

Cross-correlation Models of Angular Spreads Based on Measurements in Dual-link Communication Scenarios

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Abstract—In this paper, we propose stochastic cross-correlation models of angular spreads between two links, i.e. the Base Station (BS)- Mobile Station (MS) link and the Relay Station (RS)-MS link. It is based on measurement data collected by using the wideband multiple input multiple output (MIMO) relay-Band-Exploration-and-Channel-Sounder (rBECS) system at 3.7 GHz. The angular spreads include the azimuth of arrival (AoA) spread, the azimuth of departure (AoD) spread and the elevation of arrival (EoA) spread. The statistics of these cross-correlation models are investigated as a function of geometrical features of the dual-link. It is extracted from a large amount of observations of the cross-correlation, which are obtained in three measurement sites along more than one hundred measurement routes.

I. INTRODUCTION

Cooperative MIMO technique has been one of the most extensively surveyed topics in literatures over the past few years. It is one of the promising methods for improving spectrum efficiency and has been adopted in the standards of the fourth-generation (4G) wireless communications, such as the Long Term Evolution-Advanced (LTE-A) defined in 3GPP documents TR36.814 [1] and TR36.300 [2] and the World Interoperability for Microwave Access (WiMAX) systems defined in IEEE 802.16.

Cooperative techniques, including coordinated multi-point (CoMP) transmission, cooperative relays and beamforming, and joint-processing methods, allow exploiting the characteristics of co-existing propagation channels between multiple sources and reception nodes. These techniques can be used in different context depending on the channel correlation. For example, cooperative beamforming relies on the coherence property of the propagation channels from multiple sources to the sink. Other techniques may more depend on the uncorrelated behavior of the multiple co-existing links, because the spatial macroscopic diversity gains are expected. Therefore, channel

characteristics are important because certain characteristics of the channel, such as cross-correlation, can be favorable for one scheme but unfriendly another.

Existing channel models at present, e.g. the 3GPP spatial channel model (SCM) [3], WINNER II [4], and IMT-Advanced channel models [5] focus on characterization of single-link propagation channels e.g. between a transmitter (Tx) and a receiver (Rx). The joint characteristics of two channels, particularly the cross-correlation of parameters of the channels are only briefly addressed in these models. Notice that different from the single-link channel modeling, the multi-link channel has very flexible combination of two links involved. Thus, it is important to model the multi-link channel with respect to sensible variables which exist in most of the multi-link cases. From this perspective, multi-link channel modeling is not just a simple extension of the single-link channel modeling [6]. Multi-link channel measurements should be carefully designed and conducted by using advanced channel sounding equipments and techniques which can record the observations of two channels simultaneously.

In this paper, measurement-based modeling of the cross-correlation of angular spreads in the BS-MS and RS-MS links is presented. The measurement data were collected by using the relay Band Exploration and Channel Sounder (rBECS) system [7] in downtown residential areas in Korea. The empirical models have the form with sensible variables that are identified for characterizing the general geometrical features of multiple links. The values of the model parameters are extracted by fitting theoretical curves to the large amount of samples obtained in three measurement sites following more than one hundred measurement routes.

The organization of the rest of the paper is as follows. Section II describes the cross-correlation of the angular spreads of two links. In Section III, the measurement setup, equipments, and information of the measurement campaign are introduced. And Section VI presents the models extracted from the empirical samples of the cross-correlation coefficients. Finally,

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conclusive remarks are given in Section V.

II. THE CROSS-CORRELATION OF ANGULAR SPREADS

We are interested in cross-correlation model of the angular spreads such as, the azimuth of arrival (AoA) spread, the azimuth of departure (AoD) spread and the elevation of arrival (EoA) spread of two channels.

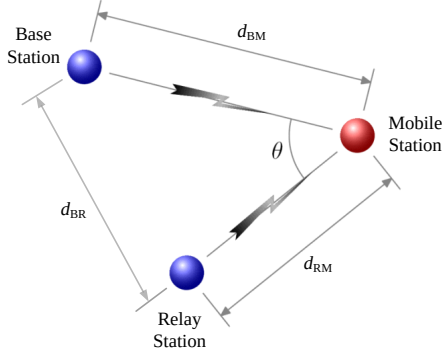


Fig. 1. Diagram of the dual-link, i.e. the links between a base station and a mobile station, and between a relay station and the mobile station.

Fig. 1 depicts a geometrical diagram of a dual-link channel which is of interest for modeling in this paper. For geometrical modeling of the dual-link channel, the following two parameters, i.e. the angle of separation and the average distance are proposed. The stochastic cross-correlation models of the angular spreads were constructed with respect to these parameters. Based on the observations of channel impulse response (CIR), the spreads are calculated. The angle spread of AoA, AoD and EoA is calculated according to the definitions reported in [8].

A. Angle of Separation (AoS)

The AoS, which is denoted as θ , is the angle between the direct link between the BS and the MS, and the direct link between the RS and the MS. The range of θ is $[0, 180^\circ]$. When the distances d_{BR} , d_{RM} and d_{BM} are known, θ can be calculated as

$$\theta = \arccos \frac{d_{RM}^2 + d_{BM}^2 - d_{BR}^2}{2d_{RM}d_{BM}} \quad (1)$$

B. Average Distance (AD)

The AD is defined as

$$\bar{d} = \frac{d_{BM} + d_{RM}}{2}. \quad (2)$$

The AD, which is denoted as $\bar{d}$, has the support of $[0, +\infty]$. The advantage of using the AD as variable is that the AD is easy to understand and very close to intuition. When the distance between the BS and MS and the distance between the RS and MS are much larger than that between the BS and the RS, the AD can be considered as a large number. In such a case, significant cross-correlation for two channels is expected since they tend to be similar when the AD increases.

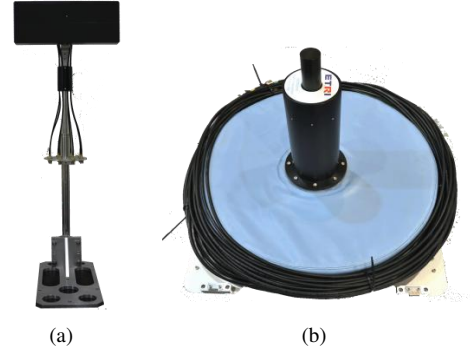


Fig. 2. (a) The planar antenna arrays used in the BS and RS, (b) the circular arrays used in the MS during the measurements.

C. Definition of cross-correlation between the large-scale parameters

Mathematically, the cross-correlation of the spreads is defined by

$$\rho_{xy} = \frac{\text{Cov}(x, y)}{\sqrt{\text{Cov}(x, x)\text{Cov}(y, y)}} \quad (3)$$

where $\text{Cov}(x, y)$ is the cross-covariance between one parameter (x) of one link and another parameter (y) of the other link.

III. MEASUREMENT CAMPAIGN

A. Measurement System

The measurement data was collected by using the relay Band Exploration and Channel Sounder (rBECS) system, which was designed and manufactured by the Electronics and Telecommunication Research Institute (ETRI), Korea. The rBECS system consists of two transmitters (Tx's) and one receiver (Rx). The Rx is capable of recording the data received from two links simultaneously.

The measurements were conducted with center frequency of 3.705 GHz. The effective bandwidth in the measurement is 100 MHz. Fig. 2 (a) and (b) depict respectively the antenna arrays used in the Tx's and the Rx. It can be observed that the Tx antenna array has double layered antenna elements. Upper layer consists of four vertically polarized elements, and the lower layer four horizontally polarized elements. The spacing of two consecutive elements is half of a wavelength. The Rx antenna array is two-ring 16-element circular array. Eight vertically polarized elements are aligned circularly at the upper layer, and eight horizontally polarized elements are aligned similarly at the lower layer.

During the measurements, the Tx transmission power is set to be lower than or equal to 36 dBm. The BS-MS link and the RS-MS link are measured simultaneously at the predefined locations along individual routes. Table I summarizes the specification of the rBECS system.



Fig. 3. Photographs of the Measurement Sites.

Item	Value
Center frequency [GHz]	3.705
Bandwidth [MHz]	100
Chip rate [Mcps]	max. 100
Code length [chips]	31 ~ 4095
Number of antennas	Tx:8, Rx:16
Tx Power [dBm]	+36
Receiver NF [dB]	<7
Channel Sampling rate [MHz]	400

TABLE I
Specification of the rBECS system

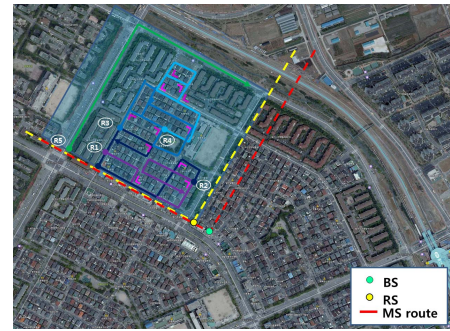


Fig. 4. Example of the measurement routes in one of the measurement sites ($d_{BR} = 50\text{m}$).

B. Measurement Scenarios

The environments where the measurement campaigns were conducted were in the residential area in the east area of the Ilsan city in Korea. Measurement data obtained in three measurement sites are considered. The pictures in Fig. 3 illustrate the environments of the measurement sites. These sites are typical residential environments with above 25% of average building density as shown in Table II. In all measurements performed, the Tx's were fixed on the rooftop of multi-story buildings along main streets, and the Rx carried by a vehicle with the Rx antenna mounted over the rooftop of the vehicle moved slowly along predefined routes. In the measurements, the Tx's played the role of the BS and the RS respectively, and the Rx is considered to be the MS. Considering the realistic operation configuration for the BS and the RS, the height of the Tx antenna and the Rx antenna were set to 25 and 2 m from the ground respectively. The picture in Fig. 4 depicts the example of the measurement routes defined for the Rx in one measurement site. Measurement data collected when the Rx moved along 143 routes in total, including 49 of them in Site 1, 52 in Site 2, and 42 in Site 3, are considered for channel characteristics analysis. Furthermore, for each measurement site, four different scenarios when the distance between the BS and RS is 50, 100, 200 and 400 m, respectively are considered.

	Average height of buildings [m]	Building Density [%]	No. of buildings [EA]
Site 1	11.92	28.41	517
Site 2	10.69	28.94	594
Site 3	7.54	28.53	739

TABLE II
Measurement Scenarios

IV. CROSS-CORRELATION MODELS

The measurement data were processing by using the high-resolution parameter estimation algorithm - Space Alternating Generalized Expectation-Maximization (SAGE) [9][10]. The parameters of individual path include the delay, the Doppler frequency, the direction of departure (azimuth and elevation), the direction of arrival (azimuth and elevation) and the polarization matrix.

The SAGE algorithm has been used to estimate 30 specular propagation paths from the received baseband data obtained in individual snapshots. The dynamic range of the channel impulse responses considered for path estimate is 30 dB. The number of iterations for updating all parameters of a path once in the SAGE algorithm is set to 20. The antenna radiation patterns (the 8 transmit antennas and 16 receive antennas) and

the calibration data are used in the SAGE algorithm.

Cross-correlation of the angular spreads were calculated based on the SAGE estimation results. The behaviors of the cross-correlation coefficients with respect to the geographic variables θ and $\bar{d}$ characterizing the BS-RS-MS constellation were investigated. The scatter plots of the cross-correlation coefficients are generated. Analytical curves are fitted to the empirical data.

Based on the GPS information of the BS, RS and MS in each measurement snapshot, we compute the distances between the BS, RS and the MS, which allow calculating θ and $\bar{d}$ for individual snapshots. The minimum and maximum values of θ and $\bar{d}$ are found first, and then the ranges specified by the minimum and maximum values are divided equally into 40 grids. Based on the grids, the measurement snapshots can be grouped into 40 groups in $\bar{d}$ for the one-dimensional (1-D) modeling scenarios, and $20 \times 20 (= 400)$ groups in $(\theta, \bar{d})$ for the 2-D scenarios. For each group, cross-correlation of the AoA spread, the AoD spread and the EoA spread of the BS-MS and RS-MS channels are calculated.

A. Cross-correlation model with respect to $\bar{d}$

Fig. 5 to 7 depict the scatter plot of cross-correlation coefficients of the AoA spread, the AoD spread and the EoA spread versus $\bar{d}$ respectively. Theoretical curves fitted to the empirical data are also plotted. It can be observed that the cross-correlation of the AoD spread and the EoA spread increases when $\bar{d}$ gets larger. This is an indication that when the MS moves away from the BS and the RS, some of the components in the CIRs get more correlated. This observation is consistent with that obtained in Fig. 8 to 10, i.e. when the MS is far from the BS and RS, resulting small θ , strong correlated components may appear in the two channels. However, there is no cross-correlation of the AoA spread with respect to $\bar{d}$ since the AoA spread is strongly related to local scatterers of the MS.

The analytical models of cross-correlation of the angular spreads with respect to $\bar{d}$ which have been identified the best fitted theoretical curves can be written as follows. And Table. III reports parameters for the models.

$$\rho(\bar{d}) = A \cdot \log_{10}(\bar{d}) - B \quad (4)$$

Parameter	A	B
AoA spread	-8.66×10^{-3}	0.470
AoD spread	0.120	0.482
EoA spread	0.122	0.388

TABLE III
MODELS EXTRACTED FOR THE CROSS-CORRELATION OF ANGULAR SPREADS WITH RESPECT TO $\bar{d}$

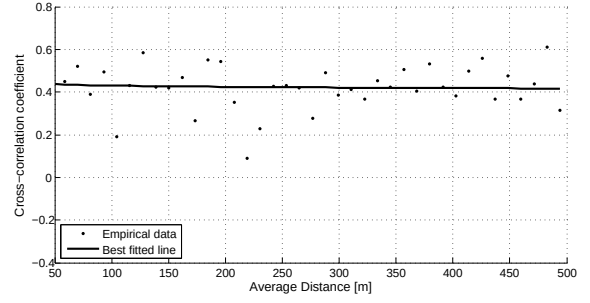


Fig. 5. The cross-correlation coefficients of the AoA spread of the BS-MS and the RS-MS links versus $\bar{d}$.

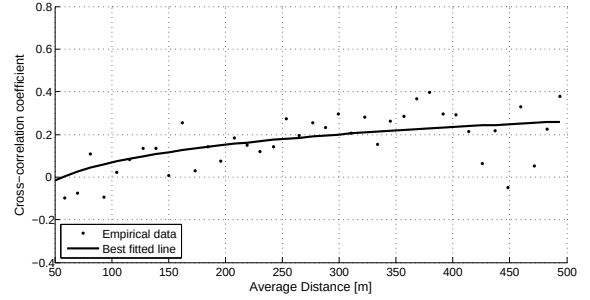


Fig. 6. The cross-correlation coefficients of the AoD spread of the BS-MS and the RS-MS links versus $\bar{d}$.

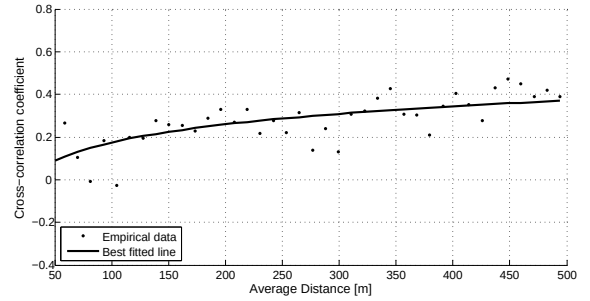


Fig. 7. The cross-correlation coefficients of the EoA spread of the BS-MS and the RS-MS links versus $\bar{d}$.

B. Cross-correlation model with respect to $(\theta, \bar{d})$

The joint distributions of the cross-correlation coefficients of the angular spreads have been investigated with respect to the 2-D variables, i.e. $(\theta, \bar{d})$. The scatter plots of cross-correlation coefficients of the angular spreads versus $(\theta, \bar{d})$ are depicted in Fig. 8 to 10. And the cross-correlation of the angular spreads is pretty high ($0.6 \sim 0.8$) when θ is small and $\bar{d}$ is large. In addition, results demonstrate that the cross-correlation of all the angular spreads is close to zero when θ gets larger than 60° . These observations indicate that virtual MIMO scheme is more favorable than virtual beamforming scheme when angle separation (θ) of the BS-MS and the RS-MS links is larger than 60° . The analytical models of cross-correlation of the angular spreads with respect to $(\theta, \bar{d})$ which have been identified the best fitted theoretical curves can be written as follows. And

Table. IV reports parameters for the models.

$$\rho(\theta, \bar{d}) = A \cdot \exp\left\{-\frac{\theta^2}{B^2}\right\} \cdot \{\log_{10} \bar{d} + C\} \quad (5)$$

Parameter	A	B	C
AoA spread	0.19	42.60	0
AoD spread	0.77	32.84	-1.88
EoA spread	0.42	43.11	-1.63

TABLE IV
MODELS EXTRACTED FOR THE CROSS-CORRELATION OF ANGULAR SPREADS WITH RESPECT TO $(\theta, \bar{d})$

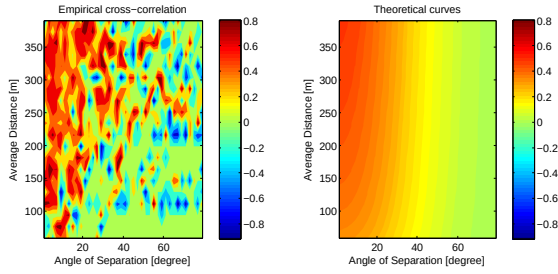


Fig. 8. The cross-correlation coefficients of the AoA spread of the BS-MS and the RS-MS links versus $(\theta, \bar{d})$.

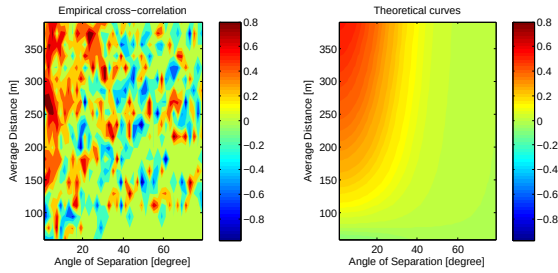


Fig. 9. The cross-correlation coefficients of the AoD spread of the BS-MS and the RS-MS links versus $(\theta, \bar{d})$.

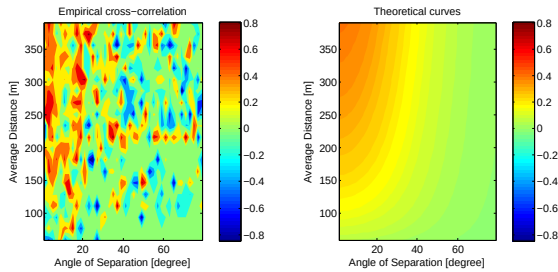


Fig. 10. The cross-correlation coefficients of the EoA spread of the BS-MS and the RS-MS links versus $(\theta, \bar{d})$.

V. CONCLUSIONS

Measurement campaigns dedicated for dual-link communication scenarios were conducted in residential areas in Korea by using the rBECS system. The measurement scenario contains the link between the BS and the MS, and between the RS and the MS. The empirical measurement-based models were presented for the cross-correlation coefficients of the angular spreads, i.e. the AoA spread, the AoD spread and the EoA spread in the two channels.

Experimental results are applied to construction of stochastic models. The 1-D and 2-D functions have been considered to fit the empirical observation. Analytical curves extracted demonstrate that the variation of the cross-correlation of the angular spreads can be modeled as a function with respect to the geometrical parameters, i.e. the angle of separation and the average distance.

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