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Optimization of PDCCH blind detection method in LTE-A system

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Abstract. In LTE-A system, physical downlink control channel (PDCCH) plays a key role in system scheduling. In order to overcome the high complexity of the conventional blind detection method which leads to the low efficiency of the terminal receiving PDCCH, the improvement is made on the basis of the conventional blind detection method. Using the channel indication information reported by UE terminal to get the current channel condition, and the optimal blind detection level is selected according to the current channel condition, and the blind detection range can be narrowed. When the downlink control information is successfully detected, mark its location, Same PDCCH candidate can be avoided duplicate detection, and optimized the condition of blind multiple DCI detection. By simulation, the improved method effectively reduces the number of times required for blind detection, and improves the efficiency of blind detection.

1. Introduction

LTE-A is an evolved version of LTE. In order to meet the requirements of people for the speed and accuracy of wireless communication systems, LTE-A not only maintains backward compatibility, but also adopts key technologies such as carrier aggregation, enhanced multi-antenna, multi-point coordinated transmission, relay, and heterogeneous network interference coordination enhancement [1], which greatly improves the peak of wireless communication systems. The rate and peak spectrum efficiency improve the cell system capacity and improve the performance of the cell edge users.

In the LTE-A system, PDCCH carries Downlink Control Information (DCI), and includes scheduling information of uplink and downlink data transmission and terminal power control commands. Therefore, whether the UE terminal can detect the required DCI information accurately and quickly is of great significance to improve the system efficiency. The eNodeB selects one of the possible PDCCH candidates to send information to the UE terminal according to the LTE-A protocol. For the UE terminal, the information type of the PDCCH transmission and the location of the required information can not be known. However, the UE terminal knows what kind of information it needs, then it should conduct the blind detection on all PDCCH candidates to find the required information.

2. PDCCH receiving process

The 3GPP protocol specifies that the control region mapping order of the downlink subframe is: first mapping Reference Symbol, then PCFICH and PHICH, and finally mapping the remaining resources to PDCCH. Therefore, the UE terminal should detect PBCH, PCFICH and PHICH before detecting PDCCH, to obtain the number of resources occupied by PDCCH. The whole PDCCH receiving
process is shown in Figure 1. The key parts include channel estimation, MIMO detection, QPSK demodulation and blind detection of PDCCH [2]. The blind detection module includes a de-rate matching module, a Viterbi decoding module, and a CRC check module. The data input to the PDCCH blind detection module is the merging of the descrambled DCI information. It needs to perform de-rate matching and Viterbi decoding operations, then use a specific RNTI sequence to descramble and perform CRC check. If the check result is successful, the current DCI information is required.

Figure 1. PDCCH receiving process

In order to reduce the complexity of blind detection, the protocol defines the concept of search space, and the available CCEs are divided into a common search space and a UE-specific search space. When the PDCCH is blindly detected, the public search space is first used, and then the UE specific search space. At the same time, the protocol also defines four PDCCH formats, corresponding to four Aggregation Level (AL) [3], and their relationship with the search space is shown in Table 1:

Table 1. Correspondence between search space and PDCCH resources

| Type of search space       | Aggregation level | PDCCH format | Number of PDCCH candidates |
|---------------------------|-------------------|--------------|----------------------------|
| Common space              | 4                 | 2            | 4                          |
|                           | 8                 | 3            | 2                          |
| UE-specific space         | 1                 | 0            | 6                          |
|                           | 2                 | 1            | 6                          |
|                           | 8                 | 3            | 2                          |

3. Conventional Blind Detection Method

In the conventional PDCCH blind detection method, in order to obtain the required DCI information, the UE terminal will generally detect all PDCCH candidates in the search space according to the ascending or descending order of the aggregation level. The PDCCH candidate under each aggregation level needs to perform de-rate matching, Viterbi decoding, and CRC check operation. The steps of the conventional blind detection method are described below.

1. Get the number of CCES: After de-mapping, demodulating, and descrambling the received data, the UE terminal will obtain the data that multiplexed by the PDCCH of the sending end, which is used as input data of the blind detection module. This data is in bits and then the data length is divided by 72 to get the total number of CCEs (i.e. $N_{CCE}$). The CCEs are labeled from the IDS 0 to $N_{CCE,A-1}$, and $k$ is the number of sub-frames [4].

2. Determine the radio network temporary indication (RNTI) for CRC descrambling and DCI format: The UE terminal determines the RNTI of the descrambling CRC and the DCI format to be detected by the DCI information that it expects [5].
3. Calculate the starting position of blind detection: Since the UE terminal cannot know the aggregation level \( L \) of the PDCCH, blind detection is started from the minimum or maximum aggregation level of the search space. The formula for calculating the starting position is:
\[
L \cdot \left( \frac{N_{\text{CCE}}}{L_{\text{MIN}}} + m \right) \mod \left( \frac{N_{\text{CCE}}}{L_{\text{MIN}}} \right) + i.
\]

4. Processing input data: De-rate matching, Viterbi decoding, and RNTI descrambling, and CRC check are performed on all PDCCH candidates under the current AL.

5. If the CRC check is successful, the information in the DCI format is recorded. Otherwise, the next aggregation level is selected according to ascending or descending order, and steps 3,4 are repeated until the terminal obtains the required DCI, or all PDCCH candidates are detected. And the blind detection is ended.

Although the conventional PDCCH blind detection method is simple to implement, its efficiency is very low. In the non-ideal case, blind detection is required 44 times. For the case of carrier aggregation, each member carrier needs to be blindly detected, and the amount of calculation is considerable, which increases the system delay. In this case, an improved method is proposed, which adds a feedback mechanism to the conventional blind detection method, so that the terminal will give priority to the most likely aggregation level to blind detection in order to reduce the number of blind detection. The UE terminal can preferentially select the most possible aggregation level for blind detection to reduce the number of system blind detection.

4. Improved blind detection method

When the eNodeB sends data to the UE terminal, the channel quality affects the eNodeB’s selection of the PDCCH aggregation level. To ensure that the transmitted information is accurately received by the UE terminal, the eNodeB selects a PDCCH candidate with a high aggregation level to carry the DCI information when the channel quality is poor, and when the channel quality is good, the PDCCH candidate with low degree of aggregation is selected to carry the DCI information to improve the utilization of system resources. Channel Quality Indicator (CQI) is defined in the protocol. The range of CQI is from 1 to 15. The mapping relationship between CQI and SNR is that the SNR value can be adjusted to an acceptable 10% BLER under the corresponding modulation mode and bit rate. The corresponding SNR value is the selected CQI value. The eNodeB estimates the current channel quality according to the value of the CQI reported by the UE. According to the previous theoretical analysis, the UE terminal can also use the CQI value to predict the current channel condition change, and combine the aggregation level of the previous successful blind detection to select the largest possible aggregation level \( L \) as the reference for the next blind detection. Compared with the conventional blind detection method, the improved method can effectively reduce the number of blind detection.

The improved blind detection method records the CQI value of the blind detection every time the blind detection is successful. The CQI values of the last two successful blind detections are \( CQI_1 \) and \( CQI_2 \), let \( N = CQI_{i+1} - CQI_i \), and judge the size of \( N \). When \( N > 0 \), it indicates that the channel condition is getting better. At this time, the blind detection should start with the aggregation level of the previous successful blind detection, and then search in the direction of decreasing the aggregation level. When \( N < 0 \), it indicates that the channel quality is declining. At this time, the blind detection should start with the aggregation level of the last successful blind detection and search in the direction of increasing the aggregation level. In the case of \( N = 0 \), the channel quality is stable. We should first detect the aggregation level of the previous successful blind detection. If the desired DCI is not detected, the search is continued in the direction in which the aggregation level is incremented or decremented. Blind detection is ended when the required DCI is detected, or all aggregation levels are traversed.

In some cases, the UE terminal may expect more than one DCI information, such as the authorization for uplink to transmit PUSCH and the indication for downlink to receive PDSCH. In this case, the UE terminal needs to detect two DCIs. If we use the conventional blind detection method, we need to repeat the whole blind detection process many times, which results in low efficiency of blind detection. When the eNodeB sends DCI information, each PDCCH candidate can only carry one DCI information. Therefore, the PDCCH candidates for successfully detecting the DCI can be excluded.
reduce the number of unnecessary detections. Specific methods: After successfully detecting one DCI information, the location information of the PDCCH candidate that carries the DCI is recorded, that is, the range of the subscript of the CCE included in the PDCCH candidate is marked. When detecting the next DCI, the first step is to check whether there is a record of successful detection of DCI PDCCH candidates. If so, for the current aggregation level, all PDCH candidates containing the marked CCEs will be skipped directly during blind detection.

The improved blind detection method uses SQI to feed back the channel quality, so as to select the optimal aggregation level for the blind detection, and optimize the situation that the terminal needs to blindly detect multiple DCIs. Taking the terminal to detect two DCIs as an example, for the conventional blind detection algorithm, in a non-ideal situation (when the channel quality suddenly changes drastically), a single carrier needs to be blindly detected 88 times. For the improved blind detection method, in the non-ideal case, the first DCI takes 44 times. When detecting the second DCI, the aggregation level is quickly determined according to the aggregation level when the current CQI and the first DCI detection succeed, and the detection is performed up to 5 times. The principle of the improved blind detection method is shown in the following figure 2:

```
Start

Select AL according to CQI

There are PDCCH candidates Location record?

Y

Skip the PDCCH candidate

Detecting DCI

Successful detection?

Y

Select next PDCCH candidate

N

Store the DCI and the location of the PDCCH candidate

Complete all PDCCH candidate detections

N

Is there any DCI that needs to be detected?

Y

End

N
```

**Figure 2.** Improved blind detection method
5. Simulation and result analysis

According to the flow of the PDCCH transmitting end and the receiving end specified in the LTE-A standard, the PDCCH simulation link is simulated on Matlab 2010b, and the improved method is compared with the conventional method. The simulation parameters are shown in the following Table 2:

| Parameters       | Simulation values |
|------------------|-------------------|
| Downlink bandwidth | 10MHz(50RB)       |
| Subframe number   | 1                 |
| Modulation mode   | QPSK              |
| Transmission mode | TM9               |
| DCI type          | DCI0/DCI1         |
| Noise type        | Gaussian noise    |

Figure 3. Comparison of two blind detection methods for detecting DCI times

It can be seen from the figure 3 that when the SNR is low, whether it is detecting one DCI or detecting two DCIs, the efficiency of the improved blind detection method is significantly better than the conventional blind detection algorithm. And with the increase of SNR, the number of blind detection of the two blind methods is getting closer. Because, as the SNR increases, the channel quality becomes better, and the transmitting end uses a lower aggregation level. In this simulation, the conventional blind detection method detects in order of aggregation level from low to high, so, the efficiency of the two blind detection methods is getting closer. When detecting two DCIs, it can be seen from the figure that the number of detections of the improved method is significantly less than that of the conventional method.

6. Conclusion

This paper proposes an improved method for the drawbacks of the conventional PDCCH blind detection method. The UE terminal predicts the aggregation level at the next blind detection according to the change of the CQI, and optimizes the blind detection of multiple DCIs by the terminal. Through simulation and analysis, compared with conventional blind detection method, the improved blind detection method has significantly improved the efficiency, which proves that the improved method is feasible and effective.

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