

Dynamic Reservation Scheme of Physical Cell Identity for 3GPP LTE Femtocell Systems

Poongup Lee*, Jangkeun Jeong*, Navrati Saxena* and Jitae Shin*

Abstract: A large number of phone calls and data services will take place in indoor environments. In Long Term Evolution (LTE), femtocell, as a home base station for indoor coverage extension and wideband data service, has recently gained significant interests from operators and consumers. Since femtocell is frequently turned on and off by a personal owner, not by a network operator, one of the key issues is that femtocell should be identified autonomously without system information to support handover from macrocell to femtocell. In this paper, we propose a dynamic reservation scheme of Physical Cell Identities (PCI) for 3GPP LTE femtocell systems. There are several reserving types, and each type reserves a different number of PCIs for femtocell. The transition among the types depends on the deployed number of femtocells, or the number of PCI confusion events. Accordingly, flexible use of PCIs can decrease PCI confusion. This reduces searching time for femtocell, and it is helpful for the quick handover from macrocell to femtocell. Simulation results show that our proposed scheme reduces average delay for identifying detected cells, and increases network capacity within equal delay constraints.

Keywords: Femtocell, Physical Cell Identity (PCI), Access Control, Long Term Evolution (LTE)

1. Introduction

The 3rd Generation Partnership Project (3GPP) is working on the standardization of asynchronous communication systems. This technology is being enhanced gradually ensuring higher user data rate, bigger system capacity, and lower cost. The wideband CDMA (WCDMA) system is standardized with 3GPP release 99/4 which is being deployed in the world. Release 5 is related to High Speed Downlink Packet Access (HSDPA), and it improves the downlink packet transmission speed theoretically up to 14.4 Mbps. High Speed Uplink Packet Access (HSUPA) is enhanced up to 5.76 Mbps in uplink, and it is standardized with the Release 6. We simply mention both HSDPA and HSUPA as High Speed Packet Access (HSPA). In release 7, High Speed Packet Access Evolution (eHSPA, HSPA+) is standardized. eHSPA is based on the HSPA network with a simple upgrade, and it supports more bandwidth efficiency and lower latency. The maximum data rate is 28.8 Mbps in downlink and 11.5 Mbps in uplink [1]. How-

ever, users still require further system improvements. The technology is dramatically enhanced in release 8, where the standard of Long Term Evolution (LTE) is currently being established. The main objectives of LTE are higher data rates, lower latency, increased capacity, enhanced coverage, and an optimized system for the packet switching network [2]. LTE also considers a femtocell, which is referred to as a home base station for an indoor coverage extension and overall network performance enhancement [3]. Recently, LTE-Advanced standard targeting of 1Gbps for low mobility is being discussed in release 9.

We look into general features and requirements of femtocells. Important issues related to access control are described, followed by our contributions and organization of the paper.

1.1 Femtocells in 3GPP LTE

According to recent survey [5], a large amount of phone calls and data services will take place in indoor environments. At the same time, the proportion of home-equipped broadband Internet has increased rapidly. On the other hand, macrocell coverage has become awfully expensive for indoor users, whose service demands are very high. Under these circumstances, femtocell, as a home base station, has recently gained significant interest due to its various benefits for the operators and consumers.

Femtocell is defined as a low-cost, low-power indoor

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base station that operates in the licensed spectrum, and enables indoor connectivity via existing broadband Internet connections [3]. We can get numerous profits such as 1) improved indoor coverage, 2) increased system capacity by offloading users from the macrocell, 3) enhanced performance and Quality of Service (QoS), 4) reduced capital and operation expenses (CAPEX/OPEX), 5) compatibility with existing handsets, and 6) offering new services at home.

Femtocell has been actively discussed as Home evolved NodeB (HeNB) at early stages of the 3GPP LTE. Since the HeNB is included in the study items at the beginning of 2007, 3GPP has cooperated closely with the Femto Forum and the Broadband Forum. Finally it is announced that the world's first femtocell standard has been published by 3GPP in April 2009 [4].

However, several challenges still need to be solved before the femtocells are deployed, because its features are different from the macrocell. When the femtocells are deployed, the performance degradation of the backhaul network is expected due to the largely increased number of base stations. The femtocells are managed by a personal customer and not by a network operator. Also, it is turned on and off at home or the office at any time, and it is installed at an unknown location. If the femtocells are manually controlled, higher operational complexity and management costs are inevitable. In order to reduce the costs, many parameters need to be self-configured and self-optimized according to the surrounding conditions. For example, access control, mobility support, and interference management are included in these problems [6].

1.2 Important Issues Related to Access Control

Access control is one of the key problems to support various features of the femtocell, including mobility support [7-8]. In the LTE, User Equipment (UE) is designed to aware the femtocell, which should be efficiently searched. The UE should be able to distinguish a cell, whether it is a macrocell or a femtocell. If the UE is not interested in the femtocell, it avoids searching any femtocells and access is not allowed. When the UE is interested, it completes the searching procedure quickly. During the cell search, the UE consumes its battery power and generates signaling load to the core network. So, the access to the femtocell should be controlled in order to avoid unnecessary signaling, and to save the UE's battery power.

For efficient access control, identification of the femtocell is performed without system information. The femtocell broadcasts its system information, which includes an identifier that notifies whether the cell is a femtocell or not. However, the UE consumes its battery power to read the

system information, particularly when the femtocells are densely deployed.

Some functions related to how to search for femtocells are discussed. In autonomous search function, when the UE begins search, and which femtocell the UE will be accessed by are determined without human intervention. Otherwise, a personal user conducts a manual search function in order to start searching for and accessing the femtocell. From the self-configuration and self-optimization point of view, the autonomous search function is appropriate. Also in the 3GPP meetings, the autonomous search function has been agreed to support mobility [9].

Handover from the macrocell to the femtocell, namely inbound handover, is not specified in the LTE. The key challenge is how the serving macrocell identifies the target femtocell. Physical Cell Identity (PCI) is normally utilized to identify a cell in the macrocell systems, where the PCIs are enough for identification. However, the PCIs are not sufficient for the femtocell, because lots of femtocells would be deployed without planning. The same PCI could be allocated to several femtocells, but it may create a PCI confusion problem. When it is reported to the network that a PCI suffers from PCI confusion, it is not able to distinguish where the PCI comes from. The PCI confusion problem should be solved to support inbound handover.

Therefore, the femtocell should be identified autonomously without the system information to support inbound handover.

1.3 Our Contributions

For successful femtocell deployment, the access control issues such as identification of the femtocell, autonomous search function, and inbound handover should be solved. The PCI can be an attractive tool for resolving these problems. In the 3GPP radio access technologies, a range that includes PCIs for exclusive use by femtocell can be signaled [7]. Also, a subset of the PCIs can be reserved for specific purpose such as identification of the femtocells [10]. However, if a fixed number of PCIs are reserved for the femtocell, the PCI confusion problem is severe when the large amount of femtocells is deployed.

We propose a dynamic reservation scheme of PCI for the 3GPP LTE femtocell systems. There are several reserving types, and each type reserves a different number of PCIs for the femtocell. The transition among types depends on the deployed number of femtocells, or the number of PCI confusion events. Accordingly, flexible use of the PCIs can decrease PCI confusion. Dynamic reservation of PCI reduces the searching time for femtocell, and it is helpful for the quick handover from the macrocell to the

femtocell.

1.4 Organization of the Paper

This paper discusses femtocell systems in the LTE regarding access control issues, particularly cell identity management. The rest of this paper is organized as follows: Section 2 presents the related work. In section 3, we propose dynamic reservation scheme of PCI for femtocell. Performance evaluations are shown in section 4. Finally, we conclude our paper in section 5.

2. Related Work

In this section, we investigate features of the cell identity in cell search procedure and existing identification schemes of the femtocell.

2.1 Cell Identity in Cell Search Procedure

One of the basic functions in any cellular system is cell search [11]. During this procedure, time and frequency synchronization are established between the UE and the network. The synchronization is the essential requirement for the LTE systems to maintain orthogonality between the uplink and downlink. Also to identify cells, physical-layer cell identity, which is the PCI, is acquired through this procedure. The cell search procedure is composed of three steps.

Step 1. Primary Synchronization Channel (P-SCH) is processed. It obtains symbol timing and frequency offset.

Step 2. Cell-identity group is acquired via processing Secondary Synchronization Channel (S-SCH). Frame timing is also obtained.

Step 3. Cell identity within the cell-identity group is detected through Common Pilot Channel (CPICH) with pilot signal strength.

The PCI is shortly detected at physical-layer and 504 different PCIs, ranging from 0 to 503, are specified in the LTE [12-13]. It is organized into 168 cell-identity groups, ranging from 0 to 167, and each group includes three identities. However, it is reused in the network, because the amount is limited. If the same PCI is used in nearby cells, the PCI confusion problem can occur.

On the other hand, Global Cell Identity (GCI) is globally unique to identify a cell [7-8]. However, to obtain the GCI, the UE should read the system information, which makes the UE consume its battery power. Moreover, the UE needs

quite a longer measurement gap, which can be maximally 160 ms in the LTE. During this gap, the UE cannot receive and transmit any data from and to the serving cell without multiple receiver capability. So, the measurement gap should be controlled by the network, and it is minimized to reduce the overall cell search time.

These identities are important parameters in Automatic Neighbor Relation (ANR) function [14]. When the UE reports a detected cell's PCI to the serving cell with signal level, the serving cell instructs the UE to read a GCI of the detected cell. After the UE measures and reports the GCI, a neighbor relation between the serving and the detected cell is established. This scheme can be applied to the femtocell systems.

2.2 Identification of the Femtocell

A cell is identified during the cell search procedure, whose performance enhancement is important, and schemes for designing the synchronization channel were proposed [11]. Configuring the PCIs and neighbor cell relation list automatically to resolve PCI conflicts was developed [12]. The PCI conflict occurs when the same PCIs are selected in two adjacent cells. Also, the PCI assignment scheme using graph coloring was proposed to avoid both PCI conflicts and PCI confusion [15]. However, these schemes do not include the femtocells, which are deployed in the conventional macrocell network.

For macrocell only system, 504 PCIs are enough to identify a cell, because the PCIs are locally unique. But a small network such as femtocell appears, and both macrocell and femtocell use the 504 PCIs together. It is expected that a very large number of femtocells could be deployed in the macrocell coverage. It is difficult for all macrocells and femtocells to allocate the 504 PCIs without any PCI confusions.

In the 3GPP Radio Access Network Working Groups (RAN WGs), to identify femtocells quickly and to reduce the overall search time, a lot of discussions regarding cell identity have been actively progressed. They commonly address a notion of Closed Subscriber Group (CSG), which groups all permitted subscribers that have access to one or more femtocells. These femtocells are operated under closed access mode, and it is referred as a CSG cell. The CSG concept makes the UE that it decides to access autonomously, target CSG cells. This reduces signaling load, and saves the UE's battery power [7].

Dedicated channel scheme could be a solution [8]. The CSG cells exclusively use a separate frequency layer, which is not assigned for macrocells. In this scheme, the PCI confusion is not a problem, including interference is-

sues. However, efficient use of the frequency resource is not possible. The different frequencies should be supported by the UE, whose complexity increases. Service discontinuity occurs during the handover procedure.

Some identifiers were proposed to discriminate a CSG cell [7-8]. A CSG identity can distinguish a CSG cell, and it is unique under the administrator's network. All CSG cells broadcast the CSG identity, and a list of the permitted CSG identities is stored in a UE. Also, when a CSG indicator's value is true, it notifies that a femtocell is operated under the closed access mode. However, these identifiers are broadcasted via the system information, which makes a UE consume its battery power.

The PCI approach, where the UE does not need to read the system information, is attractive. A subset of the PCIs can be reserved for specific purpose such as identification of the femtocells [10]. From this point of view, the PCI reservation scheme has been proposed [8, 16]. Some of the existing 504 PCIs, such as 50 PCIs, are exclusively used for CSG cells, and the reserved numbers do not vary. A UE can easily judge a detected cell as a CSG cell depending only on PCI information. But it is ambiguous how many PCIs are reserved for CSG cell. Even if a fixed number of PCI are reserved, still PCIs for CSG cells cannot be sufficient in different circumstances. Also, PCIs for macrocell are reduced, because some of the PCIs should be used for CSG cells. Therefore, the flexibility of PCI use is generally lowered.

Another solution, using the PCI approach, is the PCI extension scheme. The total number of PCIs only for CSG cell is increased to an amount such as 672 or 1008, and not the current 504 PCIs. More than the current PCIs are available, and a shortage of PCIs can be solved even though femtocell is deployed. However, signaling procedure related to physical layer specification, including P-SCH and S-SCH, should be modified to support extended PCIs. The complexity of the synchronization channel is increased, and PCI detection performance is degraded. Also, the LTE standardization schedule can be delayed.

We can also consider a scheme that each macrocell reserves a totally different number of PCIs for CSG cells. Each macrocell can reserve any number of PCIs among the 504 PCIs. Even though we do not increase the number of PCIs, each macrocell can support more femtocells. However, still there are problems and overheads. The macrocells should inform UE of the reserved PCI range for CSG cell through the system information. Also, it exchanges this information between macrocells and maintains a table that the neighboring macrocell uses. In this situation, it is difficult for UE to judge whether a detected cell is a CSG cell by using the PCI information only.

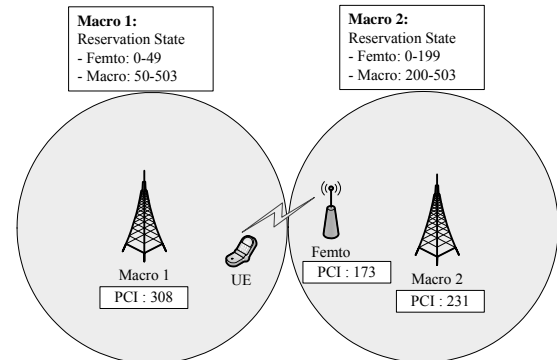


Fig. 1. Problems when a totally different number of PCIs is reserved for CSG cells

For example, Fig. 1 shows such circumstance that each macrocell reserves a totally different number of PCIs for CSG cells, PCI 0 to 49 for Cell 1, and PCI 0 to 199 for Cell 2. Near the boundary between two macrocells, a UE located in Cell 1 detects a femtocell, which belongs to Cell 2 and it uses a PCI 173. The UE receives the signal from the femtocell, but cannot know that the signal comes from the femtocell in the Cell 2. Because the UE here is located in Cell 1, the PCI 173 is reserved for the macrocell, and it considers the femtocell as a macrocell.

3. Dynamic Reservation Scheme of PCI

We describe our proposed dynamic reservation scheme of PCI for CSG cells with existing schemes. PCI assigning and type changing algorithms, identification procedure for various UEs, identification in multi-cell environment are explained. Finally, additional discussions on the proposed scheme are addressed.

3.1 Illustration of the Reservation Scheme

Before we show our proposed scheme, Fig. 2 describes the existing schemes explained in Section 2.2. If the macrocells and femtocells use the whole 504 PCIs together, as shown in Fig. 2(a), the other identity such as GCI or CSG identity should be checked to identify a detected cell. For example, the ANR function uses both the PCI and the GCI. Fig. 2(b) presents the PCI reservation scheme with 128 PCIs as an example for femtocell, where the reserved numbers do not vary. When the femtocells are densely deployed, efficient adaptation to PCI confusion is not possible.

We propose dynamic reservation scheme of PCI for CSG cells. UE can identify if detected cells are CSG cells by using PCI information. Furthermore, each macrocell can

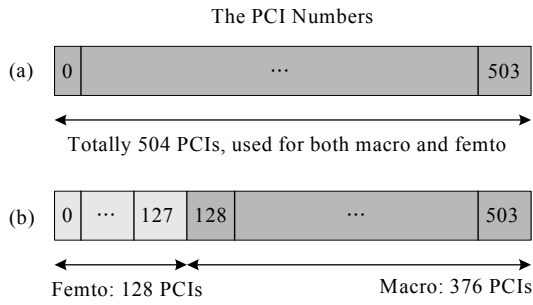


Fig. 2. The existing schemes. (a) The macrocells and femtocells use the whole 504 PCIs together. (b) Fixed PCI reservation scheme with 128 PCIs as an example for femtocell

reserve a different number of PCIs for the CSG cell.

Fig. 3 shows the concept of our proposed dynamic reservation scheme of PCI. We define (2^n-1) number of types for reserving PCIs, n is a positive integer bigger than 2. Each type reserves a different number of PCIs for CSG cells. For example, when n is 2 there are 3 types, if n is 3 there are 7 types, and so on. Depending on the value of n , we can define various types. Each macrocell selects an appropriate type according to the number of CSG cells deployed in each macrocell. From this selected type, each macrocell and CSG cell sets a PCI.

In Fig. 3, type A, B, and C reserve the amount of a , b , and c PCIs for CSG cells, respectively. The last $(2^n-1)^{th}$ type reserves x PCIs. The remainder is used for macrocells.

We define two schemes for determining how many PCIs are assigned to each reservation type, such as decision of a ,

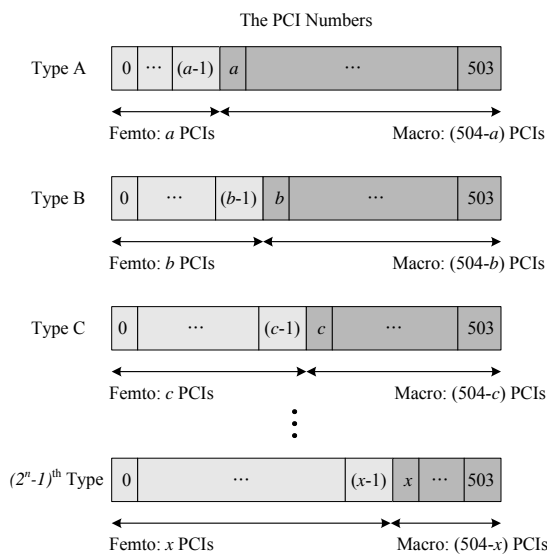


Fig. 3. The concept of our proposed dynamic reservation scheme of PCI for CSG cells. The parameters a , b , c to x should be determined.

b , c , and x values. Those are *PCI group* and *PCI value* schemes.

PCI group scheme. We define the types using the 168 PCI groups. These 168 groups are rearranged into 2^n-1 types. Each type reserves a different number of PCI groups for the CSG cell. We note that each PCI group includes 3 PCIs, the reserved amount of PCIs is three times that of the number of reserved PCI groups.

Fig. 4 describes an example, when we define 3 types ($n=2$) for reserving PCIs. Type A reserves 126 PCIs using 42 groups, type B reserves 252 PCIs using 84 groups, and type C reserves 378 PCIs using 126 groups for CSG cells, respectively. Other examples are also possible, even though we apply just 3 types.

PCI value scheme. Each PCI value is regarded as a 9-bits binary sequence. The PCIs can be arranged into each type using the front part of this bit sequence. If we define 2^n-1 types, the front n -bits are used for defining the types.

Fig. 5 and Table 1 indicate how to define the types when we reserve the PCIs as 3 types ($n=2$). The front 2-bits of the PCI binary sequence are compared. In type A, the reserved region for CSG cell, the bit sequence starts from '00'. Also, this part is used for the CSG cell in all types. The reserved region for CSG cell in type B starts from '00' and '01'. Similarly, the CSG cell region in type C begins with '00', '01', and '10'. The remaining PCIs are in the region that starts from '11', which is used for the macrocell in all types. As a result, the type A, B, and C reserves 128, 256 and 384 PCIs for the CSG cell, respectively. When we define 3 types, this proposed scheme is unique. It means other definitions are impossible for 3 types. When we use a different n -value, the number of types is changed, and a similar scheme can be applied.

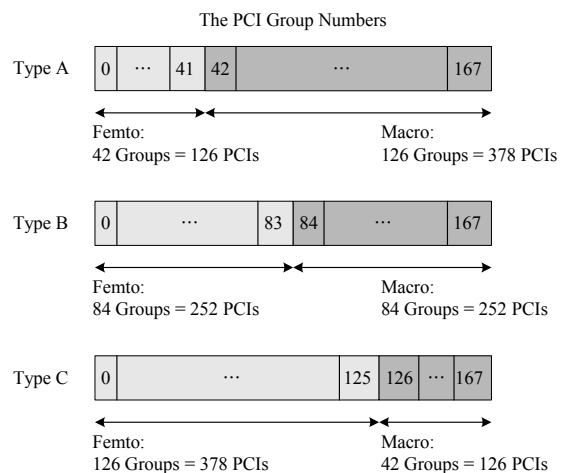


Fig. 4. PCI group scheme, where the PCIs are reserved using the 168 PCI groups. Each PCI group includes 3 PCIs. (A case of $n=2$)

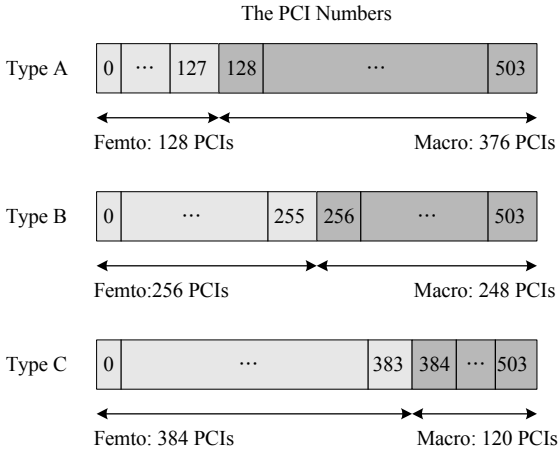


Fig. 5. PCI value scheme, where the PCIs are reserved using 9-bit binary sequence of the PCI value itself. (A case of $n=2$)

Table 1. An example of supplemental description Fig. 5. ($n=2$)

PCI range (Decimal)	PCI range (Binary)	Explanation
0 – 127	00000000 – 0011111111	CSG region in the all types.
128 – 255	010000000 – 0111111111	CSG region in type B and C. Macro region in type A.
256 – 383	100000000 – 1011111111	CSG region in type C. Macro region in type A and B.
384 – 503	110000000 – 1111101111	Macro region in the all types.

3.2 PCI Assigning and Type Changing Algorithms

Determining algorithm of PCI range for a general number of types is described in Fig. 6, and it is operated as follows:

1. The value n and the number of types are decided by the network operator.
2. In the PCI group scheme, the value n is an integer between 2 and 7. The whole 168 PCI groups are divided by 2^n , and its quotient multiplied by 3 because each PCI group contains 3 PCIs. The unit amount of PCIs to be allocated to each type is denoted by a parameter *unit*.
3. On the other hand, the value n is selected between 2 and 8 in the PCI value scheme. A 9-bit binary sequence is generated that front n zeros and following $9-n$ ones. This sequence is converted to decimal. After 1 is added, the parameter *unit* is obtained.
4. Using this *unit*, the PCI range for CSG cells in 2^n-1 types

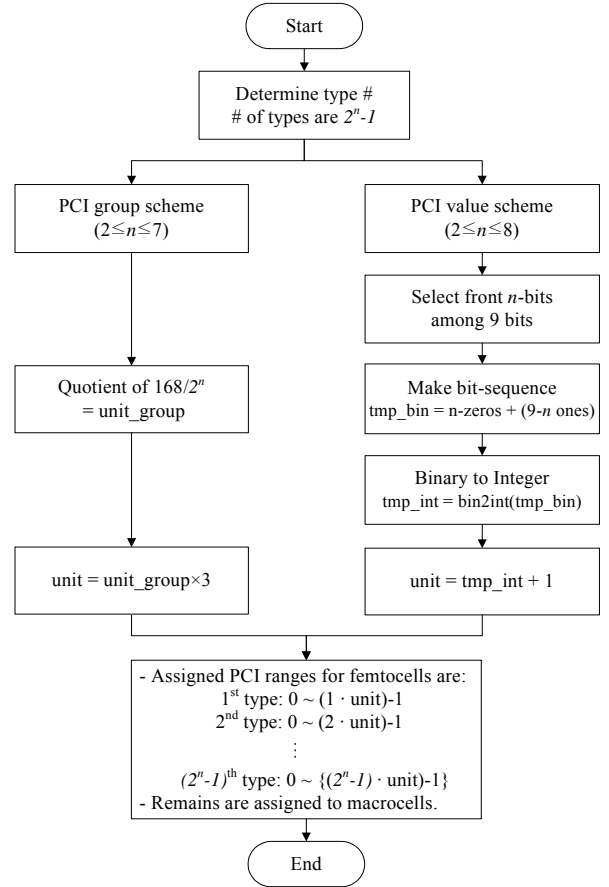


Fig. 6. Algorithm for determining how many PCIs are assigned to each reservation type in both the PCI group and the PCI value schemes

are determined. The increment of PCIs for CSG cell in each type is *unit*. Remaining PCIs are assigned to macrocells.

These types are applied as shown in Fig. 7. According to environmental variations, the type can be changed. When each femtocell turns on, it notifies the macrocell. The macrocell knows how many femtocells are active in its coverage. Otherwise, the macrocell detects the number of PCI confusion events. If more femtocells are active, more PCI confusion occurs. It is performed as follows:

1. The types are indexed by i from 1 to 2^n-1 . Thresholds, where the type is changed between two adjacent types, are managed by j from 1 to 2^n-1 .
2. Both the type and the threshold are initialized to 1. Type A is selected, and the selected threshold notifies the turning point between type A and type B.
3. Metric at current time t is measured. The type can be changed according to this metric, which is affected by environmental variations, such as the number of active femtocells, or the number of PCI confusion events.

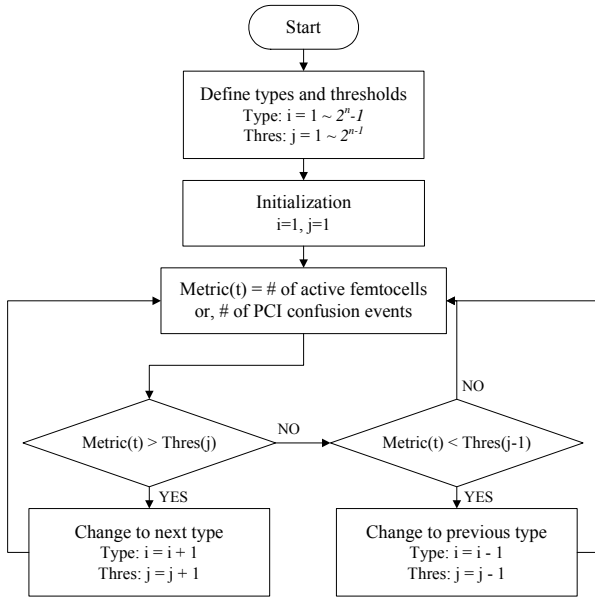


Fig. 7. Algorithm for changing types according to environmental variations, such as the number of active femtocells, or the number of PCI confusion events

4. If the metric at time t is greater than j^{th} threshold, it can be found that the more femtocells are active, or the more PCI confusion events are measured. The type is changed to the next type, which reserves more PCIs for CSG cells. Also, the threshold is increased.
5. Otherwise, if the metric is less than $(j-1)^{\text{th}}$ threshold, the indices i and j are reduced. This notifies that more of the PCIs are assigned to macrocells, because the numbers of active femtocells have decreased, or there are less PCI confusion events.
6. When the metric at time t does not meet the condition in step 4 and 5, the current type is maintained. The indices i and j are unchanged.
7. After the type and the threshold are decided, it keeps the measurement of the active femtocells or PCI confusion events. Step 3 to 6 are continuously performed.

3.3 Identification Procedure for Various UEs

There are two kinds of UEs: Non-CSG-UE and CSG-UE. The non-CSG-UE cannot access to any CSG cells. It should avoid searching for CSG cells at an early stage, especially when more CSG cells are deployed.

On the other hand, the CSG-UE can obtain access to CSG cells, when the identity of the target CSG cell is existed in the CSG-UE's whitelist. The whitelist includes the list of CSG cell identities that an UE is allowed to register on. The CSG-UE manages and stores the whitelist. If the

CSG-UE detects an allowed CSG cell, the access should be granted quickly. When the detected CSG cell is disallowed, the CSG-UE avoids it and searches other CSG cells quickly.

We explain the identification procedures for the non-CSG-UE and the CSG-UE in the proposed scheme, which is compared with the conventional ANR function [14].

ANR function for CSG-UE. We explain the ANR function for the CSG-UE first. The serving macrocell instructs the UE to search neighboring cells. The UE gets a PCI of the detected cell, and it reports the acquired PCI to serving macrocell with signal level. The PCI is obtained through P-SCH, S-SCH, and CPICH, as described in Section 2.1. After receiving the detected PCI, the serving macrocell instructs the UE to read the GCI of the detected cell. In order to get a GCI, the UE needs a longer measurement gap. After the GCI is reported, the serving macrocell decides if the detected cell is a macrocell or a CSG cell. The UE can obtain access to the appropriate cell depending on the request from the serving macrocell. If the target is a CSG cell, the UE should check the whitelist.

Proposed scheme for CSG-UE. On the other hand, the proposed scheme can decide if the detected cell is a macrocell or a CSG cell, before the UE reads the GCI. After receiving the PCI and when PCI confusion does not occur, the serving macrocell can decide if the detected cell is a macrocell or a CSG cell. The UE can obtain access to the appropriate cell, after it reads the GCI.

Skipping of the the unsuitable detected CSG cells, which is not included in the UE's whitelist, reduces the cell searching delay. The UE only reads the GCI, when it can get access to the target CSG cell. If there is PCI confusion, the decision is performed after acquiring the GCI. We note that the two kinds of reservation schemes, described in Section 3.1, are not distinguished for the CSG-UE. But we consider separately for non-CSG-UE.

ANR function for non-CSG-UE. In the ANR function, after receiving the GCI, the serving macrocell can decide if the detected cell is a macrocell or a CSG cell. It is not a problem, when the detected cell is a macrocell. But if the detected cell is a CSG cell, the already acquired GCI of the CSG cell is useless, because the non-CSG-UE cannot access any CSG cells.

Proposed scheme for non-CSG-UE. In this case, the two kinds of reservation schemes can be differently considered. When the PCI value scheme is applied, after getting the PCI, the serving macrocell can decide if the detected cell is a macrocell or a CSG cell. If the detected cell is a CSG cell, it can be skipped before the UE reads the GCI. When the PCI group scheme is used, the UE can decide if the detected cell is a macrocell or a CSG cell [7]. The decision is

made by receiving P-SCH and S-SCH, before CPICH. The UE can skip the CSG cell earlier than the PCI value scheme.

The PCI confusion is not a problem for the non-CSG-UE, because the non-CSG-UE cannot access any CSG cells. If a detected PCI corresponds to a reserved PCI region for a CSG cell, all of the CSG cells can be quickly skipped without reading the GCI. We do not need to know the GCI of the detected CSG cell in both schemes.

3.4 Identification in Multi-cell Environment

The proposed PCI reservation schemes can be applied in a multi-cell environment as follows. When the UE judges if detected cells are CSG cells, the type information of macrocells is used. The UE receives this information through Neighbor Cell List (NCL) or system information, when it turns on.

In the NCL approach, the NCL is modified so that it includes the type information of the macrocells. After receiving the NCL, the UE can know the type information of the serving and neighbor macrocells.

When the system information is used, two cases are possible: system information of each CSG cell, and of serving macrocell are these cases. In the former case, each CSG cell receives the type information from the serving macrocell. Each CSG cell broadcasts the type attaching to its system information. Otherwise, in the latter case, the serving macrocell receives the type information of neighbor macrocells. The serving macrocell broadcasts the type attaching to its own system information. As a result, the UE can acquire the type information of the serving and the neighbor macrocells.

In multi-cell environment, the UE can identify if detected cells are CSG cells by using the type information. Operational principles are presented with examples. For explanation, three-type case ($n=2$) is investigated, as shown in Fig. 8. According to location of a detected CSG cell, three cases are possible.

Case 1. A UE detects a CSG cell, which is located in the serving macrocell. Considering the types, the UE can judge the detected cell as a CSG cell using the PCI information.

For example, when a UE detects Femto 1, the UE can judge it as a CSG cell, because PCI 97 is reserved for CSG cell in Macro 1.

Case 2. A UE detects a CSG cell, which is located in the neighbor macrocell. Serving and neighbor macrocells use different types. The CSG cell uses a PCI from the overlapped region between two macrocells. In this case, the UE

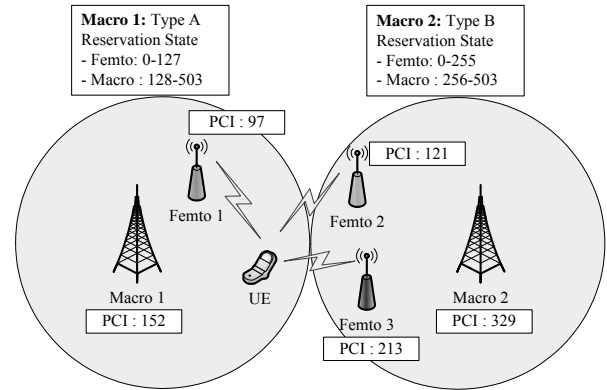


Fig. 8. Operational examples in multi-cell environment

can judge the detected cell as a CSG cell using the PCI information, because the two macrocells reserved the corresponding PCI for CSG cells together.

For example, a UE detects Femto 2. Although the Femto 2 is located in Macro 2, the UE can judge the detected cell as a CSG cell, because PCI 121 is reserved for a CSG cell between the two macrocells.

Case 3. The location of the detected CSG cell is similar to Case 2. But the CSG cell uses a PCI from the non-overlapped region between two macrocells. In this case, a UE detects a macrocell region PCI, which is not the serving macrocell PCI. The UE does not know that the corresponding PCI comes from a neighboring macrocell or a CSG cell. The serving macrocell checks the NCL, or the UE verifies the system information. Then, the UE can know the neighbor macrocell type. After verifying, the corresponding PCI is reserved for a CSG cell in the neighbor macrocell, the UE can judge the detected cell as a CSG cell.

For example, when a UE detects Femto 3, the UE detects a PCI 213, which is in the macrocell PCI region, not the serving macrocell PCI 152. Through the NCL or system information, the UE can know that there is Macro 2 using type B. The PCI 213 is reserved for the CSG cell in type B. The UE can judge the detected cell as a CSG cell.

In these three cases, the macrocell type can be easily verified by using the PCI group number, or by looking at the front n -bits of the PCI binary sequence.

3.5 Additional Discussions on the Proposed Scheme

Some modifications are required to support our proposed scheme. The contents in the NCL are modified, so that the macrocell type information could be included. However, the amount of added information is far less, and only n -bits are sufficient. Otherwise, system information from the de-

tected CSG cells or serving macrocell is utilized. Before broadcasting the system information, each macro and femto base station should know the type of the neighboring macrocells. Every base station may exchange the macrocell type information periodically. Even though such overheads are required, they can be minimized in the proposed scheme, because the NCL or the system information is necessary, only when a UE requests a case such as Case 3 illustrated in Section 3.4.

In the proposed scheme, the number of PCIs for the macrocell cannot be sufficient at times, because some PCIs are exclusively used for CSG cells. When the number of deployed CSG cell is low, or many CSG cells are turned off, the type is changed (e.g. B to A) in order to allocate more PCIs to the macrocell. However, if the PCIs for the macrocell are still insufficient, the GCI is utilized to identify detected macrocell.

Similarly, when the number of PCIs for CSG cells is deficient, due to lots of active CSG cells, the macrocell changes its type (e.g. B to C) in order to assign more PCIs to CSG cells. However, if still the PCIs are insufficient for CSG cells, because too many CSG cells are active, the GCI or the CSG identity is used for identification.

According to the proposed scheme, we can expect following effects:

1. The PCIs are flexibly used according to the number of femtocells, or the number of PCI confusion events. Each type reserves a different number of PCIs for CSG cell. Each macrocell can choose an appropriate type.
2. The PCI confusion problem can be resolved by changing the types. When lots of femtocells are deployed without planning, the same PCI could be allocated to several femtocells. Also, the femtocells are frequently turned on and off. In the proposed scheme, the types are adaptively managed to cope with the PCI confusion.
3. Various structures are possible to reserve the PCIs for CSG cell. Depending on the value of n , 2^n-1 types are possible, and the network operator decides it.
4. The detected cell can be judged as a CSG cell without GCI. If a UE detects a reserved region PCI for a CSG cell, the UE can judge it as a CSG cell. This reduces the UE's battery consumption, and it avoids unnecessary signaling load. The GCI is required only when the PCI confusion occurs.
5. Searching times for the CSG cell is decreased. It is helpful for the quick handover from macrocell to CSG cell. Before handover decision, the target CSG cell should be searched quickly. Identification of CSG cell is performed without GCI, which needs a longer measurement gap to be acquired by a UE.

4. Performance Evaluations

We explain simulation environments and scenarios. Numerical results are followed with the comparison between the existing and proposed schemes.

4.1 Experiment Environment and Scenarios

Our simulation parameters are summarized in Table 2. The overall network size is 19 two-tier macrocells, and each macrocell contains 50 to 500 femtocells. UEs are composed of non-CSG-UEs and CSG-UEs. The femtocells and the UEs are randomly located in the overall macro network. We represent the whitelist as a probability model. A CSG-UE can access a femtocell with probability from 0.1 to 0.5. When the probability is 0.1, a CSG-UE can access to one CSG cell among 10 femtocells probably. A radio frame is 10 ms long in uplink and downlink physical channels, where instruction and report messages are transmitted between a serving macrocell and UEs. No frame error and no retransmissions are assumed, so that one frame is enough to get information. A measurement gap for obtaining a GCI is set to 160 ms, which is maximal value in the LTE [7]. The PCIs from the designated range are randomly allocated to macrocell and femtocell depending on schemes.

We obtain average delay, from when a serving macrocell instructs a UE in order to search neighboring cells, to when the UE accesses to one of the detected neighboring cells. The cumulative distribution of the UEs are acquired at the

Table 2. Simulation parameters

Parameters	Value
Number of macrocells	19 (Two-tier)
Number of femtocells in a macrocell	50 – 500
Macrocell radius	280 m
Femtocell radius	30 m
Macro BS power	20 W
Femto BS power	20 mW
Number of Non-CSG-UE	300
Number of CSG-UE	300
Whitelist (Access probability)	0.1 – 0.5
Radio frame length in physical channel	10 ms
Measurement gap for GCI	160 ms
PCI allocation	Random

given delay constraints. The number of femtocells and the probability of the whitelist model are varied during the simulation.

Different channel models are applied to outdoor and indoor environments as shown in Table 3. A pathloss is dominant factor, where d is the distance between a base station and a UE in meters. In case of the indoor model, wall loss is different depending on the distance from a femto base station to a UE.

In the simulation, we consider an inbound handover case. A UE already knows the serving macrocell type. Each macro and femto base stations know the neighboring macrocell type, they can broadcast whenever the UE requests. Inter-frequency case is assumed, that the serving macrocell and the neighboring femtocells use different frequencies. A CSG-UE can be serviced by a macrocell, when any femtocells do not exist in the vicinity of the UE, or when the detected femtocell is not included in the UE's whitelist.

The experiment scenarios are listed in Table 4, which shows differences between the existing and the proposed schemes for non-CSG-UE and CSG-UE. In *ANR function* scheme, the UE always reports the GCI, which comes from all of the detected cells, to the serving macrocell. *Fix128* scheme reserves 128 PCIs for CSG cells to compare with the proposed scheme. The proposed PCI value and PCI group schemes use the case having three types ($n=2$) as described in Section 3.1, and these are denoted by

Table 3. Channel models

Model	Outdoor	Indoor
Pathloss	$28+35 \log_{10}(d)$	$38.5+20 \log_{10}(d)+$ (Wall loss)
Wall loss	7 dB, where $0 < d \leq 10$ 10 dB, where $10 < d \leq 20$ 15 dB, where $20 < d \leq 30$	

Table 4. Experiment scenarios for different UEs

Schemes	Description	Delay Performance	
		Non-CSG-UE	CSG-UE
<i>ANR function</i>	Explained in [14]	.	.
<i>Fix128</i>	Reserve 128 PCIs for CSG cell [16]	Same	.
<i>Prop(Value)</i>	Proposed PCI value scheme (3 types)		Same
<i>Prop(Group)</i>	Proposed PCI group scheme (3 types)	.	

Prop(Value) and *Prop(Group)*, respectively.

We note that *Fix128* and *Prop(Value)* schemes for the non-CSG-UE show same delay performance. The non-CSG-UE can avoid inaccessible CSG cells, if a received PCI is reserved for a CSG cell, irrespective of the PCI confusion. Also, the delay performance is equal to CSG-UE in both the *Prop(Value)* and *Prop(Group)* schemes. Because in order for the CSG-UE to report the strongest CSG cell among detected ones, the UE acquires signal strength via the CPICH. The PCI group number is obtained by the UE, before it receives the CPICH.

4.2 Numerical Results and Comparisons

We evaluate the average delay for 300 UEs, which are non-CSG-UEs and CSG-UEs with different whitelist models, as shown in Fig. 9. The results show that the proposed schemes reduce the average delay considerably. The more CSG cells are deployed, the more delay reduction is achieved.

For the non-CSG-UE, it should avoid searching for any CSG cells. Although these cells are detected, the non-CSG-UE cannot access to it. *ANR function* is aware of this after reading the GCI. However, *Prop(Value)* knows that before acquiring the GCI, and it shows same delay performance with *Fix128*. *Prop(Group)* reduces delay further, because it can find the fact that it is not accessible to found cells before the exact PCI is obtained.

For CSG-UE, the performance gains are increased as the access probability decreases. Because when the probability is low, the CSG-UE searches more CSG cells to find an accessible cell, which is included in the UE's whitelist. It takes a longer time than when the access probability is higher. In both *Fix128* and the two proposed schemes, the UE can avoid the inaccessible CSG cell using the PCI. If that PCI suffers a PCI confusion problem, the UE reads the GCI to judge access. However, there are obvious differences as follows.

The two proposed schemes change the type to allocate more PCIs for CSG cell, when the more CSG cells are deployed, or when the more PCI confusion events occur. It reduces possibility of PCI confusion, and the more CSG cells can be judged without the GCI. *Prop(Value)* and *Prop(Group)* show the same delay performance.

In the *Fix128*, the performance is similar to the two proposed schemes, until 150 CSG cells are deployed. However, after this point, the number of PCI confusion events continuously increases as the more CSG cells are deployed. This is because the usable amount of PCIs for CSG cell is fixed, and it does not increase. The delay curve approaches the *ANR function*, as the more CSG cells are deployed. It

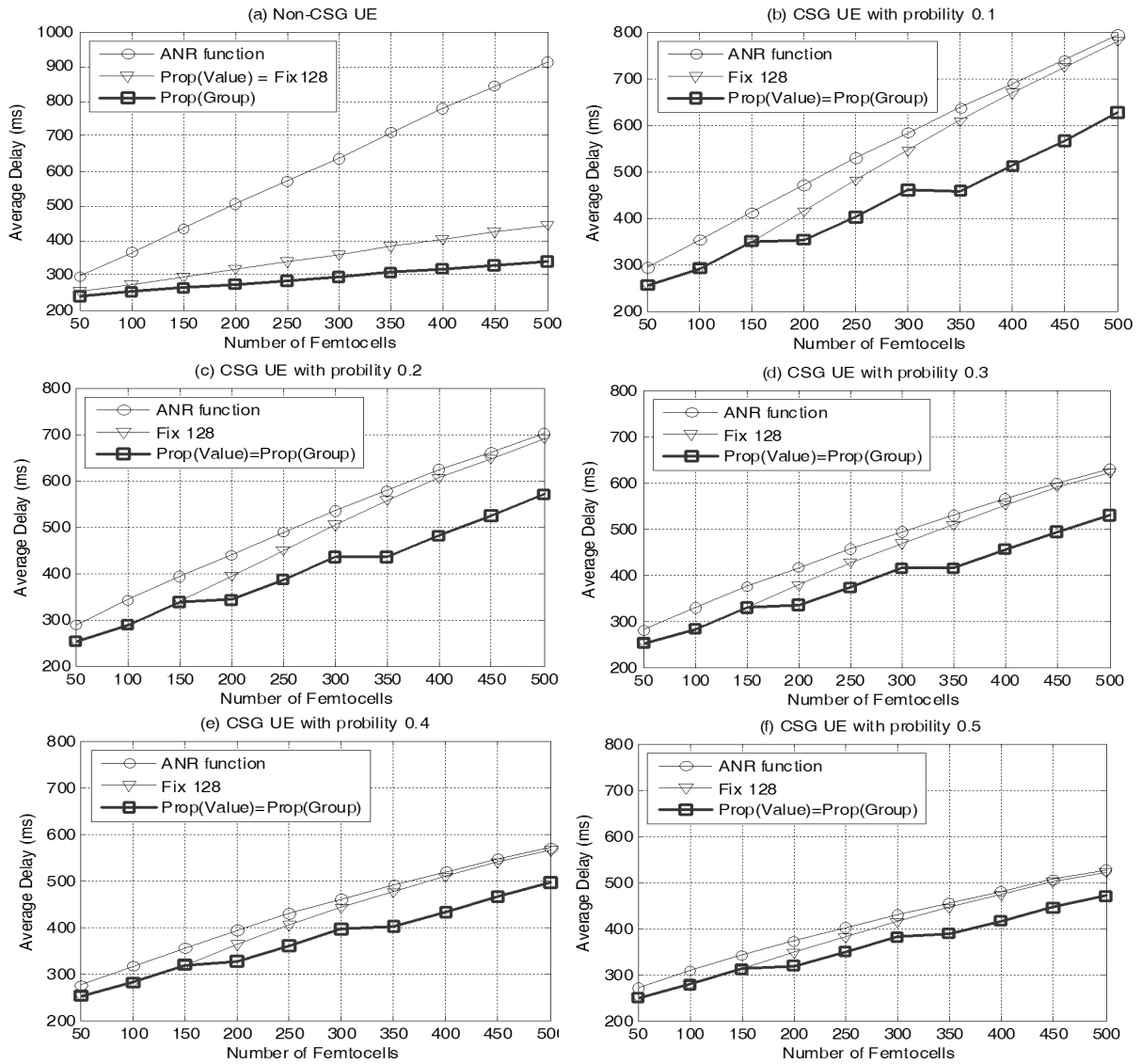


Fig. 9. Average delay of 300 UEs as the number of femtocells varies. (a) Non-CSG-UE, (b)-(f) CSG-UE with access probability 0.1, 0.2, 0.3, 0.4, and 0.5, respectively

notifies that the GCI is needed, even though the PCIs are reserved for a CSG cell.

Fig. 10 presents the average delay in a more general situation, in which various kinds of the UEs are distributed in the overall network. Among the 600 UEs, half are non-CSG-UEs and the others are CSG-UEs with different whitelist models.

The delay performance is different between the non-CSG-UE and CSG-UE as shown in Table 4. *ANR function*, *Fix128*, and *Prop(Group)* schemes are selected in the simulation. The proposed scheme reduces average delay considerably, and it shows the effects of changing types. The higher gain is achieved as the more CSG cells are deployed. When there are 500 CSG cells in a macrocell,

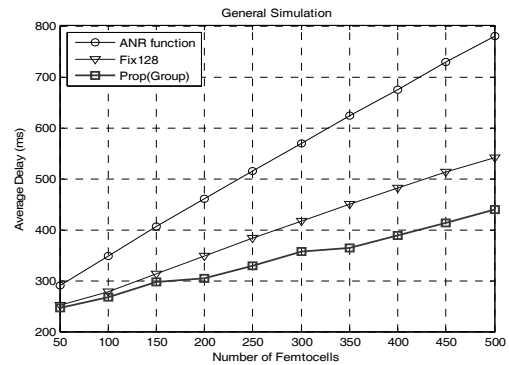


Fig. 10. Average delay of 600 UEs in a general situation. The UEs are composed of 300 non-CSG-UEs and each 60 CSG-UEs with access probability from 0.1 to 0.5, respectively.

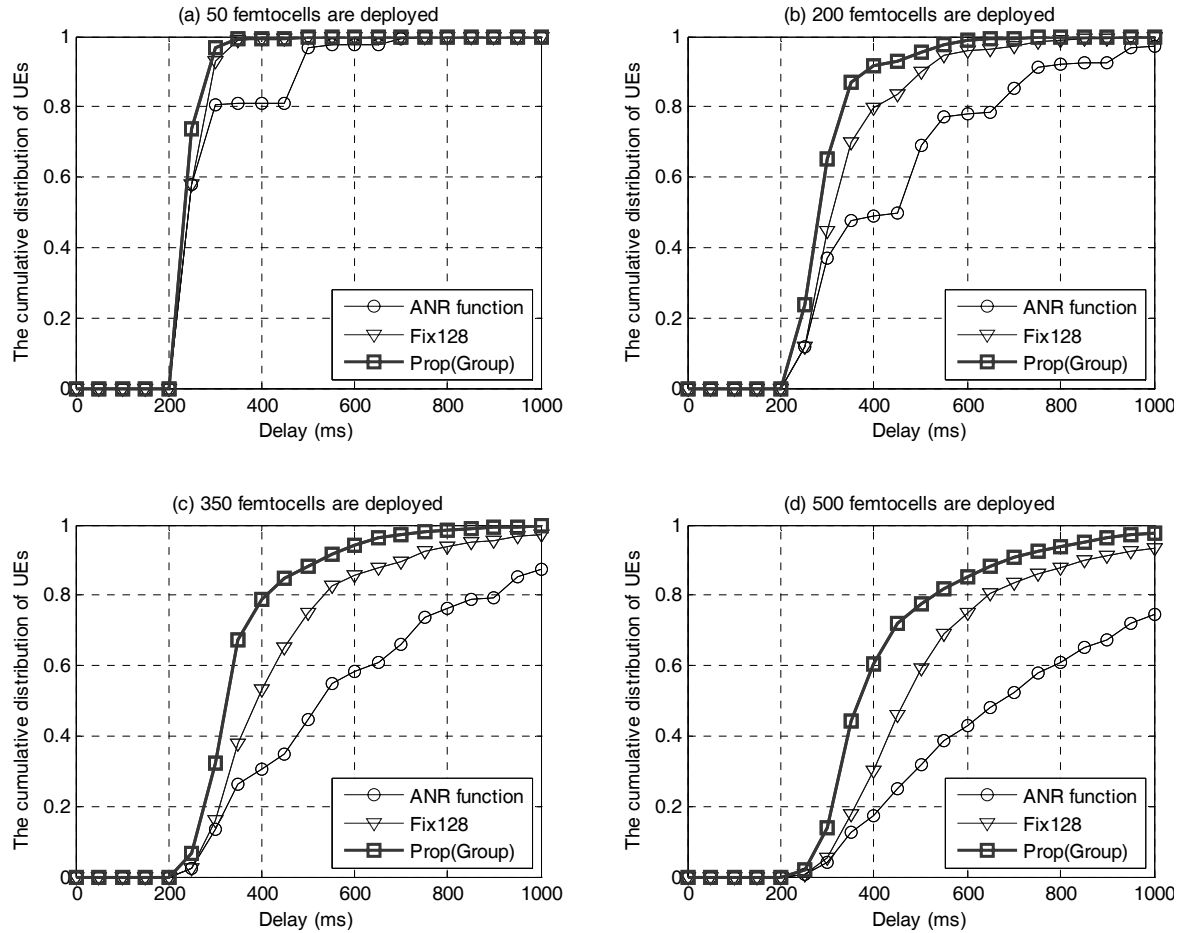


Fig. 11. Cumulative distribution of UEs as against delay constraints varies. (a)-(d) The number of femtocells in a macrocell is 50, 200, 350, and 500, respectively.

Prop(Group) scheme reduces the average delay by 18.8% and 43.6% compared with *Fix128* and *ANR function*, respectively.

The cumulative distribution of UEs for a general situation is indicated in Fig. 11. In the proposed scheme, the more UEs accomplish search procedure of neighboring cells, and it accesses the target cell quickly. Also, more UEs can be supported within the equal delay constraints, so that network capacity is enhanced. The gain is higher where the more CSG cells are deployed in a macrocell.

5. Conclusion

The femtocell, as a home base station, has recently gained significant interest due to various benefits for the operator and consumers. However, the femtocell should be identified autonomously without requiring additional system information to support inbound handover. In this paper, we propose a dynamic reservation scheme of PCI for 3GPP LTE femtocell systems. There are several reserving types,

and each type reserves the different number of PCIs for the femtocell. This type selection can be changed depending on the environmental variations. The flexible use of the PCI is beneficial for decreased PCI confusion, reduced searching time for the femtocell, and quick inbound hand-over. We have shown that our proposed scheme achieves performance enhancements in terms of the average delay for identifying the detected cells, and the network capacity within the equal delay constraints. We can conclude that the proposed scheme helps to accomplish self-configuration and self-optimization in femtocell systems.

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