Performance of Frequency Resource Assignment Schemes for Cognitive Radio Based Cooperative Communication Systems

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Abstract—Cognitive radio (CR) allows unauthorized users to access authorized band without interfering the authorized user, thereby improving the bandwidth efficiency. In addition, cooperative communications with relay stations (RSs) can be used to improve throughput performance of 4G downlink network. In this study a cognitive radio assisted cooperation (CRAC), which combines advantages of CR and cooperative communications with RSs, is considered for resources allocation in the downlink orthogonal frequency division multiple access (OFDMA) networks. Two adaptive resource allocation algorithms are presented and experimental results demonstrate that the proposed algorithms can not only enhance throughput, but also improve fairness and utility of users assuming available channels are known by base station.

Keywords: OFDMA; cooperative communications; cognitive radio; throughput; fairness; utility.

I. INTRODUCTION

Orthogonal frequency division multiple access (OFDMA) combines the orthogonal frequency division multiplexing (OFDM) and frequency division multiple access (FDMA) technology, for multiple access of multiple users with high data rate. The OFDMA not only upgrades spectrum efficiency but also provides high resistance for frequency-selective fading channels [1].

Cognitive radio (CR) for upgrading spectrum efficiency of an emerging technology can resolve currently problems of spectrum congestion on authorized spectrum. In authorized mechanism, the primary users (PU) are the authorized user. When PU is in idle state, the authorized band can temporarily be promised to other users who were not authorized users by CR schemes [2].

In wireless communications, how to enhance the bandwidth efficiency is an important research topic. In addition, due to the different mobility of users, the system available transmission capacity may fall, leading to inequitable bandwidth allocation [2-4]. Therefore, in this paper, we based on cooperative communications in OFDMA systems to improve transmission efficiency, and fairness and utility with relay stations and cognitive radio.

II. CR BASED COOPERATIVE COMMUNICATION SYSTEMS

2.1 Transmission models

The Base Station (BS) can directionally transmit to cellular users (CUs) via the allocated channel $c_D$, not via any relay station. The throughput of directional transmission can be expressed by

$$\hat{\lambda}(k,c_p,P_{cl,i}) = \log_2 \left( 1 + \frac{P_{cl,i}}{N_0} \frac{P_{cl,i}}{\bar{W}} \right), \quad (1)$$

where $c_p$ is the allocated channel by BS, $P_{cl,i}$ is received power at the $i$th CU; $h_{k,c_p}$ is the channel response of $c_p$ for the $i$th CU; $N_0$ is the power spectral density of the added white Gaussian noise (AWGN), $\bar{W}$ is the channel bandwidth; $F$ is ratio of real transmission rate to Shannon capacity which is assumed to be one.

The RS and BS share channel $C$, the allocated channel by BS, and transmit the data based on two-time-slot transmission, as shown in Fig. 1. To avoid collision, BS transmits data to RS in Time-slot 1. Then, RS transmits data to CU in Time-slot 2. The transmission rate can be obtained by
is ratio of real transmission rate to

where \( c_k \) is the allocated channel by BS, \( P_{c_k} \) is received power at the \( k \)th RS from BS. \( h_{k,c_k} \) is the channel response of \( c_k \) for BS to the \( k \)th RS; \( h_{r,k,c_k} \) is the channel response of \( c_k \) for to the \( k \)th RS to the \( r \)th CU; \( N_0 \) is the power spectral density of the added white Gaussian noise (AWGN), \( W \) is the channel bandwidth; \( \Gamma \) is ratio of real transmission rate to Shannon capacity which is assumed to be one.

When the RS transmission channel can use the cognitive radio (CR) channel \( C_r \) and the BS uses its allocated channel \( C_c \) it is full-duplex model as shown in Fig. 2. Then the throughput can be expressed by

\[
\lambda_k(k, c_k, P_{c_k}^{rs}, P_{c_k}^{bs}, r, P_{c_k}^{rs}) = \min \left\{ \frac{2P_{c_k}}{\Gamma N_0 W}, \frac{2P_{c_k}}{\Gamma N_0 W} + \frac{2P_{c_k}}{\Gamma N_0 W} \right\}, \quad (2)
\]

where \( c_k \) is CR channel as \( C_r \) shown in Fig. 2; \( P_{c_k}^{rs} \) is the received power at the 4th UE from the 4th relay via channel \( c_r \); \( h_{r,k,c_k} \) is the channel response of channel \( c_k \).

By combining three transmission modes and according to the allocated transmission channel, the communication schemes can be the following three schemes:
A. Direct transmission system (BL-1): Direct transmission and BS allocated channels.
B. Traditional cooperative communication system (BL-2): Direct transmission/half duplex cooperative transmission and BS allocated channels.

![Fig. 2. Transmission model of full-duplex with one-time-slots and two channels](image)

### Table I. Parameters of System Model

<table>
<thead>
<tr>
<th>BS location</th>
<th>(x,y) = (0,0)</th>
</tr>
</thead>
<tbody>
<tr>
<td>BS coverage range</td>
<td>Radius = 1km</td>
</tr>
<tr>
<td>BS location</td>
<td>(x,y) = (±0.3535 km, ±0.3535 km)</td>
</tr>
<tr>
<td>CU location</td>
<td>Uniformly distributed in the range of BS</td>
</tr>
<tr>
<td>Number of RS allocated channels</td>
<td>30</td>
</tr>
<tr>
<td>Central frequency of RS allocated channels</td>
<td>2000 MHz</td>
</tr>
<tr>
<td>Number of Cognitive channels</td>
<td>9</td>
</tr>
<tr>
<td>Central frequency of Cognitive channels</td>
<td>700 MHz</td>
</tr>
<tr>
<td>Bandwidth (B)</td>
<td>200 kHz</td>
</tr>
<tr>
<td>Maximal Power of RS</td>
<td>25 dBm</td>
</tr>
<tr>
<td>Maximal Power of CR</td>
<td>19 dBm</td>
</tr>
<tr>
<td>Noise power spectral density (N_0)</td>
<td>-174 dBm/Hz</td>
</tr>
<tr>
<td>Path loss model</td>
<td>COST-231 Walfisch-Ikegami Model</td>
</tr>
<tr>
<td>Channel response</td>
<td>Rayleigh fading</td>
</tr>
</tbody>
</table>

### 2.2 System models

In the system model of CRAC, each RS is assumed with cognitive radio (CR) and the cognitive channels are modelled by binary Ergodic Markov chain [2]. The parameters of system models are shown in Table I.

### 2.3 Evaluation Performance Index

In this paper, we assume that the channel response is slow fading. The received signal was constant during the OFDMA time slot.

System throughput in an OFDMA time slot can be expressed by

\[
T = \sum_{k=1}^{K} \lambda_k, \quad (4)
\]

where \( \lambda_k \) is the throughput of the \( k \)th user. The fairness of throughput, \( f_k \) can be expressed by

\[
f_k = \frac{\lambda_k}{\sum_{k=1}^{K} \lambda_k},
\]

where \( \lambda_k \) is the throughput of the \( k \)th user. The fairness of throughput, \( f_k \) can be expressed by
expressed by proposed for fairness index [3]. The degradation rate is cannot be real fairness. So the degradation rate was which is not estimated accurately. Thus, the fair index throughpt is varied with the dynamic channel state Thus, the varying fading channels the mobile users cannot obtain the desired target transmission rate. Thus, the fairness of utility, \( U \) can be expressed by assignment scheme [5]. In our cooperative communication

\[
 f_k = \left( \frac{\sum_{i=1}^{K} \lambda_i}{\sum_{i=1}^{K} \lambda_i^2} \right)^2
\]

In wireless communications systems, due to the varying fading channels the mobile users cannot obtain the desired target transmission rate. Thus, the throughput is varied with the dynamic channel state which is not estimated accurately. Thus, the fair index cannot be real fairness. So the degradation rate was proposed for fairness index [3]. The degradation rate is expressed by

\[
 d_k = \begin{cases} \frac{\lambda_{k_{\text{ envisioned}}} - \lambda_{k}}{\lambda_{k_{\text{ envisioned}}}^2}, & \lambda_{k_{\text{ envisioned}}} > \lambda_k \\ 0, & \lambda_{k_{\text{ envisioned}}} \leq \lambda_k \end{cases}
\]

where \( \lambda_{k_{\text{ envisioned}}} \) is the throughput expectation of the \( k \)th user. The fairness of degradation rate, \( f_d \) can be expressed by

\[
 f_d = \left( \frac{\sum_{k=1}^{K} d_k^2}{\sum_{k=1}^{K} d_k} \right)^2
\]

Moreover, to meet the users’ throughput demand, we define the utility, \( U_j \), by

\[
 U_j = \begin{cases} \frac{\lambda_j}{\lambda_{j_{\text{ envisioned}}}}, & \lambda_{j_{\text{ envisioned}}} > \lambda_j \\ 1, & \lambda_{j_{\text{ envisioned}}} \leq \lambda_j \end{cases}
\]

where \( \lambda_{j_{\text{ envisioned}}} \) is the maximal throughput of user; \( \lambda_{j_{\text{ envisioned}}} \) is the user’s demand throughput, \( 0 \leq D_j \leq 100\% \). The fairness of utility, \( f_u \) can be expressed by

\[
 f_u = \left( \frac{\sum_{j=1}^{K} U_j^2}{\sum_{j=1}^{K} U_j} \right)^2
\]

IV. SIMULATION RESULTS

The comparisons of system throughput and fairness of utility between random assignment (Rand) and throughput based assignment (Thr) are shown in Fig. 3 and Fig. 4, respectively. In our simulation, 1000 times of the Monti Carlo simulation was performed for different number of UEs with channel load \( P = 0.5 \) and UEs demand \( D_j = 80\% \). From Fig. 3, it is observed that the proposed throughput based method (Thr) can effectively improve the system throughput than random assignment method (Rand).

Fig. 4 shows that when 80\% of the maximum amount of transmission is set, \( D_j = 80\% \), the fairness of BL-1 and BL-2 system is almost close to 1. It means that the CA methods of Rand and Thr reached the all fair situations. However, due to limited number of cognitive channels, the CRAC system was unable to supply utility to all users. Figs. 5 and 6 show the comparisons on system throughput and utility of fairness between Thr and the Utility based method (Uti). From Fig. 5, it is observed that Uti can maintain the throughput compared to the Thr.

3.2 Throughput Based Assignment

Based on the known users’ location and channel, we can choose RS for relaying and three modes of transmission with direct transmission, full duplex and half duplex cooperative transmission. Each user in different channels is allocated the data transmission according to the received priority of the channel and its maximal transmission rate. Moreover, the channel side information (CSI) is assumed known to estimate the transmission rate on different channels. Then BS can decide the channels allocation for users.

3.3 Utility Based Assignment

Instead of the transmission rate based, we based on the level of the utility of maximum transmission rate as a benchmark. Then it will improve the chances of disadvantaged users get a better path for greatly improving the fairness of the distribution method of transmission capacity, and increasing the use of resilient channels. This allocation method considers the amount of transmission channels and user satisfaction conditions. It will also be taken into account for the remaining channels, or unused channels. When the channel avoids collision, the users which suffered fading will have a good channel choice opportunity.

3.1 Traditional Assignment Scheme

Traditional channel assignment methods can be traditional OFDMA sub-band carrier assignment scheme (CAS), interleaved carrier assignment scheme, and generalized carrier assignment scheme [5]. In our cooperative communication system, due to the signal transmission is to use each user occupies a single channel transmission chain structure, so traditional OFDMA methods can be Sequence Carrier Assignment Scheme (SCAS) and Random Assignment Scheme (RAS) [5]. In this paper, the Random Assignment Scheme (RAS) was adopted for traditional systems.
From Fig. 6, it is observed that the utility based method can maintain the highest fairness of utility compared with the throughput method. Moreover, the proposed utility method can improve the fairness index with CRAC.

V. CONCLUSION

In this study a cognitive radio assisted cooperation (CRAC), which combines advantages of CR and cooperative communications with RSs, is considered for resources allocation in the downlink orthogonal frequency division multiple access (OFDMA) networks. Two adaptive resource allocation algorithms, throughput based assignment (Thr) and utility based assignment (Uti) are presented and experimental results demonstrate that the proposed algorithms can not only enhance throughput, but also improve fairness and utility of users assuming available channels are known by base station.

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