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Mitigated Pilot Contamination to Achieve Higher Downlink Data Rate in 5G Massive MIMO Systems

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Abstract: Massive multiple-input, multiple-output (M-MIMO) is an important knowledge for fifth-generation (5G) wireless cellular networks. The pilot contamination (PC) is an issue in massive MIMO due to interference between adjacent cells. We proposed that the number of pilot sequence inside a cell could become smaller than or equal to the number of users (UEs), taking into account the different number of UEs that transmitted the same pilot sequence in the same cell. In addition, the pilot sequence became mutually orthogonal for different cells to prevent PC among cells. In this paper, we analyzed a channel estimation for time division duplex (TDD) and improved the achievable data rate by reducing the PC for limiting user capacity and using channel orthogonality for minimum mean square error (MMSE) precoding. From the simulation results, the proposed scheme provided a data rate for two several situations, with and without interference PC for an increased number of antennas. Consequently, increasing the number of coherence intervals made the channel estimation critical and provided a small data rate due to increased noise and interference at increased transmit pilot sequence.

Keywords: 5G, massive MIMO, time division duplex, minimum mean square error, pilot contamination

1. Introduction

The challenge in 5G wireless cellular networks is how to increase demand for achievable high data rate for mobile communication. The massive MIMO systems can meet growing demands for high data rates, and the massive MIMO transmits signals to every user with a huge antenna element M in the BS (Müller et al., 2013). In massive MIMO the base station (BS) transmits signal under channel reciprocity for TDD and can adopt both downlink and uplink channel responses based on pilot sequence. The challenges in future 5G wireless cellular networks is how to increased data rate to several gigabits based on higher frequencies, so an increased high data rate for mobile terminal is essential to decrease latency. Massive MIMO systems provide the degree of freedom needed with a grown number of M, which enables several UEs to exploit the similar frequency (Swindlehurst et al., 2014). Moreover, increased number of M at the BS able to increases the data rate, it is essential to use an array gain to decrease the radiated power (Larsson et al., 2014). A massive MIMO system exploits a huge number of antenna arrays at the BS to assist ten UEs' equipment However, this technique suffers from PC due to inter-cell interference that cannot be fully eliminated as shown in Fig. 1. Due to a limitation of coherence channel in multi-cell cellular systems, the orthogonal pilot reuse sequences cannot be allocated for each UEs in every cell (Lu et al., 2014; Huy et al., 2018).

The channel estimation is more severe for pilot sequence using short coherence intervals. Meanwhile, reducing the PC requires using a long coherence interval to serve a large number of UEs. From the downlink of cellular networks, obtaining channel state information (CSI) at the BSs requires uplink pilot signalling. The PC for multiple cells can be avoided using the mutually orthogonal pilot sequence. Whereas during use, a number of UEs that transmit the same pilot

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sequence in the same cell as the PC can still experience PC. The issue of massive MIMO system is still limited to PC due to non-orthogonality of pilot sequence transmitted by UEs from the same cell to neighbouring cells and this has caused a significant impact on the data rate. Therefore, it is important to enhance the performance system performance in order to obtain better CSI and also to reduce interference. The PC is the fundamental difficulty in a multi-cell cellular massive MIMO system, which impacts the data rate. Nevertheless, channel estimation can be used in time division duplex (TDD) for training channel by transmitting pilot reuse sequences because the channel estimation suffers from the PC. The author (Zhang et al., 2014) proposed the semi-orthogonal pilot reuse sequences with shifted locations for simultaneous data and pilot transmission which successful mitigate interference based on channel estimation.

In this paper, we focused on channel estimation for TDD and reduced PC by limiting user capacity. In addition to that, we used the asymptotic channel orthogonality for both scenarios, with and without interference, in downlink PC. The CSI checked the channel status by transmitting predefined pilot sequence and evaluated the response of the channel using TDD (Müller et al., 2013; Huh et al., 2012). To mitigate intra- and inter-cell interference in TDD mode, all UEs sent pilot signals that were orthogonal to other UEs inside these cells. The issue for the massive MIMO system was the growth of the large of M at the BS, causing pilot contamination (Jose et al., 2009; Appaiah et al., 2010; Li, etal., 2013; Ashikhmin and Marzetta 2012; Fernandes et al., 2013; Salh et al., 2017). The number of orthogonal pilot sequence was limited for coherence time.

Nevertheless, the orthogonal pilot sequence must reuse the pilot sequence for neighbouring cells due to short orthogonal sequences (Jubin et al., 2011).

The pilot is reused in the same cell for UEs, which used the covariance channel matrix for every user by using signal subspace, and it guaranteed channel estimation accuracy in addition to reducing pilot contamination (Li et al., 2013; Lim etal., 2015; Yucheng et al., 2018). Additionally, large diversity gains can suppressed the inter-cell interference by collective the number of M. The property of propagation was favourable to achieve the high data rate based on used properties of MMSE receivers with CSI, where the precoding MMSE resulted great performing at a high and low signal-to-noise ratio (SNR) in terms of data rate.

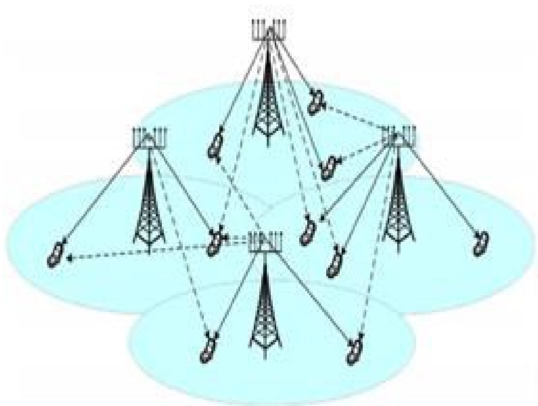

Fig. 1 - Pilot contamination between neighbouring cells (Lu et al., 2014)

2. System Model

In downlink data transmission, every BS sent signals to all active UEs in all cells. We consider a cellular system composed of one BS with $\boldsymbol{M}$ antennas and active UEs $\boldsymbol{K}$. The BS applied the beamforming based on CSI, and the received signal at the $\boldsymbol{j\ th}$ UEs is

$$\boldsymbol{x_d} = \sqrt{\boldsymbol{\beta_d}}\sum_{j=1}^{K} \boldsymbol{\gamma_k^H}\ \boldsymbol{Z_k}\,\boldsymbol{w_k} + \boldsymbol{n_k} \qquad (1)$$

The downlink transmit signal from BS to each UE $\boldsymbol{K}$ received each pilot sequence from all BS to mitigate the interference at transmit signals. The BS used the channel reciprocity to evaluate the channel status, and the transmission signal contained the desired signal and interference and noise signals. The received signal can be written as

$$x_{jk}^{d} = \underbrace{\sqrt{\beta_d}\gamma_{jk}^{H}\,Z_{jk}\,w_{jk}}_{signal\,(S)} + \underbrace{\sqrt{\beta_d}\sum_{i=1,i\neq k}^{K}\gamma_{jk}^{H}\,Z_{ji}\,w_{ji}}_{interference(I)} + \underbrace{n_{jk}}_{noise(N)} \qquad (2)$$

where γ_{jk}^{H} represents the channel vector from BS to the UE inside cell $\gamma_k = \sqrt{\varepsilon_r}\,\overline{g}_k$, g_k represents the small fading, ε_k is constant for attenuation effect, $w_{jk}$is information symbol, β_d is the pilot in the downlink for SNR, Z_{jk} is the beamforming of the ith cell, and $n_{jk}$is additive white Gaussian noise.

Due to the uplink-downlink channel reciprocity, the BS estimates the equivalent MIMO channel γ_{jk}^{H} which is the Hermitian transpose of uplink . In downlink transmission, every signal UE estimated the correlated received signal with pilot. If UEs had the same pilot sequence, the received pilot signal is correlated with UEs. In TDD, the length of pilot sequence depended on how many UEs are inside the cell and the number of cells per cluster. The pilot sequence became mutually orthogonal for different cells to prevent pilot contamination among cells. Consequently, at transmit signal the first coherence interval allowed transmitting pilot sequence to form the first user in every cell, while other users mute so every cell could estimate its UEs for channel $._{jk}$ The maximal data rate at transmit signal to kth user corresponded to the received signal for MMSE precoding (Ngo et al., 2013; Marzetta , 2010; Khansefid, and Minn,2015; Luo et al., 2016). The downlink data estimate of the $K\ th$ user and is given as

$$\hat{w}_k = \frac{\sqrt{K}\, x_{jk}^{d}}{\sqrt{\beta_d}\,\|\hat{\gamma}_{jk}\|} \tag{3}$$

The MMSE estimator reduced the MSE between channel $\hat{\gamma}_{jk}$ and estimation channel $\gamma_{jk}^{H}\,\hat{w}_k$, when the BS transmitted the orthogonal pilot sequences in different cells. In this case the pilot sequences was set for K UEs and saved data transmission due to the orthogonal property at an increased number of antennas. The optimal transmit data is expressed as

$$\frac{\sqrt{\beta_d}\left(\hat{\gamma}_{jk} + \bar{\gamma}_{jk}\right)^{H}}{\|\hat{\gamma}_{jk}\|^{2}}\hat{\gamma}_{jk} w_{jk} + \sqrt{\beta_d}\sum_{i=1, i\neq k}^{K}\frac{\gamma_{jk}^{H}}{\|\hat{\gamma}_{jk}\|}\frac{\hat{\gamma}_{ji}}{\|\hat{\gamma}_{ji}\|}\, w_i + \frac{\sqrt{K}\, n_{jk}}{\sqrt{\beta_d}\,\|\hat{\gamma}_{jk}\|} \tag{4}$$

When there was no overlap between multipath signals, the pilot sequences were effective and give good estimation channel and covariance matrices. We divided every denominator and numerator at increased number of antennas to $M \rightarrow \infty$ by $\sqrt{M}$; in the last term in (4). We could accurately detect information data, and the channel vectors became orthogonal depending on the increased number of antennas in downlink transmission.

The problem appeared when transmitting the same (orthogonal) pilot sequences from all UEs at the same time and also same cell to all neighbouring cells. Due to a limitation of coherence channel in multi-cell cellular systems, the orthogonal pilot reuse sequences cannot be allocated for all users in every cell.

The channel estimation was more severe for pilot sequences using short coherence intervals. The channel estimation was done by assigning the BS in a multi-cell system with the pilot reuse sequences. The flowchart in Fig. 2 shows that the increases of the number of transmit M from $1 \rightarrow \infty$ increased the pilot contamination due to the limited channel in massive MIMO system(Salh et al., 2017; Luo et al., 2016). To improve the transmission performance to the maximal high data rate for 5G we used pilot reuse sequences through training channel estimation for a number of coherence channel interval based on large scale fading which suppressed SINR for large scale fading.

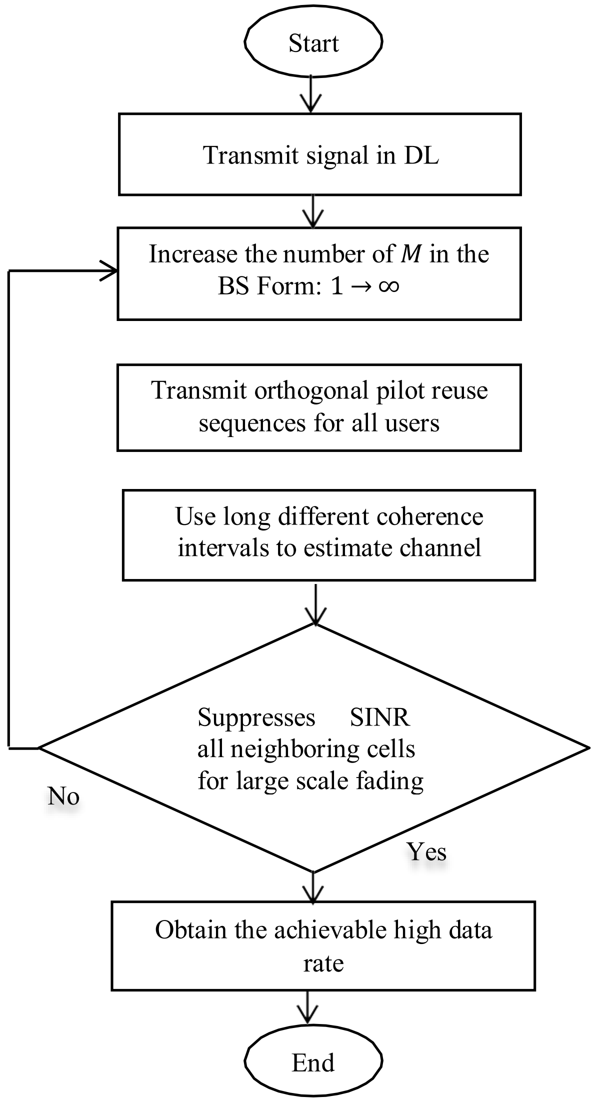

Fig. 2 - Mitigated pilot contamination to achievable high data rate

2.1 Performance Achievable Data Rate

To achieve the higher data rate, we analyzed and derived the first term of signal in (2) to obtain the desired signal for grown number of M.

$$R_{k,j}^{d} = \log_2(1 + SNR_K) = \log_2\left(1 + \frac{S}{I+N}\right) \quad (5)$$

To suppress inter-user interference for other UEs, $\gamma_{jk}^{H}\, \mathcal{Z}_{jk}$ estimated the increasing number of UEs by using Khintchine's law for a huge number of M (Li et al., 2013); and this is given by

$$S_{k,j} = \beta_d \left|\gamma_{jk}^{H} \;\; \mathcal{Z}_{jk}\right|^2 = \frac{\beta_d}{\partial_{k,j}^{2}\, MK}\left(\hat{\gamma}_{jk} + \bar{\gamma}_{jk}\right)^{H} \hat{\gamma}_{jk}\, \hat{\gamma}_{jk}^{H}\left(\hat{\gamma}_{jk} + \bar{\gamma}_{jk}\right) = \frac{\beta_d}{\partial_{k,j}^{2}\, MK}\, \mathbb{E}\left[\left|\hat{\gamma}_{jk}^{H} \;\; \hat{\gamma}_{jk}\right|^2 + \left|\bar{\gamma}_{jk}^{H} \;\; \hat{\gamma}_{jk}\right|^2\right] \quad (6)$$

Due to the increased number of M, the correlating vectors in terms of a power can be represented as

$$S_{k,j} = \frac{\beta_d}{\partial_{k,j}^{2}\, MK}\left[(M^2 + M)\vartheta_{k,j}^{4} + M\alpha_{k,j}^{2}\, \vartheta_{k,j}^{2}\right] = \frac{\beta_d (M+1)\vartheta_{k,j}^{2} + \beta_d \alpha_{k,j}^{2}}{K} \frac{\beta_d M \vartheta_{k,j}^{2} + \beta_d \varepsilon_k}{K} \quad (7)$$

where $\vartheta_{k,j}^2$ represents the accuracy of the pilot sequence, $\alpha_{k,j}^2$ represents estimation error, and where $\alpha_{k,j}^2 = \beta_d - \vartheta_{k,j}^2$. The pilot sequence in the massive MIMO system used the orthogonal pilot to avoid pilot contamination. The transmit beamforming vector was effective in the downlink channel, and the effective channel was estimated as $\hat{\gamma}_{jk}$ by computing the effective interference power condition, given as

$$\rho_{jk} = \frac{\hat{\gamma}_{jk}}{\sqrt{K}\,\|\hat{\gamma}_{ji}\|} = \frac{\hat{\gamma}_{jk}}{\partial_{k,j}\sqrt{MK}} \qquad (8)$$

In the downlink achievable data rate in the closed-form lower bound, every UE knew the expectation using the effective SINR in (8), which was achieved by selecting the power, where the SINR increased when the number of antenna elements increased. The transmission signal for interference is $w_{interf}^{pilot} = \sum_{l\in\mathcal{V}} p\, \gamma_l$. Based on channel realization the scalar eigenvalue for normalized factor

$$\partial_{k,j}^2 = \mathbb{E}\left[\hat{\gamma}_{jk}{}_{interf}^{pilot}\left(\hat{\gamma}_{jk}{}_{interf}^{pilot}\right)^H\right], \text{ when the antenna } M \to \infty.$$

Consequently, the signal transmit power at BS tried to reduce the losses of intra-cell power in order to save the power in the adjacent cell by reducing the inter-cell interference in the neighbouring cell (Shen et al., 2015; Kobayashi et al., 2017). In addition, this gave high performance in the cell edge and suppressed the SINR. These signals transmitted the same power from BS but with a different allocation according to the position of the UEs.

The BS estimated every channel matrix $\hat{\gamma}_{jk}^H$ according to (8) to check the status of the good channel and improve performance to reduce high path loss due to neighbouring cells. The estimation channel can be satisfied when $\lim_{M\to\infty} \|\hat{\gamma}_{jk}\| \to \sqrt{M}\,\partial_{k,j}$, the $\partial_{k,j} = \frac{\hat{\gamma}_{jk}}{\sqrt{M}}$, is the scalar normalized factor according(Li et al., 2013) when the $M \to \infty$; and is given as

$$\lim_{M\to\infty} \partial_{k,j}^2 = \lim_{M\to\infty} \hat{\gamma}_{jk}^H\ \hat{\gamma}_{jk} = \vartheta_{k,j}^2 \qquad (9)$$

Increasing the number of M to ∞ made the system impractical (Shen et al., 2015). Meanwhile, when all users transmitted pilot sequences at the same time, the worst case of PC occurred between cells through the training phase. The mutual independence for $\hat{\gamma}_{jk}^H$ and $\hat{\gamma}_{jk}$ using correlating vectors by reducing the power of the interference to all UEs can be expressed according (2)

$$I_{k,j} = \beta_d \left|\gamma_{jk}^H\ z_{jk}\right|^2 \sum_{i=1,i\neq k}^{k} = \quad \sum_{i=1,i\neq k}^{K} \frac{\beta_d}{\partial_{k,j}^2\, MK} \mathbb{E}\left[\left|\gamma_{jk}^H\ \hat{\gamma}_{jk}\right|^2\right] \qquad (10)$$

From (10), the properties of MMSE estimation was independency between γ_k^H and $\hat{\gamma}_k$ $i \neq k$ and the accuracy of the pilot sequence represents $\vartheta_{k,j}^2\ \varepsilon_r\ M$, where ε_d represent large-scale fading. The channels between active UEs were orthogonal, and the precoding vector was correlated with the channel (You et al., 2015), which can be simplified as

$$\mathbb{E}\left[\left|\gamma_{jk}^H\ \hat{\gamma}_{jk}\right|^2\right] = \mathbb{E}\left(\left|\gamma_{jk,1}^H \hat{\gamma}_{jk,1} + \gamma_{jk,2}^H \hat{\gamma}_{jk,2} + \cdots + \gamma_{jk,M}^H \hat{\gamma}_{jk,M}\right|^2\right)$$

$$\mathbb{E}\left[\left|\gamma_{jk}^H\ \hat{\gamma}_{jk}\right|^2\right] = M\mathbb{E}\left(\left|\gamma_{jk,m}^H \hat{\gamma}_{jk,m}\right|^2\right) + M^2 \rho_{jk} \mathbb{E}\left(\gamma_{jk,m}^H\ \hat{\gamma}_{jk,m}\ \gamma_{ji,m}^H\ \hat{\gamma}_{ji,m}\right) \qquad (11)$$

Limiting coherence channel was convenient because the channel estimation was achieved by accorded BS in a multi-cell system with pilots reuse sequence(Peiyao et al., 2015). To solve this issue, we used the pilot reuse with pairwise orthogonal. Moreover, the use of pilot sequences was proposed to limit the resource of channel estimation. The interference was mitigated by using the accurate pilot sequence at an increased number of antennas:

$$I_{k,j} = \sum_{i=1,i\neq k}^{K} \frac{\beta_d}{\partial_{k,j}^2\, MK} \vartheta_{k,j}^2\ \varepsilon_r\ M \qquad (12)$$

From (10) and (11) reducing the power of the interference to all UEs, which can be simplified as

$$I_{k,j} = \sum_{i=1,i\neq k}^{K} \frac{\beta_d (K-1)}{K}\ \varepsilon_r \qquad (13)$$

When $i = k$ at transmit signal in the same cluster and same pilot signals. The estimation channel for the precoding vector form cell is j to UE K, the cross-cell interference growths. This means that the PC becomes important, which will cancel the exceeded interference suppression ability of the MMSE (Fuqian et al., 2018); and the correlated channel is given as

$$\mathbb{E}\left[\left|\hat{\gamma}_{jk,m}^{H}\,\hat{\gamma}_{jk,m}\right|^{2}\right] = \mathbb{E}\left[\left|\tilde{\gamma}_{jk}\frac{\acute{\gamma}_{jk}^{H}}{\sqrt{k}\left\|\acute{\gamma}_{jk}^{H}\right\|}\right|^{2} + \left|\tilde{\gamma}_{jk}\frac{\tilde{\gamma}_{jk}^{H}}{\sqrt{k}\left\|\tilde{\gamma}_{jk}^{H}\right\|}\right|^{2}\right] \quad (14)$$

j

The MMSE channel estimation error is $\tilde{\gamma}_{jk} = \gamma_{jk} - \hat{\gamma}_{jk}$ where $\tilde{\gamma}_{jk}$ is uncorrelated with $\hat{\gamma}_{jk,m}$. When the signal was transmitted to every user K, there was a relationship between every user inside the cell and the covariance matrix channel (Fernandes et al., 2013), which was sensitive to the distributed UEs and is given by

$$C_{\acute{\gamma}_{jlk}^{H}\,\acute{\gamma}_{jlk}} = C_{\gamma_{jlk}^{H}\,\gamma_{jlk}} - C_{\tilde{\gamma}_{jlk}^{H}\,\tilde{\gamma}_{jlk}} = \left(1 - \frac{K\,\vartheta_{k,j}^{2}\beta_{d}}{\emptyset_{k,j}}\right) i_{M} \quad (15)$$

where i_M is the identity matrix

$$C_{\acute{\gamma}_{jlk}^{H}\,\acute{\gamma}_{jlk}} = \mathbb{E}\left[\acute{\gamma}_{jlk}^{H}\,\acute{\gamma}_{jlk}\right] = \left(\frac{\sqrt{\vartheta_{jk}\beta_{d}}}{\emptyset_{k,j}}\right)^{2} C_{\tilde{\gamma}_{jlk}^{H}\,\tilde{\gamma}_{jlk}} = \frac{K\,\vartheta_{k,j}^{2}\beta_{jk}}{\emptyset_{k,j}} i_{M} \quad (16)$$

$$\mathbb{E}\left[\left|\hat{\gamma}_{jk}^{H}\hat{\gamma}_{jk}\right|^{2}\right] = \left(1 - \frac{K\,\vartheta_{k,j}^{2}\beta_{d}(M-1)}{\emptyset_{k,j}}\right)\frac{1}{K} \quad (17)$$

where $\acute{\gamma}_{jlk}$ is the correlation between the pilot and transmitted pilot signal from BS in a cell to UEs. The precoding vector $\emptyset_{jlk}$ from BS in cell l, for UEs k in cell l becomes

$$\emptyset_{k,j} = \sum_{i\in l}\beta_{d}\,K + \sum_{i\neq l}\sum_{k=1}^{K}\frac{\beta_{d}}{K}\left(1 + \frac{\beta_{d}}{K}\left(\beta_{d}\left(1 - \frac{1}{M}\right)\right)\right) \quad (18)$$

According to (You et al., 2015), the SINR was obtained when the large number of M rose to ∞. The last term for noise power in downlink was obtained according (2), which we express as

$$N_{jk} = \mathbb{E}\left[\hat{N}_{jk}\,N_{jk}\right] = 1 \quad (19)$$

The achievable data rate per user in closed forms for lower bound was evaluated at an increased number of antennas. Consequently, the high data rate can be achieved depending on the SINR. Where, the SINR for the pilot sequence gave accurate channel estimation when the transmission signalled for interferenc. The channel estimation was more severe for pilot sequences that used short coherence intervals.

Reducing the PC required the use of long coherence intervals to serve large numbers of users, but increasing the number of coherence intervals made the channel estimation critical. Meanwhile, the BS used spatial beamforming to enhance the data rate in downlink transmission to Kth UEs, where the $\vartheta_{k,j}^{2}$ provided the accuracy of variance channel for the pilot sequence and influenced the achievable data rate, corresponding to orthogonal pilot sequence in (Khuri, et al., 2003; You et al., 2015; Lim et al., 2015; Khormuji et al., 2016). The accuracy of the pilot sequence is written as $\vartheta_{k,j}^{2} = \frac{\beta_{d}\varepsilon_{r}^{2}}{1+\varepsilon_{r}\,\beta_{d}}$, and when employing the same pilot reuse between neighbouring cells, the PC increased. If the frequency reuse utilized the same pilot between adjacent cells, it had not accurately avoided the interference between adjacent cells in the same cluster. Consequently, employing more pilot reuse sequences decreased the pilot contamination. The coherence interval was for acquiring channel knowledge at the BS, where the coherence interval $\mathcal{U}$ scheduled the number of users.

To enhance the achievable data rate, require an increase in the number of antennas M more than a number of UEs. The number of UEs was given according to a coherence interval $\mathcal{U} = T_{c}B_{c}$, where $T_{c}$and B_{c}represent coherence time and bandwidth respectively. Which able to increase the data rate by scheduling and limiting the capacity of UEs when the number of UEs was less than a coherence interval $\mathcal{U} = 0.5\,T_{c}B_{c}$. The coherence interval required scheduling the number of UEs, the pilot sequences were reused because the number of orthogonal pilot sequence were not enough when the number of users was more than the large coherence interval $\mathcal{U} = T_{c}B_{c}$. Otherwise, increasing the number of coherence interval (n_{c}) increased the estimation errors for CSI, which was not good because a greater coherence interval created more noise and interference. The pilot sequence increased the number of coherence interval affected for estimation errors for CSI, and it became bad because of the increased noise and interference. The pilot sequence in downlink for SINR is

$$\beta_{d} = \frac{B_{c}\,n_{c}}{T_{c}\,B_{c}\,n_{c} - 2K} \quad (20)$$

The achievable data rate per user in closed forms for lower bound is expressed as

$$R_{k,j}^{d} = \mathbb{E}\left(1+\frac{S}{I+N}\right) = \left(1-\frac{2K}{n_c U}\right) \ log_2[1+ \frac{M\frac{\beta_d^2\ \varepsilon_r}{1+\varepsilon_k\ \beta_d}+\beta_d}{\beta_d(K-1)\ n_c\varepsilon_r+K}] \quad (21)$$

where n_c is the number of coherence intervals, β_d represents the pilot sequence, and ε_r represents large-scale fading.

3. Results and Discussion

Fig. 3 shows that the channel estimation for MMSE in downlink transmission was varied based on the large number of PC β_d with interference. Moreover, the PC gave greater impact with SINR because the SINR increased with the increased number of antennas.

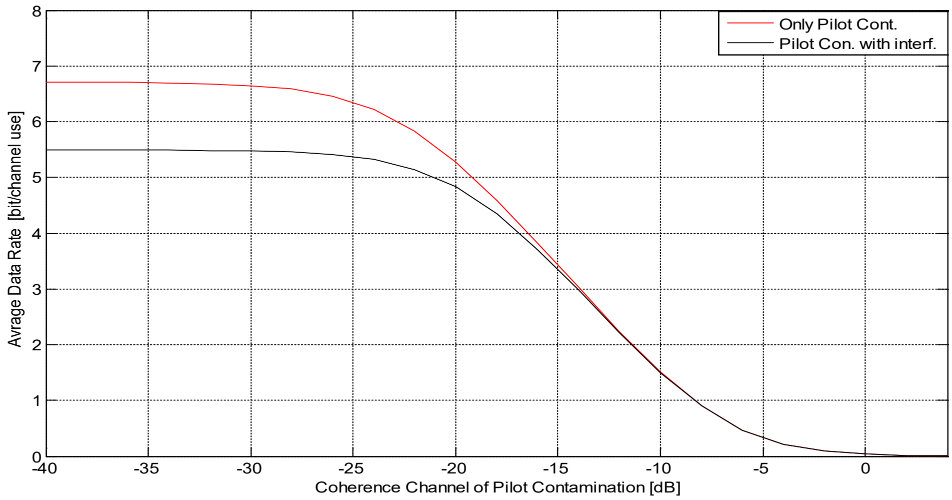

Fig. 3 - Achievable data rate with pilot contamination

In Fig. 3, both with and without pilot interference decreased due to their imperfect interference suppressions. The interference suppression can provide arise to performance improvements for achieved data rate suppressed interference in the direct-path. The achievable data rate per users depended on the strength of the PC interference. The PC with interference provided less data rates than PC without interference, which reduced inter-user interference. Suppressed PC depended on the increasing number of transmitting pilot reuse with large scale fading. It was found that the only PC provided high data rate more than PC with interference by using coherence channel.

In Fig. 4, the performance of achievable data rate depended on distributed users inside a cell and the distance from the BS to the location of users at different coherence intervals (n_c). The achievable data rate using different numbers of coherence intervals provided a high data rate when the SNR varied from -10 dB to 70 dB. Moreover, it was found that when the number of coherence interval increased at $n_c = 3$ and $n_c = 4$, it provided the same value at increased SINR. In addition to that, it provided a large value of data rate, when the number of coherence interval $n_c = 2$. Consequently, the achievable data rate was still saturated with PC at high SNR. Meanwhile, a large number of coherence intervals made the channel estimation critical and provided a small data rate due to the increased pilot sequences.

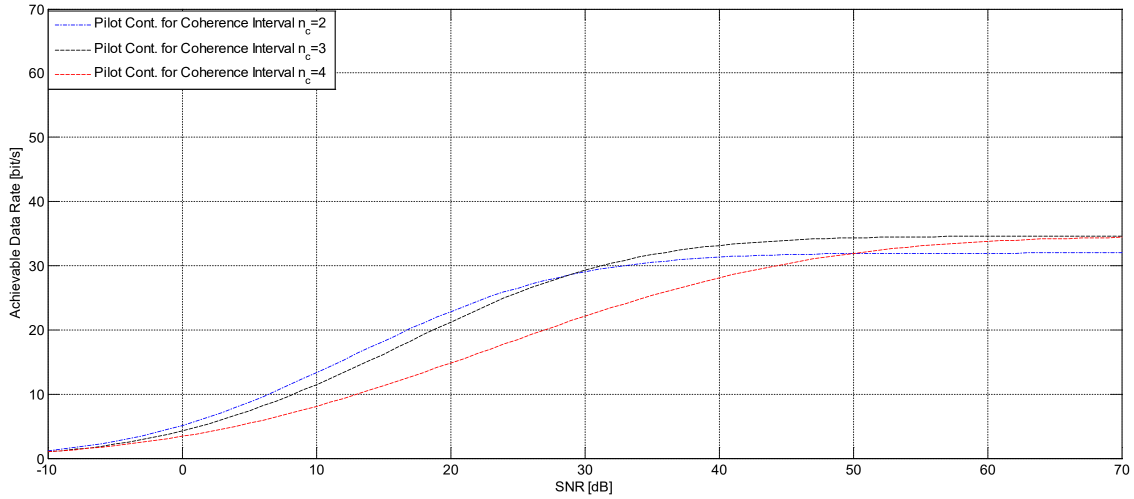

Fig. 4 - Achievable data rate with SNR

From Fig. 5, the achievable DR per cell increased monotonically with a large number of pilot reuse sequences. This was based on using a greater number of UEs in all cell where the pilot reuse provided the lower level of PC for the accuracy of channel estimation. From Fig. 5, the increase number of coherence interval $n_c = 4$ provided more achievable data rate compared to the increase number of coherence interval $n_c = 2$. Consequently, from Fig. 5, it was found that the achievable data rate first increased when the number of users was small and then decreased, where, the increasing number of users in every cell depended on the number of the propagation channel and minimized pilot reuse sequences. Furthermore, the increase number of the users in every cell increased the number of pilot reuse sequences, where, in this case, the channel estimation became critical and provided the low data rate.

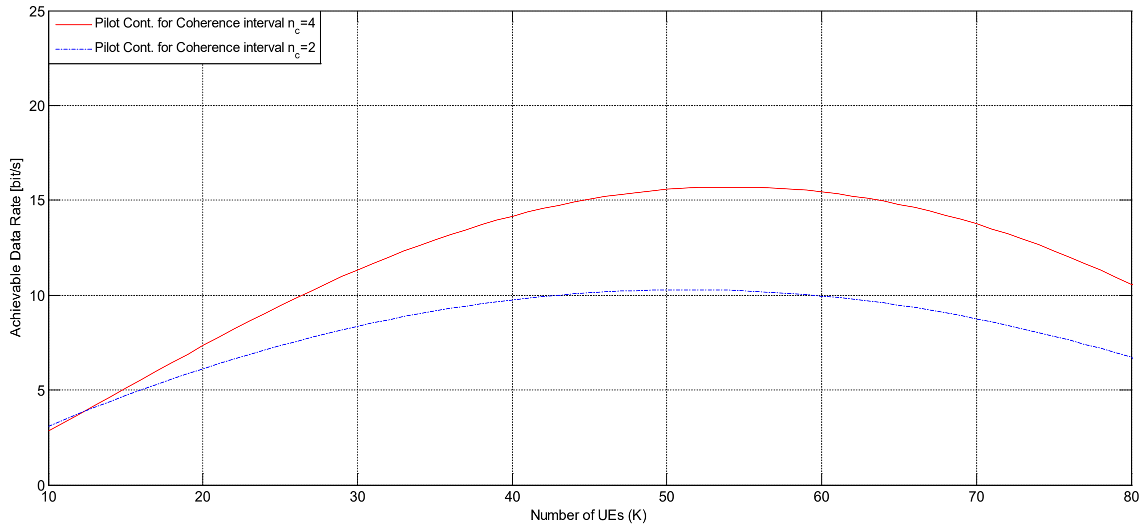

Fig. 5 - Achievable data rate with number of users *K*

In Fig. 6, we obtained the achievable data rate using large numbers of antennas M for different values of K, depending on mitigating pilot contamination by reusing the same and different pilots between neighbouring cells. Where the covariance channel matrix tended to be orthogonal, the performance of data rate using MMSE precoding rose slowly because the pilot contamination with interference was increased. The frequency reuse utilized the same pilot between adjacent cells, which could not accurately avoid the interference between adjacent cells in the same cluster. Consequently, it was found that the pilot contamination with interference achieved a lower data rate than when using only pilot contamination, as shown in Fig. 6. This is because the pilot contamination with interference from UE was orthogonal with UE under pilot contamination.

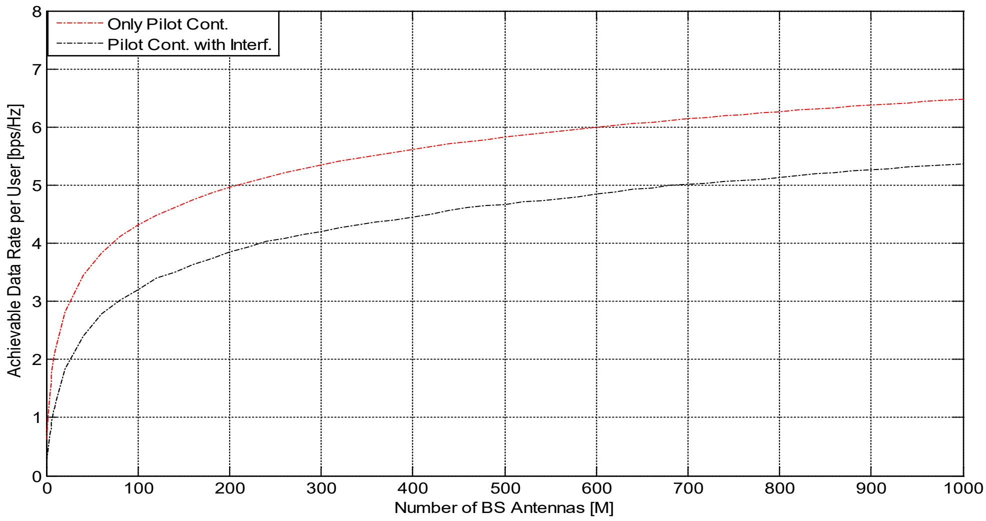

Fig. 6 - Achievable data rate with number of antennas

4. Conclusion

This paper proposed that the number of pilot sequences inside a cell became smaller than or equal to the number of users, taking into account the different number of users that transmitted the same pilot sequences in the same cell. In addition, the pilot sequences became mutually orthogonal for different cells. Consequently, scheduling a large number of users between adjacent cells reduced the inter-cell interference. In addition to that, a large number of UEs K in every cell increased the number of pilot reuse sequences. In this situation, the channel estimation became critical and provided a low data rate. From the simulation result, an increased number of coherence intervals made the channel estimation critical due to large-scale fading and large number of users provided a small data rate due to the increased pilot sequences and interference.

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