Impact of Reconfiguring Inclination Angle of Client's Antenna on Radio Channel Characteristics of IEEE802.11ac System

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Abstract — **This work presents the impact of reconfigurable antenna on radio channel characteristics of IEEE 802.11ac system, which is the next evolution of Wi-Fi systems. Reconfigurable antennas (RA) can be used to change radio channel characteristics in favor of receiver design. The results show that RA can be used to reduce power of some of the delay clusters, which lead to minimizing excess delays of these delay clusters by pushing their power to a level lower than noise floor. This is reflected in reducing the rms delay spread and increasing the coherence time of the radio channel, which has a direct impact on receiver design and operation.**

Keywords—radio channel; reconfiguable antenna; 5G Wi-Fi

I. INTRODUCTION

The successful design of any wireless communications system depends heavily on tested channel models. Channel models are supposed to describe radio channel characteristics (RCC) to some accurate extent. The RCC vary according to propagation environment such as indoor versus outdoor. The outdoor RCC vary for urban, suburban and rural, which also differ for forest area and open area as well as for line of sight and non-line of sight RF propagation [1]. The indoor RCC differ for different building categories such hotels, shopping malls, hospitals, airports, residential areas, office buildings as well as ground floor and high floors in high rise buildings. In addition to impact of the environment on RCC, there are other communication system parameters that affect the RCC. These parameters include operating frequency, bandwidth, antennas and their characteristics at the two ends of the communication link. These communication system parameters make the transmitted electromagnetic (EM) waves to interact with environments according to particular physics laws. The higher frequency of EM wave results in larger loss in both free space propagation and diffraction loss [2],[3]. The wide system bandwidth allows higher delay resolution at the receiver end. This makes multipath characteristics be different with bandwidth and operating frequency. Therefore, there is a need for channel characterization of parameters new merging Wi-Fi system under these considerations.

In this work, we investigate the impact of reconfigurable inclination angle of client's antenna on radio channel characteristics of IEEE 802.11ac system. The inclination angle changes the three dimensional pattern for both vertical and horizontal polarization. We show how it can be used to reduce powers of some of the multipath components, which would change their interaction in a different manner that cause controlled different channel characteristics. We also present how the RA can be used to change the root mean squared delay spread as well as the coherence time of the tested radio channel.

II. 5G WI-FI AND RECONFIGURABLE ANTENNA

A. *IEEE 802.11ac*

Wireless access to the Internet is becoming the default scenario. The IEEE released in 1997 first Wi-Fi standard and adopted IEEE 802.11a, b, g and n versions. The 802.11n version operates at 2.4- and 5 GHz and allows up to four data streams at a time. The increasing demand for multimedia streaming over Wi-Fi networks made the current Wi-Fi technology to meet its limitations and capabilities. This demand and similar other applications are driving for dramatic changes to current technology. The initial problem is the throughput. The next generation of Wi-Fi technology (aka 5G Wi-Fi) of IEEE 80.11 is the IEEE 802.11ac. This system works at 5 GH frequency range with bandwidth of 80 MHz and optionally can be expanded to 160 MHz. The 5 GHz band is less used compared to 2.4 GHz and thus would experience less interference. This increase in bandwidth is the biggest factor in increasing the throughput. This makes it possible to deliver very high data rates of video applications to handset. This technology supports multi-user, multi-input, multi-output (MU-MIMO) scenarios compared to single-user MIMO found in IEEE 802.11n. It also utilizes the 256 quadrature amplitude modulation (QAM), which is four times higher than the 64 QAM of the 802.11n [4],[5].

B. *Reconfigurable Antenna*

Other frontier that may result in significant improvement in performance of wireless communications system is the use of reconfigurable antenna (RA). It can be used in a manner to change RCC in favor of designing wireless system [6]. The RA, per control, can change its field pattern, frequency and polarization. The key part in gaining benefit from RA is based on understanding the interplay between superposition of complex signals of multipath components of radio channel, three dimensional antenna patterns, and velocity of mobile terminal. This interplay would affect channel characteristics in delay, direction and Doppler domains, which will have impact on their corresponding correlation parameters such coherence spectra (i.e., frequency correlation), spatial correlation and coherence time, respectively. The RF agility of RA can be used to change some of these channel correlation properties such as the coherence time and power weighted multipath dispersion metrics.

III. RADIO CHANNEL

Indoor environments where the IEEE 802.11ac is supposed to work can be categorized according to radio propagation in to different categories. The RF propagation in airports is different from RF propagation in office buildings and hotels, shopping malls, parking garage, residential buildings, etc. The RF propagation is generally confined inside the building and penetrating the building to outdoor after experiencing indoor to outdoor loss, which depends on electrical properties of the wall. The dimension of this indoor environment would have direct impact in signal multipath dispersion in different domains. In order to characterize the radio channel in different domains, the rays are described in multi-dimensions in terms of delays, angle of arrivals and angle of departure [7]. These different rays would experience different antenna gains and losses as a function of angular information, azimuthal and co-elevation departure and arrival directions.

In this work we consider cubically shaped indoor environment where multipath components include line of sight and multiple reflections. Multiple specular reflection take place via EM signal bouncing between every opposite surfaces (walls or ceiling and floor) or combination between them. This particular shape of indoor environment includes different propagation scenarios such as a corridor, office, lecture hall, convention center, etc. The core principle of the adopted and developed model in its essence is similar to that presented in [8]. The inputs to the model include environment parameters such as ceiling height, distance of AP antenna to reflecting walls and their electrical properties in addition to communication system parameters. The system parameters include operating frequency, system bandwidth, polarization of AP antenna, antenna field pattern and antenna height at transmitter and receiver. The geometrical configuration of the communication link ends with scatterers' spatial distribution has key factor in channel characterization. In this physical model, each ray is determined by its parameters defined by its delay, azimuth-co-elevation angle of arrival, and azimuth-co-elevation angle of departure. The complex amplitude of each ray is computed with electromagnetic formulations for free space loss and interaction loss due to the interaction EM signal with the scatterers in the environment. The interaction loss depends on the interaction, wave-front and geometrical properties of impinging rays and physical properties of reflecting surfaces. The reflected EM signal is related to the incident wave via a reflection coefficient defined by polarimetric matrix. Different coefficients can be used to capture the interaction losses that depend on the transmit waveform type: plane wave, cylindrical wave or spherical wave. The most commonly used reflection coefficient is the Fresnel reflection coefficient, which is valid for an infinite boundary between two mediums. The computed loss due to this propagation mechanism depends on polarization, frequency, and electrical properties of reflecting surface in terms of permittivity and conductivity of each media. The received signal is obtained as a sum of multi-ray components as vector superposition of the *N* individual rays, which can be represented as follows:

$$h(t;\lambda,\tau,\phi,\theta,\varphi,\vartheta,\mathbf{V}) = \sum_{n=1}^{N} A_n \delta(t-\tau_n) e^{-jk(r_n-\mathbf{V}\cdot\mathbf{\Psi}_n t)}$$

where $\mathbf{V}$ is the velocity vector of the client station, which is assumed as the receiver in this notation, and defined by $\mathbf{V} = v_x\vec{x} + v_y\vec{y} + v_z\vec{z}$, λ denotes to wavelength of the operating frequency, k is wave number given as $k = \frac{2\pi}{\lambda}$, and $\mathbf{\Psi}_{Rx}$ is the arrival direction vector defined for ray *n* as

$$\mathbf{\Psi}_n = \cos(\phi_n)\sin(\theta_n)\vec{x} + \sin(\phi_n)\sin(\theta_n)\vec{y} + \cos(\theta_n)\vec{z}$$

where ϕ_n is the horizontal arrival angle relative to the *x*-axis of ray *n*, and θ_n is the elevation arrival angle relative to *z*-axis of ray *n*, r_n is the path length of ray *n*

$$r_n = \sum_{p=1}^{P_n} d_{n,p} .$$

where parameter $d_{n,p}$ denotes the distance traversed by the specular wave between the (*p*-1) and *p*-th boundary intersections and the complex amplitude A_n is defined as

$$A_n = \frac{\lambda}{4\pi r_n}\sqrt{G_{tx}(\varphi_n,\vartheta_n)G_{rx}(\phi_n,\theta_n)}\prod_{p=1}^{P_n}\Gamma_p\, e^{-jkd_{n,p}}$$

Γ_p stands for the surface reflection coefficient for the *p-th* wave-interface intersection, while the term $\frac{\lambda}{4\pi r_n}$ is the free space path loss that accounts for the wave spreading loss, and $G_{tx}(\varphi_n,\vartheta_n)$ and $G_{rx}(\phi_n,\theta_n)$ are the transmitter and receiver antenna gain, respectively. In this work, we assume that client station antenna has reconfigurability in its inclination angle. For half-wavelength dipole antenna, the reconfigurable inclination angle antenna gain pattern model for vertical polarization can be written as [9]

$$G_V(\theta,\phi) = 1.64\,(\cos\theta\cos\phi\sin\alpha - \sin\theta\cos\alpha)^2\,\frac{\cos^2(\pi\,\xi/2)}{\left(1-\xi^2\right)^2}$$

where $\xi = \sin\theta\cos\phi\sin\alpha + \cos\phi\cos\alpha$ and the angle α is the inclination angle of the antenna element from *z*-axis in the vertical *zx*-plane.

IV. NUMERICAL RESULTS AND ANALYSIS

The accuracy of ray theory increases with increasing operating frequency. Thus, modeling radio channel of IEEE 802.11ac Wi-Fi system with ray theory is more accurate than that of

IEEE 802.11n Wi-Fi system operating at 2.4 GHz. The simulation environment of this work is built to study the impact of reconfigurability of inclination angle of receiver antenna at the client station of 5G Wi-Fi IEEE802.11ac system. The parameters of the communication system are given by IEEE standard where operating frequency is 5 GHz and bandwidth is 80 MHz. The dimensions of the indoor environment are selected to represent a banquet hall with height of 10 m, width of 15 m and length of 50 m. It is assumed that the AP antenna is placed on ceiling and antenna height of client station is 1.7 m. The client is assumed to move with speed of 3 km/hr, which is defined as the pedestrian speed in 3GPP standard [10]. Maximum reflection order per surface is selected to be six. More reflection orders take place for rays bounce between multiple walls. Reflecting surfaces have relative permittivity of 5 and conductivity of 0.02. The simulated temporal range is for one second for every spatial location. The temporal sampling rate is 26000 samples/sec at every spatial location. The simulated travelled route is 2 m till 10 m horizontal distance from AP with spatial resolution of 2.5 cm. Polarization of AP antenna is vertical. The results shown below are for two selected inclination angles 0^{o} and -30^{o}. The corresponding antenna patterns are shown in Figure 1. It can well be seen that the donut shape has significantly changed with -30^{o} inclination angle, which has direct impact on RCC as shown in Figure 2 and Figure 3. Figure 2 shows the spatial variant power delay profile of the channel along the measured route. The spread of excess delays and multiple delay clusters can be well seen in Figure 2a for normal scenario of conventional dipole antenna. The impact of inclination angle -30^{o} is shown in Figure 2b. It can be observed that the excess delay has significantly been reduced and power of many delay clusters have been pushed down below noise floor. The noise floor for 80 MHz is -95 dBm. Figure 2 shows samples of power delay profiles beginning and end of measured route. The difference in distance clearly shows different delay clusters. The long delay multipath components, which may cause severe frequency selective fading and inter-symbol interference (ISI), have been pushed down noise floor with reconfiguring antenna's inclination angle. This will lead to a significant simplification in receiver design and higher data rate transmission. This reduction in powers of delay clusters to below noise floor is reflected in rms delay spread, which is directly related to frequency selectivity of the channel and has direct relation to ISI and complexity of receiver design. The rms delay spread is a measure of power weighted dispersion of multipath components based on power delay profile. If the rms delay spread is reduced by reconfiguring antenna's inclination angle, so that the delay spread is smaller than the symbol period, then the channel become a flat fading channel. The impact of antenna's inclination angle on rms delay spread is shown in Figure 4. The inclination angle -30^{o} made significant reduction in rms delay spread compared to conventional dipole antenna (0^{o} degree inclination angle). The calculations formula of rms delay spread is presented in [1], [11]. Figure 5 shows clear impact of reconfiguring inclination angle on channel coherence time. The channel coherence time characterizes the rate at which the channel changes. The radio channel coherence time is extended with -30^{o} inclination angle. This makes the radio channel to be coherent for longer time, which makes the receiver to see similar RCC for this prolonged time. This results in less adaptively rate in receiver operations. The coherence time is computed from temporal channel correlation, which is presented in [11]. We considered the correlation value of 0.5 is the threshold value.

V. CONCLUSION

Reconfigurable antenna at client station may have significant improvement in the new evolution of Wi-Fi approved by IEEE standard under IEEE 802.11ac. The results of this work show that reconfiguring inclination angle can make significant changes in RCC that are directly related to performance of wireless communications system. It has significantly reduced the rms delay spread and increase the coherence time when the inclination angle was -30^{o} relative to the corresponding RCC when the antenna was the convention half-wave dipole antenna.

ACKNOWLEDGMENT

This publication was made possible by NPRP grants #: NPRP 5-653-2-268 from the Qatar National Research Fund (a member of Qatar Foundation). The statements made herein are solely the responsibility of the authors.

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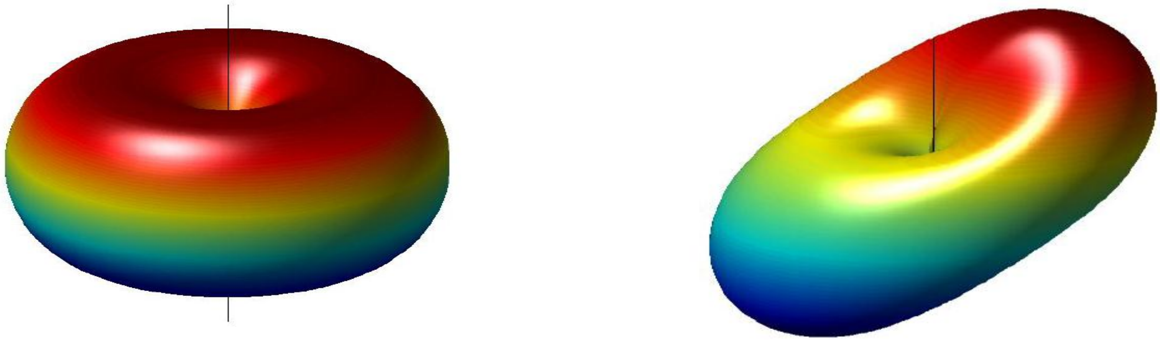
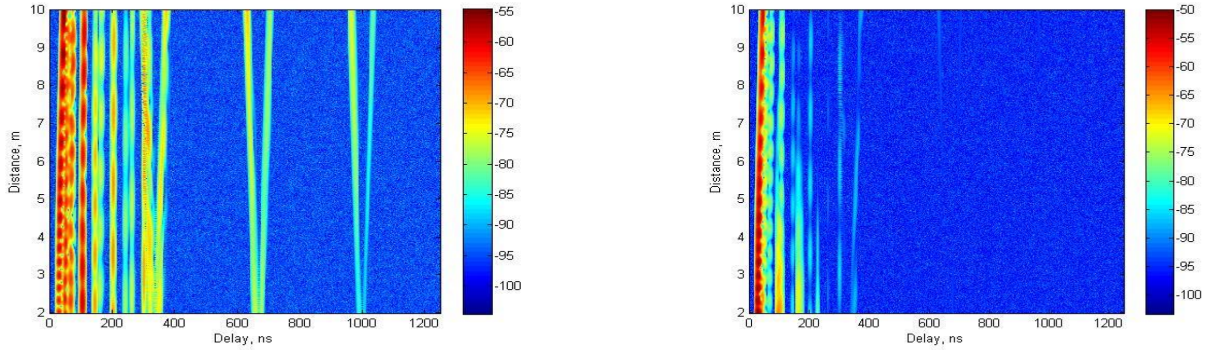


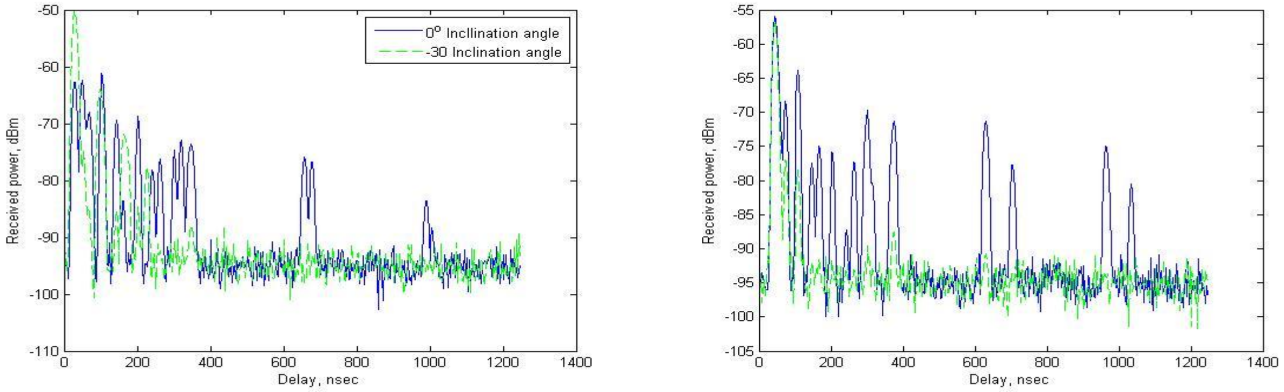
a. Inclination angle = 0^o b. Inclination angle = -30^o

Figure 1. Antenna Patterns.



a. Inclination angle = 0^o b. Inclination angle = -30^o

Figure 2. Spatial variant power delay profile.



a. Power delay profile for client station at 2 m from AP. b. Power delay profile for client station at 10 m from AP.

Figure 3. Spatial variant power delay profile.

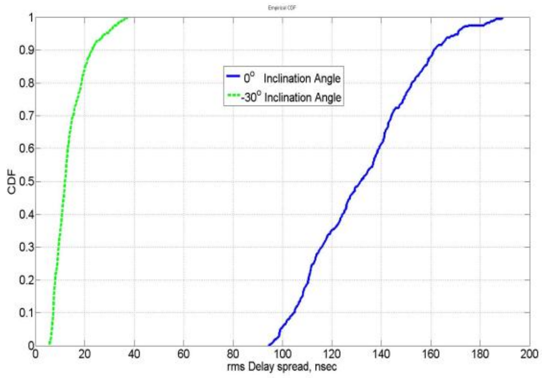


Figure 4. Channel rms delay spread.

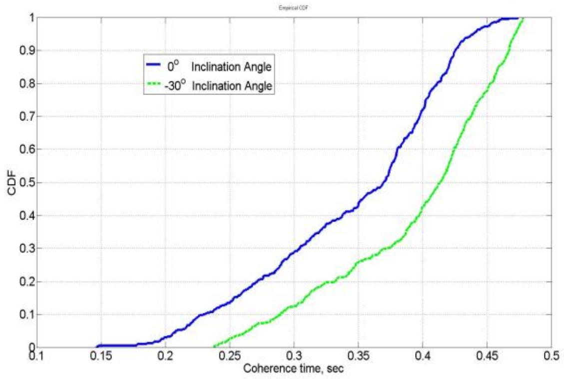


Figure 5. Channel coherence time.