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# Performance of polling disciplines for the receiver-initiated binary exponential backoff MAC protocol

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ABSTRACT

The study of polling disciplines for receiver-initiated MAC protocols has not received much attention in the literature, and simple schemes such as round-robin or uniform prioritization are usually assumed. However, not only the order, but also the rate at which nodes are polled is significant: a polling rate that is too slow may render low throughput and high delays, whereas the opposite may lead to excessive control traffic and frame collisions. Ideally, a receiver-initiated MAC protocol would perform best if nodes could know “whom” and “when” to poll based on data availability. This paper investigates the performance of three polling disciplines when applied to a specific receiver-initiated *unicast* MAC protocol that is based on a reversal of the binary exponential backoff (BEB) algorithm of the IEEE 802.11. With the BEB algorithm, the polling rate is self-regulated according to channel conditions and traffic availability at polled nodes. Additionally, this paper extends the BEB-based MAC protocol by introducing a new control frame and a frame reordering technique at MAC queues to speed up polling rounds. The performance of the polling disciplines are also compared to the traditional IEEE 802.11 with respect to control overhead, delay, fairness, and throughput, according to different topologies and traffic scenarios.

## 1. Introduction

Receiver-initiated MAC protocols for wireless ad hoc networks have long been studied due to their potential benefits in reducing the number of control frames needed for a handshake. Most importantly, the appeal for using a receiver-initiated approach comes from the fact that the *recipient* of a DATA frame is certainly better positioned to evaluate channel conditions for a successful DATA frame reception in a communication link. Consequently, frame collisions at the intended receiver may be potentially diminished if the receiver itself is the one who decides when to start receiving a DATA frame [1]. In fact, previous theoretical works have suggested that receiver-initiated MAC protocols may overcome sender-initiated ones due to a reduction in control overhead [2,3]. Ideally, best performance could be achieved if receivers were able to know not only *who* has DATA frames addressed to them, but also *when* a DATA frame is ready to be sent from a given transmitter. Obviously, this is not a trivial task to accomplish in practical scenarios.

Part of this effort has already started in applications where some time synchronization among nodes is possible, especially in duty-cycle or TDMA-based MAC protocols for sensor networks, where some nodes act as *sinks* for data collected by other nodes [4–6]. In such scenarios, it is possible to have *sink* nodes deciding *whom* and *when* they contact based on information delivered by sensor nodes in previous slot(s). However, because (i) TDMA-based MAC protocols (and their variants) strictly require time

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synchronization; (ii) the optimal scheduling of slots in multihop scenarios is an NP-hard problem [7,8]; (iii) there are other types of ad hoc networks that do not have "special" nodes that act on behalf of other nodes (i.e., all nodes are considered *equally* important) the adoption of a *random access* MAC protocol becomes the most viable option for a fast and scalable network deployment.

To date, *sender initiation* has been the preferred paradigm for random access MAC protocols, especially after the tremendous success of the IEEE 802.11 standard in the last decades. In addition, the receiver-initiated paradigm does not fit as naturally as the sender-initiated one with respect to the "store-and-forward" routing paradigm adopted by the majority of network architectures. Coupled with the lack of studies on polling disciplines suitable for the many application scenarios of ad hoc networks, random-access receiver-initiated MAC protocols are still not widely adopted today. Hence, in order to contribute for the development (and understanding) of polling disciplines for random-access receiver-initiated MAC protocols, this paper investigates the performance of three polling disciplines when applied to a specific receiver-initiated *unicast* MAC protocol earlier introduced by Bonfim and Carvalho [9]. The proposed MAC protocol is based on reversing the binary exponential backoff (BEB) algorithm of the IEEE 802.11 as a means to control the *rate* at which a node polls its neighbors. In fact, an important issue of a receiver-initiated MAC protocol is its *polling rate*, because a polling rate that is too low renders low throughput and long delays, whereas a polling rate that is too high may result in a high number of frame collisions, which also results in poor network performance. By using a reversed version of the IEEE 802.11 BEB algorithm, the transmission rate of polling frames is self-regulated according to channel contention, signal propagation conditions, and traffic availability at polled nodes. Moreover, an adaptive *polling discipline* is also improved, that controls the *priority* with which neighbors are polled based on the likelihood of a successful handshake. We name this MAC protocol as *Receiver Initiated Binary Exponential Backoff* (RIBB).

This paper also introduces two important extensions to RIBB: first, a *frame reordering* technique at transmit queues is proposed. According to this mechanism, every time a node is polled by someone, it has to look for a DATA frame addressed to the polling node in its *whole* transmit queue. This way, the polling process is not wasted simply because there is no DATA frame addressed to the polling node at the head of the queue. Second, a *nothing-to-send* (NTS) control frame is introduced. The role of this control frame is to let the polling node know that there is no DATA frames addressed to it in the *whole* transmit queue of the polled node. By doing so, the sending of an NTS frame speeds up the polling process by letting the polling node switch to another neighbor as fast as possible. The performance of RIBB is evaluated based on discrete-event simulations using the popular Network Simulator 3 [10]. Its performance is also compared to the performance of two other polling disciplines (applied to the same polling rate mechanism): the first is the plain *round-robin* mechanism, which we name it as *Receiver Initiated Round Robin* (RIRR), and the other is based on the proportional fair scheduling used in 4G networks, which we name it as *Receiver Initiated Proportional Fair* (RIPF). All three polling disciplines are evaluated with respect to MAC-level control overhead, delay, fairness, and throughput, and their performance is also compared to the sender-initiated IEEE 802.11 DCF. Two different traffic scenarios are considered under network topologies with different sparsity levels (i.e., different degrees of connectivity). In summary, the contributions of this paper are:

- Specification of an extended version of a unicast receiver-initiated random access MAC protocol based on a reversed version of the binary exponential backoff (BEB) algorithm of the IEEE 802.11;
- Introduction of a *frame reordering technique*, by which a polled node searches for a DATA frame addressed to the polling node in its whole queue;
- Introduction of the *nothing-to-send* (NTS) control frame to warn a polling node that no DATA frames addressed to it exists in the polled node, so that polling rounds can be sped up;
- Improvement of the polling discipline *Likelihood of Successful Handshake* (LSH) with a new estimator for the probability of successful handshake;
- Performance evaluation of the BEB-based MAC protocol under three polling disciplines: round-robin, proportional fair, and the LSH, along with their comparison with the IEEE 802.11;
- Evaluation of control overhead, delay, fairness, and throughput for network topologies under channel propagation effects and different sparsity levels.

The remainder of the paper is organized as follows: in Section 2 we present related works. Section 3 contains the specification of the proposed MAC protocol. Section 4 presents the polling disciplines under investigation. Section 5 describes the simulation scenarios along with numerical results, and Section 6 contains the conclusions.

## 2. Related work

In this section, we describe previous works carried out in the context of receiver-initiated MAC protocols. In particular, we look at how polling disciplines and polling rate control mechanisms have been treated in the literature. The first receiver-initiated MAC protocol proposed in the literature was the MACA By Invitation (MACA-BI) [2]. This work introduced the appealing features of such a strategy, which reduces the number of control frames used in a handshake by placing the responsibility of communication on the potential receiver of a DATA frame. In MACA-BI, a node polls some neighbor by sending a *ready-to-receive* (RTR) control frame. If the RTR is received successfully, the polled node may send a DATA frame back to the polling node if there is a head-of-line DATA frame addressed to it. If the DATA frame is received successfully, the polling node sends an acknowledgment (ACK) frame back to the polled node. Later, Tzamaloukas and Garcia–Luna–Aceves [3] have shown that MACA-BI cannot ensure perfect collision avoidance in networks with hidden