

# PERFORMANCE OF SPOTLIGHT COVERAGE IN MANAGING THE INTERFERENCE IN MULTI-ANTENNA CELLULAR ENVIRONMENT

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## Abstract

This paper presents a unique concept of 'Spotlight coverage' for outdoor multi-antenna (or DAS) cellular systems. This concept helps in achieving high Signal-to-Interference Ratio (SIR) throughout the cell coverage area by effectively controlling the leakage into the neighboring cells. Interference and coverage analysis of traditional wall mounted and street lamp mounted (providing spotlight coverage) multi-antenna cell have been presented and compared. Results show considerable improvement in the SIR for street lamp mounted multi-antenna cells.

**Keywords:** Cell layout; Outdoor DAS; Multi-antenna; spot light coverage

## 1. Introduction

The past two decades has witnessed significant progression in the field of wireless communications. This advancement has been mainly triggered by the increase in number of packet data users coupled with demand for high data rates. Initially, wireless communication industry was focused on providing circuit switched services with seamless mobility and very low data rates to the users. However, as the internet technology progressed, new web applications and services surfaced in the market that ranged from multimedia applications to business tools. This enabled many businesses to go online. In order to survive the 'dot com' boom as well as stay in competition with other broadband technologies like (DSL/ADSL, HFC etc), the wireless industry shifted their focal point from circuit switched services to packet switched services. This resulted in evolution of mobile networks from traditional circuit switched networks (like 1G and 2G) towards mobile broadband networks (e.g. HSPA, WiMAX, LTE).

The evolution process mainly brought about change in the radio access part of the network. Initially, TDMA/FDMA was used in the 2G

systems. Later, it was changed to a spectrally efficient CDMA scheme, when 3G systems stepped in. However, with the inception of new wireless broadband technologies like WiMAX and LTE, the radio interface has been revamped with an even more spectrally efficient OFDMA scheme.

Wireless communication channel, like every other transmission medium, has a cap on its maximum capacity. This capacity limit was presented in 1948 by Claude E. Shannon in his ground breaking paper 'A Mathematical Theory of Communication'. Shannon showed that for any communication channel with certain bandwidth and noise characteristics, the maximum channel capacity is given by [1]:

$$C = W \log_2(1 + SNR) \quad (1)$$

Where, C is the maximum capacity of the channel in bits per second, W is the channel bandwidth in hertz, SNR is the signal to noise ratio. Thus, one way of increasing the capacity of the channel is by increasing the channel bandwidth. Unfortunately, the RF spectrum is a scarce resource and increasing the channel bandwidth is not a viable business option for operators as it is very expensive. An alternative solution is to use the radio spectrum efficiently i.e. pack more bits per Hz by using advanced modulation schemes (e.g. m-QAM etc). However, as the order of modulation gets higher the constellation points come closer and become more susceptible to noise. This can cause high bit error rates, at the receiving end, for small signal to noise ratio and hence decrease the effective throughput of the cell, as evident from Equation (1). This is the sole reason that despite new technologies being introduced (e.g. HSPA, WiMAX etc.); the peak data rate is achieved only near the antenna region. As we go further away from transmitting antenna, the signal levels drop causing the SNR to degrade and reduce the data rate correspondingly.

In this paper, we have studied and presented a possible solution to the aforementioned problem

by using distributed antenna systems to ensure almost constant signal strength throughout the cell coverage area.

## 2. Multi-antenna cell configurations

Multi-antenna cell or outdoor distributed antenna cell is a set of small antennas spatially distributed across a geographic location and linked to one base station. The antennas may be connected to the base station by fiber optic cable or some other transmission medium. The concept of outdoor DAS has been around for quite some time but was not until recently that it started to gain momentum among the wireless carriers. The technology provides coverage in the dead spots that cannot be fulfilled by the macro cells – typically in dense urban environment. Moreover, by breaking down the macro cells into smaller pieces, it enhances the overall capacity of the system.

One of the aspects of multi-antenna system that has not been given fair attention in the literature is the practical deployment. In traditional cellular concept, frequencies are reused with a certain frequency pattern that follows a certain tessellation e.g. hexagon, square, or triangle [2-3]. These tessellations are typically used with macro cell, where the antenna is above is average roof top level. Unfortunately, such tessellations cannot be used with multi-antenna systems as the average height of the antenna is around 8-10 m (microcell scenario). Nevertheless, the multi-antenna cells have to be repeated with certain pattern in order to avoid interference with neighboring cells.

In dense urban environment, the outdoor distributed antennas are typically mounted below the rooftop level, as in microcellular case. The most common methods of deployment are; antennas mounted on walls of a building (usually facing straight) or they can be placed on street lamps.

In this paper, both wall mounted and lamp post mounted multi-antenna cellular systems have been studied and their performance have been evaluated and compared. A unique tilting concept has been presented in which the antennas mounted on a lamp post are facing downward i.e. the main lobe of the antenna is pointing directly down towards the street, as shown in Fig. 1. This orientation of the antenna results in a coverage footprint similar to that of a spotlight; hence we have named it ‘spotlight coverage’.

## 3. Simulation Environment

An ideal Manhattan grid city was created for the simulations. The fictive city is a square region with identical building blocks of size 200 m x 200 m

and building height of 50 m. The street width is 30 m and all the buildings are aligned in rows and columns.

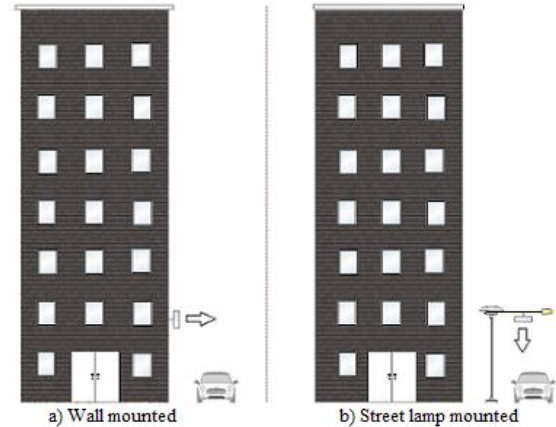


Fig. 1 a) Wall mounted b) Street lamp mounted configuration (Arrow indicates the direction of antenna bore site).

### 3.1 Simulation Scenarios

As mentioned in section 2, multi-antenna cells have to be repeated with certain tessellation in order to avoid interference with neighboring cells. In this paper, symmetric rectangular cells with 8 and 4 antennas per cell have been used, based on [4], to evaluate the performance of wall-mounted (without tilt) and street lamp mounted (downward tilted) antenna configurations. Figs. 2a-b show the different layouts for wall mounted and street lamp mounted antennas. The dots represent the position of the antennas and the different colors represent different cells. Antennas with same color are actually remote antennas belonging to the same base station.

In Fig. 2a-b, the cell bounded by a black rectangle is the middle cell which is of interest and will be considered in the performance analysis. This is due to the fact that the middle cell is surrounded by first tier of interfering cells and hence suitable for interference studies. The second tier of cells has almost negligible effect on the SIR, thus, it has not been considered in the simulation.

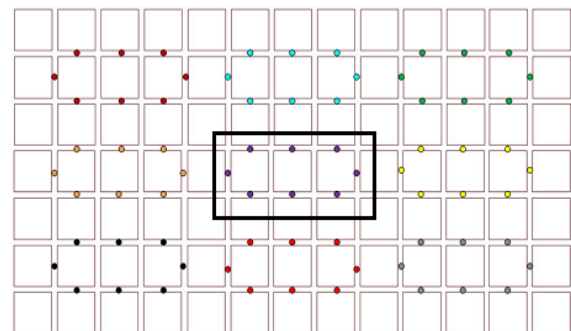


Fig. 2(a) 8 antennas per cell – Street lamp mounted configuration

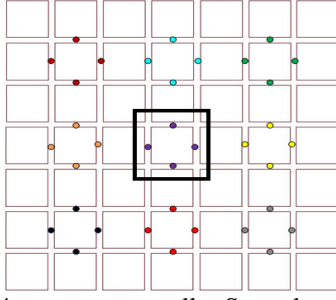


Fig. 2(b) 4 antennas per cell – Street lamp mounted configuration

### 3.2 Simulation Parameters

The simulation parameters were chosen according to dense urban environment. The antenna height for multi-antenna system was 8 m (both, for wall mounted and street lamp mounted scenario). The receivers were spatially distributed across the whole coverage area and were 5 m apart from each other. The antenna height for the receiver was 1.8 m. The transmit power per antenna was set at 10 dBm. The operating frequency was chosen to be 2100 MHz with 20 MHz system bandwidth.

One of the key antenna parameter that has some noticeable influence on the coverage as well as interference leakage is the antenna horizontal ‘Half Power Beam-Width’ or HPBW. Thus, four different antenna beam widths were chosen for the simulation: 12/30/53/82 degree horizontal HPBW. The antenna patterns for the corresponding beam widths were chosen from two well known antenna manufacturers: Andrew Corp and Kathrein. However, the choice of antennas was very limited, considering the fact that the antennas should be suitable in size for urban microcell deployment. The following table summarizes the system parameters used in the simulation:

**Table 1: System Simulation Parameters**

<i>Parameter</i>	<i>Value</i>
Operating Frequency	2100 MHz
System bandwidth	20 MHz
DAS antenna height	8 m
Receiver antenna height	1.8m
Tx power per antenna	10 dBm
DAS antenna type	Directional (microcell)
Receiver antenna type	Half wave dipole
Spacing between receivers	5m
Antenna Type 1: Kathrein 80010368	18.8 dBi gain and 12 HPBW
Antenna Type 2: Andrew DB992HG28N-B	16 dBi gain and 30 HPBW
Antenna Type 3: Kathrein 742192	11.5 dBi gain and 53 HPBW
Antenna Type4: Kathrein antenna 742290	7.1 dBi gain and 82 HPBW

## 4. Performance Analysis

Although, there are many parameters that could be considered in the performance evaluation of a system, however, in this paper we have restricted ourselves to the average Signal-to-Interference ratio over the entire coverage area and the cell coverage area. The cell layouts have been carefully designed to control the interference leakage into the other cells.

The SIR is calculated at each receiver point, based on few steps. At each receiver point, signal strengths from each multi-antenna cell are calculated using deterministic ray tracing model. The ray tracing model first calculates the propagation paths, of individual rays, at each receiver point using Shoot and bouncing method (SBR) as described in [5-6]. After calculating the propagation paths, the electric field strength is calculated by using Uniform Theory of Diffraction (UTD), as described in [5-7]. (Note: the signals coming from different antennas of the same cell are summed up and a receiver gets the total combined signal strength of that cell). After computing the signal strengths of individual cells at each receiver location, the cell dominance area is found by calculating the serving signal (the highest signal strength of a cell at a receiver is the serving signal and the rest are considered as interferers). Once the serving signal strength at each receiver point is known, the SIR is computed by using the following equation:

$$\frac{S}{I} (dB) = 10 \log_{10} \left( \frac{Pr_i}{\sum_{j=1}^N Pr_j} \right) \quad (2)$$

Where,  $Pr_i$  is the received signal strength from the serving cell, and  $Pr_j$  is the received signal strength from the  $j$ th interfering cell,  $N$  is the total number of first tier interfering cells. It is relevant to mention that the ray tracing model did not consider indoor penetration or receivers inside the buildings – Just to make the computation less complex.

## 5. Simulation Results

Due to limited space, the SIR performance maps for wall mounted and street lamp mounted multi-antenna cells for only 30 degree HPBW antenna have been shown in Figs. 3a-d. In both 8 antennas per cell and 4 antennas per cell layout, the street-lamp mounted configuration outperforms the wall-mounted multi-antenna configuration. The difference in SIR performance between street lamp mounted configuration and wall mounted configuration is attributed to the street canyon effect which has great influence on the interference

pattern. Street canyon effect is a propagation phenomenon that occurs in dense urban areas with high rise buildings and where antennas are mounted below rooftop level. In such environment, the high rise buildings give rise to canyon like propagation along the line of sight streets. In wall mounted configuration, the street canyon effect is clearly more, due to the orientation of antenna radiation pattern, and this causes interference leakage into the neighboring cells. On the other hand, as the main lobe is totally facing down towards the street, the interference is well controlled in the street lamp configuration. The spotlight coverage concept greatly reduces the street canyon effect and improves the overall SIR performance.

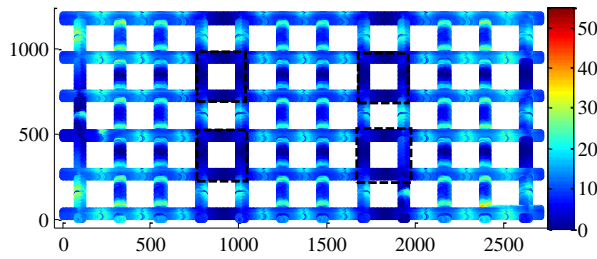


Fig. 3(a) SIR Map for 8 antennas per cell - Wall mounted multi-antenna configuration (in dB scale)

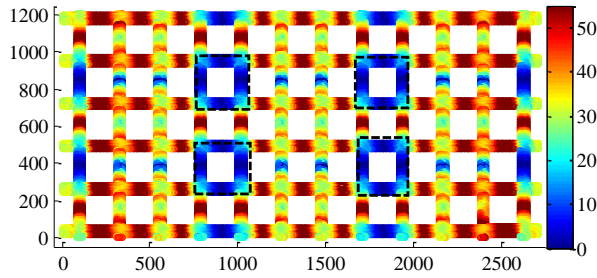


Fig. 3(b) SIR Map for 8 antennas per cell - Street lamp mounted multi-antenna configuration (in dB scale)

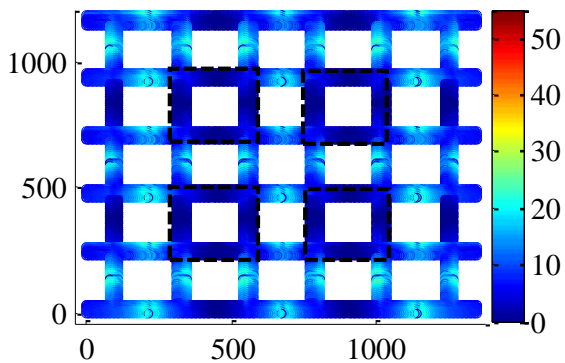


Fig. 3(c) SIR Map for 4 antennas per cell - Wall mounted multi-antenna configuration (in dB scale)

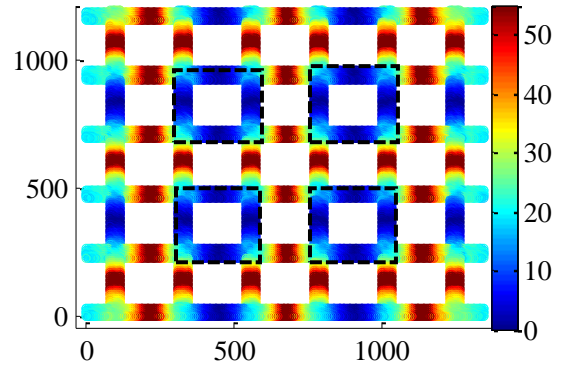


Fig. 3(d) SIR Map for 4 antennas per cell - Street lamp mounted multi-antenna configuration (in dB scale)

The CDF plot of SIR distribution, over the entire coverage area, for street lamp and wall mounted configuration for different layouts has been shown in Fig. 4. Clearly, the street lamp mounted configuration shows superior performance.

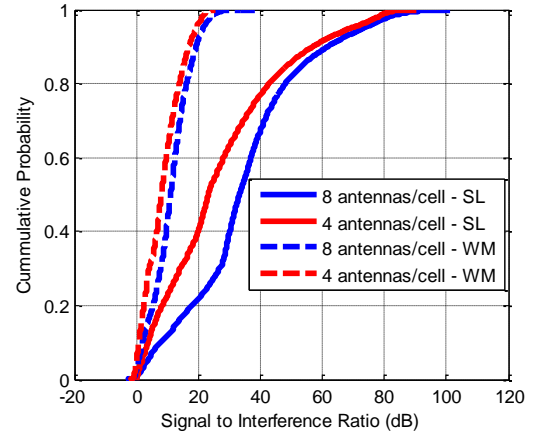


Fig. 4 SIR distribution of Street lamp (SL) and Wall mounted (WM) configuration.

In Figs. 3a-d, the regions bounded by black (dashed) rectangles are the bad SIR regions. In order to minimize the bad SIR area, additional cells were used to improve the SIR.

Figs. 5a-b show the SIR maps of street lamp mounted and wall mounted configuration for 4 antennas per cell layout. By introducing the supplementary cells in the bad SIR region, the overall SIR for wall mounted antenna got even worse, where as for street lamp mounted configuration, the SIR performance improved in bad regions with very little effect on the overall SIR distribution.

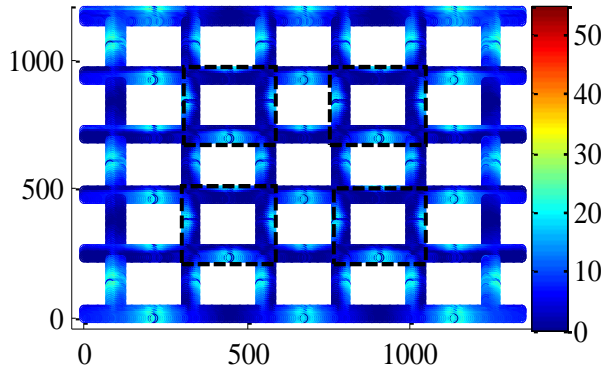


Fig. 5(a) SIR Map for 4 antennas per cell – Wall mounted configuration – with added cells (in dB scale)

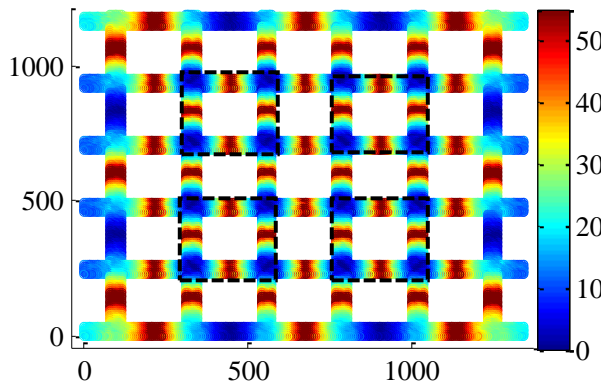


Fig. 5(b) SIR Map for 4 antennas per cell – Street lamp mounted configuration – with added cells (in dB scale)

Table 2 summarizes the average SIR results for street lamp and wall mounted configuration for different layouts and antenna beam widths:

**Table 2: SIR Performance results for street lamp and wall mounted configurations**

Configuration	HPBW	Average SIR (dB) over whole Coverage Area		Average SIR (dB) over the middle cell	
		without extra cells	with extra cells	without extra cells	with extra cells
8-antennas per cell (Street lamp mounted)	12	35.3	32.4	31.33	27.2
	30	34.72	29.2	31	27
	50	34.29	28.8	30.7	26.7
	82	31.3	26	26.71	23
8-antennas per cell (wall mounted)	12	17.01	15.5	15	12.6
	30	11.5	9.3	9.31	6.83
	50	10.8	8.01	8.01	5.3
	82	9.7	7.3	7.1	4.4
4-antennas per cell (Street lamp mounted)	30	27.24	26.1	27	23
4-antennas per cell (wall mounted)	30	8.51	7	7.38	4.79

## 5 Conclusions and discussion

In this paper, we have presented and proposed a unique concept of ‘spotlight’ coverage for multi-antenna cellular system for achieving high average SIR over the cell area. The performance of our proposed concept has been compared with traditional wall mounted multi-antenna systems.

Based on the simulations results shown in Table 2, the spotlight coverage concept outperforms the traditional wall mounted multi-antenna configuration by effectively controlling the interference leakage into the other cells. The effect of decreasing the cell size or adding extra cells, to coverage gaps, has very little effect on the down tilted configuration. Moreover, the antennas with small HPBW beam width have shown to improve the SIR, in both street lamp and wall mounted antenna configuration.

## Acknowledgements

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