IEEE 802.11 versus CDMA Technology in Wireless Ad Hoc Networks

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Abstract

Ad Hoc Networks are a technology having a wide range of applications in today’s world. These are mobile, wireless networks that can be setup anywhere at any time. Since they are constrained in terms of networking hardware and energy, special protocols need to be developed to aid them. A lot of work has gone into their development and this area receives a large amount of funding from the defense services.

This paper discusses the design and performance of a specialized version of CDMA, which is used in the MAC Layer for communication. Presently IEEE 802.11 Wireless protocol is being used in the Wireless Ad Hoc network. Random Packet – CDMA provides an alternative technology for use in the MAC Layer of Ad Hoc Networks, which achieves a high amount of throughput.
I. Introduction

Ad Hoc Networks have widespread applications in the areas of defense, mobile conferencing, sensor networks etc. Research in these networks faces a lot of challenges due to resource constraints and mobility problems. There have been a large number of solutions proposed for these problems depending on the situation and constraints. Most of these solutions address routing and TCP functions over ad hoc, though networking parameters like delay, throughput and connectivity are mainly determined by the physical layer. IEEE 802.11 has been used, which suffers from congestion, connectivity loss and delay as the load increases.

IEEE 802.11 is used in Ad hoc since it is easily available and the presence of specialized routing algorithms like AODV and DSR. In addition to being exposed to congestion, IEEE 802.11 also suffers from Exposed and Hidden node problems. The addition of RTS/CTS leads to more overhead and can cause additional congestion in Ad Hoc Networks. Studies have also shown this can lead to collision rates of 60% in cases of high load [9]. DBTMA – Delay Busy Tone Multiple Access, proposed solves this problem by addition of another channel which indicates whether a transmission is taking place or not. This reduces the number of collisions but leaves unresolved the problem of delay and congestion in cases of high load.

On the other hand if we use CDMA for medium access, we can perform multiple transmissions without interference between messages leading to less delay and congestion in case of heavy loads. However the problem here is in the detectors capability to suppress multi user interference and limits the performance of the scheme. Using advanced multi user detection techniques like assigning orthogonal signatures to users in an area, it is possible to improve the performance. Section II provides an overview on CDMA technology. Section III and IV talk about RP-CDMA and Spread ALOHA implementations for the ad hoc network. Section V describes receiver technology. Section VI discusses the simulation results.
II. CDMA: Code Division Multiple Access

Data supplied to a CDMA transmitter is first spread into a larger band by multiplying with a code. There are a set of codes which are orthogonal to each other and so data can be transmitted on the channel at the same time and frequency without interfering with each other. This is known as a spread spectrum technique and is illustrated in figures 1 and 2. It is interesting to note that the power of the transmitted signals is different.
III. Spread Aloha

ALOHA protocol is the first random access protocol developed. Though it offers very low throughput and is not very practical for IP communication, it requires very low overhead. Implementing spread spectrum technology in ALOHA protocol, we derive the Spread ALOHA. Since CDMA requires knowledge of the spreading sequence for decoding, all receivers in the system use the same code. However this limits the performance as far as interference and collision are concerned.

![Image of Spread Aloha](image)

**Fig. 3**

In Spread Aloha packets get destroyed if they overlap completely or are of insufficient power. It is possible however to recover some packets through multi packet capture if they have sufficient power. Figure 3 shows collisions occurring due to multi user interference. A matched filter is usually used for demodulation of Spread ALOHA. The signal to noise ratio for a packet $j$ is given by:

$$SNR_{S-ALOHA} = SNR_{mf,j} = \frac{P_j}{\sigma^2 + \sum_{k=1, k \neq j}^{K} \frac{P_k}{N}}$$

There are $K$ active packets in the system and $P_k$ is the received signal power of the $k^{th}$ packet. The throughput achieved by this system is also 18%, which is the same as ALOHA.
IV. RP-CDMA: Random Packet CDMA for connectionless networks

RP CDMA uses different code sequences. Since the receiver needs to know the spread sequence before decoding, the spread sequence is attached to the data as a header. Figure 4 describes the header and the frame. The header is coded using the same pre determined sequence and can lead to collisions. So the length of the header needs to be minimized.

Figure 5 shows the possible types of collision. The header and data spaces have been broken up into virtual channels. The probability of a collision can be given by:

\[ P_{coll} = P_{overlap} P_{chip} \]

With a random number generator of \( N \) bits, \( 2^N - 1 \) sequences are possible and given that this is sufficiently large, the collisions will be low.
Lₜ is the length of the header for RP-CDMA, which is nearly 50 bytes and the throughput of the system has been plotted against the offered load. From figure 6 we can see that the maximum throughput of Spread ALOHA is 18%, whereas that of RP-CDMA almost reaches the optimal value. At the optimal value the load supplied to the system/ number of packets is equal to the number transmitted. IP packets are tri modally distributed at 50, 500 and 1500 bytes with a mean value of Lₒ/Lₜ=60.

V. CDMA Multi User Detection Technology

In addition to problems of header collision, RP-CDMA is subject to interference. This requires advanced decoding technology involving partitioned spreading. Traditional multi user detection use techniques like matched filtering, zero forcing decorrelator and MMSE filtering. Partitioned Spreading technique is used which gives better performance than these. The original spreading sequence is separated into chunks called partition. Partitions are transmitted separately after passing through an interleaver. Now each partition is understood to be a part of a repetition code and decoded iteratively at the receiver using a multi stage receiver.
Figure 7 shows interleaving on the bit sequence received. The receiver operates in stages. The first stage is a conventional matched filter receiver. In subsequent iterations for demodulation, attempts are made to cancel the signal interference. The interleaver performs in the same way as for a turbo decoder. M can be varied from 1 to N, varying the rate of the code. An M=1 might be favorable for a small user environment and M=N required when there are a large number of users and high interference.

Figure 8 is the demodulation performance for an unequal power system with 54 users and for different values of $\alpha = K/N$. This shows that partition spreading can achieve the interference free SNR of 10 dB in few iterations.
VI. Simulation Results

Figure 9 shows the results of a performance analysis. The simulations have been performed on Matlab. The network uses the traditional CDMA for communication which is a good approximation. Packet generation is treated as a Bernoulli process. A node needs to send packets as well as forward packets it has received. The 3-D graphs have been plotted for a) Matched Filter Detector b) Decorrelation Detection c) Successive Cancellation Detector d) MMSE Detector. The vertical axis represents the total number of subnets created – \( \lambda \) and the ratio of maximum distance of operational nodes to the maximum distance at the time of route discovery – \( \delta \). Figures 9 a, b and c behave in the same manner. Even with medium values of packet generation probability and number of ad hoc nodes, the system has high values of \( \lambda \) and \( \delta \). However the difference between MMSE Detector and Partitioned Scheme is small, though the latter performs slightly better.
Studies were performed using a mobile test bed called the FLUX mobile robot test bed. There are 30 nodes in the system, with receivers implementing the CDMA technology. Fig 10 a shows that as packet generation probability increases the transmission probability increases linearly initially for RP-CDMA. However we can also see that after a P=0.4 the increase is decelerated by an increase in the number of header collisions. Fig 10 b shows the header collisions per node as the transmission probability, which is the sum of packet generation and forwarding increases.
VII. Conclusions

This paper discusses the problems of IEEE 802.11 wireless standard. It later shows that CDMA offers much higher throughput, especially in cases of congestion. CDMA does not suffer from hidden and exposed node problems. However, it requires additional headers and complicated detectors. The paper also shows simulation results on the performance and a comparison of the various detection technologies available.
References


