Small Cell Network Topology Comparison

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Abstract. *One of the essential problems in a mobile network with small cells is that there is only a limited number of Physical Cell Identifiers (PCIs) available. Due to this fact, operators face the inevitable need for reusing PCIs. In our contribution, we are dealing with a PCI assignment to Femtocell Access Points (FAPs) in three different topologies. The first model places FAPs randomly within the network while respecting overlapping defined. The second model places FAPs in a grid without other restrictions. The third model forms a grid as well, although buildings and roads are taken into account and FAPs are always inside buildings. The proposed models are compared and a conclusion is made based on simulation results.*

Keywords

Collision, confusion, femtocell, physical cell identifier, small cell, topology.

1. Introduction

Femtocells, also known as Femtocell Access Points (FAPs), are here for a few years yet. They are small, low-power and mainly low-cost personal or enterprise Base Stations (BSs) deployed by customers [1], not by operators as in case of macrocells, etc. Although FAPs are small, they are a big market worth $2,7 billion by 2017 [2].

Originally, FAPs were intended mainly for improving indoor coverage because poor coverage affects up to 30 % of businesses and 45 % of households [3]. Further reasons were enhancing Quality of Service (QoS) and network capacity as well as offering new services to customers and raise customer retention [1], [3].

Nowadays, FAPs and metrocells collectively called as "small cells", are used even to improve outdoor signal coverage in city centres and busy streets. For example, in Newcastle and Bristol, small cells are trail deployed and during the testing data transmission was three times faster compared to 3G network [4]. By 2016, small cells are expected to make up almost 90 % of all base stations [5]. Moreover, by 2016, small cells and Wi-Fi access points will carry up to 60 % of all mobile data traffic [6] which is a huge portion if we take into account the increase in mobile data usage.

Although small cells are a huge market, there are still some unresolved challenges. One of them is a Physical Cell Identifier (PCI) assignment mechanism. A PCI is composed of 168 unique groups each containing 3 identities which makes 504 identities in total [7]. Since every cell in the network need an identifier, this number is not sufficient and PCIs have to be reused which brings challenges, namely *i)* collision events and *ii)* confusion events.

A PCI collision means that neighbouring cells have identical identifier assigned. Such a problem produces interference which creates so-called coverage hole and none User Equipment (UE) is able to connect to any femtocell.

A PCI confusion arrives when a cell has more neighbours with the same identifier. In such a situation, when a handover should take place it will fail due to ambiguous destination where to transfer the connection [1], [3].

The aim of this paper is to develop and compare various topologies for small cell network simulations mainly dealing with PCI assignment techniques. Identifiers are assigned automatically, PCI collisions are completely avoided by scanning radio environment for neighbours' identifiers and PCI confusions are solved whenever occurred.

This paper is structured as follows. The second section briefly describes related works in this field of study which is not too wide yet. The third section is focused on three proposed topologies, their description, basic features and characteristics. The fourth section is devoted to simulations, comparing individual topologies and results. The fifth section summarizes the paper and outlines possible future work.

2. Related Works

Nowadays, identifiers are usually assigned either manually by operators using network planning tools or automatically using random selection. However, neither method is efficient. The first method is costly, time-consuming and prone to human made errors. The second method is not reliable and might produce a confusion event or even worse a confusion event.

There is a number of articles focusing on PCI assignment techniques. For example, [8], [9], [10]. However, all those works are concerned about macrocell level only.

Authors in [8] are working with real 3G network from Vodafone Germany; however, 3G network with outdoor macrocells is far from 4G network with densely deployed small cells. In [9], handover measurements are utilized just to detect issues related to identifiers in macro and microcells. In another article [10], authors simulated very few BSs not representing future dense deployments.

In all honesty, we have really tried to find out any similar study trying to compare various topology models that deal with PCI assignment techniques, but we have not discovered any.

3. Proposed Topologies

All the three proposed placements described later have a few common basic characteristics. There is always a single Macrocell Base Station (MBS) with circular coverage area under which all FAPs are deployed. For simplicity, all the FAPs have the same radius. To simulate various FAP densities (for example city centres on one hand and rural areas on the other hand), the number of FAPs generated within a topology is varying.

Although the Long Term Evolution (LTE) and LTE-Advanced (LTE-A) standards support up to 504 different PCIs, we have allowed only 480 of them at a maximum to be assigned in our simulation. The first reason behind this upper limit is that we would like to know whether a smaller portion of the identifiers is sufficient. The second reason is that other cells in a real network topology, such as macrocells, picocells, etc., require an identifier, too, so we have reserved at least a tiny PCI portion for those cells. And finally, the lower PCI range limit is required in order for the algorithm to converge and assign PCIs correctly.

FAPs need information about their neighbourhood (i.e. PCIs of neighbouring cells) whenever they are choosing an identifier in order to evade *i)* a PCI collision and *ii)* a PCI confusion.

Since FAPs have limited power, they can ask about neighbourhood only adjacent neighbours. However, this is not a sufficient amount of information when confusion events should be eliminated. To obtain data about unreachable neighbourhood in order to become aware of a greater part of the topology and evade a PCI confusion as mentioned, FAPs can employ neighbours as well simply by asking about their neighbourhood data. This is how a FAP can obtain information about neighbours multiple hops away. We term this as a hop count.

In all the three proposed topologies, a simulation works as follows. At first a MBS is generated. Then, depending on the topology selected, a defined number of FAPs is placed within the MBS area *i)* randomly, *ii)* in a precise grid, or *iii)* in a grid where FAPs are allowed to be placed only inside of buildings and forbidden outside.

Whenever a FAP is deployed, it scans radio environment for neighbouring cells. When the FAP has no neighbours we call it as a "standalone FAP" and such a FAP can select a PCI randomly. Alternatively, when neighbours are detected, the FAP selects such a PCI in order to avoid producing a PCI collision. After selecting a collision-free identifier, a bidirectional interface is established with detected neighbours for later usage. By establishing this interface a Neighbour Relation (NR) is set up and Neighbour Relation Tables (NRTs) containing lists of neighbouring PCIs are exchanged.

Now, a PCI confusion procedure check is launched. When a confusion event is discovered, a FAP that is confused by neighbours initiate a solving procedure. In our previous work, we have designed and implemented two techniques for solving confusion events, we call them "random method" and "smart method". Here, we deploy the mature one – smart method – which outperforms the other technique in terms of overhead introduced to the network.

Our "smart method" works as follows. When a FAP encounters a confusion event, it requests the involved FAPs (i.e. confusion producers) to report how many adjacent cells they have. After acquiring those numbers, the FAP with the fewest neighbours is chosen to reselect its PCI. Before a new PCI is chosen, the FAP scans radio environment (collision avoidance) and exchanges NRTs with neighbours up to 3 hops away (confusion avoidance). If the confusion event is still present, for example, when there are more than two confusion producers, this process is run again with remaining confusion producers.

Reselecting a PCI means that new NRs have to be established between neighbours and thus overhead is produced. Firstly, the FAP with a new PCI has to inform all its neighbours about this change. Secondly,

Tab. 1: Common simulation parameters.

Parameter	**Value**
MBS radius, r_{MBS}	564 m
MBS area, A_{MBS}	$1\,\mathrm{km}^2$
FAP radius, r_{FAP}	15 m
FAP count, N_{FAPs}	250–1500
PCI range	80–480
Hop count, N_{h}	3

Tab. 2: Random placement parameters.

Parameter	**Value**
FAP overlapping	< 50 %

the neighbours have to acknowledge this modification. When a FAP has n neighbours, this will eventually lead to $2n$ messages sent over the network.

Basic simulation parameters common to all topologies are stated in Tab. 1.

3.1. Random Placement

The first model is random placement which does not fully represent real conditions or a real topology even though it might be close enough by tweaking various parameters such as FAPs overlapping, etc.

In this model, FAPs are randomly placed within the MBS area using uniformly distributed pseudo-random numbers. Neighbouring FAPs can overlap each other; however, their mutual area is limited so scenarios where multiple FAPs are deployed at the same place (above each other) is eliminated. Overlapping and other parameters are stated in Tab. 2.

In Fig. 1, a demonstration of random placement is shown. Red dots represent individual FAPs. Blue lines between dots symbolise so-called NRs which means that those neighbours can communicate mutually and exchange information about neighbours including their PCIs stored in NRTs. Numbers next to red dots are PCIs assigned and numbers next to blue lines are euclidean distance between FAPs in metres.

3.2. Grid Placement #1

The second model in our comparison study is grid placement #1. It is the easiest topology where individual FAPs are deployed in a precise square grid under the area covered by a MBS. Although some spots might be left empty depending on the total number of FAPs deployed in the actual simulation. Grid placement #1 parameters are introduced in Tab. 3.

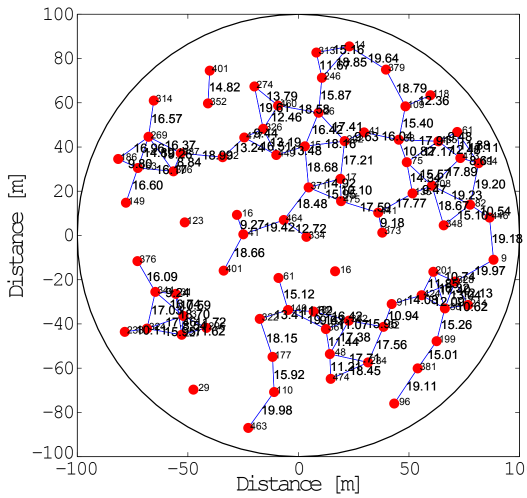

Fig. 1: Random placement demonstration.

Tab. 3: Grid placement #1 parameters.

Parameter	**Value**
Vertical side of grid	10 m
Horizontal side of grid	10 m

Grid placement #1 demonstration is depicted in Fig. 2. The meaning of red dots, blue lines and numbers are the same as in the random placement demonstration. The figure is quite similar to random placement demonstration; however, it can be seen that FAPs are not placed randomly but in a precise grid. Also, it is obvious that in this demonstration there are more standalone FAPs than in random placement.

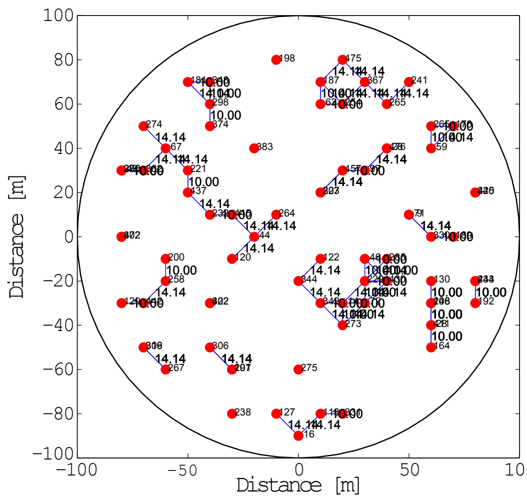

Fig. 2: Grid placement #1 demonstration.

Tab. 4: Grid placement #2 parameters.

Parameter	Value
Vertical side of grid	10 m
Horizontal side of grid	10 m
Flats in a building	10
Flat distribution	5×2 flats/building
Flat dimensions	10×10 m
Road width/height	10 m

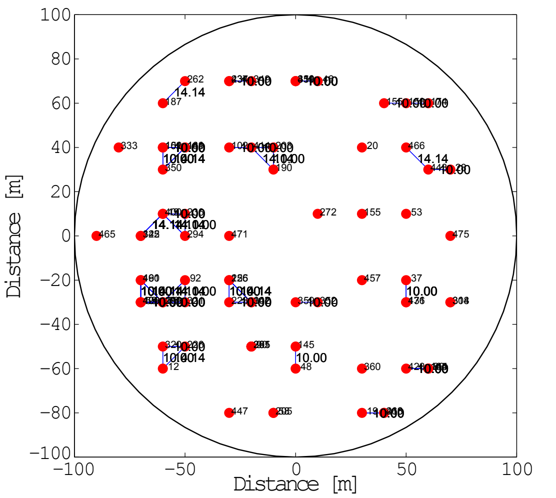

Fig. 3: Grid placement #2 demonstration.

3.3. Grid Placement #2

The third model, we have implemented for this comparison study, is grid placement #2 which is a variation on previous grid placement #1.

Area covered by a MBS is composed of single-floor rectangular buildings separated by roads. Every single building consists of flats arranged into a rectangular arrangement. Flats' and road dimensions as well as flats' distribution in buildings are the same throughout the whole topology. All the parameters are summarized in Tab. 4. And for simplicity, when a FAP is deployed, it might be placed only in the exact middle of a flat.

Figure 3 illustrates how this topology looks like. As this model is a variant of the previous one, it can be seen some similarities; however, separation of buildings by roads is very obvious at first sight. The meaning of dots, etc. is the same as in previous demonstrations.

4. Simulation Results

In Fig. 4, it can be seen that the absolute number of standalone FAPs (they have no neighbours) is not very varying in individual topologies. It is even more obvious in Fig. 5 where the number of standalone FAPs is expressed in percents of the whole topology. From these figures we can assume that all the proposed topologies are very similar eventually. The only difference seems to be in visual appearance of a particular model.

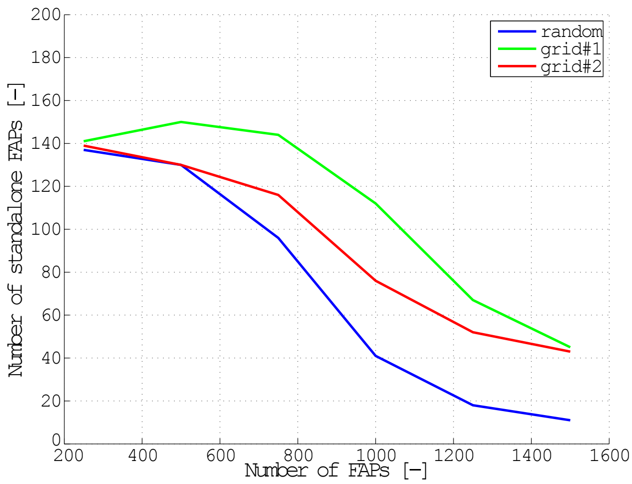

Fig. 4: Number of standalone FAPs (absolute values).

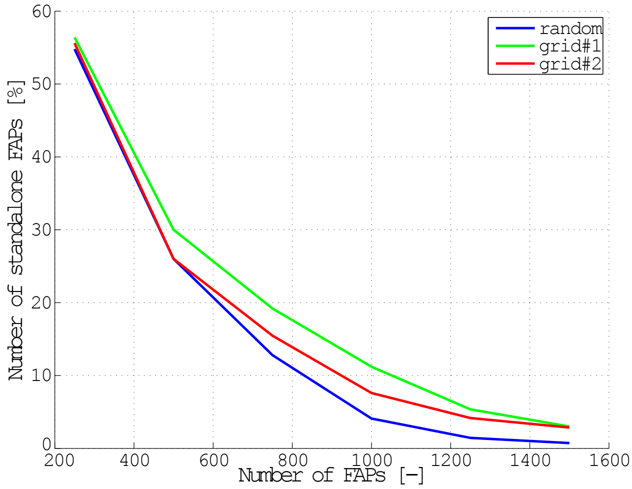

Fig. 5: Number of standalone FAPs (percents of the topology).

Figure 6 shows overhead introduced to the network while solving PCI confusion events. The overhead is counted in messages that have to be sent. This figure indicates that confusions are more common in random placement. Such a discovery is evident because FAPs in this model might be placed almost anywhere if they do not exceed allowed overlapping. However, in both grid topologies, there are more strict rules for placing FAPs. This means they can not be so close and it eventually leads to fewer confusion events.

Although grid #2 model topology experiences the fewest confusion events when only short PCI range is applied; however, with greater PCI range the differences are insignificant even when comparing to random placement as shown in Fig. 6.

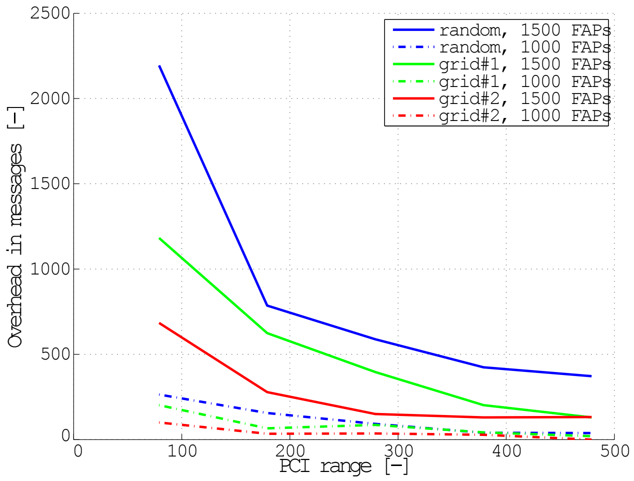

Fig. 6: Overhead caused by solving confusions events.

5. Conclusion

In this paper, we have proposed three different topologies for small cell network simulations dealing mainly with PCI assignment techniques. It has been shown that there are no significant differences among those models, although the complexity of particular topologies are considerable.

From our simulation results, we can conclude that the easiest model to implement (random placement in this case) is the most suitable at the same time.

In the future, we are going to enhance our models further. For example, by enabling FAPs to have varying radius we get closer to a reality because this option could simulate different attenuation in separated buildings. Also, having more MBSs that partially cover the same area is another way how to get more real simulation results.

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