Fuzzy Adaptive Guard Channel Assignment Strategy for Handoff in PCS System

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Abstract

The known channel allocation schemes in Personal Communications Service(PCS) operating with fixed guard channels for handoff calls can lead to fail in utilizing the limited channels such a wasting or lacking the number of guard channels, since the handoff traffics which depend on mobility of users are always not stationary. In this paper, we use Fuzzy Logic Controller (FLC) to generate proper guard channels according to fluctuating handoff traffic pattern so as not to waste or not to lack the valuable resources. Also we introduce the Fuzzy Adaptive Guard Channel with Handoff Queueing Scheme (FA_GCHQS) which combines FLC with previous guard channel plus queueing priority scheme (GCHQS). For the performance evaluation we regard originating call blocking probability, handoff forced termination probability, and GoS of network as the system performance criteria. Finally we show that the proposed method yields better performance than that of previous one through the analytical results of M/M/C/K queueing model on a assumed handoff traffic pattern of a city environment.

1. Introduction

It is a important criterion to manage successful handoff transaction in the performance evaluation of Personal Communications Service(PCS) which has more frequent inter-cell crossing rate owing to introduction of microcell. The forced termination of an ongoing call(handoff) is considered less desirable to users than blocking of a new call attempt. In this point of view, there have been many works to reduce the forced termination probability of handoff[1, 2, 4, 5, 6]. Some representative methods of those are Guard Channel Scheme(GCS, or Reserved Channel Scheme(RCS)), Queueing Priority Scheme(QPS), and combination of these named Guard Channel with Handoff Queueing Scheme(GCHQS) in this paper.

GCHQS is more flexible method to face with handoff call than GCS or QPS since handoff queue or guard channel is for private use. But the handoff traffic density which depends on users mobility relates to flow of time especially in city and is always not stationary. For that reason the strategies which employ fixed guard channels such as GCHQS, GCS have the risk of inefficient spectrum utilization according to fluctuating handoff traffic volume. So careful estimation of handoff traffic volume is essential in other to minimize the risk by determining the optimum number of guard channels[3]. The main idea of this paper is to assign proper guard channels dynamically according to randomly fluctuating handoff traffic density using fuzzy logic for optimum use of limited resources in any handoff traffic density. Also we propose more efficient method than previous one, Fuzzy Adaptive GCHQS(FA_GCHQS) combined previous GCHQS with Fuzzy Logic Controller(FLC) which is so designed as not to be wasteful or lacking the guard channels.

Finally we consider originating call blocking probability(P_b), handoff call forced termination probability(P_f), and Grade of Service(GoS) of the network as the criteria of system performance through analytical results of M/M/C/K queueing model, and show that the proposed method yields better performance than previous one in a assumed random handoff traffic pattern based on a city environment.

2. Fuzzy System

2.1 Structure of Fuzzy Logic Controller(FLC)

FLC is a special form of expert system used to control complicated system. The core part of FLC is the control rules of serial linguistic form which contains fuzzy relationships. After all, the main function of FLC is to convert the role so that the automatic controller works the control rule described control knowledge of expert as linguistic form. The {Figure 2-1} shows the block

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diagram of FLC.

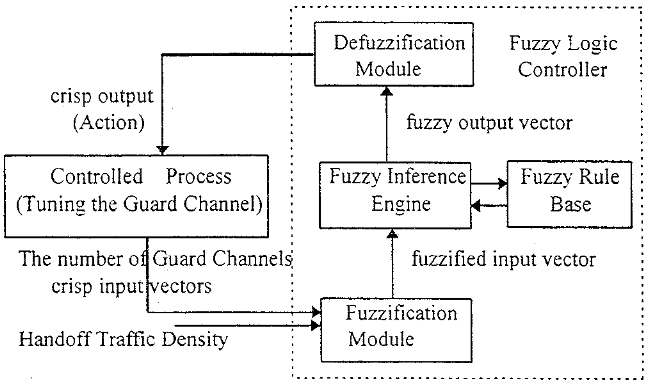


Figure 2-1 Block diagram of FLC

2.2 Fuzzification Module

In fuzzy set an element is related to a set by a membership function μ. As an example, consider a fuzzy set A and an element x, the membership function $\mu_A(x)$, specifies the relationship x to A. The membership function usually take on a value between 0 and 1, i.e., $\mu(x) \rightarrow [0,1]$ where 1 is for full membership, 0 for the null-membership, while values in between give the degree of membership. This process is referred to fuzzification. The fuzzified information is then passed on to the *Fuzzy Inference Engine.*

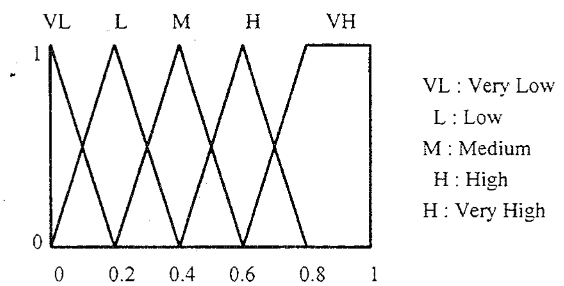


Figure 2-2 The membership functions for handoff traffic density

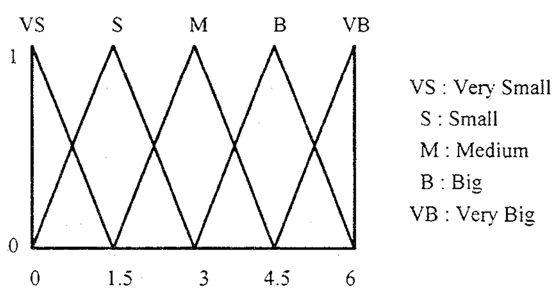


Figure 2-3 The membership functions for the number of the latest fixed guard channel

2.3 Fuzzy Rule Base

Fuzzy rule base is the place where knowledge about control object and purpose of control are described. Fuzzy logic uses linguistic variables to map the input fuzzy variables to the output fuzzy variable(s). This is accomplished by using fuzzy **IF-THEN** rule to map the fuzzy sets in the input universe of discourse $U \subset \mathbf{R}^n$, to the fuzzy sets in the output universe where $V \subset \mathbf{R}$, where **R** is the set of real numbers. The fuzzy rules, in this paper, consist of 25 rules as follows :

IF HANDOFF TRAFFIC DENSITY IS	AND LAST-GUARD CHANNEL IS	THEN LAST-GUARD CHANNEL IS TUNED BY
Very Low	Very Small	Approximately Zero
Very Low	Small	Negative Small
Very Low	Medium	Negative Medium
Very Low	Big	Negative Large
Very Low	Very Big	Negative Very Large
Low	Very Small	Positive Small
Low	Small	Approximately Zero
Low	Medium	Negative Small
Low	Big	Negative Medium
Low	Very Big	Negative Large
Medium	Very Small	Positive Medium
Medium	Small	Positive Small
Medium	Medium	Approximately Zero
Medium	Big	Negative Small
Medium	Very Big	Negative Medium
High	Very Small	Positive Large
High	Small	Positive Medium
High	Medium	Positive Small
High	Big	Approximately Zero
High	Very Big	Negative Small
Very High	Very Small	Positive Very Large
Very High	Small	Positive Large
Very High	Medium	Positive Medium
Very High	Big	Positive Small
Very High	Very Big	Approximately Zero

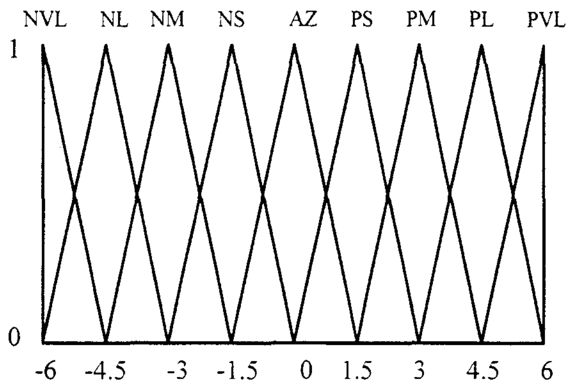
Table 2-1 25 fuzzy rules for guard channel control

2.4 Fuzzy Inference Engine

The Fuzzy Inference Engine will take the fuzzified input and perform operation on it according to the Fuzzy Rule Base(Section 2.3). In this paper the ANDing(intersection) of the membership functions of n-fuzzy variables is defined as follows :

$$\mu^l_O = \bigcap_{i=1}^{n} \mu^l_{O_i}(x_i) = \min[\mu^l_{O_1}(x_1), \ldots, \mu^l_{O_n}(x_n)] \quad (2\text{-}1)$$

The {Figure 2-4} shows membership functions of the fuzzy output.



NVL : Negative Very Large L : Negative Large
NM : Negative Medium NS : Negative Small
AZ : Approximately Zero PS : Positive Small
PM : Positive Medium PL : Positive Large
PVL : Positive Very Large

Figure 2-4 The membership function for guard channel tuning

The results produced from the rule inferences will be passed to the defuzzifier.

2.5 Defuzzification Module

The control volume derived from fuzzy inference engine has to be computed a crisp, i.e., convert the fuzzy domain back to the real world domain. This process refers to defuzzification. In this paper we use a centroid algorithm to arrive at the output value :

$$y = \frac{\sum_{i=1}^{M} \mu_O^i \frac{i}{y}}{\sum_{i=1}^{M} \mu_O^i} \qquad (2\text{-}2)$$

where $\frac{i}{y}$ denote the center of the fuzzy region.

2.6 Working Example of FLC

The degree of membership function for handoff traffic density	The degree of membership function for the latest fixed number of guard channel
$\mu_{Low}(0.3) = 0.5$	$\mu_{Medium}(4) \cong 0.33$
$\mu_{Medium}(0.3) = 0.5$	$\mu_{Big}(4) \cong 0.67$

Table 2-2 An example of fuzzification for input 0.3 and 4

An example of the {Table 2-2} shows that the handoff traffic density to a cell is 30% of its originating call volume, and the latest fixed number of guard channels are 4 in the Base Station Transceiver Subsystem(BTS) of the cell at that time. We can get some fuzzy values as we map the those crisp values to the membership function from {Figure 2-2} and {Figure 2-3}, respectively.

The fuzzifed input values from {Table 2-2} fire 4 rules from {Table 2-1} and lead theses to following 4 fuzzified output values by (2-1).

① $\mu_{Negative\ Small}$(Guard Channel Tuning) $\cong$ 0.33
② $\mu_{Negative\ Medium}$(Guard Channel Tuning) $=$ 0.5
③ $\mu_{Approximately\ Zero}$(Guard Channel Tuning) $\cong$ 0.33
④ $\mu_{Negative\ Small}$(Guard Channel Tuning) $=$ 0.5

Those four results are converted crisp value for real control by centroid algorithm of (2-2), and its volume is -1.67. Finally this value is added to the last fixed guard channel, 4 and rounded off for the exact figure. Therefore the new last set number of guard channel is 2.

3. Analytical Model

In this chapter we analyze originating call blocking probability(P_b, new call) and handoff forced termination probability(P_f, ongoing call) of GCHQS and FA_GCHQS using steady state of Markov Chain. We assume that arrival process of originating call and handoff call traffic is Poisson with arrival rates of λ_o, λ_h respectively.

A call being served in a channel may be handed off as a user crosses a boundary of two adjacent cells. At that time the age of the call in the old cell and the residual lift time of the call in a new cell have the same exponential distribution with an average $1/\mu$ due to the memoryless property of the exponential distribution[9].

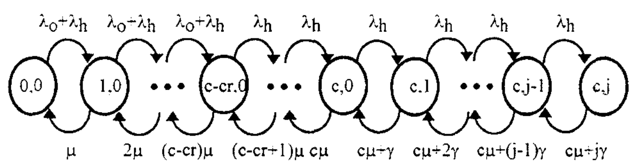


Figure 3-1 The state-transition-rate of GCHQS and FA_GCHQS

Let λ_s be $\lambda_o + \lambda_h$, then λ_s is served by c channels and is also a Poisson process because a Poisson process plus a Poisson process is still a Poisson process[9]. Because GCHQS has a exponential distribution, the timeout model of GCHQS can be modeled by a Markov process with states $S_{(n,i)}(0 \le n \le c,\ 0 \le i \le j)$, where n represents the number of busy channels, and i represents the number of calls in the waiting queue(Figure 3-1). Let $S_{(n,i)}$ be the steady state probability when n + i calls are in the system, then the balance equation of the system can be obtained like that[2,5] :

$S_{(n,i)}$ =

$$\begin{cases} \dfrac{(\lambda_s/\mu)^n}{n!} \times S_{(0,0)}, & 0 \le n \le c\text{-}c_r,\ i=0 \quad (3\text{-}1) \\ \dfrac{(\lambda_h/\mu)^{(n-c+c_r)}(\lambda_s/\mu)^{(c-c_r)}}{n!} \times S_{(0,0)}, & c\text{-}c_r+1 \le n \le c,\ i=0 \\ \dfrac{(\lambda_h/\mu)^{c_r}(\lambda_s/\mu)^{(c-c_r)}\lambda_h^{i-c}}{c! \times \prod_{k=1}^{i-c}[c\mu + k\gamma]} \times S_{(0,0)}, & n=c,\ 1 \le i \le j \end{cases}$$

From (3-1) originating call blocking probability is represented as follows :

$$P_b = \sum_{n=c-c_r}^{c} S_{(n,0)} + \sum_{i=1}^{j} S_{(c,i)} =$$

$$\left[\frac{(\lambda_s/\mu)^{(c-c_r)}}{(c-c_r)!} + \sum_{n=c-c_r+1}^{c} \frac{(\lambda_h/\mu)^{(n-c+c_r)}(\lambda_s/\mu)^{(c-c_r)}}{n!} + \sum_{i=1}^{j} \frac{(\lambda_h/\mu)^{c_r}(\lambda_s/\mu)^{(c-c_r)}\lambda_h^{i}}{c! \times \prod_{k=1}^{i}(c\mu + k\gamma)} \right] \times S_{(0,0)}, \quad (3\text{-}2)$$

Suppose that a call C_t arrives at time t when the cell is in state $S_{(c,i)}$,where $(0 \le i \le j)$. The timeout period for C_t is τ with density function[2,6]

$$f_{timeout}(\tau) = \gamma e^{-\gamma\tau}$$

Consider the c + i calls arrived already at the cell earlier than C_t. If we suppose that among these c + i calls, the first call completes or expires at the time t + t_i, then the density function for t_i is

$$f_i(t_i) = (c\mu + i\gamma)e^{-(c\mu+i\gamma)t_i}$$

Let $T_i = t_0 + \ldots + t_i$. For a call C_t arrives at state $S_{(c,i)}(0 \le i \le j)$, the probability that C_t is forced terminated is given following :

$$P_f = \Pr[\tau < T_i \mid P_{(c,i)}]$$

$$= \int_{t_i=0}^{\infty} \cdots \int_{t_0=0}^{\infty} \int_{t=0}^{t_0+\cdots+t_i} \left[\prod_{k=0}^{i} f_k(t_k) \right] \times f_{timeout}(\tau)\, d_\tau dt_0 \cdots dt_i$$

$$= \quad \cdots$$

$$= \left[\frac{(\lambda_h/\mu)^{c_r}(\lambda_s/\mu)^{(c-c_r)}}{c!} \times \sum_{i=1}^{j+1} \frac{i\gamma\lambda_h^{(i-1)}}{\prod_{k=1}^{i}(c\mu + k\gamma)} \right] \times S_{(0,0)}, \quad (3\text{-}3)$$

For the first state $S_{(0,0)}$, we use the fact that

$$\sum_{n=0}^{c-c_r} S_{(n,0)} + \sum_{n=c-c_r+1}^{c} S_{(n,0)} + \sum_{i=1}^{j} S_{(c,i)} = 1.$$

So we can get that

$$S_{(0,0)} = \left[\sum_{n=0}^{c-c_r} \frac{(\lambda_s/\mu)^n}{n!} + \sum_{n=c-c_r+1}^{c} \frac{(\lambda_h/\mu)^{(n-c+c_r)}(\lambda_s/\mu)^{(c-c_r)}}{n!} + \sum_{i=1}^{j} \frac{(\lambda_h/\mu)^{c_r}(\lambda_s/\mu)^{(c-c_r)}\lambda_h^{i}}{c! \times \prod_{k=1}^{i}(c\mu + k\gamma)} \right]^{-1}$$

The P_f and P_b in FA_GCHQS are basically same as those in GCHQS, but the difference is that the FLC resets time after time the last established the number of guard channels, c_r, in (3-2) and (3-3) according to variable traffic, λ_h.

4. Teletraffic Model

4.1 User Mobility

Mobility models can estimate inter-cell and inter-location area crossing, from which handoff and location update rates can be estimated. One simple mobility model is the fluid flow model. The model assumes that a uniform density of people throughout an cell and that the direction of user with respect to the cell border is uniform on (0, 2π]. Let ρ be the density of people per cell, and L be the length of the perimeter of the cell. Then the rate of boundary crossing(T_m) out of the cell is given as :

$$T_m = \frac{\rho v L}{\pi} \qquad (4\text{-}1)$$

4.2 Parameters for Simulation

We assume the key parameters for simulation as follows :

PARAMETERS	DESCRIPTIONS	VALUES
	User Behavior Characteristics	
ρ	people density / cell	**1,000**
$P[p_t]$	prob. that person has terminal	**0.8**
v	mean velocity	**20 km/h**
$T_{erl.}$	Utilization factor of terminal	**0.07 erlang**
$1/\mu$	mean call holding time	**2 min.**
$1/\gamma$	mean handoff area passing time	**0.3 min**
λ_{op}	call originating rate / person	**2 / hr**
λ_o	call originating rate / cell	**1600 / hr**
λ_h	handoff traffic density / cell	$\lambda_o \times 0.1 \sim \lambda_o \times 1$
	System Deployment Characteristics	
d	cell diameter(assume square cell)	**0.5 km**
d_{ha}	mean handoff area length	**0.1 km**
c	channels / BTS	**60**
c_r	the number of guard channel	**variable(0 - 6)**
j	queue length	**10**

Table 4-1 Parameters for simulation

We consider mean handoff area passing time as random variable, just as mean call holding time, and assume that this dwell time is exponentially distributed with mean $1/\gamma$ for simplicity of analysis. From given parameters we can get T_m as follows :

$$T_m = \frac{\rho v L}{\pi} = \frac{(1000 \times 0.8) \times 20 \times 2}{3.14} \cong 10191/\mathrm{hr} \quad (4\text{-}2)$$

(4-2) is the boundary crossing rate(the number of crossing / hr) of all the persons with handset. We can obtain only handoff traffic rate(the number of handoffs / hr) by multiplying (4-2) by utilization factor of terminal (T_{erl}), since a handoff call only occurs when the mobile keeps crossing the boundary of two cells as well as in conversation. So λ_h is given as follows :

$$\lambda_h = T_m \times T_{erl.} = 10191 \times 0.07 \cong 713/\mathrm{hr} \quad (4\text{-}3)$$

From the 3rd, the 4th, and 9th row in {Table 4-1} we can obtain that λ_o is 1600 times per hour and λ_h/λ_o is approximately 0.4. The user velocity, v which is not effective into λ_o but into λ_h is the mean value. For that reason if we assume λ_h is variable from the double of its size to the half of its size, then the scope of λ_h is about from 0.2 to 0.8. So, in this paper, we describe the volume of handoff traffic as ratio to originating call density under the condition that λ_o is uniform all over the cells, and define it as from 10% to 100% to the originating call density.

4.3 Performance Evaluation Model

We assume handoff traffic density pattern for performance analysis as in {Figure 4-1} owing to section 4.2. The y axis shows λ_h/λ_o, and x axis is the time from 1 p.m. to 5 p.m. including Busy Hour Call Attempt (BHCA). We define that time sampling interval is 15 minute and assume that any steady state of sampling time does not influence previous one.

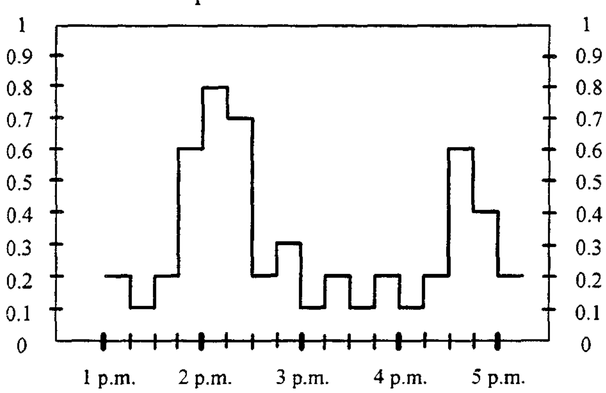


Figure 4-1 An example of handoff traffic volume pattern in a downtown

We evaluate the performance of GCHQS and FA_GCHQS on the {Figure 4-1} handoff traffic density pattern. For the general performance evaluation we classify 3 types of GCHQS according as how many the fixed number of guard channel it has, GCHQS_1, GCHQS_3, and GCHQS_6 regardless of handoff traffic density pattern. These numbers are the minimum, the medium, and the maximum value respectively in the range of the possible output number of guard channel of FLC described in chapter 2. On the other hand FA_GCHQS outputs variable guard channels on every traffic sampling in {Figure 4-1} by FLC as follows :

2, 1, 2, 4, 6, 5, 1, 2, 1, 2, 1, 2, 1, 2, 4, 3, 2

Originating call blocking probability(P_b) and handoff forced termination probability(P_f) of the proposed method and previous one are evaluated over every sampling times. Also we define the most critical criterion GoS as the weighted sum of those two criteria.

$$GoS = \frac{N_{blocked} + 50 * N_{forced}}{N_{total}} \quad (4\text{-}4)$$

where, $N_{blocked}$ is the number of lost originating calls in a cell($\lambda_o \times P_b$), N_{forced} is the number of failed handoff calls in a cell($\lambda_h \times P_f$), and N_{total} is the number of total sampled calls in a cell($\lambda_o + \lambda_h$). The reason multiplying N_{forced} by 50 is that handoff failure is considered less desirable to user than new call attempt failure.

5. Analysis of Mathematical Results & Conclusions

5.1 Analysis of originating call blocking probability

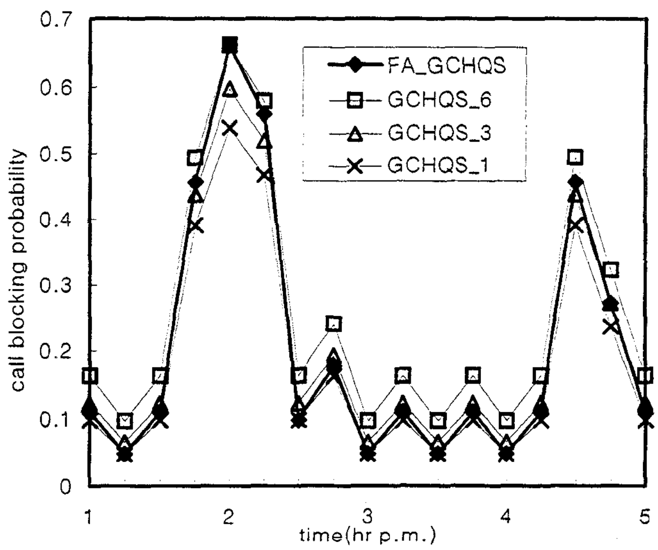


Figure 5-1 Originating call blocking probability due to handoff traffic pattern sampling

{Figure5-1} plots originating call blocking probability of each strategy about {Figure4-1} handoff traffic density pattern. FA_GCHQS results in almost the same blocking probability as that of GCHQS_1 or less blocking probability than that of GCHQS_3 in low handoff rate, and the almost same or less blocking probability than that of GCHQS_6 in high handoff rate. The reason is that the proposed method sets the same the number of guard channels as that of GCHQS_1 or less the number of guard channels than that of GCHQS_3 by FLC when mobile rate is low, and assigns the number of guard channels same as or less than that of GCHQS_6 by FLC when mobile rate is high.

5.2 Analysis of handoff forced termination probability

{Figure 5-2} plots the forced termination probability by sampled handoff traffic density.

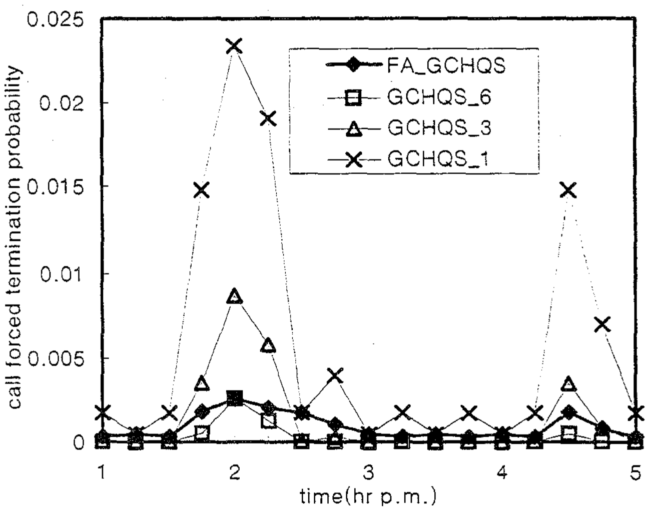


Figure 5-2 Handoff forced termination probability due to handoff traffic pattern sampling

GCHQS_6 plots the best performance among other schemes, but it contains still a week point such that the more the number of guard channels it has, the higher blocking probability of new calls it shows. On the other hand FA_GCHQS represents much less forced termination probability than that of GCHQS_1 and GCHQS_3 in high handoff rate time, and shows slightly high forced termination probability than that of GCHQS_6 in low handoff rate time. The reason is that the suitable number of guard channels are always generated by FLC which assigns the number of guard channels big enough in high handoff rate time and reassigns the number of guard channels so small in low handoff rate time. Thus the proposed scheme has the least interference with fluctuating handoff traffic density among other strategies and can keep the forced termination probability nearly constant.

5.3 Analysis of GoS of network

{Figure 5-3} is the result of GoS of each strategies. FA_GCHQS has each strong points from GCHQS_1, GCHQS_3, and GCHQS_6 in the sense that FLC distributes the proper number of guard channels each sampling time along with handoff traffic density.

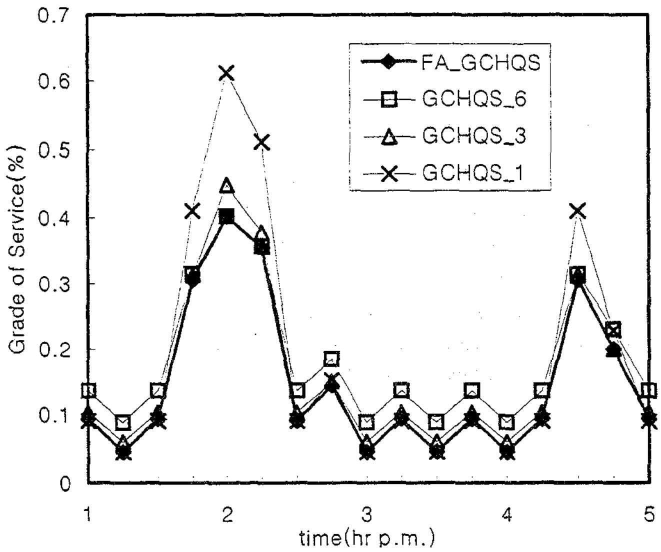


Figure 5-3 GoS of network due to handoff traffic pattern sampling

Not only in low handoff rate interval but also in high handoff rate interval it shows same or less GoS than that of GCHQS_1, GCHQS_3, and GCHQS_6. We can say that the proposed method outperforms all the other schemes, even though how many the fixed number of guard channels it would have within the FLC can adopt.

5.6 Conclusions

There have been many channel management schemes for handoff transaction so far. In this paper we designed Fuzzy Logic Controller(FLC) which can set adaptively the proper number of guard channels so as not to be wasteful or lacking resources according to fluctuating handoff traffic volume. We introduced FLC into previous Guard Channel with Handoff Queueing Scheme(GCHQS) which combined fixed Guard Channel Scheme(GCS) with Queueing Priority Scheme(QPS), and proposed Fuzzy Adaptive GCHQS(FA_GCHQS). For the performance evaluation of the proposed method and the previous one we considered originating call blocking probability, handoff forced termination probability, and GoS as criteria of system performance. We assumed possible handoff traffic density pattern in a city environment and brought mathematical results against the system criteria by means of M/M/C/K queueing model. Finally it is showed that the proposed method outperformed the previous one in the point of GoS regardless how many the fixed number of guard channels it may have within the FLC can adopt.

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