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Fuzzy Logic Based Adaptive Handoff Algorithm for Heterogeneous Network

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Abstract

Different handoff (HO) algorithms are currently available in cellular call transfer. All these algorithms take decision based on Received Signal Strength Indicator (RSSI). These algorithms failed to mitigate the requirement of a heterogeneous network consisting of Wireless Local Area Network (WLAN), Worldwide Interoperability for Microwave Access (WiMAX), Wireless Fidelity (Wi-Fi) and General Packet Radio Service (GPRS) Networks. Because in such a network much more design issues like cell coverage area, velocity of the Mobile Station (MS) and traffic density in WLAN are to be considered at a time. In this work an adaptive handoff algorithm based on fuzzy logic has been simulated. Fuzzy logic is employed as it is well known for its simplicity and ability to solve conflicting parameters. This work is focused to select a best candidate cell for handoff. Hysteresis level which is kept constant in the conventional handoff algorithms is made adaptive with distance, velocity and traffic. A fuzzy rule base is constructed to make the decision precise. Results show that this algorithm is able to make a distinct decision regarding the handoff- a fast moving user or a user in long distance is always handed to GPRS (macro cell) while an immobile or slow user in the short or medium distance is able to be connected with WLANs. Thus unnecessary handoff is neglected and the number of handoff is reduced.

I. Introduction

A Heterogeneous Network (HN) is a combination of different network technologies providing varying coverage and Quality of Service (QoS). Portable devices typically have more than one type of wireless interface built-in. To satisfy the bandwidth and QoS constraints of the applications, the mobile devices need to be able to seamlessly switch among their wireless network interfaces. Implementation of an HN between WLANs and mobile networks 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 cellular network and vice versa without interruption in their continuing connection [1].

When a MS moves from one cell to another cell without any service interruption is called handoff (HO). There are various handoff algorithms exiting for the purpose of uninterrupted call conversation. Among these RSS (Received Signal Strength) based algorithm is well established. According to this algorithm the mobile station (MS) continuously scan 16 signal strengths from the neighboring cell including the serving cell and made a list which is called Power Budget (PBGT). According to this list when the MS signal strength becomes weaker HO occurs and it will choose a new base station from the neighboring cell. These mechanisms are currently used in the GSM system and also in the limited WiMAX service [2].

This conventional algorithm cannot meet many requirements of Hybrid Network (HN). It doesn't have minimum number of Handoff (HO) 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 [1]. 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. In this work an approach to the vertical handoff decision in HN is presented to exploit the advancement of the well established mobile network (GPRS) with the emerging WLAN (WiMAX, Wi-Fi) that supports high speed data rate. The handoff decision is based on Fuzzy Logic where the input parameters are the distance, speed of the MS and traffic in three constituent networks, i.e. GPRS, WiMAX and Wi-Fi. The output variables are the Hysteresis levels of the three networks that control the handoff to any of these three networks. This hysteresis levels are made to be changed adaptively with the change in the input variables.

In an adaptive fuzzy predictor based handoff algorithm for heterogeneous network is proposed [3]. The fuzzy predictor is used to predict the received signal strength (RSS) in cellular phone network and WLAN. According to [4] an optimal handoff algorithm for hybrid networks (HNs) is put in discussion. The HN is constructed by interworking between wireless LANs (WLANs) and mobile networks. It uses mobile terminal speed estimation and traffic in the WLAN as input parameters. A handoff algorithm referred to as the fuzzy adaptive averaging-interval and hysteresis-threshold handoff (FAAH) is introduced in [5]. The algorithm consists of two fuzzy logic controllers. The first controller takes into account the signal variation and the need to change the averaging interval (AVG) accordingly. The second controller dynamically adapts the hysteresis level (HYS) with the signal differences between two stations.

II. Fuzzy Inference System

The fuzzy inference system is a computing framework based on the concepts of fuzzy set theory, fuzzy IF-THEN rules, and fuzzy reasoning. A Mamdani fuzzy inference system composed of the functional blocks shown in Figure 1 is stated below:

- Fuzzifier
- Fuzzy Rule Base
- Fuzzy Inference Engine
- Defuzzifier

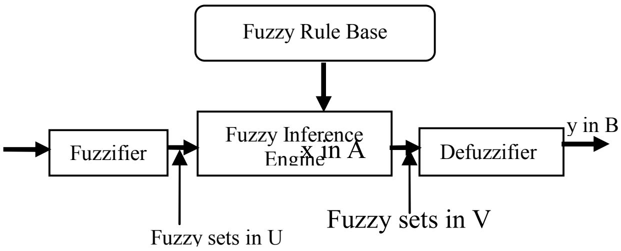

Fig. 1. Fuzzy Inference System

Fuzzifier

The fuzzifier transforms the crisp inputs into degrees of match with linguistic values. The fuzzifier maps a crisp point, $\underline{x} = [x_1, x_2, x_3, \ldots, x_n]^T \in U$, into a fuzzy set $F = \{(x_1, \mu_F(x_1)), (x_2, \mu_F(x_2)), \ldots, (x_n, \mu_F(x_n))\}$ in U, where $\mu_F : U \rightarrow [0, 1]$ is the membership function of the fuzzy set F and $\mu_F(x_i)$ is the membership degree of x_i in F. U is called the universe of discourse.

Fuzzy Rule Base

Fuzzy linguistic descriptions are formal representations of systems made through fuzzy IF- THEN rules [5]. They encode knowledge about a system in statements. IF (a set of conditions) are satisfied THEN (a set of consequents) can be inferred. Fuzzy IF-THEN rules are coded in the form:

IF (x_1 is U_1, x_2 is U_{2j}, … and x_n is U_n) THEN (y_1 is V_1, y_2 is V_2,…, y_n is V_n).

Where linguistic variables x_i , y_i *take the values of fuzzy sets* U_i and V_j respectively.

The "IF" and "THEN" clauses are called the antecedent and the consequent respectively. Each antecedent and consequent in a fuzzy logic rule forms a membership function that can be of different shapes, triangular, trapezoidal and Gaussian shapes being more popular. Each input or output fuzzy variable has a membership degree of unity at the center value of the corresponding fuzzy set.

Fuzzy Inference Engine

Fuzzy inference is the process of formulating the mapping from a given input to an output using fuzzy logic [6]. The mapping then provides a basis from which decisions can be made, or patterns discerned. Here fuzzy logic principles are used to combine fuzzy IF-THEN rules in the rule base, and fuzzy sets in $U = U_1 \times U_2 \times \ldots \times U_n$ are mapped into fuzzy sets in V. A fuzzy rule is interpreted as a fuzzy implication $F_1{}^j \times F_2{}^j \times F_3{}^j \ldots \times F_n{}^j \rightarrow G^j$ in U×V.

Defuzzifier

A defuzzifier transforms the fuzzy results of the inference engine into a crisp output, $y \in V$. A popular defuzzification method is the centroid method calculation which returns the centre of area under the curve given by

$$\frac{\sum_{i=1}^{n} x_i * \mu(x_i)}{\sum_{i=1}^{n} \mu(x_i)}, \text{ for a discrete membership}$$

and, $$\frac{\int \mu(x) x dx}{\int \mu(x) dx}, \text{ for a continuous membership function.}$$

III. Proposed Handoff Algorithm

In this proposed algorithm the adjustment of hysteresis level is carried out through fuzzy Inference system (FIS). One of the advantages of fuzzy logic is its simplicity. Fuzzy logic is a form of multi-valued logic derived from fuzzy set theory to deal with reasoning that is approximate rather than precise. Therefore conflicting criteria can be resolved using fuzzy logic. The proposed algorithm allows a systematic compromise among various characteristics based on the fuzzy logic rule base. The main complexity regarding the FIS is the building of a compact rule base. By increasing number of input variables and their increasing levels more rules can be accumulated to make a decision with higher degree of precision. To get the precision the greater number of rule base is necessary and it could be used in online environment if the system has the high computing performance.

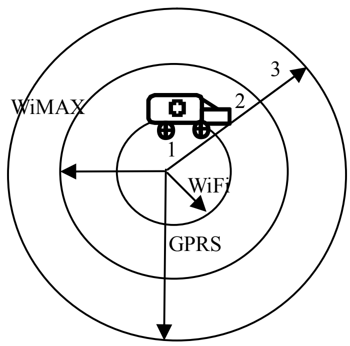

Fig. 2. Considered Heterogeneous Network

Hysteresis level termed as the required difference in RSS level of a new cell and present serving cell is used to make the handoff decision. Whenever the RSS level from the new cell exceeds that of the present serving cell by an amount equal to the hystresis level, that new cell can be considered as an eligible handoff candidate cell.

For the simulation purpose a simple, fully overlaid heterogeneous network has been considered as in Figure: 2.This scenario consists of Wi-Fi, WiMAX and GPRS connectivity. All the three networks are co-centered. The mobile station is assumed to have multi-mode connectivity that can work both in mobile network and WLAN (WiMAX, Wi-Fi) environment. The innermost circle denotes the Wi-Fi network. The outermost circle symbolizes that of a GPRS network that has a wide coverage area. The circle between these two is the cell border of WiMAX.

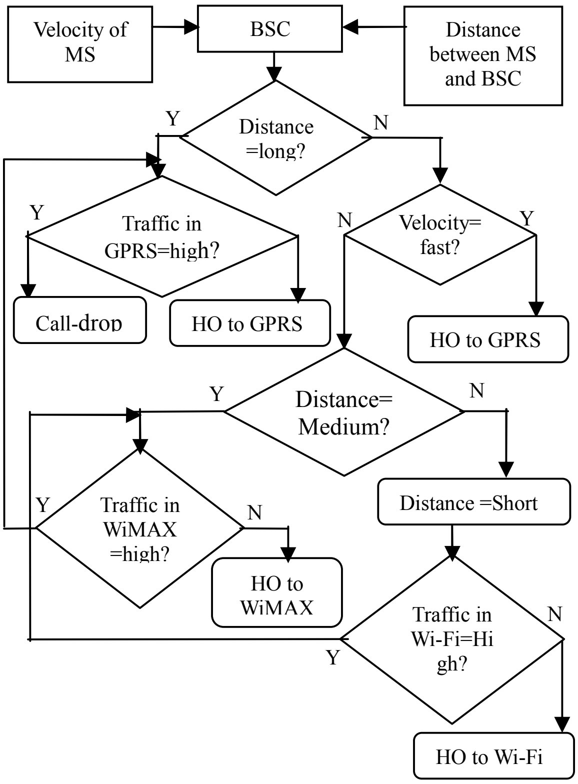

Fig. 3. Flowchart of proposed handoff Algorithm

For the simple approach a user with a mobile station (MS) is assumed to move in a linear pathway. The flowchart outlined in Figure: 3, is implemented by Fuzzy Logic. According to flow-chart, the decision parameters are evaluated serially, that is one after one. The distance is checked first then traffic in corresponding networks or the velocity. But utilization of FIS mitigates this complexity because all the parameters are evaluated in parallel there according to the rule base. This flow-chart indicates how the algorithm taking its decision regarding the handoff criteria.

IV. Simulation

First of all a fuzzy inference system has been developed in MATLAB taking Distance, Velocity, Traffic in GPRS, Traffic in WiMAX and Traffic in Wi-Fi as the input parameters. Hysteresis-GPRS, Hysteresis- WiMAX and Hysteresis-Wi-Fi were taken as the outputs of the system. In this work trapezoidal shape has been considered as it is a standard shape.

For the input variable 'Distance' three regions have been specified according to their usual cell coverage. These are:

1) Wi-Fi: 0-1 Km

2) WiMAX: 0-15 Km

3) GPRS: 0-30 Km

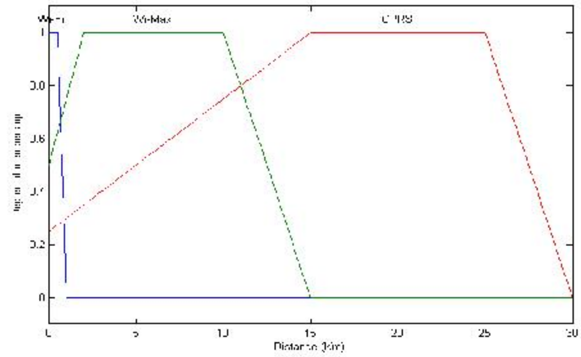

Fig. 4.1. Membership function for input variable 'Distance'.

For the second input variable 'Velocity' four regions have been declared:

1. Slowest: 0-3 Km/h
2. Slow: 2-13 Km/h
3. Medium: 10-45 Km/h
4. Fast: 35-80 Km/h

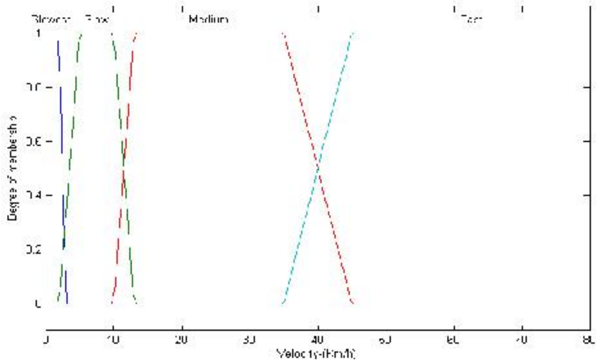

Fig. 4. 2. Membership function for input variable 'Velocity'.

The other three input variables are the number of traffic in the three networks. From the practical consideration a macro cell supports high amount of traffic at a lower data rate while the WLAN supports less traffic at a high data rate. To reflect this issue traffic pattern in each network is chosen heuristically as follows:

1. Highest number of users in GPRS =90
2. Highest number of users in WiMAX =50
3. Highest number of users in Wi-Fi =25

The hysteresis level for the three output variable is declared as follows:

1) Low: 0-8 dB
2) Medium: 5-16 dB
3) High: 13-20 dB

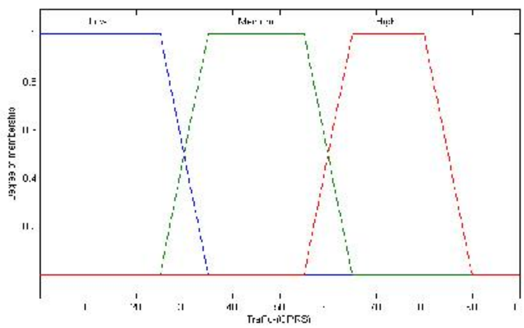

Fig. 4.3. Membership function for input variable 'Traffic GPRS'.

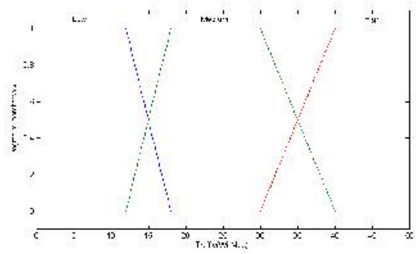

Fig. 4.4. Membership function of input variable 'Traffic-WiMAX'.

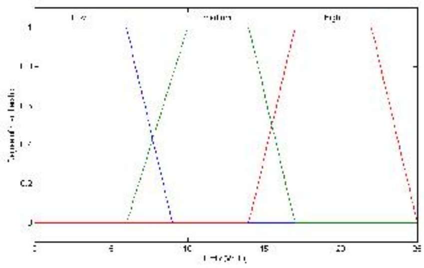

Fig. 4.5. Membership function of input variable 'Traffic-Wi-Fi'.

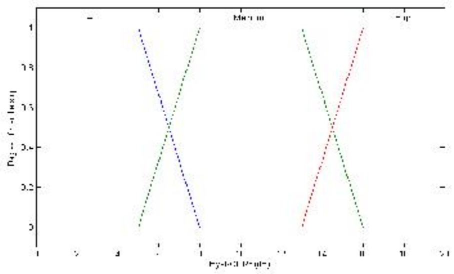

Fig. 4. 6. Membership function of the output variable 'Hysteresis-WiFi (Low)/Hysteresis –GPRS (Medium)/ Hysteresis-WiMAX (High)'

As a result the candidate cell must have a Received Signal Strength (RSS) level higher than that of the current serving cell by the amount equal to the hysteresis. The probability of handoff to the candidate cell increases with the decreasing value of hysteresis.

The rule base of the Fuzzy Logic Controller consists of 106 rules. Though the rule base is unusually large it is not unexpected as the number of input variables is 5 and each of them has 3 levels. The rule base are constructed considering each and every case that might be happen regarding the network planning shown in Table 1. Some of the rules are showed below:

Table. 1. Examples from the rule Base

Dis	Vel	TrGP	TrMX	TrFi	HyGP	HyMX	HyFi
WiFi	Slowest	Low	Low	Low	Medium	Medium	Low
WiFi	Slowest	High	Medium	High	High	Medium	High
WiFi	Slow	Low	Medium	High	Medium	Low	High
WiFi	Medium	Medium	Medium	None	Medium	Low	High
WiMAX	Slowest	Low	Medium	None	Medium	Low	High
WiMAX	Slow	High	Low	None	High	Low	High
WiMAX	Fast	Low	High	None	Low	High	High
GPRS	Slowest	Low	None	None	Low	High	High
GPRS	Slow	High	None	None	High	High	High
GPRS	Fast	High	None	None	High	High	High

For the inputs MATLAB code has been written to generate 10 random sequences of the inputs. In the case of 'Distance' (0-30 Km) and 'Velocity' (0-90 Km/h) these random values are sorted in ascending order, because it is natural that when a user is in motion he/she will pass longer distances eventually and will gain velocities with the growing instants of time. Figure 5 shows the simulation block used in MATLAB. The output levels of the hysteresis are observed in the simulink using the block 'scope'. In figure 6 the output hysteresis level of the three networks are shown. The values of the hysteresis level are tabulated in table: 2. Table 1 and 2 shows distance, velocity and traffic as an input and hysteresis as an output. The notations are as follows: dis= distance, vel=velocity, TrGP= traffic in GPRS, TrMAX= traffic in WiMAX, TrFi= traffic in WiFi, HyGP= Hysteresis in GPRS, hyMAX=hysteresis in WiMAX and HyFi= Hysteresis in WiFi. Figure 6 shows the Hysteresis level for GPRS, WiMAX and WiFi networks.

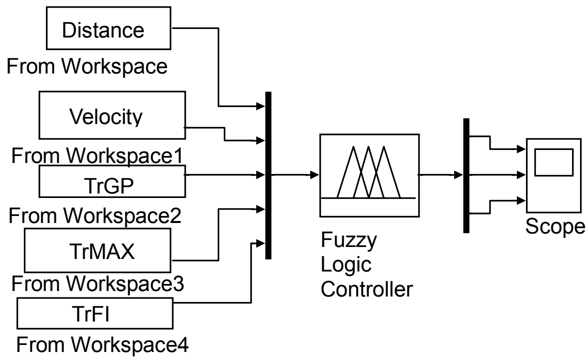

Fig. 5. Simulation block

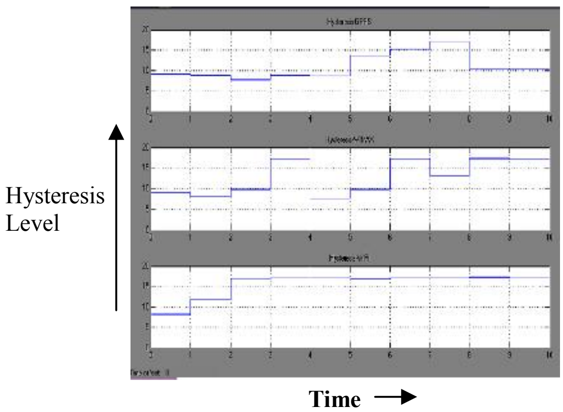

Fig. 6. Output result of the simulation

Table. 2. Input random values at ten time sequences

INPUT					OUTPUT		
Dist	Vel	TrGP	Tr MAX	Tr Fi	Hys-GP	Hys MAX	Hys-Fi
0.39	0.79	7	6	6	9.27	9.08	**8.19**
0.82	0.82	41	22	6	8.9	**8.06**	11.8
1.06	2.88	40	36	1	**7.73**	9.79	16.8
1.32	9.50	32	45	2	**8.78**	17	17
2.79	18.38	13	13	16	8.65	**7.51**	17.1
9.38	29.35	61	12	4	13.6	**9.75**	17
11.52	30.43	63	44	21	**15.1**	17.1	17.1
13.54	31.57	66	11	4	17.2	**13.2**	17.2
18.37	34.63	43	41	4	**10.5**	17.2	17.2
20.49	35.88	50	46	25	**10.5**	17.2	17.2

In table 2 the selected network is indicated by bold letter in the output Hysteresis level. At the 1st instant the user is in Wi Fi network and then switched to WiMAX at time t=1. At t=2, 3 the best candidate network for handoff is chosen as the GPRS though it was expected to be the WiMAX. But due to high traffic density in WiMAX, GPRS appeared as the best one. Due to medium velocity and medium distance WiMAX became the better candidate cell for the input profile than the GPRS at t=4, 5. At t=6 the input parameters suggests handoff to GPRS as traffic in WiMAX is high. For the input values at t=7 the session is again transferred to WiMAX as traffic in GPRS appeared as High. For the last two sequences, handoff to the GPRS is obligatory as velocity is medium and traffic in WiMAX is high.

V. Conclusion

In this work an adaptive handoff algorithm based on fuzzy logic has been presented to choose the best handoff candidate cell in a heterogeneous network structure and the simulation is carried out with the help of MATLAB. Depending on user's location, velocity and traffic in the three networks, hysteresis levels for the constituent networks are varied. As a result this handoff algorithm can work adaptively for the ranges considered for the input variables (i.e. distance= 0 to 30 Km, velocity= 0 to 80 km¥h). To make this algorithm tuned with other ranges simply the change in the input membership functions is sufficient.

This adaptive algorithm was developed under constrains that handoff should be encouraged to GPRS for a user in long distance and user with a fast velocity. Again to exploit the high data rate of the WLANs (WiMAX and Wi-Fi) handoff to the WLANs is expected for users in short or medium distances and users with slowest or slow velocities. These criteria again modulated by the traffic density in individual coverage areas.

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