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Reconfigurable Intelligent Surface aided Indoor and Outdoor User Distribution in Heterogeneous Network

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Abstract: Millimeter wave communication suffers from static blockages such as trees, buildings and so on. Reconfigurable Intelligent Surfaces (RISs) has been adapted to solve this blockage problem and enable the urban environment user to choose mmW enabled small cells as their source transmitter or to choose macro cells in case of non-line of sight exists. RIS is a promising network technology to improve the quality of service parameters such as spectral efficiency and energy efficiency by artificially reconfiguring the propagation environment of electromagnetic waves. An indoor user can be connected with mmW band if the line of sight (LOS) link exists. Otherwise, the system utilizes RIS transmission model to have reliable and low-latency communication. It reflects the capability of RISs to enable enhanced communications in challenging environments. An optimization problem is formulated to maximize the sum data rate of an indoor user by phase shift optimization at the RIS. The outage probability of the proposed scheme is analyzed under Rician fading channel. The proposed RIS enabled method targets to enhance the overall performance in terms of average spectral efficiency and achievable data rate in the presence of blockages and system imperfections. The data rate is increased by three fold times than that of the transmission without RIS. The utility of this framework is discussed for both indoor and outdoor environments.

Index Terms: Heterogeneous network, Millimeter wave, Reconfigurable Intelligent Surfaces, Blockage.

1. Introduction

Millimeter Wave (mmWave) Enabled Heterogeneous networks (Hetnet) have experienced unprecedented growth over the last few decades. A reasonable approach would be to aim at 100 Mbps full-mobility wide area coverage and 1 Gbps low-mobility local area coverage with a next-generation wireless network. In order to make complete transition from 4G to 5G, Network infrastructure must be realized with small cells to support and build digital mobile networks. Global consumer growth rate is expected to reach 20% by 2025. Yet many technical challenges are still to be addressed such as interference and blockage issues. A reconfigurable intelligent surface (RIS) is an intelligent reflecting surface and software-controlled meta surface and artificial structure consisting of radio elements, which could be adjusted according to the reflection of an electromagnetic wave. It is a smart device controlling the propagation environment. An RIS is a node that receives the signal from the transmitter and then re-radiates it with controllable time-delays and hence, with the aid of RIS such an enormous technological advancement demands a rise in environmental challenges [1]. It pays more attention to have uninterrupted connectivity and high quality-of-service (QoS) to multiple users and devices in harsh environments. RIS is a powerful tool for analyzing the above scenario in mmWave enabled Hetnet.

1.1. Background and Motivation

The concept behind Hetnet is to introduce small cells overlaid in a macro cell area, so as to provide features the macro cell itself cannot cope up with, such as extreme changes in the required user traffic and latency. Hetnet utilizes the layer of macrocell combined with the dense small cells (Microcell, Picocell and Femtocell) to enhance the coverage. Migration towards mmWave is mainly due to the cramming of traditional sub-6 GHz bands used by current cellular networks, (mmWave) frequency bands (24 GHz to 100 GHz) is considered as the most attractive enabler for 5G. Hence to provide increased capacity in public places such as stadium, shopping malls, the emergence of small cell deployment would be required with cell sizes of around 100m to alleviate dead zones of coverage.

The next generation networks (6G) with millimeter wave provide enhanced data rates of the order of a few Gigabits per second and carrier frequencies in the range of 10GHz -100GHz [2]. Due to the increase in data demand mmWave small cell communication is enabled. Though mmWave provided lot of beneficial applications, it suffers from unfavorable propagation environments [3]. A mathematical framework reveals the impact of mmWave blockage effects present in urban environment [4]. Many researchers have useful insights from the perspective of potential RIS use-cases and their efficient positioning. The use of RIS is very particular in case Non-Line of Sight (NLOS) exists due to heavy building blockage. [5] The reflecting elements of an RISs provides an addition transmission path during blockage.

In [6], the authors proposed a promising solution by steering the incident signal and maximize the sum rate of all users. The objective aim is to design the joint beam forming at the base station (BS) and the phase vector of the RIS elements. In [7] the authors have constructed wireless communication prototype using RIS having 256 two-bit elements. The prototype significantly reduced the power consumption without degrading effective isotropic radiated power (EIRP) and the hardware cost of the conventional phased arrays also reduced. The authors proposed the deep reinforcement learning for the adjustment of beamformers and phase shifts under the condition of heavy blockage. [8]

Hyper Surface-coated walls and their objects are connected to the Internet of Things in the programming environment. As such, they can receive software commands and change their interaction with electromagnetic waves. Consequently, unprecedented coverage with good signal quality is the outcome in [9]. The wave front (phase, frequency and polarization) can be adequately controlled by RIS without the need of decoding, encoding or any external radio operations [10]. Intelligent adaptive transmitter is tuned to machine learning based channel capacity based on atmospheric conditions in [11]. The authors in [12] have constructed Large Intelligent surfaces (LIS) assisted system in which LIS acts as reflector. An unmodulated carrier is intentionally reflected by the LIS. Compared to traditional relays, RIS performance is sufficiently good without incurring self-interference and low hardware cost. Urban microcells located outdoor are expected to be used for high channel capacity during wireless traffic [13]. The authors through [14-16] have studied and implemented MIMO, beamforming and backscatter communication paradigms for the benefit of society so the propagation challenges of mmWave frequencies are tougher than traditional sub- 6 GHz bands, therefore studying the different propagation characteristics provides better understanding of mmWave channel modelling for 5G deployment scenarios. So, it is possibly alleviated dead zones using RISs the propagation challenges encountered in the usage of mmWave spectrum are analyzed using the RIS. We strive to improve spectral efficiency by promoting the intelligent management of network components.

In this paper we investigate the performance of RIS assisted Urban Hetnet without a direct link between transmitter (BS) and receiver (User).

The objectives are:

- Mathematical framework is derived for Indoor and Outdoor environments.
- Multipath, shadowing and Pathloss components are discussed in severe blockage zone.
- Optimization of RIS Phase shift and their error performance are studied.

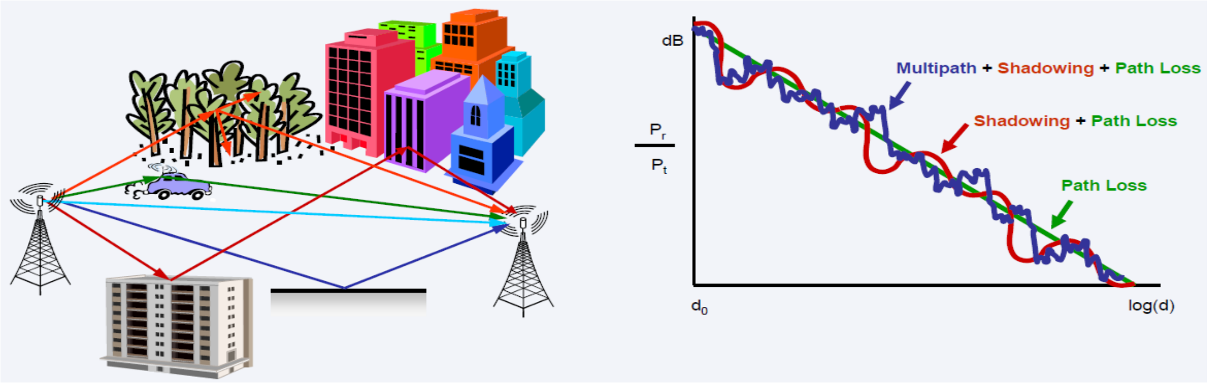

Fig.1. An RIS-assisted Hetnet system consisting of a direct path and an RIS with Path Loss

In allusion to the RIS aided communication system is depicted, the power coverage area is proposed for a typical outdoor scenario in figure 1, which has many rectangular buildings, trees and dynamic vehicles. The transmitted signal gets affected due to the environmental objects. The proposed system model offers one with the probability of a reconfigurable Meta surface covering with the users in coverage zone.

2. System Model

A generic RIS assisted multi-Tier heterogeneous network is considered where high power macrocell and picocell constitutes the outdoor tier and low power femtocell constitutes the indoor tier. The propagation of the radio waves in the environment is controlled via software in order to increase the QoS without increasing the power consumption. The indoor users are offloaded to the conventional microwave network when the direct link is not possible with a mmWave connection. Two different states have been considered, namely Line-of-Sight (LOS) and non-Line-of-Sight (NLOS) for mmWave link to study the performance of indoor small cell in the urban environment. The transmission of blocked links is carried out through RIS. The large number of low-cost reflecting elements reflects the incident signal with an adjustable phase shift or enables other unnatural EM functionalities. [17]. The System consists of base station and one RIS with N reflecting elements and user equipment.[18] The direct link between source and destination is obstructed by propagation environments such as static building blockages. The transmission is assisted by RIS using adjusted channel phases. The notations used to describe the distance are from source to destination d_{SD} (S-D), source to RIS d_{SR} (S-R) and RIS to destination d_{RD}(R-D), respectively. Under the Rician fading assumption, the channel coefficients from S-R and R-D are represented as

$$h_i^{SR} = \sqrt{\frac{K_1}{1+K_1}}h_{los}^{SR} + \sqrt{\frac{1}{1+K_1}h_{nlos}^{SR}} \tag{1}$$

$$h_i^{RD} = \sqrt{\frac{K_2}{1+K_2}}h_{los}^{RD} + \sqrt{\frac{1}{1+K_2}h_{nlos}^{RD}} \tag{2}$$

h_{los}^{SR} and h_{los}^{RD} are represented as LOS components, $h_{nlos}^{SR}$and h_{nlos}^{RD} are NLOS components. K_1 and K_2 are Rician factors of the S-R and R-D links. The phase-shift matrix is defined as a diagonal matrix $\Theta = diag(\theta_1, \theta_2, \dots \dots .. \theta_{n, \dots\dots\dots} \theta_N)$ where $\theta_n = e^{j\varphi_n}$ is the phase of *n-th* reflection element on RIS. The system performance metrics are controlled by adjusting phase shift of reflecting elements through passive beamforming optimization.

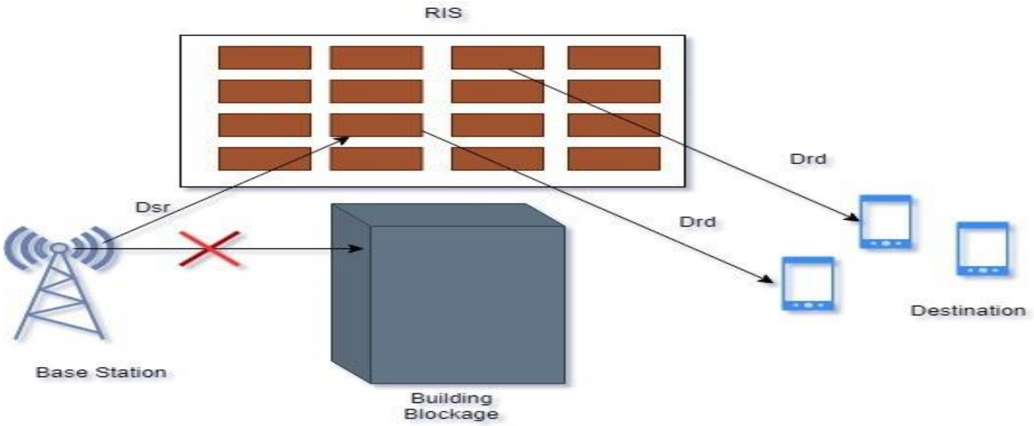

Fig.2. An RIS-assisted SISO system consisting N Reflecting elements

The signal received at user k is expressed as

$$y_k = h_{d,k}^{\mathrm{SD}}x + h_{r,k}^{\mathrm{RD}}\Theta Gx + u_k \tag{3}$$

$h_{d,k}^{SD}x$ – Direct link $h_{r,k}^{RD}\Theta Gx$- RIS aided link

where $u_k \sim CN(0, \sigma 2)$ denotes the additive white Gaussian noise (AWGN) at the k-th user receiver. Reconfigurable Intelligent Surface as a whole can control the Directivity of scattered signal, Signal absorption and polarization. RIS-assisted multi-Tier Hetnet communication for the case of slowly varying and flat fading channels, The received signal at k-th receiver is

$$y_k = \left[\sum_{i=1}^{N} h_i^{SR} e^{j\phi_i} h_i^{RD}\right]x + n \tag{4}$$

h_i^t Direct channel gain between BS and the RIS.
ϕ_i Phase difference between the RIS element and incident signal.
$\mathbf{h_i^r}$ Direct channel gain between RIS and the receiver.
In [1], Using RIS, phase alignment is obtained; consequently, the SNR is getting maximized.

$$\mathbf{\Gamma} = \frac{\left|\sqrt{\mathbf{PL_{RIS}}}\sum_{\mathbf{1=1}}^{\mathbf{N}} \boldsymbol{\alpha}_{\mathbf{i}}^{(\mathbf{1})} \boldsymbol{\beta}_{\mathbf{i}}^{(\mathbf{1})} \mathbf{e}^{\mathbf{j\Delta\phi_1}}\right| \mathbf{P_t}}{\mathbf{N_o}} \tag{5}$$

For satisfying phase alignment in RIS, $\Delta\phi_1 = 0$ for all $\mathrm{i} = 1,2,\ldots,\mathrm{N}_1$

$$r = \sqrt{p_t}\left[\sqrt{P_L^R}\left(\sum_{i=1}^{N} h_i^{SR} e^{j\Phi_i} h_i^{RD}\right)\right] x + w \tag{6}$$

The total transmitted power represented as p_t and Φ_i stands for the controllable phase shift of the ith reflecting element. x is the data symbol selected from QAM constellations. P_L^R is the pathloss assisted by RIS.[19] It can be represented as

$$PL_{RIS} = \left(\left(\frac{\lambda}{4\pi}\right)^4 \frac{G_e^i G_e^r}{d_{SR}^2 d_{RD}^2} \; \varepsilon_P\right)^{-1} \tag{7}$$

$G_e^i G_e^r$ represents the gain of incoming and received wave of the RIS. $d_{SR}^2 d_{RD}^2$ is the square product of the distance between source transmitter and RIS with RIS and receiver. ε_P is the efficiency of RIS. It is described as the ratio of transmitted signal power to received signal power. The channel coefficients are described as $h_i^{SR} = \alpha_i e^{-j\theta_i}$ and $h_i^{RD} = \beta_i e^{-j\varphi_i}$, here α_i and β_i represents channel amplitudes, whereas θ_i and φ_i denotes channel phases. The received signal is rewritten as

$$r = \sqrt{p_t}\left[\sqrt{P_L^R}\left(\sum_{i=1}^{N} \alpha_i \beta_i e^{j\triangle\Phi_i}\right)\right] x + w \tag{8}$$

$\triangle\Phi_i = \Phi_i - \theta_i - \varphi_i$ is the phase difference for *i=1,2,....., N*

2.1. Empirical Path Loss Model

The effect of an RIS Path Loss Model is used to describe the signal propagation in outdoor, indoor and RIS assisted path loss. The propagated signal of outdoor user experiences path loss and static blockage due to the building sources and small-scale fading.

Urban Micro (UM$_i$)Path Loss Models: The transmission scenarios are considered as LOS and NLOS in Indoor/Outdoor and RIS assisted pathloss.

At the frequency bands of 2 – 6 GHz, the transmission scenario is assumed as outdoor.

$$\mathbf{PL_{LOS} = 22log_{10}\,(d) + 28 + 20log_{10}(f_c\,)} \tag{9}$$

$$\mathrm{PL_{NLOS}} = 36.7\log_{10}(\mathrm{d}) + 22.7 + 26\log_{10}(\mathrm{f_c}\,) \tag{10}$$

Equations (9) and (10) express 3GPP UMi Path Loss of outdoor link from the outdoor BSs under the vicinity of both LOS and NLOS conditions, *d* is the distance and f_c is the career frequency.

UMi-Street canyon path loss model: The path loss model used in indoor tier for the mmWave link, (28 GHz) in dB, is modeled as,

$$PL_{LOS} = 21log_{10}(d) + 32.4 + 20log_{10}(f_c) \tag{11}$$

$$PL_{NLOS} = 31.7log_{10}(d) + 32.4 + 20log_{10}(f_c) \tag{12}$$

2.2. Spectral Efficiency

It refers to the information rate that can be transmitted over a given bandwidth in a specific RIS communication system. In order to assess the performance of the RIS enabled hetnet, the Signal to Noise Ratio (SNR) has been characterized as a performance metric [20].

$$\Gamma = SNR_i = \frac{(\sqrt{P_L^R}(\sum_{i=1}^{N} \alpha_i \beta_i))^2 p_t}{N_0} \tag{13}$$

The achievable data rate is expressed as,

$$R_{RIS} = log_2(1 + SNR_i) \tag{14}$$

2.3. Outage Probability

Outage Probability is defined as the probability that instantaneous SINR falls below a predetermined threshold. Γ_{th}

$$P_{outage} = P_r\{(1-\alpha)log_2(1+SNR) < \Gamma_{th}\} \tag{15}$$

$$\Gamma_{th} = 2^{(R/1-\alpha)} - 1 \tag{16}$$

R is the predefined data rate which is the minimum required data rate to accomplish successful transmission. α is the LOS probability for the link to be transmitted without blockage.

2.4. Phase Optimization

Reconfigurable Intelligent Surface as a whole can control the Directivity of scattered signal, Signal absorption and polarization. RIS-assisted multi-Tier Hetnet communication for the case of slowly varying and flat fading channels, the main objective of phase optimization is to find a solution by optimizing the phase shift of the N reflecting elements with those of the others being fixed at each time.

The phase optimization problem $\mathrm{P}(A)$ is formulated as

$$\mathrm{P}(A) \quad \underset{w,\theta}{max} \quad R_{RIS} = log_2(1+SNR_i) \tag{17}$$

$$\boldsymbol{s.t} \quad |\theta_n| = 1, \forall n = 1,2, \dots \dots . N,$$

Since the optimal phase shift solution is irrelevant to the base of the logarithm function, the natural logarithm is used. Despite the conciseness of P(A), the joint beamforming vectors and phase optimization depends on the optimization variables w and θ. The objective function is subjected to maximize the data rate. Optimization of phase shift vectors with conventional variable w is subject to individual SINR constraints at all users. The proposed phase optimization problem is based on solving convex feasibility optimization problems obtained via approximating the constraint functions.

3. Numerical Evaluation and Results

The performance of a typical user distribution in an urban multi-tier heterogeneous network is evaluated and it utilizes the RIS intelligence surfaces to overcome blockage effects. The operating frequency of mmWave network is assumed at 28 GHz and the bandwidth assigned to each user is W = 100 MHz.The path loss exponents for LOS and NLOS links α_L and α_N are 2 and 4 respectively. The distance between source, RIS and destination are varied, the pathloss and achievable data rate is calculated as per the UMi path loss model for outdoor microwave operating at 2.4 GHz and UMi-Street canyon path loss model for indoor millimeter wave operating at 28 GHz. The pathloss exponents and their pathloss are listed in for both outdoor and indoor in Table 1.

Table 1. RIS Channel Parameters

Operating Frequency	RIS Channel Parameters			
	Number of Reflecting Elements (N)	PLE	Distance	Pathloss in dB
2.4 GHz	40	3.373	50	84
	150	3.068	150	96
	200	3	200	115
28 GHz	40	3.15	20	70
	150	3.13	50	90
	200	3.03	100	100

The total no of Reflector element is varied from N=40, N=150 and N=200 of RIS, the transmit power of Macrocell is 46 dBm, Picocell is 25 dBm(Outdoor) and Femto (Indoor) cell is 15 dBm. The random phase scheme still has only a small gain, we could see the remarkable performance gain while using RIS. Furthermore, the RIS strategy enables a flexible transmission in outdoor propagation environment when the direct path is blocked. Under a single RIS-assisted scenario, an error performance limited due to the capability of reflecting the incident signal when blockage present. The locations of BS, RIS and receiver are set to x= [0, 0, 25] y= [0, 80, 40] and z = [10, 100,1.5]. In this outdoor setup the d_{SR} and d_{RD} is separated at a maximum distance of 250 m. whereas the indoor setup d_{SR} and d_{RD} are separated at maximum 100 m. The phase range chosen is $\boldsymbol{\Gamma = 0}$ dB. The results are simulated in MATLAB. We could see the outage effects in indoor and outdoor environments in figure 3 and 4.

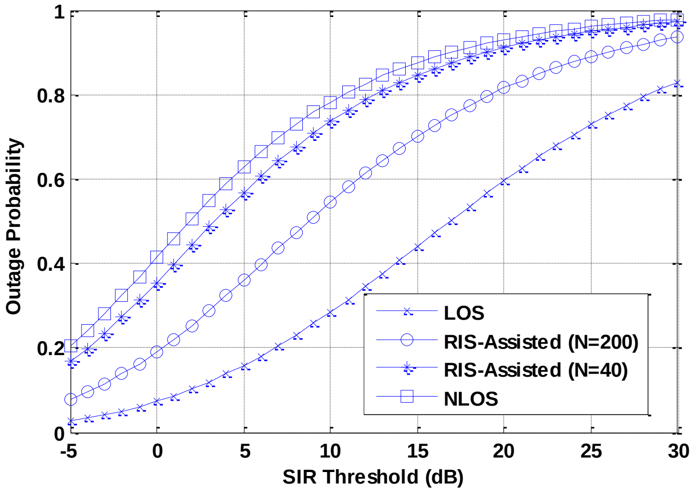

Fig.3. Outdoor Outage Probability (2.4 GHz)

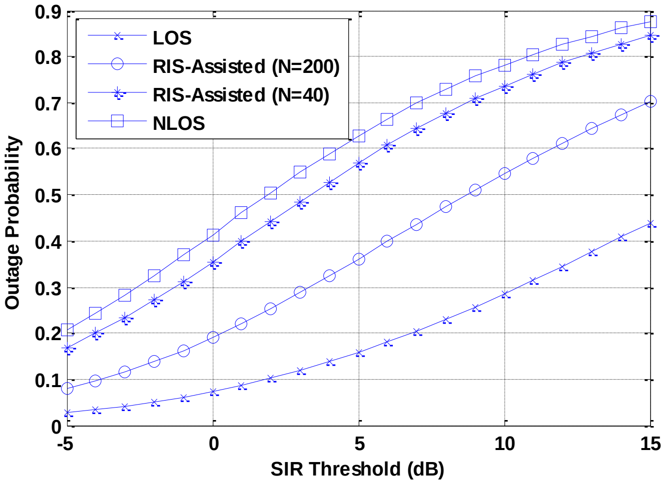

Fig.4. Indoor Outage Probability (28 GHz)

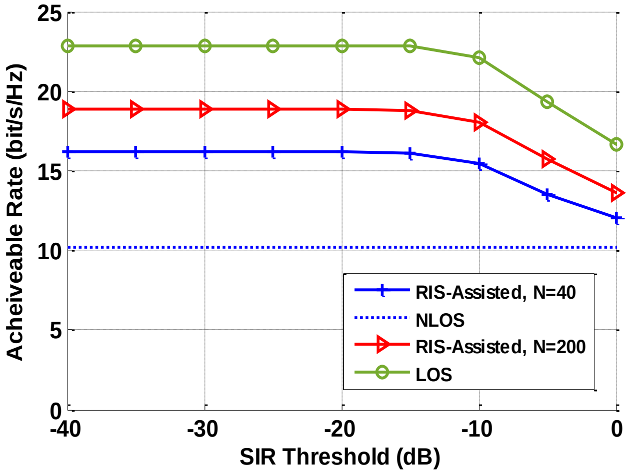

Fig.5. Acheivable Data rate for Indoor User

More users are often offloaded as indoor cell increases and significantly improves the SIR coverage of the network. It leads to lower the traffic so as to provide better coverage in the outdoor region. It is observed that lower the access probability leads to reduce the interference in the outdoor tier. It is good enough to achieve a high data rate. MmWave indoor rate coverage is shown to outperform µwave outdoor rate coverage. This is achieved, due to higher mmWave association with the indoor and it admits greater bandwidth. However, there are very less possibilities for LOS links, due to greater density of building blockages and more multi-paths, Hence, the indoor users can have an association with the µwave and it is highly depending on the distance and the selection of optimal bias. The proposed user distribution mechanism is extremely maximizing the significant data rate and to satisfy QoS requirements. It causes the RIS to initiate phase estimation errors. The imperfection results in the deteriorating received SNR. It is assumed that the phase estimation errors follow a zero mean. The effect of error performance studied in various researches.

It is highly possible to reduce the blockage effects and to improve the QoS using multiple RIS in the challenging environment. By utilizing the phase adjustment through optimization, the communication in indoor and outdoor user distribution is preserved. The distance between source and destination is taken as $d_{SD} = 30$ m for indoor performance and $d_{SD} = 250$ m for outdoor performance.

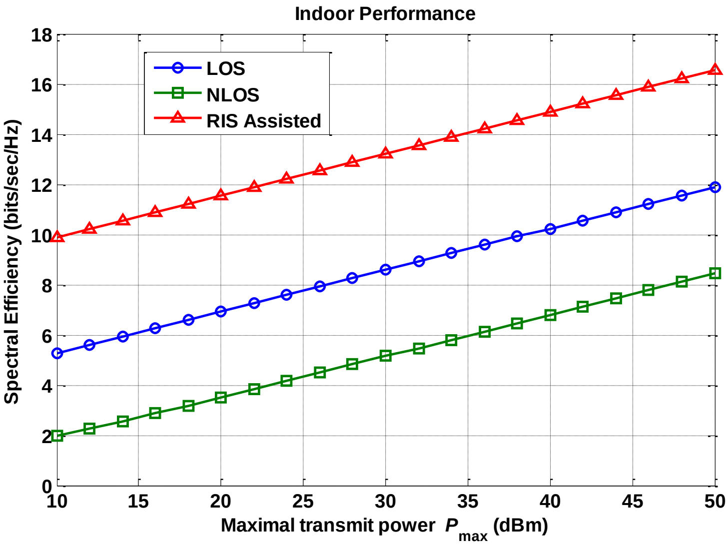

Fig.6. Spectral Efficiency for Indoor User

The indoor performance analysis is done for point-to-point LOS without fading , NLOS and RIS assisted communication. The number of reflecting elements taken as N = 40. As clearly noted the performance difference between the above said transmission scenario.Figure 6 shows that RIS assisted system provides a better performance. The reflection phases are adjusted from -140° to +140°.

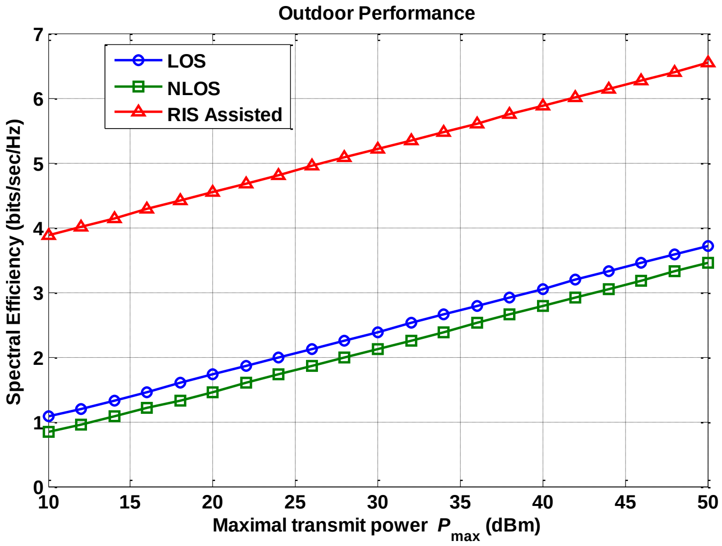

Fig.7. Spectral Efficiency for Outdoor User

Figure 6 shows the outdoor spectral efficiency performance by varying the transmit power of the outdoor cell. In order to give an insight about the outdoor performance the macrocell transmitted power is varied in accordance with the improved spectral efficient performance. The system complexity and phse shift adjustment costs are decremented by changing the adaptive transmitted power of the outdoor cells. It leads to flexible mechanism to choose the most reliable communication path under heavily blocakge zone. RIS is capable of adjusting the phse range from -180° to +180 ° even in the case of NLOS region.

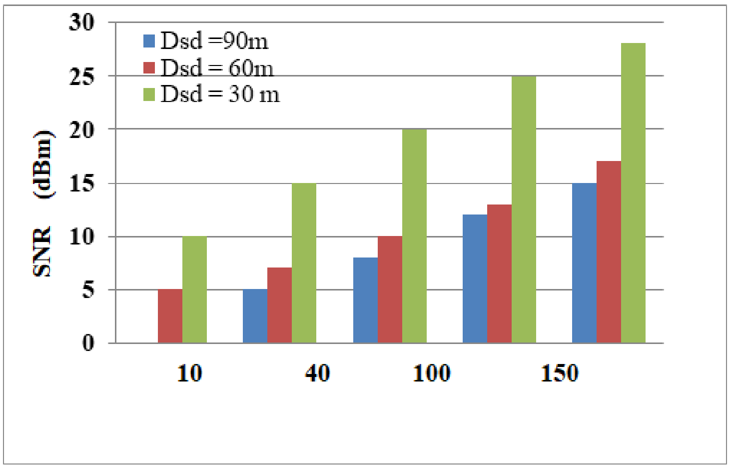

Fig.8. SNR for different distance

In real world, there may be encountered a lot of imperfect channel estimation. It results in the worsening of signal strength. Figure 7 shows the received SNR level for different distance between source and destination. When the RIS element is nearer, SNR is good for the minimum distance separation. It is large noticeable when the distance separation is large. The same system setup can be utilized with multiple RIS in indoor and outdoor environments.

4. Conclusion

In this proposed work, the impact of large-scale transmissions and the performance of a typical user distribution in an urban multi-tier heterogeneous network are analyzed. Reconfigurable Intelligent Surfaces (RISs) has been adapted to solve this blockage problem and enabled reliable communication. This adds controllable paths to the channel, which is particularly useful in propagation environments with severe blockage. The produced results are evident that the capability enhanced communications in challenging environments is improved. The given numerical results are used to illustrate the power of an RIS in the next-generation Heterogeneous Network planning and development. The achievable data rate and spectral efficiency in the presence of blockages and system imperfections is compared in three different scenarios. LOS, NLOS and RIS assisted. The number of reflecting elements increased to improve the data rate while the environment is severely blocked by the blockages. The utility of this framework is discussed for both indoor and outdoor environments. By placing these reconfigurable intelligent surfaces in an environment, the properties of radio channels can be controlled. We rigorously discuss the effect of propagation challenges required in the mmWave enabled heterogeneous networks of the future.

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