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# E-MAC: An evolutionary solution for collision avoidance in wireless ad hoc networks

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ABSTRACT

Transmission collision is a main cause of throughput degradation and non-deterministic latency in wireless networks. Existing collision-avoidance mechanisms for distributed wireless networks are mostly based on the random backoff strategy, which cannot guarantee collision-free accesses. In this paper, we design a simple collision-avoidance MAC (E-MAC) for distributed wireless networks that can iteratively achieve collision-free access. In E-MAC, each transmitter will adjust its next transmission time according to which part of its packets suffering from the collision. And the iteration of this adjustment will quickly lead group of nodes converging to a collision-free network. E-MAC does not require any central coordination or global time synchronization. It is scalable to new entrants to the network and variable packet lengths. And it is also robust to system errors, such as inaccurate timing.


## 1. Introduction

In distributed wireless networks, the overlap of more than two interfering nodes' transmission will result in transmission collisions. And it is a common phenomenon due to the broadcast nature of wireless communication and the contention for shared wireless medium. Transmission collision can be classified into two categories: the synchronized collision and the hidden node collision. The synchronized collision occurs when no less than two nodes happen to start their transmissions simultaneously, as illustrated in Case A of Fig. 1. And this usually happens in single-hop wireless networks, where more than two nodes happen to select the same backoff counter to transmit after detecting that the wireless medium is idle. Unlike the synchronized collision, in hidden-node collision, the colliding packets can be overlapped at any stages, including all the cases from A to D in Fig. 1. And the hidden-node collision is the dominating collision scenario in multi-hop networks, where there exist hidden nodes. Zhao et al. (2013, 2010) modeled hidden-node collision and analyzed its effect on end-to-end throughput demonstrating that hidden-node collision can decrease the throughput by more than 20% in high density networks.

When collision occurs, the packets cannot be correctly received and have to be re-transmitted, resulting in throughput degradation, non-deterministic latency and wastage of radio resources such as channel bandwidth and energy. To reduce the probability of collisions, currently popular collision avoidance mechanisms for wireless networks are mostly based on the random backoff strategy (such as the Binary Exponential Backoff in 802.11 DCF and its improvements; Wang and Zhuang, 2006, 2008; Van Nee, 2011; Tuysuz and Mantar, 2014; Wang et al., 2004; Madhavi and Rao, 2015). However, these mechanisms have two drawbacks. First, it cannot guarantee collision-free accesses, and second, it is not efficient due to the nature of random backoff. The situation is even worse in high-speed wireless networks such as IEEE 802.11 ac standards where the PHY rate reaches as high as 1 Gbps (Van Nee, 2011).

In this paper, we propose the E-MAC that uses elaborate, instead of random, backoff mechanism to iteratively achieve collision-free access. The basic idea of E-MAC lies in that, every node transmits at most once in a given time cycle, and if one node experiences a collision, it will adjust its transmission time in the next cycle according to which part of its packets suffering from the collision. Specifically, if the front part of the packet is collided, it will transmit latter in the next cycle; on the other hand, if the back part is collided, it will transmit earlier in the next cycle. We modified the 802.11 MAC to implement this idea and proved the effectiveness of the modification via both theoretical analysis and computer simulation. The main characteristics of E-MAC are as follows:

- Running E-MAC, the network can quickly converge to collision-free access. In the initialization process, the network efficiency

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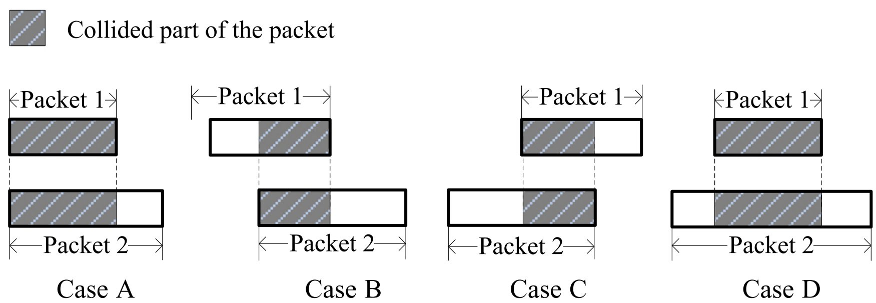


**Fig. 1.** Typical collision scenarios.

is no worse than the traditional random backoff schemes, and after achieving the collision-free access, the network efficiency can approach 100%.

- E-MAC is a totally distributed protocol, which requires neither a central coordination nor global time synchronization. Furthermore, it does not rely on the prior knowledge of channel states (for instance, the idle time slots and the busy time slots in the past transmission period).
- E-MAC is a dynamic adaptive protocol, which is resistant to possible system errors (e.g., inaccurate time slot split and time slot drift) and scalable to variable packet lengths and large number of network members.

The rest of this paper is organized as follows: Section 2 reviews related literature on collision avoidance protocol. Section 3 introduces the system model and defines the problem of this paper. Section 4 presents the proposed E-MAC protocol, followed by the theoretical analysis on its performance and then Section 5 explains the implementation issues. The performance of the proposed protocol is evaluated in Section 6 with computer simulations. Finally, Section 7 concludes this paper.

## 2. Related work

Existing medium access control protocols (MACs) for collision avoidance in wireless networks can be classified into four categories, i.e., coordination-based schemes, multi-frequency assisted schemes, slot-assignment schemes and backoff-tuning schemes.

The coordination-based schemes utilize a central coordination for resource allocation (Wang and Zhuang, 2008; Panigrahi and Raman, 2009), while multi-frequency assisted schemes either use out-of-band signaling to avoid colliding transmission (Wang and Zhuang, 2006; Haas and Deng, 2002) or use multiple frequency bands for concurrent transmission (Zhang et al., 2013; Kim et al., 2013; Jackson and Russell, 2013). Because these two schemes requires extra infrastructure, i.e., a *central coordination* (CC) or *extra frequency bands* (EFB), which limits their scalability for general distributed networks.

The basic idea of slot-assignment schemes is to combine TDMA and CSMA that reserve different time slots for different transmissions with contention (Hadded et al., 2015; Rhee et al., 2008; Lee and Walrand, 2007; Fang et al., 2013; Gong and Malone, 2012). Z-MAC (Rhee et al., 2008) assigns each node a slot in a TDMA manner. And if one node has no data to send, its slot can be borrowed with contention by other nodes in a CSMA manner. ZC (Lee and Walrand, 2007) follows the similar idea but in a more flexible manner. In ZC, each node records all the idle slots in one cycle. Once a node experiences a collided transmission, in the next transmission, it will uniformly select one slot from these idle slots and the slot it has just used. L-ZC (Fang et al., 2013) is an evolution of ZC in that it adopts different probabilities for selecting an idle slot and for selecting the slot it has just used (it selects the slot that it just used with the probability of $r$, while select one from all idle slots with the probability of $(1-r)/I$, where $I$ is the total number of idle slots). But these slot-assignment schemes require global *time synchronization* (TS), and are vulnerable to slot drifts (i.e., non-ideal clocks) (Gong and Malone, 2012).

The backoff-tuning schemes use different backoff strategies according to whether the former transmission is successful or not, which originates from Carrier Sense Multiple Access with collision avoidance CSMA/CA). However, the efficiency of CSMA/CA is low due to its random backoff process, which often using a binary exponential backoff (BEB) process. L-BEB (Barcelo et al., 2008) is an evolution of BEB that it chooses backoff values based on the status of last transmission: after a collided transmission, nodes will choose the backoff counter randomly, just as in the IEEE 802.11 DCF; on the other hand, after a successful transmission, nodes will set the backoff counter fixed as the length of one transmission cycle (namely the successful transmitter will transmit at the same time slot in each cycle). L-MAC (Fang et al., 2013) further updates L-BEB, it keeps updating selection probability for each slot. Specifically, denoting the probability that one node selects Slot $m$ in Cycle $n$ to transmit as $p_m(n)$, then $p_m(n+1)=\beta p_m(n)$ and $p_j(n+1)=\beta p_j(n)+(1-\beta)/(T-1), j\neq m$, where $\beta\in(0,1)$ represents the learning strength, and $T$ is the cycle length. Barcelo et al. (2013) extend this backoff-tuning idea to multi-hop packet radio networks in the presence of hidden nodes. Each wireless node computes the schedule length after gathering information about the number of flows in its neighborhood. Then, a deterministic backoff is used after successful transmissions and a random backoff is used otherwise. The similar idea of using a deterministic backoff after successful transmissions while using a random one after collided transmissions has also been adopted in SRB (Yong et al., 2009) and hashing backoff (Starzetz et al., 2009). The principle of these MAC protocols is that they iteratively change the transmission time of each node until all nodes converge to a collision-free schedule, and after that all nodes will persist with the transmission time in each cycle. Barcelo et al. (2012) modeled the convergence process of these schemes by an absorbing Markov chain, and derived the expected number of iterations required to reach a collision-free schedule. It shows that backoff-tuning schemes have two drawbacks. First, they have slow convergence speed. This is because that these schemes change the transmission time essentially with randomness after a collision. Second, they are vulnerable to new entrants to the wireless network. This is because that once the new entrants cause collision to existing nodes, the randomness in selecting new transmission time may cause subsequent collisions, which will take long time to achieve new collision-free schedule.

The slot-assignment schemes and the back-off turning schemes require no extra infrastructure and are applicable to general wireless networks. However, these existing schemes have three common problems except for their respective aforementioned drawbacks. First, they implicitly assume that each node's transmission