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# Performance analysis of a Multiuser Multi-Packet Transmission system for WLANs in non-saturation conditions

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ABSTRACT

Multiuser Multi-Packet Transmission (MPT) from an Access Point (AP) equipped with multiple antennas to multiple single-antenna nodes can be achieved by exploiting the spatial dimension of the channel. In this paper we present a queueing model to analytically study such systems from the link-layer perspective, in presence of random packet arrivals, heterogeneous channel conditions and packet errors. The analysis relies on a blind estimation of the number of different destinations among the packets waiting in the queue, which allows for building a simple, but general model for MPT systems with per-node First-In First-Out (FIFO) packet scheduling. Simulation results validate the accuracy of the analytical model and provide further insights on the cross-relations between the channel state, the number of antennas, and the number of active users, as well as how they affect the system performance. The simplicity and accuracy of the model makes it suitable for the evaluation of Medium Access Control (MAC) protocols for Ad Hoc or Wireless Local Area Networks supporting Multiuser MPT in non-saturation conditions, where the queueing dynamics play an important role on the achieved performance, and simple user selection algorithms are required.



## 1. Introduction

In packet-based wireless networks, the use of spatial multiplexing allows for simultaneous transmission of multiple packets, directed to a single or multiple destinations. In this paper, we focus on a scenario where an AP equipped with multiple antennas is able to simultaneously transmit multiple packets, each directed to a different single-antenna node. This scenario is known as Multiuser Multi-Packet Transmission (MPT), a packet-based extension of Downlink Space Division Multiple Access (DL-SDMA).

Research on Multiuser MPT has mainly been focused on the design of efficient joint precoding and user selection strategies, as a trade-off between computational complexity and the ability to maximize the system capacity, i.e., the number of bits per Hertz of available bandwidth that can be successfully transmitted over the channel. A comprehensive survey of such works has been presented in [1]. In these works, it is usually assumed that the transmitter has separate per-user queues that are always saturated. This reduces the problem to finding the set of users that maximize the system sum-rate capacity, based on the current state of the channel. Specific schemes for user selection range from random selection to greedy schedulers that benefit from the existing multiuser diversity [2].

The main advantage of random schedulers is their simplicity, as the specific channel conditions of the destinations are not considered for selecting the set of destinations at each transmission. Therefore, they do not need to have recent channel information from all potential destinations, but only from the ones selected for transmission, reducing the overhead required to obtain and keep this information updated. In addition, it provides a fair channel access to the competing users, as all users are selected only based on their traffic load, regardless of their

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instantaneous channel conditions. For these reasons, they are specially suitable for Ad Hoc Networks or WLANs, where on the one hand, fairness and simplicity are design requirements and, on the other hand, the sporadic and bursty traffic patterns may not allow for taking full advantage of the existence of Channel State Information (CSI) at the transmitter from all potential destinations. This approach has been widely considered in the design of MAC protocols for WLANs supporting MPT by extending the RTS/CTS mechanism [3,4].

There are still very few works that address spatial multiplexing from the link-layer perspective, and even fewer that focus on the queueing dynamics. In [5], the authors present a point-to-point MIMO system, considering both transmit diversity (STBC) and spatial multiplexing (BLAST) schemes for a single-user MPT. A similar work that overcomes the approximation done in [5] for the BLAST scenario is presented in [6], although the presented results are only valid for two antennas. To the best of our knowledge, [7] is the only work where a detailed queueing model for Multiuser MPT systems is presented. In [7], the nodes are assumed to be equipped with at least as many antennas as the AP. Therefore, the AP can use its multiple antennas to send multiple packets to a single or multiple users simultaneously, following the independent stream scheduler approach [8]. Using the independent stream scheduler, destinations are selected based on the CSI, allowing the transmission of multiple packets to the same destination if in that way the throughput is maximized.

In [9], an M/G/1 batch-service queueing model was proposed to characterize the behavior of MPT systems. However, the queueing model assumes that always the maximum number of packets can be transmitted, regardless of the number of destinations represented among the buffered packets at the AP. Therefore, the model is only valid for when the nodes are equipped with at least as many antennas as the AP. The same model was then used in [10,11] to study the queueing behavior in Multiuser MPT systems when all the receivers have a single antenna. This implies that each transmission can contain at most one packet per destination. Comparing with the analytical results from [9], the simulation results in [10,11] show the loss in performance due to having a single antenna at each destination. In [12], this performance loss is modeled analytically, by using an estimate of the number of different destinations represented among the packets waiting in the queue at the AP, which determines the number of packets that can be scheduled in each transmission. This approach was further validated in [13], where the effect of the buffer size in such systems, as well as in the accuracy of the analytical model presented, is evaluated. In all those works an ideal channel is considered, and therefore, the negative effect, in terms of lower transmission rates, caused by the simultaneous transmission of multiple packets is not included in the analysis.

In this paper, we extend the model and the results presented in [12,13] by providing a detailed analytical model that includes a realistic channel model, supports heterogeneous channel conditions, multiple transmission rates, packet errors, and a tunable scheduler based on the observed channel conditions in a scenario that consists of a multiple-antenna AP and single-antenna users. Moreover, new insights on the model accuracy in terms of the number of nodes and buffer size are provided, considering heterogeneous traffic and nodes with heterogeneous channel conditions. Hence, the presented model can be used to understand and evaluate the different interactions that exist in a Multiuser MPT system between the traffic load, the buffer size, the number of antennas at the AP, the number of different nodes, the channel characteristics, and the protocol overheads required for CSI estimation and reporting. In addition, due to the model characteristics, it can be easily coupled with other link-layer mechanisms to evaluate more complex systems.

The paper is structured as follows. The scenario, together with the system model and the assumptions considered, is introduced in Section 2. Section 3 presents the Multiuser MPT queuing model. Section 4 presents the results, including the validation of the queueing model. Finally, the main conclusions of this work are summarized and the future research lines are stated.

## 2. System model and assumptions

A network consisting of a multiple-antenna AP and $N \in [1, \infty)$ single-antenna nodes located a single hop away from the AP is considered. The AP is equipped with $M$ antennas, allowing it to create up to $\min(N, M)$ simultaneous beams and transmit a different packet in each by using a multiuser beamformer. The packets included in each transmission are selected based on a per-node FIFO scheduler as detailed in Section 2.1. Multiple transmission rates are available, but only one is used at each transmission, and is picked based on the Channel State Information (CSI) provided by the selected nodes. Despite this rate selection, we assume that packets can still suffer errors due to both transmitter and receiver hardware characteristics, such as clock drifts [14]. Erroneous packets are retransmitted until they are successfully received.

Packets of a constant length of $L_d$ bits destined to the $N$ single-antenna nodes arrive to the AP according to an aggregate Poisson arrival process of rate $\lambda$, containing independent and identically distributed shares of traffic per node.

Given that we have to keep track of the order in which packets arrive to the AP to apply the per-node FIFO packet scheduling, a single finite-buffer of size $K$ is considered, where all the available buffer space is fully shared by all arriving packets. Notice that, as traffic differentiation between nodes is not considered, compared to the use of $N$ different queues of size $\lceil K/N \rceil$, a single shared buffer of size $K$ is optimal in terms of minimizing the packet losses due to buffer overflow [15]. A detailed model of the AP architecture is shown in Fig. 1, including the single shared buffer.

Finally, it should be noted that the considered system does not take advantage of the multiuser diversity as, at each transmission, the AP only requests the CSI of the selected users. In order to consider multiuser diversity, the AP would have to request the CSI for all the nodes with packets waiting for transmission at the AP, based on which