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Pilot reuse sequences for TDD in downlink multi-cells to improve data rates

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Abstract

The exponential growth in demand for high data rate transmission to users in fifth generation wireless networks, focus there has been a particular research focus on new techniques that achievable high data rate by suppressing interference between neighboring cells. In this paper, we propose that system performance can be improved by using perfect channel estimation and reducing effective interference with pilot reuse that mitigate strong pilot contamination based on the knowledge of large-scale fading coefficients. We derived the lower bounds on the achievable data rate in downlink by analyzing the performance of the zero-forcing precoding method and derive the signal-to-interference noise ratio to mitigate interference between neighboring cells. From the simulation results, the large pilot reuse sequences improved the achievable data rate and provided better estimation for a channel. When the number of users is large, the interference between neighboring cells can be suppressed by using orthogonal pilot reuse sequences.

Keywords*: massive MIMO, signal-to-interference-nois ratio, zero forcing*

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1. Introduction

Massive multiple-input-multiple-output (MIMO) systems are a permission technology designed to be used in future cellular networks to increase the data rate and improve energy efficiency. The use of a large antenna arrays with a high degree of freedom is able to mitigate uncorrelated interference, thermal noise, and the effects of fast fading will be vanished [1, 2]. Furthermore, each cell is contaminated with the interference cause by the use of the correlated pilot sequences in the neighbouring cells. Pilot contamination occurs due to pilot reuse sequences caused by sharing the non-orthogonal pilots for users between different cells and the limited capacity of the system. The pilot reuse sequence scheduler at a base station (BS) that is able to assign and allocate the available pilot reuse sequences to users [3, 4].

The major challenge in massive MIMO systems is how to acquire channel state information (CSI) at the BS. The channel estimation is crucial in massive multiple-input-multiple output systems; it is assumed that channel reciprocities were the same in uplink (UL) and downlink (DL). On the other hand, the user sent the same pilot reuse sequences in same time during channel estimation to eliminate pilot contamination [5, 6]. Massive MIMO systems work in time division duplex mode. The channel estimation can be obtained in time division duplex (TDD) by exploited channel reciprocity, the conventional training overhead for CSI is correlated with channel training when the number of UEs is independent of the number of antennas [7, 8]. Due to the property of the law of large number of users and antennas the random channel become near deterministic, where the channel estimation is a challenges issue for achieving multi-antenna gain. Increasing the number of transmit pilot reuse sequences for large-scale fading is able to suppress pilot contamination in multi-cell massive MIMO systems [9].

The author in [10] studied pilot contamination, channel estimation, and antenna correlation for both UL and DL as the number of antennas approaches infinity at a fixed number of users using eigen-beamforming and the matched filter. The author in [11] focused on reducing pilot overhead for spatially correlated Rayleigh fading channels based on the trade-off between pilot interference and pilot overhead when the number of orthogonal pilots reuses is smaller than

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the number of users. The authors in [12] used the scheduled allocation of pilot reuse sequences based on the degradation of the users by added set of orthogonal pilot reuse sequences to mitigate pilot contamination. The authors in [13] used practical channel estimation with approximate analytical mean square error to suppress pilot contamination without previous knowledge of inter-cell interference and large-scale fading. All BS antennas can be estimated at transmit pilots in the same time based on a set of mutually orthogonal pilot reuse sequences to a neighboring cell. Another study [14] improved spectral efficiency through user scheduling and pilot assignment based on the direction of their channels and orthogonal training sequences in a DL time division duplex. We derived the lower bounds on the achievable data rate in DL by analyzing the performance of the ZF precoding method and using the SINR to mitigate interference between neighboring cells. Based on transmitting the same pilot reuse sequences in the same cell and using mutually orthogonal pilot sequences in a neighboring cell. Finally, improved data rate performance can be obtained via zero-forcing (ZF) precoding using pilot reuse sequences with an increasing number of antennas M, which increases the gain and suppresses interference between neighboring cells.

2. Research Method

We consider a DL multi-cell massive MIMO wireless system with L cells. Each cell consists of one BS with M antennas to serve K active users (UEs), where $M \gg K$. We assume that the BS has imperfect CSI. The channel vector $g_{jlk} \in \mathbb{C}^{M\times 1}$ from the lth BS and kth user of the $j\ th$ cell can be formulated as

$$g_{jlk} = \mathcal{G}_{jlk}\sqrt{\varphi_{jlk}}\ , \tag{1}$$

where $\mathcal{G}_{jlk}$ is the small-scale fading coefficient, $\mathcal{G}_{ljk} \in \mathbb{C}^{M\times 1}, \mathbb{C}\mathcal{N}(0, I_M)$, and φ_{jlk} is the large-scale fading of transmission signals from different antennas in the same BS due to path loss and shadowing. From BS l, the transmission signal to UEs is the $M \times K$ precoding matrix, and the received signal at UE K in cell j can be written as

$$\mathcal{Y}_{jk} = \sqrt{Q_d}\ \sum_{l=1}^{L} g_{jlk}\, \mathcal{W}_{jl}\, v_{jl} + n_{jk}, \tag{2}$$

where $\mathcal{W}_{jl} = [\mathcal{W}_{jl1}, \mathcal{W}_{jl2}, \ldots\ldots, \mathcal{W}_{jlk}] \in \mathbb{C}^{M\times K}$ is the precoding matrix of $M \times K, tr\left|\mathcal{W}_{jl}\mathcal{W}^{H}{}_{jl}\right| = 1$, $v_{jl} = [v_{jl1}, v_{jl2}, \ldots\ldots, v_{jlK}] \in \mathbb{C}^{K} \sim \mathbb{C}\mathcal{N}(0, I_K)$ is the complex data vector of users, Q_d is the transmission power of the BS, g_{jlk} is the channel matrix from BS to UEs in cell l and $n_{jk} \sim \mathbb{C}\mathcal{N}(0, I_M)$ is the additive white Gaussian noise (AWGN) with zero mean and covariance variables.

2.1. Channel Estemation

We assume the BS and UEs are working under a time division duplex (TDD), where every UE inside the cell transmits mutually orthogonal pilot sequences through a training phase to compute estimation channel g_{jjk}. All BS antennas can be estimated at the same time using the mutually orthogonal pilot sequences in every cell. Based on the estimation of the channel vector at the $j\ th$ BS [15], the received training signal from the pilot reuse sequences $\mathcal{X}_{jk}^{tr}$of the UEs from all neighboring cells can be written as

$$\mathcal{X}_{jk}^{tr} = g_{jjk} + \sum_{l=1, l\neq j}^{L} g_{jlk} + \frac{n_{jk}}{\sqrt{\sigma_{tr}}}\ , \tag{3}$$

where σ_{tr} is the effective training signal-to-noise ratio (SINR), according to the properties of the minimum mean square error (MMSE) of channel estimation. The accuracy of a channel depends on the large scale multiple antennas for large-scale fading at multiple $\hat{g}_{jjk}$ by $\mathcal{X}_{jk}^{tr}$ and can be written as

$$\hat{g}_{jjk} = \varphi_{jjk}\, O_{jk}\, \mathcal{X}_{jk}^{tr}. \tag{4}$$

Increasing the training phase improves the channel quality [16], and the training signal based on pilot reuse sequences will be shared by the training phases for TDD-based channel estimation to calculate channel observations as

$$\hat{\mathfrak{g}}_{jjk} = \varphi_{jjk}\, O_{jk} \textstyle\sum_{l=1,l\neq j}^{L} \mathfrak{g}_{jlk} + \frac{n_{jk}}{\sqrt{\sigma_{tr}}}. \tag{5}$$

the estimate of MMSE for the distributed channel $\hat{\mathfrak{g}}_{jjk} \sim \mathbb{C}\mathcal{N}(0, \Psi_{jjk})$, where

$$\Psi_{jlk} = \varphi_{jjk}\, O_{jk}\, \varphi_{jlk}, \tag{6}$$

the channel variance for a UE in the lth cell to the target BS antenna arrays.

$$O_{jk} = \left(\textstyle\sum_{l=1,l\neq j}^{L} \varphi_{jlk} + \frac{I_M}{\sigma_{tr}}\right)^{-1}. \tag{7}$$

From the properties and orthogonally of MMSE the estimation channel error, we can decompose the channel $\bar{\mathfrak{g}}_{jjk}$as $\bar{\mathfrak{g}}_{jjk} = \mathfrak{g}_{jjk} - \hat{\mathfrak{g}}_{jjk}$, , where $\bar{\mathfrak{g}}_{jjk} \sim \mathbb{C}\mathcal{N}(0, \varphi_{jjk} - \Psi_{jjk})$, represent uncorrelated channel and is independent of $\hat{\mathfrak{g}}_{jjk}$. The high performance system can be obtained based on the limited number of pilot reuse sequences arising from the sharing of non-orthogonal pilots for a user between different cells. The pilot contamination effected to channel, to suppress pilot contamination and increase the capacity for users, require limited the number of users by using available of pilot reuse sequences $\tau_p = K = \infty$. To estimated channel for each UE at transmission signal from BS to the UEs, we used the training signal $\mathcal{X}_{jk}^{tr}$ with known pilot reuse sequences. The received signal at the BS during pilot transmission can be written as

$$\Phi_{jlk} = \sqrt{Q_d \tau_p} \textstyle\sum_{l=1}^{L} \mathfrak{g}_{jlk} + \frac{I_M}{\rho}, \tag{8}$$

where τ_p is the symbol of pilot reuse sequences. Using the same pilot reuse sequences for users in neighboring cells leads to contamination in channel estimation. We evaluate the properties of MMSE for channel estimation to obtain better pilot reuse sequences for UE $\hat{\mathfrak{g}}_{jlk}$ using Bayesian estimators. We suppose that each channel can be estimated separately using the MMSE of the Kth UE [16], and can be expressed as

$$\begin{aligned}
\hat{\mathfrak{g}}_{jlk} &= \mathbb{E}\left\|\bar{\mathfrak{g}}_{jlk} - \mathfrak{g}_{jlk}\right\|^2 \\
&= \mathbb{E}\left\{\left|O_{jk}(\Phi_{jlk} +) - \mathfrak{g}_{jlk}\right|^2\right\} \\
&= \mathbb{E}\left\{\left|(O_{jk} - I_M)(\Phi_{jlk}) + n_{lk}\right|^2\right\} \\
&= \left\{\varphi_{jlk}(O_{jk} - I_M)(O_{jk} - I_M)^H(\Phi_{jlk}) + \sigma^2 I_M\right\} \\
\hat{\mathfrak{g}}_{jlk} &= \left\{\varphi_{jlk}(O_{jk} - I_M)(O_{jk} - I_M)^H\left(\mathcal{G}_{jlk}\left(Q_d \tau_p \textstyle\sum_{l=1}^{L} \varphi_{jlk}\right)\mathcal{G}_{jlk}^H\right)\Phi_{jlk} + \sigma^2 I_M\right\} \\
\hat{\mathfrak{g}}_{jlk} &= \left\{\varphi_{jlk}\left(\left(\frac{I_M}{\rho} + \textstyle\sum_{l=1}^{L} \varphi_{jlk}\right)^{-1} - I_M\right)\left(\left(\frac{I_M}{\rho} + \textstyle\sum_{l=1}^{L} \varphi_{jlk}\right)^{-1} - \right.\right. \\
&\quad \left.\left. I_M\right)^H \left(\left(\mathcal{G}_{jlk}\left(Q_d \tau_p \textstyle\sum_{l=1}^{L} \varphi_{jlk}\right)\mathcal{G}_{jlk}^H\right)\Phi_{jlk}\right) + \sigma^2 I_M\right\}
\end{aligned} \tag{9}$$

$$\hat{\mathfrak{g}}_{jlk} = \frac{Q_d \tau_p \varphi_{jlk}}{1 + Q_d \tau_p \sum_{i=1}^{L} \varphi_{jlk}} \mathcal{G}^H{}_{jlk} \Phi_{jlk}. \tag{10}$$

The channel matrix is independent and identically distributed (i.i.d) according to the propagation channel matrix between BSs for non-line of sight components.

2.2. Achievable Downlink Data Rate

In a massive MIMO system, it is expected that the achievable data rate can be maximized by assigning the pilot reuse sequences τ_p to kth UE in every cell. The average channel estimation that enables every BS to detect the data signal from the UEs by applying the linear precoding matrix $\mathcal{W}_{jlk} \in \mathbb{C}^M$ to receive the signal and removing the interference caused by other users. The achievable data rate based on worst-case uncorrelated noise can be written as

$$\mathcal{R}_{jk} = \sum_{l=1}^{L} \sum_{i=1}^{K} \left(1 - \frac{\tau_p K}{S}\right) \left[log_2\left(1 + \xi_{jk}^{dl}\right)\right], \tag{11}$$

where $\left(1 - \frac{\tau_p K}{S}\right)$ represents the loss of the pilot signal for the pre-log factor, and S represents the coherence block interval. We derived the lower bound of an achievable data rate in based on the SINR due to the pilot reuse sequences under perfect covariance matrix estimation, the received signal can be written as

$$\mathcal{Y}_{jk} = \sqrt{Q_d \tau_p} \mathbb{E}\{\mathscr{g}_{jjk}^{H} \mathcal{W}_{jk}\} \mathscr{v}_{jk} + \sqrt{Q_d \tau_p} \sum_{i=1, i \neq k}^{K} (\mathscr{g}_{jjk}^{H} \mathcal{W}_{jk} - \mathbb{E}\{\mathscr{g}_{jjk}^{H} \mathcal{W}_{jk}\}) \mathscr{v}_{jk} +$$
$$\sqrt{Q_d \tau_p} \sum_{l=1, l \neq j}^{L} \sum_{i=1}^{K} \mathscr{g}_{jlk}^{H} \mathcal{W}_{lk} \, \mathscr{v}_{lk} + \mathscr{n}_{jk}. \tag{12}$$

If all the channels are uncorrelated Rayleigh fading the effective SINR $\xi_{jk}^{dl} = \frac{\mathbb{E}|\mathbb{D}\,|^2}{\mathbb{E}|\mathbb{U}\,|^2}$, from [17] the desired signal $(\mathbb{D})$ for SINR, the pilot reuse sequences can be estimated between channel $\mathscr{g}_{jlk}^{H}$ and the precoding matrix with $M \times K$. Poor channel estimation can occur due to interference between neighboring cells as a result of precoding vectors with a controlling eigenvector. The SINR can be evaluated based on the desired signal

$$\mathbb{E}|\mathbb{D}\,|^2 = Q_d \tau_p \left|\mathbb{E}\left[\mathscr{g}_{jjk}^{H} \mathcal{W}_{jk}\right]\right|^2. \tag{13}$$

from the uncorrelated noise $(\mathbb{U})$ we simplify as

$$\mathbb{E}|\mathbb{U}|^2 = Q_d \tau_p \sum_{l=1, l \neq j}^{L} \sum_{i=1}^{K} \mathbb{E}\left[\left|\mathscr{g}_{jlk}^{H} \mathcal{W}_{lk}\right|^2\right] - \sum_{i=l}^{L} Q_d \tau_p \left|\mathbb{E}\left[\mathscr{g}_{jjk}^{H} \mathcal{W}_{jk}\right]\right|^2 + \sigma^2 \,. \tag{14}$$

interference increases as the number of antennas moves toward infinity. We analyze the DL SINR of the UEs in cell l. The effective SINR can be expressed as

$$\xi_{jk}^{dl} = \frac{Q_d \tau_p \left|\mathbb{E}\left[\mathscr{g}_{jjk}^{H} \mathcal{W}_{jk}\right]\right|^2}{Q_d \tau_p \sum_{l=1, l \neq j}^{L} \sum_{i=1}^{K} \mathbb{E}\left[\left|\mathscr{g}_{jlk}^{H} \mathcal{W}_{lk}\right|^2\right] - \sum_{i=l}^{L} Q_d \tau_p \left|\mathbb{E}\left[\mathscr{g}_{jjk}^{H} \mathcal{W}_{jk}\right]\right|^2 + \sigma^2} \,. \tag{15}$$

to evaluate system performance, we introduce zero-forcing precoding to achieve the array gain $(M - K)$ and mitigate strong interference from the other cells.

$$\mathcal{W}_{jk} = \frac{\mathbb{E}\left|\tilde{\mathbb{G}}_{jlk}\left(\tilde{\mathbb{G}}_{jlk}^{H} \tilde{\mathbb{G}}_{jlk}\right)^{-1}\right|}{\mathbb{E}\left\{\left\|\tilde{\mathbb{G}}_{jlk}\left(\tilde{\mathbb{G}}_{jlk}^{H} \tilde{\mathbb{G}}_{jlk}\right)^{-1}\right\|^2\right\}^{1/2}} \,. \tag{16}$$

From the numerator in (15), we use the minimum mean square error properties at the BS, which has perfect knowledge of the covariance matrices channel. The estimation row vector of $\mathscr{g}_{jlk}$ for the transmission signal from the BS between the UEs in $j\ th$ cell and the BS in the $l\ th$ cell can be estimated according to [17], with linear zero-forcing precoding able to achieve the array gain $(M - K)$ from the properties of the covariance channel in [18, 19]:

$$Q_d \left|\mathbb{E}\left[\mathscr{g}_{jjk}^{H} \mathcal{W}_{jk}\right]\right|^2 = Q_{jk} (M - K)\, var\left(\mathscr{g}_{jlk}\right) \,. \tag{17}$$

In addition, reducing the inter-user interference for signals is crucial in obtaining less noise variance. From the worst-case Gaussian noise the channel variance for precoding vector, the received training signal for large-scale fading φ_{jlk} that is reflected by the transmission signal from the BS, which should acquire the covariance matrices for the channel estimation vectors from all of the UEs, where the covariance matrix is able to suppress pilot contamination [20, 21]. The variance channel can be simplified as

$$var(\hat{\mathfrak{g}}_{jlk}) = \frac{Cov[\hat{\mathfrak{g}}_{jlk}\,\phi_{jlk}]}{var[\phi_{jlk}]} = \frac{Q_d\tau_p\varphi_{jlk}}{1+Q_d\tau_p\sum_{i=1}^{L}\varphi_{jlk}}\,. \tag{18}$$

from the denominator in (15), the number of antennas M^2 increases according to the desired signal for the average channel gain $\left|\mathbb{E}\left[\mathfrak{g}_{jlk}^{H}\mathcal{W}_{jk}\right]\right|^2$. The second term in the denominator in (15) is similar, $\rho_d\left|\mathbb{E}\left[\mathfrak{g}_{jjk}^{H}a_{jk}\right]\right|^2 = Mvar(\mathfrak{g}_{jjk})$. The transmission data signal for all variables and independent identically distributed (i.i.d.) linear vector precoders of the users [22, 23] $\{\mathcal{W}_{ji}\}_{k=1}^{K}$ is distributed as

$$\mathbb{E}[\mathcal{W}_{li}] = 1\,,\ k = 1,2,\ldots\ldots,K \tag{19}$$

$$\mathbb{E}\left[\mathcal{W}_{jk}{\mathcal{W}_{jk}}^{H}\right] = 0,\quad k \neq j \tag{20}$$

$$\sum_{l=1,l\neq j}^{L}\sum_{i=1}^{K} Q_d\mathbb{E}\left[\left|\mathfrak{g}_{jlk}^{H}\mathcal{W}_{jk}\right|^2\right] = Q_{jk}\mathbb{E}\left|\mathfrak{g}_{jlk}\right|^2 = Q_{jk}var(\hat{\mathfrak{g}}_{jlk}) \tag{21}$$

$$var[\phi_{jlk}] = 1 + Q_d\tau_p\sum_{i=1}^{L}\varphi_{jlk} \tag{22}$$

$$Cov[\mathfrak{g}_{jlk}\,\phi_{jlk}] = \sqrt{Q_d}\,\tau_p\,\hat{\mathfrak{g}}_{jlk}\,. \tag{23}$$

when the pilot reuse sequences are assigned to the UEs, both the assigned pilot reuse sequences and the UEs are removed from the pilot reuse sequence pool. We analyzed the denominator for (15) by mitigated inter-user interference at reuse pilot sequences when the number of antennas move towards infinity, and the variance channel [10, 24, 25] $var\{\tilde{\mathfrak{g}}_{ljk}^{H}\mathcal{W}_{jk}\}\xrightarrow[M\to\infty]{} 0$ is as follows:

$$Q_d\sum_{l=1,l\neq j}^{L}\sum_{i=1}^{K}\mathbb{E}\left[\left|\mathfrak{g}_{jlk}^{H}\mathcal{W}_{jk}\right|^2\right] - Q_d\left|\mathbb{E}\left[\mathfrak{g}_{jlk}^{H}\mathcal{W}_{jk}\right]\right|^2 + \sigma^2 = Q_d(M-K)\,var(\hat{\mathfrak{g}}_{jlk}) + \sum_{l=1,l\neq j}^{L}\sum_{i=1}^{K} Q_d var(\hat{\mathfrak{g}}_{jlk}) + \sigma^2\,. \tag{24}$$

In order to simplify the downlink effective SINR of the k th user for ZF precoding according to (17) and (24), for an increasing number of antennas and UEs when M and $K \rightarrow \infty$, the formula for the SINR can be derived as

$$\xi_{jk}^{dl-zf} = \frac{(M-K)var(\hat{\mathfrak{g}}_{jlk})}{(M-K)var(\hat{\mathfrak{g}}_{jlk})+\sum_{l=1,l=j}^{L}\Psi_{jk}+\sum_{l=1,l\neq j}^{L}\sum_{i=1}^{K}var(\hat{\mathfrak{g}}_{jlk})+\frac{\sigma^2}{Q_d}}\,. \tag{25}$$

The achievable high data rate with ZF precoding can be improved based on using the pilot reuse sequences are developed to allocated the pilot τ_p and mitigate pilot contamination using SINR [9, 24, 25]. The closed form for the achievable data rate in DL can be investigated based on the minimum MMSE for the channel estimation error with pilot reuse sequences and is given as

$$\mathcal{R}^{zf}{}_{jk}\ \sum_{l=1}^{L}\sum_{i=1}^{K}\left(1-\frac{\tau_p K}{S}\right)log_2\left(1+\frac{(M-K)\left(\frac{Q_d\tau_p\varphi_{jjk}}{1+Q_d\tau_p\sum_{i=1}^{L}\varphi_{jlk}}\right)}{(M-K)\frac{Q_d\tau_p\varphi_{jlk}}{1+Q_d\tau_p\sum_{i=1}^{L}\varphi_{jlk}}+\sum_{l=1,l=j}^{L}\Psi_{jk}+\sum_{l=1,l\neq j}^{L}\sum_{i=1}^{K}\left(\frac{Q_d\tau_p\varphi_{jjk}}{1+Q_d\tau_p\sum_{i=1}^{L}\varphi_{jlk}}\right)+\frac{\sigma^2}{Q_d}}\right). \tag{26}$$

3. Results and Analysis

In this section, we use Monte-Carlo simulations to analyze the numerical results. In addition to, we evaluate the system performance for linear precoding techniques of zero-forcing precoding based on an estimate the knowledge of large-scale fading coefficients of channel estimation and reducing effective interference with pilot reuse that mitigates strong pilot contamination. From Figure 1, when the number of BS antennas increases, the data rate depended on the employment of different reuse pilot sequences can be obtained based on (11), (15) and (26), where the number of orthogonal pilot reuse sequences for the users in neighboring cells whose relative good channel estimation performance according to (25). From Figure 1, the achievable data rate increases with an increase in the number of BS antennas due to the orthogonal pilot reuse sequences. Therefore, a higher data rate can be achieved based on reuse large number of pilot sequences $\tau_p = 7$, that able to suppression of the interference between neighboring cells due to orthogonal pilot reuse sequences between adjacent cells for large-scale fading when the number of pilot reuses $\tau_p = 7$, compared with the pilot reuse sequences $\tau_p = \{3, 1\}$.

Figure 2 illustrates the variation in the achievable data rate with the number of pilot sequences. When the number of pilot reuse sequences is equal to the number of users $\tau_p = K$, the high data rate can be achieved based on large pilot reuse sequences and a uniformly distributed number of users around the BS. When the number of pilot reuse sequences is large enough for the different number of antennas at the BS, i.e., where M = 16, 32, 64 and 128, pilot contamination is reduced. Moreover, according to (26), a higher data rate is achieved when the number of pilot reuse sequences is $\tau_p = 7$ compared to $\tau_p = 1$. Moreover, when the number of users is large, the interference between neighboring cells can be suppressed due to the use of orthogonal pilot reuse sequences.

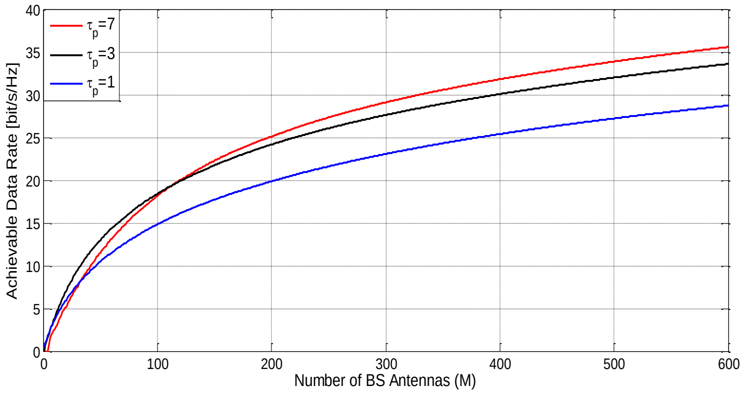

Figure 1. Achievable data rate by the number of BS antennas

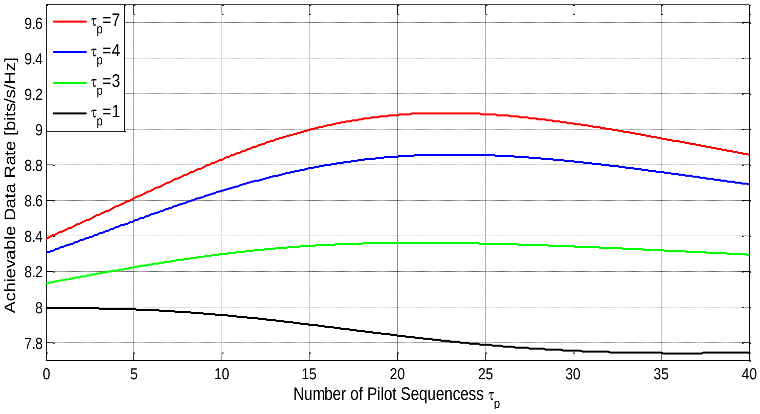

Figure 2. Achievable data rate by the number of pilot reuse sequences

4. Conclusion

In this paper, we evaluated the lower bound for the achievable data rate based on suppressed pilot contamination between neighboring cells as a result of the use of non-orthogonal pilot reuse sequences transmitted by UEs to different cells. Consequentially, the data rate can be optimized by large pilot reuse sequences and a uniformly distributed number of users around the BS. In addition to this, distributed large a number of users, the interference between neighboring cells can be suppressed due to orthogonal pilot reuse sequences. Higher data rates can be achieved by suppressing the interference between neighboring cells based on orthogonal pilot reuse sequences between adjacent cells for large scale fading.

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References

[1] Larsson EG, Edfors O, Tufvesson F, Marzetta TL. Massive MIMO for next generation wireless systems. *IEEE Communications Magazine*. 2014; 52(2):186-195.

[2] Salh A, Audah L, Shah NS, Hamzah SA. Reduction of pilot contamination in massive MIMO system. *Proceedings of IEEE Asia Pacific Microwave Conference (APMC)*. Kuala Lumpur. 2017; 885-888.

[3] Anjum MA. A New Approach to Linear Estimation Problem in Multi-user Massive MIMO Systems. *TELKOMNIKA Telecommunication Computing Electronics and Control*. 2015; 13(2): 337-351.

[4] Pan L, Dai Y, Xu W, Dong X. Multipair massive MIMO relaying with pilot-data transmission overlay. *IEEE Transactions on Wireless Communications*. 2017; 16(6): 3448-3460.

[5] Lu L, Li GY, Swindlehurst AL, Ashikhmin A, Zhang R. An overview of massive MIMO: Benefits and challenges. *IEEE Journal of Selected Topics in Signal Processing*. 2014; 8(5): 742-758.

[6] Baldemair R, Dahlman E, Fodor G, Mildh G, Parkvall S, Selen Y, Tullberg H, Balachandran K. Evolving wireless communications: Addressing the challenges and expectations of the future. *IEEE Vehicular Technology Magazine*. 2013; 8(1): 24-30.

[7] Zhu X, Wang Z, Qian C, Dai L, Chen J, Chen S, Hanzo L. Soft Pilot Reuse and Multicell Block Diagonalization Precoding for Massive MIMO Systems. *IEEE Transaction on Vehicular Technology*. 2016; 65(5): 3285-3298.

[8] Salh A, Audah L, Shah NS, Hamzah SA. Maximizing Energy Efficiency for Consumption Circuit Power in Downlink Massive MIMO Wireless Networks. *International Journal of Electrical and Computer Engineering (IJECE)*. 2017; 7(6): 2977-2985.

[9] Björnson E, Hoydis J, Sanguinetti L. Massive MIMO has unlimited capacity. *IEEE Transactions on Wireless Communications*. 2018; 17(1): 574-590.

[10] Hoydis J, Ten Brink S, Debbah M. Massive MIMO in the UL/DL of cellular networks: How many antennas do we need?. *IEEE Journal on selected Areas in Communications*. 2013; 31(2):160-171.

[11] You L, Gao X, Xia XG, Ma N, Peng Y. Pilot reuse for massive MIMO transmission over spatially correlated Rayleigh fading channels. *IEEE Transactions on Wireless Communications*. 2015; 14(6): 3352-3366.

[12] Wu Y, Liu T, Cao M, Li L, Xu W. Pilot contamination reduction in massive MIMO systems based on pilot scheduling. *EURASIP Journal on Wireless Communications and Networking*. 2018; 2018(21): 1-9.

[13] De Figueiredo FA, Cardoso FA, Moerman I, Fraidenraich G. Channel Estimation for Massive MIMO TDD Systems Assuming Pilot Contamination and Frequency Selective Fading. *IEEE Access*. 2017; 5:17733-17741.

[14] Hajri SE, Assaad M, Caire G. *Scheduling in massive MIMO: User clustering and pilot assignment*. Proceedings of IEEE 54th Annual Allerton Conference on Communication, Control, and Computing. Monticello. 2016; 107-114.

[15] Khansefid A, Minn H. On channel estimation for massive MIMO with pilot contamination. *IEEE Communications Letters*. 2015; 19(9): 1660-1663.

[16] Sadeghi M, Sanguinetti L, Couillet R, Yuen C. Large system analysis of power normalization techniques in massive MIMO. *IEEE Transactions on Vehicular Technology*. 2017; 66(10): 9005-9017.

[17] Van Chien T, Björnson E, Larsson EG. Joint pilot design and uplink power allocation in multi-cell massive MIMO systems. *IEEE Transactions on Wireless Communications*. 2018; 17(3): 2000-2015.

[18] Sengijpta SK. Fundamentals of statistical signal processing: Estimation theory. Prentice-Hall, Inc. Upper Saddle River, NJ, USA. 1993.
[19] Hanglin G. Jiaming L. Han Z. On superimposed pilot for channel estimation in massive MIMO uplink. *Physical Communication*. 2017; 25(2): 483-491.
[20] Zuo J, Zhang J, Yuen C, Jiang W, Luo W. Multicell multiuser massive MIMO transmission with downlink training and pilot contamination precoding. *IEEE Transactions on Vehicular Technology*. 2016; 65(8): 6301-6314.
[21] Nguyen TM, Ha VN, Le LB. Resource allocation optimization in multi-user multi-cell massive MIMO networks considering pilot contamination. *IEEE Access*. 2015; 3: 1272-1287.
[22] Li K, Song X, Ahmad MO, Swamy MN. An improved multicell MMSE channel estimation in a massive MIMO system. *International Journal of Antennas and Propagation*. 2014; 2014: 1-9.
[23] Marzetta TL. Noncooperative cellular wireless with unlimited numbers of base station antennas. *IEEE Transactions on Wireless Communications*. 2010; 9(11): 3590-3600.
[24] Ashikhmin A, Marzetta T. *Pilot contamination precoding in multi-cell large scale antenna systems*. *Proceedings of IEEE International Symposium on Information Theory (ISIT)*. Cambridge. 2012: 1137-1141.
[25] Su L, Yang C. *Fractional frequency reuse aided pilot decontamination for massive MIMO systems*. Proceedings of IEEE 81st Vehicular Technology Conference (VTC Spring). Glasgow. 2015; 1-6.