Optimized Channel Access Mechanisms for Decentralized Spread Spectrum Packet Networks

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Abstract

In a Spread Spectrum (SS) network with cooperative, minimum-energy routing, latency grows with the number of stations in the network due to the increasing number of hops which a packet must take en route to its destination. This is the principal factor limiting the number of stations in the network. Previously proposed channel access mechanisms for these networks were principally concerned with collision avoidance, to the detriment of latency, especially in light or moderately loaded networks. Additionally, while avoiding extremely low SNRs due to collisions, better results are obtainable for average SNR. Several new channel access mechanisms are proposed and simulated for the purpose of addressing the issues stated above. The results obtained indicate that there is potential for significant improvement in performance through the use of alternative channel access procedures.

Keywords

Spread spectrum, channel access mechanisms.

Introduction

In [Shep95] it was shown that cooperatively routed, spread spectrum packet radio networks can scale arbitrarily large, as long as the system uses automatic power control and minimum transmitted energy routing. Such as system will maintain a reasonable signal to noise ratio (SNR) even with huge numbers of stations. Unfortunately, such a network will suffer from latency problems. This is due to the fact that the number of hops (transmissions) a packet must make when traversing the network grows as a function of the number of stations in the network. This is the principal obstacle to large--scale networks of this type.

The total latency is determined by the number of hops taken and the average time per hop. The work in [Ettus97] was aimed at improving the latency situation by reducing the number of hops and minimizing congestion through alternative routing methods.

The motivation for the research described herein is to reduce the time which a packet spends waiting to be transmitted, while at the same time improving the SNR of the system as a whole. To this end, various channel access mechanisms have been investigated.

Medium Access Control

A multiple access system (i.e. TDMA, FDMA, SSMA, etc.) is used to divide up a combined bandwidth, and provide for the separation of signals from each other. The purpose of medium access control (MAC) protocols is to arbitrate and coordinate the usage of the shared channel. There are many MAC protocols which have been developed for traditional, non spread spectrum, packet networks. Commonly used ones include ALOHA, carrier sense multiple access (CSMA), and round-robin (token passing).

In ALOHA, a station may transmit whenever it has traffic to send. This works well in lightly loaded networks, and has minimal latency. In a heavily loaded network it suffers from excessive collisions, resulting in decreasing throughput with increasing load. CSMA (which is used by AX.25 networks) was invented to solve these problems. Before transmitting, a station makes sure that the channel is clear. If it is not, it waits a random time (exponential backoff), and tries again.

In the SS network investigated, we are using spread spectrum multiple access (SSMA). Stations are able to differentiate between multiple simultaneous transmissions through the use of orthogonal spreading sequences.

Many SS networks use some variation of an ALOHA MAC protocol. This has the advantage of low latency, and the use of SSMA reduces the effect of what would be collisions to a reduction in SNR. Under high loads, however, this can be a large loss in SNR, and that causes packet loss if the processing gain (PG) is not increased. A corresponding decrease in throughput occurs.

In order to avoid collisions, a localized coordination system was used in [Shep95]. This was based on a slotted system in which stations were assigned transmit and receive windows based on a pseudorandom hash function. It ensures that a station will not transmit when the desired recipient might also be transmitting, or when a nearby station might be listening. The advantage of this method is that all local collisions (those that have the greatest effect on SNR) can be avoided.

Although this system works very well, especially under heavy loads, it is not perfect. The principal disadvantage is that it is not an adaptive system. If no other stations in the network are transmitting, a station will wait until an appropriate time slot comes along anyway. On the other end of the spectrum, in a very heavily loaded network, even without local collisions, enough distant stations might be transmitting to cause the channel noise level to be high. This causes the system designer to provide enough extra processing gain to overcome these lower SNRs, even though they only **occur** during heavy load.

Overload-signal spread spectrum (OSSS) [OO98], which provided the inspiration for this research, attempts to solve this problem. Unfortunately, its use only applies to cellular networks (all transmissions to or from base stations). It relies upon the base station to sense its received noise level. When it gets too high, it sends out an “overload signal” which tells the other units to hold off on transmissions. This works best with geographically small networks.

The main thrust of this research was to investigate new MACs which would combine the desirable properties of ALOHA, CSMA, OSSS, and Tim Shepard’s slotted system (TSSS for lack of a better name).

Alternative MAC Protocols

A total of five different MAC protocols were investigated. These were ALOHA, TSSS, and three new ones, discussed below. ALOHA allows a station to transmit when it wants to, as long as it is not *already* receiving. TSSS allows a station to transmit when:

- it is in a transmit window
- the receiver is in a receive window
- there are no nearby stations in a receive window which would be stepped on

The new systems all attempt to provide throttling of transmission when the packet probably would not get through. It is impossible to implement CSMA with spread spectrum, as there are too many signals (carriers) to sense. Instead, we use noise sensed multiple access (NSMA). This is essentially an ALOHA system which will not transmit if local noise is high. So long as the noise level at the transmitter (which does the sensing), and the receiver are similar, this will prevent transmission when it would result in poor SNR on reception.

The second new system is basically the same as NSMA, but implements exponential backoff. This is designed to prevent large numbers of stations from jumping back on the channel at the same time after a noisy condition ends.

The last MAC proposed uses NSMA and TSSS. Since it is still slotted like TSSS, this will not directly improve latency. If it improves SNR, however, throughput is improved, and fewer retries are necessary.

Simulation

In order to gain a better understanding of how these various channel access mechanisms affect the performance of the network, it was necessary to perform simulations. A simulator, based on SSNetSim from [Ettus98], was developed for this purpose. The hash-based coordination function had been previously implemented, but the three noise-based functions needed to be created.

For the purposes of this simulation, a simple network was created with the following parameters:

- 300 Stations
- Uniform random station distribution
- R^2 Path loss
- Minimum transmitted energy routing
- Random traffic model

For the NSMA based protocols, a level of -6 dB was chosen as the noise threshold. Below that level, a station would hold off on transmitting.

Results

Figure 1 shows the SNR results for each of the MACs. ALOHA, as expected, had the lowest SNR performance of all. NSMA by itself was next. The best performance was with TSSS and NSMA combined, followed by TSSS by itself, and then NSMA with backoff.

NSMA with backoff did improve SNR vs. ALOHA, and was only slightly worse than TSSS in terms of SNR. Its latency properties were also favorable.

The addition of NSMA to TSSS improved the overall SNR distribution, and, more importantly, also nearly completely eliminated packets with extremely low SNR.

From figure 2, overall performance can be seen relative to TSSS. Improvements or reductions in SNR translate directly to bitrate.[1] Latency, in this model is inversely proportional to bitrate, so a combined performance factor is obtained. ALOHA is actually an improvement over TSSS due to the greatly reduced latency, according to this measure. This may not be completely accurate, as ALOHA has many packets which have very low SNR, necessitating many retransmissions.

NSMA alone actually performs worse than TSSS due to the loss in overall SNR, and large number of collisions. NSMA with backoff and TSSS/NSMA represent significant performance improvements.

Conclusions

Both NSMA with exponential backoff, and the combination of TSSS and NSMA show promise to improve overall system performance. The SNR improvements allow bitrates to be increased. Further investigation on both of these protocols is warranted.

There is still a lot of room for improvement in MACs for this type of network. An interesting experiment would be to attempt to apply the ideas of MACA [Karn91], in conjunction with NSMA and exponential backoff. This could go a long way towards solving the local collision problem encountered when not using TSSS.

References

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[1] SNR numbers represent the relative positions of the tail of the SNR distribution. The tail, and not the peak, is important. We don't want average packets to get through. We need nearly all to get through for good performance.

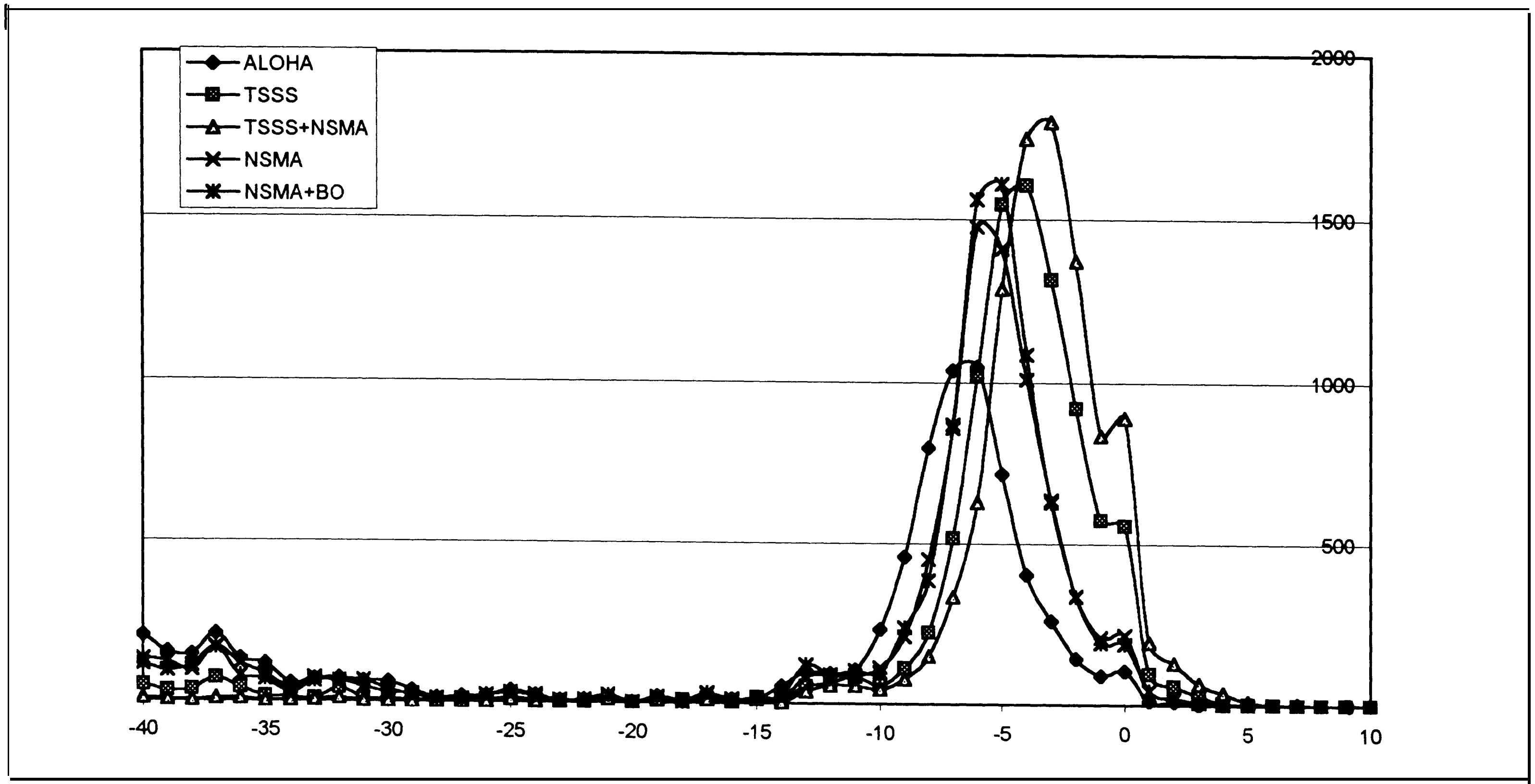

Figure 1

Protocol	Median Latency	Relative SNR	Performance Factor
ALOHA	47	-3dB	1.06
TSSS	100	0 dB	1
TSSS+NSMA	120	1.5 dB	1.17
NSMA	69	-2dB	0.91
NSMA+BO	70	-1dB	1.13

Figure 2