Performance Analysis of a New Decision-Avoided Handover Algorithm for DS-CDMA Indoor Pico-cellular Systems

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Abstract— **Handover control of indoor pico-cellular radio systems becomes unstable due to severe multipath fading in buildings. The previously proposed decision-avoided handover algorithm can greatly improve the robustness of indoor handover control. This paper analyzes soft handover control algorithms for indoor DS-CDMA systems. The soft handover algorithm exhibits the same robustness as the decision-avoided algorithm. Also, the proposed algorithm can increase the utility of pico-cell base stations, because this approach does not use any channels of the base station receiving handoff.**

I. Introduction

Indoor pico-cellular radio systems are used in severe multipath fading environments caused by radio wave reflections inside buildings. The RAKE receiver technique used in macro-cellular systems is of no use because the delay spread is too short in indoor propagation environments. This results in unstable handover control [1].

The previously proposed decision-avoided algorithm [2] exhibited highly enhanced control robustness against severe indoor fading [3][4]. This algorithm avoids a handover decision when the signal strength is small [2][3][4]. This algorithm is not only robust, but only deteriorates the telephone communication quality slightly [3][4].

This paper aims to adapt the decision-avoided algorithm to indoor DS-CDMA pico-cellular systems. First, we analyze the instability of the soft handover algorithm compared to the decision-avoided algorithm.

Second, the performance of soft handover is analyzed using an indoor propagation simulator and compared to conventional and decision-avoided algorithms. The minimum reception level of the indoor simulator was determined by using an experimental $2.4GHz$ DS-CDMA transceiver whose bit error rate is less than 10^{-6}. On the display, the indoor simulator can show the deteriorated service area caused by the cochannel base station receiving handoff. This is a feature of DS-CDMA systems and is not seen in either analog FDMA or digital TDMA systems. The simulation also shows that power control for the cochannel base stations can mitigate the severe cochannel interference.

Through the above mentioned analyses and simulations, this paper shows that it is possible to use the decision-avoided algorithm instead of the soft handover algorithm in indoor DS-CDMA systems.

II. Soft Handover Algorithm

In this paper, we examine the handover problem between two base stations, because the situation when there are more base stations is a simple extension of this case. Using *if-then* rules, the soft handover algorithm can be expressed as follows, where S_0 is the minimum received signal level.

Soft Handover Algorithm

Rule 1: *if* $S_1(r) > S_0$, *then* $, (r) = ,_1$
Rule 2: *if* $S_1(r) < S_0$ and $S_2(r) > S_0$, *then* $, (r) = ,_2$
Rule 3: *if* $S_1(r) < S_s$ and $S_2(r) < S_s$,
then $, (r) = ,_1$ and $,_2$
Rule 4: *if* $, (r) = ,_2$, *then* interchange 1 and 2

In **Rule 3**, the statement that $, (r) = ,_1$ or $,_2$ means that $, (r)$ takes two values and the system can use both base stations 1 and 2. The response of the switching function $, (r)$ for the bi-stable area is shown by the shaded area in Fig. 1(b), because $, (r)$ takes the values $,_1$ and $,_2$. For simplicity, we assume that $, (r) = ,_1$ when $S_1(r) > S_2(r)$ and $, (r) = ,_2$ when $S_2(r) > S_1(r)$. S_s is set so that the service area between b and c is 30% to 50% of the area between a and d.

Let us compare this soft handover algorithm with the conventional handover algorithm described below.

Conventional Two-Level Logic Algorithm

Rule 1: *if* $S_1(r) > S_0$, *then* $, = ,_1$
Rule 2: *if* $S_1(r) < S_s$ and $S_2(r) > S_s$, *then* $, = ,_2$
Rule 3: *if* $, = ,_2$, *then* interchange 1 and 2

The hysteresis response for the conventional bistable algorithm is shown in Fig. 1(c). This hysteresis is introduced to prevent the instability which occurs when the mobile moves along the cell boundary between base stations 1 and 2.

An important problem with bistable conventional algorithm is the response instability due to fading. In Fig. 2(b), there are many small hysteresis loops caused by fading. The two sentences related to S_s in **Rule 2** of the soft handover algorithm inhibits these hysteresis loops in the area when $S_i(r) < S_s$ $(i = 1, 2)$. However, this has the negative effect of using a radio channel of the base station receiving handoff in the shaded area in Fig. 1(b).

Next, we show the previously proposed decision-avoided

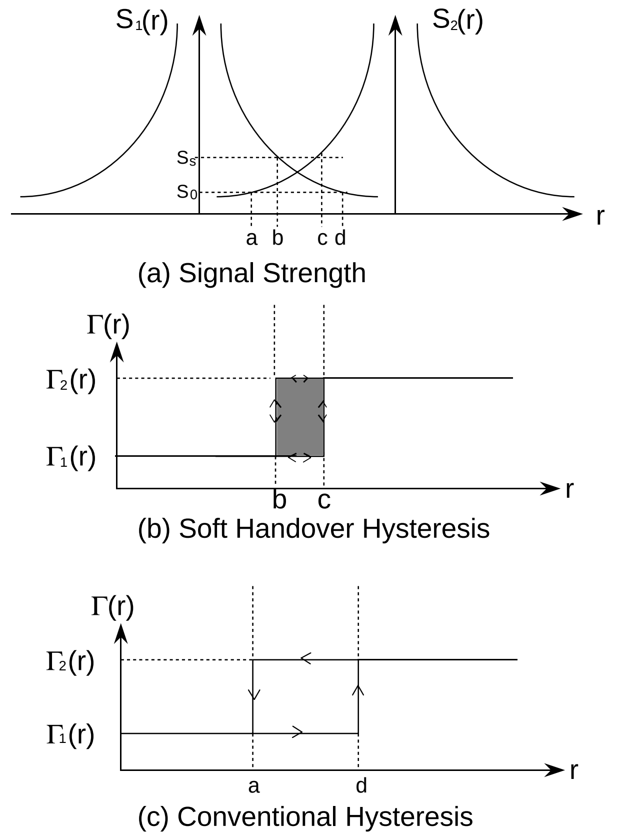

Fig. 1. The hysteresis response of the soft handover algorithm.

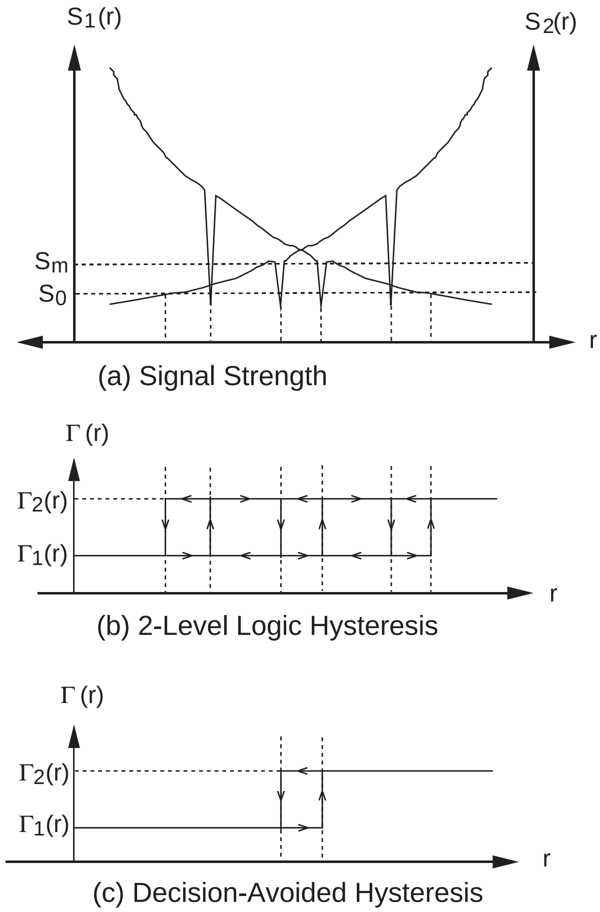

Fig. 2. The hysteresis response of the decision-avoided algorithm.

algorithm [3].

Decision-Avoided Algorithm

Rule 1: *if* $S_1(r) > S_0$, *then* , $(r) =$, $_1$
Rule 2: *if* $S_1(r) < S_0$ and $S_2(r) > S_0$, *then* , $(r) =$, $_2$
Rule 3: *if* $S_2(r) < S_m$, *then* , $(r) =$, $_1$
Rule 4: *if* , $(r) =$, $_2$, *then* interchange 1 and 2

In the above algorithm, **Rule 3** is added to the bi-stable conventional algorithm and inhibits the partial hysteresis responses as shown in Fig. 2(b). On demerit of this algorithm is that there are small areas where telephone communication quality is deteriorated because $S_i(r) < S_0$ and $S_j < S_m$, $(i, j = 1, 2)$. However, this demerit is minor compared to the merit that the radio channel of the base station is not used. This merit is very important for indoor pico-cellular systems.

This paper examines the possible use of the decision-avoided algorithm for indoor DS-CDMA pico-cellular systems when S_m is equal to S_s in the above rules.

III. Propagation Simulation & Channel Use

In order to analyze the state transitions of the switching function , (r), we set up a mobile transceiver to move about inside a concrete building. The plan of the building and position of the base stations are shown in Fig. 3. In previous papers [2][3][4], the received signal strength of the waves in this building were predicted using a propagation simulator using a ray tracing algorithm.

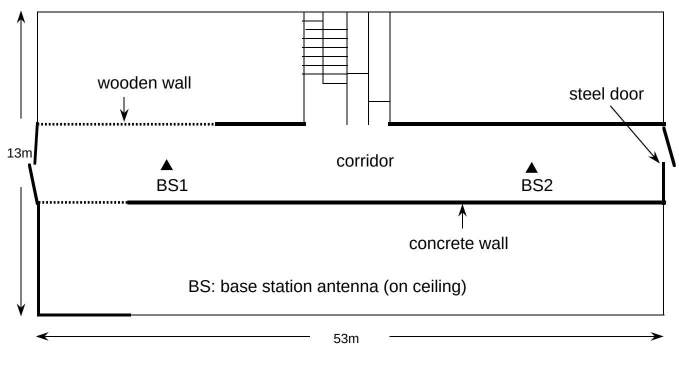

Fig. 3. The layout of the reinforced concrete building used in the experiments.

On the ceiling of the building, two base stations using the $950MHz$ band and with a transmission power of $1mW$ were attached. The mobile transceiver, which is located at a height of $1.65m$, and the base station both use a half-wave dipole vertical antenna. Because the propagation model used in the ray-tracing simulation included secondary reflected waves, the effects of the reflection from the steel doors on both ends of the corridor on the service area were very apparent. The computed signal strength is in good agreement with measured data [3] [4].

The structure of the simulator to analyze the handover control algorithm is shown in Fig. 4. The response of the switching function , (r) to the complex movement pattern of the mobile, represented by the function $P(r, dr/dt)$, is the control output. The handover algorithms used in the analysis are: the soft handover algorithm, the conventional two-level logic algorithm and the decision-avoided algorithm. The parameters used are those that describe the building shown in Fig. 3.

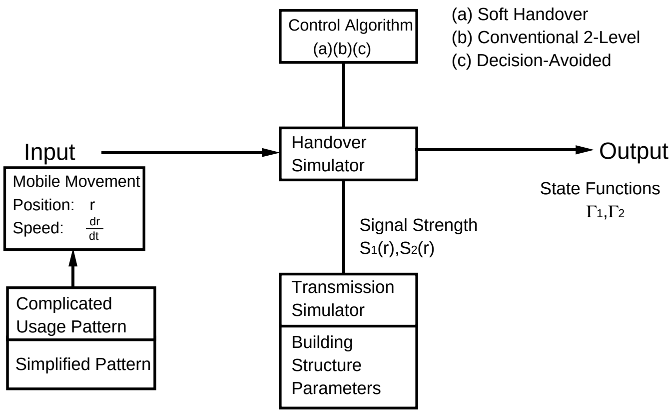

Fig. 4. The structure of the handover control simulator.

IV. DS-CDMA Experimental Setup & Simulation

In order to determine S_0, S_s and S_m, we used a commercial $2.4GHz$ transceiver. The specifications of this transceiver are shown in Table I. The transceiver used three types of M sequences for the PN spreading code and Differential BPSK (DBPSK) for the modulation. The data transmission rate is $256Kbps$, which is 4 times the rate of full rate voice transmission ($64Kbps$).

To measure the error rate performance and handle the experimental handover data, a DOS/V personal computer was attached to each of the three transceivers. The transmitted data was generated by the computers in a random or periodical fashion.

In Fig. 5, the experimental error rate is shown as a function of the D/U ratio. The undesired signal that was used was a DS-CDMA signal of the same carrier frequency modulated by pseudo-random binary data. At a error rate of 10^{-6}, the received signal strength is $-75dBm$ and is good enough for handover experimentation [5].

In Fig. 5, the same carrier frequency was used, but if different carrier frequencies are used, as shown in Table I, an improvement of $30dB$ is obtained. In the analysis of handover in DS-CDMA systems between carriers of different frequencies, the interference can be ignored.

Table I
DS-CDMA Transceiver Specifications

Signal Format	PN Code Spread Spectrum
PN Code Length	31 chips
PN Code Speed	$8Mcps$
Carrier Frequency 1	$2479.0MHz$
Carrier Frequency 2	$2489.0MHz$
Data Modulation	DBPSK
Data Rate	$256Kbps$
Spreading Bandwidth	$\leq 13MHz$
Transmission Power	$10mW/MHz$ $(total = 40mW)$
	$0.1mW/MHz$ $(total = 4mW)$
Decorrelation Method	Digital Sliding Correlator

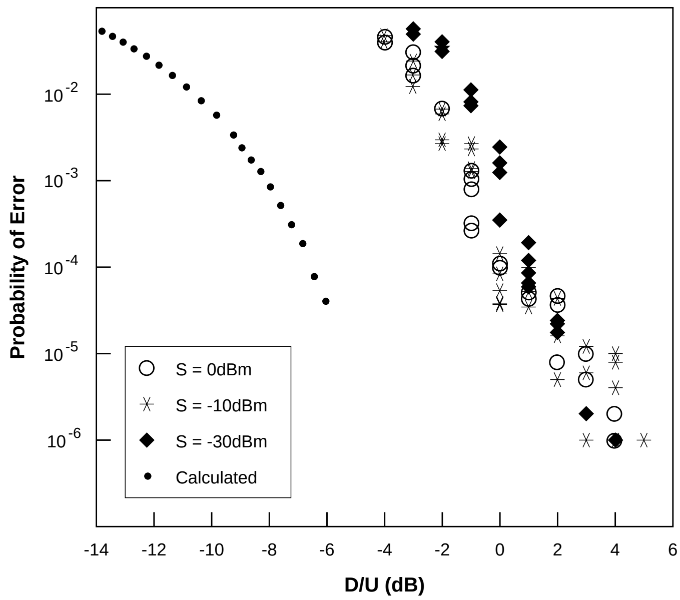

Fig. 5. The error rate of the experimental system.

To check the validity of the experimental error rate, we evaluated the error rate using a PN spreading simulator. For the PN sequence, a 31 chip M sequence, which is the same as the one used in the experiment, was used. The undesired signal was modulated by a pseudo-random pulse sequence. For simplicity, the data for the desired signal used in the simulation and experiment was the sequence 0, 1, 0, 1, $\cdots$. To simplify the simulation, the carrier frequency used was three times the data rate and BPSK modulation was used.

Demodulation of the signal including noise was performed by sampling the product of the received signal and the spreading code and then adding the samples to perform numerical integration. The simulated values are also shown in Fig. 5 as the black circles. Even though the calculation was very rough, the simulated values are only about $3dB$ away from the experimental ones.

V. Power Control/Soft Handover Effectiveness

In order to analyze the handover control performance, the simulator frequency is increased from $950MHz$ to $2.4GHz$. At first, the effectiveness of power control is analyzed for soft handover. In Fig. 6, the regions where communication is not possible, i.e., when $D/U < -5dB$, due to interference from the base station receiving handoff is shown. This is a characteristic of DS-CDMA systems and is a new problem that does not appear in the handover analysis of analog FDMA and digital TDMA systems.

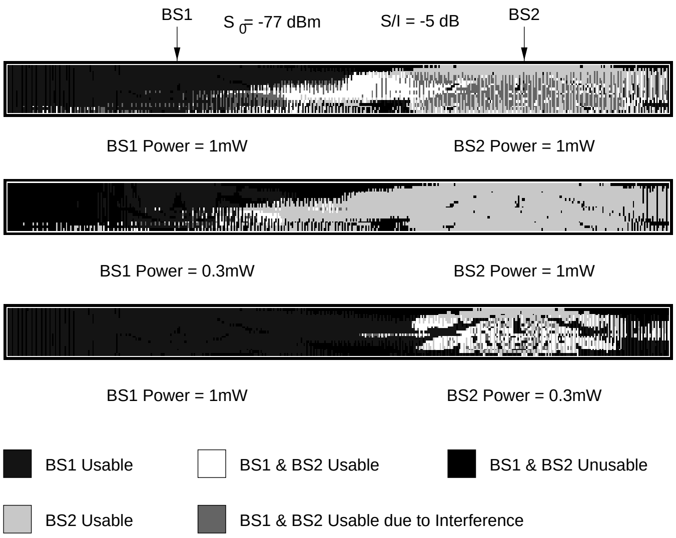

Fig. 6. The regions where the communication quality is degraded due to interference. This shows the effect of power control.

In order to prevent this, power control is carried out in steps for base stations 1 and 2 and the service areas for powers of $0.3mW$ are shown. The areas where interference is present decreases, but the service area of the mobile also decreases. It is not possible to help in cases where mobile 1 is far from base station 1 and mobile 2 is far from base station 2, but in other cases, it is possible to solve the power control problem.

Next, the service area when soft handover control is used is shown in Fig. 7. The value of $S_s = -75dBm$ was set so that the the service area is 15% of the area of the corridor. This value is half the possible service area for both base stations when different carrier frequencies are used. The mobile movement pattern was simplified to be in the width of the corridor with equal probability and move with constant speed down the length of the corridor.

When both base stations are used, a load is added to the base station receiving handoff. By defining the channel use quantitatively, it is possible to analyze the merits and demerits of soft handover. From Fig. 7, we can see that the areas where we cannot use the system due to interference are smaller than in Fig. 6. Compared to this, the areas where the base station receiving handoff is used are not large.

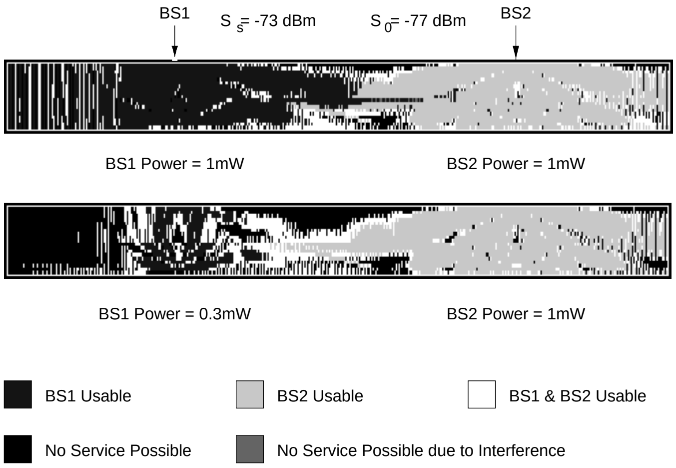

Fig. 7. Comparison of the service areas when soft handover is used in a DS-CDMA system.

Table II
Comparison of Soft, Decision-Avoided and Conventional 2-Level Logic Handover Algorithms

	Ave. No. Handovers	*Phone Quality (%)*	*Channel Use (%)*
Soft ($S_s = -70dBm$)	2.3	10.1	46.5
Decision-avoided ($S_m = -74dBm$)	3.0	12.8	0
Conventional 2-level logic	44.3	10.1	0

Using our experimental setup, we measured the performance of the soft, decision-avoided and conventional 2-level logic handover algorithms. The results are shown for a handset height of $1.65m$, which is a typical value for the height of a human ear, in Table II. The experiment was done by moving the mobile from one end of the corridor to the other. The average number of handovers were counted using measurements taken at an equal spacing of $10cm$ over the $2.9m$ wide corridor.

In order for 10% of the corridor area to be unusable, the value of S_0 was set to $-77dBm$. The values of S_s and S_m were set so that the average number of handovers, a measure of robustness, was approximately the same. To measure phone quality, we use the percentage of the floor area that is unusable, i.e., where the power level of the signal from the base station is less than S_0.

In summary, the soft handover algorithm and the decision-avoided algorithm are compared in Table III.

TABLE III
COMPARISON OF SOFT AND DECISION-AVOIDED HANDOVER ALGORITHMS

	Robustness	*Phone Quality*	*Power Control*	*Channel Use*
Soft	○	○	○	△
Decision-avoided	○	□	○	○

○ : good, □ : fairly good, △ : poor

VI. Conclusions

The performance of the soft handover algorithm for indoor pico-cellular DS-CDMA radio systems has been analyzed and compared with the previously proposed decision-avoided algorithm. The robustness against fading is the same, but the telephone communication quality of soft handover is superior to the decision-avoided algorithm.

Soft handover performance simulations at $2.4GHz$ exhibit that the areas of cochannel interference from the base station receiving handoff are shown on the display and that base station power control can mitigate the interference problems of DS-CDMA. The decision-avoided algorithm is not only effective for power control in DS-CDMA systems, but also has the important merit that the radio channel of the base station receiving handoff is not used.

Further issues are to show numerical data to quantify these comparisons.

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