IJICTR
International Journal of Information & Communication Technology Research

Volume 13- Number 1 – 2021 (19 -24)

The Effective Rate of MISO Systems over EGK Fading Channels

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Received: 14 January 2021 - Accepted: 21 March 2021

Abstract—**This study aims to examine the effective rate of a Multiple-Input Single-Output (MISO) system under independent and non-identical (i.n.i.d) distribution with the Extended Generalized-K (EGK) fading channel. The Moment Generating Function (MGF)-based method is used since it has a computational advantage over probability density function (PDF)-based methods and leads to a whole closed-form relation. Moreover, the H-function EGK distribution is employed to calculate the exact and asymptotic expression for the effective rate of MISO wireless communication system. Finally, the Monte Carlo simulation results, along with accurate and asymptotic results, are presented.**

Keywords—Multi-Input Single-Output (MISO) system; Extended Generalized-K (EGK); effective rate.

I. INTRODUCTION

In many wireless applications (e.g., voice over IP (VoIP), smart grid applications, and interactive games), not only the capacity limits but also the system delays are of great importance to evaluate the maximum achievable bit rate [1]. If the data are not transmitted during a specific time, they will be expired in such systems. To this end, a parameter called effective rate is introduced [2]. It is used as a highly efficient analytic tool to characterize the system performance under the quality of service (QoS) limitations [3-7]. In [1], the effective rate of the Multiple-Input Single-Output (MISO) system over κ-μ distribution with shadowing is investigated. In [8], the effective rate is calculated by considering the Weibull channel. In [9] and [10], the scheduling algorithm is employed for a multi-user time-division downlink system, where the effective rate is considered a critical parameter to determine the QoS. In [11], the effective rate is examined by considering the Fisher fading channel. The effective rate performance of MISO systems over α-μ fading channels was studied in [12]. The effective rate has also been introduced in studies on cognitive radio networks [13], [14].

The mathematical approach of mentioned papers is based on the probability density function (PDF) since the calculations depend on the exact or approximate PDF of the signal-to-noise ratio (SNR). In [15], a general PDF-based framework for effective rate analysis in the MISO system is proposed. However, computing a joint PDF is not available for many fading channels, and it is often very difficult or impossible to obtain an accurate PDF for analysis. For this reason, much research has been done to approximate the PDF of a sum of several fading channels [15], [16], [17]. This makes PDF-based effective rate analysis generally

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studied on a case-by-case basis. The authors in [18] proposed a new framework based on MGF to calculate the effective rate over MISO fading channels to solve this problem. MGF-based approaches often simplify analysis or make calculations of some essential performance criteria possible, while PDF-based approaches seem impractical.

Fading has a significant effect on the instantaneous capacity of the channel; hence, the effective rates are not similar in different fading scenarios [19,20]. The fading phenomena include small-scale and large-scale effects. Multi-paths cause small-scale fading, and large-scale fading is caused by shadowing. Some fading models only consider the multi-path effects and ignore shadowing; however, large-scale effects become more prominent as the frequency band increases. The extended generalized-K (EGK) distribution is a composite model encompassing both shadowing and multi-path effects [21, 22]. This distribution was proposed by Yilmaz et al. to model the power and the envelope of the received signal in 60GHz and above channels as well as free-space optical channels (FSOs) [22].

This paper calculates the effective rate of arbitrary correlated and not necessarily identical MISO fading channels over the EGK fading channel by using the MGF-based method. It is noteworthy that in cases where we are dealing with multiple channels, the instantaneous SNR at the receiver is described by a multivariate random variable, which is different from the SISO condition that univariate random variable may suffice. Asymptotic approximations are also presented to analyze the effective rate on MISO fading channels, reducing computational complexity.

II. SYSTEM MODEL

In this paper, a MISO system equipped with N antenna at the transmitter and only one antenna at the receiver is considered (Fig. 1). Accordingly, the received signal can be represented as follows

$$y = hx + n \tag{1}$$

where, x is the transmitted signal vector, $h \in C^{1\times N}$ is the channel vector between transmitter and receiver antennas (C denotes complex numbers), and n is the complex additive white Gaussian noise with zero mean and variance N_0. It is assumed that the channels are independent and non-identically distributed.

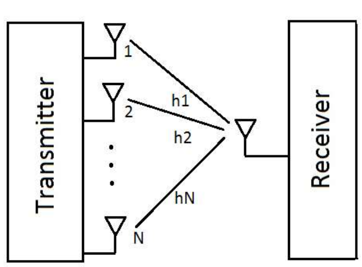

Figure 1. MISO system model.

The average transmitted SNR is displayed where P denotes the average transmitted signal power, and W represents the bandwidth. The wireless link is assumed to be under block fading, indicating that the channel changes from one block to another while remaining constant in each block. The channel state information (CSI) is also available on the receiver side. Here, the maximum ratio transmission (MRT) scheme is considered; hence, the received SNR is defined as $\gamma = \sum_{i=1}^{N} \gamma_i$. where, γ_i denotes the instantaneous channel power gain of the *ith* channel.

A. Extended Generalized-K (EGK) Fading

The EGK fading model is a composite model which, has the advantage of modeling statistics envelopes of most known wireless and optical communication channels such as Rayleigh, Nakagami-m, Weibull, Gamma, Suzuki, Weibull-Lognormal, Maxwell-Gamma, K-Distribution, and Generalized-K. The PDF of the received signal SNR, γ_i , can be displayed in the form of the Fox's H-function [23]

$$f(\gamma_i) = k_i H_{0,2}^{2,0}\left[\lambda_i \gamma_i \left| \begin{array}{c} - \\ (\mathrm{m}_i - \frac{1}{\xi_i}, \frac{1}{\xi_i}), (\mathrm{m}_{s_i} - \frac{1}{\xi_{s_i}}, \frac{1}{\xi_{s_i}}) \end{array}\right.\right] \tag{2}$$

where, $k_i = \dfrac{\beta_i \beta_{s_i}}{\Gamma(\mathrm{m}_i)\Gamma(\mathrm{m}_{s_i})\bar{\gamma}_i}$, $\lambda_i = \dfrac{\beta_i \beta_{s_i}}{\bar{\gamma}_i}$, $\beta_i = \dfrac{\Gamma(\mathrm{m}_i + 1/\xi_i)}{\Gamma(\mathrm{m}_i)}$, $\beta_{s_i} = \dfrac{\Gamma(\mathrm{m}_{s_i} + 1/\xi_{s_i})}{\Gamma(\mathrm{m}_{s_i})}$, and, m_i and m_{s_i} denote fading figure and shadowing figure, respectively. In (2), ξ_i and ξ_{s_i} represent fading shaping factor and shadowing shaping factor, respectively. $\bar{\gamma}_i$ is the average power. Moreover, $H_{p,q}^{m,n}\left[\cdot\left|\cdot\right.\right]$ denotes Fox's H-function given by [24, Eq. (1.2)]

$$H_{p,q}^{m,n}\left(\lambda \left| \begin{array}{l} (\mathrm{a}_j, \mathrm{A}_j)_{j=1:p} \\ (\mathrm{b}_j, \mathrm{B}_j)_{j=1:q} \end{array}\right.\right) = \frac{1}{2\pi j}\int_L \frac{\prod_{j=1}^{m}\Gamma(\mathrm{b}_j + \mathrm{B}_j \mathrm{s})\prod_{j=1}^{n}\Gamma(1 - a_j - A_j\,\mathrm{s})}{\prod_{j=n+1}^{p}\Gamma(a_j + A_j\,\mathrm{s})\prod_{j=m+1}^{q}\Gamma(1 - b_j - B_j\,\mathrm{s})}\lambda^{-s} ds \tag{3}$$

where $A_j > 0$ for all $j = 1\cdots p$ and $B_j > 0$ for all $j = 1\cdots q$ and the path of the integration L goes from $\sigma - i\infty$
to $\sigma + i\infty$, $i = \sqrt{-1}$, $\sigma \in \mathbb{R}$ such that all the poles of $\Gamma(\mathrm{b}_j + \mathrm{B}_j \mathrm{s})$, $j = 1, 2, \cdots m$ are separated from those of $\Gamma(1 - a_j - A_j\,\mathrm{s})$, $j = 1, 2, \cdots m$.

III. Effective Rate Analysis

In a wireless communications system, the effective rate is the maximum achievable constant rate meeting the required QoS, which can be written as follows [25]

$$R(\theta) = -\frac{1}{\theta T}\ln E\left\{e^{-\theta TC}\right\}, \qquad \theta \neq 0 \tag{4}$$

where C is the transmit rate, T is the duration of the block and θ represents the delay exponent defined in [5]. The effective rate when the transmitter sends uncorrelated circularly symmetric zero-mean complex Gaussian signals can be shown as follows [25]

$$R(\theta) = -\frac{1}{A}\log_2 E\left\{(1+\frac{\rho}{N}\gamma)^{-A}\right\} \tag{5}$$

where $A = \theta TW\log_2(\mathrm{e})$. Typically, (5) leads to an expression that includes several multivariate integrals; hence, [21] proposes a framework to calculate the effective rate by the MGF function

$$R(\theta) = -\frac{1}{A}\log_2\frac{1}{\Gamma(\mathrm{A})}H\left\{\phi(\frac{\rho s}{N}),O,P\right\}(1) \tag{6}$$

where $H\{.,.,.\}$ denotes the H transform given in [26, Eq. (40)]

$$H\{\mathrm{f(z),O,P}\}(\mathrm{s}) = \mathrm{u}\int_0^\infty H_{p,q}^{m,n}\left[vsz\left|\begin{matrix}c,C\\d,D\end{matrix}\right.\right]f(\mathrm{z})\mathrm{dz}$$
$$\begin{cases} O = (\mathrm{m,n,p,q}) \\ P = (\mathrm{u,v,c,d,C,D})\end{cases} \tag{7}$$

In order to calculate effective rate over arbitrary correlated and not necessarily identically distributed MISO fading channels O and P define as $(1,0,0,1)$, $(1,1,-,\mathrm{A}-1,-,1)$, respectively. Also, $\phi(\mathrm{s}) = \prod_{i=1}^{N}\phi_i(\mathrm{s})$ and $\phi_i(\mathrm{s}) = \mathrm{E}\{\mathrm{e}^{-s\gamma_i}\}$ represents the MGF of individual channel power gain.

A. EGK Moment Generating Function

According to the definition of MGF and relation (2), the moment-generating function of EGK can be expressed as follows

$$\phi_{\gamma_i}(s) = k_i\int_0^\infty e^{-s\gamma_i}H_{0,2}^{2,0}\left[\lambda_i\gamma_i\left|\begin{matrix}-\\(\mathrm{m}_i-\frac{1}{\xi_i},\frac{1}{\xi_i}),(\mathrm{m}_{s_i}-\frac{1}{\xi_{s_i}},\frac{1}{\xi_{s_i}})\end{matrix}\right.\right]d\gamma_i \tag{8}$$

Using the Laplace transform of the H-Function [24, Eq. (2.19)], (6) can be rewritten as

$$\phi_{\gamma_i}(s) = \frac{k_i}{\lambda_i}H_{2,1}^{1,2}\left[\frac{s}{\lambda_i}\left|\begin{matrix}(1-\mathrm{m}_i,\frac{1}{\xi_i}),(1-\mathrm{m}_{s_i},\frac{1}{\xi_{s_i}})\\(0,1)\end{matrix}\right.\right] \tag{9}$$

So the joint MGF of EGK distribution is calculated as follows

$$\phi_\gamma(s) = \prod_{i=1}^{N}\frac{k_i}{\lambda_i}H_{2,1}^{1,2}\left[\frac{s}{\lambda_i}\left|\begin{matrix}(1-\mathrm{m}_i,\frac{1}{\xi_i}),(1-\mathrm{m}_{s_i},\frac{1}{\xi_{s_i}})\\(0,1)\end{matrix}\right.\right] \tag{10}$$

B. Effective Rate Analysis of MISO System Using MGF

The H transform of the product of Fox's H-functions can be calculated as [16, Eq.(14)], in terms of multivariate Fox's H-function [24, Eq. (A.1)] computed in (11). By replacing (11) in (6), the effective rate of the MISO system can be calculated as (12).

C. Effective Rate Analysis under SISO EGK fading channel

The SISO fading channel is considered a particular case of the i.n.i.d channel, where there is only one antenna at the receiver, i.e., $\mathrm{N}=1$. Under the SISO EGK fading channel condition, the MGF can be expressed as relation (9), so the effective rate can be expressed as

$$H\left\{\phi(\frac{\rho s}{N}),O,P\right\}(1) = \prod_{i=1}^{N}\frac{k_i}{\lambda_i}H_{1,0:2,1;\cdots;2,1}^{0,1:1,2;\cdots;1,2}\left[\begin{matrix}\frac{\rho}{N\lambda_1}\\ \vdots \\ \frac{\rho}{N\lambda_N}\end{matrix}\left|\begin{matrix}(1-\mathrm{A},1,\cdots,1):(1-\mathrm{m}_1,\frac{1}{\xi_1}),(1-\mathrm{m}_{s_1},\frac{1}{\xi_{s_1}});\cdots;(1-\mathrm{m}_N,\frac{1}{\xi_N}),(1-\mathrm{m}_{s_N},\frac{1}{\xi_{s_N}})\\ -:(0,1);\cdots;(0,1)\end{matrix}\right.\right] \tag{11}$$

$$R(\theta) = -\frac{1}{A}\log_2\left(\frac{1}{\Gamma(\mathrm{A})}\prod_{i=1}^{N}\frac{k_i}{\lambda_i}H_{1,0:2,1;\cdots;2,1}^{0,1:1,2;\cdots;1,2}\left[\begin{matrix}\frac{\rho}{N\lambda_1}\\ \vdots \\ \frac{\rho}{N\lambda_N}\end{matrix}\left|\begin{matrix}(1-\mathrm{A},1,\cdots,1):(1-\mathrm{m}_1,\frac{1}{\xi_1}),(1-\mathrm{m}_{s_1},\frac{1}{\xi_{s_1}});\cdots;(1-\mathrm{m}_N,\frac{1}{\xi_N}),(1-\mathrm{m}_{s_N},\frac{1}{\xi_{s_N}})\\ -:(0,1);\cdots;(0,1)\end{matrix}\right.\right]\right) \tag{12}$$

$$R(\theta)=-\frac{1}{A}\log_2\left(\frac{1}{\Gamma(\mathrm{A})}\frac{k}{\lambda}\times H_{1,3}^{3,1}\left[\frac{\lambda}{\rho}\left|\begin{matrix}(1,1)\\(\mathrm{A},1),(\mathrm{m},\frac{1}{\xi}),(\mathrm{m}_s,\frac{1}{\xi_s})\end{matrix}\right.\right]\right) \quad (13)$$

D. Asymptotic Analysis

In this section, an asymptotic expression for the effective rate of EGK channels in high SNRs is calculated. This asymptotic expression dramatically reduces computational complexity.

Theories [24, Theorem 1.2, and Theorem 1.3] can be used to calculate asymptotic expressions of the Fox-H function. For this purpose, the residual theorem is used to compute the asymptotic expression of the H-function. Thus, at large SNRs, only the pole closest to the contour is considered, which in a SISO system is $\tau=\min\{m\xi,m_s\xi_s\}$, so if $\tau=m\xi$, the effective rate is provided by

$$R(\theta)\approx\frac{-1}{A}\log_2\left(\frac{(\lambda/\rho)^{-\tau}\Gamma(m_s-\tau/\xi_s)\Gamma(\tau)\Gamma(\mathrm{A}+\tau)}{\xi\,\Gamma(\mathrm{A})\Gamma(\mathrm{m})\Gamma(\mathrm{m}_s)}\right) \quad (14)$$

and if $\tau=m_s\xi_s$, the effective rate is provided by

$$R(\theta)\approx\frac{-1}{A}\log_2\left(\frac{(\lambda/\rho)^{-\tau}\Gamma(m-\tau/\xi)\Gamma(\tau)\Gamma(\mathrm{A}+\tau)}{\xi_s\,\Gamma(\mathrm{A})\Gamma(\mathrm{m})\Gamma(\mathrm{m}_s)}\right) \quad (15)$$

In a MISO system, the closest poles to the contour in the left side of the axis are considered, which can be obtained from $\tau=\max\{-m_i\xi_i,-m_{s_i}\xi_{s_i}\}$, so if $\tau=-m_i\xi_i$, the effective rate is computed as follows

$$R(\theta)\approx\frac{-1}{A}\log_2\left(\frac{\Gamma(\mathrm{A}+N\tau)\Gamma(-\tau)}{\Gamma(\mathrm{A})}\times\prod_{i=1}^{N}\frac{\Gamma(1/\xi_i)(\rho/N\lambda_i)^{\tau}(m_{s_i}-\tau/\xi_{s_i})}{\Gamma(\mathrm{m}_i)\Gamma(\mathrm{m}_{s_i})}\right) \quad (16)$$

and if, $\tau=-m_{s_i}\xi_{s_i}$, the effective rate is calculated as

$$R(\theta)\approx\frac{-1}{A}\log_2\left(\frac{\Gamma(\mathrm{A}+N\tau)\Gamma(-\tau)}{\Gamma(\mathrm{A})}\times\prod_{i=1}^{N}\frac{\Gamma(1/\xi_{s_i})(\rho/N\lambda_i)^{\tau}(m_i-\tau/\xi_i)}{\Gamma(\mathrm{m}_i)\Gamma(\mathrm{m}_{s_i})}\right) \quad (17)$$

IV. Effective Rate Analysis of some Special Cases of EGK Fading Channels

This section examines the effective rates on some specific fading channels, namely the i.n.i.d generalized K (GK) composite channels, the K channel, and the Weibull-gamma channel. These scenarios are efficient and are widely used in the study of wireless system performance. Also, these exceptional cases show how the proposed theorems are presented in the conditions of a particular channel.

A. Generalized K (GK) fading channels

Generalized-K (GK) distribution is a general model used in radar applications to describe the statistical behavior of composite fading and multi-path shadowing effects [26]. The PDF of generalized K fading is obtained by setting $\xi=1$ and $\xi_s=1$ in relation (2), so the effective rate can be expressed as (18).

B. K fading channels

The K distribution, which is a combination of Rayleigh and gamma distributions, is used to model various scattering phenomena such as the tropospheric emission of radio waves, optical scintillation from the atmosphere, and various types of radar clutter [27]. The effective rate of K distribution is calculated by placing $\xi=1$, $\xi_s=1$ and $m=1$ in relation (10) and computed as (19).

C. Weibull-Gamma fading channels

Weibull-gamma is also a composite distribution proposed in [28] to model fading and shadowing effects. This distribution is considered a particular case of EGK distribution; therefore, the effective rate of the MISO system over Weibull-gamma is calculated by setting $\xi_s=1$ and $m=1$ in relation (10) as described in relation (20) at the bottom of the page.

$$R(\theta)=\frac{-1}{A}\log_2\left(\frac{1}{\Gamma(\mathrm{A})}\prod_{i=1}^{N}\frac{k_i}{\lambda_i}H_{1,0:2,1;\cdots;2,1}^{0,1:1,2;\cdots;1,2}\left[\begin{matrix}\frac{\rho}{N\lambda_1}\\ \vdots\\ \frac{\rho}{N\lambda_N}\end{matrix}\left|\begin{matrix}(1-\mathrm{A},1,\cdots,1):(1-\mathrm{m}_1,1),(1-\mathrm{m}_{s_1},1);\cdots;(1-\mathrm{m}_N,1),(1-\mathrm{m}_{s_N},1)\\ -:(0,1);\cdots;(0,1)\end{matrix}\right.\right]\right) \quad (18)$$

$$R(\theta)=-\frac{1}{A}\log_2\left(\frac{1}{\Gamma(\mathrm{A})}\prod_{i=1}^{N}\frac{k_i}{\lambda_i}H^{0,1:1,2;\cdots1,2}_{1,0:2,1;\cdots,2,1}\left[\begin{matrix}\frac{\rho}{N\lambda_1}\\ \vdots\\ \frac{\rho}{N\lambda_N}\end{matrix}\left|\begin{matrix}(1-\mathrm{A},1,\cdots,1):(0,1),(1-\mathrm{m}_{s_1},1);\cdots;(0,1),(1-\mathrm{m}_{s_N},1)\\ -:(0,1);\cdots;(0,1)\end{matrix}\right.\right]\right) \quad (19)$$

$$R(\theta)=\frac{-1}{A}\log_2\left(\frac{1}{\Gamma(\mathrm{A})}\prod_{i=1}^{N}\frac{k_i}{\lambda_i}H^{0,1:1,2;\cdots1,2}_{1,0:2,1;\cdots;2,1}\left[\begin{matrix}\frac{\rho}{N\lambda_1}\\ \vdots\\ \frac{\rho}{N\lambda_N}\end{matrix}\left|\begin{matrix}(1-\mathrm{A},1,\cdots,1):(0,\frac{1}{\xi_1}),(1-\mathrm{m}_{s_1},1);\cdots;(0,\frac{1}{\xi_N}),(1-\mathrm{m}_{s_N},1)\\ -:(0,1);\cdots;(0,1)\end{matrix}\right.\right]\right) \quad (20)$$

V. NUMERICAL RESULTS

The numerical and analytical simulations are presented in this section to verify the exact and asymptotic expressions calculated in this paper. Without losing generality, the length of each block $T=1ms$ and the bandwidth $W=3kHz$ are considered. Moreover, we have run 10^7 trails for the Monte Carlo simulations. Fig. 2. shows the effective rate of single-antenna and two-antenna systems. The green diagrams represent the SISO system, and the blue one shows the MISO system with two antennas. The results are plotted for different fading channel scenarios. As observed, in all the cases, the effective rate in the MISO system is better than the SISO system, and an increased number of transmitting antennas has improved the effective rate.

The dashed lines also show the asymptotic results. As expected, the asymptotic diagrams in large SNRs are perfectly matched to the accurate results showing the effective rates for different QoS exponent values. Larger θ values are associated with more severe delay limits. As can be seen in this figure, more severe delay limits reduce the effective rate. On the other hand, an increase in SNR improves the effective rate.

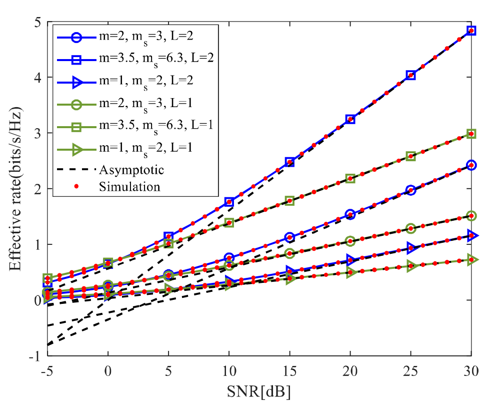

Figure 2. Effective rates with different transmit antennas in EGK fading channels with $\xi=\zeta_s=1$ and further fading and shadowing figures.

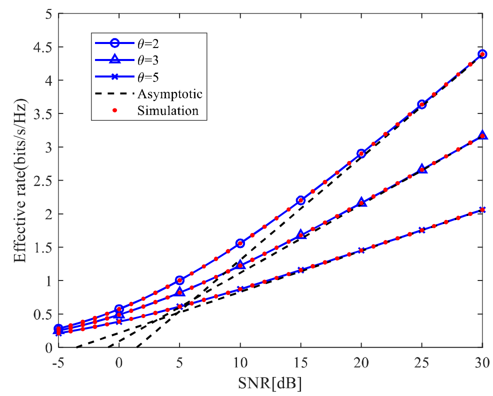

Figure 3. Effective rates with different QoS exponential θ in i.n.i.d EGK fading channels with m=2, ms=3, $\xi=\zeta_s=1$ and N=2.

VI. CONCLUSION

This paper calculates the effective rate of a MISO system, including the EGK fading channel. The EGK distribution is a composite fading model containing multi-path and shadowing effects; hence, it is suitable for modeling the millimeter waves and FSO channels. This paper uses the MGF-based method to calculate the effective rate, which has much less computational complexity than the PDF-based approach. For the simplicity of calculations, we wrote the MGF of the EGK distribution in the form of the H-function and calculated a closed-form expression for the effective rate. Then, using the residuals theorem, the asymptotic expression was calculated for the effective rate of both SISO and MISO systems.

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IJICTR
International Journal of Information & Communication Technology Research

Volume 13- Number 1 – 2021 (25 -31)

Massive MIMO Slow-varying Channel Estimation Using Tensor Sparsity

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Received: 21 January 2021 - Accepted: 28 March 2021

Abstract— **In order to exploit the advantages of the massive MIMO systems, it is vital to apply the channel estimation task. The huge number of antennas at the base station of a massive MIMO system produces a large set of channel paths which requires to be estimated. Therefore, the channel estimation in such systems is more troublesome. In this paper, we propose to leverage the temporal joint sparsity of the massive MIMO channels to offer a more accurate channel estimation. To attain this goal, we would model the problem to exploit the spatial correlation among different antennas of the BS as well as the inter-user similarity of the channel supports. In addition, by assuming a slow time-varying channel, the supports of the channel matrices of various snapshots would be equal which enables us to impose the temporal joint sparsity on the channel submatrices. The simulation results validate the efficiency and superiority of the suggested scheme over its rivals.**

Keywords- Massive MIMO; Channel estimation; Sparisity; Joint sparsity.

I. INTRODUCTION

Massive MIMO systems have attracted a great deal of attention during recent years due to some outstanding features such as higher capacity and better communication gains. Therefore, they are recognized as a key technology for the next generation of communication system [1]. To leverage the higher degrees of freedom provided by the massive MIMO systems, it is essential to have the channel state information in the transmitter side (CSIT) [2-4]. In massive MIMO systems, due to the large number of antennas in the BS, the traditional channel estimation schemes would result in large pilot overhead. Thus, we need to look deeper into the challenge of massive MIMO channel estimation. There are some features in the massive MIMO systems which can be used to estimate the channel.

A number of recent works have investigated the massive MIMO channel estimation in TDD protocol [5] [6]. In TDD systems, the estimated uplink channel can be used to estimate the downlink channel owing to the reciprocity property. In FDD systems, however, there is no reciprocity and the downlink channel shall be estimated independently. Hence, massive MIMO channel estimation in the FDD mode is more challenging [4].

The conventional channel estimation methods such as Least square (LS) [7] and minimum mean square

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