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A speed-aware handover system for wireless cellular networks based on fuzzy logic

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Abstract. Presently, the wireless mobile networks and devices are becoming increasingly popular to provide users the access anytime and anywhere. The mobile systems are based on cellular approach and the area is covered by cells that overlap each other. In mobile cellular systems the handover is a very important process, which refers to a mechanism that transfers an ongoing call from one Base Station (BS) to another. The performance of the handover mechanism is very important to maintain the desired Quality of Service (QoS). Many handover algorithms are proposed in the literature. However, to make a better handover and keep the QoS in wireless networks is very difficult. In this paper, we propose a speed-aware handover system based on fuzzy logic. The proposed system has 3 subsystems. The performance evaluation via simulations shows that proposed system has a good handover decision.

1. Introduction

The future networks (such as the third-generation and forth-generation wireless networks) aim to provide integrated services such as voice, data, and multimedia via inexpensive low-powered mobile computing devices over wireless infrastructures. As the demand for multimedia services over the air has been steadily increasing over the last few years, wireless multimedia networks have been a very active research area [1,7].

The QoS support for future wireless networks is a very important problem. To guarantee the QoS, a good handover strategy is needed in order to balance the call blocking and call dropping for providing the required QoS [5,14]. In a cellular system, when a mobile user travels from one cell to another, the serving BS changes according to the planning of the network. Frequent handovers influence the QoS, increase the signaling overhead on the network, and degrade throughput in data communications. Thus, network operators should emphasize the optimization of handover decisions.

While in wired networks the resources are reserved for the call at set-up time and are not changed after that, in cellular wireless networks when the mobile node moves from one cell to another one, the bandwidth must be requested in the new cell. During this process, the call may not be able to get a channel in the new cell to continue its service due to the limited resource in wireless networks, which will lead to the call dropping. Thus, the new calls and handoff calls have to be treated differently in terms of resource allocation. Since users are much more sensitive to call dropping than to call blocking, the handoff calls are assigned higher priority than new calls.

With the increasing demand for mobile computing services and limited available bandwidth, wireless cellular networks will increase the number of simultaneous users in the network systems by reducing the cell size. In the future, the wireless networks will adopt a micro/pico cellular architecture. However, smaller cell size naturally increases the number of handoffs a Mobile Terminal (MT) is expected to make. As the new call arrival rate or load increases, the probability of handoff failure increases. This phenomenon combined with the large number of handoffs before completion of a call increases the forced termination probability of calls [9,15].

Many metrics have been used to support handover decisions, including Received Signal Strength (RSS), Signal to Interference Ratio (SIR), distance between the mobile and BS, traffic load, and mobile velocity, where RSS is the most commonly used one. The conventional handover decision compares the RSS from the serving BS with that from one of the target BSs, using a constant handover threshold value (handover margin). The selection of this margin is crucial to handover performance. If the margin is too small, numerous unnecessary handovers may be processed. Conversely, the QoS could be low and calls could be dropped if the margin is too large. The fluctuations of signal strength associated with shadow fading cause a call sometimes to be repeatedly handed over back and forth between neighboring BSs, in what is called the ping-pong effect [10].

Recently, many investigations have addressed handover algorithms for cellular communication systems. One method uses a local averaging technique, which moves fast fading component from the received signal strength to allow the conventional handoff decision reacting more quickly to corner effects. Another work proposes a timer-based hard handover algorithm to prevent unnecessary handovers caused by fluctuations due to shadowing, by which the choice of timer interval introduces the trade off between handoff number and handoff delay. Also, a dynamic handover margin decision based on a traffic balancing rule was proposed to resize the cells according to the spatial variability of traffic. A table lookup approach was proposed to determine the handover margins based on the mobile location. Another method uses distance hysteresis for mitigating the effect of fadings on handover performance [10].

However, it is essentially complex to make handover decision considering multiple criteria. Sometimes, the trade-off of some criteria should be considered. Therefore, heuristic approaches based on Neural Networks (NN), Genetic Algorithms (GA) and Fuzzy Logic (FL) can prove to be efficient for wireless networks [2,3,6,12,13]. In [12], a multi-criteria handover algorithm for next generation tactical communication systems is introduced. The handover metrics are: RSS from current and candidate base transceivers, ratio of used soft capacity to the total soft capacity of base transceivers, and the relative directions and speeds of the base transceivers and the mobile node. In [3], a handover algorithm is proposed to support vertical handover between heterogeneous networks. This is achieved by incorporating the mobile IP principles in combination with FL concepts utilizing different handover parameters. However, these algorithms seem to be complex, because the number of fuzzy rules is high.

Rapid progress in the research and development of wireless networking and communication technologies has created different types of wireless communication systems, such as Bluetooth for personal area, IEEE 802.11-based WLANs for local area, Universal Mobile Telecommunications System (UMTS) for wide area, and satellite networks for global networking. These networks are complementary to each other and, hence, their integration can realize unified Next Generation Wireless Systems (NGWS) that have the best features of the individual networks to provide ubiquitous communication for mobile users [8, 11,16].

In NGWS, two types of handoff scenarios may arise: horizontal handoff and vertical handoff. Horizontal handoff is carried out between two BSs of the same system. Horizontal handoff can be further classified into: Link-Layer handoff (horizontal handoff between two BSs that are under the same foreign agent), and Intrasystem handoff (horizontal handoff between two BSs that belong to two different Foreign Agent (FAs) and both the FAs belong to the same system) [11]. Vertical handoff is a intersystem handoff and is carried out between two BSs that belong to two different systems [11,16].

In this paper, in different from other works by considering a mixed cell architecture, we propose a speed-aware handover system based on FL. The proposed system consists of three FLCs. The FLC1 determines the speed of MN and then FLC2 makes the handover decision for slow-speed users and FLC3 for high-speed users. In this paper, we consider a 2-layer structure, where micro cells are in the low layer and macro cells on the upper layer which serve as an umbrella. However, the work can be extended considering the universal wireless networks coverage [8].

The structure of this paper is as follows. In Section 2, we present the handover decision problem. In Section 3, we introduce the proposed system. In Section 4, we discuss the simulation results. Finally, some conclusions are given in Section 5.

2. Handover decision problem

Handoffs which are consistently both accurate and timely can result in higher capacity and better overall link quality than what is available with today systems. Now with increasing demands for more system capacity, there is a trend toward smaller cells, also known as microcells. Handover is more critical in systems with smaller cells, because for a given average user speed, handover rates tend to be inversely proportional to cell size [15].

The main objectives of handover are link quality maintenance, interference reduction and keeping the number of handovers low. Also, a handover algorithm should initiate a handoff if and only if the handoff is necessary. The accuracy of a handover algorithm is based on how the algorithm initiates the handover process. The timing of the handoff initiation is also important. There can be deleterious effects on link quality and interference if the initiation is too early or too late. A timely handover algorithm is one which initiates handoffs neither too early nor too late.

Because of large-scale and small-scale fadings are frequently encountered in mobile environment, it is very difficult for handover algorithm to make an accurate and timely decision. Handover algorithms operating in real time have to make decisions without the luxury of repeated uncorrelated measurements, or of future signal strength information. It should be noted that some of handover criteria information can be inherently imprecise, or the precise information is difficult to obtain. For this reason, we propose a FL-based approach, which can operate with imprecision data and can model nonlinear functions with arbitrary complexity.

3. Proposed system model

The Fuzzy Logic Controller (FLC) is the main part of the proposed Fuzzy Handover Decision System (FHDS) and its basic elements are shown in Fig. 1. They are the fuzzifier, inference engine, Fuzzy Rule Base (FRB) and defuzzifier. As membership functions, we use triangular and trapezoidal membership functions because they are suitable for real-time operation [4]. They are shown in Fig. 2 and are given as:

$$f(x; x_0, a_0, a_1) = \begin{cases} \frac{x-x_0}{a_0} + 1 & \text{for } x_0 - a_0 < x \leqslant x_0 \\ \frac{x_0-x}{a_1} + 1 & \text{for } x_0 < x \leqslant x_0 + a_1 \\ 0 & \text{otherwise} \end{cases}$$

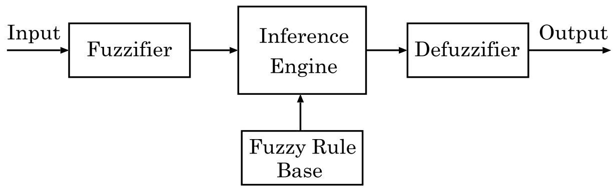

Fig. 1. FLC structure.

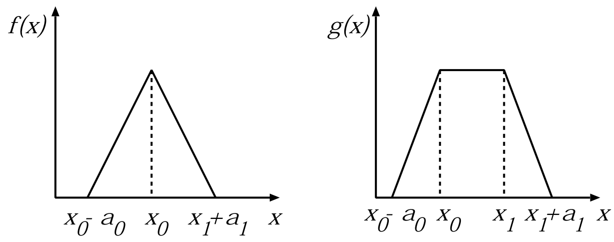

Fig. 2. Triangular and trapezoidal membership functions.

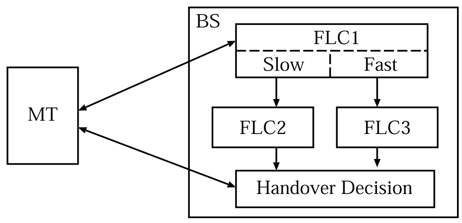

Fig. 3. Proposed system model.

$$g(x; x_0, x_1, a_0, a_1) = \begin{cases} \frac{x-x_0}{a_0} + 1 & \text{for } x_0 - a_0 < x \leqslant x_0 \\ 1 & \text{for } x_0 < x \leqslant x_1 \\ \frac{x_1-x}{a_1} + 1 & \text{for } x_1 < x \leqslant x_1 + a_1 \\ 0 & \text{otherwise} \end{cases}$$

where x_0 in $f(.)$ is the center of triangular function; $x_0(x_1)$ in $g(.)$ is the left (right) edge of trapezoidal function; and $a_0(a_1)$ is the left (right) width of the triangular or trapezoidal function.

The proposed FHDS shown in Fig. 3 has three FLC. The FLC1 determines the speed of MT and then FLC2 makes the handover decision for slow-speed users and FLC3 for high-speed users.

3.1. Design of FLC1

The input parameters for FLC1 are: Distance (*D*) and Error ratio (*Er*), while the output linguistic parameter is Prediction factor (*Pf*). The term sets of *D* and *Er* are defined respectively as:

$$T(D) = \{Small, Middle, Far\} = \{Sm, Mi, Fa\};$$

$$T(Er) = \{Small, Normal, Big\} = \{Sl, No, Bi\}.$$

The membership functions for input parameters of FLC1 are defined as follows:

$$\mu_{Sm}(D) = f(D; Sm_0, Sm_{w0}, Sm_{w1});$$

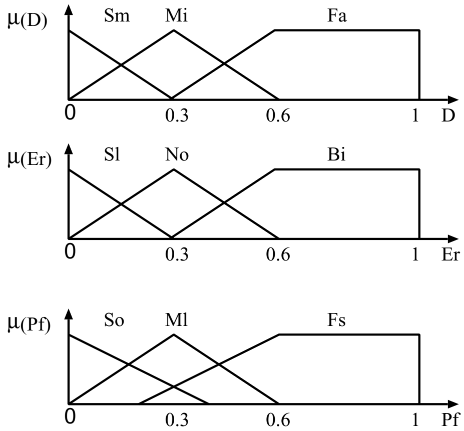

Fig. 4. FLC1 membership functions.

$$\mu_{Mi}(D) = f(D; Mi_0, Mi_{w0}, Mi_{w1});$$
$$\mu_{Fa}(D) = g(D; Fa_0, Fa_1, Fa_{w0}, Fa_{w1});$$
$$\mu_{Sl}(Er) = f(Er; Sl_0, Sl_{w0}, Sl_{w1});$$
$$\mu_{No}(Er) = f(Er; No_0, No_{w0}, No_{w1});$$
$$\mu_{Bi}(Er) = g(Er; Bi_0, Bi_1, Bi_{w0}, Bi_{w1}).$$

The small letters *w0* and *w1* mean left width and right width, respectively.

The output linguistic parameter $T(Pf)$ is defined as {*Slow, Middle, Fast*} $= \{So, Ml, Fs\}$. The membership functions for the output parameter *Pf* are defined as follows:

$$\mu_{So}(Pf) = f(Pf; So_0, So_{w0}, So_{w1});$$
$$\mu_{Ml}(Pf) = f(Pf; Ml_c, Ml_{w0}, Ml_{w1});$$
$$\mu_{Fs}(Pf) = g(Pf; Fs_0, Fs_1, Fs_{w0}, Fs_{w1}).$$

The membership functions of FLC1 are shown in Fig. 4. The FRB forms a fuzzy set of dimensions $|T(D)| \times |T(Er)|$, where $|T(x)|$ is the number of terms on $T(x)$. The FRB1 shown in Table 1 has 9 rules. The control rules have the following form: IF "conditions" THEN "control action".

In order to calculated the distance *D* parameter of moving MT, the BS uses a control message to ask the MT for its position. By considering the transmission time of the control message and the delay time of the received control message, the BS calculates the *D* parameter. If the *D* is small then the speed of MT is slow, on the other hand, when the *D* is large the speed is high. For the *Er* parameter, when the speed of MT is high, the *Er* tends to be high, while when the speed of MT is slow, the *Er* is low.

By considering *D* and *Er* input parameters FLC1 decides the speed of MT. If the speed is slow, then the FLC2 is activated, otherwise the FLC2 makes the handover decision for high speed MT.

3.2. Design of FLC2

When the MT moves with a low speed the probability to change the direction is very high. For this reason, we selected as an input parameter the angle which the MT is approaching the BS (*Aa*) and the

Table 1
FRB1

Rule	D	Er	Pf
0	Sm	Sl	So
1	Sm	No	So
2	Sm	Bi	Ml
3	Mi	Sl	So
4	Mi	No	So
5	Mi	Bi	Mi
6	Fa	Sl	Mi
7	Fa	No	Fs
8	Fa	Bi	Fs

change of the intensity of the Electric Field (*Ec*). Based on these 2 input parameters, the FCL2 makes the handover decision for low speed MT.

The term sets of *Ec* and *Aa* are defined respectively as:

$$T(Ec) = \{\textit{Very Negative, Negative, Around Zero, Positive, Very Positive}\}$$
$$= \{Vn, Ne, Az, Po, Vp\};$$
$$T(Aa) = \{\textit{Left, Front, Right}\} = \{Le, Fr, Ri\}.$$

The membership functions for input parameters of FLC2 are defined as follows:

$$\mu_{Vn}(Ec) = f(Ec; Vn_0, Vn_{w0}, Vn_{w1});$$
$$\mu_{Ne}(Ec) = f(Ec; Ne_0, Ne_{w0}, Ne_{w1});$$
$$\mu_{Az}(Ec) = f(Ec; Az_0, Az_{w0}, Az_{w1});$$
$$\mu_{Po}(Ec) = f(Ec; Po_0, Po_{w0}, Po_{w1});$$
$$\mu_{Vp}(Ec) = f(Ec; Vp_0, Vp_{w0}, Vp_{w1});$$
$$\mu_{Le}(Aa) = g(Aa; Le_0, Le_1, Le_{w0}, Le_{w1});$$
$$\mu_{Fr}(Aa) = f(Aa; Fr_0, Fr_{w0}, Fr_{w1});$$
$$\mu_{Ri}(Aa) = g(Aa; Ri_0, Ri_1, Ri_{w0}, Ri_{w1}).$$

The term set of the output linguistic parameter $T(Hf1)$ is defined as $\{\textit{Low, Middle, High}\} = \{Lo, Md, Hi\}$. The membership functions for the output parameter *Hf1* are defined as follows:

$$\mu_{Lo}(Hf1) = g(Hf1; Lo_0, Lo_1, Lo_{w0}, Lo_{w1});$$
$$\mu_{Md}(Hf1) = f(Hf1; Md_0, Md_{w0}, Md_{w1});$$
$$\mu_{Hi}(Hf1) = g(Hf1; Hi_0, Hi_1, Hi_{w0}, Hi_{w1}).$$

The membership functions of FLC2 are shown in Fig. 5. The FRB2 shown in Table 2 has 15 rules.

3.3. Design of FLC3

In the case when MT moves with a high speed, the probability to change the direction is very low. For this reason, we selected as input parameters for FLC3 the change of the RSS of the electric field intensity

Table 2
FRB2

Rule	Ec	Aa	Hf1
0	Vn	Le	Hi
1	Vn	Fr	Md
2	Vn	Ri	Hi
3	Ne	Le	Md
4	Ne	Fr	Md
5	Ne	Ri	Md
6	Az	Le	Md
7	Az	Fr	Md
8	Az	Ri	Md
9	Po	Le	Md
10	Po	Fr	Lo
11	Po	Ri	Md
12	Vp	Le	Lo
13	Vp	Fr	Lo
14	Vp	Ri	Lo

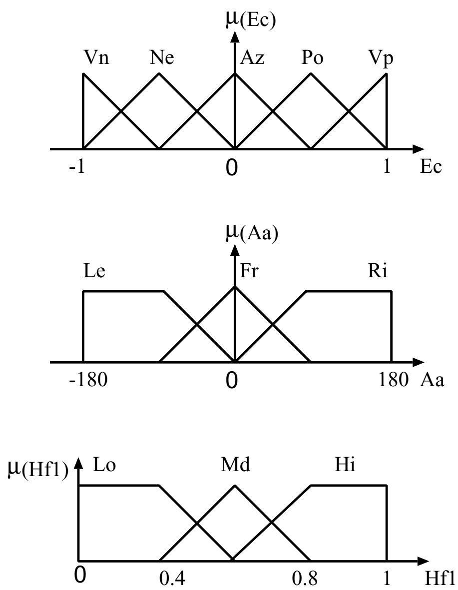

Fig. 5. FLC2 membership functions.

for neighbor BSs. The input linguistic parameters are the change of electric field intensity of BS1 ($E1c$) and the change of the electric field intensity of BS2 ($E2c$). Based on these 2 input parameters, the FCL3 makes the handover decision for high speed MT.

The term sets of *E1c* and *E2c* are defined respectively as:

$$T(E1c) = \{\textit{Negative, Around Zero, Positive}\} = \{Ng, Az1, Pi\};$$

$$T(E2c) = \{\textit{Negative, Around Zero, Positive}\} = \{Na, Az2, Pz\}.$$

The membership functions for input parameters of FLC3 are defined as follows:

$$\mu_{Ng}(E1c) = f(E1c; Ng_0, Ng_{w0}, Ng_{w1});$$

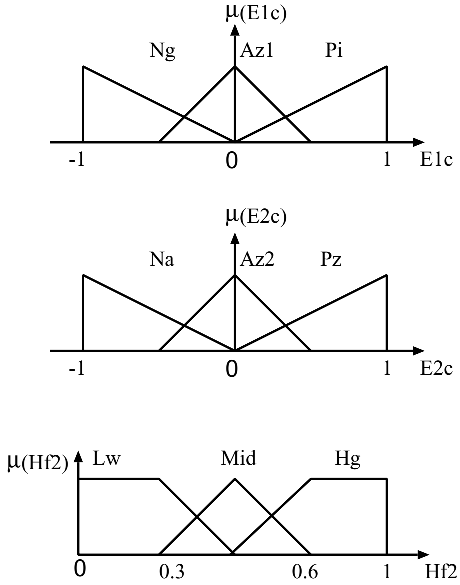

Fig. 6. FLC3 membership functions.

$$\mu_{Az1}(E1c) = f(E1c; Az1_0, Az1_{w0}, Az1_{w1});$$
$$\mu_{Pi}(E1c) = f(E1c; Pi_0, Pi_{w0}, Pi_{w1});$$
$$\mu_{Na}(E2c) = f(E2c; Na_0, Na_{w0}, Na_{w1});$$
$$\mu_{Az2}(E2c) = f(E2c; Az2_0, Az2_{w0}, Az2_{w1});$$
$$\mu_{Pz}(E2c) = f(E2c; Pz_0, Pz_{w0}, Pz_{w1}).$$

The term set of the output linguistic parameter $T(Hf2)$ is defined as $\{$*Low, Middle, High*$\} = \{Lw, Mid, Hg\}$. The membership functions for the output parameter *Hf2* are defined as follows:

$$\mu_{Lw}(Hf2) = g(Hf2; Lw_0, Lw_1, Lw_{w0}, Lw_{w1});$$
$$\mu_{Mid}(Hf2) = f(Hf2; Mid_0, Mid_{w0}, Mid_{w1});$$
$$\mu_{Hg}(Hf2) = g(Hf2; Hg_0, Hg_1, Hg_{w0}, Hg_{w1}).$$

The membership functions of FLC3 are shown in Fig. 6. The FRB3 shown in Table 3 has 9 rules.

4. Simulation results

The simulation were carried out in Linux Fedora Core5 computer by using FuzzyC software developed in our laboratory. The performance evaluation for FLC1, FLC2 and FLC3 drawing by MATLAB are shown in Figs 7, 8, and 9, respectively.

In Fig. 7 is shown the performance of FLC1. With the increase of the distance and the error ratio, the prediction factor is increased. The threshold for deciding the speed of the MT is set to 0.3. When, the speed of MT is approaching 40km/h, the MT is considered moving with high speed, but the speed is not changing too much, so the error ratio remain constant.

Table 3
FRB3

Rule	E1c	E2c	Hf2
0	Ng	Na	Hg
1	Ng	Az2	Hg
2	Ng	Pz	Mid
3	Az1	Na	Hg
4	Az1	Az2	Mid
5	Az1	Pz	Mid
6	Pi	Na	Mid
7	Pi	Az2	Mid
8	Pi	Pz	Lw

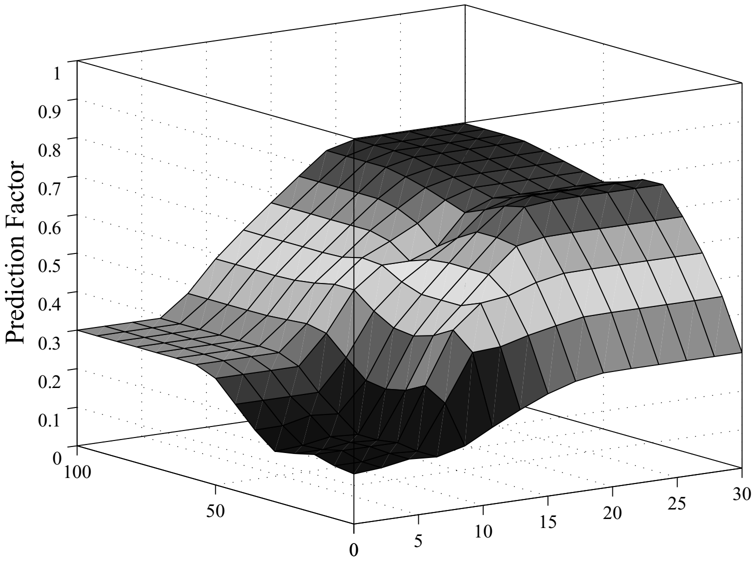

Fig. 7. FLC1 performance.

In Fig. 8 is shown the performance of FLC2. The MT is moving with a low speed. This is the case of walking persons or when the cars are slowing down the speed (when traffic signal becomes red). In order to avoid the ping-pong effect, we selected the threshold of handover factor to be 0.7. When the approaching angle is small, it means that the MT is coming directly to the BS. Therefore, the handover factor is small. With the increase of the approaching angle value and the change of the RSS, the handover factor is increased.

In Fig. 9 is shown the performance of FLC3. This is the case for moving cars, so the probability of changing direction is very small. The threshold for handover factor was set 0.5. The figure shows that with the decrease of the RSS the handover factor is increased. However, when the RSS is high, the handover factor is very small. So, it is not necessary to make handover.

In Table 4, we show the comparison of the proposed FHDS with other fuzzy-based handover systems. Our FHDS needs only 33 rules for making the handover decision. However, the algorithms proposed in [3,12] seem to be complex, because the number of fuzzy rules is high.

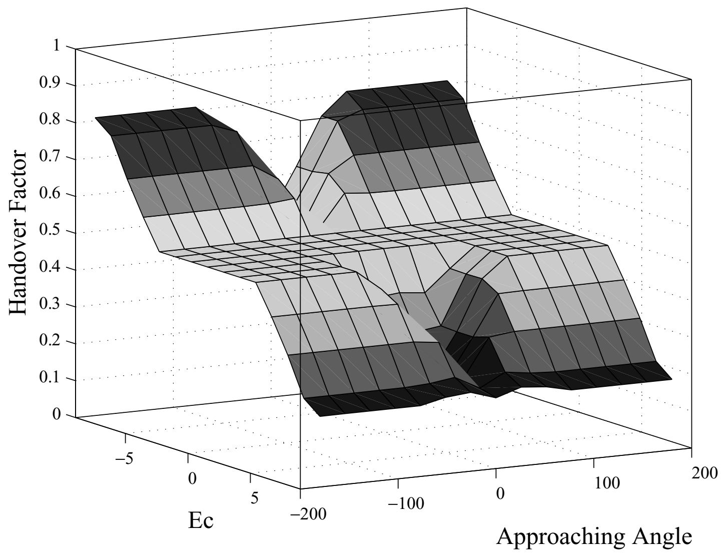

Fig. 8. FLC2 performance.

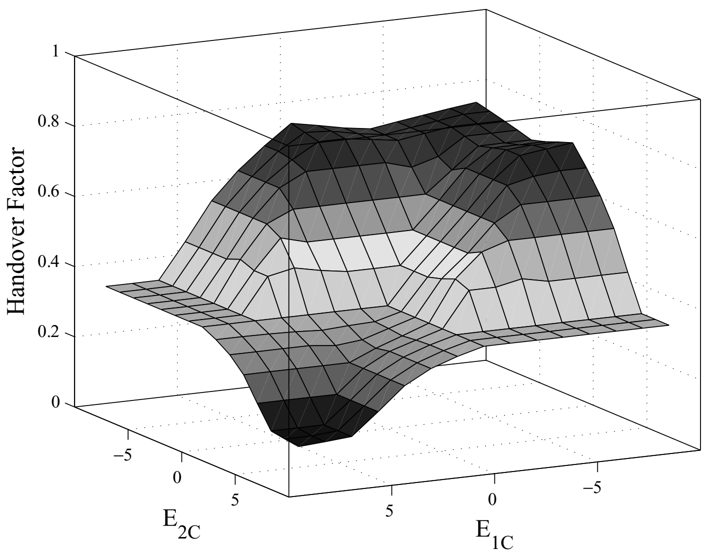

Fig. 9. FLC3 performance.

5. Conclusions

In this paper, we proposed a FHDS for wireless cellular networks. In different from other works by considering a mixed cell architecture, we propose a FL-based speed-aware handover system that consists of three FLCs. The FLC1 determines the speed of MT and then FLC2 makes the handover decision for slow-speed users and FLC3 for high-speed users.

From the simulation results we conclude as follows.

– When the approaching angle is small, it means that the MT is coming directly to the BS, so the

Table 4
Comparison of fuzzy-based systems

Systems	Fuzzy handover (Ref. [3])	Fuzzy handover (Ref. [12])	Proposed FHDS
Number of FLC	1	1	3
Number of input parameters	4	4	2;2;2
Number of membership functions	(3,3,3,3)	(3,3,3,3)	(3,3);(5,3);(3,3)
Number of fuzzy rules	81	81	33

handover factor is small.

– With the increase of the approaching angle value and the change of the RSS, the handover factor is increased.
– With the decrease of the RSS the handover factor is increased.
– When the RSS is high, the handover factor is very small. So, it is not needed to make handover.

In this paper, we consider a 2-layer structure, where micro cells are in the low layer and macro cells on the upper layer which serve as umbrella. However, the work can be extended considering the universal wireless networks coverage.

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