Novel Method to Improve Control Channel Reliability in LTE-Advanced Heterogeneous Network

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***Abstract*—Heterogeneous network (HetNet) is considered to be a promising approach to improve spectrum efficiency per area in a Long Term Evolution-Advanced (LTE-A) system and beyond, which allows multiple cells to provide service in an overlaid area. To guarantee stability of the HetNet, one challenge is how to handle inter-cell interference between different cells especially for a control channel that does not support link adaptation or retransmission. In this paper, a novel method is proposed that improves performance of downlink Hybrid Automatic Repeat-request (HARQ) feedback channel in HetNet. In the proposed method, legacy control channel transmission is shifted to another subframe with a lower interference level. Simulation results demonstrate that the downlink HARQ feedback channel performance can be significantly improved in both Frequency Division Duplex (FDD) and Time Division Duplex (TDD) systems.**

I. Introduction

In HetNet, a macro cell and low transmission power cell can function in the same frequency band (co-channel deployment) [1]. This kind of co-channel deployment is very attractive especially when the operator has few available frequency bands. In order to improve the spectrum efficiency, a range expansion (RE) scheme with biased cell selection was proposed that allows a user equipment (UE) to connect to a cell with low transmit power even when it is not the strongest cell [2]. However, this will cause the co-channel interference as illustrated in [3].

In an LTE-A system, the downlink transmission is divided into subframes in time domain. Each subframe is composed by a control region which carries control signallings and a data region which carries data transmission. To address the co-channel interference problem [4] in HetNet, time domain resource partition method achieved by configuring almost blank subframe (ABS) in the interfering cell is proposed. In the ABS, no uni-cast control information is presented in the control region, thus, the interference to the control region in victim cell can be alleviated. However, the control channel performance for the victim cell may still not be satisfied due to the transmission of system information from the interfering cell. In an LTE-A system, the physical hybrid-ARQ indicator channel (PHICH) is an essential control channel which carries acknowledgement/negative acknowledgement (ACK/NACK) for the uplink transmission in the downlink. It plays an important role on the system performance, as the unreliable reception of PHICH due to the co-channel interference may lead to more redundant re-transmissions and increase the transmission latency. In addition, the degradation in the PHICH reception will cause frequent collisions of uplink transmissions which will decrease the spectrum efficiency as well. The severe interference observed in a co-channel HetNet scenario necessitates the interference coordination in PHICH. One possible method is to extend the PHICH transmission to the data region. However, this degrades the system efficiency, since many resources in the data region must be reserved for the PHICH [1]. In this paper, we propose a novel method to handle the interference problem and improve the PHICH performance in a co-channel HetNet scenario. In the proposed method, we develop the asynchronous PHICH transmission mechanism and shift the PHICH transmission to another subframe that has a lower level of interference, the interference problem can be alleviated and the PHICH performance can be significantly improved.

The rest of this paper is organized as follows. The PHICH design for an LTE-A system and the problem implementing the design are described in section II. Section III presents the proposed method. Simulation results are illustrated in Section IV and our conclusions are given in Section V.

II. PHICH Design for LTE-A and Problem

A. *PHICH Design for LTE-A*

The PHICH transmission is a synchronous manner in an LTE-A system. When the uplink transmission occurs in subframe n, the evolved NodeB (eNB) should transmit the ACK/NACK in subframe $n+k$, where k is 4 for an FDD system as illustrated in Fig. 1, and for a TDD system, k is given in [5]. The physical uplink shared channel (PUSCH) in the figure refers to the scheduled uplink transmission. The synchronous transmission can conserve on the number of signaling exchanges since the UE can find the ACK/NACK for each uplink transmission simply through a pre-defined rule instead of additional signaling.

In an LTE-A system, parameter $maxHARQ-Tx$ [6], which represents the maximum number of re-transmission, is configured in practical systems. The re-transmission delay

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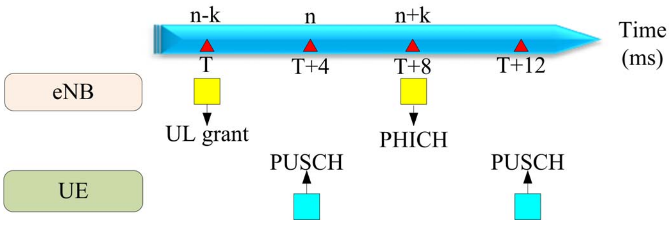

Fig. 1. HARQ timing in LTE-A (FDD case)

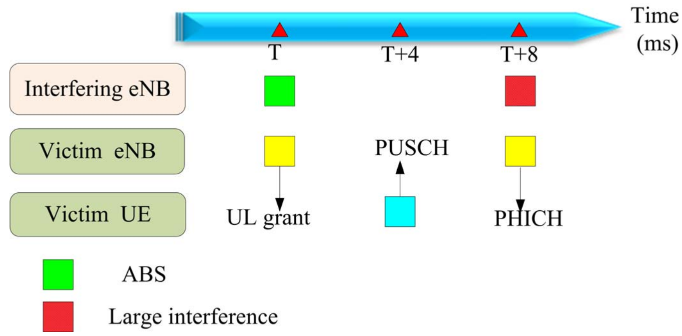

Fig. 2. Interference problem for PHICH transmission

performance can be evaluated using (1) for FDD and (2) for TDD systems. Here the re-transmission delay is defined as the time interval between the subframe that carries a NACK for the initial transmission and the subframe that carries an ACK for a certain re-transmission. If the initial transmission is successful, the re-transmission delay is equal to zero.

$$T_{FDD}^{Delay} = \sum_{i=1}^{N} 8 * i * P_e^i * P_c^i, \tag{1}$$

$$T_{TDD}^{Delay} = \sum_{i=1}^{N} 10 * i * P_e^i * P_c^i, \tag{2}$$

where i represents the re-transmission time, $P_e^i = \prod_{m=1}^{i-1} P_e^m$ represents the error probability of the uplink data before the ith re-transmission and P_c^i represents the correct received probability of the uplink data for the ith re-transmission.

As observed from (1) and (2), the delay performance is significantly influenced by the correct received probability. In this paper, we just focus on the improvement in the PHICH transmission. So we assume that each uplink transmission succeeds and we only analyze the impact due to the error reception of the PHICH. In this sense, the P_e^i and P_c^i represent the error and correct probability of the PHICH transmission, respectively.

B. Problem

As stated in Section I, in order to handle the interference problem in a co-channel HetNet scenario, the interfering eNB can configure ABS in some subframes to facilitate the scheduling of cell edge UEs served by the victim cell. However, the ABS configuration is an eNB implementation issue. The eNB can configure an arbitrary ABS pattern in principle. Since the PHICH transmission is synchronous, in some cases, it will collide with the normal transmission of an interfering cell in the victim cell. The PHICH will receive strong interference (possibly more than 20dB interference) in this case as illustrated in Fig. 2.

Even the PHICH transmission from the victim cell collides with the ABS of the interfering cell. There is a possibility that in the ABS, some system information may still be transmitted. This will bring additional interference to the PHICH transmission from the victim cell especially for a narrow system bandwidth case. In [7], the cumulative density function (CDF) curve for 8 dB RE bias in macro and pico scenarios is presented which shows the signal to interference and noise ratio (SINR) distribution with different payload ratios in the control region. We take a 5-MHz system bandwidth case as an example. When configuring an ABS subframe, even when only one control information is transmitted in the control region, nearly 20 percentage pico UE's (PUE) SINR is below the threshold which can guarantee PHICH reception. We can imagine that the interference problem will be more severe with an increase in the RE bias value or payload ratio in the ABS of the interfering system. The severe interference observed in the PHICH in a co-channel HetNet scenario has a significant impact on the system performance. This will cause the degradation of system efficiency and increase the transmission latency.

III. Novel Method

In this section, to address the performance degradation problem due to the severe interference in a HetNet, a novel method is considered. In the proposed method, we change the current HARQ timing metric for PHICH transmission. In the rest of this section, we present a detailed description of the proposed method.

A. Proposed Method

Although synchronous PHICH transmission can conserve on the number of the signaling exchanges, it may not be suitable for a HetNet scenario due to the time varying change of the interference level. We consider a time-varied procedure in which the time interval between the uplink transmission and downlink ACK/NACK is dynamically changed. In order to achieve this, we consider informing the UE of a new subframe location to receive the ACK/NACK. However, a high signaling cost is expected because additional signaling is needed for each uplink transmission. Moreover, from the delay performance viewpoint, we should first leave sufficient time, approximately 8 ms (time interval from the uplink transmission and next uplink transmission) to process the data and ACK/ANCK, and then reduce the delay as much as possible. Motivated by this concern, we propose shifting the ACK/NACK to the nearest available subframe with a lower level of interference if the original transmission suffers a high level of interference as illustrated in Fig. 3.

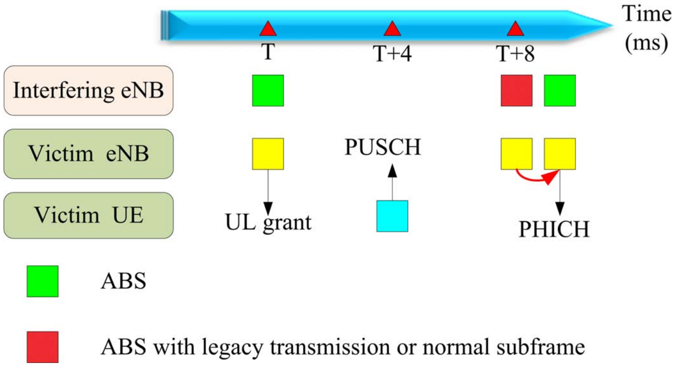

Fig. 3. Proposed method

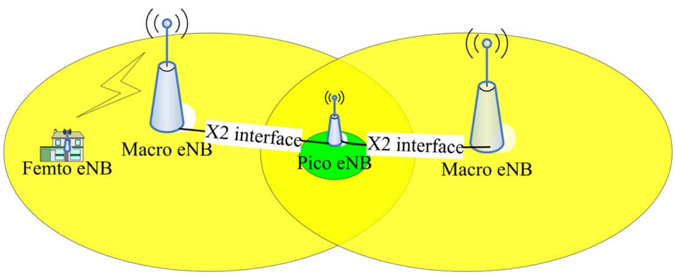

Fig. 4. Coordination between macro node and low power node

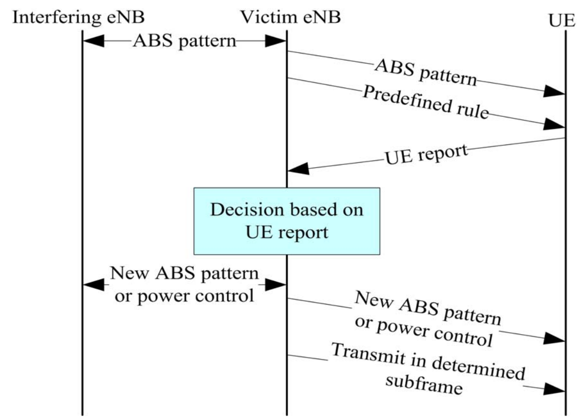

Fig. 5. Procedure for proposed method

The next nearest subframe may also suffer a high level of interference. We can consider some degree of coordination between the interfering and victim cells. Currently, coordination of the ABS pattern is already supported in macro and pico scenarios through the backhaul interface (X2 interface in Fig. 4). Although there is no high-speed backhaul interface defined for femto cells, considering that the coordination of the ABS pattern is semi-static rather than dynamic, the coordination between macro and femto cells can be achieved through an air interface or other possible interfaces as illustrated in Fig. 4. The coordination may result in a new ABS pattern or power control scheme. To further explain the proposed method, we assume that in subframe 4 within a frame for an FDD system, the victim cell needs to send the ACK/NACK to the served UEs. In this subframe, although an ABS is configured for the interfering cell, some legacy transmissions still exist. In the proposed method, we find the nearest subframe, which is subframe 5, to carry the ACK/NACK instead of subframe 4. However, in subframe 5, there are still legacy transmissions, so we shift the PHICH transmission to the next nearest subframe, which is subframe 6. In subframe 6, no legacy transmission is needed. If subframe 6 is not configured as an ABS in the interfering cell, then we need to coordinate a new ABS pattern so that in subframe 6, the interfering cell is configured as an ABS. If we do not want to change the ABS pattern, we can consider a power control method. In above example, if subframe 6 is not configured as an ABS in the interfering cell, we can reduce the transmission power in subframe 6 for interfering cell through coordination. Since in subframe 6, there is no legacy transmission, power reduction for control/data is possible. The coordination between eNBs should be semi-static considering the capacity of the backhaul linkage and should occur only when there is a large change in the network such as the powering on of a new pico eNB (PeNB), the powering down of a working PeNB, or a significant change in the traffic.

In a certain subframe, not all the served UEs in the victim cell will have a problem in receiving the PHICH. For some UEs at the cell center, although the interference is severe, the power of the desired signal is sufficiently high and can handle the interference problem. So for the UEs at the cell center, we do not need to shift the PHICH transmission to other subframes considering the latency performance. This means that the proposed method should be configured on a per UE basis. In order to avoid misunderstanding the problem, the eNB should know which served UEs are experiencing problems in receiving the PHICH, and this can be implemented through UE reporting. For example, the UE can measure the interference level of the interfering cell and then report the measurement results to the served eNB. The eNB can know whether or not the UE has a problem in receiving the PHICH by checking the report. Another possible way is for the UE to measure the interference level of the interfering cell. The UE judges if it has a problem in receiving the PHICH by comparing the measured results to some pre-defined values that are obtained from some numerical results, and providing feedback to the eNB. Furthermore, Fig. 5 shows an illustration of the flow chart for the proposed method. Here we briefly describe the overall procedure. The victim eNB should obtain the ABS pattern configuration of the interfering eNB, and inform the UE of the ABS pattern and the pre-defined rule (the pre-defined rule refers to finding the nearest available subframe with a lower level of interference in this paper) to determine the PHICH subframe location. Subsequently, the eNB should obtain a report from each UE to determine which UE has a problem in receiving the PHICH in the original subframe. Also, the UE can determine if it has a problem in receiving the PHICH itself. The eNB transmits the PHICH in the determined subframe applying the pre-defined rule for these UEs that have a problem in receiving the PHICH. In this step, coordination between eNBs may be needed.

B. Analysis of Proposed Method

In this section, we give a brief analysis of the proposed method and compare it to the conventional method based on the PHICH performance, delay performance, and signaling cost. Quantitative analysis can be found in the simulation results. From the PHICH performance aspect, we change the synchronous downlink HARQ feedback metric to an asynchronous metric. The PHICH is always transmitted in the subframe with a lower level of interference in the proposed method, and improvement in the PHICH performance is expected. From the delay performance aspect, although the delay for each re-transmission is increased, the average re-transmission delay can be decreased due to more reliable reception of the PHICH. From the signaling cost aspect, although the subframe that carries the PHICH varies, the signaling cost is relatively low since the pre-defined rule to determine the PHICH subframe is given.

IV. Simulation Results

In the simulation, there are two cells: one is the target cell and the other is the interfering cell. For the target cell, normal transmission including the PHICH is presented in the control region. For the interfering cell, we assume that an ABS is configured, reference signals and one physical downlink control channel (PDCCH) with eight control channel element (CCE) aggregation levels are transmitted in the ABS. The target cell is only interfered in the resources where the interfering cell has data transmission. We compare the PHICH performance for two cases. One case is for the conventional method in which the PHICH is transmitted in the original subframe for the victim cell. The other case is for the proposed method in which the PHICH is shifted to the nearest available subframe with a lower level of interference as explained in Section III. In the subframe with a lower level of interference, only the reference signals interfere with the PHICH transmission. In Table I, we give the detailed simulation parameters.

TABLE I
Simulation Parameters

Parameters	Values
System bandwidth	5MHz
Target quality	PHICH performance
PHICH duration	1 or 3 symbols
Number of PHICHs	1
Control region size	2 or 3 symbols
Channel model	LTE EVA3
Channel estimation	MMSE
Number of antennas	2

Fig. 6 and Fig. 7 show the performance comparison of PHICH bit error rate (BER) with different Signal to Noise Ratios (SNRs) for different control region size cases (3 symbols and 2 symbols control region sizes respectively). The SNR in the figures is defined as the received desired signal power from the target cell divided by the noise power. The interference level, e.g. 0/10/20 dB, in the figures is defined as the ratio between the received interference power from the neighboring cell and the target cell's signal power. This represents the interference condition for UEs with different locations. In the simulation, we also present the PHICH performance for a single cell case as a reference (labeled as "No interference"). Since there is no interference from the other cells, the PHICH performance is the best. As observed, the PHICH BER is decreased as the SNR increases, and the proposed method can significantly improve the performance especially when the interference level is high. This is because in the proposed method, we shift the PHICH transmission to the nearest subframe with a lower level of interference, so the PHICH performance is sure to be improved. The other observation is that the performance improvement for 3 symbols control region size case is larger than that for 2 symbols control region size case, this is because when the control region size is changed from 2 to 3 symbols, the PHICH ratio incurring interference decreases much faster for the proposed method compared to that for the conventional method. Thus, the performance improvement is larger for 3 symbols control region size case.

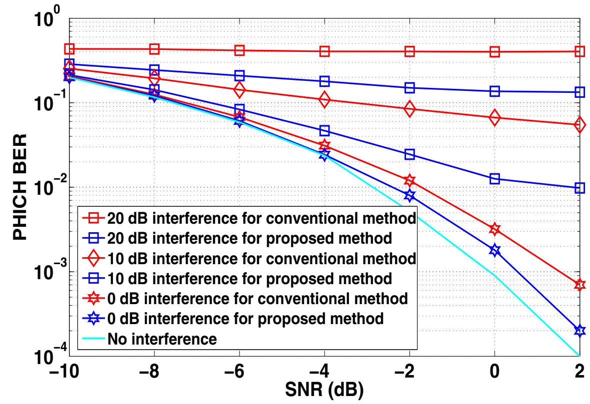

Fig. 6. PHICH performance for 3 symbols control region size

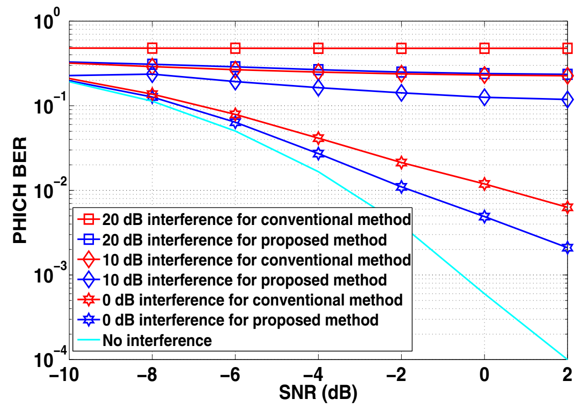

Fig. 7. PHICH performance for 2 symbols control region size

We compare the re-transmission delay performance of the proposed method to that of the conventional method for both FDD and TDD systems. The re-transmission delay performance metric was presented in Section II for the conventional method. For the proposed method, we give the delay performance metric similarly in (3) and (4).

$$T_{FDD}^{Delay} = \sum_{i=1}^{N} (9.5 + 10 * (i-1)) * P_e^i * P_c^i, \quad (3)$$

$$T_{TDD}^{Delay} = \sum_{i=1}^{N} (11.5 + 10 * (i-1)) * P_e^i * P_c^i, \quad (4)$$

where P_e^i and P_c^i have the same meaning stated in Section II. Here, we further explain the equation of the delay performance for the proposed method. We take an FDD system as an example. For the first re-transmission of downlink ACK/NACK information, considering that the subframe for the transmission of system information is fixed in a frame (subframes $0, 4, 5$ and 9 in an LTE-A system), if the collision problem occurs in subframe 0 or 5, we shift the PHICH subframe to 1 or 6 (one subframe after the legacy subframe location). If the collision problem occurs in subframe 4 or 9, we shift the PHICH subframe to 6 or 1 (two subframes after the legacy subframe location). Considering the four possible collision cases with equal probability, the ACK/NACK transmission time for the proposed method is increased by $1 * 0.5 + 2 * 0.5 = 1.5$ subframes compared to the conventional method.

The delay performance comparison is illustrated in Fig. 8 for the FDD system and Fig. 9 for the TDD system. The delay in the figures is the re-transmission delay stated above. We observe that the proposed method improves the performance when the interference level is high. This is because the probability of reception error for the PHICH is higher for the conventional method, and the re-transmission delay is increased by repeated re-transmissions. For the proposed method, although the delay for each re-transmission is increased, the average re-transmission delay is lower due to more reliable reception for each PHICH transmission. We also observe that the performance improvement from the proposed method for the TDD system is much larger than that for the FDD system. This is because the average shifted number of subframes for the TDD system is much less than that for the FDD system compared to the conventional method as calculated in (3) and (4).

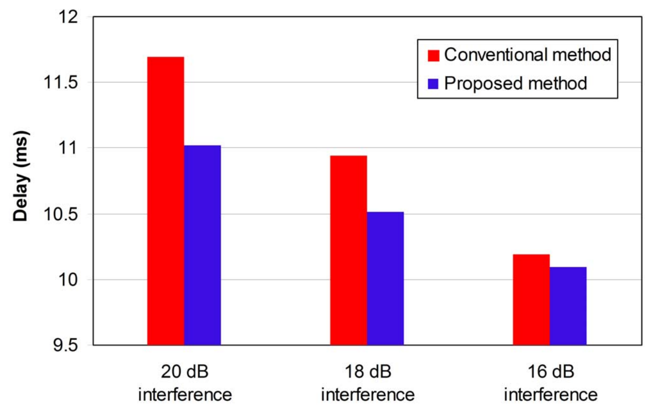

Fig. 8. Delay performance comparison for FDD system

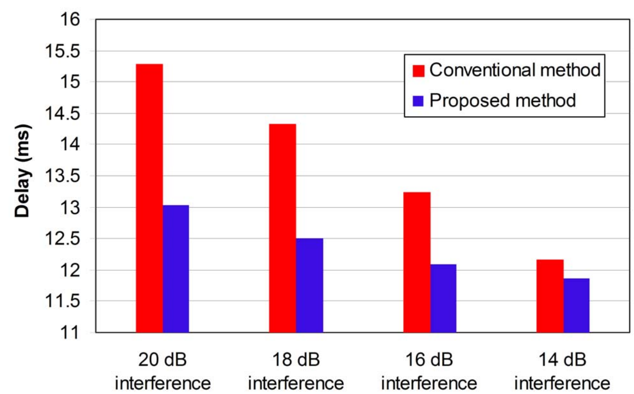

Fig. 9. Delay performance comparison for TDD system

V. Conclusions

In this paper, we presented a novel method to improve the PHICH performance for co-channel HetNet scenarios. In the proposed method, UEs that have a problem in receiving the PHICH in the original subframe are first recognized based on a measurement report. Then by changing the timing and shifting the PHICH transmission to the nearest subframe with a lower level of interference, the PHICH performance is significantly improved. Here, coordination between the interfering and victim cells may be needed. As shown in the simulation results, the proposed method has a large advantage from the PHICH BER and delay performance viewpoints compared to the conventional method.

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