# Simulation of Real SAC-OCDMA under Both S-ALOHA and $R^3T$ Random Access Protocols

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*Abstract*— **We simulate both the throughput and the delay of an experimental 7×622 Mbps SAC-OCDMA system. Our results reveal that the $R^3T$ protocol performs better than S-ALOHA CDMA protocol and provides a 4.5 dB improvement.**

## I. INTRODUCTION

Recently optical code-division multiple-access (OCDMA) has received more attention as a flexible solution for local area networks (LANs) and access networks [1]. Most research and experiments conducted in this field have been focused on the physical layer [2], [3]. However, a few authors have examined the optical link layer [4]-[7]. Because optical environment differs from the electronic one, the requirements for media access control (MAC) protocols are also different [4]. In [5] Raychaudhuri introduced a simple yet general random access CDMA protocol based on slotted ALOHA (S-ALOHA). Two protocols (with and without pre-transmission coordination) for code allocation in slotted optical CDMA packet networks were proposed in [6]. In [7] Shalaby developed a new protocol called round robin receiver/transmitter ($R^3T$) protocol that has solved some of the problems in [6].

The impact of these protocols on practical OCDMA systems has yet to be investigated (to our knowledge). In this paper we examine the efficiency of MAC protocols using experimental results for the OCDMA physical layer performance. We simulate the system throughput and the average packet delay of a 7×622 Mbps spectral amplitude coding (SAC)-OCDMA system that was recently demonstrated experimentally [2]. Both S-ALOHA and $R^3T$ protocols are considered. Following the introduction is a description of the OCDMA system and the simulation environment. The paper continues with the simulation results and some conclusions.

## II. THE OCDMA JOINT PHYSICAL AND LINK LAYERS

The physical layer is simply a star network connecting up to seven users transmitting at 622 Mbps as detailed in [2]. Balanced incomplete block design (BIBD) codes are used as the user signature codes, fiber Bragg gratings (FBGs) working in transmission are implemented at the encoders/decoders, and balanced detection is used to suppress the multiple access interference (MAI). The system is limited by the intensity noise when fully loaded as reported in [2], however acceptable bit error rate (BER) is achieved for suitable power levels.

Moving up to the optical link layer, we have the choice between S-ALOHA and $R^3T$ protocols. Using methods in [5] for S-ALOHA CDMA, the composite arrival (transmitted + retransmitted packets) rate for small population networks uses the Binomial arrival model [5]. The throughput is defined as the number of successfully received packets per slot and is obtained by solving the simple Markov chain described in [5]. The delay is then calculated according to Little's theorem.

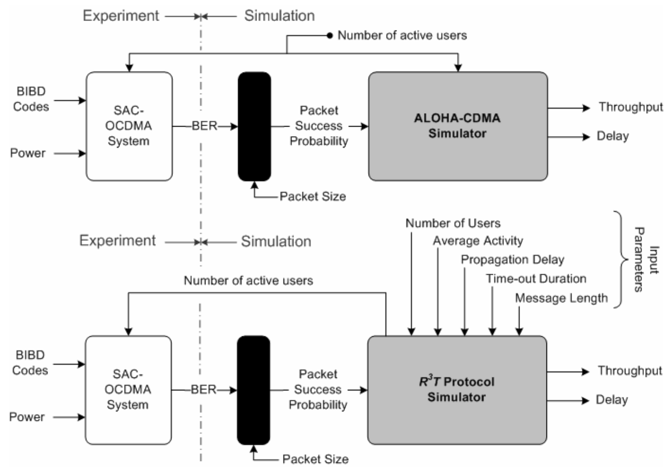


Fig. 1. The experiment/simulation environment.

On the other hand, the $R^3T$ protocol is more sophisticated since it includes request and acknowledgment modes (for connection initialization), in addition to the initial (idle), reception, transmission, and retransmission modes [7]. Also the $R^3T$ protocol allows division of a long packet (message) into smaller packets. The $R^3T$ uses a go- back $n$ ARQ that depends on the propagation delay, compared to Stop & Wait ARQ in [5]. Details of the $R^3T$ protocol can be found in [7] and are not repeated here due to space constraints.

In the $R^3T$ protocol, the number of active (transmitting and retransmitting) users in the network is obtained by numerically solving (14) in [7], which depends on the input parameters depicted in Fig. 1. The throughput and the delay are then simulated using (13) and (20) in [7], respectively. In his analysis, Shalaby used the equilibrium point analysis (EPA) instead of Markov chains because of the complexity of the state diagram of the $R^3T$ protocol. By assuming that each two users can communicate together, the number of supported users can be double the number of active users [7].

Figure 1 shows the experiment and simulation environment

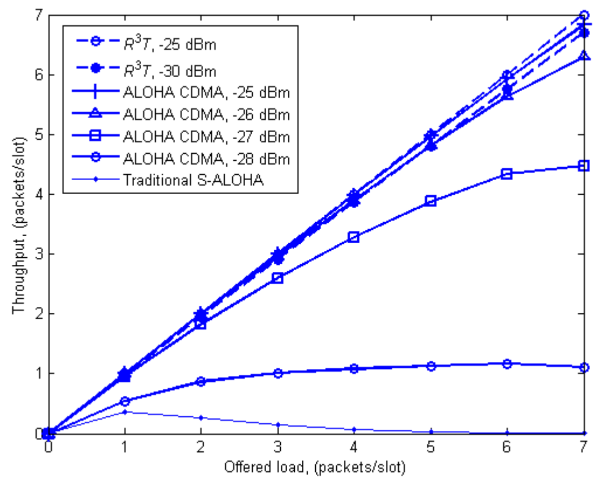


Fig. 2. Throughput versus offered load for different power levels.

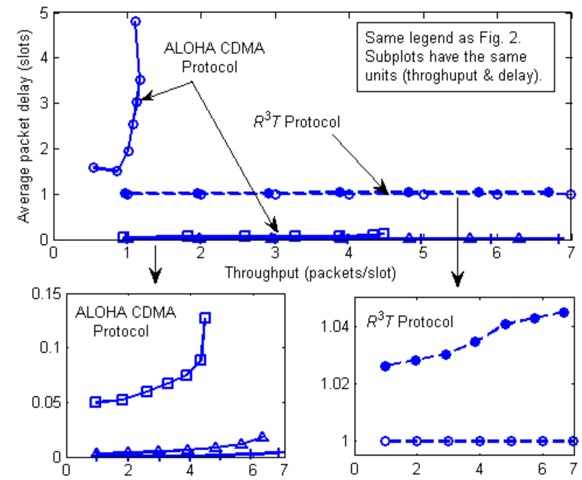


Fig. 3. Delay versus throughput (the same legend as in Fig. 2).

we used to compute the throughput and the packet delay. In the black box we assume independence between all the bits of a given packet ($K$ bits), and therefore we can write the packet success probability $P_S$ as follows

$$P_S = (1 - \mathrm{BER})^K . \quad (1)$$

## III. Simulation Results

Care was taken in the selection of simulation parameters to ensure a just comparison of the two protocols. In the $R^3T$ protocol we do not have direct control of the number of active users, as in the ALOHA-CDMA protocol (Fig. 1). However, by changing the total number of users from 2 to 14 with an increment of 2, and for a user average activity of 50%, we were able to obtain the same offered load (which is the same as the number of active users) in both the $R^3T$ and the S-ALOHA CDMA protocols. Packets of 1024 bits (1 K) are used in all simulations. Therefore a slot duration of 1.6 µs (which corresponds to the packet length) is held constant. For the $R^3T$ Protocol, a two-way propagation delay time of only 2 time slots and a time-out duration of 1 slot are used. The selection of these parameters ensures a minimum interstation distance, which corresponds to the back-to-back experiment done in [2]. Recall that the Binomial arrival model is used for the case of the slotted ALOHA CDMA Protocol.

In Fig. 2 we have plotted the throughput versus the offered load for different received power levels. It can be seen that the $R^3T$ protocol performs better than the ALOHA CDMA protocol over a larger range of power levels. We observe also that even at very small power levels (-30 dBm), the performance of the $R^3T$ is suboptimal. Time-division multiple-access (TDMA) is the optimum limit 'Throughput = Offered load', because there are no collisions between packets.

The relation between the average packet delay and the throughput is illustrated in Fig. 3. It can be inferred that the $R^3T$ exhibits larger delay (still acceptable) than the ALOHA CDMA in general. This is due to the time spent for connection initialization in the request and acknowledgment modes, and also because of the go back-*n* ARQ used in the $R^3T$ protocol. Finally, from both Figs. 2 and 3 we see as expected that increasing the received power leads to improved performance in terms of throughput and delay. Increasing the power further will not enhance the performance because BER floors appear due to the intensity noise [2].

## IV. Conclusion

In this paper we compared the use of ALOHA and $R^3T$ protocols with SAC-OCDMA. Our results show that the $R^3T$ exhibits about 4.5 dB improvement over ALOHA CDMA. Also, the $R^3T$ protocol provides more stability in terms of throughput and delay for a larger range of power fluctuations. Although the $R^3T$ exhibits a larger delay, it is still acceptable (~ 1 slot). Finally, it is worth noting that no forward error correction (FEC) codes are required with the $R^3T$ to achieve good throughput. This improvement results from the greater complexity of the $R^3T$ protocol as compared to the ALOHA CDMA protocol.

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