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A Proposal for QoE in Cooperative Wireless Local Networks

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Abstract. Cooperative Wireless Networks (CWN) have become an attractive alternative for providing ubiquitous and inexpensive connectivity to mobile users. In a CWN, some hot-spot areas may experience the problem of sporadic congestions. The appearance of this localized congestion adversely impacts the network performance in terms of effective throughput, leading to a Quality of User Experience (QoE) degradation.
The challenge then is how to ensure the QoE for the access to services, in this unplanned type of networks.
This paper proposes a QoE for CWN with no centralized entities, which is based on the IEEE 802.11e amendment to the IEEE 802.11 Standard, and employs a game theory approach. The proposed scheme permits the distribution of the load between different Access Points. It also provides to the users a mechanism for the selection of the best Access Point in order to satisfy their requirements, and to guarantee the equilibrium in the network.

1 Introduction

A permanent connection is a desirable feature for any user. Besides of the advantages of being always available, a permanent connectivity allows users to have the information at their fingertips. Nowadays, the users want to use their WLAN mobile devices to become accessible and to obtain data of interest related to the location and the context where they are. The service should be available from just about anywhere, and at any time.

Under these circumstances, and to ensure a universal coverage, it would be necessary to install a large number of access points (APs) that would give full connectivity to a city. This is a very improbable solution, taking into account the installation, operation, and maintenance costs associated to an infrastructure of this magnitude.

The CWN appears as a solution to the problem of ubiquitous access to online services for citizens and visitors in a city. The CWN is a low-cost alternative that, at some extent, satisfies this high degree of connectivity requirement. An example of a CWN is depicted in Fig. 1. In this example, users have access to online services through APs that are participating in the CWN. There is no central entity to manage and coordinate the resources available in such scheme.

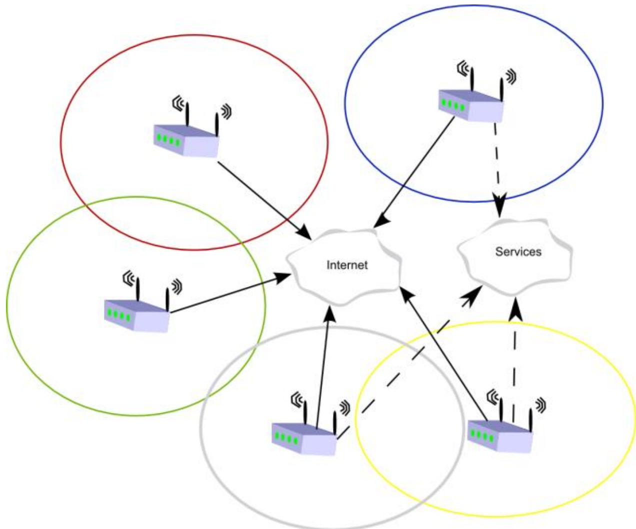

Fig. 1. Wireless Cooperative Network

Despite that the CWN are an attractive alternative to meet the current connectivity requirements, the lack of a planned growth of the network, and the use of a decentralized management, make the network components to be vulnerable to saturation. For example, if one access point is overloaded, then it is expected to look for a neighboring under-utilized AP for the balancing of traffic. However, this is a challenging task, because there are unexpected factors which may interfere with the load balancing and the AP selection mechanism. Some of these factors are: the new traffic patterns in the WLAN, the different types of user applications, the variable number of users in the network, the current load conditions at the AP, the handover latency, the unplanned growth process, and the mobility patterns of the user.

Another issue, if we consider a decentralized approach, is how to find an efficient and secure way to allow for the exchange of information about the network characteristics between APs in different domains.

Consequently, this paper focuses on how to improve and optimize the throughput of user applications, by means of the implementation of APs that comply with the 802.11e Standard (IEEE 802.11, 2005, in order to ensure QoS at the MAC layer. It is also proposed a dynamic resource management scheme for CWN in which the available resources are efficiently exploited to select the AP that offers the best service, based on the user requirements. This selection may occur during horizontal handovers or in those cases when the user requirements have changed during a connection.

To achieve the AP selection, it is necessary for the client to know the current traffic patterns, and for the AP to manage the existent user connections, especially when the resources are scarce.

The AP selection mechanism is based on an algorithm that combines the IEEE 802.11e Standard with game theory. The latter has been extensively used to model the behavior of the user in environments where they have to compete for scarce resources. As a result, the AP selection algorithm will increase the QoE.

The remainder of this paper is organized as follows: Section II gives an overview of the related work. Section III describes the scope of the problem. Section IV introduces the proposed scheme. Finally, we conclude this paper in Section IV.

2 Related Work

In this section, we provide a brief description of previous work dedicated to the enhancement of QoE in wireless networks. Ognenoski et al. (Ognenoski et al., 2009) propose an enhanced QoE in Wireless Heterogeneous Networks, by means of using the parameters of the MAC layer of the WIMAX Technology. Piamrat et al. (Piamrat et al., 2006) provide another example of a solution that employs a QoE-aware Admission Control. The admission control mechanism proposed in this solution is based on a Pseudo- Subjective Quality Assessment (PSQA) tool, which provides a statistic learning tool that uses a random neural network to learn about the level of QoE in the network. Then, the APs can use the information learned by the tool and communicate it to the other APs in an infrastructure-based mode.

A different approach called Effective Access Point selection is proposed in (Chen et al., 2006). Moreover, an AP selection strategy suitable for an office environment interconnected with a WLAN is presented by Du et al. (Du et al., 2008). This strategy uses a new field, called Information Element (IE), in the frames advertised by the APs. The IE allows balancing the stations (STAs) when they want to be associated with a particular AP. On the other hand, in Lee et al. (Lee et al., 2004) propose an AP selection method that uses a reserved field of the IEEE 802.11 frame. This field includes information about the number of connected stations and the amount of traffic currently processed by the AP. After the information is sent, the stations can decide which AP they prefer based on the information received.

Several authors have also considered the use of a game theory approach problem to tackle the problem of load balancing. Suri, Tóth and Zhou (Suri et al., 2004) applied an atomic congestion game for selfish load balancing in order to choose the server with minimum latency. According to Niyato and Hossain users (Niyato and Hossain, 2009), it is possible to use a game-theory approach for solving the problem of network selection in heterogeneous wireless access networks, and with different types of.

The scheme proposed in this paper differs from the aforementioned solutions in the fact that our users are part of a WCN, and thus each AP belongs to a different domain. In addition, those approaches do not consider the QoE requirements in an environment devoid of planning or structure.

Our study aims to cope with the QoE in a WCN. To achieve that, the problem is treated in three different fronts:

Firstly, we formulate the problem of finding the subset of preferred APs. The Qos facilities defined in the IEEE 802.11e Standard are employed to solve this problem.

In the second front, we formulate the AP selection problem using a game theory approach. To ensure a certain level of QoE means to carry out an optimal allocation of the network resources according to the current requirements of the user. Therefore, we aim to determine the user behavior and to define the best strategy to be applied for those users.

Finally, in the third front we formulate the QoS problem. Parameters such as: throughput, jitter, delay, probability of packet loss and the network round trip time (RTT) are the metrics used to ensure certain level of quality of the user experience. The traffic flows then will be transmitted according to the required priority.

Note that we do not consider any centralized entity in our proposed scheme.

3 Problem Statement

Define a Wireless Cooperative Network as a set V of N APs $\{n_1, \ldots, n_N\}$ each of which provides access to different types of services such as Internet-based or context-based services. Every AP $n_i \in V$ provides coverage in a particular area for a set U of users, though not exclusively. As WCN are unplanned networks, a user can potentially associate to any of the APs $n_i \in V$ that offer redundant coverage in that site.

Fig. 2 shows an example of a CWN with five different domains. Suppose that User 1 moves in a city from a place of interest A to another place of interest B, in which a different set of APs, excluding AP1, offers connectivity.

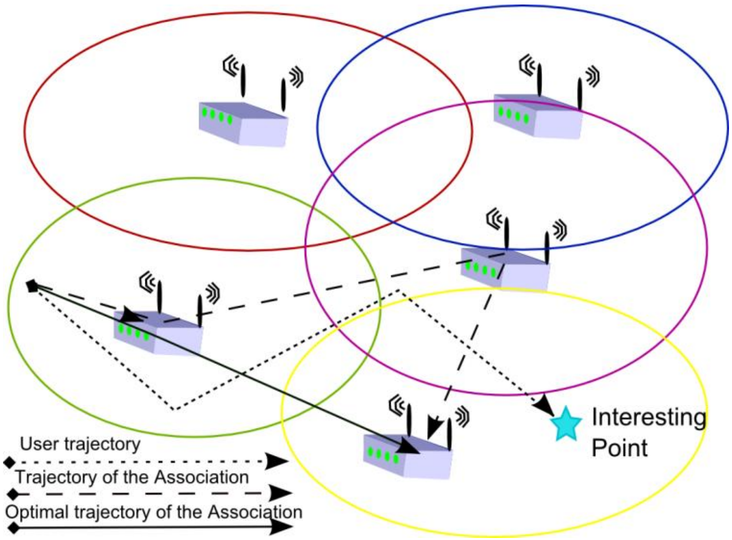

Fig. 2. WCN topology in the example

Due to the architectural conditions of the city, User 1 has to pass near to the AP1, but there are other APs that may also offer coverage to User 1. Nowadays, the mechanism used to choose an AP in the majority of the existent wireless clients is based on signal strength measurements. If that were the case in our example, User 1 will immediately try to associate to AP1. However, a decision based on signal strength does not always lead to an efficient approach, nor guarantees the end-user QoE.

Furthermore, User 1 may have strict requirements in terms of the treatment for its generated traffic, and AP1 may not be able to meet those requirements. It is also necessary to take into account that the performance of an AP decreases proportional to the number of associated users, and the amount of traffic it has to process. Consequently, it is desirable to make a careful selection of the AP, in a way that allows the user to experience the maximum performance and to ensure an efficient balancing of the traffic loads among the APs.

The objective of our proposed QoE scheme is then to guarantee, for a finite number of users $N \geq 1$, the best possible association with the APs. In turn, these users - competitors can share the bandwidth in the assigned AP according to their QoS requirements. To meet this need, we formulate the load balancing problem as a cooperative game among the APs and the users. With the application of game theory, we can model the dynamic behavior of users and can select the AP that meets the current requirements of the user, but without neglecting a network driven approach.

4 Proposed QoE Scheme

In this section, we describe the proposed mechanism for improving the QoE in CWN.

4.1 IEEE 802.11e Background

The proposed scheme is designed based on our analysis of the IEEE 802.11e Standard.

The IEEE 802.11e Standard provides enhancements in the MAC layer, in order to satisfy the QoS requirements of user applications.

Therefore, we use those QoS implementations are locate them in the QoS enhanced Access Points (QAP) and the QoS enhanced station (QSTA). The QoS enhanced Cooperative Wireless Local Area Networks (QCWN) uses some of the QoS facilities, as a supporting mechanism for the selection of the QAP that meets the user requirements as well as the load balancing between the APs.

In order to support the QoS requirements of user applications, IEEE 802.11e employs a mechanism called Enhanced Distributed Channel Access (EDCA). The mechanism is described as follows.

1) Enhanced Distributed Channel Access: According to the IEEE 802.11e Standard, entities in the network that are QoS enabled implement the Hybrid Coordination Function (HCF). The HCF can use both EDCA and HCF controlled channel access (HCCA) mechanisms. On the former, a contention based channel method, unlike HCCA, that uses a centralized control to guarantee contention-free transfer.
   The EDCA mechanism is based on the CSMA/CA scheme. It provides a differentiated access for each MAC Service Data Unit (MSDU) transmitted by the QSTAs, and uses the User Priority (UP) information. EDCA defines eight different UPs, those are support by four Access Categories (AC).
   Each of the AC permits to classify the services in: best-effort (AC BE), background (AC BK), video (AC VI) and voice traffic (AC VO). This classification ensures the prioritization of the traffic.
   Both EDCA and HCCA use a Transmission Opportunity (TXOP), as the interval of time in which a QSTA can transmit information. This value is acquired by the QSTA during a previous handshake with the QAP, and finally is reported to the QAP in the Parameter Set Information field, which is defined in the Beacon and Probe Response frames. On receiving this information, the AP can know the requirements about the priority function for the applications.
   An important consideration to ensure the QoS is the proper configuration of the different parameters defined in EDCA (Jun, 2009). This configuration may determine that a maximum performance could be reached.
2) QoS facility: When an STA is in the coverage area of an AP, it receives beacon frames1 from the AP, in which the information about the

[1] Management frames defined in IEEE 802.11

operational capabilities available at the AP are included. Then, the STA compares those capabilities with its own requirements. If there is a match, the STA requests the establishment of the association with the chosen AP by means of the invocation of the association service.

The Beacon Frame sent by QAP also includes a QoS Basic Station Set (QBSS) Load Element. This is a 56-bit element that allows knowing the amount of associated users and the level of traffic at the QBSS. Since our system model corresponds to a CWN, the QBSS is the equivalent of a QAP in our scheme.

The QBSS Load element is defined by the following fields: Element ID, Length, Station Count, Channel Utilization and Available Admission Capacity. The Station Count Field represents the total number of STAs associated to the QAP, the Channel Utilization field represents the time percentage in which the QAP is busy, and the Available Admission Capacity field specifies the remaining amount of time that can be used by explicit admission control.

Using the information in the QBSS Load element, the QSTA selects a group of QAPs according to which offer the better features for the user. This group would correspond to the potential APs for the association. We do not use the default AP-selection mechanism defined in IEEE 802.11e, because it does not always lead to an association with the best AP (Simsek, 2006).

For the case of data frames, there is a Subtype field in which the most significant bit represents the QoS subfield. This subfield permits to identify if the data corresponds to a QoS data flow. When the data frame is a QoS data flow (QoS field=1), it means that the data frame also contains QoS Control fields in its MAC header. The control fields are listed as follows: Traffic Identifier (TID) (bits 0-3), End of Service Period (EOSP) (bit 4), ACK Policy (bits 5-6), the 7-bit is reserved. The values between the bits 8 to 15 vary depending of the frame subtype. The possible subtypes of the frame are: TXOP Limit, QAP PS Buffer State, TXOP Duration Requested, and Queue Size.

The TID control field differentiates the available services for each MAC Service Data Unit (MSDU). Based on the TID, the entity that implements the MAC layer at the STA determines the UPs for each MSDU1. Then, the MSDUs are grouped per AC or Traffic Stream (TS). In this way, the IEEE 802.11e controls the medium-access in a differentiated manner, based on the QoS requirements of each dataflow. The differentiation is achieved through the MSDU traffic class and the Traffic Specification (TSPEC) negotiation.

Additionally, by using the UP value included in the QoS control field, it

[1] This usage is when the Access Point subfield specifies a Contention-based channel access (EDCA).

is possible to know in advance the type of traffic that the user is handling. When this value is configured, it is later used in the TID subfield to facilitate the management of QoS in the network. In this way, the QAP knows the type of user traffic by reading the TID subfield (a numerical value between 0 and 7) in the QoS Control field. In the event that there is no value assigned in TID, the AP may infer the type of user traffic by reading the UP subfield of the TS Info field in the associated TSPEC.
After the APs are grouped, the game theory algorithm can be used to decide which AP of the set of preferred APs is the best choice in our WCN scenario.

4.2 Game Theory approach

Consider a decentralized system with a set U of N users. Each user must select one AP out of P APs in a set V. Each element in U is connected to an element in V, thus forming a bipartite graph $G, G = (U; V; E)$. Fig. 3 illustrates the relation between the elements.

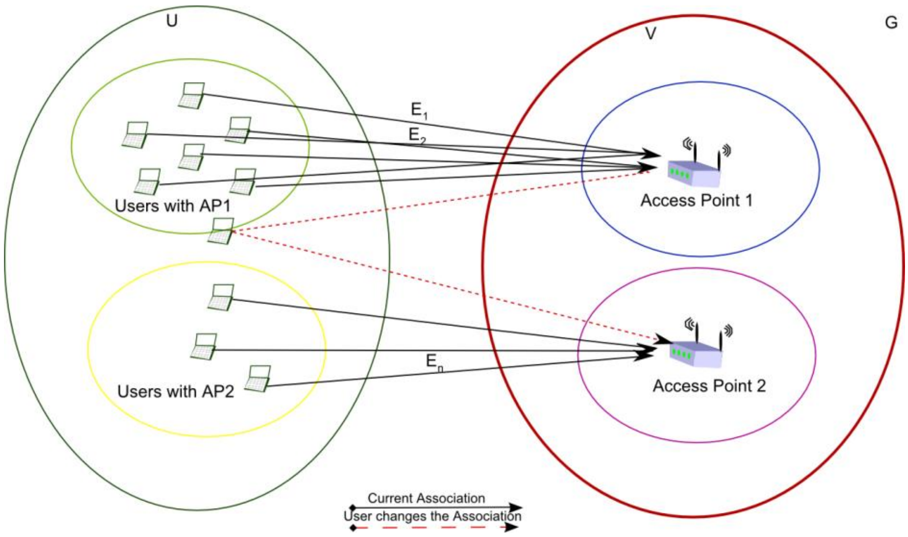

Fig. 3. Bigraph represents the example

The set V represents the group of APs that offers the best features for some users of in set U. At time t, a certain number of users in U associate with a specific AP, AP1. This association is denoted by n (t)i, where $1 \leq i \leq P$. Therefore, $\sum_{i=1}^{P} n(t)_i = N$. Since scenario is dynamic, the relation $n(t)_i$, may change continuously over time.
In this game each QSTA has a set of E strategies; those correspond to the association of the AP. The decisions made towards the association of users to each of the QAP in the QCWN, affect the total load in the other APs. Therefore, it is extremely important to find a balance. The aforementioned game theory model is

used to describe this type of scenario. The reason for using a game theory approach is because the set of users in the CWN have a selfish behavior. Every user wants to select the AP that offers the less workload, the highest performance, and the best coverage.

One of the challenges of our scheme is the selection of the best AP during an inter-domain handover, i.e., when a user leaves the area of coverage of an AP and switches its connection to a different AP. During the handover process, it is necessary to evaluate what AP has the best features of connection according with the user/applications requirements. Thus, we require an online mechanism that can respond to the dynamic environment of the CWN.

At the beginning each QSTA should estimate his current game state. The balance or strategic equilibrium (also called Nash Equilibrium) consists on every QSTA chooses his individual optimal strategy during the AP scanning process. In this way, the QSTA could identify the network that provides it the best service or price in this context before joining it.

To find the Nash equilibrium, it is necessary that the players have information about of other players (referred to as a population), one alternative to avoid the lack of information, is to permit the interplayer communication, that means, the player periodically carry his optimal strategy and deliver it to the other players. In this way, the other QSTAs from there calculate the best strategy, this leads to the QSTAs gradually learn and calculate the game again, therefore, adjust their equilibrium strategies to get the maximum QoE. It should be noted that each QSTA estimates his game and the correspond equilibrium strategy, based on information received through the beacon frames and the partial information receive from other QSTAs (distributed approach). Additionally be too considered, that these QSTAs not have full knowledge of the game, due to the dynamic represented by the CWN.

Another important factor in a CWN is the social cost. The idea behind this social cost is the optimization in the use of the common resources, if every STA chooses his Nash equilibrium strategy, no player would benefit by changing its own strategy. That way, it is possible to have a network socially efficient. This of course is not a user target, but it is a requisite to have a CWN that is socially viable for these greedy users.

Going back to the game theory model, every time that a user in U wants to establish an association with an AP in V, it has to pay a cost for it. The cost of this relation is associated with the user requirements that have to be satisfied and the current load of the AP (e.g., an AP that has a high workload would have a higher cost of association for a user that wants to associate with it). The cost has relation with the income level that each AP has, in order to maximize their net income.

As a consequence, it is important to find the different strategies that the users may use to obtain their connectivity at a lower price. The strategy (E) would be based on the information received through the beacon/probe frames by each AP, and the signal strength measurement. Similarly, each user strategy also depends on the other user's strategies. For this reason, it is of high importance that type of information that a QSTA can carry in order to balance the network.

4.3 Access-Selection Resolution

The AP selection problem consists of a series of decisions that have to be made in a repetitive manner. The decisions are influenced by the location and the bandwidth requirements of the mobile users. The system dynamics involves multiple players: APs and mobile WLAN users. The mobile WLAN users have a random behavior in this kind of scenarios (Bachalandran, 2002). To satisfy this constraint, we use a greedy algorithm that intends to assess if the AP selected is indeed the best element in the set of APs. Otherwise, the STA is disassociated from the AP and the evaluation is performed again with the next AP.

5 Conclusion and Future Work

We have proposed a way to exploit the IEEE 802.11e amendment to the IEEE 802.11 Standard to provide a fair and balancing access to the user in a Wireless Community Network. Through the management frames can be selected the AP that has the optimal condition to avoid the congestion, and with a right strategy the user can select the best AP agree with his/her requirements to avoid the performance degradation in the user applications. This proposal for QoE is full compatible with the IEEE 802.11e Standard.

The described work is in progress, and has as goal deployed through simulation the proposal mechanism, in order evaluate the performance In the future, we want to extend this proposal to a secure scheme of QoE in WCN.

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