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Session TH1B : Communications and Network **10:00-12:00, Thur. October 30, 2014** **Session Chair : Sooyoung Kim (Chonbuk National University, Korea)** **Chuanlei Zhang (Tianjin University of Science and Technology, China)**	**Room NO. 212**
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	Meixiang Zhang and Sooyoung Kim Division of Electronics Eng. Chonbuk National University, Korea
TH1B-2	**Research on Network Topology and Framework of the Perception Layer in IOT**
	Wei-Dong Fang1, Xiu-Zhi Wang1, Zhi-Dong Shi1, Guo-Qing Jia2, Ying Ma2 Lian-Hai Shan3 and Chuanlei Zhang4 1School of Com. and Information Engineering, Shanghai University, China 2College of Physics and Electronic Information Engineering, Qinghai University for Nationalities Xining, China 3Shanghai Internet of Things Co., LTD, China 4School of Computer Science and Information Engineering, Tianjin University of Science and Tech, China
TH1B-3	**Communication Networks for Wind Turbine Monitoring based on Infrared Camera**
	Shahid Hussain, Mohamed A. Ahmed, Young-Chon Kim Department of Computer Engineering Chonbuk National University, Korea
TH1B-4	**Novel Power Control Scheme for Interference Mitigation in Macro-Femtocell Heterogeneous Network**
	Sangmi Moon, Saransh Malik, Hun Choi, Cheolhong Kim, Jinyoung Kim and Intae Hwang Dept. of Electronics and Computer Engineering, Chonnam National University, Korea
TH1B-5	**Reduction of the Feedback Delay Effect on Proportional Fair Scheduler in LTE Downlink Using Nonlinear Support Vector Machine regression**
	Aladdin Djouama and Myoung-Seob Lim Division of Electronics & Information Engineering, Chonbuk National University, Korea
TH1B-6	**Block Circulant Toeplitz Jacket Matrix for Correlated MIMO Channel**
	Han Hai1, Moon Ho Lee1, Yongchae Jeong1, Yier Yan2, Liting Huang2 and Jae Seung Yang3 1Division of Electronics Engineering, Chonbuk National University, Korea 2School of Mechanical and Electrical Engineering, Guangzhou University, China 3Computer Engineering Daejin University, Korea

Session TH1C : Microwave and Antenna **10:00-12:00, Thur. October 30, 2014** **Session Chair : Jongsik Lim (SoonChunHyang University, Korea)** **Heungjae Choi (Cardiff University, United Kingdom)**	**Room NO. 209**
TH1C-1	**[Invited Paper] Observation of Change in Microwave Properties During Solid to Liquid Phase Transformation of Gallium**
	Heungjae Choi, Jerome Cuenca, Jon Hartley and Adrian Porch School of Engineering, Cardiff University, United Kingdom
TH1C-2	**Tunable Negative Group Delay Circuit With Improved Signal Attenuation**
	Junhyung Jeong, Seungwook Lee, Girdhari Chaudhary and Yongchae Jeong Division of Electronics and Information Engineering, Chonbuk National University, Korea
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	Jon Hartley, Jonny Lees, Jerome Cuenca and Heungjae Choi Centre for High Frequency Engineering, School of Engineering, Cardiff University, United Kingdom
TH1C-4	**Design of a Size-Reduced Ring Hybrid Coupler using Double-Layered Substrate and Ground Contact-Free Defected Ground Structure**
	Jongsik Lim1, Hanjoo Do1, Seok-Jae Lee2, Sang-Min Han2 and Dal Ahn2 1Department of Electrical Engineering, SoonChunHyang University, Korea 2Department of information and Communication Engineering, SoonChunHyang University, Korea
TH1C-5	**Microwave Detection of Photodielectric Effects in Antimony Tin Oxide**
	Jerome Cuenca, Heungjae Choi, Jon Hartley and Adrian Porch Centre for High Frequency Engineering, School of Engineering, Cardiff University, UK
TH1C-6	**A Design of Circular-Meander Structure Antenna for MICS Band**
	Jong Bin Park1, Dong Suk Lee1, Robert Hitchcock2, and Dong Sun Park3 1Department of Electronic&Information Engineering, Chonbuk National University, Korea 2Department of Bioengineering,University of Utah, USA 3Department of Electronics Engineering, Chonbuk National University, Korea

Block Circulant Toeplitz Jacket Matrix for Correlated MIMO Channel

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***Abstract*—In this paper, we analyze the capacity of multiple-input multiple-output (MIMO) corrlated channels in the presence of fading correlation at both the transmitter and the receiver, assuming that the channel is unknown at the transmitter and perfectly known at the receiver. We apply the block circulant Jakcet matrix to the covariance of the channel matrix, which improve the performance of the system.**

***Index Terms*—MIMO, Jacket matrix, channel capacity, block circulant matrix.**

I. Introduction

Multiple-input multiple-output (MIMO) communication systems using multiple transmit and receive antennas promise high spectral efficiency and link reliability for wireless communications [1]. Although the linear growth of capacity with the number of antennas indicates the potential of MIMO systems, the true benefits of the use of multiple antennas may be limited by spatial fading correlation due to closely-spaced antenna configurations and poor scattering environments in realistic wireless channels [4],[5]. Since the pioneering work of [1][3] in the area of multiple-antenna communications predicted remarkable spectral efficiency of MIMO wireless systems in independent and identically distributed (i.i.d.) Rayleigh fading, much subsequent work has concentrated on characterizing MIMO capacity under correlated fading [4][5]. However, the exact analytical results for the capacity such as ergodic (or mean) capacity, capacity variance, and outage capacity (i.e., capacity versus outage probability) have been known for only a few special cases, largely due to mathematical intractability (see, e.g., [3], [6] for i.i.d. flat Rayleigh fading and [2] for a one-sided correlated MIMO channel). For a more general case of correlated fading at both the transmitter and the receiver, which we will refer to as doubly correlated MIMO channels in the paper, some limited results are available: the capacity distribution for a small number of antennas are the numbers of transmit and receive antennas, respectively), upper and lower bounds on the ergodic capacity, capacity statistics for the case with a large number of antennas , and the asymptotic mean and variance of the capacity in the limit as the number of antennas tends to infinity. The temporal behavior of the capacity was analyzed in [4] in terms of level crossing rates and average fade durations.

The remainder of this paper is organized as follows. The next section states system model. Section III introduces block circulant matrices to the correlated MIMO channel, which can improve the performance of the system.

II. SYSTEM MODEL

For a MIMO system with N_T transmit and N_R receive antennas, as shown in Figure 1, a narrowband time-invariant wireless channel can be represented by $N_R \times N_T$ deterministic matrix $H \in \mathbb{C}^{N_R \times N_T}$.

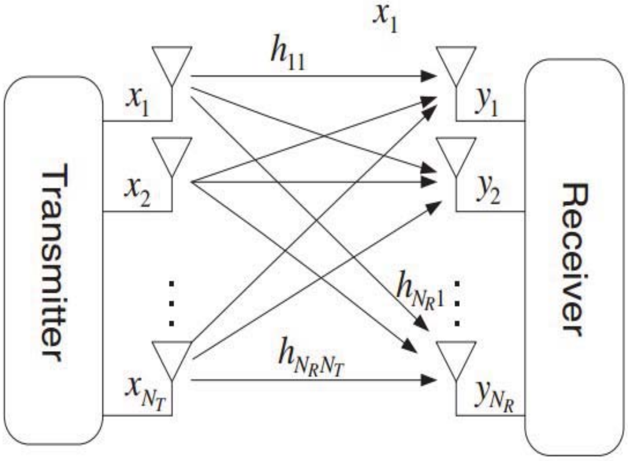

Fig. 1. Architecture of the MIMO channel.

Consider a transmitted symbol vector $x \in \mathbb{C}^{N_T \times 1}$, which is composed of N_T independent input symbols $x_1, x_2, \cdots, x_{N_T}$. . Then, the received signal $x \in \mathbb{C}^{N_R \times 1}$ can be rewritten in a matrix form as follows:

$$y = \sqrt{\frac{E_x}{N_T}} Hx + z \tag{1}$$

where $z = (z_1, z_2, \cdots, z_{N_r})^T \in \mathbb{C}^{N_R \times 1}$ is a noise vector, which is assumed to be zero-mean circular symmetric complex Gaussian (ZMCSCG). E_x is the energy of the transmitted signals. Note that the noise vector z is referred to as circular symmetric when $e^{j\theta} z$ has the same distribution as z for any θ. The autocorrelation of transmitted signal vector is defined as

$$R_{xx} = Exx^H. \tag{2}$$

Note that $Tr(R_{xx}) = N_T$ the transmission power for each transmit antenna is assumed to be 1.

In general, the MIMO channel gains are not independent and identically distributed (i.i.d.). The channel correlation is closely related to the capacity of the MIMO channel. In the sequel, we consider the capacity of the MIMO channel when the channel gains between transmit and received antennas are correlated. When the SNR is high, the deterministic channel capacity can be approximated as

$$C \approx \max_{Tr(R_{xx})=N} \log_2 \det(R_{xx}) + \log_2 \det(\frac{E_x}{N\mathbf{N}_0}\mathbf{H}_w\mathbf{H}_w^H) \quad (3)$$

From Equation (3), we can see that the second term is constant, while the first term involving $\det(R_{xx})$ maximized when $R_{xx} = I_N$. Consider the following correlated channel model:

$$H = R_r^{1/2} H_w R_t^{1/2} \quad (4)$$

where R_t is the correlation matrix, reflecting the correlations between the transmit antennas (i.e., the correlations between the column vectors of H), R_r is the correlation matrix reflecting the correlations between the receive antennas (i.e., the correlations between the row vectors of H), and H_w denotes the i.i.d. Rayleigh fading channel gain matrix. The diagonal entries of R_t and R_r are constrained to be a unity. Then, the MIMO channel is given as

$$C = \log_2 \det(I + \frac{E_x}{N\mathbf{N}_0} R_r^{1/2} H_w R_t H_w^H R_r^{H/2}) \quad (5)$$

The narrorband MIMO radio channel $H \in \mathbb{C}^{M\times N}$ which describes the connection between the MS and the BS can be expressed as

$$R_T = \begin{pmatrix} \alpha_{11} & \alpha_{12} & \cdots & \alpha_{1N} \\ \alpha_{21} & \alpha_{22} & \cdots & \alpha_{2N} \\ \vdots & \vdots & \ddots & \vdots \\ \alpha_{M1} & \alpha_{M2} & \cdots & \alpha_{MN}\cdots \end{pmatrix}.$$

where α_{mn} is the complex transmission coefficient from antenna n at the MS to antenna m at the BS. For simplicity, it is assumed that α_{mn} is complex Gaussian distributed with identical average power.

The spatial correlation matrix at the MS and the BS and is given by

$$R_{MIMO} = R_R \otimes R_T, \quad (6)$$

where $\otimes$ represents the Kronecker product. This has also been confirmed in [7].

III. Block Circulant Jacket Matrix for Correlated MIMO Channel

The bivariate or two-dimensional Gaussian PDF. The mean m_x and the covariance matrix M for this case are

$$m_x = \begin{pmatrix} m_1 \\ m_2 \end{pmatrix}, M = \begin{pmatrix} \sigma_1^2 & \mu_{12} \\ \mu_{12} & \sigma_2^2 \end{pmatrix},$$

where the joint central moment μ_{12} is defined as

$$\mu_{12} = E[(X_1 - m_1)(X_2 - m_2)]. \quad (7)$$

It is convenient to define a normalized covariance

$$\rho_{ij} = \frac{\mu_{ij}}{\sigma_i \sigma_j}, i \neq j \quad (8)$$

where ρ_{ij} satisfies the condition $0 \leq |\rho_{ij}| \leq 1$. When dealing with the two-dimensional case, it is customary to drop the subscripts on μ_{12} and ρ_{12}. Hence the covariance matrix is expressed as

$$M = \begin{pmatrix} \sigma_1^2 & \rho\sigma_1\sigma_2 \\ \rho\sigma_1\sigma_2 & \sigma_2^2 \end{pmatrix}.$$

For example, in 2×2 correlated transmitter receiver setup, let $a = [w, x, y, z]^T$ be a vector of four complex zero-mean, unit variance independent random variables. Applying the Gaxpy algorithm [6, p. 143], the lower-triangular matrix $\mathbf{C}$, result of the Cholesky decomposition of Γ,is given by shown at the bottom of the page.

Defining $A = [\alpha_{11}, \alpha_{12}, \alpha_{21}, \alpha_{22}]^T$, the channel coefficients α_{ij} are generated as

$$A = Ca, \quad (9)$$

$$\begin{pmatrix} \alpha_{11} \\ \alpha_{12} \\ \alpha_{21} \\ \alpha_{22} \end{pmatrix} = C \begin{pmatrix} w \\ x \\ y \\ z \end{pmatrix}$$

Then we can have

$$\begin{aligned} \langle \alpha_{11}, \alpha_{11} \rangle &= \frac{E[\alpha_{11}\alpha_{11}^*]}{\sigma_{\alpha_{11}}^2} && (10) \\ &= \frac{E[\alpha_{11} w \alpha_{11} w^*]}{\sigma_{\alpha_{11}}^2} && (11) \\ &= \frac{\sigma_{\alpha_{11}}^2 E[ww^*]}{\sigma_{\alpha_{11}}^2} && (12) \\ &= 1 && (13) \end{aligned}$$

since w has unit variance.

$$\begin{aligned} \langle \alpha_{11}, \alpha_{12} \rangle &= \frac{E[\alpha_{11}\alpha_{12}^*]}{\sigma_{\alpha_{11}}\sigma_{\alpha_{12}}} && (14) \\ &= \frac{E[\sigma_{\alpha_{11}} w \left(\sigma_{\alpha_{12}}\rho^* w + \sigma_{\alpha_{12}}\sqrt{1-|\rho|^2}x\right)^*]}{\sigma_{\alpha_{11}}\sigma_{\alpha_{12}}} && (15) \\ &= \frac{\sigma_{\alpha_{11}}\sigma_{\alpha_{12}}\rho E[ww^*] + \sigma_{\alpha_{11}}\sigma_{\alpha_{12}}\sqrt{1-|\rho|^2}E[wx^*]}{\sigma_{\alpha_{11}}\sigma_{\alpha_{12}}} && (16) \\ &= \rho && (17) \end{aligned}$$

$$\begin{aligned} \langle \alpha_{11}, \alpha_{21} \rangle &= \frac{E[\alpha_{11}\alpha_{21}^*]}{\sigma_{\alpha_{11}}\sigma_{\alpha_{21}}} && (18) \\ &= \frac{E[\sigma_{\alpha_{11}} w \left(\sigma_{\alpha_{21}}\mu^* w + \sigma_{\alpha_{21}}\sqrt{1-|\mu|^2}y\right)^*]}{\sigma_{\alpha_{11}}\sigma_{\alpha_{21}}} && (19) \\ &= \frac{\sigma_{\alpha_{11}}\sigma_{\alpha_{21}}\mu E[ww^*] + \sigma_{\alpha_{11}}\sigma_{\alpha_{21}}\sqrt{1-|\mu|^2}E[wy^*]}{\sigma_{\alpha_{11}}\sigma_{\alpha_{21}}} && (20) \\ &= \mu && (21) \end{aligned}$$

Therefore, we have

$$\rho_{ij} = \frac{\mu_{ij}}{\sigma_i \sigma_j}. \quad (22)$$

We will apply block circulant Jakcet matrix (BCJM) to improve time-invariant Gaussian MIMO channel capacity. Simulation computes the ergodic MIMO channel capacity when there exists a correlation between the transmit and receive antennas, with the following channel correlation matrices: $R_r = I_4$ and.

Case 1: Toeplitz channel matrix

$$R_T = \begin{pmatrix} \rho^0 & \rho^1 & \rho^2 & \rho^3 \\ \rho^3 & \rho^0 & \rho^1 & \rho^2 \\ \rho^2 & \rho^3 & \rho^0 & \rho^1 \\ \rho^1 & \rho^2 & \rho^3 & \rho^0 \end{pmatrix}.$$

$R_r = I_4$ states that no correlation exists between the receive antennas. Figure has been generated by program , from which it

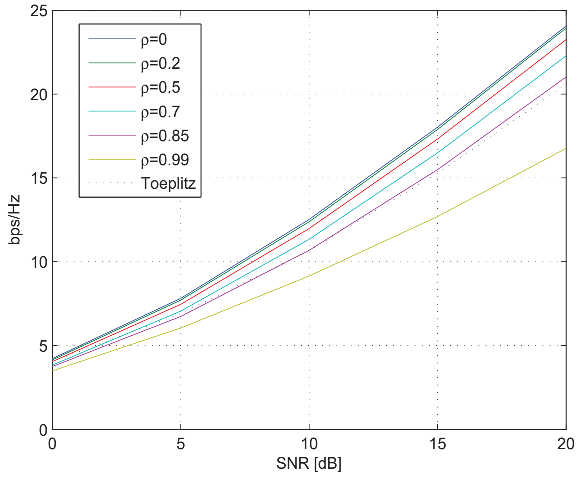

Fig. 2. Channel capacity versus SNR.

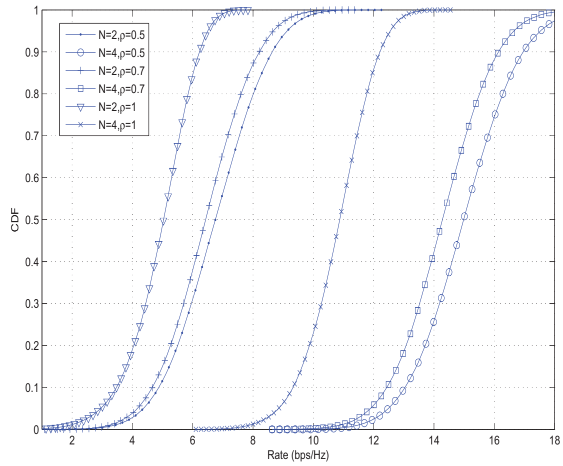

Fig. 4. CDF of channel capacity.

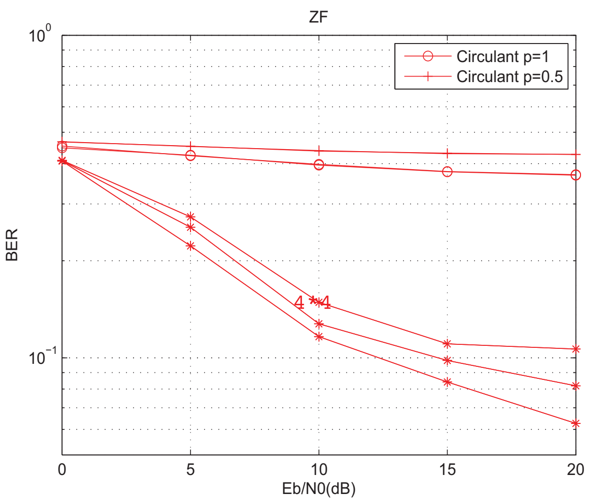

Fig. 3. Comparison of 4×4 MIMO and Block Diagonal 4×4 MIMO Symbol Error Rate.

can be shown that a capacity of 3.3 bps/Hz is lost due to the channel correlation when SNR is 18dB.

Case 2: Block circulant Jakcet matirx.

We have the R is a Block circulant matrix.

$$R = \begin{pmatrix} \begin{matrix} 1 & 1 \\ 1 & -1 \end{matrix} & \rho \begin{pmatrix} -1 & -1 \\ -1 & 1 \end{pmatrix} \\ \rho^* \begin{pmatrix} -1 & -1 \\ -1 & 1 \end{pmatrix} & \begin{matrix} 1 & 1 \\ 1 & -1 \end{matrix} \end{pmatrix}, |\rho| \leq 1$$

From Fig. 2 and Fig. 3, we observe that the block circulant Kronecker channel capacity could improve than conventional MIMO as an efficient capacity achieving scheme at high signal-to-noise ratio regime. Fig. 3 shows the average BER performance versus input SNR for comparing the proposed transceiver scheme with the existing transceiver algorithms. It can be seen that smaller correlation coefficients lead to a better performance. It shows the ability of the proposed algorithm to deal with the channel correlation. Figure 4 shows the CDFs of the correlated 2×2 and 4×4 MIMO channel capacities, it is clear from figure that the MIMO channel capacity improves with increasing the number of transmit and receive antennas.

The simulation shows the significance of proposed system.

IV. Conclusion

In this paper, we have applied the block circulant jacket matrices into correlated MIMO channel, since the transform is jacket matrices, the inverse transform is easily obtained by the reciprocal and transpose operations. Furthre, it has a fast efficient algorithm. On the other hand, since it is block circulant matrix, it can easily get the covariance of the correlated MIMO channel, which lead to a better performance.

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