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Graph Based Interference Coordination for Relay Networks

***Abstract**. Relay networks are subject to two different types of interferences, i.e., inter-cell interference and intra-cell interference. As the inter-cell interference has been well addressed in the literature, this paper is concentrated on intra-cell interference cooperation. An interference graph based interference coordination scheme is proposed to manage the intra-cell co-channel interference. Our extensive simulation results show that the proposed algorithm performs better in both the average throughput and cell edge throughput.*

***Streszczenie.** W sieci przekaźnikowej mogą występować dwa rodzaje interferencji – międzykomórkowa i wewnątrzkomórkowa. W artykule skoncentrowano się na tej drugiej interferencji. Schemat bazuje na strukturze grafu interferencji. (**Koordynacja interferencji w sieci przekaźnikowej bazująca na strukturze grafu**)*

Keywords: Intra-Cell Interference, Graph Theory, Interference Graph, Relay Network.
Słowa kluczowe: interferencje wewnątrzkomórkowe, seić przekaźnikowa.

Introduction

Relay communications have been adopted by the 3rd Generation Partner Project (3GPP) LTE-Advanced, especially, 3GPP Release 10 version (Rel-10) as relays can enhance cell capacity and expand cell coverage efficiently and effectively. With the rapid development of high-speed data services, such as video streaming applications, and a drastic increase in the number of user equipment (UE), the cell radius has becoming ever smaller in order to increase cell capacity through decreasing the pathloss at the cell edge. Therefore, we can no longer increase cell capacity through cell split like before. Nowadays, relay communications are emerging because relays can help with many scenarios perfectly, for instance, enhancing capacity of hotspots, overcoming the coverage hole, temporary deployment for conferences and group handover for vehicles [1-4].

Although relays possess many advantages as mentioned above, it also causes high co-channel interference for intra-cell, because they reuse the frequency occupied by the eNB (enhanced Node B) in the access link. If the interference is not managed properly, the effective of using relays will be impacted severely. As a result, there have been intensive debates in 3GPP RAN (Radio Access Network). Until now, there is not a consensus on how to deal with co-channel interference for physical control channels, such as the Physical Downlink Control Channel (PDCCH) and Physical Uplink Control Channel (PUCCH), as well as physical data channels, such as the Physical Downlink Shared Channel (PDSCH) and Physical Uplink Shared Channel (PUSCH).There are few papers on interference management for systems with relay. Instead, many ones on system without relay, which only concentrates on inter-cell interference rather than intra-cell interference [5, 6].

In this paper, we propose a novel interference graph based interference coordination scheme to manage the intra-cell co-channel interference in relay networks. We apply graph theory to the construction of the interference graph. Then, we classify users according to the interference graph, with the goal of precisely locating the interfering sources as well as classifying users according to the levels of interferences they experience. Furthermore, we propose a fast scheduling algorithm based upon the interference graph, which is able to assign available frequency resources to users suffering different levels of interferences.

The rest of the paper is organized as follows. Section II describes system model and propose the interference cooperative algorithm. Simulation environments and results are presented in Section III. Finally, conclusion remarks are drawn in Section IV.

System model and algorithm description

Interference graph construction

We first introduce the construction of the interference graph. The essence of graph theory based interference coordination is as follows. A user is regarded as a vertex in the inference graph. An edge linking two users indicates they interference with each other. Each edge is assigned a weight that represents the severity of the interference [7,8]. After an interference graph is constructed, serving nodes can implement resource scheduling according to the inference graph with the goal of avoiding interference.

There are mainly two methods to construct an interference graph:

1) A serving node sends data to all users. Then, each user feeds back information on its interference source to the serving node. Finally, the serving node aggregates all the interference information to a central node, e.g., the Radio Network Controller(RNC), or it constructs an interference graph through exchanging interference information via the X2 interface.

2) The central node, such as the RNC, can conctruct the interference graph through each user's serving node and the candidate set.

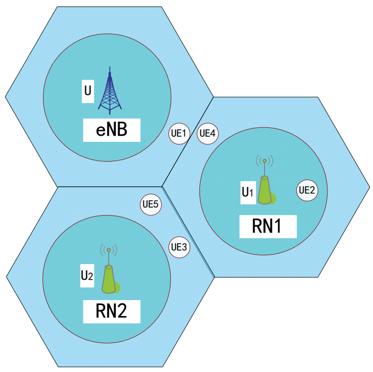


Fig. 1. Illustration of user location distribution.

There are several drawbacks for the first method. For example, a mobile device needs to distinguish interference among different sources, as well as feeding a great amount of interference information back to the serving nodes. Also, nodes need to exchange much interference information among each other. By contrast, the second method is more advantageous as a user only needs to send the candidate set of its own to the servicing node. Therefore, we employ the second method to construct the interference graph. Fig. 1 illustrates the user location distribution.

The severing node and the candidate set of the users in Fig. 1 is detailed in Table 1.

Table 1. Severing node and candidate set of users in figure 1

User	Severing node	Candidate set
UE1	A1=eNB	B1={RN1}
UE2	A2=RN1	B2={}
UE3	A3=RN2	B3={RN1}
UE4	A4=RN1	B4={eNB}
UE5	A5=RN2	B5={eNB,RN1}

We take Table 1 as an example to demonstrate how to construct an interference graph.

1) Intra-Cell Interference w_A

This type of interference exists between UE2 and UE4 because both locate in the same coverage area of serving node RN1. In this scenario, the interference between UE2 and UE4 is considered as infinite and thus has to be avoided.

2) Inter-Cell Interference w_1

This type of interference exists between UE2 and UE3, only when the candidate set of UE3 contains the serving node {RN1} of the UE2, and the candidate set of UE2 is empty.

3) Inter-Cell Interference w_2

- This type of interference exists between UE3 and UE4, only when the candidate set of UE3 contains the serving node {RN1} of the UE4, and the candidate set of UE4 is not empty.
- This type of interference exists between UE1 and UE4, when the candidate set of UE1 includes the serving node of UE4, and vice verse.

4) Inter-Cell Interference w_N

When the candidate sets of UE1 or UE3 do not include each other's serving node, there exists no interference between these two nodes.

According to the above procedure, the interference graph is constructed as shown in Fig. 2.

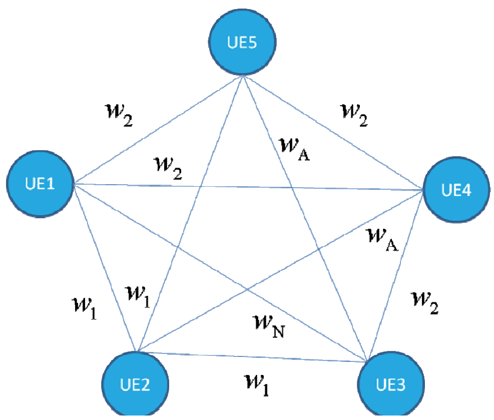


Fig. 2. Interference graph for the users in Fig. 1

Classfication of Macro UE

The Macro UE is classified according to the interferences from RN1-UE and RN2-UE into the following 9 scenarios, which is detailed in Table 2.

Table 2. Classfication of macro UE

RN2 \ RN1	w_2	w_1	w_N
w_2	$w_2\ w_2$	$w_2\ w_1$	$w_2\ w_N$
w_1	$w_1\ w_2$	$w_1\ w_1$	$w_1\ w_N$
w_N	$w_N\ w_2$	$w_N\ w_1$	$w_N\ w_N$

Bandwidth Segmentation

The eNB divides the whole bandwidth into four regions, i.e., $\bar{U}_1\cap\bar{U}_2$, $\bar{U}_1-\bar{U}_1\cap\bar{U}_2=\bar{U}_1\cap U_2$, $\bar{U}_2-\bar{U}_1\cap\bar{U}_2=U_1\cap\bar{U}_2$, $U_1\cap U_2$, according to the frequency sets information from RN1 and RN2.

These four frequency regions are further explained as follows:

$\bar{U}_1\cap\bar{U}_2$: This region is orthogonal to the occupied frequencies of RN1 and RN2, and can be used to withstand high interference, as shown in red in Table 3.

$\bar{U}_1-\bar{U}_1\cap\bar{U}_2=\bar{U}_1\cap U_2$: This region is orthogonal to the occupied frequency of RN1 and multiplexes with the occupied frequency of RN2. It is primarily used when interference is low, as shown in green in Table 3.

$\bar{U}_2-\bar{U}_1\cap\bar{U}_2=U_1\cap\bar{U}_2$: This region is orthogonal to the occupied frequency of RN2 and shares the occupied frequency of RN1. It is primarily used when interference is low, as shown in yellow in Table 3.

$U_1\cap U_2$: This region reuses the radio frequencies of both RN1 and RN2. It is primarily used when there is virtually no interference, as shown in blue in Table 3.

Table 3. Bandwidth Segmentation according to the interference categories

RN2 \ RN1	w_2	w_1	w_N
w_2	$\bar{U}_1\cap\bar{U}_2$		$\bar{U}_1-\bar{U}_1\cap\bar{U}_2=\bar{U}_1\cap U_2$
w_1			
w_N	$\bar{U}_2-\bar{U}_1\cap\bar{U}_2=U_1\cap\bar{U}_2$		$U_1\cap U_2$

Resources Scheduling

According to different application scenarios of the above four frequency regions, we allocate different frequencies to users suffering from different degrees of interference, as shown in Table 3.

The scheduling algorithm is detailed as follows:

1) In accordance with the mappings in Table 3, the 9 Marco UEs that suffer different levels of interference are divided into four groups (represented by different colours), corresponding to four different frequency sets. Then, PF scheduling is applied. The two groups of users in each scheduling set are scheduled in a different order, which is detailed in Fig. 3.

$$\bar{U}_1\cap\bar{U}_2 \longrightarrow w_2w_2 \quad w_1w_1$$
$$\bar{U}_1-\bar{U}_1\cap\bar{U}_2=\bar{U}_1\cap U_2 \longrightarrow w_2w_N \quad w_2w_1$$
$$\bar{U}_2-\bar{U}_1\cap\bar{U}_2=U_1\cap\bar{U}_2 \longrightarrow w_Nw_2 \quad w_1w_2$$
$$U_1\cap U_2 \longrightarrow w_Nw_N \quad w_Nw_1 \quad w_1w_N$$

Fig. 3. Mapping the 9 Marco UEs that suffer different levels of interference into four groups

Taking as an example the first line in Fig. 3, $\bar{U}_1\cap\bar{U}_2$ is allocated to the Macro UEs that suffer interference w_2 from RN1-UE and RN2-UE, as well as to the Macro UEs that are subject to interference w_1 from RN1-UE and RN2-UE.

In the second line, $\bar{U}_1 \cap U_2$ is allocated to the Macro UEs that suffer interference w_2 from RN1-UE and interference w_1 or w_N from RN2-UE.

In the third line, $U_1 \cap \bar{U}_2$ is allocated to the Macro UEs that are subject to interference w_2 from RN2-UE and interference w_1 or w_N from RN1-UE.

In the fourth line, $U_1 \cap U_2$ is allocated to the Macro UEs that suffer interference w_N from RN1-UE and RN2-UE, the Macro UEs that suffer interference w_1 from RN1-UE and interference w_N from RN2-UE, and the Macro UEs that suffer interference w_N from RN1-UE and interference w_1 from RN2-UE.

When applying Proportional Fairness (PF) scheduling, we first schedule the beginning Macro UEs and then the following Macro UEs.

2. In order to avoid the situations where some of the above four frequency sets are empty or load imbalance of the users corresponding to the above frequency sets, we propose an elegant solution that assigns four distinct colours to the users. The Macro UEs that have not been scheduled in step 1) can use the frequency sets around itself in the order of left (top) to right (down).

We use the following example to elaborate on the frequency borrowing procedure.

For instance, assume the system bandwidth is 10 MHz for a 3GPP LTE-Advanced cellular system with 50 RBs. The number of RBs corresponding to frequency resources $\bar{U}_1 \cap \bar{U}_2$, $\bar{U}_1 \cap U_2$, $U_1 \cap \bar{U}_2$ and $U_1 \cap U_2$ are 14, 16, 12, and 18, respectively. Among all the Macro UEs, those interfered by $w_2 w_2$ and $w_1 w_1$ from RN1 and RN2 require 10 RBs, those interfered by $w_2 w_N$ and $w_2 w_1$ need 20 RBs, those interfered by $w_N w_2$ and $w_1 w_2$ are allocated 12 RBs, and those interfered by $w_N w_N$, $w_N w_1$ and $w_1 w_N$ need 18 RBs. As a result, the user load is not balanced for the former two groups of users, which need frequency borrowing. After 10 RBs are allocated to the $w_2 w_2$ and $w_1 w_1$ users, the remaining 4 RBs are borrowed by $w_2 w_N$ and $w_2 w_1$ users.

Interference Coordination Procedure

1) A user feeds its candidate set information back to the serving node. At the same time, the RN sends to the eNB information on the frequency set that it is able to schedule.
2) The RN forwards information on the serving nodes and candidate nodes of its servicing nodes to its host station, i.e., the eNB.
3) The eNB will construct the interference graph according to its users' serving nodes and candidate nodes, as well as sorting out the whole spectrum according to the feedback from the RN.
4) The eNB schedules the Macro UE according to the PF scheduling algorithm.

Simulation environment and results

System simulation environment

Detailed system simulation parameters are summarized in Table 4 for the following evaluations.

Table 4. System simulation parameters

Parameter	Value
Cellular layout	3-sectorized Hexagonal grid with 7 cells wrap-around
System frequency	2 GHz carrier, 10 MHz bandwidth
Inter-site distance	500 m (case 1)
Relay distribution	2 relay/sector
UE distribution	20 UE/sector，Uniform distribution
UE speed	3 km/h
Traffic model	Full buffer
eNB transmission power	46 dBm
Relay transmission power	30 dBm
Antenna number	eNB-Relay-UE: 2×2×1
Antenna pattern (horizontal)	$A_H(\varphi) = -\min\left[12\left(\frac{\varphi}{\varphi_{3dB}}\right)^2, A_m\right]$ φ_{3dB} = 70 degrees, Am = 25 dB
Antenna pattern (vertical)	$A_V(\theta) = -\min\left[12\left(\frac{\theta-\theta_{etilt}}{\theta_{3dB}}\right)^2, SLA_v\right]$ θ_{3dB} = 10 degrees, SLAv = 20 dB case 1： θ_{etilt} = 15 degrees
Combining in 3D antenna pattern	$A(\varphi,\theta) = -\min\{-[A_H(\varphi)+A_V(\theta)], A_m\}$
Path loss (eNB-UE)	PL*los*(R)= 103.4+24.2log10(R) PL*nlos*(R)= 131.1+42.8log10(R) Case 1: Prob(R)=min(0.018/R,1)*(1-exp(-R/0.063))+exp(-R/0.063) R in km
Path loss (relay-UE)	PL*los* (R)=103.8+20.9log10(R) PL*nlos* (R)=145.4+37.5log10(R) Case 1:Prob(R)=0.5-min(0.5,5exp(-0.156/R))+min(0.5, 5exp(-R/0.03)) R in km
Shadowing standard deviation	Log Normal Distribution with 0 mean， 8 dB for eNB-UE, 10 dB for relay-UE
Penetration loss	20 dB for both eNB-UE and relay-UE
Thermal noise density	-174 dBm/Hz
L2S interface	Mutual Information Effective SINR Mapping (MI-ESM)

Simulation Results and Performace Anaysis

Fig. 4 depicts the cumulative distribution function (CDF) curve of the whole cell, in which the blue dash line describes the proposed scheme and the red solid line represents the method without adopting the proposed intra-cell inference coordination scheme, but reusing the whole frequency resources.

Fig. 5 clearly demonstrates that the proposed scheme outperforms the comparison method, improving 24.6% and 6.25% average throughput and cell-edge respectively.

Conclusions

In this paper, a novel interference graph based interference coordination scheme is proposed to manage the intra-cell co-channel interference in relay networks. We apply graph theory to the construction of the interference graph. The interference graph allows one to precisely locate the interfering sources as well as classifying users according to the levels of interferences they receive. Then, we map the Marco UEs that suffer from different levels of interference into different groups and divide the whole bandwidth into several regions according to the occupied frequency information fed back by relay nodes. Next, we propose a fast scheduling algorithm based upon the interference graph, which is able to assign available frequency resources to users suffering different levels of interferences. Simulation results show that the proposed algorithm performs better in both the average throughput and cell edge throughput.

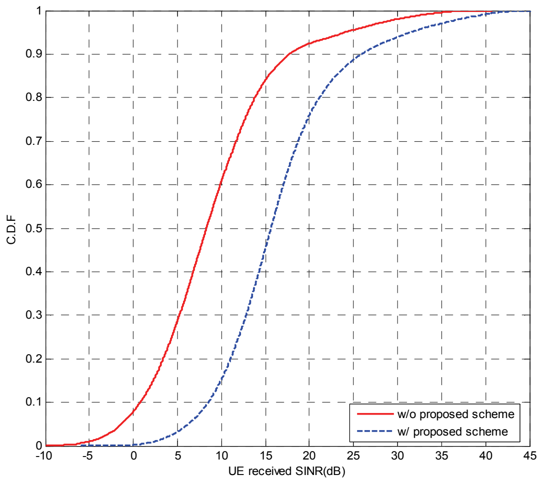
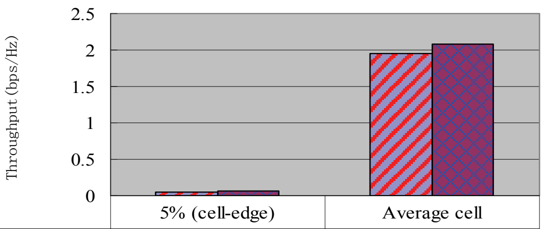


Fig. 4. CDF of theSINR of the cell



	5% (cell-edge)	Average cell
w/o proposed scheme	0.046	1.95
w/ proposed scheme	0.061	2.08

Fig. 5. Average throughput of the cell-edge and whole cell

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