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WIDE BAND CODING FOR WIRELESS ADHOC NETWORK WITH CTS-RTS PROTOCOL UPDATING

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Abstract: Enabling wideband-based solutions for MANET's results in high throughput solution. But with the usage of using wide-band based solutions have various challenges, which are essentially related to the absence of centralized control i.e., a base station. First, a code assignment protocol is needed to assign distinct codes to different terminals. This problem is trivial in small networks, but becomes dominative in large networks where the numbers of PN codes are lesser than the number of terminals, necessitating spatial reuse of the PN codes. Unlike previously proposed protocols in this paper a multiple access interference (MAI) reduction, with the addressing limiting of near-far problem that undermines the throughput performance in MANETs is been proposed. The code assignment scheme is to be developed for the proper usage of user's code under MANET's communication. This code of communication is achieved with an updated approach of CTS-RTS protocol.

Keyword: MANET's, wide band coding, protocol updation, MAI reduction, performance updation.

I. INTRODUCTION

Wireless communication standard are now emerging for the service compatibility of demanded services for coming generation wireless communication. The current wireless architecture could be failing in providing the service compatibility in next generations communication standard and need to be improved or merged with other wireless communication standard for this demand compatibility. One such evolving wireless communication technique is mobile Ad Hoc network. Mobile ad hoc networks (MANETs) have recently been the topic of extensive research. The interest in such networks stems from their ability to provide a temporary wireless networking capability in scenarios where fixed infrastructures are lacking and are expensive or infeasible to deploy (e.g., disaster relief efforts, battlefields, etc.). While wide deployment of MANETs is yet to come, many efforts are currently underway to standardize protocols for the operation and management of such networks. One fundamental challenge in MANETs is, how to increase the overall network throughput while maintaining low energy consumption for packet processing and communications. One of the advanced wireless communication standard providing such a service is the WBC based wireless communication. WBC is a spread spectrum (SS) communication techniques, in which each user occupies the entire available bandwidth. At the transmitter, a digital signal of lower bandwidth is spread using a pseudo-random noise (PN) code of larger bandwidth. The spreading concept of WBC system is developed to provide better throughput in wireless networks with minimum processing computation. The significant nature of this WBC concept could be merged with the evolving MANET architecture for providing high throughput with minimum power utilization for efficient communication in next generation wireless communication. Several WBC-based MAC protocols for MANETs have been proposed in past. These protocols, in general, are based on random channel access, whereby a terminal with a packet to transmit can proceed immediately with its transmission, irrespective of the state of the channel. We refer to such schemes as random access WBC (RA-WBC). Under appropriate code assignment and spreading-code schemes, RA-WBC protocols are guaranteed to be free of primary collisions. However, the nonzero cross-correlations between different WBC codes can induce multi-access interference (MAI), resulting in secondary collisions at a receiver (collisions between two or more transmissions that use different WBC codes). This problem is known as the near-far problem. The near-far problem can cause a significant reduction in network throughput, and is to be overcome for designing WBC-based MAC protocols for MANETs. As stated above the near far effect in WBC based MANET network can cause significant degradation in throughput in wireless network, a methodology for minimizing this MAI is to be developed for improving the performance of Mobile Adhoc network. This work focus on the development of such a methodology for the minimization of MAI in proposed WBC based MANET for efficient performance in Mobile Adhoc network.

II. PAST APPROACHES

A dynamic power allocation method is to be developed for the minimization of MAI effects in such a network. A dynamic code allocation strategy for WBC is to be developed for the controlling of this MAI in the proposed communication network. In [30] the addresses part of the packet are spread using the common code, while the rest of the packet is spread using the transmitter-based approach. A receiver notes the address of the source terminal and uses this address to switch to the corresponding code. In [15] the authors proposed the coded tone sense protocol, in which *K* busy tones are associated with *K* spreading codes. During packet reception on a certain code, the receiving station broadcasts the corresponding busy tone. In [11] all terminals send the RTS-CTS packets on a common code, while the data packet are sent using a transmitter- or a receiver-based approach. Somewhat similar approaches were proposed in [16] and [34]. In all the above protocols, the authors assume perfect orthogonality between spreading codes, i.e., they ignore the near-far problem. A reservation-based scheme was proposed in [33], whereby small control packets are used to request slot assignments for data packets. The authors investigated the use of FHSS to avoid MAI. Their approach, however, cannot be used for DSSS, which is the method of choice in recent wireless standards (e.g. IS-95). In [6] and [10] the authors proposed distributed channel assignment algorithms for SS multihop networks. Those protocols, however, do not allow for any MAI, and hence cannot support concurrent transmissions of signals with different codes. Clustering as proposed in [18] is another interesting approach for power control in WBC networks. It simplifies the forwarding function for most terminals, but at the expense of reducing network utilization (since all communications have to go through the cluster heads). This can also lead to the creation of bottlenecks. In [28] the authors proposed the use of a multiuser detection circuit at the receiver to mitigate the near-far problem in MANETs. The proposed scheme also requires the use of GPS receivers to provide accurate position and timing information. Such a scheme relies heavily on physical layer techniques to mitigate MAI, and makes no effort to account for MAI at the MAC layer. Moreover, although it is feasible to deploy multiuser GPS receivers at the base station, presently it is impractical (and expensive) to implement such receivers within the mobile terminal. Recently, an interesting approach for joint scheduling and power control in ad hoc networks was proposed [9]. This approach, however, requires a central controller for executing the scheduling algorithm, i.e., it is not a truely distributed solution. Furthermore, it assumes the existence of a separate feedback channel that enables receivers to send their SNR measurements to their respective transmitters in a contention free manner. In [5] and [8] the authors analyzed RA-WBC protocols for MANETs in the presence of MAI. They assumed that transmissions of all neighbors produce the same noise effect, and therefore, the SNR threshold can be converted into a threshold on the number of transmissions (*n*) in the receiver's neighborhood. A packet is correctly received when that number is less than the predetermined threshold *n*. hence, the protocol was called WBC/*n*. Although such an approximation may not be accurate in topologies where nodes are not equally spaced, it shows that MAI can significantly degrade network performance.

II. WIDEBAND CODING

The stated objective is developed for the evaluation of the suggested network for various factors evaluation used in wireless network. To develop the stated approach the implementation is to be developed with the modeling of a conventional randomly scattered adhoc network, where each node is provided with a WBC transmitter and receiver architecture. The WBC architecture is to be developed using IS-95 WBC standards. The developed architecture is then to be evaluated for network performance with different level of MAI in wireless channel with static code allocation. A dynamic code allocation strategy is to be then developed for these network and will be incorporated to each node and the performance evaluation will be repeated for the same scenarios as carried out for conventional approach to evaluate the performance improvement. The operational description of the proposed architecture called " controlled Access WBC" (CA-WBC) for MANET is as presented below. The CA-WBC protocol is contention based and uses a modified RTS-CTS reservation mechanism. RTS and CTS packets are transmitted over the control channel (on the common code) at a fixed (maximum) power Pmax. These packets are received by all potentially interfering nodes, as in the IEEE 802.11 scheme. However, in contrast to the IEEE 802.11 scheme and RA-WBC protocols, interfering nodes may be allowed to transmit concurrently, depending on some criteria .For the ensuring data packet, the receiver and the transmitter must agree on two Parameters: the spreading code and the transmission power. Code selection can be done according to any code assignment scheme. The choice of the power level is critical and represents a tradeoff between link quality and MAI. More specifically, as the transmission power increases, the bit error rate at the intended receiver decreases (i.e., link quality improves), but the MAI added to other ongoing receptions increases (i.e., the quality of these receptions deteriorates). In addition to accounting for these two factors, this protocol incorporates an interference margin in the power computations. This margin allows terminals at some interfering distance from the intended receiver to start new transmissions in the future. In this design, two frequency channels were used, one for data and one for control (i.e., FDMA-like partitioning). All nodes use a common spreading code over the control channel, while several terminal-specific codes can be used over the data channel. The different codes used over the data channel are not perfectly orthogonal. However, because of the frequency separation, a signal over the control channel is completely orthogonal to any signal (or code) over the data channel. The splitting of the available bandwidth into two non-overlapping frequency bands is fundamentally needed to allow a terminal to transmit and receive simultaneously over the control and data channels, irrespective of the signal power. This approach is merged with WBC architecture for power allocation in MANET nodes for minimum MAI and efficiency improvement.

III. CODING APPROACH FOR MANET'S

Several WBC-based MAC protocols for MANETs have been proposed in the literature (e.g., [30, 15, 19, 11, 16]). These protocols, in general, are based on random channel access, whereby a terminal with a packet to transmit can proceed immediately with its transmission (starting, possibly, with an RTS/CTS exchange), irrespective of the state of the channel. We refer to such schemes as random access WBC (RA-WBC). Under appropriate code assignment and spreading-code schemes, RA-WBC protocols are guaranteed to be free of primary collisions. However, as explained in details in Section 2, the nonzero cross-correlations between different WBC codes can induce multi-access interference (MAI), resulting in secondary collisions at a receiver (collisions between two or more transmissions that use different WBC codes). In the literature, this problem is known as the near-far problem [23]. As shown in Section 2, the near-far problem can cause a significant reduction in network throughput, and hence cannot be overlooked when designing WBC-based MAC protocols for MANETs. Accordingly, the main goal of this paper is to provide a WBC-based MAC solution for MANETs that addresses the near-far problem.

In our protocol, the transmission powers are dynamically adjusted such that the MAI at any receiver is not strong enough to cause a secondary collision. As indicated in our simulations, this results in a significant improvement in network throughput at no additional cost in energy consumption. In fact, the proposed protocol is shown to achieve some energy saving compared to the 802.11 schemes. To the best of our knowledge, this is the first attempt to address the near-far problem in the design of MAC protocols for MANETs.

NEAR-FARPROBLEM IN RA-WBC

The roots of the near-far problem lies in the fact that unlike FDMA and TDMA channels which can be completely orthogonal, WBC codes suffer from nonzero cross-correlation between codes. When a WBC receiver de-spreads a signal, it effectively computes the cross-correlation between the signal and a locally generated PN sequence. If this PN sequence is identical to the one used to spread the signal at the transmitter (i.e., the message is intended to *this* receiver), cross-correlation computations restore the original information data. Otherwise, such computations result in either a zero or a nonzero value, depending on whether the system is synchronous or asychnronous. A system is called time-synchronous if all signals originate from the same transmitter, as in the case of the downlink of a cellular WBC network4. In here, synchrony is manifested in two ways. First, different transmissions that are intended for different receivers will have a common time reference. Second, from the viewpoint of a given mobile terminal, all signals (intended or not) propagate through the same paths, and thus suffer the same time delays. In synchronous systems, it is possible to design *completely orthogonal* spreading codes. In fact, in the IS-95 standard for cellular WBC networks [24], each user of the channel is assigned a Hadamard (or Walsh) code. These codes are orthogonal and are used to "channelize" the available bandwidth. On the other hand, a system is called time-asynchronous if signals originate from multiple transmitters, as in the case of the uplink of cellular networks and also in MANETs. The reasons behind the naming are twofold. First, since signals originate from *different* transmitters, it is generally not feasible to have a common time reference for all the transmissions that arrive at a receiver. Second, these transmissions propagate through different paths; thus, they suffer different time delays [25]. In an asynchronous system, it is *not* possible to design spreading codes that are orthogonal for all time offsets [24]. In this case, the cross-correlation between codes cannot be neglected. In fact, codes that is orthogonal in synchronous systems (e.g., Hadamard codes) exhibit high cross-correlation when not perfectly synchronized. Instead, PN codes that are designed specifically to have low cross-correlation are used. While the code design problem is crucial in determining the system performance, of greater importance is the problem of nonzero cross-correlation of the PN codes [23]. Unintended transmissions add nonzero MAI during the dispreading at a receiver. The near-far problem is a severe consequence of MAI, whereby a receiver who is trying to detect the signal of the *i*th transmitter may be much closer in distance to, say, the j^{th} transmitter than the *i*th transmitter. When all transmission powers are equal, the signal from the j^{th} transmitter will arrive at the receiver in question with a sufficiently larger power than that of the *i*th transmitter, causing incorrect decoding of the i^{th} transmission (i.e., a secondary collision).

ARCHITECTURE

In our design, we use two *frequency* channels, one for data and one for control (i.e., FDMA-like partitioning). A common spreading code is used by all nodes over the control channel, while *several* terminal-specific codes can be used over the data channel. This architecture is shown in Figure 4. Note that the different codes used over the data channel are not perfectly orthogonal. However, because of the frequency separation, a signal over the control channel is *completely* orthogonal to any signal (or code) over the data channel. The splitting of the available bandwidth into two non-overlapping frequency bands is fundamentally needed to allow a terminal to transmit and receive simultaneously over the control and data channels, *irrespective of the signal power*. As we explain shortly, our protocol utilizes this fact to allow interference-limited transmissions that use (quasiorthogonal) data channel codes to proceed concurrently.

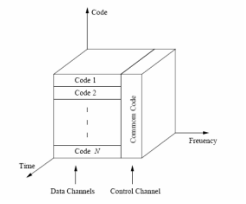


Figure 1: Data and control codes in the proposed protocol.

Channel Model and Protocol Assumptions

In designing our protocol, we assume that: (1) the channel gain is stationary for the duration of the control and the ensuing data packet transmission periods; (2) the gain between two terminals is the same in both directions; and (3) data and control packets between a pair of terminals observe similar channel gains.

In addition to the above assumptions, we assume that the radio interface can provide the MAC layer with the average power of a received control signal as well as the average interference power. Each terminal is equipped with two transceivers and a carrier-sense hardware that senses

the control channel for any carrier signal. No carrier-sense is needed for the data channel. The carrier frequency spacing between the control and data channels is enough to ensure that the outgoing signal on one channel does not interfere with the incoming signal on the other channel.

CONTROLLED ACCESS WBC (CA-WBC) PROTOCOL

Our CA-WBC protocol is contention based and uses a modified RTS-CTS reservation mechanism. RTS and CTS packets are transmitted over the control channel (on the common code) at a fixed (maximum) power *Pmax*. These packets are received by all potentially interfering nodes, as in the IEEE 802.11 scheme. However, in contrast to the IEEE 802.11 scheme and RA-WBC protocols, interfering nodes *may* be allowed to transmit concurrently, depending on some criteria that will be discussed later. For the ensuing data packet, the receiver and the transmitter must agree on two parameters: the spreading code and the transmission power. Code selection can be done according to any code assignment scheme. As explained later, even if the code assignment scheme is not correct, our protocol will still function properly. The choice of the power level is critical and represents a tradeoff between link quality and MAI. More specifically, as the transmission power increases, the bit error rate at the intended receiver decreases (i.e., link quality improves), but the MAI added to other ongoing receptions increases (i.e., the quality of these receptions deteriorates). In addition to accounting for these two factors, our protocol also incorporates an interference margin in the power computations. This margin allows terminals at some interfering distance from the intended receiver to start new transmissions in the future. In the CA-WBC protocol, terminals exploit knowledge of the power levels of the overheard RTS and CTS messages to determine the power that they can use without disturbing the ongoing receptions. In Section 4.6 we develop a distributed admission control strategy that decides when terminals at some distance can proceed concurrently with their transmissions.

INTERFERENCE MARGIN

An interference margin is needed to allow terminals at some distance from a receiver to start new transmissions in the future. In this section, we describe how this margin is computed. Consider an arbitrary receiver *i*. Let $\mu*$ be the *Eb/N*0eff ratio that is needed to achieve the target bit error rate at that receiver. It follows from (1) that to achieve the target error rate, we must have

$$\frac{P_0^{(i)}}{P_{thermal}+P_{\mathrm{MAI}}^{(i)}} \geq \mu^*$$

where *P*(*i*) 0 was defined before, *Pthermal* is the thermal noise power and *P*(*i*) MAI is the total MAI at receiver *i* (in (1) *P*(*i*) MAI = 2P*K j*=1 *Pj/*3*W*). So the minimum required received power is

(*P*(*i*) 0)*min* = $\mu*$(*Pthermal* + *P*(*i*) MAI).

The interference margin strongly depends on the network load, which itself can be conveyed in terms of the so-called *noise rise* (ξ(*i*)), defined as follows:

$$\xi^{(i)} \stackrel{\mathrm{def}}{=} \frac{(\frac{E_b}{N_0})_{\mathrm{unloaded}}}{(\frac{E_b}{N_0})_{\mathrm{loaded}}} = \frac{P_{thermal}+P_{\mathrm{MAI}}^{(i)}}{P_{thermal}}$$

Note that (*P*(*i*) 0)*min* = ξ(*i*)$\mu*$*Pthermal* is also dependent on the noise rise. While more capacity can be achieved by increasing the noise rise (i.e., allowing larger *P*(*i*) MAI), the maximum allowable noise rise is constrained by two factors. First, Federal Communications Commission (FCC) regulations limit the power to some fixed value (e.g., 1 Watt for 802.11 devices). Given this maximum transmission power, as the noise rise is increased, the received power (*P*(*i*) 0)*min* must increase ($\mu*$ and *Pthermal* are constants) and hence, the maximum range (or coverage) for reliable communication will decrease. Second, increasing the noise rise increases the power used to transmit the packet, which in turn increases energy consumption. Energy is a scarce resource in MANETs, so it is undesirable to trade off energy for throughput. We set the interference margin used by a transmitter to the maximum *planned* noise rise (ξ*max*), which is obtained by taking into account the above two restrictions on ξ(*i*). The computations are performed as follows. First, we require that the maximum range, say *d*max, of our protocol be the same as the maximum range of the 802.11 scheme. For the maximum range, the power used in our protocol equals ξ(*i*) times the power used in the 802.11 standard. Thus, ξ*max* cannot be greater than the ratio of the power limit set by the FCC and the power used in the 802.11 scheme. To account for the second constraint, we choose the interference margin in a manner that maintains the same *energy per bit* consumed in the 802.11 scheme. The value of the interference margin that achieves the above goals can be derived as follows. We assume that the transmission power attenuates with the distance *d* as *k/dn* (*k* is a constant and $n \geq 2$ is the loss factor). The minimum required transmit power in CA-WBC is:

$$P_{\text{CA-CDMA}} = \frac{\xi_{max}\mu^* P_{thermal} d^n}{k}$$

Assuming that the distance *d* is uniformly distributed from zero to *d*max, we compute the expectation of *P*CA-WBC with respect to *d*:

$$E[P_{\text{CA-CDMA}}] = \frac{\xi_{max}\mu^* \; P_{thermal} d^n_{\max}}{k(n+1)}$$

As for the 802.11 protocol, its corresponding transmission power is:

$$P_{802.11} = \frac{\mu^* \; P_{thermal} d^n_{\max}}{k}$$

Note that *P*802.11 does not depend on *d* since the 802.11 standard uses a fixed transmission power.

Accordingly, to achieve equal average energy per bit consumption, we must have:

$$\frac{E\left[P_{\text{CA-CDMA}}\right]}{R_{\text{CA-CDMA}}} = \frac{P_{802.11}}{R_{802.11}}$$

where *R*CA-WBC and *R*802.11 are the bit rates for the transmitted data packets in the CA-WBC and 802.11 protocols, respectively. The reason why these rates can be different is that in our protocol we use two distinct frequency bands, one for control packets and one for data packets, while the standard uses only one band for all packets. Hence, for a fair comparison, data packets in the CA-WBC protocol must be transmitted at a slower rate. From (6), (7), and (8), the interference margin is given by:

$$\xi_{max} = (n+1)\frac{R_{\text{CA-CDMA}}}{R_{802.11}}$$

IV. PROTOCOL UPDATION IN RTS-CTS

We now describe the admission control and channel access strategy in the CA-WBC protocol. The admission scheme allows only transmissions that cause neither primary nor secondary collisions to proceed concurrently. RTS and CTS packets are used to provide three functions. First, these packets allow nodes to estimate the channel gains between

transmitter-receiver pairs. Second, a receiver *i* uses the CTS packet to notify its neighbors of the additional noise power (denoted by *P*(*i*)
noise) that each of the neighbors can add to terminal *i* without impacting *i*'s current reception. These neighbors constitute the set of *potentially interfering* terminals. Finally, each terminal keeps listening to the control
channel regardless of the signal destination in order to keep track of the average number of active users in their neighborhoods. These functions are now explained in detail. If terminal *j* has a packet to transmit, it sends a RTS packet over the control channel at *P*max, and includes in this packet the maximum *allowable* power level (*P*(*j*) map) that terminal *j* can use that will not disturb any ongoing reception in *j*'s neighborhood. The computation of this power will be discussed shortly. The format of the RTS packet is similar to that of the IEEE 802.11, except for an additional two-byte field that contains the *P*(*j*) map value.

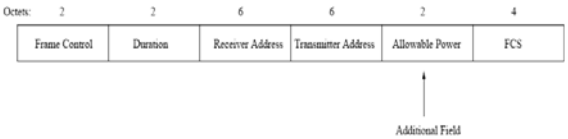


Figure 5: Format of the RTS packet in the CAWBC protocol.

Upon receiving the RTS packet, the intended receiver, say terminal *i*, uses the predetermined *P*max value and the power of the received signal *P*(*ji*)
received to estimate the channel gain *Gji* = *P*(*ji*) received/*P*max between terminals *i* and *j* at that time (note that we assume channel reciprocity, and so *Gij* = *Gji*) . Terminal *i* will be able to correctly decode the data packet if transmitted at a power *P*(*ji*) min given by:

$$P_{\min}^{(ji)} = \frac{\mu^* (P_{thermal} + P_{\text{MAI-current}}^{(i)})}{G_{ji}}$$

where *P*(*i*) MAI-current is the effective *current* MAI from all already ongoing (interfering) transmissions. Note that because of the assumed stationarity in the channel gain over small time intervals, *Gji* is approximately constant throughout the transmissions of the control packet and the ensuing data packet. Now, *P*(*ji*) min is the minimum power that terminal *j* must use for data transmission in order for terminal *i* to correctly decode the data packet *at the current level of interference*. This *P*(*ji*) min, however, does not allow for any interference tolerance at terminal *i*, and thus all neighbors of terminal *i* will have to defer their transmissions during terminal *i*'s ongoing reception (i.e., no simultaneous transmissions can take place in the neighborhood of *i*). Now, according to the link budget calculations in Section 4.5, the power that terminal *j* is allowed to use to send to *i* is given by:

$$P_{\text{allowed}}^{(ji)} = \frac{\xi_{max} \mu^* P_{thermal}}{G_{ji}}$$

If *P*(*ji*) allowed < *P*(*ji*) min, then the MAI in the vicinity of terminal *i* is greater than the one allowed by the link budget. In this case, *i* responds with a negative CTS, informing *j* that it cannot proceed with its transmission (the negative CTS is used to prevent multiple RTS retransmissions from *j*). The philosophy behind this design is to prevent transmissions from taking place over links that perceive high MAI. This consequently increases the number of active links in the network (subject to the available power constraints). On the other hand, if *P*(*ji*) allowed > *P*(*ji*) min, then it is possible for terminal *i* to receive *j*'s signal but only if *P*(*ji*) allowed is less than *P*(*j*) map (included in the RTS). This last condition is necessary so that transmitter *j* does not disturb any of the ongoing transmissions in its vicinity. In this case, terminal *I* calculates the *interference power tolerance* *P*(*i*) MAI-future that it can endure from *future* unintended transmitters. This power is given by

$$P_{\text{MAI-future}}^{(i)} = \frac{3W \ G_{ji}}{2 \ \mu^*} (P_{\text{allowed}}^{(ji)} - P_{\min}^{(ji)})$$

Note that the factor 3*W*/2 comes from the spreading gain (see (1)). The next step is to equitably distribute this power tolerance among future potentially interfering users in the vicinity of *i*. The rational behind this distribution is to prevent one neighbor from consuming the entire *P*(*i*) MAI-future.

In other words, we think of *P*(*i*) MAI-future as a network resource that should be shared among various terminals. Let *K*(*i*) be the number of terminals in the vicinity of *i* that are to share *P*(*i*) MAI-future. This number is determined as follows.

Terminal *i* keeps track of the number of simultaneous transmissions (i.e., load) in its neighborhood, which we donate by *K*(*i*) inst. This can be easily achieved by monitoring the RTS/CTS exchanges over the control channel. In addition, *i* keeps an average *K*(*i*) avg of *K*(*i*) inst over a specified window. Then, *K*(*i*) is calculated as:

$$K^{(i)} = \begin{cases} \beta(K_{\text{avg}}^{(i)} - K_{\text{inst}}^{(i)}), & \text{if } K_{\text{avg}}^{(i)} > K_{\text{inst}}^{(i)} \\ \beta, & \text{otherwise} \end{cases}$$

where $\beta > 1$ is a safety margin. Now, the MAI at terminal *i* can be split into two components:
one that is attributed to terminals that are within the range of *i* (denoted by *P*(*i*) MAI-within), and one that is caused by terminals outside that range (denoted by

$P(i)$ MAI-other). While terminal i can have some control over $P(i)$ MAI-within, it cannot influence $P(i)$ MAI-other. We account for this fact in the value of $P(i)$ noise as follows. In line with cellular systems, we assume that $P(i)$ MAI-other = $\alpha P(i)$ MAI-within, where $\alpha < 1$ and depends mainly on the propagation path loss factor (practical values for α are ≈ 0.5 for the two-ray model [22]). Accordingly, the interference tolerance $P(i)$ noise that each *future* neighbor can add to terminal i is given by

$$P^{(i)}_{\text{noise}} = \frac{P^{(i)}_{\text{MAI-future}}}{(1+\alpha)K^{(i)}}$$

When responding to j's RTS, terminal i indicates in its CTS the power level $P(ji)$ allowed that j must use. In addition, terminal i inserts $P(i)$ noise in the CTS packet and sends this packet back to terminal j at *P*max over the control channel using the common code. The format of the CTS packet is shown in Figure 6.

Figure 6: Format of the CTS packet in the proposed protocol.

A potentially interfering terminal, say s, that hears the CTS message uses the signal strength of the received CTS to compute the channel gain G_{si} between itself and terminal i. The channel gain along with the broadcasted $P(i)$ noise values are used to compute the maximum power $P(s)$ map that s can use in its future transmissions. More specifically, $P(s)$ map is taken as the minimum of the $P(k)$ noise/G_{sk} values, for all neighbors k of s (i.e., $P(s)$ map is updated dynamically whenever s overhears a new CTS). Note that it is possible for more than $K(i)$ terminals to start transmitting during i's reception and this may result in MAI at i that is greater than $P(i)$ MAI-future. We address this issue in Section 4.7.

The approach we discussed in this section provides a distributed mechanism for admission control. In contrast to cellular systems where the base station makes the admission decision, in here each terminal, and depending on previously heard RTS and CTS packets, decides whether its transmission can proceed or not. Following a successful reception of a data packet, receiver i responds with an ACK packet, which is transmitted over the data channel using the same power level that would have been used if i were to send a data packet to j. We assume that enough FEC code is used to protect ACK packets from most types of collisions (given the small size of the ACK packets, the FEC overhead is not significant). A similar argument has been used in other, previously proposed protocols (e.g., [21]).

V. SIMULATION OBSERVATION

We now evaluate the performance of the CA-WBC protocol and contrast it with the IEEE 802.11 scheme. Our results are based on simulation experiments conducted using CSIM programs (CSIM is a C-based process-oriented discrete-event simulation package). In our simulations, we investigate both the network throughput as well as the energy consumption. For simplicity, data packets are assumed to have a fixed size. Each node generates packets according to a Poisson process with rate λ (same for all nodes). The routing overhead is ignored since the goal here is to evaluate the performance improvements due to the MAC protocol. Furthermore, because the interference margin is chosen so that the maximum transmission range under the CA-WBC and 802.11 protocols is the same, it is safe to assume that both protocols achieve the same forward progress per hop. Consequently, we can focus on the one hop throughput, i.e., the packet destination is restricted to one hop from the source. The random waypoint model is used for mobility, with a host speed that is uniformly between 0 and 2 meters/sec. Note, however, that mobility has a little effect on our protocol, since an RTS-CTS exchange preceeds every packet transmission. The transmission periods for the RTS, CTS, data, and ACK packets are all in tens of milliseconds, so no significant changes in topology take place within these periods. The capture model is similar to the one in [32]. Other parameters used in the simulations are given in Table 1. These permanents correspond to realistic hardware settings [1].

Data packet size	2 KB
802.11 data rate	2 Mbps
CA-WBC data rate	1.6 Mbps
Control channel rate	400 Kbps
Processing gain	11
SNR threshold	10 dB
Reception threshold	−94 dBm
Carrier-sense threshold	−108 dBm
Thermal+receiver noise	-169 dBm/Hz
802.11 power	20 dBm
ξmax	6 Db

Table 1: Parameters used in the simulations.

5.2 SIMULATION RESULTS

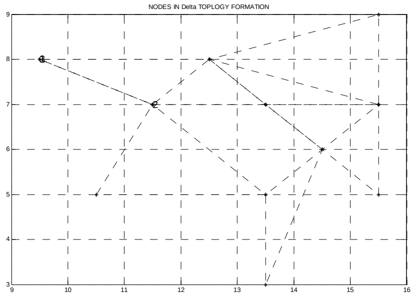
We consider two types of topologies: *random grid* and *clustered*. In the random grid topology, *M* mobile hosts are placed across a square area of length 3000 meters. The square is split into M smaller squares. The location of a mobile user is selected randomly within each of these squares.

For each generated packet, the destination node is randomly selected from the one-hop neighbors. The performance for random grid topologies is demonstrated in Figure 8. In parts (a) and (b), we set M = 36 and vary the packet generation rate (λ). Part (a) of the figure depicts the network throughput. It is shown that CAWBC achieves up to 280% increase over the throughput of the IEEE 802.11 scheme. This increase is attributed to the increase in the number of simultaneous transmissions. Furthermore, CA-WBC saturates at about twice the load at which the 802.11 scheme saturates. Part (b) of Figure 8 depicts the energy consumption versus λ. Energy consumption is the total energy used to *successfully transmit* a packet. It includes the energy of the control packets and the lost energy in retransmitting data and control packets in case of collisions. For almost all cases, CA-WBC requires less than 50% of the energy required under the 802.11 scheme. This may, at first, seem to counterintuitive, since in Section 4.5 the interference margin was chosen so that both protocols consume the same energy per packet. However, according to the topology we examine here, the transmitter-receiver separation distance is not uniform. More links are formed with neighbors that are much closer than the maximum transmission range (1061 meters in our simulations). Unlike the 802.11 scheme, CA-WBC makes use of shorter links to save energy. Note that in both protocols, the required energy increases with the load. The reason for this is that as λ increases, the probability of collisions also increases, and hence, more energy has to be spent on retransmissions.

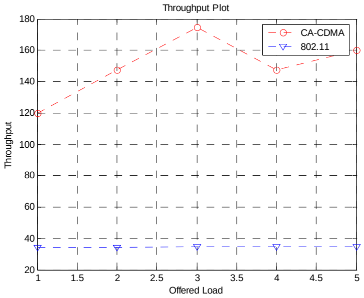
In Part (c) of Figure 8 we investigate the effect of varying the number of nodes while the dimensions of the region are kept fixed (3000m×3000m). Persistent load is used in this experiment, i.e., nodes always have packets to send. As shown in the figure, the throughput enhancement due to CAWBC increases with node density. This can be explained by noting that CA-WBC bounds the transmission power rather that prevents simultaneous transmissions. Therefore, as the density of nodes increases, more concurrent links are formed and the network throughput increases. The 802.11 scheme reserves a fixed floor, and thus, all nodes within that floor have to defer their transmissions. Therefore, the density of the nodes has little effect on the 802.11 throughput. The authors in [20] argued that traffic locality is the key factor in determining the feasibility of large ad hoc networks. This motivates studying the performance of CA-WBC under *clustered* topologies. In such topologies, a node communicates mostly with nodes within its own cluster, and rarely with neighboring cluster nodes. These topologies are common in practice (e.g., a historical site where users of wireless devices move in groups). To generate a clustered topology, we consider an area of dimensions 1000 × 1000 (in meters). We let M = 24 nodes, which are split into 4 equal groups, each occupying a 100 × 100 square in one of the corners of the complete area. For a given source node, the destination is selected from the same cluster with probability $1 - p$ or from a different cluster with probability p. In each case, the selection from within the given cluster(s) is done randomly. Part (a) of Figure 9 depicts the network throughput versus λ for $p = 0.25$. According to the 802.11 scheme, only one transmission can proceed at a time since all nodes are within the carrier-sense range of each other. However, according to CA-WBC, three to four transmissions can proceed simultaneously, resulting in a significant improvement in network throughput. In Part (b) of the figure, we further investigate the locality of the traffic by fixing λ and varying p. Indeed, as the figure shows, the locality of the traffic can highly impact the network throughput of CA-WBC, while the 802.11 performance is almost unchanged. As the traffic locality increases (i.e., p decreases) the enhancement of CA-WBC increases.

5.3 OBSERVATIONS

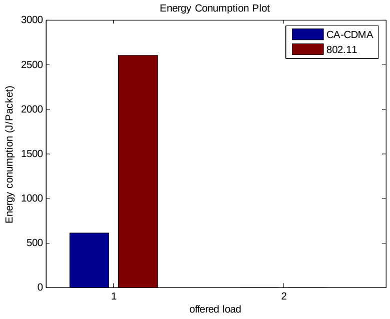
Simulation for Structure Network (Delta Topology) (Number of Nodes: 10, Offered simultaneous load : 5)



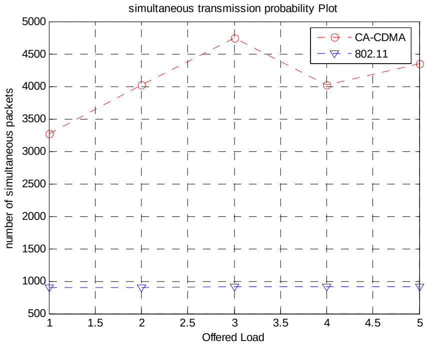
Scattered Network



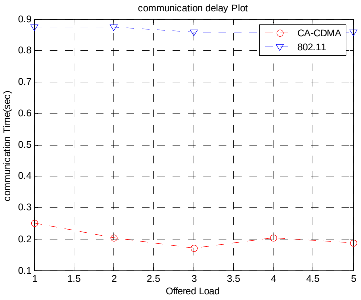
Throughput plot



Energy Consumption plot

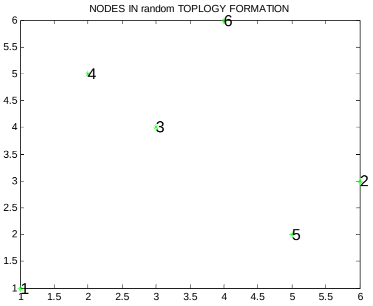


Simultaneous transmission probability

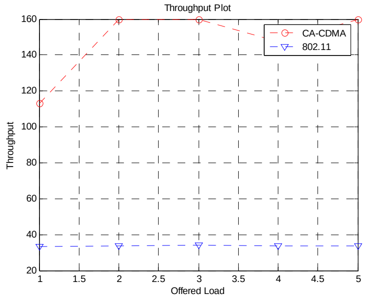


Communication Delay plot

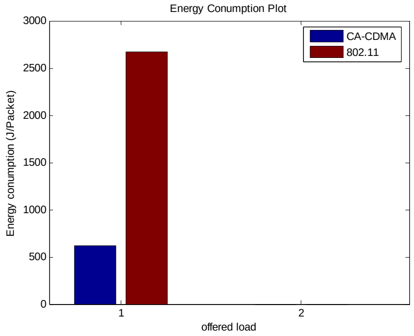
For Random Topology (Number of Nodes: 6 , Offered load 6)



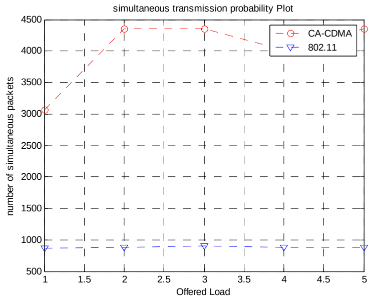
scattered Network



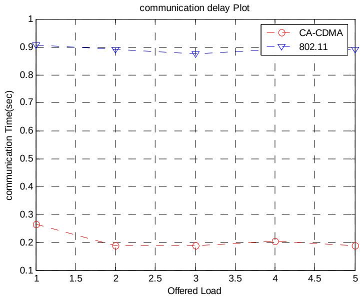
Throughput Plot



Energy consumption plot

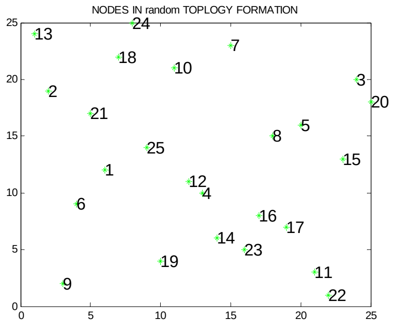


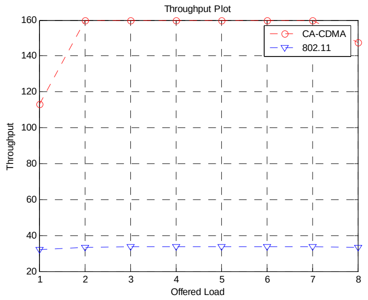
Simultaneous transmission probability

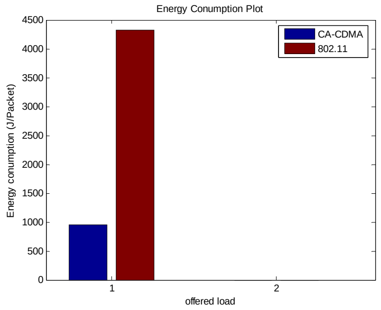


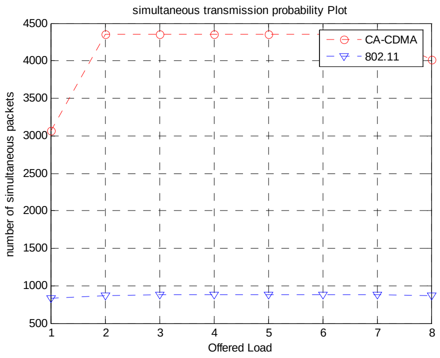
Communication delay plot

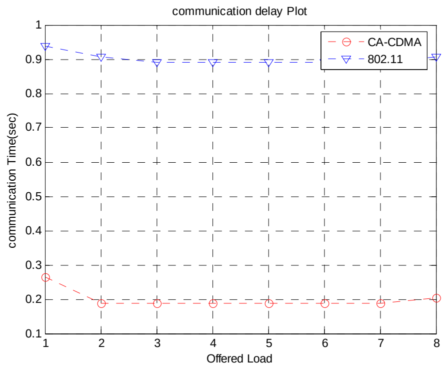
FOR Random Grid with, nodes= 25 , offered Load = 8;











VI. CONCLUSION

In this paper, we proposed a WBC-based power controlled MAC protocol for wireless ad hoc networks. This protocol, called CA-WBC, accounts for the multiple access interference, thereby solving the near-far problem that undermines the throughput performance in MANETs. CAWBC uses channel-gain information obtained from overheard RTS and CTS packets over an out-of-band control channel to dynamically bound the transmission power of mobile terminals in the vicinity of a receiver. It adjusts the required transmission power for data packets to allow for interference-limited simultaneous transmissions to take place in the neighborhood of a receiving terminal. We compared the performance of our protocol with that of the IEEE 802.11 scheme. Our simulation results showed that CA-WBC can improve the network throughput by up to 280% and, at the same time, achieve 50% reduction in the energy consumed to successfully deliver a packet from the source to the destination. To the best of our knowledge, CA-WBC is the first protocol to provide a solution to the near-far problem in WBC ad hoc systems at the protocol level.

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