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# FICHS: A Fuzzy-based Integrated CAC and Handover System for Cellular Networks

**Gjergji Mino*, Elis Kulla*, Taku Ikebata*, Leonard Barolli† and Jiro Iwashige†**

*Graduate School of Engineering
Fukuoka Institute of Technology (FIT)
3-30-1 Wajiro-Higashi, Higashi-Ku, Fukuoka 811–0295, Japan
Email: gjmino@gmail.com, eliskulla@yahoo.com, mgm10002@bene.fit.ac.jp

†Department of Information and Communication Engineering
Fukuoka Institute of Technology (FIT)
3-30-1 Wajiro-Higashi, Higashi-Ku, Fukuoka 811–0295, Japan
Email: barolli@fit.ac.jp, iwashige@fit.ac.jp

***Abstract*—Several schemes have been proposed for CAC and handover in wireless cellular networks. However, during the complexity of CAC and handover in wireless environment, many simplified models and assumptions are made. Also, the CAC and handover algorithms operating in real time have to make decisions without the luxury of repeated uncorrelated measurements or the future signal strength information. It should be noted that some of CAC and handover criteria information can be inherently imprecise, or the precise information is difficult to obtain. For this reason, we propose a Fuzzy Logic (FL) based approach for CAC and handover for wireless cellular networks (called FICHS), which can operate with imprecision data and non-linear functions with arbitrary complexity. To evaluated the performance of FICHS we use two scenarios: avoidance of ping-pong effect and enforced handover. We show that FICHS has a good behavior.**

***Keywords*- Fuzzy; CAC; Handover; Cellular Networks; Fuzzy Logic.**

## I. Introduction

During the last few years wireless multimedia networks have been a very active research area [1], [2]. The QoS support for future wireless networks is a very important problem. Call Admission Control (CAC) and handover strategies are needed for providing the required QoS [3]–[6].

Several schemes have been proposed for CAC in wireless cellular networks. However, during the complexity of CAC in wireless environment, many simplified models and assumptions are made. Some schemes consider that each mobile node will make hand-over to neighboring cells with equal probability, which may be not accurate in general.

In [7], the authors propose a simple and robust fuzzy-based algorithm to predict the Cell Loss Ratio (CLR) in large-sized systems based on both a small amount of information from small-sized systems, and the asymptotic behavior for very large systems. Unlike the model-based approaches, this approximation avoids the problem of assuming any traffic parameters or arrival process. This algorithm is used with real-time traffic measurement and provide an effective measurement-based CAC framework for ATM networks.

Since the traditional guard channel policy is not optimal for a hard constrained handoff dropping probability, new CAC algorithms have been studied in [8]. The authors discuss simplifications to the original scheme and enhance the modified scheme by considering the difference of mobility support requirement between high and low mobility users. The simulation results show that the enhanced scheme gives better performance.

CAC plays a significant role in providing the desired QoS in wireless networks. In [9], the analytical results for some performance metrics such as call blocking probabilities are obtained under some specific assumptions. It is observed, that due to the mobility, some assumptions may not be valid, which is the case when the average values of channel holding times for new calls and handoff calls are not equal.

In [10], the authors provide a CAC policy that is designed to make efficient use of the limited wireless channel. This scheme takes advantage of the diverse traffic characteristics in order to admit flows based on the requested traffic parameters. Simulation results are included to verify the validity of this approach and its importance in future wireless communication.

Handover is a key feature of mobile communication networks which mainly resides in the BS subsystem (BSS). Therefore the BSS design is heavily affected by handover process and vice versa. In [11], the handover related performance evaluation issues are outlined. Different types of handover are taken into account. Also the design methodology of the BS system architecture is discussed.

A novel class of direction biased handoff algorithms are proposed for improving the handoff performance in urban microcells [12]. Multi-cell urban microcell handoff properties are derived for a cell layout with BSs at every other intersection. The direction biased handoff algorithms are



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shown to improve cell membership properties and handoff performance by lowering the mean number of handoffs while simultaneously reducing the handoff delay. A direction estimation technique based on the signal strength history is shown to provide improved handoff performance, especially for line of sight handoffs.

In [13] is evaluated the performance of handoff schemes in microcellular Personal Communication Systems (PCS) which cater to both pedestrian and vehicular users. Various performance parameters, including blocking of new calls, channel utilization, handoff blocking and call termination probabilities for each user type are evaluated. Different queuing disciplines for handoff calls and their impact on system performance are studied. It is also studied the tradeoff in handoff blocking and call termination probabilities between user types as the handoff traffic carried by the system from each user type is varied.

The author in [14] presents an overview of published work on handover performance and control and discusses current trends in handover research. Investigations that are applicable to a single tier of cells are discused. This research is focused on macrocells, but includes a brief discussion on how things change as cell sizes shrink.

Recently, many investigations have addressed handover algorithms for cellular communication systems. 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 [15], [16].

In our previous work, in order to deal with CAC in wireless cellular networks, we proposed a CAC scheme based on FL [17], [18]. We implemented and evaluated the proposed system by comparing its performance with Shadow Cluster Concept (SCC) [19].

In [20], 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, the relative directions and speeds of the base transceivers and the mobile node.

In [21], 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.

In this paper, different from other works we propose an integrated approach for CAC and handover in wireless cellular networks. The structure of this paper is as follows. In Section II, we present CAC. In Section III we introduce the handover decision problem. In Section IV, we explain our proposed system. In Section V, we discuss the simulation results. Finally, some conclusions are given in Section VI.

## II. CAC

CAC is a provisioning strategy that limits the number of connections into the network in order to reduce the network congestion and call dropping. CAC is not a problem that is unique to wireless networks. It is applicable to almost every type of networks, but in cellular wireless networks due to users mobility the CAC becomes much more complicated.

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 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.

CAC techniques are required to guarantee that all traffic types meet their QoS requirements. In order to improve the system performance at the call level (fairness in blocking), a CAC strategy may block additional calls even if there are enough resources for their service. CAC is based on the knowledge of the statistical characteristics of ongoing and arriving calls [22]. The decision to accept an additional call involves the calculation or estimation of the consequences of the call acceptance on blocking and delay of itself and other incoming calls.

Beside the functionality of CAC, bandwidth reservation mechanism helps CAC to decide how much bandwidth is needed to be reserved in order to provide QoS guarantees to mobile users. The bandwidth reservation module, residing in each BS, dynamically changes the amount of bandwidth to be reserved by referencing traffic conditions in neighboring cells periodically or upon the call request arrival depending on the design of the system.

## III. 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 [23], [24]. Now with increasing demands for more system capacity, there is a trend toward smaller cells, also known as microcells. Handoffs are more critical in systems with smaller cells, because for a given average user speed, handoff rates tend to be inversely proportional to cell size [25]. The main objectives of handover are link quality maintenance, interference reduction and keeping the number of handoffs 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.

Because of large-scale and small-scale fades 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.

## IV. Proposed System Model

### A. FICHS Operation

In this paper different from other research works on CAC and handover, we propose and implement a Fuzzy-based Integrated CAC and Handover System (FICHS) for wireless cellular networks.

In the best of our knowledge, most of the research works deal only with CAC or handover. While, the proposed system integrates CAC and handover and improves the QoS of wireless cellular networks.

The structure of FICHS is shown in Fig. 1. First, after the BS gets the call from Mobile Terminal (MT), it checks whether this is a new generated call or not. If the call is a new generated call then the FACS is activated. If the system has enough bandwidth, then the call is accepted, otherwise the call is rejected and the MT will try again to connect with BS.

When the call is not a new generated call, then the FBHS is activated. The FBHS checks whether the MT moves in the boundary of cells or inside the cell. If the MT is moving inside the cell, the handover is carried out and then the FACS carries out the CAC procedure. Otherwise, in the case when the MT is moving in the baundary of the cells the handover is not carried out and the call is kept connected with the same BS.

The main parts of FICHS are Fuzzy-based Admission Control Scheme with Priority (FACS-P) and Fuzzy-based Handover System (FBHS), which we will explain in following.

### B. FACS-P

In our previous work (FACS) [26], we found that the distance did not have a big effect on the CAC decision. For this reason, in the new implemented system, called FACS with Priority (FACS-P) of on-going connections, instead the distance we will use the priority as a new parameter for CAC decision.

The proposed FACS-P considers the following parameters for acceptance decision: user Speed (*Sp*), user Angle (*An*),

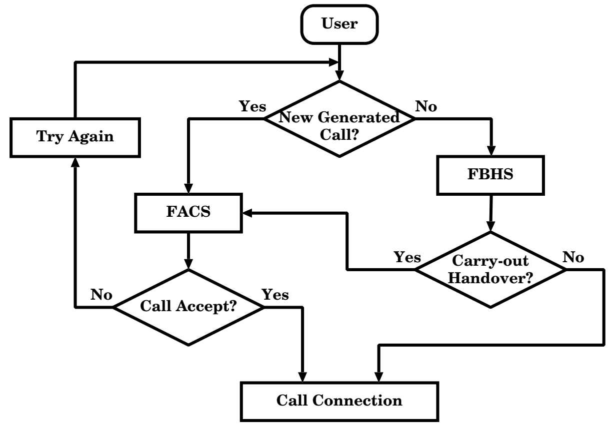


Figure 1: FICHS structure.

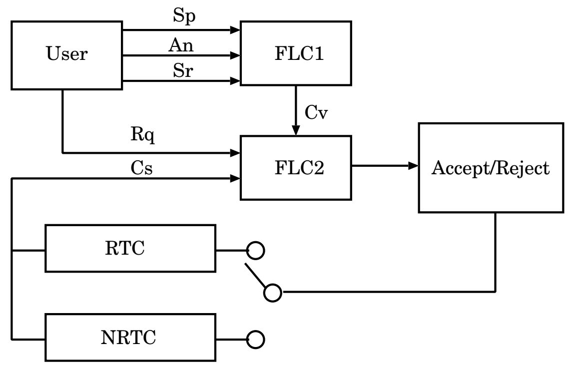


Figure 2: FACS-P proposed model.

Service request (*Sr*), Correction value (*Cv*), Required bandwidth (*Rq*), Counter state (*Cs*), Accept or Reject decision (*A/R*), Differentiated service (*Ds*), Real Time Counter (*RTC*), and Non Real Time Counter (*NRTC*). The structure of the proposed FACS-P is shown in Fig. 2.

*1) FLC1 Design:* The input parameters for FLC1 are: user Speed (*Sp*), user Angle (*An*), and the bandwidth of the application that we call Service request (*Sr*), while the output linguistic parameter is Correction value (*Cv*). The term sets of *Sp*, *An*, and *Sr* are defined respectively as:

$$\begin{aligned}
T(Sp) &= \{Slow, Middle, Fast\} = \{Sl, Mi, Fa\};\\
T(An) &= \{Back1, Left1, Left2, Straight, Right1, Right2,\\
&\quad Back2\}\\
&= \{B1, L1, L2, St, R1, R2, B2\};\\
T(Sr) &= \{Small, Medium, Big\} = \{Sm, Me, Bi\}.
\end{aligned}$$

The membership functions for input parameters of FACS-P are defined as follows:

$$\begin{aligned}
\mu_{Sl}(Sp) &= f(Sp; Sl_0, Sl_{w0}, Sl_{w1}));\\
\mu_{Mi}(Sp) &= f(Sp; Mi_0, Mi_{w0}, Mi_{w1});\\
\mu_{Fa}(Sp) &= g(Sp; Fa_0, Fa_1, Fa_{w0}, Fa_{w1});\\
\mu_{B1}(An) &= g(An; B1_0, B1_1, B1_{w0}, B1_{w1});\\
\mu_{L1}(An) &= f(An; L1_0, L1_{w0}, L1_{w1});
\end{aligned}$$

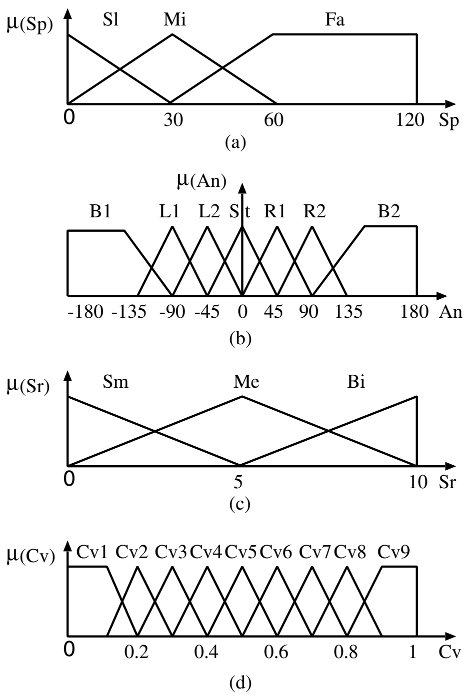


Figure 3: FLC1 membership functions (FACS-P).

$$\begin{aligned}
\mu_{L2}(An) &= f(An; L2_0, L2_{w0}, L2_{w1});\\
\mu_{St}(An) &= f(An; St_0, St_{w0}, St_{w1});\\
\mu_{R1}(An) &= f(An; R1_0, R1_{w0}, R1_{w1});\\
\mu_{R2}(An) &= f(An; R2_0, R2_{w0}, R2_{w1});\\
\mu_{B2}(An) &= g(An; B2_0, B2_1, B2_{w0}, B2_{w1});\\
\mu_{Sm}(Sr) &= f(Sr; Sm_0, Sm_{w0}, Sm_{w1});\\
\mu_{Me}(Sr) &= f(Sr; Me_0, Me_{w0}, Me_{w1});\\
\mu_{Bi}(Sr) &= f(Sr; Bi_0, Bi_{w0}, Bi_{w1}).
\end{aligned}$$

The term set of the output linguistic parameter $T(Cv)$ is defined as $\{Correction\ value\ 1, Correction\ value\ 2, \ldots$ $\ldots, Correction\ value\ 9\} = \{Cv1, Cv2, ..., Cv9\}$. The membership functions for the output parameter $Cv$ are defined as follows:

$$\begin{aligned}
\mu_{Cv1}(Cv) &= g(Cv; Cv1_0, Cv1_1, Cv1_{w0}, Cv1_{w1});\\
\mu_{Cv2}(Cv) &= f(Cv; Cv2_0, Cv2_{w0}, Cv2_{w1});\\
\mu_{Cv3}(Cv) &= f(Cv; Cv3_0, Cv3_{w0}, Cv3_{w1});\\
\mu_{Cv4}(Cv) &= f(Cv; Cv4_0, Cv4_{w0}, Cv4_{w1});\\
\mu_{Cv5}(Cv) &= f(Cv; Cv5_0, Cv5_{w0}, Cv5_{w1});\\
\mu_{Cv6}(Cv) &= f(Cv; Cv6_0, Cv6_{w0}, Cv6_{w1});\\
\mu_{Cv7}(Cv) &= f(Cv; Cv7_0, Cv7_{w0}, Cv7_{w1});\\
\mu_{Cv8}(Cv) &= f(Cv; Cv8_0, Cv8_{w0}, Cv8_{w1});\\
\mu_{Cv9}(Cv) &= g(Cv; Cv9_0, Cv9_1, Cv9_{w0}, Cv9_{w1}).
\end{aligned}$$

The membership functions of FLC1 are shown in Fig. 3 and the FRB is shown in Table I.

*2) FLC2 Design:* For the design of FLC2, we keep the same parameters with our previous work. The input parameters for FLC2 are: the output parameter of the FLC1 (*Cv*), user Request (*Rq*), and the Counter state (*Cs*), which shows the capacity of the system. While, the output linguistic parameter is the Accept/Reject decision (*A/R*).

The term sets of *Cv*, *Rq*, and *Cs* are defined as:

$$\begin{aligned}
T(Cv) &= \{Bad, Normal, Good\} = \{Bd, No, Go\};\\
T(Rq) &= \{Text, Voice, Video\} = \{Tx, Vo, Vi\};\\
T(Cs) &= \{Small, Middle, Full\} = \{Sa, Md, Fu\}.
\end{aligned}$$

The membership functions for input and output linguistic parameters of FLC2 are shown in Fig. 4 and the FRB is shown in Table II.

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

$$\begin{aligned}
\mu_{Bd}(Cv) &= f(Cv; Bd_0, Bd_{w0}, Bd_{w1});\\
\mu_{No}(Cv) &= f(Cv; No_0, No_{w0}, No_{w1});\\
\mu_{Go}(Cv) &= f(Cv, Go_0, Go_{w0}, Go_{w1});\\
\mu_{Tx}(Rq) &= f(Rq; Tx_0, Tx_{w0}, Tx_{w1});\\
\mu_{Vo}(Rq) &= f(Rq; Vo_0, Vo_{w0}, Vo_{w1});\\
\mu_{Vi}(Rq) &= f(Rq; Vi_0, Vi_{w0}, Vi_{w1});\\
\mu_{Sa}(Cs) &= f(Cs; Sa_0, Sa_{w0}, Sa_{w1});\\
\mu_{Md}(Cs) &= f(Cs; Md_0, Md_{w0}, Md_{w1});\\
\mu_{Fu}(Cs) &= f(Cs; Fu_0, Fu_{w0}, Fu_{w1}).
\end{aligned}$$

Table I: FRB of FACS-P (FLC1).

| Rule | Sp | An | Sr | Cv | Rule | Sp | An | Sr | Cv |
|---|---|---|---|---|---|---|---|---|---|
| 0 | Sl | B1 | Sm | Cv1 | 32 | Mi | St | Bi | Cv9 |
| 1 | Sl | B1 | Me | Cv3 | 33 | Mi | R1 | Sm | Cv1 |
| 2 | Sl | B1 | Bi | Cv2 | 34 | Mi | R1 | Me | Cv5 |
| 3 | Sl | L1 | Sm | Cv1 | 35 | Mi | R1 | Bi | Cv3 |
| 4 | Sl | L1 | Me | Cv4 | 36 | Mi | R2 | Sm | Cv1 |
| 5 | Sl | L1 | Bi | Cv3 | 37 | Mi | R2 | Me | Cv4 |
| 6 | Sl | L2 | Sm | Cv2 | 38 | Mi | R2 | Bi | Cv3 |
| 7 | Sl | L2 | Me | Cv6 | 39 | Mi | B2 | Sm | Cv1 |
| 8 | Sl | L2 | Bi | Cv4 | 40 | Mi | B2 | Me | Cv2 |
| 9 | Sl | St | Sm | Cv5 | 41 | Mi | B2 | Bi | Cv1 |
| 10 | Sl | St | Me | Cv9 | 42 | Fa | B1 | Sm | Cv1 |
| 11 | Sl | St | Bi | Cv7 | 43 | Fa | B1 | Me | Cv2 |
| 12 | Sl | R1 | Sm | Cv2 | 44 | Fa | B1 | Bi | Cv1 |
| 13 | Sl | R1 | Me | Cv6 | 45 | Fa | L1 | Sm | Cv1 |
| 14 | Sl | R1 | Bi | Cv4 | 46 | Fa | L1 | Me | Cv3 |
| 15 | Sl | R2 | Sm | Cv1 | 47 | Fa | L1 | Bi | Cv2 |
| 16 | Sl | R2 | Me | Cv4 | 48 | Fa | L2 | Sm | Cv2 |
| 17 | Sl | R2 | Bi | Cv3 | 49 | Fa | L2 | Me | Cv5 |
| 18 | Sl | B2 | Sm | Cv1 | 50 | Fa | L2 | Bi | Cv3 |
| 19 | Sl | B2 | Me | Cv3 | 51 | Fa | St | Sm | Cv9 |
| 20 | Sl | B2 | Bi | Cv2 | 52 | Fa | St | Me | Cv9 |
| 21 | Mi | B1 | Sm | Cv1 | 53 | Fa | St | Bi | Cv9 |
| 22 | Mi | B1 | Me | Cv2 | 54 | Fa | R1 | Sm | Cv2 |
| 23 | Mi | B1 | Bi | Cv1 | 55 | Fa | R1 | Me | Cv5 |
| 24 | Mi | L1 | Sm | Cv1 | 56 | Fa | R1 | Bi | Cv3 |
| 25 | Mi | L1 | Me | Cv4 | 57 | Fa | R2 | Sm | Cv1 |
| 26 | Mi | L1 | Bi | Cv3 | 58 | Fa | R2 | Me | Cv3 |
| 27 | Mi | L2 | Sm | Cv1 | 59 | Fa | R2 | Bi | Cv2 |
| 28 | Mi | L2 | Me | Cv5 | 60 | Fa | B2 | Sm | Cv1 |
| 29 | Mi | L2 | Bi | Cv3 | 61 | Fa | B2 | Me | Cv2 |
| 30 | Mi | St | Sm | Cv8 | 62 | Fa | B2 | Bi | Cv1 |
| 31 | Mi | St | Me | Cv9 | | | | | |

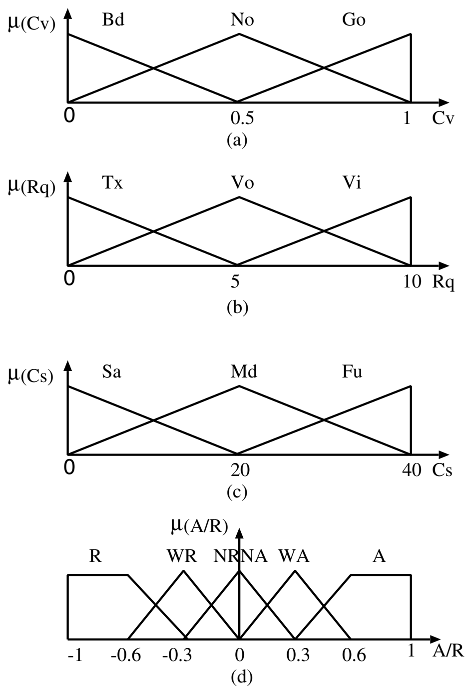


Figure 4: FLC2 membership functions (FACS-P).

Table II: FRB of FACS-P (FLC2).

| Rule | Cv | R | Cs | A/R |
|---|---|---|---|---|
| 0 | Bd | Tx | Sa | A |
| 1 | Bd | Tx | Md | NRNA |
| 2 | Bd | Tx | Fu | NRNA |
| 3 | Bd | Vo | Sa | A |
| 4 | Bd | Vo | Md | NRNA |
| 5 | Bd | Vo | Fu | WR |
| 6 | Bd | Vi | Sa | WA |
| 7 | Bd | Vi | Md | NRNA |
| 8 | Bd | Vi | Fu | WR |
| 9 | No | Tx | Sa | A |
| 10 | No | Tx | Md | NRNA |
| 11 | No | Tx | Fu | NRNA |
| 12 | No | Vo | Sa | A |
| 13 | No | Vo | Md | NRNA |
| 14 | No | Vo | Fu | NRNA |
| 15 | No | Vi | Sa | WA |
| 16 | No | Vi | Md | NRNA |
| 17 | No | Vi | Fu | NRNA |
| 18 | Go | Tx | Sa | A |
| 19 | Go | Tx | Md | A |
| 20 | Go | Tx | Fu | NRNA |
| 21 | Go | Vo | Sa | A |
| 22 | Go | Vo | Md | A |
| 23 | Go | Vo | Fu | WR |
| 24 | Go | Vi | Sa | A |
| 25 | Go | Vi | Md | A |
| 26 | Go | Vi | Fu | R |

The term set of the output linguistic parameter $T(A/R)$ is defined as {Reject, Weak Reject, Not Reject Not Accept, Weak Accept, Accept}. We write for short as {R, WR, NRNA, WA, A}. The membership functions for the output parameter *A/R* are defined as follows:

$$\begin{aligned}
\mu_R(A/R) &= g(A/R; R_0, R_1, R_{w0}, R_{w1}); \\
\mu_{WR}(A/R) &= f(A/R; WR_0, WR_{w0}, WR_{w1}); \\
\mu_{NRNA}(A/R) &= f(A/R; NRNA_0, NRNA_{w0}, NRNA_{w1}); \\
\mu_{WA}(A/R) &= f(A/R; WA_0, WA_{w0}, WA_{w1}); \\
\mu_A(A/R) &= g(A/R; A_0, A_1, A_{w0}, A_{w1}).
\end{aligned}$$

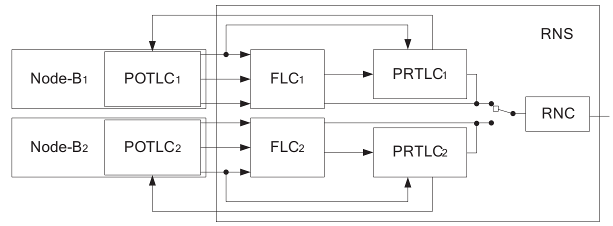


Figure 5: FBHS proposed model.

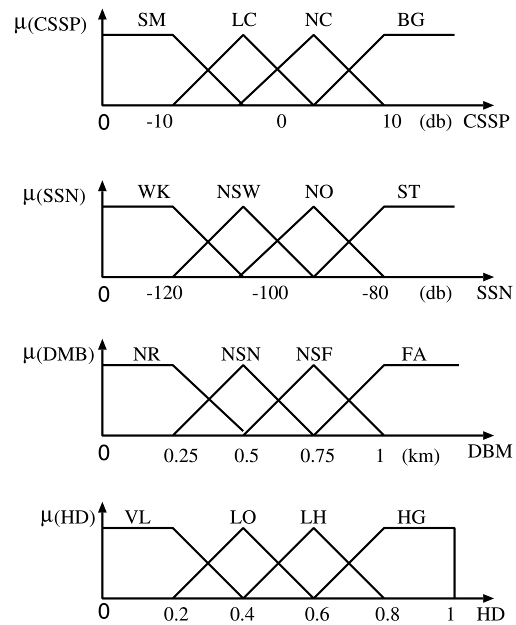


Figure 6: FBHS membership functions.

### *C. Design of FBHS*

The FBHS model is shown in Fig. 5. In this system, the *Node_B* shows the wireless transmitter and receiver of BS, RNS indicates Radio Network System. While, the POTLC stands for Post Test-Loop Controller and PRTLC for Pre Test-Loop Controller.

In FBHS we consider as the input parameter the Change of the Signal Strength of Present BS (*CSSP*). While two other parameters: Signal Strength from the Neighbor BS (*SSN*), and the distance of MS from BS (*DMB*) are kept the same. The output linguistic parameter is Handover Decision (*HD*).

Table III: FRB of FBHS.

| Rules | CSSP | SSN | DMB | HD | Rules | CSSP | SSN | DMB | HD |
|---|---|---|---|---|---|---|---|---|---|
| 1 | SM | WK | NR | LO | 33 | NC | WK | NR | VL |
| 2 | SM | WK | NSN | LO | 34 | NC | WK | NSN | VL |
| 3 | SM | WK | NSF | LH | 35 | NC | WK | NSF | VL |
| 4 | SM | WK | FA | LH | 36 | NC | WK | FA | LO |
| 5 | SM | NSW | NR | LO | 37 | NC | NSW | NR | VL |
| 6 | SM | NSW | NSN | LO | 38 | NC | NSW | NSN | VL |
| 7 | SM | NSW | NSF | LH | 39 | NC | NSW | NSF | VL |
| 8 | SM | NSW | FA | LH | 40 | NC | NSW | FA | LO |
| 9 | SM | NO | NR | LH | 41 | NC | NO | NR | VL |
| 10 | SM | NO | NSN | HG | 42 | NC | NO | NSN | LO |
| 11 | SM | NO | NSF | HG | 43 | NC | NO | NSF | LO |
| 12 | SM | NO | FA | HG | 44 | NC | NO | FA | LH |
| 13 | SM | ST | NR | HG | 45 | NC | ST | NR | LH |
| 14 | SM | ST | NSN | HG | 46 | NC | ST | NSN | LH |
| 15 | SM | ST | NSF | HG | 47 | NC | ST | NSF | HG |
| 16 | SM | ST | FA | HG | 48 | NC | ST | FA | HG |
| 17 | LC | WK | NR | VL | 49 | BG | WK | NR | VL |
| 18 | LC | WK | NSN | VL | 50 | BG | WK | NSN | VL |
| 19 | LC | WK | NSF | LO | 51 | BG | WK | NSF | VL |
| 20 | LC | WK | FA | LO | 52 | BG | WK | FA | VL |
| 21 | LC | NSW | NR | LO | 53 | BG | NSW | NR | VL |
| 22 | LC | NSW | NSN | LO | 54 | BG | NSW | NSN | VL |
| 23 | LC | NSW | NSF | LO | 55 | BG | NSW | NSF | VL |
| 24 | LC | NSW | FA | LH | 56 | BG | NSW | FA | LO |
| 25 | LC | NO | NR | LH | 57 | BG | NO | NR | VL |
| 26 | LC | NO | NSN | LH | 58 | BG | NO | NSN | VL |
| 27 | LC | NO | NSF | HG | 59 | BG | NO | NSF | LO |
| 28 | LC | NO | FA | HG | 60 | BG | NO | FA | LO |
| 29 | LC | ST | NR | LH | 61 | BG | ST | NR | VL |
| 30 | LC | ST | NSN | HG | 62 | BG | ST | NSN | VL |
| 31 | LC | ST | NSF | HG | 63 | BG | ST | NSF | LO |
| 32 | LC | ST | FA | HG | 64 | BG | ST | FA | LO |

The FBHS operates as follows. First, after receiving the control information from MS, the POTLC check the quality of the signal. If the signal strength is still good enough the handover is not carried out. If the signal strength is lower than a predefined value, then based on *CSSP*, *SSN* and *DMB*, the FLC decides whether the handover is necessary or not. If the handover is not necessary the control is returned to the present BS, otherwise another check of the signal strength is carried out in PRTLC and the present signal strength is compared with the previous signal strength. When the present signal strength is lower than the strength of the previous signal, the handover procedure is carried out.

The term sets of *CSSP*, *SSN* and *DMB* are defined respectively as:

$$\begin{aligned} T(CSSP) &= \{Small, Little\ Change, No\ Change, Big\} \\ &= \{SM, LC, NC, BG\}; \\ T(SSN) &= \{Weak, Not\ So\ Weak, Normal, Strong\} \\ &= \{WK, NSW, NO, ST\}; \\ T(DMB) &= \{Near, Not\ So\ Near, Not\ So\ Far, Far\} \\ &= \{NR, NSN, NSF, FA\}. \end{aligned}$$

The output linguistic parameter $T(HD)$ is defined as $\{Very\ Low, Low, Little\ High, High\} = \{VL, LO, LH, HG\}$. The membership functions of FLC are shown in Fig. 6 and the FRB is shown in Table III.

## V. Simulation Results

In this section, we evaluate by computer simulations the performance of FACS-P and FBHS.

### A. Simulation Consideration for FACS-P

The simulation were carried out in Linux Fedora Core5 computer. We considered the following parameters for simulations: the user speed was from 0 to 120 km/h, the user direction was changed from -180 degree to +180 degree. The required bandwidth for voice, video and text was 30%, 10%, and 60%, respectively. The requested size was 1, 5 and 10 Bandwidth Units (BU) for text, voice and video, respectively. The bandwidth of the BS was considered 40 BU. We also considered the distance between users and BS which changed between 0 to 10 km.

### B. Simulation Considerations FBHS

The cell shape is hexagonal and the coordinates of BSs are indicated as shown in Fig. 7. The BS is located in the center of the cell, the transmission antenna power is 10 W, and cell radius is 2 km. In Table IV are shown the simulation parameters.

We considered two scenarios for our simulations: Scenario 1 and Scenario 2. In Scenario 1, the MS moves in the boundary of cells, so the ping-pong effect may happen.

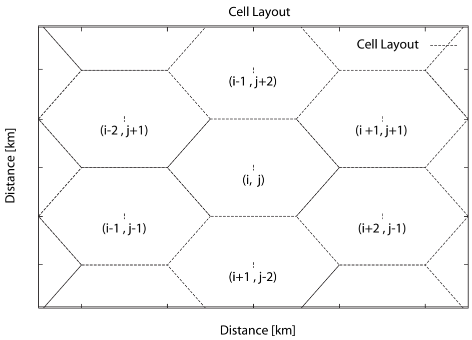


Figure 7: Cell layout.

Table IV: Simulation parameters.

| | |
|---|---|
| Distribution Law | Gaussian Distribution |
| Number of Walks | 5 10 |
| Random Types | 100 200 |
| Cell Radius | 1km 2km |
| Transmission Power | 10W 20W |
| Frequency | 2000MHz |
| Transmission Antenna Beam Tilting | 3° |
| Transmission Antenna Height | 40m |
| Receiving Antenna Height | 1.5m |
| Average Value for a Walk | 0.6km |
| $n$ | 1.1 |

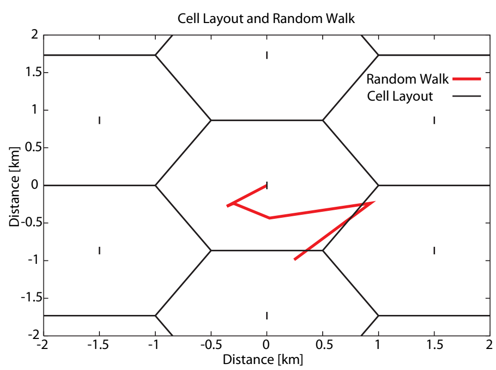


Figure 8: RW pattern for Scenario1.

While in Scenario 2, the MS moves inside the cells, so the handover becomes necessary. In Fig. 8, the MS moves in the cells: (0,0)→(2,-1)→(0,0)→(1,-2), while in Fig. 9 in the cells: (0,0)→(-1,2)→(-2,1)→(-1,2). Thus, we evaluate FBHS in the scenarios of avoiding the ping-pong effect and for handover enforcement.

In both scenarios, we consider that the handover is carried out when the output value is bigger than 0.7. We assume that during the Random Walk (RW) for each 10 km/h the signal strength is decreased 2 db.

### C. Simulation Results for FACS-P

In Fig. 10 is shown the relation between percentage of accepted calls versus number of requesting connections. In

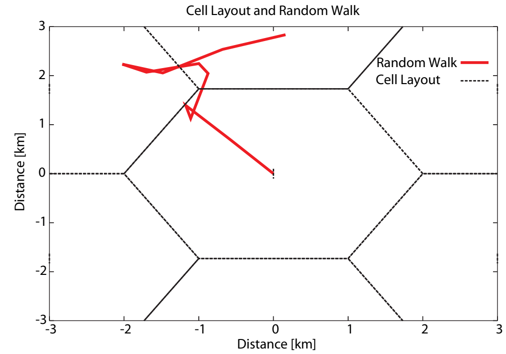


Figure 9: RW pattern for Scenario2.

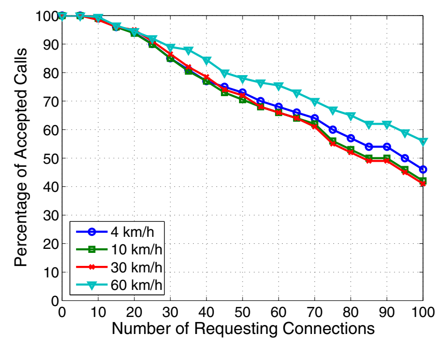


Figure 10: Percentage of no. of accepted calls for FACS-P (Speed).

this simulation, we consider the user speed as a parameter. From the simulation results can be seen that with the increase of the user speed, the percentage of the number of the accepted calls is increased. This happens because with the increase of the user speed, the user direction can not be changed easily, this results in a better prediction of the user direction and the network resources are used better. On the other hand, when the user speed is slow, the prediction of the user direction becomes difficult, which results in a small percentage of the accepted calls.

In Fig. 11, we consider the angle as parameter. We show the simulation results for different angels from 0 to 90 degree. When the user angle is small, the percentage of accepted calls is higher and is decreased with the increase of the number of requesting connections. With the increase of the angle, the user is going far from the BS, so there is not need to allocate the bandwidth for this user. This is why the percentage of the number of accepted calls is decreased with the increase of the angle value.

In order to evaluate the performance of the proposed system, we compare its performance with our previous FACS system. The simulation results are shown in Fig. 12. When the number of requesting connections is less than 25, the percentage of accepted calls for proposed system is higher than our previous system. However, when the number of requesting connections is larger than 25, FACS-P

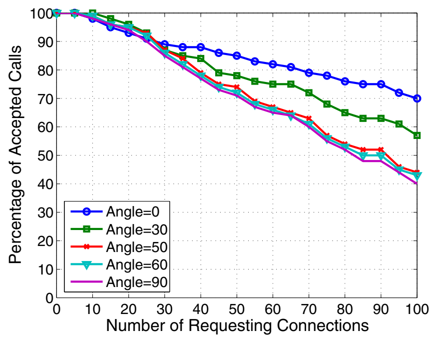


Figure 11: Percentage of no. of accepted calls for FACS-P (Angle).

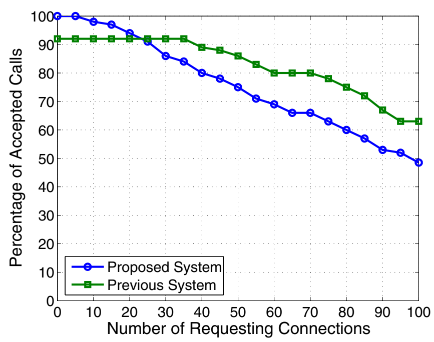


Figure 12: Performance comparison of FACS-P with FACS.

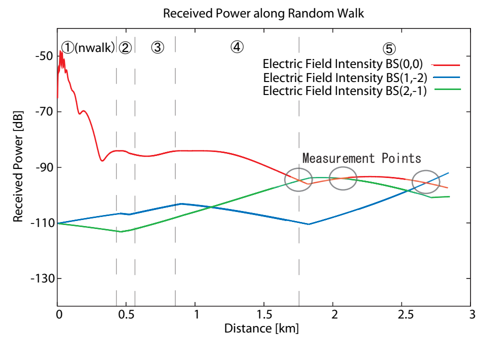


Figure 13: 3 measurement points for Scenario1.

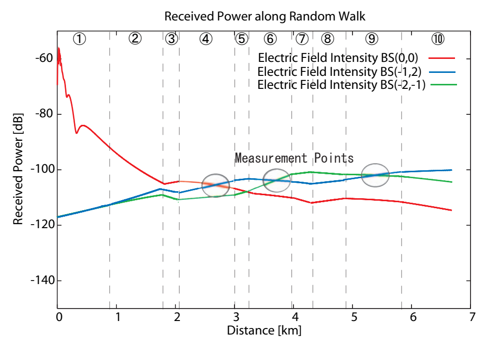


Figure 14: 3 measurement points for Scenario2.

accepts less number of connections. This is because, FACS-P guarantees the QoS of on-going calls, thus decreasing the acceptance ratio of the requesting connections.

### *D. Simulation Results for FBHS*

For evaluation of FBHS, we carried out the measurement for 3 points, where the MS is in the boundary of the 3 cells, (see Fig. 13). In Fig. 14 the handover is necessary because the MS is moving inside the neighbor cells.

We carry out 10 times simulations and calculate the average values. The simulation results of FBHS are shown in Table V and Table VI for Scenario1 and Scenario2, respectively.

In the case of Scenario1, the FBHS has an ideal behavior. As shown in Table V, all the average values are smaller than 0.7, therefore the FBHS system can avoid the ping-pong effect. For handover enforcement (Scenario 2), the FBHS has a good performance because in all cases has done 3 handovers (see Table VI).

## VI. Conclusions

In this paper, we proposed and implemented an integrated approach for CAC and handover using FL for wireless cellular networks.

We evaluated the performance of FACS-P for different scenarios. From the simulations results, we conclude as follows:

- when the user speed is slow, the prediction of the user direction becomes difficult, which results in a small percentage of the accepted calls;
- when the user angle is small, the percentage of accepted calls is higher and is decreased with the increase of the number of requesting connections;
- the proposed system keeps a higher QoS of on-going connections.

We also evaluated the performance of the proposed FL-based handover systems for two scenarios: avoidance of ping-pong effect (Scenario1) and enforced handover (Scenario2).

In the case of Scenario1, FBHS has an ideal behavior. because all the average values are smaller than 0.7. Therefore FBHS can avoid the ping-pong effect. For handover enforcement (Scenario2), FBHS has a good performance because in all cases has done 3 handovers.

In this paper, we considered only the priority of ongoing connections. In the future, we would like to consider also the priority of requesting connections.

Table V: Simulation results of FBHS for Scenario1.

| Measurement Points | Point 1 | | Point 2 | | Point 3 | |
|---|---|---|---|---|---|---|
| Speed 0 km/h | | | | | | |
| CSSP BS | −2.710 | −3.697 | −1.289 | 0.3877 | −1.189 | −1.270 |
| Neighbor BS | −93.36 | −92.49 | −92.77 | −92.77 | −94.01 | −95.28 |
| Distance | 0.8858 | 0.9453 | 0.8684 | 0.8466 | 0.9367 | 1.0183 |
| System Output Value | 0.693 | 0.600 | 0.539 | 0.497 | 0.571 | 0.600 |
| Speed 10 km/h | | | | | | |
| CSSP BS | −2.710 | −3.697 | −1.289 | 0.3877 | −1.189 | −1.270 |
| Neighbor BS | −95.36 | −94.49 | −94.77 | −94.77 | −96.01 | −97.28 |
| Distance | 0.8858 | 0.9427 | 0.8684 | 0.8466 | 0.9367 | 1.0183 |
| System Output Value | 0.693 | 0.600 | 0.583 | 0.542 | 0.600 | 0.618 |
| Speed 20 km/h | | | | | | |
| CSSP BS | −2.710 | −3.697 | −1.289 | 0.3877 | −1.189 | −1.270 |
| Neighbor BS | −97.36 | −96.49 | −96.77 | −96.77 | −98.01 | −99.28 |
| Distance | 0.8858 | 0.9401 | 0.8684 | 0.8466 | 0.9367 | 1.0183 |
| System Output Value | 0.693 | 0.600 | 0.614 | 0.574 | 0.624 | 0.640 |
| Speed 30 km/h | | | | | | |
| CSSP BS | −2.710 | −3.697 | −1.289 | 0.3877 | −1.189 | −1.270 |
| Neighbor BS | −99.36 | −98.49 | −98.77 | −98.77 | −100.0 | −101.3 |
| Distance | 0.8858 | 0.9376 | 0.8684 | 0.8466 | 0.9367 | 1.0183 |
| System Output Value | 0.693 | 0.600 | 0.632 | 0.584 | 0.645 | 0.657 |
| Speed 40 km/h | | | | | | |
| CSSP BS | −2.710 | −3.697 | −1.289 | 0.3877 | −1.189 | −1.270 |
| Neighbor BS | −101.4 | −100.5 | −100.8 | −100.8 | −102.0 | −103.3 |
| Distance | 0.8858 | 0.9351 | 0.8684 | 0.8466 | 0.9367 | 1.0183 |
| System Output Value | 0.693 | 0.600 | 0.631 | 0.582 | 0.656 | 0.662 |
| Speed 50 km/h | | | | | | |
| CSSP BS | −2.710 | −3.697 | −1.289 | 0.3877 | −1.189 | −1.270 |
| Neighbor BS | −103.4 | −102.5 | −102.8 | −102.8 | −104.0 | −105.3 |
| Distance | 0.8858 | 0.9327 | 0.8684 | 0.8466 | 0.9367 | 1.0183 |
| System Output Value | 0.693 | 0.600 | 0.631 | 0.582 | 0.656 | 0.663 |

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Table VI: Simulation results of FBHS for Scenario2.

| Measurement Points | Point 1 | | Point 2 | | Point 3 | |
|---|---|---|---|---|---|---|
| Speed 0 km/h | | | | | | |
| CSSP BS | −2.0149 | −3.4731 | −2.1681 | −3.7153 | −7.1891 | −7.9733 |
| Neighbor BS | −105.55 | −102.07 | −103.52 | −96.763 | −103.85 | −88.422 |
| Distance | 1.9597 | 2.4628 | 1.8367 | 2.3453 | 1.8021 | 3.0449 |
| System Output Value | 0.645 | **0.745** | 0.634 | **0.740** | 0.692 | **0.730** |
| Speed 10 km/h | | | | | | |
| CSSP BS | −2.0149 | −3.4731 | −2.1681 | −3.7153 | −7.1891 | −7.9733 |
| Neighbor BS | −107.55 | −104.07 | −105.52 | −98.763 | −105.85 | −90.442 |
| Distance | 1.9597 | 2.4628 | 1.8367 | 2.3453 | 1.8021 | 3.0449 |
| System Output Value | 0.632 | **0.780** | 0.634 | **0.710** | 0.671 | **0.730** |
| Speed 20 km/h | | | | | | |
| CSSP BS | −2.0149 | −3.4731 | −2.1681 | −3.7153 | −7.1891 | −7.9733 |
| Neighbor BS | −109.55 | −106.07 | −107.52 | −100.76 | −107.85 | −92.422 |
| Distance | 1.9597 | 2.4628 | 1.8367 | 2.3453 | 1.8021 | 3.0449 |
| System Output Value | 0.616 | **0.777** | 0.620 | **0.726** | 0.633 | **0.730** |
| Speed 30 km/h | | | | | | |
| CSSP BS | −2.0149 | −3.4731 | −2.1681 | −3.7153 | −7.1891 | −7.9733 |
| Neighbor BS | −111.55 | −108.07 | −109.52 | −102.76 | −109.85 | −94.422 |
| Distance | 1.9597 | 2.4628 | 1.8367 | 2.3453 | 1.8021 | 3.0449 |
| System Output Value | 0.596 | **0.743** | 0.597 | **0.756** | 0.606 | **0.730** |
| Speed 40 km/h | | | | | | |
| CSSP BS | −2.0149 | −3.4731 | −2.1681 | −3.7153 | −7.1891 | −7.9733 |
| Neighbor BS | −113.55 | −110.07 | −111.52 | −104.76 | −111.85 | −96.422 |
| Distance | 0.3536 | 0.4821 | 0.6824 | 0.9047 | 1.3158 | 1.4976 |
| System Output Value | 0.576 | **0.715** | 0.574 | **0.794** | 0.591 | **0.728** |
| Speed 50 km/h | | | | | | |
| CSSP BS | −2.0149 | −3.4731 | −2.1681 | −3.7153 | −7.1891 | −7.9733 |
| Neighbor BS | −115.55 | −112.07 | −113.52 | −106.76 | −113.85 | −98.422 |
| Distance | 0.3536 | 0.4821 | 0.6824 | 0.9047 | 1.3158 | 1.4976 |
| System Output Value | 0.545 | **0.703** | 0.553 | **0.713** | 0.579 | **0.703** |


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