Interference Control Technology for Heterogeneous Networks

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***Abstract*—To eliminate dead spots like home or office and let multiple users efficiently use limited frequency resources by providing a better mobile communication environment that enables high-capacity data transmission service, the demand for a small base station is increasing. Accordingly, the research for automatically minimizing the interference and increasing the capacity of the base station by optimizing the cell coverage has become necessary. For this purpose, extremely reducing the cell radius and providing a mobile communication environment for small business are needed. The femtocell services actively respond to the user's needs for a better mobile communication environment, and expanding business opportunities for the operators. The most important aspect to consider is the qualitative and quantitative service improvement of the technology. In this paper, we study the main technical issues, technological trends currently in progress related to femtocell, and femtocell interference management with access mode control on LTE-Advanced system for heterogeneous network.**

Keywords-SON; Femtocell; LTE-Advanced

I. INTRODUCTION

Femtocell means a small cell with around 10-20m radius. This concept is different from a macrocell which is a common cell. Typically, a femtocell supports a small space such as home or business offices. Thus, the femtocell base station is installed at home or office, coexisting with the existing network to ensure the mobility and mass transfer, mobile communication service area expansion, increasing the service performance and capacity of the base stations, and offering various telecommunication services.[1]

These kinds of femtocell features in home or office environment, supporting the user's requirements, minimize the operator CAPEX (Capital Expenditure, services and facilities for investment cost) / OPEX (Operational Expense, operating costs) by reducing the additional time for installation and the operation cost. It provides a new mobile communication environment that improves the quality of service [2][3].

In the ongoing standardization technology development by 3GPP (3rd Generation Partnership Project), HeNB (Home evolved Node B) is the terminology for a femtocell to support the compact base station. Customer-premises equipment, UE(User Equipment) is connected over an E-UTRAN(Evolved Universal Terrestrial Radio Access Network) wireless air interface to a mobile operator's network using a broadband IP backhaul [2].

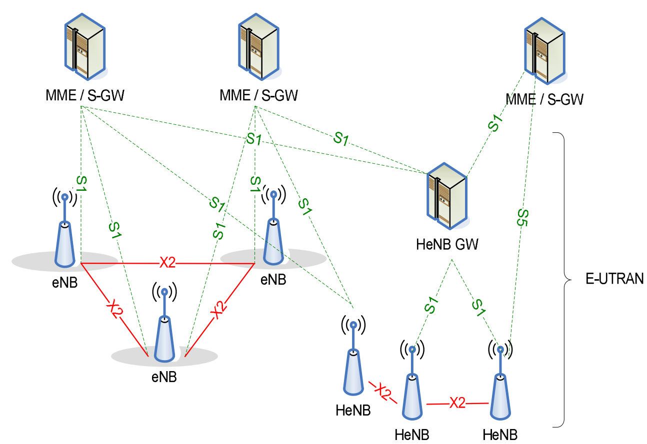

Figure 1. LTE -Advanced system Network Architecture

Figure 1 shows a 3GPP LTE (Long Term Evolution)-Advanced system Network Architecture [4]. The E-UTRAN consists of eNBs. The eNBs are interconnected with each other by means of the X2 interface. The eNBs are also connected by means of the S1 interface to the EPC (Evolved Packet Core), more specifically to the MME (Mobility Management Entity) by means of the S1-MME interface and to the Serving Gateway (S-GW) by means of the S1-U interface. The S1 interface supports a many-to-many relation between MMEs / Serving Gateways and eNBs [4][5].

Detailed SON(Self Organizing Network) technology is composed of automatically configuring information for the base station (Self Configuration) technology and

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automatically optimizing the base station's operating information (Self Optimization) [6][7]. Femtocell core technology is comprised of efficient mobility control technology, interface technology, and interference control technology.

HeNB cannot transmit the radio signals until the HeNB installation is completed. After the installation, if the HeNB causes a serious spectral interference to the nearby environment, then the service interruption can occur. New installation of a HeNB should not affect the operator's network planning, and the HeNB users should not feel the differences compared with the existing use of the base station in terms of user experience. The registration overhead and burden of paging should be minimized. And, the existing base stations should not be affected in terms of range and capacity. In addition, HeNB offers the CSG (Closed Subscriber Group) concept that only authorizes a given user group for access to the network entry [2].

II. SON Core Technology

In the fields of mobile communication systems, there exists an increasing interest in SON technology which is an automated operation approach for the network to be more reliable and efficient, and also configured extensively to perform a given function. A femtocell is installed without pre-installation process by the user. So, it detects and collects the information from the nearby environment, and it performs the optimization by itself rather than being it done by the service operators. Therefore, SON technology should lead to an installation and self-setup of indoor or outdoor base stations such as femtocell through the configuration of mobile communication environment appropriate to the surrounding cells, by performing optimization, and improving the management capabilities.

For these functions, SON element technique (Figure 2) comprises of configuration information automatic setting functions and management information automatic setting functions [8]. In order to reduce OPEX for this large number of nodes from more than one vendor, the concept of SON is introduced. Automation of network planning, configuration and optimization processes by using SON functions can help the network operator reduce OPEX by reducing manual involvement in such tasks.

SON technology includes coverage and capacity optimization, energy savings, interference reduction, automated configuration of PCI (Physical Cell Identity), mobility robustness optimization, mobility load balancing optimization, RACH (Random Access Channel) optimization, ANR (Automatic Neighbor Relation) function, and inter-cell interference coordination for each use case [3].

If the solution for a particular SON-related use case is best provided at the network level, the associated SON algorithm(s) will reside in one or more network elements. This is an example of a distributed SON architecture.

If the solution is best provided in the existing network management system or in an additional standalone SON function or server, then the SON algorithm(s) will most likely reside either at the DM (Domain Manager) or the NM (Network Manager) level. This is an example of a centralized SON architecture.

It is possible that the solution could require SON functionality partly at the network level and partly in the management system. This is an example of hybrid SON architecture.

- Centralized SON: SON solutions where SON algorithms are executed in the OAM (Operations, Administration, and Management) system. In such solutions SON functionality resides in a small number of locations, at a high level in the architecture.
- Distributed SON: SON solutions where SON algorithms are executed at the network element level. In such solutions SON functionality resides in many locations at a relatively low level in the architecture.
- Hybrid SON: SON solutions where some of the SON algorithms are executed in the OAM system, while others are executed at the NE level.

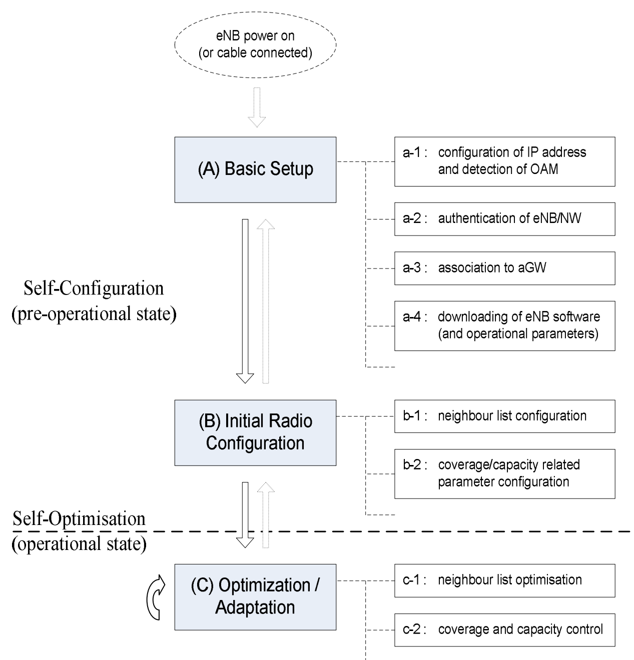

Figure 2. Ramifications of Self-Configuration /Self-Optimization functionality

A. *Self Configuration*

Self-configuration process is defined as the process where newly deployed nodes are configured by automatic installation procedures to get the necessary basic configuration information for system operation [8].

This process works in a pre-operational state. Pre-operational state is understood as the state from when the HeNB is powered up and has the backbone connectivity until the RF transmitter is switched on [9][10].

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As depicted in Figure 2, functions handled in the pre-operational state like:

- Basic Setup and
- Initial Radio Configuration

are covered by the Self Configuration process.

Depending on the finally chosen functional distribution, the feasibility of the following items should be studied e.g.:

- To obtain the necessary interface configuration;
- Automatic registration of nodes in the system can be provided by the network;
- Alternative possibilities for nodes to obtain a valid configuration;
- The required standardization scope.

B. Self Optimization

Self-optimization process is defined as the process where UE and eNB measurements, and performance measurements are used to auto-tune the network [10].

This process works in the operational state. Operational state is understood as the state where the RF interface is additionally switched on.

As depicted in Figure 2, functions handled in the operational state like:

- Optimization / Adaptation

are covered by the Self Optimization process.

Depending on the finally chosen functional distribution, the feasibility of the following items should be studied e.g.:

- The distribution of data and measurements over interfaces;
- Functions/entities/nodes in charge of data aggregation for optimization purpose;
- Dependencies with O&M and O&M interfaces, in the self optimization process;
- The required standardization scope.

III. HETEROGENEOUS NETWORK

Heterogeneous networks (HetNets) are an attractive means of expanding mobile network capacity. A heterogeneous network (HetNet) is typically composed of multiple radio access technologies, architectures, transmission solutions, and base stations of varying transmission power. Mobile-broadband traffic is increasing. In parallel, new applications are raising expectations for higher data rates in both the uplink and the downlink. Creating a heterogeneous network by introducing low power nodes is an attractive approach to meeting these traffic demands and performance expectations. By combining low power nodes with an improved and densified macro layer, very high traffic volumes and data rates can be supported. The nature of the existing network, as well as technical and economic considerations, will dictate which approach – improving the macro layer; densifying the macro layer; or adding pico nodes – or combination of approaches best meets volume and data-rate targets [8].

This traffic growth, driven by new services and terminal capabilities, is paralleled by user expectations for data rates similar to those of fixed broadband. Actual figures per subscriber can vary greatly depending on geographical market, terminal type and subscription type; some users with mobile devices are already creating traffic in the order of gigabytes and predictions are estimated to be several GB per month for some devices and certain user behavior. The mobile industry is, therefore, preparing for data rates in the order of tens of Mbps for indoor use as well as outside and gigabyte traffic volumes.

Complementing the macro networks with low power nodes, such as micro and pico base stations, has been considered a way to increase capacity for mobile data communication systems for some time now. This approach offers very high capacity and data rates in areas covered by the low power nodes. Performance for users in the macro network improves if low power nodes can serve a significant number of hotspots and coverage holes. Deploying low power nodes can be challenging, as performance depends on close proximity to where traffic is generated. In addition, due to the reduced range of low power nodes, more of them are required. Overcoming these challenges requires proper design and integration of the low power nodes [10][11].

A. Interference Control

Mobile communication system such as LTE-Advanced system requires hundreds of Mbps high-speed data transfer rates at mobile and stationary. To meet this requirement, various techniques have been proposed and OFDMA (Orthogonal Frequency-Division Multiple Access) is one of the most critical transmission technologies among them. OFDMA technology compared with single-carrier technology has superior spectral efficiency with ease of implementation at broadband, but it has some problems like the reduction in performance in the cell boundaries due to interference, because all cells can use the same frequency. Resolution for these issues can be identified into interference randomization, interference cancellation, interference coordination, antenna technique, etc. And it was discussed that solving the problem through interference coordination is most efficient.

In macrocells and femtocells collocated environment, co-channel interference can occur due to the link direction, femtocell location, access method, and the channel usage. Channel usage can be classified as follows [12].

- Co-Channel: the macro sharing the entire frequency band with femto (macro-femto interference is fatal)
- Partial Co-Channel: Use a macro full band, some band shared by femto (macro-femto interference is fatal)
- Dedicate Channel: macro and femto using different frequency bands (macro-femto no interference, femto-femto major interference)

When we define the interference environment factor as the critical factor affecting the interference, different kinds of interference, when the macrocell and femtocell coexist, depend on how these factors apply to each different kind of interference occasions. Therefore, each appropriate interference mitigation techniques should be applied in order to avoid possible interference scenarios following different kinds of interference.

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In Figure 4, 1 through 6 shows critical interference scenarios depending on the environment, and situation is represented on the position of the terminal based on 3GPP TR 25.820 [13].

Interference scenarios consist of macro-femto (interference scenarios 1-4), and femto-femto interference (scenarios 5 and 6). Interference is classified by the link direction and femtocell position.

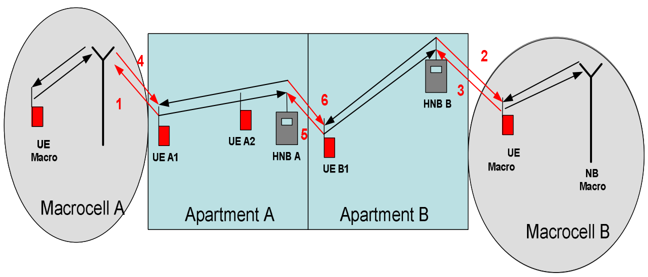

Figure 3. Interference Scenario

Base station uses various scheduling methods for frequency reallocation to minimize the neighbor cell interference. The frequency distribution methods are classified as FFR (Fractional Frequency Reuse), SFR (Soft Frequency Reuse), and PFR (Partial Frequency Reuse).

Frequency reuse means that same frequency can be used in different cells for improving the system capacity greatly. OFDMA systems supporting FFR for interference mitigation divides frequency and time resources into several resource sets. Typically, each resource set is reserved for a certain reuse factor and is associated with a particular transmission power profile.

Basic principle for FFR is that the total available bandwidths are divided by 3 groups. Every cell/sector selects one group as its major bands, and others as its minor bands. Upper limit of the transmit power for major bands is higher than the minor bands, where the major bands can be used in the whole cell area. Minor bands are used only in the inner zone of the cell with limited transmit power.

The idea of PFR is to partition the whole frequency band into two parts, with reuse factor 1 on one part and reuse factor 3 on the others. The parts using the reuse factor 3 of the frequency band are called the cell edge bands, and the other parts are called as the cell center bands. The restrictions of frequency access for the cell center/edge users are the same as in SFR, that the cell edge users are only allowed to use the cell edge band, while the cell center users are allowed to access both the cell center and edge band, but with lower priority than the edge users [14].

Adjustment of the inter-cell interference in the 3GPP LTE base stations across the embedded load information of pre-defined indicators is done by exchanging messages via the X2 interface and the surrounding state of the cell to determine the frequency range to cause interference. Load information transmitted via the message indicator is defined in 3GPP TS 36.423 specification, which includes IOI (Interference Overload Indicator), HII (High Interference Indicator), and RNTP (Relative Narrowband Tx Power) [15].

B. *Access Mode Classification*

There are three fundamentally different Femtocell access classes, also known as cell access modes, envisioned to match requirements from different use cased:

- Closed Subscriber Group (CSG) Femtocell: This is meant for the business or home application, where the customer of the Femtocell service wants to restrict its usage to own demands, e.g., the cell is not part of the public coverage for the operator. The cell in closed access mode is accessible in normal service state only for the members of the CSG of that cell.
- Hybrid mode Femtocell: In this case, part of the capacity is ‘reserved’ for the UE belonging to the configured CSG, but a part of the capacity is left open for more public usage. This is solution benefits the operator as part of the interference problem is alleviated and this may in return lead to a lower Femtocell operation cost for the end user(or even revenue generated from sharing backhaul and radio capacity). The CSG membership can be also used to differentiate in the service offer between the subscribers.
- Open mode Femtocell: The last category is fully open to all subscribers and its use is thus envisioned for hot-spot applications as part of the managed wide area network. From the UE’s perspective, the open Femtocell is like a normal macrocell.[1]

IV. Interference Avoidance

A. *Victim UE Problem*

The interference problem for the downlink case is shown in Figure 4, where the signal received by macro UE from the macrocell eNB has low power due to the high path loss [16][17]. Therefore, macro UE may experience large interference from the CSG HeNB if both HeNB and eNB use non-orthogonal radio resources to serve femto UE and macro UE. There will also be potential interference at the femto UE from the eNB. Serious UE outage occurred at victim macro UE near the HeNB.

Similarly, in the uplink case, macro UE may have to transmit at high power, due to the high path loss to the macrocell eNB. As a result, the CSG HeNB will suffer from high interference from macro UE, if both macro UE and Femto UE are assigned non-orthogonal radio resources. There will also be potential interference at the eNB from the Femto UE. In femtocell deployment, interference has to be controlled under certain level to guarantee the system performance and efficiency. Therefore, there is a tradeoff between sharing radio resources and system efficiency. For closed access HeNBs, protection of the downlinks of other cells is an important consideration and can be done on the basis of managing the usage of power and/or resource blocks. This may restrict the operation of the HeNB such that the HeNB performance may be degraded. To avoid restricting the HeNBs unnecessarily, it could be useful to detect whether there are victim UEs in the vicinity of the HeNB. If so then full protection could be provided. If not

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then a reduced level of protection can be provided. So, victim UE problem is that, in a macro-femto scenario, the macro UEs (not allowed to access the femtocell) near a femtocell suffer from severe interference from the femto-eNB[17][18].

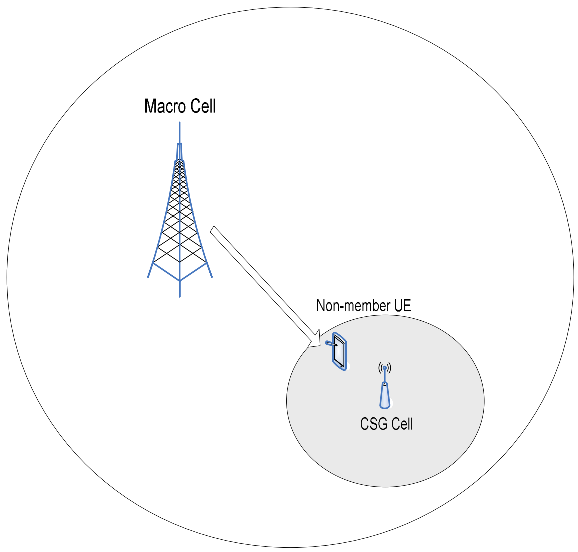

Figure 4. DL interference

B. *Dynamic Access Mode Change*

The access mode of CSG cell only can be modified at H(e)NB off-line state for the more simpler process flow. The reconfiguration of access mode on-line may bring out some complication. We understand that there may be some problems, for example, whether the new reconfiguration should affect the active UE(s) or not, and how can we perform the process. But there are some reasonable usecases for this case including victim UE problem that mentioned above. We will discuss the situations of case respectively.

Case-1 : Interference situation

The macro UE located within the coverage area of a non-allowed CSG cell had a serious problem to receive from a macrocell on the same frequency due to the interference from the non-allowed CSG cell. However, if they are already camped on a macrocell on the same frequency, there is no mechanism available to trigger reselection or handover to non-allowed CSG cell or another carrier frequency. Hence it is inevitable that macro users will be denied service when they happen to be in close proximity to a non allowed CSG cell. And it is also make trouble to the CSG member by the interference.

In this case if we change the access mode of CSG cell "closed" into "hybrid" during operation, it is the one of the solution for protecting the CSG member from this interference situation.

Case-2 : Congested CSG cell situation

A H(e)NB operating in hybrid access mode should give preferential access to members of its CSG relative to all other members .

- In hybrid access mode when services cannot be provided to a CSG member due to a shortage of H(e)NB resources it shall be possible for established communication of non-CSG members via a CSG cell to be diverted from the CSG cell.
- In a H(e)NB in hybrid access mode, to minimise the impact of non-CSG established communication on CSG members, it shall be possible for the network to allow the data rate of established PS communication of non-CSG members to be reduced.

If the hybrid access mode cell becomes congested, then it may become necessary for the H(e)NB to redirect any established non-CSG members from its cell if a CSG member (preferential user) attempts to gain service access. One way to address this issue would be by changing the access mode of the cell from hybrid to closed mode, when it is congested [5].

Case-3 : H(e)NB enterprise model utilization

In a shopping centre or any large building, indoor coverage from macrocells is generally not sufficient to service large number of users. In this case, hybrid access HeNB can be deployed by each individual shop owner or sections of the building to provide good quality of service and coverage. This essential creates some sort of zoning of services within the indoor area, and such zoning concept is thought to be best implemented by a hybrid cell rather than a CSG cell due to the reason that capacity of HeNB can be better utilised. In addition, the owner of HeNB can provide better environments for high speed internet service and voice calls, draw more customers into the premises and increase the business opportunity, and allow preferential treatment for preferred and high value customers. Like this, there are many service cases for H(e)NB Enterprise model with access mode[5]. For the load balancing aspect and the operation of the flexibility, changing CSG mode is useful. The advantage of the access mode reconfiguration during operation is obvious, such as UE(s) would not be deleted from the H(e)NB and the configuration is so timely that UE(s) can get new service more effectually.

Case-4: Avoid unnecessary reselections, registrations & handover to hybrid/open cells

If H(e)NB is fulfilled it's capacity, it is meaningless operating as hybrid/open mode cells. At that time, it can change the access mode of cell to "closed" for unnecessary reselections, registrations and handover.

V. CONCLUSION

A femtocell is a small cellular base station desinged for usage in residential or small business environments. A femtocell allows service providers to extend service coverage inside the user's home - especially where access would otherwise be limited or unavailable – without the need for expensive cellular towers. It also decreases backhaul costs since it routes mobile phone traffic through the IP network. Femtocell standardization is currently underway, but the world's leading mobile communications companies are already making prototypes to promote the introduction of femtocell. Because of the insufficient study on femtocells, in

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this paper we presented the SON and femtocell definitions for the LTE-Advanced system, technology trends, and analyzed the current SON and femtocell technologies. And also, we discussed the reason for access mode modification of CSG cell during operation. The reconfiguration of access mode on-line may bring out some complication, but we propose this method that access mode of CSG cell can be modified during operation for the above usecases.

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