A Mobility-Based Cost Model in a 2-hop Relay Wireless Hotspot

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Abstract: In this paper, we study the effects of mobile nodes on various performance metrics such as delay, throughput and loss rates. We endeavour to look into the issue of fairness towards stationary nodes when mobile nodes are moving at a high speed and we derive the normalised cost a node (mobile or stationary) has to pay towards using the wireless network. We also try to understand the consequences of having a certain percentage of mobile nodes among all nodes within the same area and observe the impact on network performance.

1. Introduction

Most Wireless Local Area Networks (WLAN) assume a single hop between access point and the source node, however, this is going to change in the next generation WLAN with the trend of moving towards multi-hop since it can improve network performance and extend range. The effect of mobility in multi-hop relay is not well understood. Source and relay movement has a great effect in relaying functionality. Multi-hop route changes over time, resulting in additional routing overhead and increase in packet losses. So as a consequence of node mobility, the overall network performance will vary as well over time.

In the 2-hop network discussed in this paper, we use a 2-hop path for an uplink transmission (from source node to relay node, and then from relay node to access point) and a single-hop path for a downlink transmission (from access point to source node). There are many advantages justifying this configuration [1,2]. Mainly, a single-hop downlink is chosen over a 2-hop downlink from the access point because the access point is assumed to have infinite power whereas clients are assumed to have limited power (justifying a 2-hop uplink). These assumptions are realistic because most wireless access points have wired backbone connection.

2. Mobility-Based Cost Model

Hotspot providers are looking into ways to price their services fairly and improve their customer satisfaction/experience. The performance gains of a single AP network can be represented by four parameters, namely, throughput, latency, energy consumption and loss rate. We also derive a mobility-based cost model to penalise nodes that lead to detrimental of network performance.

In multi-hop WLAN, mobility gives rise to many issues. User mobility results in changes in network topology over time that may cause break in the multi-hop path and failure of wireless links. There have been multiple studies on the performance of WLANs, mostly theoretical. Gupta and Kumar [3] demonstrate that the best throughput performance achieved is approximately $1/\sqrt{n\log(n)}$, when n sources are fixed, and distributed randomly in the network. In the same way, Bansal and Liu [4] prove that if we add mobile nodes functioning as relays, there will be an improvement in performance proportional to their number in the network. In [5], it is shown that the achievable throughput increases significantly when nodes are mobile rather than stationary, using relaying functionality among nodes. Consequently, these theoretical results show that the performance of the overall network is affected positively by the user mobility but only within a certain speed range. When nodes move at a very high speed, the effects of mobility become very destructive with additional radio-signal impairments like Doppler Effect.

In this paper, we focus on uplink transmission in a mobile multi-hop WLAN where registered users wanting to communicate with an access point (AP) can go through a relay node if there is one available. We propose a function that calculates the cost a node has to pay for his communication based on its speed. We denote these ranges by $\{r_i \,; \mathrm{i} \geq 0\}$ which corresponds to the whole range; $\{r_i \,; \mathrm{i} > 0\}$ corresponding to speed values for mobile nodes and r_0 relates to stationary nodes. We associate a coefficient α_i to each range r_i. This coefficient must be between -1 and 1, a positive value of coefficient indicates that the node has to pay more than another node with a negative value of coefficient. The number of nodes for a range r_i is referred by n_i. The cost computed represents the normalized user payment to communicate in the wireless network.

For a node X with a speed in the range of r_j , the cost is defined by the following function C:

$$X \in r_j \Rightarrow C(X) = \frac{1+\alpha_j}{\sum_{i\geq 0} n_i \left(1+\alpha_i\right)} \quad ; \forall i \geq 0 \quad -1 < \alpha_i < 1 \qquad (1)$$

The precision of the function C is related to the speed values used by the different nodes inside the network; which means it is related to the environment of the wireless network. If many nodes in the network are within a close speed values range, a smaller speed interval is needed. However, if nodes in the network have widely spread out speed values (with high deviation, i.e. large wireless networks), loose speed ranges will be satisfactory.

3. Experimental Studies

In this study, we use the network simulator NS-2 [6] to simulate a virtual environment of 260×260 m for 40s simulation time. We model a two-hop network, in which we have an access point in the middle of the simulated environment and a given number of nodes randomly distributed in the area. All the nodes are in the transmission range of the access point. However, some nodes may have limited resources (such as battery power) and may want to use a lower transmission power. In order to reach the access point, this node has to be either near the access point or rely on a relay. For relaying, we use a two-hop path, because it gives reasonably good network performance in comparison with a single-hop path connection based on simulation results from [2]. We evaluate network performance with metrics such as local throughput, local delay and packet loss rate for the different schemes.

Local throughput: the total number of packets successfully received at the access point per second.

Local delay: the average time that a packet takes to travel from the sender application to the receiver application.

Packet loss rate: the ratio between the total number of dropped packets and the total number of sent packets by all source nodes.

The nodes in the network move according to the “random way point” model. During simulation, each node randomly selects a destination and moves towards it with a specified speed. On reaching this destination it repeats the above procedure until the end of the simulation. The simulations run with different speed values ranging to 150m/s. The scheme where nodes are stationary is modelled by the speed value of zero. The access point is stationary throughout the entire simulation period.

All nodes except the access point are sending data over 802.11b transmission channel. The packet size is 1024 Bytes. Traffic sources in the simulation are CBR (constant Bit Rate). We use CBR because it gives “raw analysis”, has a fixed bandwidth and it is typically used by applications like video and audio. As verified in [7], AODV (Ad hoc On-demand Distance Vector) has better performance results compared to other ad hoc routing protocols implemented in NS-2 (DSR, DSDV, TORA). Our simulations use AODV as routing protocol.

4. Results and discussions

The first scenario consists of the network described earlier varying the number of mobile nodes in it (10, 20 and 40 nodes) in function of the nodes’ speed. We compute the throughput, delay and packet loss rate to evaluate the performance. In the second scenario, we check whether the mobility of a given number of nodes in the network can affect the network performance. For this, we fix the number of network node to 20 and vary the number of mobile nodes within the 20 nodes.

Scenario 1: From figures 1, 2 and 3, we notice that the throughput decreases, delay and packet loss rate increase with increasing speed at the first observation. This result was expected because we use AODV routing protocol in the relaying and that routing information needs a substantial amount of overhead to cope with variation of the network. Then, we observe that at low mobility (<20m/s) the throughput is higher for a 20 and 40 mobile nodes network than for no mobile nodes case (at speed of 0m/s) at 1.4 Mbps and 0.9 Mbps respectively. However, the delay and loss rate for a 40 mobile nodes is incredibly high compared to a 10 and 20 mobile node network. It is also noted that a small number of mobile nodes in the network (such as 10) actually cause a reduction in the throughput to less than 1.9Mbps as compared with 10 stationary nodes (having an overall throughput of 1.9 Mbps). As the speed of node increases from 20m/s to 150m/s, the overall throughput decreases by 0.4 Mbps for 20 mobile nodes and by 0.5Mbps for 40 mobile nodes. The observed behaviour tally with the theoretical results presented in [4] that demonstrates the achievable throughput is proportional to the number of mobile nodes and inversely proportional to the number of sources.

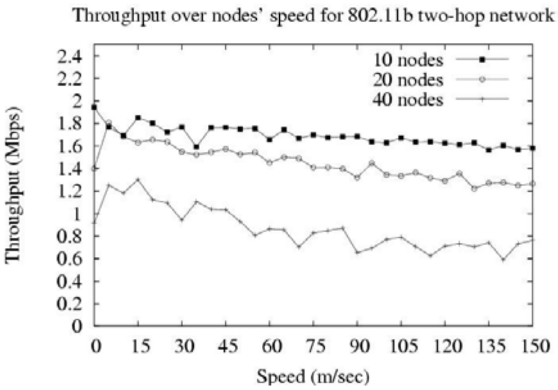

Figure 1 Throughput versus Speed – Scenario 1

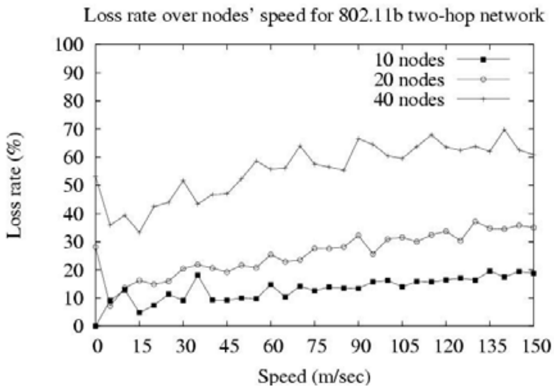

Figure 2 Loss rate versus Speed – Scenario 1

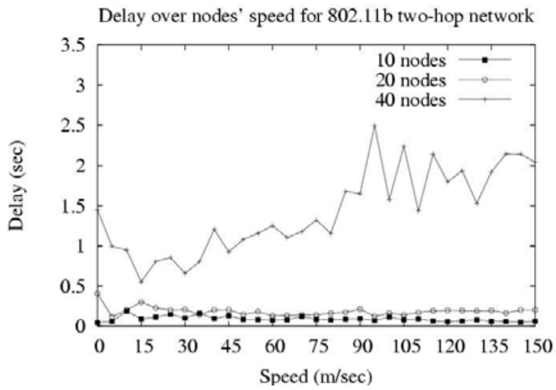

Figure 3 Delay versus Speed – Scenario 1

Scenario 2: Figures 4 and 5 show the overall throughput, average delay and overall loss rate of a network with a maximum of 20 nodes consisting of two types of nodes: stationary and mobile. Similar to the first scenario, the throughput performance improves for low nodes' mobility and then decreases for high mobility. As the speed of the mobile nodes increases from 0 to 20m/s, the gradient of the rising slope (refer to Figure 4) is steeper for a 20 mobile nodes network in comparison with a 2 mobile nodes with 18 stationary nodes. When it comes to the decreasing gradient of the slope (refer to Figure 4) as the speed increases beyond 20m/s, the network with 20 mobile nodes has a steeper slope than the other one. At low mobility (< 15m/s), we can see that the more mobile nodes we have, the greater the gain in performance. At higher mobility (> 60m/s), it is advantageous to have less mobile nodes among total number of nodes to attenuate the high mobility effects. From our work, we conclude that the best performance (max. throughput of 1.8Mbps) occurs when there exists a large number of mobile nodes (the case where all nodes in the network are mobile) at a maximum speed that does not exceed 15m/s. From figures 4 and 5, we differentiate four different groups based on the speed. The first one corresponds to stationary nodes, the second to mobile nodes with speed less than 20m/s, the third group to mobile nodes with speed that ranges from 20 to 60m/s and finally the fourth group to mobile nodes with speed that exceeds 60m/s. For the cost model, the first and the third group should have the same transmission cost because the network performance is quite similar, for example they have a coefficient α (α < 0) for both of them. The second group should have the smallest cost because it has the best achievable performance, so smallest coefficient α' (α' < α). And the fourth group should pay the largest cost due to the poor performance obtained, the coefficient will be α'' (α''>0).

So using our cost function in Section 2 and the figures below, we manage to derive a fair and simple way to compute the user communication cost in a mobile WLAN, and at the same time we incite users to avoid high mobility that will deteriorate the overall network performance.

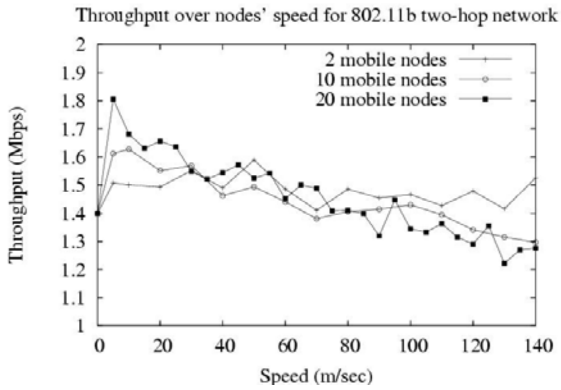

Figure 4 Throughput versus Speed – Scenario 2

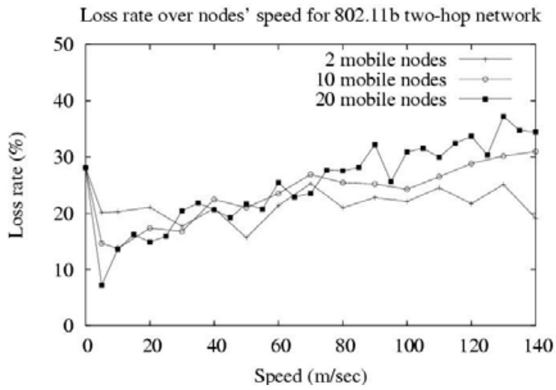

Figure 5 Loss rate versus Speed –Scenario 2

5. Conclusions

The main contribution of this paper is the presented communication cost function based on mobility of nodes. We also carried out simulation scenarios to verify network performance with mobility. From the simulation results, we demonstrated that the number of mobile nodes and their speed have an effect on the network performance. For low mobility, this effect is as beneficial as expected in many of the theoretical results undertaken in this field. For high mobility, we prove that what was concluded before in the theoretical results did not fit because we have relatively mediocre results for throughput, delay and packet loss rate especially for large number of mobile nodes. To conclude, scalability for mobile wireless networks is an important issue that should be carefully analysed. As future work, we have to propose new thoughts on how to achieve acceptable network performance for large mobile wireless networks.

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