

Cross-correlation Characteristics of Multi-link Channel based on Channel Measurements at 3.7GHz

Myung-Don Kim*, Jae Joon Park*, Hyun Kyu Chung* and Xuefeng Yin**

*Wireless Telecommunications Research Department,
Electronics and Telecommunications Research Institute,
138, Gajeong-dong, Yuseong-gu, Daejeon, 305-700, Korea

**Department of Electronics Science and Technology, Tongji University, China

*{mdkim, jjpark, hkchung}@etri.re.kr, **yinxuefeng@tongji.edu.cn

Abstract— This paper presents cross-correlation characteristics of multi-link channels considering cooperative communication scenarios. We introduce the wideband multiple input multiple output (MIMO) relay channel sounding system to simultaneously measure multi-link channels at 3.7GHz frequency band. The outdoor channel measurement campaign has been performed by realization of two-link channels in residential environments of Korea. We define a signal model with an angle and a relative distance of mobile station. We analyze the cross-correlation characteristics of large-scale channel parameters in terms of delay spread and shadow fading based on measured results. The empirical cross-correlation characteristics show that each two channels are highly correlated when the angle of separation is low, and when the mobile station is away from both base station and relay station with the same distance.

Keywords— cross-correlation, channel sounder, MIMO, cooperative communication

I. INTRODUCTION

Recently, cooperative MIMO technologies have been gradually adopted into wireless communication standards. Cooperative MIMO aims to utilize distributed antennas on multiple radio devices to achieve some benefits similar to those provided by conventional MIMO systems. The basic idea of cooperative MIMO is to group multiple devices into virtual antenna arrays to emulate MIMO communications [1]. Three types of cooperative MIMO schemes have been proposed for wireless communication systems: coordinated multipoint transmission (CoMP) [2], fixed relay [3], and mobile relay [3]. As the most mature cooperative MIMO technology, fixed relays have been incorporated into the IEEE 802.16j WiMAX standard. Meanwhile, the Third Generation Partnership Project (3GPP) is currently evaluating cooperative MIMO technologies for its fourth-generation (4G) cellular communication standard, Long Term Evolution-Advanced (LTE-Advanced).

To allow accurate assessments and fair comparisons of new cooperative MIMO technologies, realistic cooperative MIMO channel models are indispensable [4]. The existing standardized MIMO channel models, such as the 3GPP spatial channel model (SCM) [5], the WINNER II channel model [6],

and the IEEE 802.16j channel model [7], can be used to simulate individual point-to-point channels. However, since cooperative MIMO involves multiple point-to-point links, its channel model should consider not only the properties of the individual links, but also the system-level variations (or heterogeneity) and correlation of multiple links in a multi-cell environment. Furthermore, the conventional cellular systems are only concerned with a link between the base station (BS) and mobile station (MS). However, in fixed and mobile relay cooperative MIMO systems, more links involved with the relay station (RS) need to be considered (for example, BS-RS, RS-RS, RS-MS, and MS-MS links). Therefore, we need to extend conventional channel models to cover new cooperative communication paradigm. One of essential features for multi-link MIMO channel modelling will be using correlation characteristics between multiple cooperative links.

In this paper, we investigate cross-correlation characteristics of multiple MIMO channels based on channel measurement at 3.7GHz carrier frequency. The remainder of this paper is organized as follows. In section II, we introduce the wideband MIMO relay channel sounder which developed by ETRI to measure multi-link channels simultaneously. We also present the channel measurement campaign using our channel sounder. The outdoor channel measurement campaign has been performed by realization of two-link channels (BS-MS and RS-MS) in typical residential environment of Korea. Section III introduces our proposed signal model, and defines the cross-correlation of large-scale channel parameters such as delay spread and shadow fading. In section IV, we show the empirical channel characteristics of cross-correlation based on measured results. Finally, to wrap up the work, conclusions are given in Section V.

II. MEASUREMENT EQUIPMENT AND CAMPAIGN

A. Wideband MIMO Channel Sounder

The channel measurement campaign has been performed by using the relay Band Exploration and Channel Sounder (rBECS) system which is developed by Electronics and Telecommunications Research Institute (ETRI), Korea [8]. The rBECS system is a wideband MIMO channel sounder for

measuring the spatial and temporal characteristics of the radio channel at 3.7 GHz carrier frequency and 100 MHz bandwidth, and it is specially designed for measuring multi-link channels simultaneously considering various cooperative MIMO communication scenarios. This system is a configurable channel sounder with both a transmitter and a receiver, and it can be conducted as a role of the base station (BS), or the relay station (RS), or mobile station (MS) depending on the selected sounder mode as user's purpose. Figure 1 shows the rBECS system and MIMO antenna arrays used in the measurement. The specification and the performance of rBECS system are described in [8].

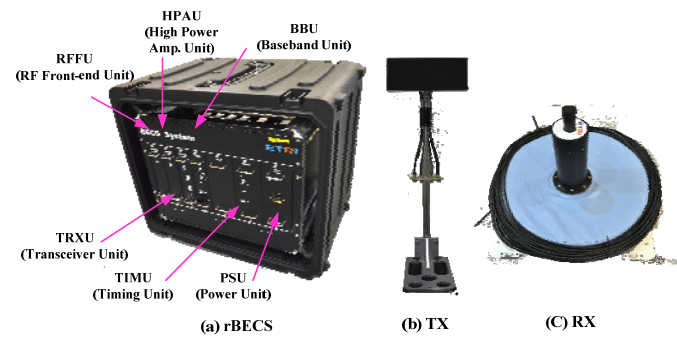


Figure 1. rBECS system and MIMO antenna arrays

For the measurement campaign, we have designed two kinds of antenna arrays. The Tx antenna array is a 2 x 4 planar array (PLA8) which has double layered antenna elements. Upper layer consists of four vertically polarized elements, and another four horizontally polarized elements are aligned linearly at lower layer. In each layer, the spacing of each elements is $\lambda/2$. The Rx antenna array is a two-ring 16-element uniform circular array (UCA16). All eight vertically polarized elements are aligned circularly at the upper layer, and lower layer consists of eight horizontally polarized elements. All element types are patch type, and diameter of UCA16 is λ . Inter-layer distance of PLA8 and UCA16 is $\lambda/2$. Figure 2 (a) and (b) depict respectively the antenna arrays.

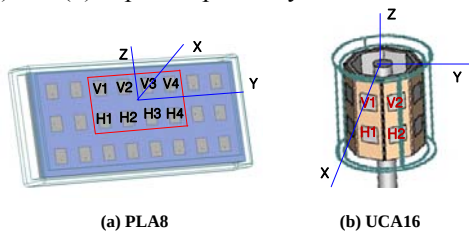


Figure 2. The Planar antenna arrays used in the BS and RS, and the circular arrays used in MS

B. Measurement Campaign

The channel measurement campaign has been performed in east area of Ilsan city in Korea. Totally two sites (Site 1 and Site 2) were carefully selected based on GIS database, and these sites are typical residential environments with above 25% of average building density as shown in Table 1. Figure 3 and Figure 4 depict surrounding environment of each measurement area.

TABLE 1. MEASUREMENT SCENARIOS

	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

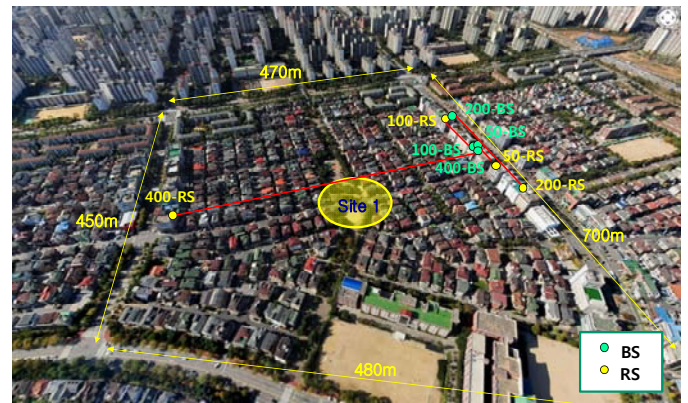


Figure 3. Photographs of the Site 1



Figure 4. Photographs of the Site 2

In this measurement, we considered the scenario when both the BS and the RS transmit the signal cooperatively to the MS as shown in Figure 5. The measurements have been conducted with 4 different scenarios when the distance between the BS and RS is 50, 100, 200 and 400 m, respectively. For each scenario, the MS measured the channel of BS-MS link and the channel of RS-MS link simultaneously. For the BS and the RS, the rBECS system with a PLA8 antenna is installed on the rooftop of buildings, respectively. The MS channel sounder is carried in a vehicle, and the UCA16 antenna is mounted over the rooftop of the vehicle. The height of Tx antenna for the BS and RS is about 25 m from the ground and the height of Rx for the MS is 2 m. The MS are moving and gathering channel measurement data along the planned routes of each two area (Site 1 and Site 2).

From this measurement campaign, the MS collected measured data at 1,478 points within the service area of Site 1, and at 1,662 points of Site 2. At each point, the MS channel sounder has measured channel data of both BS-MS link and RS-MS link, and 10 samples (1 sample = 8x16 channel responses) are saved within the range of 10λ . Therefore,

totally 62,800 experimental samples (= 3,140 points x 2 links x 10 samples) are gathered and considered for analysis of multi-link channel characteristics from this measurement campaign. The measurement data contains three parts: the baseband representation of the received signal, the calibration data and the GPS positions of the BS, RS and MS.

III. SIGNAL MODEL AND LARGE-SCALE CHANNEL PARAMETERS

A. Signal model

Figure 5 depicts a geometrical diagram of a multi-link channel which is of interest for modelling in this contribution. For geometrical modelling of the multi-link channel, the following two parameters, i.e. the angle of separation and the relative distance are proposed. The stochastic cross-correlation models constructed for the multi-link channel describe the statistics of the cross-correlation coefficients of the parameters of interest with respect to these parameters. In the sequel, the definitions of these parameters are presented.

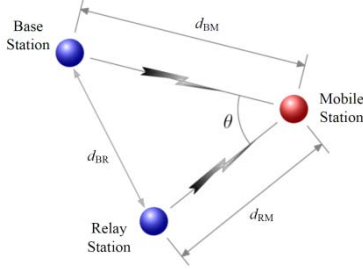


Figure 5. Diagram of multi-link, i.e. the links between a mobile station and a base station, and between the mobile station and a relay station

1) Angle of Separation (AoS): The AoS 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 support of θ is $[0, 2\pi]$. When the distances d_{BR} , d_{RM} and d_{BM} are known, θ can be calculated as

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

2) Relative Distance (RD): The RD $\tilde{d}$ is defined as

$$\tilde{d} = \log_{10} \frac{d_{BM}}{d_{RM}} \quad (2)$$

The support of $\tilde{d}$ is from $[-0.3, 0.3]$. When the MS is away from the RS and the BS with the same distance, $\tilde{d} = 0$.

B. Large-scale channel parameters

We estimated large-scale channel parameters (LSPs) such as shadow fading and delay spread from measured data as follows.

1) Shadow fading (SF): The shadow fading in the i -th sample can be calculated as

$$P_{SF,i} = P_i - \bar{P}_i \quad (3)$$

where P_i denotes the power of the channel represented in terms of a coefficient, usually called as narrowband channel

representation, $\bar{P}$ represents the power of the channel predicted by using the path loss model. In our case, the path loss model was extracted based on all available samples.

2) Composite delay spread (DS): In our case, the composite delay spread is calculated by using the SAGE estimates [9] of multiple propagation paths, i.e.

$$\sigma_\tau = \sqrt{\frac{\sum_{\ell=1}^L (\tau_\ell - \bar{\tau})^2 P_\ell}{\sum_{\ell=1}^L P_\ell}} \quad (4)$$

where p_ℓ denotes the power of the ℓ -th estimated propagation path, i.e. $p_\ell = |\alpha_\ell|^2$, $\ell \in [1, \dots, L]$ with L representing the total number of paths. In (4), $\bar{\tau}$ is the power weighted average of the delays of all estimated paths, i.e.

$$\bar{\tau} = \frac{\sum_{\ell=1}^L \tau_\ell P_\ell}{\sum_{\ell=1}^L P_\ell} \quad (5)$$

C. Cross-correlation of the LSPs

In this paper, we define cross-correlation of DSs (ρ_{DS}) and cross-correlation of SFs (ρ_{SF}) as large scale channel parameters between two links when the BS and the RS are connected to the same mobile station. The cross-correlations are caused by the scatterers contributing to the two links, and thus are measurement of the similarity of the environments creating the two links. Mathematically, the cross-correlation is defined by

$$\rho_{12} = \frac{C_{12}}{\sqrt{C_{11}C_{22}}} \quad (6)$$

, where C_{12} is the cross-covariance of parameters between link 1(BS-MS) and link 2(RS-MS).

IV. EMPIRICAL CROSS-CORRELATION CHARACTERISTICS

A. Cross-correlation of SF and DS with respect to θ

The cross-correlation coefficients of the shadow fading and delay spread of the BS-MS and RS-MS links are calculated based on the measured channel impulse responses for all designed routes in Site 1 and Site 2.

The statistics of the cross-correlation coefficients with respect to θ , i.e. the angle between the direct links from the BS to the MS, and the link from the RS to the MS, is investigated. The range of the variable θ is determined by the minimum and maximum values of θ computed based on constellation of the BS, RS and MS. Then, the range is split into N grids with equal width. For the n -th grid ($n = 1, \dots, N$), the cross-correlation coefficients ρ_{SF} computed with $\theta \in [\theta_n, \theta_{n+1}]$ are considered. The average of these ρ_{SF} is calculated.

Figure 6 depicts respectively theoretical curves fitted to the obtained ρ_{SF} with respect to θ with $N = 40$. The curve can be written as

$$\rho_{SF} = 0.749 \exp(-\theta^2/619) \quad (7)$$

Figure 7 depicts theoretical curve fitted to the obtained cross-correlation coefficients of the DS (ρ_{DS}) with respect to θ . The best fitted curve can be written as

$$\rho_{DS} = 0.67 \exp(-\theta^2/1132) \quad (8)$$

Each dot of Figure 6 and Figure 7 represents an averaged value of hundreds of coefficients which are estimated from measured samples within $\theta \in [\theta_n, \theta_{n+1}]$.

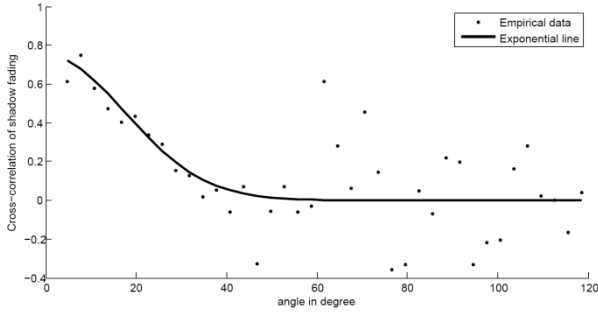


Figure 6. The average cross-correlation coefficients of the SF of the BS-MS and the RS-MS links versus θ . The fitted curve reads $\rho_{SF} = 0.749 e^{-\theta^2/619}$.

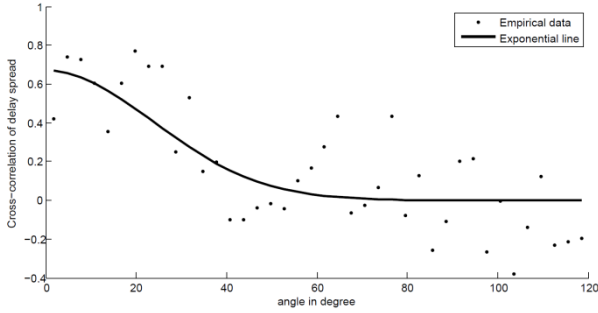


Figure 7. The average cross-correlation coefficients of the DS of the BS-MS and the RS-MS links versus θ . The fitted curve reads $\rho_{DS} = 0.67 e^{-\theta^2/1132}$.

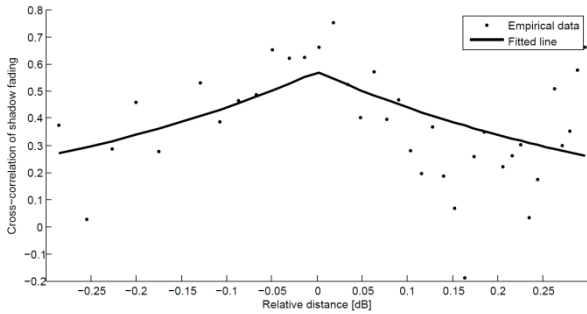


Figure 8. The average cross-correlation coefficients of the SF of the BS-MS and the RS-MS links versus $\tilde{d}$ [dB]. The curve reads $\rho_{SF} = 0.572 e^{-|\tilde{d}|^2/0.38}$.

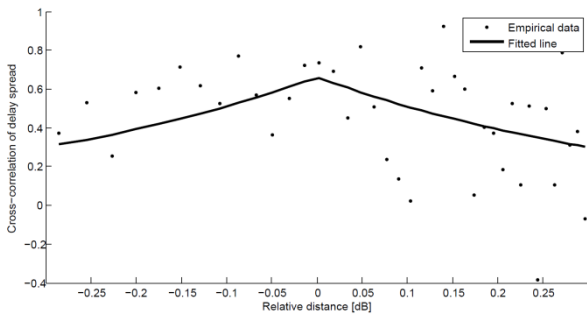


Figure 9. The average cross-correlation coefficients of the DS of the BS-MS and the RS-MS links versus $\tilde{d}$ [dB]. The curve reads $\rho_{DS} = 0.663 e^{-|\tilde{d}|^2/0.38}$.

It can be observed from both Figure 6 and Figure 7 that the truncated Gaussian curve fits the best with the empirical data. The cross-correlation coefficients of the shadow fading and the delay spread show that each two channels (BS-MS and RS-MS) are highly correlated when the angle of separation θ is lower than 20° .

B. Cross-correlation of SF and DS with respect to $\tilde{d}$

The statistics of the cross-correlation coefficients of the shadow fading with respect to $\tilde{d}$, i.e. the relative distance represented in decibel of the direct links from the BS to the MS, and the link from the RS to the MS, is investigated. The range of the variable $\tilde{d}$ is determined by the minimum and maximum values of $\tilde{d}$ computed based on constellation of the BS, RS and MS. Then, the range is split into N grids with equal width. For the n -th grid ($n = 1, \dots, N$), the cross-correlation coefficients ρ_{SF} computed with $\tilde{d} \in [\tilde{d}_n, \tilde{d}_{n+1}]$ are considered. The average of these ρ_{SF} is calculated.

Figure 8 depicts respectively theoretical curves fitted to the obtained ρ_{SF} with respect to $\tilde{d}$ with $N = 40$. The curve can be written as

$$\rho_{SF} = 0.572 \exp(-|\tilde{d}|^2/0.38) \quad (9)$$

Figure 9 depicts respectively theoretical curve fitted to the obtained ρ_{DS} with respect to $\tilde{d}$. The best fitted curve can be written as

$$\rho_{DS} = 0.663 \exp(-|\tilde{d}|^2/0.38) \quad (10)$$

Each dot of Figure 8 and Figure 9 represents an averaged value of hundreds of coefficients which are estimated from measured samples within $\tilde{d} \in [\tilde{d}_n, \tilde{d}_{n+1}]$.

It can be observed from both Figure 8 and Figure 9 that each two channels (BS-MS and RS-MS) are highly correlated when the MS is away from both BS and RS with the same distance. Furthermore, the correlation becomes lower when the position of MS is close to the BS, relatively far from the RS, and when the MS is approaching to the RS, relatively away from the BS.

V. CONCLUSIONS

In this paper, the cross-correlation coefficients of the parameters of two channels are measured by using the rBECs system. The multi-link scenario contains the link between the base station and mobile station, and between the relay station and mobile station. The cross-correlation characteristics of large scale parameters such as shadow fading and delay spread are investigated from measured data. The empirical cross-correlation characteristics show that each two channels are highly correlated when the angle of separation is low, and when the mobile station is away from both base station and relay station with the same distance. We found that these curves are applicable for describing the variation of the cross-correlation of channel parameters with respect to the geometrical parameters, i.e. the angle between the BS-MS link and the RS-MS link, as well as the relative distance which is

the ratio between the length of the direct link between BS and MS to that for RS to MS, represented in dB.

These experimental results can be applied to construction of stochastic channel model for cooperative MIMO communication. Further studies are needed for considering more geometrical parameters and various indoor and outdoor environments.

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REFERENCES

- [1] Y. Fan and J. S. Thompson, "MIMO Configurations for Relay Channels: Theory and Practice", *IEEE Trans. Wireless Commun.*, vol. 6, no. 5, May 2007, pp. 1774–86.
- [2] M. K. Karakayali, G. J. Foschini, and R. A. Valenzuela, "Network Coordination for Spectrally Efficient Communications in Cellular Systems," *IEEE Commun. Mag.*, vol. 44, no. 8, Aug. 2006, pp. 56–61.
- [3] D. Soldani and S. Dixit, "Wireless Relays for Broadband Access," *IEEE Commun. Mag.*, vol. 46, no. 3, Mar. 2008, pp. 58–66.
- [4] C. X. Wang, X. Hong, X. Ge, X. Cheng, G. Zhang, J. Thompson, "Cooperative MIMO channel models: A survey", *IEEE Communications Magazine*, vol. 48, Issue 2, 2010, pp 80-87.
- [5] 3GPP TR 25.996, "Spatial Channel Model for Multiple Input Multiple Output (MIMO) Simulations (Rel. 6)," Sept. 2003.
- [6] P. Kyosti et al., "WINNER II Channel Models," *IST-WINNER II D1.1.2*, Nov. 2007.
- [7] G. Senarath et al., "Multi-hop Relay System Evaluation Methodology (Channel Model and Performance Metric)," *IEEE 802.16j-06/013r3*, Feb. 2007.
- [8] M. D. Kim, J. J. Park, H. K. Kwon, and H. K. Chung, "Performance Evaluation of Wideband MIMO Relay Channel Sounder for 3.7 GHz," *IEEE Asia Pacific Wireless Communication Symposium*, Aug. 2011.
- [9] B. H. Fleury, M. Tschudin, R. Heddergott, D. Dahlhaus, and K. I. Pedersen, "Channel Parameter Estimation in Mobile Radio Environment Using the SAGE Algorithm", *IEEE Journal on Selected Areas in Communications*, vol. 17, No. 3, pp. 434-450, March 1999.
- [10] M. D. Kim, H. K. Kwon, W. S. Kim, J. J. Park, and H. K. Chung, "Performance Evaluation of Bi-directional MIMO channel Sounding System", *ICWN2008*, vol. 1, 2008, pp704-708.
- [11] H. K. Chung, "Multi-link MIMO wireless channel characterization for cooperative communications," *Invited talk of IEEE Asia Pacific Wireless Communication Symposium*, Aug. 2011.