Seamless Spectrum Handover Considering Differential Path-loss in Cognitive Radio Systems

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Abstract—In cognitive radio systems, spectrum handover occurs when a secondary user changes frequency due to the appearance of a primary user. Spectrum handover may result in degraded system performance because of the different propagation loss of the different frequency. In this case, data transmission is disrupted and it is more difficult to provide seamless service. Here, we propose a seamless handover scheme based on the prediction of cell coverage. The proposed handover scheme can avoid service disruption and can reduce redundant handovers. The efficiency of the scheme is validated by simulation results.

Index Terms—Cognitive radio, spectrum handover, QoS, cell outage.

I. INTRODUCTION

C OGNITIVE radio [1][2] promises to satisfy the increasing demand of wireless communication. In cognitive radio systems, spectrum handover is essential for opportunistic spectrum access. However, spectrum handover may affect the quality of service (QoS) of secondary users significantly and adversely. This is because changing frequency not only imposes a burden on the system due to signaling overhead, but may also even cause cell outage due to the difference in path loss. Therefore, it is very important that cognitive radio systems provide link maintenance for secondary users [5].

Usually, the available spectrum pool of a cognitive radio system is very wide. However, as is generally known, high frequencies suffer from large path loss. By contrast, in the case of low frequencies, path loss is relatively small. Thus, the propagation characteristic should be taken into account for the transmission of data in a cognitive radio system. Propagation has not been considered in conventional communication systems, in which only the licensed frequency band is operative. However, the effect of frequency on path loss in cognitive radio systems is great. QoS can degrade significantly due to a change of frequency. We here state the critical problem in cognitive radio systems and propose an efficient scheme to overcome it.

II. SYSTEM MODEL

We here consider a multicell cognitive radio system, in which each base station (BS) can use a different frequency based on spectrum sensing to minimize the interference. In this case, there is a concern that QoS will be severely affected due to cell outage when the frequency of a BS is changed. If the frequency of a BS is changed to a higher frequency due to spectrum handover, the cell coverage is reduced due to increased path loss. We consider Wi-Fi 2.0, as proposed by Google, as a multicell cognitive radio system to reflect the problems that exist in real environments. Wi-Fi 2.0 may use frequencies of UHF TV band from 54 MHz to 698 MHz. Then, each channel has 6 MHz bandwidth. In Fig. 1, we can easily see the effect of frequency on path loss by applying the Okumura-Hata model for path loss [3] [4], one of the most popular models.

As shown in Fig. 1, cell coverage will be drastically reduced at high frequencies because of poor propagation. We assume that the area of cell coverage is defined as the region in which the signal-to-noise ratio (SINR) is greater than 0dB. This is not an explicit definition of cell coverage, but it will serve to show the effect of changing frequency on cell coverage. Fig. 1 shows that spectrum handover may cause cell outage, which generates significant problems, such as service disruption and redundant intercell handovers. In the case of the conventional spectrum handover scheme, variation of cell coverage according to frequency is not taken into account. Even in the IEEE 802.22 system [6], which is the only standardized cognitive radio system, cell outage is not considered because IEEE 802.22 is based on a single-cell structure.

In the conventional spectrum handover that is presented in Fig. 2, it is possible for the serving BS to choose a higher frequency than the original frequency that was used by the serving BS. In this case, the coverage of the new frequency is reduced. Then, the service of terminals that are located out of the coverage of the new frequency will be disrupted. These disrupted terminals must re-enter additional intercell handovers to maintain a connection. In the worst case, the terminals must re-enter the network anew due to connection loss.

III. SEAMLESS HANDOVER SCHEME

Using the estimation of cell outage as a basis, we propose a seamless spectrum handover scheme that can reduce not only the probability that cell outage will occur, but also
Fig. 2. Operation of conventional spectrum handover.

the number of handovers. The proposed spectrum handover procedure can be divided into two cases: spectrum handover from a low frequency to a high frequency (Low to High case), and spectrum handover from a high frequency to a low frequency (High to Low case). In the Low to High case, coverage would be reduced, while in the High to Low case, it would be expanded. Therefore, it is more difficult to guarantee QoS in the Low to High case, because it is possible that cell outage will occur. To overcome this difficulty, we propose a novel spectrum handover scheme to avoid cell outage in the Low to High case. Moreover, for the High to Low case, we propose another efficient scheme to avoid redundant intercell handovers.

The main contribution of the proposed spectrum handover scheme is to consider the difference in propagation at each frequency. Using the proposed scheme, an intercell handover can be enforced before changing the frequency. This is to avoid cell outage generated by a reduction in coverage. In addition, the suspension of the intercell handover of a terminal at the edge of a cell can be enforced if coverage is expanded. We here define two conditions related to intercell handover: the enforcing condition of intercell handover and the stopping condition of intercell handover.

<Enforcing condition of intercell handover:>

\[ \{ \gamma(f') < \delta_{1h1} \} \cap \{ i, s.t. \gamma(f_i) > \delta_{1h2} \} \] (1)

<Stopping condition of intercell handover:>

\[ \{ \gamma(f) < \delta_{1h1} \} \cap \{ \gamma(f') > \delta_{1h2} \} \] (2)

where \( f \) is the original frequency of the serving BS, \( f' \) is the new frequency of the serving BS, \( f_i \) is the frequency of a neighbor BS indexed by \( i \), \( \delta_{1h1} \) is the threshold for triggering intercell handover, \( \delta_{1h2} \) is the threshold for determining intercell handover, and \( \gamma \) is defined as the SINR received for each frequency.

A. Low to High case

If the enforcing condition of intercell handover given in equation (1) is satisfied in the Low to High case, the detailed procedure shown in Fig. 3 is carried out.

B. High to Low case

If the stopping condition of inter-cell handover given in equation (2) is satisfied in the High to Low case, the detailed procedure presented in Fig. 4 is carried out. In the proposed scheme, some terminals that satisfy the enforcing condition of intercell handover do not immediately change to a new frequency, even if a primary user is detected. Instead, they carry out an enforced intercell handover procedure. This is because cell outage is predicted due to the reduction in coverage. Unfortunately, the cell outage generates another intercell handover to maintain the connection. Therefore, by using the proposed scheme, service disruption generated from cell outage can be avoided. In addition, the total number of handovers can be reduced by avoiding redundant intercell handovers. Here, the total number of handovers is defined as the sum of the number of intercell handovers and the number of spectrum handovers.
IV. PERFORMANCE EVALUATION

For the performance evaluation, the system environment was based on Wi-Fi 2.0 to reflect real environment. The available frequency spectrum was ranged from 54 MHz to 698 MHz, the bandwidth of each channel was 6 MHz, transmission power was 100 mW, the Okumura-Hata model was used to estimate path loss, the number of neighbor BSs was assumed to be six, and the number of users in a cell was assumed to be 10. During spectrum handover, the new frequency was assumed to be selected at random from the available frequency spectrum interval. In addition, terminals were assumed to be located randomly in a cell. We evaluated the performance of the proposed spectrum scheme with respect to the outage probability and the total number of handovers.

Outage is deemed to occur when a terminal is out of coverage when the new frequency is used. It occurs because of a reduction in coverage in the Low to High case. In the proposed scheme, the terminals that satisfy the enforcing condition of intercell handover can avoid outage even if they are located out of coverage when the new frequency is used. This is because the terminals are forced to conduct inter-cell handover to a neighbor BS before the frequency changes. The probability of outage can be expressed as follows:

\[ P_{out}^{conv} = P\{\gamma(f') < \delta_{th1}\} \quad (3) \]
\[ P_{out}^{prop} = P\{\gamma(f') > \max_i \gamma(f_i) \cap \delta(f') < \delta_{th1}\} \quad (4) \]

where \( P_{out}^{conv} \) is the outage probability of the conventional scheme, and \( P_{out}^{prop} \) is the outage probability of the proposed scheme.

Here, we assumed that the two intercell handover parameters, \( \delta_{th1} \) and \( \delta_{th2} \), were equal to 0 dB for the simulation. Fig. 5 shows the improvement of the proposed scheme with respect to outage probability.

It can be seen from Fig. 5 that the outage probability is reduced drastically under the proposed scheme. The original frequency of the serving BS means the frequency that the serving BS was using before a primary user was detected. We can see that the outage probability decreases because the Low to High transition probability decreases as the original frequency of the serving BS increases. This is because the probability that the coverage is expanded is high when the original frequency of the serving BS is relatively high.

Total number of handovers \( N_{tot} \) is defined as follows.

\[ N_{tot} = N_s + N_i \quad (5) \]

Here, \( N_s \) is the number of spectrum handovers and \( N_i \) is the number of intercell handovers. When we assume that each cell contains \( k \) users, the total number of expected handovers can be calculated by using the outage probability of equation (3) and equation (4) as follows:

\[ E[N_{tot}^{prop}] = (1 - P_{out}^{prop}) \ast k + (P_{out}^{conv} - P_{out}^{prop}) \ast k \quad (6) \]
\[ E[N_{tot}^{conv}] = (1 - P_{out}^{conv}) \ast k \quad (7) \]

where \( E[N_{tot}^{conv}] \) is the total number of expected handovers in the conventional scheme, and \( E[N_{tot}^{prop}] \) is the total number of expected handovers in the proposed scheme.

In the conventional scheme, \( (1 - P_{out}^{prop}) \ast k \) spectrum handovers and additional \( (P_{out}^{conv} - P_{out}^{prop}) \ast k \) intercell handovers occur. However, in the proposed scheme, the total number of handovers is reduced to \( (1 - P_{out}^{prop}) \ast k \) by removing redundant handovers. Fig. 6 shows the improvement of the proposed scheme with respect to the total number of handovers.

As shown in Fig. 6, the total number of handovers is reduced by up to 30%. We can see that the total number of handovers increases as the original frequency of the serving BS increases. This occurs because the probability that cell outage will occur is reduced in the Low to High case. Therefore, the number of terminals that experience cell outage decreases.

V. CONCLUSIONS

We have investigated a critical problem in multicell cognitive radio systems. To overcome the problem, we proposed a seamless handover scheme that considers the likelihood that outage will occur. The proposed scheme reduced the outage probability and the total number of handovers. Hence, it can provide seamless service in cognitive radio systems.

REFERENCES