Geo-Location Based Self-Organization Scheme for Femtocell Networks

Mujeeb Ahmed, Sung-Guk Yoon, Seungbeom Jeong, Saewoong Bahk
INMC, School of EECS, Seoul National University, Seoul, Korea
mujeeb@netlab.snu.ac.kr, sgyoon@netlab.snu.ac.kr, sbjeong@netlab.snu.ac.kr, sbahk@snu.ac.kr

Abstract—**The massive and random deployment of Femto Base Stations (FBSs) by users generates several technical challenges. This work investigates self-organization in an LTE femtocell network. Specifically, each FBS self-configures locally unique Physical Cell ID (PCI) and Neighbor Cell List (NCL). As more and more FBSs are being deployed, PCI reuse is inevitable, which aims to minimize cell ID collision and confusion. In addition to PCI assignment, NCL management is also important for smooth handoff operation and reduction in call dropping. In this paper, we propose a PCI assignment and NCL management scheme based on geo-location information of each FBS. We also proposed Borrowing based Conflict Resolution method for conflict free PCI assignment in hierarchical femtocell and macrocell networks. The case with Geo-location error is also investigated. The simulation results show that even for a densely deployed femtocell network, our algorithm consumes a small number of PCIs owing to the benefit of our PCI reuse policy. Extensive Simulations show the performance gain of our algorithm as compared with other schemes.**

Keywords-Femtocell; PCI Assignment; NCL management; Self-Organizaing Network

I. INTRODUCTION

Self-organization is important for the deployment of future wireless networks as envisioned by 3rd Generation Partnership Project (3GPP), Next Generation Mobile Networks (NGMN), and Femto Forum [1]. The femtocells will be deployed randomly and in a large number. Therefore, to integrate those with the existing network, self-organizing network (SON) technology is required. In the past, network planning and optimization was done by network operators using some optimization tools and drive tests. In some cases, networks are well planned and managed by operators using manual methods, but it incurs high cost of capital expenditure (CAPEX) and operating expenditure (OPEX)[1]. The reference signal sequences in LTE (which are comparable to scrambling codes in 3G networks) are really important for physical layer processes [2]. These reference and synchronization signals (including primary and secondary synchronization signals) are generated from sequences with direct mapping to the Physical Cell ID (PCI) [3]. PCI is needed to identify a cell physically. There are a total of 504 unique PCIs defined in LTE standard [4]. Therefore, the PCI plays an important role at physical layer and it is a first parameter which should be assigned to each base station (BS) before it starts communication with a UE. It is important for a FBS to have a locally unique PCI.

The role of PCI is vital when a handoff to a neighbor BS occurs. To support handoff, each BS needs its Neighbor Cell List (NCL). In a densely deployed scenario, it takes a long time for a UE to scan for handover preparation. The NCL management is not so simple as it is difficult to know the exact coverage of each FBS, especially under indoor environments. In this work, we perform the analysis for an extreme case, assuming that all the FBSs transmit at their maximum allowed power, and accordingly create their maximum coverage. Femtocell networks need an algorithm that provides a conflict-free PCI reuse policy to cover the case of densely deployed thousands of FBSs. This paper presents distance based self configuration algorithm and extend the earlier work in [13] , by providing analytical framework and comparative study of the proposed scheme.

Our proposed algorithm has two important merits: i) it is able to adapt to network changes, and ii) it operates without any additional signaling because the algorithm does not depend on UE or downlink receiver measurements.

The rest of the paper is organized as follows. In Section II, the background of this work is highlighted. Section III describes our considered system model. Our proposed PCI assignment and NCL management algorithms are explained in Section IV. Then we show the simulation results in Section V, and conclude our paper in Section VI.

II. BACKGROUND

A. PCI Collision

If two neighboring cells have the same PCI they will result in a PCI collision. In Fig. 1, FBSs 'B' and 'C' are in collision.

B. PCI Confusion

If any two neighbors of a cell have same PCIs the problem is known as PCI confusion. The FBS 'E' in Fig. 1 has this problem and cannot decide where to handover.

C. Cross Layer PCI and NCL management

Assigning PCI and managing the neighbor list in hierarchical cell structure needs a careful analysis. PCI conflicts may occur between FBSs and macro BSs (MBSs) even though there would be no conflict within the single layer if seen separately. In Fig. 1, MBS is assigned 20 as its PCI and same is also assigned to FBS 'H' by an independent and

This research was supported by Basic Science Research Program through the National Research Foundation of Korea (NRF) funded by the Ministry of Education, Science and Technology (No. 2012R1A1A2006171).

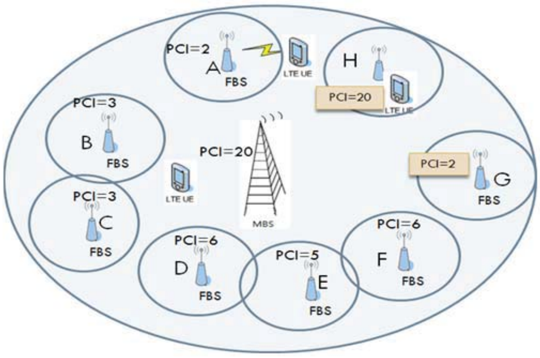

Figure 1. An Example of PCI Conflict Scenario

separate process. This PCI assignment might be unique within femtocell and macrocell layer but a UE in coverage of both will not be able to distinguish between the two. We refer this problem as cross layer PCI collision. Solution to this problem is splitting the whole *PCI* set of 504 PCIs provided by LTE standard in two reserved sets for femtocell ($RPCI_{femto}$) and macrocell ($RPCI_{macro}$) networks respectively [6].

Splitting the PCI set between two layers, ensures PCI collision free assignment but PCI confusion may still happen. As an example, if we look at the Fig. 1, FBSs 'A' and 'G' have the same PCI (based on proposed PCI reuse policy), which is conflict free assignment within femtocell layer but can be a source of cross layer confusion. For an inbound handover (macrocell to femtocell), MBS will not be able to know whether it's FBS 'A' or 'G' and result in failed handoff. This problem will occur when MBS has both the conflicting FBSs in its NCL. To solve this problem, dynamic NCL management for MBS is proposed. Using this scheme we do not need to maintain all FBS's IDs in Macro Neighbors Cell List (*MNCL*) for handovers, instead *MNCL* can be dynamically generated. $MNCL_i$ for MBS 'i' can be constructed as union of 'j' neighboring MBS PCIs (NCL_{MBS}) and the set of 'k' neighboring FBSs (NCL_{FBS}) reported by UE dynamically depending on its location.

$$MNCL_i = NCL_{MBS} \cup NCL_{FBS}, \qquad (1)$$

D. Related Work

Mobile-assisted measurements have been extensively used to resolve PCI conflict and NCL management among neighbor cells. Authors in [5], employ this mechanism for LTE MBS deployment to manage PCI and NCL. Y. Liu et al. [7] used the down link MBS receiver to measure the neighbor's signals and then assign PCI. Bandh et al. [2] used graph coloring method for PCI assignment and minimize the number of used PCIs. The work in [3], discussed the problem of PCI self-organization for FBS. It is based on the downlink receiver measurements. All the previous works have a major drawback, i.e. their method depends on the availability of UE, proper location of UE to identify all the potential neighbors and coverage of BS (downlink receiver based schemes). Differently from related works, our proposed scheme solves the problem based on the geo-location of the FBS and hence reducing overhead. Geo-location information is an important requirement for LTE as specified by the 3GPP standard [8, 9].

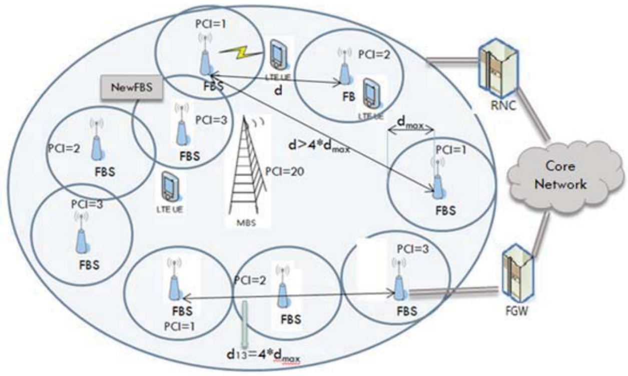

Figure 2. Distance based PCI allocation

III. System Model and Approach

The basic femtocell network infrastructure is shown in Fig. 2. We assume that the location of the FBS is known to the system and Femto-Gateway (FGW) manages Operation and maintenance (OAM) information such as cell identification and location [8, 10]. In addition, we present indoor localization techniques along with their accuracies and robustness. We also did performance analysis based on error in location information. There are many techniques which could be used for femtocells scenario but we recommend RADAR, Ekahau [11] with accuracies up to 3~4 m, 1 m respectively and both are based on WLAN. We can also use GSM fingerprinting [12] based scheme with an accuracy up to 5 m. These techniques do not use any additional infrastructure. There are more sophisticated techniques [11] with higher accuracies but those need large infrastructure deployment making them unsuitable for our purpose.

We proposed a centralized scheme as recommended by 3GPP [8]. Therefore, our proposed algorithm is operated in FGW. All the FBSs are assumed to transmit at maximum Pilot Power P_{max} and correspondingly have maximum coverage of d_{max} as shown in Fig. 2. All the BS and UE transmitters are considered to be omni-directional. Any two FBSs are considered as neighbors if they have overlapping coverage area or even tangentially touch each other (farthest neighbors). The maximum distance between any two neighbors can be $2d_{max}$. We define 'd', as the relative distance between any two FBSs. For a newly installed FBS at location $p= (x,y)$, we calculate its relative distance from all 'f' FBSs.

$$d_f = \sqrt{(x - x_f)^2 + (y - y_f)^2} \quad \forall \text{ f FBSs} \qquad (2)$$

To construct Neighbor Cell List (NCL) we need to check (2) and create the NCL for any new FBS 'q' (NCL_q) by definition.

$$NCL_q = NCL_q \cup PCI_f \text{ , } \forall \text{ f if } d_f \le 2d_{max} \qquad (3)$$

Also update the NCL_f for all the 'f' neighbors in the NCL_q by adding PCI_q to NCL of each.

$$NCL_f = NCL_f \cup PCI_q \text{ , } \forall \text{ f FBSs} \qquad (4)$$

Algorithm1: ***Distance based PCI assignment***

Input : newFBS location, P_{max}, Set of reserved PCIs for FBS (R_{PCI}), existing PCIs in the network (*PCI)*

Output : Assigned PCI of the newFBS (PCI_x), *NCL*

Function (newFBS, P_{max}, *PCI*, R_{PCI}):

1. calculate distance, $D=\{d_1, d_2, d_3,\ldots,d_n\}$; for 'n' FBSs
2. FOR all i,

    IF $d_i \leq 4*d_{max}$,

    $U_{PCI} = U_{PCI} \cup PCI_i$

    END IF

    IF $d_f \leq 2*d_{max}$,

    $NCLq = NCLq \cup PCI_f$

    END IF

    END FOR
3. $A_{PCI} = [R_{PCI} - U_{PCI}]$; // Determine available PCIs,
4. IF $A_{PCI} \neq \emptyset$,

    $PCI_x = A_i$ where $i = \arg\min_j d_j$

    ELSE,

    Call CRB( ),

    $PCI_x = PCI_i$ where $i = \arg\max_j d_i$

    END IF
5. *Return* PCI_x , *NCL*

Following the above definitions, the FBSs within distance range of $d_f \leq 4d_{max}$ have a potential for PCI conflict (collision or confusion) with any new FBS 'q'. For example in Fig. 2, d_{13} between two FBSs is $4d_{max}$ therefore we assign unique PCIs to all three BSs in range.

If FBS on right would be more than $4d_{max}$ apart, we would simply reuse PCI 1 instead of 3. We may reuse PCI_f for new FBS for which $d_f \geq 4d_{max}$, to minimize PCI usage (we define this procedure as PCI reuse policy based on distance). Let's consider a scenario where maximum available PCIs are 3. Suppose the BS labeled as 'NewFBS' in Fig. 2, just appeared in the network; where all the PCIs in $RPCI_{femto}$ have been used for $d_f \leq 4d_{max}$. We define 'reuse distance' as the maximum relative distance ($\max(d_f)$) between 'NewFBS' and others within $d_f \leq 4d_{max}$. Therefore PCI equal to 3 is assigned to 'NewFBS' based on reuse distance as it is farthest among all the others under consideration. Reuse distance policy tries to mitigate the PCI collision and minimize the PCI confusion; however a conflict may not be avoided (see section IV.B).

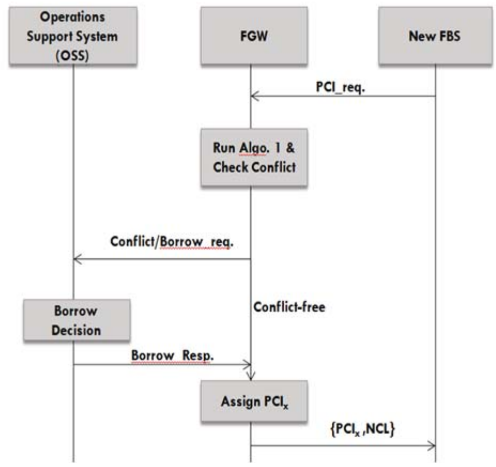

Figure 3. Conflict resolution by borrowing (CRB) procedure

IV. Proposed Algorithm

A. *PCI Assignment and NCL Management*

The proposed PCI assignment scheme is explained in Algorithm 1. The goal of this algorithm is to assign a locally unique PCI for each FBS without any conflict and minimize the number of used PCIs based on reuse policy. The detailed procedure is explained as follows:

1. In the first step, it calculates relative distance 'd' between the newly deployed FBS and other already existing FBSs in the system. The required information about the existing FBSs, i.e. position and PCI of each FBS, rests with the femto gateway.

2. For all those FBSs (where $d_i \leq 4d_{max}$), check their PCIs in database and mark these as 'used PCIs' (U_{PCI}) for each i^{th} FBS as:

$$U_{PCI} = U_{PCI} \cup PCI_i \quad (5)$$

It also checks for neighbors and constitute a *NCL* based on neighbor definition in (3).

3. In this step, it will look for available PCIs by subtracting the U_{PCI} from R_{PCI} set.

$$A_{PCI} = [R_{PCI} - U_{PCI}] \quad (6)$$

4. If A_{PCI} is not empty assign first available PCI in the set (based on the sequential assignment, first in the list will be the one earliest used), to new FBS. If the set A_{PCI} is empty, our algorithm assigns that PCI to newly deployed FBS which is farthest from it depending on 'reuse distance'.

5. The algorithm returns the *NCL* and PCI_x (PCI to be assigned to new FBS) and finishes execution by updating the PCI list maintained by the system.

B. *Conflict Resolution by Borrowing*

If the returned PCI_x in step 4, results in a conflict at new FBS, it can be resolved through proposed Conflict Resolution by Borrowing (CRB) procedure shown in Fig. 3. FGW is responsible for checking PCI conflicts. If there is no conflict, FGW assigns PCI_x to new FBS. If conflict is found, FGW sends a PCI borrowing request to Operations Support System (OSS) to borrow PCI from macro-cellular network.

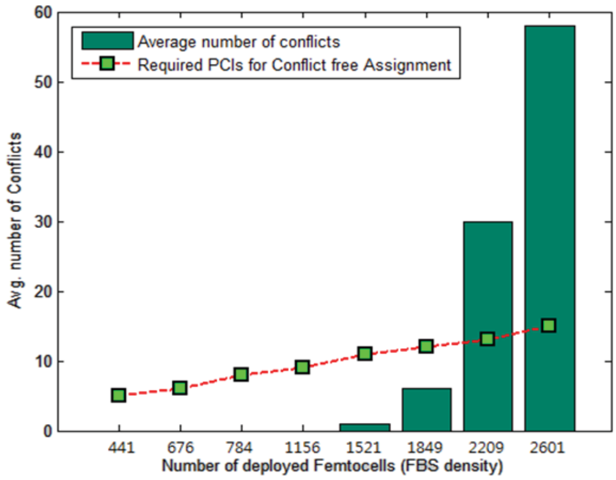

Figure 4. Avg. number of conflicts and required PCIs vs. FBS density

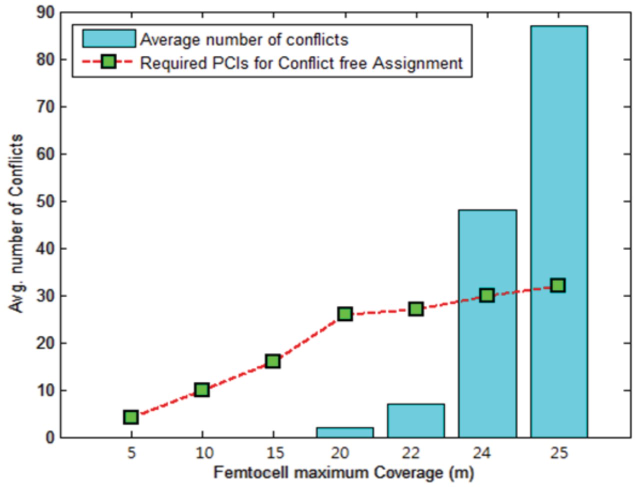

Figure 5. Avg. number of conflicts and required PCIs vs.FBS coverage

OSS checks for available PCIs from the reserved PCI set for MBSs and makes a borrowing decision based on status of the available PCI set. This decision is notified to FGW through borrow_response message. FGW sends NCL list and assigned PCI to FBS and update NCL of other neighbors.

C. *Analytical Model*

We formulated the analytical model to verify simulation results. The expected number of FBSs in a cluster can be found, given deployment probability (P_d):

$$\Pr[N_{b,c} = k / N_{g,t} = n] = \binom{n}{k} (p_d)^k (1 - p_d)^{n-k} \quad (7)$$

$$E\left[\frac{N_{b,c}}{N_{g,t}} = n\right] = \sum_{k=0}^{n} k \binom{n}{k} (p_d)^k (1 - p_d)^{n-k} \quad (8)$$

Where $N_{b,c}$ are FBSs and $N_{g,t}$ are total grids in a cluster, given as:

$$N_{g,t} = \frac{\pi * (radius\ of\ cluster)^2}{Area\ of\ the\ grid} \quad (9)$$

As long as the number of FBSs, is less than available PCIs per cluster probability of PCI conflict is zero. Expected number of conflicts per cluster can also be found by calculating P_s (probability 'x' FBSs have same PCI in the same cluster). Probability there are 'i' FBSs given deployment probability can be calculated as:

$$\Pr[M = i] = \binom{N_{g,t}}{i} (p_d)^i (1 - p_d)^{N_{g,t} - i} \quad (10)$$

$$p_s = \Pr[i > PCI_{max}] \quad (11)$$

$$p_{reuse} = p_s = \sum_{i=PCI_{max}+1}^{N_{g,t}} \Pr[M = i] \quad (12)$$

$$\Pr[M = x / N_{b,c}] = \binom{i}{x} (p_s)^x (1 - p_s)^{i-x} \quad (13)$$

$$E[M / N_{b,c} = i] = \sum_{x=0}^{i} x \binom{i}{x} (p_s)^x (1 - p_s)^{i-x} \quad (14)$$

A comparison between simulation and analytical results for proposed algorithm is presented in section V.

V. PERFORMANCE EVALUATION

The P_{max} and sensitivity of femto BS is set to 15 dBm and -92.36 dBm respectively. Indoor propagation is modeled as L[dB]= 37 +32log(R) +n L_w where Wall Loss (L_w) is 6.9 dB. We considered a macro-cellular area of 1 Km^2. We divided simulated area in 10 m x 10 m size grid and then placed a FBS in a grid with the given dense probability, where dense probabilty of 0.1 on average has 1000 FBSs and 0.9 has as high as 9000 FBSs which is very high density. There is no specific number of reserved PCIs for FBS but some authors use as low as 30 [5].

Fig. 4 details the results obtained with the proposed algorithm, showing the average number of PCI conflicts as a function of increased femtocell density. We can observe that by increasing the density, PCI conflicts will also increase but even at the very high density of 2,601 FBSs only 58 conflicts occur. The required number of PCIs for the conflict free assignment is 15, which is really small number as compared to number of FBSs. The results in Fig. 5, shows the average number of conflicts as we increase the coverage range of a FBS. In here, we fix the maximum number of PCIs equal to 15 and number of FBSs equal to 2,600.

The results show that by increasing the coverage of a FBS , average number of conflicts also increases, but for the typical 10 to 20 m coverage of a FBS only conflicts at d_{max}=20 m are 2, with required PCIs around 15 showing robustness of our algorithm to changes in coverage region. To simulate extreme case scenario, we fix maximum number of reserved PCIs for FBS equal to 10 for the result shown in Fig. 6, 7. The simulations are done for both scenarios i.e., with and without error in location information. The error depends on the accuracy of the used technique. In our recommended positioning algorithms minimum accuracy is 5 m, hence this value is used in simulations to perform worst case analysis. The number of conflicts increase with error in location information for all schemes but increase is not too high and proposed scheme can be used efficiently. In addition, proposed distance based scheme performs much better than UEnd downlink measurement schemes. Fig. 8, shows the comparison of proposed scheme's simulated result to analytical

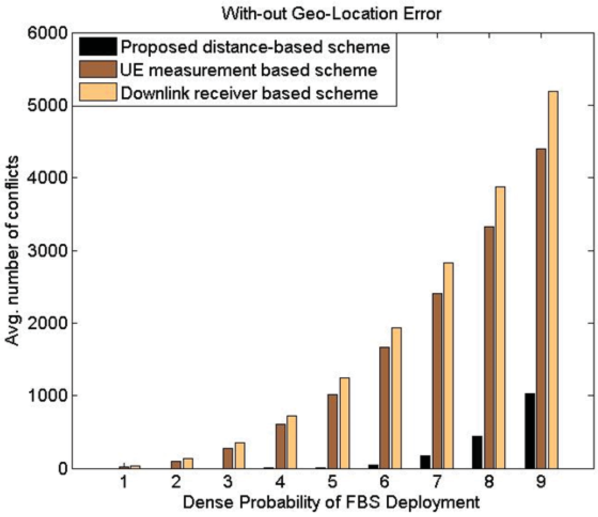

Figure 6. Avg. number of conflicts for proposed and reference schemes without error

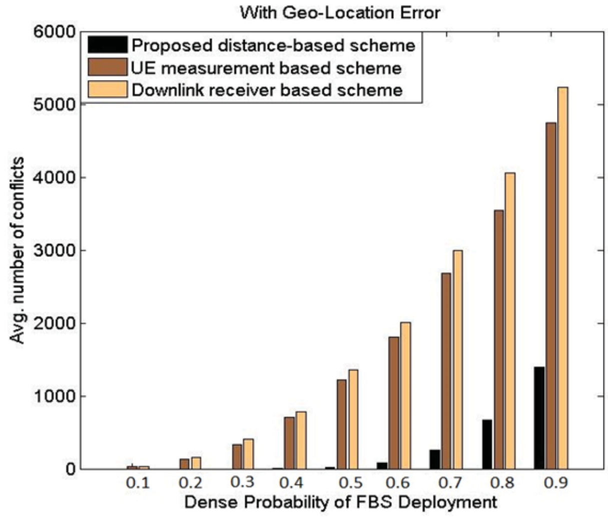

Figure 7. Avg. number of conflicts for proposed and reference schemes with error

calculations regarding number of conflicts and expected FBSs in a cluster. The difference is too small on average sense and can be neglected without losing generality supporting our simulated results.

VI. Conclusion

We presented a self-organized PCI assignment scheme in femtocell network. Large scale deployment of femtocells makes the problem more important. We proposed proficient algorithm for PCI assignment and NCL management, which is based on geo-location information of FBS. For the densely deployed environment, where system runs out of PCIs, Conflict Resolution by Borrowing (CRB) is proposed. Our results have shown that the proposed algorithm is efficient in terms of number of used PCIs and average number of conflicts.

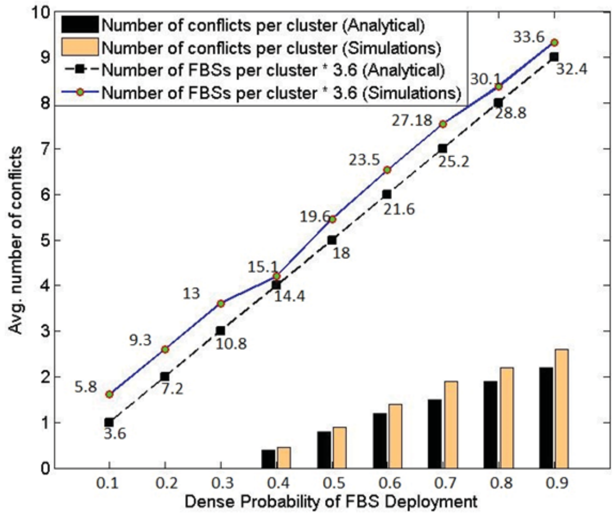

Figure 8. Avg. number of conflicts and number of FBSs per cluster

References

[1] J. Zhang and G. de la Roche, Femtocells: Technologies and Deployment, Wiley, 2010.

[2] T. Bandh, G. Carle, and H. Sanneck, "Graph Coloring Based Physical-Cell-ID Assignment for LTE Networks,"IEEE IWCMC, Jun. 2009.

[3] Y. Wu, H. Jiang, Y. Wu, and D. Zhang, "Physical Cell Identity Self-Organization for HeNB Deployment in LTE," IEEE WiCOM, Sep. 2010.

[4] 3GPP TS 36.211, "Evolved Universal Terrestrial Radio Access (E-UTRA): Physical Channels and Modulation", Dec. 2009.

[5] M. Amirijo, P. Frenger, F. Gunnarsson, H. Kallin, J. Moe and K. Zetterberg, "Neighbor Cell Relation List and Physical Cell Identity Self-Organization in LTE," IEEE ICC, May 2008.

[6] 3GPP R3-082228, "Framework for Distributed PCI Selection," 3GPP TSG-RAN WG3 # 61, Aug. 2008.

[7] Y. Liu, W. Li, H. Zhang, and L. Yu, "Distributed PCI Assignment in LTE Based on Consultation Mechanism," IEEE WiCOM, Sep. 2010.

[8] 3GPP R3-080812, TS 36.902, "Automated Configuration of Physical Cell Identity Use Case," 3GPP TSG-RAN WG3, Apr. 2008.

[9] 3GPP TS 22.220 V9.1.1, "Service Requirements for Home NodeBs and Home eNodeBs," Jun. 2009

[10] H.-C. Lee, D.-C. Oh, and Y.-H. Lee, "Mitigation of Inter-Femtocell Interference with Adaptive FFR," IEEE ICC, May 2010.

[11] Y. Gu, A. Lo, and I. Niemegeers, "A Survey of Indoor Positioning Systems for Wireless Personal Networks," IEEE Comm. Surveys, 2009.

[12] V. Otsason, A. Varshavsky, A. LaMarca, and E.D. Lara, "Accurate GSM Indoor Localization," UbiComp 2005.

[13] M. Ahmed, S-G. Yoon, and S. Bahk, "Self-Organizing Neighbor Cell List and Conflict-Free Physical Cell ID Assignment in LTE Femtocells," IEEE APWCS, Aug. 2011.