Influence of Mobile User Velocity on Data Transfer in a Multi-Network Wireless Environment

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***Abstract*—Heterogeneous wireless environments are now a reality in many urban areas. Designing and deploying a wireless network in such an environment is complicated by the unpredictable propagation paths of radio signals and by the unpredictable behaviour of the network users themselves. Network simulation and modelling can be used to assist in the design process. However, in order for simulation models to be effective they must be realistic. Efforts have been made to render simulation models more realistic through the analysis of real world wireless networks and through the examination and evaluation of existing simulation models. The most fundamental characteristics of a mobile user are their mobility, and the speed at which they move. The various velocities used in simulation models are unrealistic with respect to pedestrian behaviour in urban environments. In addition, the possible influence of mobile user velocity on the amount of data transferred by the user is not considered. In this paper we examine the influence of a mobile user's velocity on throughput in a wireless network using a range of realistic velocities.**

***Index Terms*—heterogeneous wireless network environment, user mobility, user velocity, throughput.**

I. Introduction

Heterogeneous multi-network wireless environments provide a mobile user with the ability to connect to various networks. Wireless networking allows the user to access network services from different locations and even while moving. Urban planners are deploying wide area wireless networks in various cities (e.g. San Francisco [1]) in order to attract both visitors and additional businesses.

One of the defining characteristics of a mobile user is their ability to change position at various velocities. As any mobile phone user is acutely aware, changes of position may result in signal quality modifications. It is reasonable to assume that changes of position have some effect on the amount of data transferred by a mobile user using wireless communications links. This assumption raises various questions, including the following:

- Would a mobile user's velocity have a noticeable effect on the amount of data transferred?
- If user's velocity affects the amount of data transferred, is the effect constant for certain changes in user's velocity?

In order to be able to provide a cost effective, efficient wireless network it is necessary to understand how a mobile user's behaviour within such an environment affects the service they receive. The design and deployment of wide area wireless networks in urban areas is complicated by the random propagation paths taken by radio signals within a built environment and the unpredictable behaviour of mobile users themselves. Network simulation and modelling can play an important part in the design process and for this reason it is important to consider the possible effects of user movement on performance within a simulated environment. This paper investigates how a mobile user's velocity influences the data throughput they achieve within a simulated network environment.

The paper is organised as follows: section II presents related work, section III describes the simulation setup and scenarios used and section IV contains the results of the simulations performed. Section V presents an analysis of the simulation results and section VI conclusions are drawn.

II. Related Work

A large amount of work has been carried out in the area of wireless networks, their users and the way in which users seek to take advantage of the wireless environment. This work looks at both real-world wireless networks and simulation work.

A deployed metropolitan-area wireless network is analysed by Tang and Baker [1], while Henderson, Kotz and Abyzov [2] and Schwab and Bunt [3] analyse campus-wide wireless networks. Although the influence of mobile user velocity on network performance in not examined in this work they provide many other useful insights. McNett and Voelker in [4] note in passing the average velocity of network users and even compare it to velocities used in simulation work but make no reference to its impact on the network. Work has also been undertaken that evaluates simulations and mobility models. Kotz et al in [5] examine assumptions commonly used in simulation work through experimentation. None of the assumptions examined concern mobile user velocity. Jardosh et al in [6] suggest the development of more realistic mobility models through the introduction of obstacles into simulations

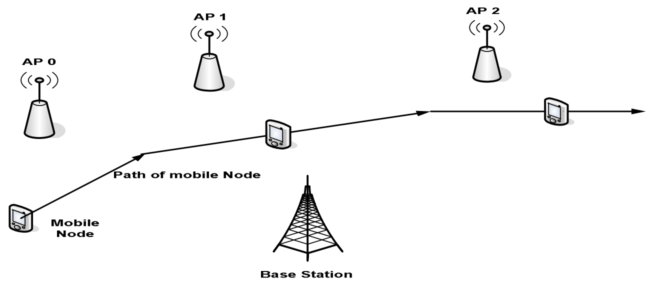

Fig. 1 Multi-network Wireless Environment

and the construction of movement paths. Again, mobile user velocity is not mentioned as a contributor to realistic models.

A survey of various mobility models used in ad hoc networks was carried out by Camp, Boleng and Davies [7]. Mobile node velocity is illustrated in a graph of the number of packets delivered against the mobile node speed. The graph shows a decrease in the number of packets delivered as the node speed increases but the authors do not address this issue or comment on it.

Our work differs from previous work in its examination of mobile user velocity as a central issue that has been ignored in previous work. We believe that mobile user velocity is central to user impact on wireless networks and we examine the influence of mobile user velocity on data throughput using realistic velocity values.

III. Multi-network wireless environments

Several types of wireless technologies can be used by a mobile user to access data networks. These include various types of cellular network technologies (e.g. GPRS, WCDMA), WiFi (IEEE 802.11 /b/g) or mobile WiMAX (IEEE 802.16e).

Each type of network has its own advantages and disadvantages. WiFi networks offer low-cost high-capacity network access over relatively small areas. Cellular networks offer higher-cost, lower capacity access to data networks over much greater areas; they are also more common than WiFi networks and cover most urban areas.

IV. Simulation Setup

For the examination of the user velocity influence on the amount of data transferred, this paper makes use of a simulated urban heterogeneous wireless environment like the one presented in Figure 1. The environment consists of three WiFi networks and one cellular network. Network simulation package NS2 [8] and TeNS NS2 extension package [9] are used. The TeNS extension provides NS2 with the ability to use directional antennas and simplifies power control of the antennas.

A simulated topology measuring 800m X 800m containing three, IEEE 802.11b Access Points (AP) and one 3G Base Station (BS) was created. The antenna transmit power of the APs was set at 5mW and the antenna transmit power of the BS was set at 5W. A single mobile node was configured to follow the same path, at a different velocity for each simulation run.

TABLE I
ARC OF ACCEPTANCE
FOR SIMULATED WIFI (802.11G) DIRECTIONAL ANTENNAE

Node	Arc Angle (degrees)
Access Point 0	40
Access Point 1	40
Access Point 2	90
Mobile Node	30

TABLE II
ARC OF ACCEPTANCE
FOR SIMULATED 3G ANTENNAE

Node	Arc Angle (degrees)
Base Station	360
Mobile Node	360

The path followed by the mobile node consisted of three, connected straight segments. This decision was taken as the authors of [10] show that pedestrians move in straight lines whenever possible and not in the randomised patterns favoured by many mobility models [5]. Also, vehicular traffic movement in urban environments cannot be random, with regard to direction or road placement, since the traffic must follow defined routes, travelling in defined directions.

We sought to isolate the mobile nodes rate of movement as the only variable within the simulated environment. In order to achieve this aim, the simulated environment was very restricted; all communications between the mobile node and the APs or the BS were Constant Bit Rate (CBR) data streams over UDP connections. The data transfers were from the mobile node to the APs or the BS. A field survey carried out by the author in an urban environment had shown that a mobile user connected to WiFi networks could suffer from sudden, unexpected and complete loss of connectivity. To mimic this behaviour within the simulation environment the following modelling decisions were made:

- Each simulated WiFi AP and the mobile node was fitted with a directional antenna. These directional antennas had restricted coverage arcs and narrow arcs of acceptance. Communications between the APs and the mobile node could only be established when the arcs of acceptance of the directional antennas were aligned. When the arcs of acceptance of the directional antennas went out of alignment, the communications link was lost. This mimicked the sudden losses of connectivity observed during the field trial. As stated previously, WiFi APs have a smaller coverage area than cellular Base Stations; this was modelled by using a low transmission power for the APs.
- A cellular networks BS has a greater coverage area and lower data transfer capacity than a WiFi AP. To mimic these characteristics, the node designated as the cellular network BS was given an omni-directional antenna, having a greater transmission power than the APs. A suitable antenna was also attached to the mobile node to enable communications between BS and mobile node. The BS node was configured to have a far lower data transfer rate than the APs. So, although the coverage /

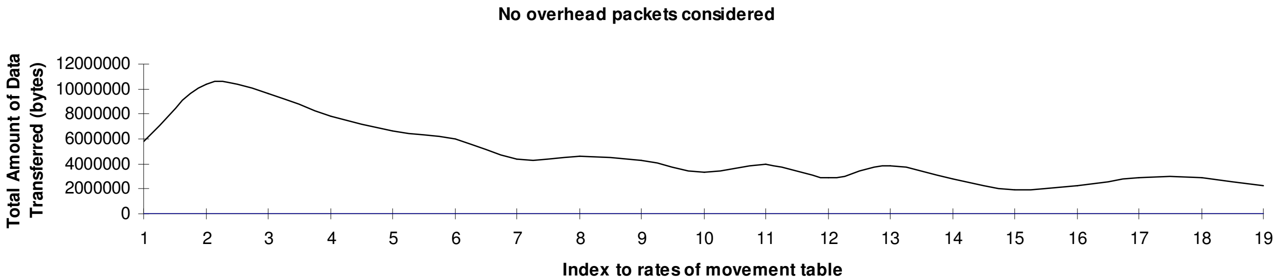

Fig. 2 Total amount of data (in bytes) transferred at velocity shown in Table 4, calculated *without* overhead packets

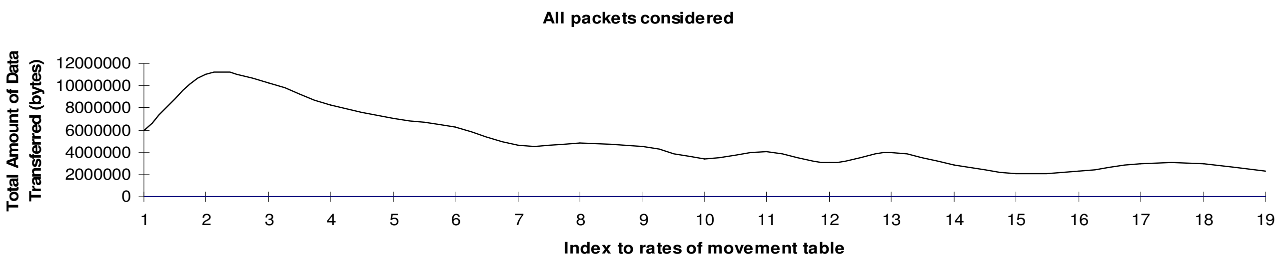

Fig. 3 Total amount of data (in bytes) transferred at velocity shown in Table 4, calculated *with* overhead packets

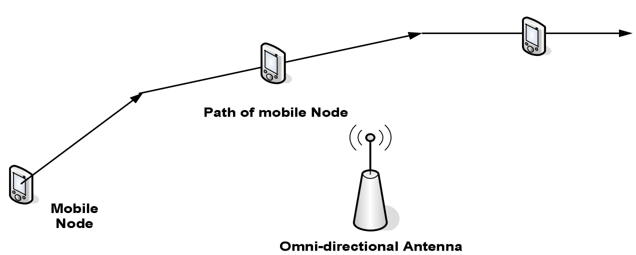

Fig. 4 Wireless environment with one mobile and one stationary node

range were greater, thereby allowing connectivity for longer periods, less data could be sent.

The arcs of acceptance for the various antennae are shown in Table 1 and Table 2 and were chosen arbitrarily. The only criterion used was that the arcs be sufficiently narrow so as to cause rapid, unexpected disconnections when alignment with other directional antennae was lost. In order to investigate the effects of changes in the mobile user's velocity on the total amount of data transferred, various mobile user velocities were defined. It was decided to select four different velocities for the mobile node. The following velocities for the mobile node were selected:

1) 1 m/s (approximately 3.6 km/h) – this was the observed to approximate speed of mobile users with PDAs [4]
2) 1.3 m/s (approximately 4.68 km/h) – the average rate of movement of a pedestrian in a free flowing urban setting [11, 12, 13, 14, 18]
3) 3 m/s (approximately 10.8 km/h) – the average speed of a public bus in urban conditions at peak traffic times [15, 16].
4) 4.7 m/s (approximately 16.92 km/h) – the average speed achieved by public buses during off-peak hours [15].

For the purpose of the simulations, connections between the mobile node and the APs were modelled on IEEE 802.11b data rates and the connection between the mobile node and the BS was modelled on 3G data transfer rates with all rates fixed. The simulation consisted of the mobile node moving along a pre-defined path through the wireless environment. The path carried the mobile node past the three APs and the BS, affording the mobile node the opportunity of connecting to each. The simulation was run a total of four times with the mobile node moving at a different rate, as described above, each time. In each of the simulations the mobile node started from the same initial position. The rate of movement was not altered during the course of a simulation run.

V. Testing Results

The flow of data during the simulation runs was, primarily, from the mobile node to one of the stationary nodes, either an AP or the BS. Total number of bytes transferred was calculated at the receiving station and did not include overhead packets such as routing packets, etc. The information used to calculate this value was extracted from the NS2 trace files using a Perl script [17].

Table 3 shows the total amount of data transferred to each AP along the mobile nodes path through the simulation environment. It can be clearly seen, that for each AP, as the velocity of the mobile node increased, the amount of data received at an AP decreased. The total amount of data transferred was calculated without considering overhead packets and is shown in megabytes. The value shown in brackets is the percentage decrease in the amount of data transferred from the highest amount observed for that node. Table 3 also shows the total amount of data received at the Base Station. As is the case with the APs, the total amount of data received decreased as the mobile nodes rate of movement

TABLE III
DATA TRANSFERRED
(IN BYTES) AND OBSERVED DECREASE IN COMPARISON WITH THE LOWEST SPEED CASE (AS PERCENTAGE)

Speed (m/s)	AP 0 (MBytes)	AP 1 (MBytes)	AP 2 (MBytes)	BS (MBytes)
1	41.47	42.26	21.90	7.70
1.3	31.83 (23.24% decrease)	30.05 (28.9% decrease)	16.40 (25.12% decrease)	6.94 (9.85% decrease)
3	13.58 (67.3 % decrease)	14.1 (66.67% decrease)	22.3 (89.8% decrease)	4.44 (42.39% decrease)
4.7	8.47 (79.6% decrease)	7.3 (82.78% decrease)	2.74 (98.75% decrease)	3.58 (53.55% decrease)

TABLE IV
MOBILE NODE SPEEDS IN THE COMPARISON-BASED SIMULATION

X-axis value	Associated velocity (m/s)
1	0.25
2	0.5
3	0.75
4	1
5	1.3
6	1.5
7	1.75
8	2
9	2.25
10	2.5

X-axis value	Associated velocity (m/s)
11	2.75
12	3
13	3.25
14	3.5
15	3.75
16	4
17	4.25
18	4.5
19	4.75

increased. The results from each simulation showed a similar trend, that is, a significant decrease in total amount of data transferred for increases in a mobile user's velocity. It was unclear, however, if this was as a result of the four velocities chosen, the use of directional antennas, a combination of these or a more generalised phenomenon. In order to test the relationship between mobile user velocity and the total amount of data received at either an AP or BS it was decided to run a second set of simulations.

The second simulation setup illustrated in Figure 4 contained only two nodes, one mobile and the other stationary. The stationary node was configured with an omni-directional antenna and the mobile node was fitted with an antenna suitable for transmitting data to the stationary node. In this simulation the mobile node also followed the same route as the mobile node in the first set of simulations and started from the same initial position each time. Again, communications between the two nodes was primarily from the mobile node to the stationary node. The basic data rate of the stationary node was equivalent to the IEEE 802.11b standard with an antenna transmit power of 5mW. Unlike the first set of simulations that only used four different velocities for the mobile node, this set of simulations used nineteen different velocities (Table 4).

The simulation was run once for each of the velocities shown in Table 4, and the total amount of data transferred was calculated at the stationary node. For completeness, this value was calculated twice, once including overhead packets and once without overhead packets. The resulting values were plotted on graphs and are presented in Figure 2 and Figure 3. The integer values along the x-axis of the graphs in these figures are used to index the 19 rates of movement. For example, the value 3 on the x-axis refers to the rate of movement of 0.75 m/s in Table 4. A comparison of results plotted in Figure 2 and Figure 3 shows that calculating the total amount of data transferred with or without the inclusion of "overhead" packets has no discernible effect on the observed trend.

VI. ANALYSIS OF RESULTS

The total amount of data received at an AP or BS was calculated using the information contained within the NS2 trace files. These trace files are generated during the simulation process. In the first set of simulations the total number of bytes received at an AP or BS was calculated without considering "overhead". For the receiving nodes in each of the first series of simulations, the total amount of data received was observed to decrease as the velocity of the mobile node increased. In the second set of simulations, as the mobile user's velocity begins to increase, a sharp initial increase in the total amount of data received is observed (Figure 2 and Figure 3); this increase is only observed in the velocity range 0.25 to approximately 0.6 m/s. However, as the mobile user's velocity increased beyond 0.6 m/s the total amount of data received decreased. Overall the effect is one of decreasing transferred data totals as mobile user velocity is increased. This holds true for nodes having either directional or omni-directional antennas and regardless of the underlying data transmission capabilities of the nodes. The sharp, initial increase in the amount of data received at an AP for increased mobile user velocity seen in the second set of simulations (Figure 2 and Figure 3) appears to be the result of the mobile node reaching the area of optimal throughput faster than at the lower velocity. However, once the mobile user's velocity exceeds approximately 0.6 m/s the observed total amount of data transferred decreases. This is due to the fact that, as velocity increases less and less time is spent in the area of optimal throughput. The general decrease in the amount of data transferred is observed regardless of whether or not this value is calculated using all packets received at a node or a subset of the packets received.

The cause of the decrease in the total amount of data transferred for a mobile user as their velocity increases lies in the nature of the wireless network components. Every wireless node (AP, BS or mobile device) has a limited transmit/receive range; the range differs from node to node depending on various factors such as the type of node, its physical capabilities, etc. Proximity to an AP or a BS in conjunction with the number of concurrent users determines the amount of data a user can send or receive. A mobile user moving through a heterogeneous wireless environment may be moving towards or away from such an AP or BS, thereby increasing or decreasing the amount of data they can send or receive. In addition there will invariably be breaks in network coverage caused by blocked signals or non-overlapping networks, resulting in loss of connectivity. Within a wireless environment there will be areas of optimal performance and conversely, there will be areas of sub-optimal performance.

For a mobile user the amount of data sent or received depends on the amount of time spent in the area of optimal performance of an AP or BS. Intuitively, we may feel that by increasing their rate of movement, a mobile user will spend less time in areas of sub-optimal performance and will move into areas of optimal performance faster. While this is the case, increased rates of movement also mean that a mobile user spends less time in areas of optimal performance and also moves into areas of sub-optimal performance sooner.

VII. CONCLUSIONS

The results obtained from the simulations show that, within a simulated environment, the rate at which a mobile user changes position does have an impact on the total amount of data transferred by the user. Moreover, this is a negative impact with the total amount of data transferred decreasing as the mobile user's rate of movement increased. This decrease was observed in simulations using both directional and omni-directional antennas and it occurred over a range of mobile user rates of movement. It has also been observed in ad hoc networks [7]. Furthermore, the rate of decrease was not found to be constant across a range of rates of movement.

If simulation software is employed in the design phase of a wireless network it is necessary to consider all elements that might impact on the results obtained, since skewed results may lead to incorrect design decisions being reached. The elements considered should include the rate of movement of a mobile user since this is shown to have a significant impact on the level of performance they achieve within a simulated environment.

VIII. FUTURE WORK

The results of the simulations need to be verified by testing using real equipment in a controlled environment. The simulations also require replication in network simulation software other than NS2. This is to ensure that the results obtained by the simulation work outlined in this paper are not a performance anomaly particular to NS2 and TeNS.

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