한국경영과학회/대한산업공학회 춘계공동학술대회
관동대학교 양양캠퍼스 2001년 4월 27 - 28일

복수 주파수채널을 가진 CDMA 이동통신시스템에서 핸드오프호 제어전략

백천현+, 진고환*, 차동완**

\+ 동의대학교 기계산업시스템 공학부
Tel:051-890-1660, FAX:051-890-1619, E-mail:chpaik@hyomin.dongeui.ac.kr
* Spread Telecom. 기술계획부
** 한국과학기술원 경영대학원

Abstract

This paper addresses handoff management in a multi-frequency CDMA system with non-uniform traffic loads over cells. We propose a new handoff scheme, called here the adaptive handoff management (AHM), in which the inter-cell hard handoffs, not only incurring equipment cost burden but also degrading call quality, are totally removed. Also contained in the AHM is the call control capability of adaptively reflecting the traffic environment. Traffic and mobility analysis is first conducted on a single isolated cell with two co-centered circle boundaries, thereby rendering two key performance measures. Computational experiments are conducted to illustrate the superiority of AHM in two key performance criteria.

1. Introduction

In a real-world CDMA system in operation, the numbers of frequencies (or frequency assignments (FAs) as used by service providers) assigned to cells often vary owing to unbalanced traffic loads imposed on cells [2,4,6,9]. Since the same frequency can be used at neighboring cells, a designated single frequency is commonly used at all cells in the whole service area at the initial phase of CDMA service provision. Cells are then assigned further frequencies in accordance with the level of demand increase therein, rendering the non-uniform multi-frequency assignments over cells.

In this multi-frequency CDMA system, there often occurs the inter-cell hard handoff (RHH) that a mobile station (MS), when crossing a cell boundary to a target cell, is handed off to a different frequency used at the target cell. The occurrences of RHHs, however, should be avoided as much as possible, from the resulting poor communication quality as compared to the soft handoff [1,8]. Furthermore, implementing the RHH requires that the target cell be time synchronized with the incoming MS [2,6].

In an attempt to remove the occurrences of such undesirable RHHs in a multi-frequency environment, this study proposes a new method of handoff operation, called the *Adaptive Handoff Management* (AHM), incorporating intra-cell hard handoffs (AHHs). Note that the operation of AHH does not require any additional equipment since performed within the cell. Another advantage to note is that the quality of an ongoing call experiencing the AHH is not so degraded as the one under RHH.

2. Handoff Managment Method

For exposition convenience, we consider a simplified CDMA cellular configuration consisting of seven circular cells, in which the common frequency F_1 is used throughout the service area and an additional frequency F_2 is assigned only to the cell of interest (center cell), as shown in Fig. 1. This setting, though simple, has most of performance-related attributes of a general multi-frequency environment, so that its modeling and analysis can easily be extended to a more complicated situation of multi-frequency assignments.

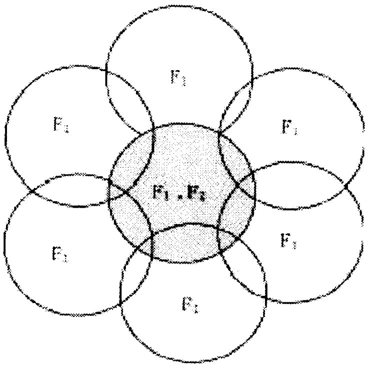

Fig.1. An exemplar multi-frequency CDMA system

MSs undergo either type of handoffs when leaving the center cell with two frequencies, unless otherwise specified. One is the SH in which a frequency used by an MS, F_1 in Fig. 2, is present at both the center and the target cells. The other type is the RHH in which the frequency used by an MS, F_2, in the center cell is not supported at the target cell.

Before describing the AHM, the following is defined first. As in [2], the area of center cell is partitioned into two regions: central and peripheral. The boundary between two regions are configured by the RTD from the serving BS to the MSs, the measurement of which is always possible because the MSs are synchronized to the serving BS. The central region means the one within which the measured RTD of an MS does not exceed a predetermined value, which is denoted by REG1 (Fig 2). The peripheral region, defined vice versa, is denoted by REG2. The radii of cell and REG1 are R and R_1 respectively.

New calls originated in REG2 as well as inbound handoff calls from outside are assigned F_1, whereas those new calls originated in REG1 F_2. For an MS moving from REG1 to REG2 while being served by F_2, the AHH to frequency F_1 is enacted upon crossing the RTD boundary. And for an MS which is currently supported by F_1 in REG2 and moving toward REG1, the AHH to F_2 is performed randomly with a constant probability α upon the MS's boundary crossing.

Note that under AHM, the MSs in REG2 are all operated only on F_1, while those in REG1 on both F_1 and F_2. Therefore, all inter-cell handoffs are made by the SH under AHM.

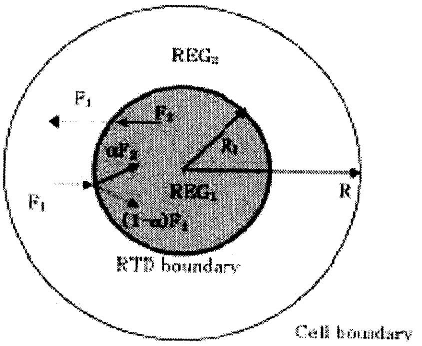

Fig. 2. Illustration of AHM in the cell with RTD boundary

The key enabler of inter-cell SH is the AHH, which can easily be implemented since an MS is already synchronized to the frequency to be handed off. Furthermore, the two parameters of AHM, R_1 and α can be adapted to varying traffic environments to minimize the number of AHHs, the issue of which will be detailed in Section-4.

3. Traffic Modeling

3.1 New call case

Consider a cell, divided into two regions as given in Fig. 2, on which MSs are randomly located. Assume that the velocity V and the direction ϕ of MSs are uniformly distributed respectively on intervals $[0, V_m]$ and $[0, 2\pi]$, and that they remain constant during their travels. Then the location of an MS is represented by its distance r and direction ϕ from the BS located at the center of the cell.

Assume that an MS randomly chooses its travel direction. If we define the travel direction of an MS by the absolute angle θ between its moving direction and the direction from its position to the cell, the uniformly distributed assumption on the travel direction guarantees the independence of variables r and θ.

Now, consider an MS whose (new) call is generated in region REG1 or REG2. An MS's travel path from its origination point to either boundary will be denoted by the notation $(i_0 \to i_1 \to \cdots \to i_k \to xb)$. The first element i_0 indicates the region of origination, i_k (k=1, ...) the traversed regions, and the last element xb represents either the RTD (xb=rb) or the cell boundary (xb=cb). For compact exposition, the Arabic numbers 1 and 2 are used to express the regions REG1 and REG2 and the letters rb and cb the RTD and cell boundaries, respectively.

Let T^n_P be the travel duration of the new calls (MSs) with travel path P. Hereafter, the quantities pertaining to new calls will be denoted by superscript n. Due to the lack of spaces, only the results of the travel path $(1\rightarrow 2\rightarrow cb)$ is now presented. For those of other remaining cases and their deriving processes, refer to [6]. And refer to [8,11] for similar approaches on other applications.

$$f_{T^n_{(1\rightarrow 2\rightarrow cb)}} = \begin{cases} \displaystyle\int_{\sqrt{R^2-R_1^2}/t}^{V_m} f_1(t,v)dv \\ \text{for} \quad (R-R_1)/V_m \le t \le (R+R_1)/V_m \\ \displaystyle\int_{(R-R_1)/t}^{(R+R_1)/t} f_1(t,v) \\ \text{for} \quad (R+R_1)/V_m \le t \end{cases}$$

where

$$f_1(t) = v\frac{\sqrt{-(R^2-R_1^2)+2(R^2+R_1^2)(tv)^2-(tv)^4}}{\pi R^2 tv}$$

3.2 Handoff call case

Consider an MS handed off to the center cell from its neighboring cell (an inbound handoff call). Note that in this case the range of random variable θ becomes $[-\pi/2, \pi/2]$ and that other assumptions on an MS's moving pattern remain the same as for a new call. Let $(i_1\rightarrow\cdots\rightarrow i_k\rightarrow xb)$ be the travel path of an inbound handoff call, assuming that the corresponding MS is generated at the cell boundary. All quantities pertaining to an inbound handoff call will be denoted by superscript h. We now list the result of path $(2\rightarrow 1\rightarrow 2\rightarrow cb)$ and are others omitted.

$$f_{T^h_{(2\rightarrow 1\rightarrow 2\rightarrow cb)}}(t) = \begin{cases} \displaystyle\int_{2\sqrt{R^2-R_1^2}/t}^{V_m} f_2(t,v)dv \\ \text{for} \quad 2\sqrt{R-R_1^2}/V_m \le t \le 2R/V_m \\ \displaystyle\int_{2\sqrt{R^2-R_1^2}/t}^{2R/t} f_2(t,v)dv \\ \text{for} \quad 2R/V_m \le t \end{cases}$$

where $f_2(t,v) = v\dfrac{1}{2R}\dfrac{1}{\sqrt{(2R/tv)^2-1}}\dfrac{2v}{V_m^2}$

4. Performance Measures

Consider two performance measures: the outage probability and the rate of AHH. The outage probability is the probability that servicing an ongoing call is discontinued when a required level of quality service is not guaranteed any further owing to heavy traffic congestion at a cell [8]. The rate of AHH means the number of MSs making AHHs per unit time, which is introduced to identify the level of their negative effect on system performance [2].

Assume that the duration T of a call is exponentially distributed with mean $1/\mu$, and that new and inbound handoff calls at the cell are generated according to independent Poisson processes with rates λ^n and λ^h, respectively.

Given two AHM parameters, R_1 and α, the rate of AHH from F_1 to F_2 is represented by $AR_{1,2}(R_1,\alpha)$ and the one in the reverse direction by $AR_{2,1}(R_1,\alpha)$. With these notations, the following relations are found after some analytical manipulations.

$$AR_{2,1}(R_1,\alpha) = \lambda^n P^n_{1\rightarrow rb} + \alpha(\lambda^n P_{(2\rightarrow 1\rightarrow rb)} + \lambda^h P^h_{(2\rightarrow 1\rightarrow rb)})$$

$$AR_{1,2}(R_1,\alpha) = \alpha(\lambda^n P^n_{2\rightarrow rb} + \lambda^h P^h_{(2\rightarrow rb)})$$

where

$$P^k_P = \Pr\{T > T^k_P\} = \int_0^\infty e^{-\mu t} f_{T^k_P}(t)dt, k = n,h \quad (1)$$

The total rate of AHHs, $AR(R_1,\alpha)$, is the sum of $AR_{1,2}(R_1,\alpha)$ and $AR_{2,1}(R_1,\alpha)$.

Now turn our attention to the outage probability. Given the offered load OL to the cell in the single-frequency CDMA system, Viterbi et al. [8] have reported a simple approximate measure of the outage probability. In order to exploit this approximate measure, we need to calculate the offered loads of frequencies F_1 and F_2.

Let the random variable $T^k_{H,P}$ be the minimum of the duration T of a call and its travel duration T^k_P with travel path P, that is,

$$T^k_{H,P} = \min\{T, T^k_P\}, \ k = n,h.$$

With $\overline{T^k_{H,p}\$}$ denoting the mean of $T^k_{H,P}$, and given R_1 and α, we can obtain two offered loads, $OL_1(R_1,\alpha)$ and $OL_2(R_1,\alpha)$, which are not given due to the lack of space. The outage probability, denoted by $OP_i(R_1, \alpha)$, of frequency F_i (i=1,2) can be obtained by equation (1) and offered loads $OL_i(R_1, \alpha)$.

5. Numerical Examples

According to the optimal parameter values, R_1^* and α^*, the whole range of traffic load can be divided into three subranges. The first subrange, having $R_1^* = 0$ and $\alpha^* = 0$, represents the light load environment in which a single frequency suffices for the traffic demand. The second subrange is with $R_1^* > 0$ and $\alpha^* = 0$, which shows the medium level of traffic load requiring two frequencies. In this case, the AHM can be activated, completely removing AHHs from REG2 to REG1. The case of heavy load corresponds to the third subregion with $R_1^* > 0$ and $\alpha^* > 0$, in which the AHM reduces the overload on frequency F_1 by systematically forcing a larger number of MSs to use the additional frequency F_2.

In the AHM, we adjust the parameter of the RTD boundary R_1 to take the preemptive responsibility for traffic load increase. As the load increases, R_1 is first increased to its largest allowable value, and then the traffic ratio α starts increasing to take charge of further load increase. Note that this order of load bearing aims at minimizing the occurrences of AHHs.

6. Conclusion

In this paper, we have presented an adaptive handoff management (AHM) method in a multi-frequency CDMA cellular system. The existing handoff methods in a multi-frequency system cannot but employ RHHs, which not only incur additional cost burden but also degrade the quality of calls undergoing handoff. But in the proposed AHM method, these undesirable RHHs can be completely removed by introducing AHHs for the MSs crossing the RTD boundary. Another key advantage of using the AHM method is its ability of adaptively changing its two parameters according to the traffic environment.

Appendix

[1] EIA/TIA IS-95, Mobile Station-Base Station Compatibility Standard for Dual-Mode Wideband Spread Spectrum Cellular System, Washington: Telecommunications Industry Association, July, 1993.

[2] Qualcom, CDMA System Engineering Training Handbook, Qualcomm Inc., 1993.

[3] G.W. Jin, Ph.D thesis, Dept. of Management Science, Korea Advanced Institute of Technology,1998.

[4] S.K. Kwon, H.G. Jeon. and H. Lee, ``A channel assignment scheme for integrated services in DS-CDMA cellular systems,'' Proc. of IEEE ICUPC '97, vol.1, pp 642-645, Oct., 1997.

[5] C.H. Paik, G.W. Jin, J.H. Ahn, and D.W. Tcha, ``Integrated Call Control in a Cellular System,'' To appear in IEEE Trans. Veh. Technol..

[6] P. Satarasinghe, ``A novel method for CDMA hard handoff,'' Proc. of the IEEE Globalcom '96, London, UK, pp. 1766-1768, 1996.

[7] D.W. Tcha, S.Y. Kang and G.W. Jin, ``Load Analysis of the Soft Handoff Scheme in a CDMA Cellular System,'' To appear in IEEE J.Select.Area Commun..

[8] A.M. Viterbi, A.J. Viterbi, ``Erlang capacity of a power controlled CDMA System,'' IEEE J.Select.Area Commun., vol 11, pp 892-900, 1993.

[9] J.S. Wu, J.K.Chung, and Y.C. Yang, ``Proposed multi-channel access schemes for hot-spot underlaying CDMA cellular systems,'' IEICE Trans. Commun., Vol. E81 B. No.4April, pp 745-753, 1998.