Enhanced Inter-cell Interference Coordination in Heterogeneous Networks for LTE-Advanced

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***Abstract*—Femtocells, a kind of low power nodes in a heterogeneous network for LTE-Advanced, have become an attractive device to offer better system performance and user experience. However, due to co-channel deployments with the macro cell, the home eNB which serves closed subscriber groups will impose serious interference on macro users especially on their PDCCHs which spans over the whole system bandwidth. In this paper, we propose an enhanced ICIC mechanism to suppress such interference by blanking two OFDM symbols. Furthermore, for Release 10 victim users, a novel repetitively designing PDCCH scheme is proposed such that the interference can be avoided effectively. Analysis shows that our approach is backward compatible and can support LTE TDD and FDD systems simultaneously. And simulations demonstrate that satisfying performance can be obtained by using our methods.**

***Index Terms*—closed subscriber group (CSG), heterogeneous networks, home eNB (HeNB), inter-cell interference coordination (ICIC), LTE-Advanced (LTE-A)**

I. Introduction

Heterogeneous networks have received much attention these days as a new paradigm for increasing cellular capacity and are under standardization for LTE Release 10. In heterogeneous networks, some low power nodes (LPNs) are introduced to the traditional macro cellular deployment, which include micro eNBs, pico eNBs (PeNBs), home eNBs (HeNBs), relay nodes (RNs), etc [1, 2]. Among them, HeNBs are an effective solution to enhance indoor coverage where a macro eNB (MeNB) is limited or unavailable. Fig.1 illustrates the basic concept of heterogeneous networks in an LTE-Advanced (LTE-A) system. However, due to the co-channel deployment with the macro cell, it is inevitable that macro users will be interfered by the HeNBs in the downlink (DL) transmission. The latest documents of 3GPP [3] have identified that the dominant interference for the scenario of a macro cell plus femtocells is the interference from HeNBs, especially when the macro user equipments (MUEs) are in close proximity of femtocells which only serve a closed subscriber group (CSG).

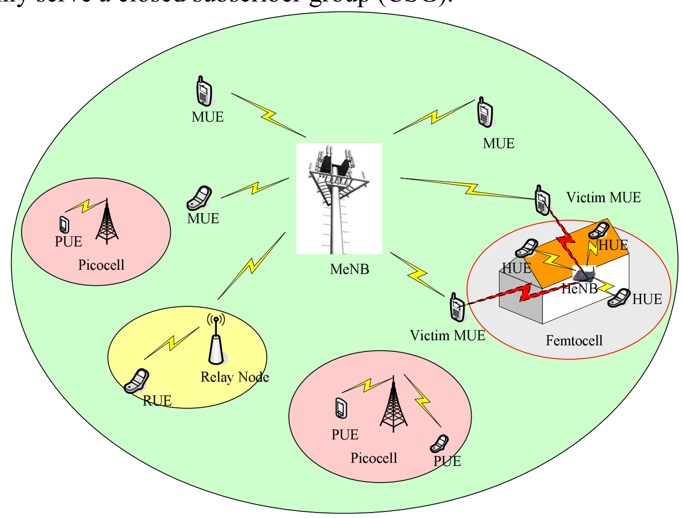

Fig. 1 Illustration of heterogeneous networks in an LTE-Advanced system.

Although some inter-cell interference coordination (ICIC) techniques have been proposed for Release 8 and 9, in this scenario, they are not fully effective in mitigating control channel interference [4]. In LTE systems, Physical Downlink Control Channel (PDCCH) is one of the most important DL channels and responsible for the main function to transport resource assignments and other control information for UEs [5]. While interference to PDCCH is a critical aspect to be addressed in the CSG deployment, the available ICIC techniques are restricted to time shifting, frequency partitioning, relaxing the CSG constraints and power control [6–9]. Actually, these existing approaches encounter more or less challenges on considering the backward compatibility and simultaneously supporting LTE time division duplexing (TDD) systems and LTE frequency division duplexing (FDD) systems.

In this paper, we propose a novel scheme to realize enhanced ICIC of PDCCH for LTE-A systems meanwhile supporting backward compatibility and both LTE systems. To be backward compatible, the method of blanking two OFDM symbols is proposed thereby the interference to PDCCH of MUEs can be mitigated greatly. Moreover, for Release 10 users,

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by utilizing repetitively designing PDCCH, the interference from an HeNB can be almost completely suppressed. Analysis and simulation results demonstrate that the proposed mechanisms are effective, and the developed scheme is equally applicable for both LTE TDD and FDD systems.

The rest of the paper is organized as follows. Section II describes the system model of the heterogeneous network and addresses the problem. In Section III, the proposed mechanism aiming to effectively suppress harmful DL interference from an HeNB is elaborated. For Release 10 users, a novel repetitively designing PDCCH mechanism is proposed in Section IV and the implementation details are described in a real LTE-A system. Performance evaluation and discussions are presented in Section V and Section VI gives some concluding remarks.

II. System Model

In our work, the potential of the LTE-Advanced technology as a platform is addressed and the mechanism to perform enhanced ICIC of DL control channels are raised. In LTE-A, the downlink control channels can be configured to occupy the first 1, 2 or 3 OFDM symbols in a subframe, extending over the entire system bandwidth. Downlink control information (DCI) for one single UE or a group of UEs is mapped on PDCCH. From PDCCH, UE can obtain information on both uplink (UL) and DL resource allocations and power control [5]. UEs will listen to the PDCCH and try to decode it blindly in all DL subframes. Carrying the most vital DCI, in our work we consider enhanced ICIC for PDCCH.

Femtocells are LPNs and operate in the licensed UMTS/LTE spectrum while their backhaul connection makes use of a broadband connection such as optical fiber or digital subscriber line (DSL). However, being unknown of the position of an HeNB and deployed within the coverage area of the existing macro cell, they can cause strong performance degradation of macro cells. The addressed problems are illustrated in Fig.1, where two MUEs enter into the coverage of the HeNB thus receiving strong interference from it.

In this paper, we consider the access strategy for the femtocell is *Closed Access* and the femtocell reuses the whole DL frequency bands with the macro cell in an LTE-A system. In this scenario, the victim device is the macro UE which is in the proximity of an HeNB. Considering the small coverage of an HeNB, we think the number of interfered MUEs is not large. In the initial stage, an HeNB needs to register to its anchored MeNB such that it can perfectly synchronize to the MeNB. In addition, an HeNB is deployed randomly in a macro cell, consequently, the interference from Physical Downlink Share Channel (PDSCH) of femtocells is innegligible in some cases. Furthermore, information exchanging between an MeNB and an HeNB can be performed by UE-assisted relaying or over-the-air broadcasting [10]. In the following section, we will propose novel mechanisms to suppress DL interference on PDCCH of MUEs in the heterogeneous network of a macro cell plus femtocells. The proposed scheme can support Release 8, 9 and 10 users and is feasible equally for LTE TDD and LTE FDD systems. In addition, performance analyses of these methods in terms of network interference and throughput are provided.

III. Blanking Two OFDM Symbols for Release 8, 9 and 10 Users

For the addressed problem, how to identify the victim MUEs is a preliminary problem. Before the proposed interference mitigation scheme is elaborated, we will present two ways to identify which MUEs are interfered by the HeNB, which is an important aspect of our approach.

A. Identifying Victim Macro UEs

Method 1: HeNB detects UL reference signals from victim MUEs. UL reference signals (RSs) have distinctive properties which means that they are terminal specific and an HeNB can identify the victim MUE by deriving its characteristic. The HeNB then reports the characteristic of the detected UL RS to the MeNB such that the MeNB knows which MUEs are victims. Also an MeNB can communicate the corresponding mapping relationship between characteristic of an UL RS and the Cell Radio Network Temporary Identifier (C-RNTI) of MUEs to the HeNB in advance. As a result, an HeNB can determine which MUEs are interfered and then report their C-RNTIs to the MeNB directly.

Method 2: MeNB uses the UL interference report from MUEs. Once interfered severely by an HeNB, an MUE will be triggered to send an UL interference report to the MeNB directly then the MeNB knows which MUEs are in the coverage of a femtocell.

B. Broadcasting 'V' Subframes Information

After the MeNB receives the information of victim MUEs, the procedure of enhanced ICIC for PDCCH is initialized. Obtaining the information on victim MUEs, the MeNB broadcasts the scheduling information on victim MUEs to the HeNB which is illustrated in Fig. 2.

In Fig. 2, two subframes which are remarked as 'V' mean that victim MUEs will be scheduled only in these two subframes whilst other MUEs can be scheduled in any subframes.

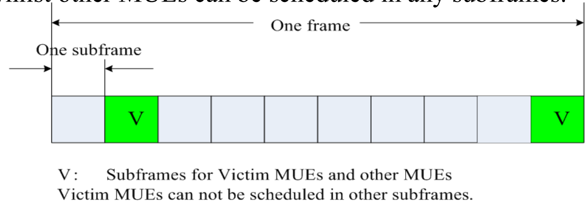


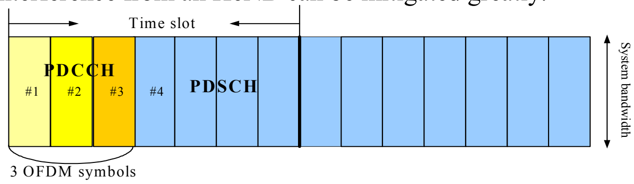
Fig. 2. Allocation for downlink subframes.

Note that

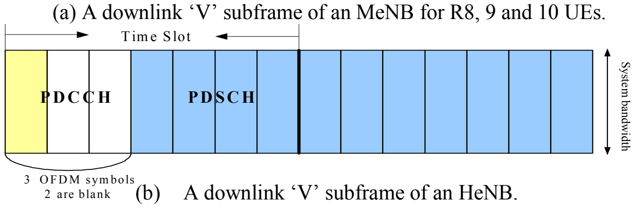
- Since the coverage of an HeNB is limited the number of victim MUEs is very small. Hence, the number of 'V' subframes is also limited.
- Whether the victim MUEs are scheduled or not, other MUEs are scheduled normally in all DL subframes.
- The information exchanging between the MeNB and an HeNB can be performed by UE-assisted relaying or over-the-air broadcasting [10].

C. Enhanced ICIC on PDCCH for Release 8, 9 and 10 users

For the MeNB, after identifying the UEs' attribution by using the methods presented in Part A, to support backward compatibility, an approach of blanking two OFDM symbols is proposed. As shown in Fig. 3, for a 'V' subframe, the MeNB must allocate its PDCCH to occupy the first 3 OFDM symbols completely, namely symbol#1, #2 and #3. However, the HeNB limits its DL control information to be within 1 OFDM symbol (symbol#1) and OFDM symbol#2 and #3 are blank. By doing so, interference from an HeNB can be mitigated greatly.



(a) A downlink 'V' subframe of an MeNB for R8, 9 and 10 UEs.



(b) A downlink 'V' subframe of an HeNB.

Fig. 3 Proposed PDCCH format in a heterogeneous network for Release 8, 9 and 10 users.

Note that

- Such PDCCH allocation happens only on 'V' subframes.
- For both the MeNB and the HeNB, PCFICH is 3.
- For the HeNB, although 2 OFDM symbols are wasted, considering such 'V' subframes is very limited, the spectrum efficiency will not be impacted obviously.

IV. Repetitively Designing PDCCH for Release 10 UEs

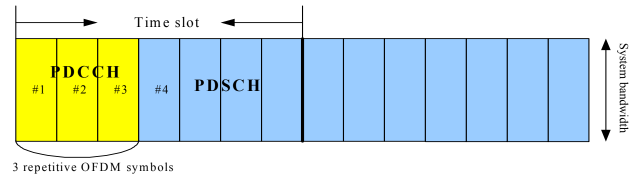
The above method is feasible for Release 8, 9 and 10 LTE users. When the victim MUEs are only Release 10, a novel repetitively designing PDCCH scheme is proposed. Being randomly deployed in the macro network, two kinds of different PDCCH designing schemes are proposed in the following corresponding to the different interference of PDSCH from the HeNB.

A. Tolerable Interference from PDSCH of an HeNB

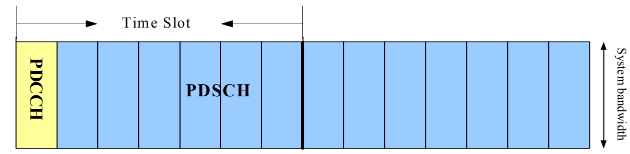
For this case, an HeNB and victim MUEs may be not at the edge of a macro cell or power control is performed on the HeNB. In this scenario, we restrict the PDCCH of an HeNB to take one OFDM symbol (OFDM symbol #1) and the PDSCH can use the left OFDM symbols. However, to avoid the interference from the HeNB, we propose PDCCH of the MeNB to occupy the first three OFDM symbols. Different from the current PDCCH mapping, we allocate the same PDCCH in these three OFDM symbols which means that although only one OFDM symbol is enough to transmit PDCCH it will be sent on OFDM symbol #2 and #3 repetitively. Consequently, the victim MUEs can decode the PDCCH on each OFDM symbol independently. The proposed scheme of repetitively designing PDCCH on DL 'V' subframes is presented in Fig. 4.

B. Intolerable Interference from PDSCH of an HeNB

For this scenario, an HeNB and victim MUEs are all at the edge of a macro cell as shown in Fig.1. In this case, the interference of the PDSCH from the HeNB is severe and must be avoided in the proposed method. To solve this problem, the DL 'V' subframes of the MeNB use the same repetitive designing proposal described above whereas a different DL 'V' subframe will be realized in the HeNB.



(a) A downlink 'V' subframe of an MeNB for Release 10 MUEs.



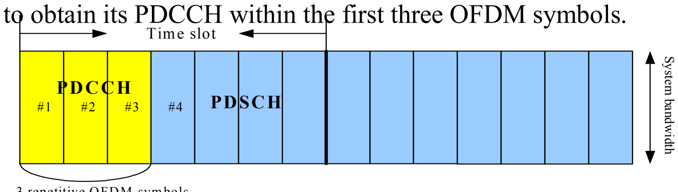
(b) A downlink 'V' subframe of an HeNB.

Fig. 4 Proposed PDCCH format for Release 10 UEs when the interference of PDSCH from the HeNB is tolerable.

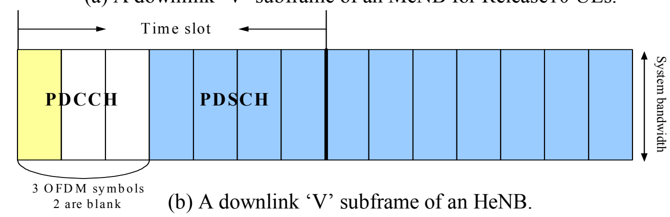
C. Intolerable Interference from PDSCH of an HeNB

For this scenario, an HeNB and victim MUEs are all at the edge of a macro cell as shown in Fig.1. In this case, the interference of the PDSCH from the HeNB is severe and must be avoided in the proposed method. To solve this problem, the DL 'V' subframes of the MeNB use the same repetitive designing proposal described above whereas a different DL 'V' subframe will be realized in the HeNB.

As Fig. 5 shows that in the HeNB PDCCH also fully occupies 3 OFDM symbol. Different from the normal DL subframes, symbol #2 and #3 are blank. Hence, PDCCH in the MeNB will not be interfered by the PDSCH from the HeNB on the symbol #2 and #3 and a victim MUE has a high probability to obtain its PDCCH within the first three OFDM symbols.



(a) A downlink 'V' subframe of an MeNB for Release10 UEs.



(b) A downlink 'V' subframe of an HeNB.

Fig. 5 Proposed PDCCH format for Release 10 UEs when the interference of PDSCH from the HeNB is intolerable.

Note that

- An additional bit should be used in PCFICH to inform Release 10 UEs to decode PDCCH within a symbol.
- For the scenario of tolerable PDSCH interference, PCFICH is 3 for the MeNB and 1 for the HeNB. However, for the scenario of intolerable PDSCH interference, PCFICH is 3 for both the MeNB and the HeNB.

The complete procedure of our proposed PDCCH interference cancellation mechanism is summarized as follows.

Step1: HeNB identifies the victim MUEs by using the UL RSs and then reports to MeNB. Or the MeNB directly determines the interfered MUEs by using the UL interference report from MUEs.

Step 2: An MeNB broadcasts the scheduling information of 'V' subframes in which victim MUEs can be scheduled only. Other MUEs will be scheduled in any subframe.

Step 3: If the victim MUEs are only Release 8, 9 or a mixture of Release 8, 9 and 10, the HeNB and the MeNB arrange their own DL 'V' subframes according to Section III. Otherwise, if the victim MUEs are only Release 10, a repetitively designing PDCCH scheme described in Section IV will be utilized.

V. SIMULATION AND PERFORMANCE ANALYSIS

A. Simulation Parameters

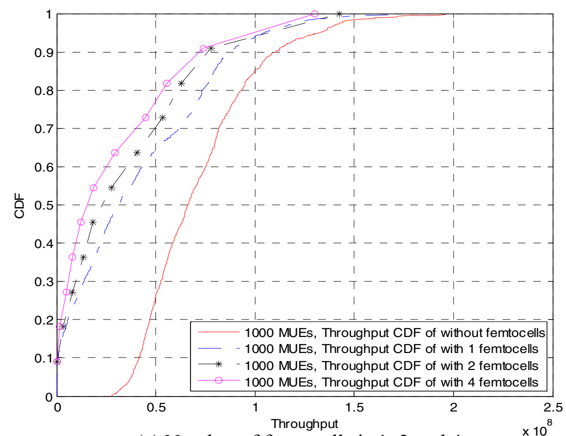
The topology of the heterogeneous network will be modeled in a fashion way where femtocell users are distributed in a randomly placed cluster with an inter-site distance (ISD) of 30m and cellular users are also dropped uniformly through the cell with an ISD of 500m. We ignore the interference from a neighboring macro cell for simplifying the simulations and there are altogether 4 femtocells which are placed at the four corners in the macro cell to avoid the interference from the MeNB. In each femtocell, 10 users are placed with regards to the number of macro UEs changing from 500 to 2000. The maximum transmission power (Tx power) of the MeNB is set as 46dBm whereas an HeNB has a Tx power changing from a minimum 20dBm to a maximum 30dBm [11]. Considering more than 80% wireless communications happens indoor, a 20dB penetration loss is included to calculate the received power from the MeNB to an MUE [12]. The other parameters are set up according to [11 – 14] and are presented in Table 1.

TABLE I. PARAMETERS FOR SIMULATIONS

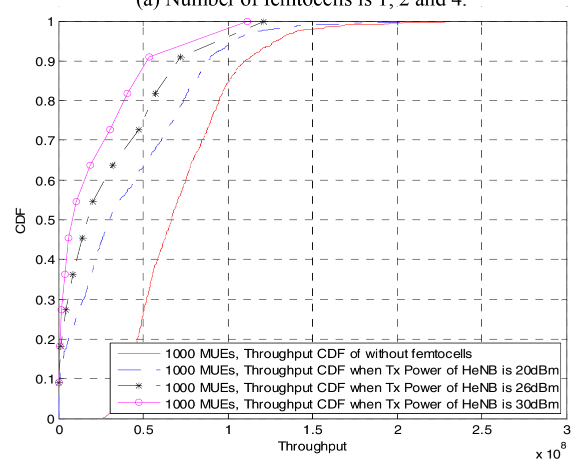
Macro Cell ISD	500 m
Femtocell ISD	30m
Noise Power Density	-174 dBm/Hz
Distance-dependent path loss	Indoor: PL(dB) = 15.3 + 37.6log10 (r), r is the transmitter-receiver separation in meters
	Outdoor: PL(dB) = 15.3 + 37.6log10 (r) + Penetration Loss, r is the transmitter-receiver separation in meters
Carrier frequency	2000MHz
System bandwidth	10 MHz
Number of UEs per femtocell	10
Number of UEs per macro cell	from 500 to 2000
Max Macro Tx Power	46dBm
HeNB Tx Power	from 20dBm to 30dBm
Traffic model	Full buffer

B. Simulation Results and Discussions

To investigate the interference to the PDCCH of a macro cell from the HeNB, Fig. 6(a) and (b) firstly present the cumulative distribution function (CDF) curves of macro system throughput when femtocells are placed and the number of MUEs is 1000. We plot the simulation results when the number of femtocells changes from 1 to 4 and transmission power changes from 20dBm to 30dBm, respectively. Two observations can be made from these two figures. Firstly, HeNBs impose significant interference to the PDCCH of macro users and such interference can degrade the macro system performance greatly. With the increase of the femtocells, the interference on the PDCCH of macro users becomes more serious so that the system throughput becomes worse. Secondly, the throughput performance is highly related to the number of femtocells and transmission power of an HeNB. It is an intuitive result in that more femtocells and higher transmission power can lead to more serious interference to the PDCCH such that worse throughput performance.



(a) Number of femtocells is 1, 2 and 4.



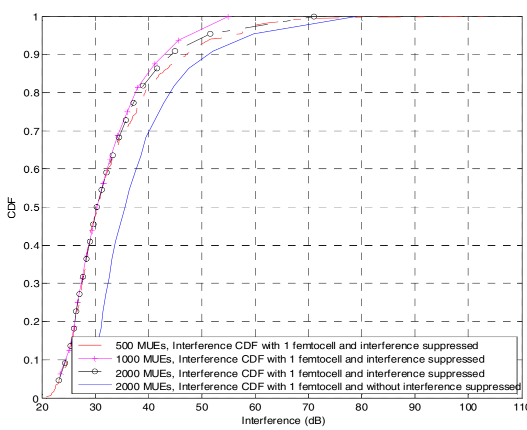
(b)Tx Power of an HeNB is 20, 26 and 30dBm.

Fig. 6. CDF of macro system throughput when the number of femtocells and transmission power of an HeNB change.

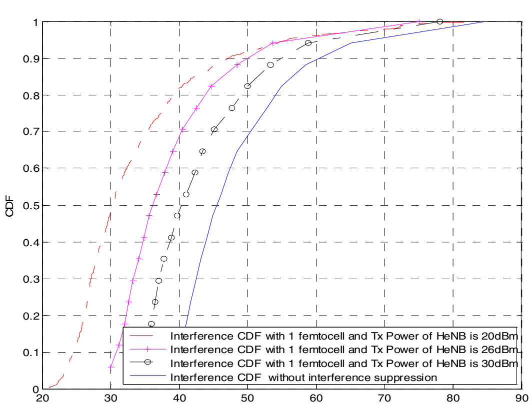
In order to prove the performance of our method, in Fig. 7, we show the simulations of macro PDCCH interference CDF after using the proposed mechanism for Release 8, 9 and 10 victim MUEs. To simplify the simulation scenario, only one femtocell operates in the macro cell and the curve of macro PDCCH interference CDF without any interference suppression is shown here as contrast. To evaluate the performance after the number of macro users changes, we first plot the results when the number of MUEs is from 500 to 2000 in Fig. 7 (a). From this figure we can conclude that the interference to PDCCH of macro users is mitigated significantly after using our method and the number of MUEs has no obvious impact on the system performance. Fig. 7(b) shows the simulations when the transmission power of an

HeNB varies from 20dBm to 30dBm. An obvious conclusion can be made that with the decrease of the transmission power, a better interference suppression performance can be obtained.

In order to evaluate the performance of our scheme for Release 10 MUEs by using repetitively designing PDCCH, we present successfully decoding ratio of PDCCH in Fig. 8 corresponding to the scenario that PDSCH interference from an HeNB is tolerable. The adopted threshold of successfully decoding PDCCH is the signal-to-interference-plus-noise ratio (SINR) of a victim MUE which is defined as the ratio of the accepted power of macro signals from the MeNB to the noise power plus interference power from an HeNB and this SINR is set up as -4dB [13]. We also consider some slight asynchronization between the MeNB and the HeNB which means that a victim MUE will be still interfered slightly from the PDCCH of the HeNB in symbol #2. From Fig. 8 we can see that a substantial improvement occurs after using our scheme and this method is very effective for three kinds of transmission powers. For example, for the worst case that a 30dBm transmission power is used by an HeNB, the successfully decoding ratio of PDCCH varies from 25.96% on symbol #1, 55.54% on symbol #2 to the final 90.15% on symbol #3.



(a) Number of MUEs is 500, 1000 and 2000.



(b)Tx Power of an HeNB is 20, 26 and 30dBm.

Fig. 7. CDF of macro system received interference when the number of MUEs and transmission power of an HeNB change.

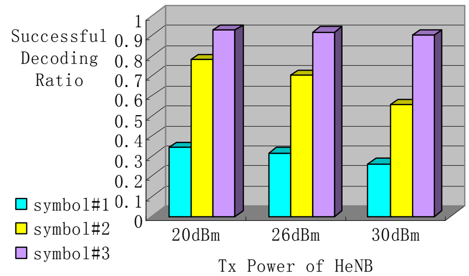


Fig. 8 Successfully decoding ratio vs. transmission power of an HeNB for Release 10 MUEs.

VI. CONCLUSIONS

The mechanism of suppressing DL interference of PDCCH from HeNBs in a heterogeneous network for LTE-Advanced is addressed in this paper. After identifying the victim macro users, the scheme of blanking two OFDM symbols is proposed for Release 8, 9 and 10 UEs. Moreover, for Release 10 victim users, a novel repetitively designing PDCCH mechanism is suggested. Analysis shows that our methods are backward compatible and feasible for LTE TDD and FDD systems simultaneously. Simulations proved that the performance of the proposed method is satisfying.

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