Inter-Cell Interference Coordination (ICIC) Technology

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Long Term Evolution (LTE) is a promising standard for next-generation cellular systems targeted to have a peak downlink bit rate of 150 Mb/s. However, as adjacent cells use the same frequency, interference between adjacent cells may degrade the bit rate at cell edges, preventing sufficient throughput from being obtained. Inter-cell interference coordination (ICIC) is a promising technology for alleviating this degradation and improving the bit rate at cell edges. In the LTE standard, an interface between adjacent base stations is specified for exchanging ICIC information. However, no methods or control algorithms have been specified for using this interface, leaving it to base station vendors to develop them on their own. This paper outlines ICIC technology in the LTE system, describes the original ICIC algorithm we have developed, and discusses its evaluation.

1. Introduction

As an extension of the third-generation mobile communications system, the Long Term Evolution (LTE) system is aimed at achieving high spectral efficiency through the use of a one-cell-reuse frequency allocation system that allocates the same frequency to adjacent cells, the same as in the third-generation system.[note 1)] In a one-cell-reuse system, however, there is much interference between cells, which may prevent sufficient throughput from being obtained at cell edges. The need was therefore felt for making further improvements in LTE spectral efficiency, and to this end, a throughput at a cell edge throughput 2-3 times that of the high speed downlink packet access/high speed uplink packet access (HSDPA/HSUPA) 3.5th generation mobile communications system was established as a target.[1)] In light of the above, the 3rd Generation Partnership Project (3GPP)—the LTE standardization body—energetically discussed drawing up specifications for inter-cell interference coordination (ICIC) as a technology for reducing inter-cell interference and improving throughput at cell edges. These discussions resulted in the specification of an interface between base stations (the X2 interface) for exchanging interference-coordination information.[2)] However, no methods or control algorithms have been specified by the 3GPP for using this interface, leaving it to base station vendors to develop them on their own.

In this paper, we first describe the basic principle behind ICIC technology and outline the interface between base stations specified in the LTE standard. We then describe the original ICIC algorithm that we developed to implement ICIC and present the results of computer simulations that we performed to assess the effectiveness of this algorithm.

note 1) In a mobile communications system, "cell" refers to a region in which radio signals from a specific base station antenna dominate.

2. ICIC operation principle

Figure 1 shows different frequency-

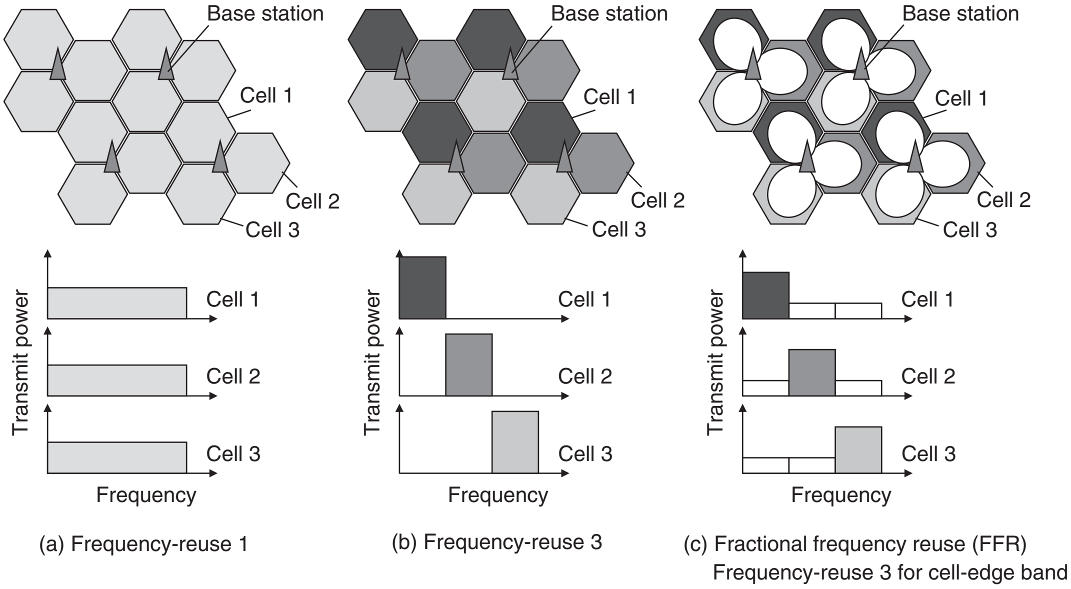

Figure 1
Frequency allocation methods for cellular systems.

usage scenarios when one base station is used to configure three cells (sectors). Inter-cell interference becomes a problem when the same frequency band is used for adjacent cells, as shown in Figure 1(a). This type of interference can be reduced by allocating different frequency bands to adjacent cells (frequency reuse), but this narrows the band that can be used by each cell, which reduces throughput, as shown in Figure 1(b). This is why frequency reuse is not executed in normal LTE systems, which instead use only one frequency in a method called "frequency-reuse 1." To resolve this issue, a method called fractional frequency reuse (FFR) was developed. As shown in Figure 1(c), the FFR method separates the frequency bands allocated to the areas near a base station where no signal interference from adjacent base stations occurs from the frequency bands allocated to the areas far from the base station where signal interference from an adjacent base station can occur. The transmit power is reduced and the frequency-reuse factor is set to 1 for the frequency band allocated to the cell area where no signal interference from adjacent base stations occurs, and conversely, the transmit power is increased and the frequency-reuse factor is set to 3 for the frequency band allocated to the cell area where signal interference from an adjacent base station can occur. This improves the signal to interference plus noise ratio (SINR) and throughput for users located at the cell edge without degrading spectral efficiency.

ICIC based on FFR is therefore considered to be an effective method for use in the LTE downlink. For the uplink, a method based on this principle (shifting the bands used by users in areas where signal interference from an adjacent base station can occur) should also be effective.

3. ICIC standardization

To implement FFR, the frequency band allocated to a user at a cell edge must be different from that allocated to another user in the adjacent cell, as shown in Figure 1(c). The LTE standard specifies an inter-base-station interface that enables adjacent base stations to exchange information on bands generating large interference in other cells and on bands that are affected by large interference from other cells.

The following describes interference-coordination signals that can be used for implementing ICIC in the downlink and uplink.

1) Downlink

The signal used for interference coordination in the downlink is called relative narrowband transmit power (RNTP). This signal can take a value of 0 or 1 and is sent to multiple base stations serving adjacent cells for each resource block (RB).[note 2] Specifically, this value is set to 0 if the ratio between the transmit power of the downlink signal allocated to the RB and the average transmit power of the system frequency band is guaranteed to be under a certain threshold and to 1 otherwise.[3] This scheme enables a base station to learn about an RB that may be transmitting at high power in an adjacent cell and to reduce interference by avoiding allocating that RB to a user experiencing poor reception. Increasing the transmit power above the system average for a user experiencing poor reception should also improve the quality of that user's reception.

2) Uplink

There are two types of signals for interference coordination in the uplink: high interference indicator (HII) and interference overload indicator (OI). The HII signal is used by a base station to notify to multiple base stations serving adjacent cells of the uplink RB it has allocated to a cell-edge user. This enables cell-edge users in adjacent cells to be allocated different bands, the same as in the downlink approach, which means that improved throughput can be expected for these cell-edge users. The OI signal, on the other hand, is used by a base station to notify to multiple base stations serving adjacent cells the results of measuring interference power for each RB and classifying those results into multiple levels. Thus, the base station of a cell that receives notification of high interference power from an adjacent cell can reduce the transmit power of its users and thereby reduce the amount of interference created in the adjacent cell.

note 2) RB is a unit of allocation in the frequency domain having a bandwidth of 180 kHz.

4. Proposal of original algorithm

4.1 Conventional interference-coordination method and associated problems

We decided to investigate the control signals introduced in the previous section for achieving ICIC and algorithms for using them. On examining techniques proposed at 3GPP standardization meetings, we found that a method for changing the transmit power of the cell-edge band on the basis of the RNTP from an adjacent cell had been proposed,[4] which we can treat as a conventional interference-coordination method. In this method, cell-edge bands are uniformly fixed, as in Figure 1(c). In actual cellular mobile communications, however, the following several factors make cell shape complex and difficult to predict.

1) Radio propagation characteristics differ in accordance with topography and buildings.
2) Base stations with different transmit powers and antenna heights coexist.
3) Distances between base stations are not uniform due to restrictions on where they can be installed.
4) User distribution is non-uniform, generating bias.

This makes it difficult to determine the cell-edge band for each cell. Moreover, the optimal cell-edge band can be considered to change over time. Thus, if the method for allocating cell-edge bands between adjacent cells is fixed, an optimal ICIC effect may be difficult to obtain.

4.2 Interference-coordination method considering user distribution

For ICIC based on FFR, it can be seen from the above discussion that a mechanism is needed to automatically determine the cell-edge band for each cell under various conditions such as a biased user distribution and non-uniform cell arrangement. At the same time, a variety of factors in actual cellular mobile communications as described above are likely to affect the distribution of signal quality for users within a cell. In response to this situation, we developed an original ICIC algorithm for LTE base station equipment to automatically optimize cell-edge bands by focusing on user distribution (in particular, receive-power distribution).[5] We outline the proposed algorithm below.

This ICIC algorithm adaptively selects a cell-edge band of a cell on the basis of coordination information from adjacent cells and notifies the base stations of the adjacent cells of the band selected. The base station of each cell uses the received information and the following equation to compute cell-edge-band metric A_k for each sub-band.

$$A_k = \sum_{j \in J} w_j X_{j,k}$$

Here, $X_{j,k}$ denotes received information on sub-band k from adjacent cell j. It takes a value of 1 for a cell-edge area and 0 otherwise (this information can be exchanged between base stations using the RNTP or HII signals). The symbol w_j denotes weight with respect to adjacent cell j, that is, the number of users for which the difference between the power of the signal received from the serving cell and the power of the signal received from the adjacent cell is less than a threshold value (i.e., the number of users near the cell edge in the service cell). In the example shown in **Figure 2**, a comparison of the received-power values from cells 0 and 1 indicates a user count at the cell edge of 2, resulting in weight w_1=2. Now, the sub-band for which cell-edge-band metric A_k is smallest is considered to be the band that would be least affected by interference from another cell. This area is selected as the cell-edge band of the serving cell, and the base stations of the adjacent cells are so advised. Repeating this process across all cells enables the allocation of frequency bands to cell-edge areas to be optimized over the system and to be adjusted with changes in user distribution.

In short, calculating weights that take user distribution into account and using these weights in the allocation of cell-edge bands can minimize interference between adjacent cell edges. A flowchart for the above sequence of operations is shown in **Figure 3**.

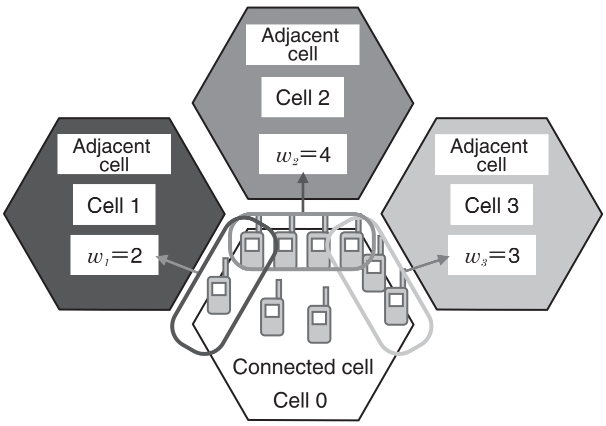

Figure 2
Example of determination of cell weights.

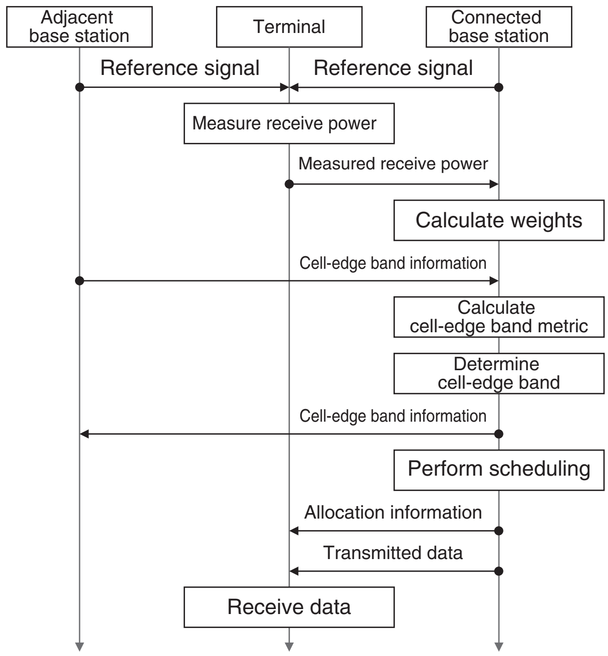

Figure 3
Flowchart for interference-coordination method considering user distribution.

5. Computer simulation

We evaluated the effectiveness of the proposed ICIC algorithm on the downlink by computer simulation. **Table 1** lists the simulation conditions. These conditions conform to the general conditions described in the 3GPP specifications: a configuration consisting of 19 base stations and 3 cells per base station for a total of 57 cells with 10 users per cell.[6] Users are distributed randomly within a cell, and shielding effects (shadowing) due to topography and buildings are taken into account, resulting in a model in which considerable variance exists in the distribution of signal quality for users within each cell. In the simulation, four methods were compared:

1) no ICIC
2) ICIC (fixed bands, frequency-reuse 3 at cell edge)
3) ICIC (proposed method, frequency-reuse 3 at cell edge)
4) ICIC (proposed method, frequency-reuse 4 at cell edge).

Method 2, using ICIC with fixed bands, divides the total system bandwidth into three sub-bands, each of which is allocated as a cell-edge band to one of the three cells configured by a base station, as shown in Figure 1(c). This method is considered to be optimal for cell-edge band allocation provided that signal quality distribution is uniform. The proposed method was simulated for two cases: three sub-bands and four sub-bands. Increasing the number of sub-bands can increase the frequency-reuse factor at the cell edge and therefore improve the quality of reception for users allocated a cell-edge band, but since this also narrows the bandwidth at the cell edge, throughput may drop. Increasing the frequency-reuse factor also makes it more difficult to determine optimal frequency allocation.

The simulation results are listed in **Table 2**. Cell-average throughput is the average throughput across the 57 cells, while cell-edge throughput is taken as the throughput that 95% of the users can receive. It can be seen that using ICIC improves cell-edge throughput without significantly decreasing cell-average throughput. Furthermore, for three sub-bands (frequency-reuse 3 at cell edge), cell-edge throughput with the proposed method is about the same as with ideal allocation using the conventional FFR method. For four sub-bands (frequency-reuse 4 at cell edge), cell-edge throughput is significantly improved (about 1.5 times compared to without ICIC). These results show that the algorithm proposed here can automatically allocate the most appropriate cell-edge bands regardless of the frequency-reuse number at the cell edge.

For the uplink as well, the automatic coordination of cell-edge bands should improve throughput for cell-edge users in the same way.

Table 1
Simulation conditions.

Item	Description
Cell layout	19 base stations, 57 cells (3 cells/base station)
Center frequency, bandwidth	2 GHz, 5 MHz
Antenna configuration	2-transmit, 2-receive MIMO (Multiple input multiple output)
Base-station transmit power	46 dBm
No. of users	10 users/cell
Cell radius	0.5 km
Fading frequency	1–200 Hz
Scheduling	Proportional Fairness[7]
Traffic model	Full buffer
Path model	Extended Pedestrian A[8]

Table 2
Simulation results.

Method	Throughput (kb/s)	
	Cell average	Cell edge
No ICIC	5543	86
ICIC (fixed bands, 3 sub-bands)	5387	121
ICIC (proposed method, 3 sub-bands)	5551	121
ICIC (proposed method, 4 sub-bands)	5623	131

6. Conclusion

This paper provided an overview of inter-cell interference coordination technology for use with the Long Term Evolution system and presented an original ICIC algorithm focusing on the distribution of users in a cell. The proposed algorithm enables stable interference coordination under various conditions and improves downlink throughput for users at cell edges by about 1.5 times compared to without ICIC.

As the future spread of LTE services makes mobile broadband a reality, improving transmission speed at cell edges will become a pressing problem. We intend to solve this problem and to contribute to the future expansion of mobile communications systems by applying our ICIC algorithm to LTE base station equipment.

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