Admission Control and Route Discovery for QoS Traffic in Ad Hoc Networks

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Abstract. As wireless networks become more widely used, there is a growing need to support advanced services, such as real-time multimedia streaming and voice over IP. Real-time traffic in wireless ad hoc networks often have stringent bandwidth or delay requirements. For example, a delay of over 150 ms in voice transmissions is felt as disturbing by most users. To support quality of service (QoS) requirements of real-time applications, various traffic control mechanisms such as rate control and admission control are needed. In this paper, an admission control and route discovery scheme for QoS traffic is proposed. It is based on on-demand routing protocols and performs admission control implicitly during the route discovery process. Local bandwidth measurements are used in admission control decisions. Simulation results have shown that this admission control scheme can greatly improve network performance such as packet delivery ratio and delay.

1 Introduction

A wireless mobile ad hoc network (Manet) is an autonomous system where all nodes are capable of movement and can be connected dynamically in an arbitrary manner. Without a network infrastructure, network nodes function as routers which discover and maintain routes to other nodes in the network. As wireless networks become more widely used, there is a growing need to support advanced services, such as real-time multimedia streaming and voice over IP. Real-time traffic in wireless ad hoc networks often have stringent bandwidth or delay requirements. For example, a delay of over 150 ms in voice transmissions is felt as disturbing by most users. QoS support for real-time applications in wireless ad hoc networks is a challenge. It has been recognized that traditional mechanisms for providing guaranteed or hard QoS (such as ATM, or IP integrated services) are not suitable for wireless networks where network conditions constantly change due to node mobility and shared medium access.

Since shared wireless resources are easily over-utilized, traffic load in the network must be controlled properly so that acceptable quality of service for real-time applications can be maintained. In other words, the wireless channel must be kept from reaching the congestion point where loss and delay increase rapidly with the traffic load. For example, Figure 1 (obtained from an analytical model of the IEEE 802.11 MAC [1]) shows that for a typical 802.11 network (basic access, without RTS/CTS), both throughput efficiency and packet delay deteriorate considerably as the number of traffic sources increases. Therefore admission control is necessary to maintain the QoS performance within an acceptable region.

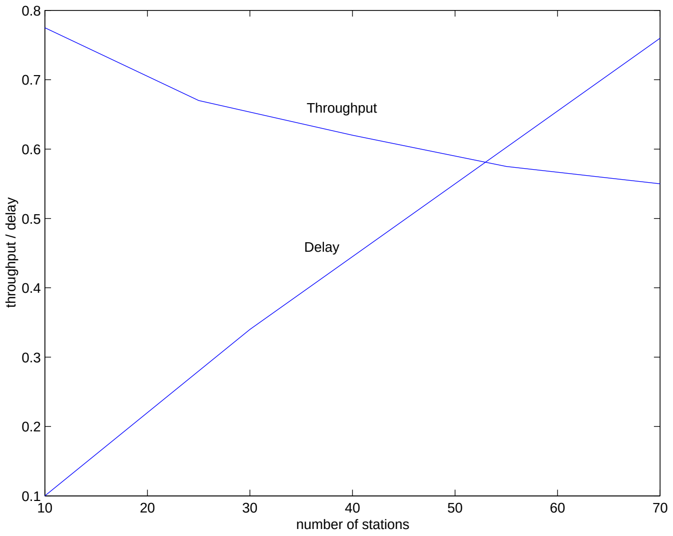

Fig. 1. Throughput efficiency and packet delay vs. number of sources

In this paper, an admission control and route discovery scheme for QoS traffic is proposed. It is based on on-demand routing protocols and performs admission control implicitly during the route discovery process. Local bandwidth measurements are used in admission control decisions. Simulation results have shown that this admission control scheme can greatly improve network performance such as packet delivery ratio and delay.

2 Related Work

QoS has attracted a lot of attention recently in the ad hoc research community. At the MAC layer, the dynamic nature of ad hoc networks makes it difficult to assign a central controller to maintain connection states and reservations. Therefore best-effort distributed MAC controllers such as the IEEE 802.11 Distributed Coordination Function (DCF) are widely used in existing ad hoc networks. Recently a number of distributed control schemes have been proposed to support service differentiation at the MAC layer, e.g. [2].

At the network layer, most of the ad hoc routing schemes proposed so far are also best-effort, i.e. no QoS support. INSIGNIA [3] is an in-band signalling system that supports adaptive reservation-based services in ad hoc networks. It represents a general-purpose approach to delivering QoS (mainly the signalling aspect) and does not address the issue of admission control. In [4] a distributed call admission controller is introduced, which is based on service curve provisioning. The drawback of this scheme is that it is difficult to accurately measure the service curve of the network. Further, their admission criterion is the deterministic universal service curve which can be very conservative. In [5], Ahn *et al.* proposed SWAN, a stateless network model which uses distributed control algorithms to deliver service differentiation in ad hoc networks. It uses rate control for UDP and TCP best-effort traffic, and sender-based admission control for UDP real-time traffic. Explicit congestion notification (ECN) is employed to dynamically regulate admitted real-time traffic in traffic overload conditions. Although SWAN indeed supports soft QoS (e.g. low delay) for real-time traffic, it does so at the expense of very low goodput for TCP traffic, which is a main drawback of SWAN. We will compare our work with SWAN in more detail in the next section.

3 Measurement-Based Admission Control

We consider an ad hoc network where on-demand or reactive routing is used. The goal is to limit the number of connections and find routes that satisfy bandwidth requirements for accepted real-time flows. Compared to proactive routing protocols, on-demand routing protocols are more efficient by minimizing control overhead and power consumption since routes are only established when required. AODV (ad hoc on-demand distance-vector) [6] and DSR (dynamic source routing) [7] are two of the on-demand protocols currently under active development in the IETF Manet working group.

In an on-demand protocol, when a source is in need of a route to a destination, it broadcasts a Route Request (RREQ) message to its neighbors, which then forward the request to their neighbors, and so on, until the destination is located. The RREQ packet contains the source node's address and current sequence number, the destination node's address and last known sequence number, as well as a broadcast ID. During the process of forwarding the RREQ, intermediate nodes record in their route tables the address of the neighbor from which the first copy of the broadcast packet is received, thereby establishing a reverse path. Here we assume intermediate nodes do not reply to RREQs. Once the RREQ reaches the destination, the destination responds by unicasting a Route Reply (RREP) back to the source node. Information obtained through RREQ and RREP messages is kept with other routing information in the route table of each node. To provide quality of service, extensions (extra fields) can be added to these messages during the route discovery process. Here we consider bandwidth as the QoS parameter and add an extra field in the RREQ packets for bandwidth requirement of the real-time flow. Only bandwidth is considered here, because it has been regarded as the most important QoS parameter for most real-time applications. In addition, our simulation results show that admission control based on bandwidth requirement not only improves traffic throughput, but also reduces average delay. In [5] admission control is also used to provide differentiated QoS for real-time flows. However our approach is different from the SWAN mechanism of [5] in that, unlike SWAN that uses separate probing packets after route establishment, our method piggybacks QoS (bandwidth) information with route request packets, which incurs minimum control overhead. In this sense route discovery messages in our scheme also act as probes for distributed admission control. Moreover, in our method intermediate nodes make admission decisions based on local measurements, while in SWAN it is the source that accepts/rejects incoming connections based on the probe response.

In the proposed framework, each node needs to periodically measure the bandwidth of its outgoing wireless links. Bandwidth measurements are used here for admission control and route discovery for traffic flows with certain amount of bandwidth requirements. More specifically, each node measures the number of packet transmissions in its carrier sensing range over a specific time interval (T) and calculates the occupied average bandwidth of existing real-time traffic using the following weighted moving average:

$$B_{avg}(j) = B_{avg}(j-1) * \alpha + (1-\alpha) * Rate(j), \tag{1}$$

where α is the weight (or smoothing factor), $B_{avg}(j)$ is the average bandwidth at the measurement window j and $Rate(j)$ is the measured instantaneous bit rate at j. Our simulations indicate that the above measurement method is able to provide bandwidth estimates accurate enough for the purpose of admission control, and is easy to implement and cost effective.

A requested bandwidth extension is added to RREQ messages, which indicates the minimum amount of bandwidth that must be made available along an acceptable path from the source to the destination. When any node receives such a RREQ, it will perform the following operation: if its available bandwidth cannot satisfy the QoS (bandwidth) requirement, the node drops the RREQ and does not process it any further. Otherwise, the node continues processing the RREQ as specified in the best-effort on-demand routing protocol. For admission control purposes, let B_{th} be the admission threshold rate. Then to admit a new QoS flow the available bandwidth (B_{avail}) must be greater than the required bandwidth (B_{req}) of the new flow:

$$B_{avail} = B_{th} - B_{avg} > B_{req} \tag{2}$$

Here B_{th} is a critical parameter. Due to the MAC overhead and the fact that interferences from signals transmitted by nodes located further away than one hop (e.g. nodes within the carrier sensing range) may have an impact on the channel medium [8], the admission threshold can be very conservative, say, a small percentage of the total channel capacity. We will elaborate more on this later in Sections 4 and 5 of this paper.

After a new flow is admitted, it immediately starts transmission and consumes network bandwidth. Since the available bandwidth is measured continuously at each node, the newly admitted flow will be taken into account for any future admission control decisions. Similarly, when a flow stops, the available bandwidth will increase, creating space for other flows to be admitted.

4 Performance Evaluation

Extensive simulations have been conducted using the network simulator ns-2 [9]. In our simulations, we use the two-ray ground propagation model and omni-directional antennas. The wireless channel capacity is 11 Mbps. Ten nodes are randomly distributed in an area of 670 m by 670 m. Each node has a transmission range of 250 m and carrier sensing range of 550 m. The routing protocol we use is the AODV routing protocol [6] and the MAC protocol is IEEE 802.11. The bandwidth measurement interval T is 1 second. The traffic used in these simulations is generated by a number of video connections. Each video connection is modelled as a 200 kbps constant bit rate (CBR) source sending 512-byte packets at the rate of 50 packets per second. So B_{req} is 200 kbps. CBR connections are established between any two nodes selected randomly. We increase the number of connections one by one every 5 seconds until the number of connections reaches eight, hence after 40 seconds of simulation time all connections are active.

Figure 2 shows the measured traffic rate at a single node. It can be seen that at this particular node the traffic fluctuates over time and the maximum throughput achieved is around 1.4 Mbps. This may be a discouraging result at first sight given the total traffic load of 1.6 Mbps and the channel capacity of 11 Mbps. However, both theoretical analyses and previous experiments have shown that the usable bandwidth (or throughput) in a wireless network is often far less than the nominal channel capacity. For example, the authors of [10] showed that, the theoretical maximum throughput (TMT) of the IEEE 802.11 MAC is given by:

$$TMT(x) = \frac{8x}{ax+b} \quad \text{Mbps} \tag{3}$$

where x is the MSDU (MAC service data unit) size in bytes, a and b are parameters specific to different MAC schemes and spread spectrum technologies. For example, when the channel data rate of a high-rate direct sequence spread spectrum MAC is 11 Mbps, MSDU is 512 bytes and the RTS/CTS scheme is used, the theoretical maximum throughput is only 2.11 Mbps ($a = 0.72727, b = 1566.73$). Further, this TMT is defined under a number of idealized assumptions such as zero bit error rate, no losses due to collisions, etc. In an ad hoc environment we also have to consider the effect of interference of traffic from neighboring nodes that are possibly more than one hop away (e.g. hidden nodes, exposed nodes [11])[1]. Therefore it is not surprising that effective throughput is even less than

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[1] Generally, how to identify interfering nodes intelligently and precisely is still an open question.

the theoretical maximum throughput. Figure 2 indicates the need of admission control for real-time traffic, because a lot of packets would have been lost due to medium contention and congestion if no admission control is implemented. It also gives us valuable insight into the optimal range of selecting the admission threshold rate.

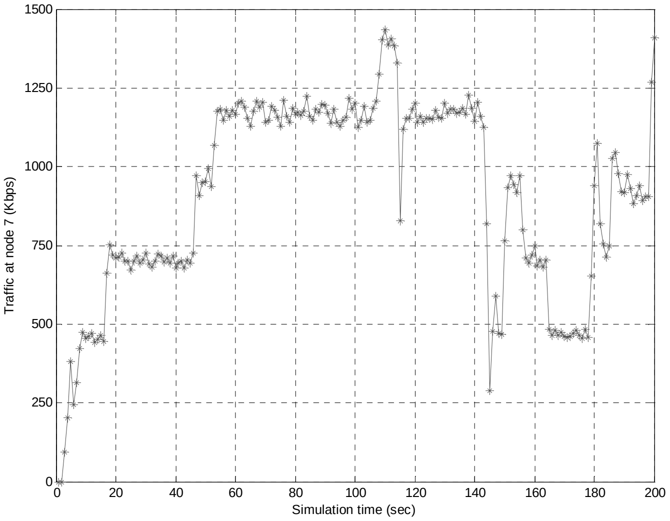

Fig. 2. The measured traffic at a particular node

Figure 3 compares the packet drop ratios of the network with admission control and that without control. In ad hoc networks both unavailability of routes and congestion (queue overflow) result in packet drops. It is clear that admission control with a threshold of 1 Mbps is very effective in reducing packet loss (drop ratio close to zero). Figure 4 presents the packet delivery ratios under different traffic loads. Admission control with threshold of 1 Mbps achieves nearly 100% packet delivery ratio, while the performance without admission control degrades significantly as traffic load increases. Admission control with a threshold of 1.2 Mbps has some improvements compared to the case of no control, but not as pronounced as the case with an admission threshold of 1 Mbps. Clearly a trade-off exists here: smaller admission threshold guarantees better QoS at the expense of denying more connection requests and potentially wasting available bandwidth, whereas larger threshold accepts more connections at the cost of degraded QoS. From another perspective, Figures 5 and 6 present the number of packets sent and successfully received during the simulation for both cases of control and no-control. It is evident that lack of an admission control protocol results in significant packet loss, particularly when the traffic load is high. With admission control, most of the packets are delivered to their destinations, which ultimately gives better packet delivery ratio.

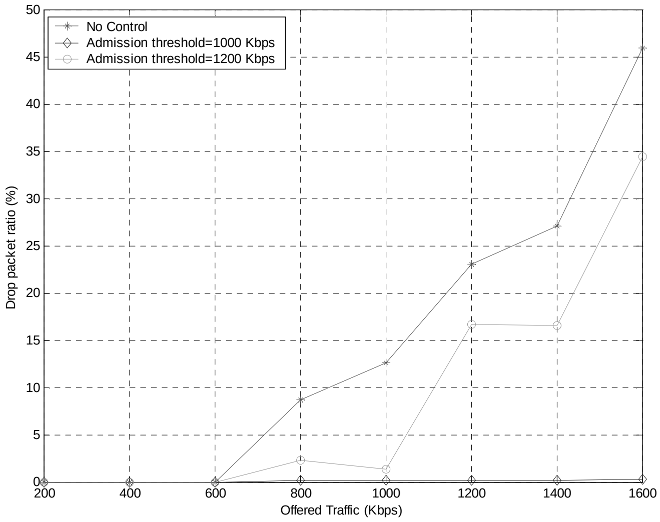

Fig. 3. Packet drop ratio vs. offered load

Figure 7 plots the total number of RREQ packets processed over a time period of 100 seconds. It is clear that with admission control quite a few RREQ packets are dropped due to insufficient bandwidth at high loads, which results in an effect of call blocking similar to that in connection-oriented networks. This effect is also evident from Figure 5 and Figure 6, where we can see that with admission control the total number of packets sent at high load is less than that in a network without control.

The overall average end-to-end delay is shown in Figure 8 and the delay for a particular node is shown in Figure 9. The offered traffic load is 1000 kbps. With admission control the delay is not only smaller, but also nearly constant (small jitter), which is an important requirement of real-time multimedia applications. From Figure 9, it can be noted that without control the delay can peak up into the range of 15 to 20 msec. This is because, when the channel becomes congested packets are queued heavily resulting in prolonged delays and large delay variations. This is avoided using admission control. Figure 10 plots the overall delay against traffic load, which shows admission control improves packet delay as offered load increases.

The above simulation results have been obtained for the scenario of stationary nodes. Next we introduce mobility into the model. We use the random waypoint model where the pause time is 25 seconds, and each node moves with a maximum

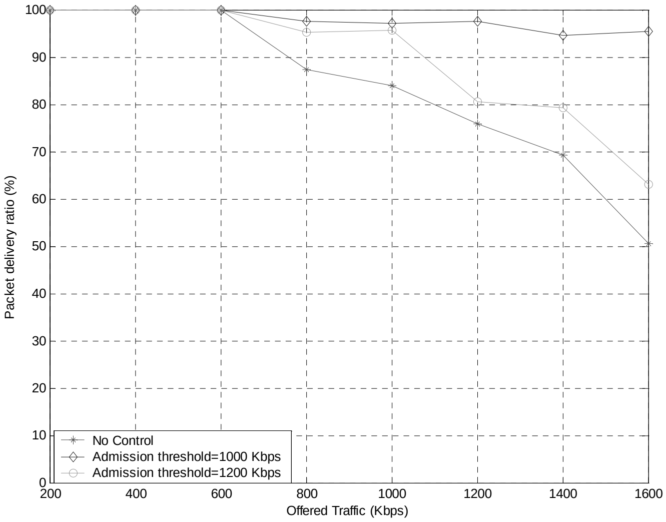

Fig. 4. Packet delivery ratio vs. offered load

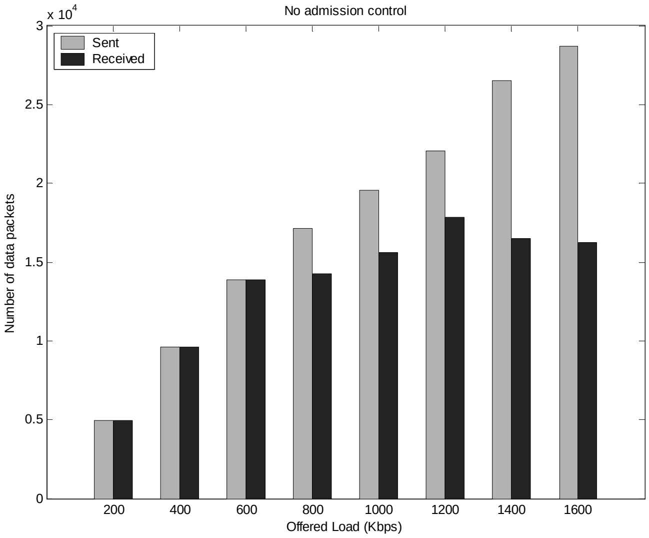

Fig. 5. Number of packets sent/received vs. offered load (without control)

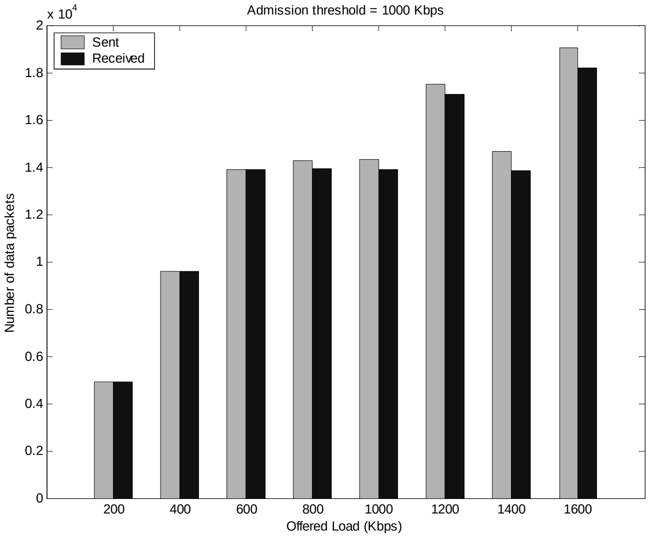

Fig. 6. Number of packets sent/received vs. offered load (with admission control)

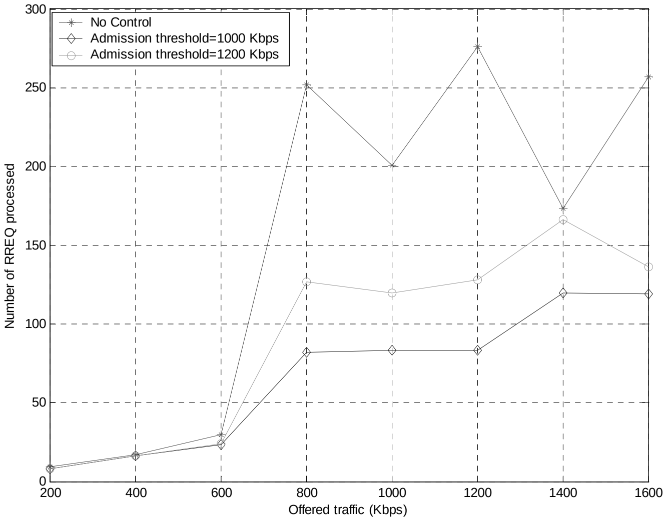

Fig. 7. Number of RREQs processed

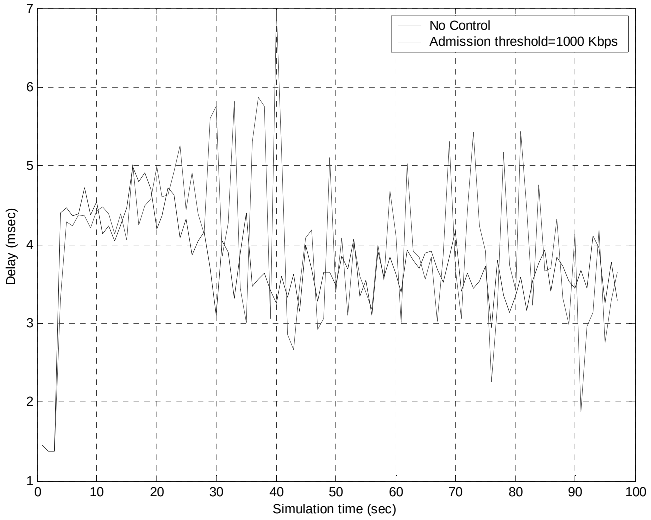

Fig. 8. Overall average delay for all the packets

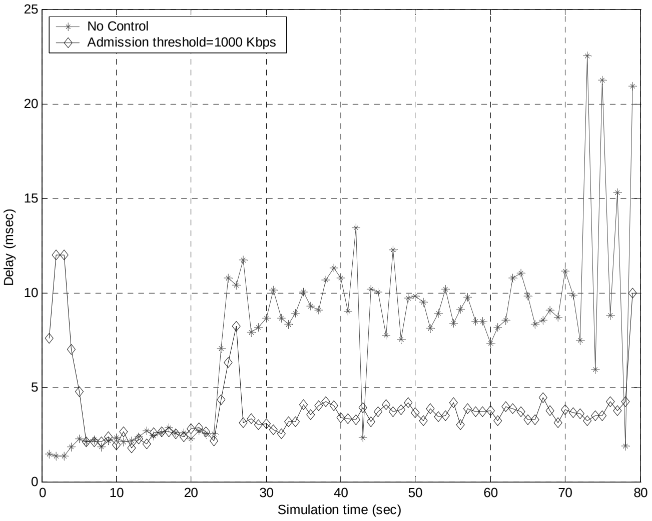

Fig. 9. Average delay of a single node

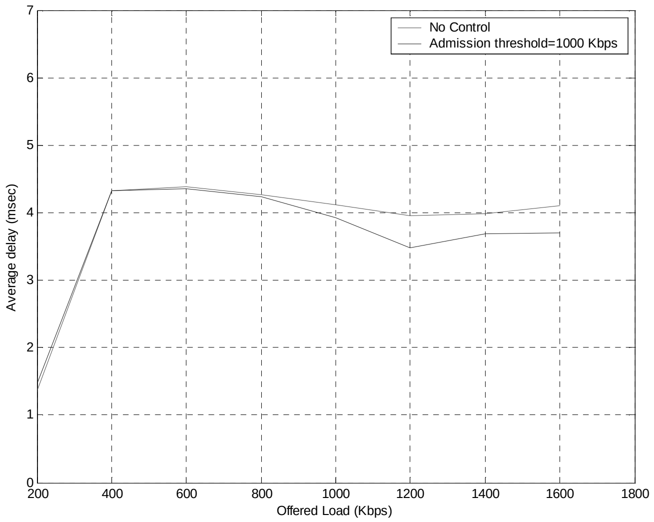

Fig. 10. Average delay vs. offered load

speed of 5 m/sec. Figure 11 clearly shows the improvement of packet delivery ratio when admission control is implemented. On the other hand, mobility indeed degrades the performance due to topology change and re-routing, as shown in Figure 12.

To test our algorithm further, we add two TCP connections as background traffic. Figure 13 demonstrates the superior performance of admission control.

In summary, our admission control mechanism is able to achieve high packet delivery ratio while keeping constant low delay. It therefore can be used effectively to support real-time video or voice applications with QoS requirements.

5 Adaptive Admission Control

As mentioned previously the usable bandwidth (or throughput) in a wireless ad hoc network is often far less than the nominal channel capacity. Therefore to be on the safe side (avoiding the violation of QoS), admission policies often have to be quite conservative. For example, in a network of 11 Mbps channel capacity, the admission threshold rate is often set as merely 1 Mbps.

To have a more intelligent way of determining this admission threshold with the aim of maintaining QoS while achieving high network utilization, we propose to adapt the threshold according to channel conditions (e.g. the number of nodes contending for the channel). Here we can use MAC delay as an indication of the channel condition. MAC delay (in a RTS-CTS-DATA-ACK cycle) is a very useful metric to identify congestion hotspots and measure link interference in an ad hoc network [12], and it continuously fluctuates throughout the time. The

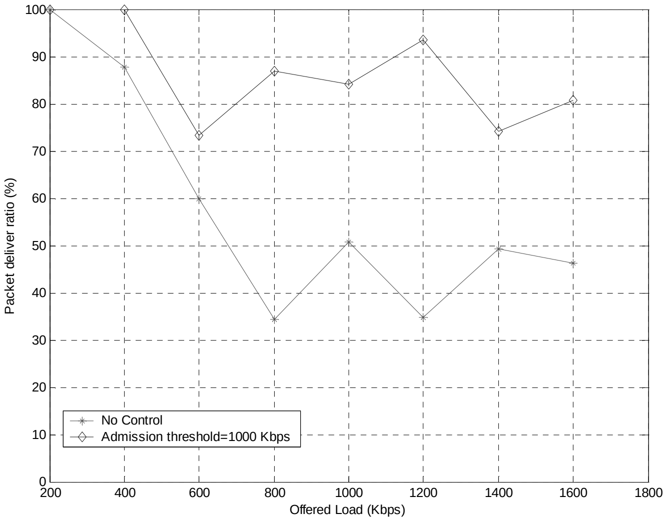

Fig. 11. Packet delivery ratio vs. offered load (mobility scenario, with control and without control)

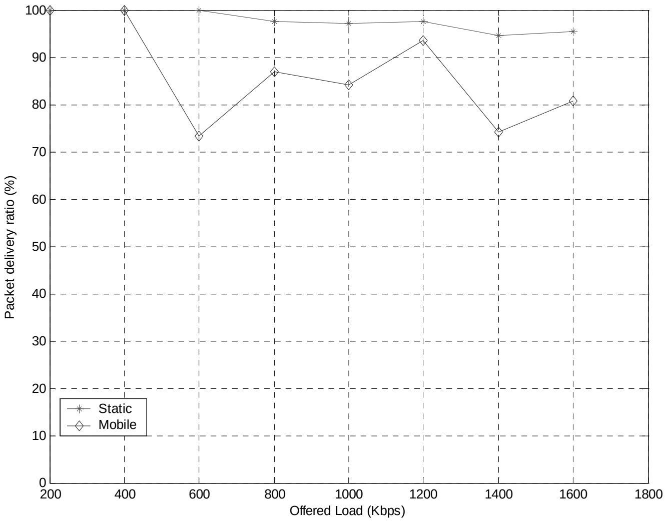

Fig. 12. Packet delivery ratio vs. traffic load (stationary and mobile nodes, both with admission control)

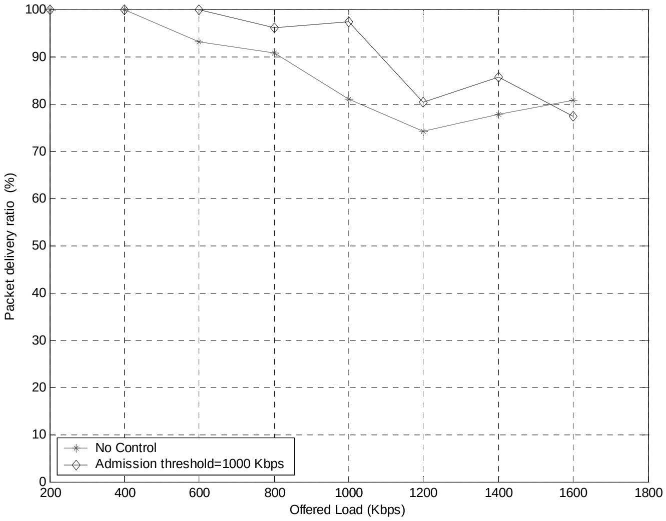

Fig. 13. Packet delivery ratio vs. offered load (with background TCP traffic)

MAC delay of a packet represents the time it takes to send the packet between the transmitter and receiver including the total deferred time (including possible collision resolution) as well as the time to fully acknowledge the packet. It is easy to measure: at the source node subtracting the time that a packet is passed to the MAC layer (ts) from the time an ACK packet is received from the receiver (tr): $D = tr - ts$.

Assume that we have two thresholds A_1 and A_2, where $A_1 > A_2$. For instance, in an 11 Mbps network, $A_1 = 1.3$ Mbps, $A_2 = 1$ Mbps. Then switching of admission threshold is dependent on two key parameters [12]: (i) MAC delay threshold D, and (ii) N, the number of times that the measured MAC delay measurements exceed a predetermined threshold D consecutively. Specifically, at the beginning the admission threshold is A_1. When the measured MAC delay measurements exceed a predetermined threshold (i.e., D) for more than N times consecutively, the threshold is changed to a more conservative one, A_2. Hence when the wireless medium is busier (MAC delay is higher) the admission control policy becomes more strict, i.e. accept fewer connections. When the admission threshold is changed to A_2, it remains so for at least 5 seconds. After that if the MAC delay is smaller than D, the threshold is reverted back to A_1 automatically.

The two parameters D and N have an impact on network performance. When D and N are configured as large values, admission control is too loose and accepts too many connections rendering the protocol to be less effective against moderate congestion. In contrast, when N and D are configured with small values, admission control is very conservative and network utilization is low. Therefore, the appropriate choice of these parameters is important for admission control to function properly. We intend to investigate the choices of N and D and evaluate the performance of this adaptive admission control scheme using simulations and results will be reported in future publications.

6 Conclusion and Future Work

Real-time applications such as video streaming often have stringent QoS requirements. Current ad hoc routing protocols do not address the issue of QoS provisioning. In this paper QoS is considered in the route discovery process and admission control is performed implicitly by dropping RREQ packets. Bandwidth is considered as the QoS parameter here and local bandwidth measurement is used in admission control and route discovery. The bandwidth monitoring mechanism makes use of the built-in ability of the 802.11 wireless channel and only incurs moderate CPU overhead (simple bandwidth calculation). The admission control process does not incur excessive overhead either, since QoS information is carried together (piggybacked) with route discovery packets. It has been shown that the proposed admission control scheme is very effective in keeping packet loss and delay very low for real-time flows.

It is worth pointing out that our method does not rely on a QoS-capable MAC, so it can be readily applied to current 802.11-based ad hoc networks. On the other hand, it would be interesting to investigate the performance gain of admission control when it is combined with some of the recently proposed QoS MAC protocols, e.g. AEDCF [13]. These MAC protocols can provide priorities to real-time traffic over best-effort traffic and admission control is only applied to real-time services. Wireless bandwidth measurement is another important research issue. Other measurement techniques such as those proposed in [14] [15] and their applicability in admission control in ad hoc networks are topics of further study.

The proposed QoS method does not depend on any particular routing protocol: it can generally be applied to any on-demand routing protocol. Admission control policies based on other QoS metrics can also be incorporated into the framework, e.g. MAC delay, buffer occupancy and packet loss. Recent experimental studies have suggested that more attention be paid to link quality when choosing ad hoc routes [16]. To this end, route discovery to find routes with better signal quality and stability can be done using the approach proposed in this paper for on-demand protocols. The main challenges, however, involve practical estimates of link quality (e.g. signal-to-noise ratio) and techniques to find feasible paths based on these link metrics.

As an example, we consider the problem of finding bandwidth-constrained least delay routes for real-time flows. In our admission control and route discovery framework, when the destination node generates a RREP in response to a RREQ, it includes in the RREP a delay field whose initial value is zero. As the RREP propagates along the reverse path, each intermediate node forwarding the RREP adds its own estimated MAC delay time to its one hop upstream node to the delay field. Thus when the source node receives the final RREP message, it would obtain an estimate of the path delay. The above strategy will result in multiple paths, which can provide a more robust packet delivery. The source node then can choose the minimum delay route that (automatically) satisfies the bandwidth constraint (not necessarily the minimum hop-count route). This idea is deemed as a subject of our future work.

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References

1. H. Wu, Y. Peng, K. Long, S. Cheng, and J. Ma. Performance of reliable transport protocol over IEEE 802.11 wireless LAN: Analysis and enhancement. In *IEEE INFOCOM*, 2002.
2. I. Aad and C. Castelluccia. Differentiation mechanisms for IEEE 802.11. In *IEEE INFOCOM*, 2001.
3. S. Lee, G. Ahn, and A. Campbell. Improving UDP and TCP performance in mobile ad hoc networks with INSIGNIA. *IEEE Communications Magazine*, June 2001.
4. S. Valaee and B. Li. Distributed call admission control for ad hoc networks. In *IEEE VTC*, 2002.
5. G. Ahn, A. Campbell, A. Veres, and L. Sun. SWAN: Service differentiation in stateless wireless ad hoc networks. In *IEEE INFOCOM*, 2002.
6. C. Perkins, E. M. Belding-Royer, and S. Das. Ad hoc on-demand distance vector (AODV) routing. *RFC 3561*, 2003.
7. D. Johnson, D. A. Maltz, and Y. Hu. The dynamic source routing protocol for mobile ad hoc networks (DSR). *Internet Draft*, 2003.
8. K. Bertet, C. Chaudet, I. Guerin Lassous, and L. Viennot. Impact of interferences on bandwidth reservation for ad hoc networks: a first theoretical study. In *IEEE GLOBECOM*, 2001.
9. K. Fall and K. Varadhan. ns notes and documentation. Technical report, The VINT Project, 2000.
10. J. Jun, P. Peddabachagari, and M. Sichitiu. Theoretical maximum throughput of IEEE 802.11 and its applications. In *IEEE International Symposium on Network Computing and Applications*, 2003.
11. S. Xu and T. Saadawi. Does the IEEE 802.11 MAC protocol work well in multihop wireless ad hoc networks. *IEEE Communications Magazine*, pages 130–137, June 2001.
12. S. Lee and A. Campbell. HMP: hotspot mitigation protocol for mobile ad hoc networks. In *IEEE/IFIP IWQOS*, 2003.
13. L. Romdhani, Q. Ni, and T. Turletti. Adaptive EDCF: enhanced service differentiation for IEEE 802.11 wireless ad-hoc networks. In *IEEE WCNC*, 2003.
14. M. Kazantzidis and M. Gerla. End-to-end versus explicit feedback measurement in 802.11 networks. In *IEEE ISCC*, 2002.
15. K. Chen, K. Nahrstedt, and N. Vaidya. The utility of explicit rate-based flow control in mobile ad hoc networks. In *IEEE WCNC*, 2004.
16. K. Chin, J. Judge, A. Williams, and R. Kermode. Implementation experience with MANET routing protocols. *ACM Computer Communication Review*, 32(5), 2002.