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Interference Management and Traffic Adaptation of Femto Base Station based on TD-LTE

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Abstract

As a mainstream technology in the 4G systems, TD-LTE (Time Division-Long Term Evolution) introduces Femto nodes to improve spectral efficiency per unit area. However, inter-cell cross-slot interference and uplink/downlink configuration are the key problems in TDD (Time Division Duplexing) system. In the paper, a traffic adaptation scheme with consideration of traffic demands and interference level is proposed to select optimal uplink/downlink configuration and efficiently improves system capacity.

Keywords: *TD-LTE; Femto; cross-slot interference; traffic adaptation; uplink/downlink configuration*

1. Introduction

LTE-Advanced, adopted as future international standard for 4G by ITU, will lead the trend of the development of future communication. The simultaneous evolution pattern of TDD (Time Division Duplexing) and FDD (Frequency Division Duplexing) formed from the beginning of the LTE/LTE-A system standardization [1], our country vigorously advocates the TDD duplex mode. In October 2012, our country determined to make all the 2.6GHZ band to TDD spectrum, which will greatly accelerate the commercial process of the TD-LTE. Compared with the FDD mode, the LTE system of TDD mode can provide flexible deployment without the requirement of spectrum resources pair. In order to share all spectrum uplink/downlink, TDD system does not allow simultaneous configuration, and keeps time synchronization strictly between different base stations [2]. While interference problem between neighborhoods is more serious in OFDM system, configuration design of TDD will bring new interference-inter-cell cross-slot interference.

In order to meet the demand of IMT - Advanced and get more cell division gain, 3GPP (The 3rd Generation Partnership Project) introduced the new Femto base type based on the LTE heterogeneous network. Because it is usually deployed in family environment, it is known as Femto cell at the beginning. According to their demand, Home users can flexibly deploy Femto site. Through the Internet or the Femto cell gateway access network operators, the base station can provide high-speed download rate and VoIP business. While such layered network architecture will make inter-cell cross-slot interference more complex, there may be a direct threat to the system gain of heterogeneous network deployment of TDD. Therefore, research of the uplink/downlink interference management and Adaptation enhanced in TD-LTE system has appeared in LTE R11 version(Further Enhancements to LTE TDD for DL-UL Interference Management and Traffic Adaptation, eIMTA) [3]-[6] at the RAN#51 conference in

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3GPP. The selection of frame uplink/downlink configuration for Femto base station will decrease the cell capacity due to more serious inter-cell cross-slot interference while only considering the cell traffic demands, and will not satisfy user's business demand while only considering inter-cell cross-slot interference.

Based on the mentioned problems, this paper firstly analyzes various of inter-cell cross-slot interference scenarios and evaluates the interference level, then a traffic adaptation scheme with consideration of traffic demands and interference level is proposed to efficiently improve system capacity in Femto. The proposed scheme can effectively solve the problem of serious inter-cell cross-slot interference at low complexity.

2. System Model and Interference Analysis

2.1. TD-LTE Timeslot Structure

As one of the 4G standards, TD-LTE system evolutes from the TD-SCDMA (Time Division-Synchronous Code Division Multiple Access). So the frame structure inherited the design ideas of the TD-SCDMA system. TD-LTE frame structure includes two types of 5ms cycle and 10ms cycle. In the 5ms cycle, subframe 1 and 6 is configured as the special subframe; while in 10ms cycle, subframe 1 is configured as a special subframe. The rest subframe of the two types is configured as uplink/downlink subframe. At present, TD-LTE allows asymmetric uplink /downlink configuration, as shown in Table 1, and can provide seven different uplink/downlink configurations by semi static to meet different load demand. It can provide 25%minimum, 90% maximum downlink sub frame. As one of the biggest advantages of TDD system, these seven different uplink/downlink allocations greatly satisfy various of uplink/downlink traffic demands, and make you can configure the system resources flexibly.

Table 1. Rate Configuration List of UL/DL Subframe

configuration		0	1	2	3	4	5	6
Switching Cycle (ms)		5	5	5	10	10	10	5
Number Of Subframe	0	D	D	D	D	D	D	D
	1	S	S	S	S	S	S	S
	2	U	U	U	U	U	U	U
	3	U	U	D	U	U	D	U
	4	U	D	D	U	D	D	U
	5	D	D	D	D	D	D	D
	6	S	S	S	D	D	D	S
	7	U	U	U	D	D	D	U
	8	U	U	D	D	D	D	U
	9	U	D	D	D	D	D	D
Downlink Subframe ratio		25%	50%	75%	67%	78%	89%	38%

2.2. Interference Analysis Principle

According to the difference of deployment band of Macro station (Macro evolved NodeB, MeNB) and Femto base stations (Femto evolved NodeB, FeNB), we can divide them into two modes. One is the intra-frequency networking mode with high frequency of reuse efficiency; the other is the inter-frequency networking mode, with low frequency of reuse efficiency and smaller influence on the existing macro cellular networks. The intra-frequency networking mode has intra-frequency interference, *i.e.*, the useless signal and useful signal received by a receiver is completely the same, and useless signal will interfere in source receiver decoding, which cause the decoding error .Interference calculation of intra-frequency interference is simple, just to add the numbers of various interference signal and then analysis. Under the inter-frequency networking mode, there is adjacent frequency interference between macro cell and Femto cell. *i.e.*, the useless signal and useful signal received by a receiver has different but adjacent frequency, and the adjacent signal of the intruder power into the receiver and cause interference. Adjacent frequency interference is partly caused by the transmitter and receiver filter band-pass characteristics and sensitivity of the radio frequency. Adjacent frequency Interference is not superposition calculation directly and have to use a different carrier frequency coexistence of Adjacent Channel Interference Ratio (Adjacent Channel Interference the wire, ACIR) model to measure:

$$ACIR = \frac{1}{\frac{1}{ACLR} + \frac{1}{ACS}} \qquad (1)$$

The adjacent channel leakage ratio (ACLR) is defined as the transmitting power and the adjacent channel on the measured power ratio; Adjacent Channel Selection（ACS) is defined as the receiver filter in the specified channel frequency on the attenuation and the adjacent channel frequency on the attenuation ratio, relates to filter the window; ACIR is in the simulation fitting a model of factors value fitting correlated interference.

2.3. The Scenarios and Analysis of the Cross-slot Interference

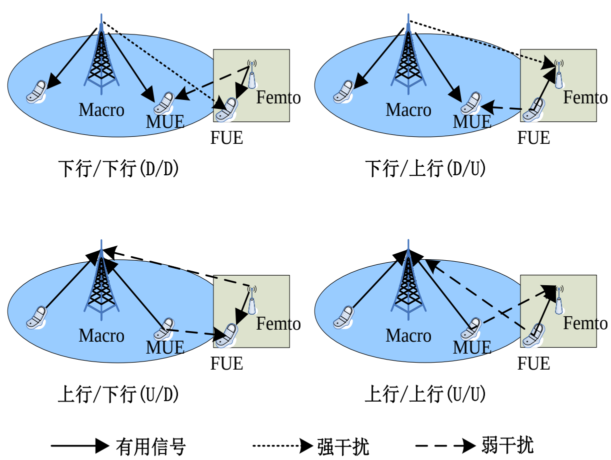

Figure 1. Interference Scenarios of Different UL/DL Configurations

While the macro cells and Femto cells respectively and independently choose the subframe configuration according to their traffic demands, whatever networking modes chosen, there may be four kinds of cross-slot interference scenarios due to the seven uplink/downlink configurations. As shown in Figure 1. When the macro cell and Femto cell are in the downlink configuration, there are interference of macro station on the Femto users (Femto UE, FUE) and interference of Femto base station on the macro users (Macro UE, MUE). The downlink transmit power from the macro station is much heavier than the Femto base station.

When the macro cell is in downlink allocation and the Femto cell is in uplink allocation, the interference of macro station is more serious than the Femto base station due to the heavier transmitting power from macro station. Though there is interference of FUE on MUE, it is lighter due to FUE's lighter transmitting power.

When the macro cell is in uplink allocation and the Femto cell is in downlink allocation, due to the lighter transmitting power from Femto base station and FUE, the interference of macro user on Femto user and the interference of Femto base station on macro station is lighter, but exists.

When the macro cell and the Femto cell are both in uplink allocation, due to the lighter transmitting power from the users and the farther distance from the interference source, the interference of MUE on Femto base station and the interference of FUE on macro station is lighter, and can be neglected.

In order to analyze clearly and directly the different interference of every link allocation, Figure 2 shows the different interference level of the same frequency network under different scenarios. Taken the most serious interference of the macro station on FUE as the standard, the other interferences get their relative values. From Figure 2, we can get the same conclusion as our analysis: the interference of down/downlink and down/uplink allocation is more serious; the interference of up/downlink allocation is lighter, but in negligible; the interference of up/uplink allocation is lightest and negligible.

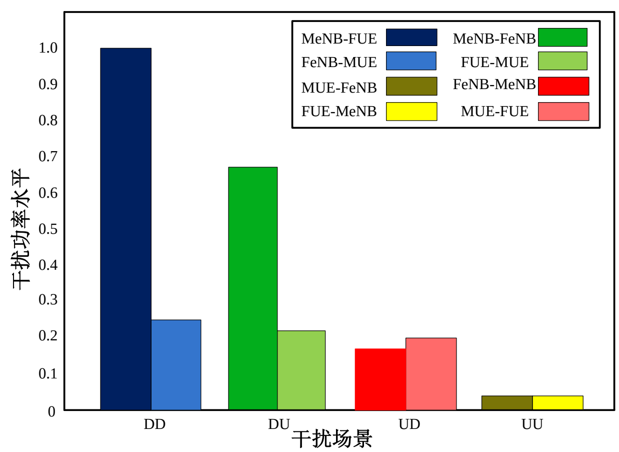

Figure 2. Interference Level of Intra-frequency Networking

3. Traffic Adaptive Scheme

The conclusion comes from above analysis of the interference of every link allocation can provide powerful evidence for Femto in the choice of uplink/downlink subframe configuration. Based on the business demands of Femto cell, and considering the level of the interference, we try to seek the most suitable uplink/downlink configuration to maximize the system capacity. In consideration of the complexity of the problem and the sequence of the procedure, the scheme proposed in this paper can be divided into two sub programs: The selection of uplink/downlink configuration sets and The selection of uplink/downlink configuration target.

3.1. The Selection of Uplink/Downlink Configuration Sets

This part of the process is to narrow the range of uplink /downlink allocation selection, according to the requirements of traffic demands and compromise cross-slot interference level system; the optional 7 uplink/downlink allocation can be reduced to kinds of uplink/downlink configuration. The method is to introduce the parameters Φ ,which is the tolerance of interference level to realize. Assume that the uplink/downlink business demand can be expressed by the downlink subframe ratio $\Upsilon(0 < \Upsilon < 1)$. For example, only consider the traffic demand, when $\Upsilon = 65\%$, the uplink/downlink service demand ratio is about 2:1, then the configuration 3 of the table 1 is more appropriate. But in reality, the downlink timeslot of macro cell may be more, and the down / downlink scenario is more concentrated, so the inter-cell cross-slot interference is more serious, eventually led to the system capacity decrease. Therefore we introduce the interference level tolerance Φ to extend range of selective uplink/downlink configuration in Femto cell, rather than only choose the only one configuration that closest downlink sub frame ratio Υ to the traffic needs corresponding. So the range of new downlink sub frame ratio Υ^* updated to

$$\Upsilon - \Phi < \Upsilon^* < \Upsilon + \Phi \qquad (2)$$

The value of Φ is determined by the Femto base station, the bigger of Φ , the smaller the system can tolerate. The more optional uplink/downlink configurations are needed to find the optimal configuration which can reduce the interference level. On the contrary, the larger the interference system can tolerate, it will not need too much downlink configuration selection, and focus on traffic demands. We get the traffic demands of the Femto cell, Femto base station calculate the downlink sub frame ratio Υ first, and then calculate the new downlink subframe ratio Υ^* according to the interference tolerance of the system. Finally, we make comparisons the range of Υ^* with subframe downlink ratio of seven uplink/downlink configuration, if in the range it can included in the optional uplink/downlink configuration set. The whole process is only related with the Femto cell, the macro cell is independent, and there is no need to collect any information of the macro cell.

3.2. The Selection of Uplink/Downlink Configuration Target

According to the above process, after getting the optional uplink/downlink configuration set, we need to choose a most suitable configuration further. This part is mainly based on the uplink/downlink configuration allocation of the macro cell, considering more about inter-cells cross-slot interference. The core idea is to seek an up/downlink configuration for Femto cell to minimize the inter-cell cross-slot interference with macro cell. And how to determine the degree of interference is the key of this sub scheme.

According to the theoretical analysis and simulation results above, different up /down scenario may have different interference levels. Down / downlink scenario interfered most, next is down / uplink scenario and up / downlink scenario, and up / uplink scenario has the minimum interference. Therefore, according to the Femto cell and the macro cell user distribution and other relevant information, for each downlink scenario of the inter-cell interference, we set an interference level weights λ_{DD} , λ_{DU} , λ_{UD} , λ_{UU} to represent the comprehensive interference levels. The specific values of four weights by the base station and user deployment are set in advance, and their relationships are

$$\begin{cases}\lambda_{DD} > \lambda_{DU} > \lambda_{UD} > \lambda_{UU} \\ \lambda_{DD} + \lambda_{DU} + \lambda_{UD} + \lambda_{UU} = 1\end{cases} \quad (3)$$

Compare the 10 subframes of each configuration elements of Femto cell downlink configuration in the collection and the macro cell downlink configuration of the 10 sub frames. If it is the downlink / downlink scenario, then $\lambda_n = \lambda_{DD}$, and $\lambda_n = \lambda_{DU}$ when it is downlink/uplink scenario, $\lambda_n = \lambda_{UD}$ when it is uplink/downlink scenario, $\lambda_n = \lambda_{UU}$ if it is uplink/uplink scenario. After comparing the ten subframes, select the uplink/downlink configuration which satisfies the following condition as the Uplink/downlink configuration of the Femto cell.

$$\min\{\sum_{n=0}^{9} \lambda_n\} \quad (4)$$

Choose quantization with minimum interference level of a downlink configuration as the Femto uplink/downlink configuration in the collection of the optional uplink/downlink.

In a word, the traffic adaption scheme should consider the cell service demand factors into optional uplink/downlink configuration set first, and then choose a most suitable uplink/downlink configuration in the set range according to the cross-slot interference factors.

4. Simulation Results and Analysis

In order to evaluate the performance of our adaptive scheme, we deployed the TD-LTE platform of Femto. For Femto point distribution, this paper uses Dual-stripe model which is commonly used in 3GPP. Full buffer model is used as the platform business model to ensure there is a steady stream of interference. Randomization scheme and traffic adaptation scheme are used as reference. Randomization scheme makes Femto choose up/downlink configuration randomly without considering the traffic demands. Traffic adaptation scheme is a rapid scheme for Femto base station only to consider the traffic demands and neglect the interference level.

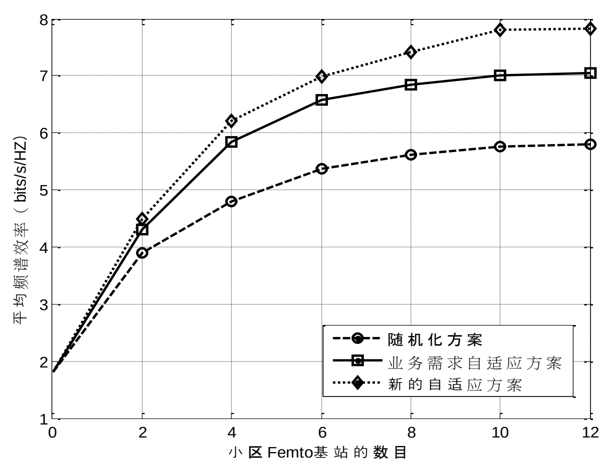

Figure 3. System Capacity of Intra-frequency Networking

Figure 3 shows the average spectral efficiency of different scheme for the Femto cell and macro cell in intra-frequency networking. From Figure 3 we can see a traffic adaptation scheme has a better performance of system capacity than Randomization scheme and adaptation scheme which only considers the traffic demands. Because of non-considering of any factors on up/downlink configuration according to the resource and demands, randomization scheme has a poor system performance. And the traffic adaptation scheme with consideration of traffic demands can change uplink/downlink configuration flexibly, so the performance of the system get more promoted; Traffic adaptation scheme proposed in this paper not only consider the traffic demand, but also take the inter-cell interference into consideration, so it is effective on prevent certain up/downlink configuration interference from influencing the system performance. From figure 3 we also can see cell system capacity gradually increase with the number of Femto base stations, and the extra gains of the proposed scheme is more obvious.

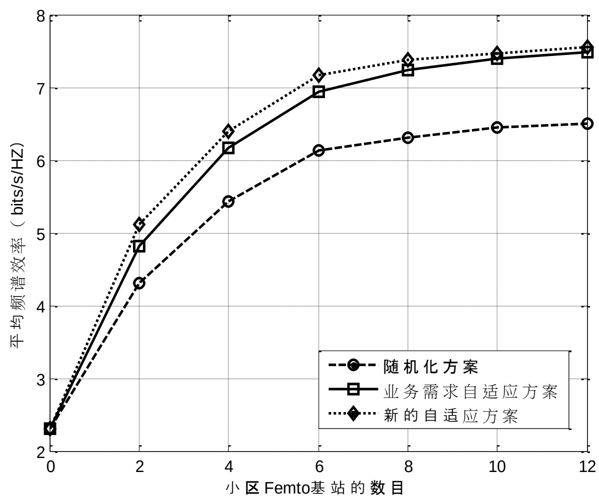

Figure 4. System Capacity of Inter-frequency Networking

Figure 4 shows the average spectral efficiency of different scheme for the Femto cell and macro cell in inter-frequency networking. From Figure 4, we can draw the same conclusion from inter-frequency networking as intra-frequency networking, and the scheme proposed can also provide the best system performance. Unlike the conclusion, compared with the others, the scheme proposed in this paper can provide more performance improvement in intra-frequency networking than inter-frequency networking, because the inter-cell cross-slot interference in intra-frequency networking is more serious and the advantage of the scheme proposed to harmonize the inter-cell interference can be reflected more obviously.

5. Conclusion

In this paper, we propose a uplink/downlink configuration traffic adaptation in TDD system. We firstly calculate the uplink/downlink configuration according to traffic demands, and then based on the inter-cell cross-slot interference level seek the most suitable configuration to effectively improve the performance of the system with also has the universality of the network mode.

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