A MOVABLE SAFETY ZONE SCHEME IN URBAN FIBER-OPTIC MICROCELLULAR SYSTEMS

Ho-Shin Cho, Jae Kyun Kwon, and Dan Keun Sung

Department of Electrical Engineering,
Korea Advanced Institute of Science and Technology, Korea

Abstract— **We consider a urban fiber-optic microcellular environment in which a cigar-shaped cell consists of several microzones with their own antenna sites connected to a central station through optical fibers. To increase the efficiency of radio resources and to reduce unnecessary handoff calls between microzones, we propose a movable safety zone scheme in which each communicating user has his own safety zone not permitting cochannel reuse. His safety zone also can move if his cochannel interference is not met as he moves to an adjacent microzone. Considering user mobility characteristics and urban microcell shapes, we analyze and evaluate the proposed system in terms of intercell/intracell handoff rate, call blocking probability, and channel reuse parameter. The proposed system can handle the traffic capacity of about 12 erlangs for 7 traffic channels under the call blocking probability of 1%, and generates a negligibly small number of intracell handoffs compared with intercell handoffs.**

I. Introduction

Recently, optical feeder systems and their related technologies such as subcarrier multiplexing (SCM) and spectrum delivery switching (SDS) have been extensively investigated to be utilized in implementing emerging microcellular networks. Fiber-optic microcellular systems have several advantages in the future microcellular network; it is feasible to design a low-cost and compact radio base station and easy to implement dynamic channel assignment (DCA) [1]-[8].

Frequent user handoffs between microzones can be handled by a simple antenna switching mechanism with SDS in a central station (CS) [5] - [6], [9]. For packet communications, some antenna ports which pick up user's signal can be virtually grouped for macro-diversity [10]. However, conventional fiber-optic microcellular systems in which a radio carrier can be used only once in CS coverage are inefficient to be applied in urban microcellular systems with a large-scaled CS and short frequence reuse distance.

In this paper, we consider a urban fiber-optic microcellular environment in which a cigar-shaped cell consists of several microzones with their own antenna sites connected to a central station through optical fibers. To increase the efficiency of radio resources and to reduce unnecessary handoff calls between microzones, we propose a movable safety zone scheme in which each communicating user has his own safety zone not permitting cochannel reuse. His safety zone also can move if his cochannel interference is not met as he moves to an adjacent microzone. In urban areas, user mobility characteristics and urban microcell shapes are different from those of conventional macrocellular environments [11]-[13]. We assume that microzone sites are located in the middle of a street block, which results in a cigar shaped cell [13]. Considering user mobility characteristics in the cigar-shaped urban microcells, we evaluate the performance of the proposed system in terms of intercell/intracell handoff rate, call blocking probability, and channel reuse parameter.

The paper is organized as follows. In section II, a urban fiber-optic microcellular network is introduced, and the movable safety zone concept is proposed. In section III, a mathematical analysis is given. In section IV, some numerical results are taken. Finally, conclusions are drawn in section V.

II. System Description & Movable Safety Zone Concept

In this section, we introduce a urban fiber-optic microcellular network as shown in Fig. 1. We consider a grid-structured urban area with horizontal and vertical streets. A group of rectilinear antenna ports (zone sites) forms a cigar-shaped cell. All antenna ports within a cell are connected to a central station (CS) through optical fibers. The cigar-shaped cell consists of a line of blocks called microzones. We here consider one antenna port per microzone, although several antenna ports may be installed for diversity effects. The CS has radio channel control functions such as handoffs and channel assignments. Channels are dynamically assigned by SDS in CS.

The basic concept of the proposed movable safety zone scheme is as follows. Each communicating user has his own safety zone. When a user occupies a channel at his current microzone, a safety zone consists of a group of microzones within the frequency reuse distance from his current microzone. The same channel cannot be allocated within the safety zone because of cochannel interference. However, the same channel can be reused outside the safety zone. If separating n microzones is required to avoid cochannel interference, the safety zone is maximally composed of $2n+1$ microzones. In this case, the minimum cochannel distance is given by $n+1$.

We now illustrate how to operate the movable safety zone scheme in Fig. 2. Let a mobile user generate his safety zone by occupying channel i at microzone j at $t = t_0$. When he moves to the adjacent microzone $j+1$ at $t = t_0 + T$, and channel i is still not in use at microzone $j+n+1$ belonging to his new safety zone, he can continuously use the channel

i through the new antenna port of microzone $j+1$, and his safety zone boundary also moves by one microzone in the moving direction (Fig. 2(a)). On the other hand, if channel i is being used by other user at microzone $j+n+1$ at $t=t_0+T$, channel i cannot be used by him anymore. If there exists an available channel within the cochannel distance from microzone $j+1$, channel i needs an internal switching called an internal handoff, and a new safety zone is formed by a new handoff channel as shown in Fig. 2(b). If there is no available channel, his call is terminated.

III. System analysis

In order to analyze the proposed movable safety zone scheme, we have the following assumptions:

- Users make new calls at uniformly distributed random points in cigar-shaped cells.
- New call generations follow a Poisson process with rate λ_n.
- Call holding time T_{ch} is exponentially distributed with mean $1/\mu_{ch}$.
- For both new calls and handoff calls, dwelling time in one microzone, $T_{dw}^{(1)}$ has a r-stage Erlang distribution with mean $1/\mu_{dw}$. Then, the total dwelling time in i microzones $T_{dw}^{(i)}$ is another Erlang distributed random variable, and its probability density function $f_{T_{dw}^{(i)}}(t)$ is given by

$$f_{T_{dw}^{(i)}}(t)=\frac{r\mu_{dw}(r\mu_{dw}t)^{ir-1}}{(ir-1)!}\exp(-r\mu_{dw}t). \quad (1)$$

- The distributions of $T_{dw}^{(1)}$ in all microzones are independent and identical.
- No priority is given to intercell handoff calls.
- Minimum cochannel distance is equal to 2 for mathematical simplicity.

In this analysis, M and N denote the number of microzones and channels of a cigar-shaped cell, respectively.

A. Channel holding time T_{cho}

Channel holding time, T_{cho} is the time duration between a channel occupancy and the channel release. Fig. 3 shows three cases that an occupied channel is released : a call completion (case a), user's straight movement to an adjacent cell, called a straight-handoff(case b), and user's turning at intersections, called a turning-handoff(case c). Let T_{th} be the dwelling time from a channel occupancy to turning-handoff, and T_{sh} be the dwelling time from a channel occupancy to straight-handoff. Then we can express T_{cho} as

$$T_{cho}=\min(T_{ch},T_{th},T_{sh}). \quad (2)$$

The cumulative distribution function of T_{th}, $F_{T_{th}}(t)$ is obtained by

$$\begin{aligned} F_{T_{th}}(t) &= 1-\Pr(T_{th}>t) \\ &= 1-\sum_{i=1}^{\infty}\Pr(T_{th}>t|m_t=i)\Pr(m_t=i) \\ &= 1-\sum_{i=1}^{\infty}\Pr(T_{dw}^{(i)}>t)P_s^{i-1}(1-P_s), \end{aligned} \quad (3)$$

where m_t is the number of microzones that a user passes before a turning-handoff and P_s is the probability of straight movement without turning at intersections. From Eqn.(1),

$$F_{T_{th}}(t)=1-\exp(-r\mu_{dw}t)(1-P_s)\sum_{i=1}^{\infty}P_s^{i-1}\sum_{n=0}^{ir-1}\frac{(r\mu_{dw}t)^n}{n!}. \quad (4)$$

Similarly, the cumulative distribution function of T_{sh} is

$$\begin{aligned} F_{T_{sh}}(t) &= 1-\Pr(T_{sh}>t) \\ &= 1-\frac{\exp(-r\mu_{dw}t)}{M}\sum_{i=1}^{M}\sum_{n=0}^{ir-1}\frac{(r\mu_{dw}t)^n}{n!}, \end{aligned} \quad (5)$$

where m_s is the number of microzones that a user passes before a straight-handoff. Then the cumulative distribution function of T_{cho} , $F_{T_{cho}}(t)$ is written as

$$\begin{aligned} F_{T_{cho}}(t) &= \Pr(T_{cho}\le t) \\ &= F_{T_{ch}}(t)+F_{T_{th}}(t)+F_{T_{sh}}(t)-F_{T_{ch}}(t)F_{T_{th}}(t) \\ &\quad -F_{T_{ch}}(t)F_{T_{hs}}(t)-F_{T_{th}}(t)F_{T_{sh}}(t) \\ &\quad +F_{T_{ch}}(t)F_{T_{th}}(t)F_{T_{sh}}(t). \end{aligned} \quad (6)$$

Finally, the average channel holding time can be expressed as

$$E[T_{cho}]=\int_0^{\infty}\left(1-F_{T_{cho}}(t)\right)dt. \quad (7)$$

B. Blocking probability

Let the system state S represent the number of users being served in the cigar-shaped cell. Then the maximum value of S, S_{max} is given by

$$S_{max}=\lceil M/2\rceil\cdot N \quad (8)$$

where $\lceil x\rceil$ means a smallest integer larger than or equal to x.

Let η_k be a reuse factor, representing the number of users using channel k. We assume that

$$\eta_i-\eta_j\le 1 \qquad \forall \quad i,j\in\{1,2,\cdots,N\}. \quad (9)$$

From Eqn.(9), when $S=aN+b$, $(0\le b<N)$, the channels of the cigar-shaped cell are classified into two sets, G_a and G_{a+1} according to their reuse factor

$$\begin{cases} \text{channel } k\in G_a, & \text{if } \eta_k=a \\ \text{channel } k\in G_{a+1}, & \text{if } \eta_k=a+1 \end{cases} \quad (10)$$

for all $k\in\{1,2,\cdots,N\}$. Therefore, the number of channels in G_a and G_{a+1} is given by

$$\begin{aligned} \#(G_a) &= N-b, \\ \#(G_{a+1}) &= b. \end{aligned} \quad (11)$$

The cigar-shaped cell has symmetry with respect to its center. From this property, we can assign a position number to each microzone with a position function $\pi(p)$ defined by

$$\pi(p) = \begin{cases} p, & p \leq \lceil M/2 \rceil \\ M-p+1, & p > \lceil M/2 \rceil \end{cases} \quad (12)$$

where p is the microzone number $(1 \leq p \leq M)$. For microzone p, let α_zone, β_zone and γ_zone be microzones having $\pi(p)-1$, $\pi(p)$ and $\pi(p)+1$, respectively. Under the condition that minimum cochannel distance is 2, the number of cases that a given channel is being used at a microzones among M microzones at an arbitrary instant, denoted by $C[M,a]$, is obtained by

$$C[M,a] = \binom{M-a+1}{a}. \quad (13)$$

Let $n_\alpha^{(a)}$, $n_\beta^{(a)}$, $n_\gamma^{(a)}$ be the number of the cases that a given channel belonging to G_a is used at α_zone, β_zone and γ_zone among all the cases that the channel is used at a microzones, respectively. $n_{\alpha\gamma}^{(a)}$ is the number of the cases that the channel is used at both α_zone and γ_zone. Then,
i) $\pi(p)=1$

$$\begin{aligned} n_\alpha^{(a)} &= n_{\alpha\gamma}^{(a)} = 0 \\ n_\beta^{(a)} &= C[M-2,a-1] \\ n_\gamma^{(a)} &= C[M-3,a-1] \end{aligned}$$

ii) $\pi(p)=2$

$$\begin{aligned} n_\alpha^{(a)} &= C[M-2,a-1] \\ n_\beta^{(a)} &= C[M-3,a-1] \\ n_\gamma^{(a)} &= C[M-2,a-1]-C[M-5,a-2] \\ n_{\alpha\gamma}^{(a)} &= C[M-4,a-2] \end{aligned}$$

iii) $2 < \pi(p) \leq \lceil M/2 \rceil$

$$n_\alpha^{(a)} = \begin{cases} \sum_{k=1}^{\pi(p)-3}(-1)^{k+1}C[M-2k,a-k]+ \\ (-1)^{\pi(p)-1}C[M-2\pi(p)+3,a-\pi(p)+2], & \pi(p)-3<a \\ \sum_{k=1}^{a}(-1)^{k+1}C[M-2k,a-k], & \pi(p)-3 \geq a \end{cases}$$

$$n_\beta^{(a)} = \begin{cases} \sum_{k=1}^{\pi(p)-2}(-1)^{k+1}C[M-2k,a-k]+ \\ (-1)^{\pi(p)}C[M-2\pi(p)+1,a-\pi(p)+1], & \pi(p)-2<a \\ \sum_{k=1}^{a}(-1)^{k+1}C[M-2k,a-k], & \pi(p)-2 \geq a \end{cases}$$

$$n_\gamma^{(a)} = \begin{cases} \sum_{k=1}^{\pi(p)-1}(-1)^{k+1}C[M-2k,a-k]+ \\ (-1)^{\pi(p)+1}C[M-2\pi(p)-1,a-\pi(p)], & \pi(p)-1<a \\ \sum_{k=1}^{a}(-1)^{k+1}C[M-2k,a-k], & \pi(p)-1 \geq a \end{cases}$$

$$n_{\alpha\gamma}^{(a)} = \begin{cases} \sum_{k=1}^{\pi(p)-3}(-1)^{k+1}C[M-2k-2,a-k-1]+ \\ (-1)^{\pi(p)-1}C[M-2\pi(p)+1,a-\pi(p)+1], & \pi(p)-3<a \\ \sum_{k=1}^{a-1}(-1)^{k+1}C[M-2k-2,a-k-1], & \pi(p)-3 \geq a. \end{cases}$$

In the proposed system, a new call generated at microzone p is blocked if every channel is being used at least once at α_zone, β_zone or γ_zone of microzone p. From the condition of Eqn.(9), we can obtain the probability that a new call generated at microzone p is blocked at $s=aN+b$, $P_{b\_p}^{(s)}$

$$\begin{aligned} P_{b\_p}^{(s)} &= \left[\frac{n_\alpha^{(a)}+n_\beta^{(a)}+n_\gamma^{(a)}-n_{\alpha\gamma}^{(a)}}{C[M,a]}\right]^{N-b} \times \\ &\left[\frac{n_\alpha^{(a+1)}+n_\beta^{(a+1)}+n_\gamma^{(a+1)}-n_{\alpha\gamma}^{(a+1)}}{C[M,a+1]}\right]^{b}. \end{aligned} \quad (14)$$

We assume that arrival streams of straight-handoff calls and turning-handoff calls are both Poisson processes with rates λ_{sh} and λ_{th}, respectively. Therefore the sum of arrival streams for new calls, straight-handoff calls and turning-handoff calls is approximated by a Poisson process with the following rate

$$\lambda = \lambda_n + \lambda_{th} + \lambda_{sh}. \quad (15)$$

Considering Poisson call arrivals, generally distributed service time, and finite system capacity S_{max}, we can represent the proposed system as an $\mathrm{M/G/S_{max}}$ loss system. The limiting distribution of the system state is identical to that of an $\mathrm{M/M/S_{max}}$ loss system due to the insensitivity property[14]. The state transition diagram for the $\mathrm{M/M/S_{max}}$ loss model corresponding to the proposed system is shown in Fig. 4. In this figure, $P_b^{(s)}$ represents the conditional blocking probability at state s. Solving the balance equations, we can obtain the steady state probability.

$$P(s) = \begin{cases} \frac{1}{s!}\left(\frac{\lambda}{\mu}\right)^s P(0), & 0 \leq s \leq N \\ \frac{1}{s!}\left(\frac{\lambda}{\mu}\right)^s \prod_{k=N}^{s-1}\left(1-P_b^{(k)}\right)P(0), & N < s \leq S_{max} \end{cases} \quad (16)$$

where

$$\begin{aligned} P(0) &= \left[\sum_{k=0}^{N}\frac{1}{k!}\left(\frac{\lambda}{\mu}\right)^k + \sum_{k=N+1}^{S_{max}}\frac{1}{k!}\left(\frac{\lambda}{\mu}\right)^k \prod_{i=N}^{k-1}\left(1-P_b^{(i)}\right)\right]^{-1}, \\ \mu &= \frac{1}{E[T_{cho}]}. \end{aligned}$$

The blocking probability in microzone p, P_{b_p} can be obtained as

$$P_{b\_p} = \sum_{s=N}^{S_{max}-1} P_{b\_p}^{(s)}P(s) + P(S_{max}), \quad (17)$$

where $P_{b\_p}^{(s)}$ is the blocking probability in microzone p at state s.

IV. Numerical Examples

We now evaluate the proposed system in terms of blocking probability, internal handoff rate, and cell capacity. We

TABLE I
List of system papameters

Average channel holding time, $E[T_{ch}]$	100 s
Average dwelling time in a microzone, $E[T_{dw}^{(1)}]$	500 s
Stage of Erlang distribution, r	5
P_s	0.5
Number of microzones in a cigar-shaped cell, M	10
Number of channels per cigar-shaped cell, N	7

utilize a numerical method in calculating the system state probability. The parameters used in our analysis are listed in TABLE I.

Fig. 5 shows the blocking probability at each state. In the case of N=7, the conventional cellular system usually has the blocking probability 1 at state 7, but the proposed system yields the blocking probability about 10^{-4} at state 7. Even if we increase the system state up to 13, we can keep the blocking probability below 1%.

The proposed system may generate internal handoff calls. Fig. 6 compares the external (intercell) handoff call rates, i.e., turning-handoff call rate and straight-handoff call rate with internal (intracell) handoff call rate versus new call rate λ_n. We can note that the internal handoff call rate is small enough to be neglected, compared with the external handoff call rates. The internal handoff call rate is about 0.0004 for $\lambda_n = 0.2$, which corresponds to only one internal handoff among 500 new calls.

We define channel reuse parameter f_r at $s = aN + b$, as

$$f_r = \sum_{s=0}^{S_{max}} \frac{a(N-b)+(a+1)b}{N} P(s). \qquad (18)$$

The channel reuse parameter f_r represents the average number of channel reuse in a cell. Fig. 7 shows the channel reuse parameter for varying offered traffic load. We can see that the channel reuse parameter increases as the offered traffic load increases. This implies that the system capacity can be expandable up to $\lceil M/2 \rceil \cdot N$ due to channel reuse as the offered traffic load increases. For example, under the acceptable blocking probability level 1% with the offered load of about 12 erlangs as shown in Fig. 5 , the channel reuse parameter is about 1.5, which implies that the system can handle 1.5×7 channels.

V. Conclusions

We have proposed a movable safety zone scheme in urban fiber-optic microcellular systems. We have also evaluated the proposed urban fiber-optic microcellular system in terms of call blocking probability, intra/inter cell handoff rate, and channel reuse parameter by considering user mobility characteristics in the cigar-shaped urban microcell.

Utilizing the movable safety zone, we can reuse traffic channels within a cell and reduce unnecessary handoffs between radio zones. Therefore we can significantly increase the efficiency of radio resources, which can yield a considerable improvement in the system traffic capacity. For example, the proposed system can handle 12 erlangs under the blocking probability 1% for 7 channels. These results can be utilized in urban microcellular systems, especially in Manhattan streets.

Acknowledgement

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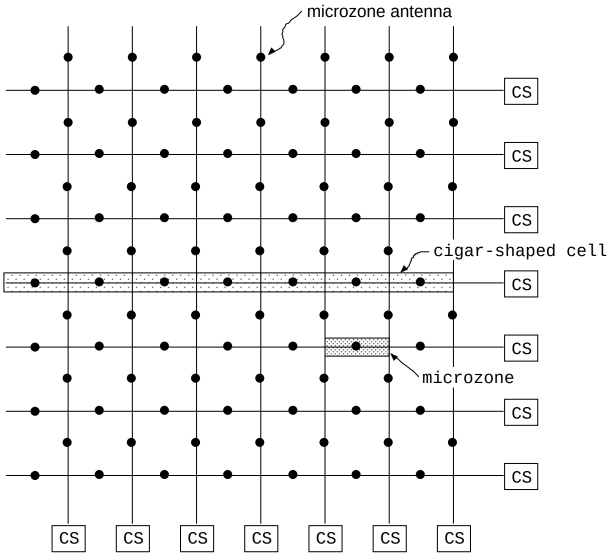

Fig. 1. Urban fiber-optic microcellular system

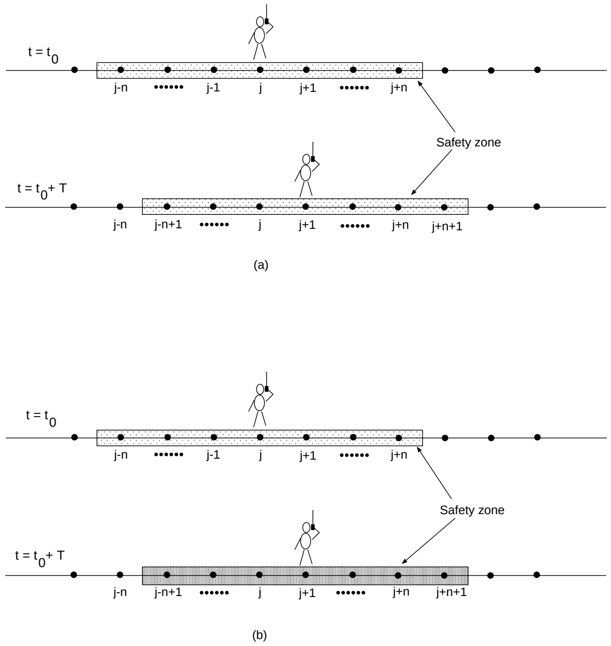

Fig. 2. Movable safety zone : (a) movable case (b) immovable case

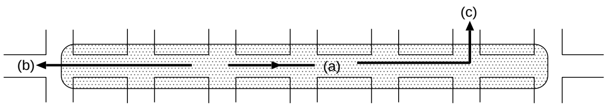

Fig. 3. Three cases of releasing an occupied channel

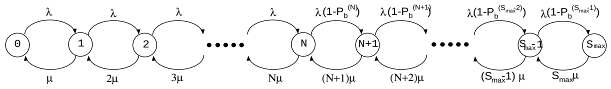

Fig. 4. State transition diagram

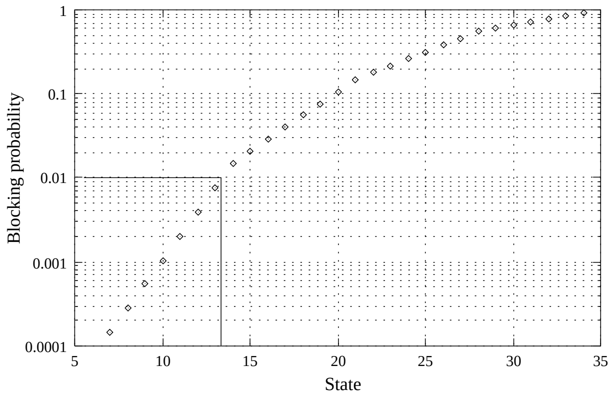

Fig. 5. Blocking probability at each state

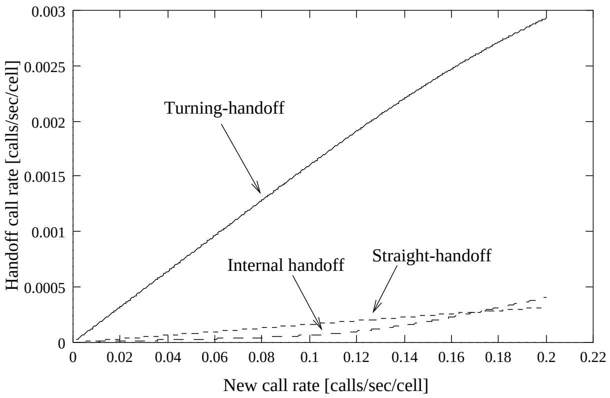

Fig. 6. Handoff call rates

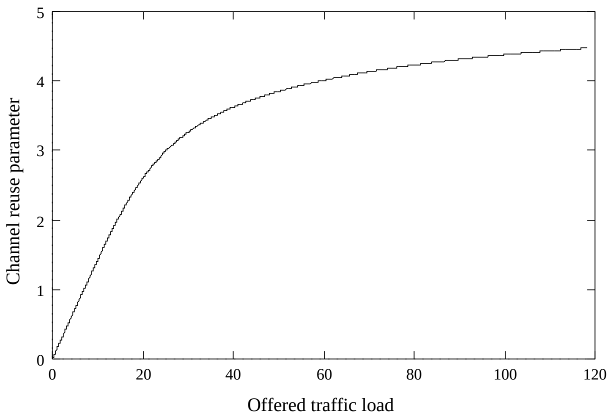

Fig. 7. Channel reuse parameter