Impact of Sectorization/Vehicular Traffic on Minimum Cell Size for Information Capacity Increase in Cellular Systems

Kwashie A. Anang, Predrag B. Rapajic, and Ruiheng Wu

Abstract—**In this paper results of mathematical analysis supported by simulation are used to study the impact of sectorization/vehicular traffic 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 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 for sectorized cellular wireless communication system operating at carrier frequency greater than 2 GHz and having smaller cell size radius in a traffic environment the second tier co-channel interference still becomes active. This causes a decrease in the information capacity of the cellular wireless system. For example for a heavy vehicular traffic environment, 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, because of interference from the second tier was 5.47, 3.36 and 2.78%.**

Index Terms—**Breakpoint distance, land mobile radio cellularsystem, radio propagation, spectrum efficiency, sectorization.**

Original Research Paper
DOI: 10.7251/ELS1317021A

I. INTRODUCTION

THE radio frequency spectrum is an important parameter in the design and implementation of a wireless communication system. Because it is limited and regulated by international agreements [1], [2]. Cellular wireless systems are therefore 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 has 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 (BERs) 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 greater than 2 GHz [6]–[8].

Increasing carrier frequency leads to an increase in free space path loss and diffraction loss. An increase in the path loss means cell size radius needs to be reduced to smaller radius. For smaller cell size radius cellular system co-channel interference becomes severe and more difficult to control [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].

Results from a study by Anang et al. shows that at higher microwave carrier frequencies greater than 2 GHz co-channel interference outside the first tier, (second tier) becomes active and it was reported that there is a theoretical limit to cell size radius reduction [12]. However, the study was for a non-sectorized cellular wireless system. A study on the impact of vehicular traffic on the information capacity of a non-sectorized cellular wireless system, operating at carrier frequencies greater than 3 GHz was presented in [13]. The impact of cell sectorization on the information capacity of cellular wireless networks was presented in [14], without the inclusion of the effect of vehicular traffic. However, at higher carrier frequencies and smaller cell size radius; vehicles, pedestrians and other objects on the road affect the

Manuscript received 10 April 2013. Accepted for publication 7 May 2013.
This is an expanded version of work presented at the IX International Symposium Industrial Electronics INDEL 2012, Banja Luka, Bosnia and Herzegovina, November 2012 and at the 5th IEEE European Symposium on Computer Modeling and Simulation EMS 2011, Madrid, Spain, November 2011.
K. A. Anang, P. B. Rapajic and R. Wu are with the Wireless and Mobile Communication Research Centre, School of Engineering, University of Greenwich, Chatham Maritime, ME4 4TB, UK, Fax : +44-(0)-1634-883153. The corresponding author, K. A. Anang can be reached on Tel: +44-(0)-1634-883873, and E-mail: k.anang@gre.ac.uk.

information capacity performance of cellular wireless systems [7]. Therefore, the main contribution of this paper is as follows:

- We study the impact of cell sectorization on the information capacity performance 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 dominant.
- We study the impact of cell sectorization/vehicular traffic 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/vehicular traffic 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 form clusters (co-channel cell) around reference cells. BSs located at the center of each cell receive signals from all users in the system which is 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 (Ms) 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

$$\rho_{r,\theta}(r,\theta) = \frac{(r-R_0)}{\pi(R-R_0)^2}; R_0 \le r \le R, 0 \le \theta \le 2\pi\ , \tag{1}$$

where R_0 corresponds to the minimum distance a 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 the purposes of this study, we make the simplifying assumption that shadowing and multipath fading is negligible. That is leaving only 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:

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

where K is the constant path loss factor, and it is the free space path loss at a reference distance r_0 = 1 m, r [m] is the distance between BS and MS. α is the basic path loss exponent (roughly 2), ρ is the additional path loss exponent (between 2-8). 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

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

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 [15]. Therefore, the ratio of carrier to noise CNR reduces to the carrier-to-interference power ratio CIR. All inter-channel interference is considered to be negligible [15]. All BSs are assumed to transmit the same power, and for simplicity we assume each cell to be circular shape.

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

$$N_n = N_I \times n; (n = 1,2,3,4,...)\ , \tag{4}$$

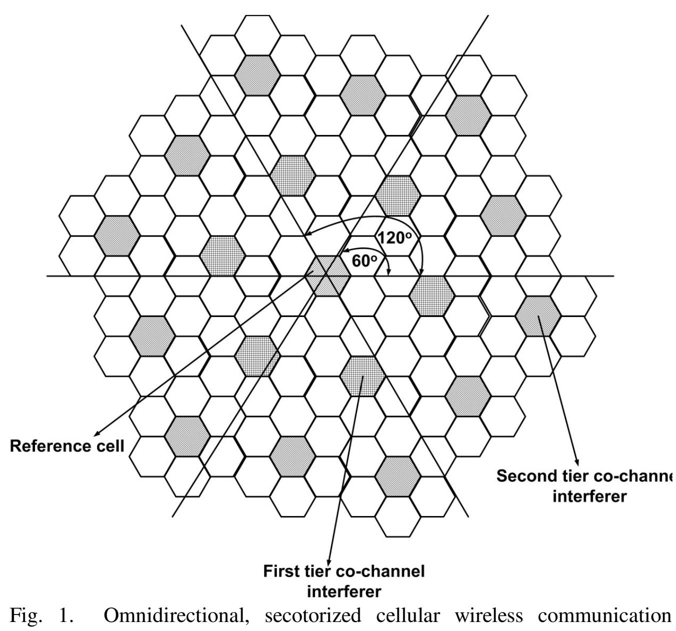

Fig. 1. Omnidirectional, secotorized cellular wireless communication systems showing first and second tier co-channel interferers.

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:

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

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

Reference [16] 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. Therefore, the desired user CIR, γ, can be written as follows:

$$\gamma = \frac{P_d}{P_I} = \frac{P_d(r)}{\sum_{i1=1}^{N_{I1}/S} P_{i1}(r_{i1}) + \sum_{i2=1}^{N_{I2}/S} P_{i2}(r_{i2})}, \tag{6}$$

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 [17]. 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, the number of users/km^2, etc. However in this paper, we adopted the definition suggested by [18]. 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 [18] 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 [18] 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 $CIR(\gamma)$ 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. Sectorized Impact Analysis

In this section, we analyse the impact of sectorization on the information capacity performance of smaller cell size radius cellular 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 broad-cast, (downlink) high speed data in emerging communication services, because of space we confine our study on the uplink between a MS-to-BS.

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 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 distances r_{i1} = D [m] and r_{i2} = $2D$ [m]

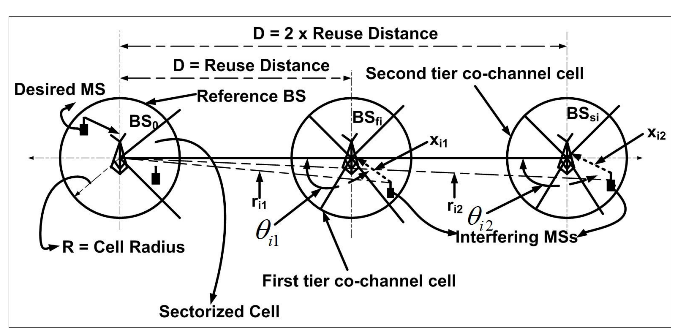

Fig. 2. Sectorized cellular system geometry of the desired and interfering mobile in two co-channel cells.

from the desired MS's as shown in Fig. 2. Note power control is essential for direct sequence CDMA systems; therefore we did not consider it in our analysis. Assuming that the transmitted power of all users is the same and substituting (3) into (6) yields

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

where τ 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 of sectors in the cell. Because γ is a function of r, the desired user capacity is given by

$$\langle C(r, N_{I1}, N_{I2})\rangle = W_0 \log_2(1+\gamma(r, N_{I1}, N_{I2})). \quad (12)$$

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

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

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 $\langle A_e\rangle$, because it appears to be mathematically intractable to explicitly solve analytically. Fig. 3 shows a simulation flowchart for the ASE of a sectorized cellular system, and 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:

TABLE I
SIMULATION PARAMETERS

Parameter	Value
Type of system	omni, 3-sector and 6-sector
Cell radius, R	100 to 1000 m
Effective road height, h	0.23 and 1.3 m [7], [19]
Path loss exponent,(α),	2
Additional path loss exponent, (ρ)	2
Cluster size, N_C	7
BS antenna height, h_B	15 m [19]
MS antenna height, h_M	1.5 m [20]
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 [18]
Frequencies, f_C	0.9, 2, 3.35, 8.45 and 15.75 GHz

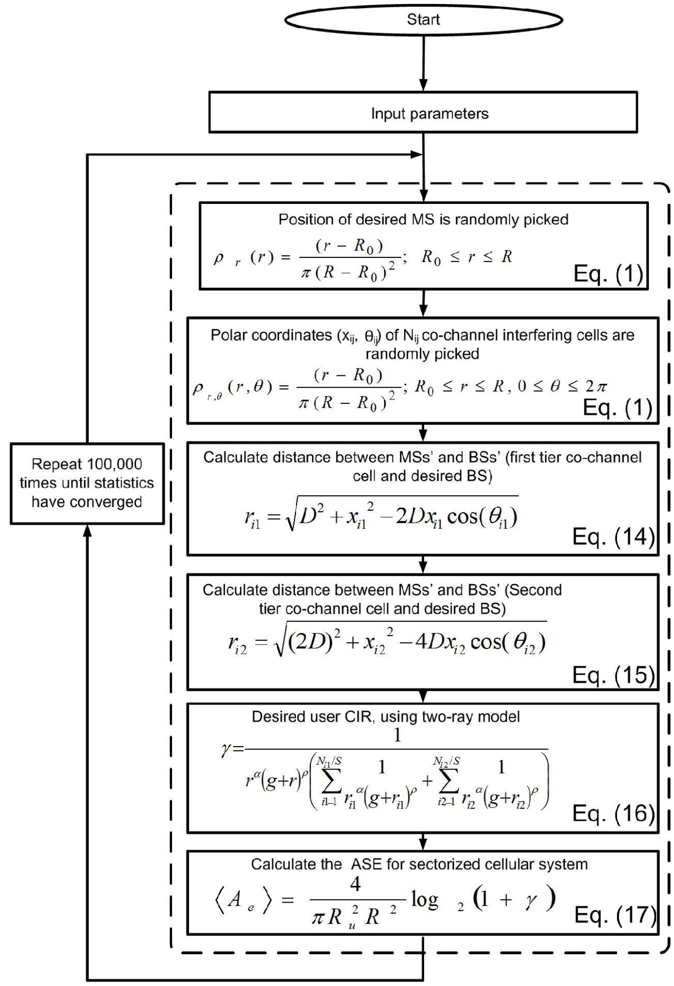

Fig. 3. Flowchart for sectorized cellular system area spectrum efficiency simulation.

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

$$r_{i1} = \sqrt{D^2 + x_{i1}^2 - 2Dx_{i1}\cos(\theta_{i1})}. \quad (14)$$

3) The distance r_{i2} for each co-channel interferer from the second tier to the desired BS is calculated as

$$r_{i2} = \sqrt{(2D)^2 + x_{i2}^2 - 4Dx_{i2}\cos(\theta_{i2})}. \quad (15)$$

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

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

5) The ASE, A_e is calculated as

$$\langle A_e \rangle = \frac{4}{\pi R_u^2 R^2} \log_2(1+\gamma). \quad (17)$$

Repeating the proceed above (from steps 1-5) 100000 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).

C. Numerical and Simulations Results

Figs. 4, 5 and 6 show plot of ASE as a function of cell size radius for omni-directional, three sectors 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. 4 show the plot for an omni-directional cellular system for different carrier frequency f_c, using the interference model presented in [18], 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, 8.45and 15.75 GHz, the decrease in information capacity was 3.17, 4.0, 4.88, 7.42 and 9.42%.

The curves in Fig. 5 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,

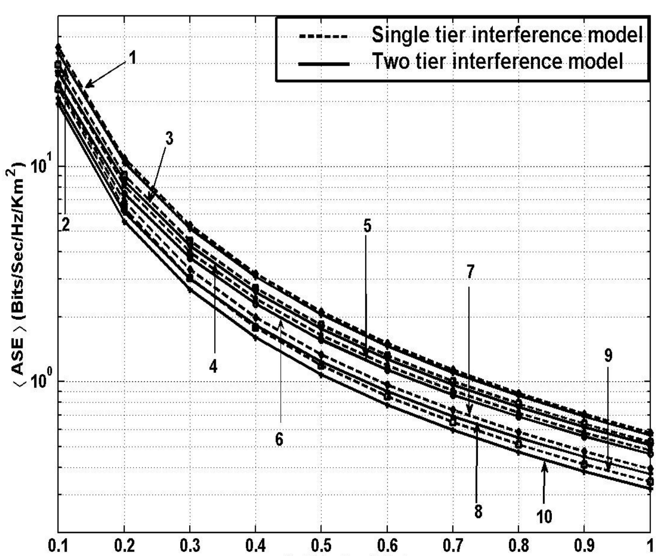

Fig. 4. Average uplink Area Spectral Efficiency (ASE) versus cell radius for omnidirectional cellular system at different carrier frequencies f_c. (Fully-loaded system with 6 and 12 co-channel interfering cells in first and second tier N_{I1} = 6 and N_{I2} = 12; basic and extra path loss exponent: α = 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).

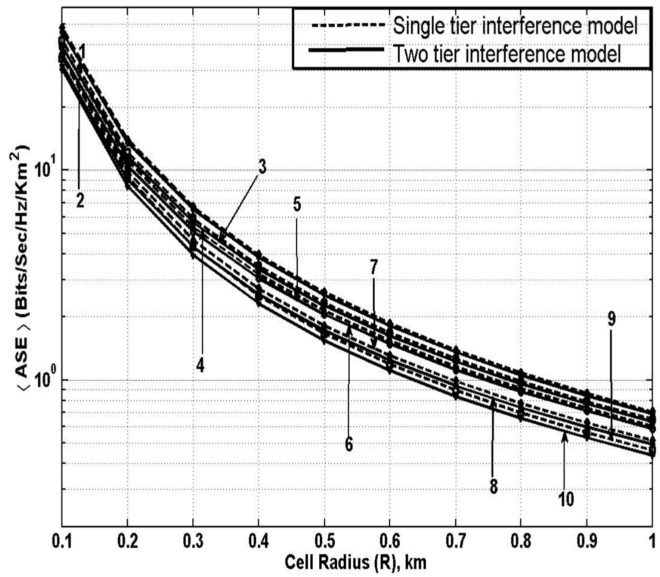

Fig. 5. Average uplink Area Spectral Efficiency (ASE) versus cell radius for three sector cellular system at different carrier frequencies f_c. (Fully-loaded system with 6 and 12 co-channel interfering cells in first and second tier N_{I1} = 6 and N_{I2} = 12; basic and extra path loss exponent: α =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

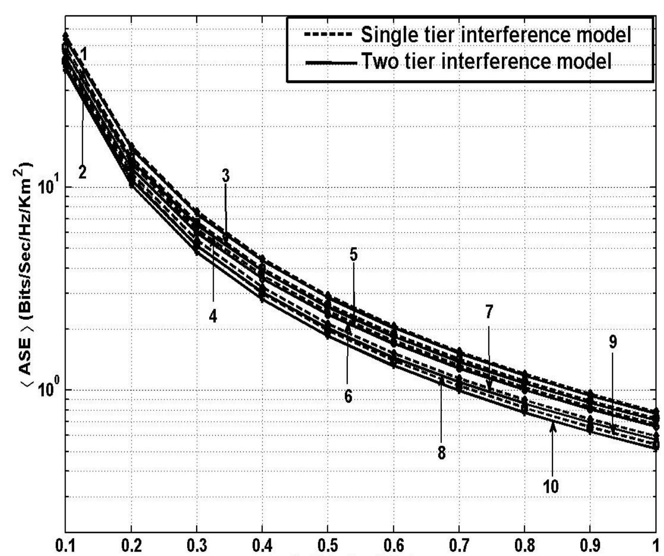

Fig. 6. Average uplink Area Spectral Efficiency (ASE) versus cell radius for six sector cellular system at different carrier frequencies f_c. (Fully-loaded system with 6 and 12 co-channel interfering cells in first and second tier N_{I1} = 6 and N_{I2} = 12; basic and extra path loss exponent: α = 2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

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. 6 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 conclude that for a sectorized cellular wireless communication system as the carrier frequency increases and cell size radius reduces, second tier co-channel interference becomes dominant. Tables II, III and IV show the results of percentage decrease in ASE between the two interference models; for different cellular network sectorization; carrier frequency f_c and cell size radii R: 0.1, 0.3 and 0.5 km.

D. *Combined Effect of Sectorization and Vehicular Traffic*

In this section, we consider the ASE of a fully loaded sectorized cellular system in a light/heavy vehicular traffic environment, by including effective road height in the two-slope path loss model. This is the scenario for an urban line-of-sight (LOS) environment, when carrier frequencies are greater than 2 GHz.

1) Analyses-Modified Breakpoint Distance: The modified breakpoint distance proposed by Masui et al. [7], is incorporated into the system model, (that is the path loss model), for the study of impact of vehicular traffic on the information capacity performance of a sectorized cellular wireless system. The modified breakpoint distance g_m is given by [7], as

TABLE II
DECREASE IN ASE BETWEEN THE TWO INTERFERENCE MODEL: OMNIDIRECTIONAL CELLULAR SYSTEM
h_m = 1.5 m, h_b = 15 m and α = 2

Cell Radius (km)	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

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 (km)	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

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 (km)	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

$$g_m = \frac{4(h_b - h)\times(h_m - h)}{\lambda_c}, h < h_m, \tag{18}$$

where h is the effective road height, which is due to vehicles, pedestrians and other objects on the road. Now, h depends on the average height of traffic on the road, which is the average height of vehicles and pedestrians height on the road [7]. For light vehicular traffic the value of h is between 0.23 and 0.74 m, and for heavy vehicular traffic, it is between 1.29 and 1.64 m [19].

For the simulation of the combine effect of sectorization and vehicular traffic on the information capacity performance of the cellular wireless system, step 4) of the algorithm described in Section IV-B is changed as follows to incorporate the modified breakpoint.

$$\gamma = \frac{1}{r^{\alpha}(g+r)^{\rho}\left(\sum_{i1=1}^{N_{I1}/S}\frac{1}{r_{i1}^{\alpha}(g_m + r_{i1})^{\rho}} + \sum_{i2=1}^{N_{I2}/S}\frac{1}{r_{i2}^{\alpha}(g_m + r_{i2})^{\rho}}\right)} \tag{19}$$

E. *Simulations Results – Sectorized/Vehicular Traffic*

The combined effect of sectorization and vehicular traffic on the ASE of a smaller cell size radius cellular system, operating at different carrier frequencies f_c is shown in Figs. 7-10. The results show that the ASE curves conserve the same relative shape as Figs. 5 and 6. Comparing the figures, it can be seen that both secotrized cellular systems operating in traffic environment have higher area spectrum efficiency than the secotrized cellular systems when there is no traffic.

The ASE of a three sector cellular system for light and heavy vehicular traffic is shown in Figs. 7 and 8. The curves show that for light vehicular traffic, and carrier frequencies $f_c = 0.9$, 2, 3.35, 8.45 and 15.75 GHz, at cell size radius $R = 0.1$ km, the decrease in the information capacity between the two interference models was 4.29, 6.02, 7.42, 9.94 and 11.26%. For 0.3 km, the decrease in the information capacity between the two interference models was 2.82, 3.63, 4.44, 6.56 and 8.22%, and for 0.5 km, it was 2.51, 3.00, 3.59, 5.19 and 6.82%.

From the three sector and heavy vehicular traffic result, the decrease in information capacity between the two interference models for carrier frequencies f_c = 0.9, 2, 3.35, 8.45 and 15.75 GHz at cell size radius R = 0.1 km, is 2.55, 2.97, 3.45, 4.91 and 6.40%. For 0.3 km, it is 2.15, 2.30, 2.49, 3.10 and 3.81%. For 0.5 km, the decrease was 1.91, 2.17, 2.27, 2.69 and 3.16%. These results are tabulated in Table V and VI.

The ASE of a six sector cellular system in a light and heavy vehicular traffic environment is shown in Figs. 9 and 10. The curves show that for light vehicular traffic, and carrier frequencies f_c = 0.9, 2, 3.35, 8.45 and 15.75 GHz, at cell size

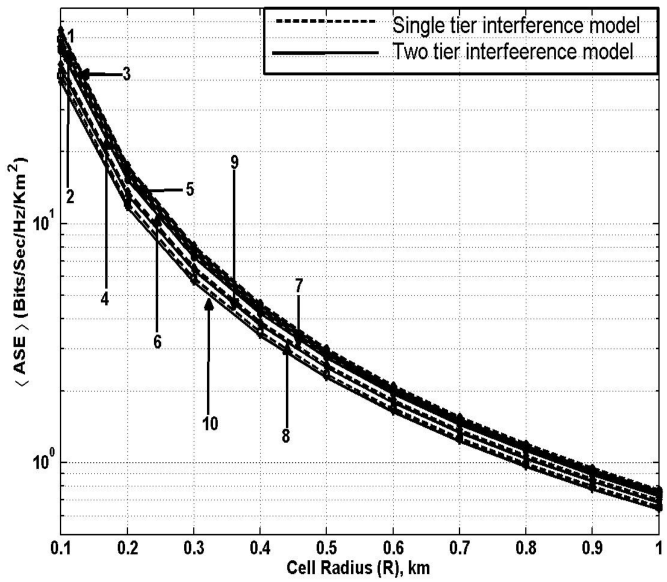

Fig. 8. Average uplink Area Spectral Efficiency (ASE) versus cell radius for three sector cellular system and heavy vehicular traffic at different carrier frequencies f_c. (Fully-loaded system with 6 and 12 co-channel interfering cells in first and second tier N_{I1} = 6 and N_{I2}= 12; basic and extra path loss exponent: α = 2 and ρ = 2; MS and BS antenna heights: h_m = 1.5 m and h_b = 15 m; effective road height h = 1.3 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).

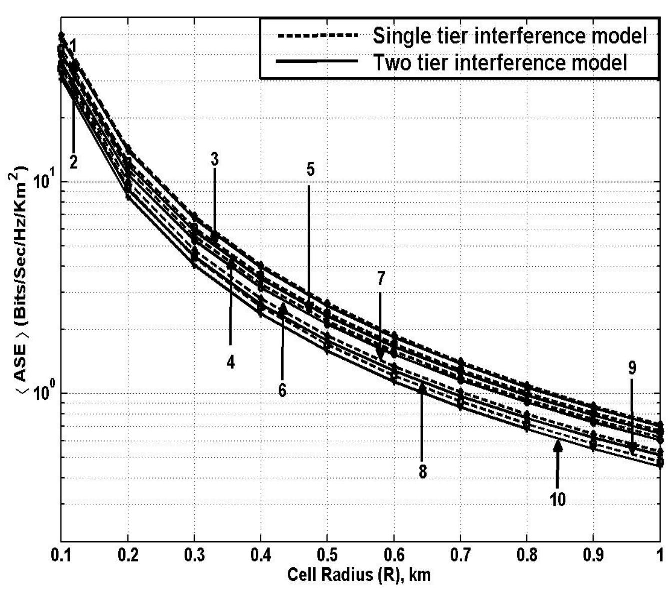

Fig. 7. Average uplink Area Spectral Efficiency (ASE) versus cell radius for three sector cellular system and light vehicular traffic at different carrier frequencies f_c. (Fully-loaded system with 6 and 12 co-channel interfering cells in first and second tier N_{I1} = 6 and N_{I2}= 12; basic and extra path loss exponent: α = 2 and ρ = 2; MS and BS antenna heights: h_m = 1.5 m and h_b = 15 m; effective road height h = 0.23 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).

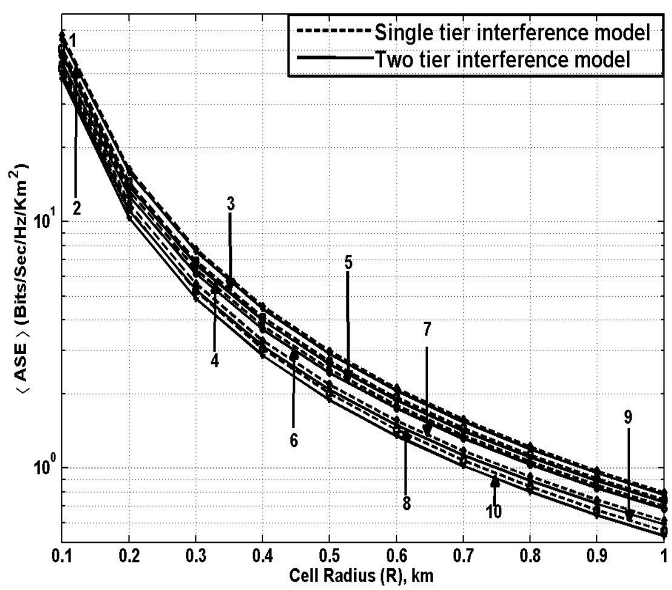

Fig. 9. Average uplink Area Spectral Efficiency (ASE) versus cell radius for six sector cellular system at different carrier frequencies f_c. (Fully-loaded system with 6 and 12 co-channel interfering cells in first and second tier N_{I1} = 6 and N_{I2} = 12; basic and extra path loss exponent: α = 2 and ρ = 2; MS and BS antenna heights: h_m = 1.5 m and h_b = 15 m; effective road height h = 0.23 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).

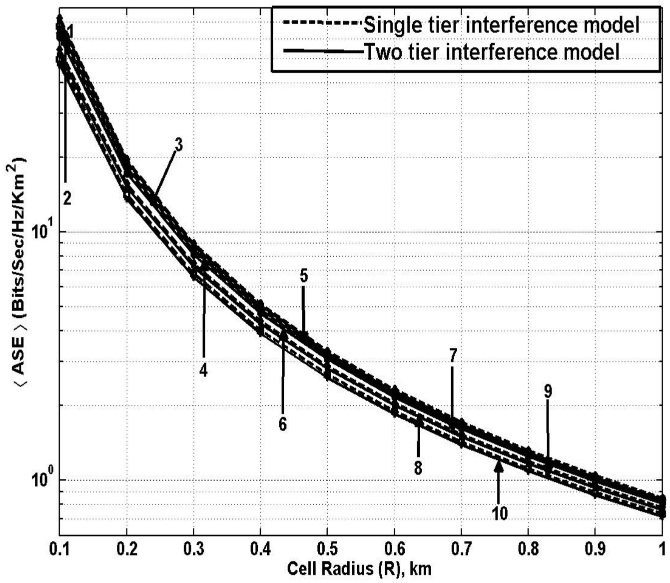

Fig. 10. Average uplink Area Spectral Efficiency (ASE) versus cell radius for six sector cellular system at different carrier frequencies f_c. (Fully-loaded system with 6 and 12 co-channel interfering cells in first and second tier N_{I1} = 6 and N_{I2} = 12; basic and extra path loss exponent: α = 2 and ρ = 2; MS and BS antenna heights: h_m = 1.5 m and h_b = 15 m; effective road height h = 1.3 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).

radius R = 0.1 km, the decrease in the information capacity between the two interference models was 3.73, 5.17, 6.33, 8.45 and 9.53%. For 0.3 km, the decrease in the information capacity between the two interference model was 2.52, 3.19, 3.82, 5.66 and 7.05%, and for 0.5 km, it was 2.25, 2.69, 3.14, 4.54 and 5.87%.

For the six sector and heavy vehicular traffic the decrease in information capacity between the two interference models for carrier frequencies f_c = 0.9, 2, 3.35, 8.45 and 15.75 GHz, at cell size radius R = 0.1 km, is 2.29, 2.65, 3.03, 4.24 and 5.47%. For 0.3 km, the decrease in the information capacity

TABLE V
DECREASE IN ASE BETWEEN THE TWO INTERFERENCE MODEL: THREE-SECTOR CELLULAR SYSTEM/LIGHT VEHICULAR TRAFFIC
h_m = 1.5 m, h_b = 15 m, h = 0.23 m and α = 2

Cell Radius (km)	Carrier Frequency	Decrease in ASE (%)
0.1	900 MHz	4.31
	2 GHz	6.02
	3.35 GHz	7.42
	8.45 GHz	10
	15.75 GHz	11.24
0.3	900 MHz	2.84
	2 GHz	3.64
	3.35 GHz	4.46
	8.45 GHz	6.56
	15.75 GHz	8.23
0.5	900 MHz	2.48
	2 GHz	3.00
	3.35 GHz	3.59
	8.45 GHz	5.19
	15.75 GHz	6.76

TABLE VI
DECREASE IN ASE BETWEEN THE TWO INTERFERENCE MODEL: THREE-SECTOR CELLULAR SYSTEM/HEAVY VEHICULAR TRAFFIC
h_m = 1.5 m, h_b = 15 m, h = 1.3 m and α = 2

Cell Radius (km)	Carrier Frequency	Decrease in ASE (%)
0.1	900 MHz	2.55
	2 GHz	2.97
	3.35 GHz	3.45
	8.45 GHz	4.91
	15.75 GHz	6.40
0.3	900 MHz	2.15
	2 GHz	2.30
	3.35 GHz	2.49
	8.45 GHz	3.10
	15.75 GHz	3.81
0.5	900 MHz	1.91
	2 GHz	2.17
	3.35 GHz	3.55
	8.45 GHz	2.69
	15.75 GHz	3.16

TABLE VII
DECREASE IN ASE BETWEEN THE TWO INTERFERENCE MODEL: SIX-SECTOR CELLULAR SYSTEM/LIGHT VEHICULAR TRAFFIC
h_m = 1.5 m, h_b = 15 m, h = 0.23 m and α = 2

Cell Radius (km)	Carrier Frequency	Decrease in ASE (%)
0.1	900 MHz	3.73
	2 GHz	5.17
	3.35 GHz	6.33
	8.45 GHz	8.45
	15.75 GHz	9.53
0.3	900 MHz	2.52
	2 GHz	3.19
	3.35 GHz	3.82
	8.45 GHz	5.66
	15.75 GHz	7.05
0.5	900 MHz	2.25
	2 GHz	2.69
	3.35 GHz	3.14
	8.45 GHz	4.54
	15.75 GHz	5.87

between the two interference model was 2.0, 2.08, 2.23, 2.78 and 3.36%, and at 0.5 km, it was 1.87, 2.0, 2.07, 2.39 and 2.78%. These results are tabulated in Table VII and VIII.

From these results, we can conclude that, for a sectorized cellular system, operating at higher carrier frequency and having smaller cell size radius in a traffic environment, the second tier co-channel interference still becomes dominant. The result confirms the need to include second tier co-channel interference in the information capacity performance analysis of future and emerging cellular wireless communication systems. We can also conclude that the presence of vehicles and pedestrians in the environment tends to mitigate the severity of the co-channel interference.

V. CONCLUSION

In this paper, because of the importance of co-channel interference on the information capacity performance of cellular system, we have shown that even for sectorized cellular wireless system operating at carrier frequency greater than 2 GHz and smaller cell size radius, in a traffic environment second tier co-channel interference still becomes dominant. Therefore there is a need to include second tier co-channel interference in the design and system model of

TABLE VIII
DECREASE IN ASE BETWEEN THE TWO INTERFERENCE MODEL: THREE-SECTOR CELLULAR SYSTEM/HEAVY VEHICULAR TRAFFIC
h_m = 1.5 m, h_b = 15 m, h = 1.3 m and α = 2

Cell Radius (km)	Carrier Frequency	Decrease in ASE (%)
0.1	900 MHz	2.29
	2 GHz	2.65
	3.35 GHz	3.03
	8.45 GHz	4.24
	15.75 GHz	5.47
0.3	900 MHz	2.0
	2 GHz	2.08
	3.35 GHz	2.23
	8.45 GHz	2.78
	15.75 GHz	3.36
0.5	900 MHz	1.87
	2 GHz	2.0
	3.35 GHz	2.07
	8.45 GHz	2.39
	15.75 GHz	2.78

emerging and future cellular wireless communication systems. Future work will focus on including multiple tiers of co-channel interfering cells, correlation coefficient, shadowing and multipath fading. In future we will also use more realistic propagation and system model's scenario in terms of user's distribution and radio environment.

REFERENCES

[1] W. C. Y. Lee, “Spectrum efficiency in cellular,” IEEE Trans. Veh.Technol., vol. 38, pp. 69–75, May 1989.
[2] K. Pahlavan and A. H. Levesque, “Wireless data communication,” proc.ieee, vol. 82, pp. 1398–1430, Sept. 1994.
[3] Y. Yao and A. U. H. Sheikh, “Investigations into co-channel interference in microcellular mobile radio systems,” IEEE Trans. Veh. Technol., vol. 41, no. 2, pp. 114–121, May 1992.
[4] T. K. Sarkar, Z. Ji, K. Kim, A. Medouri, and M. Salazar-palma, “A survey of various propagation models for mobile communication,” IEEETrans. Antennas Propagat., vol. 45, pp. 51–74, Jun. 2003.
[5] S. Zhou, M. Zhao, X. Xu, J. Wang, and Y. Yao, “Distributed wireless communication system: a new architecture for future public wireless access,” IEEE Commun. Mag., vol. 41, pp. 108–113, 2003.
[6] J. Takada, J. Fu, H. Zhu, and T. Kobayashi, “Spatio-temporal channel characterization in a suburban non line-of-sight microcellular environment,” IEEE J. Select. Areas Commun., vol. 20, no. 3, pp. 532–538, April 2002.
[7] H. Masui, T. Kobayashi, and M. Akaike, “Microwave path-loss modeling in urban line-of-sight environments,” IEEE J. Select. Areas Commun., vol. 20, no. 6, pp. 1151–1155, Aug 2002.
[8] G. Hern´andez-valdez, F. A. Cruz-p´erez, and D. Lara-rodr´ıguez, “Sensitivity of the system performance to the propagation parameters in los microcellular environments,” IEEE Trans. Veh. Technol., vol. 57, no. 6, pp. 3488–3508, Nov. 2008.
[9] V. H. Macdonald, “The cellular concept,” Bell Systems TechnologyJounarl, vol. 58, no. 1, pp. 15–41, Jan. 1979.
[10] P. Harley, “Short distance attenuation measurements a t 900 mhz and 1.8 ghz using low antenna heights for microcells,” IEEE J. Select. AreasCommun., vol. 7, no. 1, pp. 5–11, Jan. 1989.
[11] Y. Liang, A. Goldsmith, G. Foschini, R. Valenzuela, and D. Chizhik, “Evolution of base station in cellular networks: denser deployment versus coordination,” ieee international conference on communications, pp. 4128 – 4132, May 2008.
[12] K. A. Anang, P. B. Rapajic, T. I. Eneh, and Y. Nijsure, “Minimum cell size for information capacity increase in cellular wireless network,” in Proc. 73rd IEEE Vehicular Technology Conference (VTC'2011), Budapest, Hungary, May 2011, pp. 305–311.
[13] K. A. Anang, P. B. Rapajic, T. I. Eneh, L. Bello, and G. Oletu, “Impact of vehicular traffic on information capacity of cellular wireless network at carrier frequencies greater than 3 ghz,” in Proc. 5th IEEE EuropeanModelling Symposium on Mathematical modelling and Computer Simulation (EMS' 2011), Madrid, Spain, Nov. 2011, pp. 430–434.
[14] K. A. Anang, P. B. Rapajic, and R. Wu, “Impact of sectorization on the minimum cell size for information capacity increase in cellular wireless network,” in IX International Symposium Industrial Electronics (INDEL'2012'), Banja Luka, Bosnia and Herzegovina, Nov. 2012, pp. 220–225
[15] W. C. Y. Lee, Mobile communication design fundamentals. New York, NY: John Wiley & Sons, 1993, p. 142.
[16] S. Singh, N. B. Mehta, A. F. Molisch, and A. Mukhopadhyay, “Moment matched lognormal modeling of uplink interference with power control and cell selection,” IEEE Trans. Wireless Commun., vol. 9, no. 3, pp. 932 – 938, Mar. 2010.
[17] D. N. Hatfield, “Measures of spectral efficiency in land mobile radio,” IEEE Trans. Electromagn. Compat., vol. emc-19, no. 3, pp. 266–268, Aug. 1977.
[18] M. Alouini and A. J. Goldsmith, “Area spectral efficienc y of cellular mobile radio systems,” IEEE Trans. Veh. Technol., vol. 48, no. 4, pp. 1047–1065, Jul. 1999.
[19] ITU, “Propagation data and prediction methods for planning of short range outdoor radio communication systems and radio local area networks in the frequency range 300 mhz to 100 ghz,” Recommendation ITU-R P.1411 - 1, iTU Radio communication Assembly.
[20] G. TR25.996, “3gpp scm channel models,” 3GPP TR25.996, vol. v6.1.0, Sept. 2003.