# About Joint Stable User Association and Resource Allocation in Multi-Rate IEEE 802.11 WLANs


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## ABSTRACT

This paper aims at proposing an alternative approach for both the modeling of the IEEE 802.11 resource allocation scheme and the design of mechanisms to reduce the impact of the anomaly of the protocol. We use game theory to model the IEEE 802.11 resource allocation and mobiles users to APs association as a coalition matching game. We propose a new mechanism that gives mobile users and APs the incentive to associate with each others in a way that both absorbs the load and reduce the negative impact of the anomaly in IEEE 802.11.


## 1. INTRODUCTION

It is known that the IEEE 802.11 protocol may lead to unpredictable or poor performances due to its anomaly at the MAC layer and the use of a strongest signal (best-RSSI) association scheme. In fact, the throughputs both depend on the heterogeneity of the data rates of the nodes and the congestion of the medium. In this paper, we propose to use game-theory to model the resource allocation scheme induced by the IEEE 802.11 protocol and solve the association problem so as to reduce the impact of the anomaly and balance the load among the APs (according to some given fairness criteria). More particularly, we show that the IEEE 802.11 protocol and related modifications (proposed in the literature in view of reducing the anomaly) can be modeled as a Nash bargaining [1] over the resource. As examples, this includes the throughput fairness allocation in the saturated regime with equal packet sizes or the time-based fairness. Using recent game-theoretical results, we show that these allocation schemes guarantee the existence of some (core) stable [3] associations between the mobile users and the APs. We use matching games with complementarities and peer effects to reach the stable association. Finally, we propose a novel three-stages controlled coalition game (among selfish and throughput maximizing players) for the modeling and control of load balancing, resource allocation and user association. We show that our mechanism can reduce the negative impact of peer effects such as the anomaly in IEEE 802.11 and greatly improve the efficiency of 802.11 with heterogeneous nodes. Our mechanism can be used at the connectivity management layer to achieve efficient APs-mobile user associations without modification of the MAC layer.


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## 2. MECHANISM

We now show our three-steps mechanism including (i) a Nash bargaining-based load balancing[1] among the APs (ii) a controlled coalition game with Nash bargaining for resource allocation among the players in each cell (iii) a core stable matching algorithm. We show our three-steps mechanism in Figure 1. In the first step (block **LS**), APs perform a Nash bargaining over the users in order to share those covered by several APs. The resulting quantities are called quotas and should be enforced by the following steps of the mechanism. The second step (blocks $\mathbf{\Omega}$ and $\mathbf{\Phi}$) is a controlled coalition game. The control of the game is designed so as to provide the players [2] the incentives to form coalitions of cardinalities given by the quotas. The fact that the players are both selfish and throughput interested naturally reduce their heterogeneity in the resulting association (thus reducing the impact of anomaly in the IEEE 802.11). The third step (block $\mu$) is a decentralized matching game using a core stable matching algorithm [4]. This matching game results in a core stable structure induced by the individual preferences provided by the controlled coalition game. More details about the mechanisms are given in Figure 1. The proposed mechanism can be implemented as a virtual layer on top of the IEEE 802.11 MAC protocol. Mobile users and APs form coalitions based on the "virtual rates" provided by this virtual layer. Once associated, users access the channel using the unmodified 802.11 MAC protocol.

## 3. NUMERICAL RESULTS

In this section, we assume equal packet sizes and saturated queues (each node always has packet to transmit). In this case, the cell throughput is equally shared among the mobile users and AP in a cell (throughout-based fairness) . The analytical expressions of the throughputs are taken from [2]. Figure 2 shows the two scenarios we consider in this paper. In the absence of any mechanism, the mobile users and APs

[1]The Nash bargaining achieves the proportional fair allocation in the utility space, see [1].

[2]By assumption, selfish and individual throughput maximizers.

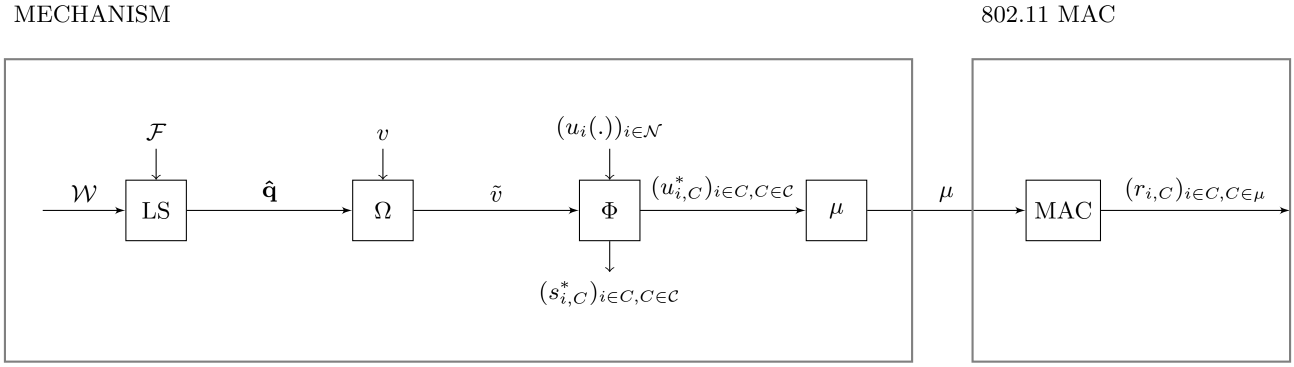
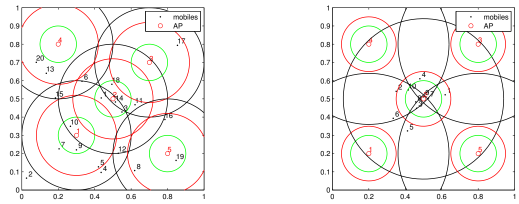
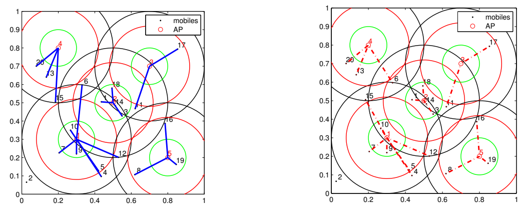



Figure 1: Block diagram of the mechanism. Block **LS** shows the load balancing scheme (negociated quotas). Block **Ω** shows the control changing the original characteristic function $v$ in the modified characteristic function $\tilde{v}$. Block **Φ** shows the Nash bargaining for the resource allocation. Then, the players emit preferences over the coalitions on the basis of their shares and enter a stable matching mechanism in block $\mu$. This block outputs a stable AP-user association $\mu$. In the block **MAC**, the nodes transmit their packets according to the unmodified IEEE 802.11 MAC protocol.



(a) Scenario 1 (b) Scenario 2

Figure 2: Scenarios 1 and 2. Two spatial distribution of APs (smallest red circles) and devices (black points). Circles show the coverage areas corresponding to different data rates.

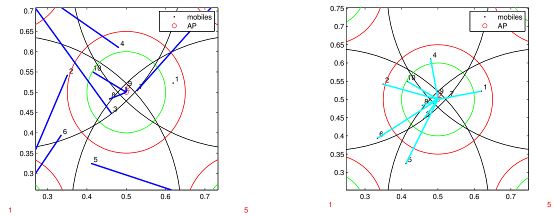


(a) Stable matching resulting from a Gaussian cost and BDAA. (b) Global optimum matching with Gaussian cost.

Figure 3: Controlled matching game in scenario 1. Comparison of the association obtained from (a) BDAA, (b) the global optimum for Gaussian costs with variance $\sigma = 0.2$.

associate in a one-to-one form and a high number of mobile users may remain unassociated. This shows the natural incentives of the system with selfish players solely interested in maximizing their individual throughputs. Our mechanism changes the structure of throughputs in a way that provides the players (mobile users and APs) the incentives to associate with each others according to a many-to-one matching rather than a one-to-one. Figure 4 compare our approach to the best-RSSI scheme. The load is shared among the APs and the individual throughputs are multiplied by 3 to 5 in this scenario.

## 4. CONCLUSION



(a) Stable matching resulting from Gaussian cost and BDAA. (b) Matching resulting from the best-RSSI scheme.

Figure 4: Comparison of the association obtained from (a) BDAA and (b) the best-RSSI scheme in scenario 2. Figures are zoomed towards the center AP.

In this paper, we have presented a newl association mechanism in multi-rates IEEE 802.11 WLANs. Using game-theory, we have formulated the resource allocation and association problems as a coalition matching game and we have provided a new mechanism that provides devices the incentive to form coalitions both resolving the unemployment problem and reducing the impact of the anomaly in IEEE 802.11. Simulations results have shown that the proposed mechanism can provide significant gains in terms of increased throughput by minimizing the impact of the anomaly through the overlapping between APs. his work is a first step in the field of controlled coalition games for achieving core stable associations in distributed wireless networks.

## 5. REFERENCES

[1] J.F. Nash, The Bargaining Problem, Econometrica, Vol. 18, No. 2, pp. 155-162, April 1950.

[2] A. Kumar and E. Altman and D. Miorandi and M. Goyal, New Insights From a Fixed-Point Analysis of Single Cell IEEE 802.11 WLANs, IEEE/ACM Transactions on Networking, Vol. 15, No. 3, June 2007.

[3] M. Pycia, Stability and Preference Alignment in Matching and Coalition Formation, Econometrica, Vol. 80, No. 1, pp 323-362, January 2012.

[4] M. Touati, R. El-Azouzi, M. Coupechoux, E. Altman, J.-M. Kelif, Core stable algorithms for coalition games with complementarities and peer effects, Workshop NetEcon, ACM Sigmetrics & EC, June 2015.