

# PAC: Perceptive Admission Control for Mobile Wireless Networks

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## Abstract

*Traditional approaches to guarantee quality of service (QoS) work well only with predictable channel and network access. In wireless mobile networks, where conditions dynamically change as nodes move about the network, a stateless approach is required. As wireless networks become more widely used, there is a growing need to support advanced services, such as multimedia streaming and voice over IP. Since shared wireless resources are easily over-utilized, the load in the network must be controlled so that an acceptable QoS for real-time applications can be maintained. If minimum real-time requirements are not met, these data packets waste bandwidth and hinder other traffic, compounding the problem. To address this issue, we propose the Perceptive Admission Control (PAC) protocol. PAC monitors the wireless channel and dynamically adapts admission control decisions to enable high network utilization while preventing congestion. Through discussion and simulations, we show that PAC achieves this goal and ensures low loss and delay for all admitted flows.*

## 1. Introduction

Wireless devices are becoming prevalent because of their ability to provide mobile communication. Since many common applications, including voice and multimedia, require low packet loss and delay, quality of service (QoS) is becoming an important requirement for these networks. In contrast to traditional wired networks, mobile networks operate under harsh conditions that include mobility, a shared wireless channel and limited bandwidth. Traditional attempts to provide guaranteed QoS are unable to cope with the constantly changing network conditions. Meeting hard real-time QoS constraints in wireless mobile networks is unrealistic because of node mobility and shared medium access. Instead, solutions that provide a stateless service and offer better than best-effort packet delivery for high priority packets are more successful, such as DiffServ and IEEE 802.11e. Unfortunately, these solutions still fail to provide

the low loss and delay that real-time applications require if the network becomes congested.

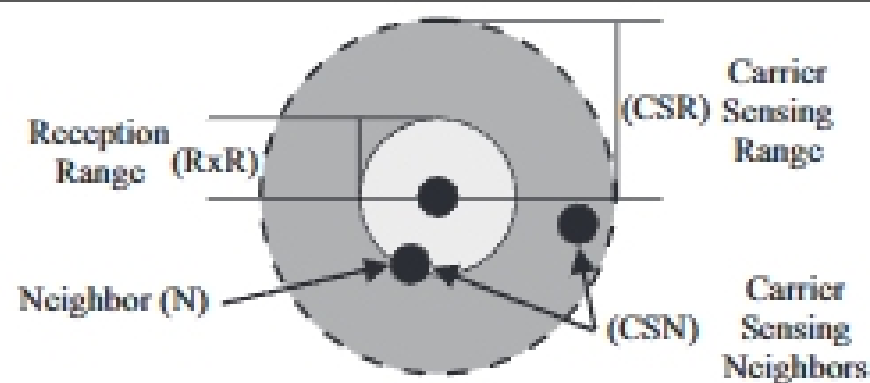
High quality of service without fully coordinated channel and network access is achievable. The wireless channel must be kept from reaching the congestion point, since loss and delay increase rapidly once this point is reached. Maintaining the utilization below the congestion point is difficult because the channel is shared between nodes that may not be able to communicate directly; therefore, nodes need to passively determine the network utilization. Once the amount of available bandwidth is determined, nodes can then adapt their data traffic to keep the channel from becoming congested.

We propose the Perceptive Admission Control (PAC) protocol to control the amount of traffic in the network and provide high quality service to all admitted traffic. PAC ensures the network congestion point is not reached through the requirement of call admission for all new flows. To make an admission decision, PAC considers not only the limited area within a sender's transmission range, but the entire area that a new flow may impact. We show that the time that the wireless channel is sensed as busy is a good estimator of available bandwidth. Using this measure, PAC performs admission control for new flows to avoid congestion. We begin our discussion by focusing on single hop admission control. We then describe how to easily extend PAC for multihop paths.

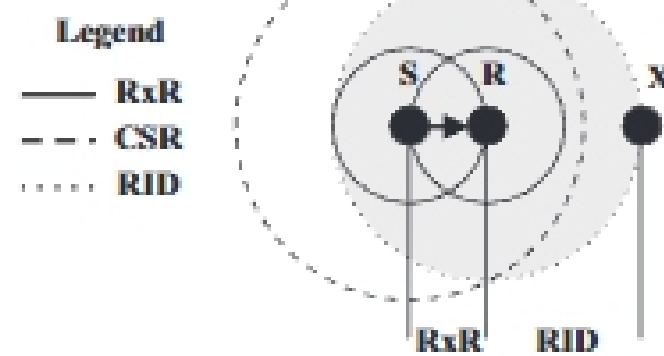
The rest of this paper is organized as follows. Section 2 provides background on wireless transmissions, including methods for determining the available bandwidth and previous approaches for providing high packet delivery and low delay in wireless networks. In Section 3 we describe PAC, our approach for admission control. In Section 4 we demonstrate the performance of PAC in simulation and describe how it avoids the shortcomings of previous approaches. Finally, Section 5 concludes the paper.

## 2. Background

To perform admission control in wireless networks it is important to understand how a wireless transmission impacts other nodes. In Section 2.1 we describe the important distances for packet transmission and reception. Since ad-



**Figure 1.** Approximation of reception range ( $RxR$ ) and carrier sensing range ( $CSR$ ). Nodes within reception range are called neighbors ( $N$ ), while carrier sensing neighbors ( $CSN$ ) are all nodes within carrier sensing range.



**Figure 2.** The receiver interference distance ( $RID$ ) is the distance between a receiver ( $R$ ) and another sender ( $X$ ), such that the receiver can successfully receive  $S$ 's packets and  $X$  can simultaneously send a packet to another receiver.

mission control decisions depend on accurate estimation of the available bandwidth, we examine several methods for calculating the available bandwidth in Section 2.2. In Section 2.3 we categorize related work and discuss why most proposed solutions are insufficient. In Section 2.4 we describe the solution most closely related to our proposed approach.

## 2.1. Impacted Area

For admission control purposes, there are multiple notable ranges for wireless communication. Each distance is important for the measuring channel utilization and predicting the available bandwidth. At a short range, we assume that nodes are capable of direct communication. We refer to the maximum separation between a sender and receiver for successful packet reception as  $RxR$ , as shown in Figure 1. Nodes within  $RxR$  of a particular sender are considered its neighbors ( $N$ ).

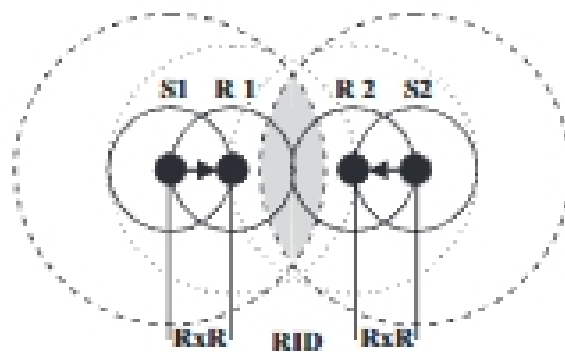
Nodes that are within carrier sensing range of a sender can sense packet transmissions. The nodes inside a sender's carrier sensing range are called carrier sensing neighbors ( $CSN$ ). These nodes detect a transmission but may not be able to decode the packet. The maximum distance that a node can detect an ongoing packet transmission (carrier signal) is called the carrier sensing range ( $CSR$ ). This range is typically much larger than the reception range. In wireless MAC protocols based on CSMA, such as IEEE 802.11, all  $CSN$  of the sender are unable to initiate a packet transmission while the sender is transmitting because they sense the channel is busy. In CSMA networks, a large  $CSR$  prevents multiple transmissions from simultaneously occurring close together and helps avoid interference at receivers. In contrast, a smaller  $CSR$  allows for more spatial reuse, though more collisions and interference may occur.

When a carrier signal is sensed by a receiver, packet reception from another sender may not be impacted. For correct packet reception, the area surrounding a receiver must be free of multiple interfering transmissions. If another node transmits a packet close to the receiver it may interfere with

an ongoing packet reception, even if the two senders are outside each others carrier sensing range. To quantify this effect we define the receiver interference distance ( $RID$ ) as the distance between a receiver and another sender, such that this receiver's ability to decode a packet from its sender is not affected. For example, in Figure 2 if node  $X$  is outside node  $R$ 's  $RID$ , node  $X$  can transmit at the same time as node  $S$  without affecting packets received by node  $R$  from node  $S$ . If node  $X$  is inside node  $R$ 's  $RID$  and transmits at the same time as node  $S$ , node  $R$  is unable to successfully receive packets from node  $S$ . In both cases, node  $X$  is not prohibited from transmitting because node  $S$  is outside its carrier sensing range; it cannot sense an ongoing transmission between nodes  $S$  and  $R$ . The exact size of the  $RID$  depends on many factors, including transmission power, minimum reception power, propagation model and hardware capture abilities. Note that  $CSR$  (dashed line) is larger than  $RID$  (dotted line) and  $RID$  is larger than  $RxR$  (solid line), as shown in Figure 2. These line styles will be used throughout the paper to denote the different ranges.

For two simultaneous transmissions transmitted to be successfully received by different receivers, the transmissions (and nodes) must be separated in space. The distance between two senders to ensure proper packet reception at a receiver is  $RxR + RID$ . This distance holds for all possible network scenarios. At any distance smaller than  $RxR + RID$ , it is possible that the transmissions of two senders will interfere with a receiver's ability to properly decode a packet. If the distance is larger than  $RxR + RID$ , by definition, the receiver and another sender cannot be closer than  $RID$ .

These communication distances are for networks where all nodes use omnidirectional antennas and transmit packets with the same transmission power on the same channel. Further we assume that there are no obstacles and only simple fading occurs. We plan on exploring relaxation of these conditions as future work.



**Figure 3.** Spacing requirement for simultaneous transmissions in wireless networks that utilize acknowledgments. Since the sender's RID and receiver's CSR are not important to the interference calculation, they are not shown.

### 2.1.1. MAC Layer Acknowledgments

Acknowledgments (ACKs) are used in many MAC protocols, such as IEEE 802.11, to immediately inform the sender that successful reception has occurred. If an ACK is not received the sender will retransmit the packet a maximum number of times. The Data-ACK mechanism is used to combat packet loss at the MAC layer due to collisions and errors introduced by the wireless channel. Generally carrier sensing is not performed by the receiver prior to sending an ACK. This is because carrier sensing might silence a receiver, upon successful data reception, and therefore require the sender to retransmit the packet. This in turn would waste wireless resources and power and increase delay.

When receivers do not perform carrier sensing prior to sending an ACK after successful data reception, the receivers must also be separated by RID. In this type of network, the separate sets of data and ACK transmissions should not overlap. If they do overlap, the data transmissions and ACKs will cause collisions. These collisions will result in unsuccessful packet reception.

Given that the two receivers are separated by RID and each sender-receiver pair is separated by RxR, the distance between two senders for successful simultaneous transmissions is

$$2 * RxR + RID \quad (1)$$

A network topology illustrating this distance is shown in Figure 3. In this situation, if the two senders are closer than  $2 * RxR + RID$ , communication will suffer since the data and ACK pairs will collide if the transmissions overlap in time.

## 2.2. Determining the Available Bandwidth

The goal of our work is to allow nodes to depend on their estimation of the available bandwidth to make correct admission control decisions. In this section we examine several methods to determine the available bandwidth. The most common way to calculate the available bandwidth ( $B_{avail}$ ) is to measure the network utilization ( $U$ ). Given the network utilization and the maximum bandwidth ( $B_{max}$ ),

the available bandwidth is estimated using the following equation [11]:

$$B_{avail} = (1 - U) * B_{max} \quad (2)$$

where  $0 \leq U \leq 1$ . There are many techniques to measure the network utilization. Some metrics of network utilization are:

- MAC Layer Congestion Window
- Queue Length
- Number of Collisions
- Delay
- Channel Busy Time

The first three methods provide little or no information regarding network utilization if a node is not actively transmitting packets. For example, a collision only occurs if a packet fails to send. If a node does not send any packets, it cannot determine the current state of the channel. The same holds true for the MAC layer congestion window and the queue length. Since these techniques are not adequate for determining the available bandwidth, we explore the two remaining techniques, delay and channel busy time, in more detail.

Both delay and channel busy time can be used to determine the current bandwidth usage; however, channel busy time has several advantages. These include no additional overhead, no measurement gaps and adaptable measurement range. The simulation results comparing these two techniques are omitted due to space limitations; see [2] for additional detail.

Channel busy time is a direct measure of the channel utilization. In wireless networks, carrier sensing enables nodes to detect three states; transmitting, receiving and busy. If the node detects a carrier signal it senses that the channel is busy, but it is only able to decode the packet contents if it is within RxR. By measuring the amount of time the channel is sensed busy (CS), sending (TX) or receiving (RX), a node can measure not only transmissions that occur within its reception range, but also those within its carrier sensing range. Using this metric, more transmissions result in a busier channel. We define the busy time to be the total time within an interval that a node is transmitting packets, receiving packets or sensing packet transmissions.

With any measurement technique it is common that instantaneous values vary, sometimes widely. For our approach we utilize an equally weighted sliding window to obtain the wireless utilization. Through testing, we determined a window size that was large enough to make an accurate estimate and small enough to quickly adjust to changing traffic conditions. An alternate weighting technique, such as a weighted average that favors recent measurements, may provide a better estimation of the utilization and available bandwidth.