High Performance Detection Using Three Different weight Blind Algorithms in ZF Receiver for Uplink Multi-User Massive MIMO in 5G Wireless Communications

Sarun Duangsuwan and Chakree Teekapakvisit
Electronic Engineering, Prince of Chumphon Campus, King Mongkut's Institute of Technology Ladkrabang, Thailand
Email: sarun.du@kmitl.ac.th; t.chakree@gmail.com

Abstract —A novel of an uplink multi-user massive Multi-Input Multi-Output (MIMO) in 5G wireless communication that is an increasing efficiency of massive MIMO detection, in order to support a very high speed Giga-Wireless (GiWi). One of the most focused on the Zero-Forcing (ZF) receiver, but due to it has no optimal. In this paper, we present blind algorithms to optimize the performance of ZF because of their low complexity. The three different weight blind algorithms are various proposed by using the Conventional Constant Modulus (CCM), Supervised Constant Modulus (SCM), and the Variable Step Size Constant Modulus (VSSCM). The performance results show as a channel response, Mean Square Error (MSE), and Bit Error Rate (BER) is discussed. It can be shown that the proposed blind algorithms can optimal efficiency of ZF receiver under an assumption of no required CSI.

Index Terms—5G wireless communication, ZF receiver, three different blind algorithms, multi-user massive MIMO system.

I. INTRODUCTION

For wireless technology in 2020, the fifth generation (5G) becomes to next generation of global connectivity world. 5G wireless communications are developing at an explosive rate and the biggest areas of research within academia and industry. Especially, the signal processing techniques are playing the most important role. A number of new signal processing techniques have been proposed for 5G system and are being considered for international standards development and deployment. There are mainly four group parts: Firstly, a new modulation and coding. Secondly, new spatial processing techniques are used. Thirdly, a new spectrum opportunity, and finally is a new system-level enabling technique [1]-[3].

Massive MIMO is one of the new spatial processing techniques. To support a higher throughput, wireless Giga-bit (Gbps) and low latency, including reliable radio link. The massive MIMO has promised vast gains in spectral efficiency, increasing in energy efficiency, and reduction in network interference, all of which are keys to address the demands of a data-centric world where spectrum and energy are increasingly precious. The basic of concept of multi-user massive MIMO is shown in Fig. 1, where a Base Station (BS) is using M antennas to spatially multiplex k user in each cell i.

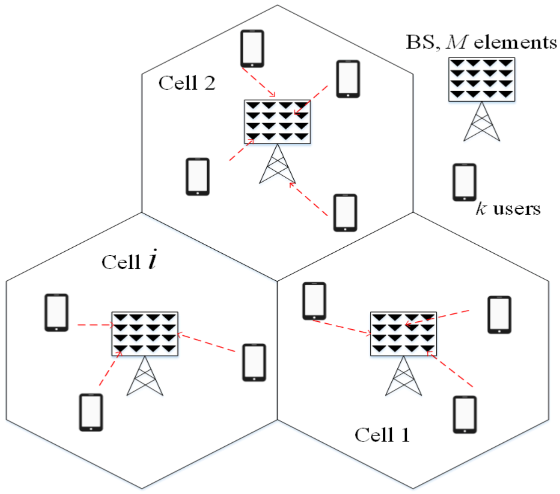


Fig. 1. The uplink multi-user massive MIMO system in 5G wireless communications

The success of such a spatial multiplex, in both uplink and downlink, relies on several important concepts. One of the most important requirements is that the base station should have sufficiently good knowledge of the propagation channel in both directions on which efficient downlink precoder and uplink detector can be based. Since acquisition of Channel State Information (CSI) is generally infeasible in the downlink, massive MIMO systems typically rely on channel reciprocity, uplink channel estimation, and Time-Division Duplex (TDD). With the massive number of channels to estimate between base station and users, a long enough channel coherence time is needed to allow for efficient operation. The accuracy at which we can estimate the channel and the time interval over which it can be assumed constant bring fundamental limitations to massive MIMO [4].

Many of the algorithms required for massive MIMO are also found in other wireless communication systems, such as channel estimation, equalization, and detection or decoding. The research work found that the use to more antennas leads to a factor of independent and identically distributed (i.i.d.) or noise enhancement each antenna [4], [5]. In addition, uplink massive MIMO system is limited from a pilot contamination seriously [6]. The problem of pilot contamination cannot be improvable even if the

Manuscript received February 20, 2018; revised August 20, 2018.
Corresponding author email: sarun.du@kmitl.ac.th.
doi:10.12720/jcm.13.9.512-517

number of Base Station (BS) antennas is unlimitedly large [7]. In [8], a pilot based channel estimation method has been proposed to avoid the non-orthogonal pilots from adjacent cells. Nevertheless, using of their pilot based channel estimation requires the linear receiver such as the Maximum Ratio Combining (MRC) [9] or ZF receiver [10]. Then, an uplink interference analysis for massive MIMO system with MRC and ZF receiver has been presented in [11]. The authors showed that the proposed ZF receiver avoids the interference of pilot contamination as well. Because ZF receiver can recover the Inter-Symbol Interference (ISI) in massive MIMO successively [12], suffers to the closed-form distributed of SNR receiving (therein eq. 12) that it has more accuracy to improve the Symbol Error Probability (SEP). Meanwhile, in [13] confirmed that the ZF receiver could apply to cancel ISI in multipath environments. In fact, using of ZF receiver has to increase the number of the antennas in order to optimize the recovery signal detection [14]. Thus, ZF receiver has been resolved by using adaptive equalizer for optimal detection that as described in [15]. In [15], the adaptive ZF receiver was simulated based on imperfect channel estimation and instantaneous CSI. The authors have provided two adaptive algorithms to compute the robust ZF receiver for massive MIMO systems. However, they have been considered based on channel model uncertainty, which is perfect channel model. From the discussion, the ZF receiver based on the gradient search algorithm or blind algorithm gives the better results than the conventional ZF receiver, in particular the regime of higher noise i.i.d. However, it is lack of experiment in worst-case of channel. In [16], the performance of massive MIMO uplink by using the ZF receiver has been studied under realistic channels. By using the ZF receiver is non-preferable since its BER performance is imperfect, because of aging problem occurs in propagation scenarios, e.g., ZF receiver is very sensitive to the multipath fading and noise enhancement.

In this paper, we emphasize on the limiting in [15] and [16] by approaching blind algorithms in ZF receiver under the assumption no required CSI. The various three blind algorithms as proposed the CCM algorithm, the SCM algorithm, and the VSSCM algorithm for optimizing the ZF receiver. To control a varying of coherence time, the weight iterative convergence can resolve estimate error of channel. Hence, a comparison result of three different blind algorithms is presented under realistic propagation channel model.

The rest of this paper is structured as follows: Section II and Section III present the signal and channel model. Section IV describes the results and discussion, finally, the conclusion presents in Section V.

II. Signal Model

The uplink transmission is shown in Fig. 1, where the k users transmit signals to the BS. Let $\mathbf{s}_k$ is the signal transmitted from the kth users. Denote that k user share the same time and frequency resource, the $M\times 1$ received signal vector at the BS is the combination of all signals transmitted from all k users. Therefore, the received signal in uplink channel as

$$\mathbf{y}_{\mathrm{ul}} = \sqrt{\gamma_{\mathrm{u}}}\sum_{j=1}^{k}\mathbf{h}_k\mathbf{s}_k + \mathbf{n} \tag{1}$$

where γ_{u} denotes the SNR of uplink channel, $\mathbf{h}_k$ is channel gain vector, and $\mathbf{n}$ is the additive noise vector.

Generally, uplink transmitted signal employs a pilot sequence, k users in each cell are assigned p orthogonal pilot sequences, and then, each has a length of τ symbols. The orthogonal pilot sequences are reused from cell to cell. Then, the received signal in (1) can be rewritten as

$$\mathbf{y}_{\mathrm{ul}} = \sqrt{\gamma_{\mathrm{u}}}\sum_{j=1}^{k}\mathbf{h}_k^{\psi}\mathbf{s}_k^{\psi} + \mathbf{n} \tag{2}$$

where ψ is the subset of $k\times\tau$ in each cell.

A. Conventional Method

In the massive MIMO detection, a receiver has to provide sufficient output SNR (γ) in signal detection. The linear receiver such as MRC [9] and ZF receiver [10] is widely implemented, because SNR is close to an acceptable level.

The well-known of linear signal detector equation is given by

$$\begin{aligned}\mathbf{r} &= \mathbf{w}^H\mathbf{y}_{\mathrm{ul}} \\ &= \sqrt{\gamma_{\mathrm{u}}}\mathbf{w}^H\mathbf{h}\cdot\mathbf{s} + \mathbf{w}^H\mathbf{n}\end{aligned} \tag{3}$$

where $(\cdot)^H$ denotes conjugate transpose of $\mathbf{w}$, and $\mathbf{w}$ is the channel estimated matrix.

Each stream is then decoded independently. The complex is on the order of $M\times k$. The k streams of $\mathbf{y}_{\mathrm{ul}}$, which is used to decode s_k, is given by

$$y_{\mathrm{ul},k} = \sqrt{\gamma_{\mathrm{u}}}\mathbf{w}_k^H\mathbf{h}_k s_k + \sqrt{\gamma_{\mathrm{u}}}\sum_{j=1}^{k}\mathbf{w}_k^H\mathbf{h}_{k'}s_{k'} + \mathbf{w}_k^H\mathbf{n} \tag{4}$$

where k' denotes an inter-user interference (IUI).

Note that the second term of (4) is an inter-user interference (IUI); Hence, the received of signal-to-interference-plus-noise ratio (SINR) of k stream is given by

$$\bar{\gamma}_{\mathrm{u}} = \frac{\gamma_{\mathrm{u}}\left|\mathbf{w}_k^H\mathbf{h}_k\right|^2}{\gamma_{\mathrm{u}}\sum_{j=1}^{k}\left|\mathbf{w}_k^H\mathbf{h}_{k'}\right|^2 + \left\|\mathbf{w}_k^H\right\|^2} \tag{5}$$

By using massive MIMO at the BS to maximize the received SINR in (5) and ignoring the effect of pilot contamination and the multiuser interference, the k column of the MRC receiver matrix is

$$\mathbf{w}_{\mathrm{mrc},k} = \arg\max \frac{\gamma_{\mathrm{u}} \left| \mathbf{w}_k^H \mathbf{h}_k \right|^2}{\left\| \mathbf{w}_k \right\|^2} \tag{6}$$

Since,

$$\frac{\gamma_{\mathrm{u}} \left| \mathbf{w}_k^H \mathbf{h}_k \right|^2}{\left\| \mathbf{w}_k \right\|^2} \le \frac{\gamma_{\mathrm{u}} \left\| \mathbf{w}_k \right\|^2 \left\| \mathbf{h}_k \right\|^2}{\left\| \mathbf{w}_k \right\|^2} = \gamma_{\mathrm{u}} \left\| \mathbf{h}_k \right\|^2 \tag{7}$$

and equality holds where $\mathbf{w}_k = \mathrm{const} \cdot \mathbf{h}_k$, the MRC receiver is $\mathbf{w}_{\mathrm{mrc},k} = \mathrm{const} \cdot \mathbf{h}_k$. By the substitution $\mathbf{w}_{\mathrm{mrc},k}$ into (6), the received SINR of the k stream for MRC receiver is given by

$$\bar{\gamma}_{\mathrm{mrc,u}} = \frac{\gamma_{\mathrm{u}} \left\| \mathbf{h}_k \right\|^4}{\gamma_{\mathrm{u}} \sum_{k' \neq k}^{K} \left| \mathbf{h}_k^H \mathbf{h}_{k'} \right|^2 + \left\| \mathbf{h}_k \right\|^2} \tag{8}$$

From (8), the MRC is optimal the SINR in each stream for the massive MIMO system. Actually, the BS can adapt the power control when the SINR is lower than the threshold level, afterward the MRC receiver can achieve the power gain for the detection. By considering the effects of IUI, the comparison results of performance between MRC receiver and ZF receiver is discussed. The ZF receiver is more optimal than MRC receiver [11].

In contrast to MRC receiver, ZF receiver in [16] considers the IUI, but neglects the effect of noise. In ZF, the multiuser interference is completed with nulling out by projecting each stream onto the orthogonal complement of the IUI.

The ZF criterion matrix depends on the pseudo-inverse of the channel matrix $\mathbf{h}$. Generally, the signal detection is given by

$$\begin{aligned} \mathbf{r}_{\mathrm{zf}} &= \left(\mathbf{h}^H \mathbf{h} \right)^{-1} \mathbf{h}^H \mathbf{y}_{\mathrm{ul}} \\ &= \sqrt{\gamma_{\mathrm{u}}}\, \mathbf{s} + \left(\mathbf{h}^H \mathbf{h} \right)^{-1} \mathbf{h}^H \mathbf{n} \end{aligned} \tag{9}$$

where $M \ge k$, the channel matrix $\mathbf{h}^H \mathbf{h}$ is invertible.

Moreover, each stream of $\mathbf{r}_{\mathrm{zf}}$ in (9) is multi-user interference free. The ZF receiver works well to suppress the IUI, but increases the noise (i.i.d). Furthermore, if the channel is imperfect, the pseudo-inverse amplifies the noise significantly. Therefore, the signal detection is very poor

B. Proposed Method

In order to eliminate the increasing noise level from inverting of pseudo-inverse matrix in the ZF criterion, the weight blind algorithms method is given by

$$\mathbf{y}_{\mathrm{o}} = \mathbf{r}_{\mathrm{zf}} \cdot \mathbf{w}_{\mathrm{proposed}} \tag{10}$$

The blind weight algorithm is based on unsupervised pilot sequence to update the iterative of weight output. The proposed algorithms is given by

- *CCM*, a gradient algorithm. The update of weight control of the convergence depends on the stochastic gradient algorithm as

$$\mathbf{w}_{\mathrm{ccm}} = \mathbf{w}_{\mathrm{i-1}} + \mu \cdot \mathbf{r}_{\mathrm{zf}} \cdot \varepsilon \tag{11}$$

  where μ is a step size, and ε is error signal, and w_{i} denotes the number of iteration.

- *SCM* based on initialization of using the output autocorrelation of the ZF receiver. The expression of autocorrelation is given by

$$R_{\mathrm{xx}} = E[\mathbf{r}_{\mathrm{zf}} \mathbf{r}_{\mathrm{zf}}^H] \tag{12}$$

  The convergence update of weight control that is

$$\mathbf{w}_{\mathrm{scm}} = \mathbf{w}_{\mathrm{i-1}} + \mu \cdot R_{\mathrm{xx}} \cdot \varepsilon \tag{13}$$

- *VSSCM* is utilized to improve of fix the step size constant of CMA. In order to speed up the convergence, a suitable step size condition is given by

$$0 < \hat{\mu} < \frac{2}{3\mathrm{tr}[R_{\mathrm{xx}}]} \tag{14}$$

  where $\mathrm{tr}[\cdot]$ denotes the trace function. Therefore, the convergence update of weight control can be rewritten to express as

$$\mathbf{w}_{\mathrm{vsscm}} = \mathbf{w}_{\mathrm{i-1}} + \hat{\mu} \cdot \mathbf{r}_{\mathrm{zf}} \cdot \varepsilon \tag{15}$$

  where $\hat{\mu}$ denotes the variable step size

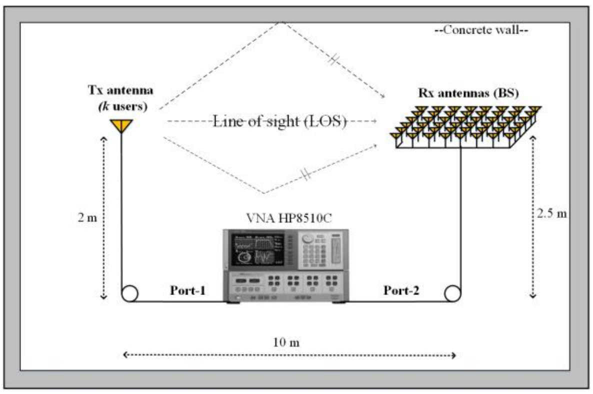


Fig. 2. Channel sounding model and measurement setup.

III. Channel Model

Note that the channel model is taken into account from the channel sounding as shown the measured setting in Fig. 2, where the measurement setup and simulation parameters are listed in Table I.

TABLE I: MEASUREMENT SETUP AND SIMULATION PARAMETERS

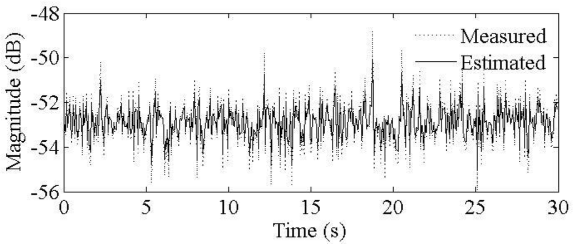
List of measurement setup and simulation parameters	
Parameter	**No.**
Frequency bands	5 GHz – 6 GHz
Frequency sweeping point	1601
Dynamic range (dB)	80
Intermediate frequency bandwidth (IFBW)	100 MHz
Number of Rx antenna elements (BS)	128
Number of *k* users with a single antenna	100
Transmit power (dB)	-10
Data bit rate (Gbps)	1
QAM modulation	64
Step size fixed	0.001

Fig. 2 shows the measurement setup, where the height of the Tx antenna was 2 m and Rx antennas (BS) 2.5 m, the separated distance is 10 m in the far field radiation. The Tx antenna is connected to port-1 and Rx antennas are connected to port-2 of the vector network analyzer (VNA) HP8510C model. The measured frequency range is 5 GHz to 6 GHz where set the frequency sweeping point as 801. We simulate the *k* users as 100 in the uplink channel to the Rx antennas as the massive MIMO to 128 elements. The channel sounding is conducted while no one is in the measured area to ensure the stationary of the propagation indoor scenario.

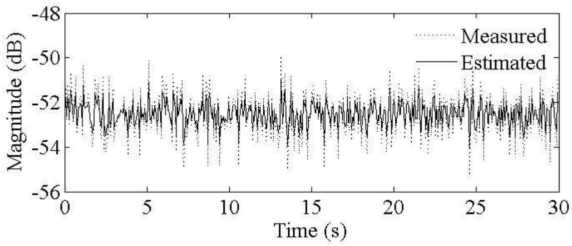
IV. RESULT AND DISCUSSION

A. Channel Response

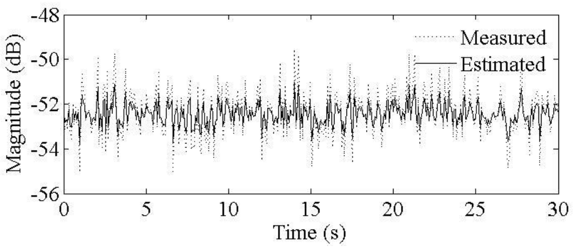
The measured and estimated data of the channel response in each proposed methods are shown in Fig. 3. Obviously, the channel response varies in time coherence. It is well known that in the fast fading channel, the received signals strength varied from the superposition of multipath propagation. In Fig. 3 (a), the variance between the measured data and the estimated data is high, the additive noise variance still remain. The conventional ZF receiver proposed in [16] can estimate the measured data perfectly, compared to the proposed method as shown in Fig. 3 (b). The ZF with CCM distinguishes in estimated data, because the algorithm controls weight of the error signal output is close to optimal. The magnitude variance increases to 2 dB compared to the measured data. Accordingly, we observe that the using ZF with SCM based estimated data is perfect than the measured data clearly as shown in Fig. 3 (c). The effect of estimation error is better than that of the conventional ZF receiver in Fig. 4 (a), where the variance is 3.1 dB, which compared to the measured data. Furthermore, we found that the variance is reduced by using ZF with VSSCM as shown in Fig. 3 (d), the MSE is converged.



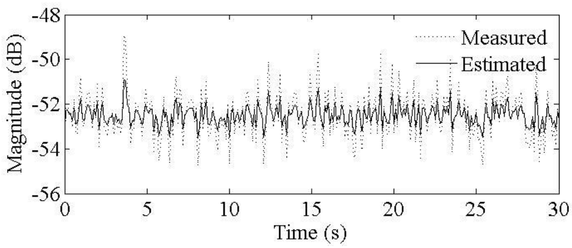
(a) ZF criterion [16]



(b) Proposed ZF with CCM.

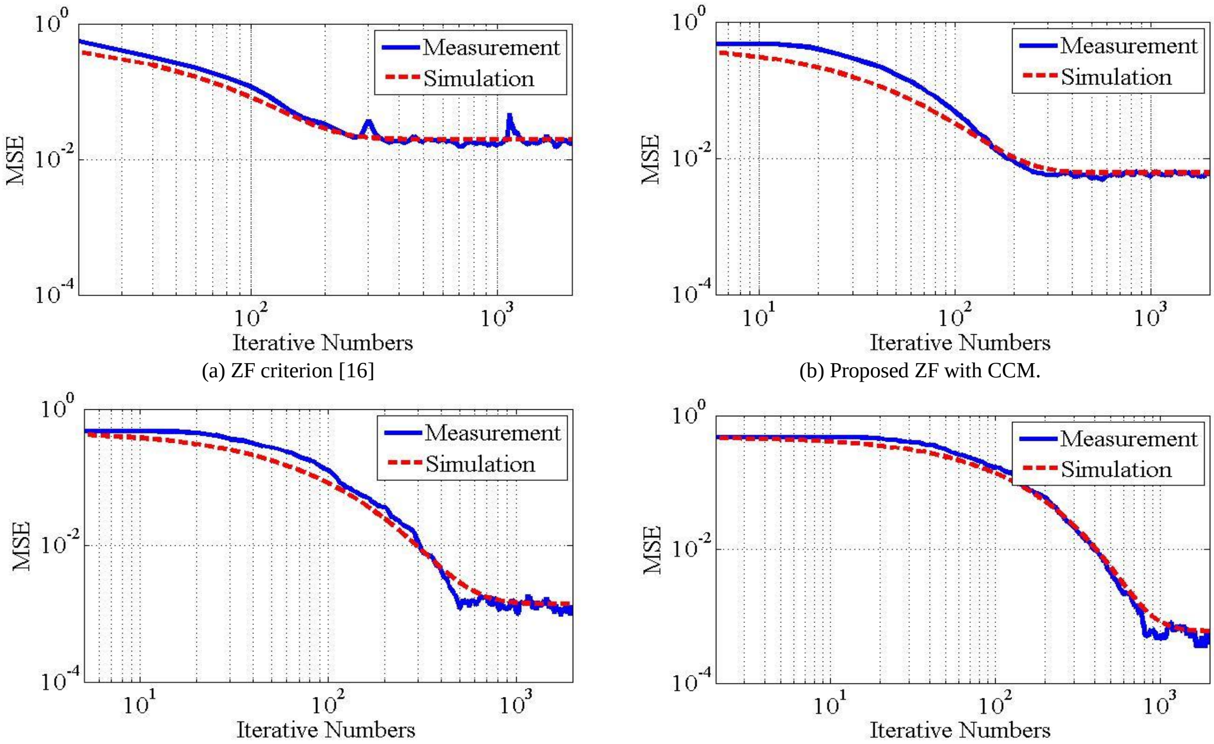


(c) Proposed ZF with SCM.



(d) Proposed ZF with VSSCM.

Fig. 3. Channel response between the measured and estimated data.



(a) ZF criterion [16]

(b) Proposed ZF with CCM.

(c) Proposed ZF with SCM.

(d) Proposed ZF with VSSCM.

Fig. 4. MSE performance between the calculative measured data and estimated data.

B. *MSE Performance*

After discussing the results of the channel response in Fig. 3, the MSE convergence rate can be carried out by the performance of weight iterations. The MSE calculated by the different of between the measured data and the estimated data from the Fig. 3. The performance results are shown in Fig. 4, where Fig. 4 (a)-(d) depicts both the measurement and the simulation results. From these results, it can discuss that the providing of the pseudo-inverse channel matrix from substitution in (10), the conventional of ZF receiver needs to optimal the detection. In Fig. 4 (a) considered at 100 iterations, the MSE rate converges slowly and stable after 200 iterations. In addition, the proposed of ZF with CCM is shown in Fig. 5 (b). The MSE convergence rate is better than the conventional ZF, when the weighted at 200 iterative. As the same way, the proposed of ZF with SCM and ZF with VSSCM as shown in Fig. 5 (c)-(d), the MSE is converged as perfection. The results give the best performance by using the ZF with VSSCM.

C. *BER performance*

The performance of proposed methods is shown in Fig. 5. The ZF criterion [16] performance is acceptable as 10^{-4} when the SNR is more than 40 dB. On the other hand, the BER of ZF with CCM has a better performance is lower than 10^{-6} at the same SNR regime. In addition, the ZF with SCM and ZF with VSSCM is the best perfect. The BER is acceptable to lower 10^{-8} where proposed with the massive MIMO system. We carry out that the ZF criterion can be optimized by using three weights these blind algorithms in order to suppress noise. The best performance of ZF with VSSCM is close to MRC theory.

Finally, we mentioned that the even through of ZF criterion is popular work on massive MIMO system, but the performance of signal detection still be needed to optimize. To take into account of the optimized method, the higher performance detection in ZF receiver can be accomplished by using CCM algorithm, SCM algorithm and VSSCM algorithm as effectively.

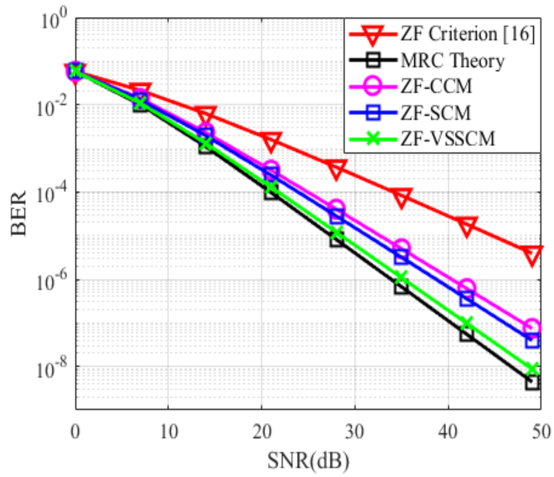


Fig. 5. BER performance detection of three different weight blind algorithms in ZF receiver.

V. Conclusions

Under the assumption of no require CSI at the BS, we have proposed the three different weight blind algorithms to optimize the ZF receiver for multi-user massive MIMO. The high performance detection based on the weight blind algorithms are proposed with CCM algorithm, SCM algorithm and VSSCM algorithm. Furthermore, the channel model has been examined under the indoor realistic propagation channel scenario, which considers both measurement and simulation parameters. From the result, we found that the best result achievable MSE convergence rate is ZF-VSSCM by guarantee lower two-hundred iterations, and BER is achieved to 10^{-8} in a higher throughput (Gbps). Although the best performance is weighted by using VSSCM algorithm, the performance under the assumption of requires CSI at the BS will be considered to the next research.

ACKNOWLEDGMENT

The authors wish to thank the KMITL research funds and KMITL to support the financial of this paper.

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Sarun Duangsuwan received the B.Eng. degree, and M.Eng. in Information Engineering, and the D.Eng. in Electrical Engineering from the King Mongkut's Institute of Technology Ladkrabang, Thailand, in 2008, 2010, and 2015 respectively. From June 2014 to April 2016, he was a research and development with the Huawei Technology (Thailand). Currently, he has been a lecturer in Electronic Engineering with the King Mongkut's Institute of Technology Ladkrabang Prince of Chumphon Campus, Thailand. His research interests in massive MIMO, antenna and propagation, channel modeling and 5G signal processing.

Chakree Teekapakvisit received the B.S in Electronic Technology from the King Mongkut's Institute of Technology Ladkrabang, Thailand, in 1990, M.S. degree and Ph.D. degree in Electrical Engineering from the University of Sydney, Australia, in 2000 and 2006, respectively. Currently, he has been an assistant professor in Information Engineering, the King Mongkut's Institute of Technology Ladkrabang Prince of Chumphon Campus. His research interests include in massive MIMO, signal detections, wireless communications, OFDM, and an iterative receiver.

