A New Physical Cell Indetifier Structure in Femtocell Networks

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***Abstract*—In densely populated areas, a quite high number Femto Access Points (FAPs) can be deployed and operate under one macro base station. Due to limited number of available Physical Cell Identifiers (PCI), these identifiers have to be inevitably reused in the network. However, the repetition of identifiers under one macrocell results in confusion events at the macro base station. To deal with the confusions and scarcity of identifiers in a highly dense femtocell environment, we propose dividing a macrocell into smaller logical regions, called clusters, and enhance the PCI structure about the cluster identifier. Additionally, we discuss the assignment process of FAPs into particular clusters and analyze possible solutions how to implement the new cluster identifier in today's mobile networks.**

Keywords: LTE/LTE-A, femtocells, synchronisation signals, cell identifier, implementation.

I. INTRODUCTION

The wireless traffic has significantly grown over the past decade and there is no indication this growth will slow down. Rather contrary, due to new range of applications, massive increase of connected devices and extended usage of video oriented applications, there are predictions that the traffic growth trend will also continue in the next decade [1]. Handling this traffic in an affordable and sustainable way is one of major challenges of emerging wireless communication systems such as Long Term Evolution (LTE) and LTE-Advanced (LTE-A). A cost-effective mean to manage this growth represents small-cell/local-area deployments (i.e., femtocells, picocelles, or metrocells). Network densification and thereby bringing network nodes physically closer to the users enables handling two shortages of present mobile systems: capacity and indoor coverage. The low-power nodes make possible to provide high traffic capacity and high user throughput locally, e.g., in indoor and outdoor hotspots. Hereafter, we focus on the femtocell concept.

Femtocells can be seen as small cells covered by inexpensive, low-power base stations that are, in general, deployed by customers themselves. These base stations are denoted as Femto Access Point (FAP). FAPs are connected to mobile operator's networks using either a wired, or a wireless backhaul; e.g., ADSLs, optics, WiFi, or nowadays even satellite links [2]. The FAPs can be configured to operate either in open access, or closed access, or hybrid access [3]. Closed access cells are accessible to a set of users, whereas in open access cells any user can get access to the network. Finally, in case of hybrid access, the priority is given to owner of the FAP but additional selected users can be accepted as well.

Compare to the present macro/micro base stations, the number of FAPs within a mobile network can be huge. Therefore to enable smooth, simple and mass deployment of femtocells, self-organizing concept has to be employed when deploying femtocells. Customers cannot be expected to have whatever knowledge how to install/configure FAPs, all configurations have to be done automatically by FAPs themselves, or with a network assistance.

As in case of conventional macrocell base stations (MBSs), among others, a newly introduced FAP needs to be assigned a cell identifier that unambiguously identifies the cell in the given area. In LTE/LTE-A systems, this (macro/femto) cell identifier is called Physical Cell Identifier (PCI) and the number of identifiers is limited to 504 PCIs [4]. The PCI pool is shared by all types of cells in the network (femto, pico, metro, macro, etc.). The PCI is derived from LTE/LTE-A physical layer signals known as Primary Synchronization and Secondary Synchronization Signal (PSS, SSS, [5]).

A PCI should be selected in such a manner to avoid collision (i.e., a PCI is unique in the area that the cell covers, see $FAP_{A,B}$ in Fig.1) and confusion (i.e., a cell has no neighboring cells that have identical PCI, see FAP_E and $FAP_{C,D}$ in Fig.1) events [6]. Notice that these events can occur as from the point of femtocell level (collision: FAP_A - FAP_B, or confusion: FAP_C - FAP_D) as from the point of macrocell level (collision: MBS - $FAP_{A,B}$, or confusion: MBS - $FAP_{C,D,F}$).

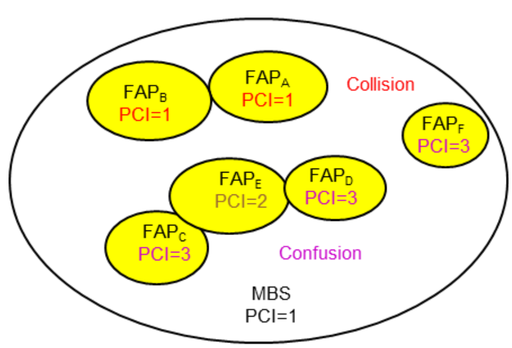

Figure 1. Example of collision and confusion events in a macrocell.

In view of the fact that FAPs are usually in possession of customers, a PCI assignment method has to be automatic and adaptive to manage FAPs movement; in case a customer decides changing the FAP location. In highly populated metropolises, a quite high number of femtocells can operate under coverage of one macro base station, e.g., Paris population density is about 21 thousands per km^2 [7]. Due to the limited number of PCIs, the PCIs have to be inevitably reused in the network. Thus, confusion events from the point of a macro base station can occur (MBS - FAP$_{C,D,F}$ in Fig.1). To deal with both confusion events and lack of identifiers, we propose: i) increasing number of PCIs, ii) dividing a superior macrocell into several smaller regions denoted as FAP clusters, and iii) enhancing the PCI structure about FAP cluster sub-identifier. Additionally, we discuss possible ways of FAP cluster identifier implementation in the LTE/LTE-A mobile networks.

The rest of this paper is organized as follows. The next section provides brief overview of related works and our motivation. Section III details the proposed clustering concept. Possible implementation of femtocell cluster in mobile networks is presented in section IV. Finally, major findings are concluded in the last section.

II. RELATED WORKS AND BACKROUND

In conventional macrocell deployment, several PCI assignment methods have been investigated last couple of years [8]. These methods can be in general classified as distributed (e.g., random, or radio scanning methods) and centralized (e.g., network planning approach, or use of specific network entity). Authors usually employ a graph coloring approach to cope with the collision/confusion problems [9-11]. However, the femtocell deployment has certain specificities compare to the macrocell one. These include: i) larger number of base stations, ii) unstable position of base stations in time, and iii) a base station placement is not really managed and controlled by operators.

To handle femtocell collision/confusion events, authors in [12] combine the radio scanning and random methods. The former method helps a newly introduced FAP to identify neighboring PCIs that are in the second phase omitted when randomly choosing a PCI. In the femtocell scenarios, researchers mainly focus on how to distribute PCIs among different type of cells. For example in [13], authors discuss how to split the PCI range among different FAP access types, i.e., open, closed and hybrid. The sharing of PCIs between macro base station and FAPs are discussed in [14], where an automatic PCI allocation method is modified according to the PCI utilization and the scale of base stations. New dynamic reservation schemes are introduced in [15]. The authors present several reserving types and each type corresponds to a different femtocell PCI pool. The transition among the types depends on the number of deployed FAPs, or the number of occurring PCI confusion events. However, in all previously mention works, the number of considered femtocells is relatively low, the number FAP remains below 503 femtocells (one PCI is dedicated to the MBS).

To the best of our knowledge, a research work regarding the macrocell-femtocell collision/confusion issue in the dense FAP environment has not been carried out. To illustrate the problem, let’s consider a simple scenario where we randomly distribute femtocells within a macrocell; the standard uniform distribution is used to generate FAP positions. An example of FAP distribution in a macrocell is illustrated in Fig. 2. In this scenario, we would like to just demonstrate the problem of high number of femtocells per macrocell; femtocell related issues such as cell interferences, attenuation of signals, etc. are not taken into account.

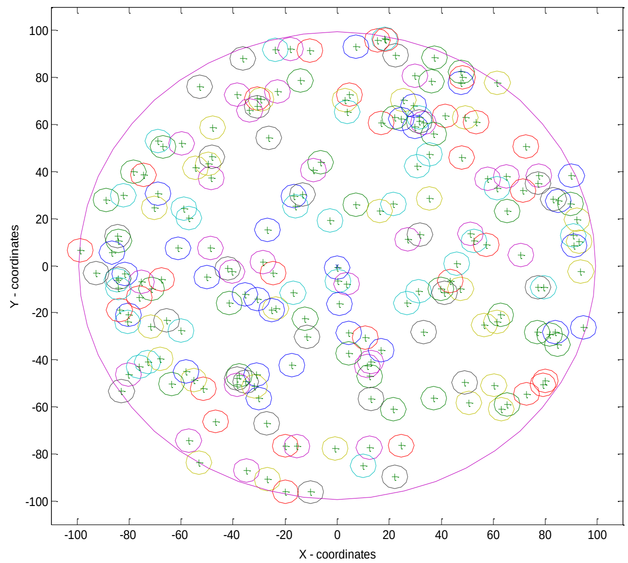

Figure 2. Example of FAPs placment in macrocell.

Fig. 3 shows number of femtocells per macrocell for different macrocell radius (denoted as R_m in the figure) and parameter k that is given as:

$$k = \frac{\sum_{i}^{N} S_i^{femto}}{S^{macro}} \tag{1}$$

where S^{Macro} denotes the macrocell surface, S_i^{Femto} is surface of *i-th* femtocell, and N is number of femtocells per macrocell. In this analysis, we consider femtocells to be circles with radius (R_f), which is same for all femtocells. Thus, the equation (1) can be simplified and rewritten as:

$$k = N \cdot r^2 \tag{2}$$

where r represents ratio R_f / R_m. For k = 1, the sum of all femtocell surfaces theoretically entirely fulfilled the macrocell surface, i.e., femtocells do not overlap. However, femtocells can and do overlap and therefore the macrocell surface is not entirely fulfilled by femtocells for k = 1. Fig. 4, subsequently, shows number of femtocells per macrocell for different femtocell radius. Results illustrate that for certain combinations of R_f and R_m, we can rather quickly begin missing PCI (the LTE max. value of PCI is indicated in both

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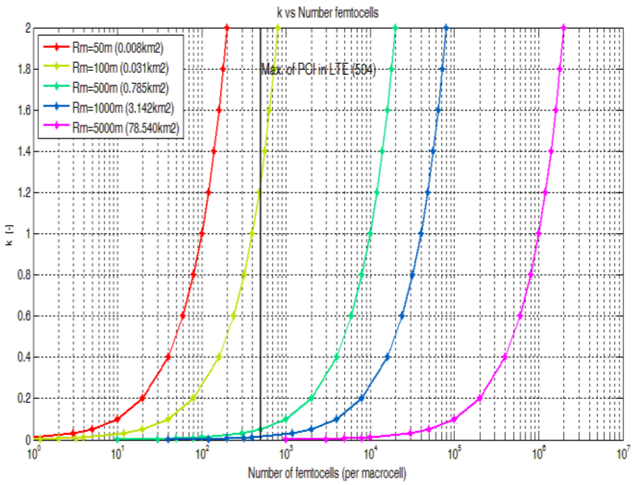

Figure 3. Number of femtocells for various macrocell radius (R_m), R_f = 5m.

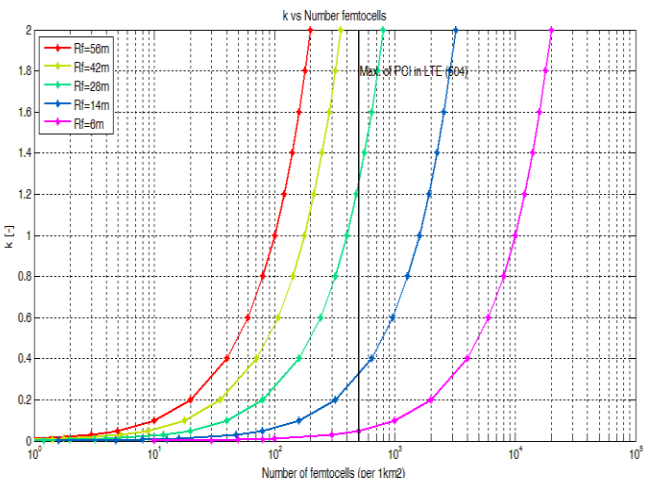

Figure 4. Number of femtocell for various femtocell radius (R_f), R_m = 564m.

figures by vertical black lines). For example, already in case of about 35% of macrocell surface is covered by femtocells (Fig. 4, R_f =14m), we run out of unique PCIs.

In [16], two deployment models are considered for the femtocell environment: i) suburban model, and ii) dense-urban model. In case of the dense-urban model, there are assumed 6928 households per km^2. Thus, if we consider 1km^2 macrocell and 10% FAP penetration (that gives 693 households equipped with FAPs), we would need to repeat 190 PCIs within the given macrocell.

The previous analysis shows that even if the PCIs are ideally distributed and there are no collision/confusions at the femtocell level, we start to have macrocell-femtocell confusions since PCIs has to be repeated in the given area.

III. FAP CUSTER CONCEPT

As discussed in the previous section, even in case of ideal PCI assignment as the number of FAPs in the given macrocell exceeds 503, the PCIs have to be inevitably repeated and confusion events at the macrocell-femtocell level takes place. To deal with this issue, we propose: a) increasing PCI range, and b) introducing FAP clusters. The FAP cluster concept can be described as follows.

A superior macrocell (or microcell) is divided into several smaller logical regions, called FAP clusters, where a FAP cluster is formed by set of neighboring FAPs. A FAP is part of a FAP cluster if the FAP can hear (detect) at least one FAP of the cluster, i.e., a FAP cluster contains at least two FAPs. Thus, a macrocell is composed of at least one (see next), or several FAP clusters (see Fig 5).

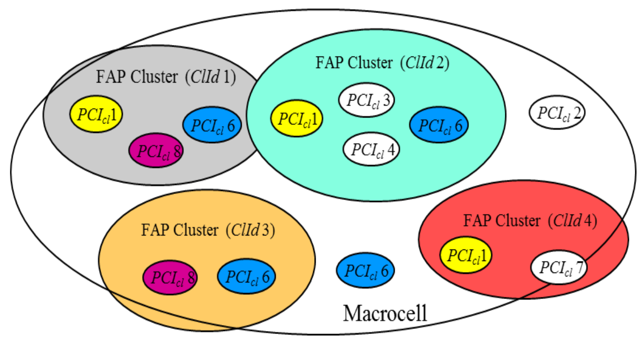

Figure 5. FAP cluster concept.

Each cluster within a macrocell is assigned a unique FAP cluster identifier, called as *ClId*. Within a FAP cluster, a FAP is assigned, if possible, collision/confusion free PCI, denoted as PCI_{cl}. Notice that any kind of PCIs assignment methods can be used here to avoid collision/confusion events. The same PCI_{cl} can be subsequently repeated in other FAP clusters (see for example PCI_{cl} = 1 in Fig. 5). The suggested PCI structure can be illustrated in Fig. 6.

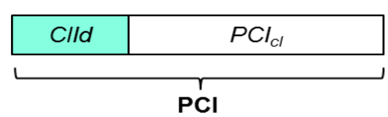

Figure 6. Enhanced PCI structure.

All isolated FAPs, i.e., a FAP that cannot detect any other FAP in its vicinity, form a FAP cluster called isolated FAP cluster (see for example PCI_{cl} = 2, or 6 in Fig. 5). Therefore, there is always at least one FAP cluster within a macrocell. In the next, we abbreviate the isolated femto access point as FAP_{is} and the isolated FAP cluster as FAP_{ISCL}. The FAP_{ISCL} is assigned a predefined, default, value of *ClId* that is known by all MBSs and FAPs in the network, e.g., *ClId* = 0.

Based on the FAP density evolution, the number of FAP clusters can vary in time and from macrocell to macrocell. A MBS knows the current number of FAP clusters in its macrocell and informs all FAPs under its coverage about the *ClId* values. To do that, MBS/FAP broadcast channels, or femtocell backhaul can be employed to distribute this information. Notice that if there are only $FAPs_{is}$ in the macrocell, the *ClId* value does not have to be distributed as

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the *ClId* is known, which reduces signaling overhead in the network. In other words, the today's way of PCIs assignment, without the FAP cluster concept, can be seen as if *ClId* = 0. Thus, the FAP cluster approach can be gradually introduced in todays' networks.

When introducing a new FAP (FAP_{new}), the following three scenarios can occur; the scenarios and steps are summarized in the flow chart in Fig. 7:

a) Joining an isolated cluster . Not detecting any FAP, the FAP_{new} selects the predefinied value of *ClId* for the FAP_{ISCL}. This scenario will mainly occuer in the initial phase of FAPs deployment when the number of FAPs within a macrocell is small. As stated above, this scenario can be also seen as today's approach without the FAP clusters.

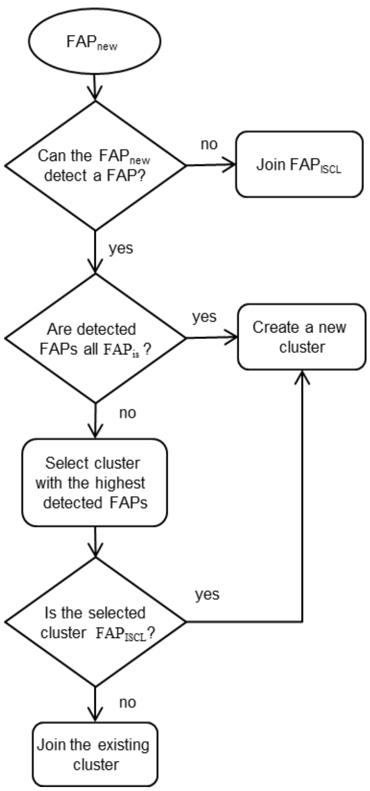

Figure 7. Steps when introducing a new FAP within a macrocell.

b) Joining an existing cluster. Detecting only *non-*$FAPs_{is}$ belonging to one, or more FAP clusters, the FAP_{new} selects and joins a cluster in which detects the highest number of FAPs. This solution enables keeping FAP clusters compact otherwise clusters would become mixed with each other.

c) Creating a new cluster. Detecting one, or more FAPs belonging to one, or more FAP clusters, the FAP_{new} selects and joins a cluster (including the FAP_{ISCL}) in which detects the highest number of FAPs. If the joined cluster coresponds to FAP_{ISCL}, the FAP_{new} initiate creation of a new FAP cluster that will be composed of all detected FAP_{is} (they update their *ClId*). Thus, the number of FAP_{ISCL} is kept as low as possible within the macrocell. The FAP cluster creation is done with the network/MBS assitance and results in updating of *ClId* value that is spread out in the macrocell.

IV. IMPLEMENTATION OF FAP CLUSTER IDENTIFIER

To implement the FAP cluster concept in the present LTE/LTE-A mobile networks, there can be considered three approaches denoted as: a) sub-identifier, b) new identifier, and c) alternate transmissions.

A. Sub-identifier

The simplest and easiest way to implement the FAP cluster identifier, *ClId*, is to dedicate from the existing PCIs range certain PCIs to the FAP cluster identifiers. This is a similar approach like propositions in [13-15] where authors suggest splitting PCIs range among different type of cells (MBSs/FAPs, open/closed/hybrid). However, the small number of PCIs still remains a limiting factor, i.e., the confusion events at macrocell level remain. Therefore, this solution is only reasonable in a case of relatively low density femtocell environment where the PCI range reduction can be accepted.

B. New identifier

In this case, the *ClId* is considered to be a new independent part of the present PCI structure (see Fig. 6).

The LTE radio frame, 10ms long, is divided into 10 sub-frames of 1 ms duration. Each sub-frame is further split in two 0.5ms slots. A slot contains seven, resp. six, OFDM symbols in case of normal cyclic prefix, resp. extended cyclic prefix. In LTE-FDD mode, the PSS is embedded in the last OFDM symbol and the SSS in the second last OFDM symbol, of the sub-frame 0 and 5 in each radio frame [5]. The PCI is obtained by decoding PSS in the first phase (which represents one of three possible cell identities) and then decoding the SSS (which represents one of 168 cell-group-identities).

In the frequency domain, 6 Resource Blocks (RB) around the DC subcarrier are reserved for transmission of the synchronization signals; an RB is formed by 12 subcarriers with a subcarrier spacing of 15 kHz.

Both synchronization signals, PSS and SSS, are based on Zadoff–Chu (ZC) sequences [5]. Since the PSS uses only 62 of the 72 reserved subcarriers (6RBs x 180 kHz), the required length of ZC is 63 (62 subcarriers and 1 un-used DC subcarrier, which is punctured). Thus, the ZC sequence is padded with five zeros at the edges. The same sequence is repeated in both PSS symbols.

Similar to the PSS, the SSS has 62 non-zero elements ZC sequence. The 62 elements are an interleaved concatenation of two length-31 sequences, each taking 31 different values. Contrary to the PSS, the SSS sequence in sub-frame 0 and 5 are different from each other.

The FAP cluster identifier can be implemented by extending the PSS and SSS signals and called Extended Synchronization Signals (ESS), as it is proposed in [17].

Within the ESS proposal, the authors propose replacing the padding zeros by additional information elements. These 20 zero-elements can be used for different purposes, in our case for implementing the FAP cluster identifier (*ClId*). In comparisons with the solution A (sub-identifier), this implementation solution makes possible to increase and flexibly adapt PCIs range based on evolution of FAP density in a macrocell. For example, allowing 8 FAP clusters would extend the PCI range up to 4031 (theoretically) non-confusion FAPs.

C. Alternate transmissions

The third way of implementing FAP clusters could be either periodically scrambling the PSS with a *ClId* specific scrambling sequence, or periodically alternate transmissions of PSS and *ClId* in the sub-frame 0 and 5. The switching period between PSS and *ClId* would have to be sufficiently long to allow a FAP/terminal to correctly decode the PSS. In the first step a FAP/terminal would decode the PSS and in the second step the cluster identifier. A drawback of this solution represents the extra time the FAP/terminal needs to decode the PSS and *ClId*.

V. CONCLUSIONS

In this paper, we discuss an approach of assigning physical cell identifier to FAPs in highly dense femtocell environment. We show that in such scenario even if the PCIs are ideally distributed among FAPs and there are no collisions/confusions from the point of view of femtocells, once the number of FAPs under a macrocell exceeds the PCI range, the PCIs need to be repeated and we begin to have confusion events at macrocell-femtocell level.

To deal with this problem, we propose a part of increasing number of PCI to divide a macrocell into smaller logical regions, that we denote FAP clusters, and to enhance the current PCI structure about the cluster identifier. Based on the FAP density evolution in the macrocell, the number of FAP clusters can be progressively adjusted. Finally, three possible implementation approaches of the FAP cluster identifier within todays' LTE/LTE-A mobile networks are outlined and discussed.

The main aim of this paper has been to describe the principle of the proposed FAP cluster concept and its possible implementation and deployment in LTE/LTE-A mobile networks. In the next step, we plan to evaluate performance of the clustering method via simulation by taking into account different scenarios and parameter settings. In addition to that, we also intend to investigate more sophisticated methods that would take into consideration several aspects before deciding, which FAP cluster the newly introduced FAP should join; e.g., positions of detected FAPs, number of FAP clusters in the macrocell, or number of FAPs in the macrocell.

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