A JMAC Protocol with Dynamic Priority Adjustment for Multimedia Traffic in Wireless Ad-hoc Networks

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Abstract: - Although IEEE 802.11e EDCA supports prioritized multimedia traffic, it does not consider the problem of continuous contention failures and the problem of unfair bandwidth sharing among high- and low-priority traffic. This paper presents a jamming-based MAC (JMAC) scheme for multimedia traffic in wireless ad-hoc networks. The main idea behind the JMAC scheme is that mobile nodes can be differentiated by transmitting different lengths of jamming noise; the one with the longest jamming length can win the contention and begin its frame transmission. To avoid the possibilities of system deadlock and low-priority starvation, in our design the jamming length issued by a mobile node can be dynamically adjusted based on its current priority (local), a global priority (broadcasted by the winner of the previous contention round), and the number of contention retries experienced by a frame. For the purpose of performance evaluation, the proposed JMAC is simulated through NS-2. The simulation results show the effectiveness and the superiority of our proposed scheme when comparing with other previous works.

Key-words: - Jamming noise, Priority adjustment, Ad-hoc, MAC, Wireless networks, Multimedia traffic.

1 Introduction

In the last decade, the emergence of mobile computing has led to the rapid evolution of wireless networks. Owing to the obvious advantages, such as supporting host mobility and reducing deployment cost [1-2], more and more wireless networks have been widely deployed in hot spots instead of wired infrastructures. One of the important techniques in wireless networks is to design a medium access control (MAC) protocol with which mobile nodes can effectively share the wireless medium (WM) in a distributed manner.

A wireless ad-hoc network is a spontaneous, wireless network operating in a peer-to-peer model without any centralized points, such as access points and base stations. For ad-hoc networks, CSMA is one of the most pervasive MAC schemes. The well-known protocols are the IEEE 802.11 standard [3] and the IEEE 802.11e draft [4]. Unlike 802.11, designed for the best-effort services only, 802.11e, an enhanced version of the former, is developed for the growing demand of throughput-sensitive and delay-sensitive applications with QoS guarantees. Recently, many mechanisms have been proposed to improve the performance of 802.11e by modifying some of its contention parameters [5-6]. The schemes presented in [7-9] dynamically adjusted the contention window of each traffic category according to the network conditions, while those in [10-11] replaced the exponential backoff algorithm with another random backoff algorithm. However, the previously proposed protocols have the limitation in providing delay guarantees for the real-time traffic [12-13], in addition to the problem of low-priority starvation.

Another group of CSMA-based MAC schemes provide differentiated service based on the two phases: (1) Contention phase: after the AIFS (arbitration interframe space) medium idle time, each competing node lasts a pre-calculated duration to jam the channel. The jamming signal is intended to let the other nodes sense carrier from the transmitting node. Since no data are carried, the energy of jamming signal is much smaller than usual. (2) Transmission phase: once the first phase ends, the node with the longest jamming duration wins the contention round and starts data transmission, while the other ones keep silent until sensing the channel is idle for duration of AIFS again. Note that no backoff algorithms are invoked in such schemes. In this work, we propose a jamming-based MAC (JMAC) scheme with dynamic priority adjustment. With the ability to alleviate the packet delay/jitter of real-time traffic,
to avoid the possible starvation of low-priority traffic, and to achieve more efficient bandwidth utilization, the proposed JMAC is expected to be very feasible, attaining QoS provisioning at the MAC layer in wireless ad-hoc networks.

The remainder of this paper is organized as follows. Section 2 discusses related works in this area. In Section 3, we describe the JMAC scheme. The simulation results and discussions are presented in Section 4. Finally, concluding remarks are given in Section 5.

2 Related Works

For starters, Sobrinho et al. [12] presented black-burst (BB) contention, in which the real-time nodes have access priority over the data ones by sending a sequence of pulses to let them sense that the channel is busy when the channel becomes idle. No considering other network performance metrics except for real-time constraints, the duration of a BB is simply a direct function of the contention delay experienced by it. Obviously, the low-priority traffic of data nodes could starve with the BB contention and the two classes of traffic are not sufficient to support multiclass traffic. Chen et al. [13] proposed an adaptive retransmission scheme with QoS support. In general, their scheme is similar to the BB. The significant contribution in [13] is that the length of jamming noise is randomly generated according to a truncated geometric distribution, of which the two parameters, successful probability and truncated window, are determined by minimizing a retransmission cost. The retransmission cost is expressed as a function of the number of nodes, the size of frames, and the limit of retries. However, it is difficult to gather all of these parameters for a node in a fully distributed system.

On the other hand, a group of collision-prevention MAC protocols are proposed for differentiated services [14-16]. A mobile station selects an appropriate competition number to represent its unique sequence, used for contention. Assuming that all mobile stations are synchronized bit by bit and there are $k$ bits in a competition period, at the first bit slot, a station will transmit a short signal in its prohibitive range (In other words, the mobile node will survive in this bit slot.) if its most significant bit is one, and keep silent otherwise. Only the stations that survived in all of the first $(j - 1)$ bit slots are allowed to continue contention in the $j$th bit slot for $j = 2, 3, \ldots, k$. Finally, a station surviving all $k$ bit slots will win the competition round and start data transmission. Unfortunately, two problems arise from these schemes: (1) The bit-level synchronization among all stations is too complicated to implement in wireless ad-hoc networks; (2) After a competition round, the contention delay incurred by a station must be larger than the duration of $k$ bits even when the network is lightly-loaded.

Supporting multiple classes corresponding to different priorities, we associate each mobile node with two priorities: local and global. The local priority as well as the other contention parameters for each mobile node is adaptive to the network conditions and contributes to the primary increment of the length of jamming noise. Once a mobile node senses that it has transmitted the longest length of jamming noise, it will broadcast its local priority to update the global priorities of the other ones. In this way, all of the nodes have the same global priority and the value acts as a threshold that prohibits the nodes with local priorities lower than it from participating in the next contention round.

3 The Proposed Scheme

3.1 Parameter Descriptions

Consider $M$ different traffic categories (TC’s) over a wireless ad-hoc network, where the priority of category $m_1$ is lower than that of category $m_2$ if $m_1 < m_2$. For each mobile node, multiple traffic categories can exist in parallel and each category, behaving as a virtual node (VN), contends for transmission opportunity independent of the others. Contentions among the VN’s inside a single node are resolved internally by permitting the one with the longer duration of jamming noise to jam the channel and forcing the others to perform a failure response. The proposed JMAC scheme associates each VN with the following parameters.

- $m_i$: the traffic category of VN $i$, where $1 \leq m_i \leq M$.
- $L_i$: the local priority of VN $i$, where $m_i \leq L_i \leq M$.
- $G$: the global priority, which is equal to the local priority of the winner in the previous contention round, where $1 \leq G \leq M$.
- $B_i$: the number of failed contention rounds for VN $i$ in which it didn’t send the longest duration of jamming noise but one of the
other nodes did. In the situation, VN $i$ is said to be blocked.

- $C$: the number of failed contention rounds for VN $i$ in which it sent the longest duration of jamming noise and so did one or more of the other nodes. In the situation, VN $i$ is said to be collided with.

- $Lcf$: short for the length of contention frame (in units of slot time).
- $S$: a factor used to adjust the range of $Lcf$.
- $Rlimit$: the upper limit of contention retries for each frame.

Any VN with its local priority larger than or equal to the global priority is allowed to contend for access to the WM. $Lcf$ generated by VN $i$ is denoted as $Lcf_i$ and determined by the following equation.

$$Lcf_i = (L_i - G)S + \text{Random()} + \max\{0, B_i - Th(m_i)\} + C_i = (L_i - G)S + \text{Random()} + f(Th(m_i), B_i, C_i) \tag{1}$$

where $\text{Random()}$, intended to resolve collisions among the VNs with the same local priority, is a random integer drawn from a uniform distribution over $[0, S-1]$. For example, given that $G = 1$, VN $i$ with $L_i = 2$, VN $j$ with $L_j = 3$, and $f(Th(m_i), B_i, C_i) = f(Th(m_j), B_j, C_j)$, the maximal $Lcf_i$ is $S + (S - 1) + f(Th(m_i), B_i, C_i)$, while the minimal $Lcf_i$ is $2S + 0 + f(Th(m_j), B_j, C_j)$, which is still larger than $Lcf_j$ by one. Thus, a VN with higher local priority can issue a longer duration of jamming noise than any other node with lower local priority regardless of the last term in the formula of $Lcf$. $Th(m_i)$ is used to avoid increasing the length of jamming noise excessively, since the network is considered less congested when a VN fails in a contention round due to being blocked. $Th(m_i)$ can be defined as a non-increasing function of the traffic category.

### 3.2 The JMAC Algorithm

The pseudo-code of the JMAC algorithm for each node $i$ is listed in Figure 1. Initially, let $L_i = m_i$, $G = m_i$, $B_i = C_i = 0$. At the beginning of a contention round, that’s, at the instant when the wireless medium is idle for a predefined duration, called arbitration interframe space (AIFS), node $i$ starts to jam the channel for a duration of $Lcf_i$ if its local priority is larger than or equal to the global priority. Once sensing that $Lcf_i$ is longest (i.e. node $i$ is the winner), node $j$ will immediately broadcast its local priority to update the global priority of the other nodes and then, transmit the data frame. Otherwise, $B_i$ will add one on receiving the local priority from the winner if a winner comes out of the contention round. The other three conditions are dealt with the following three modules, collision avoidance, deadlock prevention, and starvation prevention.

#### 3.2.1 JMAC Algorithm

1. **Collision avoidance**: when node $i$ and one of the other nodes jam the channel for the same duration, collision occurs. To raise the successful possibility in the next contention round, $C_i$ will be increased by one and $\text{Random()}$ will be distributed over a larger interval $[0, 2S-1]$.

2. **Deadlock prevention**: $G$ is defined as the local priority of the winner in the previous contention round. Considering the situation when the winner has no more frames to transmit and every one of the other nodes has its local priority smaller than $G$, it is found that no nodes are allowed to contend for the upcoming contention. Such situation is referred to as “deadlock” and it can be detected by a node if the medium is still idle after the AIFS. To prevent from inefficient
utilization of bandwidth, node $i$ will reset the global priority whenever a deadlock is identified.

- Starvation prevention: To avoid possible low-priority starvation, node $i$ with a frame to transmit will increase its local priority when the local priority from the winner is received. Since no local priority received means no winner, the local priority of node $i$ remains unchanged in order not to make contention stiffer. Such design is beneficial for the collision avoidance.

Note that a frame at node $i$ will be dropped if the number of contention retries for it exceeds $R_{limit}$.

4 Simulation Results

We evaluate the performance of the JMAC via simulations on NS-2 [17]. The performance metrics include the contention-success probability, the system throughput, and the packet dropping ratio. Unless explicitly specified, all simulation results are obtained from averages of 20 random samples, each with a running period of 30 seconds.

The environment we consider is a fully connected wireless network consisting of 100 nodes, each with a buffer size of 15 packets. All nodes are configured according to the DSSS system parameters and MAC-layer parameters as shown in Table 1. The channel condition is assumed to be error-free. Each node contends for access to the channel to transmit user datagram protocol (UDP) packets at a constant bit rate (CBR) of 500 packets per second and operates only one flow destined to one of the other nodes.

| Frame payload | 800–8000 bits (100–1000 bytes) |
| MAC header    | 224 bits                     |
| PHY header    | 192 bits                     |
| ACK           | 112 bits + PHY header        |
| RTS           | 160 bits + PHY header        |
| CTS           | 112 bits + PHY header        |
| Channel capacity | 10 Mbps         |
| Propagation delay | 1 us              |
| SIFS          | 10 us                       |
| DIFS/AIFS     | SIFS +σ                    |
| Slot time (σ) | 20 us                       |

In the first experiment scenario, 5 (10, 15, or 20) of the 100 nodes generate their respective traffic flows and the category associated with each flow is a random integer uniformly distributed over $[1, M]$, where $M$ is set to 4. The contention-success probability for a frame is measured as a reciprocal of the number recorded in a counter, which adds one every contention round and resets on successful data transmission. Figure 2 shows the contention-success probabilities for the four traffic categories with respect to the number of flows in the wireless network. It is demonstrated that the JMAC provides differentiated service among different traffic categories and owing to the module of starvation prevention (SP), the access rights won by low-priority traffic don’t drop drastically and approach zero. As a result, Figure 3 illustrates the packet dropping ratio (PDR) with respect to the number of flows for the case whether the JMAC is quipped with the module of SP or not. In expectation, PDR increases as the increase of the number of flows. However, low-priority traffic, such as traffic categories 1 and 2, will never win transmission opportunity without SP when competing with high-priority traffic, such as traffic categories 3 and 4, so that they may suffer from serious PDR (black lines). The phenomenon of low-priority starvation is significantly improved with SP (blue lines) since it is possible for low-priority traffic to get the access rights by increasing their associated local priority round by round. However, the PDR of traffic category 4 with SP is slightly larger than that without SP. This is because little reduction on the transmission opportunity of the highest-priority traffic can bring considerable improvement on the performance of the other low-priority traffic.

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<th>Table 1. System parameters used in the simulation</th>
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<td>Frame payload</td>
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<td>MAC header</td>
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<td>PHY header</td>
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<td>ACK</td>
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<td>Slot time (σ)</td>
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Although the EDCA is substantially a different design from the JMAC, we make a comparison between the overall system throughputs of the two schemes since the former is an upcoming standard. EDCA parameters for the four traffic categories are set according to Table 2 at each node. As shown in Figure 4, it is found that the system throughput (in Mbps) of the JMAC (black line) is always superior to that of the EDCA (blue line) since our proposed jamming-based scheme never performs random
backoff algorithms, which could cause unexpected packet delay, and the larger the packet delay is, the smaller the system throughput is. Therefore, not only can the JMAC provide service differentiation but also it can utilize the system bandwidth more efficiently at the expense of little power used to jam the channel.

To compare with Chen’s scheme [13], we design the second experiment scenario, in which \( M \) is set to 2 instead of 4. Focusing on the moderately or heavily loaded condition (i.e. at least ten of the 100 nodes generate traffic flows.), Figures 5 and 6 show the differences, in terms of the contention-success probability, between our scheme and Chen’s for sending variable-size packets and fixed-size packets, respectively. It is obvious from both figures that with Chen’s scheme, the contention-success probability of low-priority traffic, traffic category 1, approaches zero while that of high-priority traffic, traffic category 2, benefits greatly by blocking any transmission attempts from traffic category 1. Furthermore, as shown in Figure 5, the service differentiation between traffic categories 1 and 2 becomes more evident for Chen’s scheme if the size of packet is variable. The main reason is that Chen’s QoS differentiation strongly depends on the so-called truncated geometric distribution, which has different truncated windows corresponding to different frame sizes, and different truncated windows result in less possibility of collisions among the high-priority flows. The QoS differentiation of our scheme (black lines) is a little less distinctive than Chen’s (blue lines) due to the module of SP. However, it is noteworthy that our scheme outperforms Chen’s for both low- and high-priority traffic when the size of packet is fixed (see Figure 6) since fixed-size frames only result in one truncated window and, consequently, increase the possibility of collisions among the high-priority flows for Chen’s.

5 Conclusions

We have presented a jamming-based MAC (JMAC) scheme with dynamic priority adjustment in wireless ad-hoc networks. With a frame to transmit, each mobile node sends a pre-calculated length of jamming noise to contend for the transmission opportunity and the one with the longest length of jamming noise can win the contention. The contention parameters used to determine the jamming length are dynamically adjusted to adapt to the network congestion. From the simulation results, it is demonstrated that the JMAC can not only provide differentiated services among different traffic classes but also improve the QoS limitations in the previously proposed schemes; the starvation of low-priority traffic can be avoided by the JMAC. In addition, the JMAC utilizes the system bandwidth more efficiently than the emerging standard, EDCA, at the expense of little power consumed to jam the channel. Comparison between the JMAC and other jamming-based schemes, proposed by Chen et al., also shows the superiority of the JMAC.

References


