THE EFFECTS OF HANDOFFS ON MICROCELL-BASED PCN NETWORKS

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Abstract As the number of users in mobile communications increases, it is suggested to reduce the cell size as a means to increase traffic capacity. Even though the mobile systems with small sized cells may handle large traffic capacity, they may cause the degradations in quality of services, such as the increase of handoff failures and long processing time due to the increasing number of handoffs.

In order to investigate the effect of handoffs on microcell-based personal communication networks, we first model the personal mobility problem in microcell environments and estimate the required signaling traffic load due to handoff calls in a given network configuration. Finally, a typical PCN network configuration with some network parameters is numerically evaluated in terms of the signaling traffic on each signaling link between PCN network elements, such as basestation controllers, mobile switching centers, and visitor location registers.

1 INTRODUCTION

In order to implement the microcell-based personal communications network (PCN), we need to overcome many problems, such as fading, power control, channel assignment, radio resource management, security, microcell planning, and mobility. Among them, we here focus on the handoff calls in microcell environments. Even though microcell-based PCN may handle large traffic capacity, they may cause the degradations in quality of services. Thus, it is important to understand the characteristics of handoffs on microcell environments.

Most of the studies on handoff calls have been done in the cellular systems. Hong and Rappaport [1] modeled the handoff phenomena in hexagonal shaped macrocells and Thomas et al [2] analyzed them by using a fluid flow model. In case of PCN system, rectangular microcells may be suggested by considering artificial structures, such as roads lined with buildings and passages in buildings.

In this paper, we first model the personal mobility problem in rectangular microcell environments in order to investigate the effect of handoffs on microcell-based personal communication networks and then estimate the required signaling traffic load due to handoff calls in a given network configuration. Finally, a typical PCN network configuration with some network parameters is numerically evaluated in terms of the signaling traffic on each signaling link between PCN network elements, such as basestation controllers, mobile switching centers, and visitor location registers.

The overall organization of this paper is as follows. In section 2, we model the personal mobility in microcell environments in order to describe mobile users on the roads lined with buildings. In section 3, we describe handoff scenarios and the corresponding signaling message length based on the GSM specifications and CCITT recommendation when a call is handed off. In section 4, we first investigate the total length of signaling messages in bytes when a handoff call is generated, and then derive the total handoff traffic load in bytes on signaling links between the Commen Channel Signaling System No.7 (CCS 7) entities in the given network after the computation of the number of handoffs.

2 MOBILITY MODEL

2.1 Mobility Modeling

It is important to model the personal mobility as closely to the real situation as possible when we investigate the effect of movements of users in personal communication networks. We propose a personal mobility model in microcells with the following assumptions:

- One side length of cells is d.
- Users are uniformly distributed in square shaped microcells.
- Users may either stay or move with constant speeds for call durations.
- Users move straight until they change directions, i.e. turn right, left, or back and then continue to move straight again.
- Direction changes occur according to Poisson process.

A typical user's moving pattern is shown in Figure 1. Since this model represents the random moving behavior with the above mentioned assumptions, we need to define the following random variables in order to elaborate the mobility modeling:

S : The distance between the present position and cell boundary in the moving direction
X : The distance between turning points, from the starting point to the first turning point, or from the last turning point to the ending point
V : User's moving speed
T : The call holding time
M : The number of direction changes
β : The mean number of handoffs

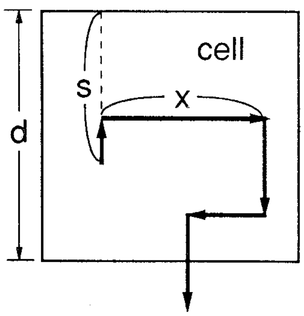

Figure 1. Moving aspect of a user

Since users may either stay or move straight with their own constant speeds, the moving speed can be represented by a hybrid random variable with a following probability density function

$$f_V(v) = \begin{cases} P(staying)\delta(v) & , v=0 \\ \dfrac{1-P(staying)}{V_{\max}} & , 0<v<V_{\max} \\ 0 & , o.w. \end{cases} ,$$

where the expectation of V is $V_{\max}/2 \cdot P(moving)$ and $P(staying)+P(moving)=1$. The probability density function (pdf) of the random variable S is uniformly distributed.

$$f_S(s) = \begin{cases} \dfrac{1}{d} & , 0<s<d \\ 0 & , o.w. \end{cases}$$

The pdf of random variable T is exponentially distributed with a parameter μ

$$f_T(t) = \begin{cases} \mu e^{-\mu t} & , t>0 \\ 0 & , o.w. \end{cases}$$

and thereby $E(T)=1/\mu$. Since the random variable M is Poisson distributed, X is exponentially distributed with a following pdf

$$f_X(x) = \begin{cases} \dfrac{1}{\theta} e^{-\frac{x}{\theta}} & , x>0 \\ 0 & , o.w. \end{cases} ,$$

where $E(X)=\theta$. The mean number of handoffs per the random variable X can be computed as follows :

$$\begin{aligned} K &= 1\times \Pr(S<X<S+d)+2\times \Pr(S+d<X<S+2d) \\ &\quad +\ldots+n\times \Pr(S+(n-1)d<X<S+nd)+\ldots \\ &= \frac{\theta}{d} . \end{aligned}$$

Thus, the mean number of handoffs during a call duration, β is given by

$$\beta = E_{V,T}\left(\frac{VT}{E_X(X)}\right)\cdot K = \frac{E(V)\cdot E(T)}{d} .$$

From the above equation, we can infer that the mean number of handoffs is independent of the distance between the turning points, X and the mean number of handoffs in the turning motion model is also equal to that in the straight motion model.

Figure 2 shows the analytical and simulational results for the mean number of handoffs versus the mean distance between the turning points, θ. We can see that the mean number of handoffs of the turning motion model is nearly identical to the straight motion model. This result indicates the validity of the above derived equation for the number of handoffs.

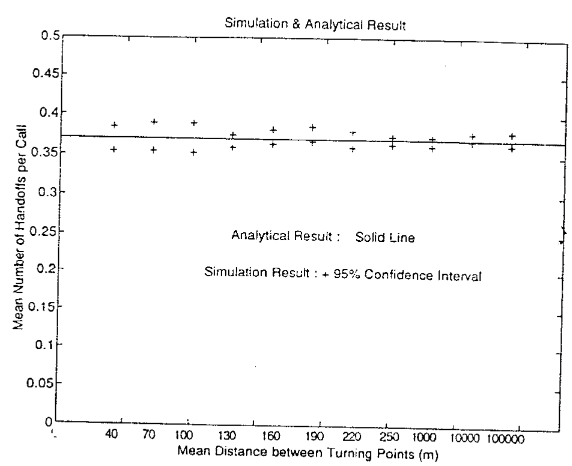

Figure 2. Verification of analytical model

3 HANDOFF SIGNALING MESSAGES

3.1 Call Scenarios [3,4,5,6]

We now consider the call scenarios based on the GSM system in order to investigate the effect of handoffs on PCN networks.

Figure 3 depicts the message flow in case of inter-Basestation Controller (Inter-BSC) handoff. The collected measurements are continuously sent from the mobile station (MS) to the Basestation Controller A (BSC-A). The Base Transceiver Station B (BTS-B) simply forwards them to the BSC-A for further processing. A complex decision algorithm determines whether "handoff required" message is sent by the old BSC (BSC-A) to the Mobile Switching Center (MSC). Upon reception of "handoff required" message, the MSC sends "handoff request" message to the new BSC (BSC-B) requiring radio resources. If radio resources become available, the BSC-B indicates this by sending "handoff request acknowledge" message. The "handoff command" message is sent to the BSC-A. If the BSC-B checks the received message and once it is sure that the correct MS has been captured, then it sends "handoff complete" message to the MSC. It follows that "clear command" message is sent to the BSC-A and the previously occupied channels are released.

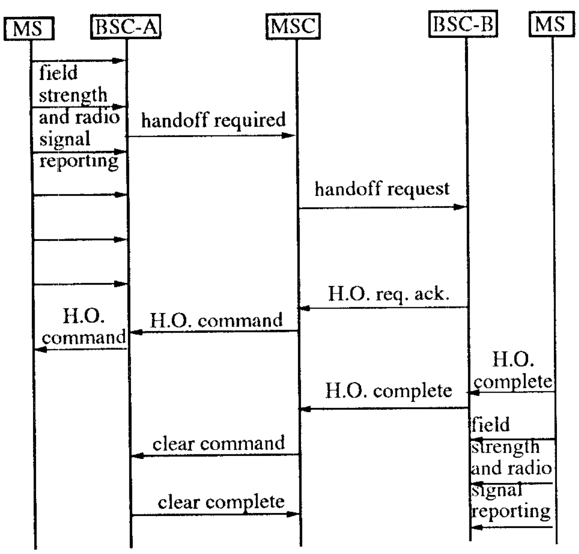

Figure 3. Signaling message flow of a successfully completed Inter-BSC handoff

Figure 4 describes the message flow in Inter-MSC handoff (Gateway MSC (GMSC)→MSC). We only explain the signaling message flow for the different procedures compared with those of Inter-BSC handoff. When the old MSC (MSC-A) determines a call to be handed off to the new MSC (MSC-B), it sends "perform handoff" to the MSC-B. If a radio channel can be assigned to the Visitor Location Register (VLR) within a specified time, the MSC-B requests its associated VLR to provide a handoff number between the MSC-A and the MSC-B and the associated VLR (VLR-B) returns a handoff report. The MSC-B returns "radio channel acknowledge" to the MSC-A when a new radio channel is assigned. If the MSC-B reserves a radio channel, the MSC-A initiates the establishment of a connention between the MSC-A and the MSC-B. When the radio path has been established on the MSC-B, the MSC-B indicates this event to the MSC-A by "send end signal".

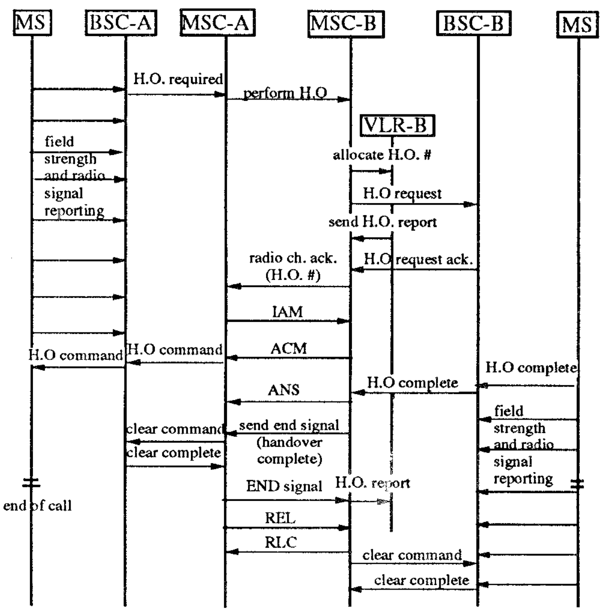

Figure 4. Signaling message flow of a successfully completed Inter-MSC handoff (GMSC→MSC)

In case of an Inter-MSC handoff (MSC→GMSC), the signaling message flow is the same as the previous Inter-MSC(GMSC→MSC) except the establishment of a traffic channel using "IAM" , "ACM" and "ANS". The handoff between two MSCs is also progressed by the control of the GMSC.

3.2 Message Length

We now estimate the total signaling message lengh used to handle the handoff calls according to the above mentioned call scenarios. When a call is handed off, the total message length on each signaling link is calculated as follows (optional parts aren't considered here) [6,7,8,9]:

For an Inter-BSC handoff, the number of bytes between entities is

- originating BSC and (G)MSC : 175 bytes
- terminating BSC and (G)MSC : 161 bytes

It is also applied to Inter-MSC handoffs.

For an Inter-MSC handoff(GMSC→MSC),
- GMSC and MSC : 270 bytes
- MSC and VLR : 106 bytes

For an Inter-MSC handoff(MSC→GMSC),
- GMSC and MSC : 240 bytes
- MSC and VLR : 46 bytes

For an Inter-MSC handoff(MSC→MSC),
- GMSC and MSC : (218+224) bytes
- MSC and VLR : (106+92) bytes

4 SIGNALING TRAFFIC LOAD

We now consider a network configuration and then calculate the total signaling traffic load due to handoff calls in the given network configuration.

4.1 Frequency of Handoffs

We assume that a network is configured as shown in Figure 5 in order to analyze the required signaling traffic. The GMSC controls Inter-MSC handoff calls and the call connections from other networks, i.e. PSTN, ISDN, and PDN in addtion to the functions of MSCs. Each MSC has its own VLR and carries out Inter-BSC handoffs. The BSC handles Intra-BSC (Inter-BTS) handoffs and thus can significantly reduce the processing load of the MSC.

We consider three cases of handoffs, i.e. Inter-BTS, Inter-BSC, and Inter-MSC handoffs in the square-shaped network management areas. For mathematical convenience, we simply assume a network configuratrion with the following number of entities:

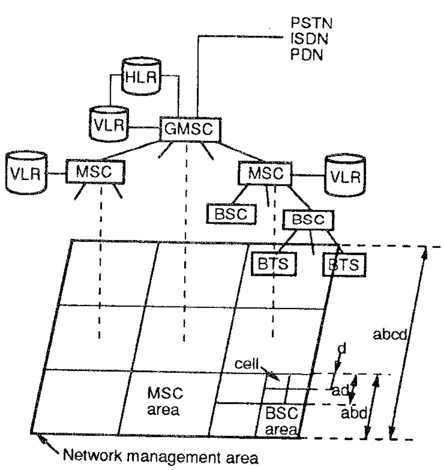

Figure 5. Network configuration

- c^2 : No. of MSCs in a given network
- b^2 : No. of BSCs per MSC
- a^2 : No. of BTSs per BSC

Then, the network management area is given by

$$(area) = (abc)^2 \times d^2$$

The mean number of handoffs per unit time in a cell, H is obtained by

$$H = \frac{(No.\ of\ terminals)}{km^2} \times \frac{erlangs}{terminal} \times \frac{1}{(average\ call\ holding\ time)} \times (area\ of\ cell) \times \beta$$

$$= \frac{(No.\ of\ terminals)}{km^2} \times \frac{erlangs}{terminal} \times d \times E(V).$$

The number of handoffs per unit time for three different cases is summarized in Table 1. In cases of Inter-MSC handoffs, we can classify them into three ones, i.e. GMSC→ MSC, MSC→GMSC, and MSC→MSC. The ratio of each Inter-MSC handoff is also given in Table 2..

Table 1. Number of handoffs per unit time

Cases	No. of handoffs
Inter-BTS	$a(a-1)b^2c^2H$
Inter-BSC	$ab(b-1)c^2H$
Inter-MSC	$abc(c-1)H$

Table 2. Ratio of Inter-MSC handoff

Cases	Ratio
GMSC→MSC	1/4 ,c=2 1/c(c-1) ,c>2
MSC→GMSC	1/4 ,c=2 1/c(c-1) ,c>2
MSC→MSC	1/2 ,c=2 1-2/c(c-1) ,c>2

4.2 Signaling Traffic Load

Table 3. Mean number of bytes between entities per handoff

Handoff \ Link		GMSC-MSC	GMSC-BSC	MSC-BSC	MSC-VLR in MSC
Inter - BSC (h1)		-	$(175+161)/b^2c^2$	$(161+175)/b^2c^2$	-
Inter-MSC	GMSC→MSC (h2)	$270/(c^2-1)$	$175/b^2$	$161/b^2(c^2-1)$	$106/(c^2-1)$
	GMSC←MSC (h3)	$240/(c^2-1)$	$161/b^2$	$175/b^2(c^2-1)$	$46/(c^2-1)$
	MSC→MSC (h4)	$(218+224)/(c^2-1)$	-	$(175+161)/b^2(c^2-1)$	$(106+92)/(c^2-1)$

We now calculate the handoff signaling traffic load between the Common Channel Signaling System No.7 (CCS 7) network entities by considering the previously described call scenarios. In particular, the signaling traffic of Inter-BSC handoffs and Inter-MSC handoffs are calculated on the signaling links between GMSC-MSC, GMSC-BSC, MSC-BSC, and MSC-VLR. The result is summarized in Table 3.

The total number of bytes due to handoff per unit time on the signaling links in the given network management area, W is given by

For c=2,
$$W = ab(b-1)c^2H \times h1 + abc(c-1)H \times [1/4 \times (h2+h3) + 1/2 \times h4]$$

For c>2,
$$W = ab(b-1)c^2H \times h1 + abc(c-1)H \times [1/c(c-1) \times (h2+h3) + \{1-2/c(c-1)\} \times h4] .$$

4.3 A Numerical Example

Table 4. Network parameters

Parameters	Values
Network area (km^2)	300
No. of terminals ($/km^2$)	684
Average speed of moving users (km/h)	2
Busy hour traffic (erlangs/terminal)	0.12
Mean call time (hour)	100/3600
No. of MSC per network area (c^2)	9
No. of BSC per MSC (b^2)	16
No. of BTS per BSC (a^2)	49
P(moving)	0.5

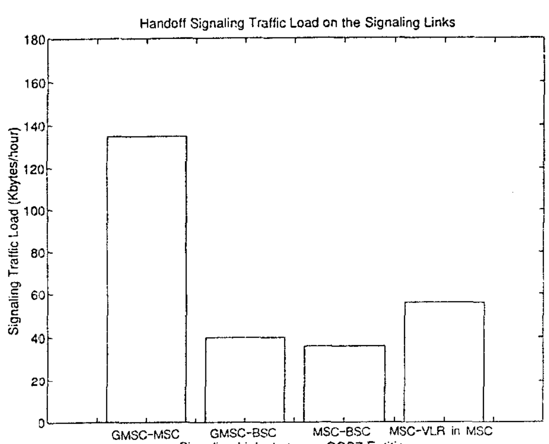

Figure 6. Handoff signaling load on CCS 7 signaling links

We choose network parameters as shown in Table 4 and calculate the signaling traffic on the signaling links between GMSC-MSC, GMSC-BSC, MSC-BSC, and MSC-VLR. The result is shown in Figure 6. From the viewpoint of signaling traffic load, the heaviest signaling link is the one between the GMSC and the MSC because Inter-MSC handoff calls require many signaling messages according to the complex handoff call procedures.

5 CONCLUSION

Even though the personal communications network based on microcells may handle large traffic capacity, they may cause many problems, including handoffs, location updates and power control. In this paper, we proposed a new model for the personal mobility in squared microcells in order to investigate the effects of handoffs on personal communications network and then estimate the required signaling traffic load due to handoff calls in the given network configuration. The result of this study can be utilized in the design or planning of PCN network configurations.

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