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Analysis of Uplink co-channel Interference on Cell Coverage for a Six Sectoring Antenna pattern in an IEEE 802.16m System

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Abstract - A analytical system design model is proposed to estimate the uplink co-channel interference (CCI) on cell coverage and achieve a high capacity in an IEEE 802.16m system. To achieve high system capacity a six-sector antenna patterns is introduced in IEEE 802.16m system. This proposed model is based on signal-to-interference-plus-noise (SINR) requirement, which satisfies each mobile user's minimum SINR requirement. The shadow fading effect and random location of mobile users are taken into consideration to calculate average interference power. The simulation results suggest that increment of outage probability due to CCI can leads to reduction in cell coverage. The proposed model helps to build an advanced 4G network including LTE and WiMAX.

***Key Words*: CCI, six sector antenna pattern, cell coverage, outage probability, capacity improvement.**

1.INTRODUCTION

In recent years, the cellular communications system has evolved rapidly, mainly moved by the increase of smart applications and user requirements. The increasing demands for high-speed data transmission have led to improvements in facilities and usability of service through cellular networks. The concept of the Fourth Generation (4G) network is characterized by the integration of different heterogeneous networks including LTE, WMAN, and WiMAX. To enhance the cellular network capacity a six-sector antenna pattern is used. In this paper 16-ary quadrature amplitude modulation scheme is adopted to increase the data transmission rate [1]-[5]. For better utilization of limited spectrum, a frequency reuse plan is deployed. But, the adoption of frequency reuse plan can increase CCI by a significant amount. LTE and WiMAX are basically based on Orthogonal Frequency Division Multiplexing (OFDM) technology which can overcome multipath fading and provide high spectral efficiency. OFDM leads to a reduction in CCI as compared to WCDMA.

Several antenna patterns have been studied on intercell interference problem in OFDM-based cellular systems [6-8]. But most of studies focused on the fractional frequency reuse (FFR) scheme to mitigate Intercell interference problem. Here, an analytical model is presented to estimate CCI impact and increasing the cell coverage area of IEEE 802.16m system. This paper also based on SINR requirement and the power control mechanism which can satisfy their target SINR in each cell.

2. PROPOSED SYSTEM MODEL

2.1. Antenna radiation pattern

A high-capacity six-sector antenna pattern is used. To configure a six-sector cell, here we placed two three sectoring antennas back-to-back i.e., a phase shift of 180^0 in fig 1.

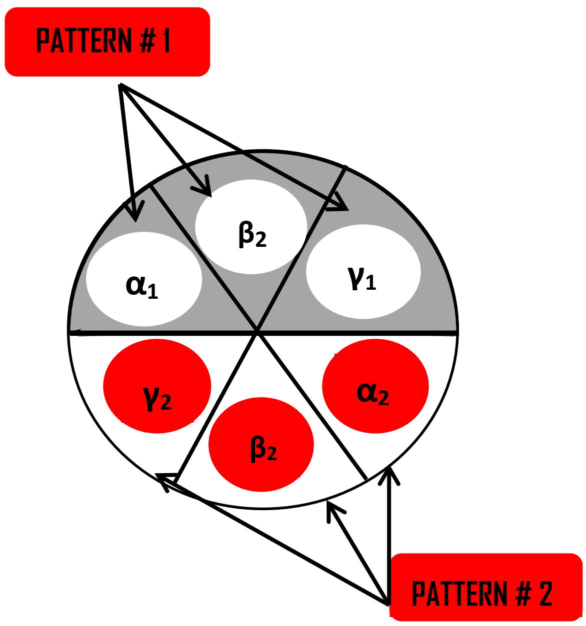

Fig-1 Arranging two three sector antenna patterns to make a six-sector for optimum performance.

There are several ways that the six sectors can be configured. All three sectors of the first pattern can be deployed on one side and the second pattern on the other side. Another method, where a sector of the first pattern is adjacent to two sectors of the second pattern. The first method yields the best performance, improved signal demodulation, and lower power requirements [9]. The way of these sectors can be arranged to impact the performance of six sectors. In this proposed model three sector antenna pattern is designed by 3GPP TR 36.942 [10] as

$$A(\theta) = -\min\left[12\left(\frac{\theta}{\theta_{3dB}}\right)^2, A_m\right], \quad -90^0 \le \theta \le 90^0 \qquad (1)$$

where,

θ_{3dB} is 3-dB beamwidth (corresponds to 65^0)
A_m is maximum attenuation, set to 20dB.

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The antenna gain of BS is assumed to be 15dBi and for MS, an antenna gains of 0 dBi with an omnidirectional pattern is assumed.

2.2 Analysis of Uplink co-channel interference

To design the system model first, we have to consider the CCI impact between two co-channel cells as shown in fig. 2. Here, in each cell, one BS is deployed with an 180^0 phase shift and each BS has six sectors. Now we consider two mobile users MS_1 and MS_2 continuously communicate with their base station BS_1 and BS_2 respectively.

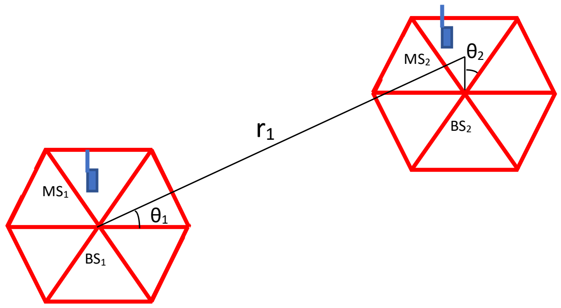

Fig-2. CCI impacts from adjacent cells.

These two cells are using the same set of frequencies. In this situation, they must suffer from CCI impact because BS_1 can receive some co-channel signals which are being radiated from MS_2. The received interference power at BS_1 can be written as

$$I_1 = Pt_2 \cdot L_1 \cdot G_{MS2} \cdot G_{MS1} \cdot A_1(\theta_1 - 30^0) \quad (2)$$

where, Pt_2 is the transmission power of MS_2; L_1 is the path loss between BS_1 and MS_1; G_{MS2} and G_{BS1} are the antenna gain of MS_2 and BS_1 respectively; A_1 represents the antenna pattern of BS_1, and reference antenna pattern is shifted to $\theta_1 = 30^0$.
In this condition, BS_2 must receive sufficient power from MS_2. So, we can say that the received power at $BS1$ can be written as

$$Pr_2 = Pt_2 \cdot L_2 \cdot G_{MS2} \cdot G_{BS2} \cdot A_2(\theta_2 - 30^0) \quad (3)$$

where L_2 is the path loss between MS_2 and BS_2; G_{BS2} is the antenna gain of BS_2; A_2 denotes the antenna pattern of BS_2. For simplification let us assume two base stations have same antenna gain. So, we can write from eq (1) and eq (2)

$$I_1 = Pr_2 \cdot \frac{L_1}{L_2} \cdot \frac{A_1(\theta_1 - 30^0)}{A_2(\theta_2 - 30^0)} \quad (4)$$

Now shadow fading effect is taken into consideration for calculating path loss between MS_2 and BS_1 can be expressed as [11].

$$L_1 = C_1 \cdot r_1^{-\mu 1} \cdot 10^{-\varepsilon 1/10} \quad (5)$$

where C_1 is constant, μ_1 represents the path-loss exponent, and ε_1 denotes shadow fading effect.
So, path loss between MS_2 and BS_2 can be expressed as

$$L_2 = C_2 \cdot r_2^{-\mu 2} \cdot 10^{-\varepsilon 2/10} \quad (6)$$

For simplification consider that $C_1 = C_2 = C$, $\mu_1 = \mu_2 = \mu$ and ε_1, ε_2 are two independent and identical random variables. From eq (3) and eq (5), we can note that the interference power I_1 primarily depends on random location of mobile users and fading effects. Let us consider the random location of mobile subscribers and the shadow fading effect are mutually independent. So, the value of I_1 can be written as [12]

$$E(I_1) = Pr_2 \cdot E\left[10^{(\varepsilon 2 - \varepsilon 1)/10}\right] \cdot E\left[\left(\frac{r_1}{r_2}\right)^{-\mu} \cdot \frac{A_1(\theta_1 - 30^0)}{A_2(\theta_2 - 30^0)}\right] \quad (7)$$

As we can say the difference between the random variables is also a log-normal distribution with variance $2\sigma^2$ and zero mean. So, we can write as

$$E\left[10^{(\varepsilon 2 - \varepsilon 1)/10}\right] = e^{(0.1 \cdot \sigma \cdot \ln 10)^2} \quad (8)$$

The expected value of mobile user MS_2 may create some interference due to its random nature. So, this interference power might be estimated by integration over the sector area. Therefore, expected interference power (I_0) at BS_1 is written as

$$E(I_1) = Pr_2 \cdot e^{(0.1 \cdot \sigma \cdot \ln 10)^2} \cdot \int_0^R \int_0^{\frac{\pi}{3}} \left(\frac{r_1}{r_2}\right)^{-\mu} \cdot \frac{A_1(\theta_1 - 30^0)}{A_2(\theta_2 - 30^0)} \cdot f(r_2, \theta_2)\, d\theta_2\, dr_2 \quad (9)$$

where, R is the radius of BS_2 and $f(r_2,\theta_2)$ represents the probability function of the random location of MS_1. If we consider the random location of mobile subscribers is uniformly distributed over 60^0 sectors. Then probability density function will be

$$f(r_2, \theta_2) = \frac{3r_2}{\pi R^2}, \quad 0 < r_2 < R; \quad 0 < \theta_2 < 60^0. \quad (10)$$

We can replace eq (8) as

$$E[I_1] = M_{12} \cdot Pr_2 \quad (11)$$

where ,

$$M_{12} = e^{(0.1 \cdot \sigma \cdot \ln 10)^2} \cdot \int_0^R \int_0^{\frac{\pi}{3}} \left(\frac{r_1}{r_2}\right)^{-\mu} \cdot \frac{A_1(\theta_1 - 30^0)}{A_2(\theta_2 - 30^0)} \cdot f(r_2,\theta_2) d\theta_2 dr_2$$

Similarly, we can analyze the uplink CCI impact at BS_2 and also calculate the expected value of interference power, which can be written as

$$E[I_2] = M_{21} \cdot Pr_1 \quad (12)$$

Where Pr_1 is the required receive power at BS_1 and

$$M_{21} = e^{(0.1 \cdot \sigma \cdot \ln 10)^2} \cdot \int_0^R \int_0^{\frac{\pi}{3}} \left(\frac{r_b}{r_a}\right)^{-\mu} \cdot \frac{A_1(\theta_1 - 30^0)}{A_2(\theta_2 - 30^0)} \cdot f(r_a,\theta_a) d\theta_a dr_b$$

2.3. Calculation of SINR

For uplink transmission, to satisfy their target SINR, a power control mechanism is used. The power control mechanism is specified in 3GPP, which can decrease CCI and also reduce the system throughput. The power control mechanism defined in [13] can provide an initial power at MS. In this situation, each BS has enough power to control the MS radiation to maintain their require SINR. To satisfy the target SINR, the excess MS power can be compensated by path loss. With consideration of the receiver noise figure, we can calculate the minimum SINR requirement at BS_1 [14] as

$$SINR_1 = \frac{Pr_1}{NF\,(E[I_1]+N_0)} = \frac{Pr_1}{NF\,(M_{12}\cdot Pr_2+N_0)} \quad (13)$$

where, N_0 is the white noise power
For k, number of subchannel, receiver noise power may be written as

$$N_{0(dBm)} = -174dBm/Hz + 10\log_{10}(k\cdot BW_{subch}) \quad (14)$$

where, BW_{subch} is bandwidth of subchannels.
Similarly, the SINR requirement at BS_2 is as

$$SINR_2 = \frac{Pr_2}{NF\,(E[I_2]+N_0)} = \frac{Pr_2}{NF\,(M_{21}\cdot Pr_1+N_0)} \quad (15)$$

By solving these two equations we can have the power at BS_1 and BS_2 are Pr_1 and Pr_2 respectively can be written as

$$Pr_1 = \frac{SINR_1\cdot NF\cdot N_0\cdot (SINR_2\cdot NF\cdot M_{12}+1)}{1-SINR_1\cdot SINR_2\cdot NF^2\cdot M_{12}\cdot M_{21}} \quad (16)$$

$$Pr_2 = \frac{SINR_2\cdot NF\cdot N_0\cdot (SINR_1\cdot NF\cdot M_{21}+1)}{1-SINR_1\cdot SINR_2\cdot NF^2\cdot M_{12}\cdot M_{21}} \quad (17)$$

Now consider all inner cell uplink CCI signals from another cell at the same time. Let assume there are n + 1 number of base stations. Then the expected interference power can be received at BS_i as

$$E[I_i] = \sum_{j=1, j\neq i}^{n} M_{ij}\cdot Pr_j \quad (18)$$

For each BS the SINR requirement can be written as

$$SINR_i = \frac{Pr_i}{NF\,(E[I_i]+N_0)} = \frac{Pr_2}{NF\sum(M_{ij}\cdot Pr_j + N_0)} \quad (19)$$

The required power level at each BS can be written as

$$\begin{bmatrix} (SINR_1\cdot NF)^{-1} & -M_{12} & -M_{13} & \cdots & -M_{1n} \\ -M_{21} & (SINR_2\cdot NF)^{-1} & -M_{23} & \cdots & -M_{2n} \\ & \vdots & & & \vdots \\ -M_{n1} & -M_{n2} & \cdots & & (SINR_n\cdot NF)^{-1} \end{bmatrix} \cdot \begin{bmatrix} Pr_1 \\ Pr_2 \\ \vdots \\ Pr_n \end{bmatrix} = \begin{bmatrix} N_0 \\ N_0 \\ \vdots \\ N_0 \end{bmatrix} \quad (20)$$

2.4. Service Outage Probability and Cell Coverage

Service outage probability is the probability of failure of a system that means there will be no communication link between the MS and BS. We now examine the handset power limitation on system performance due to the co-channel interference. Then we have to analyze that the MS has enough power to support the given SINR requirement. The required transmission power at the mobile station can be written as

$$Pt_1 = \frac{Pr_1}{C\cdot r_a^{-\mu}\cdot 10^{\varepsilon_1/10}\cdot G_{MS1}\cdot G_{BS1}\cdot A_a(\theta_a - 30^0)} \quad (21)$$

There will be no communication link between MS and BS when the required transmission power is greater than the mobile handset power. We can mathematically express as

$$P_{outage} = P(Pt_0 > P_{max}) \quad (22)$$

Where P_{max} represents maximum output power supported by the mobile handset. So outage probability can be rewritten as [18]

$$P_{outage} = 1 - Q(x) = 1 - \frac{1}{\sqrt{2\pi}}\int_x^{\infty} exp\left(-\frac{v^2}{2}\right)dv \quad (23)$$

where,

$$x = \frac{10}{\sigma}\log_{10}\cdot \frac{Pr_1}{C\cdot r_a^{-\mu}\cdot 10^{\varepsilon_1/10}\cdot G_{MS1}\cdot G_{BS1}\cdot A_a(\theta_a - 30^0)\cdot P_{max}}$$

Here r_a defines the distance between MS and BS. The distance between the user equipment and its BS leads to increments of outage probability.
The coverage area will be maximum for that value of r_a when service outage probability is less than the acceptable level which is set at 0.1 i.e., a good communication link can be established in this coverage area. Therefore, the coverage of a cell can be mathematically given by [14]

$$D_{coverage} = \max\{r_a : P_{outage} < \delta\} \quad (24)$$

where δ is an acceptable level for outage probability. In this study, the value of outage probability is taken as 0.1.

3. NUMERICAL RESULT

For six sectoring a total number of seven base stations are placed in seven clusters, having seven cells each. Each cell has six sectors and is deployed in a hexagonal grid with a distance of 5R. Now we need to focus on victim BS_1 for analysis of the CCI impacts.

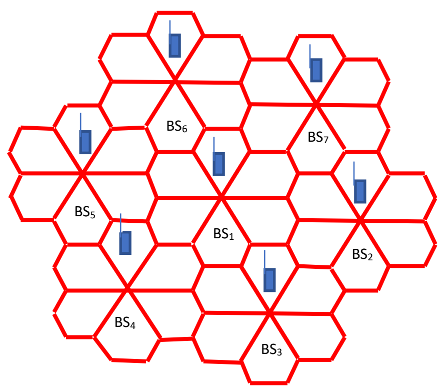

Fig-3. Cell Layout

In this research, Hata propagation model (COST-231) is used for calculating path loss is given by [15]

$$Path\ loss_{(dB)} = 35.2 + 35\log_{10}(d) + 26\log_{10}(f/2) \quad (25)$$

where d represents the distance(m) and f is the frequency in gigahertz. In this study, the carrier frequency f is set to 2.3 GHz, $C = 10^{-3.77}$ and $\mu = 3.5$.

Table 1 consists of some parameters which are taken into consideration for calculating the numerical result.

TABLE -1

VALUES IN NUMERICAL CALCULATION PARAMETERS

Frequency Band	2.3 GHz
Sector Bandwidth	15 MHz/sector
Total Subchannel	48
BS antenna gain	15 dBi
MS antenna gain	0 dBi
BS Noise Figure	5 dBi
Cell radius	250 m
Standard deviation of fading	8 dB
MS antenna height	32 m
BS antenna height	1.5 m

From the previous derivation, we must say outage probability is inversely related to the distance between MS and BS. Here we consider each sector is using a single subchannel and assume θa = 300. Fig 4 shows the plot of the outage probability and distance between BS to MS for different SINR requirements. The simulation result indicates that SINR 6 dB cell coverage is more than 250m, and the outage probability is also an acceptable level, but the signal quality is not so good. In the case of SINR 11.5 dB, the call quality is good, but the outage probability is more i.e. less coverage. The communication link has an increment in outage probability because of the interference from co-channel cells. So, an increment of outage probability indicates a reduction in cell coverage.

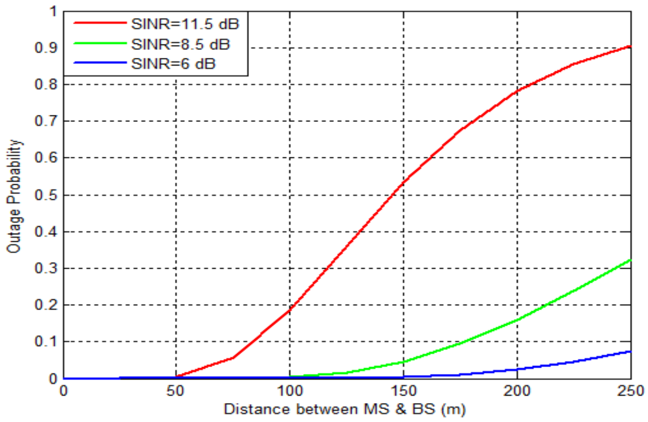

Fig-4. Outage probability versus Distance between MS & BS for different SINR.

The simulation results also indicate that for an interference-free environment, the user's equipment can produce SINR more than 15dB even at the cell boundary and then can achieve a higher throughput of 4 bps/Hz for downlink and 2 bps/Hz for uplink. The throughput of the link quality can be estimated and truncated from Shannon bound. The maximum throughput can be achieved by Shannon bound over the AWGN channel for a given SINR. According to the 3GPP TR 36.942 [10], the following equations approximate the throughput over a channel with a given SNR when using link adaption.

$$\text{Thr} = \begin{cases} 0, & \text{SINR} < \text{SINR}_{\min} \\ \alpha.\log_2(1+\text{SINR}), & \text{SINR}_{\min} < \text{SINR} < \text{SINR}_{\max} \\ \text{thr}_{\max}, & \text{SINR} > \text{SINR}_{\max} \end{cases} \tag{26}$$

Where α represents the attenuation factor. For uplink communications, α = 0.4 and for downlink, α = 0.6; $SINR_{min}$ = −15 dB; $SINR_{max}$ = +15 dB. Figure 5 also represents the theoretical Shannon bound: $log_2(1+SINR)$.

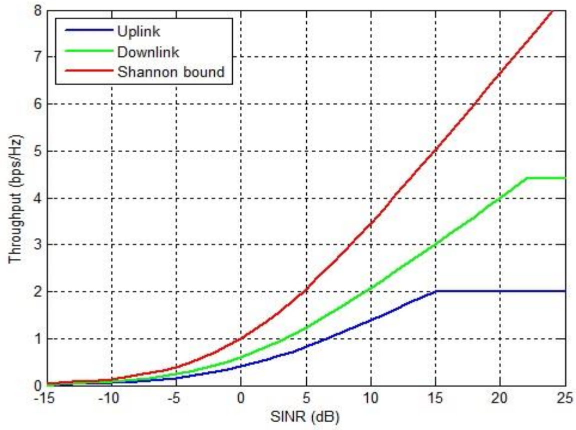

Fig-5 Baseline throughputs for adaptive modulation scheme.

For a large amount of data transmission, the mobile user needs more subchannels. In this situation, the CCI impacts will be more on service outage probability. Fig 6. Shows the impact of subchannel assigned to the mobile subscriber on the outage probability for SINR = 6 dB. Outage probability is exceeded the acceptable level when the mobile users need more subchannels for a large amount of data transmission.

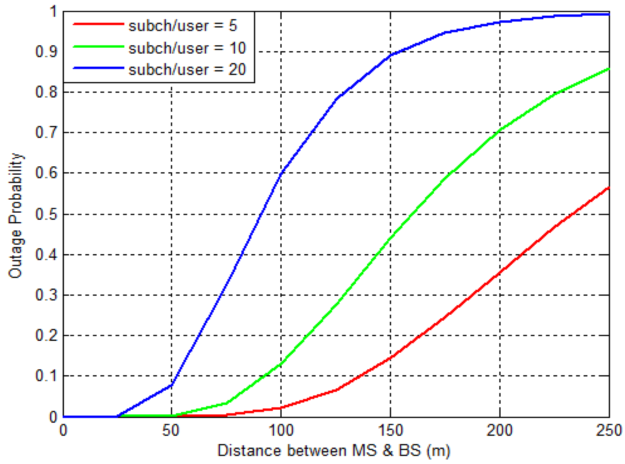

Fig-6. Outage probability versus Distance between MS & BS for different Subchannels.

For reliable uplink communication, the user equipment power is generally a dc power supplier, which significantly affects the call quality. Hence, it is not desirable for high-quality or long-distance communication. Fig 7. Shows the influence of handset power on outage probability with required SINR = 6dB. Here each user is assigned one subchannel. The simulation result suggests that the outage probability is decreased with an increase in supply power. From this graph, we can say that the cell coverage is about 240 m if supplied power is 1w.

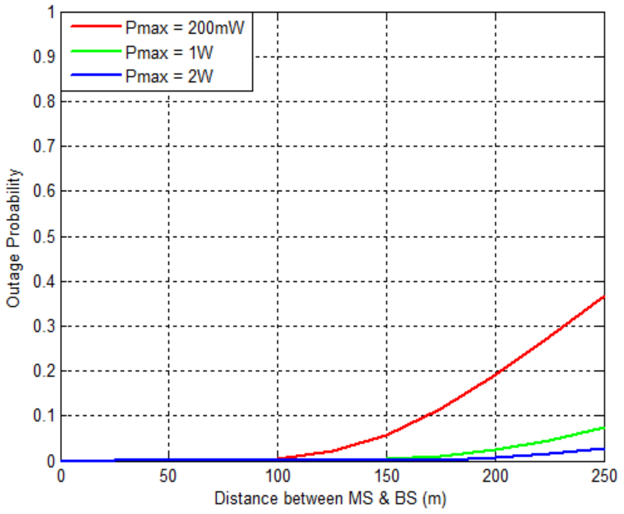

Fig-7. Outage probability versus Distance between MS & BS for different power.

Next, we study the effect of subchannels per user on cell coverage with their corresponding SINR requirement. Fig 8. Shows the impacts of subchannels per user and cell coverage in the presence of CCI, with handset power of 1W. The simulation result suggests that the increment of subchannels per user results in a decrease in cell coverage keeping SINR constant.

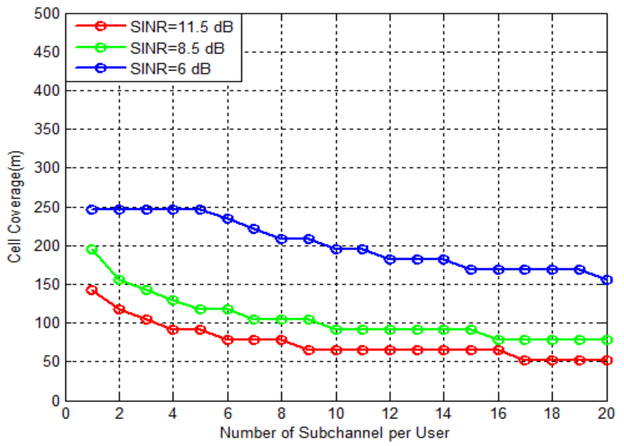

Fig-8. Cell Coverage versus Distance between MS & BS for different SINR.

4. CONCLUSION

In this research work, a system model is proposed to increase the system capacity and estimate uplink CCI in an IEEE 802.16m standard. By using six sector antenna design, we can improve the system capacity by more than 70 percent. This type of model can be used in highly dense area to accommodate large number of users with high internet connectivity. Shadow fading effect and random location of mobile user takes into account for calculating average interference power. Cell coverage area and outage probability are defined by keeping handset output power in a tolerable range. Through our proposed model, the health hazards radiation problems can be solved by limiting the power control provision. The simulation result suggests that we can support a high-quality link at a low power i.e. good battery lifetime. The simulation result also shows that an increment of outage probability can leads to a significant reduction in cell coverage due to uplink CCI.

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