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Fuzzy Load Balancing for IEEE 802.11 Wireless Networks

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Abstract

Wireless networks (WNs) are today used in many areas thanks to several benefits deriving from the ease of installation and maintenance and the high scalability. However, in large areas, the increasing number of nodes implies that Access Points (APs) are the main responsible of clients' connection. An overloaded access point may compromise requirements in terms of timeliness of data exchanged among the clients. This paper proposes a load balancing technique for IEEE 802.11 networks based on fuzzy logic in order to ensure the achievement of typical constraints that characterize a wireless scenario. To validate the goodness of the proposed approach several real test-bed scenarios were implemented and load distribution was evaluated.

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Keywords: IEEE 802.11; Load Balancing; Fuzzy Logic; Access Points

1. Introduction

WNs are increasingly used in real-time constrained environments. Researchers discussed a lot about problems that can arise from the use of wireless technology: what is the best protocol to use [1], how to better manage the life cycle and the energy consumption of each network entity [2] and network load balancing. Load balancing is a technique though which it is possible to equally distribute the network load, generated by

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connected clients, among all available access points based on predefined policies. Load balancing comes into play when different access points cover the same area or there is an overlapping zone in which clients can choose to connect to, at least, two access points. Load balancing techniques can be classified into two categories: centralized and distributed. The first one is characterized by policies implemented within a single network device. On the contrary, in distributed approaches load balancing policies are performed by all the access points of the network. Centralized approaches ensure the devices interoperability, but unlike distributed approaches, are not fault-tolerant, i.e., the malfunction of the device may determine the failure of the whole network. The association of a client to an access point can be regulated using the following different approaches: association management [3], admission control [4] or coverage adjustment. The technique described in [3] is based on the possibility that an access point can send a disassociation frame to a client; so, the client can be connected to another less overloaded access point, if it exists. In admission control [4] mechanism, an access point can reject the association of a new client in case there is an overload risk. Some access points, instead, provide specific policies based on the reduction, in case of overload risk, of the transmission power in order to avoid association requests. This technique is also known as coverage adjustment [9]. In standard approaches, the AP-client association is based on the Received Signal Strength Indication (RSSI) and consequently it is possible that all clients may choose only few overloaded access points leaving others idle. Moreover, as known, the IEEE 802.11 standard [5] uses the Carrier Sense Multiple Access with Collision Avoidance protocol (CSMA/CA) to regulate the medium access [6]. So, if many stations are connected to the same access point, the probability of collisions increases causing, at the same time, the reduction of network throughput (defined as the real use of the available bandwidth). For this reason, it is necessary to use an appropriate load balancing technique in order to make the associations to access points "load-aware". The main contribution of this paper is represented by a new load balancing algorithm, based on fuzzy logic, that improves some approaches known in literature.

2. Related Works

In literature, several association metrics have been evaluated taking into account several factors like the packet loss [7], the access point RSSI [8] and the bandwidth utilization [9]. Load balancing definition is firstly analysed in [10] in order to prove the strong correlation between load balancing and max-min fair bandwidth allocation. Then, the authors describe an algorithm to achieve max-min fairness based on min-max load balancing. Using this algorithm and gathered information, the network can balance load and notify new ideal associations to connected clients. The authors of [11] present a load balancing algorithm that claims to find the best associations between access points and clients ensuring the best quality of service (QoS) level. This algorithm, that run within a load balancing server, uses several network information related to associated stations, traffic coursed by access points and users QoS requirements. This information has to be exchanged among WLAN entities and stored in an updated database. The load balancing server should periodically download a set of specific parameters from each access point. It executes the load balancing algorithm in order to find the best clients' distribution among access points. The result will be then broadcasted in the system. In [12] the authors describe a dynamic load balancing approach used in real-time industrial contexts. Each access point, connected to the backbone, communicates with a network controller that performs corrective actions in case of performance degradation. However, this approach presents the same problems of centralized load balancing algorithms described previously. In [13], load balancing decisions are performed by each AP, in a distributed way, and not by a network controller only. The main aim is to provide a mechanism for load distribution in order to obtain less deadline miss possible considering that a deadline miss (DM) occurs when a packet misses its relative deadline. A station that measures a DM number exceeding a threshold value is characterized by performance degradation and will be managed.

3. The Proposed Approach

The proposed algorithm, called Fuzzy Load Balancing Algorithm (FLBA) and depicted in Fig. 1, at firsts scans all clients and access points of the network.

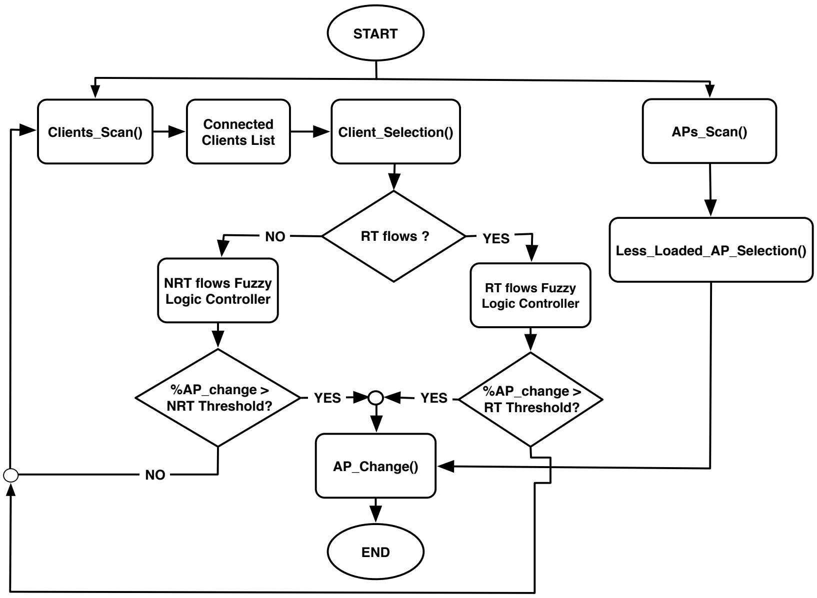

Fig. 1. The Proposed Algorithm (FLBA)

Client_Scan() is done in order to create a list of all clients connected to a specific access point. The list is then cyclically controlled in order to select each client and measure its performance. Information coming from the selected client is provided to a specific fuzzy logic controller depending on traffic type sent by the selected client. If a client sends soft Real Time traffic flows (RT), the fuzzy controller input variables are the deadline miss number and the signal quality as depicted in Fig. 2 (a). Instead, if the selected node sends Non Real Time traffic flows (NRT) the input variables are the packet loss number and the signal quality, as depicted in Fig. 2 (b). The output variable is always represented by the need to change access point (%AP_change). If the %AP_change value is more than a threshold value, that clearly depends on QoS parameters set by the application for each specific traffic flow (40% for RT traffic and 70% for NRT traffic), the client will be moved toward a less loaded access point identified through the APs_Scan(). Value ranges of input/output variables are shown in Table 1.

Table 1. Variable range values

Value (I/O)	Min value	Max value
Signal Quality (I)	-100 dB	0 dB
Deadline Miss (I – RT traffic flows)	0	200
Packet loss number (I – NRT traffic flows)	0	200
Need to change AP	0%	100%

As known, through fuzzy logic it is possible to identify information with a policy based on the sets theory, more flexible than the concept of exclusive membership (classical logic), introducing the concept of degree of membership of an element of a set [14]. Moreover, fuzzy logic has been extensively used for QoS management in WSNs [15]. Three membership functions (LOW, MEDIUM, HIGH) were defined for each variable. Fig. 2 (c) shows how all variables are generically fuzzyfied. The Y-axis specifies the degree of membership of a variable to the specific membership function. Considering a generic variable *v* containing a range of values from the minimum to the maximum value that the variable itself can assume, each membership function can be represented by the triangular-shaped membership function *trimf (v, [x; y; z])* as depicted in Fig. 2(c).

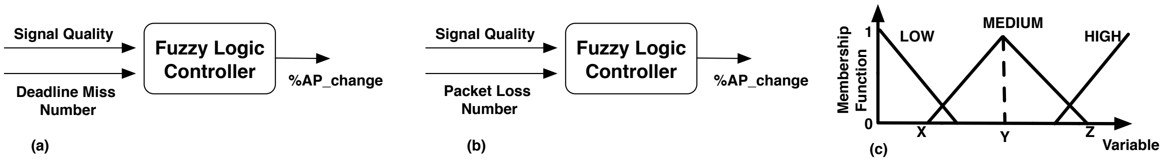

Fig. 2. (a) RT flows fuzzy controller; (b) NRT flows fuzzy controller; (c) triangular-shaped membership function

The output value is determined through 9 fuzzy rules (Table 2) based on the IF-THEN statement of classic programming languages. For example, considering the rule 7, *if* the Deadline Miss number measured by the client is High *and* the Signal Quality is Low, *then* the probability to change the access point for that client will be High.

Table 2. Fuzzy Rules

Rule	Deadline Miss or Packet loss	Signal Quality	AP% change
1	Low	Low	Medium
2	Low	Medium	High
3	Low	High	Low
4	Medium	Low	Low
5	Medium	Medium	Medium
6	Medium	High	High
7	High	Low	High
8	High	Medium	Low
9	High	High	Medium

4. Performance evaluation

In order to demonstrate the efficiency of the proposed approach, several measurements were carried-out realizing different real scenarios using specific hardware devices. For our purposes, we developed both access points and clients using the microcontroller PIC24FJ256GB108 [16] by Microchip and the WiFi module RN-171-XV by Roving Networks [17]. The evaluation scenario consists of up 28 clients and 3 access points, as depicted in Fig. 3 (a). The measurements have been carried-out considering that the packet size was 64 bytes and the transmission period was 10 ms, equal to the relative deadline. We carried out four simulations. 16 active clients characterized the first simulation. In the second simulation there were 20 active clients, in the third 24 active clients and finally all available clients characterized the fourth simulation. Each simulation lasts 240 seconds and was repeated three-times: one using our approach, one using the Dynamic Load Balancing Approach (DLBA) approach discussed in [12] and one in standard conditions.

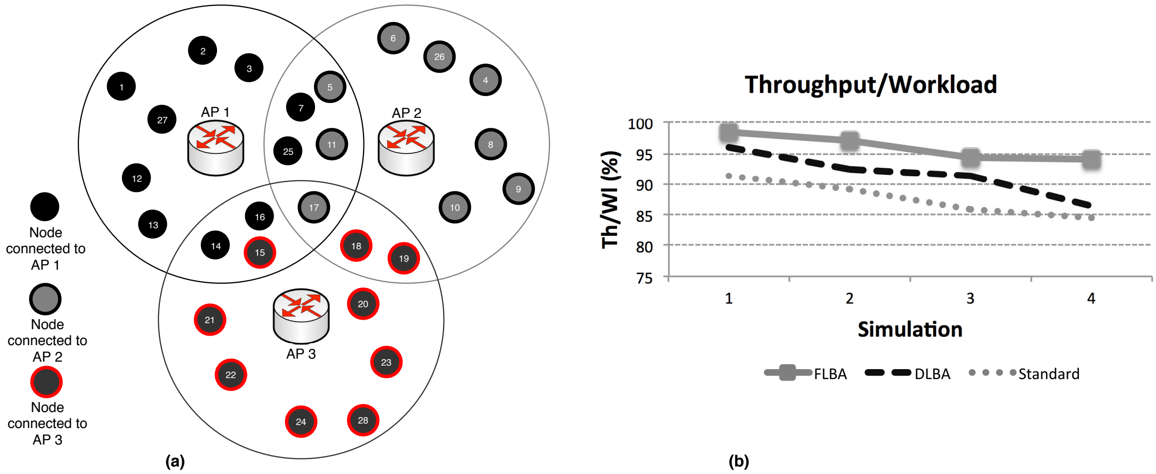

Fig. 3. (a) The simulation scenario; (b) Throughput/Workload performance

We measured the Throughput/Workload (Th/Wl) percentage, defined as the number of packets that reached their destination divided by the network load. How it is possible to see in Fig. 3 (b), the Th/Wl percentage is better than other compared approaches. At simulation 4, for example, the Th/Wl percentage is about 95% against 87% and 84% obtained by the DLBA approach and the standard approach respectively. This means that using our approach more packets reach their destination respecting their deadlines. Load distribution is depicted in Fig. 4. As it is possible to see, by increasing the number of active clients, our algorithm equally balances the network load. To better understand the results, considering the fourth simulation (28 active clients), on each access point have been measured about 17000 transited packets.

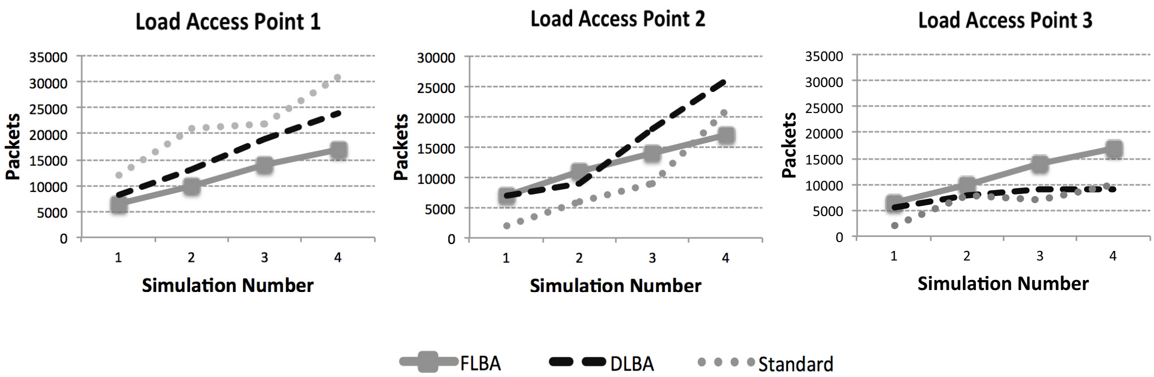

Fig. 4. Load measured on each access point

5. Conclusions

In this paper a load balancing approach, for IEEE 802.11 networks, based on fuzzy logic has been proposed. Starting from the state of art analysis, it has been possible to verify how most of the existing approaches are based on metrics not suitable for real-time constrained communications. Fuzzy logic is well suited to this kind of applications as it is based on natural reasoning principles. The fuzzy controller decides, through the natural reasoning, whether or not to move a client towards a less loaded access point based on information provided by the network. Obtained results, in a network characterized by 3 access points and up to 28 clients, are very promising and show how the network load can be equally distributed ensuring, at the same time, good performance in terms of Throughput/Workload percentage. Now, we are working in order to improve the proposed approach taking into account the localization of each client [18].

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