International Journal of Computing and Digital Systems
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Femtocell Interference, SINR and the Probability of Connection at Downlink

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Received 12 Oct.2013, Revised 8 Nov. 2013, Accepted 15 Jan. 2014, Published 1 May. 2014

Abstract: A Femtocell (FMC) is a low power cellular home base station, which is low in cost and operating in licensed spectrum. Nowadays, because of the requirement for high data rate and large area coverage indoors, FMC provides the solution to these requirements. FMC is deployed mainly indoors and sometimes outdoors at the cell edge to increase the area of coverage, capacity and in order to enhance the received signal in the user's premises. In this paper, a novel technique and a Monte Carlo simulation is implemented to calculate the interference, the SINR and the probability of connection at the downlink for a varied number of FMCs based on LTE and WiMAX OFDMA range. Moreover, a novel Monte Carlo simulation is used to carry out the comparison of interference, SINR and probability of connection for three different numbers of FMCs. Furthermore, a novel comparison of FMCs at various SINR threshold values is presented. The downlink interference occurs from neighbouring FMCs to the target user equipment (UE) when the signal transmits from the serving FMC to the target UE and the signals which are transmitted from the neighbouring FMCs would have the same subchannels during the downlink transmission. This paper will explore the appropriate number of FMCs that could serve a specific indoor area and the proper number of UEs in the specified area.

Keywords: Femtocell, Home Base Station, Interference, SINR, User Equipment, Indoors, Downlink

1. INTRODUCTION

The increasing requirements for wireless communication services in improving cellular systems and the essential need of data services at the indoor environment for internet access, phone calls and other communication uses make the cellular network companies and research committes conduct extensive research on better solutions. A Femtocell (FMC) is a low power cellular home base station, low in cost and operating in licensed spectrum. Nowadays, because of the requirement for high data rate and wide area coverage indoors, FMC provides the solution to these requirements. FMCs are deployed mainly indoors and sometimes outdoors at the cell edge to increase the area of coverage, provide higher capacity and in order to enhance the received signal in the user's premises[1-3]. An FMCs is installed on the subscriber's property to supply a cellular service and improve coverage at home or in a business environment. FMC is secure that can be allowed to the specified user and it has the benefits of decreasing the use of battery indoors where the user will connect to FMC with a very short distance and path loss than connecting to the macro base station. FMC decreases the bandwidth load on the macro base station where instead of the user connect to the macro base station the user will connect to the FMC. Also it has independent installation where the user can install it without the need to be installed by a service operator. In signal propagation, the deployment of FMC will raise the data rate efficiency, increase the network's coverage and decrease the likelihood of low signal to interference and noise ratio (SINR) in the indoor areas[4-8]. In cellular systems there are many issues that affect the signal propagation from FMC to UE and from the UE to the FMC in the indoors such as the poor deployment strategies, which is caused by using an inadequate number of FMCs in the network area which doesn't satisfy the performance aspects. Moreover the biggest issue is the improper use and distribution of subchannels and subcarriers in the cellular network which leads to the interference. Interference is one of the biggest challenges for FMC, in the indoor areas and even for the outdoor deployment as cell-edge coverage. In this paper we evaluate interference in a FMC network. The interference is used to find the received signal to interference and noise ratio (SINR) and to calculate the probability of connection for a different numbers of FMCs in an indoor area. The probability of connection shows the deployment and coverage of the FMCs network. The area covered by the FMCs contains much higher average signal to interference and noise ratios (SINRs) than other areas because of the reduced path loss and short propagation distances. In previous papers, FMC deployment has been studied without a detailed interference, SINR and the probability of connection issues. In this paper the concept of interference efficiency and SINR

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in a specific area is presented. This allows us to evaluate the probability of connection for a different numbers of FMCs to find out the appropriate number that could serve a specific indoor area and improve the coverage techniques of cellular mobile radio systems indoors. In addition, this paper characterizes the FMC cellular system coverage with respect to spectral efficiency and analyse how to make the best use of the spectrum.

Even there is no similar to this work has done. However[9] evaluated the interference for frames and calculated the throughput, while this work evaluated the interference for subcarriers and calculated the probability of connection between the femtocells and the user equipment devices. Where [10]discussed the path loss of femtocells indoors, while this work evaluated the interference, SINR and the probability of connection between the femtocells and the user equipment devices.

The remainder of this paper is organized as follows. Section 2 introduces the downlink FMC system model. Section 3 explains the downlink FMC interference. Section 4 provides the downlink simulation scenario for 120 m x 120 m coverage area. Section 5 summaries and concludes the paper.

2. DOWNLINK FEMTOCELL SYSTEM MODEL

A. *Interference Concept*

The deployment of FMCs makes a dramatic change to indoor network communication. However, when FMCs and UEs transmit their signals in the same frequency band within the same geographic area, interference will occur. Moreover, FMCs are randomly distributed in indoor areas surrounded by outdoor BSs which are the main feeder for the FMCs, therefore, inter-cell interference (ICI) would occur if the FMCs and UEs were given the same subchannels which had been given to the BS. Indoors FMCs interference will occur during the deployment when the FMCs transmit their signals in the same subchannels within the same geographic area[11-15]. The advantage of FMC deployment is the increase in coverage and the improvement of capacity, while the main disadvantage is the high probability of interference in the absence of network architecture design.

B. *FMC Coverage*

FMC provides extension of the coverage within strength for the signal. Nevertheless, the coverage provided by BS outdoors to UEs is acceptable but insufficient indoors due to the shadowing effect of the buildings, and the attenuation that is caused by walls, windows and doors[16, 17]. Therefore, FMCs were designed and implemented as a solution to extend and provide better quality indoor network coverage. However, this will lead to increase interference outdoors for non-subscribers who are passing near to the FMCs.

C. *Terminology*

The terms used in this paper are listed as in Table I.

TABLE I. SUMMARY OF TERMINOLOGY USED IN THIS PAPER

Terms	**Description**
BS	LTE or WiMAX macro base station
FMC	Femtocell home base station access point
UE	Femtocell user equipment device
BS_{UE}	LTE or WiMAX macro base station user equipment device
FMC-UE	Interference transmitted from interferer Femtocells to target user equipment
UEs-FMC	Interference transmitted from interferers user equipment devices to serving Femtocell
FMC-BS	Interference transmitted from FMC to LTE or WiMAX macro base station
$BS\text{-}FMC_{UE}$	Interference transmitted from LTE or WiMAX macro base station to FMCuser equipment device

D. *Downlink OFDMA*

In OFDMA systems, the BS typically transmits using a different carrier frequency than FMCs, which helps in interference avoidance. Interference that comes from internal layer such as other FMC or external layer such as the BS will lead us to the intercarrier interference (ICI) that takes us to the loss of orthogonality between subcarriers which may bring the system down completely[18]. Moreover, in an OFDMA system, if one UE is indoor and receiving a signal from an indoor FMC and the other is outdoor and receiving a signal directly from an outdoor BS, then downlink interference will occur if the two users have the same subchannels.

3. DOWNLINK FEMTOCELL INTERFERENCE

A. Co-Layer Interference

Co-Layer interference happens when a signal is transmitted from an FMC and received by neighboring FMCs in other houses or apartments because of the loch of radio frequency isolation between them. Therefore, to avoid such problems FMC must be fixed in the proper location[19]. Interference occurs in downlink, when the signal transmitted from the serving FMC to the target UE is not strong enough compared to the interference which is coming from the neighboring FMCs to the target UE, when the serving FMC and the neighbor FMC transmit as the same subchannel. Therefore, if the FMCs in this area transmits as the same subchannel, interference will occur and here the victim is the target UE and the aggressors or the source of interference is the neighboring FMCs. Moreover, to determine the interference between FMCs and to arrange uplink and downlink, transmission time division duplex (TDD) systems and synchronization must be applied. Therefore on the downlink, all FMCs are synchronized for transmission within the same area. In the absence of synchronization between FMCs in the uplink and downlink, the interference will arise as the uplink and the downlink will overlap in time. Therefore, TDD and synchronization must be applied, to ensure that the FMCs transmission time would match each other and the interference would be in control. TDD is essential to synchronize the FMCs transmission and mitigate the interference.

B. BS - FMC_{UE} Interference

BS - FMC_{UE} interference occurs at downlink when an unwanted signal is received at an FMC UE which has been sent from BS, which is called cross-layer interference because the victim which is a FMC_{UE} and the aggressor the BS are coming from different layers in the network[20, 21]. Moreover, interference that comes from an internal or external layer will lead to intercarrier interference (ICI) that leads to the loss of orthogonality between the subcarriers which make data detection impossible. Inter-cell interference (ICI) would happen if the users were given the same subchannels which had been given to BS. Orthogonal channels should be assigned and different subchannels must be allocated as a solution. Therefore, when the FMC is positioned far from the BS, and suppose that the UE is near to the FMC and far away from doors or windows, hence the interference caused by BS to UE will be the minimum. When the FMC is positioned closer to the BS, the FMC coverage area will be reduced according to the interference from the BS, so the FMC signal is strong only when the UE is very close to the FMC. Moreover the UE placed near a window is more likely to connect to an outside BS than to the indoors FMC.

4. DOWNLINK SIMULATION SCENARIO FOR 120 M X 120 M COVERAGE AREA

A. Scenario Network Layout

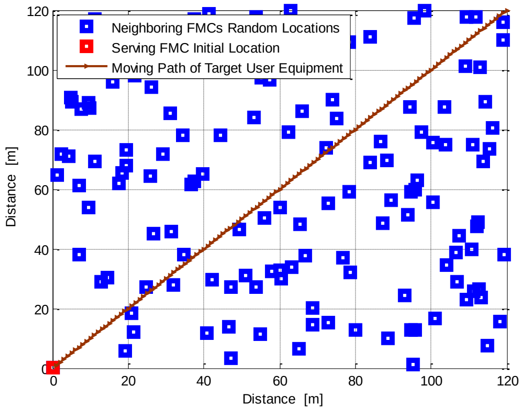


Figure 1. Serving FMC Initial Location, Neighbouring FMCs Locations and Moving Path of Target User Equipment

We model the FMC network as a set of indoor base stations that transmit signals in regular sites characterized by the site distance d. In this scenario we assumed a one floor building which is 120 m long by 120 m wide. The inside of the building consists of a large supermarket, various shops each 10 m by 10 m and a reasonable number of facilities as shown in the floor plan in Fig. 1 with 144 FMCs installed indoors. This is a downlink scenario and the signal is transmitted from the serving FMC to the target UE, while the interference is transmitted from the neighbouring FMCs to the target UE. The serving FMC is located in the coordinate (0.2 m , 0.2 m) and the target UE is suggested to be moving in 45 degree deviation east north. Even though FMCs and UEs were located in a random way, but we expect that at least one FMC is installed in each shop or facility and each FMC serves 4 UEs at a time.

B. Propagation Loss Model

This model is dependent upon the measurements considered at 3.5 GHz as described by equation (1) [10, 22]. This simulation concentrates on the results for the indoor residential premises.

$$PL = 50.3 + 31.21 \log10(d) + 3.8\text{dB} \qquad (1)$$

Equation (1) used to evaluate the path loss power by two measured distances, the first is the distance from the main signal which is between the serving FMC and the target UE, here d is the distance between them and it is varied from 1 up to 160 m. The second is the distance from the interference signal which is between the interferers FMCs and the target UE, the distance between them which is obtained by the following equations,

$$X = FMC\_in\_x + d1 \cdot \text{Sin}(\Theta) \qquad (2)$$

$$Y = FMC\_in\_y + d1 \cdot \text{Cos}(\Theta) \qquad (3)$$

$$\Theta = \pi / 4 \qquad (4)$$

$$d = \sqrt{((X - X(k))^2 + (Y - Y(k))^2)} \qquad (5)$$

here d1 is the distance between the serving FMC and the target UE and is varied from 1 m up to 140 m, equations (2) and (3) are used to calculate the coordinate X and Y for the target UE. Equation (4) shows the Angle measurement. Finally d in equation (5) is used to calculate the distance between the target UE and the k^{th} interferer FMC.

C. FMC-UE Interference Analysis

Interference occurs in downlink when the signal transmitted from the specific FMC to the target UE overlap in subchannel with the signals which transmits from the neighbouring FMCs. This simulation neglect WiMAX BS to FMC interference, and concentrate on the FMC, neighbouring FMCs and UE interference[23].

$$S_i = P_i \cdot G_i \cdot L_i \cdot PL_{ix} \cdot G_x \cdot L_x \text{dB} \qquad (6)$$

where Si is the received signal by the target UE from the serving FMC, P_i is the serving FMC transmission power, G_i is the serving FMC antenna gain, L_i is the serving FMC cable loss, PL_{ix} is the path loss between the serving FMC and the target UE, G_x is the target UE antenna gain, L_x is the target UE loss.

$$S_j = P_j \cdot G_j \cdot L_j \cdot PL_{jx} \cdot G_x \cdot L_x \text{dB} \qquad (7)$$

hereS_j is the received signals from the interferer FMC by the target UE, G_j is the interferer neighbouring FMC antenna gain, L_j is the interferer neighbouring FMC cable loss, PL_{jx} is the path loss between the interferer neighbouring FMC and the target UE. Our simulation will accumulate to compute the interference value that caused by all interferers neighbouring FMCs on the target UE. The transmitted signal from the specific FMC to the target UE is considered as the mean signal, and the sum of the transmitted signals of all interferers neighbouring FMCs to the target UE as the interference.

$$n = -174 - 30 + 10 \log_{10}(f/SC)\text{dB} \qquad (8)$$

$$\sigma = n + n_F \text{dB} \qquad (9)$$

here, n is the thermal noise in dB, f is the Channel bandwidth frequency which is 5 MHz, and SC is the total subcarrier used which is 512, n_F is the noise Figure of the target UE which is 8 dB.σ [1] is the sum of the thermal noise and the target UE noise Figure.

$$SINR = S_i / (\textstyle\sum S_j + \sigma) \quad \text{dB} \qquad (10)$$

Where, S_i is the transmitted signal from the serving FMC to the target UE, S_j is the accumulation of all the transmitted signals from the interferer FMCs to the target UE. Our simulation would compute the SINR value that is caused by all interferers neighbouring FMCs on the target UE.

5. SIMULATION RESULTS

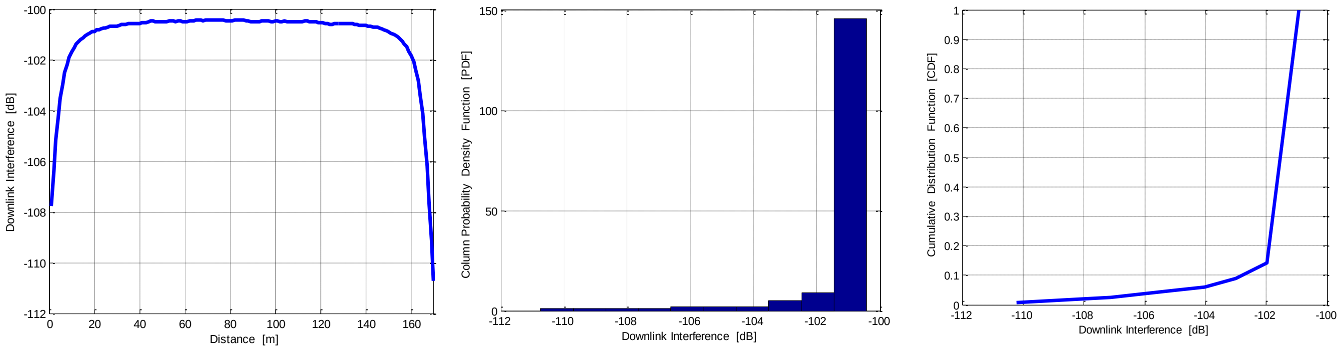
TABLE II. SUMMARY OF SYSTEM SIMULATION PARAMETERS

Parameter	Value
Number of FMCs	144
Carrier frequency	3.5 GHz
Channel bandwidth	5 MHz
Total subcarriers	512
Data subcarriers	318
Subchannels	8

Parameter	**Value**
Distance of Area	120 m x 120 m
FMC TX power	10 dBm
FMC antenna gain	0 dBi
FMC cable loss	0 dBi
FMC noise Figure	4 dB
UE Tx power	23 dBm
UE antenna gain	0 dBi
UE cable loss	0 dB
UE noise Figure	8 dB

In this study a number of simulations were carried out. Each simulation has a number of iterations to calculate the interference, SINR and to find out the probability of connection from the serving FMC to the target UE which is known as the downlink located indoors. The optimum FMC coverage distance is 10 m in each direction, therefore 10 m by 10 m area will be covered by the individual FMC. In this simulation, a fixed number which is 144 FMCs was used; the serving FMC is placed initially at 0.2 m by 0.2 m in the X and Y axis's then after that chosen as the nearest FMC to the target UE. The target UE is moving in a diagonal direction east north from the serving FMC with a varied d range of 1 m up to 170 m. Moreover, comparisons of interference, SINR and probability of connection for three different FMCs numbers are presented. The neighboring FMCs are scattered and allocated in locations randomly, the serving FMC initial location and the neighboring FMCs random locations are shown in Fig. 1. The simulation parameters were used from Table II.

A. Interference

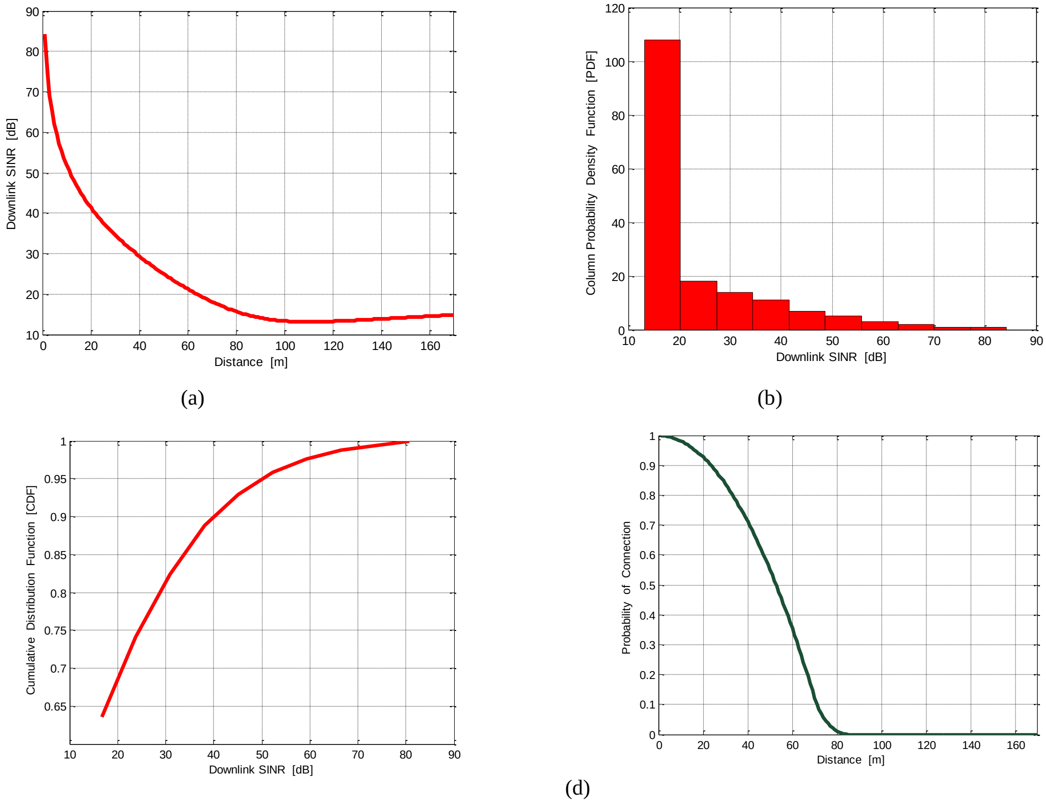


(a) (b) (c)

Figure 2. FMCs-UE (a) Interference, (b) PDF Columns for the Interference, and (c) CDF Curve for the Interference

In Fig. 2(a) the downlink interference is calculated from the interferer neighbouring FMCs to the target UE, at a varied d which is from d equal 1 m up to 170 m. The simulation shows that the interference magnitude increases gradually from 1 m up to 30 m in the range -107.8 dB to -100.5 dB, which is the best distance that the signal can be received by the serving FMC from the target UE. Beyond this up to 140 m the interference fluctuates slightly in the range -100.5 dB to -100.25 dB. Finally from d equal 141 m up to 170 m the interference decreases gradually from -100.5 dB at 141 m up to -110.7 dB at 170 m, which is the building border point. The area under the columns of the column histogram probability density function (PDF) for the interference which is illustrated in Fig. 2(b) indicates the interval under which the interference drops. While Fig. 2(c) shows the cumulative distribution function (CDF) for the interference interval probability that the interference lies in.

B. SINR



(a)

(b)

(c)

(d)

Figure 3. FMCs-UE (a) SINR, (b) PDF columns for SINR, (c) CDF Curve for SINR, and (d) Probability of Connection

The simulation calculates the signal-to-interference and noise ratio (SINR) for various values of d which is from d equal 1 m up to 170 m. This is evaluated by the mean signal which is transmitted from the serving FMC to the target UE, and the interference that are accumulated from the interferers neighboring FMCs to the target UE. Fig. 3(a) illustrates a graph for the accumulated SINR at the varied range of d. The column histogram probability density function (PDF) for SINR is shown in Fig. 3(b). The area under the graph shows the interval for the SINR. The cumulative distribution function (CDF) for SINR which is shown in Fig. 3(c) indicates the interval that SINR lies in. Therefore, the SINR decreases with the increase of d. The simulation shows that the maximum SINR reading value is 85 dB when d equal to 1 m and the minimum SINR reading value is 14 dB when d is equal to 120 m. The curve after 120 m up to 170 m rose very slightly because the FMCs are distributed randomly.

C. Probability of Connection

The probability of connection from the FMCs to the UEs in a varied range of d is declined gradually from 1 m up to 80 m. The probability of connection decreases as the UE moves away from the FMC. This starts with the highest probability at the first 10 m then declines slowly over the distance to reach the worst probability at d being 85 m as shown in Fig. 3(d).

D. Comparison of Connection at Various FMCs Numbers

Figs. 4-6 show the interference, SINR and the probability of connection for 3 cases, each case consists of a different number of FMCs number, the first case curve shows the number of 144 FMCs, the second case curve is the number of 72 FMCs and the third case curve is the number of 36 FMCs. In Fig. 4 the interference is raised dramatically within the increase of FMCs number. However, in Fig. 5 the SINR is raised slightly with the increase of FMCs number. The probability of connection value is high in the 144 FMCs and 72 FMCs cases in the range of d 1 m up to 10 m and it is the maximum for the case of 144 FMCs, while it gives approximately 42 % for the case of 72 FMCs and it shows the minimum for the case of 36 FMCs.

TABLE III. Summary for the Probability of Connection Values in Various Numbers of FMCs and 1–170 m

Distance in m	**Probability of Connection**		
	36 FMCs	***72 FMCs***	***144 FMCs***
10	14.54 %	41.59 %	98.23 %
20	05.23 %	39.28 %	92.96 %
30	02.12 %	35.48 %	83.91 %
40	01.05 %	30.21 %	71.32 %
50	00.21 %	23.35 %	55.11 %
60	00.24 %	15.01 %	35.45 %
70	00.07 %	05.15 %	12.28 %
80	00.01 %	00.41 %	01.00 %
90	00.00 %	00.00 %	00.00 %

Table III shows the probability of connection values for the 3 cases. For instance at d is 30 m the probability of connection value is 83.91 % for the case of 144 FMCs, while it is 35.48 for the case of 72 FMCs and 2.12 for the case of 36 FMCs. Moreover, at d is 90 m the probability of connection values is 0 for all cases as shown in Fig. 6.

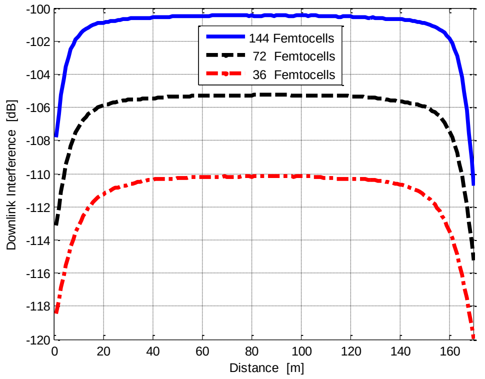


Figure 4. Interference with Various Number of FMCs

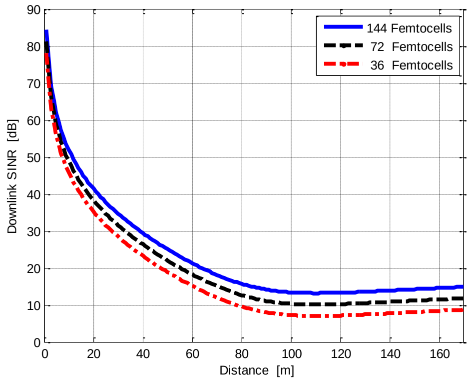


Figure 5. SINR at Various FMCs

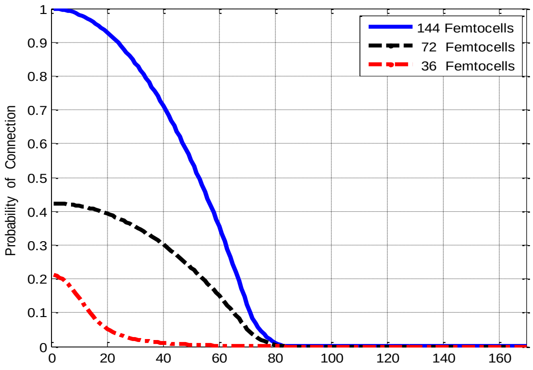


Figure 6. Probability of Connection at Various FMCs

E. Comparison of FMCs at Various SINR Threshold Values

In Fig. 7 we have presented the probability of connection for the downlink from the FMC to the UE in a various SINR threshold values which are 0 dB, 5 dB, 10 dB, 15 dB and 20 dB.

Fig. 7(a) and Table IV show the probability of connection with 18 FMCs. In addition, the probability of connection is good at 0 dB SINR threshold value in all the range of d which is 1m up to 110 m, while at 5 dB SINR threshold value the probability is good in the range of d equal 1m up to 74 m. However, at 10, 15 and 20 dB SINR threshold values, the probability of connection is in the range of d equal 1m up to 56 m at 10 dB, 1m up to 43 m at 15 dB and 1m up to 33 m at 20 dB.

Fig. 7(b) and Table V show the probability of connection with 36 FMCs. the probability of connection is good at 0 dB SINR threshold value in all the range of d which is 1m up to 110 m, while at 5 dB SINR threshold value the probability is good in the range of d equal 1m up to 106 m. However, at 10, 15 and 20 dB SINR threshold values, the probability of connection is in the range of d equal 1m up to 70 m at 10 dB, 1m up to 54 m at 15 dB and 1m up to 42 m at 20 dB.

Fig. 7(c) and Table VI show the probability of connection with 72 FMCs. the probability of connection is good at 0 and 5 dB SINR threshold values in all the range of d which is 1m up to 110 m, while at 10 dB SINR threshold value the probability is good in the range of d equal 1m up to 89 m. However, at 15 and 20 dB SINR threshold values, the probability of connection is in the range of d equal 1m up to 65 m at 15 dB and 1m up to 51 m at 20 dB.

Fig. 7(d) and Table VII show the probability of connection with 144 FMCs. The probability of connection is good at 0 dB, 5 dB and 10 dB SINR threshold values in all the range of d which is 1m up to 110 m, while at 15 dB SINR threshold value the probability is good in the range of d equal 1m up to 78 m. However, at 20 dB SINR threshold value the probability of connection is in the range of d equal 1m up to 60 m.

Table VIII presents the summary for the probability of connection in d is varied from 1 m up to 110 m, at various numbers of FMCs which are 18 FMCs, 36 FMCs, 72 FMCs and 144 FMCs and in various SINR threshold values which are 0 dB, 5 dB, 10 dB, 15 dB and 20 dB. The simulation illustrated that the probability of connection for the number of 144 FMCs distributions is high in 0 dB, 5 dB and 10 dB SINR threshold values, while the probability of connection is high in 0 dB and 5 dB SINR threshold values with the number of 72 FMCs distributions. In addition, with the number of 36 FMCs distributions and the number of 18 FMCs distributions the probability of connection is high in 0 dB SINR threshold value.

TABLE IV. PROBABILITY OF CONNECTION FOR 18 FMCS

Threshold SINR Value	The Probability of Connection
0 dB	1 m – 110 m
5 dB	1 m – 74 m
10 dB	1 m – 56 m
15 dB	1 m – 43 m
20 dB	1 m – 33 m

TABLE V. PROBABILITY OF CONNECTION FOR 36 FMCS

Threshold SINR Value	The Probability of Connection
0 dB	1 m – 110 m
5 dB	1 m – 106 m
10 dB	1 m – 70 m
15 dB	1 m – 54 m
20 dB	1 m – 42 m

TABLE VI. PROBABILITY OF CONNECTION FOR 72 FMCS

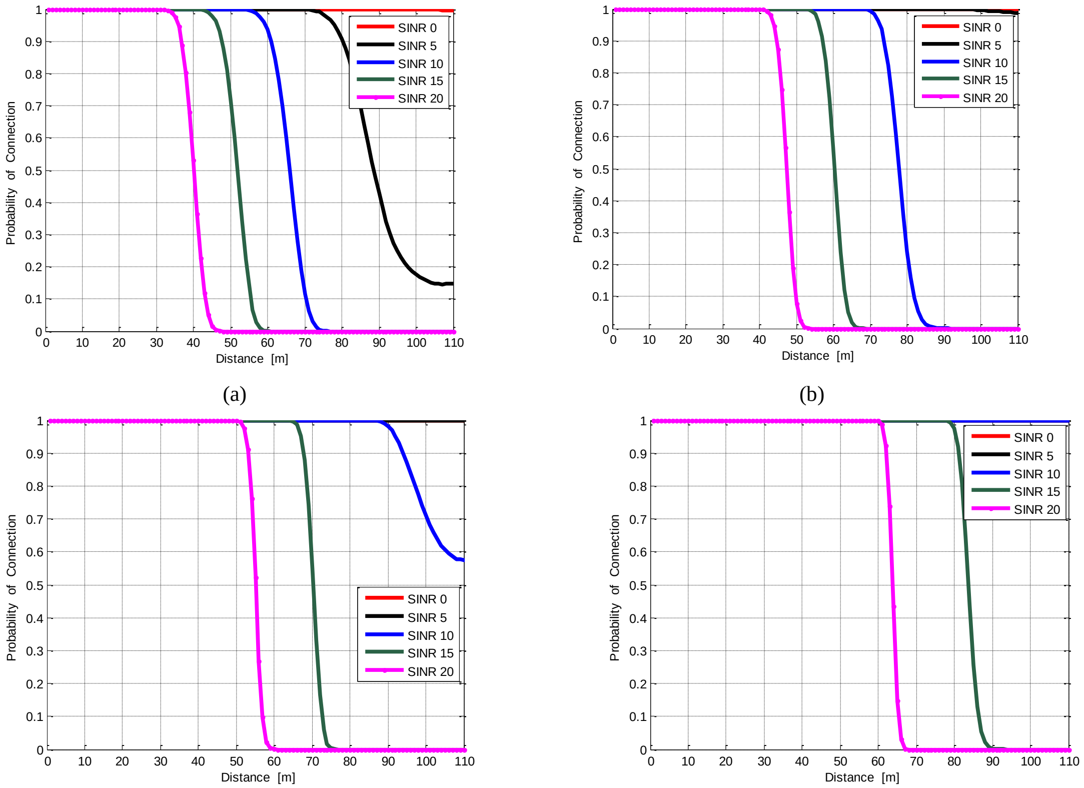
Threshold SINR Value	The Probability of Connection
0 dB	1 m – 110 m
5 dB	1 m – 110 m
10 dB	1 m – 89 m
15 dB	1 m – 65 m
20 dB	1 m – 51 m

TABLE VII. PROBABILITY OF CONNECTION FOR 144 FMCS

Threshold SINR Value	**The Probability of Connection**
0 dB	1 m – 110 m
5 dB	1 m – 110 m
10 dB	1 m – 110 m
15 dB	1 m – 79 m
20 dB	1 m – 60 m

TABLE VIII. SUMMARY FOR THE PROBABILITY OF CONNECTION IN VARIOUS NUMBERS OF FMCS AND 1–170 M

Threshold SINR	**Number of FMCs**			
	36 FMCs	***36 FMCs***	***72 FMCs***	***144 FMCs***
0 dB	1 – 110 m	1 – 110 m	1– 110 m	1– 110 m
5 dB	1– 74 m	1 – 106 m	1– 110 m	1 – 110 m
10 dB	1– 56 m	1 – 70 m	1– 89 m	1 – 110 m
15 dB	1– 43 m	1– 54 m	1– 65 m	1– 79 m
20 dB	1– 33 m	1– 42 m	1– 51 m	1– 60 m



(a)

(b)

(c)

(d)

Figure 7. Probability of Connection at Various SINR Threshold Values with, (a) 18 FMCs, (b) 36 FMCs, (c) 72 FMCs, and (d) 144 FMCs

6. CONCLUSIONS

Strong downlink interference occurrs when the serving FMC and the neighbor FMC are transmitted at the same subchannel. This paper investigates the downlink of FMCs deployment strategies indoors for mobile radio networks.

In this simulation, the FMC-UE distance d varies from 1 m up to 170 m and a fixed number of FMCs of 144 is considered. The main contribution of this work is to evaluate the interference and SINR caused from interferer FMCs to the target UE and then calculate the probability of connection which is from the serving FMC to the target UE. Moreover, this paper introduces a comparison of the interference, SINR and the probability of connection for 3 different numbers of FMCs. The simulations show that for these studies and simulated scenarios in the specified areas and under the employed number of FMCs, the probability of connection value increases as the number of FMCs increases.

In addition, this work evaluates the interference and SINR that is caused from interferer FMCs to the target UE and then calculated the probability of connection which is from the serving FMC to the target UE at various SINR threshold values. This simulation investigates the downlink of FMCs deployment indoors, in which the FMC-UE distance d is varied 1 m up to 110 m and 4 cases of different but fixed numbers of FMCs which are 18, 36, 72 and 144. These simulations calculate the probability of connection in 0 dB, 5 dB, 10 dB, 15 dB and 20 dB SINR threshold values. The simulation illustrated that the probability of connection for the number of 144 FMCs distributions is high in 0 dB, 5 dB and 10 dB SINR threshold values, while the probability of connection is high in 0 dB and 5 dB SINR threshold values with the number of 72 FMCs distributions. In addition, with the number of 36 FMCs distributions and the number of 18 FMCs distributions the probability of connection is high for the 0 dB SINR threshold value. Therefore the probability of connection is the best with 144 number of FMCs, while with 72 number of FMCs the probability is less than that with 144 FMCs. Moreover, the probability of connection for 36 number of FMCs is less than that with 72 FMCs and the probability of connection for 18 number of FMCs is the worst in all the 4 cases.

Therefore, the interference can be managed if appropriate number of FMCs and different subchannels are used. Furthermore, we have presented that by using FMCs indoors the capacity and coverage increased on downlink because the UEs served by FMCs can process higher data rates than by BS.

REFERENCES

[1] R. Madan, A. Sampath, A. Khandekar, J. Borran, and N. Bhushan, "Distributed interference management and scheduling in LTE-A femto networks," in *Global Telecommunications Conference (GLOBECOM 2010), 2010 IEEE*, 2010, pp. 1-5.

[2] S. F. Hasan, N. H. Siddique, and S. Chakraborty, "Femtocell versus WiFi-A survey and comparison of architecture and performance," in *Wireless Communication, Vehicular Technology, Information Theory and Aerospace & Electronic Systems Technology, 2009. Wireless VITAE 2009. 1st International Conference on*, 2009, pp. 916-920.

[3] A. Golaup, M. Mustapha, and L. B. Patanapongpibul, "Femtocell access control strategy in UMTS and LTE," *Communications Magazine, IEEE*, vol. 47, pp. 117-123, 2009.

[4] S. Prasad and R. Baruah, "Femtocell mass deployment: Indian perspective," in *Anti-counterfeiting, Security, and Identification in Communication, 2009. ASID 2009. 3rd International Conference on*, 2009, pp. 34-37.

[5] I. O. Kennedy, P. Scanlon, and M. M. Buddhikot, "Passive steady state rf fingerprinting: A cognitive technique for scalable deployment of co-channel femto cell underlays," in *New Frontiers in Dynamic Spectrum Access Networks, 2008. DySPAN 2008. 3rd IEEE Symposium on*, 2008, pp. 1-12.

[6] S. Saunders, S. Carlaw, A. Giustina, R. R. Bhat, V. S. Rao, and R. Siegberg, *Femtocells: opportunities and challenges for business and technology*: Wiley, 2009.

[7] Z. R. Bharucha, "Ad hoc wireless networks with femto-cell deployment: a study," 2010.

[8] M. Simsek, T. Akbudak, B. Zhao, and A. Czylwik, "An LTE-femtocell dynamic system level simulator," in *Smart Antennas (WSA), 2010 International ITG Workshop on*, 2010, pp. 66-71.

[9] J. Zhang and G. De la Roche, *Femtocells: technologies and deployment*: Wiley Online Library, 2010.

[10] J. Boccuzzi and M. Ruggiero, *Femtocells: design & application*: McGraw-Hill Professional, 2010.

[11] T. Alade and H. Zhu, "Joint Signal Processing in Femtocell Based Distributed Antenna Systems in High Buildings," in *Vehicular Technology Conference Fall (VTC 2010-Fall), 2010 IEEE 72nd*, 2010, pp. 1-5.

[12] V. Chandrasekhar, J. Andrews, and A. Gatherer, "Femtocell networks: a survey," *Communications Magazine, IEEE*, vol. 46, pp. 59-67, 2008.

[13] M. I. Rahman, E. Dahlman, D. Astely, A. Wallén, and L. R. Wilhelmsson, "A Study of UE-to-UE Interference between TDD Systems," in *Vehicular Technology Conference (VTC Spring), 2012 IEEE 75th*, 2012, pp. 1-5.

[14] D. Choi, P. Monajemi, S. Kang, and J. Villasenor, "Dealing with loud neighbors: The benefits and tradeoffs of adaptive femtocell access," in *Global Telecommunications Conference, 2008. IEEE GLOBECOM 2008. IEEE*, 2008, pp. 1-5.

[15] C. M. de Lima, M. Bennis, K. Ghaboosi, and M. Latva-aho, "Interference management for self-organized femtocells towards green networks," in *Personal, Indoor and Mobile Radio Communications Workshops (PIMRC Workshops), 2010 IEEE 21st International Symposium on*, 2010, pp. 352-356.

[16] F. Richter, A. J. Fehske, and G. P. Fettweis, "Energy efficiency aspects of base station deployment strategies for cellular networks," in *Vehicular Technology Conference Fall (VTC 2009-Fall), 2009 IEEE 70th*, 2009, pp. 1-5.

[17] V. Chandrasekhar, M. Kountouris, and J. G. Andrews, "Coverage in multi-antenna two-tier networks," *Wireless Communications, IEEE Transactions on*, vol. 8, pp. 5314-5327, 2009.

[18] D. López-Pérez, G. de la Roche, A. Valcarce, A. Juttner, and J. Zhang, "Interference avoidance and dynamic frequency planning for WiMAX femtocells networks," in *Communication Systems, 2008. ICCS 2008. 11th IEEE Singapore International Conference on*, 2008, pp. 1579-1584.

[19] M. Yavuz, F. Meshkati, S. Nanda, A. Pokhariyal, N. Johnson, B. Raghothaman, *et al.*, "Interference management and performance analysis of UMTS/HSPA+ femtocells," *Communications Magazine, IEEE*, vol. 47, pp. 102-109, 2009.

[20] H. Claussen, "Performance of macro-and co-channel femtocells in a hierarchical cell structure," in *Personal, Indoor and Mobile Radio Communications, 2007. PIMRC 2007. IEEE 18th International Symposium on*, 2007, pp. 1-5.

[21] M. Z. Chowdhury, W. Ryu, E. Rhee, and Y. M. Jang, "Handover between macrocell and femtocell for UMTS based networks," in *Advanced Communication Technology, 2009. ICACT 2009. 11th International Conference on*, 2009, pp. 237-241.

[22] S. Y. Seidel and T. S. Rappaport, "914 MHz path loss prediction models for indoor wireless communications in multifloored buildings," *Antennas and Propagation, IEEE Transactions on*, vol. 40, pp. 207-217, 1992.

[23] T. Zahir, K. Arshad, A. Nakata, and K. Moessner, "Interference management in femtocells," 2012.

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