4. Experimental Result and Discussion

In this chapter, we explore the experimental results of EPA SCMA and decentralized architecture of EP. We first discuss about the performance of SCMA including the rotation design and theoretical performance. Then, we describe the result of decentralized architecture. The experiment of decentralized EP involves various number of QAM modulation, MU-MIMO system, comprehensive performance evaluation, and also the convergence rates observation.

4.1 EPA SCMA

The simulation parameters are set as follows: $M = 4$ point codebook, $S = 4$, and $U = 6$ as proposed in [41]. For MU-MIMO system, each user has $N_t = 2$ and the BS has $N_r = 4$. As the SE is derived from a large scale system, we increase the transmit and receiver antennas in the four following settings: 1) $N_t = 16$, $N_r = 32$, 2) $N_t = 32$, $N_r = 64$, 3)$N_t = 64$, $N_r = 128$, 4) $N_t = 128$, $N_r = 256$. In this way, we can observe the BER performance of EPA SCMA from small to the large scale system. The rotation rule in codebook design is based on the codebook design proposed in [4].

We provide a comparison between proposed rotation in [5] to the original rotation designed in [35]. Figure 4.1 illustrates the result. We investigate that both of the rotation design have a very similar performance. Thus, we conclude that rotation design is not very important matter in SCMA. This argument supports the idea to declaim the rotation design in SCMA.

Obviously, in small scale system as presented in Figure 4.2, MPA SCMA which can be viewed as an optimal detector has a better performance than EPA SCMA. However, as the numbers of transmit and receive antennas grow, EPA SCMA performance improves significantly. Furthermore, EPA SCMA successfully achieves near optimal

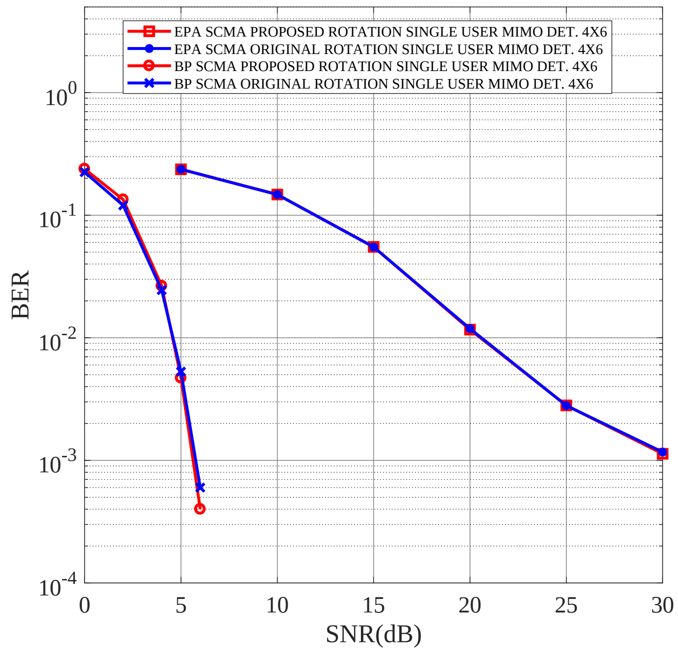

Figure 4.1. Proposed rotation vs original rotation in EPA SCMA

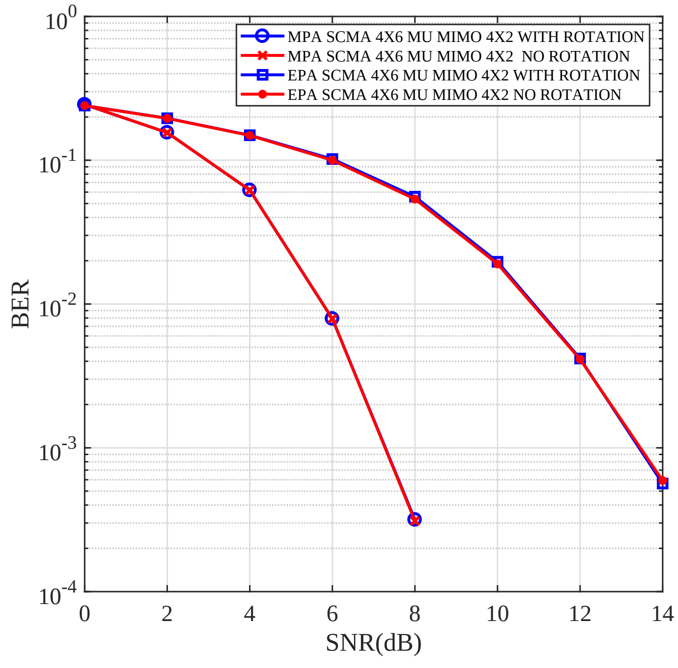

Figure 4.2. Rotation and no rotation in EPA SCMA comparison

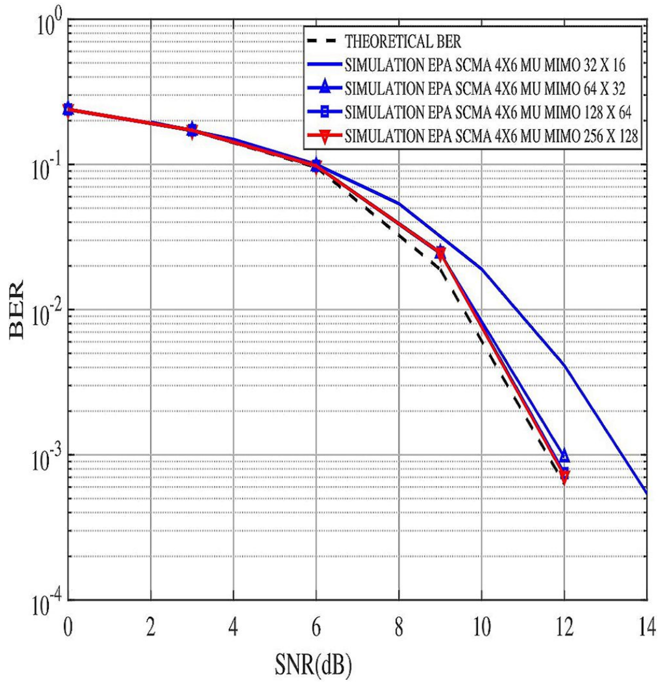

Figure 4.3. Performance analysis of EPA SCMA

performance as illustrated in Figure 4.2 and also has been proved in [27]. At the same time, under the parameter setting in Figure 4.2, we cannot evaluate the MPA SCMA performance. We indicate that the complexity of MPA SCMA rises extremely high, and becomes prohibitive to be implemented. For this reason, there is no MPA SCMA BER performance can be presented in Figure 4.2 as MPA SCMA fails to overcome its complexity problem.

Figure 4.3 also proves the argument on the need of putting a rotation value in the SCMA codebook as proposed in [35], [41], and [4]. Figure 4.3 describes that the BER performance between the EPA SCMA and MPA SCMA without rotation is identical to that with rotation. Consequently, the rotation value is unnecessary for the uplink scheme SCMA system. To support this argument, let the channel response on different users are vary and $\Delta_i = 0$ indicating that no rotation is included. Channel vector $\mathbf{h}_{k,s}$ for all k and s remains distinct. Therefore, no data interference occurs.

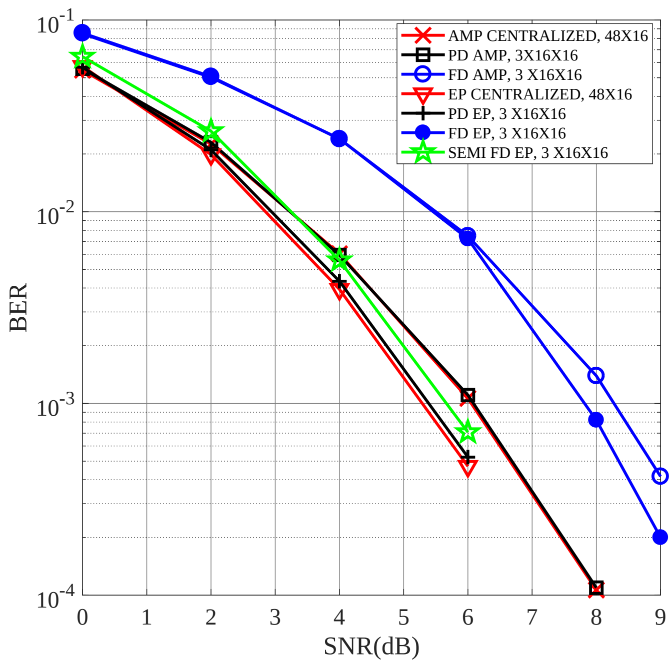

Figure 4.4. Decentralized EP, 4QAM Modulation

4.2 Decentralized EP

In this section, we provide a comprehensive comparison of EP with approximate message passing (AMP)[4] in each decentralized system architecture. We use several number of QAM modulation. We focus on analyzing two decentralized system ($C = 2$) and three decentralized system ($C = 3$) model. Several number of decentralized systems are also observed in convergence rates analysis. For semi FD architecture, we define the number of jointly solving equalization as a number of outer loop and the number of each decentralized system iteration as the number of inner loop iteration. We set the inner loop number = 2 and the outer loop number = 3.

As a comparison baseline, we simulate an uncoded centralized 32 x 16 and 48 x 16 massive MIMO system. The purpose of this discussion is to prove that EP outperforms AMP. Moreover, we evaluate each decentralized system architecture performance inclusively. In addition, we indicate that AMP can not work under high correlated channel.

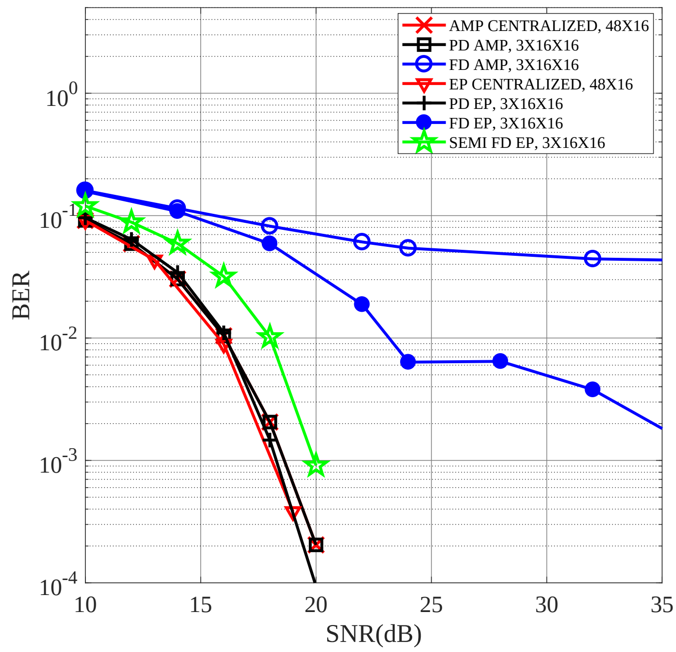

Figure 4.5. Decentralized EP, 64QAM Modulation

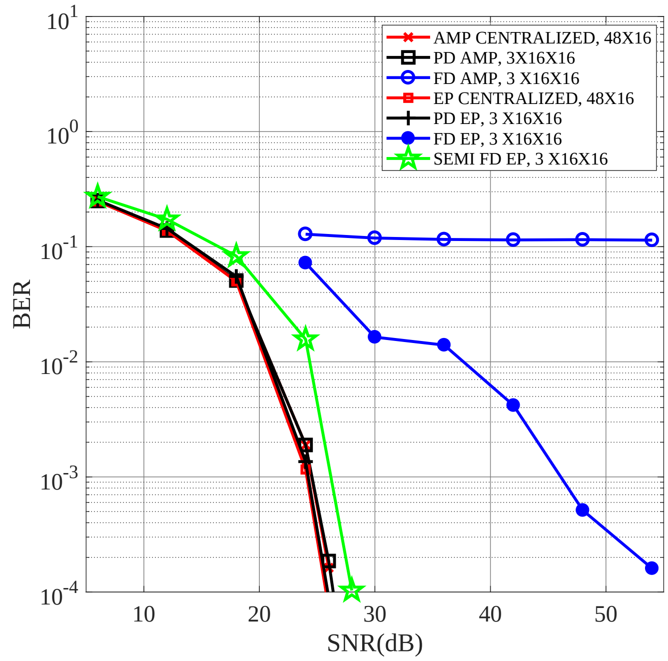

Figure 4.6. Decentralized EP, 256QAM Modulation

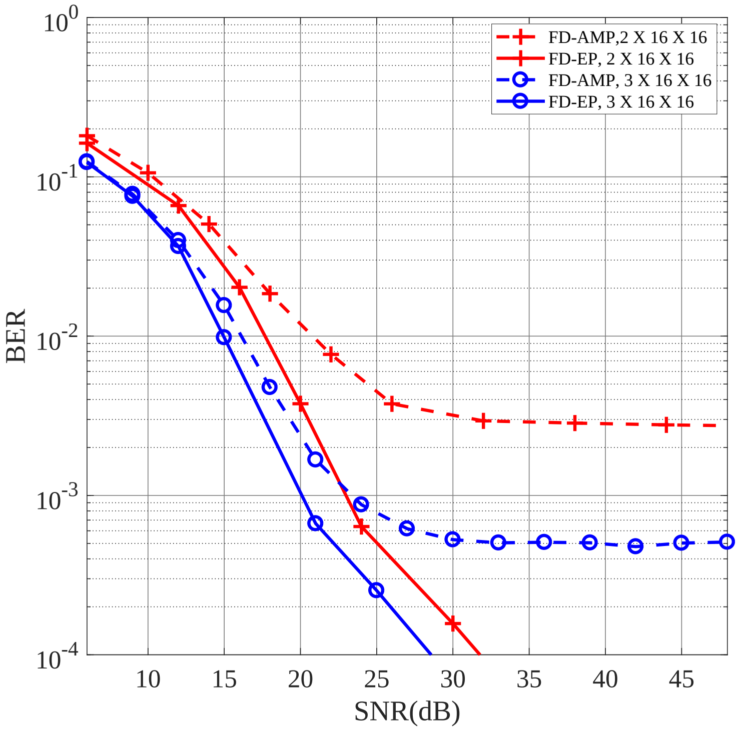

Figure 4.7. Fully Decentralized EP vs AMP

In Figure 4.4, 4.5, 4.6, we compare all of decentralized EP architecture, i.e. FD architecture, PD architecture, semi FD architecture, and centralized architecture in several number of QAM modulation. We employ 4QAM, 64QAM, 256QAM modulation. The simulation result state declares that EP performance is better than AMP performance for all decentralized architecture. Particularly in small constellation, such as 4QAM modulation EP performance is much better than AMP. It is also clearly been seen that semi FD-EP performance is near to the EP centralized performance.

Figure 4.7 illustrated a comparison between EP and AMP, particularly in fully decentralized system. We set 16 QAM, 64 QAM modulation for $C = 2$, $C = 3$ decentralized system. As a result, AMP fails showing a good performance. On the other hand, EP still achieve 10^{-3} BER performance. Furthermore, we specify that fully decentralized architecture has a poor performance as described on Figure 4.7.

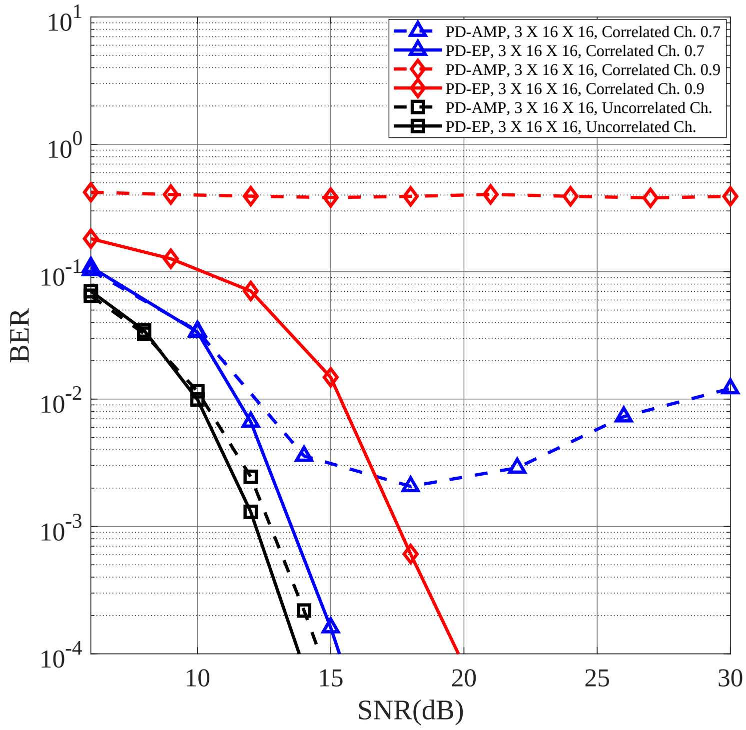

Figure 4.8. Partial Decentralized EP vs AMP

The poor performance of FD structure is due to the system clustering separation, which means compared to PD architecture, each cluster in FD architecture will not has enough information to approximate the transmitted signals. Thus, the performance of each cluster in FD structure will be poor. If each cluster has a poor performance, the outcome performance after equalization process will also be defective.

Figure 4.8 describes an extensive comparison between AMP PD and PD-EP, under the correlated channel. In general practical scenario, correlated channel is a common challenging situation that has to be faced by the massive MIMO communication system. We introduce correlation coefficient $\rho = 0.9$ and $\rho = 0.7$ for three decentralized ($C = 3$) of an uncoded 48 x 16 massive MIMO system. The simulation result indicates that AMP cannot work under the correlated channel. On the contrary, EP can handle the correlated channel. In highly correlated channel scheme, EP performance was significantly reduced around 5 dB. Under the uncorrelated channel, EP performance

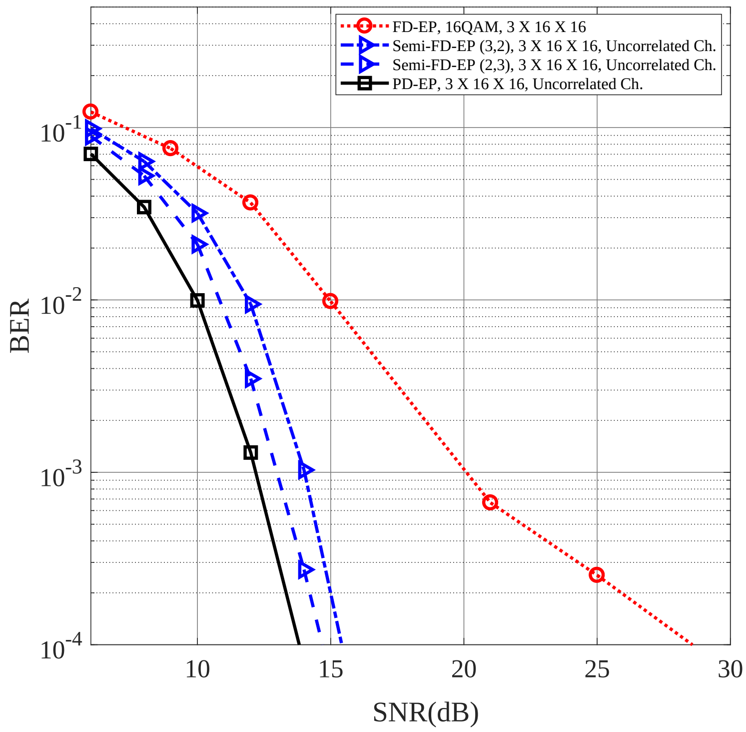

Figure 4.9. Semi Fully Decentralized EP Performance

is also better than AMP. Therefore, after a comprehensive comparison in Figure 4.7 and Figure 4.8, we make two short conclusions i.e. 1)EP is vastly superior to the AMP 2) fully decentralized system is not suitable for decentralized systems due to its poor performance.

Although FD architecture do not perform well, it gives a lot of advantages, such as a low latency and easy to implement. We wish to maintain the advantages of FD architecture while improving its performance. Hence, we propose a semi fully decentralized (Semi-FD) architecture. The Semi-FD architecture has been assessed, as the result can be viewed in Figure 4.9. We define the number of jointly solving equalization as a number of outer loop and the number of each decentralized system iteration as the number of inner loop iteration. We set the inner loop number = 2 and the outer loop number = 3. The performance of Semi-FD-EP is assessed by comparing its performance with the PD-EP performance. Under the correlated channel, PD-

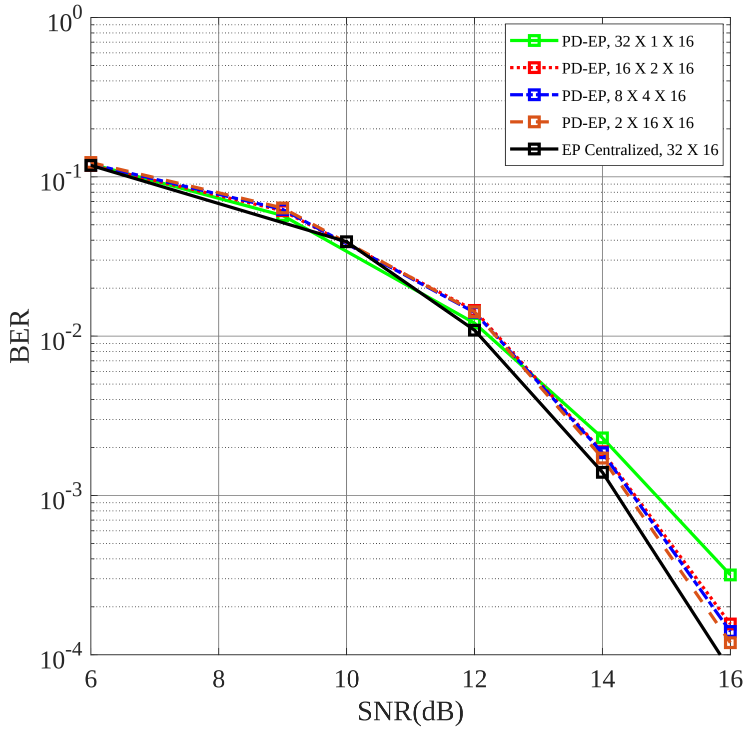

Figure 4.10. Partial Decentralized EP Performance

EP performance is 2 dB better than Semi-FD-EP. In uncorrelated channel case, the performance difference significantly reduce unto 1 dB.

EP computational complexity lies on the dimension of the inverse of variance matrix ($\mathbf{v}_A^{post}$). The dimension of $\mathbf{v}_A^{post}$ is related to the number of receiver antennas. As the receiver antennas grow, EP complexity increases significantly. We use the PD-EP to solve the complexity problem of the centralized EP. Basically, PD-EP is able to reduce the complexity of centralized system by decentralizing the computation of inverse $\mathbf{v}_A^{post}$. The decentralizing computation results a diminishing dimension of inverse $\mathbf{v}_A^{post}$. After the equalization process, the complete computation of inverse $\mathbf{v}_A^{post}$ can be achieved. Therefore, PD-EP successfully decreases the complexity of centralized EP without sacrificing its performance.

In Figure 4.10, we prove that PD architecture has a similar performance to its centralized system. We employ PD-EP system ($C = 3$) and ($C = 6$). The similar

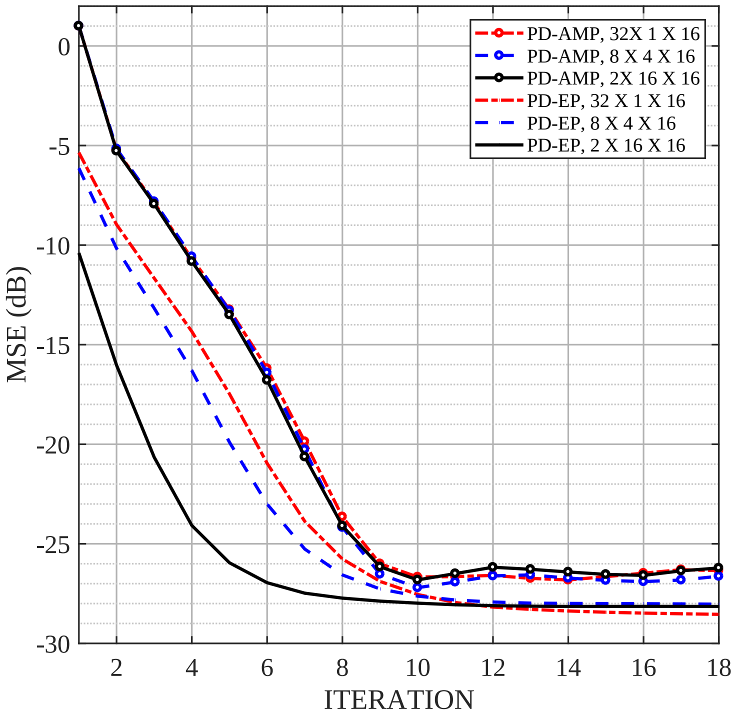

Figure 4.11. Convergence Rates of Decentralized EP

performance of PD system and centralized system strengthens our argument that PD-EP can be used as a low complexity version of EP algorithm. However, The convergence rates will be the trade off.

Figure 4.11 provides a comparison of convergence rates for EP and AMP. We set the signal to noise ratio (SNR) value is 12 dB. An uncoded 32 x 16 massive MIMO system which is decentralized into several C decentralized system is observed. We set the SNR = 12 dB. As pointed out in Figure 4.11, the bigger the number of EP decentralized systems (C), the slower the convergence rates. There is a trade off between convergence rates and computational complexity in PD-EP systems. On the other hand, in AMP, the convergence rates will be identical for any number of C. So, there is no trade off for convergence rates in AMP. However, EP convergence rates for ($C = 32$) which is a maximum decentralized number for 32 x 16 massive MIMO system, is still better than AMP convergence rates as proved in Figure 4.11.