Effective SNR Based Handoff Scheme in Heterogeneous Cellular Environments

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Abstract—In cellular systems, a handoff process is defined to transfer an active call of an MS from one cell to another in order to provide a seamless service to this MS. Generally, a handoff decision is made based on received signal strength (RSS) values from the current base station (BS) and neighboring BSs. In the traditional mobile communication systems, measured RSS directly indicates the quality of the communication link because the same transmission/reception technologies are utilized for all devices. However, emerging cellular systems are defined to utilize various transmission/reception technologies, e.g., Multiple-Input Multiple-Output (MIMO), and different BSs and MSs might be capable of different technologies. Because RSSs do not indicate the quality of the link directly in such cases, we here propose to use a new metric, called effective SNR, for handoff decision and show that the proposed scheme significantly improves the system performance when heterogeneous types of devices co-exist in the network.

Index Terms—Handoff, MIMO, Effective SNR, Heterogeneous Environments

I. INTRODUCTION

In cellular systems, mobile stations (MSs) cross several cells during on-going communications. In order to provide a seamless service to these MSs, a handoff process is defined to transfer an active call from one cell to another. Out of a handoff process, the handoff decision scheme which decides when to initiate a handoff is very important for the system performance. Generally, a handoff decision is made based on received signal strength (RSS) values from the current base station (BS) and neighboring BSs. Based on the measured RSS values, the BS with the strongest RSS is chosen as the target cell of a handoff [1]. Hysteresis-based algorithms have been also proposed to reduce the handoff overhead by decreasing unnecessary handoffs induced by signal fluctuations. In the hysteresis-based algorithms, a handoff is initiated when a neighboring BS’s RSS exceeds the serving BS’s RSS by a hysteresis value. As argued in [2], the handoff decision problem is sometimes formulated as an optimization to obtain the best trade-off between the expected rate of handoffs and the link quality by adjusting the hysteresis value. Some algorithms have been proposed to make use of the location information for handoff decision [3] as well as the measured RSS. However, most commercial devices trigger a handoff based on the measured RSS because additional equipments such as Global Positioning System (GPS) are necessarily required to get such location information.

In the traditional mobile communication systems, measured RSS directly indicates the quality of the communication link because the same transmission/reception technologies are utilized for all devices. However, emerging cellular systems are defined to utilize various transmission/reception technologies, e.g., Multiple-Input Multiple-Output (MIMO), and different BSs and MSs might be capable of different technologies. Because RSSs do not indicate the quality of the link directly in such cases, a handoff decision merely based on RSS is not very efficient.

Therefore, we in this paper propose to use a new metric, called effective SNR for handoff decision. Because the effective SNR metric reflects the devices’ capabilities, it can provide more accurate measure for the cell coverage. Furthermore, we can easily apply the techniques which have been utilized in RSS-based handoff schemes such as hysteresis based handoff decision algorithms after adjusting the parameters. We show that the proposed scheme significantly improves the system performance when heterogeneous types of devices co-exist in the network.

The rest of the paper is organized as follows. In Section II, we introduce our motivation of developing a new handoff metric in the heterogeneous environment. Based on the motivation, we propose the effective SNR based handoff scheme in Section III, and the performance of the proposed scheme is evaluated in Section IV. In Section V, a hysteresis concept is applied to the effective SNR based handoff by adjusting the parameter appropriately, and finally, we conclude this paper in Section VI.

II. HETEROGENEOUS ENVIRONMENTS

Recently-deployed cellular technologies, e.g., IEEE 802.16e [4] and 3GPP LTE [5], have defined various transmission/reception schemes based on the multiple antenna technology. However, some devices cannot utilize all the transmission technologies defined in the standard due to their capabilities, e.g., a limited number of antennas. Because it is difficult to upgrade all the existing devices simultaneously, the existence of such heterogeneous devices is expected to be common in the emerging systems. Furthermore, femto-cell networks, composed of small BSs bought and installed by customers for indoor communication, are emerging [6]. Femto-cell BS’s capability would depend on the price, and its capability is generally limited compared with macro BS’s.
Accordingly, heterogeneous environments can appear in many cases.

In a heterogeneous environment, BS-MS pairs can use different transmission schemes so that RSS itself cannot properly represent the cell coverage. It is conceptually described in Fig. 1. In the figure, BS 1 has a single antenna, e.g., femto-cell BS, so that the coverage based on effective SNR is not very different from one estimated by RSS. However, if we assume that BS 2 with two antennas can utilize $2 \times 1$ transmit beamforming scheme, the effective coverage of BS 2 should be larger than the estimated coverage merely based on RSS. Therefore, the handoff spot should be shifted according to the effective coverage while a RSS based handoff cannot reflect it.

**III. EFFECTIVE SNR BASED HANDOFF**

As explained in the previous section, a handoff decision based on RSS might provide inaccurate estimation for the effective cell coverage due to heterogeneous capabilities of BSs and MSs. In order to solve this problem, we propose to use effective SNR as a metric for handoff decision. Based on the measured channel status, an MS can estimate the effective SNR of each transmission scheme which is directly related to the effective link performance. Effective SNR calculations for some specific transmission/reception schemes are found in [7].

In this paper, the number of transmit and receive antennas are equal to or less than 2, and we assume that the space-time block code (STBC) is used for $2 \times 2$ MIMO transmissions and the optimal transmit/receive beamforming schemes are used for the other antennas settings. Then, the effective SNR values for STBC and optimal beamforming schemes are given as (1) and (2), respectively, as shown in [8].

$$\gamma_{\text{STBC}} = \frac{\|H\|_F^2}{2},$$

$$\gamma_{\text{BF}} = \|H\|_F^2 \bar{\gamma},$$

1) BS periodically informs its capabilities, e.g., number of antennas and preferable transmission schemes, directly to MSs or neighboring BSs.
2) MS acquires the BSs’ information and measures the channel status from the candidate BSs.
3) MS calculates the effective SNR of each candidate BS based on the its capability and measured channel status.
4) If the best effective SNR out of the neighboring cells exceeds the effective SNR of the serving cell by a predefined hysteresis value, a handoff is triggered.

By associating with the BS which provides the best effective SNR, data transmission efficiency is improved and loads are distributed more properly.

Handoff measurement protocol before a handoff decision should be updated to support the proposed scheme. In the current cellular networks, RSS measurements before a handoff are typically performed on reference signals which are not necessarily transmitted from the same set of antenna elements used for the data transmissions. For example, a preamble signal for RSS measurement can be transmitted from a single antenna in the current cellular systems while MSs should measure the channel status from all the antenna elements which will be used for the data transmissions. We introduce a simple protocol to estimate the effective SNR. A BS transmits the preamble signal through different antennas in each frame, and the antenna index is notified to MSs through specific messages. It is common that MSs can directly read some messages from the neighboring cells during a handoff measurement. If it is impossible, the serving BS can deliver the information to the MSs on behalf of neighboring BSs. The new protocols improve the implementation complexity, but the improved performance can compensate it.

Our proposed scheme looks simple and straightforward, but it is not true because using the handoff metric taking into account the effective data rates is not always excellent due to the implementation complexity. In the environments where all the devices have the same capabilities, handoff spots are not changed much even though the new handoff metric is used, and thus we cannot expect large performance improvement. That is why the handoff decisions have been conducted based on RSS measurements in general. On the other hand, we have focused on the heterogeneous environment and it is shown that the proposed scheme is particularly worthy there. Performance enhancement for heterogeneous environment is an important topic today because the heterogeneous environment is becoming common. Furthermore, we have also discussed some issues which should be considered to utilize the proposed scheme in the practical system. For example, new protocols for quality measurement protocols before a handoff decision have been presented. In Section V, the hysteresis parameter is carefully adjusted to apply the hysteresis concept in the effective SNR based handoff scheme.

**IV. PERFORMANCE EVALUATION**

In this section, we evaluate the performance of the proposed handoff scheme using simulations. We assume that 19 cells
with the radius of 600 m form a 2-tier wrap-around cellular structure as shown in Fig. 2. The fixed transmit power of each BS and the noise power are assumed 46 dBm and −95 dBm, respectively. We use the outdoor pathloss model in the ITU-R M.1225 [9], and assume that the fast fading of each link follows the independent Rayleigh distribution. From [9], pathloss is modeled as $PL = 40 \log_{10} \left( \frac{d}{1000} \right) + 30 \log_{10} (f) + 49$ (in dB), where $d$ is the distance (in meters) and $f$ is the center frequency of the system (in MHz) which is fixed at 2300 MHz in this paper. MSs choose their moving directions randomly while their moving speed is fixed at 30 m/s. During the simulation time, calls dynamically arrive according to the Poisson process with a predefined arrival rate. The life time of each call is determined by the exponential random distribution with the service rate of 0.01 (1/sec).

We assume that a call has a fixed downlink bandwidth requirement. A target BS of a call accepts the newly arrived or handoff call if the BS can instantaneously meets the bandwidth requirement, but blocks or drops the calls if the remaining resources of the cell is not enough to provide the required bandwidth. Each BS or MS has a single or two transmit/receive antennas with the probability of 0.5. According to the antenna setting of a BS-MS pair, an optimal beamforming scheme is chosen and utilized. Note that a handoff scheme only determines the cell selection. Though the RSS based handoff is utilized, an optimal MIMO beamforming technology can be utilized according to the antenna settings. The hysteresis value is set to zero in the simulations of this section, i.e., a handoff is triggered whenever the neighboring cell’s effective SNR is better than the serving cell’s one. The impact of the hysteresis value on the system performance is discussed in Section V.

Two important metrics for evaluating a handoff technology are call dropping and call blocking rates. The call blocking rate is the probability that an active call is terminated due to the lack of resources during a handoff and the call blocking rate is the probability that a new call request is denied due to the lack of resources. In Fig. 3(a), the call dropping rate and the call blocking rate of the proposed scheme are compared with those of the RSS based handoff scheme for various arrival rates. We observe that the proposed scheme significantly reduces the call dropping and blocking rates in the whole region. Furthermore, in Fig 3(b), it is shown that the call failure rate performance, which is defined as the total probability that an MS experiences a call failure before its departure, is also reduced significantly.

The proposed scheme enhances the system performance by reducing and balancing the loads in the wireless links properly. If we define the load as the amount of utilized resource in the wireless links, the proposed scheme reduces the total system load by assigning better BSs which provides the higher data transmission rates to some MSs. Furthermore, the proposed scheme distributes the system loads more evenly than the RSS based handoff scheme, because more MSs are assigned to the BS with better capability which can deal with more traffic in general.
V. ADJUSTMENT OF THE HYSTERESIS VALUE

Extensive study has been done for the handoff algorithms based on RSS with hysteresis. In the hysteresis-based algorithms, a handoff is initiated when a neighboring BS's RSS exceeds the serving BS's RSS by a hysteresis value. The larger the hysteresis value, the smaller the number of handoffs, but the larger the probability that MSs suffer from poor signal quality. Because both the frequent handoffs and signal quality degradation influence the system performance, the hysteresis value should be carefully determined. The hysteresis value has been optimized by simulations [10] and a numerical analysis [2] in the literature to obtain a good tradeoff between the number of handoffs and the instantaneous signal quality.

We extend the hysteresis concept of the RSS based handoff scheme to the effective SNR based handoff because the handoff metrics are similar. However, we need to carefully adjust the hysteresis value. Applying the same hysteresis value used in RSS based handoffs to the effective SNR based scheme does not provide a good performance because the characteristics of the two metrics, i.e., RSS and effective SNR, are different.

We consider a simplified system model and scenario in order to analyze the tradeoff between the number of handoffs and the signal quality according to the hysteresis values. A network consists of two BSs A and B separated by 1200 m, and an MS performs handoffs while it moves from A to B along a straight line with constant velocity of 20 m/s. Furthermore, we assume that the MS conducts a handoff decision in every 500 ms. Two metrics, i.e., the average number of handoffs and outage rate, are measured during simulations where the outage rate is defined as the probability that the received effective SNR is below threshold, i.e., $-3$ dB, during the simulation time. The settings for the number of antennas is represented by $K = (k_A, k_B, k_{MS})$, where $k_A$, $k_B$, and $k_{MS}$ are the numbers of antennas in BS A, BS B, the MS, respectively. Note that the RSS based handoff always assumes that all the devices have a single antenna, i.e., $(1,1,1)$, regardless of the actual antenna settings.

Fig. 4 illustrates the average number of handoffs and the outage rate with the various hysteresis values on the effective SNR. The larger hysteresis value, the smaller number of handoffs, but the larger outage rate. In case of $(1,1,1)$, the hysteresis value seems dominantly affecting the average number of handoffs while the outage rate is relatively robust to the range of the hysteresis value. On the other hand, in case of $(2,2,2)$, the hysteresis value seems dominantly affecting the outage rate. Therefore, we intuitively expect that the optimal hysteresis value is different according to the antenna setting and the small hysteresis values are preferred by the devices which have many antennas.

We define a cost function as the following to find the optimal hysteresis value $h$ for the various antenna numbers qualitatively:

$$U(h) = cE[N_H(h)] + E[N_O(h)],$$

where $E[N_H]$ and $E[N_O]$ are the average numbers of handoffs and outages, respectively. Here, $c$ is a tradeoff parameter which can be interpreted as the relative cost of a handoff versus an outage. This type of cost function has been widely used in the literature [2].

The optimal hysteresis values are found in the simulation results when $c$ is fixed at 0.05. The optimal hysteresis values and the corresponding costs are given in Table I. As expected, the optimal hysteresis values are different according to antenna settings, and the cost function is minimized with the smaller hysteresis value when the multiple antennas are equipped.
Therefore, we need to adapt the hysteresis values according to the antenna settings. The fourth column in Table I shows the costs when $h^*_\text{rss}$, which is optimal only for the RSS based handoffs in the single antenna networks, is applied. In the results, we observe that the performance is severely degraded by directly reusing the optimal hysteresis obtained in the RSS based handoffs. Careful considerations are required when we apply the existing schemes used in RSS based handoff schemes to the effective SNR based handoff schemes.

VI. Conclusion

A handoff is generally triggered based on RSS values independently of the data transmission schemes. In this paper, we propose to use the effective SNR metric to trigger a handoff. In the simulations, it is shown that the proposed scheme efficiently improves the system performance, i.e., call blocking rate, call dropping rate, and call failure rate, when the devices in the cellular system have heterogeneous capabilities. We also show that the hysteresis value should be carefully chosen in the effective SNR based handoff schemes to obtain a good tradeoff between the average number of handoffs and signal quality.

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References