Downlink Channel Allocation Scheme deploying Cooperative Channel Monitoring for Cognitive Cellular-FemtocellNetworks

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***Abstract* – Cognitive cellular-femtocell networks are considered as future mobile communication networks which can satisfy challenging requirements of current mobile communications including high user density, quality of service (QoS) provision and efficient spectrum utilization. In this paper, we present a novel downlink channel allocation scheme which allocates downlink channels to new connection requests of real-time connections in cognitive cellular-femtocell networks. In the scheme, a cognitive femtocell access point (CFAP) cooperates with other 2-hop neighbor CFAPs to establish a cooperative channel monitoring group for monitoring and exchanging information of channel occupancy among the CFAPs belonging to the group. Upon receiving a new connection request from a femtocell user (FU), the serving CFAP uses the information of channel occupancy updated from neighboring CFAPs and interference level of channels to allocate a channel, which is expected to cause the minimum interference to macro users (MUs) of the covering macro base station (MBS). Simulation results prove that the proposed scheme can provide better performance than the conventional downlink channel allocation scheme which does not exploit the cooperation of CFAPs in channel monitoring.**

Keyword: Cognitive radio, femtocell, resource management

I. INTRODUCTION

4th generation (4G) mobile communications is able to provide high downlink transmission rate up to 1 Gb/s for low mobility/stationary applications and 100Mbps in high mobility situations [1]. Considering the huge number of mobile customers, deployment scenarios (indoor, outdoor, urban, suburban etc.) and applications (voice, video, Internet services) it can be foreseen that future mobile communications demand high capacity, intelligent coverage and efficient resource utilization [2]. To fulfill the requirements of future mobile communications, cognitive radio and femtocell are proposed as core technologies for providing wireless voice and broadband services to customers in small areas such as homes, offices or designated locations. The femtocells can be deployed and installed by subscribers or mobile network operators [3, 4].

Femtocell has been proposed as an efficient solution to increase indoor coverage and capacity [5]. At the beginning, femtocell is considered as a low power access point (denoted as Femtocell Access Point – FAP) for indoor environment as well as for outdoor environment where femtocells are used as traditional picocells [5]. FAPs can be deployed by users or mobile operators in residential, enterprise and open areas forming a so-called femto network in which interference management becomes an important task [6]. In cognitive cellular-femtocell systems proposed recently, FAPs are equipped with cognitive functionalities (thus denoted as cognitive femtocell access point - CFAP) for spectrum sensing and resource allocation [7].

We have taken a research survey of downlink resource allocation for femtocell networks which shows different research issues as following. In [8], Kim et al. presented a comprehensive investigation on the performance of two-tier femtocells networks with co-channel femtocell deployment in downlink connection. Co-channel femtocell deployment brings benefits in reusing the spatial frequency spectrum where the interference from macrocell users (MU) are sensitive to femtocells users (FU). Moreover, QoS constraint requirement has significant effect to capacity gain of the system. User's QoS demand is a significant factor during resource management process. In [9], Peng Liu et al. considered maximizing QoS of different traffic types and proposed QoS-based resource allocation. Work in [10] by Shao-Yu Lien et al. considered general aspect of cognitive radio which femtocells perform periodical channel sensing to identify the radio resource usage of macro cells then utilizing radio resource identifies as unoccupied by MUs. That hence mitigates cross-tier interference from macro cells to femtocells. In contrast, the resource management approach presented in [11] treated FUs and MUs with the same priority. It just tried to maintain FU's QoS if possible while protecting

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primary MUs were not considered. In [12], Rahman et al proposed a novel dynamic inter-cell interference coordination scheme using downlink multi chunk allocation to enhance cell edge performance of per-tier networks. The chunk is defined as a collection of consecutive subcarriers over a defined time period. Based on received interference level on each channel which was measured at user terminals, each sector of base station sends requests to the center controller which incorporates a tentative list of chunk to be restricted at surrounding dominant interference sector. This center controller gathers all requests to prepare and redefined list of chunk restriction that this list will be applied in all involve sectors of different cells. In [13] the authors proposed a joint channel allocation scheme and a fast power control method for downlink transmission in cognitive femtocel networks. In the joint channel allocation scheme, FUs can report the measured interference level on each channel to its serving CFAP, when having a new connection request from FU, the serving CFAP uses the received information to allocate the best channel with minimum interference to FU.

To our best knowledge, there is not any research considering the cooperation of CFAP in channel monitoring. In the paper, we will present our downlink channel allocation scheme which deploys a cooperative channel monitoring mechanism at CFAPs in order to accurately assign low interference channels to downlink real time connections requests of FUs. We aim to focus on the interference management in downlink channel allocation taking in to account co-channel deployment and cooperation between macrocells and femtocells. We propose a new effective downlink channel allocation scheme for cognitive cellular-femtocell networks that performs desirable better performance results comparing with those of the conventional scheme which does not apply cooperative channel monitoring.

This paper is organized as follows. In section II, we present the system model and channel allocation schemes. In section III, we present our simulation model which is used for performance evaluation. In section IV, performance results are presented and discussed. Finally, the conclusion remarks are given in the last section.

II. SYSTEM MODEL AND DOWNLINK CHANNEL ALLOCATION

A. System model

Fig. 1 shows a cognitive cellular-femtocell network model which was first introduced in our previous paper [14]. In the network, Femto Management System (FMS) and Mobile RAN Management System (MRMS) have periodical information exchange for radio resource management. In this paper, we consider a practical CFAP deployment scenario where CFAPs are deployed in a dense distribution e.g. in high building residential areas. Assume that MBSs and CFAPs use the same downlink frequency range in which MBSs operate as the primary system. CFAPs operate as the secondary system and apply cognitive functions of spectrum sensing and channel monitoring for downlink channel allocation to FUs. Cognitive radio is effective for opportunistic access [15] in which channels are allocated to mobile users in a certain short period. When considering real-time communications with strict QoS requirements, the channel allocated to a real-time connection has to be available for a long period.

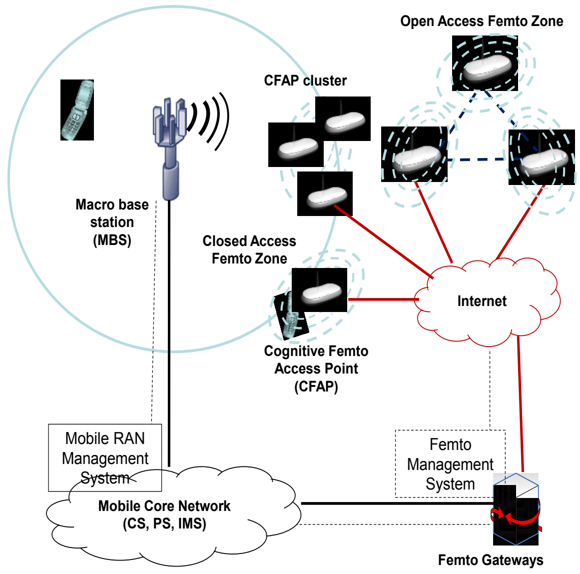


Figure 1 Cognitive Cellular-Femtocells Network

In the system model, assume that the cognitive femtocell-cellular mobile network has N^C downlink orthogonal channels. MBSs and CFAPs are able to use any channel in this channel pool. In a MBS or a CFAP, at any given time, a downlink channel is allocated to only one ongoing MU or ongoing FU, respectively. MUs are primary users for which the MUs have a certain guaranteed downlink SINR. When a CFAP allocates a downlink channel to a FU, the channel first has to provide the required downlink SINR of the FU's connection. However, the FU must not cause SINR degradation to the connections of MUs which are using the same channel.

To protect the downlink SINR of MUs, a channel verification procedure operates as follows: After a CFAP allocates a downlink channel k to a new connection request of a FU, the serving CFAP sends a verification request to the FMS to verify if the connection's QoS of other MUs using the channel k are violated. The FMS forwards the verification request to the MRMS and waits for a time out period. The MRMS send connection's QoS control inquiry to MBSs, which are the covering MBS of the CFAP and neighbors of the covering MBS. If a MU using channel k has connection's QoS violation, the MBS covering of this MU will send QoS control reply to MRMS. The MRMS forwards the QoS control reply to the FMS and stops the QoS controlinquiry sending. FMS sends the QoS verification reply to the CFAP and terminates the time out period. During the verification period, the FU is temporarily connected with the CFAP. If there is not any MU which has QoS violation, the CFAP permanently accepts the FU and allocates the channel k to the FU. Otherwise, the CFAP will terminate the connection and consider that the connectionrequest is not successful (unsuccessful request).

B. Downlink channel allocation

When a CFAP receives a new connection request from a femtocell user, it has to allocate a downlink channel to the FU. Because MUs are considered as primary users whose QoS must be guaranteed [16], the CFAP has to select a downlink channel which causes minimum effects to the downlink connection's QoS of MUs of the covering MBS [17]. In the scope of this paper, downlink signal-to-interference and noise ratio (SINR) is considered as a QoS parameter at the physical layer denoted as the connection's QoS. The SINR of a user **j** is measured by this equation:

$$\mathrm{SINR_j}=\frac{\mathrm{Pr}_j^k}{I_j^k+noise} \tag{1}$$

Downlink SINR of a MU might be strongly affected by the downlink signal of a nearby FU which had been allocated the same channel. That rises to a demand of finding an efficient solution for downlink channel allocation which is able to not only satisfy downlink SINR of FUs but also doest not violate downlink SINR of ongoing MUs. In a high density CFAP area, MU's downlink SINR might be strongly degraded by nearby CFAPs which are consuming same channels for their downlink connections.

In order to eliminate SINR degradation of MUs, we propose a cooperative channel monitoring mechanism. In this scheme, a CFAP will form a cooperative channel monitoring group with its 2-hop neighbor CFAPs. In the monitoring group, the CFAP performs cooperative channel monitoring by exchanging the information of channel occupancy. The information exchange may be performed either in a centralized mode in which FMS works as a centralized channel management entity, or in a distributed mode in which CFAPs in a group will use a common control wireless channel for information exchange. In the proposed cooperative CFAP channel allocation scheme (denoted as Cooperative CFAP scheme), a CFAP is periodically updated bad channel lists of its 2-hop neighbor CFAPs. A channel will be denoted as a bad channel, when it used to be allocated recently to a connection request of a FU but did not pass the channel verification procedure. Bad channel lists should be refreshed after a certain period in order to refresh status of channels. When receiving a new connection request of a FU, the CFAP selects the downlink channel k which satisfies three criteria: 1) it does not belong to any bad channel lists updated from 2-hop neighbor CFAPs in its CFAP's cooperative channel monitoring group, 2) it is not using by other FUs of the CFAP, and 3) it has the minimum interference level measured at the CFAP.

Fig. 2 shows an illustration of the deployment of cooperative channel monitoring. In this figure, FMS acts as controller which gather local information from CFAP in the same cluster via wire connections. For example, we suppose that f1 and f2 are the channels which have recently failed allocation by CFAP1 and CFAP2 respectively. The channels are denoted as bad channels and updated by CFAP1 and CFAP2 to FMS and CFAP3 in their cooperative channel monitoring group. When CFAP3 has to allocate a channel to FU3, the CFAP3 will not choose the channel f1 and f2 in order to avoid high-interference channels. The channel allocation not only causes minimum cross-tier interference to MUs but also directly reduce total interference in the system.

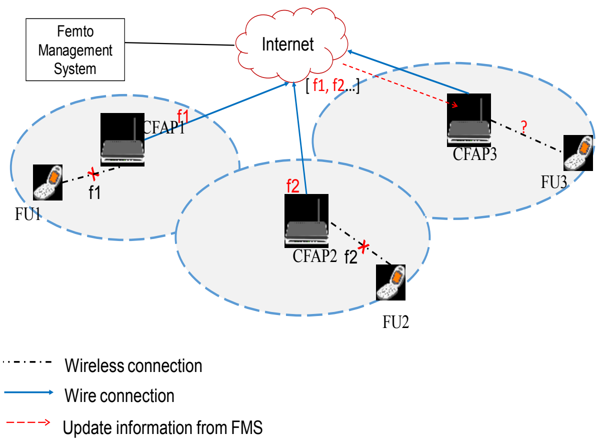
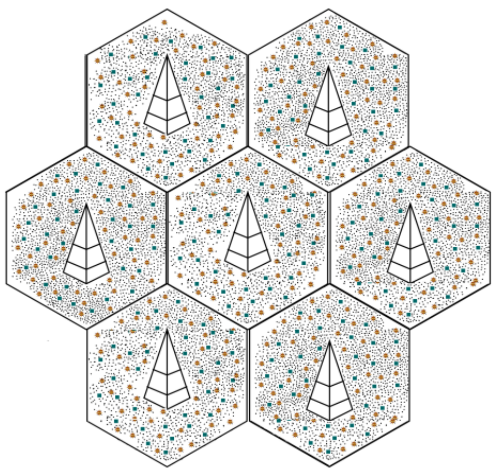


Figure 2 Deployment of Cooperative Channel Monitoring

For performance comparision, we analyze another cognitive channel allocation scheme (denoted as CFAP-based scheme). In this scheme, each CFAP will measure interference level of all downlink channels which are not allocated to ongoing FUs. When a CFAP receives a new call request, the CFAP selects the channel k among the available downlink channels which has the minimum interference level.

III. SIMULATION MODEL

Simulation scenarios use the 7-cell simulation model as shown in Fig. 3. The performance metric is the unsuccessful probability (P_R) of new connection requests defined as below:



$$P_R=\frac{Number\_Of\_Unsuccessful\_Request}{Total\_Request} \tag{2}$$

Figure 3 Layout of Simulation Model

Each MBS provides the cell coverage radius of 500m with the antenna height of 30m. In each MBS, a number of CFAPs is uniformly distributed. The CFAP coverage radius is 15m and has antenna height between 1m to 5m.

When a CFAP forms its cooperative channel monitoring group, the CFAP selects CFAPs of 2-hop neighbors. They will exchange information of channel occupancy to each other in its group. MUs are also uniformly distributed in each MBS. We only consider stationary MUs and FUs with the antenna the height is 1m. MBSs and CFAPs manage the same number of downlink channels $N^C = 100$. The power transmission range of MBSs in eachdownlink connection is between 1mW and 200mW [18], whereas the power transmission of CFAPs in each downlink connection is controlled from 1mW and up to 25mW. The downlink transmission power of MUs is controlled with the SINR target of 5 dB [6]. The FU's downlink QoS requirement (SINR) is 10dB. Consider CFAPs and FUs are indoor devices whereas MBSs and MUs are outdoor devices. Standardized path loss models used for calculating SINR are given in Table 1. The transmitted signal between a base station and users can be classified into four cases: indoor to indoor, indoor to outdoor, outdoor to outdoor and outdoor to indoor link [18]. The path los models (Cost231-Okumura-Hata, ITU P.1411 and ITU P.1238) are used according to given propagation case as described in Table 2.

Table 1 Simulation Parameters

Parameters	Values
Frequency	2000 MHz
MU's downlink QoS requirement	5dB
FU's downlink QoS requirement	10dB
Antenna height of MBS (h_b)	30m
MBS's transmission power range of a downlink connection	1mW to 200mW
CFAP's transmission power of each downlink connection	1mW to 25mW
Indoor to indoor lognormal shadowing standard deviation	4dB
Indoor to outdoor lognormal shadowing standard deviation	12dB
Outdoor to outdoor lognormal shadowing standard deviation	8dB
Outdoor to indoor lognormal shadowing standard deviation	10dB

Okumura-Hata [COST231] is derived from experiment and observation and well-accepted by mobile cellular community. Hence, it is the most extensive implemented and available as the main model in almost radio planning tools. The expression of OH built – up as follows:

$$L = 46.3 + 33.9\log(f) - 13.82\log(h_B) + (44.9 - 6.55\log(h_B))\log(d) - f(h_M) + C \quad (3)$$

With C = 0 dB for small to medium-size cities.

Where:

$$f(h_M) = (1.1 * \log(f) - 0.7) * h_M - (1.56 * \log(f) - 0.8) \quad (4)$$

The above term of $f(h_M)$ for small to medium city and the other for large city

h_B: Base station height above ground (m)

h_M: Mobile height above ground (m)

*d: D*istance from base station to mobile (d > 1 Km)

150 MHz $< f <$ 2000 MHz

30m $< h_B <$ 200m

$1 < h_M <$ 10m

ITU P.1238 path loss modeling was use for predicts path loss between two indoor terminals assuming aggregate loss through furniture and internal as follows:

$$L_{total} = 20\log_{10} f + N\log_{10} d + L_f(n) - 28 \quad (5)$$

Where:

f: frequency (MHz)
N: distance power loss coefficient
d: distance between base station and portable terminal (d>1m)
L_f = floor penetration loss factor (dB)
n: number of floors between a base station and a mobile terminal

ITU P.1411 was designed for the planning of short range outdoor systems and recommended applies to situations where the two terminals are in LoS but are surrounded by buildings. In this paper, we used the lower bound for the path loss using the following expressions:

$$L(dB) = \begin{cases} L_{bp} + 20\log_{10}\left(\dfrac{d}{R_{bp}}\right) & for \quad d \le R_{bp} \\ L_{bp} + 40\log_{10}\left(\dfrac{d}{R_{bp}}\right) & for \quad d > R_{bp} \end{cases} \quad (6)$$

Where the breakpoint distance is given by $R_{bp} = 4h_bh_m/\lambda$. The basic transmission loss at the breakpoint distance is given by:

$$L_{bp} = \left|20\log_{10}(\lambda^2 / 8\pi h_b h_m)\right| \quad (7)$$

With λ is the wavelength (*m*); h_m and h_b are the height above the street level of the base station and the mobile unit, respectively (*m*); *d* is the distance from the base station (*m*).

Table 2 ITU Pathloss Model

Parameters	Values
External wall loss	20dB
Window loss	5dB
Indoor to indoor path loss modeling	ITU P.1238
Indoor to outdoor path loss modeling	ITU P.1411+ wall/window loss
Outdoor to outdoor path loss modeling	Cost231 Okumura-Hata: edge of macro cell cases ITU P.1411: near macro cell cases
Outdoor to indoor path loss modeling	Cost231-Okumura-Hata for edge of macro cell cases + wall/window loss ITU P.1411: for near macro cell cases + wall/window loss

IV. PERFORMANCE RESULTS

In the first simulation scenario, 50 CFAPs are randomly distributed in a MBS's coverage. The maximum number of active MUs of each MBS (considered as MBS's mamixum load) is 60 i.e. MBS's load is up to 60%. Consider a CFAP can serve simultaneously 5 or 10 FUs (denoted as CFAP's load) in the case of home or enterprise femtocell, respectively [19].

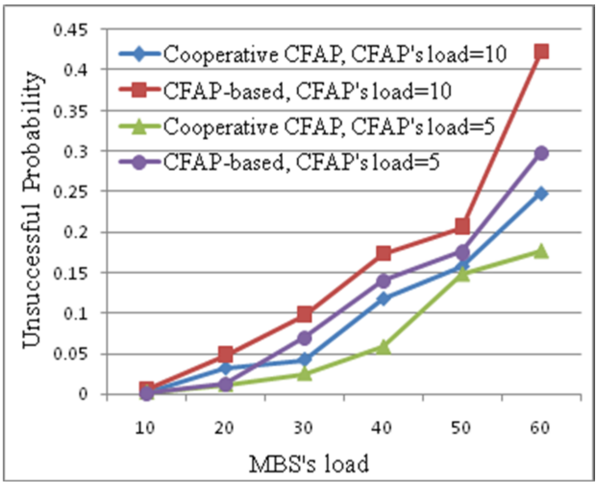


Figure 4. Performance comparision with two cases of CFAP's load

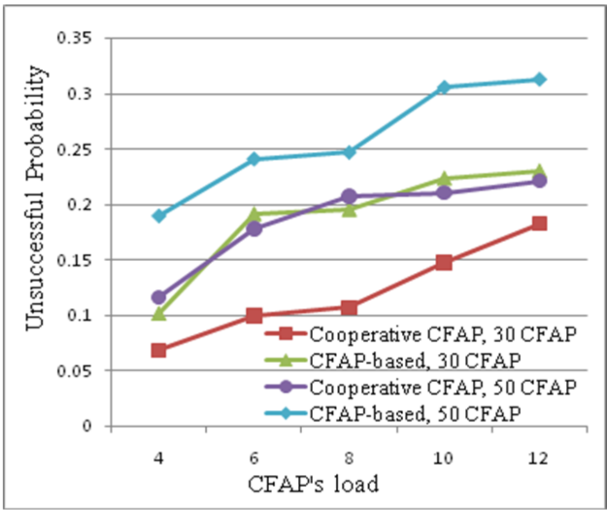


Figure 5. Performance comparision with different number of CFAP

Fig. 4 clearly shows that in both cases of high-load CFAP and low-load CFAP, the proposed Cooperative CFAP scheme provides a lower unsucessful probability comparing to the conventional downlink channel allocation scheme (CFAP-based scheme). When using low-load CFAP (CFAP's load is 5), the simulation result shows that for the system has home-type femtocells, using Cooperative CFAP scheme can provide at least 50% better performance than that of the CFAP-based scheme. Besides, the same performance also keeps for enterprise femtocells (CFAP's load = 10). The Cooperative CFAP scheme also shows better performance at different MBS's loads because when using the Cooperative CFAP scheme, CFAPs will choose the channel which not only has minimum interference level but also is not in the bad channels list. Thus, the requested FU will not cause SINR degradation to MUs consuming the selected channel.

Fig. 5 shows the performance results of the second scenario which aims to observe the network performance in two cases: the number of CFAP is 30 and 50 in each MBS i.e. different CFAP density. The MBS's load is fixed at 50 while the CFAP's load is varied between 4 and 12. Fig.5 shows that the Cooperative CFAP scheme outperforms the conventional CFAP-based scheme. That means the proposed scheme can work well in different CFAP distribution scenarios.

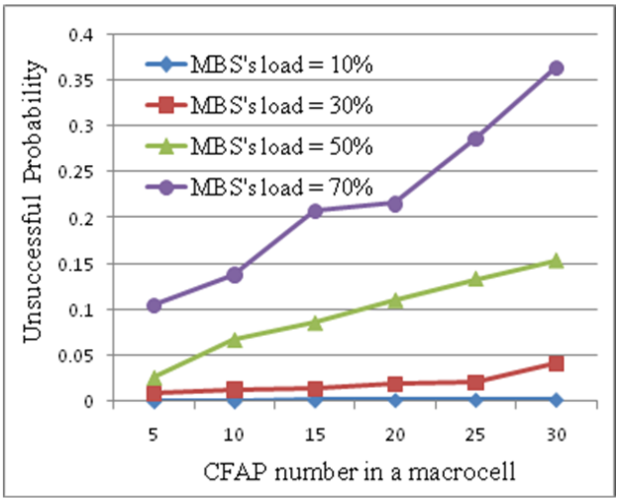


Figure 6. Performance of the Cooperative CFAP scheme with different MBS's load

Fig.6 shows the performance of the Cooperative CFAP scheme in the simulation scenario where the number of CFAPs in a MBS coverage varied between 5 and 30 in each MBS. Performance evaluation is carried out for different MBS's loads (10%, 30%, 50% and 70%). The CFAP's load is set to 5 FUs. Performance results show that the Cooperative CFAP scheme can work very well at low MBS's load (10% and 30%) When MBS's load increases more than 50 or 70, the overall unsuccessful probability are also very high because the high number of MU in a MBS's coverage causes the cross-interference in two-tier increasing dramatically.

Fig. 7 shows the performance of the CFAP-based scheme and the Cooperative CFAP scheme when CFAPs have different transmission radius. The Cooperative CFAP scheme still offers better performance than that of the CFAP based scheme. The reason is when CFAPs have larger coverage, the information exchange among CFAPs is more effective. Updating bad channel lists between CFAPs will help CFAPs eliminating high interference channels. From the sresult, we notice that cooperative channel monitoring mechanism can work well for common small-cell networks.

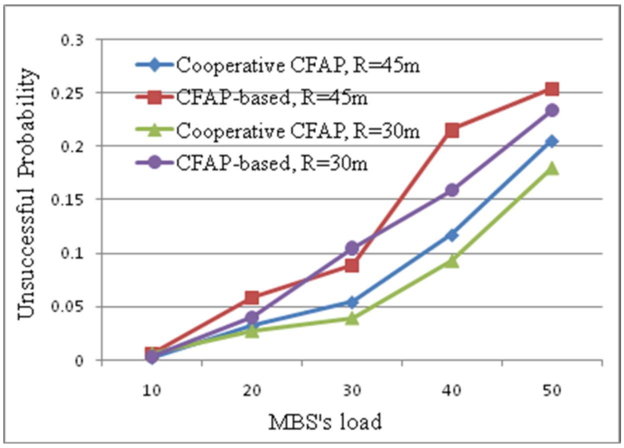


Figure 7. Performance result of Cooperative CFAP scheme with difderent CFAP's tranmission radius

V. CONCLUSION

In this paper, we have proposed a new effective downlink channel allocation scheme for cognitive cellular-femtocell networks and compare its performance with that of the conventional CFAP-based scheme. In our research, we consider a practical femtocell deployment scenario in which femtocells are densely deployed in high density user areas. The proposed Cooperative CFAP scheme operates based on the cooperative channel monitoring of CFAPs aming to avoid allocating bad channels to FUs. Performance results obtained by computer simulation show that the Cooperative CFAP scheme outperforms the CFAP-based scheme in terms of low unsuccessful probability. In order to achieve high system capacity and resource utilization in dense distribution of CFAPs, the information exchange of CFAPs in cooperative spectrum monitoring group will play important role. Future works will investigate the performance of the Cooperative CFAP scheme in a more dynamic scenario where mobile FUs and handover issues are taken into account.

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