Multidimensional Analysis of LTE Network Roll out with Typical and Non-Typical Antenna configuration

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ABSTRACT

Higher order sectorization and the site densification are the two renowned solutions for the cellular system capacity crunch. However, in order to take adequate benefits of these techniques they should be implemented with optimal antenna configuration. This chapter highlights the gain of using an optimized antenna configuration for 3-, and 6-sector sites in achieving a better network coverage and network quality i.e. capacity. Unlike traditional wide 65° HPBW antenna, this chapter also focuses on the use of other narrow HPBW antennas for 3-, and 6-sector sites. This chapter provides detailed analysis of network performance from coverage, capacity, spectral efficiency, power efficiency, and cost efficiency point of view. It also provides a fair comparison between the network rollout with traditional 3-sector sites and higher order 6-sector sites. Similarly, the impact of site densification along with sector densification is also studied in this chapter.

Keywords: System Performance, Dense and Ultra Dense Network, Antenna Configuration, Cellular Network, Higher Order Sectorization, Antenna Downtilting, Antenna Beamwidth, Cost efficiency, Power Efficiency, Spectral Efficiency

INTRODUCTION

Mobile networks have evolved tremendously in the last two decades. Indicators are showing that in future the internet and the mobile traffic will increase at an exponential rate, and in the coming years the number of mobile devices connected to the network will surpass the number of people on planet "Earth". By the year 2019 there will be nearly 1.5 devices per person (Cisco White Paper, 2015). In terms of coverage and data rates the expectations from users have also gone high. Users now expect to have high data rates with continuous and homogeneous coverage. Enormous growth in smartphones' penetration, hunger of higher per user data rates, cheap data plans etc, act as a catalyst for the multifold increase in capacity demand. To fulfill the requirement of services of such a large number of connected devices, a mobile network needs to provide a huge capacity. There are several ways by which the network capacity can be enhanced e.g. by adding more spectrum, by site densification as shown in references (Bhushan, N., et al., 2014) (Yunas, S., Valkama, M., Niemelä, J., 2015) (Richter, F., and Fettweis, G., 2010) (Hiltunen, K., 2011), by sector densification i.e. higher order sectorization (Sheikh, M. U., and Lempiainen, J., 2013) (Sheikh, M. U., Ahnlund, H. and Lempiainen, J., 2013), by deploying heterogeneous network i.e. mix of macro, micros, femtos and picos (Hwang, I., Song B. and Soliman, S. S., 2013) (Soh, Y. S., et al., 2013) , by using Multiple Input Multiple Output (MIMO) antennas using spatial multiplexing (Sheikh, M. U., Jagusz, R. and Lempiainen, J., 2011), by using smart adaptive antennas, by using higher order modulation and coding scheme etc. However, this paper focuses only on site densification and higher order sectorization.

In heterogeneous networks, still a macro layer is considered as a baseline layer for providing a basic coverage and capacity to the users. Therefore, in this paper a special attention is given to macro and micro sites only.

Frequency spectrum is the scarce and limited resources. Therefore, most of the time adding a spectrum is not a possible solution for the mobile operators. However to increase the network capacity, we can reuse the allocated spectrum as frequently as possible. By increasing the site density in a certain geographical area, the intersite distance between the sites is reduced. It means that more often the same frequency resources can be reused which can result in larger system capacity. Theoretically, an increase in the capacity of a network should be directly proportional to the increase in the density of sites. However, it is reported by (Yunas, S., et al., 2015) and (Yunas, S., et al., 2013) that the gain of site densification starts to saturate in dense networks due to severe interference coming from the neighboring sites. In real networks, sometimes the identified site location in nominal plan is not available for acquisition or landlord does not allow placing an antenna mast there. In such situation, the higher order sectorization is a feasible solution to increase the site capacity without adding an additional site. In case of higher order sectorization the number of sectors at an existing site is increased from three to six sectors or even higher. From the OPEX and CAPEX point of view, the higher order sectorization is an attractive solution for mobile operators (Sheikh, M. U., and Lempiainen, J., 2013) (Sheikh, M. U., Ahnlund, H. and Lempiainen, J., 2013). In a network with macro site deployment, it is challenging to avoid interference from the neighboring sites. Signal propagation can be restricted by lowering the antenna height, and also by tilting the antenna in the downward direction. In case of micro sites, generally the antennas are placed on the building walls and below the average rooftops which helps in minimizing the interference in system (Lempiainen, J., and Manninen, M., 2001). Antenna downtilting can be achieved either by mechanically tilting the antenna in downward direction, or by electrically changing the phase of the antenna elements (F. Athley, et al., 2010). With the help of Remote Electrical Tilt (RET), an antenna can be electrically down tilted without physically visiting the site, which can save a handsome amount of operational cost (OPEX) for the mobile operators. Antenna down tilting can provide a certain level of inter-cell interference reduction and beamforming gain (F. Athley, et al., 2010). Similarly, adopting an antenna with narrow beamwidth can also help in interference reduction.

Available resources can be efficiently utilized by optimizing the antenna configuration. Non-optimal antenna configuration may cause extra interference in the network. According to Shannon's capacity formula, decrease in Signal to Interference plus Noise Ratio (SINR) leads to a loss in system capacity. Therefore, it is utmost important to use an optimal antenna configuration which can help in maximizing the utilization of available resources.

Earlier in scientific literature provided by (Johansson, B.C.V., and Stefansson, S., 2000) (Wacker, A., et al., 1999) (Laiho-Steffens, J., Wacker, A., and Aikio, P., 2000) and (Song, T.I., Kim, D.J., and Cheon, C.H., 2002), the impact of antenna pattern has been studied in traditional networks where the ISD was fairly large compared to future ultra dense networks. The aim of this paper is to highlight the effect of optimal antenna configuration i.e. beamwidth, tilt, and power on a traditional 3-sector and higher order sectored sites in a dense and ultra dense networks. It reveals the importance of using non typical antenna beamwidth antennas for 3-, and 6-sector sites, especially in dense and ultra dense networks. Traditionally, a 3-sector site is deployed with 65° HPBW antenna, whereas in this paper the impact of using 32° and 16° HPBW antenna for 3-sector, and 32 , 16° and 12° HPBW antenna for 6-sector is studied in a network with different site densities. The metrics considered for the performance analysis in this chapter includes received signal strength, signal quality (SINR), single server cell dominance in 3 dB window, cell spectral efficiency, area spectral efficiency, relative capacity gain, power efficiency and cost efficiency. For this study, LTE is used as a network technology for conducting simulations. All the simulations are performed using a static indigenous MATLAB simulator developed by the authors of this chapter. The results acquired from this study can be generalized for other technologies as well.

BACKGROUND

LTE and Beyond

Long Term Evolution (LTE) is a well known 4G technology, and was standardized by 3rd Generation Partnership Project (3GPP). First time LTE was introduced in Release 8 of 3GPP. With basic LTE the target was to achieve 100 Mbps in Downlink (DL) direction and 50 Mbps in Uplink direction (UL) with maximum of 10 ms round trip time using 20 MHz of frequency spectrum. The feature of enhanced modulation and coding scheme i.e. 64QAM for DL direction and Multiple Input and Multiple Output (MIMO) antennas with spatial multiplexing made LTE technology superior to its predecessors. LTE uses Orthogonal Frequency Division Multiple Access (OFDMA) in DL direction and Single Carrier Frequency Division Multiple Access (SC-FDMA). The evolution of LTE continued, and later in LTE-Advanced (LTE-A) the downlink and uplink throughput was further enhanced with the help of carrier aggregation. As far today, mobile operators using LTE technology are already offering around 300 Mbps in downlink direction in their commercial networks (Nokia press release, December, 2014). Similarly, to cope with the challenge of interference in the system the Inter-Cell Interference Coordination (ICIC), Enhanced ICIC (eICIC) and, Further enhanced ICIC (FeICIC) were introduced in 3GPP Rel. 8, Rel. 10 and Rel. 11, respectively (3GPP TS 36.300 V8.0.0., 2007) (3GPP TS 36.300 V11.3.0., 2012). It was reported by (Polignano, M., et al., 2014) that ICIC is more efficient for small cells in open environment i.e. in rural and suburban areas with tower mounted antennas compared to wall mounted antennas in streets.

5G technology is currently in developing phase and is yet not a fully standardized technology. However, a jaw opening target of 1000 times more capacity compared to LTE has been set for 5G. Massive MIMO and Millimeter wave communication are assumed to be an integral part of 5G communications. One can also expect that 5G will natively support the Device-to-Device (D2D) connectivity and the Machine-to-Machine (M2M) communication (Huawei Technologies White paper, 2013). Other solutions which can help in achieving the target of 1000x more capacity include deployment of dense and ultra dense networks, deployment of heterogeneous network, Coordinated Multipoint (CoMP) transmission, and relay nodes etc (Jungnickel, V. et al., 2014). No matter what technology will be adopted for air interface, but special attention is needed to deal with the interference. Therefore, the importance of antenna configuration cannot be neglected even in the future networks.

Site Densification and Sector Densification

Commercial mobile Networks are planned from two perspectives i.e. from coverage and capacity point of view. In order to provide a minimum quality of services during the initial roll out phase a more priority is given to coverage planning, and macro sites are deployed to provide continuous coverage. Both, outdoor and indoor users are served with macro sites, and macro layer acts as a coverage and capacity layer. With time, the number of subscriber increases in the system and then the network needs to evolve to meet the capacity demand. There are several ways by which the capacity can be added in the network, however for the mobile operators with limited spectrum the easiest ones are site densification and sector densification. As the networks are initially deployed with macro cells, therefore the densification of network starts with macro layer. When the macro layer starts to saturate then the low power below the rooftop micro cells can be deployed. These macro cells and micro cells forms a hierarchical cellular structure in which macro cells act as a coverage layer and micro cells act as a capacity layer (Lempiainen, J., and Manninen, M., 2001).

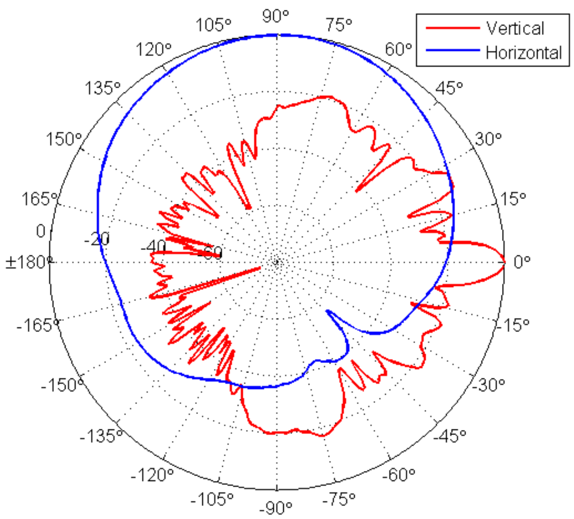
In today's competitive mobile market, the cellular operators are striving to achieve handsome Average Revenue per User (ARPU) while offering better services at lower price. Unfortunately, both the network infrastructure CAPEX and OPEX increases with the increase in number of base station in the network. Therefore, for the capacity limited hotspots where the additional sites are not allowed either due to non-availability of new site locations or due to restrictions from the landlords, there the higher order sectored site can be considered as a suitable option. Higher order sectorization benefits in saving operational cost as well as in saving capital investment. There is an easy and smooth transition from 3-sector site to 6-sector site. Theoretically, doubling the number of sectors should double the network capacity. However, the sectoring efficiency does not increase linearly with the increase in number of sectors due to interference and non-optimal antenna radiation pattern (Sheikh, M. U., and Lempiainen, J., 2013) (Sheikh, M. U., Ahnlund, H. and Lempiainen, J., 2013). Practically, the coverage areas of adjacent sectors overlap over each other to support the handovers between the cells. However, a large overlapping area results in significant interference which degrades the quality of service and system capacity. In transition from traditional 3-sector site to 6-sector site the number of sectors at individual site is increased and the spatial separation between the sectors is reduced, therefore it was recommended to use narrow antenna pattern for higher order sectored sites to minimize the overlapping area between the sectors (Sheikh, M. U., and Lempiainen, J., 2013) (Sheikh, M. U., Ahnlund, H. and Lempiainen, J., 2013).

Antenna Configuration

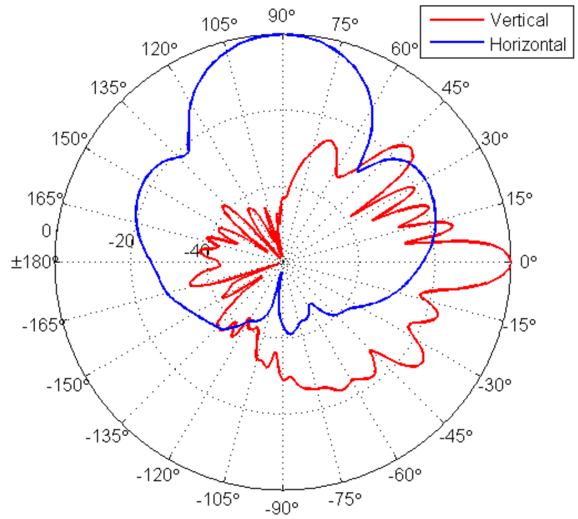
In telecommunication industry, the inter-sector interference has always been a hot topic of discussion for the optimization engineers. Antenna configuration i.e. radiation pattern, half power beamwidth, antenna height, and transmit power have a strong impact in terms of coverage and quality not only in the serving cell but also in the neighbor cells. Signal propagation can be successfully restricted by tilting the antenna in the downward direction. Antenna downtilting can be done either by physically tilting an antenna in the downward direction also known as mechanical downtilting, or by changing the phase of the antenna elements known as electrical tilting (F. Athley, et al., 2010). Mechanical tilting of antenna works like a lever or see saw, when the front lobe of antenna is tilted down the back lobe of antenna is tilted in upward direction which can cause shooting in the back lobe. However, the problem of lifted back lobe can be mitigated by mounting an antenna on the walls of the buildings. Whereas, the electrically down tilted antenna not only squeezes the radiation pattern of front lobe rather it also shrinks the side and back lobe (Niemela, and J., Lempiainen, J., 2004) (Niemela, J., Isotalo, T., and Lempiainen, J., 2005). As a result, electrically tilted antennas help in avoiding interference to the other sectors.

The height of the antenna is typically selected according to the environment and deployment type i.e. macro or micro. In macro type deployment, the antennas are placed above the average rooftops of the buildings and uses high transmission power, whereas in micro cell deployment the antenna is placed below the rooftop on the walls of the building or on street lamps and comparatively use low power (Lempiainen, J., and Manninen, M., 2001).

Another factor which affects the coverage of the cell is the beamwidth of an antenna in the horizontal (azimuth) plane and in the vertical (elevation) plane. It is denoted by the term Half Power Beamwidth (HPBW), and is calculated from the –3 dB point in the radiation pattern with respect to main lobe. Antenna with narrow HPBW also offers higher antenna gain, as antenna gain is inversely proportional to the beamwidth of an antenna. The selection of an antenna beamwidth plays a crucial and an important role in sectoring, especially for the case of higher order sectorization as shown by (Johansson, B.C.V., and Stefansson, S., 2000) (Wacker, A., et al., 1999) (Laiho-Steffens, J., Wacker, A., and Aikio, P., 2000) and (Song, T.I., Kim, D.J., and Cheon, C.H., 2002). For the optimization purpose, it is equally important to minimize the overlapping area of different servers. Sample radiation patterns of antennas with different beamwidths are shown in Figure 1, which are later used for simulations and research work of this study. In Figure 1, the blue line represents the antenna radiation pattern in horizontal (azimuth) domain, and the red line represents the antenna radiation pattern in vertical (elevation plane). It can be seen in Figure 1 (a), the antenna pattern has a wide HPBW of 65° in horizontal domain, whereas the HPBW is squeezed to 32° in Figure 1(b). The HPBW in horizontal domain is further reduced to 16° and 12° in Figure 1(c) and Figure 1(d), respectively. It is important to mention here that in commercially available conventional wide beam (traditional) antennas for base station, the multiple antenna elements are placed vertically in linear array. Therefore, the antennas have significantly small HPBW in vertical domain as compared with horizontal domain, as it can also be seen in Figure 1(a) to Figure 1(d).



(a)



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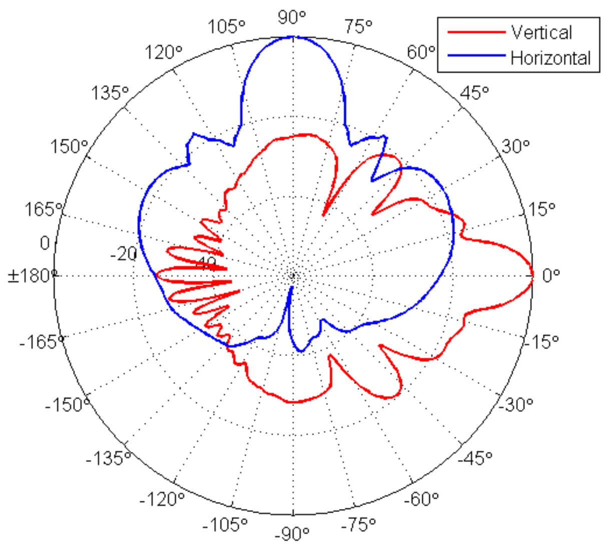
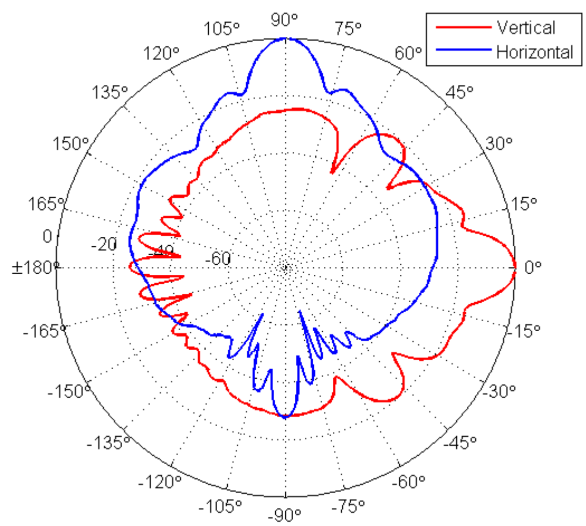




(c) *(d)*

Figure 1. Horizontal and vertical radiation patterns of antennas, (a) 65° horizontal HPBW, (b) 32° horizontal HPBW, (c) 16° horizontal HPBW, and (d) 12° horizontal HPBW

Network Efficiency Metrics

This section defines different network efficiency metrics considered in our study e.g. spectral efficiency, area spectral efficiency, power efficiency, and cost efficiency.

Spectral Efficiency

Network performance in terms of coverage and capacity is analyzed using different performance and planning metrics e.g. signal strength (received signal level), signal quality (SINR), cell dominance area (single server within window of certain dBs), cell spectrum utilization (cell spectral efficiency), and area spectrum utilization (area spectral efficiency). Signal strength is used to define the coverage of the cell, whereas SINR and spectrum utilization are used to evaluate the capacity of the system. Spectral efficiency is directly proportional to the cell SINR, and it is estimated using famous Shannon's capacity formula given in bits per second per hertz (bps/Hz). Average area spectral efficiency η_{Area} is expressed in [bps/Hz/km^2] as shown in Equation 1 (Shannon, C., 1949) (Alouni, M. and Goldsmith, A., 1997),

$$\eta_{Area} = \eta_{Cell} * \mathrm{N}_{\mathrm{Cell}} \qquad \textit{Equation 1}$$

where in Equation 1, $\boldsymbol{\eta_{Cell}}$ is the average cell efficiency expressed in [bps/Hz], and $\mathbf{N_{Cell}}$ is the number of cells covering that area. Area spectral efficiency can be considered as a sophisticated and fair way to study the effects of network densification and higher order sectorization in the cellular network, and to compare the performance of site densification with sector densification. As a result of site and sector densification, the spatial reuse within an area increases which should correspondingly increase the area spectral efficiency. However, it is interesting to see that how the area spectral efficiency increases when the number of cells is increased through site densification and sector densification. From the mobile operators' point of view more area spectral efficiency means more revenue, and from the end users' perspective the higher area spectral efficiency means higher data rates. Therefore, a solution which can increase an area spectral efficiency is beneficial for both the parties.

Power Efficiency

Power is a scare resource like frequency spectrum, therefore only a limited power is available. Nowadays, it is an era of green communication, and therefore mobile operators are conscious about the power usage in their network. Power efficiency can be considered as a performance indicators for mobile operators to track the power consumption in their cellular network. Higher power efficiency directly translates to lower costs. The unit for power efficiency (P_{eff}) is [bps/Hz/kW] and is defined as:

$$P_{eff} = \frac{\eta_{\mathrm{Area}}}{P_{\mathrm{km^2}}}, \qquad \textit{Equation 2}$$

$$P_{\mathrm{km^2}} = \frac{P_{\mathrm{BS}} * N_{\mathrm{BS/km^2}}}{A_{\mathrm{cov}}}, \qquad \textit{Equation 3}$$

where in Equation 2, $P_{\mathrm{km^2}}$ is the area power consumption with unit [kW/km^2]. In Equation 3, P_{BS} is the power consumption of a single base station, $N_{\mathrm{BS/km^2}}$ is the number of base stations required to cover 1 km^2 area, and A_{cov} is the reference area in [km^2]. In our calculation the reference area A_{cov} is one square kilometer. In order to compute the correct area power consumption, a power consumption model is presented by (Yunas, S.F., Niemela, J.,Valkama,M., and Isotalo,T., 2014) and is given in Equation 4

$$P_{\mathrm{BS}} = P_{\mathrm{const}} + P_{\mathrm{load}} * F, \qquad \textit{Equation 4}$$

In Equation 4, P_{const} is the load-independent power consumption factor, P_{load} is the load-dependent power consumption factor and F is the load factor. For considering a worst case scenario, it is assumed that the BS is operating at full load, thus $F = 1$. The load-independent variable P_{const} includes the following power consuming sources: a rectifier, a fiber optic link (for backhaul connection) and sometimes an air conditioning unit. However, in some case the air conditioning unit can be left out since new pole-mounted BS sites are already available in the markets. The load-dependent variable P_{load} includes the following power consuming components: a Power Amplifier (PA), transceiver and Digital Signal Processing unit (DSP). It is assumed that the efficiency of the PA is 45 % in this analysis to match the values utilized by (Yunas, S.F., Niemela, J.,Valkama,M., and Isotalo,T., 2014) and (Sheikh, M. U., Sae, J. & Lempiainen, J., 2017, August). Relevant parameters related to power consumption model are provided in Table I. In this study, authors have considered the RF power of micro and macro BS as 37 dBm and 43 dBm, respectively, as these values have been previously used in the studies carried out by(Yunas, S.F., Niemela, J.,Valkama,M., and Isotalo,T., 2014) and (Sheikh, M. U., Sae, J. & Lempiainen, J., 2017, August).

Table I. Power consumption parameters

Parameter	Unit	Value
Transmit power at antenna	dBm	37/43
Power consumption of DSP unit	W	100
Power Amplifier efficiency	%	45
Power consumption of tranceiver	W	100
Power consumption of rectifier	W	100
Power consumption of fiber optic unit	W	7.5
Load factor (F)	%	100

Cost Efficiency

In order to evaluate the feasibility or workability of any project, it is important to analyze the different financial aspects of that project before making any investments. Capital expenditure (CAPEX) and Operational expenses (OPEX) evaluation together tells about the expected cost the network required for implementation and maintenance. In order to normalize the costs between different technologies, a more general metric is required for the cost analysis. Thus, the metric chosen for this study is the total cost per spectral efficiency c_{eff} [bps/Hz/k€] defined as by (Yunas, S.F., Niemela, J.,Valkama,M., and Isotalo,T., 2014) :

$$c_{\mathrm{eff}} = \frac{\eta_{\mathrm{Area}}}{T_{\mathrm{cost/km^2}}}, \qquad \textit{Equation 5}$$

In Equation 5, $T_{\mathrm{cost/km^2}}$ is the total cost per km^2, which is achieved by normalizing the total cost of BS sites over one square kilometer. From the mobile operator's point of view the capital investment and the operational cost of the network is of extreme importance, therefore the cost efficiency of the network is an important metric from the financial perspective. Table II and

Table III shows the estimated CAPEX and OPEX cost for both micro and macro base stations, respectively. The cost related parameters shown in Table II and

Table III are later used in this chapter for calculating the cost efficiency of different antenna configurations.

Table II. Capital expenditure (CAPEX)

CAPEX	Macro BS	Micro BS
BS equipment 3-sector site	10 k€	7.5 k€
BS equipment 6-sector site	20 k€	15 k€
Site deployment cost 3-sector	5 k€	1.5 k€
Site deployment cost 6-sector	7 k€	2.5 k€
Total CAPEX 3-sector	15 k€	9 k€
Total CAPEX 6-sector	27 k€	17.5 k€

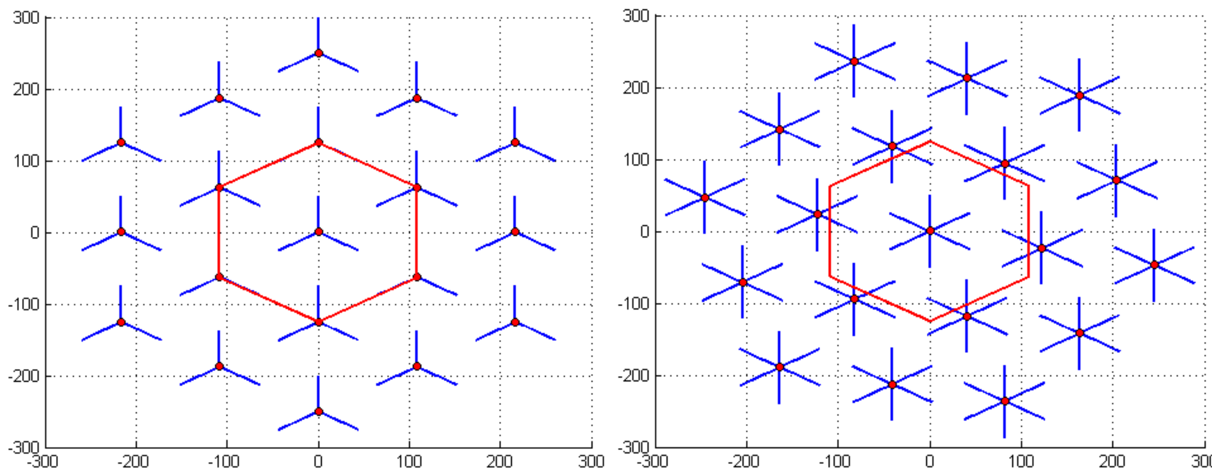
Table III. Operational expenses (OPEX)

OPEX	Macro BS	Micro BS
Site rent (lease)	5 k€/year	3 k€/year
Leased line rent (backhaul)	2.25 k€/year	2 k€/year

O&M for 3-sector site	5 k€/year	4.5 k€/year
O&M for 6-sector site	7 k€/year	6 k€/year
Total OPEX 3-sector	12.25 k€/year	9.5 k€/year
Total OPEX 6-sector	14.25 k€/year	11 k€/year

SIMULATION ENVIRONMENT, CASES AND PARAMETERS

The key assumptions and the simulation tool used in the study of different antenna configurations and site densification are explained in this section. For the study of this article, a MATLAB based static simulator was indigenously developed for system level simulations. In order to take into account the impact of interference coming from the neighboring sites, for the simulation purpose a group of 19 sites are selected which means two tiers of interfering neighbors are included for the centre site. All the considered sites are assumed to have equal intersite distance with same radio conditions. Regular network tessellations were used only for selecting the site's location however no hard cell boundaries were defined with respect to network layout. Cloverleaf layout and Snowflake layout is used for the case of 3-sector and 6-sector sites deployment, respectively, as shown in Figure 2.



(a) *(b)*

Figure 2. Network layout for simulations (a) 3-sector clover layout with 125 m ISD, (b) 6-sector snowflake layout with 125 m ISD

For all the considered cases, the antennas of different sectors pointing in different directions (azimuths) are assumed to be co-located at the same site location. Moreover, there is an equal separation between the antennas of the different sectors of the same site in an azimuth (horizontal) plane. For investigating the impact of antenna beamwidths and downtilts on the performance of sector and site densification, 65° HPBW antenna with 15.39 dBi gain, 32° HPBW antenna with 18.20 dBi gain, 16° HPBW antenna with 21.15 dBi gain, and 12° HPBW antenna with 22.5 dBi gain is considered. Horizontal and vertical antenna patterns of the selected antennas are shown in Figure 1. For the performance comparison with different site densification, the following cases are analyzed.

- 3-sector site with 65° HPBW antenna.
- 3-sector site with 32° HPBW antenna.
- 3-sector site with 16° HPBW antenna.
- 6-sector site with 32° HPBW antenna.
- 6-sector site with 16° HPBW antenna.
- 6-sector site with 12° HPBW antenna.

Later for finding the relative gain, a case of 3-sector site with 65° HPBW and 2° downtilt is used as a reference case. A homogeneous propagation environment with flat terrain, and without any clutter information is assumed. Therefore, all the cells are expected to experience same radio propagation conditions. Hence, for the post processing and analysis purpose, the data is extracted only from the hexagon shaped "Focus Zone", which is highlighted by a red polygon as shown in Figure 2. The size of the focus zone is variable and is proportional to the intersite distance i.e. the size of the focus zone increases with the same ratio as the intersite distance increases, and vice versa. For the coverage prediction and for estimating the received signal power at the receiver locations, a COST231-Hata Model for urban environment is used. In order to evaluate the performance in worst condition in term of interference, the cell loading of 100% is assumed in the network i.e. serving cell and all the neighboring cells are transmitting with their maximum transmission power. Fixed hexagonal dominance area is not assumed for cells; however it is defined by the best serving cell. Two different base station types are considered i.e. macro and micro base stations. Macro base stations are assumed to have maximum transmit power of 43 dBm and antenna height of 20 meters. Whereas for micro base station in order to limit the radio propagation the maximum transmit power is set to 37 dBm with 10 m antenna height. For smaller ISD of 100 m and 125 m micro base station configuration is used, and for other higher ISDs the macro base station configuration is used. Other general parameters used for the simulations are presented in Table IV.

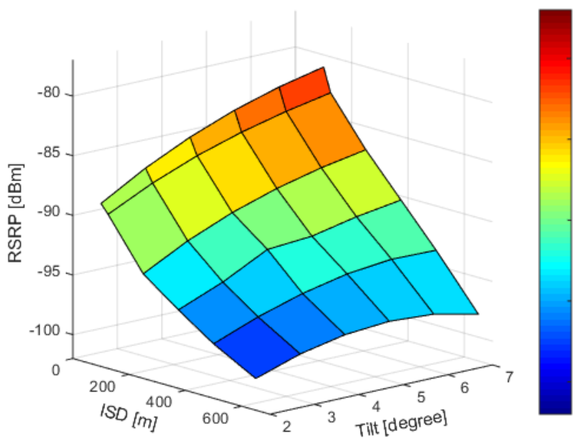
Table IV. General simulation parameters

Parameter	Unit	Value
Frequency band	MHz	2600
LTE bandwidth	MHz	20
UE noise figure	dB	8
eNB power	dBm	37/43
TX height	m	10/20
RX height	m	1.5
LTE orthogonality		1
Slow fading margin	dB	8
Antenna downtilt	degree	2-7
Antenna horizontal HPBW	degree	65/32/16/12

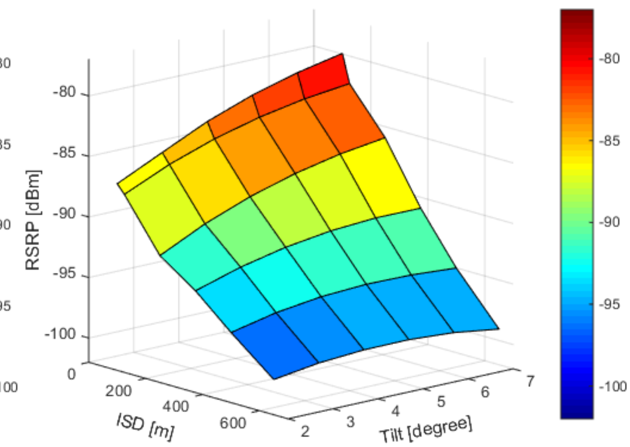
SIMULATION RESULTS, ANALYSIS AND DISCUSSION

Figure 3 shows the mean values for the reference signal received power (RSRP) for the cases of 3-sector sites with different antenna beamwidths and antenna downtilts. Figure 3(a) to Figure 3(c) shows three dimensional mesh plots. The x-axis indicates the intersite distance in meter; y-axis shows the antenna downtilt angle in degrees, and the z-axis represents the corresponding RSRP in dBm. We can divide our analysis into two parts i.e. analysis of site densification and secondly analyzing the impact of antenna downtilting. One thing is clearly evident from Figure 3 that the RSRP significantly improves with aggressive downtilting considering all intersite distances ranging from 100 m to 650 m. It shows that the main lobe of the beam is steered in the coverage (serving) area of the cell by tilting the antenna in the downward direction. In real mobile networks a macro 3-sector site is traditionally deployed with 65° HPBW antenna. It can be seen in Figure 3(a) and Figure 3(b), that for large intersite distance of 650 m which is a common ISD for macro site in urban environment, almost similar mean RSRP is achieved with 32° and 65° HPBW antennas, whereas the mean RSRP degrades with 16° BW antenna as shown in Figure 3(c). For smaller intersite distance, the 32° BW antenna provides almost 2 dB better results compared to

65° BW antenna. However, it is interesting to see that for ultra dense network (ISD = 100 m and 125 m) 16° BW antenna exhibit even better results compared with 32° and 65° antenna. In radio optimization, it is a common practice to use antenna down tilting to improve the dominance area of the cell, especially in small cells.



(a)



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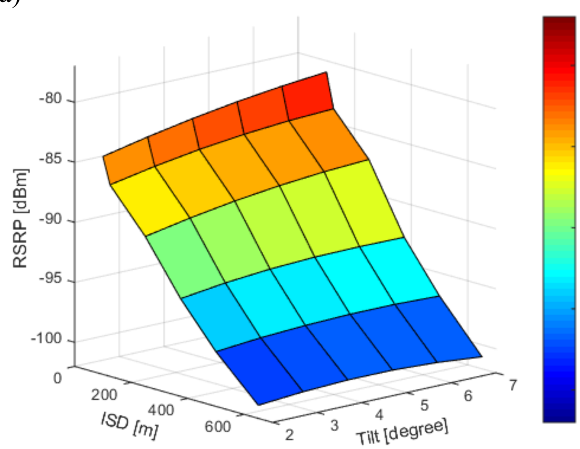
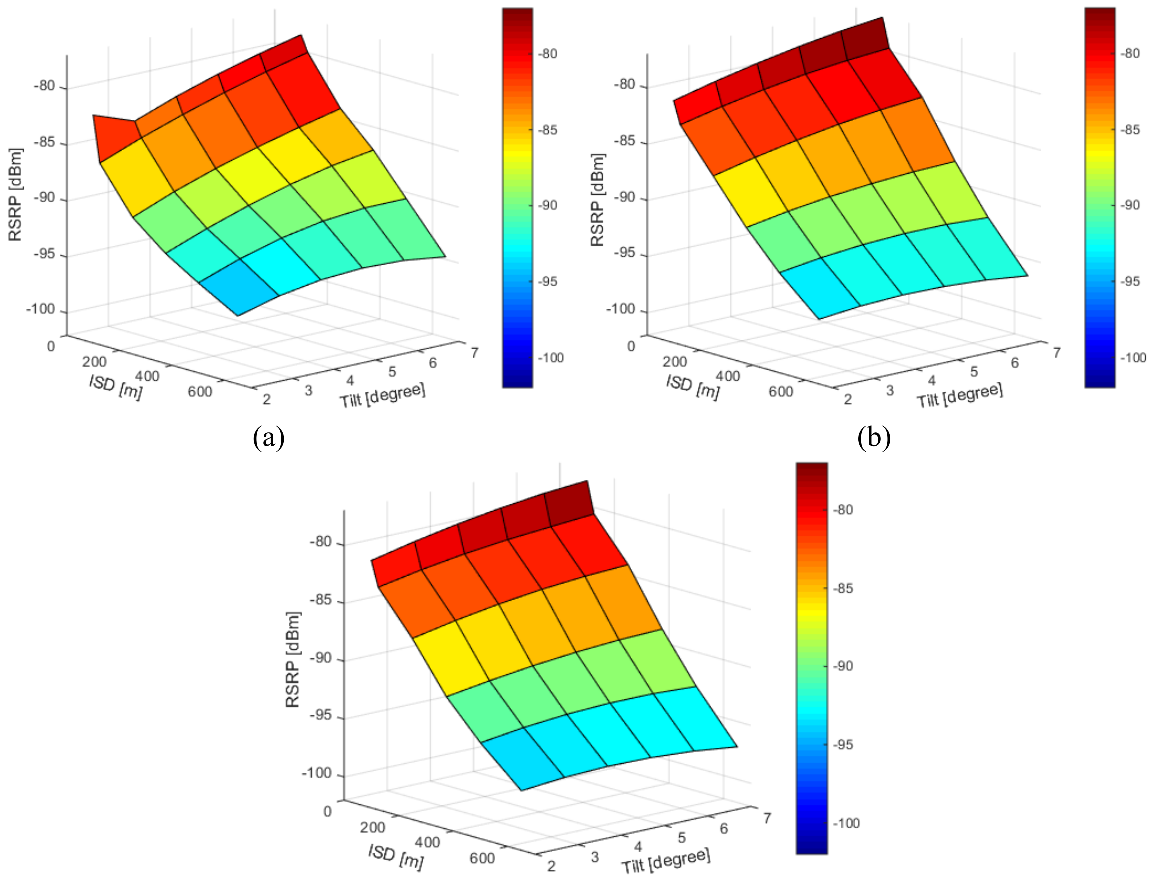


(c)

Figure 3. Mean RSRP of 3-sector sites with, (a) 65° horizontal HPBW antenna, (b) 32° horizontal HPBW antenna, (c) 16° horizontal HPBW antenna

Figure 4 shows mean reference signal received power (RSRP) for 6-sector sites deployed with different antenna beamwidths and downtilts. By adding more sectors to the same site, the spatial separation shrinks between the sectors. In references (Sheikh, M. U., and Lempiainen, J., 2013) (Sheikh, M. U., Ahnlund, H. and Lempiainen, J., 2013) the authors recommended to use narrower antenna pattern for 6-sector sites, and therefore instead of 65° HPBW antenna a maximum of 32° HPBW antenna is chosen for 6-sector sites. By comparing the results presented in Figure 3 and Figure 4, it is clearly evident that the sector densification improves the received signal strength by significant margin. Similar trend of graphs are observed in Figure 4 as witnessed in Figure 3. For intersite distance of 300 m and above, a 6-sector site with 32° HPBW and 7° tilt provides better RSRP among the considered cases. However, for denser networks, the performance of 6-sector site is improved by employing 16° HPBW antenna with 7° tilt. In ultra dense network the performance of 12° HPBW antenna is almost identical as 16° HPBW antenna.



(c)

Figure 4. Mean RSRP of 6-sector sites with, (a) 32° horizontal HPBW antenna, (b) 16° horizontal HPBW antenna, (c) 12° horizontal HPBW antenna

The impact of down tilting in improving the cell dominance area can be seen in Figure 5 and Figure 6. Generally, the strongest RSRP becomes the serving RSRP, and it defines the coverage area of the serving cell. However, if any offset value is not used for cell selection/reselection procedure then the serving RSRP is not necessarily the clearly dominant one (few dBs better than others). Therefore, in order to observe the clear cell dominance the percentage of area with single server within 3 dB of overlapping window is often used as a planning KPI in mobile networks. It is measured as a percentage of total area where the second strongest server (interferer) is atleast 3 dB lower than the strongest (serving) server. This parameter also gives information about the pilot pollution in the network. Figure 5 presents the single server dominance area with 3 dB window for 3-sector sites. It can be seen that especially at small ISDs the 65° HPBW antenna cause huge overlapping between the sectors, and therefore the cell dominance area lies only in the direction of main beam. It is interesting to see that the dominance area can be significantly improved by using antenna downtilting, specifically at smaller ISD of 100 m and 125 m. It was found that antennas with wider beamwidth i.e. 65° HPBW experience large Improvement in cell dominance area with antenna downtilting. Antenna with 16° HPBW is already quite narrow for 3-sector site deployment therefore there is no significant improvement in cell dominance area. However, it is worth mentioning here that for ultra dense networks even with 16° HPBW antenna a fairly large cell dominance area can be achieved. Overall, the 32° HPBW antenna was found as a best solution for 3-sector site for better cell dominance area; at small ISD with aggressive downtilt i.e. 7° and at large ISDs with minor 2° tilt.

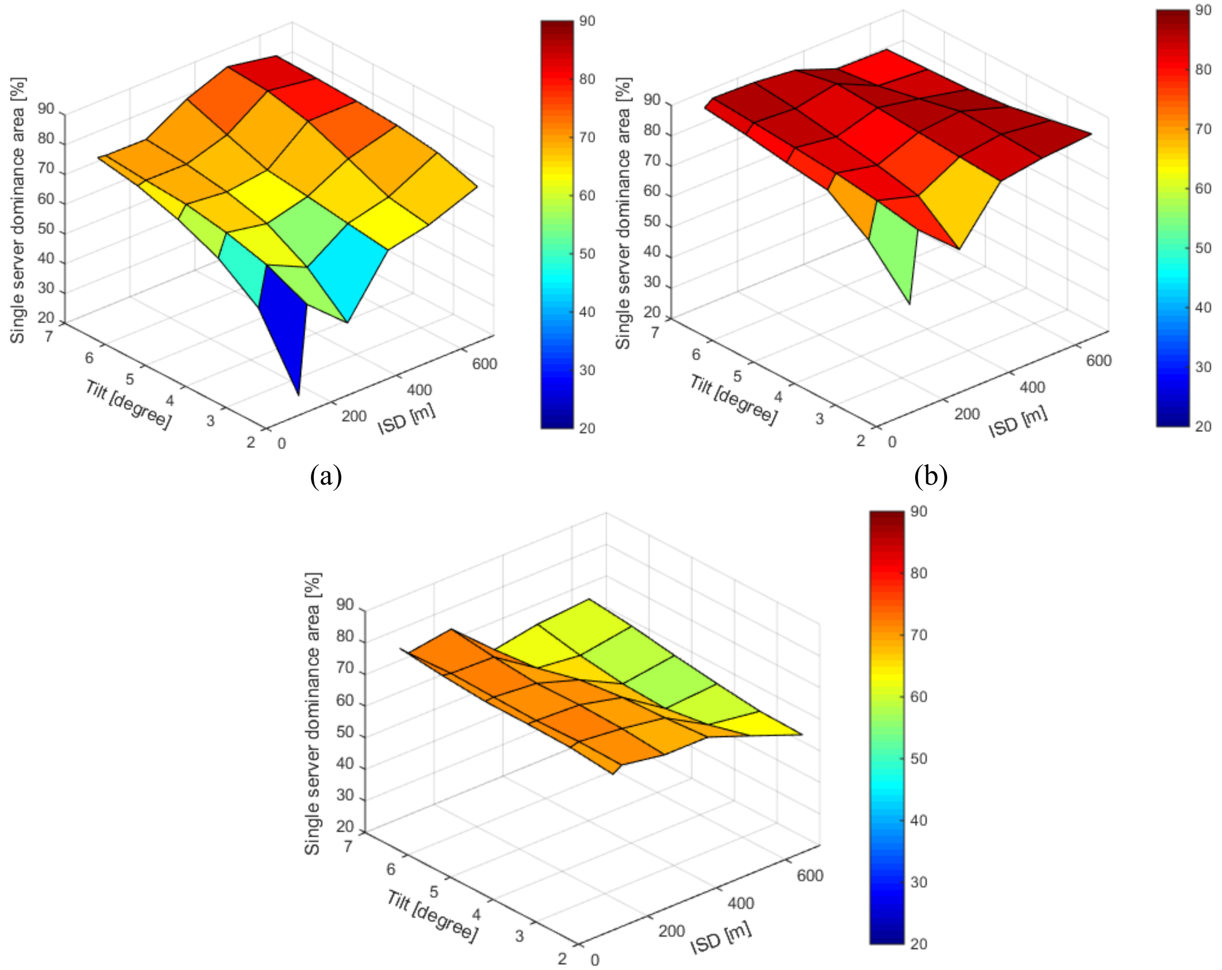
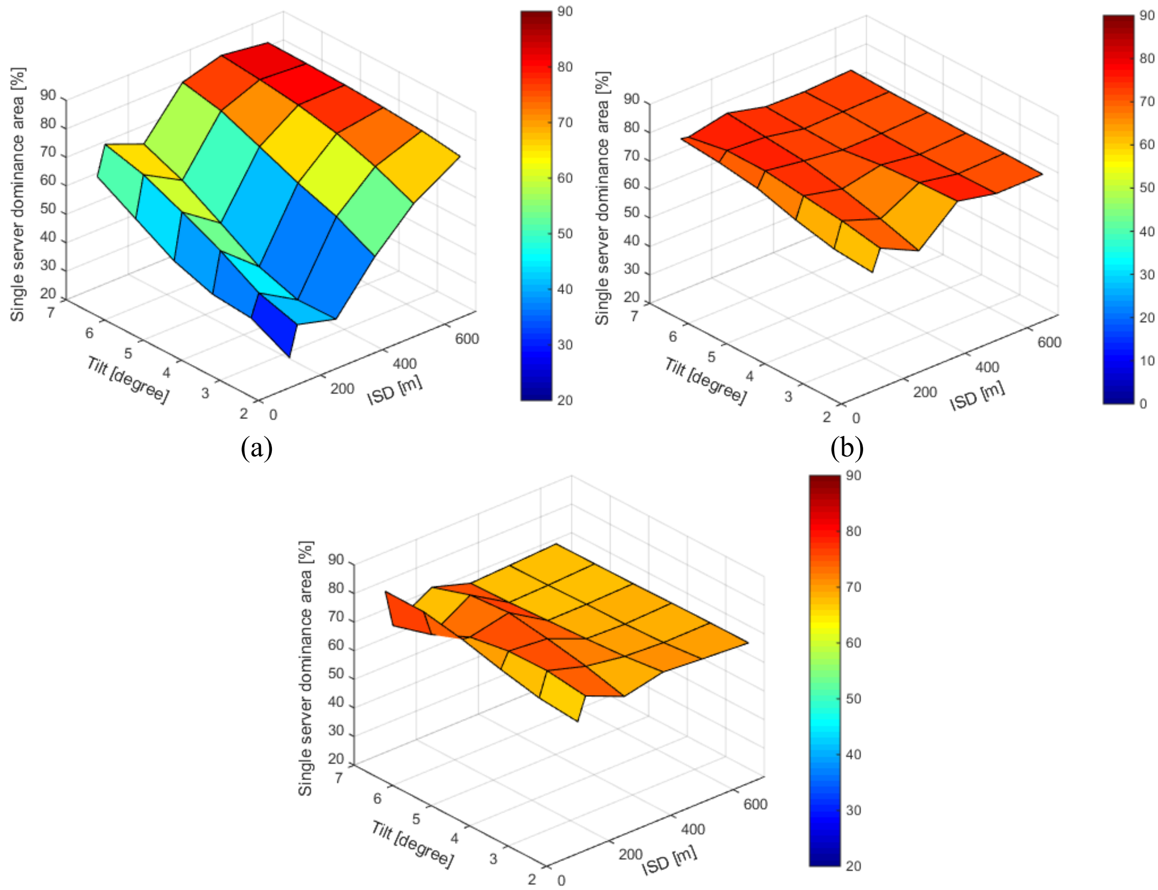


Figure 5. Single server dominance with 3 dB window of 3-sector sites with, (a) 65° horizontal HPBW antenna, (b) 32° horizontal HPBW antenna, (c) 16° horizontal HPBW antenna

Figure 6 shows the single server dominance area with 3 dB window for 6-sector sites. It shows that in terms of cell dominance area the 32° HPBW antenna is not always a good choice for 6-sector site. For the case of 6-sector sites, the spatial separation between the sectors is less compared with 3-sector sites. Therefore, there is a large overlapping area between the sectors with wide beam antennas at small intersite distances. However, antenna downtilting is also found helpful for 6-sector site for improving the cell dominance area. For 6-sector site with large intersite distance 32° HPBW antenna with aggressive tilt was found better, whereas for small ISDs the 16° HPBW antenna with 7° tilt provides the best result. Although, the number of sectors increase with 6-sector site deployment, but it was found that the cell dominance area or in other words the cell overlapping area can be maintained upto large extend by using antennas with optimum beamwidths and tilts. It should also reflect this result in maintaining a healthy signal to interference plus noise ratio.



(a) (b) (c)

Figure 6. Single server dominance with 3 dB window of 6-sector sites with, (a) 32° horizontal HPBW antenna, (b) 16° horizontal HPBW antenna, (c) 12° horizontal HPBW antenna

Another metric considered for the performance analysis of the network is the quality of the network i.e. SINR. Reference signal received power only tells about the signal strength, but the SINR is the capacity metric of the network. Individually RSRP or SINR does not give complete information about the user experience in the network, therefore they both need to be analyzed together to get the insight information. Figure 7 shows the mean SINR values for the cases of 3-sector sites with different antenna beamwidths and tilts. The x-axis indicates the intersite distance in meter, y-axis shows the antenna downtilt angle in degrees, and the z-axis represents the SINR in dB scale. It was found that large spatial separation between the sites (large intersite distance) provides better SINR compared to denser networks. Although the mean signal strength in cell is improved with site densification, but on the other hand the SINR degrades with higher density of sites. It was observed that aggressive tilts helps in not only improving the cell dominance area rather it also improves the SINR. For macro sites with large ISD of 500 and 650 m, 65° HPBW antenna with 7° tilt shows the best SINR of 7.6 dB and 8 dB, respectively. However, 32° HPBW antenna with 7° tilt shows slightly lower SINR of 7 dB and 7.6 dB at 500m and 650 m ISD, respectively. For the other lower intersite distances, the finest results are obtained with 32° HPBW antenna with 7° tilt. Interestingly, it was found that for antenna with 16° has almost flat response over all ISDs, and is not favorable for 3-sector sites deployment. The drop in SINR while shifting from 125 m ISD to 250 m ISD is due to change of base station type i.e. from micro to macro base station. As micro base station was using low transmission power and lower antenna height compared to macro base station, therefore causes less interference to the neighboring cells. Interestingly, in terms of antenna configuration it is found that the configuration which provides the better RSRP also provides the better SINR.

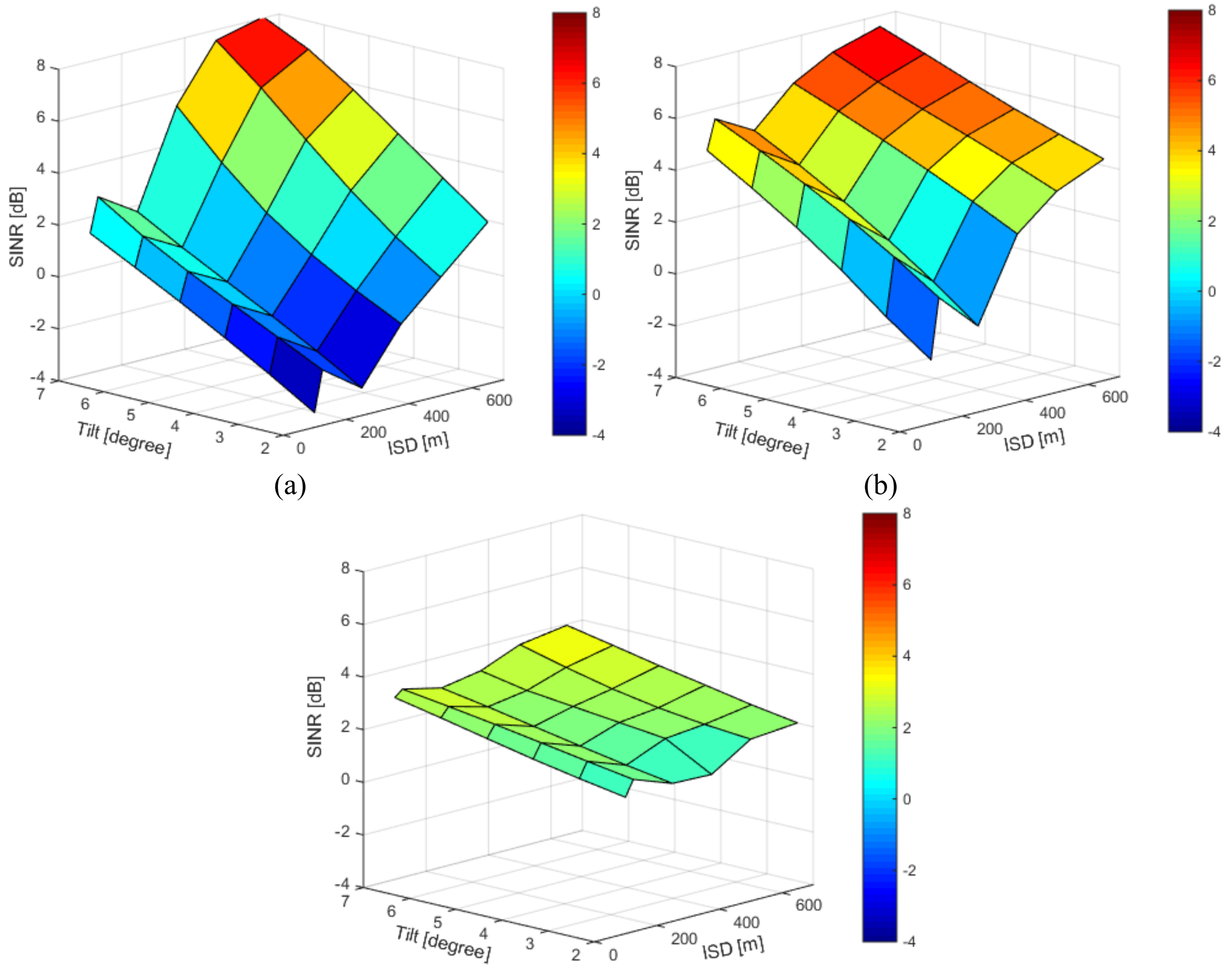


Figure 7. Mean SINR of 3-sector sites with, (a) 65° horizontal HPBW antenna, (b) 32° horizontal HPBW antenna, (c) 16° horizontal HPBW antenna

Figure 8 shows the mean SINR values for the cases of 6-sector sites with different antenna beamwidths and tilts. For 6-sector sites, among the considered configurations the 32° HPBW antenna with 7° tilt provides better results at large intersite distances of 375 m , 500 m and 650 m. However, for denser networks 12° HPBW antenna with 7° tilt is the preferred configuration in terms of achieving better SINR. It can be seen in the Figure 8 that significant improvement in SINR can be achieved by employing aggressive tilts, even at large intersite distances while using 32° HPBW antenna. From the results presented in Figure 7 and Figure 8, it is revealed that antennas with larger beamwidths e.g. 65° and 32° experiences more gain in terms of achieving better SINR and RSRP results by employing aggressive tilts, irrespective of the intersite distance. It is necessary to mention here, that sector densification has improved the mean signal strength at cell level, but on the other hand it degrades the mean cell SINR. Despite of using narrower antenna pattern for higher order of sectored sites, the drop in SINR is witnessed at cell level. Cell spectral efficiency is directly proportional to the SINR. In the light of the results presented in Figure 7 and Figure 8, it can be concluded that the cell spectral efficiency decreases with site densification. Now, it is interesting to find the ratio of drop in cell spectral efficiency, and gain in achieving better area spectral efficiency by employing site and sector densification.

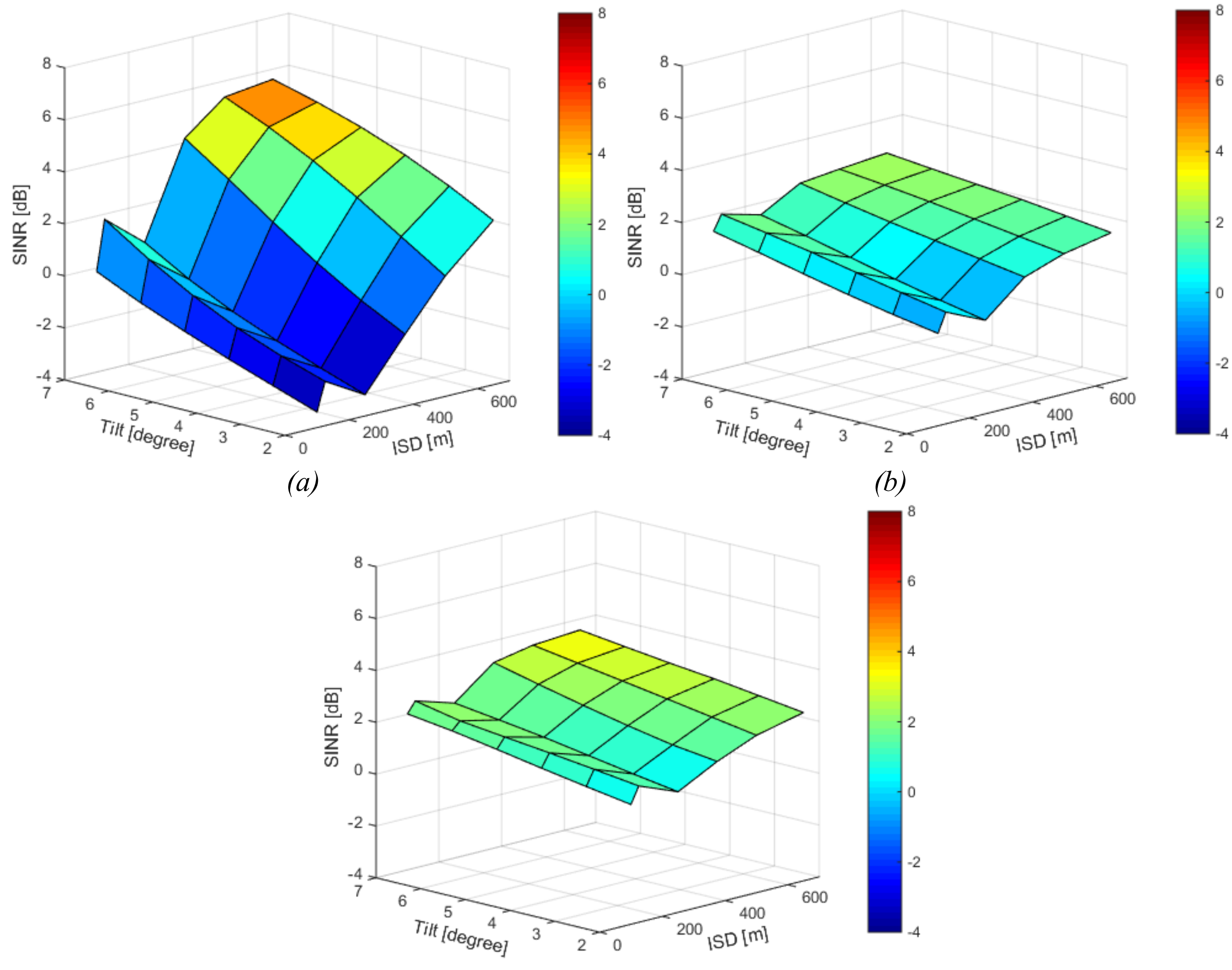


Figure 8. Mean SINR of 6-sector sites with, (a) 32° horizontal HPBW antenna, (b) 16° horizontal HPBW antenna, (c) 12° horizontal HPBW antenna

Figure 9 shows the mean area spectral efficiency for the cases of 3-sector sites with different antenna beamwidths and downtilts. It is already established from the results presented earlier in this chapter that the cell spectral efficiency degrades with site and sector densification. However, it can be seen from the results presented in Figure 9 that the area spectral efficiency increases with site densification. As in case of site densification there is more number of cells covering the same area, therefore despite of losing the cell spectral efficiency the overall area spectral efficiency is enhanced. In Figure 10, to have a better view at large intersite distances, the area spectral efficiency of 3-sector sites with intersite distance 250 m and above is highlighted. At 650 m ISD, the 65° BW antenna with 7° tilt provides the maximum area spectral efficiency of around 23 bps/Hz/km^2 which is then increased to 38.5 bps/Hz/km^2 at 500 m ISD with the same antenna configuration. The rising trend of area spectral efficiency continues while going towards denser networks (shorter intersite distances). Among all the considered 3-sector configurations and intersite distances, the maximum area spectral efficiency of 667 bps/Hz/km^2 was recorded at the smallest ISD of 100 m with 32° BW antenna and 7° tilt.

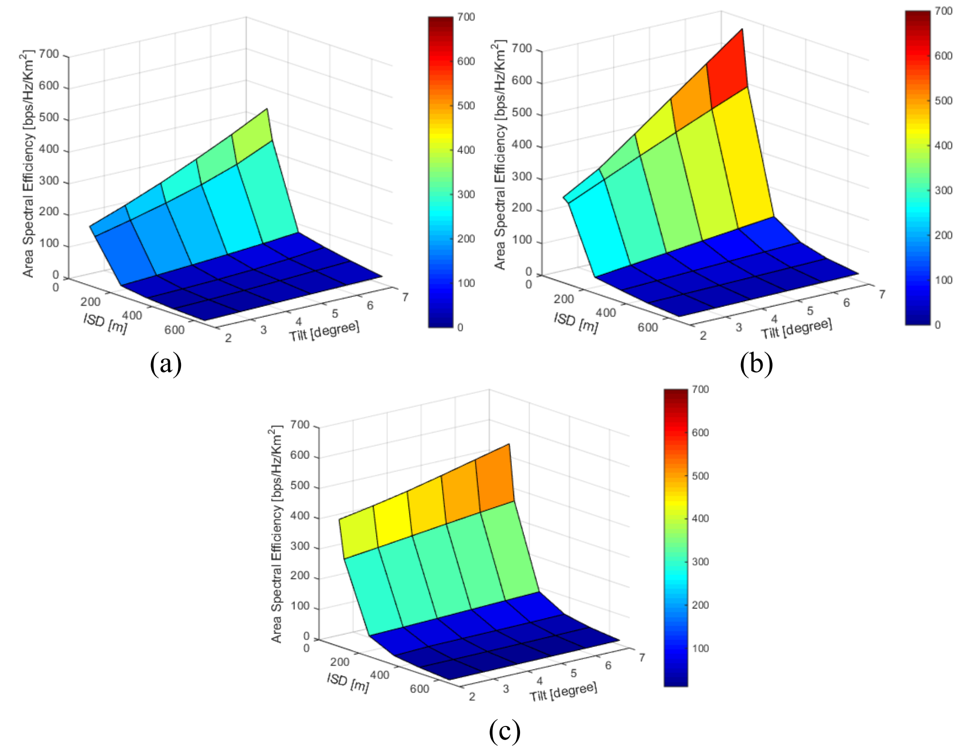


Figure 9. Area spectral efficiency of 3-sector sites with, (a) 65° horizontal HPBW antenna, (b) 32° horizontal HPBW antenna, (c) 16° horizontal HPBW antenna

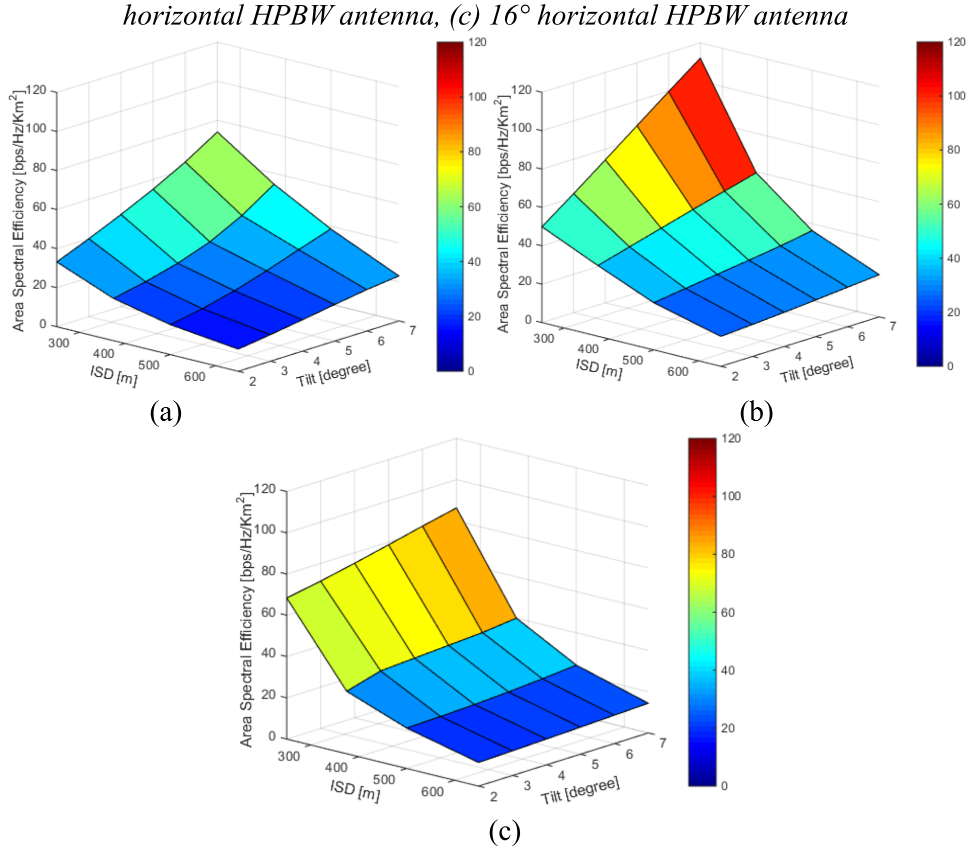


Figure 10. Area spectral efficiency of 3-sector sites with intersite distance 250 m and above, (a) 65° horizontal HPBW antenna, (b) 32° horizontal HPBW antenna, (c) 16° horizontal HPBW antenna

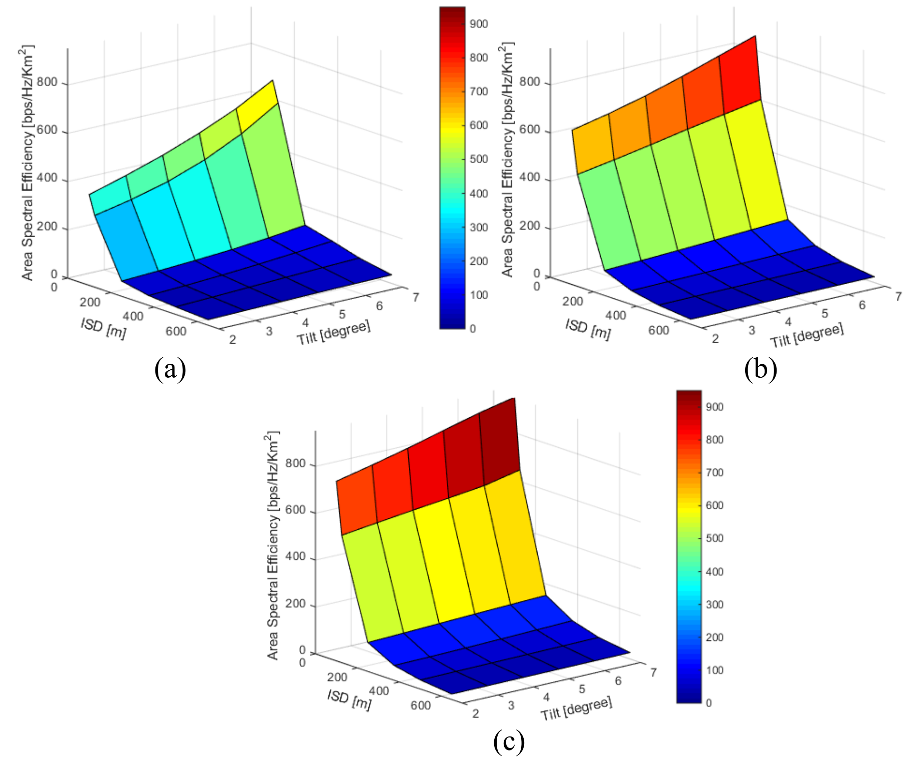


Figure 11. Area spectral efficiency of 6-sector sites with, (a) 32° horizontal HPBW antenna, (b) 16° horizontal HPBW antenna, (c) 12° horizontal HPBW antenna

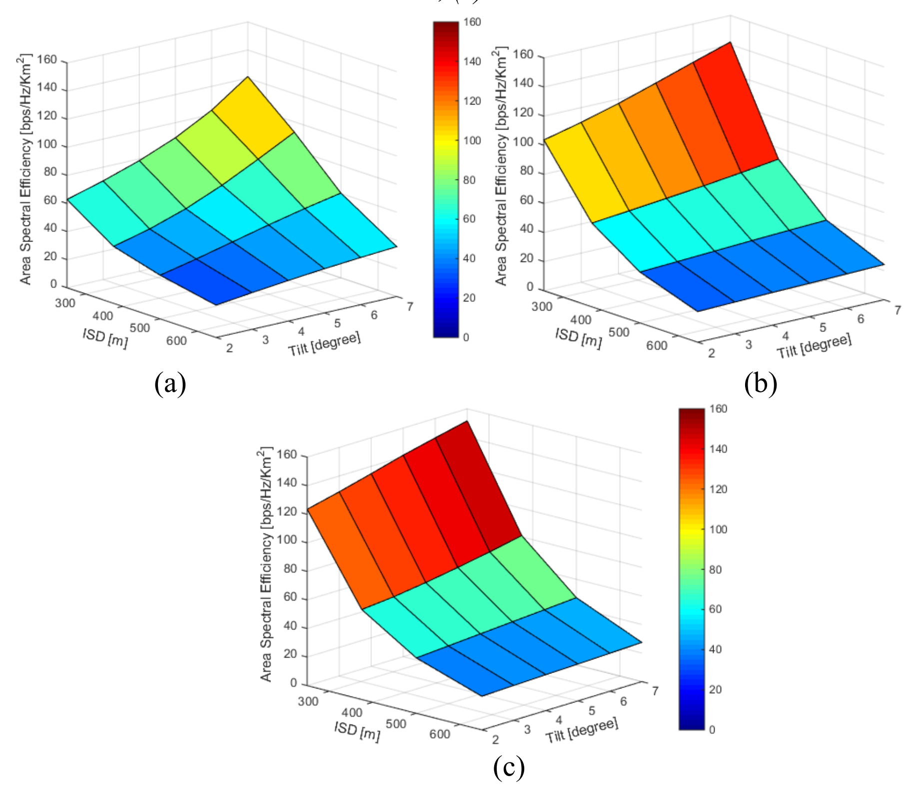


Figure 12. Area spectral efficiency of 6-sector sites with intersite distance 250 m and above, (a) 32° horizontal HPBW antenna, (b) 16° horizontal HPBW antenna, (c) 12° horizontal HPBW antenna

Figure 11 shows the mean area spectral efficiency for the cases of 6-sector sites with different antenna beamwidths and tilts. Six-sector site with 32° HPBW and 7° tilt at 650m ISD offers area spectral efficiency of 35.5 bps/Hz/Km^2 whereas with 3-sector site it was limited to 23 bps/Hz/km^2, at 500 m ISD area spectral efficiency is increased to 60.5 bps/Hz/km^2 by 6-sector site while a maximum of 38.5 bps/Hz/km^2 was achieved with 3-sector configuration. Six-sector site continues to show better results compares with 3-sector sites for rest of the other intersite distances. Surprisingly, area spectral efficiency of about 952 bps/Hz/km^2 can be achieved with sector site deployed with narrow 12° HPBW antenna and 7° tilting. These results support the deployment of higher order sectored sites at large and small intersite distances to enhance the network capacity without installing the additional sites. It also shows that for ultra dense networks, 6-sector site with narrow antenna pattern can provide better results compared to traditional 3-sector sites.

From the results presented so far in this paper, now it is established fact that the site densification and sector densification increases the area spectral efficiency, however it would be interesting to see the relative gain achieved by aforementioned techniques at the cost of utilizing extra cells.

In this paper a case of 3-sector site with 65° HPBW antenna with 2° downtilt tilt at 500 m intersite distance is assumed as a reference case. The relative cell density in 1 km^2 area for all ISDs is computed assuming a reference cell density of 500 m intersite distance case. The relative cell density of 0.57, 1, 1.78, 4, 15.85, and 24.78 corresponds to the ISD of 650 m, 500 m, 375 m, 250 m, 125 m and 100 m, respectively. The relative results presented in Figure 13 and Figure 14 are with respect to the considered reference case. The x-axis indicates the intersite distance in meters, the y-axis shows the antenna downtilts in degrees, and the z-axis shows the relative area spectral efficiency gain in times. From the results presented in Figure 13 and Figure 14 it can be seen that the relative area spectral efficiency does not increase linearly with relative cell density, rather it starts to saturate rapidly after relative cell density of 15.85. With 32° and 16° HPBW antennas higher relative gains are achieved. As discussed earlier in this paper, 32° HPBW antenna with 7° tilt shows maximum relative gain. It shows that 43.5 times better area spectral efficiency can be achieved by adding 24.78 times extra cells, and by changing 65° BW antenna with 32° BW antenna, and by adding 5° of extra tilt to the reference case. Similarly, other relative gains against the relative cell density can be seen Figure 13 and Figure 14.

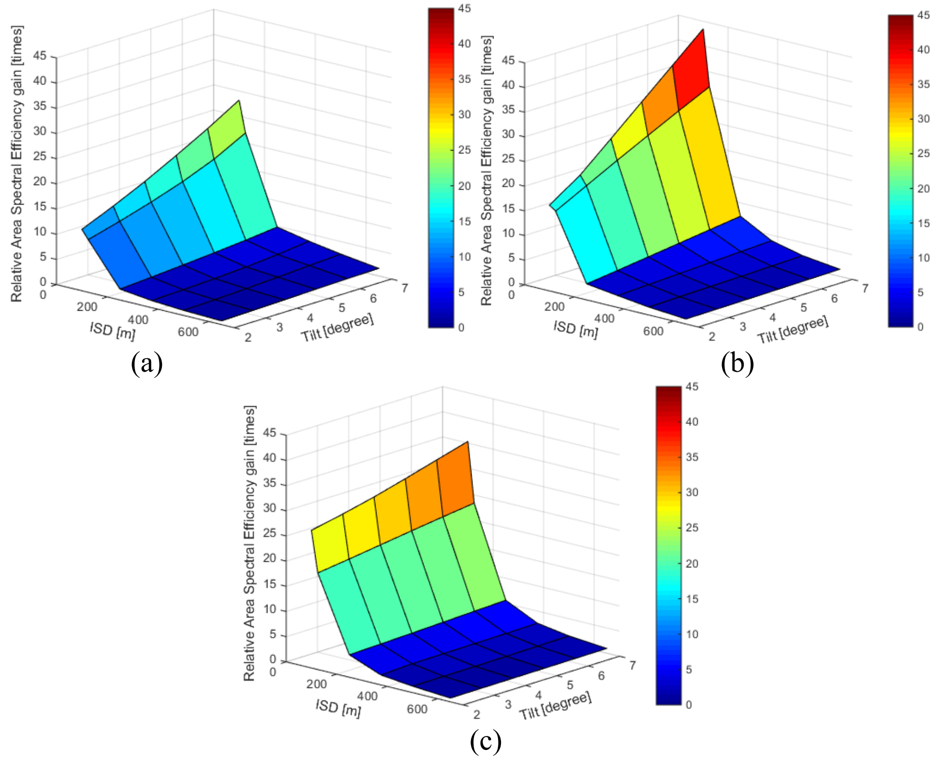


Figure 13. Relative area spectral efficiency gain of 3-sector sites with, (a) 65° horizontal HPBW antenna, (b) 32° horizontal HPBW antenna, (c) 16° horizontal HPBW antenna

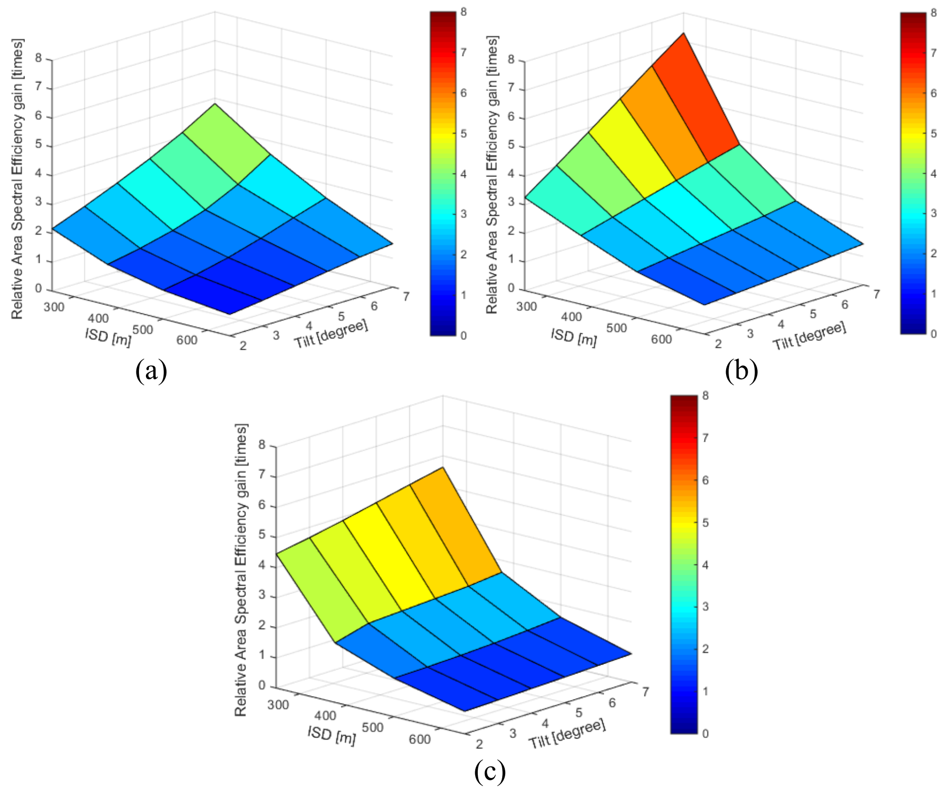


Figure 14. Relative area spectral efficiency gain of 3-sector sites with 250 m ISD and above, (a) 65° horizontal HPBW antenna, (b) 32° horizontal HPBW antenna, (c) 16° horizontal HPBW antenna

Figure 15 and Figure 16 show the relative area spectral efficiency gain for the cases of 6-sector sites with different antenna configurations. It is important to mention here that the relative results presented in Figure 15 and Figure 16 are again with respect to the reference case of 3-sector sites with 65° HPBW antenna and 2° downtilt tilt at 500 m ISD. For smaller relative cell density i.e. large intersite distances of 500 m and 650 m, a 32° HPBW antenna with 7° tilt offers highest relative gain of 3.93 and 2.30 for 500 m and 650 m, respectively. However, for large relative cell densities i.e. for ISD from 100 m to 375 m the best results are obtained with 12° HPBW antenna and 7° downtilt. For better understanding, more detailed comparison and in depth statistical analysis of cell and area spectral efficiency for 3- and 6-sector sites with different antenna configurations is presented in Table. II and Table. III, respectively. As we have only limited space in this chapter therefore results with only least and maximum value of downtilt are presented in Table II and Table thee i.e. with 2° and 7° downtilt. There are two columns showing the values for 'Global relative gain' and 'Local relative gain', where the global relative gain is with respect to the Global Reference (GR) case of 3-sector site with 65° BW and 2° tilt, and the local relative gain is with respect to the Local Reference (LR) case. For different antenna beamwidths and tilts, the case with 500 m ISD is taken as a local reference case. The idea behind the local relative gain was to find only the "densification gain" for the particular antenna configuration, whereas the global relative gain shows the collective gain achieve by using tilt and different antenna beamwidth with respect to global reference case.

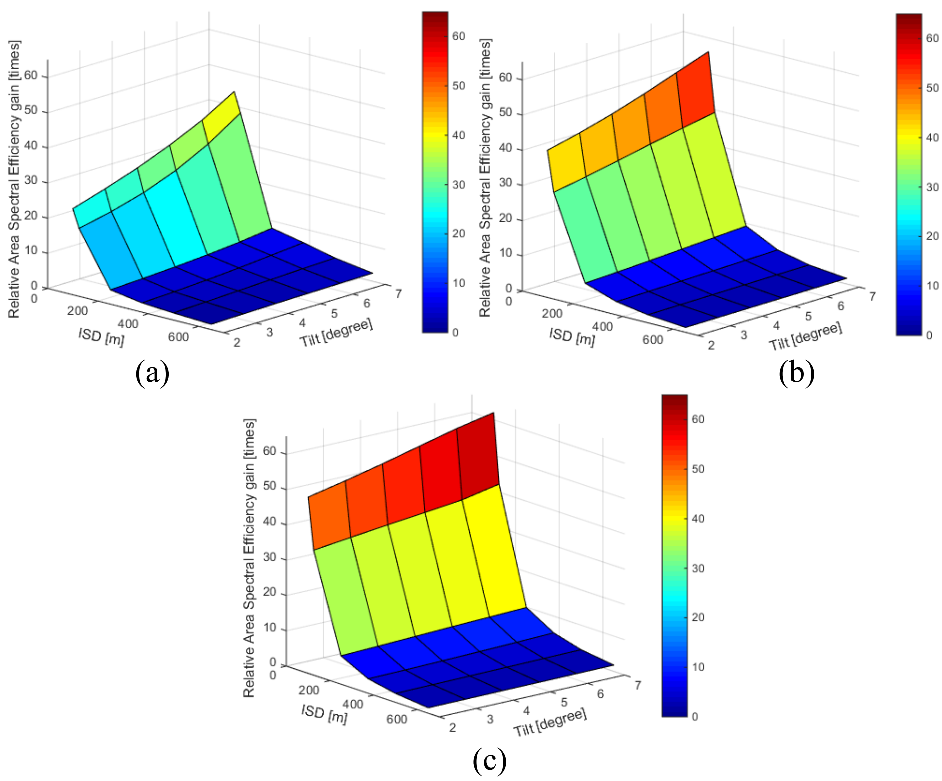


Figure 15. Relative area spectral efficiency gain of 6-sector sites with, (a) 32° horizontal HPBW antenna, (b) 16° horizontal HPBW antenna, (c) 12° horizontal HPBW antenna

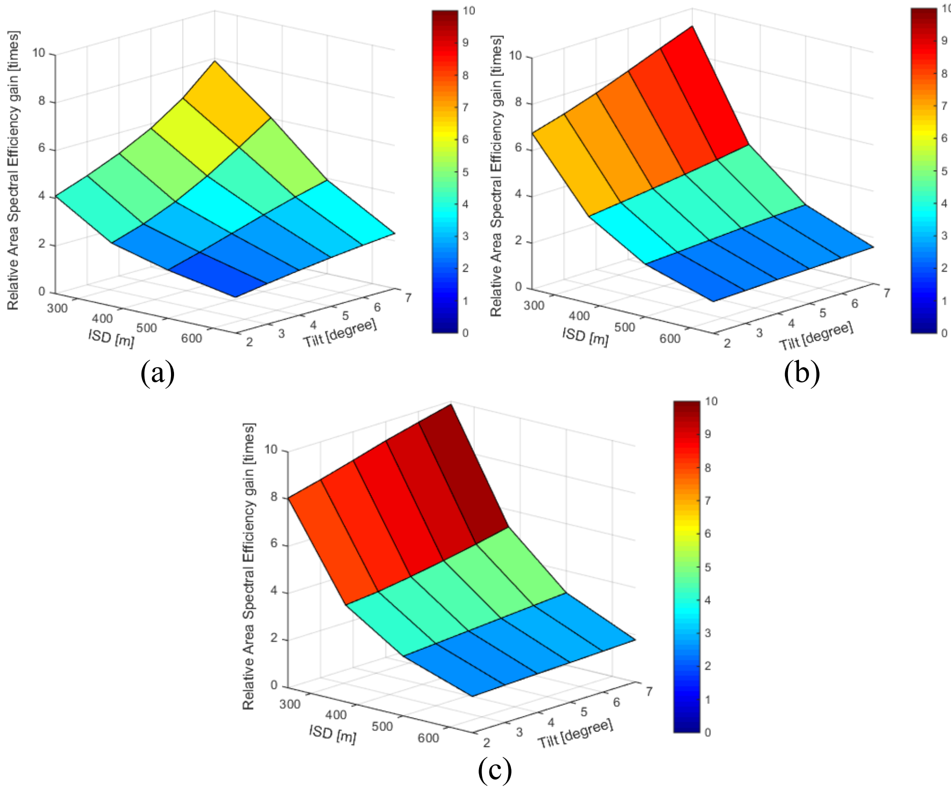


Figure 16. Relative area spectral efficiency gain of 6-sector sites with 250 m ISD and above, (a) 32° horizontal HPBW antenna, (b) 16° horizontal HPBW antenna, (c) 12° horizontal HPBW antenna

Table V. Statistical analysis of spectral efficiency and relative gain for 3-sector sites.

3-sector with 2 degree tilt							
Case	**SINR Mean (dB)**	**Mean Cell Efficiency (bps/Hz)**	**Cells per km^2 (No.)**	**Relative Cell Density (Times)**	**Area Efficiency (bps/Hz/km^2)**	**Local Rel. Gain (Times)**	**Global Rel. Gain (Times)**
65 degree Antenna							
3-sector ISD-100m	-3.43	0.54	347	24.79	187.27	12.20	12.20
3-sector ISD-125m	-1.87	0.72	222	15.86	160.54	10.46	10.46
3-sector ISD-250m	-2.94	0.59	56	4	33.18	2.16	2.16
3-sector ISD-375m	-0.85	0.87	25	1.79	21.63	1.41	1.41
3-sector ISD-500m (GR)	0.56	1.10	14	1	15.35	1.00	1.00
3-sector ISD-650m	2.24	1.42	8	0.57	11.35	0.74	0.74
32 degree Antenna							
3-sector ISD-100m	-1.53	0.77	347	24.79	266.72	10.84	17.38
3-sector ISD-125m	0.80	1.14	222	15.86	252.92	10.28	16.48
3-sector ISD-250m	-0.68	0.89	56	4	49.93	2.03	3.25
3-sector ISD-375m	2.50	1.47	25	1.79	36.84	1.50	2.40
3-sector ISD-500m (LR)	3.77	1.76	14	1	24.60	1.00	1.60
3-sector ISD-650m	4.55	1.95	8	0.57	15.56	0.63	1.01
16 degree Antenna							
3-sector ISD-100m	1.18	1.21	347	24.79	419.76	21.40	27.35
3-sector ISD-125m	1.78	1.33	222	15.86	294.44	15.01	19.18
3-sector ISD-250m	1.24	1.22	56	4	68.40	3.49	4.46
3-sector ISD-375m	1.20	1.21	25	1.79	30.31	1.55	1.97
3-sector ISD-500m (LR)	2.15	1.40	14	1	19.61	1.00	1.28
3-sector ISD-650m	2.30	1.43	8	0.57	11.46	0.58	0.75
3-sector with 7 degree tilt							
Case	**SINR Mean (dB)**	**Mean Cell Efficiency (bps/Hz)**	**Cells per km^2 (No.)**	**Relative Cell Density (Times)**	**Area Efficiency (bps/Hz/km^2)**	**Local Rel. Gain (Times)**	**Global Rel. Gain (Times)**
65 degree Antenna							
3-sector ISD-100m	1.38	1.16	347	24.79	432.78	11.22	28.20
3-sector ISD-125m	2.71	1.33	222	15.86	337.35	8.75	21.98
3-sector ISD-250m	1.76	1.25	56	4	73.98	1.92	4.82
3-sector ISD-375m	5.45	2.03	25	1.79	54.34	1.41	3.54
3-sector ISD-500m (LR)	7.60	2.54	14	1	38.58	1.00	2.51
3-sector ISD-650m	8.04	2.69	8	0.57	23.05	0.60	1.50
32 degree Antenna							
3-sector ISD-100m	4.46	1.94	347	24.79	667.27	18.33	43.48
3-sector ISD-125m	5.61	2.22	222	15.86	491.39	13.50	32.02
3-sector ISD-250m	4.78	2.13	56	4	112.07	3.08	7.30
3-sector ISD-375m	6.22	2.34	25	1.79	59.41	1.63	3.87
3-sector ISD-500m (LR)	7.04	2.53	14	1	36.40	1.00	2.37
3-sector ISD-650m	7.57	2.54	8	0.57	21.98	0.60	1.43
16 degree Antenna							
3-sector ISD-100m	2.91	1.49	347	24.79	542.46	22.29	35.34
3-sector ISD-125m	3.15	1.36	222	15.86	358.99	14.75	23.39
3-sector ISD-250m	2.81	1.45	56	4	86.32	3.55	5.62
3-sector ISD-375m	3.08	0.99	25	1.79	40.00	1.64	2.61
3-sector ISD-500m (LR)	3.69	1.08	14	1	24.33	1.00	1.59
3-sector ISD-650m	3.95	1.17	8	0.57	14.41	0.59	0.94

Table VI. Statistical analysis of spectral efficiency and relative gain for 6-sector sites.

6-sector with 2 degree tilt							
Case	**SINR Mean (dB)**	**Mean Cell Efficiency (bps/Hz)**	**Cells per km^2 (No.)**	**Relative Cell Density (Times)**	**Area Efficiency (bps/Hz/km^2)**	**Local Rel. Gain (Times)**	**Global Rel. Gain (Times)**
32 degree Antenna							
6-sector ISD-100m	-3.40	0.54	693	49.5	376.23	12.12	24.51
6-sector ISD-125m	-2.30	0.67	444	31.71	296.71	9.56	19.33
6-sector ISD-250m	-3.18	0.57	111	7.93	62.82	2.02	4.09
6-sector ISD-375m	-1.23	0.81	50	3.57	40.50	1.30	2.64
6-sector ISD-500m (LR)	0.63	1.11	28	2.0	31.05	1.00	2.02
6-sector ISD-650m	2.33	1.44	16	1.14	23.00	0.74	1.50
16 degree Antenna							
6-sector ISD-100m	-0.46	0.93	693	49.5	641.69	18.37	41.81
6-sector ISD-125m	0.28	1.05	444	31.71	465.17	13.32	30.31
6-sector ISD-250m	-0.41	0.93	111	7.93	103.59	2.97	6.75
6-sector ISD-375m	0.86	1.15	50	3.57	57.53	1.65	3.75
6-sector ISD-500m (LR)	1.38	1.25	28	2.0	34.93	1.00	2.28
6-sector ISD-650m	1.73	1.31	16	1.14	21.04	0.60	1.37
12 degree Antenna							
3-sector ISD-100m	0.62	1.11	693	49.5	766.79	19.78	49.96
3-sector ISD-125m	1.26	1.22	444	31.71	543.53	14.02	35.41
3-sector ISD-250m	0.65	1.11	111	7.93	123.48	3.19	8.05
3-sector ISD-375m	1.44	1.26	50	3.57	62.98	1.62	4.10
3-sector ISD-500m (LR)	2.07	1.38	28	2.0	38.77	1.00	2.53
3-sector ISD-650m	2.49	1.47	16	1.14	23.55	0.61	1.53
6-sector with 7 degree tilt							
Case	***SINR Mean*** **(dB)**	**Mean Cell Efficiency (bps/Hz)**	**Cells per km^2 (No.)**	**Relative Cell Density (Times)**	**Area Efficiency (bps/Hz/km^2)**	**Local Rel. Gain (Times)**	**Global Rel. Gain (Times)**
32 degree Antenna							
6-sector ISD-100m	-0.13	0.97	693	49.5	677.59	11.23	44.15
6-sector ISD-125m	1.80	1.29	444	31.71	590.43	9.79	38.47
6-sector ISD-250m	0.54	1.02	111	7.93	121.22	2.01	7.90
6-sector ISD-375m	4.17	1.83	50	3.57	92.60	1.53	6.03
6-sector ISD-500m (LR)	5.38	2.07	28	2.0	60.33	1.00	3.93
6-sector ISD-650m	5.61	2.14	16	1.14	35.44	0.59	2.31
16 degree Antenna							
6-sector ISD-100m	1.36	1.16	693	49.5	861.31	20.79	56.12
6-sector ISD-125m	1.94	1.30	444	31.71	603.12	14.55	39.30
6-sector ISD-250m	1.54	1.17	111	7.93	141.82	3.42	9.24
6-sector ISD-375m	2.37	1.39	50	3.57	72.32	1.75	4.71
6-sector ISD-500m (LR)	2.53	1.41	28	2.0	41.44	1.00	2.70
6-sector ISD-650m	2.68	1.43	16	1.14	24.22	0.58	1.58
12 degree Antenna							
6-sector ISD-100m	2.02	1.23	693	49.5	952.03	20.19	62.03
6-sector ISD-125m	2.44	1.15	444	31.71	649.14	13.77	42.29
6-sector ISD-250m	1.98	1.10	111	7.93	151.60	3.22	9.88
6-sector ISD-375m	3.16	1.46	50	3.57	80.90	1.72	5.27
6-sector ISD-500m (LR)	3.45	1.58	28	2.0	47.15	1.00	3.07
6-sector ISD-650m	3.58	1.60	16	1.14	27.41	0.58	1.79

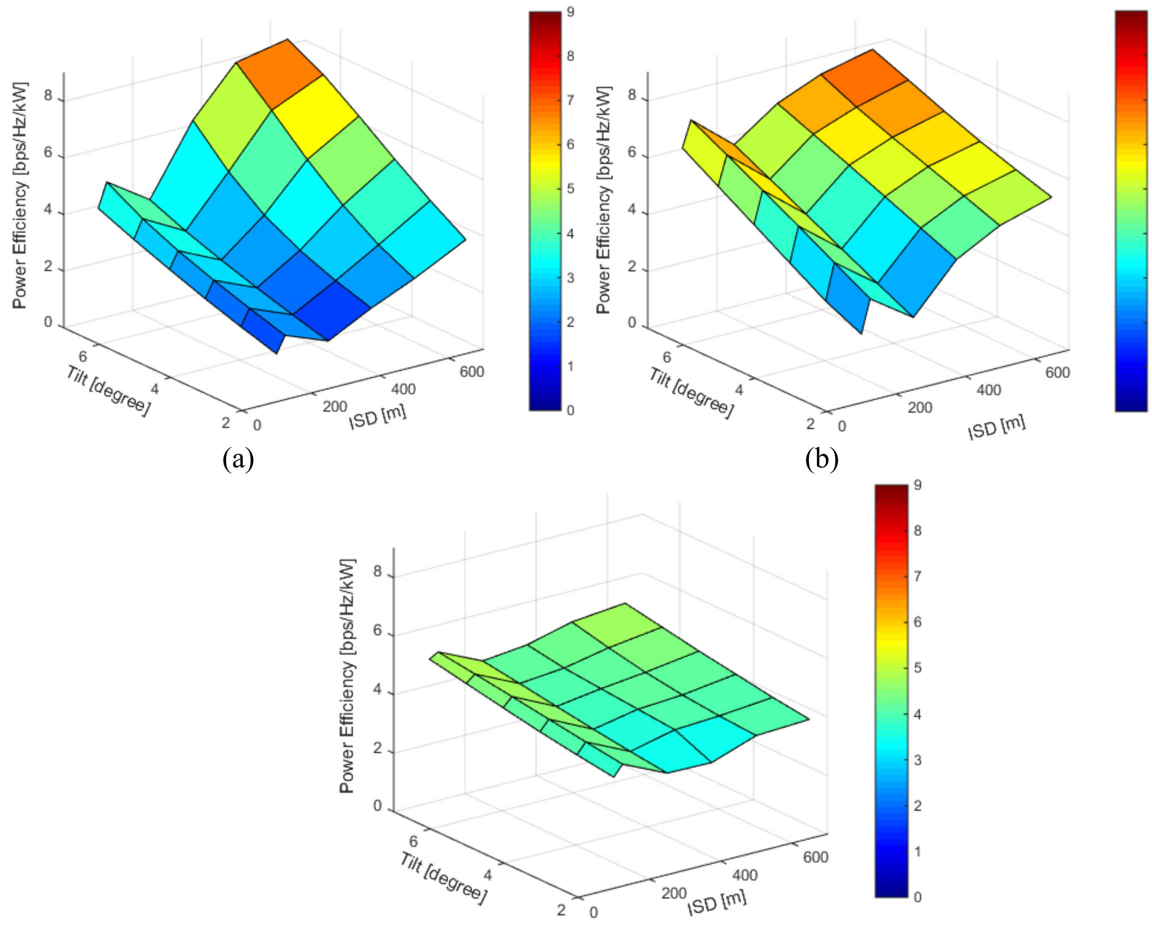


Figure 17. Power efficiency of 3-sector sites with, (a) 65° horizontal HPBW antenna, (b) 32° horizontal HPBW antenna, (c) 16° horizontal HPBW antenna

Figure 17 shows the power efficiency of 3-sector sites with different antenna configurations. Power efficiency is expressed as bps/Hz/kW. The x-axis indicates the antenna downtilt angle in degrees; y-axis shows the intersite distance in meter, and the z-axis represents the corresponding power efficiency in bps/Hz/kW. It is important to mention here that in this study it is considered to have micro base stations and macro base stations for small and large intersite distances, respectively. For 100 m and 125 m ISD, sites are deployed with micro BS station which means less transmission power, and for all other larger intersite distances macro BS is used. It is already shown in Figure 9 that higher area spectral efficiency is achieved with smaller intersite distances, however, Figure 17 shows that higher area spectral efficiency is attained at the cost of extra sites and extra power in the system. Among all considered cases, the highest power efficiency of 8.19 bps/Hz/kW is achieved at 650 m ISD with 65° HPBW antenna and 7° downtilt, and then the power efficiency of the system starts to reduce gradually with site densification. The shape of the power efficiency curve is quite identical to the shape of the SINR curve shown in Figure 7. Similar, trends are observed in Figure 17(a) to Figure 17(c) as observed in SINR curves shown in Figure 7(a) to Figure 7 (c). Again, downtilting is also found as one way to improve the power efficiency of the system.

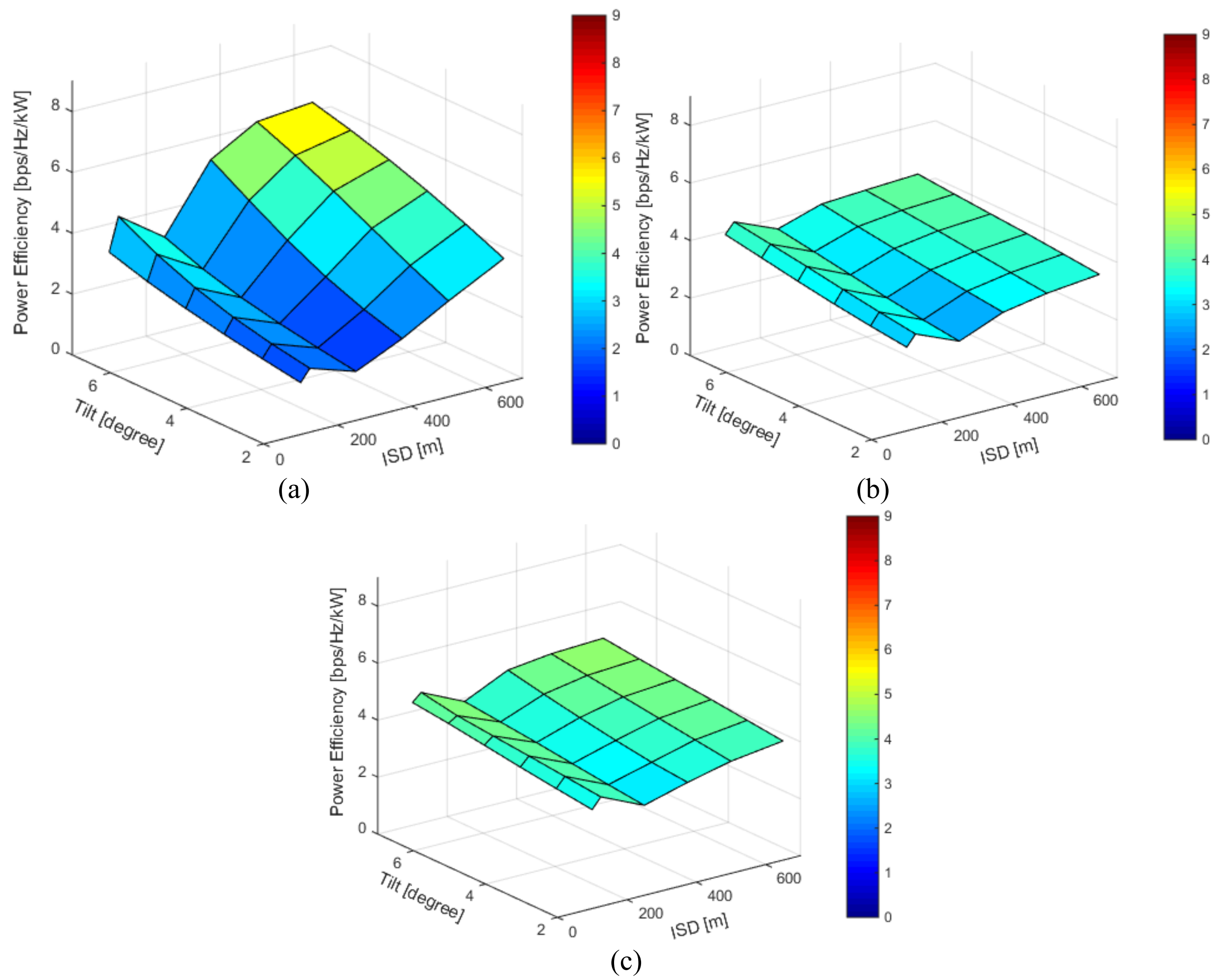


Figure 18. Power efficiency of 6-sector sites with, (a) 32° horizontal HPBW antenna, (b) 16° horizontal HPBW antenna, (c) 12° horizontal HPBW antenna

Figure 18 shows the power efficiency of 6-sector sites with different antenna configurations against different intersite distance and downtilts. By comparing the power efficiency of 3-sector and 6-sector site deployment configurations it is learned that although 6-sector site provides higher area spectral efficiency, but on the other hand 6-sector sites are less power efficient compared with 3-sector sites. Highest power efficiency of 6.29 bps/Hz/kW is achieved with 6-sector site at 650 m ISD with 32° HPBW antenna and 7° downtilt. For 6-sector system with 350 m and less ISD, antenna with 12° HPBW provides better power efficiency compared with 32° and 16° HPBW antenna.

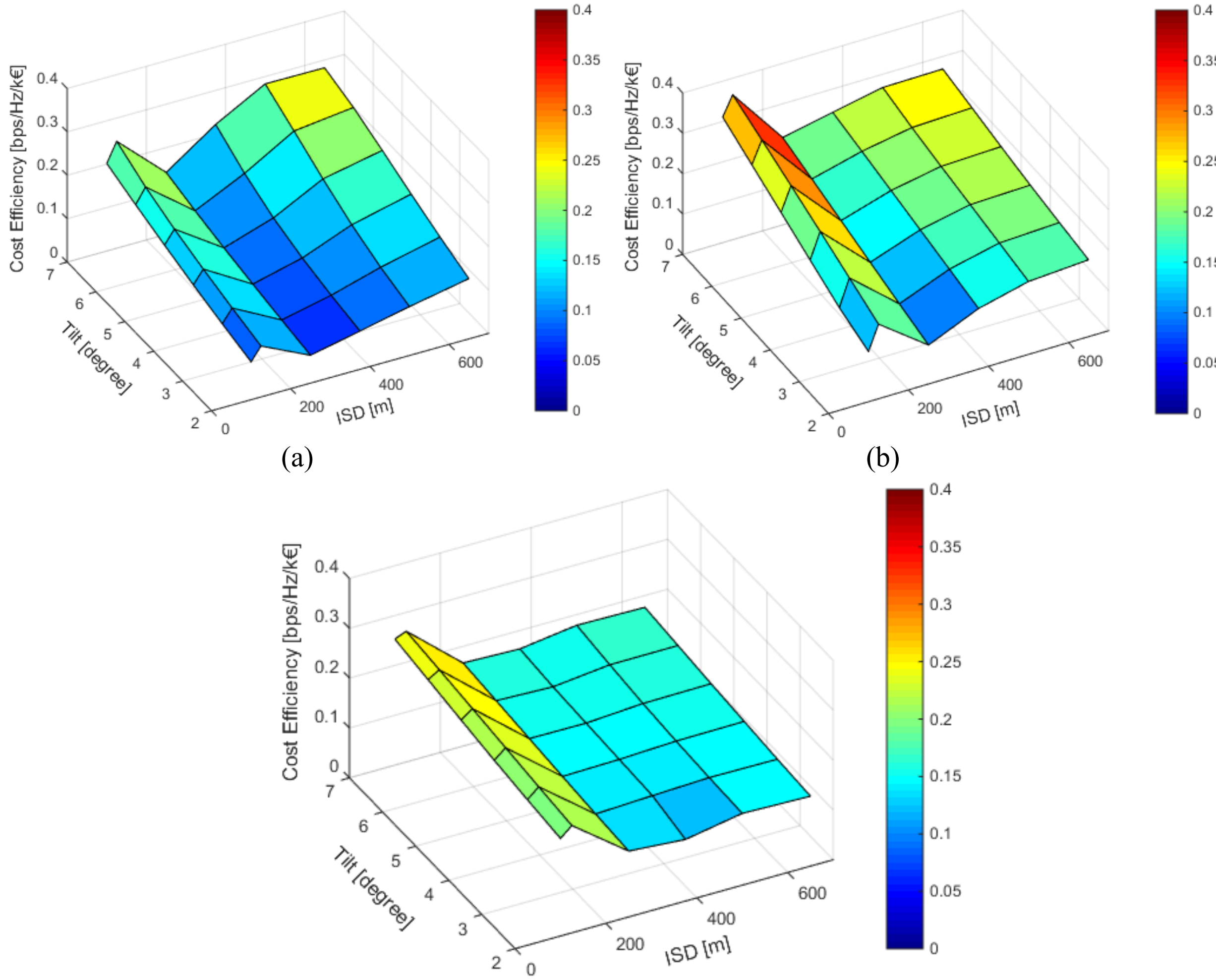
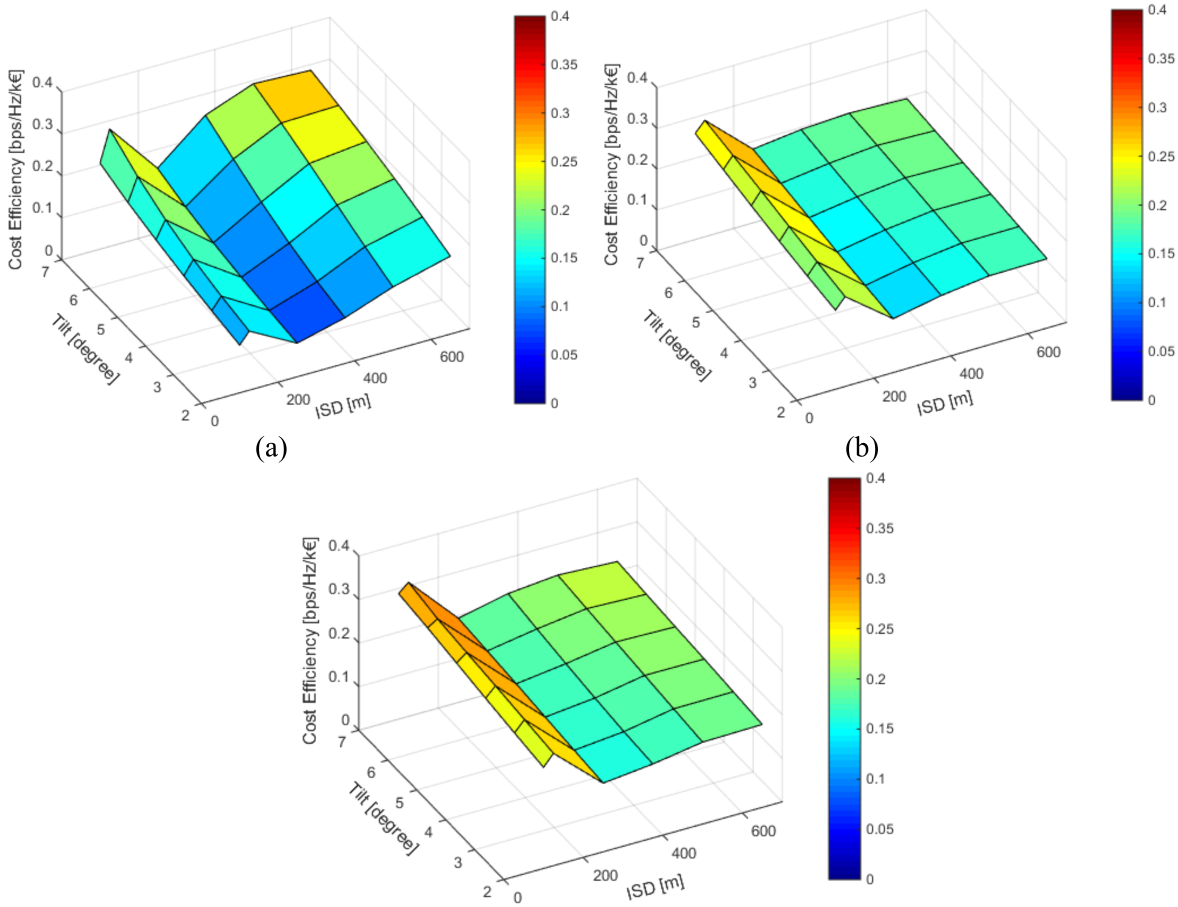


Figure 19. Cost efficiency of 3-sector sites with, (a) 65° horizontal HPBW antenna, (b) 32° horizontal HPBW antenna, (c) 16° horizontal HPBW antenna

In the last section of this chapter, the financial aspects of 3- and 6-sector site deployment are discussed. In the cost analysis, the relevant cost parameters presented in Table II and Table III are considered. Here it is important to bring the attention of the readers that in this study all four antennas of 65°, 32°, 16°, and 12° HPBW are assumed to have same cost price. However, generally the antennas with narrower HPBW are more expensive compared with wider HPBW antenna. Figure 19 shows the cost efficiency of 3-sector sites with different antenna configurations against different. It is learned from the analysis that the most cost effective site deployment strategy for three-sector site among the considered cases is to deploy a micro BS with 32° HPBW antenna at 250 m ISD. Highest cost efficiency of 0.36 bps/Hz/k€ is achieved with the best available deployment strategy. However, at large ISD of 500 m and 650 m, 65° HPBW antenna is slightly more cost effective than 32° HPBW antenna in providing better spectral efficiency.

It is a general perception that due to the addition of extra antennas at the same site location, the 6-sector site deployment is more cost efficient solution in terms of providing a better area spectral efficiency. However, from the results presented in Figure 19 and Figure 20, it is deduced that 3-sector site deployment is more cost efficient than 6-sector site deployment in terms of cost per bps/Hz. It is due to the fact that the addition of extra sectors at the same site does not increase the area spectral efficiency of the system with the same factor as with which extra cells are added. Therefore, the cost efficiency of 6-

sector site is slightly less than 3-sector site. On the other hand, if we consider the same number of cells in the system with 3-sector and 6-sector site i.e. double the number of 3-sector sites in the same area as the number of 6-sector site then the 6-sector site deployment is clearly a better solution. Again for 100 m and 125 m ISD, 12° HPBW antenna is the choice for deployment and for other ISDs 32° HPBW antenna should be used.



(a) (b)

(c)

Figure 20. Cost efficiency of 6-sector sites with, (a) 32° horizontal HPBW antenna, (b) 16° horizontal HPBW antenna, (c) 12° horizontal HPBW antenna

CONCLUSION

From the mobile operators' point of view, it is the core responsibility of the optimization engineers to deploy their network with the best possible antenna configuration in order to provide supreme quality of service and quality of experience to their users. In this chapter, the importance of optimized antenna configuration i.e. antenna beamwidth and antenna downtilt in dense and ultra dense network is shown. Number of cells in the network can be increased either by site densification i.e. increasing the site density by reducing the intersite distance or by increasing the number of sectors at individual site i.e. higher order sectorization. For the research work of this paper, a huge campaign of simulations was done. Post analysis of the simulation results revealed that we need to deploy the sites with non-typical narrow beamwidth antennas for a network with less than 375 m intersite distance. Traditionally, a 3-sector site is deployed with 65° HPBW antenna and the simulation results show that it works fine for a network with large ISD e.g. 500 m and 650 m ISD. However, when the ISD is further reduced and network get more densified, then the 32° HPBW antenna shows better results compared to 65° HPBW antenna. Similarly, in earlier studies it was recommended to use 32° HPBW antennas for 6-sector site, but it was found that for ultra dense network with micro sites it is more beneficial to use 12° HPBW antenna. It was also observed that further narrowing the antenna pattern e.g. 16° HPBW for 3-sector sites does not provide any additional gain, rather the network performance e.g. signal strength, SINR, spectral efficiency and single server dominance area degrades with 16° HPBW antenna for 3-sector site. However the spatial separation between the sectors is fairly small in case of 6-sector site compared to 3-sector site, therefore the SIR was further improved by adopting a narrow 12° HPBW antenna for 6-sector site. The simulation results also validate the fact that an antenna downtilting is an easy and simple way to limit the radio wave propagation. Interestingly, antenna downtilting not only helps in enhancing the network quality rather it also improves the signal strength, single server dominance area, power efficiency and cost efficiency of the system..

Simulation results show that impact of neighboring interferer becomes stronger with site and sector densification the, which in turn reduces the SIR, cell spectral efficiency, and power efficiency. For finding the relative gain of different antenna configurations in terms of area spectral efficiency the traditional 3-sector site with typical 65° HPBW antenna and 2° tilt at 500 m ISD was used as a reference case. Further reducing the ISD or adding sectors (cells) at existing site will relatively increase the cell density in the network. For the case of 3-sector sites, the relative cell density of 0.57, 1, 1.78, 4, 15.85, and 24.78 in 1 square kilometer corresponds to the cases with ISD of 650 m, 500 m, 375 m, 250 m, 125 m and 100 m, respectively. For the reference case of 3-sector site with 65° HPBW antenna and 2° tilt, increasing a cell density by 24.78 times gives a capacity gain (area spectral efficiency gain) of nearly 12.2 times only, which shows the spectral in-efficiency of site densification. However just by changing the antenna tilt from 2° to 7°, a relative gain of 28.2 times in area spectral efficiency can be achieved with 24.78 times cell density. Similarly, changing the 65° HPBW antenna to 32° HPBW antenna along with 7° downtilt boost up the capacity and can give upto 43.5 times more area spectral efficiency compared to the reference case. For the case of 6-sector sites, the relative cell density of 1.14, 2, 3.57, 7.92, 31.71, and 49.5 in 1 square kilometer corresponds to the cases with ISD of 650 m, 500 m, 375 m, 250 m, 125 m and 100 m, respectively. With 32° HPBW antenna and 2° downtilt the relative gain of 24.51 times can be achieved with 49.5 times cell density, whereas the relative gain surge to 42.3 and 62.02 times by adopting 12° HPBW antenna for six sector sites with 31.71 and 49.5 times cell density, respectively.

In the last part of this research work, a comprehensive power and cost analysis was performed. It is concluded that higher area spectral efficiency is attained at the cost of extra sites and extra power in the system. Higher power efficiency is achieved at larger intersite distance with 65° HPBW antenna and aggressive downtilt, and then the power efficiency of the system starts to reduce gradually with site and sector densification. It was found that the most cost effective site deployment strategy for three-sector site among the considered cases was to deploy a micro BS with 32° HPBW antenna. The cost efficiency of 6-sector site was slightly less than 3-sector site assuming same number of sites in the area. While considering the same number of cells in the system with 3-sector and 6-sector site i.e. double the number of 3-sector sites in the same area as the number of 6-sector site then the 6-sector site deployment is found as more cost effective solution.

For future work, it would be interesting to concentrate on analyzing the gain of using vertical sectorization along with horizontal sectorization. It would be interesting to study the impact of antenna beamwidth in horizontal and vertical plane for two dimension (2D) sectorization.

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