Multi-Receiver Aloha Systems – A Survey and New Results [4]

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Introduction

Joint work with Andrea Munari and Gianluigi Liva.

Random Access (RA) Medium Access (MAC) protocols are simple and effective when the nature of the traffic is unpredictable and random but

- collisions hurdle RA protocols.

Receiver's performance can benefit from

- the capture effect

allowing the retrieve with non-zero probability packets subject to collisions.

The benefit is even more prominent when the capture effect is used in conjunction with

- multi-packet reception capable receivers.

Diversity has been introduced in RA protocols, both in terms of

- time diversity, DSA, CRDSA and IRSA
- space diversity, Multi-receiver Aloha [1]

Multi-Receiver Aloha Systems

- Review of latest results on multi-recevier Aloha
- Introduction of three channel models, where two model closely the PHY layer
- Comparison of the channel models under analytical and simulative scenarios

System Model

- An infinite population of terminals is spread over a disc of radius R and area $A = \pi R^2$.
- We consider a slotted system.
- The overall traffic pattern follows a Poisson point process of intensity ρ $[pk/slot/m^2]$, where U nodes accessing the channel and can be modeled as a Posson r.v. with parameter $\lambda = \rho A$
$$\Pr\{U = u\} = \frac{\lambda^u e^{-\lambda}}{u!}.$$
- A set $\mathbb{R} = \{\mathcal{R}_k\}$ of receivers is available to retrieve infromation.

- A packet is said to be collected if it is decoded by at least one of the receivers.
- The system throughput T_K, is the average number of collected data units per slot.

On-Off Fading Channel (OOF)

- The wireless links connecting any user-receiver pair are i.i.d. packet erasure channels [1].
- With probability ε a packet is erased.
- Collisions are destructive.

Perfect Power Control (PPC)

- Rayleigh fading is considered, although no spatial effect is considered.
- Received power is i.i.d. exponential r.v. with mean $1/\nu$ and p.d.f. $f_P(a) = \nu e^{-\nu a}$, $a \geq 0$.
- Threshold decoding is assumed, i.e. a packet is assumed to be correctly received if
$$\gamma_k > \gamma^*$$
- With $\gamma_k = P_j / \sum_{i \neq j} P_i$, $P_j = \max_i \{P_i\}_k$ and γ^* the decoding threshold of the recevier.

[1] A. Munari, M. Heindlmaier, G. Liva and M. Berioli „The Throughput of Slotted Aloha with Diversity", 51st Allerton Conference on Communication, Control, and Computing, Monticello, IL, 2013.

Equal Transmission Power (ETP)

- Rayleigh fading is considered, with spatial effects.
- The mean of the exponentially distributed r.v. depends here on the terminal-receiver distance.
- SIC is also introduced.

Analytical Comparison under OOF and PPC

The analytical framework follows some previous work [1], [2], [3].

- At a single receiver, being $\pi_0(u)$ the probability that none of the u transmitted packets over a slot are successfully decoded, the thorughput T is
$$T = \sum_{u=0}^{\infty} \Pr\{U = u\}(1 - \pi_0(u))$$
- For $K = 2$, the throughput is
$$T_2 = 2T - \sum_{u=0}^{\infty} \Pr\{U = u\} u p_r(u)^2$$
- Where $p_r(u) = (1 - \pi_0(u))/u$ is the probability for a decoder to collect the packet of interest.
- For a generic number of receivers K, the throughput follows
$$T_K = \sum_{k=1}^{K} (-1)^{k-1} \binom{K}{k} \sum_{u=0}^{\infty} \Pr\{U = u\} u p_r(u)^k$$
- For the OOF, a packet is correctly received only if it reaches the collector unfaded while all the concurrent packets are erased, so
$$p_r(u) = (1 - \varepsilon)\varepsilon^{u-1}.$$
- For the PPC model we exploit the work of [2], and we adopt on a simple approximation.
- Assuming a sufficiently large population u of users accessing the channel, the aggregate power can be approximated as a normal distribution $\varphi_u(x)$.
- The mean and variance of $\varphi_u(x)$ are given by the sum of the corresponding moments of exponential r.v. conditioned on having values lower than $x\bar{\gamma}$, where x is here the total received power and $\bar{\gamma} = \frac{\gamma^*}{1+\gamma^*}$, so
$$\pi_0(u) \cong \int_0^{\infty} \varphi_u(x)\,(1 - e^{-x})dx$$
- And $\varphi_u(x)$ is expressed as [2]
$$\varphi_u(x) = \frac{1}{\bar{\gamma}\sqrt{2\pi\sigma^2(x)}} \exp\left(-\frac{\left(x - \bar{\gamma} m_u(x)\right)^2}{2\bar{\gamma}\sigma^2(x)}\right)$$

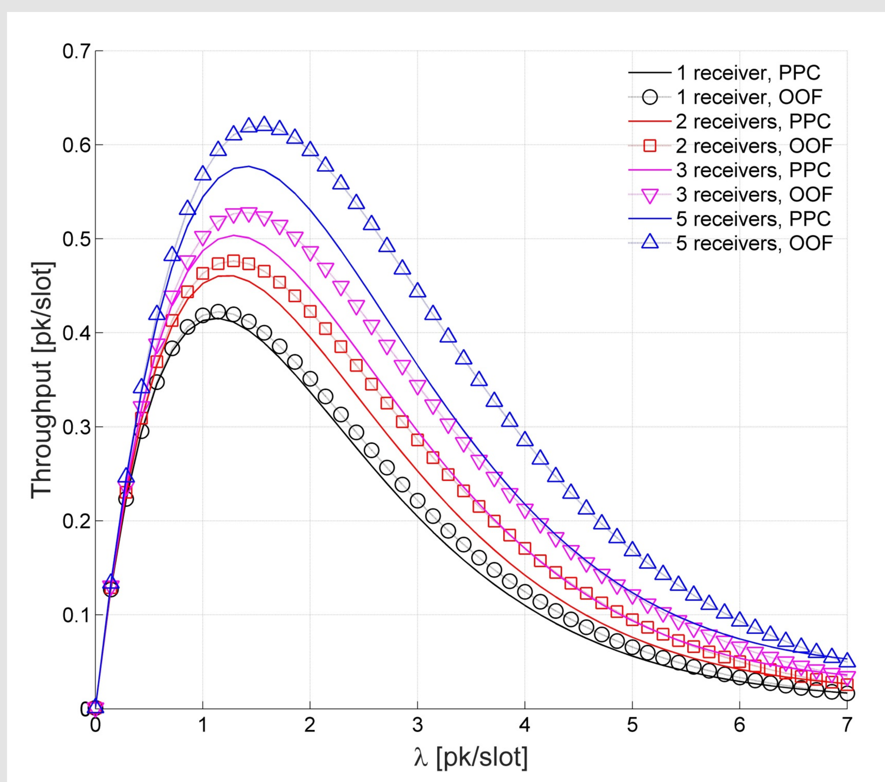

Figure 1. Aggregate system throughput vs. Channel load. $\varepsilon = 0.15$ and $\varepsilon(1-\varepsilon) = 1/(1+\gamma^*)$

[2] A. Zanella and M. Zorzi, „Theoretical Analysis of the Capture Probability in Wireless Systems with Multiple Packet Reception Capabilities", IEEE Transactions on Communications, vol. 60, no. 4, pp. 1058-1071, April 2012.

[3] M. Zorzi, „Mobile Radio Slotted ALOHA with Capture, Diversity and Retransmission Control in Presence of Shadowing", Wireless Networks, vol. 4, pp. 379-388, August 1998.

Numerical Results

We compare the PPC and ETP and evaluate the ETP under various scenarios.

The simulation set up is

- $K = 2$
- $h = 0.02R$
- Transmitters uniformly distributed on an area A
- $\gamma^* = 4$ dB

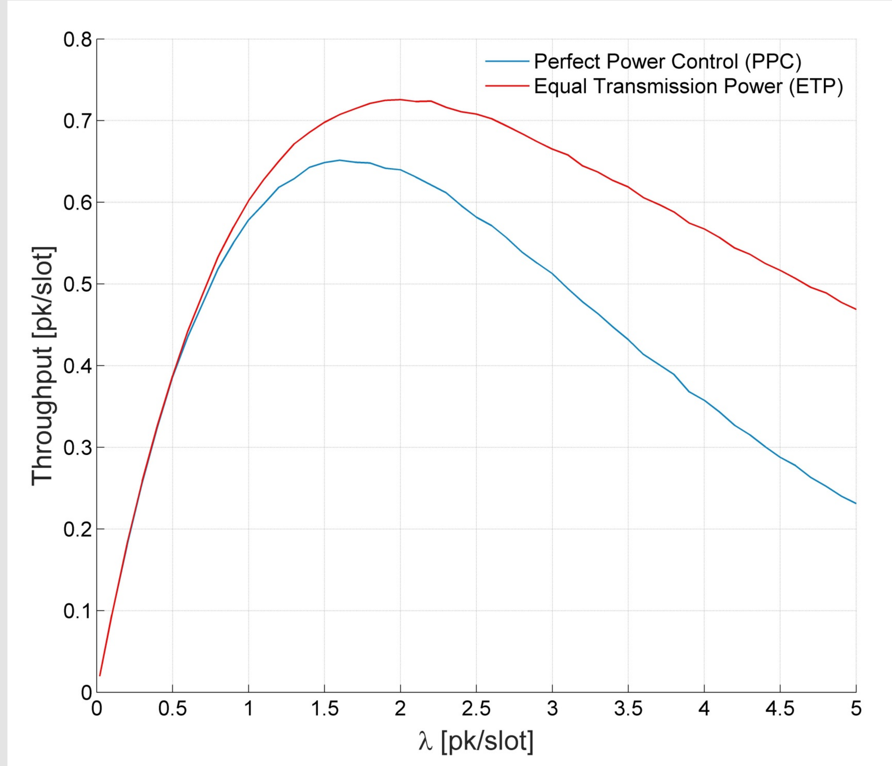

Figure 2. Throughput vs. channel load for PPC and ETP, for co-located receivers.

ETP has a **better performance** under medium to high channel loads due to the **additional diversity**.

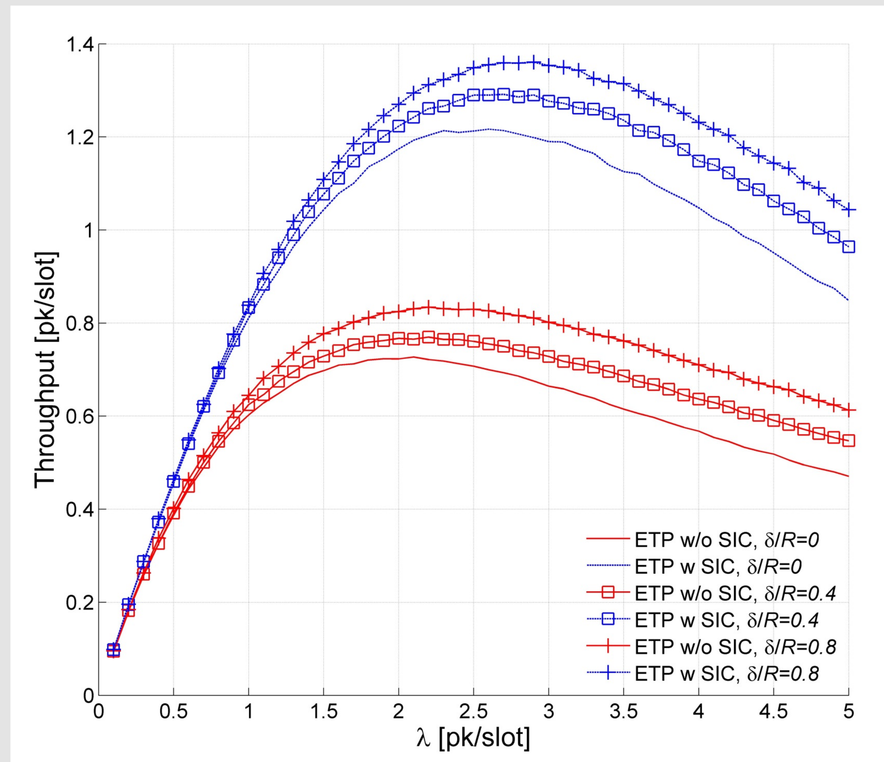

Figure 3. Throughput vs. channel load for ETP under various δ/R normalized recevier distances.

SIC brings gains in the order of 70% or more compared to common receivers.

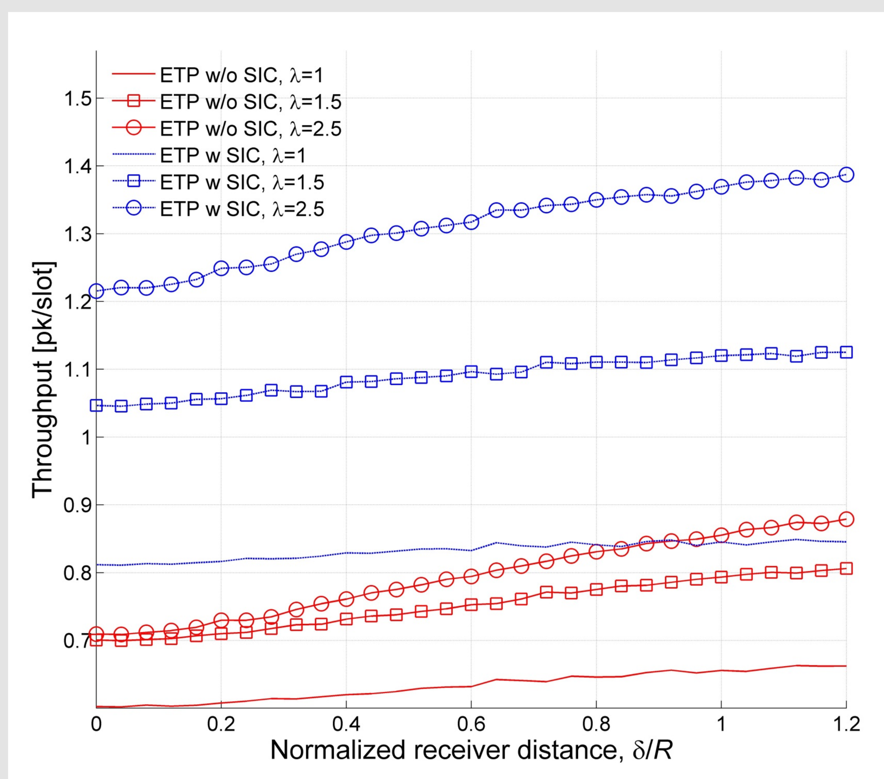

Figure 4. Throughput vs. Normalized receiver distance for ETP under various channel loads.

The **throuhgput** is **monotonically increasing** with the **receiver distance.**

[4] A. Munari, F. Clazzer and G. Liva, „Multi-Receiver Aloha Systems – a Survey and New Results", IEEE International Conference on Communications (ICC), London 2015, MASSAP WS.

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