Interference Management in Femtocell Networks using Power Control

Nanda B P, Radhika K R

Abstract— ***Interference is the result of superimposing of two or more signals that causes change in original signal properties. Interference in wireless networks is of major concern these days. Many interference control algorithms have been proposed to overcome the same. In fact, interference can be only controlled but cannot be completely avoided. In femtocell network which is discussed in later section of this work, signal interference chances are more as in these networks, the base station are deployed in Ad-hoc environment also, these networks are responsible for in-building coverage to provide call continuity and to reduce the overhead of service providers in installing large towers and Base station antennas. The work develops the power control algorithm and simulate using MATlab to demonstrate the in-building environment with randomly distributed cell phone users with in the building and checking the interference at co-tier level (between two or more in-building base stations) both at uplink and downlink and then later introduce Dynamic Assignment of Transmit Power (DATP) algorithm to the situation and analyse how the interference is controlled.***

Index Terms— ***Base Station (BS), DL (Downlink), FBS (Femtocell Base Station), FUE (Femtocell User Equipment), Interference, MBS (Macrocell Base Station), Mobile Station (MS), MUE (Macro User Equipment), UL (Uplink)***

I. INTRODUCTION

Femtocell base station (FBS) is deployed both in residential and commercial areas to overcome the investment overhead of the service providers on large macrocell towers. FBS provides low coverage range of 12m to 15m and uses the dedicated broadband of the service provider (ISP) to send data and voice. FBS is deployed as shown in figure 1.1. Femtocell concepts are acceptable for 3G networks rather than 2G, as the data rates is less as compared to 3G. Femtocell network architecture [1] supports the following key requirements: Service parity, Call continuity, Security, Self Installation & Simple operational management and Scalability. Common Elements of the Femtocell Network Architecture are: Femtocell Access Point (FAP), Security Gateway (SEGW), and Femtocell Device Management System (FMS).

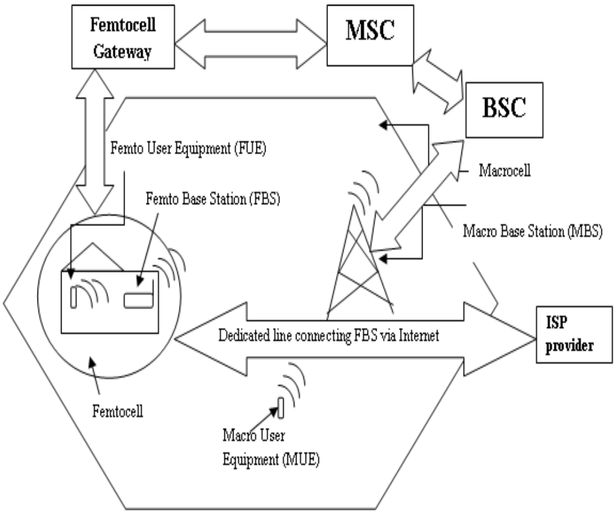

Figure 1.1 Architecture of Femtocell Base Station Deployment

Femtocell in wireless industry is a developing technology. The main reason for its demand and deployment is; it ensures good coverage within the closed premises, keeps the continuity of the call, overcomes the cost overhead of the service provider in terms of deployment of macrocell base station (MBS). FBS operate at frequency range of 2.4GHz to 5GHz and have very limited coverage area of 12m to 15m. FBS uses the broadband dedicated line from the service providers and transmits via internet. Two or more FBS are connected to and their status is monitored by Femtocell gateway. A single FBS can handle not more than 4 cell phones. As the FBS deployment is Ad-hoc in macrocell coverage, it suffers from and also create interference problem. Interference can be either from other FBS or MBS. Many techniques such as Frequency splitting, power planning, etc have been researched to reduce interference. Femtocell technologies [2] are generally considered for 3G (3GPP & 3GPP2). GPRS anyways provides lower data rates as compared to 3G also here CDMA uses 1.25MHz where as WCDMA is a 3G evolution of GSM that uses pair of 5MHz channels (Duplex) with FDD. WiMAX forum and IEEE802.16 has begun to develop standards for femtocell operations. WiMAX femto access points (WWFAPs) are miniature BS with the size of WiMAX customer equipment (CPE) or WiFi access points (APs) which indoor wireless coverage to MSs with the help of fixed broadband Internet connections – Digital subscriber line (DSL). WiMAX forum commenced the development of femtocell standards in two phases. The phases are – Phase I based on IEEE 802.16 in 2009. Phase II enables enhanced femtocell systems with IEEE802.16m [3].

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Nanda B P, Information Science, BMSCE, Bangalore, India.
Dr. Radhika K R, Information Science, BMSCE, Bangalore, India.

II. EXPLANATION

Interference management in femtocell networks is the challenging task. Many techniques have come into existence such as interference cancellation and interference avoidance. There are two types interference [4]–[13]:

- Co-tier interference (Femto to Femto)
- Cross-tier interference (Femto to Macro)

In each of the above two categories, both UL and DL interference exist. In UL interference (where an FUE interferes with other FBS) and downlink interference (where an FBS interferes with other FUE) in Co-tier interference as shown in figure 2.1.

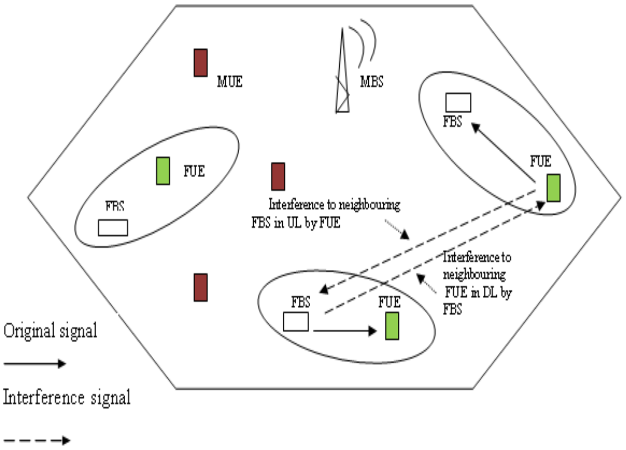


Figure 2.1 Co-Tier Interference

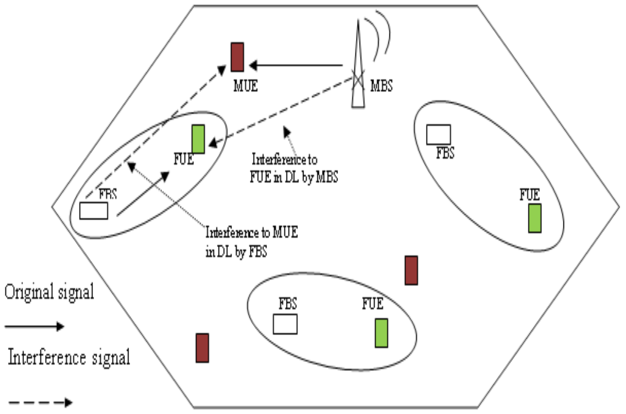


Figure 2.2 Cross-Tier Interference

And similarly in cross-tier, UL interference (where FUE close by to the MBS interfere with it other than MUE) and DL interference (where an MBS close by to the FUE interferes with it other than FBS) in Cross-tier interference such as shown in figure 2.2.

III. METHODOLOGY

A. Existing Algorithm

Adaptive Step Power Control (ASPC) for 3G [14]; There is a need for fast adjustment of transmitted power. The value of the fixed step might be too large or small. Hence, the work proposes the adaptive step by replacing fixed step.

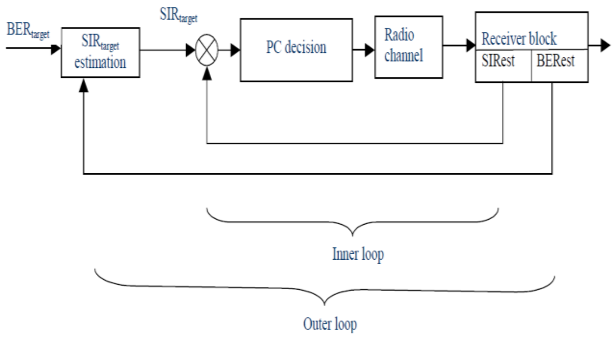


Figure 3.1 Power control in WCDMA system. In the receiver block, the received SIR and BER are estimated and used respectively for the inner-loop and the outer-loop

Power control (PC) in WCDMA is a closed-loop PC [14] which is a combination of outer and inner closed loop control as in figure 3.1. The inner closed loop PC adjusts the transmitted power in order to keep the received Signal-to-Interference Ratio (SIR) equal to a given target. This SIR target is fixed according to the received BLER (Block Error Rate) or BER (Bit Error Rate). The setting of the SIR target is done by the outer loop PC, which is part the Radio Resource Control Layer (Layer 3), in order to match the required BLER. Outer loop PC update frequency is 10-100 Hz. The BLER target is a function of the service that is carried. Ensuring that the lowest possible SIR target is used results in greater network capacity. The inner closed-loop PC measures the received quality, defined as the received Signal-to-Interference Ratio (SIR) and sends commands to the transmitter (i.e., the mobile in the case of uplink) for the transmitted power update. In order to estimate the received SIR, the receiver estimates the received power of the connection to be power controlled and the received interference. The obtained SIR estimate, noted SIRest, which is then used by the receiver to generate PC commands. ASPC is based on the principle that if the transmitter detects several simultaneous up commands, the step is increased. Similarly, for several simultaneous down commands. The update step is decreased if an alternative succession of up and down appears, showing that the update step is probably too large. Algorithm: The initial value of the power update step is Δ_0, expressed in dB. The APSC works in up or down commands as in the case of WCDMA algorithms with the difference that the power update step may change in some cases. These cases are given in the following:

- ✓ The update step is multiplied by u when n_1 successive up commands are received.
- ✓ The update step is multiplied by v when n_0 successive down commands are received.
- ✓ This value is divided by y when the power update command sequence is an alternate sequence of n_{01} up and down commands (i.e., for a received sequence up-down-up-down or down-up-down-up, if n_{01} is equal to 4).

Adaptive Step Power Control method is applicable to downlink only.

Distributed Constrained Power Control (DCPC) [15]; this work has proposed a distributed power control algorithm that uses a stochastic search technique in order to solve linear systems of equations for power update in CDMA cellular radio systems. The proposed algorithm is developed by applying Bremermann's evolutionary computation algorithm to the CDMA power control problem. The major gain from the applied evolutionary computation algorithm is more rapid optimization on linear systems of equations compared with the simple genetic algorithm (SGA). Employing the distributed constrained power control (DCPC) as a reference algorithm, DS-CDMA system is implemented. As per [16], the work introduces an adaptive power level setting scheme based on DL reception from strongest MBS and UL reception power from neighbouring MS. Fixed power: value is preconfigured and common for all FBS irrespective of RF conditions of macrocells. This method is simple to implement. But drawback is in difficulty to adapt to the surrounding RF conditions of macrocells. With respect to the downlink reception power from MBS: FBS measures the reception power at the initial configuration phase and adaptively set the transmit power level. FBS close to the MBS, transmit power improves and the FBS placed at the edge of the MBS interfere less with MUE. Drawback is indoor may constitute different materials that result in penetration loss. This may result in more interference from FBS to MBS. With respect to the downlink reception power from MBS and uplink reception power from MUE: here the DL co-channel reception power of the reference signal of the strongest MBS and UL reception power from neighbouring MUE. This solves the problem of downlink reception power from MBS. FBS are low-power indoor cellular BS that operates in licensed spectrum. They are typically deployed indoors to improve coverage and provide excellent user experience, including high data rates. Some of the basic challenges of FBS are due to the following factors:

User Installation: FBS are installed by subscribers without special training or knowledge regarding antenna placement and system configuration. Because of this, the femtocell should be capable of self-configuration.

Unplanned Deployment: Unlike a macro network, FBS are deployed without network planning; no special consideration is given to traffic demand or interference to/from other cells.

Restricted Association (or Restricted Access): To protect the use of limited resources (femtocell capacity, DSL/modem connection), FBS may be configured to limit access to only a few authorized subscribers (e.g., family members or hotel guests).

Legacy System Support: Currently available handsets are femto-unaware; FBS need to support these handsets as well as femto-aware handsets. Moreover, they need to interface with existing access and core networks [5]. Considerations to be taken for designing FBS are: Calibration of femtocell downlink transmits power to limit interference to the macro network while providing good coverage for the femtocell user, adaptive UL attenuation at the femtocell to mitigate interference caused by a nearby interfering macro and/or femto user not controlled by the femtocell, carrier selection for femtocell combined with inter-frequency handover for macrocell users to avoid inter-femto and femto-to-macro interference and limiting a femtocell user's uplink transmit power to minimize the interference caused to the UL of the macro network [5]. Interference management based channel allocation in femtocell networks [9]: The interference graph G = (V, E) is constructed in femtocell networks. Here, V is the vertex set and each vertex represents a femtocell; E is the edge set and the edge between two nodes represents that there exists intolerable interference between these two femtocells. Each colour corresponds to a different sub-channel and each vertex connects to a list of available colours. By this way, sub-channel allocation problem in the femtocells can be transformed into a graph vertex colouring problem. The object that graph colouring algorithm proposed in this work guarantees maximizing the femtocell throughput. Distributed interference management algorithm [10] dynamically adjusts femtocell pilot powers in response to detected user activity. Users connected to macrocells or other femtocells will be detected as a sudden increase in the noise level. Femtocells temporarily adjust their pilot signals downward by a pilot reduction factor of α for the duration of the detected user activity. When the detected noise level returns to the baseline level, the femtocell resets its pilot to its original level, thereby restoring coverage. Temporary pilot adjustments allow femtocells to reduce interference when needed, while continuing to maintain a high level of coverage. Pseudo code for distributed dynamic pilot adjustment [10] is as follows:

```
$c \leftarrow$ number of neighbouring femtocells
$i \leftarrow 0$
While no users connected do
    $d \leftarrow$ detected noise level
    If $u(d) > i$ then
        $\alpha i \leftarrow \frac{1}{2(1+f(c,d))}$
        $Ppilot \leftarrow \alpha i Ppilot$
        $i \leftarrow i + 1$
    Else if $u(d) < i$ then
        $Ppilot \leftarrow Ppilot/\alpha i$
        $i \leftarrow i - 1$
    End if
End while
```

Table below summarises the interference effects and approaches to overcome the same.

Table 3.1 Interference effects and approaches to overcome in femtocell networks

UL Interference Scenario	Interference Type	Problem Caused		Approaches proposed by literatures	
		CDMA femtocell	OFDMA femtocell	CDMA femtocell	OFDMA femtocell

A	Cross-tier	Indoor-outdoor macrocell coverage hole	Indoor-outdoor macrocell coverage hole & Inter-carrier Interference at MUE	Adaptive power control at FBS	Orthogonal channel assignment
B	Cross-tier	Femtocell coverage hole	Femtocell coverage hole	Adaptive power control at FBS	Intelligent sub-channel allocation
C	Co-tier	Noise rise at victim FUE	Noise rise at victim FUE and femtocell coverage hole	Adaptive power control	Intelligent sub-channel allocation

Fractional Frequency Reuse (FFR), whole frequency band is divided into several sub-bands, and each sub-band is differently assigned to center zone and edge zone of the cell. While reuse factor of the center zone is one, the edge zone adopts bigger reuse factor. As a result, intra-cell interference is removed, and inter-cell interference is substantially reduced. At the same time the system throughput is enhanced [17]. Using 3-sectored FFR, sub-band allocation problem can be optimized.

B. Proposed Algorithm

Dynamic Assignment of Transmit Power (DATP). This can be applicable to reduce both downlink and uplink co-tier interference management.

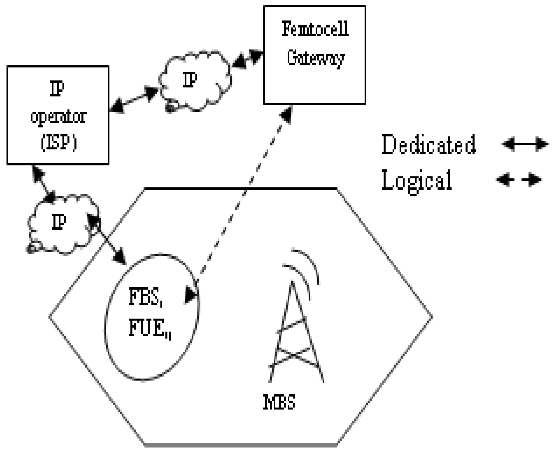


Figure 3.3 Core Femtocell network

In the existing algorithm [14] power levels are adaptively increased or decreased with the step size of $\Delta_{0.}$ This process makes the femtocell network processing slower if more number of FBS are deployed due to iterativeness of the algorithm. Considering Co-tier interference (femto to femto), uplink/downlink interference avoidance in proposed algorithm is processed based on the threshold value of transmitter power of FUE and transmitter power of FBS (Pt_{FUE} / Pt_{FBS}) respectively. Threshold Pt_{FUE} and Pt_{FBS} values are pre-calculated and Pt_{FBS} of particular FBS is made to vary among the other FBSs present in the network and these power levels expressed in dB if controlled and maintained by the Femtocell gateway center this can control the uplink interference by instructing each FUE under its coverage to transmit at assigned power level as soon as FBS detects the respective FUE on first come first serve (FCFS) basis. FBS uses pilot signal to detect any FUE in its coverage and sets pilot bit i.e. Pbit to 1. Later instructs the FUE to operate at designated power level by synchronizing signal and once successful will set the Sbit to 1 and also PCbit to 1. In case of downlink, the FBS power levels are registered on start-up in femtocell gateway center and the power within the power level is assigned to each downlink channels of the particular FBS it handles.

IV. PARAMETERS AND FLOWCHART

A. *Parameters for co-tier Interference management*

Like Base station antennas connect to Base station controller (BSC), FBS's also connect to the Femtocell Gateway center (FG) which then connects to the internet service provider (ISP) network as shown in figure 3.3. Uplink interference from FUE_{ij} (i=2,3,..N) to FBS_i (i=1) and Downlink interference from FBS_i (i=1) to FUE_{ij} (i=2,3,..N).

iFBS_ID – Unique identification number logically assigned to the particular FBS by the FG to recognize the FBS with its Power Pt. The table below is to be maintained.

Table 4.1 FG database

iFBS_ID	**Pt_{iFBS}**
1FBS_ID	Pt_{1FBS}
2FBS_ID	Pt_{2FBS}
.	.
NFBS_ID	Pt_{NFBS}

$Pt_{NFBS}...<Pt_{2FBS}<Pt_{1FBS}$ ..... (4.1)

Pt_{ijFUEt} – Value is set by the FUE instructed up on FBS based upon the FBS database table maintained at FBS which uses FUE_ID to recognize the FUE within the particular FBS range and its respective SNR_{FUEt}

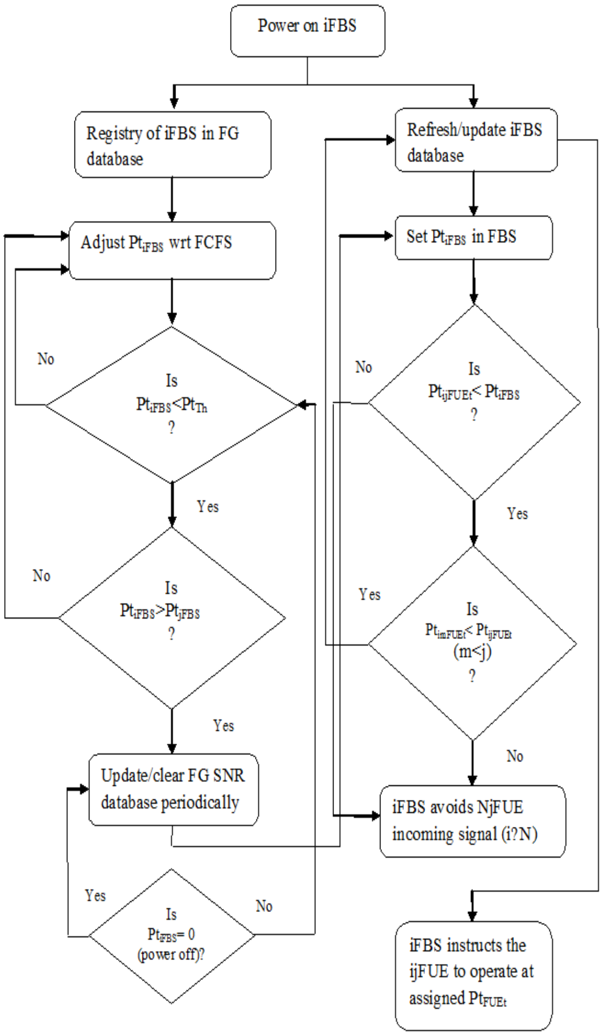
Table 4.2 FBS database

ijFUE_ID	**Pt_{ijFUEt}**
11FUE_ID	Pt_{11FUEt}
12FUE_ID	Pt_{12FUEt}
.	.
1MFBS_ID	Pt_{1MFUEt}

$Pt_{12FUEt}<Pt_{11FUEt}<Pt_{1MFBS}$ ….. (4.2)

Path loss factors – these decide the amount of signal attenuation within the building due to Floor attenuation factor (FAF) and partition attenuation factor (PAF) expressed in dB. FAF includes either a ceiling material or concrete duct and PAF includes loss due to elevator, wooden racks, cubical, etc [18].

B. *Flowchart*



LHS: For Downlink interference management and RHS: For Uplink interference management

Figure 4.1 Flowchart for Co – Tier interference management

C. *Simulation Parameters*

Table 4.3 Parameters used in simulation

Femtocell radius	12 mts
Path Loss from FBS to FUE	30+20*log10(d(n))+0.57*d(n)+FAF+PAF; FAF=13dB, 2 dB (concrete, ceiling)
Antenna gain	3dB
Distribution of FBS	Uniform
Distribution of FUE	Random
Building material	1. Concrete Block wall 2. Ceiling duct
Operating frequency range	2.4 to 2.48 GHz

V. IMPLEMENTATION

A. *Path loss Model*

Placement and positioning of FBS inside building majorly depends upon the signal propagation within the indoor. Indoor cannot be considered to be free space as such there can be path loss due to partitions and floors. Two major attenuation factor is always taken into consideration for indoor purposes, these are: Floor Attenuation Factor (FAF) and Partition Attenuation Factor (PAF). Let P_{ijk} to be the uplink power in sub-region (i, j, k) ranging from $0 \leq P_{ijk} \leq P_{max}$; PR_m denotes the received power at FBS m which is given by [18]

$$PR_m = P_{ijk} - L_{d0} - 10\alpha\log_{10}\left[\frac{d_{ijk}^{m}}{d_0}\right] + \varsigma_\sigma \qquad \text{... (5.1)}$$

Where, L_{d0} – Loss of signal with reference to shortest distance d_0 in DB d_0 – shortest distance from the transmitter.
A – path loss (signal attenuation rate) with respect to distance. ς_σ – Zero mean Gaussian variable with standard deviation σ. *A* can have different values to model different buildings. But since the concern is more within the building, path loss due to floor attenuation also becomes a concern and hence (5.1) can be rewritten as

$$PR_m = P_{ijk} - L_{d0} - 10\alpha\log_{10}\left[\frac{d_{ijk}^{m}}{d_0}\right] + \varsigma_\sigma - L_{FAF} \qquad \text{... (5.2)}$$

Where, L_{FAF} – path loss due to FAF

B. *FBS coverage*

Number Consider the following Hexagonal sub-region (i, j, k) in 3D view in figure 5.1 [19], [20]
Hence, the coordinates of midpoint,
M = ((i/2) r, (j-1/2) r, (k-1) h) … (5.3)

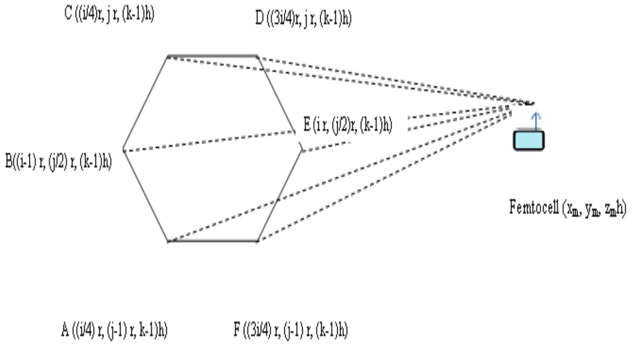


Figure 5.1 Hexagon sub-region

Hence, the coordinates of midpoint,
M = ((i/2) r, (j-1/2) r, (k-1)h) … (5.4)

Distance from femtocell to the midpoint and to the point B of the sub-region is given by,
X-coordinate = $|x_m - (i/2)\ r| + (1+i)\ r$ … (5.5)
Y-coordinate = $|y_m - (j-1/2)\ r| + ((1+j)/2)\ r$ … (5.6)
Z-coordinate = $|(z_m - k + 1)\ h - \eta|$ … (5.7)

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Hence,

$$d_{ijk}^{m} = \sqrt{\begin{pmatrix} (|\ xm - (i/2)\ r| + (1+i)r)^2 + \\ (|\ ym - (j - 1/2)\ r| + \\ ((1+j)/2)\ r)^2 + (|\ (zm - k + \\ 1)\ h - \eta|)^{2} \end{pmatrix}} \qquad \text{... (5.8)}$$

VI. SIMULATION

Case 1: Building dimension = 90 ft x 90 ft, Number of floors = 1, Building Material = concrete block wall only, having best case - moderate number of users- 5 per floor.

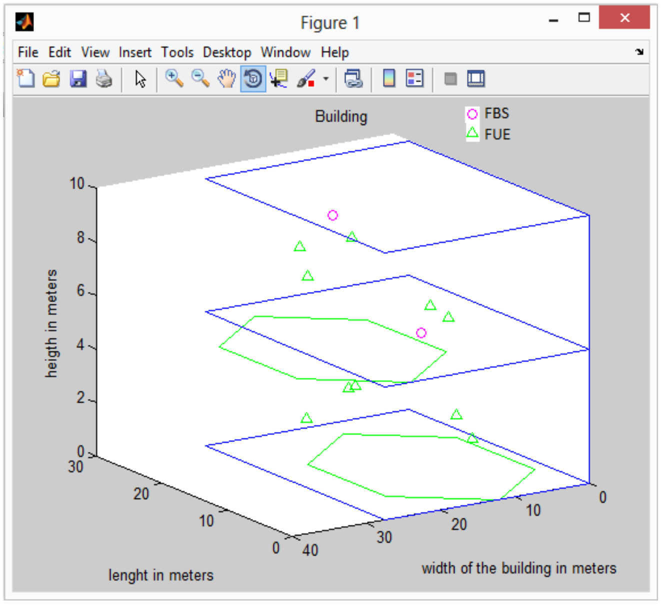

Figure 5.1 Building with dimension 90 ft x 90 ft and ceiling with concrete wall block case 1

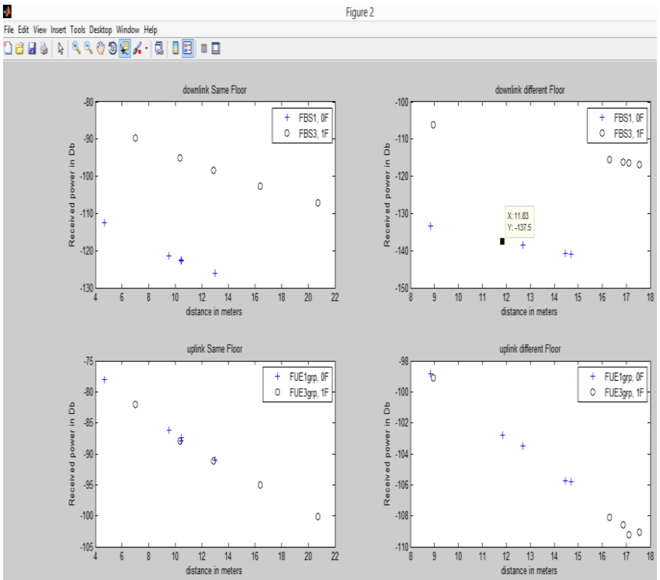

Figure 5.2 Both UL and DL power level representation of case 1 - with interference as shown: overlapping bubbles and plus symbols.

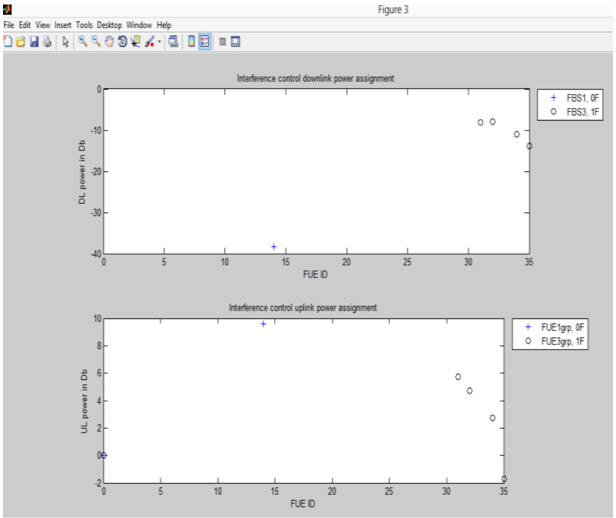

Figure 5.3 Both UL and DL power level representation of case 1 with controlled interference

Case 2: Building dimension = 90 ft x 90 ft, Number of floors = 1, Building Material = Ceiling duct only, having best case - moderate number of users- 5 per floor.

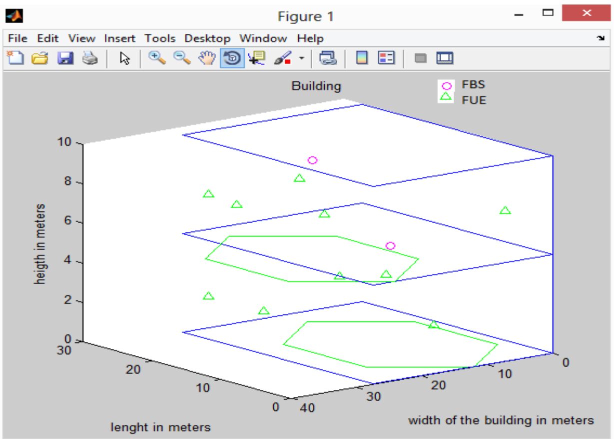

Figure 5.4 Building with dimension 90 ft x 90 ft and ceiling with ceiling duct case 2

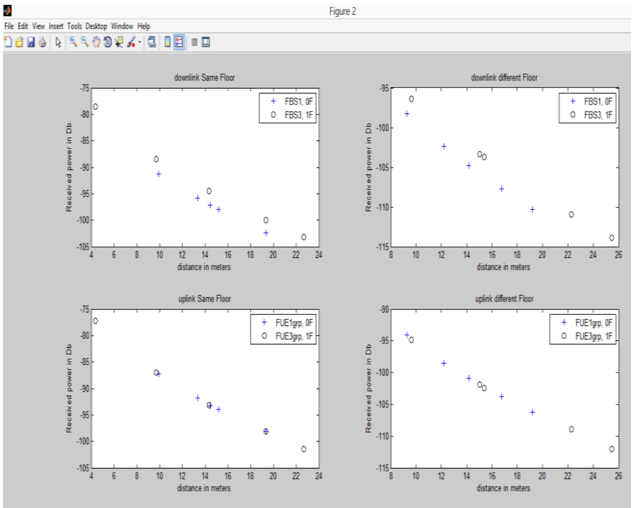

Figure 5.5 Both UL and DL power level representation of case 2 with interference as shown: overlapping bubbles and plus symbols.

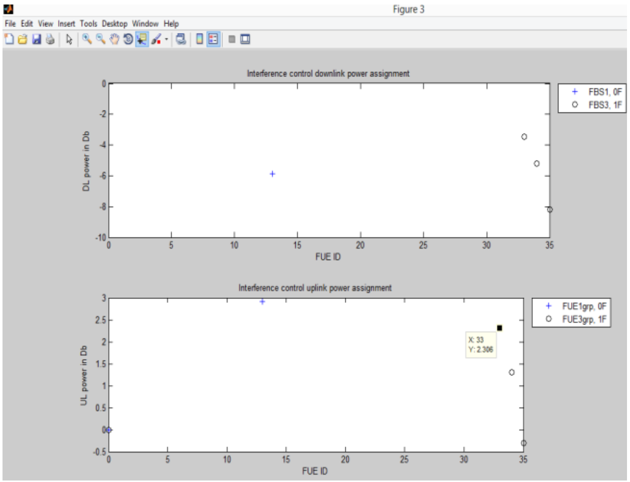

Figure 5.6 Both UL and DL power level representation of case 2 with controlled interference

Case 3: Building dimension = 90 ft x 90 ft, Number of floors = 1, Building Material = Concrete Block wall only, having worst case - more number of users-10 per floor.

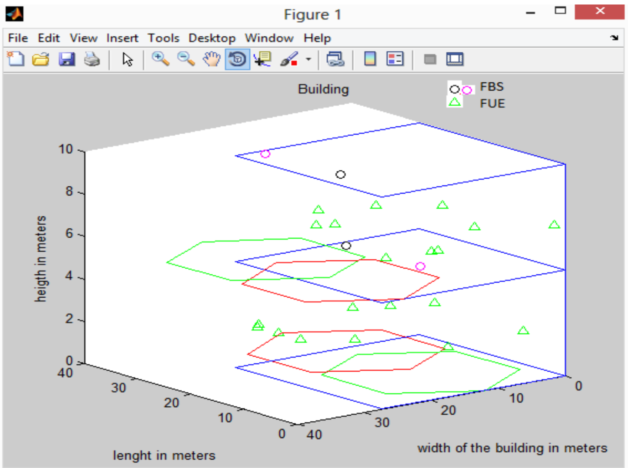

Figure 5.7 Building with dimension 90 ft x 90 ft and ceiling with Concrete block wall case 3

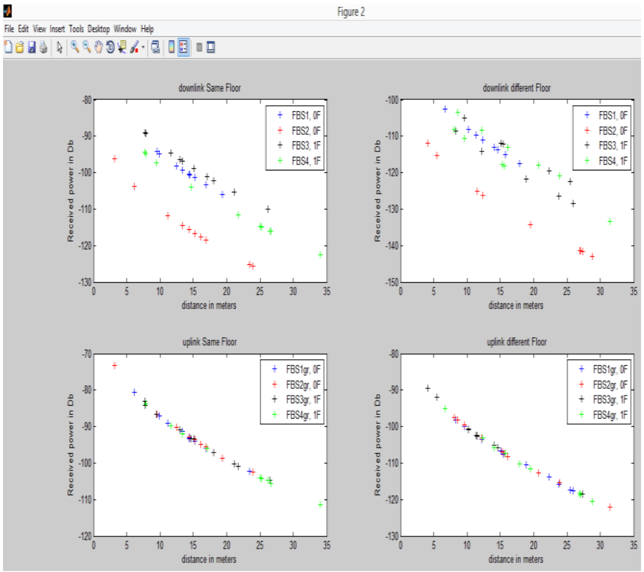

Figure 5.8 Both UL and DL power level representation of case 3 with interference as shown: overlapping bubbles and plus symbols.

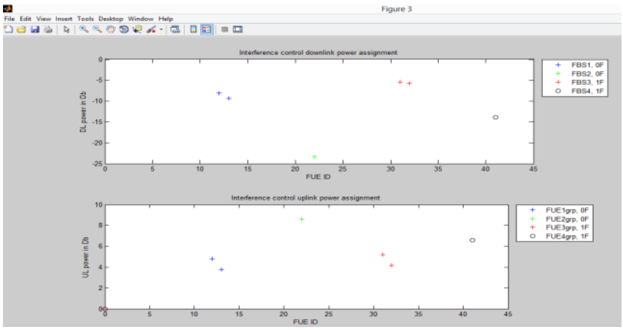

Figure 5.9 Both UL and DL power level representation of case 3 with controlled interference

Case 4: Building dimension = 90 ft x 90 ft, Number of floors = 1, Building Material = Ceiling duct only, having worst case - more number of users- 10 per floor.

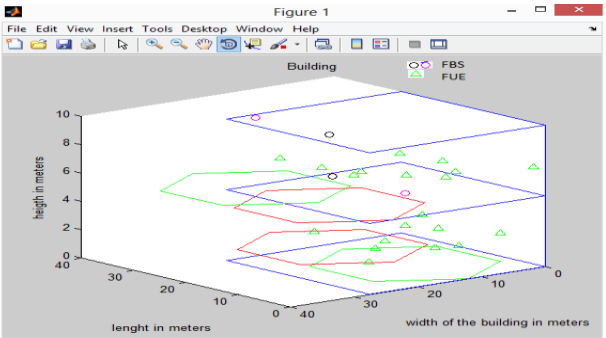

Figure 5.10 Building with dimension 90 ft x 90 ft and ceiling with Ceiling duct case 4

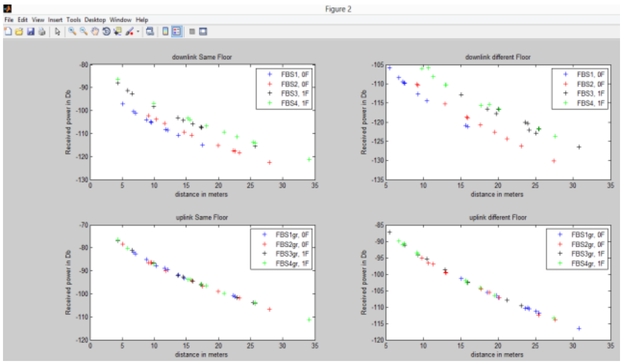

Figure 5.11 Both UL and DL power level representation of case 4 with interference as shown: overlapping bubbles and plus symbols.

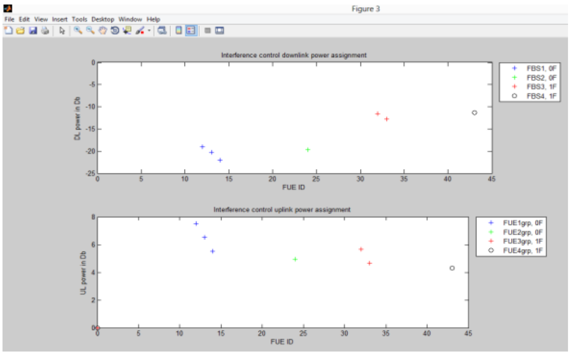

Figure 5.12 Both UL and DL power level representation of case 4 with controlled interference

VII. CONCLUSION

A. Conclusion

The proposed work carried out in this project could successfully control interference at co-tier level (femto-femto) both in UL as well as in DL. FUEs that are at diminishing power levels those measured by the FBS are dropped by the particular FBS.

B. *Future S*cope

Further work can be carried out to avoid the dropping of FUEs due to the diminishing power levels and to improve the throughput of femtocell networks by appending this DATP with the handoff algorithms. Also slight modification in the proposed algorithm may solve the interference problem at cross-tier level (macro to femto).

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AUTHORS PROFILE

Nanda B P is a PG Scholar in Computer Networks and Engineering at B.M.S College of Engineering, Bangalore. His research area is Wireless Networks.

Dr. Radhika K R is a professor at department of Information Science Engineering, BMS College of Engineering, Bangalore. She is Sr. Member at IEEE.