AN ADAPTIVE FUZZY LOGIC BASED HANDOFF ALGORITHM FOR INTERWORKING BETWEEN WLANS AND MOBILE NETWORKS

Amir Majlesi, Babak H. Khalaj

EE Department, Sharif University of Technology, Azadi Str, Tehran 11365, Iran, {majlesi,khalaj}@sharif.edu

Abstract - In this paper, the goal is to propose an optimal handoff algorithm for hybrid networks (HNs), which are constructed by interworking between wireless LANs (WLANs) and mobile networks. The proposed algorithm is an adaptive fuzzy logic based algorithm that can adapt itself with the dynamic conditions in HNs. It uses mobile terminal speed estimation and traffic in the WLAN as additional input parameters. This algorithm is designed to meet special requirements of HNs. The simulation results show that it has much better performance than conventional algorithms.

Keywords – Handoff, Fuzzy Logic, Interworking, WLANs, Mobile Networks,

I. INTRODUCTION

The needs of mobile users for data services with more bandwidth are increasing. Applications like high speed internet and intranet access, video conferencing, interactive multimedia services, are needed by today users. In response to these needs, WLANs are successful in providing high speed access to network resources. 11 Mbps technology (IEEE 802.11b) is now available worldwide and 54 Mbps technologies (IEEE 802.11a, Hiperlan 2) are entering the market. In addition, new mobile generations emerged to provide high speed data services: GPRS technology (2.5G), which is implemented in many places, can support up to 171 Kbps data rate and UMTS (3G) can provide up to 2 Mbps.

By implementing interworking between WLANs and mobile networks, these two technologies can complement each other for providing more facilitated data services to mobile users, so that in hot spots and places where high speed and low cost data services is required, users can connect to WLAN while roaming to mobile network elsewhere. WLANs can give cellular operators the possibility of exploiting their worldwide roaming infrastructure to provide users with cheap and cost effective high bandwidth data services. Supporting mobility between different networks, users may roam from WLAN to mobile network and vice versa without interruption in their continuing connection. This will need dual mode terminals that can work with both networks. Interworking has many advantages for both users and operators, it makes more bandwidths available for users and saves considerable cost and power consumption while reduces traffic and interference in the mobile network. Designing a reliable handoff(HO) algorithm is a critical factor for providing seamless communication services in HNs. HO has an impact on traffic matching and traffic density in the cells of both networks, also HO impacts QOS and throughput of the system. Recently, new HO algorithm are emerging which based on advanced techniques like pattern recognition, neural networks and fuzzy logic systems [4-8]. These complicated algorithms are necessitated by the complexity of the HO problem and dynamic conditions of wireless networks.

In this paper, HO in HNs is investigated and an optimal algorithm based on fuzzy logic is presented. In section 2, HO in HNs is introduced and the requirements of HO algorithm in HNs are outlined. In section 3 a conventional HO algorithm for HNs which is based on receive signal strength(RSS) threshold and hysteresis values is presented and in section 4 the adaptive HO algorithm for HNs which is based on fuzzy logic is proposed and described. in section 5, the performance of this algorithm is compared with the conventional algorithm by simulation. Finally, summary and conclusion is given in section 6.

II. HANDOFF IN HYBRID NETWORKSS

In cellular networks, when a mobile terminal(MT) moves away from a base station the signal level degrades and there is a need to switch to another base station. HO is the mechanism by which an ongoing connection between MT and its correspondent terminal or host is transferred from one point of access to the fixed network to another. In mobile networks, such point of attachments are referred to as base stations(BSs) and in WLANs they are called access points(APs). In HNs, which consists of large mobile network cells(macrocells) and several small WLAN cells inside of them, HO may take place in four cases (Fig. 1): HO from macrocell to macrocell, HO from a macrocell to a WLAN, HO from a WLAN to another WLAN and HO from a WLAN to a macrocell. When MT leaves the coverage area

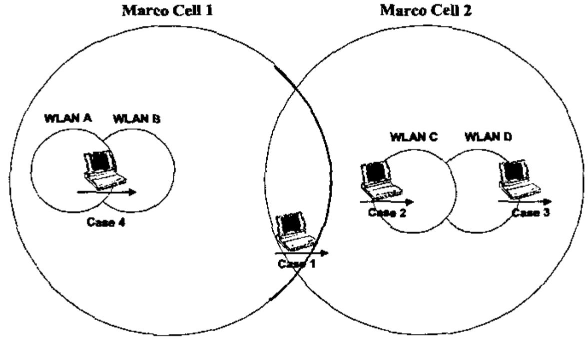

Fig. 1- Handoff in Hybrid Networks

of a macrocell and enters another macrocell, HO from macrocell to macrocell occurs(case 1). When MT is in the coverage of a macrocell and enters a WLAN coverage, HO from macrocell to WLAN occurs (case 2). Even though the RSS from the macrocell is usually greater than WLAN this type of HO is done with high priority since connecting to WLAN is more desirable because it provides more bandwidth and is cost effective and power efficient and reduces interference in the mobile network. But when WLAN has heavy traffic or the MT velocity is too high, it's better to not make HO to WLAN and MT remains connected to macrocell.

When MT leaves WLAN coverage and enters a macrocell, HO from WLAN to macrocell occurs (case 3). This type of HO is done with low priority and it's desirable that MT remains connected to WLAN as much as possible. Finally, when MT leaves WLAN coverage and enters another WLAN, HO from WLAN to WLAN occurs (case 4).

The requirements of HO algorithm in hybrid networks which should be considered in design of HO algorithm are as follows:

1- HO should be done fast and its delay should be minimum.
2- Number of HOs should be minimum since excessive HOs results in degradation in signal quality and increasing call dropping probability and additional loads on the network.
3- HO procedure should be reliable and successful and after HO the signal quality should be good.
4- HO algorithm should be simple and has minimum computational complexity.
5- In a HN, usage of WLAN should be maximum and HO to WLAN should be done with high priority. Because WLAN can provide users more bandwidth and can save power and cost. Also connecting users to WLAN will reduces traffic and interference in the mobile network.
6- When traffic in the WLAN becomes too high and overflow occurs, HO to WLAN should be avoided. Mobile network coverage are available everywhere, so it's not necessary to connect users to WLAN when it can't provide desirable service.
7- In a HN, fast users should remain connected to mobile network and prevented from connecting to WLAN since WLAN is designed for low velocity users and has small coverage (~100m).

III. CONVENTIONAL HANDOFF ALGORITHM FOR HYBRID NETWORKS

In this section, a conventional handoff algorithm, which based on RSS threshold and hysteresis values[5], is presented. Fig. 2 illustrates block diagram of the algorithm. First, in sampling intervals RSS values are measured and their averages are computed in the averaging window. Then, HO initiation mechanism indicates if HO process will be started or not. This mechanism, when the current cell is a WLAN, compares current RSS (RSSc) with a threshold value (THw), if RSSc is less than THw, HO will be started. When the current cell is a macrocell, this mechanis will start

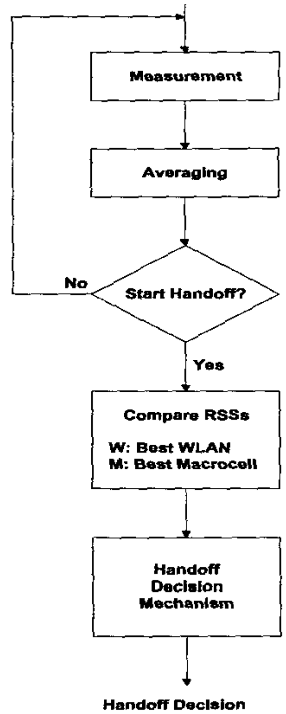

Fig. 2- Conventional HO Algorithm for Hybrid Networks

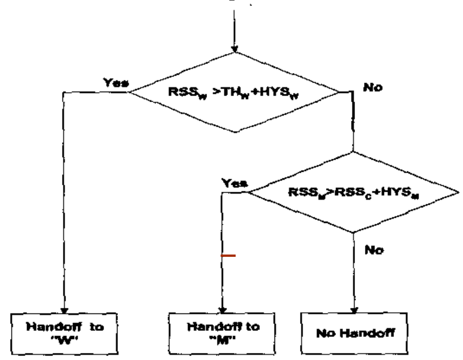

Fig. 3- HO Decision Mechanism (Current Macrocell)

HO in two cases: either current RSS (RSSc) is less than a threshold (THm) or RSS from a WLAN is more than a threshold (THw). If HO is started, cell selection mechanism selects best available macrocell ("M") and best available WLAN ("W") by comparing all RSS values. The HO decision mechanism is the main part of the algorithm. If the current cell is a macrocell, mechanism in Fig. 3 will be done and if the current cell is a WLAN, mechanism in Fig. 4 will be done as follows:

- When the current cell is a macrocell (Fig. 3), since the priority is to make HO to WLAN, first RSS of the suggested WLAN (RSSw) is checked. If RSSw exceeds the threshold (THw) by an amount HYSw, HO will be done to "W", otherwise HO to the suggested macrocell "M" is investigated. If RSSm exceeds RSSc by an amount HYSm, HO is made to "M", otherwise no HO occurs.

- When the current cell is a WLAN (Fig. 4), first the suggested WLAN ("W") is investigated. If RSSw exceeds RSSc by an amount HYSw, HO will be done to "W", else an attempt is made for HO to the suggested macrocell "M". If RSSm exceeds THm by an amount HYSm, HO will be done to "M", otherwise no HO occurs.

This conventional algorithm cannot meet many requirements of HNs. It doesn't have minimum number of HOs and short HO delay since it uses a fixed RSS averaging window. For a fixed averaging window, if MT velocity is high, HO delay is long and this delay may result in poor signal quality and possibly disconnection before making HO, but if MT velocity is low, HO delay is short and number of unnecessary HOs is increased. So a fixed averaging window only in a certain velocity has optimum performance. In addition, this algorithm doesn't consider traffic conditions in the WLAN, also it doesn't prevent fast users from connecting to WLAN.

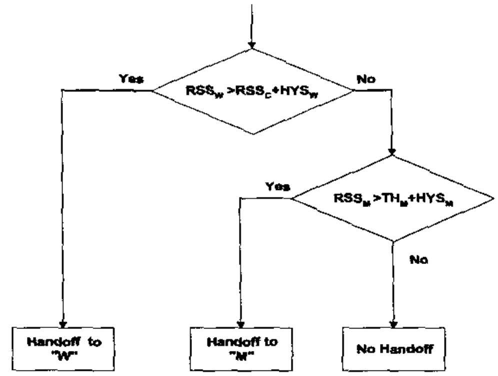

Fig. 4- HO Decision Mechanism (Current WLAN)

IV. ADAPTIVE FUZZY LOGIC BASED HANDOFF ALGORITHM

In this section the adaptive fuzzy logic based HO algorithm for HNs is presented. Fig. 5 depicts block diagram of the algorithm. In this algorithm MT speed and traffic in the WLAN are used as input parameters. We assumed that MT speed can be estimated. In [8] methods for estimating the speed of MT, which are based on doppler frequency are proposed. In this algorithm, averaging window is adapted according to MT speed. When MT speed is high the window will be reduced, so the HO delay is decreased and when the MT speed is low averaging window will be increased, so unnecessary HOs are avoided. Handoff initiation mechanism and cell selection mechanism are the same as before. Handoff decision mechanism is similar to previous algorithm (Fig. 3 and Fig. 4), the only difference is that, here HYSm and HYSw values are updated by a fuzzy logic system(FLS). Inputs of the FLS are MT speed and traffic in the "W" (TRw). The FLS is designed to meet special requirements of HNs. When the velocity of the MT is high or the traffic in the WLAN is heavy, HO to WLAN should be discouraged; otherwise HO to WLAN should be encouraged. The FLS increases HYSm and decreases HYSw when HO to WLAN must be discouraged and HO to macrocell be encouraged and it decreases HYSm and increases HYSw when HO to macrocell should be discouraged and HO to WLAN be encouraged. Fig. 6 to 9 illustrate the membership functions of the input and output fuzzy variables. The fuzzy variable "speed" has five fuzzy sets (Slowest, Slow, Normal, Fast, Fastest) and fuzzy variable "TRw" has three fuzzy sets (Low, Normal, High). Output fuzzy variables "HYSm" and "HYSw" have five fuzzy sets (Lowest, Low, Normal, High, Highest). It should be noted that modifying the membership functions will

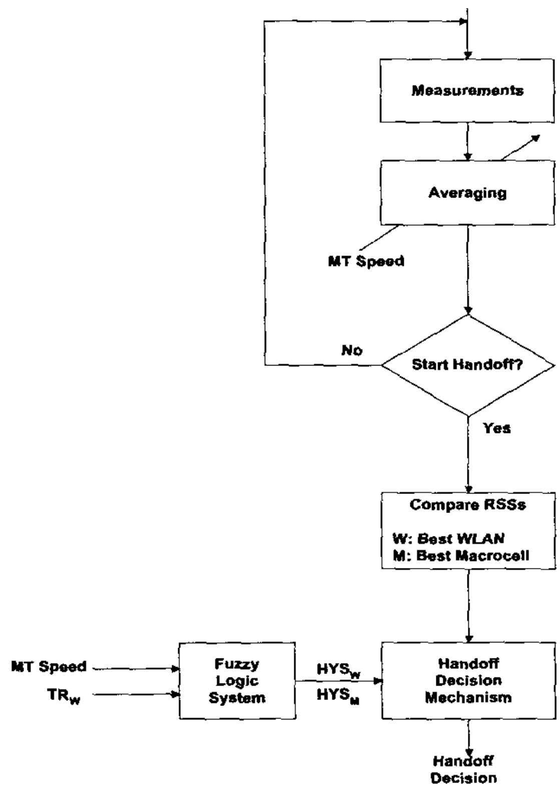

Fig. 5 - Adaptive Fuzzy Logic Based HO Algorithm for Hybrid Networks

change the sensitivity of FLS output to its inputs. Also increasing the number of fuzzy sets of the variables will provide better sensitivity control but also increases computational complexity of the system.

Table 1 shows the rules used in the FLS. For example when speed has the "fast" value and TRw is "high", this condition indicates that HO to macrocell should be encouraged and HO to WLAN should be avoided so HYSw is increased ("Highest") and HYSm is decreased ("Lowest"), this is rule No. 4 in the table. When speed is "slow" and TRw is "low", HO to WLAN should be encouraged, so HYSw is decreased and HYSm is increased (Rule No. 15).

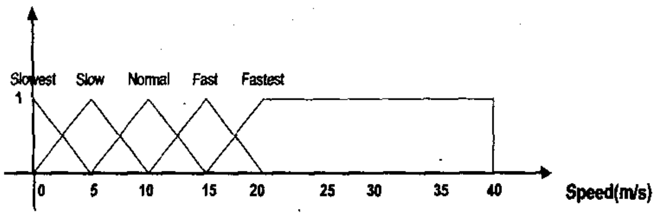

Fig. 6 – Membership Function of Fuzzy Variable Speed

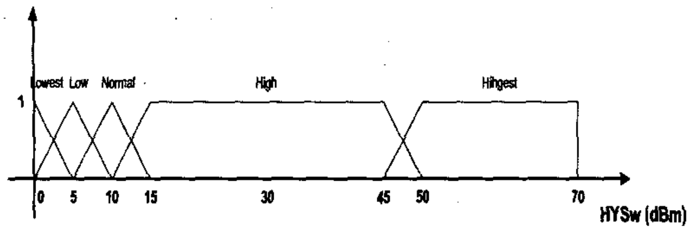

Fig. 7 – Membership Function of Fuzzy Variable HYSw

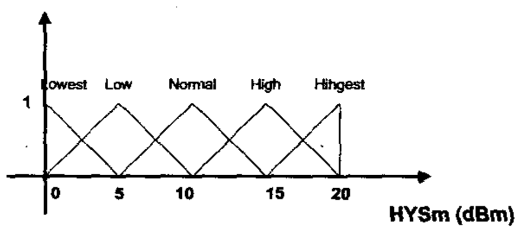

Fig. 8 – Membership Function of Fuzzy Variable HYSm

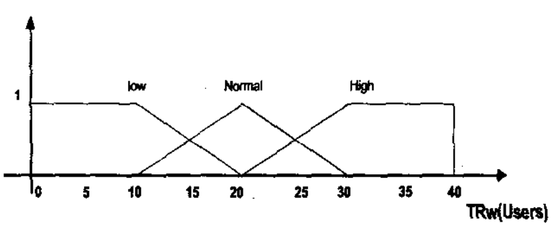

Fig. 9 – Membership Function of Fuzzy Variable TRw

V. SIMULATION

In order to compare two proposed algorithms and investigate their performance under different conditions, a simulation was done using C++.

The simulation environment is similar to Fig. 1. It consists of two macrocells, each has 1 km radius and the distance between BSs (BS1 and BS2) is 1.8 km. Inside macrocell 1, two WLANs are located, each has 100m radius and the distance between APs (AP A and AP B) is 180m. The transmit power of BSs is 1 Watt and the transmit power of APs is 100 mWatt.

The channel propagation model used for receive signal strength at distance **d** is given by [5]:

$$\mathbf{RSS(d) = Pt - PL(d) + X_\sigma \quad dB}$$

Where **Pt** is the transmit power and **PL(d)** is the path

Table.1- Fuzzy Logic System Rules

Rule No	INPUT		OUTPUT	
	Speed	TRw	HYSw	HYSm
1	Fastest	High	Highest	Lowest
2	Fastest	Normal	Highest	Lowest
3	Fastest	Low	High	Low
4	Fast	High	Highest	Lowest
5	Fast	Normal	High	Low
6	Fast	Low	Normal	Normal
7	Normal	High	Low	Low
8	Normal	Normal	Normal	Normal
9	Normal	Low	Low	High
10	Slow	High	Normal	Normal
11	Slow	Normal	Low	High
12	Slow	Low	Lowest	Highest
13	Slowest	High	Low	High
14	Slowest	Normal	Lowest	Highest
15	Slowest	Low	Lowest	Highest

loss at distance **d** and $\mathbf{X_\sigma}$ is a zero-mean Gaussian random variable with standard deviation σ modeling shadow fading. σ depends on the environment and has values between 6-12 dB. The path loss at distance **d** is given by:

$$\mathbf{PL\ (d) = S + 10.n.Log\ (d) \quad dB}$$

Where **S** is the path loss constant depends on propagation environment and **n** is the path loss exponent at which path loss increases with distance and has values between 2-4.

In this model, the effect of multi-path fading is neglected since the average values of RSSs are important and it gets average out because of its rapid variations.

Table 2 shows the used values for simulation parameters in macrocell (according to GPRS) and WLAN environments (according to IEEE 802.11b).

A. Simulation Results

In this section, results of the simulation are presented for four cases:

In case 1, MT moves from AP B toward BS 1 in constant velocity. In this case no other WLAN is available and HO to macrocell will be done. Fig. 10 shows the RSSc when MT moves away from AP B (speed is 10m/s). Number of HOs in different speeds is shown in Fig. 11 for both algorithms. For each point simulation was done 5 times and the average was considered. As we expected, first algorithm doesn't have the same performance in different speeds since it uses a fixed averaging window. In low speeds number of HOs is high and as speed is increased, number of HOs is decreased. But second algorithm which is the proposed algorithm,

Table 2- Simulation Parameter Values

Parameter	Macrocell	WLAN
Pt	1 Watt	100 mWatt
Cell Size	1 km	100 m
Sampling Time	0.1 S	0.1 S
n	4	3.3
Σ	6 dB	7 dB
S	19 dBm	28.7 dBm
Threshold	-105 dBm	-85 dBm

adapts the averaging window with the speed, so the number of HOs is remained minimum in different speeds. Fig. 12 shows the call dropping probability in different speeds for both algorithms. In high speeds, the probability of call dropping is increased in the first algorithm because of the long delay in performing HO, but in second algorithm call dropping probability is reduced since it decreases the averaging window. Also the HYSm value is decreased by the FLS causing the HO done faster.

In case 2, MT moves back from BS 1 to AP B in constant speed. In this case when MT approaches WLAN B, although RSSc from BS 1 has an acceptable value, the HO initiation mechanism initiates HO process when RSSw from WLAN B exceeds the threshold. Fig. 13 depicts HO distance from BS 1 for both algorithms in different speeds. HO distance here is the distance at which last HO is done and MT leaves macrocell and joins WLAN for the last time. In the second algorithm, when MT speed is high, by increasing HYSw and decreasing HYSm, HO to WLAN is discouraged, so HO is done late or is not done at all while first algorithm doesn't consider the MT speed. Fig. 14 illustrates the probability of HO to WLAN B versus different traffics in WLAN B for the second algorithm. When the traffic in WLAN B is high, HO to WLAN is discouraged by decreasing HYSm and increasing HYSw, while WLAN traffic doesn't have any effect on the first algorithm.

In case 3, MT moves from AP A to AP B in constant velocity. In this case the first algorithm always perform HO to WLAN B, but second algorithm only when the traffic in WLAN B and MT speed are normal, performs HO to WLAN B, otherwise it will make HO to macrocell 1. Fig. 15 indicates the probability of HO to WLAN B versus different traffics for the second algorithm (speed is 6 m/s). As we expected, when the WLAN traffic is high, probability of HO to it is reduced. Fig. 16 shows the probability of HO to WLAN B in different speeds for the second algorithm. Again, when the speed is high, probability of HO to WLAN B is reduced.

In case 4, MT moves from BS 1 to BS 2 in constant velocity. In this case, no WLAN is available and HO will be done to BS 2. Fig. 17 shows HO distance from BS 1 in different speeds for both algorithms. When the MT speed increases, the second algorithm makes HO to macrocell 2 faster since it reduces HYSm. But for first algorithm in high speeds, HO is done late since number of unnecessary HOs is high.

VI. CONCLUSION

In this paper, HO in hybrid networks, which are constructed by interworking between mobile networks and WLANs was investigated. Two HO algorithms for hybrid networks are introduced and investigated. The first algorithm is a conventional algorithm that uses RSS threshold and hysteresis values for making decision. The second algorithm, which is the suggested algorithm, is an adaptive algorithm based on fuzzy logic that adapts the averaging window and the hysteresis values dynamically by using the mobile speed estimation and the traffic the WLAN as input parameters, so better efficiency in hybrid networks is achieved and special requirements of hybrid networks is met. Simulation results show that the proposed algorithm have much more desirable performance.

This algorithm decreases handoff delay and number of unnecessary handoffs by changing the RSS averaging window according to MT speed. Also by using a fuzzy logic system which is quite suitable for this purpose, the hysteresis values is updated according to mobile speed and the traffic in WLAN ,so it can meet special requirements of hybrid networks, such that the high speed users remain connected to mobile network and are prevented from connecting to WLAN and also when WLAN traffic is heavy HO to WLAN is avoided.

REFERENCES

[1] A. Majlesi, "Interworking between Wireless LANs and Mobile Networks", M.Sc. thesis, EE Department, Sharif University of Technology, Dec 2001.

[2] J. Schiller, "Mobile Communications", Addison-Wesley, London, 2000.

[3] L.X. Wang, "Adaptive Fuzzy Systems and Control", Prentice Hall, New Jersey, 1994.

[4] K. Pahlavan, P. Krishnamurthy and A. Hatami," Handoff in Hybrid Mobile Data Networks", IEEE Personal Comm. Mag., April 2000.

[5] N. D. Tripathi, J. H. Reed and H.F. Vanlandinghum, "Adaptive Handoff Algorithm for Cellular Overlay Systems using Fuzzy Logic", IEEE 49th Vehicular Technology Conference, , Volume: 2, 1999.

[6] S.S. Lau, K.F. Chungand and J.C. Chuang , " Fuzzy Logic Adaptive Handoff Algorithm", Global Telecomm Conference, GLOBECOM '95, Volume: 1 , 1995.

[7] N.D. Tripathi, J..H. Reed and H.F. Vanlandinghum," Pattern Classification Based Handoff using Fuzzy Logic and Neural Nets", ICC 98, IEEE Conference Proceedings, Volume: 3, 1998.

[8] M. D. Austinand and G. L. Stuber, "Velocity adaptive handoff algorithm for microcellular systems", IEEE Trans. Veh. Tech., Vol. 43, No.3, Aug. 1994.

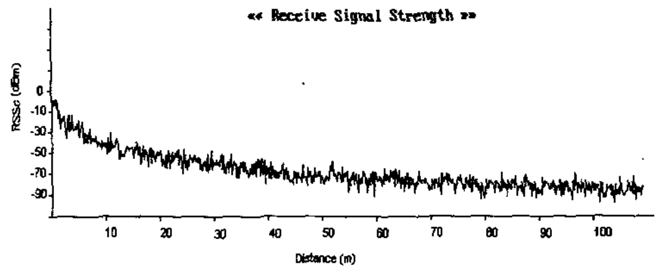

Fig. 10- RSSc variations in case 1

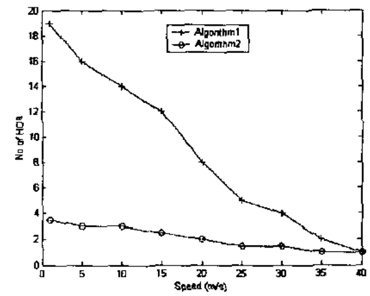

Fig. 11-Number of HOs versus MT speed in case 1

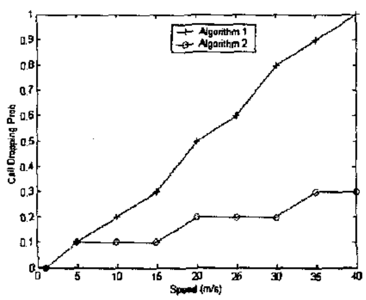

Fig.12- Call dropping probability in different speeds (case 1)

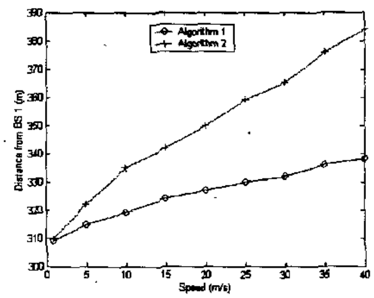

Fig. 13- HO distance in different speeds (case 2)

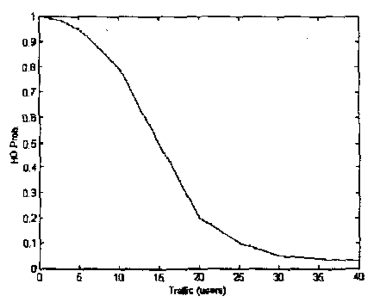

Fig.14- Probability of HO to WLAN in the different traffics for the second algorithm (case 2)

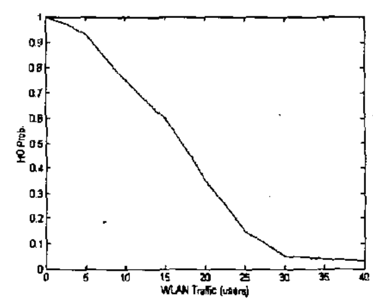

Fig.15- Probability of HO to WLAN in the different traffics for the second algorithm (case 3)

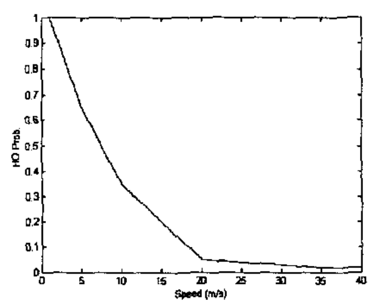

Fig. 16- Probability of HO to WLAN in different speeds for the second algorithm (case 3)

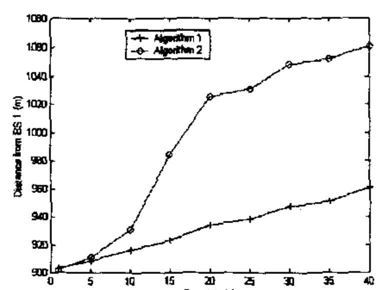

Fig. 17- HO distance from BS 1 in different speeds (case 4)