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FLBA: A fuzzy algorithm for load balancing in IEEE 802.11 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. Moreover, continuing advances in technology have led to the development of low cost devices characterized by always increasing performance. In large areas, the coverage is guaranteed by the presence of Access Points (APs) that are responsible for clients' connection. Performance of a large wireless network, covered by several APs, mainly depends on load balancing management policies. An overloaded access point may, in fact, compromise requirements in terms of timeliness of information 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 Quality of Service (QoS) constraints that characterize a wireless scenario. To validate the goodness of the proposed approach, several real test-bed scenarios were implemented and many QoS parameters were evaluated.

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1. Introduction

Load balancing comes into play when different access points cover the same area or there is an overlapping area in which the clients can choose to connect to, at least, two access points. Load balancing is a technique through which it is possible to equally distribute the network load, generated by the connected clients, among all available access points, based on predefined policies. Load balancing techniques can be classified into two categories: centralized and distributed. Centralized approaches (Balachandran et al., 2002) are characterized by policies implemented within a single network device. On the contrary, in distributed approaches (Velayos et al., 2004) load balancing policies are performed by all access points of the network. Clearly, each approach is characterized by advantages and disadvantages (Sandeep Sharma et al., 2008). Centralized approaches ensure the devices interoperability, but unlike distributed approaches, they are not fault-tolerant, i.e., the malfunction of the device may determine the failure of the whole network. Load balancing mechanisms are characterized by three basic steps:

- Selection of the client to be moved from an access point towards another one.
- Selection of the new access point (characterized by better performance) to which to connect the selected client.
- Association client–access point.

The selection of the client to move can be done randomly or choosing the best candidate. Random selection (ElBadawy, 2011) is a technique through which it is possible to randomly choose a client connected to an overloaded access point, in order to connect it to another access point (always randomly chosen). Clearly, this approach is not optimal because it may determine the choice of a client that does not generate high traffic flows when the overload could be instead determined by another not selected client. On the contrary, the best candidate (Fengyuan, 2010) technique consists in choosing the appropriate client, based on specific metrics such as the traffic generated or the packet loss percentage. The access point selection can be done using two different mechanisms (Akl et al., 2013): the threshold-based approach and the relative threshold technique. In threshold-based approaches, an access point accepts an association request if an established load metric does not exceed a predefined threshold value. The relative threshold technique selects the best access point considering load metric of all available access points. In both cases, the approaches do not consider the real network performance in order to meet Quality of Service (QoS) requirements. Finally, the association of a client to an access point can be regulated using the following different approaches:

- Association management.
- Admission control.
- Coverage adjustment.

The association management technique (Seonwook Kim et al., 2013) is based on the possibility that an access point can send a disassociation frame to a client. So, the client can be connected to

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another less overloaded access point, if it exists. Admission control (Hu et al., 2009) mechanism uses an algorithm that allows an access point to reject the association of a new client in case of overload risk, taking into account some QoS requirements (Alam et al., 2012). Some access points, instead, provide specific policies based on the reduction of the transmission power in order to avoid association requests. This technique is also known as coverage adjustment (Changyi et al., 2010). Using the IEEE 802.11 standard (IEEE, 2012), a client chooses the access point, to which to connect, just based on the Received Signal Strength Indication (RSSI) and, consequently, it is possible that the clients may choose only few overloaded access points leaving others idle, as depicted in Fig. 1.

Moreover, as known, the IEEE 802.11 standard (IEEE, 2012) uses the Carrier Sense Multiple Access with Collision Avoidance protocol (CSMA/CA) to regulate the medium access. So, if many stations are connected to the same access point, the probability of collisions increases and consequently also the transmission delays increase causing, at the same time, the reduction of the network throughput (defined as the real use of the available bandwidth). This phenomenon is called the network congestion. Many times, by using wireless technologies, this phenomenon is due to the re-transmission of frames. It creates an unexpected additional workload that compromises the performances of network. For this reason, it is necessary to use an appropriate load balancing technique in order to make the associations to access points 'load-aware'. Several other parameters, such as the current network load and QoS indexes (for example the current deadline of packets to be transmitted in soft real-time environments, i.e., industrial networks), must be taken into account.

1.1. IEEE 802.11 standard

The IEEE 802.11 standard (IEEE, 2012) defines a multi-channel architecture that allows the use of 14 channels (Fig. 2), of which, 3 are perfectly orthogonal (channel 1, channel 6 and channel 11).

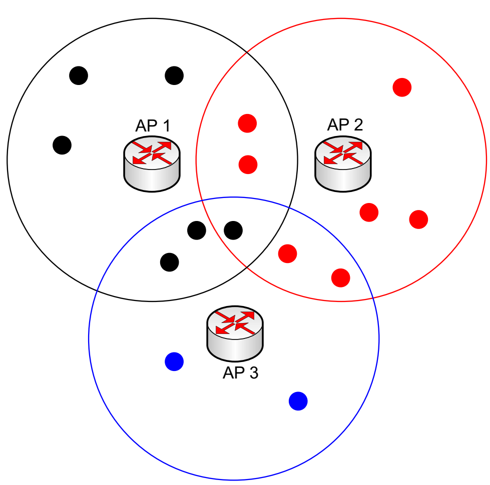

Fig. 1. An unbalanced wireless network.

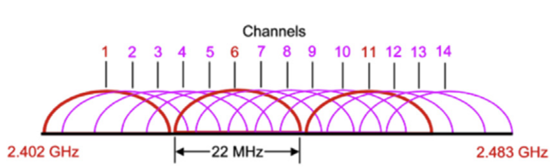

Fig. 2. IEEE 802.11 channels.

Performance depends (Siping et al., 2013) on the management of wireless channels, i.e., the problem is how to manage all clients that are using a specific channel. The scanning procedure can be accomplished either in passive or in active mode according to the IEEE 802.11 standard. The traditional association procedure (passive mode), using IEEE 802.11 standard protocol, is the following: a client will listen to all possible channels for the beacon frames periodically sent by access points. The beacon frame contains useful information such as the RSSI. After the scanning procedure, the client chooses the access point with the highest RSSI. In an active scanning mode, the client to broadcast probe requests evoking probe responses from APs actively without waiting for any beacon frames. The client, that stays in the scanning , broadcasts a probe request frame to APs in each channel and sets on a probe timer in order to receive the responses. After all channels have been scanned, all information received from probe responses is processed so that the station can select a best AP to join next. As a consequence of these scanning procedures, the total network load is not balanced among all available access points and this situation determines an increasing worsening throughput caused by the fact that the network capacity is partially used. Moreover, imagining that clients are moving, it is necessary to manage the handover. A station that performs a disassociation from an AP must be re-associated with a new AP that provides a better service. For example in Fig. 3, one of the mobile stations is moving from the coverage area of AP2 and AP3, to the covered area by AP1 and AP2.

The basic building block of an IEEE 802.11 WLAN (IEEE, 2012) is the Basic Service Set (BSS), which is a unit of network consisting of an AP (Access Point) and several MSs (Mobile Stations). According to IEEE 802.11n standard (IEEE, 2012), the signal coverage of an AP is around 100 m. An MS sends and receives packets through the AP within this signal coverage and needs to hand off to another AP when it moves away from the coverage of the current AP or, in order to improve network performances, in case of a load balancing approach was implemented. During the handoff procedure, MS cannot send and receive data packets. The main contribution of this paper is represented by a load balancing algorithm based on fuzzy logic that determines the association client–AP based on the signal quality and the number of deadline miss measured or the packet loss (in case of non-real-time traffic flows). This work analyzes an innovative method in order to determine the best AP if the area of MS is covered from several APs. This paper does not focus on the handover technique that allows us to maintain the connection when the user is moving, as it focuses exclusively on choosing the best AP. A standard

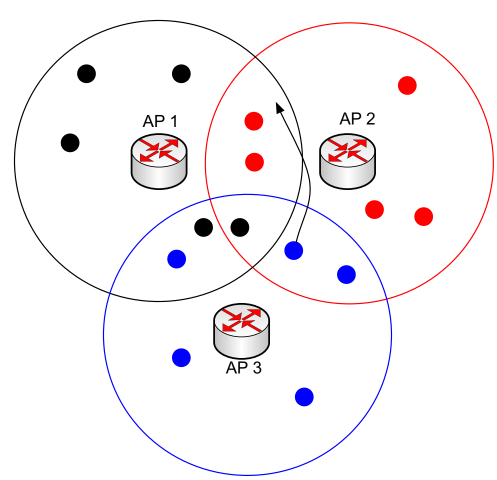

Fig. 3. A balanced wireless network.

handover technique is used and delays, due to handover mechanism, are not analyzed. The goal of this work is to show an innovative balancing algorithm in order to improve Quality of Service (QoS) parameters. A separate discussion deserves the handoff procedure and how it could be involved in the performance of QoS. The paper is organized as follows: Section 2 describes some load balancing solutions already existing in the literature; Section 3 shows the proposed algorithm describing how the approach intends to solve the load balancing problem; in Section 4 the results obtained in several real scenarios are shown. Finally Section 5 summarizes the paper suggesting some possible future works.

2. State of the art

The IEEE 802.11 standard (IEEE, 2012) does not provide any mechanism for load balancing management. As a result, over the years several researchers focused their interest in the study of this issue. Some vendors developed, directly into their devices, techniques in order to manage the association client–access point taking into account specific load metrics. Several literature works have shown approaches based on different association metrics. They take into account factors such as the network fairness (Bejerano and Han Seung-Jae, 2009), the access point RSSI (Feifei, 2013), the bandwidth utilization (Tingting, 2011), the QoS parameters (i.e. a technique packet loss aware is described in Ling et al., 2009). Although these mechanisms are really interesting, the paper addresses to very large literature papers that deal with load balancing metrics based on QoS parameters. So, in the following, the section focuses on QoS-based mechanisms.

In Balachandran et al. (2002) the authors describe a mechanism called the Explicit Channel Switching through which the association with an AP is not done merely on the basis of signal strength, but it is based on user's workload. This algorithm allows us to connect a wireless client to a new AP if the total cell workload (covered by the same AP) can include the load due to the new client that is trying the association. The algorithm trades off signal strength with load by forcing the user to switch from an overloaded cell containing the AP with a stronger signal to a neighboring lightly loaded cell where the signal to the access point may possibly be weaker. It relies on the existence of at least one AP within a range of the MS. This AP must have enough capacity to ensure the QoS requirements of MS. However, this assumption may not always be valid, in some cases it is necessary to establish a trade off between connection service and degradation of network performances. In any case the authors of Balachandran et al. (2002) propose a technique called the network-directed roaming. They resolve the problem by using the network that can provide feedback suggesting potential locations to which users can roam to get the desired level of service. However this solution introduces a new problem: when the network cannot handle a user's service request in the user's current location, the user is likely to roam in the network to find a cell with connectivity.

In Papanikos and Logothetis (2001) the authors propose a load balancing procedure, which acts at two separate levels. At the first level, the access points are either distributed across the channels (if the number of AP is small) or located in the same channel that is specified by taking into account the channel–location and the received RSSI of the neighbor access point. At the second level, the clients are distributed across all the available access points based not only on RSSI measures but also on the number of clients already associated to the AP and other link quality measures. Another load balancing solution is analyzed in Bejerano et al. (2007) in order to prove the strong correlation between load balancing and max–min fair bandwidth allocation. To maximize the overall system throughput, the clients should be moved towards less loaded access points. A system provides a fair service if all clients have the same allocated bandwidth. Unfortunately, this fairness level can cause a significant network throughput reduction (Bejerano et al., 2007). Moreover, the bandwidth allocation respects "max–min fairness" if there is no way to increase bandwidth for a specific host without decreasing bandwidth of other hosts. In many cases the fairness of the network is not able to satisfy the QoS requirements, especially in deadline-aware scenarios. For example, in Jabri et al. (2008), the authors describe an algorithm to achieve "max–min fairness" based on "min–max load balancing", in order to find the best associations between access points and clients ensuring the best QoS level. This algorithm that runs 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 between 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 balancing algorithm in order to find the best mobile station distribution among access points. The result will be then broadcasted in the system.

In Collotta et al. (2010, 2012) the authors describe a novel dynamic load balancing approaches used in real-time industrial contexts, where the main scope is to meet QoS requirements. In an industrial scenario the network nodes cannot be at the same level, because some devices could be having some hard requirements that request different treatments by network. As in Jabri et al. (2008), the solution shown in Collotta et al. (2010) provides that each access point, connected to the backbone, communicates with a network controller that performs corrective actions in case of performances degradation. However, this approach presents the same problems of centralized load balancing algorithm described previously. In Collotta et al. (2012) load balancing decisions are performed by each AP, in a distributed way, and not by a network controller only, in this way it was possible to improve some network performance. As mentioned in Collotta et al. (2012), the main challenge of a typical scenario, such as industrial process control environment where the main requirements are to meet deadlines, suggests to develop approaches based on mechanisms for load distribution in order to reduce the deadline miss as much as possible. Consider that a Deadline Miss (DM) occurs when a packet misses its relative deadline. A station which measures a DM number exceeding a threshold value is characterized by performance degradation and will be managed. During station management, the system must dynamically choose a more suitable access point in order to ensure good performance. The choice is made measuring each access point load, which is a function of all deadline miss measured by the connected stations. After the new access point selection the proposed algorithm will move the client from the current access point towards the new one. Most of the load balancing techniques are based on load metrics that often do not meet QoS requirements. In several real contexts (e.g. home and factory automation) it is really important to consider some QoS network values such as the throughput, the packet delay, the deadline miss number (if traffic flows are characterized by soft real-time constraints) and the signal quality measured by each client connected to an access point. This information is fundamental in order to evaluate if it is necessary, or not, to change access point for the specific client. The motivation that encouraged this work is that the main weakness, of most of the works described, is that they do not take into account of QoS network requirements in terms of deadline miss. Moreover the network performances change dynamically with the increase or decrease of clients, but this is not the main aspect to analyze. In fact by using wireless connection several factors can influence the network performances such as interferences and retransmissions. In the next section it is shown the proposed algorithm that determines the selection of the AP, also consider the case in which the node is moving from an overlapping area to another one or to an area fully covered by the new AP.

3. The proposed approach

In order to make wireless networks suitable for a network QoS-aware, a number of requirements have to be met:

- *Predictability*: The network shall provide tools allowing the end user to simulate his network environment and determine in advance end-to-end performances of the system. It shall provide mechanisms to guarantee (at least statistically) given time bounds on all the components which may introduce delay, while limiting jitter as much as possible. In this direction EDCA (Enhanced Distributed Channel Access) protocol of IEEE 802.11e allows us to define a Traffic Prioritization. It depends on 2 timing parameters that vary for each MS: AIFSN (Arbitrary Inter-Frame Space Number) and CW (Contention Window). It allows us to implement a probabilistic priority mechanism to allocate bandwidth based on a set of traffic categories.
- *QoS and real-time constraints*: The network shall implement advanced QoS mechanisms and policies to ensure guaranteed performances for communication. At least two QoS classes should be handled. Real-time periodic traffic flows that are characterized by regular arrival times and real-time constraints (i.e. to meet deadline miss). Non-Real-time traffic flows that may exhibit varying arrival patterns and do not impose strict real-time constraints.
- *Reliability*: The network should tolerate potential interferences and high variation of the radio signal strength. Resistance to interferences is a major concern.
- *Scalability*: Large networks may include a very lot of devices and high node density. Moreover, while such networks should cover a large area, the radio coverage is 100 m, according to IEEE 802.11n standard (IEEE, 2012), but in indoor environment this value is quite small. As a result, multiple cells will be required to provide coverage and the system shall support their interconnection.
- *Mobility support*: The network shall provide support for communication between mobile nodes during handover between different wireless cells. The movement of the nodes can be free or cyclic (along predefined paths). A bounded handover time shall be measured in order to maintain the real-time requirements of traffic.

A typical hierarchical network architecture that allows us to satisfy the above-mentioned requirements will be made up of several wireless cells grouped in cluster, each managed by a controller network (Fig. 4).

The network controller is the central entity that coordinates all the wireless cells in order to provide the application requirements, and the QoS requirements in terms of desired real-time behaviour and reliability network. It could be also connected to a real-time backbone, in order to reach other wireless cells coordinated by other network controllers. The network controller could be an access point directly connected to wired backbone in order to be replaced, in case of fault, by another controller also connected to backbone.

The proposed algorithm works into a network controller.

The algorithm, here described, does not bind the choice of controller node. It could be implemented a mechanism that allows an election controller node. But this is not the scope of the paper. For example, it could be implemented an election approach by using IEEE standard (IEEE, 2012) or one of several literature algorithms, that could allow us to the less loaded access point the role of

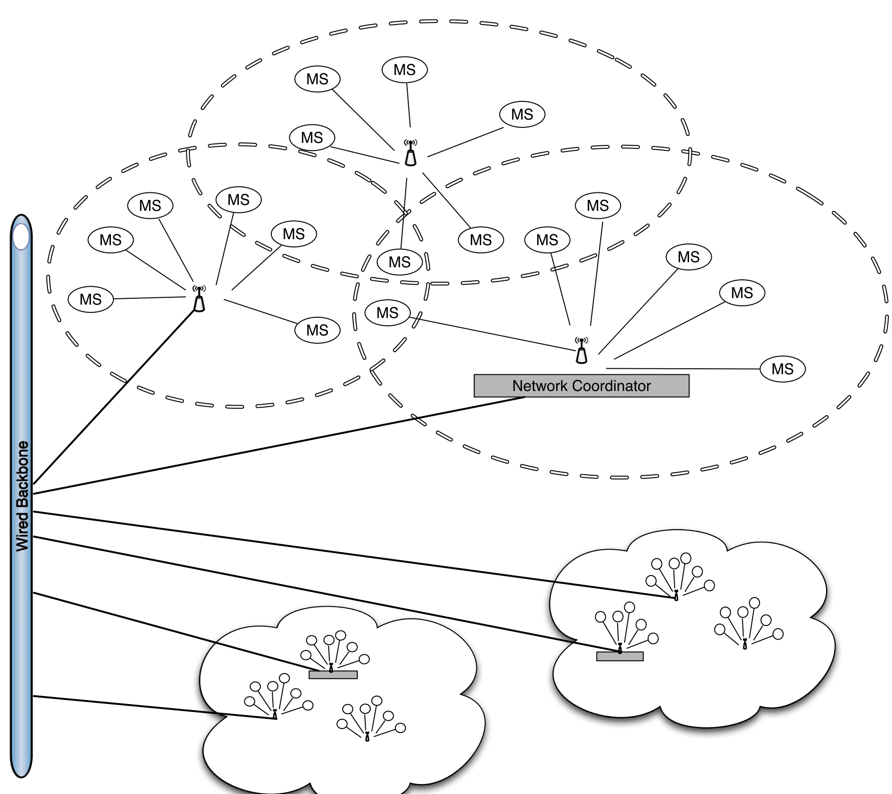

Fig. 4. Typical wireless scenario.

network controller. It will run the load balancing algorithm. But it is not the scope of this work. Since the controller node switches load information between alive APs connected to wired backbone, it is always possible to ensure the functioning of the whole network. The sequence diagram, depicted in Fig. 5, introduces all steps of the proposed fuzzy load balancing algorithm.

Each AP sends its load information (theoretical bandwidth) to the controller. The controller also receives, from each client, the detected signal quality, the deadline miss number or the packet loss number (depending if the selected client sends real-time or non-real-time traffic flows). The Fuzzy Load Balancing Algorithm (here called FLBA) determines if it is necessary or not to change access point starting the standard handover procedure. Information exchanged among access points and between clients and access points is contained within the data field of the MAC payload. While the reserved bit, in the PLCP header, is used to specify if the data to transmit is characterized by soft real-time constraints or not. It is not sufficient to implement the priority classes of IEEE 802.11e protocol, because, as mentioned before, EDCA algorithm allows only probabilistic time access delay to wireless channel. In other words it manages the collision window at MAC layer and, in some case, it allows us to improve time delay (Vittorio, 2008).

The FLBA algorithm, shown in Fig. 6, scans all clients and access points of the network. Client_Scan() is done in order to create a list of all clients connected to a specific access point.

The list is cyclically scanned in order to select each access point 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. The traffic flows will be examined by FLBA by using their characterization as following:

- If the client sends soft real-time traffic flows (S-RT) the fuzzy controller input variables (Fig. 7) are the deadline miss number and the signal quality.
- If the selected client sends non-real-time traffic flows (NRT), the input variables (Fig. 8) are the packet loss number and the signal quality.

The output variable is always represented by the percentage need to change access point (%AP_change) as depicted in Figs. 7 and 8. That value is determined by using fuzzy logic approach. Since it needs to get information (deadline miss % and packet loss %) from each client, the proposed algorithm does not cause a lot of communication overhead. This kind of information is a simple number value, it could be sent by using data field, together to application information typically sent by MSs. Moreover the client can receive (from AP) updates about load balancing algorithm, by using data information within the data field of the MAC payload. The information regards only the new best AP, in case it is necessary to move the client from overloaded AP to another.

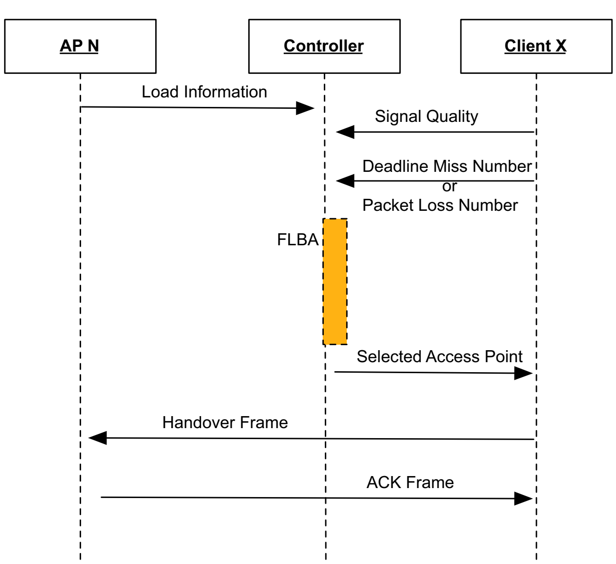

Fig. 5. Fuzzy load balancing Algorithm sequence diagram.

In case of the %AP_change, value is more than a defined threshold value that clearly depends on traffic type (see Table 1), the client will be moved toward a less loaded access point identified through the APs_Scan().

As known, through fuzzy logic it is possible to identify information with a policy based on sets theory, more flexible than the concept of exclusive membership (classical logic). It introduces the concept of degree of membership of an element to a set. To this end, three membership functions are defined for each variable (LOW, MEDIUM, HIGH). Membership functions have been developed considering these value ranges for the considered input/output variables:

- (Input for both traffic flows) Signal quality [−100 to 0] dB.
- (Input for RT traffic flows) Deadline Miss [0–200].
- (Input for NRT traffic flows) Packet loss Number [0–200].
- (Output) The need to change access point [0–100]%.

Figure 9 shows how all variables are generically fuzzyfied. The *Y*-axis specifies the degree of membership of the 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 generic triangular-shaped membership function *trimf* (v, [x; y; z]).

Tables 2, 3 and 4 contain all membership function values for Signal Quality, Deadline Miss/Packet Loss and %AP_change respectively.

The output value is determined through 9 fuzzy rules (Table 5) based on IF–THEN controls. If the calculated access point change percentage is more than an established threshold value, the algorithm starts the handover procedures. In order to assess the performances of the proposed approach, several tests were made using MATLAB for the evaluation of the fuzzy controller. The main objective was to determine that the most promising sets of rules were selected among all the possible combinations, and then they were experimentally compared to identify the most appropriate one, which is listed in Table 5.

For example, considering the rule no. 3, if the Deadline Miss number is Low and the Signal Quality is High, the probability to change the access point, for that client, will be Low. There is no reason to change access point, if the performance measured are good. On the contrary, considering the rule no. 7, if the Deadline Miss number, measured by the client, is High and the Signal Quality is Low, the probability to change the access point, for that client, will be High. As a consequence, for the selected client the handover procedures toward the less overloaded access point will be started. In practice, and in this specific case, the fuzzy controller strongly suggests the change of access point. This is due to the fact that probably the access point serves many clients. A low signal quality, measured by a client, produces an increasing number of deadline miss related to the specific client itself. Clearly, if the client will stay under the same access point. Hence, there is a need to change access point in order to reduce the deadline miss number and the packet loss percentage.

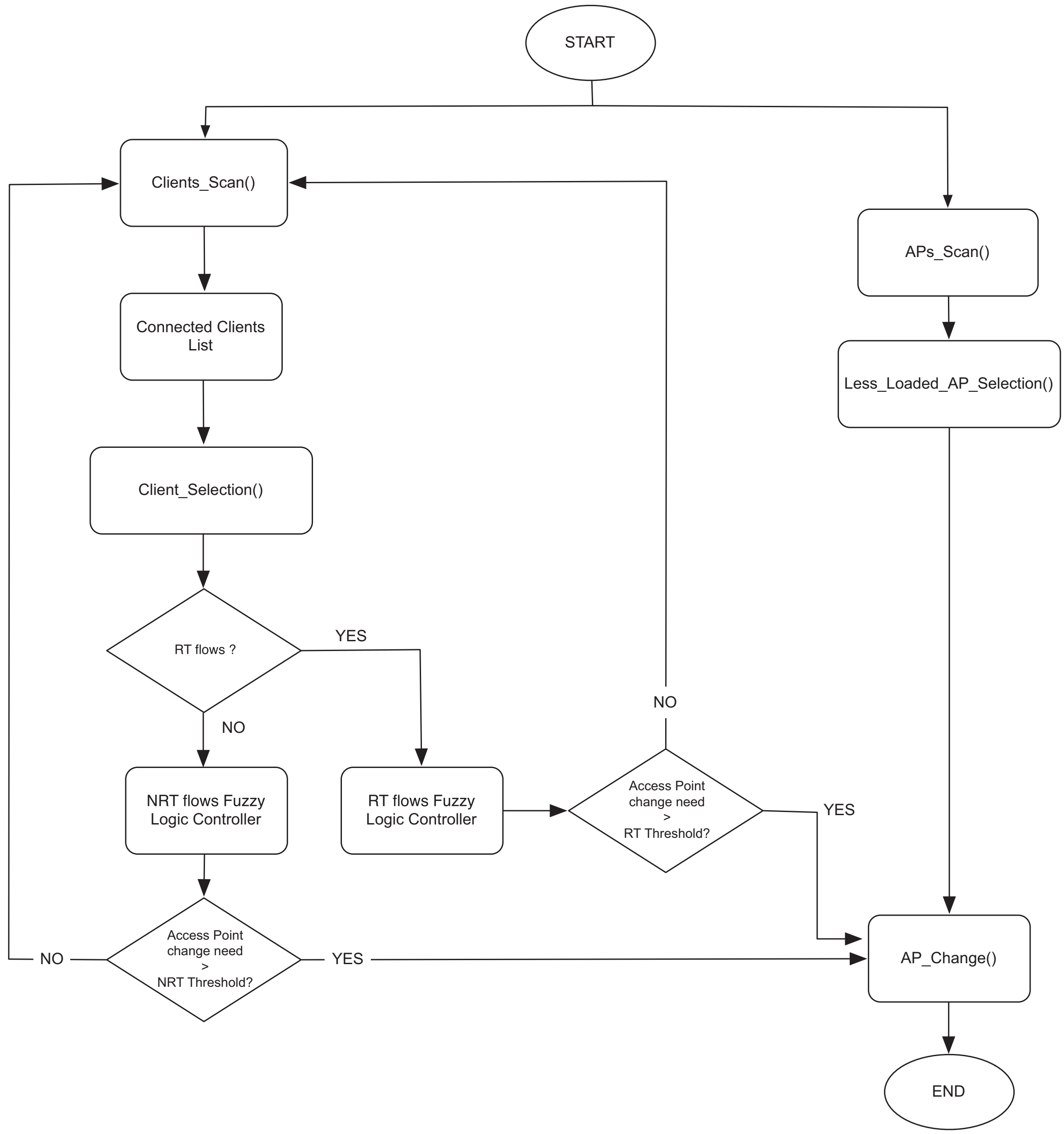

Fig. 6. The proposed algorithm.

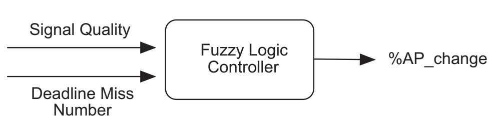

Fig. 7. S-RT flows fuzzy logic controller.

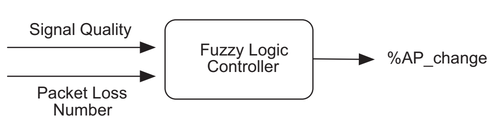

Fig. 8. NRT flows fuzzy logic controller.

Table 1
Threshold values.

Traffic type	Threshold (%)
S-RT	40
NRT	70

4. Performance evaluation

In order to demonstrate the goodness of the proposed approach, several measures were carried-out realizing different real scenarios and using specific hardware devices. For our purposes, we developed both access points and clients using the microcontroller PIC24FJ256GB108 (Microchip) by Microchip and the WiFi module RN-171-XV by Roving Networks (Microchip). Figure 10 indicates the referred scenario, the circle is only an indication of the coverage area. In order to create the co-coverage area (from two o three APs) the common areas have been selected by using the intersection of circles (depicted in Fig. 10 as intersection between two or three circles), within them the MSs receive the APs signal radio as indicated in the figure. In case one of the

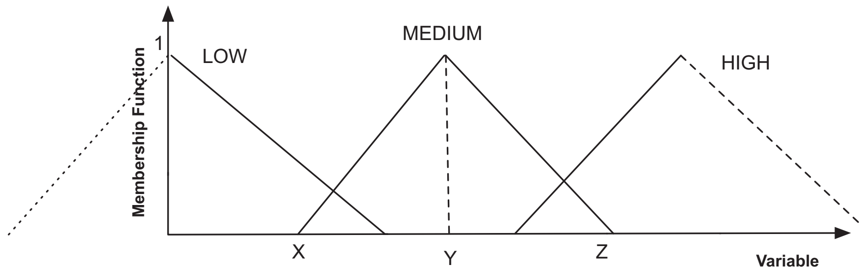

Fig. 9. Membership functions.

Table 2
Signal Quality membership function values.

Membership function	*V* (dB)	*X*	*Y*	*Z*
LOW	[−100 to 0]	−140	−100	−60
MEDIUM	[−100 to 0]	−90	−50	−10
HIGH	[−100 to 0]	−40	0	40

Table 3
Deadline Miss/Packet Loss membership function values.

Membership function	*V* (dB)	*X*	*Y*	*Z*
LOW	[0–200]	−80	−0	80
MEDIUM	[0–200]	20	100	180
HIGH	[0–200]	120	200	280

Table 4
%AP_change Membership Function values.

Membership function	*V* (dB)	*X*	*Y*	*Z*
LOW	[0–100]	−40	−0	40
MEDIUM	[0–100]	10	50	90
HIGH	[0–100]	60	100	140

Table 5
Fuzzy inference rules.

Rule no.	Deadline miss or packet loss	Signal quality	%AP_change
1	Low	Low	Medium
2	Low	Medium	Low
3	Low	High	Low
4	Medium	Low	High
5	Medium	Medium	Medium
6	Medium	High	Low
7	High	Low	High
8	High	Medium	High
9	High	High	Medium

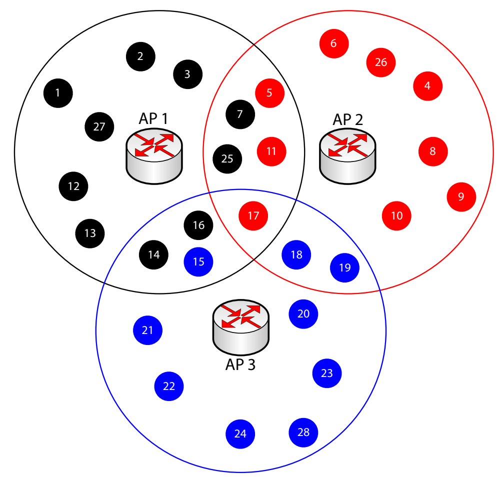

Fig. 10. The evaluated scenario.

Table 6
Network traffic parameters.

Parameter	Value
Packet size	64 bytes
Transmission period of SRT traffic flows	10 ms
Transmission period of NRT traffic flows	15 ms
Experimental time	240 s

Table 7
Traffic flows for each scenarios.

Active clients	SRT workload (Mbps)	NRT workload (Mbps)
16	0.81	0.55
20	1.02	0.68
24	1.23	0.82
28	1.43	0.96

MSs has received additional signal radio from an AP, not considered in referred scenario (Fig. 10), the MS has been moved out of AP coverage area, in order to obtain an intersection area similar to the representation in Fig. 10.

The evaluation scenario consists of up to 28 moving clients and 3 access points as depicted in Fig. 10.

Measures were carried-out considering that the packet size was 64 bytes and the transmission period, for SRT traffic flows, was 10 ms, equal to the relative deadline, while the NRT traffic flows are analyzed taking into account a periodic traffic with transmission period equal to 15 ms. Each real scenario lasts 240 s. The network traffic parameters are summarized in Table 6.

The paper shows four scenarios as summarized in Table 7. The first was characterized by 16 active clients. In the second scenario there were 20 active clients, in the third 24 active clients and finally the fourth scenario was characterized by all the available clients.

The proposed approach (FLBA) has been compared with the Dynamic Load Balancing Approach (DLBA) discussed in Collotta et al. (2012) and with the Bajerano et al. Approach (BA) shown in Bejerano et al. (2007). The distribution and movements performed by clients have been considered random. The experiment was repeated several times in order to validate the correct behaviour of the proposed approach. In Bejerano et al. (2007) the clients are

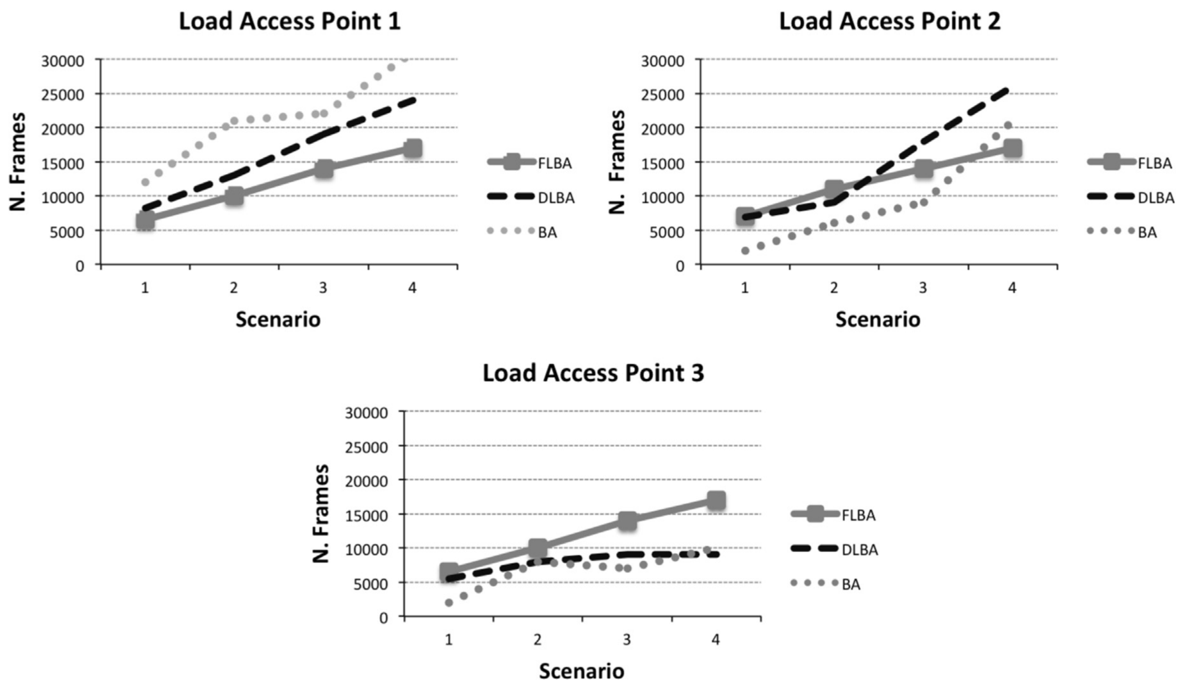

Fig. 11. Load measured (average value) on each access point.

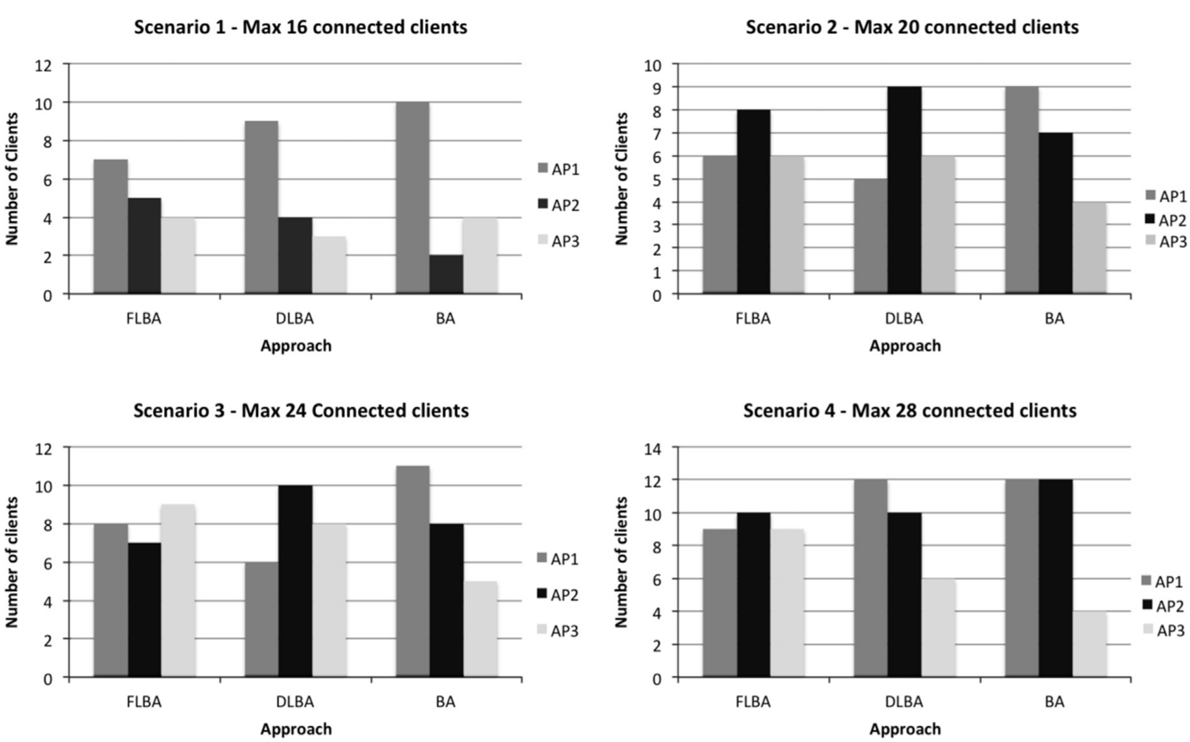

Fig. 12. Average number of clients connected to each access Point.

distributed across all available APs based not only on RSSI measures but also on the number of clients already associated to an AP. The obtained load distribution, measured in the number of frames managed by each AP, is depicted in Fig. 11. It shows the average load value for each AP, during the considered scenario.

As it is possible to see, by increasing the number of active clients, the proposed algorithm equally balances the network load. To better understand, considering the scenario number 4 (28 active clients) on each access point about 17,000 transited frames have been measured. In Fig. 12 it is possible to see the average number of connected clients during each scenario.

So explained in the previous sections, the load distribution is not sufficient to demonstrate the goodness of the proposed approach. The main goal of FLBA is to achieve QoS parameters in terms of real-time constraints. For this reason it is necessary to measure packets loss value, deadline miss ratio, mean delay and Throughput/Workload ratio. Thus the assessed values are the following:

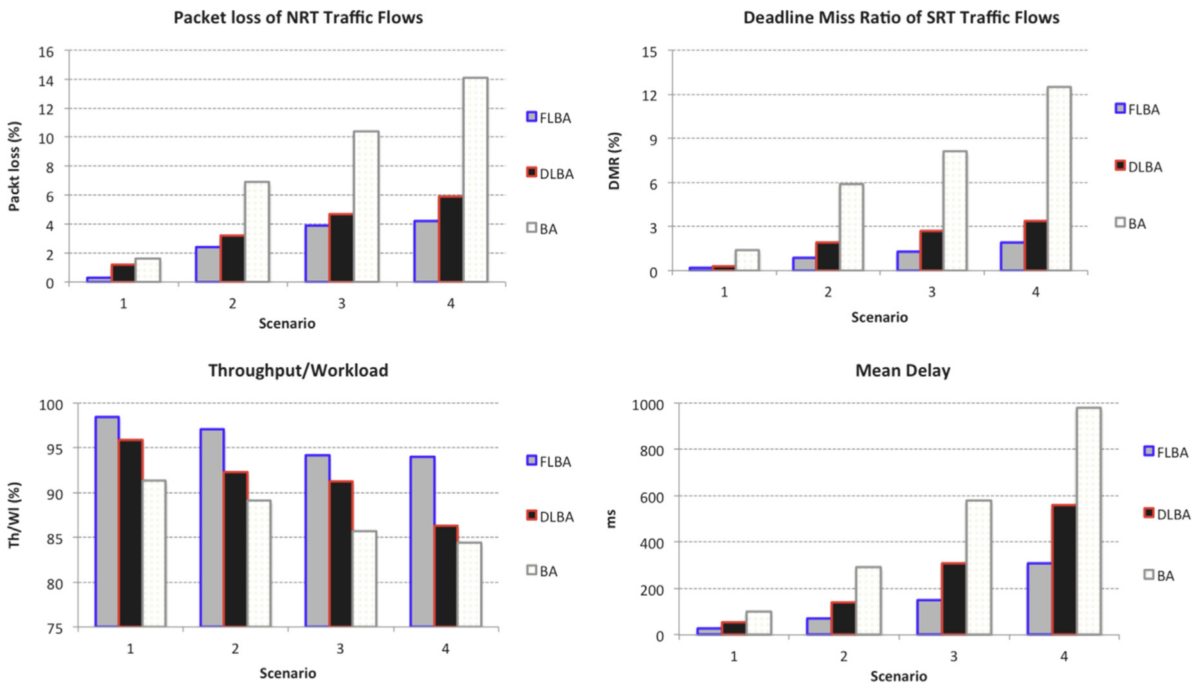

Fig. 13. Measured QoS parameters.

- *Packet Loss value*: It is the number of NRT frames that do not reach the destination, or the frames that reach the destination with errors.
- *SRT Deadline Miss Ratio*: It is defined as the number of packets which arrived at destination after their relative deadline divided by the number of arrived packets.
- *Mean Delay measured in the whole network*: It is defined as the difference between the receiving time and the sending time.
- *Throughput/Workload percentage*: It is defined as the number of packets that reached their destination divided by the network load.

Figure 13 shows the measured QoS parameters. The packet loss, the deadline miss ratio and the mean delay increase more slowly using the proposed approach and this is due to dynamic load balancing policy based on fuzzy reasoning. In overall scenarios the measured values demonstrate the effectiveness of the proposed approach with respect to DLBA and BA. However a main attention could be addressed to the scenario number 4, where the number of clients is higher than other scenarios. Specifically, the packet loss measured with 28 active clients (scenario 4) is 4.2% while the packet loss measured using the DLBA approach is 5.9% and finally 14.1% in standard conditions.

The deadline miss ratio measured in scenario 4 is 1.9% against the 3.4% measured using the DLBA approach and the 12.5% obtained without load balancing control. The mean delay measured is 311 ms against 562 ms obtained using the DLBA and 983 ms obtained without load balancing control. Finally, even the throughput/workload percentage is better than other compared approaches. This means that using the proposed approach more packets reach their destination respecting their deadlines, despite the increasing of clients, and consequently the workload of network.

5. Conclusions and future works

In this paper a load balancing approach, for IEEE 802.11 networks, based on fuzzy logic was discussed. Starting from the state of the art analysis, it has been possible to verify how most of the existing approaches are based on metrics not suitable for communications QoS-aware. Fuzzy logic is well suited to this kind of applications as it is based on natural reasoning principles. The proposed approach therefore implemented an experimental fuzzy based algorithm on each access point. The network coordinator (one of the APs involved) that manages the communication inside the wireless cell will decide (through the fuzzy reasoning) whether or not to move a client towards a less loaded access point based on information provided by the client itself. More in detail, the controller processes the signal quality and the deadline miss number measured (SRT traffic flows) or packet loss number (NRT traffic flows). Obtained results are very promising. The parameters measured denote an improvement of QoS performances. A mean reduction of 45% of deadline miss respect to DLBA and 70% with respect to BA was measured. While FLBA introduces an improvement of TH/WL, especially in case of scenario 4, where an increasing of 10% respect other approaches analyzed. Moreover, a possible improvement of the approach, based on neuro-fuzzy systems, will be considered. The reason for this is that traffic flows are uncertain and depend on some factors such as the network complexity, interference, and presence of other wireless technologies. Through an appropriate training system, based on these factors, a predictive model able to further improve the system performance could be investigated. Finally a check of handoff delays and a possible affect to the network workload could be managed by the future version of proposed algorithm, it will be analyzed in order to understand the influences on QoS performances.

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