.C. San Diego. A key aspect of our trace is the focus on handheld PDA users. Even more so than laptop users, we expect handheld PDA users to exhibit high degrees of both casual and extended wireless access and mobility.

Our research has three goals. First, we characterize the high-level mobility and access patterns of handheld PDA users, and compare these characteristics to previous workload mobility studies focused on laptop users. Second, we develop two wireless network topology models for use in wireless mobility studies: an *evolutionary topology model* that represents connectivity among users solely based on observed network proximity, and a *campus waypoint model* that serves as a trace-based analog to the popular random waypoint model. Previous work frequently uses synthetic models of user mobility patterns to drive simulations, and we argue that such work can benefit significantly from mobility models based on actual user behavior. Finally, we use our wireless network topology models as case studies to evaluate wireless network protocols and applications, such as ad-hoc routing algorithms, in a realistic setting. Since wireless protocol evaluation under realistic user settings has been rare [5], we know little about the tradeoffs and applicability of these algorithms to common situations.

In the rest of this paper, we describe the trace that we use to perform our study (Section 2), summarize the mobility behavior of our PDA users (Section 3), describe the two new mobility models that we derive from our trace (Section 4), and present initial results of ad-hoc routing simulations using our models and discuss future work (Section 5).

2 Data Collection

We collected trace data from 292 freshmen PDA users for an 11 week period between September 21, 2002 and December 7, 2002. The freshmen were the initial students in a new UCSD college representing most majors on campus. Each PDA was equipped with a Symbol Wireless Networker 802.11b Compact Flash card. The PDAs consisted of approximately 100 Jornada 548s and 200 Jornada 568s running the Windows Pocket PC 2000 and 2002 operating systems, respectively. We identify users using their wireless card MAC address and assume that there is a fixed one-to-one mapping between users and wireless cards. We have no mapping of MAC address to user names and no attempt was made to discover this information.

We equipped each PDA with a background data collection tool we developed called WTD (Wireless Topology Discovery). For this trace, WTD periodically recorded *all* 802.11b access points (APs) that the PDA NIC could sense when it was powered on, not just the AP it was associated with. The period was 1 minute to tradeoff the granularity of the samples with the resource and power overhead of collecting them. Occasionally, WTD contacted a server to upload its sample collection in bulk. The UCSD campus has extensive 802.11b coverage in which students can roam. In our trace, students associated with over 400 unique APs.

Figure 2 shows the number of active PDAs each hour for the Fall 2002 quarter, with an inset graph showing activity for the first week. The number of active users declines over the term as PDA usage declines.

3 User Behavior

First we characterize the mobility and access patterns of our PDA users, focusing only on user mobility among access points on campus (Figure 3), user session length (Figure 4), and user session count (Figure 5) due to space constraints.

We find that students are relatively mobile and use their PDAs in many locations. Over half of the students associated with at least 20 APs on campus, and in extreme cases some students associated with more than 140 APs. Compared to the laptop users in the Kotz and Essien study [4], we find that the typical wireless PDA user is twice as mobile as the typical laptop user in terms of associated access points. In [4], the typical laptop user associated with a median value of only 9 APs over a 77-day duration.

We also find that student usage of PDAs is relatively bursty, likely reflecting the ease with which users can carry and activate their PDAs as well as the constraints of using PDAs for extended periods of time. The median session duration, or the time a PDA remains connected to the wireless network, was only 6 minutes compared to 17 minutes for laptop users [4]. Further, only 15% of all sessions are at least an 1 hour, compared to 29% for laptop users.

Finally, although some students used their PDAs extensively, many only used them only occasionally. Over 10% of the students had 300 sessions over the 77-day trace, roughly using their PDA four times a day. However, 50% of the students used their PDA at most once per day or less.

4 Mobility Models

Previous work frequently uses synthetic models of user mobility patterns, such as the popular random waypoint model, to derive wireless network topologies that change due to user mobility. To complement these synthetic models, we propose two new models of network topologies that incorporate user mobility patterns from our traces. Our *evolutionary topology model* represents connectivity among users solely based on observed network proximity: an edge connects two nodes if two users can reasonably communicate with each other. As a reasonable approximation of direct connectivity, we create an edge between two users during a time slot if the intersection of the set of APs sensed by their PDAs is non-empty, and remove the edge if the intersection of APs becomes empty again. In this model, the network topology evolves over time as nodes and edges appear and disappear based upon PDA on/off events and movements observed in our trace. Figure 6 shows an example topology derived from this model for 36 users on a typical Monday in Roosevelt College.

Our *campus waypoint model* serves as a trace-based analog to the random waypoint model. In this model, we associate users with geographic locations on campus and model their mobility vectors and potential interactions as they access the wireless network over time. However, rather than choosing user locations, speeds, and directions using random distributions, we instead use the access and mobility patterns of users in our trace. We determine user location based upon the set of APs they sense and the known locations of those APs. We model user mobility based upon (1) the evolving set of sensed APs over time, and (2) the disappearance and reappearance of users at different AP locations on campus assuming reasonable velocities.

Our preliminary results indicate that the basic random waypoint model does not serve well as a mobility model for our setting. Unlike node mobility in the typical random waypoint simulation, we find that only a small percentage of users are actually in motion at any one time. In addition, these movements rarely exceed a few feet per second. Another important difference is that users appear and disappear in the trace. This behavior, absent in most documented simulations, can and does have drastic effects on network topology and connectivity. Perhaps the reason for the absence of this behavior in most simulations is in part due to the fact that node on/off events are not currently implemented in the popular ns2 simulator. We have, however, extended ns2 to model these events for the protocol evaluations of Section 5.

Our evolutionary model also emphasizes the limitation of the popular two-ray ground reflection model for radio propagation in an environment containing obstacles. This radio propagation model is often used in wireless networking simulations to determine when nodes are within communication range by calculating the strength of the received signal(s). Figure 6 shows that the evolutionary model accounts for obstacles to generate a more realistic connectivity graph than the two-ray ground model. For this geographic setting, the two-ray ground model would create a completely connected graph under typical radio settings.

5 Routing Evaluation

Groups of users with handheld PDAs have often been used as a motivating setting for ad-hoc networking. Therefore, we use our trace data to study ad-hoc routing algorithms on the network topologies formed among users of modern wireless PDAs.

As an initial evaluation, we used ns2 version 2.1b8 to compare the performance of the DSR, DSDV, and AODV ad-hoc routing protocols. Our study focused on the Roosevelt College student housing area from noon to 1pm on Monday, September 23, 2002. This area consisted of eight buildings laid out in approximately a 130mx130m square area (lower right corner of Figures 1(a) and 1(b)). We chose this area and time for initial study because it corresponds to one of the higher node densities in our trace. Though node numbers fluctuated, there were at least 30 PDAs active during the hour of simulated communication.

Using the default ns wireless constant bit rate (CBR) traffic of 4 packets/sec, 512 byte packets, we ran simulations with a random 10, 25, and 50 percent of the nodes communicating at any one time. Preliminary simulation results indicate that all three protocols perform well in this scenario using the evolutionary topology model (Figure 6). Even with nodes appearing and disappearing, all three protocols were able to quickly adapt to find new routes between senders and receivers to deliver nearly all deliverable packets.

These results reflect the low rate of change of our network topology. Students moved around in the network during the hour, but the rate of movement was slow compared to the ability of the routing protocols to adapt. Although admittedly dependent upon our trace scenario, these preliminary results suggest that many ad-hoc routing simulations are overly aggressive in their parameter choices for speed (up to 20 m/sec) and mobility (sub-minute). Such choices emphasize topological change and, consequently, perhaps place too much emphasis on an *uncommon* case. In other words, the basic routing protocols perform quite well in this scenario and do not appear to require significant additional optimization. As ongoing work, we are also evaluating other scenarios at other locations on campus and at other time periods to derive more general conclusions.

Because this simulation area was only 130mx130m, we did not evaluate the campus waypoint model for this scenario since all users would be in direct range of each other. We are developing a campus waypoint model that models the movement of users across the entire campus as well as across longer time periods.

References

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