Similarity Measure of Fading Profiles of Different Antenna States of Reconfigurable Antennas

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Abstract— Design of antenna states in reconfigurable antenna based wireless communication system require careful characterization process based on interplay between pattern of an antenna state and directional impulse response of propagation channel. This work introduces similarity and distance (i.e., dis-similarity) measures that are used in other field of science for characterizing interaction of antenna pattern and propagation channel. The distance/similarity measures are presented in cumulative distribution functions that characterize the interplay of different antenna states with propagation channels and show which antenna states that behave similarly. The presented approach may help in devising a design process to select the antenna state that may enhance the performance of wireless communication systems.

1. INTRODUCTION

Smart antenna research has been well explored and investigated based on array signal processing theories [1]. It was considered that at least two antennas are needed to achieve a performance gain from array signal processing theories. However, this research field assumed that the antenna pattern of each antenna element is assumed to be fixed. Reconfigurable antenna is a field that adds one more degree of freedom for wireless communications. It is based on possibility of altering some of antenna characteristics such as antenna pattern, pointing direction, polarization and resonance frequency [2]. This makes wireless system based on either a single antenna or a multiple antennas to be more flexible than conventional antenna technology. Reconfigurable antennas usually have several antenna states, where each state defines some particular antenna characteristics. The interplay between each antenna state with multipath component of propagation environment results in different fading profiles. For similar directional radio channel response, there will be different fadinglevels with different antenna states.

In this work, we present methods to characterize the similarity and dis-similarity measures [3, 4] between fading profiles that correspond to their responses of different antenna states for same directional impulse channel response. The dissimilarity measures indicate the amount of differences between fading profiles by providing information onhow much we can gain from diversity of antenna states. While the similarity index refers to amount of similar behavior of different fading profiles. The results might be used as input to design of antenna states process to know which antenna states that behave differently from others and may provide a frontier to the receiver for better channel conditions. The presented results are for dissimilarity (or distance) measures named as Sorenson coefficient and Canberra distance. The Canberra distance is normalized to feature vector length to transform it to Canberra coefficient. The presented results for similarity measure are for Jaccard coefficient [4].

2. RADIO CHANNEL MODEL AND RECONFIGURABLE ANTENNA

This work adopts physics based radio channel model for LOS propagation conditions. The multipath components are based on specular reflection mechanism that results from interaction of radio waves with reflection surfaces. Each ray is characterized with multi-dimensional parameters in delay and direction domain in terms of its delay, azimuth and co-elevation angle of arrival, azimuth and co-elevation angle of departure. The amplitude is computed with free space electromagnetic formulation and interaction with surface via the known Fresnel coefficient based on angle of incidence on wall and electrical properties of the surface. These parameters are given in explicit mathematical expression for cubical indoor environment such as a corridor, office, lecture hall, convention center, etc.. The mathematical forms are derived based on image theory. It is based on same essence as in [5, 6] but extending it for RF propagation indoor environment. The simulated propagation characteristics are determined by the input parameters to the model a communications link setup. The input parameters to the channel model include operating frequency, system bandwidth, antenna's polarization and the heights of transmitter and receiver, antennas' field pattern, electrical properties of scatterers, etc.. The communication link setup includes the locations of transmitter and receiver antennas with respect to the scatterers and reflecting surfaces such as ceiling, side and opposite walls, etc.. The complex signals arrive receiver antenna in multipath channels interact and combined together that results in constructive and destructive interference based on their amplitudes and phases. The multi-domain RF characteristics depend on the dispersion patterns in their corresponding domain such as delay, direction and Doppler. The impulse response of the LOS radio multipath channel is obtained as a linear superposition of $N+1$ individual rays, and it can be represented as follows:

$$h(t) = \frac{\lambda}{4\pi r_{los}} \sqrt{G_{tx}(\varphi_{los}, \vartheta_{los}) G_{rx}(\phi_{los}, \theta_{los})} \times \delta(t - \tau_{los}) e^{-jk(r_{los} - \mathbf{V}\cdot\mathbf{\Psi}_{los} t)}$$
$$+ \sum_{n=1}^{N} \frac{\lambda}{4\pi r_n} \sqrt{G_{tx}(\varphi_n, \vartheta_n) G_{rx}(\phi_n, \theta_n)} \prod_{p=1}^{P_n} \Gamma_p e^{-jkd_{n,p}} \times \delta(t - \tau_n) e^{jk(\mathbf{V}\cdot\mathbf{\Psi}_n)t}$$

where λ is the wavelength of operating frequency, Γ_p denotes the Fresnel reflection coefficient for the p-th wave-interface intersection, k is the wave number expressed as $k = \frac{2\pi}{\lambda}$, $\mathbf{\Psi}_n$ stands forthearrival direction vector defined for ray n as

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

$\mathbf{V}$ is the velocity (speed and direction) of the mobile terminal, which is assumed as the receiver in this notation, and defined by $\mathbf{V} = v_x\vec{x} + v_y\vec{y} + v_z\vec{z}$ and $d_{n,p}$ denotes the distance traversed by the specular wave between the $(p-1)$ and p-th boundary intersections, r_{los} is the length of LOS path and r_n is the specular reflection path length, $G_{tx}(\varphi_n, \vartheta_n)$, $G_{rx}(\phi_n, \theta_n)$ are the transmitter and receiver reconfigurable antenna (RA) gain, respectively, where ϕ_n and θ_n are the horizontal and co-elevation arrival angles of ray n (or LOS ray when subscript is los) relative to the x-axis and z-axis, respectively.

The RA can altercharacteristics of its field pattern such as resonance frequency,polarization and pointing direction. The main idea in gaining benefit from RA is based on understanding the interplay between directional impulse response of multipath components of radio channel, three dimensional antenna patterns, and velocity of mobile terminal. This interplay would affect channel characteristics in RF propagation domains, i.e., delay, direction and Doppler domains. This is reflected in impact on their corresponding correlation parameters such as coherence spectra (i.e., frequency correlation), spatial correlation and coherence time, respectively. In this work, RA pattern of a mobile device is simulated in terms of reconfiguringinclination angle (α) of the antenna, which modifies antenna gain pattern for vertical polarization that can be written as [7]

$$G_v(\theta, \phi) = 1.64 (\cos\theta\cos\phi\sin\alpha - \sin\theta\cos\alpha)^2 \frac{\cos^2(\pi\zeta/2)}{(1-\zeta^2)^2}$$

and its antenna gain pattern for horizontal polarization is

$$G_h(\theta, \phi) = 1.64 \sin^2\phi \sin^2\alpha \frac{\cos(\pi\zeta/2)^2}{(1-\zeta^2)^2}$$

where the angle α is from z-axis in the vertical zx-plane, $\zeta = \sin\theta\cos\phi\sin\alpha + \cos\phi\cos\alpha$ and, ϕ, the coefficient 1.64 corresponds to the directivity of the half-wavelength dipole antenna. Impact of orientation angle on multi antenna radio channels [9, 10] can also be studied and investigated using this RA model to characterize the dis-similarity between different sub-channels.

3. SIMILARITY MEASURE OF FADING CHANNEL PROFILES

A similarity measure is a function that assigns a number to a pair of patterns that describe quantitatively level of resemblanceof how close two objects are [3, 4]. For the same multipath propagation channel, radio channels supported with RA may have different interplay results for different antenna states of RA. This difference in interplay results comes from different weighting of multipath components due to different antenna states. In order to measure the similarity of different fading profiles due to different antenna states, we need a metric that describe the similarity or dis-similarity (i.e., distance) between different fading patterns. There are already different measures in literature that are used to measure the distance between two features. The selection of dis-similarity/similarity

Table 1: L_1 Dis-similarity and inner product similarity measure families [4].

L_1 Dis-similarity Measure	Sorensen	$D_{sor} = \frac{\sum_{i=1}^{n} \lvert \mathcal{M}_i - \aleph_i \rvert}{\sum_{i=1}^{n} \lvert \mathcal{M}_i + \aleph_i \rvert}$
	Canberra	$D_{Can} = \frac{1}{n} \sum_{i=1}^{n} \frac{\lvert \mathcal{M}_i - \aleph_i \rvert}{\lvert \mathcal{M}_i + \aleph_i \rvert}$
Inner Product Similarity Measure	Jaccard	$S_{Jac} = \frac{\sum_{i=1}^{n} \mathcal{M}_i \cdot \aleph_i}{\sum_{i=1}^{n} \mathcal{M}_i^2 + \sum_{i=1}^{n} \aleph_i^2 - \sum_{i=1}^{n} \mathcal{M}_i \aleph_i}$

metric depends on measurement type of features [8]. The most widely measure is the Euclidian distance. It is justified in maximum likelihood perspective when the feature has Gaussian distribution. The other commonly used is the Manhattan distance, which is justified when the feature has exponential (or double exponential) distribution. In many applications, the assumption as either Gaussian or Exponential is invalid. However, these two measures are members of L_P Minkowski family. The generalized formula for Minkowski distance measure family can be written as $d_{MK} = \sqrt[P]{\sum_{i=1}^{n} \lvert \mathcal{M}_i - \aleph_i \rvert^P}$ where $P = 1$ for Manhattan (aka city block, taxicab rectilinear) distance and $P = 2$ for Euclidean distance, where $\mathcal{M}$ and $\aleph_i$ are vectors of features. Different normalization forms are available for Manhattan Distance measure that are combined in L_1 family. The other similarity measure family incorporates inner product, $(\mathcal{M}_i \cdot \aleph_i)$ in their definition. The inner product refers to number of matches or overlap between $\mathcal{M}_i$ and $\aleph_i$ in case of binary vectors. This work presents (dis)-similarity measures that are presented in the Table 1.

4. NUMERICAL RESULTS

The radio channel model is used to generate radio channel realizations for different antenna states that represent different inclination angles (i.e., 0°, 20°, 60°, 80°). The simulation results assume vertical polarization with operating frequency of 5 GHz. Access point antenna is placed at ceiling of the indoor environment at height of 10 m. Receiver antenna height is 1.7 m. Maximum specular reflection order is 6 from every reflection surface (i.e., four walls, ceiling and floor). Relative Permittivity of each reflection surface is set 6. Two distance measures and one similarity have been selected for presentation in this work. Sorensen and Canberra distance coefficients measure dis-similarity between two fading profiles, while Jaccard coefficient measures the similarity between fading profiles. Jaccard similarity measure was originally developed for binary data but we extend its application in this work. They are proportion coefficients expressed as proportions of maximum distance possible. Figure 1 shows samples of fading profiles of received powers and their corresponding Jaccard Sorensen and Canberra coefficients. The results are given in terms of similarity and dis-similarity ratios. For Jaccard similarity index, when it is equal to one, then, the two profiles are identical and when it is zero, they are completely different. The opposite scale takes place with Sorensen distance measure (i.e., when it is zero, it means that there is no distance difference). The radio channel model has been used to generate 13026000 channel samples for every antenna states. Channel samples have organized into channel vectors of 1040 samples that correspond to a time duration of 40 ms, which is considered as two word codes of 20 ms length. The similarity and dissimilarity coefficient for each block of power offast fading signals of 1040 samples have been computed for different states as shown on legend of Figure 2. The number of computed (dis)-similarity blocks is 12525 for every antenna state versus other received power blocks of other antenna states.

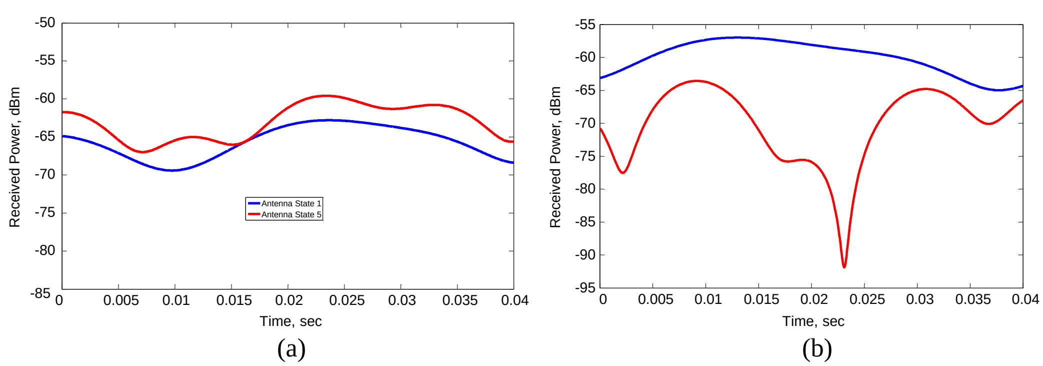

Figure 1: (a) $S_{Jac} = 0.9663$, $D_{sor} = 0.0816$, $D_{Can} = 0.0941$. (b) $S_{Jac} = 0.0747$, $D_{sor} = 0.8466$, $D_{Can} = 0.8137$.

The computed coefficients are presented in cumulative distribution curves (CDF) as presented in Figure 2. The CDF curves are for thetwo selected different dis-similarity measures (i.e., as Sorenson and Canberra distance measures) and one similarity measure, (i.e., Jaccard similarity measure). The presented (dis)-similarity coefficients are ranged from zero to one. The zero values for Sorenson and Canberra distances correspond to the one value of Jaccard similarity, which indicate to very similar or identical vectors and vice versa for other extreme value. The statistics of the three tested (dis)-similarity measures are presented in Table 2. The closer values to zeros for Sorenson and Jaccard coefficients indicate the closer to each other fading profiles from different antenna states. Fading profiles of antenna state 1 and antenna state 5 have largest dis-similarity. The second largest

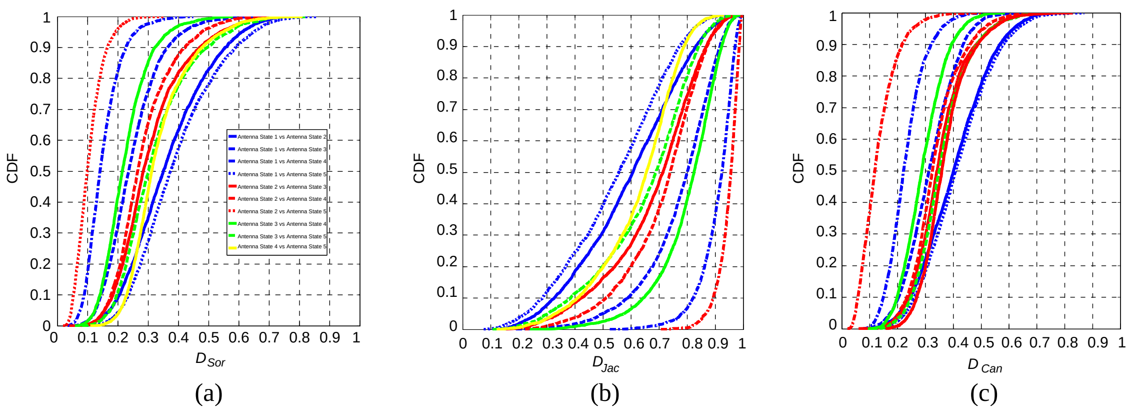

Figure 2: Cumulative distribution functions of (dis)-similarity measures of fading profiles for different antenna states. (a) Sorenson Coefficient. (b) Jaccard Coefficient. (c) Canberra Coefficient.

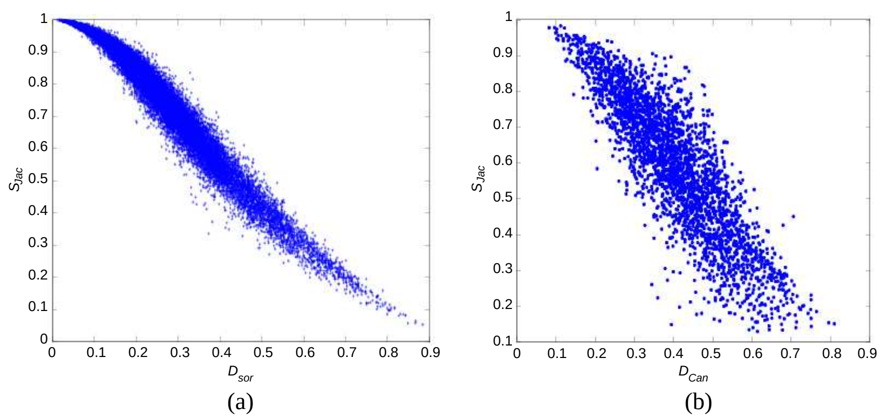

Figure 3: Scatter plot of similarity measure versus dis-similarity measures for fading profiles of antenna state 1 and that of antenna state 2. (a) Jaccard Coeff. vs Sorenson Coeff. (b) Jaccard Coeff. vs Canberra Coeff.

Table 2: Statics of tested (dis)-similarity measures for different combinations of antenna states.

	Sorenson Measure		Canberra Measure		Jaccard Measure	
	Mean	StdDev	Mean	StdDev	Mean	StdDev
Antenna 1 vs Antenna 2	0.3656	0.1336	0.4038	0.1240	0.5917	0.1874
Antenna 1 vs Antenna 3	0.2476	0.0901	0.3175	0.0910	0.7723	0.1340
Antenna 1 vs Antenna 4	0.1510	0.0587	0.2299	0.0679	0.9065	0.0653
Antenna 1 vs Antenna 5	0.3935	0.1355	0.4164	0.1225	0.5421	0.1834
Antenna 2 vs Antenna 3	0.3074	0.1145	0.3518	0.0962	0.6784	0.1681
Antenna 2 vs Antenna 4	0.2839	0.0978	0.3365	0.0907	0.7118	0.1422
Antenna 2 vs Antenna 5	0.1053	0.0456	0.1302	0.0658	0.9458	0.0395
Antenna 3 vs Antenna 4	0.2259	0.0771	0.2930	0.0771	0.8005	0.1162
Antenna 3 vs Antenna 5	0.3243	0.1186	0.3593	0.0956	0.6493	0.1737
Antenna 4 vs Antenna 5	0.3349	0.1028	0.3700	0.0890	0.6250	0.1481

dis-similar coefficient is between fading profiles of antenna state 1 and antenna state 2. However, the dis-similarity measure between fading profiles of antenna state 2 and antenna state 5 is quite low to indicate that they are quite similar. This indicate in a setup of antenna states, 1, 2 and 5, there will be effectively two antennas that cause different fading profiles. If the design requires two antenna states, then, it is easy to select the best two antenna states that generates diversity in fading profiles so the RA system can switch between them. However, the situation becomes more complicated if three antenna states are needed due to similar behavior of some of antenna states. According to our simulation results, the following combination sets may be a good choice, a) antenna states 1, 2, and 3. b) Antenna states 1, 3 and 5. It is shown that Sorenson and Canberra coefficients results in similar behavior in their distance measure between different fading profiles of different antenna states. Jaccard coefficient has a strong negative correlation with both Sorenson and Canberra coefficients as shown in Figure 3.

5. CONCLUSION

This work presents results of different distance and similarity measure that describe the resemblance between different fading profiles. The similarity of measures are already being used in other field of science but we introduce them here for fading radio channels of different antenna states. These measures help in design of best selection antenna states technique that enhance performance of RA based wireless communication systems. Both Sorenson and Canberra coefficient shows similar behavior as distance measure, while Jaccard coefficient shows strong negative correlation with both Sorenson and Canberra coefficient. For three antenna states design, the simulation results show that two different sets may work well for enhancement of RA based wireless communications; i.e., a) antenna states 1, 2, and 3. b) Antenna states 1, 3 and 5.

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