Fuzzy Logic Predictive Algorithm for Wireless-LAN Fast Inter-Cell Handoff

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***Abstract*—Data transmission systems based on the IEEE 802.11 standard, universally known as WiFi wireless communications, is strengthening its already dominant position as the powerhorse of wireless Internet in homes and public hot spots due to the new IEEE 802.11n standard, capable of delivering up to 450 Mbps. 802.11 standard was initially designed without provision of QoS guarantees. Eventually the need to include voice and video urged the development of the 802.11e standard, which provides a proficient level of QoS for real time applications. With the two former additions IEEE 802.11 systems are poised to join the family of 4G wireless networks, comprised by LTE (Long Term Evolution) and WiMax. However, still remains a challenge to overcome in the transfer of a session from one cell to another. Considering that the inter-cell handover consumes around 300 ms, it becomes unsuitable for real-time applications like Voice over IP (150 ms maximum delay) and video (200-400 ms).**

A proposals to reduce the IEEE 802.11 system handoff time is presented. A predictive method using fuzzy logic is developed in order to adapt to the requirements of constraining time applications like Voice over IP.

***Index Terms*—fuzzy-predictive-controller, handoff, Mamdani-fuzzy-system, 802.11-WLAN**

I. Introduction

WiFi (Wireless Fidelity) Access Points (AP) provide an easy way to set up a Wireless Local Area Network (WLAN) with Internet access at homes or small offices. Its use has spread to public areas (hot spots) like airports, cafés, etc., boasting over 25,000 hot spots worldwide [1]. WiFi has also lured smartphones and tablet users, who's market share in 2011 account for 58 % of new WiFi enabled devices, well over the 38 % for laptops and netbooks [2].

Wi-Fi relies on the IEEE 802.11 [3] radio standards, the Wi-Fi Protected Access (WPA) and WPA2 security standards, and the EAP (Extensible Authentication Protocol) authentication standard.

A WiFi AP provides wireless connectivity to Mobile Stations (MS) within 120 ft. (indoors). In conformance with IEEE 802.11 standard, a wider area can be covered with multiple APs (Fig. 1), deployed in a multi-cell cluster capable of providing seamless connectivity to users traversing from one cell to another. When a mobile station moves beyond the radio range of its currently associated AP to enter a neighboring AP's Basic Service Set (coverage area), a Handoff process is triggered. During the handoff process, management frames are exchanged between the MS and the AP. Also the APs involved may exchange certain context information pertaining to the MS.

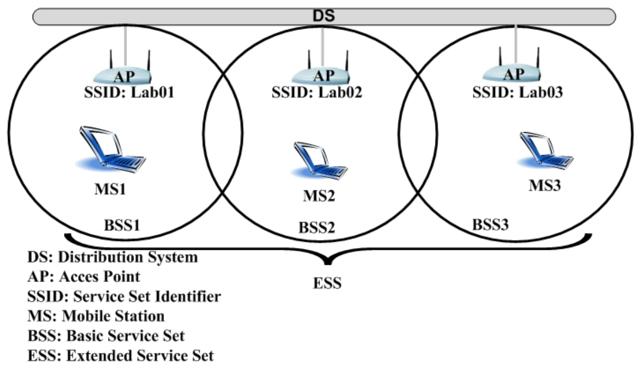

Fig. 1. Extensible coverage with multiple cells.

Various data rates are available, depending on the standard release. A chronological list stating year, version, data rate and access technology is as follows. 1997: 802.11/1~2 Mbps/ Direct-Sequence Spread Spectrum (DSSS), 1999: 802.11a/ 54 Mbps/Orthogonal Frequency Division Multiplexing (OFDM), 1999: 802.11b/11 Mbps/DSSS, 2003: 802.11g/ /54 Mbps/OFDM, 2009: 802.11n/450 Mbps/OFDM.

On the other hand, as the Internet Protocol (IP) becomes the common platform of understanding among different technologies (cable, cellular, satellite, etc.) and service providers, Voice over IP (VoIP) is a revenue source they are striving to tap. In order to offer it, Quality of Service (QoS) guarantees have to be provisioned in the networks. Originally WiFi was a data dedicated network, unable to provide commercial-grade VoIP. IEEE 802.11n incorporates QoS mechanisms on a per cell basis. Nevertheless, the lengthy handoff processing time might cause call interruption or at best, uncomfortable loss of information. The main issues that stand in the way are: (a) WLAN cells have a small coverage area, and a fast moving MS may produce frequent, short-time interval handoffs. (b) There is a latency (≈300 msec.) [4] involved in the handoff process during which the MS is unable to send or receive any kind of traffic. (c) VoIP requires one-way end-to end delay of less than 150ms [5].

Sustaining VoIP calls while the user itinerates in a WiFi

Manuscript received July 10, 2011; and accepted August 15, 2011.

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network becomes of prime importance, which can be better understood through the following statistics: In 2009, 139.9 million phones with Wi-Fi were sold [6], becoming potential customers for VoIP services. ABI Research forecasts that the annual purchase of smartphones devices will exceed 500 million units by 2014, and 90% of them will be WiFi enabled [7].

In order for QoS delay constraints for VoIP to be fulfilled during an inter-cell handover, we propose a Fast Handoff Scheme based on a Fuzzy Logic Predictive Control (FLPC), which allows to skip the channel scanning process stated in 802.11 standard, greatly reducing the handoff time. The remainder of the paper is organized as follows. Section II explains 802.11 handoff procedure, a selection of other variants looking to reduce the time consumed in the process, and our solution. Section III discusses the FLPC implementation. Section IV presents the simulation results and Section V concludes the paper.

II. INTER-CELL HANDOFF PROCEDURES

A. 802.11Handoff Standard

The AP´s radio signals propagating through the air are severely affected by various ambience factors, such as attenuation, fading, multipath and interference. Thus, when the MS is approaching the limits of its BSS, the intensity and quality of its signal has deteriorated to a critical point. At the same time it is receiving strong signals from neighboring APs, so that when the local signal faints to a predefined threshold (i.e. 80 dBm), the handoff process is initiated. See Fig. 2 [8].

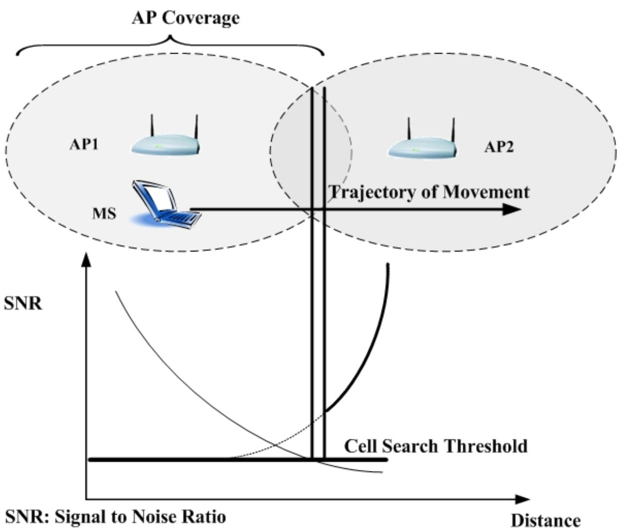

Fig. 2. Inter-cell overlap zone for handoff realization.

The IEEE 802.11 provides two options for the handoff procedure: Active and Passive scanning.

Passive Scanning

AP's transmits beacons at intervals of 100 ms [9]. In "passive scanning" (Fig. 3) an MS "listens" periodically the beacon frames generated by all the surrounding APs. A polling scheme is used to scan each channel, up to eleven (limit stated in 802.11 standard) [10]. The receiving MS must determine when it needs to be transferred to a neighboring cell, which AP has the best signal, and then authenticate and associate with the selected AP. This procedure may take up to 1,000 msec. [4].

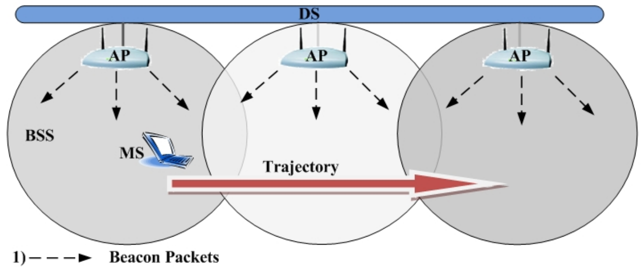

Fig. 3. Passive Scanning.

Active Scanning

In "active scanning" (Fig. 4) mode, when an MS triggers the handoff process, it generates request messages in specific channels, in order to find the AP with the best signal, these messages are called probe request frames (polling).

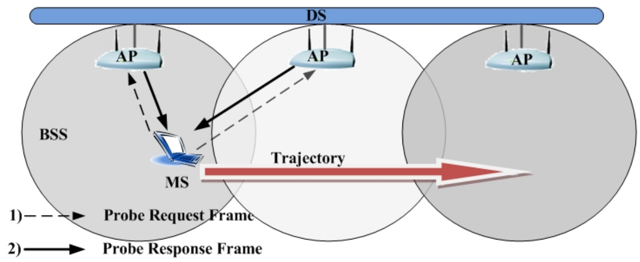

Fig. 4. Active Scanning.

The MS continuously sends probe request frames, actively seeking to join a network, and waits for the probe response from nearby access points. This process is repeated through all available channels. The information provided by the AP to the mobile station in the probe response frame is almost identical to the beacon message information. The probe response frame contains all the necessary information an MS needs to know before joining a new cell. An active scanning-based handoff takes around 300 msec.

B. Related work

Mishra et al. [11] present an analysis of the handoff latency at the link layer, where they break latency in several components, and demonstrate that the channel scanning process is the main contributor to the total handoff delay, resulting in poor QoS for many applications. Shin et al. [12] propose a method aimed at reducing the discovery stage using a selective scanning algorithm and a caching mechanism. To achieve this, when an MS is scanning channels, a channel mask identifying a subset of selected channels is built. This mask is used in the next handoff to scan only the predefined subset, reducing the scanning delay by 30% to 60% compared to the standard procedure. Further work was done by Li et al. [13], whose proposal uses a neighbors´ graphics caching mechanism to reduce scanning latency. The mobile station will know beforehand the channels used by the neighboring access points, so there is no need to explore all available channels. Chang et al. [14] present a method to assess the average change in the intensity of signal received by the MS, which indicates the more appropriate AP to serve the handoff. Song et al. [15] address the latency incurred in a 802.11 sub-net to sub-net handover using the Fast Handovers for Mobile IPv6 protocol

(FMIPv6), and introduce improvements. Our focus is on handoffs over the same sub-net, so FMIPv6 and its improvements are not applicable. Purushothaman and Roy's work [4] reduce the number of channels to scan by using a client-based database which stores information about the APs' channel numbers with stronger signals from the MS perspective. Ong and Khan [16] take a different approach to trigger the handoff, instead of using power signal metrics, they use a QoS criteria, namely, the number of VoIP packets lost, which should not exceed 2 % of the total sent in a period of time. This eliminates the need for the scanning process, which expends 90% of the 802.11 standard handoff time [4].

Some works have relied on the use of fuzzy logic (FL) in diverse aspects of the WLAN operation. Patil and Kolte [17] describe a five-parameter FL algorithm for handoff optimization. Nevertheless, it is generic and is not fitted to the 802.11 WLAN case. Gharehbaghi and Badamchizadeh [18] perform a comparison of four FL algorithms for Congestion Control, an special high volume packet arrival situation which could prevent a handoff initiation, in spite that the power signals conditions are met.

Synthesizing, [4, 12 and 13] aim at reducing the number of channels to scan, obtaining significant reductions in the order of 30%-60% of the active scanning time. While [16] eliminates this stage and the time consumed altogether. Nevertheless at the cost of greater network complexity brought about by the need of an increased network-wide information exchange.

C. *Highest-aptitude -AP prediction algorithm*

Our proposal relies on the link layer received-signal-power detection already in use, and the calculation of the direction of the MS in relation to the neighboring APs (used in [13]), to build a two input Fuzzy Logic Predictive Control (FLPC) designed to compute in advance which AP has the highest aptitude value to admit the MS when handoff initiation becomes necessary. With this decision making tool, the scanning of all channels can be omitted, saving the time to perform this process. Our approach thus, yields the same result as [16], but modification are confined to the MS, instead of the whole network.

III. FAST CELL HANDOFF FUZZY CONTROLLER DESIGN

A. *Best AP prediction algorithm*

In this section an FLPC aimed at reducing the handoff latency is explained. Because of its predictive nature, the proposal renders useless the scanning process specified by the IEEE 802.11 standard at the time of the handoff, thus eliminating the time taken by the polling sequence to scan eleven channels.

Fig. 5 illustrates the FLPC, which is fed with the information broadcast by the APs beacons every 100 msecs. With this periodicity the FLPC performs an analysis that yields the channel number identifying the AP with the highest aptitude value at that time. In this manner, the MS has an updated knowledge of the best fitted AP to associate with it, which it will use at the time a threshold situation is encountered.

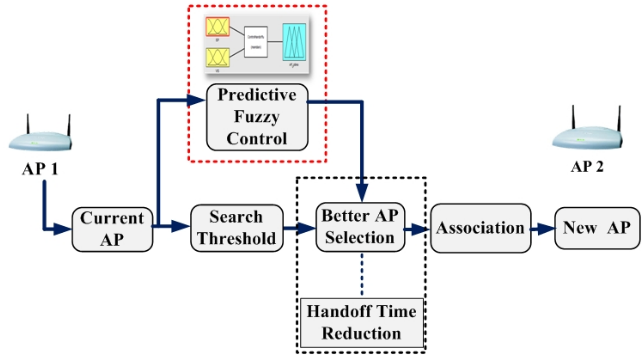

Fig. 5. Predictive handoff scheme.

So when the SNR (signal to noise ratio) local AP falls to the search threshold, triggering the handoff, the system will know the channel of the contiguous APs with higher aptitude, which will automatically be designated as the new serving AP, omitting the active scanning process, and the time needed to perform it.

B. *Fuzzy Logic Implementations*

Simulations were developed in a MatLab/Simulink platform. A Mamdani type fuzzy system was designed to predict, from a group of cells, which AP is best fitted to serve the itinerant MS. Fig. 6, illustrates the two-inputs-one-output fuzzy controller. The first entry represents the Average Signal Intensity (ASI), calculated at two seconds intervals from the beacon signal received by the mobile station every 100 msec. ASI constitutes a major metrics typically used in wireless systems to measure signal quality for purposes of performing the handoff. While the MS beacon signal does not fall to cell search threshold, the handoff process is not triggered. The second input is the Signal Intensity Variation (SIV), parameter that provides information on the direction of the MS with respect to the AP (approaching or distancing).

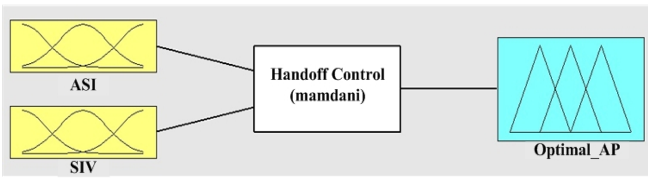

Fig. 6. Fuzzy System Inputs and Outputs.

Both inputs feed the fuzzy controller, which based on historic data and knowledge rules allow it to estimate and select the optimal AP to serve the MS.

The inference mechanism applied is "*max-min*" widely known as the Mamdani method, characterized by its implementation simplicity and effectiveness. Also, the centroid method is used, because it provides more representative results from the output-weighted values of various membership functions.

The methodology to suit membership functions to the variables' (two inputs, one output) range is described following:

- Input variable: Average Signal Intensity

Four membership functions were furnished for ASI: Low, Medium, Good and Excellent. The first and last are trapezoidal and the rest triangular, as shown in Fig. 7.

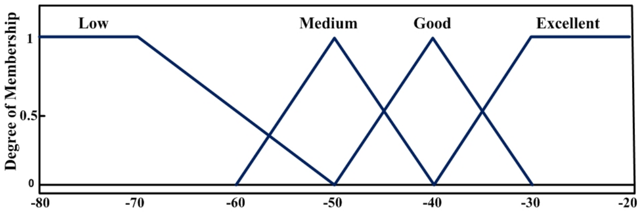

Fig. 7. Average signal intensity in dBm.

The choice of the linguistic terms correspond to the quality of received signal.

The expression proposed by Chang et al. [13] is used to obtain the ASI received by the mobile station.

$$\mathrm{ASI}(t) = \frac{\sum_{t=1}^{n} SSbeacon(t,i)}{n} \quad (1)$$

The universe of discourse proposed for the ASI variable is shown in Fig. 7, ASI is expressed by (1), where t is the current time, n represents the number of beacon frames received at a time t, and finally $SSbeacon$ (t, i) represents the intensity of the signal received at time "t-i" (Fig. 8).

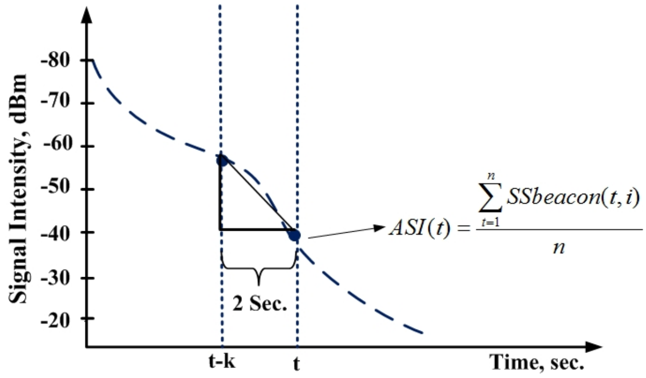

Fig. 8. Formula for use with the input variables ASI.

▪ Input Variable: Signal Intensity Variation (SIV)

For the relative position of an MS with respect to a specific AP, SIV represents the rate of change of two ASI readings made two seconds apart. Three membership functions were defined for SIV, whose linguistic terms are "Negative", "Zero" and "Positive", being two of trapezoidal shape, and one triangular as illustrated in Fig. 8.

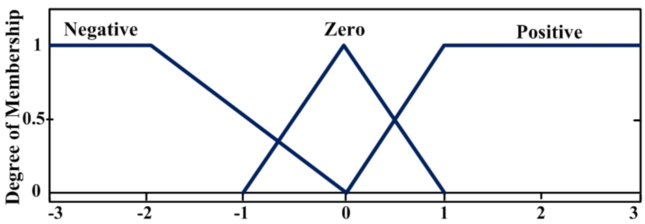

Fig. 9. Signal intensity variation.

The expression to calculate SIV is given in Equation (2). $SSa(t)$ is the ASI value at the present time, and $SSA(t$-$k)$ represents an ASI reading k seconds before. The range for this variable is set to (-3, 3).

$$\mathrm{SIV}(t) = \frac{SSa(t) - SSa(t-k)}{t-(t-k)} \quad (2)$$

Thus, the variation of signal intensity contains information about the speed of movement of the MS, and about direction of the MS in reference to the AP. (Fig. 10). A positive value is indicative of displacement towards the AP and a negative value, of moving apart.

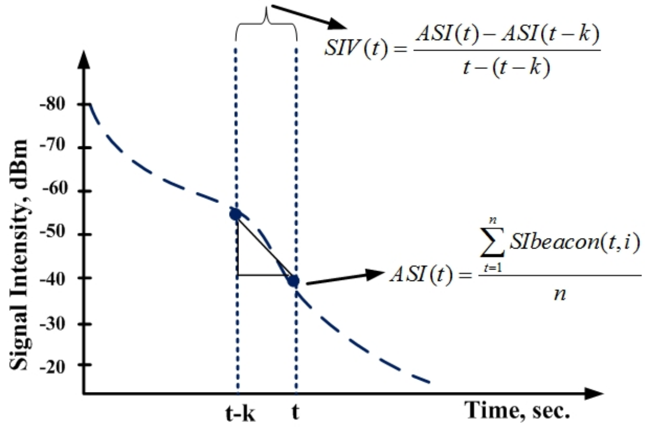

Fig. 10. Variation of signal strength.

The traditional handoff scheme considers only the ASI, whereas ASI and SIV, yield a better picture of the MS behavior.

▪ Variable Output: Aptitude.

Aptitude represents the decision taken on the basis of historic data of the two inputs ASI and SIV. Five membership functions were considered appropriate for this variable: Negative, Small Negative, Zero, Small Positive and Positive, as shown in Fig. 11. The range is (-2 2).

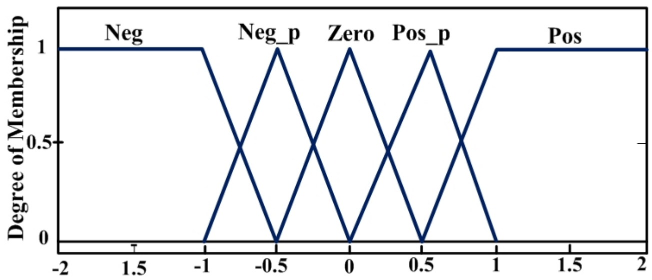

Fig. 11. Output variable Optimal AP.

The fuzzy system's decision making capability is defined by its knowledge base, comprised by 12 rules:

1. If ASI is excellent and SIV is Positive then Aptitude is Positive.
2. If ASI is excellent and SIV is Zero then Aptitude is Positive.
3. If ASI is excellent and SIV is Negative then Aptitude is Small Positive.
4. If ASI is good and SIV is Positive then Aptitude is Positive.
5. If ASI is good and SIV is Zero then Aptitude is Small Positive
6. If ASI is good and SIV is Negative then Aptitude is Zero.

7. If ASI is Media and SIV is Positive then Aptitude is Small Positive.
8. If ASI is Medium and SIV is Zero then Aptitude is Zero.
9. If ASI is Medium and SIV is Negative then Aptitude is Neg.
10. If ASI is Low and SIV is Positive then Aptitude is Zero.
11. If ASI is d Low own and SIV is Zero then Aptitude is Small Negative.
12. If ASI is Low and SIV is Negative then Aptitude is Negative.

The number of linguistic terms of each entry sets the number of rules, in this case $4 \times 3 = 12$ rules. The knowledge base arrangement is illustrated by the matrix shown in Table I. The decision taken by the predictive fuzzy control is clearly defined by the two inputs values.

Table I. Fuzzy System rules matrix.

ASI \ SIV	Positive	Zero	Negative
Excellent	Pos	Pos	Pos_p
Good	Pos	Pos_p	Zero
Medium	Pos_p	Zero	Neg_p
Low	Zero	Neg_p	Neg

The visor of rules of the fuzzy system is presented below (Fig. 12). It shows the rules that are activated by the inputs ASI and SIV. Specifically for ASI = -48.6 and SIV = 2.06 rules 4 and 7 are activated. Finally, the centroid defuzzification method computes an Aptitude value of 0.734.

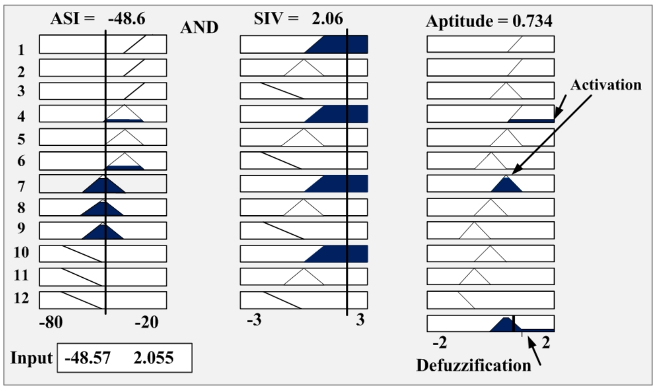

Fig. 12. Fuzzy System Rules Visor.

Table II provides a synthesis of the values that define the membership functions.

IV. EXPERIMENTS AND RESULTS

This section presents some of the tests performed in order to validate the FLPC outputs.

A. Single MS, single serving cell

Fig. 13 illustrates the basic scenario of an MS moving around within an IEEE 802.11 cell's boundaries. AP's beacon signal strength measures are taken every 100 msec.

Table II. Parameters of membership functions.

Linguistic variable	Linguistic term	Parameters
Average Signal Intensity	*Low*	*-80 -80 -70 -50*
	Medium	*-60 -50 -40*
	Good	*-50 -40 -30*
	Excellent	*-40 -30 -20 -20*
Signal Intensity Variation	Negative	-3 -3 -2 0
	Zero	*-1 0 1*
	Positive	*0 1 3 3*
Antitude	Negative	-2 -2 -1 -0.5
	Small Negative	*-1 -0.5 0*
	Zero	*-0.5 0 0.5*
	Small Positive	*0 0.5 1*
	Positive	*0.5 1 2 2*

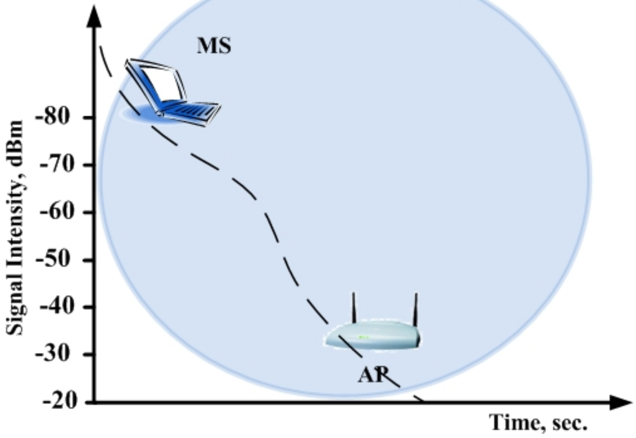

Fig. 13. Minimum detectable signal strength.

Table III shows some sample values of the AP's signal intensity received by the MS.

Table III. Intensity values received by the MS.

Signal intensity (dBm)	-79.12	-78.73	-78.52	-77.92	77.40	…	-78.00
Sequence of beacons	1	2	3	4	5	…	20
Time in (msec.)	100	200	300	400	500	…	2000

The first value is close to the minimum detectable signal strength, indicating that the MS is far from the AP and near a boundary. As the MS moves, the values start increasing, which implies that the MS is getting closer to the AP.

Since a user can find obstacles and move around to avoid them, signal intensity by itself is not a good reference to determine an MS's direction. So the data collected is used to calculate the ASI every two seconds, as stated before in equation 1 (see Fig. 8).

This process is repeated every two seconds by the predictive fuzzy control system, and stored for later use to calculate the SIV. Table IV shows various ASI values obtained from a sequence similar to the one in Table III.

SIV, the second input criteria, describes how fast the MS is approaching or moving away from the AP (Eq. 2).

Table IV. ASI values.

ASI (dBm)	-78.44	-76.55	-74.54	-72.54	…	-20
Time (sec.)	2	4	6	8	…	n

The FLPC performs the SIV calculation every two seconds (see Fig. 10).

As illustrated in Fig. 6, the FLPC performs its decisions based in the two inputs (ASI, SIV) and its knowledge base, yielding a numerical result, known as aptitude value. In our design, +3 is the maximum aptitude, and -3 the minimum. Fig. 14 presents an instance of calculation.

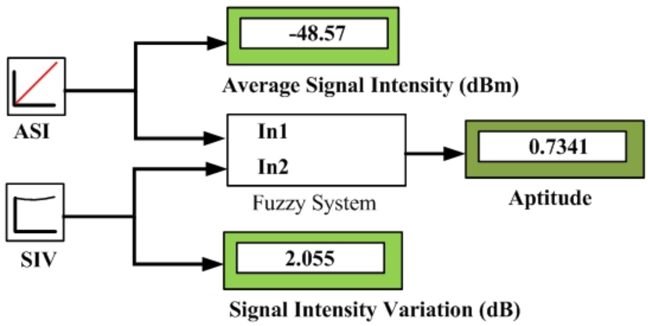

Fig. 14. Fuzzy System with AP.

5.2 Cluster of cells with 11 APs

Single MS, cluster of cells

The simulation considers an MS receiving the beacon frames from a group of surrounding cells, as illustrated in Fig. 15.

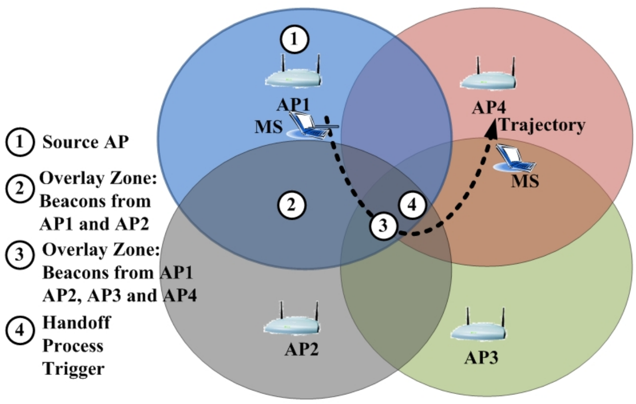

Fig. 15. Multiple APs.

The FLPC residing in the MS performs ASI and SIV calculations every two seconds to obtain the aptitude for up to eleven APs (according to the IEEE 802.11 standard) and selects the one with the higher value. When the proper conditions are met to trigger a handoff, the best Aptitude value, its corresponding AP and channel are known.

As the MS travels along the trajectory it navigates through different coverage areas, aptitude values are computed, and beacon signals from various cells become significant and competitive vs. the local's, but it is until the MS gets to point 4, when the conditions are set to trigger a Handoff. Fig. 16 shows the FLPC, with the selection of a best aptitude figure.

Under normal conditions IEEE 802.11 proceeds to a scanning process of eleven channels, to determine the one with highest signal strength, and then decide which one will be the target AP.

In our proposal there is no need for the scanning process, since the MS knows in advance which AP has the higher aptitude, estimated from historic data, and can do the decision immediately.

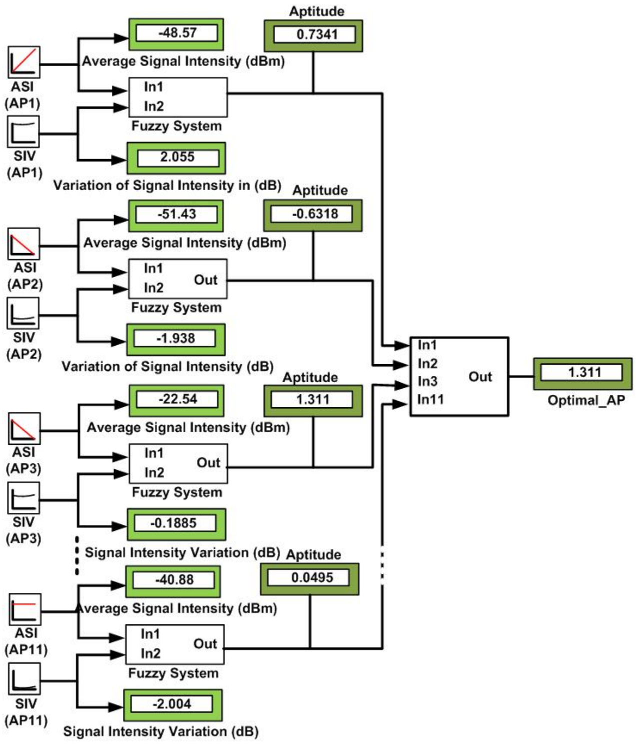

Fig. 16. Fuzzy control in operation with multiple APs.

The Optimal_AP is constantly known by the MS, and updated every two seconds, so at any given time that the Handoff is triggered, the channel scanning process is skipped and the Optimal AP is selected to receive the MS. Thus the handoff can be completed in around 30 msec. since the scanning eats up around 90% of the traditional handoff time [4].

Figure 17 shows the three-dimensional control surface computed by the Mamdani type FLPC. The axes values correspond to the ASI, SIV and Aptitude. As can be seen, when SIV is negative and ASI is minimum, Aptitudes values are negative, indicating an AP which should not be considered as the destination for a Handoff. The highest values of Aptitude ($1 < z \leq 2$) are obtained from the conjunction of high ASI values ($-30 < x \leq -20$ dBm), and positive SIV values ($2 < y \leq 3$).

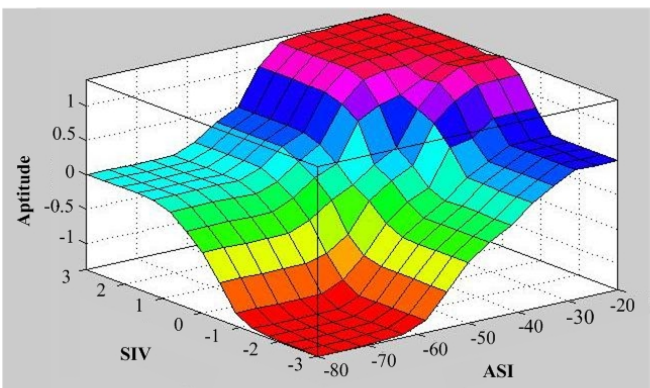

Fig.17. Fuzzy system control surface.

V. CONCLUSION

The capability to maintain uninterrupted VoIP connections while crossing through multiple WiFi cells is fundamental for this communication system's survival in the contested wireless arena. A Fuzzy Logic Predictive Control which computes the Average Signal Intensity and the Signal Intensity Variation, and feed them to the fuzzy inference algorithm, to obtain an Access Point Aptitude value is developed and validated. The FLPC selects the highest among up to eleven Aptitude values as the designated AP for handoff. This approach reduces the handoff inter-cell time by 90% thus providing better QoS to VoIP and other real time applications.

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