Mobile Information Systems 5 (2009) 339–361
DOI 10.3233/MIS-2009-0087
IOS Press

Implementation and performance evaluation of two fuzzy-based handover systems for wireless cellular networks

Gjergji Mino[a], Leonard Barolli[b,*], Fatos Xhafa[c], Arjan Durresi[d] and Akio Koyama[e]
[a]*Graduate School of Engineering, Fukuoka Institute of Technology* (*FIT*), *3-30-1 Wajiro-Higashi, Higashi-Ku, Fukuoka 811-0295, Japan*
[b]*Department of Information and Communication Engineering, Fukuoka Institute of Technology* (*FIT*), *3-30-1 Wajiro-Higashi, Higashi-Ku, Fukuoka 811-0295, Japan*
[c]*Department of Languages and Informatics Systems, Polytechnic University of Catalonia, Jordi Girona 1-3, 08034 Barcelona, Spain*
[d]*Department of Computer and Information Science, Indiana University Purdue University Indianapolis, 723 W. Michigan Street SL 280, Indianapolis, IN 46202, USA*
[e]*Department of Informatics, Yamagata University, 4-3-16 Jonan, Yonezawa 992-8510, Yamagata, Japan*

Abstract. Wireless mobile networks and devices are becoming increasingly popular to provide users the access anytime and anywhere. We are witnessing now an unprecedented demand for wireless networks to support both data and real-time multimedia traffic. The wireless 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. Many handover algorithms are proposed in the literature. However, to make a better handover and keep the QoS in wireless networks is very difficult task. For this reason, new intelligent algorithms should be implemented to deal with this problem. In this paper, we carried out a comparison study of two handover systems based on fuzzy logic. We implement two Fuzzy-Based Handover Systems (FBHS) called FBHS1 and FBHS2. The performance evaluation via simulations shows that FBHS2 has better behavior than FBHS1 and can avoid ping-pong effect in all simulation cases.

1. Introduction

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).

The QoS in cellular networks is defined as the capability of the cellular service providers to provide a satisfactory service which includes voice quality, signal strength, low call blocking and dropping probability, high data rates for multimedia and data applications [1,2]. Due to host mobility, scarcity

---

[*] Corresponding author. E-mail: barolli@fit.ac.jp.

of bandwidth, and an assortment of channel impairments, the QoS provisioning problem is far more challenging in wireless networks than in their wireline counterparts [3]. 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 [4,5]. 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 Station (MS) 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 [6,7].

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). However, the fluctuations of signal strength associated with shadow fading cause the ping-pong effect [8]. 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.

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 [9–20]. In [17] 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 [18], 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 [19,20], we proposed and implemented a Fuzzy-Based Handover System (FBHS). We showed that the proposed system has a good behavior for handover enforcement, but in some cases can not avoid the ping-pong effect.

In this paper, we carried out a comparison study of two FBHS: FBHS1 and FBHS2. The performance evaluation via simulations shows that new implemented system FBHS2 has better behavior than FBHS1 and can avoid ping-pong effect in all simulation cases.

The structure of this paper is as follows. In Section 2, we present the handover decision problem. In Section 3, we give a brief introduction of RW model. In Section 4, we present the application of FL for control. In Section 5, we introduce the implemented FBHSs. In Section 6, we discuss the simulation results. Finally, some conclusions are given in Section 7.

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 [21,22]. 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 [6].

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. A timely handover algorithm is one which initiates handoffs neither too early nor 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 the 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. RW Model

The Monte Carlo (MC) method is a technique that uses random numbers and probability to solve problems. It is often used when the model is complex, nonlinear, or involves more than just a couple uncertain parameters.

The MC method can be used for analyzing uncertainty propagation, where the goal is to determine how random variation, lack of knowledge, or error affects the sensitivity, performance, or reliability of the system that is being modeled. MC simulation is categorized as a sampling method because the inputs are randomly generated from probability distributions to simulate the process of sampling from an actual population. The data generated from the simulation can be represented as probability distributions (or histograms) or converted to error bars, reliability predictions, tolerance zones, and confidence intervals.

We use the MC method for realizing RW model. We consider a 2-dimensional field. The initial position is considered as a origin point and we decided based on MC method the moving pattern for each walk. If we consider n user movements and the angle θ and distance d for each walk are generated by general or Gaussian distribution, when the movement changes in x and y directions are Δx and Δy, respectively, then we have the following relations.

$$\Delta x_n = d_n cos\theta_n, \quad \Delta y_n = d_n sin\theta_n \tag{1}$$

$$x_{n+1} = x_n + \Delta x_n, \quad y_{n+1} = y_n + \Delta y_n \tag{2}$$

The BS position can be expressed by Cartesian coordinates. By converting Cartesian coordinates to polar ones, we can calculate the angle θ.

We consider that in the cellular system each cell has a hexagonal shape and the BS is located in the center of the cell. The angle θ between Dipole Antenna (DA) and vector $\boldsymbol{r}$ is $D(\theta) = \sin\theta$. If we consider the transmission power as W, the antenna radiation intensity can be calculated as follows:

$$\boldsymbol{E} = \sqrt{45W}\sin\theta\frac{e^{-j\kappa r}}{r^n}\boldsymbol{u}_{\mathrm{o}} \tag{3}$$

where, the DA gain is $G = 1.5$ and $\boldsymbol{u}_{\mathrm{o}}$ is the unit vector that shows DA direction. In Fig. 1, the $\boldsymbol{u}_{\mathrm{o}}$ is in Z direction.

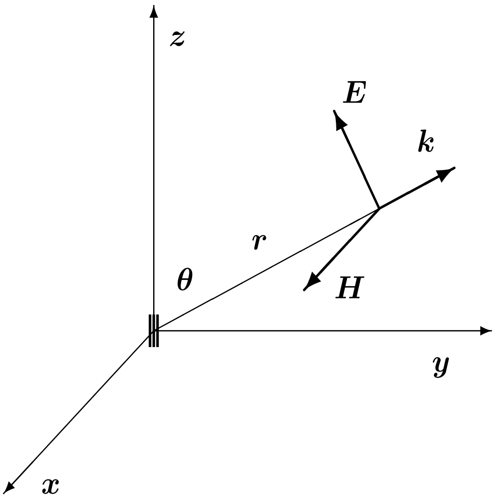


Fig. 1. Dipole antenna.

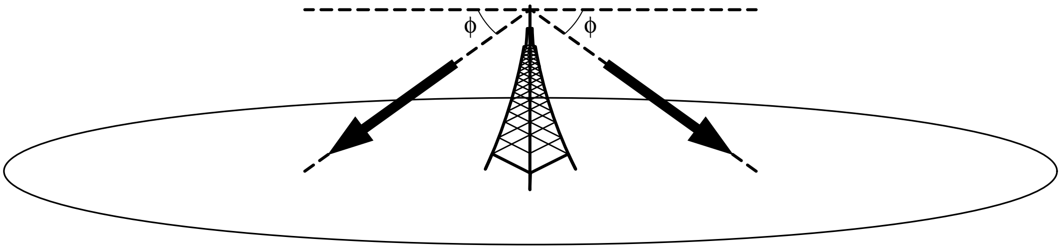


Fig. 2. Beam tilting.

In Eq.(3), when $\theta = 90°$, the E value will be maximal in horizontal direction. However, in real situations, the direction of antenna is set up as shown in Fig. 2 in order to cover better the cell area. If we consider the beam tilting angle and the distance, the E can be calculated by the following equation.

$$\boldsymbol{E} = \sqrt{45W} \sin(\theta - \phi) \frac{e^{-j\kappa r}}{r^n} \boldsymbol{u}_{\mathrm{o}} \tag{4}$$

4. FL applied for control

FL is the logic underlying modes of reasoning which are approximate rather then exact. The importance of FL derives from the fact that most modes of human reasoning and especially common sense reasoning are approximate in nature. FL is based on the concepts of linguistic variables and fuzzy sets. The fuzzy sets are used for representing linguistical labels. This can be viewed as expressing an uncertainty about the clear-cut meaning of the label. But important point is that the valuation set is supposed to be common to the various linguistic labels that are involved in the given problem.

The fuzzy set theory uses the membership function to encode a preference among the possible interpretations of the corresponding label. A fuzzy set can be defined by examplification, ranking elements according to their typicality with respect to the concept underlying the fuzzy set [23,24]. The prototypical element receives the greater membership grade. Fuzzy set naturally appears in non-strict specification. It may be soft constraints or flexible requirements for which slight violations can be tolerated (e.g., the dead line is today, but tomorrow is still acceptable although less good), or elastic classes of objects, approximate descriptions of types of situation to which a given procedure can be applied, or even procedures with fuzzy stated instructions. In each case fuzzy sets preserve a gradual and smooth transition from one category into another and avoid abrupt discontinuities that would be caused by the assignment of precise boundaries for the considered subsets. The specification thus becomes more robust and adaptive. In this case, fuzzy sets provide a tool for bridging the gap between the perceived continuity of the world and human discrete cognitive representation [23].

The ability of FL to model gradual properties or soft constraints whose satisfaction is matter of degree, as well as information pervaded with imprecision and uncertainty, makes them useful in a great variety of applications. The most popular area of application is fuzzy control. In the fuzzy control systems, expert knowledge is encoded in the form of fuzzy rules, which describe recommended actions for different classes of situations represented by fuzzy sets. An interpolation mechanism provided by the fuzzy control methodology is then at work. The current situation encountered by the system partially resembles two or more prototypical situations for which recommended control actions are known, and a control action that is intermediary between these recommended ones is computed on the basis of the resemblance degrees.

A fuzzy control unit can do the same work as a PID controller, since it implicitly defines a numerical function tying the control variables and the observed control variables together. The difference between classical and fuzzy control methods lies in the way this control law is found. In the context of classical automatic control, especially optimal control theory, the control law is calculated using a mathematical model of process, whereas the FL approach, consistent with artificial intelligence, suggests that the control law be built starting from the expertise of a human operator. In applications of PID controllers, the philosophy is close to FLC controllers, since the tuning of the PID parameters is usually done in an ad hoc way. However, only linear control laws can be attained with a PID, while the fuzzy controller may capture non-liner laws, which may explain the success of the fuzzy controllers over PID controllers. In fact, any kind of control law can be modelled by the fuzzy control methodology, provided that this law is expressible in terms of "if . . . then . . . " rules, just like in the case of expert systems. However, FL diverges from the standard expert system approach by providing an interpolation mechanism from several rules. In the contents of complex processes, it may turn out to be more practical to get knowledge from an expert operator than to calculate an optimal control, due to modelling costs or because a model is out of reach.

Fuzzy systems promise to offer a rich language for traffic control by providing soft and flexible control action, characterizing imprecise quantities (e.g., signal strength, speed, angel and mobile user movement prediction), and capturing linguistic, rule based control strategies. The philosophy on which the FL based handover systems are built exploits the FL capability to deduce a system model on the basis of linguistic variables, fuzzy sets and fuzzy inferences. The rules are expressed in approximate terms, but at the same time corresponding to an expert description. This allows the rules to be translated into a rigorous fuzzy inferential system, which has a good performance. The inferential system which describes the proposed handover systems is simple and can be implemented in hardware, thus improving both the cost and processing speed.

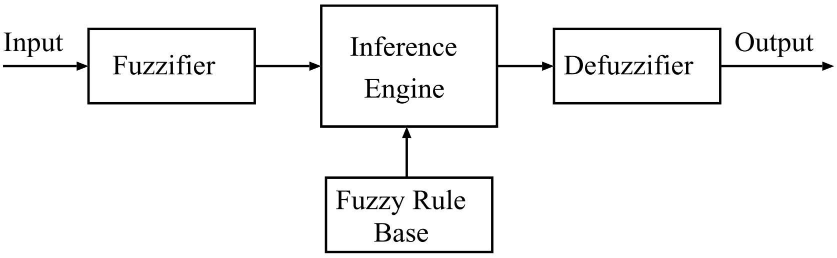


Fig. 3. FLC structure.

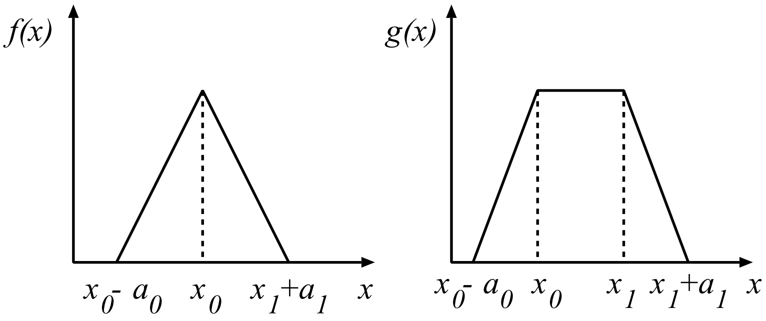


Fig. 4. Membership function shapes.

5. Implemented system models

5.1. FLC structure

The Fuzzy Logic Controller (FLC) is the main part of the FBHS and its basic elements are shown in Fig. 3. 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 [23,24]. They are shown in Fig. 4 and are given as:

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

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

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.

5.2. Design of FBHS1

The FBHS1 model is shown in Fig. 5. The $Node\_B$ shows the wireless transmitter and receiver of BS and RNS indicates Radio Network System.

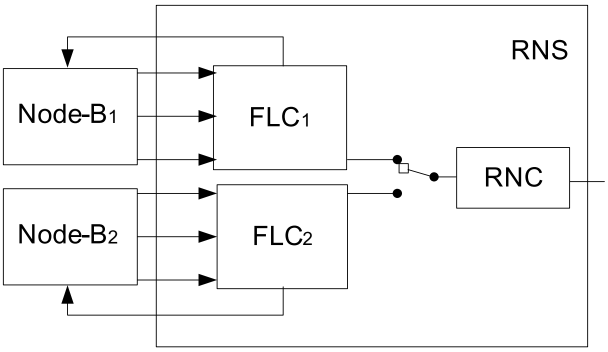


Fig. 5. FBHS1 model.

As the input linguistic parameters for FBHS1, we consider: Signal Strength from the Present BS (*SSP*), Signal Strength from the Neighbor BS (*SSN*), and the distance of MS from BS (*D*). The output linguistic parameter is Handover Decision (*HD*).

The term sets of *SSP*, *SSN* and *D* are defined respectively as:

$$\begin{aligned} T(SSP) &= \{Weak, Not\ So\ Weak, Normal, Strong\} = \{W1, NSW1, N1, S1\}; \\ T(SSN) &= \{Weak, Not\ So\ Weak, Normal, Strong\} = \{W2, NSW2, N2, S2\}; \\ T(D) &= \{Near, Not\ So\ Near, Not\ So\ Far, Far\} = \{NR, NSN, NSF, FA\}. \end{aligned}$$

The output linguistic parameter $T(HD)$ is defined as $\{Very\ Low, Low, Little\ High, High\} = \{VL, LO, LH, HG\}$.

The membership functions of FBHS1 are shown in Fig. 6. The FRB1 forms a fuzzy set of dimensions $|T(SSP)| \times |T(SSN)| \times |T(D)|$, where $|T(x)|$ is the number of terms on $T(x)$. The FRB1 is shown in Table 1 and has 64 rules. The control rules have the following form: IF “conditions” THEN “control action”.

5.3. Design of FBHS2

The FBHS2 model is shown in Fig. 7. In this system, the same as FBHS1 model, 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.

Different from FBHS1, in FBHS2 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*).

The FBHS2 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.

Table 1
FRB1

Rules	SSP	SSN	D	HD	Rules	SSP	SSN	D	HD
1	W1	W2	NR	VL	33	N1	W2	NR	VL
2	W1	W2	NSN	VL	34	N1	W2	NSN	VL
3	W1	W2	NSF	VL	35	N1	W2	NSF	LO
4	W1	W2	FA	LO	36	N1	W2	FA	LO
5	W1	NSW2	NR	LO	37	N1	NSW2	NR	LO
6	W1	NSW2	NSN	LO	38	N1	NSW2	NSN	LO
7	W1	NSW2	NSF	LO	39	N1	NSW2	NSF	LH
8	W1	NSW2	FA	LH	40	N1	NSW2	FA	LH
9	W1	N2	NR	LH	41	N1	N2	NR	LH
10	W1	N2	NSN	LH	42	N1	N2	NSN	LH
11	W1	N2	NSF	HG	43	N1	N2	NSF	LH
12	W1	N2	FA	HG	44	N1	N2	FA	HG
13	W1	S2	NR	LH	45	N1	S2	NR	LH
14	W1	S2	NSN	LH	46	N1	S2	NSN	LH
15	W1	S2	NSF	LH	47	N1	S2	NSF	LH
16	W1	S2	FA	HG	48	N1	S2	FA	HG
17	NSW1	W2	NR	VL	49	S1	W2	NR	VL
18	NSW1	W2	NSN	VL	50	S1	W2	NSN	VL
19	NSW1	W2	NSF	LO	51	S1	W2	NSF	VL
20	NSW1	W2	FA	LO	52	S1	W2	FA	VL
21	NSW1	NSW2	NR	LO	53	S1	NSW2	NR	VL
22	NSW1	NSW2	NSN	LO	54	S1	NSW2	NSN	VL
23	NSW1	NSW2	NSF	LH	55	S1	NSW2	NSF	VL
24	NSW1	NSW2	FA	LH	56	S1	NSW2	FA	LO
25	NSW1	N2	NR	LH	57	S1	N2	NR	LO
26	NSW1	N2	NSN	LH	58	S1	N2	NSN	LO
27	NSW1	N2	NSF	LH	59	S1	N2	NSF	LO
28	NSW1	N2	FA	HG	60	S1	N2	FA	LH
29	NSW1	S2	NR	LH	61	S1	S2	NR	LO
30	NSW1	S2	NSN	LH	62	S1	S2	NSN	LO
31	NSW1	S2	NSF	LH	63	S1	S2	NSF	LH
32	NSW1	S2	FA	HG	64	S1	S2	FA	LH

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

$$T(CSSP) = \{Small, Little\ Change, No\ Change, Big\} = \{SM, LC, NC, BG\};$$

$$T(SSN) = \{Weak, Not\ So\ Weak, Normal, Strong\} = \{WK, NSW, NO, ST\};$$

$$T(DMB) = \{Near, Not\ So\ Near, Not\ So\ Far, Far\} = \{NR, NSN, NSF, FA\}.$$

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. 8 and the FRB2 is shown in Table 2.

6. Simulation results

In both simulation systems, the cell shape is hexagonal and the coordinates of BSs are indicated as shown in Fig. 9. The antenna power distribution is shown in Fig. 10. 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 3 are shown the simulation parameters.

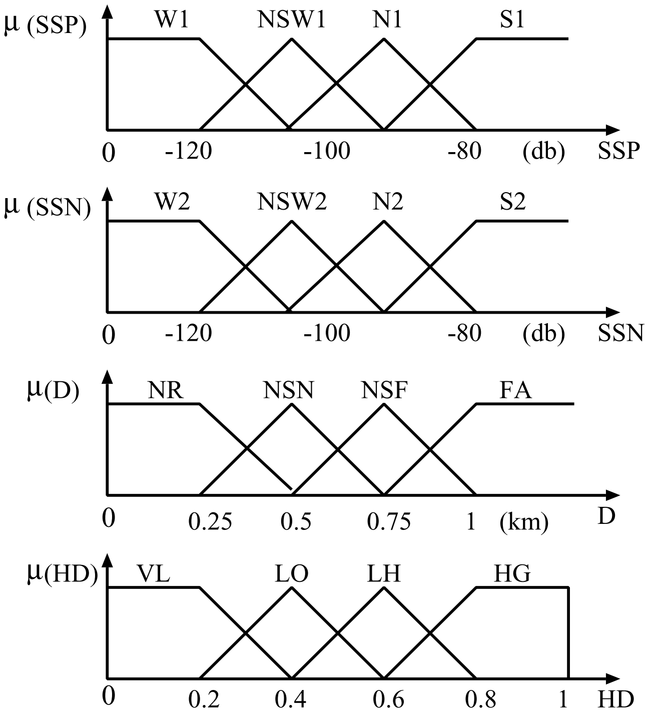


Fig. 6. FBHS1 membership functions.

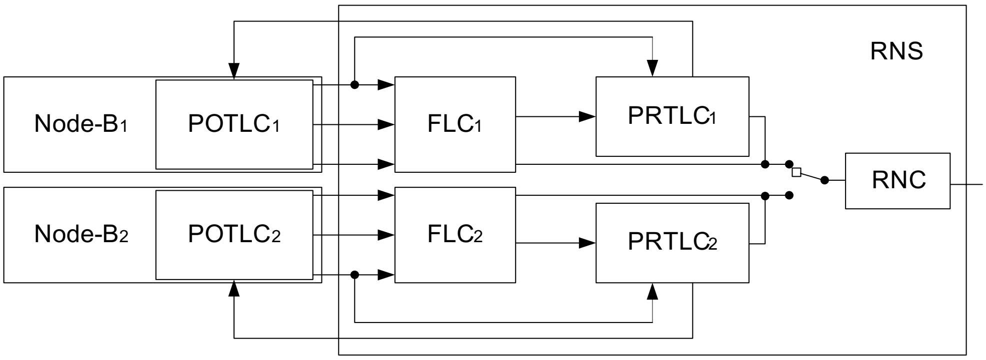


Fig. 7. FBHS2 model.

We considered for simulations two scenarios: Scenario1 and Scenario2. In Scenario1, the MS moves in the boundary of cells, so the ping-pong effect may happen. While in Scenario2, the MS moves inside the cells, so the handover becomes necessary. In Fig. 11, the MS moves in the cells: (0,0)→(2,−1)→(0,0)→(1,−2), while in Fig. 12 in the cells: (0,0)→(−1,2)→(−2,1)→(−1,2). Thus, we evaluate FBHS1 and FBHS2 in the scenario of avoiding the ping-pong effect and for handover enforcement.

In Fig. 13 is shown the aggregated received power for Scenario1, while in Fig. 14, Fig. 15 and Fig. 16 are showing the received power from the BS(0,0), BS(2,−1), and BS(1,−2) in Scenario1. As can be seen from Fig. 14, when the MS is going far from the BS the received power is decreased, while when

Table 2
FRB2

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

Table 3
Simulation parameters

Distribution law	Gaussian distribution
Number of walks	5, 10
Random types	100, 200
Cell radius	1 km, 2 km
Transmission power	10 W, 20 W
Frequency	2000 MHz
Transmission antenna beam tilting	3°
Transmission antenna height	40 m
Receiving antenna height	1.5 m
Average value for a walk	0.6 km
n	1.1

the MS is approaching neighbor BS the received power from these BSs is increased (see Fig. 15 and Fig. 16). In Fig. 17 is shown the aggregated received power for Scenario2, while in Figs 18, 19 and 20 are showing the received power from the BS(0,0), BS(−1,2), and BS(−2,1) in Scenario2.

For evaluation of the FBHS1 and FBHS2, we carried out the measurement for 3 points, where the MS is in the boundary of the 3 cells. In Figs 21 and 22 are shown the measurement points for Scenario1

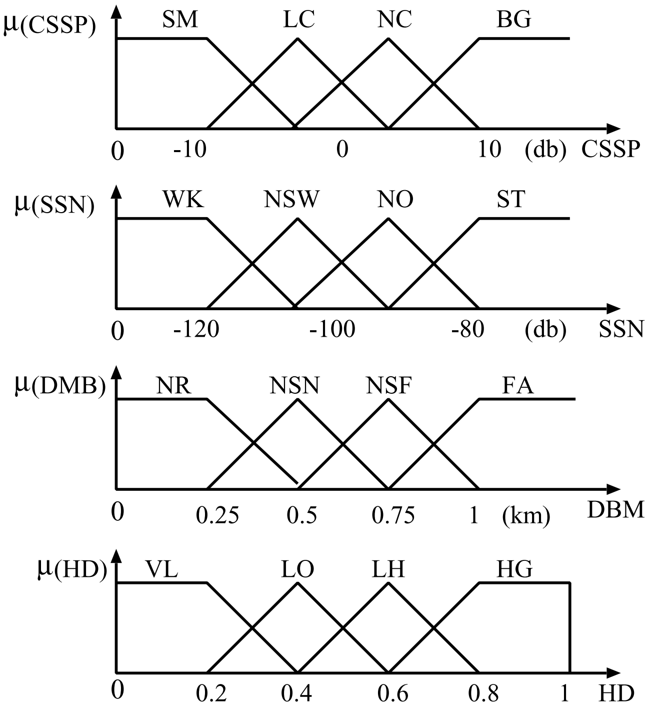


Fig. 8. Membership functions for FBHS2.

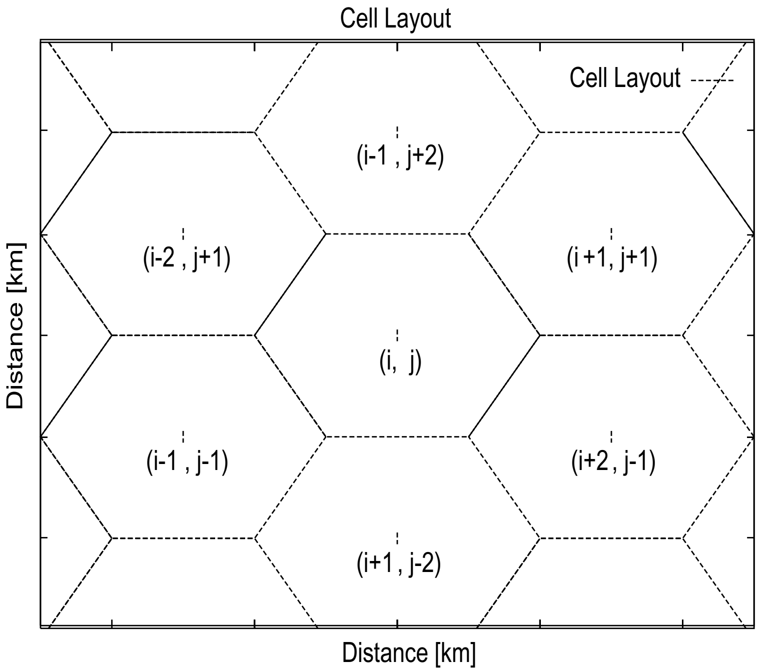


Fig. 9. Cell layout.

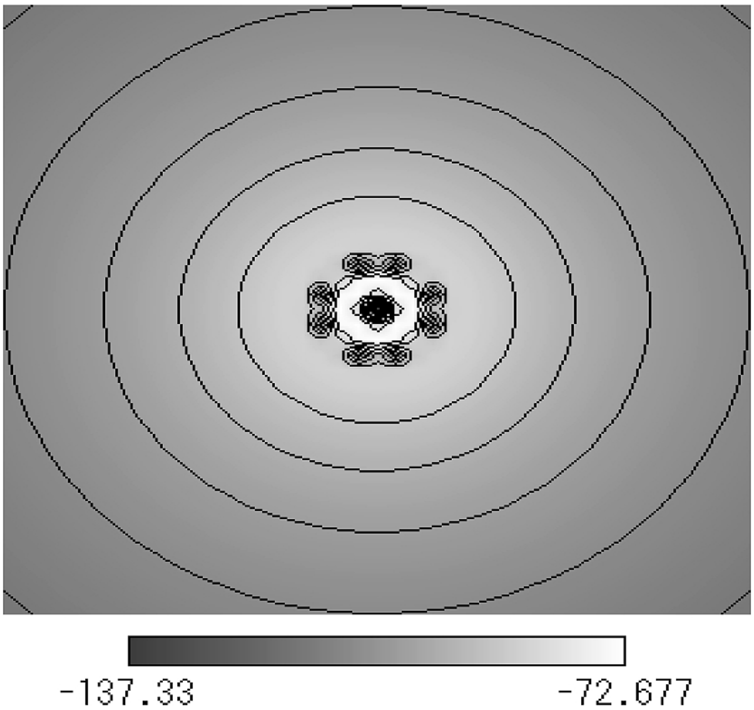


Fig. 10. Antenna power distribution.

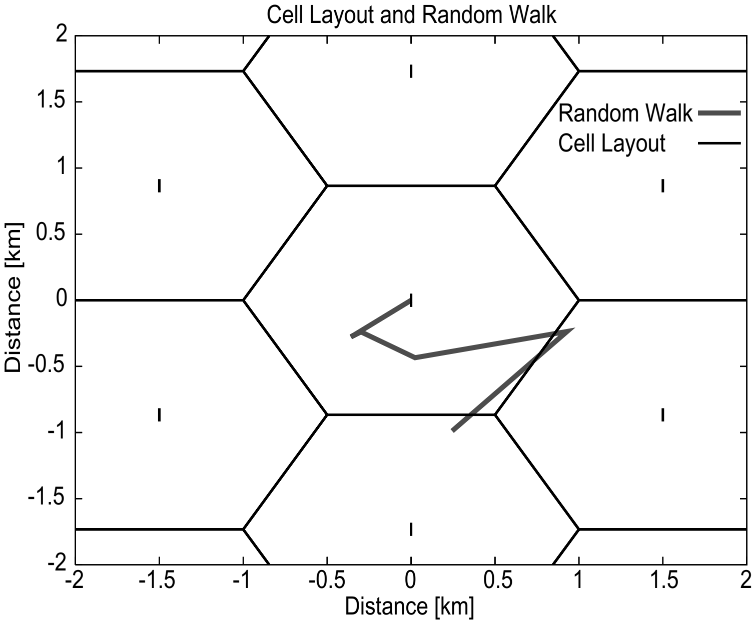


Fig. 11. RW pattern for Scenario1.

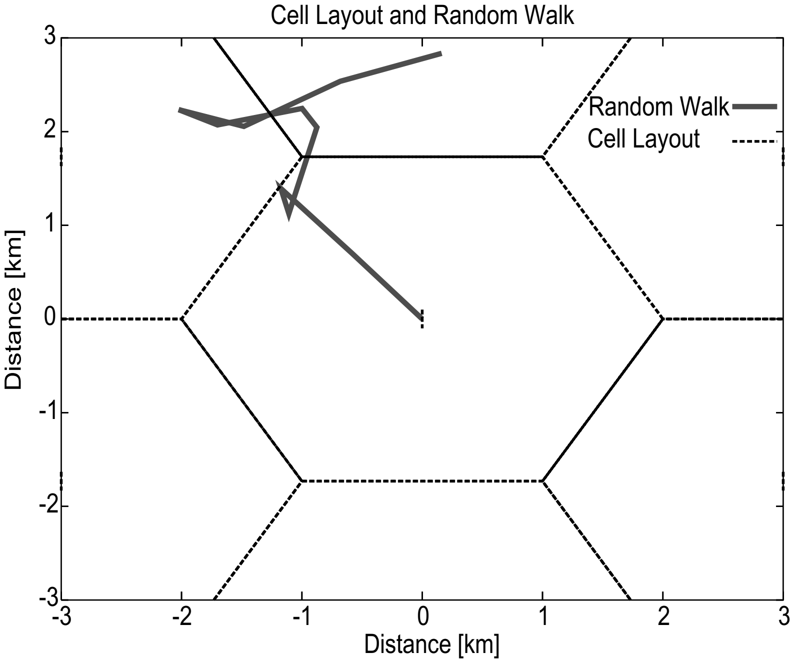


Fig. 12. RW pattern for Scenario2.

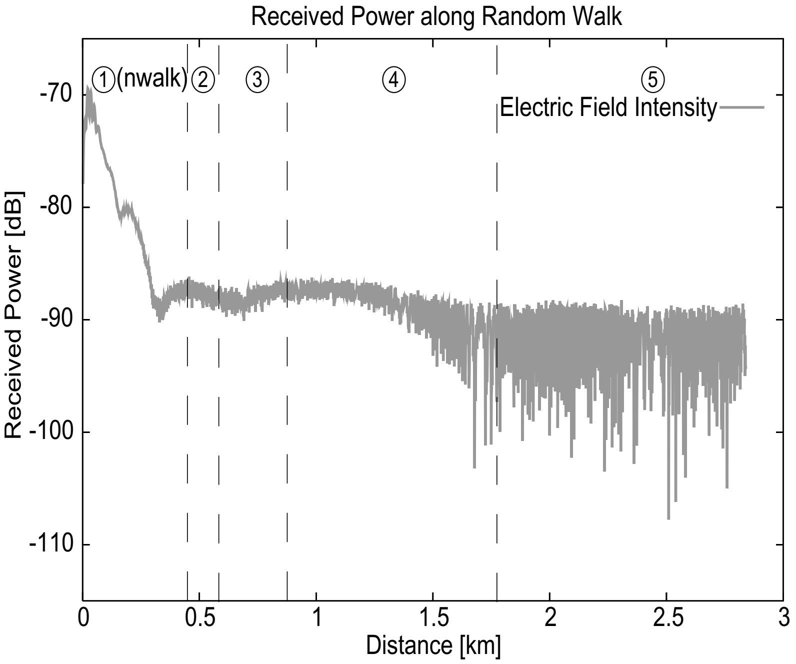


Fig. 13. Aggregated received power for Scenario1.

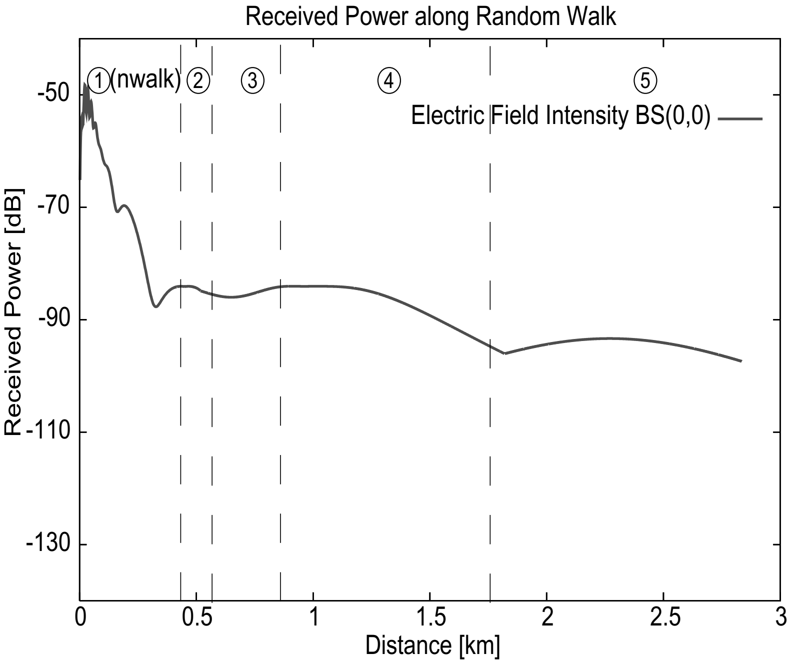


Fig. 14. Received power from BS(0,0) (Scenario1).

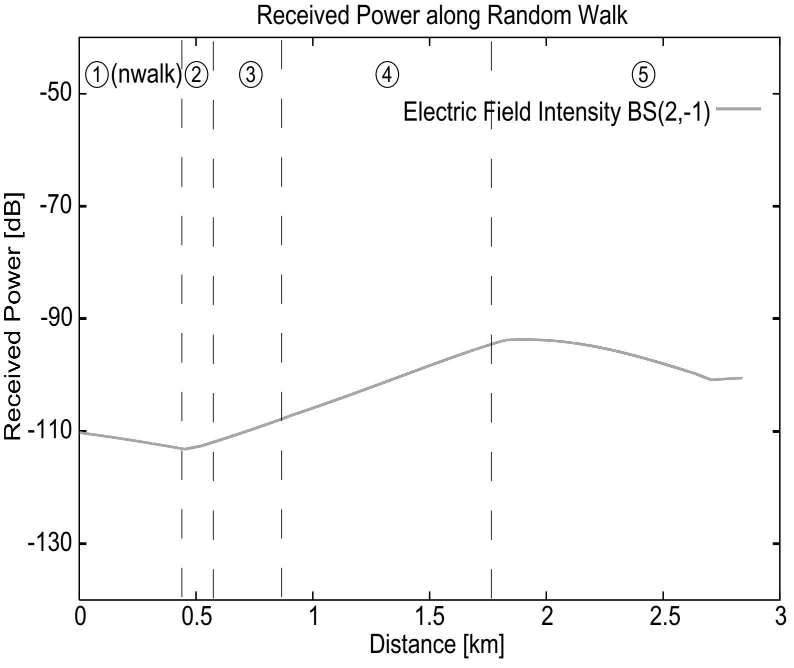


Fig. 15. Received power from BS(2, −1) (Scenario1).

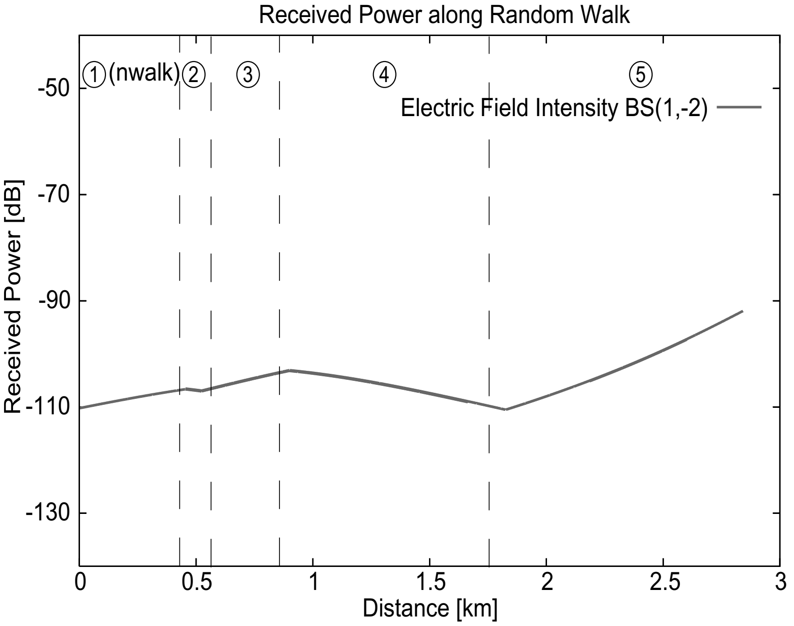


Fig. 16. Received power from BS(1,−2) (Scenario1).

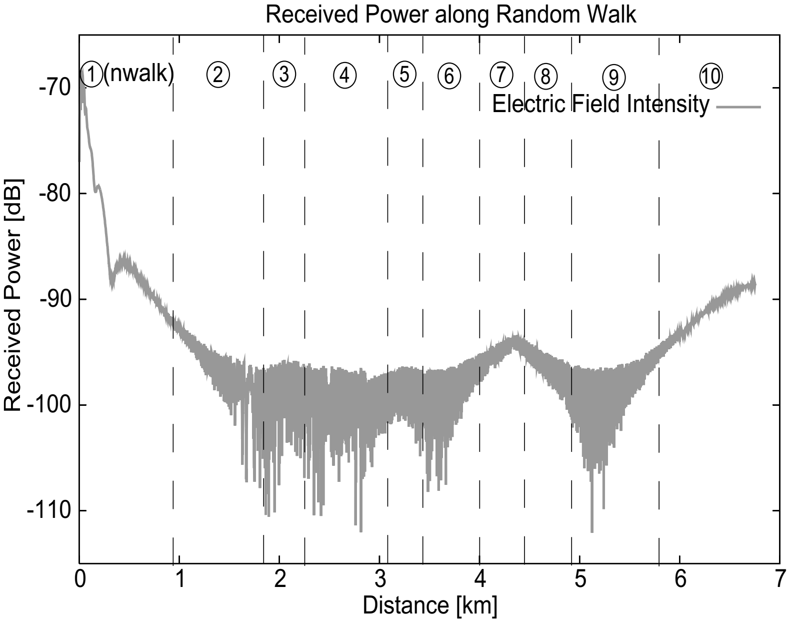


Fig. 17. Aggregate received power for Scenario2.

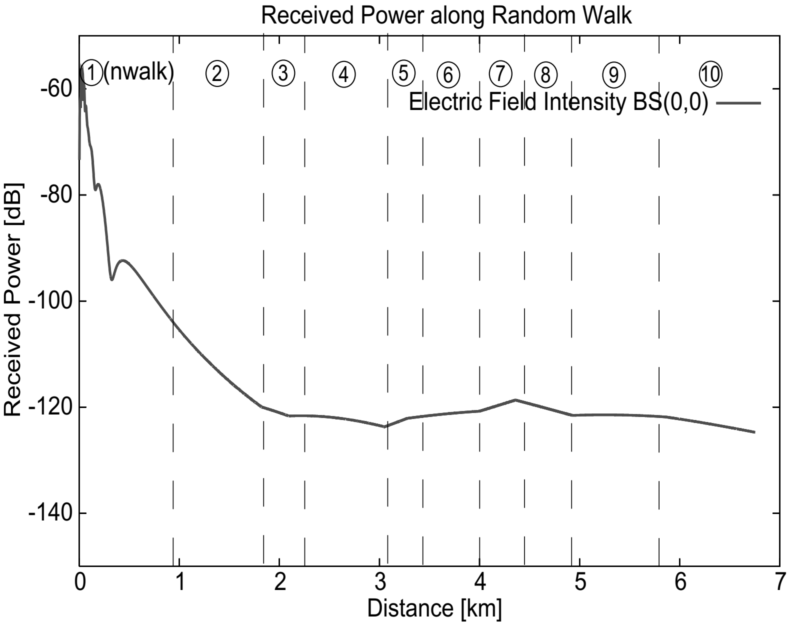


Fig. 18. Received power from BS(0,0) (Scenario2).

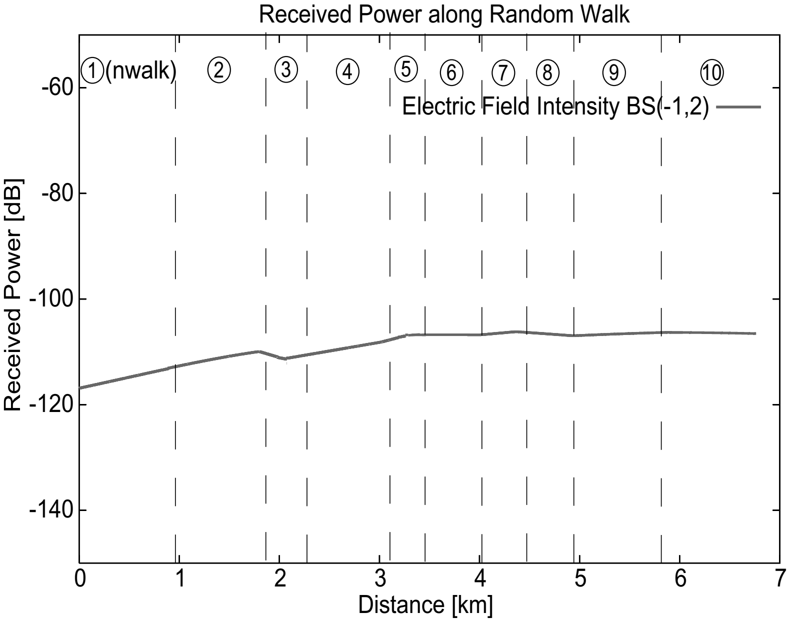


Fig. 19. Received power from BS(−1,2) (Scenario2).

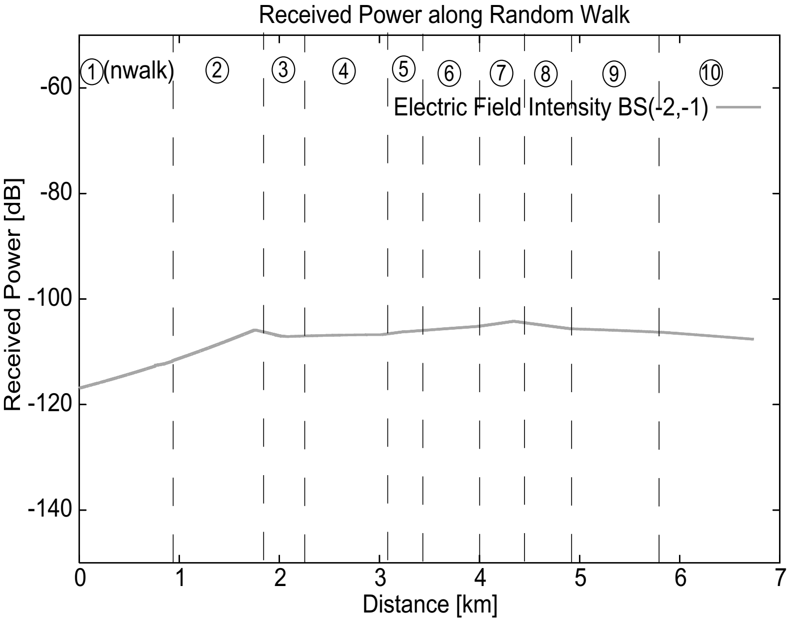


Fig. 20. Received power from BS(−2,1) (Scenario2).

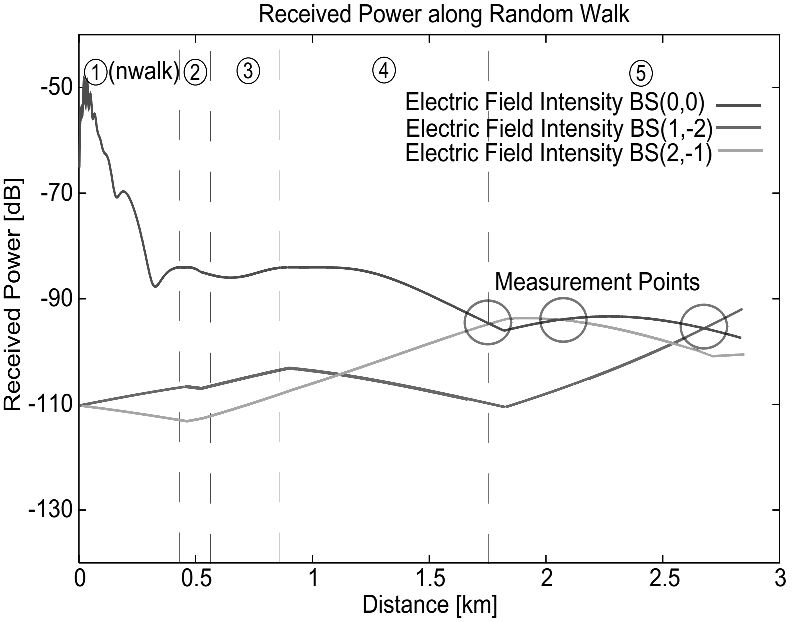


Fig. 21. 3 measurement points for Scenario1.

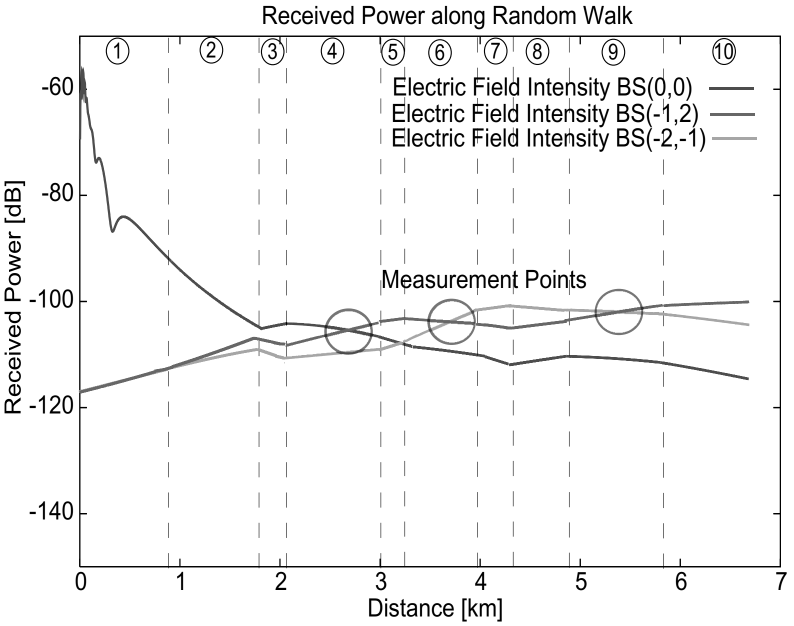


Fig. 22. 3 measurement points for Scenario2.

and Scenario2, respectively. In Fig. 21, the handover should not be carried out, because we will have the ping-pong effect, while in Fig. 22 the handover is necessary because the MS is moving inside the neighbor cells.

In both system, we consider that the handover is carried out when the output value is bigger than 0.7. We assume that during the RW for each 10 km/h the signal strength is decreased 2 db. We carry out 10 times simulations and calculate the average values. The simulation results of FBHS1 for Scenario 1 and Scenario2 are shown in Tables 4 and 5, respectively.

In the case of Scenario1, the MS moves in the boundary of cells. Thus if the handover will be carried out, we will have the ping-pong effect. As can be seen from Table 4, in most of the cases FBHS1 shows a good behavior. However, there are two values in the Measurement Point 3 that the value is more than 0.7. In this case, the FBHS1 carries out an un-necessary handover. In the case of handover enforcement, the FBHS1 shows a very good behavior. In all 3 measurement points, the FBHS1 carried out 3 handovers.

In the case of Scenario2, the FBHS2 has an ideal behavior. As shown in Table 6, all the average values are smaller than 0.7, therefore the FBHS2 system can avoid the ping-pong effect. For handover enforcement, the FBHS2 has a good performance because in all cases has done 3 handovers (see Table 7).

All our simulation results show that the selection of the parameters for making the handover decision is very important.

7. Conclusions

We are witnessing now an unprecedented demand for wireless networks to support both data and real-time multimedia traffic. But, in order to support the multimedia traffic, the cellular networks need to guarantee the QoS. To maintain the QoS, a good handover strategy is needed in order to balance the call blocking and call dropping for providing the required QoS.

Table 4
Simulation results of FBHS1 for Scenario1

Measurement points	Point 1		Point 2		Point 3	
Speed 0 km/h						
Present BS	−93.06	−94.11	−92.86	−92.47	−94.01	−95.28
Neighbor BS	−93.36	−92.49	−92.77	−93.98	−93.99	−91.28
Distance	0.8804	0.9431	0.8684	0.8466	0.9367	1.0183
System output value	0.595	0.629	0.602	0.576	0.623	**0.704**
Speed 10 km/h						
Present BS	−95.06	−96.11	−94.86	−94.47	−96.01	−97.28
Neighbor BS	−95.36	−94.49	−94.77	−95.98	−95.99	−93.28
Distance	0.8858	0.9431	0.8684	0.8466	0.9367	1.0183
System output value	0.598	0.649	0.600	0.578	0.623	**0.728**
Speed 20 km/h						
Present BS	−97.06	−98.11	−96.86	−96.47	−98.01	−99.28
Neighbor BS	−97.36	−96.49	−96.77	−97.98	−97.99	−95.28
Distance	0.8804	0.9431	0.8684	0.8466	0.9367	1.0183
System output value	0.568	0.621	0.572	0.538	0.590	0.696
Speed 30 km/h						
Present BS	−99.06	−100.11	−98.86	−98.47	−100.01	−101.28
Neighbor BS	−99.36	−98.49	−98.77	−99.98	−99.99	−97.28
Distance	0.8804	0.9431	0.8684	0.8466	0.9367	1.0183
System output value	0.522	0.585	0.531	0.482	0.542	0.662
Speed 40 km/h						
Present BS	−101.06	−102.11	−100.86	−100.47	−102.01	−103.28
Neighbor BS	−101.36	−100.49	−100.77	−101.98	−101.99	−99.28
Distance	0.8804	0.9431	0.8684	0.8466	0.9367	1.0183
System output value	0.534	0.597	0.521	0.497	0.590	0.672
Speed 50 km/h						
Present BS	−103.06	−104.11	−101.86	−104.47	−104.01	−105.28
Neighbor BS	−103.36	−102.49	−102.77	−103.98	−103.99	−101.28
Distance	0.8804	0.9431	0.8684	0.8466	0.9367	1.0183
System output value	0.576	0.625	0.566	0.549	0.600	0.668

Table 5
Simulation results of FBHS1 for Scenario2

Measurement points	Point 1		Point 2		Point 3	
Speed 0 km/h						
Present BS	−105.23	−108.70	−104.64	−107.96	−103.95	−111.93
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	0.596	**0.706**	0.615	**0.748**	0.601	**0.800**
Speed 10 km/h						
Present BS	−107.23	−110.70	−106.64	−109.96	−105.95	−113.93
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	0.595	**0.715**	0.616	**0.799**	0.601	**0.800**
Speed 20 km/h						
Present BS	−109.23	−112.70	−108.64	−111.96	−107.95	−115.93
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	0.592	**0.701**	0.699	**0.799**	0.602	**0.800**
Speed 30 km/h						
Present BS	−111.23	−114.70	−110.64	−113.96	−109.95	−117.93
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	0.632	**0.705**	0.618	**0.733**	0.603	**0.800**
Speed 40 km/h						
Present BS	−113.23	−116.70	−112.64	−115.96	−111.95	−119.93
Neighbor BS	−113.55	−110.07	−111.52	−104.76	−111.85	−96.422
Distance	1.9597	2.4628	1.8367	2.3453	1.8021	3.0449
System output value	0.602	**0.711**	0.660	**0.711**	0.647	**0.800**
Speed 50 km/h						
Present BS	−115.23	−118.70	−114.64	−117.96	−113.95	−121.93
Neighbor BS	−115.55	−112.07	−113.52	−106.76	−113.85	−98.422
Distance	1.9597	2.4628	1.8367	2.3453	1.8021	3.0449
System output value	0.693	**0.746**	0.694	**0.748**	0.683	**0.800**

Table 6
Simulation results of FBHS2 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

Table 7
Simulation results of FBHS2 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**

Due to host mobility, scarcity of bandwidth, and an assortment of channel impairments, the QoS provisioning problem is far more challenging in wireless networks than in their wireline counterparts.

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.

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. Some of handover criteria information can be inherently imprecise, or the precise information is difficult to obtain.

During handover decision in cellular networks, there is a risk of making incorrect decision based on incomplete or outdated information. For this reason, we use Fuzzy Logic (FL) which can operate with imprecision data.

In different from other works, we used Random Walk (RW) model and FL to design the FBHS1 and FBHS2. We evaluated the performance of the proposed FL-based handover systems by computer simulations. We considered two scenarios: un-necessary handover and enforced handover. As scenario of un-necessary handover, we considered the case when the MS moves in the boundary of cells. While, as enforced handover we considered the case when MS moves inside the cells. The simulation results have shown that the FBHS2 has a better behavior than FBHS1.

Acknowledgment

This work is partially supported by Japanese Society for the Promotion of Science (JSPS) and Fukuoka Institute of Technology (FIT). The authors would like to thank JSPS and FIT for the financial support.

References

[1] R. Berezdivin, R. Breining and R. Topp, Next-generation Wireless Communication Concepts and Technologies, *IEEE Communication Magazine* **40**(3) (2002), 108–116.

[2] Y. Guo and H. Chaskar, Class-based Quality of Service Over Air Interfaces in 4G Mobile Metworks, *IEEE Communication Magazine* **40**(3) (2002), 132–137.

[3] C. Abondo and S. Pierre, Dynamic Location and Forwarding Pointers for Mobility Management, *Mobile Information Systems* **1**(1) (2005), 3–24.

[4] W. Wang, X. Wang and A.A. Nilsson, Energy-efficient Bandwidth Allocation in Wireless Networks: Algorithms, Analysis, and Simulations, *IEEE Transactions on Wireless Communications* **5**(5) (2006), 1103–1114.

[5] Y. Fang and Y. Zhang, Call Admission Control Schemes and Performance Analysis in Wireless Mobile Networks, *IEEE Transactions on Vehicular Technology* **51**(2) (2002), 371–382.

[6] K.D. Wong and D.C. Cox, A Pattern Recognition System for Handoff Algorithms, *IEEE J-SAC* **18**(7) (2000), 1301–1312.

[7] S. Kovvuri, V. Pandey, D. Ghosal, B. Mukherjee and D. Sarkar, A Call Admission Control (CAC) Algorithm for Providing Guaranteed QoS in Cellular Networks, *International Journal of Wireless Information Networks* **10**(2) (2003), 73–85.

[8] H.P. Lin, R.T. Juang and D.B. Lin, Validation of an Improved Location-based Handover Algorithm Using GSM Measurement Data, *IEEE Transactions on Mobile Computing* **4**(5) (2005), 530–536.

[9] P. Fiengo, G. Giambene and E. Trentin, Neural-based Downlink Scheduling Algorithm for Broadband Wireless Networks, *Computer Communication* **30**(2) (2007), 207–218.

[10] L. Barolli, A. Koyama, T. Suganuma and N. Shiratori, Gaman: a GA Based QoS Routing Method for Mobile Ad-Hoc Networks, *Journal of Interconnection Networks* (*JOIN*) **4**(3) (2003), 251–270.

[11] M. Ikeda, L. Barolli, A. Koyama, A. Durresi, G. De Marco and J. Iwashige, Performance Evaluation of an Intelligent CAC and Routing Framework for Multimedia Applications in Broadband Networks, *Journal of Computer and System Science* (*JCSS*) **72**(7) (2006), 1183–1200.

[12] L. Barolli, M. Ikeda, G. De Marco, A. Durresi, A. Koyama and J. Iwashige, A Search Space Reduction Algorithm for Improving the Performance of a GA-based Routing Method in Ad-Hoc network, *International Journal of Distributed Sensor Networks* (*IJDSN*) **3**(1) (2007), 41–57.
[13] M. Ikeda, L. Barolli, A. Koyama and M. Takizawa, Hierarchical QoS Routing Using Heuristics Algorithms, *Journal of Information Processing of Japan* **49**(2) (2008), 692–705.
[14] J. Anno, L. Barolli, A. Durresi, F. Xhafa and A. Koyama, Performance Evaluation of Two Fuzzy-Based Cluster Head Selection Systems for Wireless Sensor Networks, *Mobile Information Systems* **4**(4) (2008), 297–312.
[15] E. Natsheh and T. C. Wan, Adaptive and Fuzzy Approaches for Nodes Affinity Management in Wireless Ad-hoc Networks, *Mobile Information Systems* **4**(4) (2008), 273–295.
[16] L. Barolli, A Speed-aware Handover System for Wireless Cellular Networks Based on Fuzzy Logic, *Mobile Information Systems* **4**(1) (2008), 1–12.
[17] T. Onel, C. Ersoy and E. Cayirci, A Fuzzy Inference System for the Handoff Decision Algorithms in the Virtual Cell Layout Base Tactical Communications System, *IEEE Military Communications Conference* (*MILCOM-2002*) **1** (2002), 436–441.
[18] P.M.L. Chan, R.E. Sheriff, Y.F. Hu, P. Conforto and C. Tocci, Mobility Management Incorporating Fuzzy Logic for a Heterogeneous IP Environment, *IEEE Communications Magazine* **39**(12) (2001), 42–51.
[19] L. Barolli, A. Durresi, F. Xhafa and, A. Koyama, A Fuzzy Based Handover System for Wireless Cellular Networks: A Case Study for Handover Enforcement, *Proc of NBiS-2008*, Torino, Italy (2008), 212–222.
[20] L. Barolli, J. Anno, F. Xhafa, A. Durresi and A. Koyama, A Context-Aware Fuzzy-based Handover System for Wireless Cellular Networks and Its Performance Evaluation, *Journal of Mobile Multimedia* (*JMM*) **4**(3/4) (2008), 241–258.
[21] S. Mohanty and I.F. Akyildiz, A Cross-Layer (Layer 2+3) Handoff Management Protocol for Next-Generation Wireless Systems, *IEEE Transactions on Mobile Computing* **5**(10) (2006), 1347–1360.
[22] F. Yu and Y. Krishamurthy, Optimal Joint Session Admission Control in Integrated WLAN and CDMA Cellular Networks with Vertical Handoff, *IEEE Transactions on Mobile Computing* **6**(1) (2007), 126–139.
[23] D. Dubois, H. Prade and R. Yager, (Eds.), Fuzzy Sets for Intelligent Systems, Morgan Kaufman Publishers, 1993.
[24] A. Kandel and G. Langhholdz, (Eds.), Fuzzy Control Systems, CRC Press, 1994.

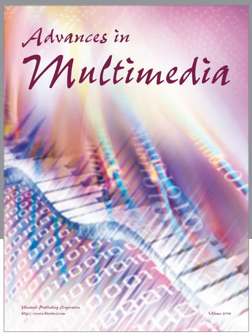
Gjergji Mino was graduated in Electronics at Tirana Polytechnic University, Albania in 1995.After the graduation, he was working for different telecommunication companies in Albania. From 1997, he worked for different companies such as Digital Corporation, Compaq, Computer Technology Solutions and Peripheral Computer Support in US. Presently, he is a PhD candidate at Graduate School of Engineering, Fukuoka Institute of Technology (FIT), Japan.His research interests include wireless networks, CAC, handover and fuzzy logic.

Leonard Barolli received BE and PhD degrees from Tirana University and Yamagata University in 1989 and 1997, respectively. From April 1997 to March 1999, he was a JSPS Post Doctor Fellow Researcher at Department of Electrical and Information Engineering, Yamagata University. From April 1999 to March 2002, he worked as a Research Associate at the Department of Public Policy and Social Studies, Yamagata University. From April 2002 to March 2003, he was an Assistant Professor at Department of Computer Science, Saitama Institute of Technology (SIT). From April 2003 to March 2005, he was an Associate Professor and presently is a Full Professor, at Department of Information and Communication Engineering, Fukuoka Institute of Technology (FIT). Dr. Barolli has published more than 300 papers in referred Journals and International Conference proceedings. He has served as a Guest Editor for many International Journals. Dr. Barolli has been a PC Member of many International Conferences and was the PC Chair of IEEE AINA-2004 and IEEE ICPADS-2005. He was General Co-Chair of IEEE AINA-2006 and IEEE AINA-2008, Workshops Chair of iiWAS-2006/MoMM-2006 and iiWAS-2007/MoMM-2007, Workshop Co-Chair of ARES-2007, ARES-2008 and IEEE AINA-2007 and AINA-2009. Presently, he is General Co-Chair of CISIS-2010 and IEEE AINA-2010. Dr. Barolli is the Steering Committee Chair of CISIS International Conference and is serving as Steering Committee Member in many International Conferences. He is organizers of many International Workshops. His research interests include network traffic control, fuzzy control, genetic algorithms, agent-based systems, ad-hoc networks and sensor networks, Web-based applications, distance learning systems and P2P systems. He is a member of SOFT, IPSJ, and IEEE.

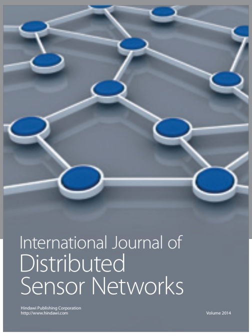
Fatos Xhafa holds a PhD in Computer Science (1998) from the Department of Languages and Informatics Systems, Polytechnic University of Catalonia, Barcelona, Spain. He was graduated in Mathematics from the Faculty of Natural Sciences (FNS), University of Tirana (UT), Albania, in 1988. During 1989–1993 he was an Assistant Professor at the Department of Applied Mathematics of the FNS, UT (Albania). He joined the Polytechnic University of Catalonia as a Visiting Professor at the Applied Mathematics Department I, and later he entered the Department of Languages and Informatics Systems (LSI) as a PhD student and in 1996 as an Assistant Professor. Currently, he is an Associate Professor at the Department of Languages and Informatics Systems and member of the ALBCOM Research Group. He is also a collaborator of the Open University of Catalonia (Barcelona, Spain). His current research interests include parallel and distributed algorithms, combinatorial optimization and approximation, meta-heuristics for complex problems, distributed programming, Grid and P2P computing. His research is supported by several research projects from Spain, European Union and NSF/USA. He collaborates with different international research groups. He has published in leading international journals and conferences and has served in the Organizing Committees of many conferences and workshops. He served as the Organizing Chair of ARES-2008, PC Chair of CISIS-2008, Workshops Co-chair of CISIS-2008 and General Co-chair of HIS-2008 conferences. Presently, he is General Co-Chair of CISIS-2010 and PC Co-Chair of IEEE AINA-2010. He is also member of editorial board of several international journals.

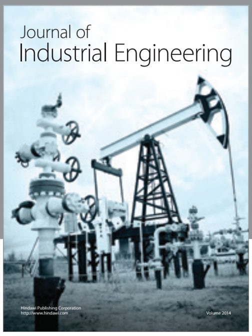
Arjan Durresi received his BE, MS and PhD at Polytechnic University of Tirana, Albania in 1986, 1990 and 1993, respectively. He holds a Post-Graduate Degree from Italian Telecommunication Institute, La Sapienza University, Italy in 1991. He also got another PhD degree at Tokyo Denki University, Japan in 2006. Presently, he is an Associate Professor of Computer Science at Indiana University Purdue University in Indianapolis, Indiana. In the recent past, he also held roles as Associate Professor at Louisiana State University, Research Scientist of Computer Science and Adjunct Assistant Professor of Electrical and Computer Engineering at The Ohio State University. Dr. Durresi serves as Area Editor of Ad Hoc Networks Journal. He is on Editorial Boards of many International Journals. He has been a Guest Editor for many Special Issues. He was Workshops Co-Chair for 21th IEEE International Conference on Advanced Information Networking and Applications AINA-2007. He was Program Co-Chair of the AINA-2006. He is organizing many International Workshops. He has authored more than 50 papers in Journals and more than 80 in Conference Proceedings. Dr. Durresi's research interest include: network architectures, heterogeneous wireless ad hoc and sensor networks, security, QoS routing protocols, traffic management, grid computing, optical and satellite networks, multimedia networking, and bioinformatics.

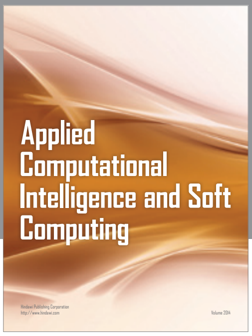
Akio Koyama received his BE and PhD degrees from Yamagata University in 1987 and 1998, respectively. From April 1999 to March 2002, he was an Assistant Professor at the Faculty of Computer Science and Engineering, the University of Aizu. From April 2002 to March 2008, he was an Associate Professor and presently is a Full Professor at the Faculty of Engineering, Yamagata University. Dr. Koyama has published about 100 papers in refereed journals and international conference proceedings. He has been a PC member of many international conferences. He was the General Co-chair of MNSA-2005 and Workshop Co-Chair of IEEE AINA-2008. His research interests include medical and care communication systems, routing protocols, high-speed network protocols, agent-based systems, distance learning systems and mobile communication systems. He is a member of the IEEE Computer Society, IPSJ and IEICE.

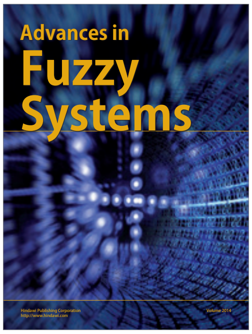

Advances in
Multimedia

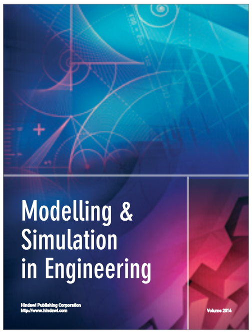

The Scientific World Journal

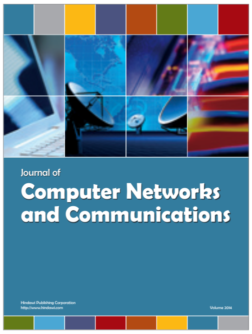

International Journal of
Distributed Sensor Networks

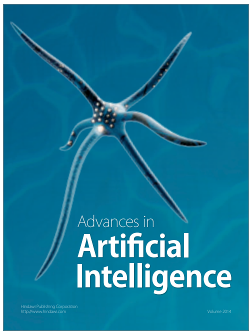

Journal of
Industrial Engineering

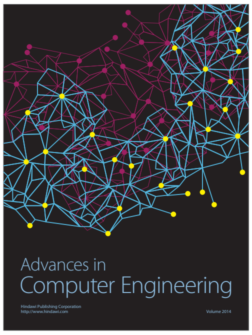

Applied Computational Intelligence and Soft Computing


Advances in
Fuzzy Systems

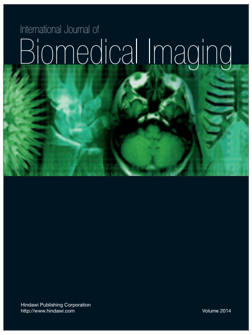

Modelling & Simulation in Engineering

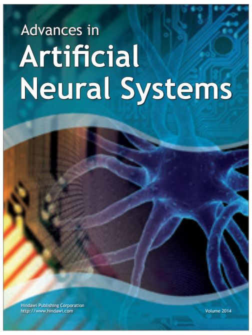

Journal of
Computer Networks and Communications

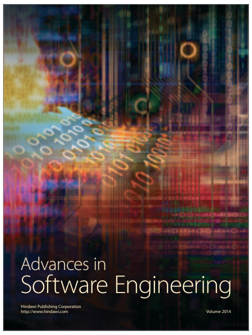

Advances in
Artificial Intelligence


Advances in
Computer Engineering

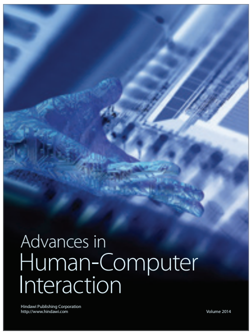

International Journal of
Computer Games Technology

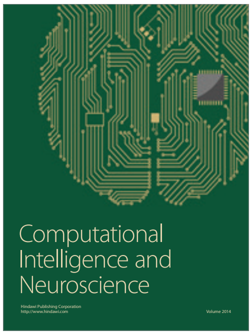

International Journal of
Biomedical Imaging


Advances in
Artificial Neural Systems


Advances in
Software Engineering


Journal of
Robotics


Advances in
Human-Computer Interaction


Computational Intelligence and Neuroscience


International Journal of
Reconfigurable Computing


Journal of
Electrical and Computer Engineering