Impact of Sectorization on the Minimum Cell Size for Information Capacity Increase in Cellular Wireless Network

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***Abstract*—In this paper results of mathematical analysis supported by simulation are used to study the impact of sectorization on the theoretical limit for cell size radius reduction in cellular wireless communication systems. Information capacity approach is used for the analysis. Attention is given to the active co-channel interfering cells. Because at microwave carrier frequencies greater than 2 GHz, co-channel interfering cells beyond the first tier becomes dominant as the cell size radius reduces. Results show that even for sectorized cellular wireless communication system operating at carrier frequency greater than 2 GHz and smaller cell size radius the second tier co-channel interference becomes active. Which causes a decrease in the information capacity of the cellular wireless system. For example at a carrier frequency f_c = 15.75 GHz, basic path loss exponent α = 2 and cell radius R = 100, 300 and 500 m for a six sector cellular the decrease in information capacity was 10, 7.43 and 6.24%.**

***Index Terms*—land mobile radio cellular system; radio propagation; spectrum efficiency; sectorization.**

I. Introduction

The frequency spectrum is an important parameter in the design and implementation of a wireless communication system. Because it is a limited resource and regulated by international agreements [1], [2]. Cellular wireless systems are partly used to achieve spectral efficiency and have been in operation since the late 1970's.

A high overall spectral efficiency is achieved at the frequency planning level by reducing the cell size radius [3]. Reducing cell size radius have caused cell sites to be installed in ever increasing densities [4]. However, Zhou et al. reported that there may be a limit to cell size radius reduction [5], because of an increase in co-channel interference. Since co-channel interference is one of the ultimate factors which determines the bit error rates (BER's) available to a user.

The rapid development of high-speed data rate wireless communication system by service providers and the need for high-bit-rate services at mobile terminals have spurred the use of broadband channels in wireless communication systems. Thus the UHF bands (900 and 1900 MHz) normally used for cellular wireless communication are not suitable for wireless broadband application. For broadband channels carrier frequency needs to be increased [6]. Therefore future and emerging cellular wireless communication systems beyond the third generation (B3G) will be accommodated at carrier frequencies above 2 GHz [6]–[8].

The free space path loss and the diffraction loss increase according to any increase in carrier frequency. Due to an increase in the path loss the cell size radius needs to be reduced to smaller radius. Thus co-channel interference becomes severe and more difficult to control in smaller cell size radius environment [6].

Numerous studies on cellular wireless communication systems have given ranges of maximum and minimum cell size radius for information capacity increase [5], [9]–[11]. Most of these studies to proceed analytically took into account co-channel interference from the first tier, assuming interference outside the first tier to be negligible. Because of the assumption of large path loss exponent [5].

The results from the work by Anang et al. have shown that at higher microwave carrier frequencies greater than 2 GHz co-channel interference outside the first tier (second tier) becomes active and reported that there is a theoretical limit to cell size radius reduction [12]. Sectorization of cells, however, was not included in the modelling. But for a given cluster size, sectorization yields two effects. It reduces co-channel interference. Because of the front-to-back ratio in antenna gain, the number of stations that are interfered with a particular base station (BS) is reduced. Thus signal-to-interference ratio (S/I) is improved. Sectorization divides the cells into smaller sectors. Since the allocated spectrum are now distributed into smaller sectors instead of a single cell, trunking efficiency is reduced [13]. The main contribution of this paper is as follows:

- We study the impact of cell sectorization on the information capacity of future and emerging cellular wireless systems, which will be operating at higher microwave carrier frequency greater than 2 GHz and smaller cell size radius, where first and second tier co-channel interference are active.

The rest of the paper is organised as follows. Section II describes the system models for propagation, secotrized co-channel interference, user distribution and outlines the basic assumptions used in the modeling. Section III focus on the spectral efficiency of the cellular wireless system used for our information capacity analysis. Section IV presents theoretical analysis and simulation results for the impact of cell sectorization on the information capacity. Finally, we conclude this paper in Section V.

II. Propagation and System Models

A two-dimensional hexagonal smaller cell size radius network is assumed where the BSs are uniformly distributed. Cells forms clusters (co-channel cell) around reference cells. BSs

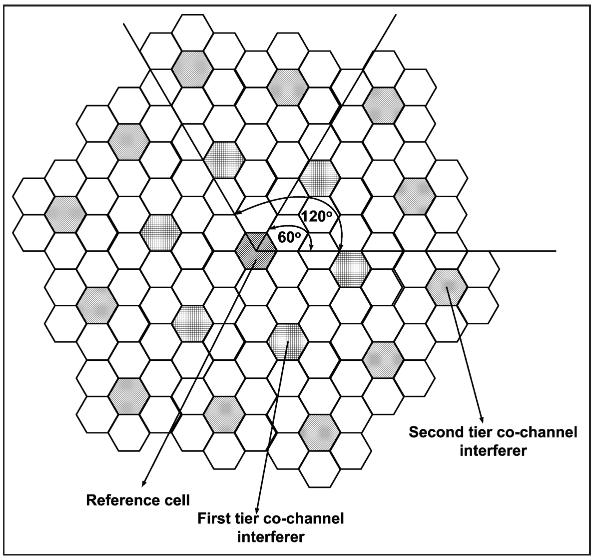

Fig. 1. Omnidirectional, secotorized cellular wireless communication systems showing first and second tier co-channel interferers.

located at the center of each cell receives signals from all users in the system which are attenuated according to the power-law path loss.

A. Users' Distribution

The cell shape is approximated by a circle of radius *R*, for mathematical convenience. It is assumed that all mobiles (desired and interfering users) are uniformly and independent distributed in their cells. Mobile stations (MSs') are also assumed to be located in the far field region. The probability distribution function (PDF) of a MS location relative to a BS in polar co-ordinate is given by

$$p_{r,\theta}\left(r,\theta\right)=\frac{(r-R_0)}{\pi(R-R_0)^2};\ R_0\leq r\leq R,\ 0\leq\theta\leq 2\pi. \quad (1)$$

where R_0 corresponds to the minimum distance the mobile can be from the BS antenna (to be in the far field region), which defines a small circular area around the MS to be kept free from interferes. A reasonable value around 20 m is recommended for smaller cell size radius systems.

B. Propagation Path Loss

The radio environment of a cellular system is described by: (1) path loss, (2) shadowing and (3) multipath fading. For purposes of this exploratory study, we make the simplifying assumption that shadowing and multipath fading is negligible.

This leaves one more item, that is the variation of averaged received power with distance. The analysis and simulation uses the two-slope path loss model [10], to obtain the average received power as function of distance. From this model the average received signal power P_r [W] is given by:

$$P_r=\frac{K}{r^{\alpha}(1+r/g)^{\rho}}P_t, \quad (2)$$

where *K* is the constant path loss factor, and it is the free space path loss at the reference distance r_0 = 1 m, r [m] is the distance between the BS and the MS, α is the basic path loss exponent (roughly 2), ρ is the additional path loss exponent (between 2-8) and P_t [W] is the transmitted signal power. The breakpoint distance g = 4 $h_b h_m/\lambda_c$, where λ_c is the carrier wavelength. BS antenna height h_b = 15 m, and MS antenna height h_m = 1.5 m. In this work the exact value of *K* and P_t is not required for the analysis. Therefore we assume *K* = 1, P_t = 1 and focus on the attenuation factor

$$P_r=r^{-\alpha}(1+r/g)^{-\rho}. \quad (3)$$

C. Sectorized Two Tier Co-channel Interference

The first and second tiers of co-channel interference are considered for interference generation. The desired mobile is located in the central cell and the interfering mobiles are in cells in the first and second tiers as shown in Fig. 1. To simplify the analysis the following assumptions have been made in the co-channel interference model. First the system is considered to be interference-limited, with thermal noise power negligible relative to the co-channel interference power [14]. Thus, the ratio of carrier to noise *CNR* reduces to the carrier-to-interference power ratio *CIR*. All inter-channel interference are considered to be negligible [14]. All BSs' are assumed to transmit the same power, and for simplicity we assume each cell to be circular shape.

From [12], for an omidirectional antenna cell site layout pattern the number of co-channel interfering cells in a given tier N_n is given by

$$N_n=N_I\times n;\ (n=1,2,3,4,\cdots) \quad (4)$$

where N_I is the number of interfering cells in the first tier and *n* is the nth tier number and it is always an integer. Now for sectorized cells (direction antennas), (4) is modified as follows:

$$N_n=\frac{N_I\times n}{S};\ (n=1,2,3,4,\cdots) \quad (5)$$

where *S* is the number of sectors in the cell. For omnidirectional cellular system, *S* = 1, for 120^o and 60^o sectorized cellular system *S* = 3 and 6.

Reference [15] stated that the uplink interference at a served BS is the non-coherent sum of interference signals from the user served by the BS and the users served by other BSs. Likewise the desired user *CIR*, γ, is defined as the ratio of averaged received signal power from a MS at a distance r [m] from the desired BS to the sum of interfering received signal power. Thus, the desired user *CIR*, γ, can be written as follows:

$$\gamma=\frac{P_d}{P_I}=\frac{P_d(r)}{\sum\limits_{i1=1}^{N_{I1}/S}P_{i1}(r_{i1})+\sum\limits_{i2=1}^{N_{I2}/S}P_{i2}(r_{i2})}. \quad (6)$$

where P_d [W], is the received power level of desired MS and P_I [W] is the power sum of individual interferers in tiers 1 and 2. N_{I1} and N_{I2} is the number of co-channel interfering cell in tiers 1 and 2 of an omnidirectional cellular system. For hexagonal cell site layout with cluster size N_c = 7, N_{I1} = 6 and N_{I2} = 12. P_{i1} and P_{i2} [W] is the average power level received from the ith interfering MSs' at distances r_{i1} and r_{i2} [m] from the desired BS.

III. Area Spectral Efficiency

The ultimate capacity of a land mobile radio system is directly related to its spectral efficiency [16]. The spectral efficiency of a cellular wireless system can be expressed in a number of ways such as number of channels per cell, Erlangs/km^2, number of users/km^2, etc. However in this paper, we adopted the definition suggested by [17]. This definition gives a more complete picture of the spectrum efficiency by expressing it in terms of capacity, bandwidth, and area. The area spectral efficiency (ASE) is defined as the achievable sum rate [bits/sec] (of all users in a cell) per unit bandwidth per unit area which is given by [17] as:

$$A_e = \frac{\sum_{k=1}^{N_s} C_k}{\pi W (D/2)^2} \tag{7}$$

where W is the total bandwidth allocated to each cell, D is the reuse distance, N_s is the total number of active serviced channels per cell. The achievable sum rate C_k is the Shannon capacity of the kth user, which depends on γ, the received carrier to interference power ratio *CIR* of that user, and W_k the bandwidth allocated to the user. The Shannon capacity formula assumes the interference has Gaussian characteristics. Because both the interference and signal power of the kth user vary with mobiles locations and propagation conditions, γ varies with time, therefore the average channel capacity of the kth user is given by [17] as

$$\langle C_k \rangle = W_k \int_0^{+\infty} log_2(1+\gamma)\ p_\gamma(\gamma)\ d\gamma, \tag{8}$$

where $p_\gamma(\gamma)$, is the probability distribution function (PDF) of the average mean *CIR* (γ) of the kth user.

The transmission rate is assumed to be continuously adapted relative to the *CIR* in such a manner that the *BER* goes to zero asymptotically. In (8) assuming that all users are assigned the same bandwidth, $\langle C_k \rangle = (\langle C \rangle)$ becomes the same for all users, therefore $\langle A_e \rangle$ can be written as

$$\langle A_e \rangle = \frac{4 N_s \langle C \rangle}{\pi W D^2} = \frac{4 N_s \langle C \rangle}{\pi W R_u^2 R^2}, \tag{9}$$

where R_u is defined as the *normalized reuse distance* and is given by the ratio of reuse distance and cell radius (*D/R*). For a TDMA system, the total bandwidth is allocated to only one active user per time slot (that is N = 1, W_k = W). Substituting this into (9) yields

$$\langle A_e \rangle = \frac{4}{\pi R_u^2 R^2} \int_0^{+\infty} log_2(1+\gamma)\ p_\gamma(\gamma)\ d\gamma. \tag{10}$$

IV. Sectorizied Impact Analysis

In this section, we compute the impact of sectorization on the information capacity of smaller cell size radius cellular wireless communication system operating at carrier frequency greater than 2 GHz, in the presence of first and second tier co-channel interference. The analysis applies to a TDMA (time-division multiple access) based cellular wireless system. Because it is the most representative of cellular wireless system. The analysis is based on fully loaded systems with fixed cluster size N_c = 7. Though there is an excessive demand to broadcast (downlink) high speed data in emerging communication services, because of space we confine our study on the uplink between a MS-to-BS.

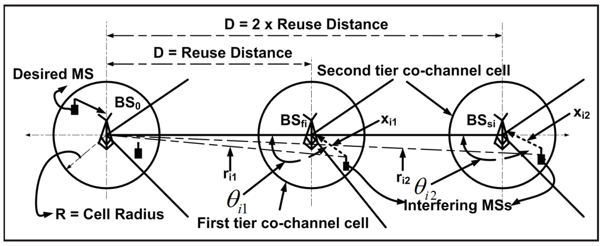

Fig. 2. Sectorized cellular system geometry of the desired and interfering mobile in two co-channel cells.

A. Analysis

Recall from section II-A; user are randomly located in their respective BSs', therefore γ is a random variable which depends on the random position of the user and the sums of interference from tier 1 and tier 2. Without power control the average-case interference configuration corresponds to the case where all the N_{I1} and N_{I2} co-channel interferes are at the center of their respectively BSs', at a distance r_{i1} = D [m] and r_{i2}= 2D [m] from the desired MS's as shown in Fig. 2. Note power control is essential for direct sequence CDMA systems. Assuming that the transmitted power of all users is the same and substituting (3) into (6) yields

$$\gamma(r, N_{I1}, N_{I2}) = \frac{P_d(r)}{\sum_{i1=1}^{N_{I1}/S} P_{i1}(r_{i1}) + \sum_{i2=1}^{N_{I2}/S} P_{i2}(r_{i2})}$$
$$= \frac{r^{-\alpha}(1+r/g)^{-\rho}}{\sum_{i1=1}^{N_{I1}/S} r_{i1}^{-\alpha}(1+r_{i1}/g)^{-\rho} + \sum_{i2=1}^{N_{I2}/S} r_{i2}^{-\alpha}(1+r_{i2}/g)^{-\rho}} =$$
$$\frac{r^{-\alpha}(1+r/g)^{-\rho}}{\sum_{i1=1}^{N_{I1}/S} \Upsilon^{-\alpha}(1+\Upsilon/g)^{-\rho} + \sum_{i2=1}^{N_{I2}/S} (2\Upsilon)^{-\alpha}(1+(2\Upsilon)/g)^{-\rho}}$$
$$= \left(\frac{2\Upsilon}{r}\right)^{\alpha} \cdot \left(\frac{g}{g+r}\right)^{\rho} \cdot$$
$$\left(\frac{S N_{I2}}{2^{\alpha} N_{I1} N_{I2} \left(\frac{g}{g+\Upsilon}\right)^{\rho} + \left(\frac{g}{g+2\Upsilon}\right)^{\rho}}\right), \tag{11}$$

where Υ is the product of R_u and R, R_u is the normalized reuse distance and R is the cell size radius. S is the number sectors in the cell. Because γ is a function of r, the desired user capacity is given by

$$\langle C(r, N_{I1}, N_{I2}) \rangle = W_o\ log_2(1 + \gamma(r, N_{I1}, N_{I2})), \tag{12}$$

Substituting (12) in (9) yields the ASE conditioned on the desired mobile position r, for a fully-loaded system. Integrating (12) over the desired user's position PDF (1) yields the

TABLE I
SIMULATION PARAMETERS

Parameter	Value
Type of system	omni, 3-sector and 6-sector
Cell radius, R	100 to 1000 m
Path loss exponent,(α),	2
Additional path loss exponent, (ρ)	2
Cluster size, N_c	7
BS antenna height, h_b	15 m [18]
MS antenna height, h_m	1.5 m [19]
Mobile Distribution	Uniform/Random
Number of co-channel tiers	2
Co-channel interferences	Random and first and second tiers
Frequency reuse factor, R_u	4 [17]
Frequencies, f_c	0.9, 2, 3.35, 8.45 and 15.75 GHz

average *ASE* for the average interference configuration as:

$$\langle A_e(r, N_{I1}, N_{I2})\rangle = \frac{4}{\pi R_u^2 R^2}\int_{R_0}^{R} log_2(1+\gamma)p_r(r)\ dr, \quad (13)$$

It is clear from (13), that the average ASE mainly depends on the mean *CIR*, which is a function of random locations of the MS. This makes the *ASE* mathematically intractable to solve. A computer simulation is therefore used to solve it.

B. Simulations

Monte Carlo simulation is used to estimate the $\langle A_e\rangle$. Because it appears to be mathematically intractable to explicitly solve analytically. The basic parameters used for the simulation are presented in Table I. In the simulation the desired user is randomly located, and uniformly distributed as described in subsection II-A of section II. When the desired user position is located the simulation algorithms is composed of the following steps:

1) The polar coordinates (x_{i1},θ_{i1}) and (x_{i2},θ_{i2}) of the N_{I1} and N_{I2} co-channel interferes are randomly picked according to (1).
2) From Fig. 2 (geometry for analysis) the distance r_{i1} for each co-channel interferer from tier 1 to the desired BS is calculated as.
$$r_{i1} = \sqrt{D^2 + x_{i1}^2 - 2\ D\ x_{i1}\cos(\theta_{i1})}. \quad (14)$$
3) The distance r_{i2} for each co-channel interferer from the second tier to the desired BS is calculated as.
$$r_{i2} = \sqrt{(2\ D)^2 + x_{i2}^2 - 4\ D\ x_{i2}\cos(\theta_{i2})}. \quad (15)$$
4) The two-slope path loss model (2), is used to calculate the average received signal power of the desired user and interfering mobiles in the first and second tier of co-channel cells (P_d, $P'_{i1}s$ and $P'_{i2}s$), therefore the *CIR* is calculated as.

$$\gamma = \frac{1}{r^{\alpha}(g+r)^{\rho}\left(\sum\limits_{r_{i1}=1}^{N_{I1}/S}\frac{1}{r_{i1}^{\alpha}(g+r_{i1})^{\rho}} + \sum\limits_{r_{i2}=1}^{N_{I2}S}\frac{1}{r_{i2}^{\alpha}(g+r_{i2})^{\rho}}\right)} \quad (16)$$

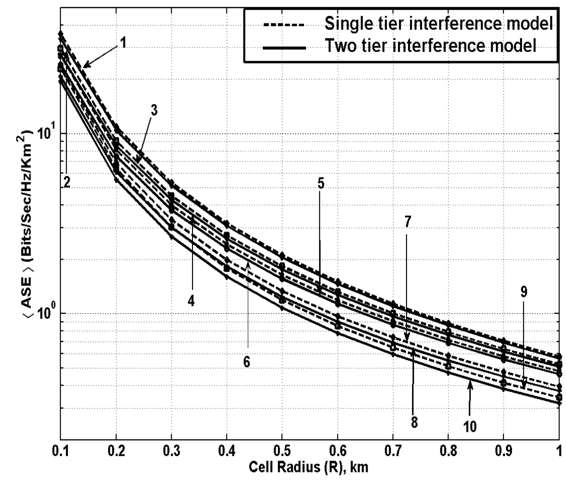

Fig. 3. Average uplink Area Spectral Efficiency (*ASE*) versus cell radius for omnidirectional cellular system at different carrier frequencies f_c. (Fully-loaded system with 6 and 12 co-channel interfering cells in first and second tier N_{I1} = 6 and N_{I2} = 12; basic and extra path loss exponent : α = 2 and ρ = 2; MS and BS antenna heights : h_m = 1.5 m and h_b = 15 m.)

1 Single tier interfering model (f_c = 900 MHz)
2 Two tier interfering model (f_c = 900 MHz)
3 Single tier interfering model (f_c = 2 GHz)
4 Two tier interfering model (f_c = 2 GHz)
5 Single tier interfering model (f_c = 3.35 GHz)
6 Two tier interfering model (f_c = 3.35 GHz)
7 Single tier interfering model (f_c = 8.45 GHz)
8 Two tier interfering model (f_c = 8.45 GHz)
9 Single tier interfering model (f_c = 15.75 GHz)
10 Two tier interfering model (f_c = 15.75 GHz)

5) The *ASE*, A_e is calculated as
$$\langle A_e\rangle = \frac{4}{\pi R_u^2 R^2}\log_2(1+\gamma_d). \quad (17)$$

Repeating the proceed above (from steps 1-5) 100 000 after locating the desired user position. $\langle A_e\rangle$ is estimated by taking the average of all the observations of A_e as given by (17).

TABLE II
DECREASE IN *ASE* BETWEEN THE TWO INTERFERENCE MODEL-OMNI-DIRECTIONAL CELLULAR SYSTEM

h_m = 1.5 m, h_b = 15 m and α = 2		
Cell Radius (m)	Carrier Frequency	Decrease in ASE (%)
0.1	900 MHz	6
	2 GHz	8.55
	3.35 GHz	10.5
	8.45 GHz	13.73
	15.75 GHz	15.3
0.3	900 MHz	3.7
	2 GHz	4.9
	3.35 GHz	6.15
	8.45 GHz	9.18
	15.75 GHz	11.39
0.5	900 MHz	3.17
	2 GHz	4.0
	3.35 GHz	4.88
	8.45 GHz	7.42
	15.75 GHz	9.42

C. Numerical and Simulations Results

Figures 3, 4 and 5 shows plot of *ASE* as a function of cell size radius for omni-directional, three sector and six sector cellular systems. The figures quantified the fact that sectorization reduces co-channel interference, thus improves *CIR*, which causes an increase in information capacity of the cellular wireless systems.

The curves in Fig. 3 show the plot for an omni-directional cellular system for different carrier frequency f_c, using the interference model presented in [17] and the model presented in this work (11). The curves show that when f_c = 900 GHz and R = 0.1 km the decrease in information capacity was 6%. Now for f_c = 2, 3.35, 8.45 and 15.75 GHz the decrease in information capacity was 8.55, 10.5, 13.73, and 15.31%. At R = 0.3 km for f_c = 0.9, 2, 3.35, 8.45 and 15.75 GHz the decrease in information capacity was 3.7, 4.9, 6.15, 9.18, and 11.39%. In the case of R = 0.5 km for f_c = 0.9, 2, 3.35, 8.45 and 15.75 GHz the decrease in information capacity was 3.17, 4.0, 4.88, 7.42 and 9.42%.

The curves in Fig. 4, show the case of a three sector cellular wireless communication system. The curves show that for f_c = 0.9, 2, 3.35, 8.45 and 15.75 GHz at cell radius R = 0.1 km, the decrease in the information capacity between the two interference model was 4.62, 6.51, 7.94, 10.36 and 11.56%. For 0.3 km at carrier frequencies f_c = 0.9, 2, 3.35, 8.45 and 15.75 GHz. The decrease in *ASE* was 3, 3.9, 4.81, 7.09 and 8.72%. For 0.5 m the decrease was 2.61, 3.22, 3.85, 5.62 and 7.28%. We can therefore conclude that for a three sector cellular wireless communication system as the carrier frequency increases and cell size radius reduces, second tier co-channel interference becomes severe.

The curves in Fig. 5, show the case of a six sector cellular wireless communication system. The curves show that for f_c = 0.9, 2, 3.35, 8.45 and 15.75 GHz at cell radius R = 0.1 km, the decrease in the information capacity between the two interference model was 4.02, 5.57, 6.77, 8.8 and 10%. For 0.3 km at carrier frequencies f_c = 0.9, 2, 3.35, 8.45 and 15.75 GHz. The decrease in *ASE* was 2.64, 3.4, 4.17, 6.05 and 7.43%. For 0.5 m the decrease was 2.32, 2.83, 3.35, 4.89 and 6.24%. We can therefore conclude that even for a six sector cellular wireless communication system as the carrier frequency increases and cell size radius reduces, second tier co-channel interference becomes severe. Tables II, III and IV show the results of percentage decrease in *ASE* between the two interference model; for different cellular network sectorization; carrier frequency f_c and cell size radii R: 100, 300 and 500 m. The result confirms the need to include second tier co-channel interference in the performance analysis of future and emerging cellular wireless communication systems.

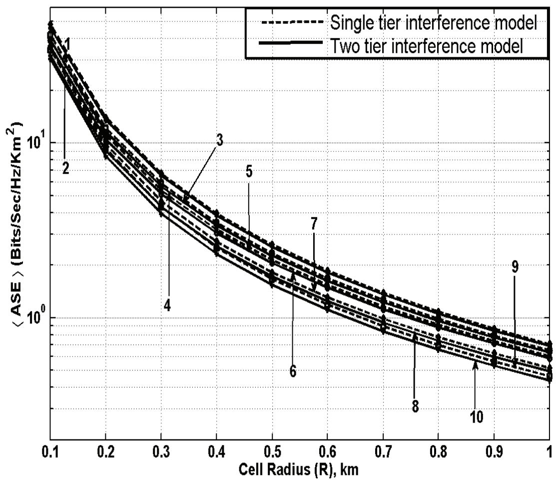

Fig. 4. Average uplink Area Spectral Efficiency (*ASE*) versus cell radius for three sector cellular system at different carrier frequencies f_c. (Fully-loaded system with 6 and 12 co-channel interfering cells in first and second tier N_{I1} = 6 and $N_{I2} = 12$; basic and extra path loss exponent : α = 2 and ρ = 2; MS and BS antenna heights : h_m = 1.5 m and h_b = 15 m.)

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8 Two tier interfering model (f_c = 8.45 GHz)
9 Single tier interfering model (f_c = 15.75 GHz)
10 Two tier interfering model (f_c = 15.75 GHz)

TABLE III
DECREASE IN *ASE* BETWEEN THE TWO INTERFERENCE MODEL-THREE-SECTOR CELLULAR SYSTEM

h_m = 1.5 m, h_b = 15 m and α = 2		
Cell Radius (m)	Carrier Frequency	Decrease in ASE (%)
0.1	900 MHz	4.62
	2 GHz	6.51
	3.35 GHz	7.94
	8.45 GHz	10.36
	15.75 GHz	11.56
0.3	900 MHz	3
	2 GHz	3.9
	3.35 GHz	4.81
	8.45 GHz	7.09
	15.75 GHz	8.27
0.5	900 MHz	2.61
	2 GHz	3.22
	3.35 GHz	3.85
	8.45 GHz	5.62
	15.75 GHz	7.28

V. CONCLUSION

In this paper, because of the importance of co-channel interference on the information capacity performance of a cellular wireless communication system, we have showed that even for sectorized cellular wireless communication system operating at microwave carrier frequency greater than 2 GHz and smaller cell size radius some of the second tier co-channel interference becomes dominant. Therefore second tier co-channel interference need to be considered in the design of emerging and future sectorized cellular wireless communication systems. Future work will focus on including multiple tiers of co-channel interfering cells, correlation coefficient and multipath fading. In future we will also use more realistic propagation and system model's scenario in terms of user's distribution

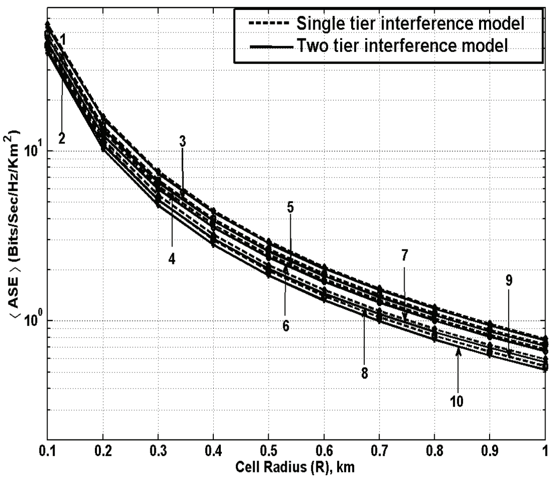

Fig. 5. Average uplink Area Spectral Efficiency (*ASE*) versus cell radius for six sector cellular system at different carrier frequencies f_c. (Fully-loaded system with 6 and 12 co-channel interfering cells in first and second tier N_{I1} = 6 and N_{I2} = 12; basic and extra path loss exponent : α = 2 and ρ = 2; MS and BS antenna heights : h_m = 1.5 m and h_b = 15 m.)

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8 Two tier interfering model (f_c = 8.45 GHz)
9 Single tier interfering model (f_c = 15.75 GHz)
10 Two tier interfering model (f_c = 15.75 GHz)

and radio environment.

TABLE IV
DECREASE IN *ASE* BETWEEN THE TWO INTERFERENCE MODEL-SIX-SECTOR CELLULAR SYSTEM

h_m = 1.5 m, h_b = 15 m and α = 2		
Cell Radius (m)	Carrier Frequency	Decrease in ASE (%)
0.1	900 MHz	4.02
	2 GHz	5.57
	3.35 GHz	6.77
	8.45 GHz	8.80
	15.75 GHz	10
0.3	900 MHz	2.64
	2 GHz	3.4
	3.35 GHz	4.17
	8.45 GHz	6.05
	15.75 GHz	7.43
0.5	900 MHz	2.32
	2 GHz	2.83
	3.35 GHz	3.35
	8.45 GHz	4.89
	15.75 GHz	6.24

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