An Adaptive Hard Handoff Algorithm for Mobile Cellular Communication Systems

Huamin Zhu and Kyung Sup Kwak

ABSTRACT—In this letter, we propose an adaptive hard handoff algorithm with a dynamic hysteresis value based on the received signal strength from the serving base station, for mobile cellular communication systems. A discrete-time method is presented to evaluate handoff algorithms analytically. Performance is evaluated in terms of the average number of handoffs, the probability of link degradation, and the average handoff delay. Numerical results and simulations demonstrate that the proposed algorithm outperforms the handoff algorithm with fixed hysteresis values and the handoff algorithm using both threshold and hysteresis.

Keywords—Adaptive hard handoff, hysteresis, cellular communication.

I. Introduction

Handoff, the process of transferring the serving base station (BS) of a mobile station (MS) from one to another when the MS moves across a cell boundary, is an essential component of mobile cellular communication systems. In this letter, we concentrate on hard handoffs in a cellular system. The term handoff is henceforth used to refer to hard handoff.

The received signal strength (RSS) measurement is one of the most common criteria to initiate a handoff. In traditional handoff algorithms, handoff is initiated if the new RSS of the new BS is sufficiently stronger by a hysteresis value than that of the serving BS. Here, the hysteresis value h is designed to reduce the number of unnecessary handoffs and to prevent a ping-pong effect. Therefore, selection of this hysteresis value becomes important for optimizing handoff performance. If h is too small, numerous unnecessary handoffs may be processed, increasing the network burden; if h is too large, the long handoff delay may result in a dropped-call or low quality of service (QoS).

In this study, an adaptive handoff algorithm is developed by dynamically determining the hysteresis value as a function of the RSS from the serving BS. The handoff performance criterion is based on minimizing the average number of handoffs, the probability of link degradation, and the average handoff delay for the given propagation parameters and mobile path. A tradeoff exists among these conflicting performance measures.

II. Discrete-Time Method of Handoff Analysis

A basic system consisting of two BSs separated by a distance of D is considered in this letter [1]-[4]. It is assumed that the MS is moving along a straight line with a constant velocity v between the two BSs, labeled BS_1 and BS_2. It is assumed that the RSS is affected by path loss as well as the shadowing effect. In addition, Rayleigh fading exists. However, this is averaged out and can be ignored because handoff algorithms cannot respond to short-term fading. The handoff condition is checked at the sampling instant, where the sampling time is t_s.

For the handoff algorithm with fixed hysteresis h, a handoff occurs if the following condition is met:

$$R_{target}(k) > R_{current}(k) + h\ , \tag{1}$$

where $R_{target}(k)$ and $R_{current}(k)$ are the RSSs of the target BS and the serving BS at time instant k , $1 \leq k \leq N$, and N is the total number of sample points along the path.

Let us define $x(k)$ as

$$x(k) = R_1(k) - R_2(k)\ , \tag{2}$$

where $R_1(k)$ and $R_2(k)$, the RSSs of BS_1 and BS_2 at time instant

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k, are Gaussian with mean $m_1(k)$ and $m_2(k)$, respectively, and variance σ^2, where σ is the standard deviation of the shadow fading.

Let $P_{1\to2}(k)$ and $P_{2\to1}(k)$ be the transition probabilities that the MS hands over from BS_1 to BS_2 at time instant k and vice versa. Thus,

$$P_{1\to2}(k) = \Pr\{x(k) < -h\}, \quad (3)$$

$$P_{2\to1}(k) = \Pr\{x(k) > h\}. \quad (4)$$

Let us define $P_1(k)$ and $P_2(k)$ as the assignment probabilities that the serving BS of the MS is BS_1 and BS_2, respectively. Once the above transition probabilities are found, the assignment probabilities can be calculated recursively using the following formulas:

$$P_1(k) = P_1(k-1)(1-P_{1\to2}(k)) + P_2(k-1)P_{2\to1}(k), \quad (5)$$

$$P_2(k) = P_2(k-1)(1-P_{2\to1}(k)) + P_1(k-1)P_{1\to2}(k), \quad (6)$$

under the initial condition $P_1(1)=1$, $P_2(1)=0$.

The probability of handoff $P_{ho}(k)$ is determined by

$$P_{ho}(k) = P_1(k)P_{1\to2}(k) + P_2(k)P_{2\to1}(k). \quad (7)$$

The expected number of handoffs, NO_{ho}, is given by

$$NO_{ho} = \sum_{k=1}^{N} P_{ho}(k). \quad (8)$$

To provide an insight and to make the solution tractable analytically, here we assume that the shadow fading is not correlated. Therefore, $x(k)$ is an independent Gaussian random variable with mean $m(k) = m_1(k) - m_2(k)$ and variance $2\sigma^2$. The transition probabilities can be expressed as follows:

$$P_{1\to2}(k) = Q\left(\frac{h+m(k)}{\sqrt{2}\sigma}\right), \quad (9)$$

$$P_{2\to1}(k) = Q\left(\frac{h-m(k)}{\sqrt{2}\sigma}\right), \quad (10)$$

where $Q(\ )$ is the Q-function (complementary cumulative distribution function).

The probability of link degradation P_{ld} is

$$P_{ld}(k) = P_1(k)Q\left(\frac{\Delta - m_1(k)}{\sigma}\right) + P_2(k)Q\left(\frac{\Delta - m_2(k)}{\sigma}\right), \quad (11)$$

where Δ is the threshold of link degradation.

Figure 1 shows the assignment probabilities and also the probabilities of handoff, provided D=2000 m. Both simulation data and numerical results obtained from analysis are shown in the figure for $h=4$ in which we can see that the two sets of data match each other very well. The agreement between analysis and simulation indicates the soundness of the proposed discrete-time method of handoff analysis. The intersection between $P_1(k)$ and $P_2(k)$ shifts to the right as the hysteresis increases, which indicates the increasing handoff delay. It is clear that the probability of handoff decreases with increasing hysteresis value.

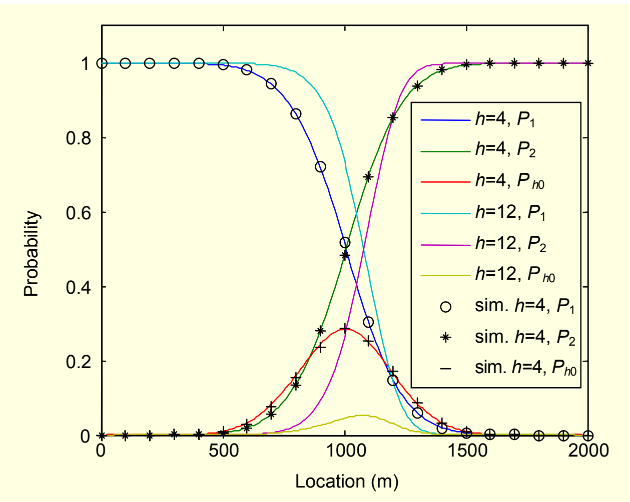

Fig. 1. Assignment probabilities and handoff probabilities.

III. Proposed Adaptive Handoff Algorithm

A primary objective of a handoff algorithm is to provide good signal quality. With the algorithm presented here, we attempt to reduce the average number of handoffs by dynamically adjusting the hysteresis value based on RSS. Generally, high RSS means good signal quality, so the handoff to another BS can be considered unnecessary, because the MS is being served well by the current serving BS. The main proposal in this letter is to use a high hysteresis level to restrain the MS from handing over to other BSs if the RSS from the serving BS is high, and to use a low hysteresis level to encourage the MS to hand over to an adjacent BS with better link quality if the RSS from the serving BS is low.

In the proposed adaptive handoff algorithm, the hysteresis value h is determined by

$$h(k) = \max\left\{ a\left[\min\left(\frac{R(k)-\Delta}{a}, 1\right)\right]^n, b \right\}, \quad (12)$$

where $R(k)$ is the RSS from the serving BS, a, b, and n are positive numbers, and Δ is the threshold of link degradation.

As demonstrated above, h equals a dB for $R(k)$ larger than $\Delta + a$, and it decreases from a to b dB as the RSS from the serving BS decreases from $\Delta + a$ to Δ. If the current RSS from the serving BS is larger than $\Delta + a$ and no handoff occurs, the probability of link degradation at the next time instant is approximately less than $Q(a/\sigma)$, which should be considerably low. For instance, it is about 0.0013 for the case $a = 15$ and $\sigma = 5$. The minimal hysteresis value is b to prevent a ping-pong effect. Exponent n determines the speed at which h decreases from a to b. In this way it controls the handoff performance when a and b are fixed.

Since the hysteresis value is varied based on RSS, the proposed algorithm can intelligently reduce the probability of unnecessary handoffs while maintaining the QoS.

IV. Performance Evaluation

The parameters used for simulation are commonly used to analyze handoff performance [1]-[4], and are presented in Table 1. The transmission power of each BS is normalized to be 0 dB to estimate the performance at each parameter setting. 100,000 realizations were used in order to get stable results and smooth curves. We compare the proposed algorithm with a handoff algorithm with fixed hysteresis values and a handoff algorithm using both threshold and hysteresis [1] in terms of the average number of handoffs, the probability of link degradation, and the average handoff delay.

We found through our simulation that the minimal hysteresis value b has a negligible effect on handoff performance for $b \leq 6$ dB. Without loss of generality, 2 was chosen to be the default value of b in this study. Comparisons of key performance criteria are presented in Table 2 for different settings of a and n. Provided that n is fixed, the probability of link degradation and average handoff delay decrease as a decreases, while the average number of handoffs increases

Table 1. Parameters used for simulations.

Parameters	Description
$D = 2000$ m	Distance between two BSs
$K = 30$	Path loss factor
$\sigma = 5$ dB	Shadow fading standard deviation
$d_c = 30$ m	Correlation distance
$v = 20$ m/s	Mobile velocity
$t_s = 0.5$ s	Sampling time
$\Delta = -105$ dB	Threshold of link degradation

Table 2. Comparisions of key performance criteria.

a (dB)	n	Probability of link degradation	Average number of handoffs	Average handoff delay (m)
20	1/4	0.04297	1.0481	206.36
15	1/4	0.02387	1.1916	119.12
10	1/4	0.01223	1.8209	38.545
20	1/2	0.01945	1.2306	111.34
15	1/2	0.01457	1.4061	75.529
10	1/2	0.01027	1.9264	34.103
20	1	0.00828	1.9049	37.719
15	1	0.00828	1.9058	37.656
10	1	0.00794	2.1061	28.575

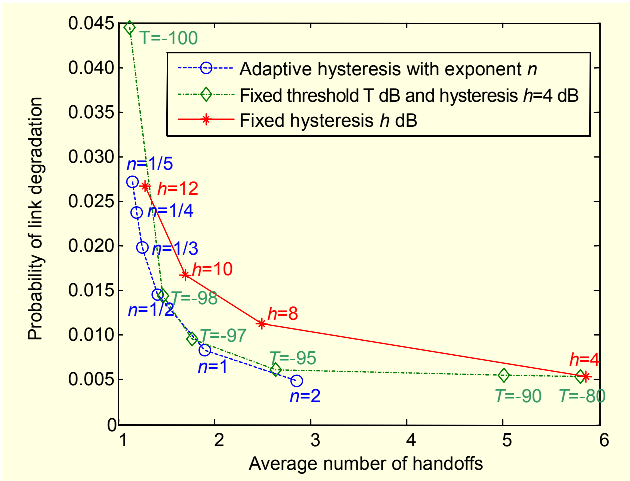

Fig. 2. Probability of link degradation versus average number of handoffs.

with decreasing a. The effect of a becomes weak for large n.

Provided that a is fixed, the probability of link degradation and average handoff delay decrease as the exponent n increases, while the average number of handoffs increases with increasing n. The effect of n becomes weak for small a.

Table 2 provides a set of feasible parameters for system designers to choose according to the QoS requirements. For example, the setting of $a=15$ and $n=1/2$ is selected if the probability of link degradation and the average number of handoffs are assumed to be less than 0.015 and 1.5, respectively.

The tradeoff curves are plotted in Fig. 2 and Fig. 3 for different values of n provided with $a=15$ and $b=2$. Figure 2 shows the tradeoff curves between the probability of link degradation and the average number of handoffs. It is clear that the proposed algorithm achieves a better tradeoff than the other two handoff algorithms. Figure 3 shows the tradeoff curves between the average handoff delay and the average number of

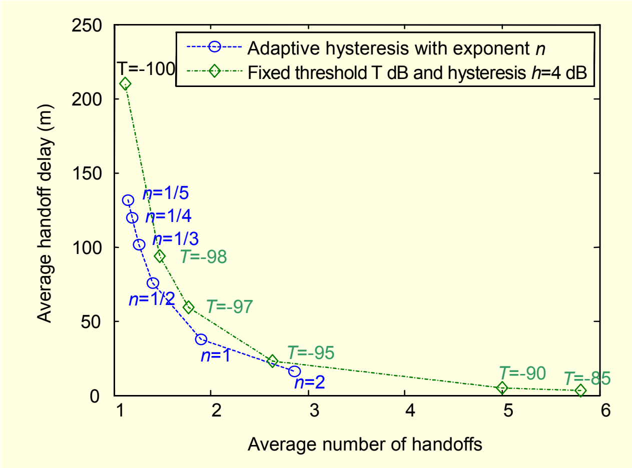

Fig. 3. Average handoff delay versus average number of handoffs.

handoffs. We can conclude that our algorithm performs better than the handoff algorithm using both threshold and hysteresis.

V. Conclusions

An adaptive hard handoff algorithm with dynamic hysteresis value was proposed in this study. To the best of our knowledge, it is the first time that an explicit formula has been proposed to calculate the hysteresis value dynamically based on RSS. We also presented a discrete-time method to evaluate handoff algorithms analytically. Simulation results show that our algorithm performs better than the handoff algorithm with fixed hysteresis values and the handoff algorithm using both threshold and hysteresis. The proposed handoff algorithm can achieve a smaller average number of handoffs and a shorter handoff delay, while lowering the probability of link degradation. Compared with other handoff algorithms, the only overhead of the proposed algorithm is calculating the hysteresis value according to (12), which is extremely simple and does not require lookup tables. Therefore, our algorithm can improve handoff performance effectively at the cost of very marginal overhead.

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