# Topological Planning and Design of Heterogeneous Mobile Networks in Dense Areas

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*Abstract:* **Mobiles have become very essential part of our everyday life begin of voice call to internet access. Therefore, the cellular industry is a very competitive market in the whole world. As the development 4G mobile wireless standards the operator need to know how to design and update their networks so that they can provide the best services to the lowest possible cost. This topic has become a hot topic in the industry. In this paper, we present a literature review on the topological planning problem of LTE Advanced-based Heterogeneous mobile Networks. After describing the need of heterogeneous mobile networks, the architecture is presented. A comparison is made between components to justify the necessity of components we will use in the planning process. We focus on base stations layout and the main problems faced in this planning. This paper provides a high level overview of different parameters constraints and challenges that operators must tackle in order for these networks to reach their potential so that it is used as a starting point for future research on topological design of Dense Areas Heterogeneous mobile Networks.**

*Keywords: network planning; cell planning; mobile network; Heterogeneous Mobile Networks; Dense Areas*

## I. INTRODUCTION

LTE Advanced-based Heterogeneous Networks is introduced to improve spectral efficiency per unit area. LTE Advanced-based Heterogeneous Networks use a mix of Macro, Pico, Femtocell and Relay base stations [1]. Heterogeneous networks enable flexible and low-cost deployments and provide a uniform broadband experience to users anywhere in the network.

Over 70 percent of total data traffic is expected to be generated in indoor environments [2]. With such rapid growth of mobile data and the poor indoor coverage, wireless operators are urgently seeking cost-effective solutions to achieve good indoor coverage with high capacity.
The new multimedia services and high data rate applications intensifies the need of good quality indoor coverage [3]. Hence, providing good quality indoor voice and data services is of great importance. This would also be beneficial for the cellular operators in the form of increased revenue and reduced churn. Mobile cellular networks have gained reputation for poor indoor coverage resulting in inferior call quality, QoS issues becomes more predominant as mobile users begin using 4G services. Due to the penetration losses, the indoor user requires high power from the serving Base Station (BS), which means other users would have less power and as a result the overall system throughput is reduced. It is also very expensive to have a large number of outdoor BSs to meet the needs of a high capacity network. The large number of BSs would pose larger burden on network planning and optimisation as well. Therefore we need some indoor coverage solutions. Nevertheless, one of the most critical issues in indoor network planning is the potential interference between nearby indoor base stations and from indoor base stations to macrocells or to mobile handsets, thus mitigating the overall system capacity. In this paper, we have discussed mechanisms which can be deployed to lessen the interference and increase the user capacity. Therefore, we provide a survey on the different interference types.

The next section discusses the network architecture and compare between proposed solutions to coverage indoor environments. Section 3 the pathloss model, Section 4 discusses the Heterogeneous Networks interference Scenarios. Section 5 summarizes the road map for dense area network planning. The paper's conclusions are presented in Section 6.

## II. NETWORK ARCHITECTURE

The core network of the LTE-Advanced system is separated into many parts. Figure 1 show how each component in the LTE-Advanced network is connected to one another [4] [5] [6]. NodeB in 3G system was replaced by evolved NodeB (eNB), which is a combination of NodeB and radio network controller (RNC).
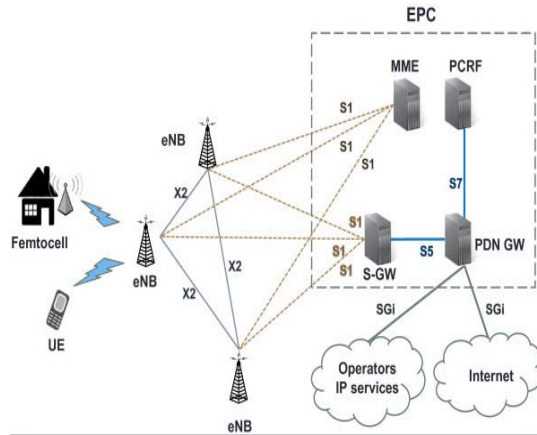
CPS

Figure 1. Network Architecture of LTE-Advanced

The eNB communicates with User Equipment's (UE's) and can serve one or several cells at one time. Home eNB (HeNB) is also considered to serve a femtocell that covers a small indoor area. The evolved packet core (EPC) comprises of the following four components. The serving gateway (SGW) is responsible for routing and forwarding packets between UE's and packet data network (PDN) and charging. In addition, it serves as a mobility anchor point for handover. The mobility management entity (MME) manages UE access and mobility, and establishes the bearer path for UE's. packet data network gateway (PDN GW) is a gateway to the PDN, and policy and charging rules function (PCRF) manages policy and charging rules [7].

Figure 2 illustrate types of cell according to the surrounding environments.

Mobile terminal location can be outdoor or indoor. If the mobile terminal is located inside buildings the environment is called indoor, otherwise it is outdoor. Antenna location, it can be above or below the average rooftop level. In case, when base station antenna array is above average height of the buildings, the environment is considered to be macro-cellular and, in case, when base station antenna array is below average height of the buildings, the environment is considered to be microcellular. There is even smaller type of the cells than macro and micro cells, so called pico cells for which the antennas are located mainly in indoor environments if it located in shopping mall or enterprise.
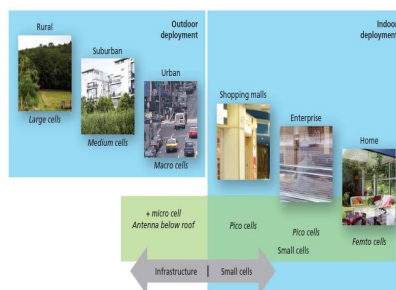
In Femto cells, the antennas are located mainly in indoor environments if it located in home. The radio propagation characteristics are different for macro-cellular, micro-cellular and indoor environment. Urban, suburban and rural area types are determined by the variation of size and density of both manmade and natural obstacles located in surroundings of User Equipment (UE) and base station sites [8]. Figure 3, shows the type of base station according to propagation environment. A Heterogeneous Network (HetNet) is a mix of high power macro-eNBs [9] responsible for umbrella coverage mainly for outdoor users, and low-power micro/Pico/Femto/relay BSs that are deployed for incremental capacity growth and coverage enhancement.

Macrocells: A Macrocell provides the largest area of coverage within a mobile network. Its antennas can be mounted on ground-based masts, rooftops or other structures and must be high enough to avoid obstruction. Macrocells provide radio coverage over varying distances, depending on the frequency used, the number of calls and the physical terrain. Typically they have a power output in tens of watt. Macrocells are conventional base stations with power between 20 W to 160 W, that use dedicated backhaul, are open to public access and range is about 1 km to 20 km. In case of indoor coverage, QoS cannot be guaranteed due to the variations in channel conditions.

Microcells: Microcells provide additional coverage and capacity in areas where there are high numbers of users, for Example, urban and suburban areas. Microcells cover around 10% of the area of a Macrocell. The antennas for microcells are mounted at street level, are smaller than Macrocell antennas and can often be disguised as building features so that they are less visually intrusive. Microcells have lower output powers than macrocells, usually a few watts. Microcells are base stations with power between 2 W to 20 W, that use dedicated backhaul, are open to public access and range is about 500 m to 2 km.

Due to losses, the indoor user require high power from the serving Base Station (BSs), which cannot be meet by mobile operator's because it is very expensive to have a larger number of outdoor Base Station (BS) to meet the needs of high capacity network.



Figure 2. Types of cell according to surrounding environments



Figure 3. Type of Base Station According to Propagation Environment

Distributed Antenna Systems DAS [3]: This system comprises of a number of distributed antenna Elements (AEs) and a home Base Station (BS). The antenna elements are connected to the home Base Station offline through dedicated lines, usually optic fibre cables or dedicated RF links. This can provide good quality communication to areas where outdoor BSs cannot reach. In addition to good quality indoor coverage, DAS can also reduce the transmit power which leads to reduced interference and hence high capacity. It is one of the popular solutions among vendors as it is less expensive as compared to Picocells and microcells. The AEs in a DAS are distributed over the area of interest, these AEs comprise of RF transceivers and relays information back to the BS, where all the processing is done [10].

Picocells: Picocells provides more localized coverage. These are generally found inside buildings where coverage is poor or where there is a dense population of users such as in airport terminals, train stations and shopping centers. Picocells are categorised as hotspots [11]. Picocells are low power base stations with power ranges from 50 mW to 1W, which use dedicated backhaul connections; open to public access and range is about 200 m or less. Picocells work the same way as macrocells and are connected to each other and macrocell BSs through cables.

Relay Node (RN): For efficient heterogeneous network planning, 3GPP LTE-Advanced has introduced concept of Relay Nodes (RNs). Relaying is used to improve the performance of LTE, in terms of coverage and throughput. According to 3GPP, the use of relays will allow the following improvements [6]:

- Provide coverage in new areas.
- Temporary network deployment.
- Cell-edge throughput.
- Coverage of high data rate.
- Group mobility.
- Cost reduction: The cost of a relay, by itself, should be less than the cost of an eNB, assuming that the complexity of a relay is less than the complexity of an eNB. Due to the lack of a wired backhaul, the deployment cost and time should also be reduced, compared to an eNB.
- Power consumption reduction: The single-hop distance between the eNB and the UE is divided into two distances: the distance from the eNB to the relay, and the distance from the relay to the UE.

In Figure 4, the basic scheme in which relays are planned to be deployed in LTE-Advanced is depicted.

A wireless relay is also placed inside a building to compensate the penetration loss caused by the walls of the building. The relaying is mainly performed in two types, Amplify and Forward relaying (AF) and Decode and Forward relaying (DF) [12], [13]. In AF relaying mode, the relay terminal after reception of the signal, amplifies the signal and retransmits it. In this mode, the received signal can be a disrupted one due to noise and fading and can cause the channel capacity to decrease. On the other hand, in DF relaying, the received signal is first decoded and demodulated before retransmission
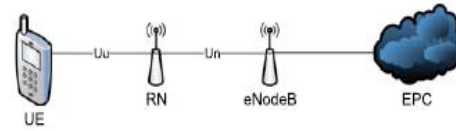


Figure 4. Relay basic scheme

which reduces the overall noise level. It is observed that mostly the DF relaying technique is more advantageous as compared to AF relaying [14].

Femtocells: Femtocell base stations allow mobile phone users to make calls inside their homes via their Internet broadband connection. Femtocells provide small area coverage solutions operating at low transmit powers. Femtocells are consumer deployable base stations that utilize consumer's broadband connection as backhaul, may have restricted association and power between 10 mW to 200 mW.

Indoor femtocell technology gained attention because it is extent the capacity and coverage at low cost [15]. The femtocell network is a new technology which enhances the cellular coverage and capacity in indoor area by use the advantage of an Internet backbone [16]. Femtocell Access Points (FAPs) are tiny base stations that are deployed by the end-users on their home or office site [17]. They were initially designed by the mobile operators to extend indoor coverage, aiming to solve the problem of coverage holes, improve system capacity and offload data traffic from the Macrocell Base Station (MBS), allowing the mobile operator to focus on outdoor and mobile users. Some other key benefits of femtocells are infrastructure cost reduction and signal quality enhancement.

The Femtocell called home base are low-cost short-range low-power BSs installed by the customer for better indoor data and voice reception. The user-installed device communicates with the mobile network over a broadband connection such as modem or digital subscriber line (DSL), or a separate radio frequency (RF) backhaul channel [9].

The advantages of using femtocells are that there is little direct cost to the service provider and better capacity and coverage [18] [5].

The femtocell base station deployment and placement planning strategies are still in question. The impact of the building dimensions, plan structure, and floor or wall partition play significant roles in the placement and planning of femtocell base station [19]. The femtocells have a gain or degradation depending on the access-mode and user type. Therefore, a three dimensions evaluation is important. Besides transmit power, FAP density and the distances to the macro site have an impact on interference and coverage quality. Table 1 compare between different type of base stations.

## III. PATHLOSS MODEL

The effect of Building-Penetration Loss (BPL) is that buildings act as "natural shields" that attenuate signal power from outdoor macrocells into the buildings. BPL also reduces interference from the indoor system to outdoor networks [20].

Table 1. Comparison between different type of base stations

| Cell type | Typical Cell Size | PA Power: Range & (Typical Value) |
|---|---|---|
| Macro | 1-30 km | 20 W~ 160 W (40 W) |
| Micro | 500 m-2 km | 2 W ~ 20 W (5 W) |
| Pico | 4-200 m | 250 mW ~ >2 W |
| Femto | 10 m | 10 mW~200 mW |

- At one extreme with BPL=∞, the indoor and outdoor systems are isolated from each other. There is no inter-layer interference between the two, and the indoor capacity is the highest. This is the best-case scenario. Examples with almost infinite BPL are subway stations, basements, and underground parking garages.
- At the other extreme with BPL=0, there is no isolation between the indoor and outdoor systems. In this case, the two systems are strongly coupled and the inter-layer interference is at its highest, especially if the buildings are located close to the center of the Macrocell. In this case adding small cells to the building (with the same frequency) is like adding cells to the center of another cell. This is the worst-case scenario.

In most real-life situations, the BPL is neither zero nor infinity, so the situation lies somewhere between the two extremes. The higher the BPL, the less the inter-layer interference will be, and vice versa.

BPL values vary at different locations within a building. For example, a location behind the first wall will experience much lower penetration loss compared to a location behind a second wall.

Note that, even for buildings with few interior walls, it is generally true that the deeper the location is inside the building, the higher the penetration loss. One example is a large shopping mall. Malls typically do not have many interior walls, but there are usually dead zones near the center of the mall, especially on the first floor.

In the case of tall buildings, the upper floors will likely have lower BPL (and thus higher received power levels from outdoor macrocells) than the lower floors, due to the fact that surrounding buildings and other "clutter" produces higher shadowing effects, which increases the effective BPL on lower floors.

These observed facts are generally important for indoor deployment regardless of whether it is 4G or 3G or 2G), because RF engineers can take advantage of unequal interference levels at different locations in a building. For 4G indoor systems, RF resource allocation can take the following factors into consideration:

For areas with high BPL, few or no restrictions are needed on femtocell-allocated RF resources (bandwidth and time), which means higher indoor capacity.

Interference mitigation techniques, generally require some type of restrictions on RF resources so they almost always result slightly lower capacity, are only needed for locations with low BPL, such as areas near the windows.

## IV. HetNet Interference Scenarios

Femtocells can be deployed in homes, public areas or office buildings. The potential interference scenarios vary among the different types of deployment (Figure 5). In heterogeneous multi-cell networks, interference is a major obstacle that can damage the potential gain of small cells and its pattern is highly diverse, e.g. ,interferences in macro-to-macro, femto-to-femto, and macro-to-femto. As the number of small cells increases, the number of users at cell edges suffering from low through put due to severe interference also grows.

For dense metropolitan residential femtocell deployments, there are two main interference scenarios:
(1) Inter-layer interference: Interference between indoor femtocell-layer and outdoor macrocell/microcell layer. If BPL is too small, this type of interference is the main interference of concern. If BPL is very large, then it is less of a concern.
(2) Interference within the femtocell layer: Interference among neighbouring femtocells within the building can also be a major concern. For enterprise deployment, femtocell locations are carefully planned rather than randomly placed. Hence, the randomness of femtocell locations in residential environments causes major interference concern among neighbouring cells because some femtocells may be located too close to each other, as shown in Figure 6. The SINR distribution for a network with random eNB placement will likely have a "long tail" with the worst-case SINR < –10 dB. UE located in areas with poor SINR will need extra help from interference mitigation techniques like ICIC or eICIC.

LI is the path loss under indoor environments. LI according to ITU-R model [21], [22] is represented as:
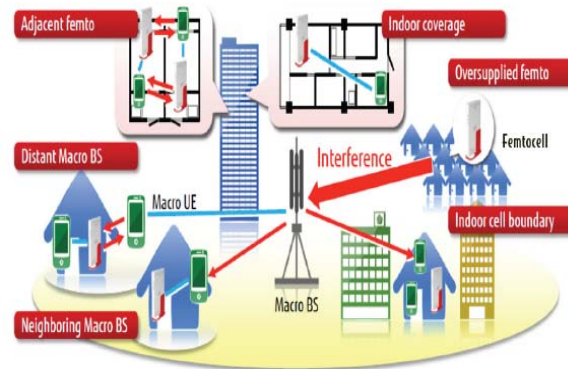


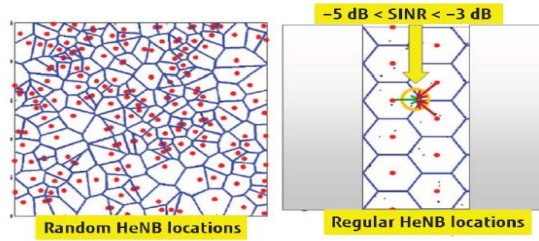Figure 5 Different types of femtocell deployment scenarios have different interference concerns

Figure 6. Residential femtocell locations are likely to be random but femtocell locations in an enterprise environment should be planned.

$$L_I = L_{fs} + L_c + \sum k_{wi} \; L_{wi} + n^{(\frac{n+2}{n+1} -b)} L_{fi} \quad (1)$$

Where $L_{fs}$ is a free space loss between transmitter and receiver. And it is represented as

$$L_{fs} = -10 \; log_{10}(\frac{\lambda}{4\pi R}) \qquad (2)$$

Where $\lambda$ is a wavelength and R is a distance between transmitter and receiver.

Lc is constant loss and it is normally set to be 37dB.

kwi and Lwi are number of penetrated walls of type i and loss of wall type i respectively. n is number of penetrated floors and Lfi is loss between adjacent floor.

Typical values of Lwi and Lfi are described in Table 2.

b means an empirical parameter, typically set to 0.46.

## V. ROAD MAP FOR DENSE AREA NETWORK PLANNING

In mass deployment, we have to satisfy the QoS requirements of macro and femtocell UEs and at the same time enhance the capacity and coverage of the network. In addition, we have come up with the following guidelines for planning a dense area.

First, when we plan indoor we must consider the penetration of each type of hall.

Second, the advantages of using femtocells are that there is little direct cost to the service provider and better capacity and coverage.

Table 2.  Pathloss Parameters And Values Regarding Wall Structures

| Parameters | Description | value |
|---|---|---|
| $L_{w1}$ | Plasterboard | 3.4 |
| $L_{w2}$ | Concrete, brick | 6.9 |
| $L_{f1}$ | Reinforced concrete | 18.3 |

Third, the femtocell base station deployment and placement planning strategies are still in question.

Fourth, when plan the femtocells location we must consider Inter-layer interference and Interference within the femtocell layer.

Fifth, to achieve higher user offloading to the femto network tier, femto access points should be deployed at places where there are no coverage.

## VI. CONCLUSION

In this paper, we have presented the two main challenges of dense area network planning which are the interference, and pathloss.  A comparative study was conducted for the related solutions and current works aiming to mitigate the corresponding problems and challenges. A road map for network planning is finally presented based on the discussed solutions. Future work will consist of developing an algorithm for macro-femto offloading based on the proposed road map and studying its performance for an efficient network planning.

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