Analysis of Channel Capacity for Heterogeneous Network based on Femto Cells using Path Loss Models

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Abstract: Femtocell network are designed to overcome the problem of channel capacity which is the key dispute in heterogeneous network. In this paper, we investigated the channel capacity solution for indoor and complex urban environment of heterogeneous networks. Overall channel capacity is calculated via different strategies of deployment of femtocells that are present in macro and the overall system channel capacity strategy is proposed that maximizes the criterion. The simulated results prove that the shared spectrum strategies with open access strategies are better for outdoor and indoor mobile users. For various pathloss model's throughput has been calculated and has been proven that users near to base station has best results.

Keywords: Femtocell, Channel Capacity, Heterogeneous Networks, Pathloss Models

I. INTRODUCTION

In this era architecture and topology of cellular networks are going through many changes. Circuit switched network are going under paradigm shift towards packet switched network. Cellular network is getting larger and larger day by day. Capacity of wireless system has almost doubled every two years over last 10 decades. The number of users is increasing exponentially resulting in requirement of better and efficient system. This demand has triggered many wireless standards and systems like WiMAX, HSPA, LTE, etc

In the word "FEMTOCELL" 'Femto' denotes a factor of 10^{-15}. Femtocells have procured this name due to their size as compared with standard wireless base stations serving towers. These are low power cellular base stations that improve cellular reception inside an office building or home. In third generation capacity of spectrum has been increased through various ways like using much number of relays, introducing microcells and nano cells, enhancing antennas configurations, etc. But all of the abovementioned ways have different type of limitations. Like when it comes to indoor communication increasing the number of relays is not worth it. Therefore, theory of femtocell came into existence. It is the biggest solution to improve the coverage area and improves the capacity of spectrum.

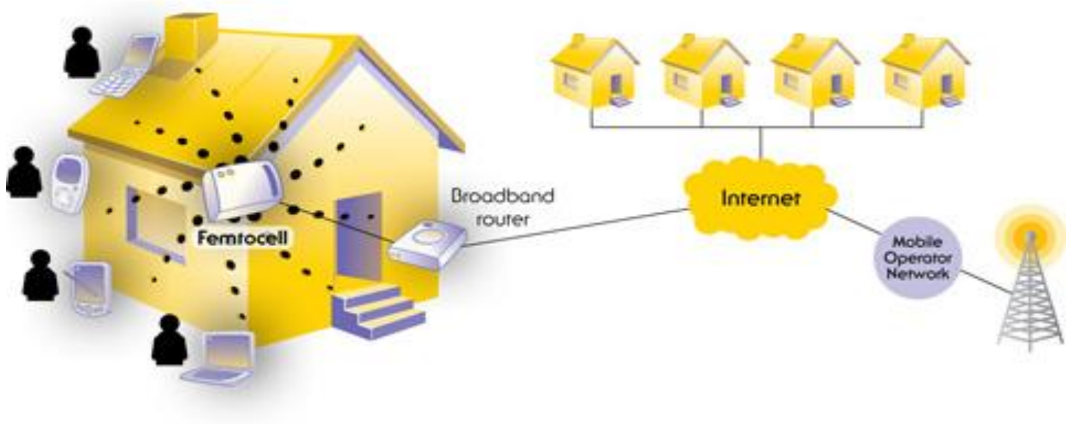

Figure 1. Femtocell Scenario

FAP (Femtocell Access Points) networks are in high demand nowadays as the indoor users are increasing day by day and are in major concern in both literature and commercial applications. In the presence of macro-cell base stations FAP networks are implemented are creating interest in public mind. In new practical scenarios the communication channel capacities is investigated for development and implementing FAP and other future cellular technologies.

There is interference present in inter-FAP and FAP in presence of MBS (Macro-cell Base Station). Studies have shown that MBS's uplinks are the major cause of interference. To reduce inter-FAP interference in an OFDM system water-filling algorithm is being proposed earlier.

Various strategies are investigated which have been deployed and system channel capacity strategy is proposed that maximizes the criterion. The deployment of FAP networks is observed on the basis of four different types considering two parameters i.e. frequency spectrum and services distribution:

a) Shared Spectrum Assignment where FAP network shares the Macrocell network,
b) Dedicated Spectrum Assignment where FAP network is assigned different frequency spectrum than of Macrocell network,
c) Closed Subscriber Group where predefined group of users can access each FAP, and
d) Open Subscriber Group where mobile switching center request the nearest FAP for various services.

Various propagation condition models are taken into considerations i.e. indoor and outdoor. As femtocells are deployed inside a building then various path losses occurs outdoor-to-indoor and indoor-to-outdoor.

II. CALCULATION OF CHANNEL CAPACITY

Channel capacity is calculated using Shannon's capacity theorem keeping into account all the cases of frequency spectrum and service distributions. All the various configurations are analyzed with Shannon's capacity theorem. Let B_t be the total spectrum assigned to Macro Base Station (MBS) and Femto Access Point (FAP) and also let the total bandwidth received by the users is same means each user receives equal portion of provided bandwidth (B_t). Assume that all the femto and macro base stations transmit together to all the users who are active to calculate the channel capacity. The four possible configurations are

a) SSA with CSG

Assume that B_t i.e. total spectrum bandwidth which is shared by both MBS and the FAP network

There are two cases

Case 1.

For the $i_F th$ MS indoor user present in FAP coverage the channel capacity is given by

$$C_{SSA_{CSG_{indoor_i}}} = B_{tN} \log_2\left(1 + \frac{S_{Fi}}{kTB_{tN} + \sum_{j=1, j\neq 1}^{J} I_j + \sum_{l=1}^{L} I_l}\right) \quad (1)$$

- Where $B_{tN} = \frac{B_t}{N}$ is a normalized bandwidth to number of users, N, served by the FAP
- S_{Fi} is the received strength of the FAP signal at the $i_F th$ *MS* user's location served by the i_Fth *∈(1: J) FAP,*
- Interference strength of the *lth*∈(1: L) MBS is denoted by I_l
- *L -T*otal number of the MBSs in the network.
- Interference strength of the neighbor *jth ∈ (1: J) FAP is given by* Ij*.*
- J- Total number of the FAPs *in* the network
- Thermal noise is denoted by kTB_t, where k is the Boltzmann constant and T is a temperature in degrees.

Case 2.

The capacity of the i_M *th* outdoor MS user can be obtained as follows

$$C_{SSA\_CSG\_outoor\_i} = B_{tP} \log_2\left(1 + \frac{S_{Mi}}{kTB_{tP} + \sum_{j=1}^{J} I_j + \sum_{l=1, l\neq i}^{L} I_l}\right) \quad (2)$$

- Where $B_{tP} = \frac{B_t}{P}$ is a normalized bandwidth to number of users P
- S_{Mi} *is the signal* strength of the *lth* ∈(1: L) MBS *at* the i_M *th ∈(1: P) MS location.*

b) SSA with OSG

In SSA with OSG there is a possibility that outdoor Mobile Station is served by FAP unlike SSA with CSG. This is the main difference between SSA with CSG and SSA with OSG.

The channel capacity of the outdoor user served by FAP is given by:

$$C_{SSA_{OSG_{outdr_{iF}}}} = B_{tN} \log_2\left(1 + \frac{S_{Fi}}{kTB_{tN} + \sum_{j=1, j\neq 1}^{J} I_j + \sum_{l=1}^{L} I_l}\right) \quad (3)$$

The decision of serving a user is taken according to the threshold value of the signals received by FAP and Macro Base Station. Handover is done if user is in FAP area but receiving signal has more power of Macro Base Station.

c) DSA with CSG

Dedicated spectrum is a technique in which a spectrum is allocated to each femtocell network. There is least interference between macrocell and femtocell network as they both have their different spectrum to communicate. In this type of configuration total bandwidth B_t is divided between MBS and FAP networks. This allocation of bandwidth is non-uniform as the number of users is not same in both FAP network and MBS network

Case 1.

The channel capacity for i_F th indoor MS user in the FAP network coverage is analyzed by:

$$C_{DSA\_CSG\_indoor\_i} = B_{tNd}\log_2(1+\frac{S_{Fi}}{kT\,B_{tNd}+\sum_{j=1,j\neq 1}^{J} I_j}) \quad (4)$$

Where

$$B_{tNd} = \frac{FNR.B_t}{N}$$

FNR is the FAP network ratio in the total spectrum B_t.

Case 2.

The channel capacity for i_M th user outside the FAP network served by MBS is analyzed by:

$$C_{DSA\_CSG\_outdoor\_i} = B_{tPd}\log_2(1+\frac{S_{Mi}}{kT\,B_{tPd}+\sum_{l=1,l\neq 1}^{L} I_l}) \quad (5)$$

Where

$$B_{tPd} = \frac{FNR.B_t}{P}$$

is the normalized bandwidth for a number of users which is dedicated to them.

d) DSA with OSG

Considering the DSA with OSG configuration, the channel capacity of the outdoor i_F *th MS* users served by the i_F *th* $\in (1: J)$ *FAP* can be obtained as follows:

$$C_{DSA\_OSG\_outdoor\_iF} = B_{tNd}\log_2(1+\frac{S_{Fi}}{kTB_{tNd}+\sum_{j=1,j\neq 1}^{J} I_j}) \quad (6)$$

Where

$$B_{tNd} = \frac{FNR.B_t}{N}$$

N stands for the total number of users served by i_F *th* $\in (1: J)$ FAP for all the outdoor and indoor.

III. PROPAGATION PATHLOSS (PL) MODELS

The RSSI (Received Signal Strength Indicator) indicates the signal strength by the urban propagation conditions when an outdoor Mobile Station is served by the MSB between the MSB and MS. The propagation conditions in urban environment are characterized by over-roof top phenomena and by the multiple scattering. The figure below shows Non line of Sight condition of propagations in urban environment characterized by scattering and multiple diffraction phenomena. For an outdoor located mobile station the path loss is given as

$$L(r) = 41.3 + 30\log f_{[MHz]} + 30\log r_{[km]} + L_{fading} \quad (7)$$

Where $$L_{fading} = \frac{\gamma_0^4 l_v^3 F^4(z_1, z_2)}{\alpha|\Delta|^2[\frac{\alpha r}{4\pi^3} + (z_2 - \overline{h})^2]} \quad (8)$$

Range between the terminal antennas is given by ‘r’ (in km). Heights of MS and BS antennas are given by ‘z_1’ and ‘z_2’ respectively. Density of building contours is given by ‘$\gamma_0 = 2\overline{L}v/\pi$’ (in km). Average length of buildings is given by ‘$\overline{L}$’ (in km). Number of building for square kilometer is given by ‘v’. Wall roughness is given by ‘l_v’. Absolute value of reflection coefficient is given by ‘Δ’.A profile function is given as

$$F(z_1, z_2) = \begin{cases} (h_1 - z_1) + \frac{(\Delta h)^2 - (h_2 - z_2)^2}{2\Delta h}, h_1 > z_2, h_2 > h_1 > z_1 \\ \frac{(h_2 - z_1)^2 - (h_2 - z_2)^2}{2(\Delta h)}, \quad h_1 < z_2, h_2 > h_1 > z_1 \end{cases} \quad (9)$$

Where maximum and minimum heights of buildings are given as h_2 and h_1.

Here we are assuming suburban deployment scenario. In the downlink transmission between transmitter (macro BSs or Femto BSs) and receiver (MUEs or FUEs) propagation loss encountered are described by Propagation pathloss (PL) models. Pathloss formulas are applicable for where the distance between Tx and Rx is larger than 1m.

Some of the pathloss models formulas are discussed here:

- **UE to Macro BS**

a) UE is located outside

This is the case of pathloss when the receiver is either outdoor FUE or outdoor MUE and transmitter is a macro base station and it is given by:

$$\text{PL}(dB) = 15.3 + 37.6 \log R \quad (10)$$

b) UE is located inside a building

This is the case of pathloss when the transmitter is a macro base station and receiver is either indoor FUE or indoor MUE and it is given by:

$$\text{PL}(dB) = 15.3 + 37.6 \log R + L_{ow} \quad (11)$$

- **UE to Femto BS**

a) UE and Femto BS are in the same house:

This is the case of pathloss when the receiver is either indoor FUE or indoor MUE and transmitter is a Femto base station and it is given by:

$$\text{PL}(dB) = 38.46 + 20\log R + 0.7\text{d2D,indoor} \quad (12)$$

b) UE is outside:

This is the case of pathloss when the transmitter is a Femto base station and receiver is either outdoor FUE or outdoor MUE and it is given by:

$$PL(dB) = \max(15.3 + 37.6 \log R, 38.46 + 20 \log R) + 0.7 d2D; indoor + Low \quad (13)$$

c) UE is located inside different house

This is the case of pathloss when the receiver is either FUE or MUE present inside some different building and transmitter is a Femto base station than that of Femto base station which is given by:

$$PL(dB) = \max(15.3 + 37.6 \log R, 38.46 + 20 \log R) + 0.7 d2D, indoor + Low, 1 + Low, 2 \quad (14)$$

Where

- distance between transmitter and receiver is denoted by *R*
- The penetration losses of outdoor walls is denoted by Low, Low,1 and Low,2 which are 10dB.
- The distance inside each house is denoted by d2D, indoor in the case of UE located inside the same house.

IV. SIMULATION RESULTS

The results are stimulated with the help of above written parameters and formulas'.

Case 1

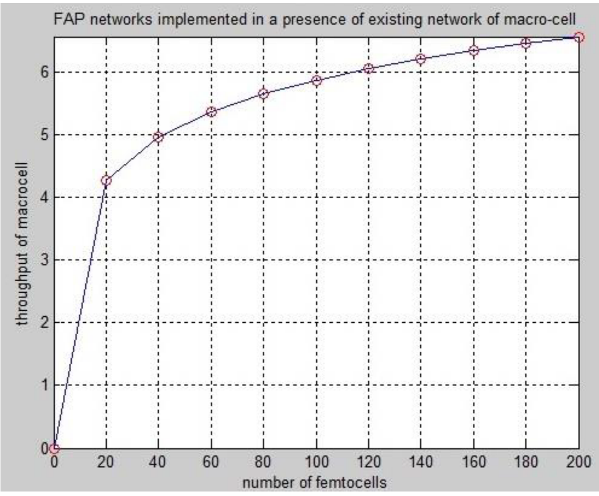

Fig. 2 Implementation of FAP networks in the presence of existing network of microcell.

Case 2

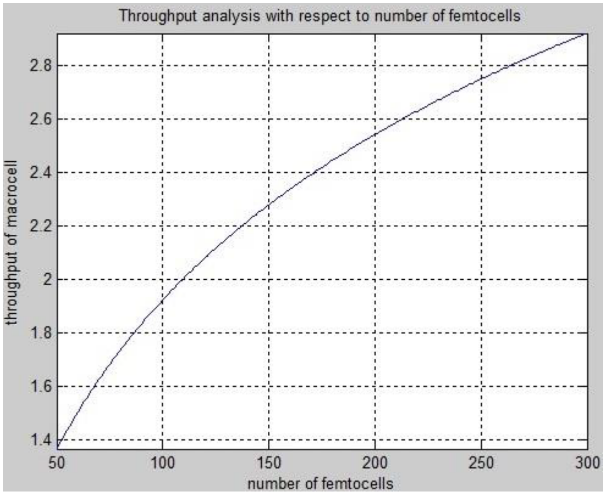

Figure 3. Throughput analysis with respect to number of femtocells.

Case 3

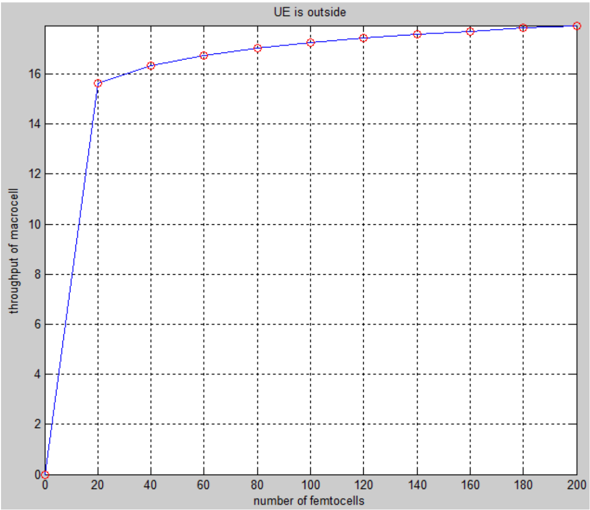

Fig. 4 Pathloss when UE is outside to Macro BS

Case 4

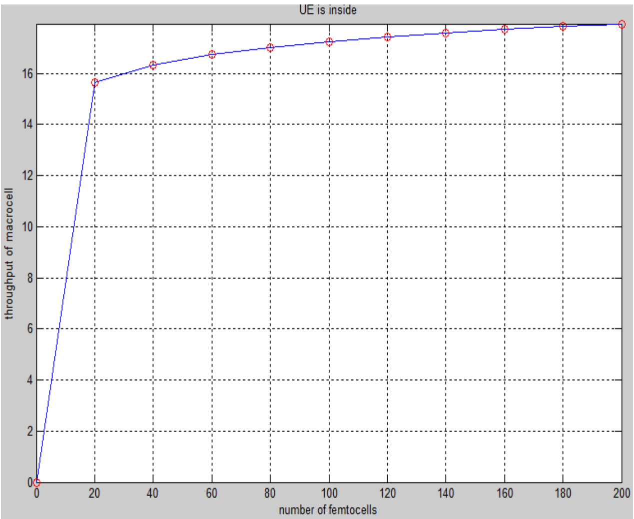

Fig. 5 Path loss when UE is inside to Macro BS

Case 5

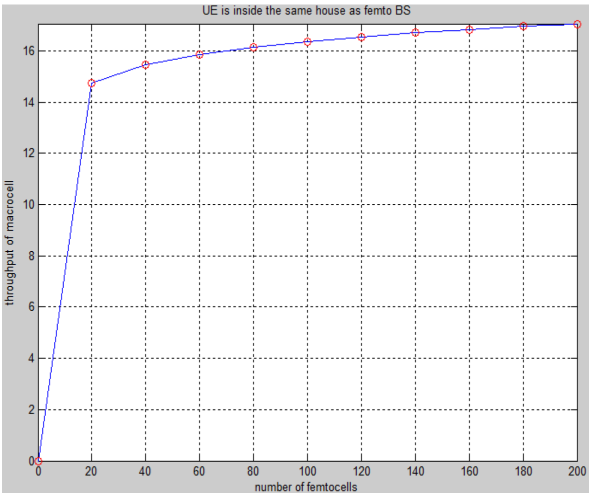

Fig. 6 Pathloss when UE is inside the same house as femto BS

Case 6

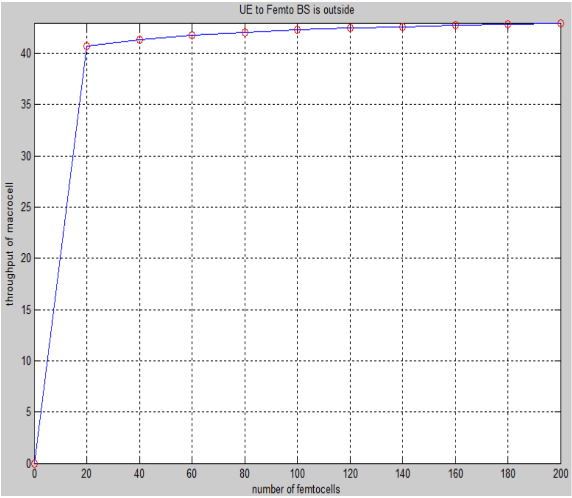

Fig. 7 Pathloss when UE to Femto BS is outside

Case 7

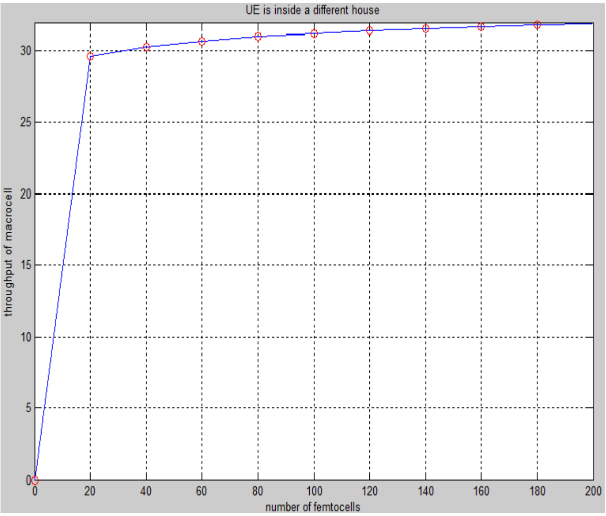

Fig. 8 Pathloss when UE is inside a different house

Case 8

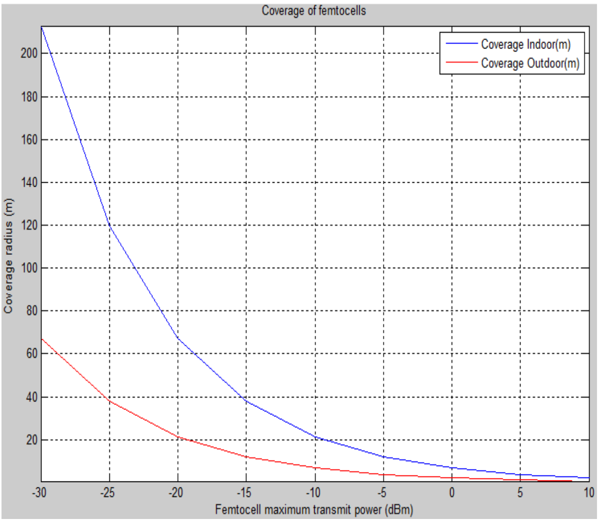

Fig. 9 Coverage of femtocell

Case 9

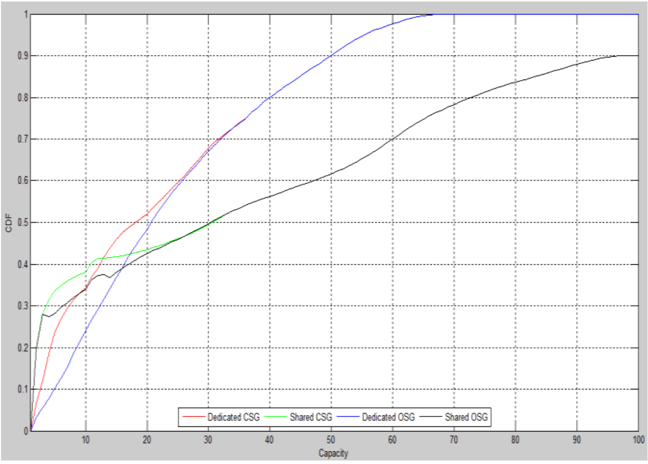

Fig. 10 Capacity Comparison

V. CONCLUSIONS

Analysis of channel capacity in the heterogeneous networks that consists of the femto cells and the macro base stations is considered in this work. Overall channel capacity is calculated via different deployment strategies. The simulations prove that the shared spectrum strategies are better than the dedicated spectrum strategies, and the open access strategies are better than the closed strategies. The inter-FAP downlink and FAP-to-MBS downlink interference are the main controlling factors observed during this work. For various pathloss models throughput has been calculated and has been proven that due to penetration users near to base station has the best results.

Conflict of interest: The authors declare that they have no conflict of interest**.**

Ethical statement: The authors declare that they have followed ethical responsibilities.

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