Capacity of Single-Radio *Ad Hoc* Networks for Handling High Bit-Rate Real-Time Internet Applications

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CAPACITY OF SINGLE-RADIO AD HOC NETWORKS FOR HANDLING HIGH BIT-RATE REAL-TIME INTERNET APPLICATIONS

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ABSTRACT

Until now, the main focus in Ad hoc networking has been improving Routing and Medium Access Control (MAC) strategies. As a result, a diverse range of routing and MAC protocols have been proposed. To evaluate these protocols, much of the existing research has been based on simulation scenarios which assume ideal channel conditions and low node and traffic densities. Therefore, despite a few studies which have shown the performance limitations of ad hoc networks theoretically, there has not been many simulation studies performed which investigate the performance of ad hoc networks over high node and traffic density. This paper investigates the performance of ad hoc networks under a high node density and high-bit rate real-time traffic such as VoIP. Our results show that the performance of single radio Ad hoc networks drops significantly as traffic density is increased. To improve the performance of Ad hoc networks, a number of different strategies and research areas are described.

1. INTRODUCTION

Ad hoc networks promise a self-reliant approach to interconnecting wireless devices, by introducing distributed and decentralized routing. In these networks, all nodes are capable of transmitting, receiving and determining multi-hop routes. Ad hoc networks may be mobile, static or both, the Ad networks which contain mobile nodes are commonly referred to as Mobile Ad hoc Networks (i.e MANETs).

Over the last decade the research in Ad hoc networking has been predominantly around developing routing and strategies to share the wireless medium in a distributed manner. This has resulted in the proposition of a wide range of routing and medium access control strategies [6][5]. Much of this research has been studied using ideal or less restrictive networking conditions such as small node and traffic density, ideal channel conditions and unlimited power. Given these limitations in the previous literature, there has been a growing doubt in the research community about the capabilities of Ad hoc networks with currently available hardware (e.g. 802.11 radios), for real-time multi-media applications such as Voice over IP (VoIP) [7][4]. Hence, there is a need to investigate the performance of Ad hoc networks under these applications. This paper investigates the performance of Ad hoc networks under VoIP type traffic.

VoIP is rapidly becoming the more preferred method of voice communications compared to the traditional circuit switched voice networks. This is due to the significantly lower call costs provided by this technology, as it enables calls to be routed over the Internet, and hence share the available bandwidth with other applications and users.

While VoIP is a well proven service over fixed networks, VoIP performance over radio networks is an on-going research area. The widespread penetration of 802.11 has prompted numerous studies of VoIP performance over 802.11 links. The relatively high maximum rate of 802.11 links (11 Mbps for 802.11b, 54Mbps for 802.g and 802.11a respectively), coupled with the relatively low capacity needed for VoIP (tens of kilobits per second), would indicate that 802.11 links can handle high call volumes, e.g. many hundreds of calls. However, the relatively strict delay and loss requirements for acceptable voice quality limit VoIP call capacity [12], even without background data traffic. Additionally, most studies of VoIP performance over 802.11 links have considered a single radio hop only, as this is the most common implementation. However, the Ad hoc networks will generally comprise multiple (802.11) links, and hence VoIP performance must be considered in this multi-hop environment.

The rest of this paper is organized as follows. Section II and Section III present the simulation scenario and metrics used evaluate the performance of multi-hop ad hoc networks under VoIP type traffic. Section IV presents a discussion on the simulation results. Section V describes possible improvements to the single radio wireless ad hoc network model and future research in area. Section VI presents the conclusions of this paper.

2. SIMULATION MODEL

To simulate the behavior of Ad hoc networks, the GloMoSim simulation package was chosen [1]. GloMoSim is an event driven simulation tool specifically designed to simulate and investigate the performance of wireless Ad hoc networks over various types of networking conditions and protocols. Here we outline the simulation model parameters used in our study.

The simulations were performed for 20 and 100 node networks, migrating in a 5000m x 3000m area. This represents a sparse and a densely populated network respectively. To emulate the behaviour of a radio device for ad hoc networks, the IEEE 802.11 DSSS (Direct Sequence Spread Spectrum) was used with maximum transmission power of 15dbm at 11Mb/s data rate. In the MAC layer, IEEE 802.11 was used in Distributed Coordination Function (DCF) mode. The radio capture effects were also taken into account. A two-ray path loss characteristic was considered as the propagation model. An omni-directional antenna model was used, with a height of 1.5m and a gain of 15dbm, with a potential transmission range of up to 2.1km. The radio receiver threshold was set to -81 dbm and the receiver sensitivity was set to -91 dbm according to the Lucent Wavelan card [2]. The AODV routing protocol was used to determine routes between nodes over multiple hops [3]. AODV is a hop-by-hop routing protocol which has be designed to minimize overheads during routing by determining routes on-demand.

Random way-point mobility was used model the mobility and the movement pattern of each node. This model is used to investigate the performance of the Ad hoc networks under various levels of mobility levels (e.g. from a highly mobile network to a static network). In Random way-point model, nodes travel at a constant speed in a particular direction, then pause for a specified length of time and then travel to a different direction for set period of time. In the simulations, the node mobility was set to vary from 0 to 20m/s and pause time was varied between 0 and 200s.

The simulations ran for 200s and each simulation was averaged over four different simulation runs using different seed values. To generate traffic in to the network, Constant Bit Rate (CBR) traffic model was used to transmit data between nodes. Each CBR packet contained 28 Bytes and was transmitted at 0.02s intervals, which emulates VoIP type traffic.

The simulations were ran for 5, 10 and 20 client/server pairs [1] and each session begin at different times and was set to last for the duration of the simulation.

3. PERFORMANCE METRICS

The following performance metrics where used to investigate the performance of the ad hoc network:

Packet Delivery Ratio (PDR) Normalised Control Overhead (O/H) End-to-End Delay

PDR is the Ratio of the number of number of packets received by the destination to the number of packets sent by the source. The Normalised Control Overhead (O/H) is the ratio of the number of control packets transmitted for each data packet which was successfully transmitted. The End-to-End Delay represents the average delay experienced by each packet when traveling from the source to the destination.

4. RESULTS

This section presents a discussion on the simulation results obtained from Glomosim.

4.1. Packet Delivery Ratio

Figure 1, 2, 3 and 4 illustrate the PDR for the 20 and 100 node scenario. The first two figures show a single radio Ad hoc network achieves over 99% PDR. Therefore, the results suggest that in sparely populated ad hoc networks VoIP could operate successfully. However, in a dense network (in this case a 100 node network), the PDR performance of a single radio Ad hoc network worsens significantly. This is because, in this model, only one radio (and one frequency) is used for all communications. Hence, as the network and traffic becomes denser, the channel contention between all nodes increases, which means the available bandwidth for each node, will be lower. The drop in performance becomes significantly more evident when the number of flows is increased in the 100 node scenario. This is due buffer flows at each node, which result more data packets being dropped.

4.2. Normalised Control Overheads

Figure 5, 6, 7 and 8 illustrate the normalised control overhead for the 20 and 100 node scenario. For the first three scenarios, the amount of traffic due to control packets is less than 7%, leaving the

[1] Note that the terms Client/Server, src/dest and Flows are used interchangeably

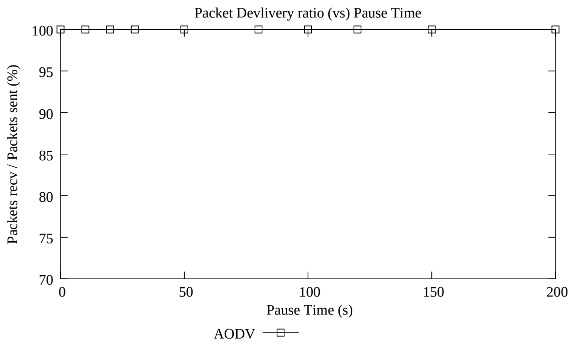

Figure 1: PDR: 20 Nodes and 5 Flows

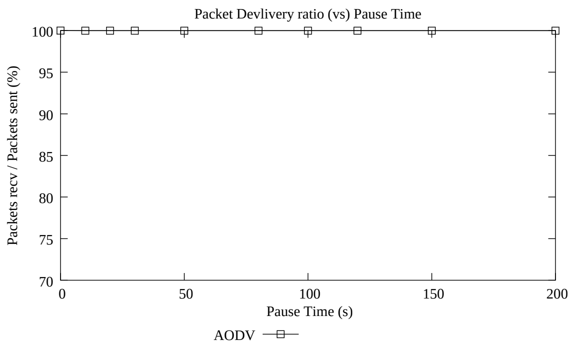

Figure 2: PDR: 20 Nodes and 10 Flows

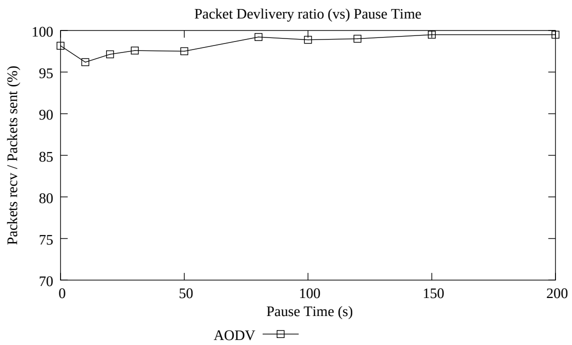

Figure 3: PDR: 100 Nodes and 10 Flows

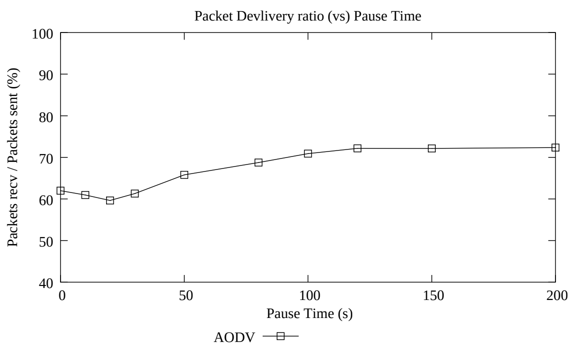

Figure 4: PDR: 100 Nodes and 20 Flows

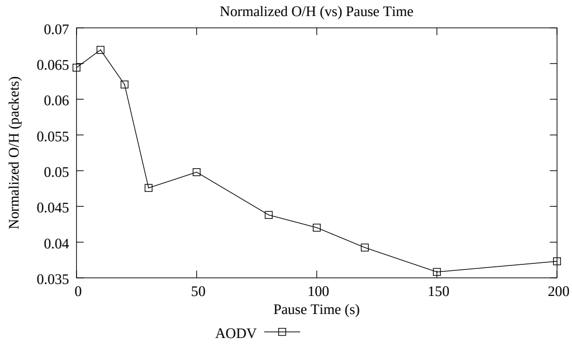

Figure 5: O/H: 20 Nodes and 5 Flows

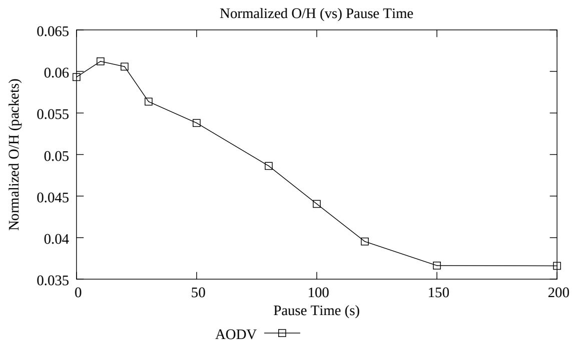

Figure 6: O/H: 20 Nodes and 10 Flows

remaining network capacity for application, such as VOIP. However, for the 100 node network with 20 flows, this figure increases up to 15.5%, representing a more significant burden on the network. This increase in control overhead is due to an increase in demand for additional routes required in the 20 Flow scenario. Consequently, as the number of flows increases, the level of control overhead introduced into the network plays a more significant role in the level of scalability achieved in an Ad hoc network. Hence, minimising the level of control overhead in Ad hoc networks is still an important in high-bit rate applications.

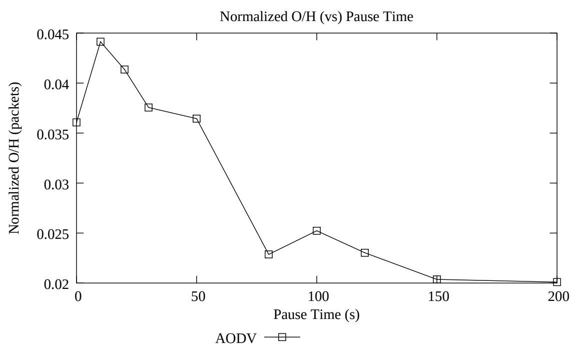

Figure 7: O/H: 100 Nodes and 10 Flows

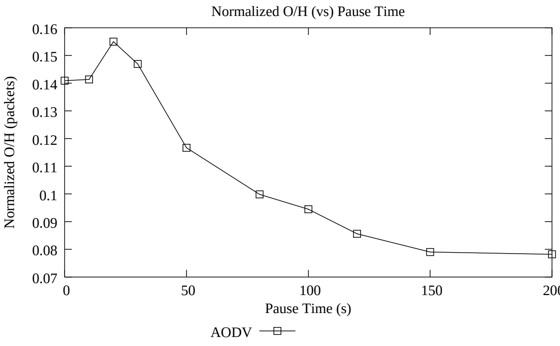

Figure 8: O/H: 100 Nodes and 20 Flows

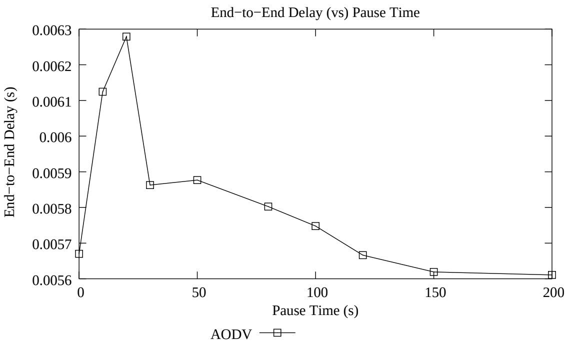

Figure 9: Delays: 20 Nodes and 5 Flows

4.3. Delays

Figure 9, 10, 11 and 12 illustrate the end-to-end delay for the 20 and 100 node scenario. The average delay produced in the first two figures is mostly lower than 10ms, which will not significantly affect VOIP performance. However, Figure 11, the delay is significantly higher, exceeding 200 msec at times, a level which will noticeably impact VOIP performance. This increased delay is due to higher channel contention (arising from higher node density), compared to the 20 node scenarios. Another factor that contributes to increasing delay is the increased control overhead associated with higher node densities. The increase in delay becomes more evident in figure 12 when the delay becomes too high to sustain VoIP traffic. Therefore, a single radio model would not provide efficient and low delay routes as the traffic and node density increases.

5. IMPROVEMENT STRATEGIES AND FUTURE RESEARCH

From the results obtained in the previous section it can be seen that single radio ad hoc networks may not scale under high bit rate applications such as VoIP. In this section we describe a number of different strategies and new research areas which could improve the scalability and capacity of wireless Ad hoc networks.

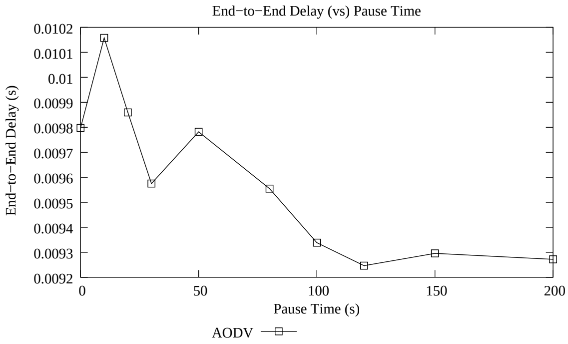

Figure 10: Delays: 20 Nodes and 10 Flows

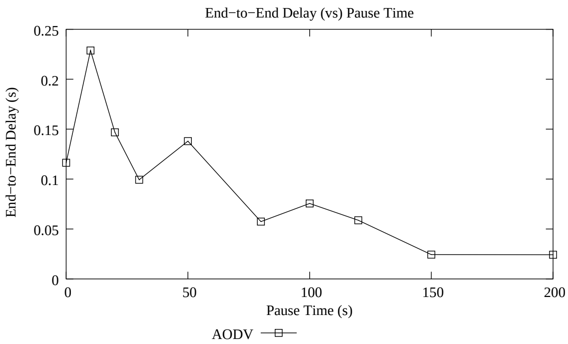

Figure 11: Delays: 100 Nodes and 10 Flows

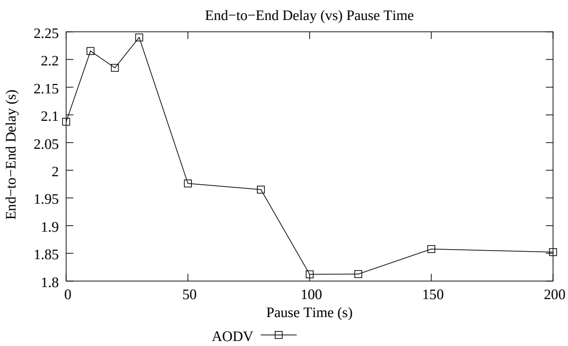

Figure 12: Delays: 100 Nodes and 20 Flows

5.1. Multi-Radio Ad-hoc Networking

One way to improve the scalability of Ad hoc networks is by integration of various types of radio in each end-user Ad hoc network device. A multi-radio ad hoc networking devices provides the following advantages of the traditional single radio devices:

- Allows to dedicate one or more radios for backhaul communication, between areas, and one for local area communications. This may increase the available bandwidth for both local and backhaul communications. A dedicated radio for backhaul means that interference with local communications would be minimised.
- Allows for integration of different radio-models in one device (i.e. 802.11a and 802.11b), means that channel contention would be reduced, and resulting in greater scalability.
- Provides more bandwidth as more radio and channels can be used to transfer data.

Up to now the focus of research on ad hoc networks has been on single radio devices. Therefore, the research in Multi-radio ad hoc networks is still in its infancy. Further research is required to develop new MAC and routing strategies, which take advantage of the availability of multiple radios.

In the future, we plan to develop a multi-radio ad-hoc network test-bed and compare its performance to a single radio ad hoc network model.

6. CONCLUSIONS

This paper presents a performance study of Ad hoc networks over both sparse and densely populated nodes handling VoIP type traffic. Our results indicate that single radio Ad hoc nodes may perform well in sparse scenarios, however as the network becomes denser and the traffic increases their performance may reduce. In improve the performance of single radio wireless Ad hoc networks a number of different strategies where described. In the future, we plan to investigate the performance of multi-radio ad hoc networks over densely distributed ad hoc networks.

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