Peer-to-Peer Wireless LAN Consortia: Economic Modeling and Architecture*

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Abstract

In this paper we address the incentive issues that arise in a Peer-to-Peer WLAN Consortium [1]. We explore the use of flexible rules on reciprocity to guide domain policies and develop a suitable economic model that demonstrates the basic characteristics of our system.

1. Introduction

Ubiquitous access to the Internet is becoming a necessity. However, the required infrastructure is not yet in place. Wireless Internet Service Providers (WISPs) relying on the IEEE 802.11 set of technologies are facing difficulties that limit their coverage to selected hotspots. What we propose is a community of peer WLAN Administrative Domains (ADs) that offer network access to each other's registered users. We call such a community a Peer-to-Peer WLAN Consortium (PWC) [1]. Roaming users can enjoy various network services (e.g. Internet access) from other ADs, thus benefiting from the community formed and, hopefully, compensating for their AD′s cost of providing similar services to visiting members of other domains.

Unlike existing roaming schemes [2][3], PWC allows the ADs to make independent decisions concerning the amount of resources (e.g. access bandwidth) they contribute. In that sense, PWC is a 'pure' P2P system. No central entity controls the interaction between the peers (the ADs), which dynamically enter and leave the system having full control of their participation level in the community. This distinctive characteristic of the PWC enables a more scalable, flexible, low-cost and economically efficient solution for global broadband wireless coverage than existing schemes. In a PWC, however, without the appropriate incentives, actions are taken by individual ADs without taking into account the costs and benefits to other ADs in the system. The result of this is, in general, inefficient usage of the system, as relevant studies [4] demonstrate for the case of similar in principle existing P2P systems such as Gnutella.

In the following, we present the PWC high-level architecture and develop an economic model to support the use of reciprocity rules for efficient resource allocation in a PWC.

2. High-level architecture

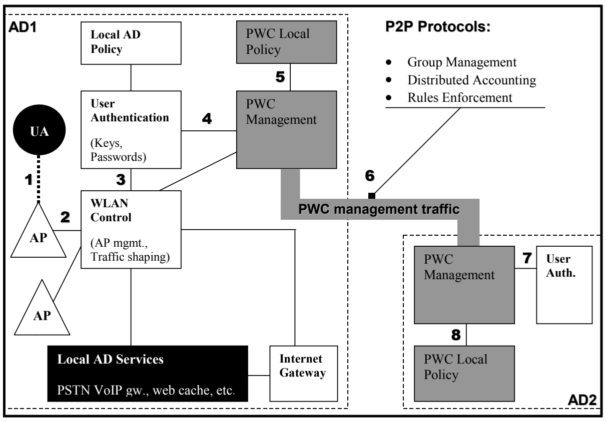

Figure above shows two administrative domains, AD1 and AD2 and the sequence of actions of a visitor login. In white, we represent the support modules that would exist anyway in a typical WLAN administrative domain. These modules include the WLAN control module, which manages the WLAN Access Point (AP) network and shapes traffic; the User Authentication module, which checks user credentials and decides what services the user is authorized to access. The module that handles the P2P related communication between domains is represented by the PWC Management module. The Local PWC Policy module encapsulates the strategy of a domain as a participant in a PWC (the amount of resources offered to visitors, the request rate allowed for its own registered users, etc.). In [5] we discuss in more detail the components of the PWC architecture and identify certain key architectural and implementation issues that require further research (in some cases providing directions for the design of mechanisms to address them).

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3. Incentives

So, what are the appropriate mechanisms that are needed in order to give to peers the correct incentives to contribute their resources to the P2P system? In standard markets, prices provide the appropriate incentives. However in P2P systems where no global information is available (peers acquire information only by communicating with other peers) and there are externalities (the contribution and consumption of resources of one peer affects the utility and cost of all the others), freely-determined (unregulated) prices would not lead to efficient behavior. Moreover, the complexity of implementing price mechanisms involving real money in a highly distributed P2P system, motivates the search for simpler to implement incentive mechanisms.

As a result, there may be no explicit prices, but implicit ways to account for production and consumption of resources by individual peers. Our approach is to use rules for influencing the behavior of the peers instead of prices. As we will argue, such rules can approximate arbitrarily closely the effects of prices, and are simpler to implement. One may think of these rules (e.g. constraints on the relation between consumption and contribution of resources) as being designed and enforced by a regulator whose goal is to improve the economic efficiency of the overall system by avoiding free riding.

4. Economic Modeling

We propose a mathematical model which allows us to evaluate the effect of various parameters in the economic performance of the overall system. It also justifies the use of rules as a substitute to prices.

Let $b_i(\{Q_j\},\{r_{ij}j\})$ be the rate of benefit obtained by peer i when the rate of service requests (roaming members of this AD) directed to peer j is r_{ij}, and these are served by peer j with quality Q_j. In our case, think of Q_j as expressing the specific success probability that user agents face while requesting access from peer j (or packet delay in the case that service requests are always accepted but assigned to congested resources).

The rate of cost incurred by peer i is denoted by $c_i(Q_i, \sum_k r_{ki})$, where Q_i is the quality level maintained for serving the requests of its peers (to simplify notation, we implicitly assume that the sum is for all $k \neq i$). This cost is a function of the resources allocated by peer i for serving the other peers with quality Q_i. Then the social welfare (the sum of peers' net utilities) is

$$SW = \sum_i [b_i(\{Q_j\},\{r_{ij}\}) - c_i(Q_i, \sum_k r_{ki})] \quad (1)$$

Our goal (think of us as the social planner) is to seek prices under which the maximum is achieved in (1). Assuming that the benefit function is increasing and strictly concave (expressing saturation effects), and the cost function is increasing and strictly convex in both their arguments, for all i, we can easily compute the optimal prices, in order to induce each peer i to operate at the socially optimal levels of Q_i^* and r_{ij}^*, which would be

$$p_i^Q = \sum_{j \neq i} \frac{\partial b_j}{\partial Q_i},\ p_i^r = \frac{\partial c_i}{\partial r},$$

where the derivatives are computed at the optimum of (1). Using these prices, peer i offering quality level Q_i is rewarded a negative charge (receives) $p_i^Q Q_i$, and incurs a positive charge (pays) $\sum_{j \neq i} r_{ij} p_j^r$. The resulting prices motivate the use of a rule of the form

$$Q_i \geq \sum_{j \neq i} a_{ij} r_{ij} + \beta_i$$

where the vectors of weights α_{ij}, β_i, are defined for each peer i based on the optimal prices. More specifically, it can be easily proven that for

$$a_{ij} = \frac{p_j^r}{p_i^Q},\ \beta_i = Q_i^* - \frac{\sum_{j \neq i} p_j^r r_{ij}^*}{p_i^Q}$$

the above rules lead the system to the optimal equilibrium. Observe that since optimal prices need to be personalized, optimal rules must also be personalized in the general case where peers are not symmetric. In practice (for instance when there is a large number of peers, each peer being 'small'), uniform prices and hence uniform rules are expected to perform adequately.

5. Conclusion

We have introduced the concept of a Peer-to-Peer Wireless LAN Consortium and motivated its existence in economic terms. We supported our view that rules based control is more appropriate in this setting than a price based, free market approach and discussed the relationship between prices and rules.

References

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