Collision-Free Operation in Ad Hoc Carrier Sense Multiple Access Wireless Networks

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***Abstract*—The CSMA/CA algorithm proposed in the IEEE 802.11 standard does not exclude collisions between transmitted packets. Regardless of whether RTS/CTS packets are used or not, these collisions do always have a more or less negative effect on system performance, especially at high loads. In this letter a method of avoiding collisions by using busy energy bursts is proposed. The algorithm used is based on the 802.11 standard and depends only on the assumption that each node can hear the transmissions of all other nodes. Colisions are avoided by transmitting short sequences of energy bursts without the need of any further communication between nodes contending for the use of the channel. The proposed method provides better average packet delays also as higher maximum system loads than conventional CSMA/CA. In addition to this, it renders the use of acknowledgment packets unnecessary.**

***Index Terms*—Ad hoc networks, CSMA/CA, energy bursts.**

I. INTRODUCTION

PACKET collisions are intrinsic to carrier sense multiple access (CSMA) based wireless networks. This is due to the delayed perception each node has of the other nodes' transmissions. The section of the IEEE 802.11 standard that deals with the MAC mechanism proposed for ad hoc wireless networks uses a randomly chosen backoff time before each packet transmission for the reduction of the collision probability. This method does not eliminate completely the possibility of a collision between two or more packets transmitted simultaneously, but also increases the amount of time the channel remains idle due to the necessary backoff time. These two drawbacks become more significant at high system loads, when collisions occur more often and the algorithm tries to overcome the problem by increasing the average backoff period, thus further reducing the useful transmission time. Furthermore the nonzero probability of collisions makes the transmission of acknowledgment packets necessary, also reducing the efficiency of the utilization of the channel. In [1] the use of energy bursts has been introduced for the avoidance of collisions between real time packets in an ad hoc network. However this method cannot be used for burst traffic, which is the case of data packets, because of the introduced randomness.

In this letter we propose an algorithm based on the transmission of energy bursts but suitable for data traffic. The busy tones are designed in such way that if two or more nodes are contending for the channel no packet collisions will occur. More specifically, the contending nodes figure out which one of them has been idle for a longer period. The winner of the contention period then transmits its packet, while all the others remain silent, thus nullifying the possibility of a collision. The scheme is based on simple carrier sensing and not only ensures collision-free transmission of packets, but also reduces the average data packet delay and increases the maximum load of the system. Furthermore, it can be overlaid on the IEEE 802.11 implementation of CSMA/CA with minor modifications: the random retransmission scheme is turned off and in substitution, the possibility of sending energy bursts is enabled. In this paper a scheme for sorting of the access rights of the nodes at a minimum loss in transmission time is devised for a general ad hoc network without hidden nodes. The performance of the algorithm is compared with that of the CSMA/CA scheme of the IEEE 802.11 standard in an ad hoc wireless LAN.

Section II describes the proposed mechanism, while the results of the comparison are presented in Section III.

II. COLLISION-FREE OPERATION USING ENERGY BURSTS

The scheme presented in this letter deploys a sequence of busy tones before each packet transmission for the collision-free operation of CSMA/CA based ad hoc wireless LANs. For the algorithm to operate correctly, two factors must be taken into consideration. At first we have to ensure that each transmitting node is able to produce a unique pattern of tones. The second issue is that the pattern must be adequate to allow only one node to be considered as the one granted transmit. In addition to this, the total duration of the energy bursts must be as short as possible, regardless of the number of contending nodes. For our analysis we consider a wireless LAN of N nodes numbered from 1 to N, that use CSMA/CA at the MAC sublayer. We also assume that every node can hear all other nodes in the network. Then, it is possible that each one is able to count the number of packets transmitted since its own last successful transmission. Since no two nodes could have transmitted successfully at the same time, the number of packets a_i node i would count is a unique integer at any given time. To ensure that a_i remains bounded even for nodes that have been idle over a long period of time, node i checks the header of every packet and increases its counter only if the source node has not transmitted since the last successful transmission of i. Thus, at any moment a_i ranges from 0 to $N-1$ and $a_i \neq a_k$ for $i \neq k$. Each a_i is appointed a priority level equal to its value, level $N-1$ being the one with the highest priority. In Fig. 1 the calculation of the priority levels for a network of

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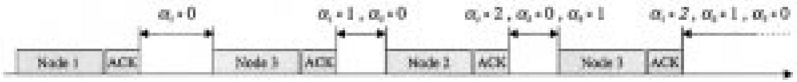

Fig. 1. Time diagram illustrating priority level calculation.

3 nodes is exemplified[1]. It is obvious that nodes that have been idle for a long period of time have priority over those that have recently transmitted their packets. In a network with a uniform distribution of data load between nodes, this scheme enforces a round-robin discipline and doesn't allow great fluctuation of the packet delays, keeping them close to the average.

The first packet that a node sends, when it enters the network,is transmitted using the conventional CSMA/CA method. Thereafter it enters the energy bursts mode and all consecutive packets are transmitted using the energy bursts algorithm. Node i uses a_i for the formation of its energy bursts sequence each time it has a packet to transmit. As in the IEEE 802.11 standard definition of the CSMA/CA scheme, a node starts its attempt to transmit its packet by sending its sequence, only if the channel has been idle for period of time equal or greater than DIFS. The sequence starts with the transmission of an initiative energy bursts to indicate that at least one node is contending for the use of the channel and to invite nodes with packets ready for transmission to participate in the contention. All nodes can hear the energy burst and synchronize their own energy bursts,unless they have also started a contention simultaneously, thus being already properly synchronized. Right after the transmission of the first indicative energy burst of length t_{init}, a contention period of fixed time length is introduced. Every node with packets stacked transmits its current priority level, which is calculated as stated above, according to the following algorithm:

- `The priority level is converted into a binary number of fixed bit-length` M`, filling the remaining MSBs with 0's, whereas` 2^M `is the maximum number of nodes in the network.`
- `The number is read bit per bit, starting at the most significant one.`
- `Each time a 1 is read, the node transmits an energy burst of length` t_{slot}`.`
- `Each time a 0 is read, the node listens to the medium for` t_{slot} `and exits the contention, giving up its access rights, if it receives an energy burst from another node. It further sets its NAV` **[2]** `to point at the end of the contention period.`

In Fig. 2 a contention between three nodes is exemplified. 25 packets have been transmitted since node's A last transmission, which corresponds to a priority level equal to 25. Similarly, nodes B and C have a priority level of 26 an 15 accordingly.

The length of t_{slot} should be at least equal to the maximum round-trip path delay of the network, for the nodes to be able to synchronize properly. The above-mentioned algorithm is capable of producing only one winner in every contention period, the winner being the node with the highest priority level. Every other contending node abandons the contention and discontinues the transmission of further energy bursts, as long as it hears a busy tone from another node during one of its reception intervals. The highest priority level corresponds to a binary number that has the biggest number of MSB's with 1s, than the ones of the lower levels. At the end of the contention period, the remaining node starts the transmission of its packet. No acknowledgment packet is necessary to ensure that there has been no collision.

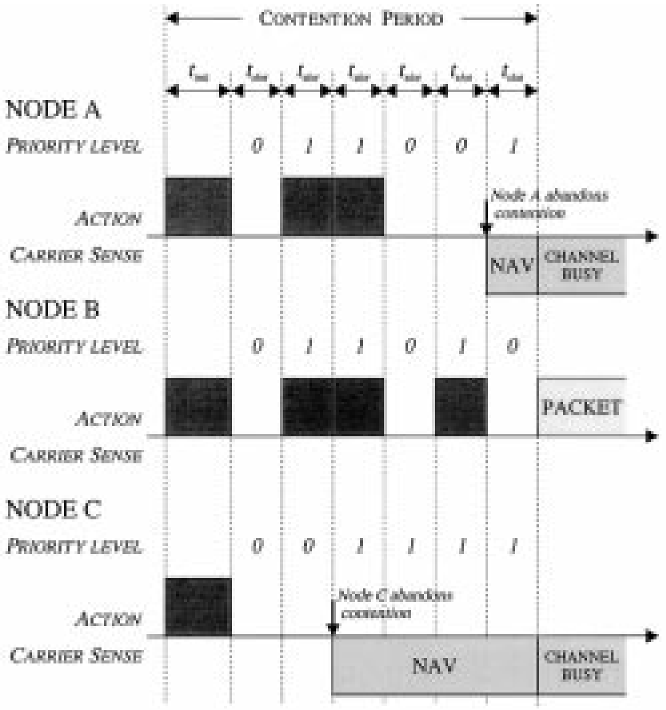

Fig. 2. Contention between three nodes.

To ensure that this method functions properly on any occasion, the transmission of the initiative energy burst causes non-contending nodes to set their network allocation vector to indicate the end of the contention period. This means that they perceive the channel as busy for $t_{\text{init}} + M \cdot t_{\text{slot}}$. If a node has a packet ready for transmission after the start of the current contention period, it is not allowed to participate and must wait for the next one.

The algorithm substitutes the random exponential backoff time of the CSMA/CA scheme, with the fixed-length contention period. For low network traffic, the average backoff time is comparable to the length of the contention period. However, at high loads the average backoff time and also the number of collisions are excessively increased, thereby increasing the average data packet delay and reducing the maximum total load, which is furthermore compromised by the need of acknowledgment packets in CSMA/CA.

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[1] The labels indicate the source node of each packet

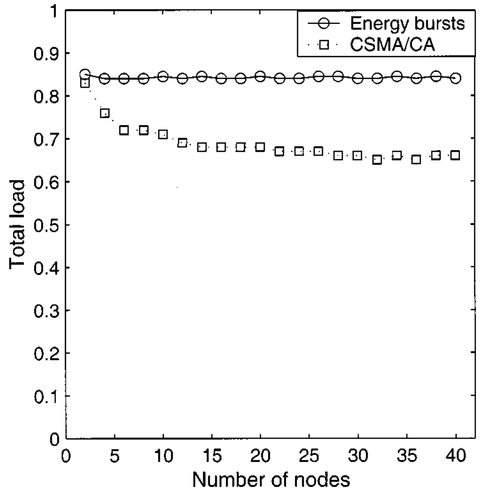

Fig. 3. Maximum total load versus number of nodes for stable operation.

III. RESULTS AND CONCLUSIONS

After extended simulation trials, very promising results are presented. We assume that all nodes can hear each other's transmissions, so that node mobility has no impact on the channel access scheme and, therefore, is not explicitly modeled. The modeled network is basically an implementation of the direct sequence spread spectrum version of the IEEE 802.11 standard, with minor changes to accommodate the energy bursts algorithm. Nominal values for the parameters of the system have been taken, when applicable, from the direct sequence spread spectrum version of the IEEE 802.11 standard. The channel bit rate is $r_c = 2$ Mbits/s and each packet has a physical (PHY) layer header $T_{phy} = 192$ μs and a MAC-layer header $h = 34$ bytes. Both the initiative and the subsequent slots have a duration of $t_{\text{init}} = t_{\text{slot}} = 20$ μs. The maximum number of nodes in the network has been chosen as 64, which corresponds to $M = 6$ slots per contention period. The packet payload is $b_{pkt} = 825$ bytes for every packet.

The algorithm was tested using a custom discrete time simulation written in C ++. The energy bursts algorithm is independent of the regularity of arrival and the size of the packets, since these two parameters do not affect either the contention nor the carrier sense mechanism and therefore only fixed length data packets were modeled. The data packets arrive at each node according to a Poisson process with an arrival rate of $\lambda = \rho r_c / N b_{\text{pkt}}$, where ρ is the total load and N the number of nodes in the network.

We compare the performance of our algorithm with that of the conventional CSMA/CA of the IEEE 802.11[2] standard. Fig. 3 shows the maximum total load that can be supported by each method as a function of the number of nodes in the network. Since the average delay is not essential for data traffic, we consider the network as stable when the average delay is bounded. It is clear that while the increase in the number of nodes deteriorates the performance of CSMA/CA based network, this is not the case for the energy bursts implementation. The maximum total load remains virtually constant, regardless of the number of nodes in the system. It should be also noted, that at loads approaching the maximum load, 0.5%–2% of the packets are discarded in the CSMA/CA based network, after they have reached the retransmission limit set by the algorithm. On the other hand, no packets are discarded in a network using the energy bursts method, even at peak loads.

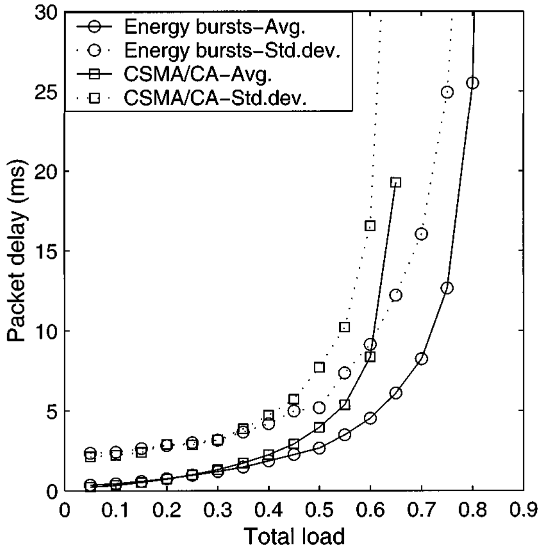

Fig. 4. Average and standard deviation of packet delays both under energy bursts multiple access and CSMA/CA versus total load.

Fig. 4 shows the average and standard deviation of packet delays both under energy bursts multiple access and CSMA/CA as a function of total load for an ad hoc network consisting of 40 nodes. At very low loads the performance of the energy bursts algorithm is slightly worse than the CSMA/CA method. The former operates however at medium and high loads considerably better, even exceeding the maximum load limit of CSMA/CA. At 0.85 Erlang total load, the energy burst algorithm achieves an average delay of ≈ 90 ms, yet remains stable. Although the delay is somewhat great, it is obvious that the system is not destabilized even at peak load conditions. We can see that the energy bursts method keeps the average packet delay acceptable over a wider range of load conditions than CSMA/CA, which can make possible, through a careful design of the system, even the consistent transmission of real-time packets.

REFERENCES

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