An Optimal Handover Decision for Throughput Enhancement

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***Abstract*—This letter proposes an optimal handover decision algorithm from the perspective of throughput enhancement. By considering two handover schemes (soft handover and fast cell selection), the proposed algorithm decides a handover only when a throughput gain exists. In order for this decision to be made, a new measurement parameter, *Interference to other-Interferences-plus-Noise Ratio* (IINR), is defined. The proposed IINR-based handover decision demonstrates optimal throughput performance, while the legacy signal to interference-plus-noise ratios (SINR)-based handover decision presents a tradeoff between throughput and feedback overhead.**

***Index Terms*—Handover decision, throughput enhancement, soft handover.**

I. Introduction

HANDOVER provides not only service continuity in the entire network area, but also improved throughput in the cell-edge region. Soft handover (SHO) or macro diversity handover (MDHO) offers a diversity gain to a handover user since both a serving cell and an adjacent target cell transmit the same signal simultaneously [1]. Fast cell selection (FCS) or partial frequency reuse eliminates the major source of interference during the handover period since the target cell does not schedule the radio resources that the handover user is utilizing [2]. Such handover techniques that employ the cooperation of an adjacent cell easily mitigate inter-cell interference (ICI) and thus improve the quality of the signal received by the handover user. Cooperation-based handover schemes can therefore be an effective solution for the enhancement of cell-edge throughput, which is a major issue in fourth generation (4G) standardization [3].

To mitigate ICI, the radio resource of a cooperating cell is required. Because this requirement affects the overall system performance, the execution of handover must be carefully determined. If a mobile station (MS) that does not have enough cooperation gain (i.e., marginal throughput improvement) is selected to execute a handover, this results in the waste of the radio resource of the cooperating cell and eventually degrades the aggregate system throughput. On the contrary, if an MS with enough cooperation gain is not selected, the cell-edge throughput cannot be improved. Therefore, it is important to select an appropriate MS to execute the handover because this decision will influence both the aggregate system throughput and the cell-edge throughput. In this letter, we consider two typical handover schemes (SHO and FCS) and propose an optimal handover decision algorithm with the objective of throughput enhancement.

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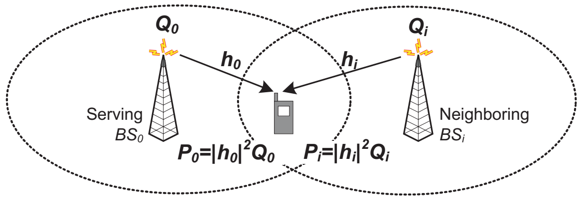

Fig. 1. System model for handover decision.

II. System Model

Fig. 1 shows the system model for the handover decision. There is a serving base station (BS), an arbitrary neighboring BS, and an MS between the two. Let Q and P denote the transmission power of BS and the receiving power of MS, respectively, and let h denote the channel from the BS to the MS. The signal power that the MS receives from the BS_i is given by $P_i = |h_i|^2 Q_i$. Here, the index i indicates the cell number, and the number zero specifically stands for the serving cell.

The signal to interference-plus-noise ratios (SINRs) from the serving BS_0 and the neighboring BS_i, respectively, are given by

$$\text{SINR}_0 = \frac{P_0}{\sum_{\forall k, k \neq 0} P_k + N_0} = \frac{P_0}{P_i + I_i} \quad (1)$$

$$\text{SINR}_i = \frac{P_i}{\sum_{\forall k, k \neq i} P_k + N_0} = \frac{P_i}{P_0 + I_i} \quad (2)$$

where N_0 is the background noise power and I_i is defined as the sum of the noise and the interference from all other BSs except for the serving BS_0 and the neighboring BS_i, that is, $I_i = \sum_{\forall k, k \neq \{0,i\}} P_k + N_0$.

III. Handover Decision Algorithms

A. Legacy Handover Decision

Legacy handover decision algorithms have been designed mainly to guarantee continuity of service because from an operator's point of view, seamless service is the first consideration [4]. A basic principle of such algorithms is to use the difference between the quality of the signal received from the serving BS and from the neighboring BS, so the legacy handover decision algorithm can be simply expressed as[1]

$$\text{SINR}_0 - \text{SINR}_i < \delta \quad (3)$$

where δ is the handover add threshold determined by the system.

[1]The practical handover decision algorithm used in the cellular system is more elaborate for this robust operation, but it still follows the basic algorithm expressed by (3) [5]. Instead of the SINR, the received signal strength (RSS), signal-to-interference ratio (SIR), and bit error rate (BER) can be used and also other criteria such as bandwidth, delay and policy can be considered [6].

For execution of the handover, the MS first designates the neighboring cells that satisfy (3) to become candidate cells for the handover. If the MS reports the identity and the SINR information of candidate cells to its serving BS, then the serving BS finally determines a target cell among the reported candidate cells.

B. Optimal Handover Decision

The optimal strategy for a handover decision to achieve throughput enhancement is to execute a handover if and only if a throughput gain exists, in spite of the cost of the cooperating cell [7]. In the cases of FCS and SHO, the optimal decision criteria can be simply expressed as

$$R_0 < R^i_{FCS} \quad \text{for FCS} \tag{4}$$
$$R_0 < R^i_{SHO} \quad \text{for SHO} \tag{5}$$

where R_0 is the achievable data rate of MS when the handover is not used, and R^i_{FCS} and R^i_{SHO} are the achievable data rate when the FCS and SHO, respectively, are used with the neighboring BS$_i$. By using the Shannon capacity,[2] the optimal decision criteria are re-expressed as

$$log_2(1+\text{SINR}_0) < \frac{1}{2}log_2(1+\text{SINR}^i_{FCS}) \quad \text{for FCS} \tag{6}$$
$$log_2(1+\text{SINR}_0) < \frac{1}{2}log_2(1+\text{SINR}^i_{SHO}) \quad \text{for SHO} \tag{7}$$

where the factor $\frac{1}{2}$ corresponds to the cooperation cost, which arises from the fact that the target cell sacrifices its own radio resource for the handover MS. SINR$^i_{FCS}$ and SINR$^i_{SHO}$ are the effective SINR values when the FCS and SHO, respectively, are used with the neighboring BS$_i$, so they are defined as

$$\text{SINR}^i_{FCS} = \frac{P_0}{\sum_{\forall k, k\neq\{0,i\}} P_k + N_0} = \frac{P_0}{I_i} \tag{8}$$
$$\text{SINR}^i_{SHO} = \frac{P_0+P_i}{\sum_{\forall k, k\neq\{0,i\}} P_k + N_0} = \frac{P_0+P_i}{I_i}. \tag{9}$$

Note that the MS cannot measure the exact values of SINR$^i_{FCS}$ and SINR$^i_{SHO}$ before the execution of each handover scheme [8]. In practice, therefore, it is impossible to use the above optimal decision criteria in the form given.

C. Proposed Handover Decision

Using (6) and (8), we expand the optimal handover decision criterion for the FCS as follows:

$$\begin{aligned} log_2(1+\text{SINR}_0) &< \frac{1}{2}log_2\left(1+\frac{P_0}{I_i}\right) \\ (1+\text{SINR}_0)^2 &< 1+\frac{P_0}{I_i} \\ (1+\text{SINR}_0)^2 &< 1+\frac{(P_i+I_i)\text{SINR}_0}{I_i} \\ \text{SINR}_0^2 + \left(1-\frac{P_i}{I_i}\right)&\text{SINR}_0 < 0 \\ \therefore 0 < \text{SINR}_0 &< \frac{P_i}{I_i} - 1. \end{aligned} \tag{10}$$

[2]The Shannon capacity is the maximum achievable channel capacity and commonly used for purposes of analytical simplicity.

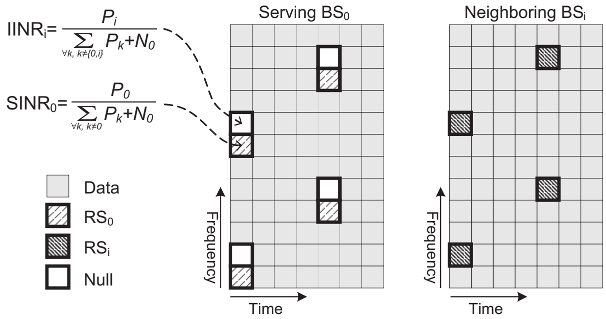

Fig. 2. Measurement of SINR and IINR.

In the same way, from (7) and (9), the optimal decision criterion for the SHO is expanded as

$$\begin{aligned} log_2(1+\text{SINR}_0) &< \frac{1}{2}log_2\left(1+\frac{P_0+P_i}{I_i}\right) \\ (1+\text{SINR}_0)^2 &< 1+\frac{P_0+P_i}{I_i} \\ (1+\text{SINR}_0)^2 &< 1+\frac{(P_i+I_i)\text{SINR}_0+P_i}{I_i} \\ \text{SINR}_0^2 + \left(1-\frac{P_i}{I_i}\right)&\text{SINR}_0 - \frac{P_i}{I_i} < 0 \\ \therefore -1 < \text{SINR}_0 &< \frac{P_i}{I_i}. \end{aligned} \tag{11}$$

Interestingly, these two solutions contain the same term, P_i/I_i. Thus, we define a new parameter called *Interference to other-Interferences-plus-Noise Ratio* (IINR) as

$$\text{IINR}_i := \frac{P_i}{I_i} = \frac{P_i}{\sum_{\forall k, k\neq\{0,i\}} P_k + N_0}. \tag{12}$$

Finally, the proposed handover decision algorithm is represented by

$$\text{SINR}_0 - \text{IINR}_i < -1 \quad \text{for FCS} \tag{13}$$
$$\text{SINR}_0 - \text{IINR}_i < 0 \quad \text{for SHO} \tag{14}$$

where both the SINR and IINR are on a linear scale. As shown, the proposed handover decision algorithm is operated by a simple comparison between the SINR and the IINR. Unlike the legacy handover decision algorithm, the proposed algorithm uses the IINR$_i$ instead of the SINR$_i$ and has a fixed threshold value in each of the FCS and SHO.

IV. Practical Consideration

To make the proposed algorithm feasible, we must consider how to reliably measure the IINR value in a practical system. To this end, we will consider the 3GPP Long Term Evolution (LTE) system. Basically, the LTE provides a cell-specific reference signal (RS) (i.e., pilot) for downlink channel estimation. The RS is transmitted together with the data signal according to a predefined arrangement pattern. Six different RS patterns are available, and the adjacent BSs are coordinated beforehand to employ a different RS pattern each other [7].

Fig. 2 illustrates the method of measurement for SINR and IINR. The MS measures the SINR from its serving BS (i.e., SINR$_0$) based on the serving BS's RS (i.e., RS$_0$). On the other hand, the MS measures the IINR from the neighboring BS$_i$ (i.e., IINR$_i$) based on the neighboring BS$_i$'s RS (i.e.,

TABLE I
SIMULATION SETUP

Parameter	Assumption
Cell layout	Hexagonal 19 cells, 3 sectors per cell
Inter-BS distance	1732 m
Number of MSs per sector	30 (uniform distribution)
Carrier frequency / Bandwidth	2 GHz / 10 MHz
BS transmission power	46 dBm
Distance-dependent path loss	128.1+37.6$log_{10}R$ [dB], R in km
Noise figure	9 dB
Shadowing standard deviation	8 dB
Channel model	Typical urban

RS_i) after making sure that the serving BS does not transmit data signals on the resource elements (REs) corresponding to the RS_i positions. This *nulling* operation enables the MS to measure the IINR_i exactly according to its definition because the signal power from the serving BS has been removed. For measurement of the IINR, it is reasonable that the serving BS only needs to change its RE composition, and that the neighboring BS does not need to know this. It is also possible for the MS to measure the IINR autonomously without a request for nulling if there is no data transmission at the serving BS during the measurement period.

V. RESULTS AND DISCUSSIONS

We performed a system level simulation to validate the proposed handover decision algorithm. In our simulation, we observed the evaluation methodology of 3GPP [9]. Table I summarizes the parameters and assumptions of the simulation. The proposed decision algorithm is compared with the legacy SINR-based decision algorithm and the optimal decision algorithm, under the assumption that the exact values of SINR^i_{FCS} and SINR^i_{SHO} are known.

Fig. 3 shows the cell-edge user throughput when the FCS or SHO is used. Here, the cell-edge user is defined as the MS that has a low SINR, which is less than -1 dB [7]. In both handover schemes, the proposed IINR-based decision algorithm exactly coincides with the optimal decision algorithm. The reason for this is that the proposed algorithm was originally derived from the optimal decision criteria. The throughput of the SINR-based decision improves as the handover threshold increases because the larger threshold value offers more candidate cells for the final decision. However, its throughput does not achieve an optimal performance.

Fig. 4 shows the cell-edge user throughput and the number of feedbacks according to the handover threshold value. The number of feedbacks is defined as the number of neighboring cells that satisfy each handover decision algorithm, which eventually leads to the uplink feedback overhead. The SINR-based decision offers a tradeoff between the performance of throughput and the amount of feedback according to the handover threshold. The proposed IINR-based decision, however, is irrelevant to the handover threshold and demonstrates optimal throughput performance and very low feedback overhead.

VI. CONCLUSIONS

We have found a new handover decision parameter, IINR. In the FCS and SHO, the proposed IINR-based decision is optimal from the perspective of throughput enhancement. From a practical perspective, the proposed algorithm is simple to apply and is compatible with LTE standards.

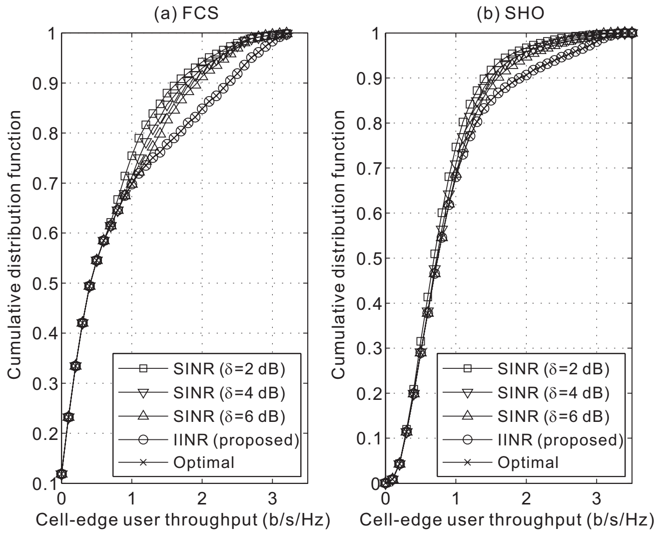

Fig. 3. Cumulative distribution function of cell-edge user throughput: (a) FCS and (b) SHO.

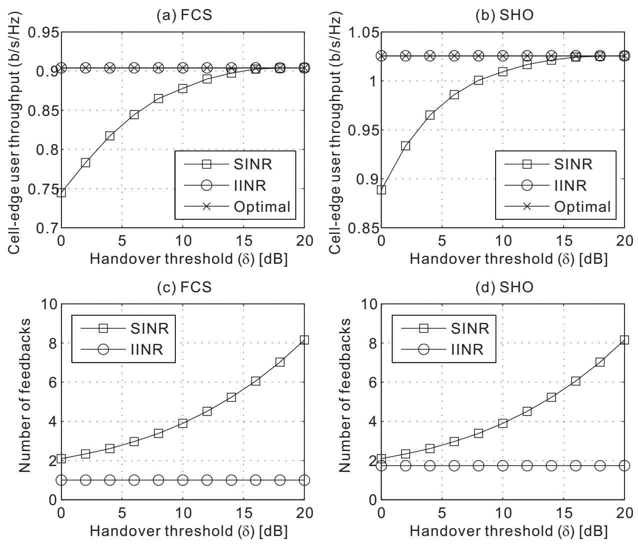

Fig. 4. Cell-edge user throughput and number of feedbacks vs. handover threshold: (a, c) FCS and (b, d) SHO.

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