

# Optimal Transmission Parameters of Hopping Pilot Beacon for Inter-frequency Handoff in CDMA Mobile Cellular Networks

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## ABSTRACT

In this paper, optimal parameters of a hopping pilot beacon are analyzed in a CDMA mobile cellular network. The hopping pilot beacon is used for inter-frequency handoff. It can reduce the number of pilot beacons needed for the inter-frequency handoff by transmitting neighbor frequency pilots periodically through a pilot beacon. The optimal parameters for transmission time and period of the hopping pilot beacon are derived by mathematical approach. We recommend the optimal values for the hopping pilot beacon under various operation environments.

## I. INTRODUCTION

In CDMA (code division multiple access) mobile cellular networks, handoff plays an important role in determining overall system performance [1,2]. The handoff process is essential in maintaining quality of a call in progress and in keeping as low as possible both forced terminated calls and load to the network from signaling and switching [3-6].

When the MS moves from the BS to another BS and these two BSs have different frequency, inter-frequency handoff is required in order to maintain a call in progress. In the inter-frequency handoff, the radio link is interrupted during a short time while support is switched from one frequency to another [7]. The inter-frequency handoff has two basic types: *hand-down* and *handover*. The handdown is a hard handoff between two different frequencies within the same cell. A MS entering a sector configured as border is instructed to issue frequent and periodic pilot strength measurement messages. This allows the BS to closely monitor the MS situation without waiting for reports triggered by pilot. When the pilot report indicates that the serving pilot has dropped below a threshold, the MS is directed to handdown from serving frequency to target frequency. The handdown from one frequency to another is done without knowledge of another frequency's pilot energy level. It works well for a border area where traffic flow is linear and predictable. For the handdown, the border area needs to deploy multi-

ple frequencies (i.e. Dummy FA) [8,9].

The handover is a hard handoff between two different cells with different frequencies. In the handover, the MS simply handoffs from one frequency to another directly with the help of *pilot beacon*. The pilot beacon provides pilots of neighbor cells for the serving cell. In this situation, the MS handoffs frequency from the serving one to the target one when the pilot energy level from the pilot beacon exceeds that of the serving frequency by the predetermined margin. Hopping pilot beacon is a modified pilot beacon, and it replaces simultaneous transmission of multiple pilot signals by periodic transmission of multiple pilot signals. The hopping pilot beacon periodically changes transmission of the neighbor pilots.

In this paper, we analyzed the optimal parameters of hopping pilot beacon for inter-frequency handoff in the CDMA mobile cellular networks. The optimal transmission time of a hopping pilot beacon is closely related with pilot search and handoff algorithms. We derive the optimal values of parameters for the hopping pilot beacon.

The rest of our paper is organized as follows: In section II, the pilot search and handoff algorithms are described. In section III, optimal parameters for mobile stations are derived in traffic state. In section IV, numerical examples are presented. In section V, conclusions are drawn.

## II. SYSTEM MODEL

### A. Transmission Pattern of Hopping Pilot Beacon

The hopping pilot beacon periodically changes frequencies to simulate multiple pilot beacons transmitting pilot information as shown in Figure 1. It periodically transmits  $n$  different neighbor pilots of neighbor frequencies on a serving frequency. The transmission time of the hopping pilot beacon can be typically modeled by three parameters,  $T_{on}$ ,  $T_{off}$ , and the number of different neighbor pilots  $n$ . The  $T_{on}$  and  $T_{off}$  denote the du-

ration during which each neighbor pilot is transmitted and a switching time between the neighbor pilots, respectively. Then, a MS can receive each neighbor pilot during the transmission time period ( $T_{on}$ ), and can not receive it during the null period ( $T_{null}$ ) in a periodic manner. The  $T_{null}$  can be obtained in terms of  $T_{on}$ ,  $T_{off}$  and  $n$ , and given by

$$T_{null} = (n-1) \cdot T_{on} + n \cdot T_{off}, \quad (1)$$

### B. Pilot Search Time

The required time for the MS to search a pilot depends on the pilot search algorithm and hardware complexity (the number of correlators). According to the number of correlators for searcher, the MS of the IS-95 CDMA system is classified into two modes: 1) 1x search mode – the searcher employs two correlators for in-synch and out-of-synch hypotheses. In the 1x mode, double-dwell search algorithm is used for pilot search. 2) 8x search mode – the searcher uses eight times the number of correlators for the 1x mode. Typically, single-dwell search algorithm is used for the pilot search in the 8x mode.

In a double-dwell search algorithm, an early dump test is performed to save search time. The MS generates PN (pseudonoise) sequence for a given offset, and calculates partial correlation with the received pilot signal for early dump integration time,  $T_e$ . To obtain robustness to phase error, non-coherent accumulation is performed in calculation of the partial correlation. If the partial correlation value exceeds the given early dump threshold energy,  $E_{th}$ , the correlation value for search integration time,  $T_{int}$ , is calculated. Otherwise, the MS generates the next PN sequence and repeats the same procedure. The MS completes searching for the pilot after investigating all possible PN offsets in window size,  $S_w$ . The pilot search time of the double dwell search algorithm may vary for the number of PN offsets of which partial correlation values exceed the early threshold energy,  $N_{th}$ . Then, the pilot search time for the 1x search mode is given by

$$T_{search\_time} = T_e \cdot N_p \cdot S_w + (T_{int} \cdot N_p - T_e \cdot N_p) \cdot N_{th} \leq T_{int} \cdot N_p \cdot S_w, \quad (2)$$

where  $N_p$  denotes the number of non-coherent accumulation passes.

### C. Pilot Search Period of Mobile Station

The MS searches pilots in a predetermined order. It firstly searches all the pilots included in active/candidate sets. After all the pilots in the active/candidate sets are searched, the pilot in the neighbor set is searched. Then, the MS searches all the

pilots in the active/candidate sets again, and repeats the search in the predetermined order. The pilot in the remaining set is searched once for every fifty times of active pilot searches [9]. Thus, the search period of the active pilots is small enough to neglect that of the remaining pilots. The search period of active pilot is given by

$$T_{search\_period} = N_{act} \cdot T_{aci\_srch\_time} + T_{ngbr\_srch\_time}, \quad (3)$$

where  $N_{act}$  denotes the total number of pilots included in the active/candidate set. If the MS is in idle state,  $N_{act} = 1$ . If the MS is in traffic state, the  $N_{act}$  is determined according to the handoff situations.

### D. Timing Diagram

The pilot signal from the hopping pilot beacon is periodic with period  $T_{on} + T_{null}$  as shown in Figure 1. Let the time when the MS starts searching a pilot (we assume this pilot as pilot A) be  $x(t)$ . The  $x(t)$  can be modeled as a uniformly distributed random variable, and its *p.d.f.* is given by

$$f_X(x) = \frac{1}{T_{on} + T_{null}}, \quad 0 \leq x \leq T_{on} + T_{null}, \quad (4)$$

The timing diagram of transmission time of a hopping pilot beacon and the start time when the MS starts to search pilot A is shown in Fig. 2. If the MS starts to search pilot A at  $x(t)$ , the MS periodically searches the pilot A at  $x(t) + k \cdot T_{search\_period}$ ,  $k = 1, 2, \dots, \infty$ .

## III. PERFORMANCE ANALYSIS

The parameters of the hopping pilot beacon should be selected to obtain reasonable handoff performance. The MS includes the pilot of the neighbor or the remaining set in the pre-candidate set if its energy level exceeds  $T\_ADD$ . The counter of newly included pilot in the pre-candidate set is set to be 2, and is increased by 1 whenever it exceeds  $T\_ADD$ . While, the counter will be decreased by 1 whenever its energy level drops below  $T\_ADD$ . The pilot is returned to the neighbor set if the value of counter reaches zero. If the value of counter reaches 7, the MS sends the pilot strength measurement message to the BS, and includes the pilot in the real-candidate set.

**A. Case A:**  $T_{search\_period} \leq T_{on} - T_{signal\_need}$

The following constraints should be satisfied for the MS to continuously search the pilot A more than  $k$  times.

$$0 \leq x(t) \leq T_{on} - T_{signal\_need} - (k-1) \cdot T_{search\_period}, \quad (5)$$

Since the  $x(t)$  is a uniformly distributed random variable, the probability that the MS continuously searches pilot A more than  $k$  times is given by

$$P[0 \leq x(t) \leq T_{on} - T_{signal\_need} - (k-1) \cdot T_{search\_period}] = \frac{T_{on} - T_{signal\_need} - (k-1) \cdot T_{search\_period}}{T_{on} + T_{null}}, \quad (6)$$

where  $T_{on} > T_{signal\_need} + (k-1) \cdot T_{search\_period}$ . The  $T_{on}$  should satisfy the following two constraints:

$$T_{on} \geq T_{signal\_need} + 4 \cdot T_{search\_period} \quad \text{and} \quad (7)$$

$$\max\{P[0 \leq x(t) \leq T_{on} - T_{signal\_need} - 4 \cdot T_{search\_period}]\} = \max\left\{\frac{T_{on} - T_{signal\_need} - 4 \cdot T_{search\_period}}{T_{on} + T_{null}}\right\}. \quad (8)$$

The pilot signal which the MS receives in the pre-candidate set has the second order Chi-distribution with mean  $T_{ADD}$ .

To ensure that the MS can continuously search more than 11 times to obtain the reasonable handoff performance, we can conclude that the  $T_{on}$  should be maintained as follows:

$$T_{on} \geq T_{signal\_need} + 10 \cdot T_{search\_period}. \quad (9)$$

The probability that the MS can continuously search pilot A more than 11 times is given by

$$P[0 \leq x(t) \leq T_{on} - T_{signal\_need} - 10 \cdot T_{search\_period}] = \frac{T_{on} - T_{signal\_need} - 10 \cdot T_{search\_period}}{T_{on} + T_{null}}. \quad (10)$$

If the energy level of the pilot in the real-candidate set is larger than  $T_{DROP}$ , a drop timer is enabled. The MS searches the pilot, and sends pilot strength measurement message before the drop timer expires according to the result of  $T_{COMP}$  test or  $T_{ADD}$  test. The MS sends the pilot strength measurement message to request handoff if the strength of the pre-filtered pilot in the real-candidate set is larger than that of the pilot in active set by  $T_{COMP} \times 0.5$  dB for five consecutive times in  $T_{COMP}$  test. Hence, it is recommended that the MS be able to continuously search the pilot A of the real-candidate set five times. If the following criterion is satisfied, it is guaranteed that the MS can search the pilot in the real-candidate set at least five times whenever the pilot is included in the real-candidate set before the  $T_{DROP}$  timer expires.

$$T_{DROP} > 10 \cdot T_{search\_period} + T_{null} + T_{active\_search\_time}. \quad (11)$$

From the fact that  $T_{null}$  equals to  $(n-1) \cdot T_{on} + n \cdot T_{off}$ , the

recommended value of  $T_{on}$  is upper and lower bounded by

$$\begin{aligned} T_{signal\_need} + 10 \cdot T_{search\_period} &< T_{on} \\ &< \frac{T_{DROP} - 10 \cdot T_{search\_period} - T_{active\_search\_time} - n \cdot T_{off}}{n-1}, \end{aligned} \quad (12)$$

where

$$\begin{aligned} T_{signal\_need} + 10 \cdot T_{search\_period} \\ < (T_{DROP} - 10 \cdot T_{search\_period} - T_{active\_search\_time} - n \cdot T_{off}) / (n-1) \end{aligned}$$

#### B. Case B:

$$T_{null} + T_{signal\_need} \leq T_{search\_period} \leq T_{null} + T_{on}, \quad \text{where } m \text{ (integer)} \geq 0$$

From the Figure 3, the following criterion should be satisfied for the MS to continuously search the pilot A for 11 times at its every search period.

$$\frac{10 \cdot (T_{on} + T_{null}) + T_{signal\_need} - T_{on}}{10} \leq T_{search\_period} \leq T_{on} + T_{null}, \quad (13)$$

Since the  $x(t)$  is a uniformly distributed random variable, the probability that the MS continuously searches the pilot A for 11 times at its own search period is given by

$$\begin{aligned} P(T_{on} + T_{null} - T_{search\_period} \leq x(t) \leq T_{on} - T_{signal\_need} + 10 \cdot T_{search\_period} - 10 \cdot (T_{on} + T_{null})) \\ = \frac{10 \cdot T_{search\_period} - 10 \cdot n \cdot (T_{on} + T_{off}) - T_{signal\_need} + T_{on}}{n \cdot (T_{on} + T_{off})} \end{aligned} \quad (14)$$

From the fact that  $T_{null}$  equals to  $(n-1) \cdot T_{on} + n \cdot T_{off}$ , the recommended value of  $T_{on}$  is upper and lower bounded by

$$\frac{T_{search\_period} - n \cdot T_{off}}{n} \leq T_{on} \leq \frac{10 \cdot T_{search\_period} - 10 \cdot n \cdot T_{off} - T_{signal\_need}}{10 \cdot n - 1} \quad (15)$$

We can find that the case A ( $T_{search\_period} \leq T_{on} - T_{signal\_need}$ ) is more suitable than the case B for the handoff of the MS in traffic state because the probability that the MS continuously searches the pilot A for 11 times for the case A is larger than that of the case B.

## IV. NUMERICAL RESULTS

From the results of section III, the optimal value of the  $T_{off}$  for the hopping pilot beacon should be the allowable minimum value since the  $T_{off}$  is inversely proportional to the handoff success probability. The optimal bound of the  $T_{on}$  is given by

$$\begin{aligned} T_{signal\_need} + 10 \cdot T_{search\_period} &< T_{on} \\ &< \frac{T_{DROP} - 10 \cdot T_{search\_period} - T_{active\_search\_time} - n \cdot T_{off}}{n-1}, \end{aligned} \quad (16)$$

where

$$T_{null} < \frac{T_{signal\_need} + 10 \cdot T_{search\_period} - T_{TDROP} - 10 \cdot T_{search\_period} - T_{active\_search\_time} - n \cdot T_{off}}{n-1}$$

Though the handoff performance can be improved as the  $T_{on}$  increases, the appropriate margin should be considered in selecting the  $T_{on}$  in order to reflect channel conditions. The

$T_{null}$  is determined in terms of  $T_{on}$ ,  $T_{off}$ , and the number of different neighbor pilots  $n$  as follows:

$$T_{null} = (n-1) \cdot T_{on} + n \cdot T_{off} \quad (17)$$

For the numerical examples, the followings are assumed: 1)  $T_{TDROP} = 1$  sec, 2) Neighbor window size = 80 chip, 3) Active window size = 28 chip, 4)  $T_{int}$  (search integration time) = 512 chip, 5)  $N_p$  (number of non-coherent accumulation passes) = 1, and 6)  $T_{off} = 1$  ms.

In Fig. 4 and Fig. 5, the bounds on  $T_{on}$  vs. the number of pilots in the active and candidate set are shown for two and three hopping pilot beacons, respectively. The bounds on  $T_{on}$  may vary for the different number of pilots in active set and candidate set, and the number of pilots included in the active and candidate set depends on the channel environments and handoff situations. The  $T_{on}$  should be selected as the value between the lower and the upper bound.

The bounds on  $T_{on}$  with four hopping pilot beacons are shown in Figure 6. The optimal value of  $T_{on}$  can not be found because the lower bound of the 1x mode MS is higher than the upper bound of the 1x mode MS. We can conclude that the four pilots transmitted by the hopping pilot beacon are not adequate because the number of pilots in the active and the candidate set can be four in the real handoff situations.

The bounds of  $T_{on}$  with five hopping pilot beacons are shown in Figure 7. As shown Figure 6, the 1x mode MS can not be supported when the number of pilots in the active/candidate set is over 2.

## V. CONCLUSIONS

In this paper, we analyzed the transmission parameters of a hopping pilot beacon, and recommended the optimal values of the parameters. We recommended the optimal values for the hopping pilot beacon under various operation environments.

It is expected that the handoff performance will be improved as the  $T_{on}$  becomes larger. However, appropriate margin in selecting  $T_{on}$  should be considered reflecting channel

propagation environments and handoff situation. The recommended maximum number of pilots transmitted by the hopping pilot beacon is three, and the recommended value of  $T_{on}$  is about 300 ms when the pilot beacon periodically transmits three pilots [10].

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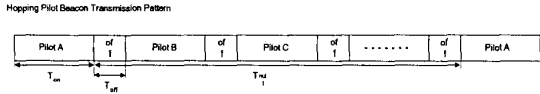


Fig. 1. Transmission pattern of a hopping pilot beacon.

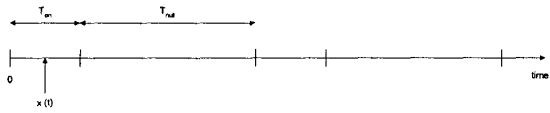


Fig. 2. Timing diagram for search and transmission time of a hopping pilot beacon.

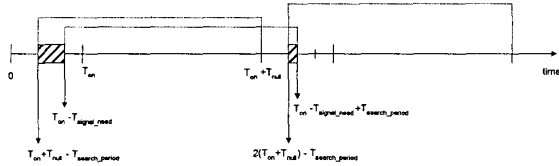


Fig. 3. Timing diagram for search and transmission time for  $T_{null} + T_{signal\_need} \leq T_{search\_period} \leq T_{null} + T_{on}$ , where  $m(\text{integer}) \geq 0$

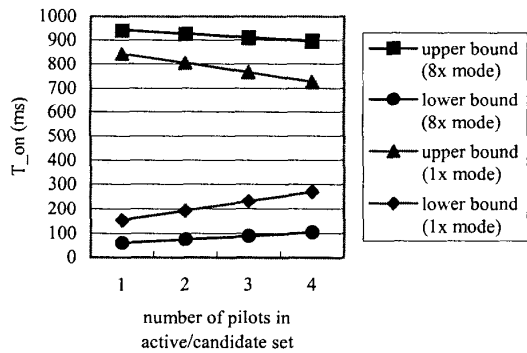


Fig. 4. Bounds of  $T_{on}$  with two hopping pilot beacons.

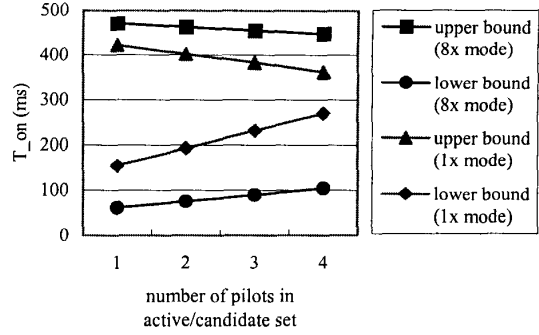


Fig. 5. Bounds of  $T_{on}$  with three hopping pilot beacons.

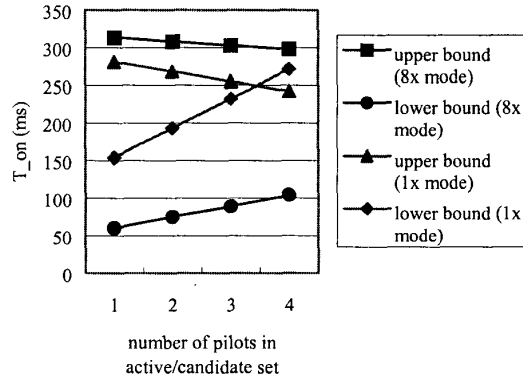


Fig. 6. Bounds of  $T_{on}$  with four hopping pilot beacons.

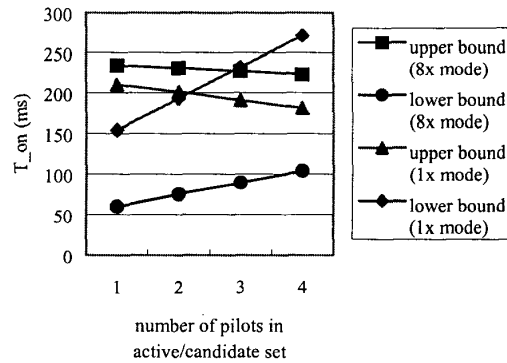


Fig. 7. Bounds of  $T_{on}$  with three hopping pilot beacons.