METHODS TO ACHIEVE CAPACITY AND QUALITY OF SERVICE IN AD HOC NETWORKS

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ABSTRACT

The Synchronous Collision Resolution medium access control protocol uses contention resolution signaling to arbitrate access to a shared wireless medium. This signaling also provides a mechanism that enables the protocol to provide quality of service and to manage physical layer characteristics. We explain how it: ensures that nodes sending higher priority packets get precedence in gaining access enables a node to reserve the use of the channel, conserves energy, and enables the coordinated use of multiple channels simultaneously in a flat network architecture. We describe and provide simulation results of how the use of multiple spread spectrum channels can dramatically increase the already extraordinary spatial capacity of the protocol.

1. INTRODUCTION

In the prequel [Stine et. al. 2002], we described how our protocol, Synchronous Collision Resolution (SCR)[1], uses collision resolution signaling (CRS) to select a subset of nodes across a network to exchange packets simultaneously. In this paper, we describe how CRS can be expanded to provide quality of service (QoS), conserve energy, and enhance capacity. In Section 2 we describe the signaling mechanism, review its effects, and introduce an extension to the signaling that manages QoS and physical layer parameters. Sections 3 though 5, in order, discuss priority access, resource reservation, and energy conservation. Section 6 discusses coordination of multiple channel use in the same network. Finally, in Section 7, we provide simulation results demonstrating the capacity improving effect of using code division multiple access with SCR. Section 8 provides a brief summary.

2. SYNCHRONOUS COLLISION RESOLUTION (SCR)

Figure 1 illustrates the SCR protocol. The channel is organized into consecutive transmission slots that are then grouped into constant bit rate (CBR) frames. Each transmission slot is preceded by collision resolution signaling (CRS). All nodes with traffic contend in each transmission slot using the CRS protocol. The CRS protocol resolves these contenders into a subset of contenders that are spatially separated from each other by at least the range of their signals

At the conclusion of the CRS protocol, survivors attempt to execute a request-to-send (RTS) – clear-to-send (CTS) handshake with their desired destination. If successful, contenders exchange protocol data units (PDU) with the destination. Note that all survivor RTS packets are sent simultaneously. Similarly, all destination CTS packets are sent simultaneously. A handshake is successful when both destinations and sources can capture the packets.

There are numerous ways to design signaling. The general approach is to use multiple consecutive signaling slots. These slots are grouped into phases of one or more signaling slots. A contender either survives or defers from contending after each phase. A node survives a phase by signaling using a higher or equal priority to that of all its neighbors. Priority is assigned to each slot of a phase. One approach to assign priority is highest priority first. The contender that signals first survives the phase. This approach is easily expanded to assign priority based on service requirements. The first phase of Figure 1 illustrates an example assignment. We use this design to explain how different services are managed

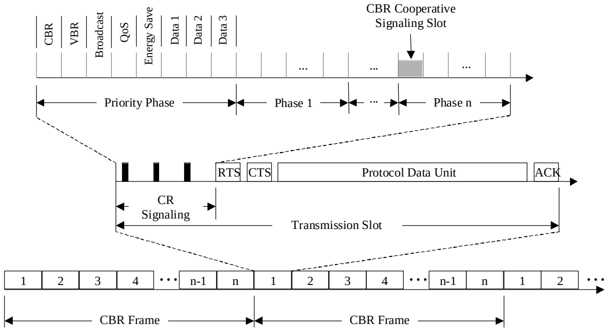

Figure 1. The Synchronous Collision Resolution protocol

3. PRIORITY ACCESS

The CRS mechanism is easily adapted to guarantee that highest priority traffic always gains access first. In a first-to-assert signaling phase, one slot is assigned to each packet priority in order of priority. If a node has a packet with the highest priority of those amongst its neighbors it will always gain access ahead of its neighbors since it will signal first. In our sample signaling design of Figure 1 we show three levels of best effort traffic labeled data 1, 2, and 3. Data 1 traffic will always gain access ahead of data 3 traffic.

4. RESOURCE RESERVATION

SCR enables the reservation of resources. Our proposed method works as follows. A node desiring to reserve a slot for a real time stream will signal in the QoS priority slot. If it wins the contention and successfully exchanges a packet, it may then use the constant bit rate (CBR) priority in the same ordinal slot of the next CBR Frame. This is a use-it or lose-it mechanism. The node may continue to use the CBR priority in this same slot of consecutive frames so long as it used the transmission slot in the previous frame. Destinations cooperate in the reservation of the signaling slots. It is necessary to assure that no nodes within range of the destination will interfere with the destination's reception of the CBR packet. A destination knows when it hears a CBR priority access attempt in a transmission slot if it was the destination in the same ordinal slot of the previous frame. If so, it will also signal in the highest priority slot of the last signaling phase. Only CBR sources and destinations may use this slot. Thus, the destination prevents any interference.

CBR frames are sized to enable one packet per frame to support the minimum CBR data rate. If greater bandwidth is required, the node may reserve more slots within the CBR frame. Since some streamed traffic tends to be bursty, we enable a vari-

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[1] Patent pending.

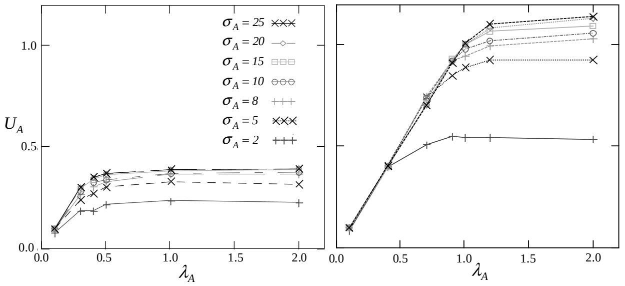
able bit rate (VBR) priority. Nodes that are using the CBR priority to support a stream may use the VBR priority in a best effort way to send additional packets of the same CBR stream. The CBR reservation mechanism may be repeated across multiple hops in an ad hoc network to support multihop streams. By cascading multihop reservations appropriately, multihop streams can achieve delay guarantees.

5. ENERGY CONSERVATION

Handheld radios operate using battery power. It is desirable to prolong the life of these batteries. This is especially a challenge for software defined radios (SDR) since the analog-to-digital converters in these radios consume a lot of energy and must operate continuously in order to detect an incoming signal. The most effective method to reduce energy consumption is to turn off circuits such as these analog-to-digital converters when they are not needed. SCR offers three energy conservation modes: default, periodic, and coordinated. In the default mode, a node may enter a low energy state for the remainder of a transmission slot once it has determined that it will not send nor receive a packet, which is normally after the RTS packet is transmitted. The periodic mode is designed to conserve energy in low use networks. A node can identify when there is a low load on a network when it does not hear any other nodes attempt to contend for access. If this occurs, the node may enter a low energy state for some number of transmission slots. Nodes in a periodic doze state wake up in a specified transmission slot that is know by all nodes in the network. They then remain awake as long as there is traffic. Coordinated dozing is designed for low energy nodes that use the network infrequently. They establish their own dozing period and announce it to their neighbors. Neighbors forward traffic to these nodes only when they are awake. Neighboring nodes with traffic to send to these dozing nodes may use the special energy save priority to gain access. The dozing nodes will remain awake after waking-up so long as the energy save or higher priority is used to gain access. When a lower priority is used, these nodes return to their low energy state until their next scheduled wake-up. We provide a more complete description of energy conservation mechanisms in [Stine and de Veciana 2002].

6. CHANNEL ASSIGNMENT

It has frequently been proposed that using multiple channels can increase the capacity of wireless networks. This is challenging for contention based protocols since special steps must be taken to ensure that a destination knows on which channel it should listen. There is a need for a broadcast channel that all nodes listen to and multiple peer-to-peer channels for directed packets. In contention based protocols, nodes never know which type of packet will be sent next. We solve this problem in the signaling mechanism. We assume a receiver directed channel assignment scheme. Sources will send directed packets to destinations using a channel assigned to the receiver or will use a broadcast channel for broadcast packets. All nodes listen to the signaling and identify the priority used to gain access. Note that there is a broadcast priority in the priority phase. If a node detects the use of the broadcast priority to gain access, it will listen on the broadcast channel, otherwise it will listen on its receiver channel.



a. Spatial capacity with *PG = 1* b. Spatial capacity with *PG = 100*

Figure 2. Comparison of spatial use of the medium with and without using CDMA for different node densities and spatial loads. U_A is the number of exchanges per transmission area per transmission slot, λ_A is the number of packet arrivals to the nodes in a transmission area per transmission slot, and σ_A is the density of nodes in a transmission area. PG is the processing gain.

7. INCREASING CAPACITY

Our simulations have shown that the average density of surviving nodes is approximately 1.5 nodes per transmission area (i.e. the area subsumed by the range of a transmission) when the density of contending nodes is 10 or more. The fraction of these nodes that ultimately exchange packets is dependent on the capture conditions that exist during the RTS, CTS, PDU, and ACK packet exchanges. Capture can be improved by three techniques, using a routing strategy that prefers shorter hops, using directional antennas to reduce interference, and/or using different channels for these packet transmissions. In Figure 2, we illustrate the results of a simulations that compare the performance of the access protocol when a single channel is used to when different direct sequence spread spectrum (DSSS) channels with a processing gain of 100 are used. The density of packet exchanges increases nearly three fold. These results are based on a simulation that randomly selects destinations that are within range of the sources. In the DSSS scenario more long hops are successful. When considering forward progress of packets together with the density of exchanges, the DSSS network has 4.5 times more capacity than the network that does not use DSSS.

8. CONCLUSION

We have described how the collision resolution signaling mechanism of SCR enables QoS and physical layer management. CRS guarantees that the node with the highest priority packet will have precedence in gaining access. It provides a mechanism that enables a node to reserve the channel for streamed traffic. It enables the use of low energy states to conserve energy. It enables the coordination of the use of multiple channels while retaining a flat network architecture. Additionally, all of this is achieved without sacrificing capacity. In fact, the use of multiple channels can increase the already extraordinary capacity of this protocol several times over.

REFERENCES

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