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# MIMO Capacity Analysis For Spatial Channel Model Scenarios

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***Abstract:*** *With the advancement of wireless communication and extensive research for new technologies for more reliable, secure and high speed connection, MIMO is coming up as the foremost competitor. In this research, we investigate MIMO system capacity using Spatial Channel Model (SCM) proposed by 3GPP-3GPP2 standard for the third generation systems and compare to one major physical model i.e. the One Ring Model. Also, we contrast with a theoretical model namely independent and identically distributed (i.i.d.) model. We present a system model for investigating MIMO systems followed by detailed analysis of channel parameters and capacity analysis. A simulation tool is developed to evaluate the capacity of N-LOS MIMO systems in SCM with scenario of multipath propagation. Further, it is compared with i.i.d. and One Ring model. The study shows that the channel capacity increases in almost linear fashion with addition of number of antennas, but the rate of linearity is higher in Waterfilling schemes and comparatively lower in Equal Power schemes. For practical implementation, the compact MIMO systems are more desirable, so we investigate the effect of mutual coupling due to closely spaced antennas. This study shows that mutual coupling leads to increase in the capacity for which the spacing is less than approximately 0.4 λ.*

***Keywords:*** *MIMO, Multipath, Mutual Coupling, Induced EMF, SCM, Equal Power, Waterfilling, i.i.d., One Ring, Scatterers*

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## I. Introduction

Recent years have witnessed drastic changes in the growth of telecommunication industry, specifically in the realm of wireless communication domain. These changes have a significant impact on everybody's life on one way or other business. The growth of telecom industry is supported by the wide spread usage of mobile telephones and wireless devices. Despite the throughput rate being limited as compared to that of the wired connections, the recent advents in the wireless industry have succeeded in providing a competitive solution. Moreover, with the enhancement of wireless subscribers and the growth of internet industry, it is obvious that the usage of wireless medium and devices is going to rise exponentially in next few years. With the increase in usage, the need and the demand of the customers for a better application and high performance and speed is expected. Radio spectrum in wireless communication is a finite resource. Numerous researches and efforts are being conducted so as to make prudent use of the available limited spectrum. This enables the efficient use of spectrum and fulfills the increasing need and demand of the wireless communication, industry and makes it possible for efficient communication.

This research primarily focuses on analysis of capacity of MIMO for spatial channel model (SCM) and we need to review the fundamentals literature of MIMO system capacity i.e. MIMO system capacity, modelling of MIMO channel model and effect of mutual coupling on MIMO capacity. In today's era the demand is growing rapidly for the wireless communication system with high capacity, excellent development of applications and increase in the data transmission rate (capacity). The MIMO system has the potential to increase the data throughput in a spectrum limited scenario. The spectrum efficiency improvement in physical layer will be overloaded as the complexity and traffic of wireless application will grow. So, MIMO is being promoted as the best major feature for next generation wireless networking [1, 2]. In contrast to traditional smart antennas (SA), which enhances the single data stream quality, the MIMO system offers multiple independent transmission channels leading (certain condition imposed) to a channel capacity that grows linearly with the antenna element numbers [3]. As there are much advancement in the wireless communications and these have lead to focus the wireless modeling channel. Improvements in the wireless technologies and complications of the system broadcast calls for further research. Furthermore, the role of technology is imperative in studying the capacity of the MIMO system. The variations in the characteristics of channel allow the comparison of MIMO with independent and identically distributed. Researchers, in order to know the capacity of MIMO, have applied the independent and identically distributed channel model [4, 5]. Based on the parameters of channel the MIMO communication can be categorized in to the physical as well as in the non-physical modeling [6].

One Ring model is characterized as having the scattered environment and also involves the MIMO channel model with scattering measurements. Here, the one ring model has been used for the comparison with the independent and identically distributed model. One Ring model focuses on the distance between the elements that can help study the effects of correlation as well as of coupling [7, 8]. If the distance between elements of antenna is low then this would strengthen the mutual coupling. Usually, mutual coupling means that the current produced in one antenna will also provide voltage to the elements of the closed antenna. MIMO system capacity is decreased by the signal correlation and several of the antenna elements. One type of MIMO system is compact MIMO system and in that system these types of correlation are produced more because the distance is small. Additionally, we can say that with the small distance the mutual coupling of antennas becomes more significant [9, 10, 11]. The affect which mutual coupling puts on the MIMO system capacity has gained much of the attention of the researchers. If we talk about the practicality then the small spacing is good for the mobile users and mobile devices like telephones and laptops. However, this is also empirically seen that the small spaces in the antennas affect the mutual coupling and creates signal correlation among the elements of antennas. In the MIMO system, to calculate the mutual coupling mathematically, the Induced Electromotive Force can be used. EMF is the approach of moments. Through this, the numerical computation is also possible. If the order is same, then there are the chances for the increase in the computational complexity. The focus of this study is the induced electromotive force.

If the mutual coupling exits then the capacity performance can surely be affected as the mutual coupling creates the different among wide ban and narrow band cases. In wide band case, the antenna system in dipole can reduce the capacity performance at the level of antenna separation. This, on the other side, does not happen in narrow band case. The environment that has been analyzed, that the capacity has been decrease by 30% in comparison to the ideal model of the system [12, 13].

## II. Memo Channel Model and System Capacity Analysis

### 2.1 SYSEM MODEL

MIMO system composed of three main elements: Transmitter ($TX$), Channel ($\boldsymbol{H}$) and the Receiver ($RX$). Consider a MIMO system composed with '$T$' transmit antenna and '$R$' receive antennas as shown below in Figure 1. These antennas are Omni-directional which can transmit and receive equally in all direction. Let us first understand the transmitter end of MIMO system. Since, there are '$T$' number of transmit antenna so '$T$' symbol can be transmitted on '$T$' transmit antennas. Stack '$T$' symbol into vector$\{x_1, x_2, \dots \dots, x_T\}$. So now it represents as '$T$' dimensional vector. Similarly, we have '$R$' number of receive antenna, therefore '$R$' symbol can received on '$R$' receive antennas. Thereby, resulting $\{y_1, y_2, \dots \dots, y_R\}$ receive vector. MIMO channel transfer '$T$' dimensional input vector into '$R$' dimensional output vector, therefore we have channel matrix '$\boldsymbol{H}$' which is $R \times T$ dimensional matrix.

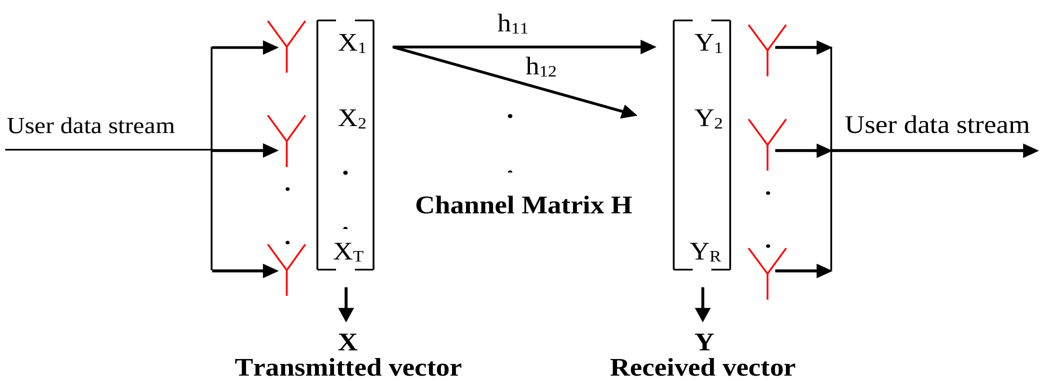



Figure 1: MIMO System Model

Where $h_{ij}$ in the channel matrix '$\boldsymbol{H}$' is channel coefficient between $i^{th}$ receive antenna and $j^{th}$ transmit antennas and $i^{th}$ represents the complex gain between transmitting and receiving antenna. So, MIMO system equation with '$T$' transmit and '$R$' receive antennas is:

$$\boldsymbol{y} = \boldsymbol{Hx} + \boldsymbol{n} \quad (1)$$

**2.2 i.i.d. CHANNEL MODEL**

Independent and identically distributed (i.i.d.) channel model is used for theoretical evaluation of channel capacity where multi-element antennas with enough spacing between transmitter and receiver are employed. This model has additive Gaussian channel with the assumption of having random channel matrix of zero mean, independent and identically distributed entries. Mathematically evaluation of i.i.d. channel model [14, 15] is:

An i.i.d. flat Rayleigh fading MIMO channel is defined as:

$$h_{ij} = \mathcal{N}\left(0,\frac{1}{\sqrt{2}}\right) + j\,\mathcal{N}\left(0,\frac{1}{\sqrt{2}}\right) \quad (2)$$

Where, $h_{ij}$ represents the complex gains between the $i^{th}$ transmit and $j^{th}$ receive antennas, $\mathcal{N}\left(0,\frac{1}{\sqrt{2}}\right)$ is the normal distribution with zero mean and $\frac{1}{\sqrt{2}}$ standard deviation. The independent and identically distributed channel is also known as spatially white channel, which is indicated by $\boldsymbol{H_n}$.

**2.3 ONE RING CHANNEL MODEL**

The One Ring channel model is used for geometry based stochastic channel model. Actually, One Ring model is assumed to a physical model. This model describes an environment on the basis of double directional electromagnetic wave propagation between transmitter and receiver sides.

Considering a single transmission path from $n^{th}$ transmit antenna to $m^{th}$ receive antenna intercepted and reflected by $l^{th}$ scatterers [16, 19], the complex channel gain coefficient can be expressed as:

$$h_{mn} = \frac{1}{\sqrt{L}} \sum_{l=1}^{L} \alpha_l \; exp\left[-j\frac{2\pi}{\lambda}\,(D_{nl} + D_{lm})\right] \quad (3)$$

where, $h_{mn}$ represents the complex gains between $n^{th}$ transmit and $m^{th}$ receive antenna, $\alpha_l$ is scattering coefficient from $l^{th}$ scatter (i.e. $k = 1,2, \ldots .. K$), $\lambda$ is wavelength, $D_{nl}$ is the distance between $l^{th}$ scatter and $n^{th}$ transmit antenna and $D_{lm}$ is the distance between $m^{th}$ receive antenna and $l^{th}$ scatter. Since, scattering coefficient from the $l^{th}$ scatter is modeled as a normal complex random variable with zero mean and unit variance.

**2.4 Spatial Channel Model**

From 3rd Generation Partnership Project (3GPP TR 25.996 version 10.0.0 Release 10), the standardized model is developed to designate the parameter and produce to evaluate system and link levels for spatial channel modelling. It combines ad-hoc group (AHG) with 3GPP-3GPP2 SCM is spatial channel model [10]. It is a two dimensional (2-D) parameter channel model that consists of *n* clusters of scatters where each corresponds to a path and unresolvable *m* sub-paths within a path.

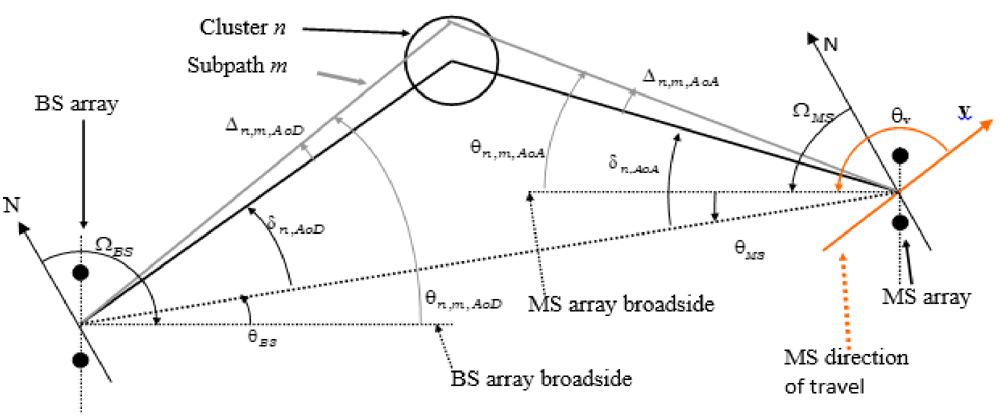



Figure 2: BS and MS angle Parameters of SCM Channel Model

In 3GPP SCM, there is a fixed number of paths, i.e. 6, in every scenario and each is made up of 20 spatially separated sub-paths. A diagrammatic representation of SCM is presented in Figure 2.
The channel coefficients can be produced using the parameters. Complex amplitudes from *U-by-S* matrix are used for one *N* multipath components in the channel coefficients where *(u, s)* component are $s = 1, \dots, S$; $u = 1, \dots, U$. For a *U* element linear MS array and an *S* element linear BS array, $n^{th}$ multipath component where $n = 1, 2, \dots, N$, for channel matrix is indicated as $\boldsymbol{H}_n(t)$ is given by:

$$h_{u,s,n}(t) = \sqrt{\frac{P_n \sigma_{SF}}{M}} \sum_{m=1}^{M} \begin{pmatrix} \sqrt{G_{BS}\left(\theta_{n,m,AoD}\right)} \exp\left(j\left[kd_s \sin\left(\theta_{n,m,AoD}\right) + \Phi_{n,m}\right]\right) \times \\ \sqrt{G_{MS}\left(\theta_{n,m,AoA}\right)} \exp\left(jkd_u \sin\left(\theta_{n,m,AoA}\right)\right) \times \\ \exp\left(jk\|\mathbf{v}\|\cos\left(\theta_{n,m,AoA} - \theta_v\right)t\right) \end{pmatrix} \quad (4)$$

**2.4 MIMO System Capacity with Equal Power**

Assuming that noise is uncorrelated between branches, noise covariance matrix i.e. $K^x = \sigma^2 \boldsymbol{I}$.
The MIMO fading channel capacity can written as:

$$C = log_2\left[\det\left(\boldsymbol{I} + \frac{P_T}{N_T \sigma^2} \boldsymbol{H}\boldsymbol{H}^{\dagger}\right)\right] \quad \text{bps/Hz} \quad (5)$$

For number of transmit antenna and number of receive antennas, the equal power capacity is:

$$C_{EP} = log_2\left[\det\left(\boldsymbol{I} + \frac{\rho}{N_T} \boldsymbol{H}\boldsymbol{H}^{\dagger}\right)\right] \quad \text{bps/Hz} \quad (6)$$

where, $\boldsymbol{det}(.)$ denotes the determinant of a matrix, $\boldsymbol{I}$ is an $N_R \times N_T$ identity matrix, $\rho$ is the average received signal to noise ratio and $\boldsymbol{H}^{\dagger}$ is the complex conjugate transpose of $\boldsymbol{H}$.
Similarly, Equation 6 can be written as in [20, 23],

$$C_{EP} = \sum_{i=1}^{m} log_2\left(1 + \frac{\rho}{N_T}\lambda_i\right) \quad \text{bps/Hz} \quad (7)$$

where, $\lambda_1, \lambda_2 \dots\dots \lambda_m$ are the non-zero eigenvalues of $\boldsymbol{W}$, $m = min(N_R, N_T)$ i.e. . $\lambda_1 \geq \lambda_2 \geq \lambda_3 \dots\dots \geq \lambda_m$ and,

$$\boldsymbol{W} = \begin{cases} \boldsymbol{H}\boldsymbol{H}^{\dagger} & N_R \leq N_T \\ \boldsymbol{H}^{\dagger}\boldsymbol{H} & N_T < N_R \end{cases}$$

**2.5 MIMO System Capacity with Waterfilling**

Waterfilling procedure is employed to optimize the transmitted signal power plan if the transmitter has precise information about the channel. In accordance with the principle of Waterfilling techniques, the total power is distribute in such a manner that the channel with high gains receives higher portion where as a channel with low gains receives less or even none [23, 24].
The capacity of MIMO with Waterfilling solution can be expressed as:

$$C_{WF} = \sum_{i=1}^{m} log_2(\mu\lambda_i)^{+} \quad \text{bps/Hz} \quad (8)$$

Where,

$$\rho = \sum_{i=1}^{m} (\mu - \lambda_i^{-1})^{+} \quad \text{bps/Hz} \quad (9)$$

It is concluded, the Waterfilling algorithm has significant benefits at low signal noise ratio as compared to the equal power scheme. The benefit of Waterfilling has reciprocal relation with SNR i.e. increase in SNR results in decrease in benefit.

**2.5 MIMO Model with Mutual Coupling**

Mutual coupling is well known in the antenna community. Since, coupling between antenna elements is one of the most important properties to consider in antenna design. However, this phenomenon is rarely accounted for studied in the signal processing or communications literature. It is a simple matter to include the coupling effect in the model for the received voltage.
By inserting a mutual matrix in the MIMO system model, proposed system Equation as [24]:

$$y = CHx + n \quad (10)$$

$$y = C_{MR} H C_{MT} x + n \quad (11)$$

Where, coupling matrix at the transmitter $C_{MT}$ is $R \times R$ and the corresponding matrix at the receiver $C_{MR}$ is $T \times T$ matrix respectively.

The coupling effects into the channel by combining the two terms into a new channel matrix $H_M$ is:

$$H_M = C_{MR} H C_{MT} \quad (12)$$

So, Equation 11 becomes:

$$y = H_M x + n \quad (13)$$

MIMO capacity expressions are proposed as:

$$C_{EP} = log_2 \left[\det\left(I + \frac{\rho}{N_T} H_M H_M^{\dagger}\right)\right] \quad \text{bps/Hz} \quad (14)$$

And,

$$C_{WF} = \sum_{i=1}^{m} log_2 \, (\mu \lambda_i)^{+} \quad \text{bps/Hz} \quad (15)$$

Where, $\lambda_i$ are the eigenvalues of $H_M H_M^{\dagger}$.

## III. Results and Analysis

### 3.1 Algorithms

1. Chose the Scenario
- Urban Micro-Cell Scenario (less than 1Km distance BS to BS)
- Urban Micro-Cell Scenario (Approximately 3Km distance BS to BS)
- Sub-Urban Macro-Cell Scenario (3Km distance BS to BS)
2. Find the user parameters for channel coefficients for all scenario
- Distance and orientation parameters
- Channel correlation parameters viz: Delay Spread (DS), Angle of Spread (AS) and Log-normal shadow fading (SF)
- Random delay and Random Average power for each of N multipath components
- Angle of Departures (AODs) and Angle of Arrivals (AOAs) for each of N multipath components
- Powers, Phases offset, Angle of Departures and offset Angle of Arrivals for M = 20 subpaths for each of N path
- Antenna gain of the BS and MS subpaths
- Pathloss for each environment
3. Generate the channel coefficients for multipath propagation scenarios
- Use Equation 2 for i.i.d. model
- Use Equation 3 for One Ring Model
- Use Equation 4 for SCM Model
- Take fft, sum fft and take ifft of sum to obtain each element of complex channel matrix from 6 multipath channel elements
4. Calculate the MIMO system capacity
- ❖ Calculate mean capacity (bps/Hz) as the function of number of antennas
- Use equation 7 for capacity with Equal Power Scheme
- Use Equation 8 for capacity with Waterfilling Scheme
- ❖ Calculate mean capacity (bps/Hz) as a function of Inter-element distance
- Calculate the proposed complex channel matrix as: $H_M = C_{MR} H C_{MT}$
- Use equation 14 for capacity with Equal Power Scheme
- Use Equation 15 for capacity with Waterfilling Scheme
5. Compare the result with Equal Power and Waterfilling Scheme between i.i.d., One Ring and SCM Model Scenarios
6. Conclusions

### 3.2 Simulation Results

The simulation results of mean capacity (bps/Hz) versus the number of antenna at particular value of Signal Noise Ratio (SNR) are presented first. For all cases below the number of antenna at Base Station (BS) and Mobile Station (MS) are Equal i.e. NT = NR.

The effect of mutual coupling due to closely spaced antenna on the capacity of MIMO system are also explored. The simulation results of mean capacity (bps/Hz) versus the inter-element distance of MS antenna in wavelength at particular value of Signal Noise Ratio (SNR) are presented. For all the time spacing in BS antenna array is kept constant to 0.5 λ.

### 3.2.1 Mean Capacity Vs. Number of Antenna (NT=NR)

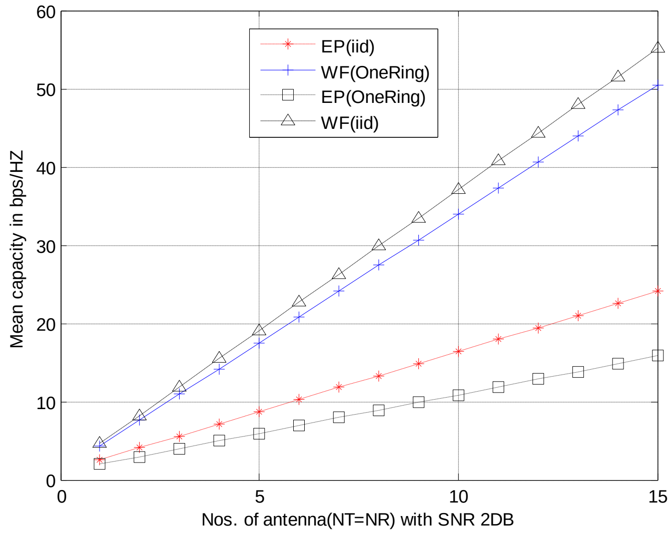
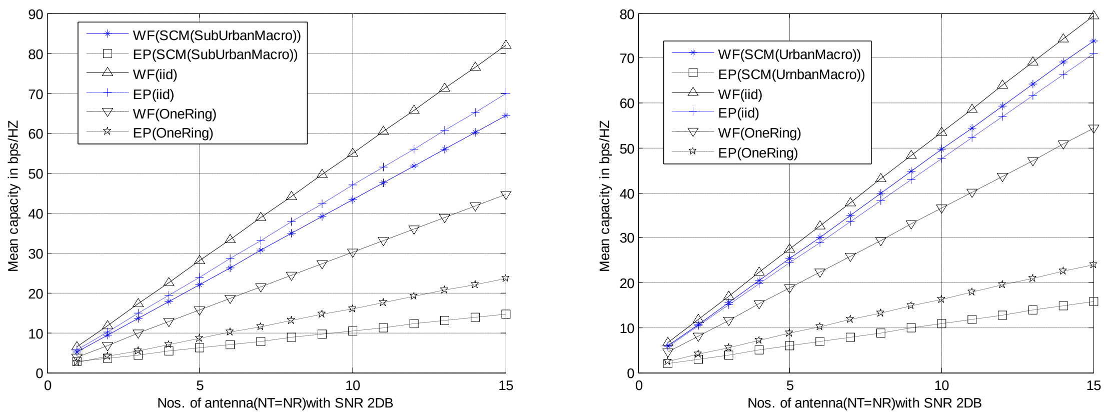
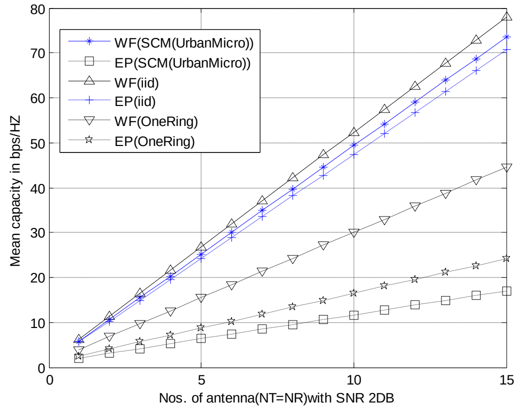



Figure 3: Mean Capacity Vs. Nos. of Antenna in i.i.d. and One Ring Model

The results showed that the mean capacity is linearly increasing with the number of antenna but the rate of linearity is higher in Waterfilling scheme and comparatively lower in Equal Power scheme in i.i.d. model. Similarly, mean capacity is linearly increase with the number of antenna in One Ring model also but the rate of linearity slightly less than i.i.d. model for both Waterfilling and Equal Power scheme. So, in this result, capacity seems to be higher in i.i.d. rather than One Ring model.




(a) (b)




(c)

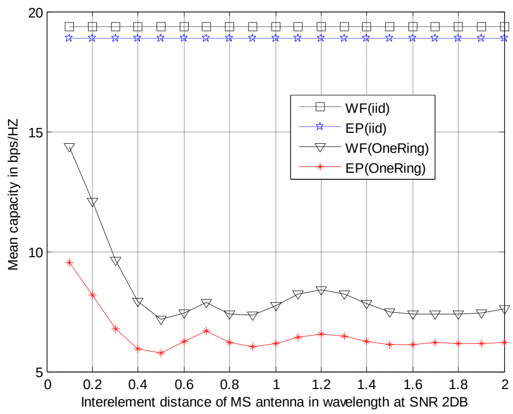
Figure 4: Mean Capacity Vs. Nos. of Antenna in i.i.d., One Ring and SCM

(a) Sub Urban Macro Cell, (b) Urban Macro Cell and (c) Urban Micro Cell

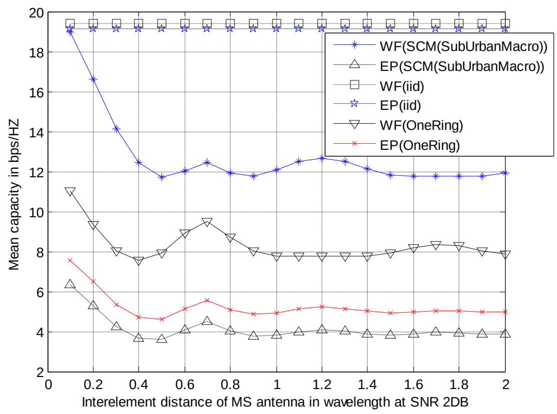
Mean capacity for SCM in multipath propagation scenarios i.e. Sub Urban Macro Cell is shown in this result. This result showed that capacity in Waterfilling conditin is higher in One Ring model but in Equal Power condition, it is not improving.

In Urabn Macro and Urban Micro cell environment, the mean capacity is slightly improving in Waterfilling scheme rather than Sub Urban Macro cell but Equal Power scheme has no remarkable improvement.

### 3.2.2 Mean Capacity Vs. Inter-element Distance




(a)

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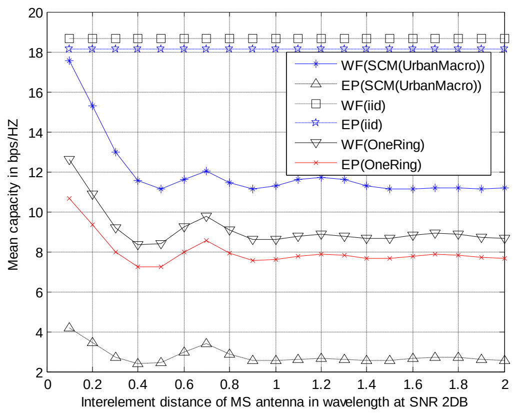


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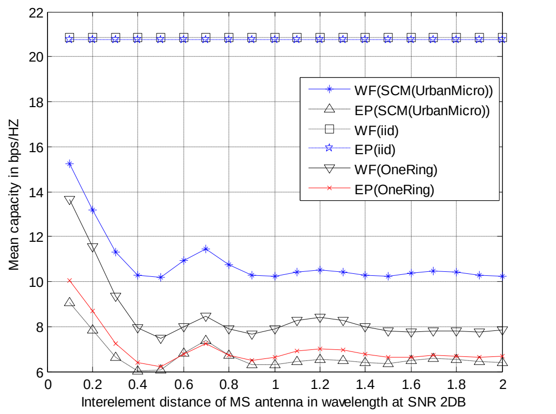


(d)

Figure 4: Mean Capacity Vs.MS Antenna Spacing in i.i.d., One Ring and SCM

(a) i.i.d. and One Ring Model, (b) Sub Urban Macro Cell, (c) Urban Macro Cell and (d) Urban Micro Cell

This result showed that mean capacity vs. inter-element distance of MS antenna in i.i.d. and One Ring model. Mean capacity in One Ring is increasing in small antenna spacing. For MS antenna spacing approximately less than 0.4 λ, the capacity is increasing but it is almost constant after 0.4 λ spacing. But i.i.d. capacity is constant as it is not affected by mutual coupling.

This result showed that comparison of mean capacity Vs. MS antenna spacing in Sub Urban Macro cell. The effect of mutual coupling for closely spaced antenna is almost same as described earlier in One Ring model case. MS antenna spacing approximately less than 0.4 λ, the capacity increasing but it is almost constant after 0.4 λ spacing.

This result showed that comparison of mean capacity Vs. MS antenna spacing in Urban Macro and Urban Micro cell environments. The trend of capacity increasing for MS antenna spacing approximately less than 0.4 λ and almost constancy after 0.4 λ spacing is remained same in both Urban Macro and Urban Micro cell environments.

## IV. Conclusion

Mean capacity is linearly increasing with the number of antenna for all channel model but the rate of linearity is higher in Waterfilling and comparatively lower in Equal Power scheme. Regarding SCM, capacity in Waterfilling condition is higher in One Ring model but in Equal Power condition it is not improving. Mean capacity in Urban Macro and Urban Micro cell environment is slightly improving in Waterfilling scheme rather than Sub Urban Macro cell but Equal Power scheme has shown no remarkable improvement. Mutual coupling effect is negligible for inter-element distance higher than approximately 0.4 λ and it leads to increase in capacity with spacing lower than this.

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