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Analysis of handoff in distributed mobile communications system based on remote antenna unit selection

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Abstract: A remote antenna unit (RAU) selection model is presented, and two kinds of handoffs, intra-cell handoff (HO) and inter-cell HO, are defined in distributed mobile communications systems (DAS). After that, an inter-cell HO model is proposed, in which the average power of the active set (AS) is used to predict the position of the mobile station (MS). The total power of the AS and the handoff set (HOS) are utilized to determine whether an inter-cell HO is necessary. Furthermore, the relationship between HO parameters and performance metrics is studied in detail based on RAU selection. Simulation results show that both the intra-cell HO and the inter-cell HO can achieve perfect performance by appropriate settings of HO parameters.

Key words: distributed mobile communications system; handoff; generalized cell; remote antenna unit selection

The distributed mobile communications system (DAS) has been proposed as a promising alternative to the conventional wireless access system employing centralized antennas[1–3]. In this system, handoffs are unnecessary when an MS moves inside a GN-cell (generalized-cell). However, the coverage of a GN-cell is limited, so handoffs are unavoidable when an MS moves across GN-cells. Moreover, the simulcast system will lead to degradation of link quality[1–4]. In Ref. [5], a controlled CDMA DAS is proposed to reduce this disadvantage, and it is verified by simulation that both uplink and downlink qualities can be improved by RAU selection. Recently, limited work has been reported in the literature regarding handoff schemes in DAS. On the contrary, HO algorithms have been studied well for conventional cellular network with single antenna, and some analytic models have been developed in Refs. [6 – 8]. An HO scheme for DAS based on the averaged total received signal strength (RSS) is presented in Ref. [9]. It is found that increasing the number of antennas will bring better overall handoff performance in DAS. However, it cannot achieve RAUs selection gain because of the absence of RAU selection. In this paper, the performance of the HO in DAS is analyzed based on RAU selection.

1 System Structure and Channel Model

A distributed mobile communications system consisting of two GN-cells is shown in Fig. 1, where MSC is the mobile switch center. Each GN-cell has N RAUs denoted as $\mathrm{RAU}_i^{(j)}$ ($j = 1, 2$ and $i = 1, 2, \ldots, N$). In the analysis, we adopt a discrete time model with sampling time t_s, and refer to instant k simply as time k[8]. An MS moves from GN-cell_1 toward GN-cell_2 with constant speed v along a straight line. Thus, the sampling distance is $d_s = vt_s$, the current service GN-cell is GN-cell_1 and the target GN-cell is GN-cell_2. And $d_i^{(1)}(k)$ is the distance between the MS and the i-th RAU in GN-cell_1 at time k.

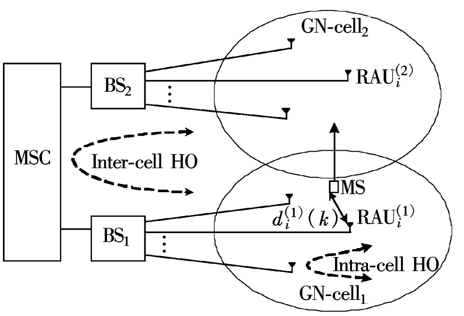

Fig. 1 System structure and two types of handoffs

In a GN-cell, the MS is served by several selected RAUs simultaneously. To manage connections between RAUs and the MS, a type of RAU list is formed and denoted as an active set (AS), whose members depend on certain threshold criteria that are based on RSS measurements. Two types of handoffs are defined in DAS and shown in Fig. 1. An intra-cell HO occurs when the state of the AS has changed during the sampling interval t_s, while an intra-cell HO means a change of the serving BS. The intra-cell HO provides seamless service in a GN-Cell, and the inter-cell HO guarantees

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continuous communication between GN-cells.

In HO algorithm models, the influence caused by short-term fading is ignored, because of its much shorter correlation distance compared to that of shadowing fading, and it can be averaged out at the time scale[6-9]. Therefore, the MS received signal power from surrounding RAUs is determined by the mean signal strength and shadow fading. Let $s_i^{(j)}(k)$ be the instantaneous signal power the MS received from the i-th RAU in GN-cell$_j$ at time k. It is

$$s_i^{(j)}(k) = C_1 - 10C_2\log(d_i^{(j)}(k)) + u_i^{(j)}(k) \tag{1}$$

where C_1 is determined by the transmitter power and C_2 accounts for the path loss; $u_i(k)$ is the shadow fading. In our scheme, shadows in different paths are considered to be independent, and shadows in the same path at different instants are considered as jointly normal-distributed. Consequently, received signals from different RAUs are independent of each other.

To guarantee the stability of the AS and handoff algorithms, the RSS is averaged by an exponential window to average out multi-path and shadow fading fluctuations[6-9]. It has been proved that averaging with an exponential window is accurate than with a rectangular window[10]. Thus, the averaged signal from the i-th RAU in GN-cell$_j$ at time k is[9]

$$\hat{s}_i^{(j)}(k) = d_s \sum_{m=0}^{k} \frac{s_i^{(j)}(k-m)\exp\left(-\dfrac{md_s}{d_{avg}}\right)}{d_{avg}} \tag{2}$$

This can be written recursively as

$$\hat{s}_i^{(j)}(k) = \frac{d_s s_i^{(j)}(k)}{d_{avg}} + \hat{s}_i^{(j)}(k-1)\exp\left(-\frac{d_s}{d_{avg}}\right) \tag{3}$$

where d_{avg} is the distance constant of the averaging window.

2 Intra-Cell HO Analysis

The intra-cell HO is defined as the state transition of the AS when the MS travels in a GN-cell. Whether an RAU joins in or drops from the AS depends on two parameters: adding threshold (T_{add}) and dropping hysteresis (h_{drop}). When averaged RSS from an RAU is beyond T_{add} at time k, the RAU will be added in the AS. Denoting $T_{drop} = T_{add} - h_{drop}$, when the RSS of an RAU in the AS is below T_{drop}, the RAU is removed from the AS. Because of the independency of RAUs, we only need to analyze the state of one RAU. For a certain MS, an RAU is either inside its AS or outside the AS (denoted as A_1 and A_0, respectively). Its state can be described as a two states Markov chain shown in Fig. 2. Probabilities of the state transition are described as Eq. (4).

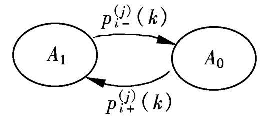

Fig. 2 State transition diagram of $\mathrm{RAU}_i^{(j)}$

$$\left.\begin{aligned} p_{i-}^{(j)}(k) &= P\{\hat{s}_i^{(j)}(k) < T_{drop} / \hat{s}_i^{(j)}(k-1) > T_{add}\} \\ p_{i+}^{(j)}(k) &= P\{\hat{s}_i^{(j)}(k) > T_{add} / \hat{s}_i^{(j)}(k-1) < T_{drop}\} \end{aligned}\right\} \tag{4}$$

Let an indicative function $I_i^{(j)}(k)$ describe the state of $\mathrm{RAU}_i^{(j)}$, as

$$I_i^{(j)}(k) = \begin{cases} 1 & \mathrm{RAU}_i^{(j)} \text{ staying in } A_1 \text{ at time } k \\ 0 & \mathrm{RAU}_i^{(j)} \text{ staying in } A_0 \text{ at time } k \end{cases} \tag{5}$$

Denoting the AS at k instant as $S_{AS}(k)$, so

$$S_{AS}(k) = \{\mathrm{RAU}_i^{(j)} / I_i^{(j)}(k) = 1\} \qquad i = 1, 2, \dots, N \tag{6}$$

Let $\boldsymbol{P}_{i,A}(k) = \{p_{i,A_1}(k), p_{i,A_0}(k)\}$ be the probability vector of MS staying in states in Fig. 2. Given the initial value of $\boldsymbol{P}_{i,A}(0)$, we can achieve $\boldsymbol{P}_{i,A}(k)$ by an iterative way. Then, the probability of $\mathrm{RAU}_i^{(j)}$ staying inside the AS is

$$p_i^{(j)}(k) = P\{\mathrm{RAU}_i^{(j)} \in S_{AS}(k)\} = \\ p_i^{(j)}(k-1)(1 - p_{i-}^{(j)}(k)) + (1 - p_i^{(j)}(k-1))p_{i+}^{(j)}(k) \tag{7}$$

The intra-cell HO just reveals state transitions of the AS during the MS movement. The first metric we are concerned with is the expected size of the AS, denoted as $N_{act}^{(j)}(k)$, where j is the serial number of the current serving BS, so

$$N_{act}^{(j)}(k) = \sum_{i=1}^{N_{RAU}} p_i^{(j)}(k) \tag{8}$$

In CDMA DAS, in uplinks, signals from the MS are received by RAUs in the AS and combined in the BS; in downlinks, the MS receives signals from these RAUs employing a rake receiver with enough fingers. On the one side, a larger AS will bring more diversity gain for both links; on the other side, a larger AS will expend more downlink resources and lead to more interferences in downlinks. The update rate of the AS also should be taken into account. The probability of an intra-cell HO occurring at k instant is

$$p_{\text{intra, ho}}^{(j)}(k) = P\{S_{AS}(k) \neq S_{AS}(k-1)\} = \\ 1 - \prod_{i=1}^{N} (1 - p_{i-,2}^{(j)}(k) + p_{i,\mathrm{AM}}^{(j)}(k-1)(p_{i-,2}^{(j)}(k) - p_{i+,1}^{(j)}(k))) \tag{9}$$

Therefore, the average number of intra-cell handoffs is

$$N_{\text{intra, ho}}^{(j)} = \sum_{k=1}^{K} p_{\text{intra, ho}}^{(j)}(k) \tag{10}$$

where K is the total sampling number. Since only RAUs in the AS can communicate with the MS, an outage will occur once the AS is empty. Denoting the outage probability at time k as $P_{\text{out}}^{(j)}(k)$, so

$$P_{\text{out}}^{(j)}(k) = P\{S_{\text{AS}}(k) = \varnothing\} = \prod_{i=1}^{N}(1 - p_i^{(j)}(k)) \tag{11}$$

3 Inter-Cell HO Analysis

On the one hand, an inter-cell HO should be prevented when the RSS from the serving GN-cell remains strong enough; on the other hand, it should be performed immediately as the RSS goes bad. Let all RAUs in the AS be located in the same GN-cell. It means that there is no macro-diversity between BS_1 and BS_2 because: ① The AS serving for the MS has offered diversities which can improve the quality of links; ② Macro-diversity between BS_1 and BS_2 would consume more network resources. Therefore, RAUs in the target GN-cell are prevented from joining in the AS before an inter-cell HO.

In the inter-cell scheme, first, the position of the MS to the target GN-cell is predicted. Then, the handoff set (HOS, denoted as $S_{\text{HOS}}(k)$) is constituted, which is comprised of selected RAUs located in the target GN-cell. Finally, whether an inter-cell HO occurs or not is judged by the averaged power of the AS and the HOS. The average power of the AS (denoted as $T_{\text{avg}}(k)$) is used to predict the position of the MS because T_{avg} is high when MS stays inside the GN-cell, and it will become lower with MS moving near the boundary, and this will be verified in section 4. The total power of the AS at time k is

$$Z_{\text{AS}}(k) = \begin{cases} 10\log_{10}\left(\sum_i 10^{\frac{s_i^{(j)}(k)}{10}}\right) & S_{\text{AS}}(k) \neq \varnothing; \\ & i \in \{n/\text{RAU}_n^{(j)} \in S_{\text{AS}}(k)\} \\ T_{\text{add}} & S_{\text{AS}}(k) = \varnothing \end{cases} \tag{12}$$

where j is the serial number of the current service GN-cell. If $S_{\text{AS}}(k) = \varnothing$, let $Z_{\text{AS}}(k) = T_{\text{add}}$. Therefore,

$$T_{\text{avg}}(k) = \begin{cases} 10\log_{10}\left(\frac{10^{\frac{Z_{\text{AS}}(k)}{10}}}{N_{\text{act}}(k)}\right) & S_{\text{AS}}(k) \neq \varnothing \\ T_{\text{add}} & S_{\text{AS}}(k) = \varnothing \end{cases} \tag{13}$$

When $\max\limits_{i=1,2,\ldots,N}\{s_i^{(m)}(k)\} > T_{\text{avg}}(k)$, it means that MS has moved near the boundary between GN-cell$_j$ and GN-cell$_m$, and GN-cell$_m$ is the target GN-cell. Consequently, HOS is constituted in GN-cell$_m$ based on the RAU selection model and the total power of HOS (denoted as $Z_{\text{HOS}}(k)$) is measured.

$$Z_{\text{HOS}}(k) = \begin{cases} 10\log_{10}\left(\sum_i 10^{\frac{s_i^{(m)}(k)}{10}}\right) & S_{\text{HOS}}(k) \neq \varnothing; \\ & i \in \{n/\text{RAU}_n^{(m)} \in S_{\text{HOS}}(k)\} \\ T_{\text{add}} & S_{\text{HOS}}(k) = \varnothing \end{cases} \tag{14}$$

Both $Z_{\text{AS}}(k)$ and $Z_{\text{HOS}}(k)$ are averaged by an exponential window, denoted as $\hat{Z}_{\text{AS}}(k)$ and $\hat{Z}_{\text{HOS}}(k)$, respectively. When $\hat{Z}_{\text{HOS}}(k) > \hat{Z}_{\text{AS}}(k) + h_{\text{add}}$, an inter-cell HO occurs; i. e., the current serving GN-cell of the MS switches from GN-cell$_j$ to GN-cell$_m$, and the HOS becomes the new AS. Here, h_{add} is the hysteresis of the inter-cell HO, large h_{add} can reduce HO number but lead to handoff delay, and we will analyze it in section 4 by simulation.

As assumed in Fig. 1, the MS moves from GN-cell$_1$ toward GN-cell$_2$. Denoting probabilities that the MS served by GN-cell$_1$ and GN-cell$_2$ are $p_{\text{in}}^{(1)}(k)$ and $p_{\text{in}}^{(2)}(k)$, respectively. Consequently, the expected size of the AS at k instant is

$$N_{\text{act}}(k) = \sum_{j=1}^{2} p_{\text{in}}^{(j)}(k) N_{\text{act}}^{(j)}(k) \tag{15}$$

Assuming $p_{2/1}(k)$ and $p_{1/2}(k)$ are the probabilities that an inter-cell HO occurs from GN-cell$_1$ to GN-cell$_2$ and from GN-cell$_2$ to GN-cell$_1$ at time k, the probability that there is an inter-cell HO occurring at time k is

$$p_{\text{inter, ho}}(k) = p_{\text{in}}^{(1)}(k-1)p_{2/1}(k) + p_{\text{in}}^{(2)}(k-1)p_{1/2}(k) \tag{16}$$

Thus, the mean number of the inter-cell HO is

$$N_{\text{inter, ho}} = \sum_{k=1}^{K} p_{\text{inter, ho}}(k) \tag{17}$$

During an inter-cell HO, if the AS and the HOS are empty, an outage occurs, and the outage probability is

$$P_{\text{out}}(k) = P\{S_{\text{AS}}(k) = \varnothing, S_{\text{HOS}}(k) = \varnothing\} = P_{\text{out}}^{(1)}(k)P_{\text{out}}^{(2)}(k) \tag{18}$$

4 Simulation Results

The simulation scenario is shown in Fig. 3. The MS moves from point A toward point B with constant velocity, $v = 10$ m/s. Sampling instant $t_s = 0.1$ s; the variance of shadow fading, $\sigma^2 = 6$ dB; C_1 and C_2 are equal to 0 and 30 dB, respectively; the distance constant of the smoothing window, $d_{\text{avg}} = 20$ m. In order to achieve accurate statistics, each trajectory is simulated 10 000 times.

The adding threshold T_{add} and the dropping hysteresis h_{drop} are two key parameters for the intra-cell HO. According to the simulation scenario and the val-

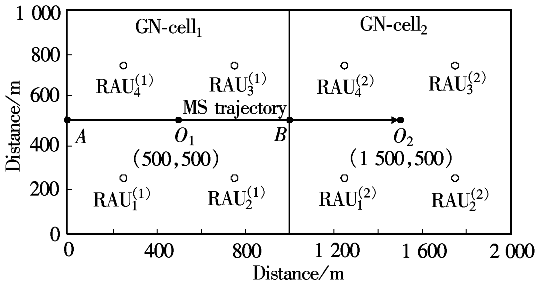

Fig. 3 GN-cell structure and MS trajectory

ues of C_1 and C_2 provided above, $T_{add} = -76$ dB is the lowest threshold for covering a GN-cell seamlessly, and when $T_{add} = -90$ dB, the AS is comprised of almost all RAUs. A lower T_{add} creates a larger AS and smaller outage probability. It is shown in Fig. 4. We also find from Fig. 4 that the AS will be enlarged, and the outage probability will be reduced, when T_{add} is constant and h_{drop} increases. At this moment RAUs dropping out the AS will be delayed when their RSS become poor, which will lead to degradation of diversity gain. When $T_{add} < -78$ dB and $h_{drop} > 2$ dB, P_{out} is below 5%.

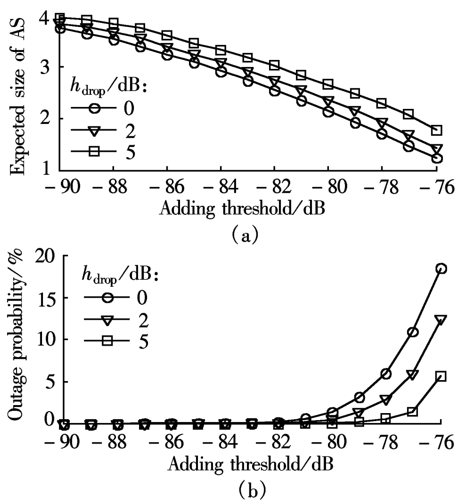

Fig. 4 Expected size of AS and outage probability. (a) Expected size of AS; (b) Outage probability

Fig. 5 (a) shows the tradeoff curves between the expected AS size and the mean number of the intra-cell handoffs with different T_{add} and h_{drop} when the MS moves from point A to point B shown in Fig. 3. This tradeoff curve is useful in determining reasonable values of HO parameters. $N_{intra, ho}$ decreases with the increase of N_{act}. This conclusion is suitable for other situations. Practically, $N_{intra, ho}$ is relevant to the travel speed of the MS. When the MS moves fast, a larger AS will be maintained for it to obtain fewer handoffs and better link quality by macro-diversity. However, when it is a slower MS, a smaller AS can be provided to save the expending of network resources. Fig. 5 (b) shows the relationship between the averaged power of the AS and the expected size of the AS. It is observed that T_{avg} is greater than T_{add} and almost keeps constant when T_{add} and h_{drop} change. Actually, when the MS moves near the boundary of GN-cells, it will decrease to about -76 dB. To this end, constituting the HOS based on (13) is suitable.

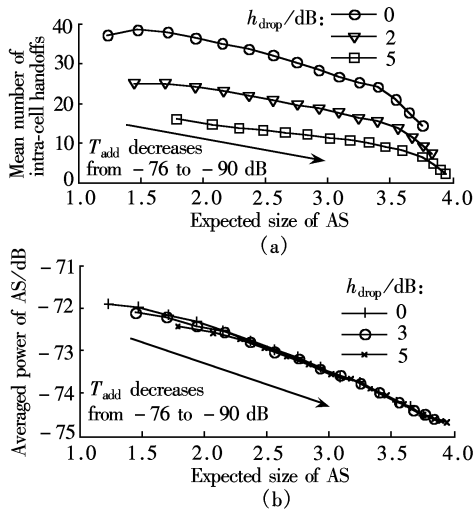

Fig. 5 Active set performance. (a) Tradeoff curve; (b) Averaged power of AS

During the analysis of the inter-cell HO, we assume that the MS moves from the point O_1 toward the point O_2 shown in Fig. 3. Tab. 1 offers the average position where the HOS is constituted and the average position where the first inter-cell HO occurs with and without prediction, denote them as P_1, P_2 and P_3, respectively. In Tab. 1, $h_{drop} = h_{add} = 2$ dB. It can be observed that the prediction does not influence the natural characteristics of the inter-cell HO because P_2 equals P_3 approximately. P_1 lies around 900 m, which is the reasonable range to prepare for an inter-cell HO.

Tab. 1 Positions statistics

T_{add}/dB	P_1/m	P_2/m	P_3/m
−78	908.56	1 006.3	1 006.2
−79	910.46	1 006.6	1 006.4
−80	900.48	1 005.3	1 005.2
−81	894.73	1 005.9	1 005.7
−82	886.65	1 008.5	1 008.3
−83	882.56	1 006.9	1 006.8
−84	886.48	1 008.1	1 008.0

In simulation, we observe that the AS changes smoothly, and h_{add} has little effect on N_{act}, $N_{intra, ho}$, P_{out} in the inter-cell HO. When $T_{add} = -76$ dB, P_{out} is about 15%, but when $T_{add} \leqslant -78$ dB, it will be below 5%. In Fig. 6, the mean number of the inter-cell handoffs is plotted versus the adding hysteresis in three different scenarios. The first scenario is the conventional mobile cellular system with one RAU (antenna) in the BS, denoted as the single RAU in Fig. 6. In the simulation, two RAUs are located at the points O_1 and O_2, respectively. The second scenario is shown in Fig. 3 and the inter-cell HO is based on RAU selection, denoted as RAU-Sel in Fig. 6. The third scenario is as same as the second one, but there is no RAU selection when performing an inter-cell HO (i. e. the handoff scheme proposed in Ref. [9]), denoted as Non-RAU-Sel in Fig. 6. Because of the RAU selection, the number of RAUs for the inter-cell HO is equal to N_{act}, which is less than or equal to the total number of RAUs in the GN-cell. Thus, according to the conclusion in Ref. [9] (i. e. the mean number of inter-cell handoffs decreases with the increase of the number of RAUs in the AS), the performance of the inter-cell HO based on RAU selection is not worse than that of single RAU, and not better than that of Non-RAU-Sel. This can be verified by Fig. 6. When $T_{add} = -90$ dB, N_{act} is nearly the total number of RAUs in the GN-cell, therefore the mean number of handoffs of RAU-Sel and Non-RAU-Sel are almost equal. We also find that when h_{add} is greater than 2 dB and T_{add} is less than -80 dB, the expected number of the inter-cell handoffs is approaching its best bounds closely.

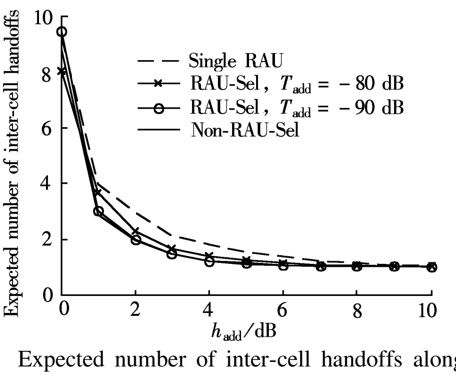

Fig. 6 Expected number of inter-cell handoffs along the path from O_1 to O_2

Greater h_{add} achieves smaller probabilities of the inter-cell HO which means fewer $N_{inter,ho}$; however, it also leads to larger delays of the inter-cell HO. The delay of the handoff can be measured by the crossover point[6-7] (COP). Here we define it as the point between two GN-cells, where probabilities of the MS served by two GN-cells are equal to 0.5. Fig. 7 shows the tradeoff curve of $N_{inter,ho}$ and the COP. The perfect operating point is at the "knee" of the curve. COP is useful for finding the optimum operating point so that the inter-cell HO delay is minimized, while $N_{inter,ho}$ is also minimized to reduce network load during the inter-cell HO.

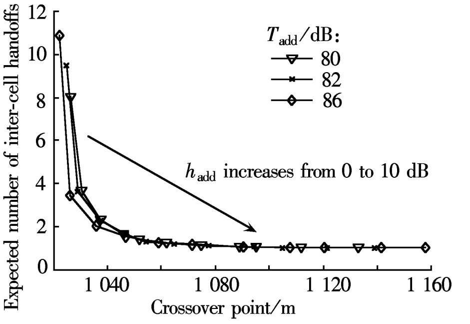

Fig. 7 Tradeoff curve between the expected number of inter-cell handoffs and COP

5 Conclusion

In this paper, the intra-cell HO and the inter-cell HO in GAS are analyzed in detail. T_{add} is the key factor in determining the size of the AS. High h_{drop} is propitious to maintain stability of the AS and reduce the number of the intra-cell handoffs, but it also leads to the degradation of diversity gain. In practical application, perfect performance of the intra-cell HO can be achieved when parameters are related to the MS profile. h_{add} is an important parameter for the inter-cell HO. Higher h_{add} means fewer inter-cell handoffs, but it results in larger handoff delays which will increase interference between GN-cells. The tradeoff curve between $N_{inter,ho}$ and COP provides a method to determine the optimum operating point of inter-cell handoffs.

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分布式移动通信系统中基于天线选择的切换分析

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摘要: 首先给出了一种远端天线单元选择的分析模型,并定义了分布式移动通信系统中 2 种类型的切换:小区内切换(intra-cell HO)和小区间切换(inter-cell HO);然后提出了一种小区间切换的模型,该模型利用激活集的平均功率强度来预测移动台(MS)的位置,通过比较激活集和切换集的总功率,来判断移动台是否需要进行一次越区切换. 此外,在 RAU 选择的基础上,详细分析了 2 种切换方式中切换参数和切换性能指标之间的关系. 仿真结果表明,通过合理地选择切换参数,2 种切换方式都能够取得良好的性能.

关键词: 分布式移动通信系统;切换;广义小区;远端天线单元选择

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