Poster: Rate Maximization under Reactive Jamming Attacks

Salvatore D'Oro
University of Catania
Catania, Italy
sdoro@dieei.unict.it

Eylem Ekici
The Ohio State University
Columbus, Ohio, USA
ekici@ece.osu.edu

Sergio Palazzo
University of Catania
Catania, Italy
spalazzo@dieei.unict.it

ABSTRACT

Jamming attacks are able to partially or completely disrupt wireless communications. To overcome such a harmful attack, optimal scheduling of user transmissions should be achieved. Providing effective scheduling policies is a hard task which is made more complicated when *reactive jamming* attacks triggered by user transmissions are considered and no information about the jammer is available, e.g., the triggering threshold is not known. In this paper, we address the problem of maximizing network performance and guaranteeing minimum QoS requirements when reactive jamming attacks are ongoing. Specifically, to maximize network performance and avoid the triggering of the jammer, we formulate and solve a joint user scheduling and power control problem. The proposed solution is then assessed through numerical simulations.

Keywords

Scheduling, power control, jamming, learning, QoS

1. INTRODUCTION

Wireless networks are especially vulnerable to a large variety of attacks. Among them, jamming attacks are the most detrimental ones as they can partially or completely disrupt ongoing communications [3]. In particular, *reactive jamming* attacks are performed by malicious users which continuously monitor the wireless channel searching for transmission activities. When a transmission activity is detected, i.e., the received signal strength indicator (RSSI) on the channel monitored by the jammer is higher than a *triggering threshold*, an attack is performed [4]. It has been shown that such an attack is hard to be detected and is highly efficient as it can achieve a high jamming probability while consuming a small amount of energy. It is clear that providing efficient communications when the network is under such a harmful attack is a hard task and several anti-jamming mechanisms have been proposed in the literature [2]. However, those approaches do not consider the case where no information about the transmission power and the triggering threshold of the jammer is available, and a given Quality-of-Service (QoS) level has to be guaranteed to network users. Since the activation of the jammer is triggered by user transmissions that exceed a given RSSI threshold value, in this work we exploit power control to favor low transmission power levels and avoid jamming attacks. Accordingly, we formulate the network performance maximization problem as a joint user scheduling and power control problem which we solve through dynamic programming and exponential learning techniques. The remainder of this poster is organized as follows. In Section 2, we introduce the system model and in Section 3 we discuss the joint power control and user scheduling problem and its solution. In Section 4, the proposed solution is evaluated through numerical simulations. Section 5 conclusions and future works are drawn.

2. SYSTEM MODEL

We consider an uplink wireless system where a set $\mathcal{U}$ of users communicate with a base station (BS) and access the network through a set $\mathcal{S}$ of orthogonal time-slotted channels. At any given slot, we assume that only one user is allowed to transmit on a given channel. Also, we assume that users can transmit on a single channel at any given slot and their transmission power level is bounded by a maximum value P. We consider *Additive White Gaussian Noise* (AWGN) block-fading channels which vary each T slots. Specifically, let g_{us}, h_s and h_{us} be the channel gain coefficients between user u and the BS on channel s, between the jammer and the BS on channel s, and between user u and the jammer on channel s, respectively. Let us denote the triggering threshold and the transmission power of the reactive jammer with P_{th} and P_J, respectively. For each user u transmitting on channel s, we define the *triggering indicator* $\tau_{us}(p)$ such that $\tau_{us}(p) = 1$ if $ph_{us} \geq P_{th}$, where p is the transmission power for u on channel s. Otherwise, $\tau_{us}(p) = 0$. Let us consider $s \in \mathcal{S}$ and let p^m and p^M be two transmission power levels for user $u \in \mathcal{U}$ such that $0 \leq p^m < p^M \leq P$. In this paper, we assume that $\tau_{us}(p^m) = 0$ and $\tau_{us}(p^M) = 1$. Furthermore, under the assumption that the value of the jammer triggering threshold P_{th} is unknown, the probability of triggering the jammer when transmitting with power p given both p^m and p^M can be modeled as the CDF of a uniform distribution:

$$\mathrm{F}_{us}(p) = \begin{cases} 0 & \text{if } p \leq p^m \\ \frac{p-p^m}{p^M-p^m} & \text{if } p^m < p < p^M \\ 1 & \text{otherwise} \end{cases} \tag{1}$$

Permission to make digital or hard copies of part or all of this work for personal or classroom use is granted without fee provided that copies are not made or distributed for profit or commercial advantage and that copies bear this notice and the full citation on the first page. Copyrights for third-party components of this work must be honored. For all other uses, contact the owner/author(s).

MobiHoc'16 July 04-08, 2016, Paderborn, Germany

© 2016 Copyright held by the owner/author(s).

ACM ISBN 978-1-4503-4184-4/16/07.

DOI: http://dx.doi.org/10.1145/2942358.2942401

3. PROBLEM FORMULATION

Under the AWGN assumption, the achievable rate of user u on channel s is $C_{us}(p) = \log\left(1 + \frac{g_{us}p}{\sigma^2 + \tau_{us}(p)h_s P_J}\right)$. Note that the value of $\tau_{us}(p(j))$ is available only when a slot ends, therefore it is not possible to calculate $C_{us}(p)$ a priori. For any $u \in \mathcal{U}$ and $s \in \mathcal{S}$, let $\mathbf{p}(j) = (p_{us}(l))_{u,s,l<j}$ be the set containing all the transmission policies taken up to slot j. Accordingly, let $\pi_{us}(j) = \left(p^m_{us}(j), p^M_{us}(j)\right)$ be the *history* up to slot j, where $p^m_{us}(j) = \max\{p_{us}(l) \in \mathbf{p}(j) : \tau_{us}\left(p_{us}(l)\right) = 0,\ l < j\}$, $p^M_{us}(j) = \min\{p_{us}(l) \in \mathbf{p}(j) : \tau_{us}\left(p_{us}(l)\right) = 1,\ l < j\}$ where $\pi_{us}(1) = (0, P)$ for all $u \in \mathcal{U}$ and $s \in \mathcal{S}$ by assumption. Therefore, the expected achievable rate can be written as follows:

$$E_\tau\{C_{us}(p)|\pi_{us}(j)\} = \frac{p - p^m_{us}(j)}{p^M_{us}(j) - p^m_{us}(j)} \log\left(1 + \frac{g_{us}p}{\sigma^2 + h_s P_J}\right) + \left(1 - \frac{p - p^m_{us}(j)}{p^M_{us}(j) - p^m_{us}(j)}\right) \log\left(1 + \frac{g_{us}p}{\sigma^2}\right) \tag{2}$$

Accordingly, the joint power control and user scheduling problem can be formulated as Problem (**P1**):

$$(\mathbf{P1}) : \max_{\boldsymbol{x}, \mathbf{p}}\ \mathrm{E}_{\boldsymbol{\tau}} \left\{ \sum_{j \in \mathcal{T}} \sum_{s \in \mathcal{S}} \sum_{u \in \mathcal{U}} x_{us}(j) C_{us}(p_{us}(j)) \right\}$$

$$\text{s.t.} \sum_{s \in \mathcal{S}} x_{us}(j) \leq 1, \qquad \forall u \in \mathcal{U},\ j \in \mathcal{T} \tag{3}$$

$$\sum_{u \in \mathcal{U}} x_{us}(j) \leq 1, \qquad \forall s \in \mathcal{S},\ j \in \mathcal{T} \tag{4}$$

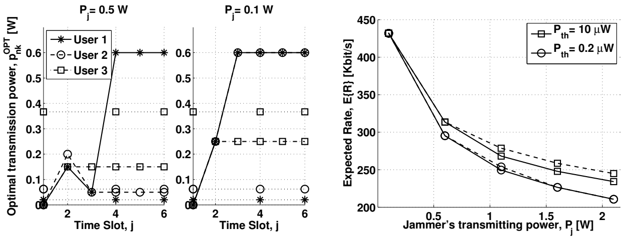
$$\mathrm{E}_{\boldsymbol{\tau}} \left\{ \sum_{j \in \mathcal{T}} \sum_{s \in \mathcal{S}} C_{us}(p_{us}(j)) \right\} \geq C^*_u, \qquad \forall u \in \mathcal{U} \tag{5}$$

$$x_{us}(j) \in \{0,1\}, p_{us}(j) \in [0, P], \forall u \in \mathcal{U}, \forall s \in \mathcal{S}, j \in \mathcal{T} \tag{6}$$

where $\boldsymbol{x} = (x_{us}(j))_{u \in \mathcal{U}, s \in \mathcal{S}, j \in \mathcal{T}}$; $\boldsymbol{p} = (p_{us}(j))_{u \in \mathcal{U}, s \in \mathcal{S}, j \in \mathcal{T}}$ are the decision variables; $\boldsymbol{\tau} = \left(\tau_{us}(p_{us}(j))\right)_{u,s,j}$; and C^*_u is a minimum rate requirement for user u. In Problem (**P1**), Constraint (3) guarantees that a user is allocated to only one channel. To avoid possible collisions among users, Constraint (4) ensures that only one user is allocated to a given slot. Constraint (5) ensures that the expected rate of each user is higher than or equal to C^*_u, and Constraint (6) guarantees the feasibility of the decision variables. Problem (**P1**) is a Mixed Integer Non-Linear Problem (MINLP) which can be proven to be NP-hard. Also, it can be shown that the joint power control and user scheduling problem can be decomposed and solved separately. Therefore, to solve the user scheduling problem, we use a dynamic programming approach. Whereas, to solve the power control problem we use exponential learning techniques which provably converges to the optimal power control policy [1].

4. NUMERICAL RESULTS

We consider a wireless network consisting of $U = 3$ users and $S = 2$ channels. We assume $P_J = 0.6\,W$ and, for illustrative purposes, we assume that users, the BS and the jammer are located along a 1-dimensional map. In Fig. 1(a) we show how power control policies vary at each slot. Dotted lines show the lowest transmission power that triggers the jammer. Finally, the impact of the triggering threshold on the achievable rate is shown in Fig. 1(b). Our results show that larger values of P_{th} allow users to transmit with a higher transmission power, which implies higher performance. Instead, for small values of P_{th}, the jammer can be triggered even for low transmission power levels, thus causing performance losses. Furthermore, the achievable rate decreases as P_J increases as well.



(a) (b)

Figure 1: a) Learning process on a single channel; b) Expected rate of the system as a function of P_j for different values of P_{th}.

5. CONCLUSIONS

In this paper, we focused on the problem of network performance maximization problem under reactive jamming attacks. We considered the worst-case scenario where no information about the jammer is available. Accordingly, we formulated the problem as a joint power control and scheduling problem with minimum QoS guarantee, which turns out to be a NP-hard MINLP. However, we proposed both dynamic programming and exponential learning techniques to decompose the problem and solve it. Numerical results show the impact of the jammer on the achievable performance of the network and how learning is effectively exploited to adapt to the jammer's behavior and improve network performance. In our future work, we will focus on the design of sub-optimal low-complexity approximation algorithms with provable performance bounds.

References

[1] S. D'Oro, P. Mertikopoulos, A. L. Moustakas, and S. Palazzo. Interference-based pricing for opportunistic multicarrier cognitive radio systems. *IEEE Transactions on Wireless Communications*, 14(12), Dec 2015.

[2] K. Grover, A. Lim, and Q. Yang. Jamming and anti–jamming techniques in wireless networks: a survey. *International Journal of Ad Hoc and Ubiquitous Computing*, 17(4), 2014.

[3] R. Poisel. *Modern Communications Jamming: Principles and Techniques.* Artech House, 2011.

[4] M. Wilhelm, I. Martinovic, J. B. Schmitt, and V. Lenders. Short paper: reactive jamming in wireless networks: how realistic is the threat? In *Proceedings of the fourth ACM conference on Wireless network security.* ACM, 2011.