Bayesian statistical methods for joint user activity detection, channel estimation and data decoding in dynamic wireless network

Fakher Sagheer[†]
[†]Telecom SudParis

5G-Communications

In 5G-Communcations, high data rates, cloud services and super reliable communication are required. As in the case of IOT devices, some devices may have sporadic activity and high latency requirements, so allocating whole blocks of resources to such devices as done in the previous multiple access schemes is the wastage of resources. So, we are using non-orthogonal multiple access scheme where devices share same resource elements. Moreover, in the grant based access, there is high energy consumption and high delay, so we need to move to grant-free access. It gives rise to the problem of user activity detection in addition to data decoding and channel estimation. In order to perform these tasks at the receiver end, we are exploring statistical signal processing methods based on factor graphs.

Model

Orthogonal frequency division multiplexing-Interleaved division multiple access(OFDM-IDMA) model of the system is given by the following equation

$$\mathbf{y}_n = \sum_{u=1}^{U} \theta^{(u)} \sqrt{E_s^{(u)}} d_n^{(u)} \mathbf{x}_n^{(u)} + \mathbf{w}_n \tag{1}$$

In the above equation, x is the channel frequency response of u-th user, d is the modulated variable, θ is the user activity variable and w is the white gaussian noise. Modulated variables are obtained by performing the forward error correction on the information bits of each of the user, then random interleaving and finally converting the binary bits to complex valued sequences belonging to some modulation constellation. $\theta^{(u)}$ is a binary variable being zero if the user is inactive and one if it is active. We assume that channel frequency response follows a Gauss Markov model

$$\mathbf{x}_n^{(u)} = \mathbf{x}_{n-1}^{(u)} + \boldsymbol{\delta}_n^{(u)} \tag{2}$$

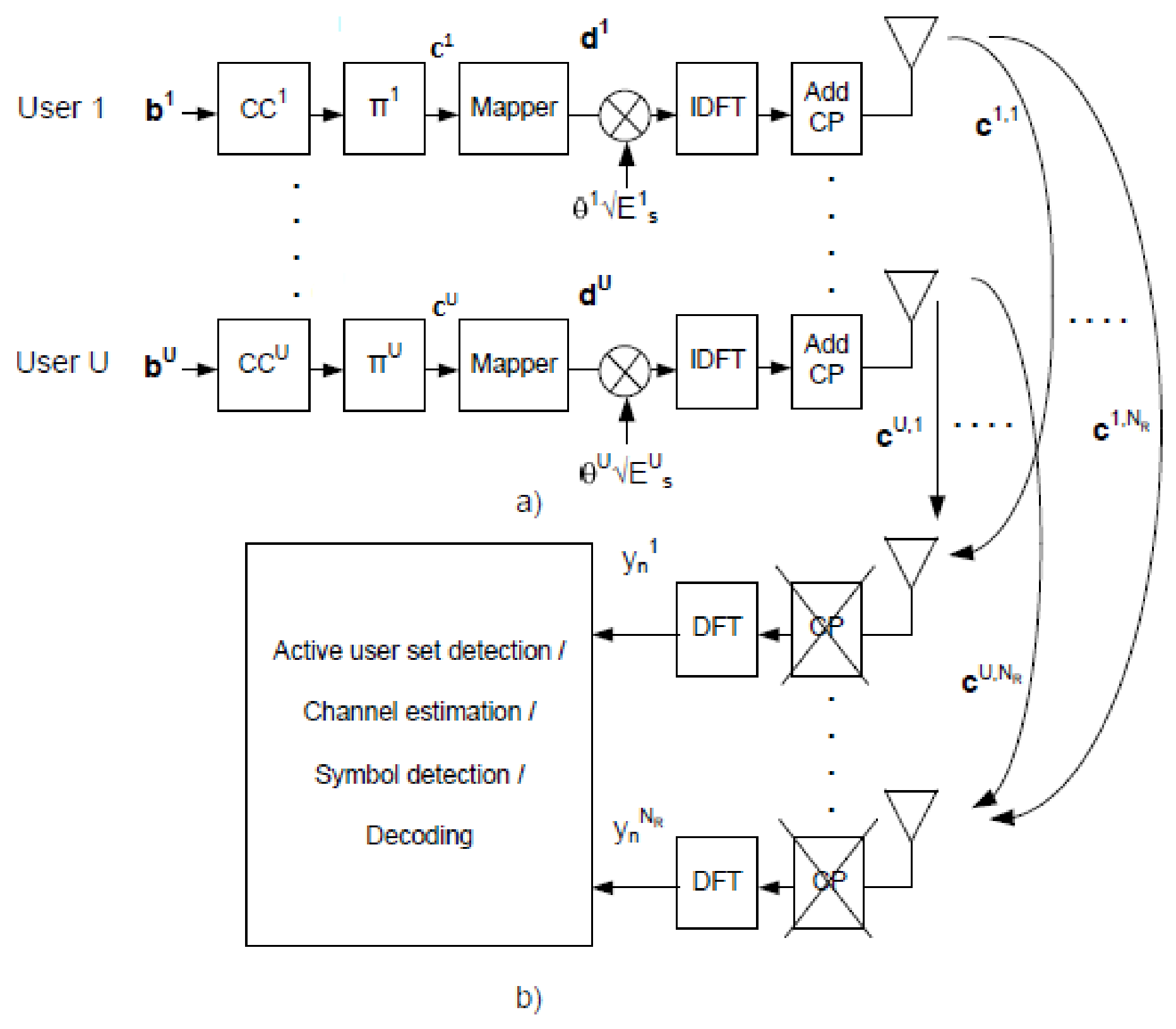

Fig. 1: Transmitter and receiver model for OFDM-IDMA system

Estimation problem

The parameters to be estimated in the above model are channel frequency response, information bits and user-activity variables. This bayesian estimation problem for the user activity variables can be written as

$$argmax_{\theta^{(u)}} p(\theta^{(u)}|\mathbf{y}) = argmax_{\theta^{(u)}} \sum_{\sim\theta^{(u)}} \int p(\mathbf{b},\mathbf{c},\mathbf{d},\mathbf{X},\boldsymbol{\theta}|\mathbf{y}) d\mathbf{X} \tag{3}$$

Factor graph

Above joint distribution can be factorized using the Bayes' rule, markov model of the channel frequency response and the independence of the random variables as

$$\begin{aligned} p(\mathbf{b},\mathbf{c},\mathbf{d},\mathbf{X},\boldsymbol{\theta}|\mathbf{y}) \propto & \left(\prod_{n=0}^{N-1} p(\mathbf{y}_n|\mathbf{d}_n,\mathbf{x}_{n,j},\boldsymbol{\theta})\right) \prod_{u=1}^{U} p(\theta^{(u)}) p(\mathbf{x}_0^{(u)}) \\ & \left(\prod_{n'=1}^{N-1} p(\mathbf{x}_{n'}^{(u)}|\mathbf{x}_{n'-1}^{(u)})\right) p(\mathbf{d}^{(u)}|\mathbf{c}^{(u)}) p(\mathbf{c}^{(u)}|\mathbf{b}^{(u)}) \end{aligned} \tag{4}$$

Factor graph for the above factorization of the function is shown in the following figures

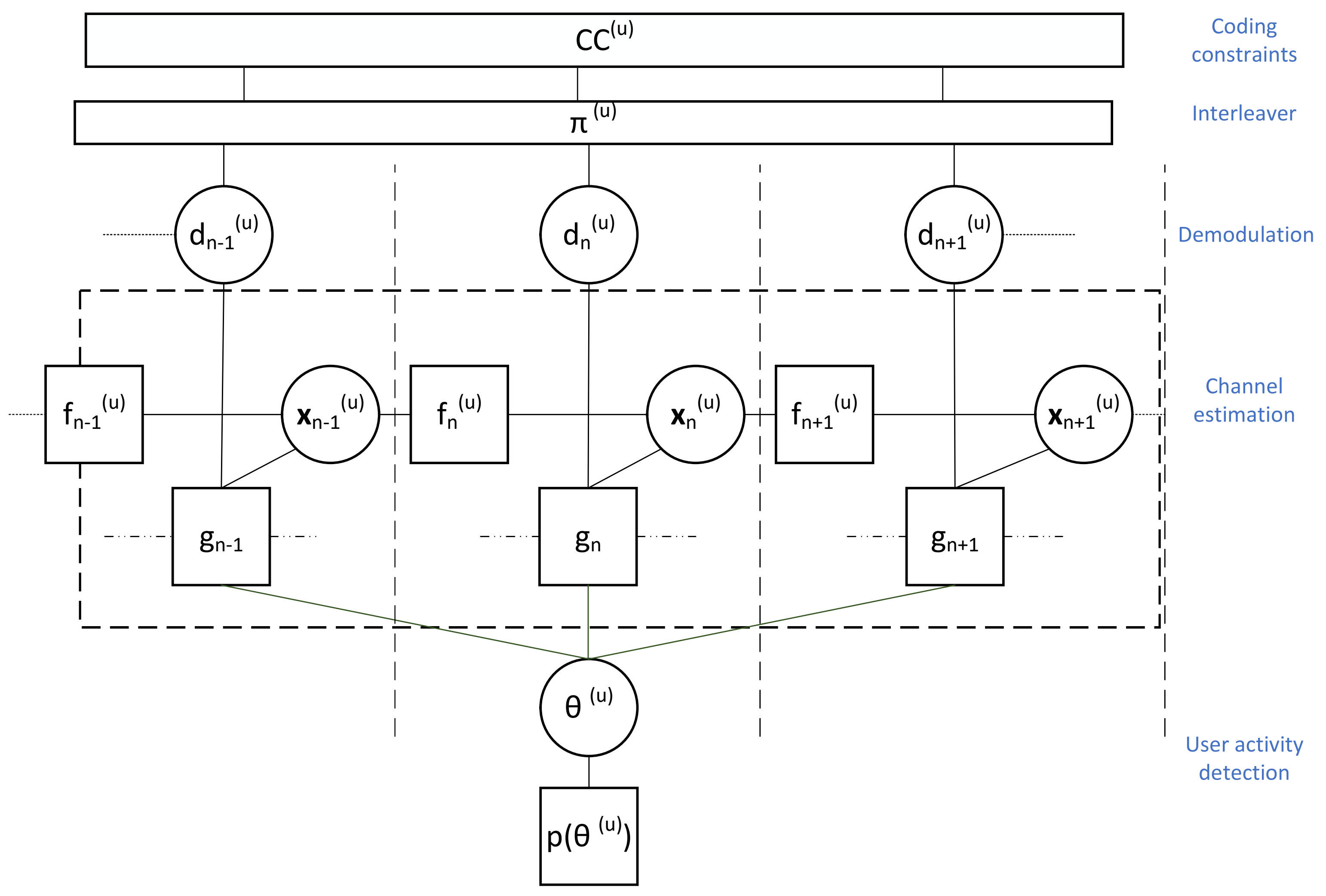

Fig. 2: Factor graph of the OFDM-IDMA system

The parameters can be estimated by computing the marginal a posteriori distribution of each of them which in turn is computed by applying the message-passing algorithms on the factor graph.

Expectation propagation algorithm

Message from a factor to a variable node

$$\mu_{f\to x}(x) = \frac{proj_{\Phi}\left(\mu_{x\to f}(x)\int f(\mathbb{X})\prod_{y\in ne(f)\setminus\{x\}}\mu_{y\to f}(y)d\sim x\right)}{\mu_{x\to f}(x)} \tag{5}$$

Message from a variable to a factor node

$$\mu_{x\to f}(x) = \frac{proj_{\Phi}\left(\prod_{h\in ne(x)}\mu_{h\to x}(x)\right)}{\mu_{f\to x}(x)} \tag{6}$$

The difference between the expectation propagation algorithm and sum-product algorithm is that in the case of sum-product all the messages are pmfs so the summation has to be performed on multiple number of variables to compute the message while in the case of expectation propagation, the messages are projected to gaussian distributions.

Expectation propagation results

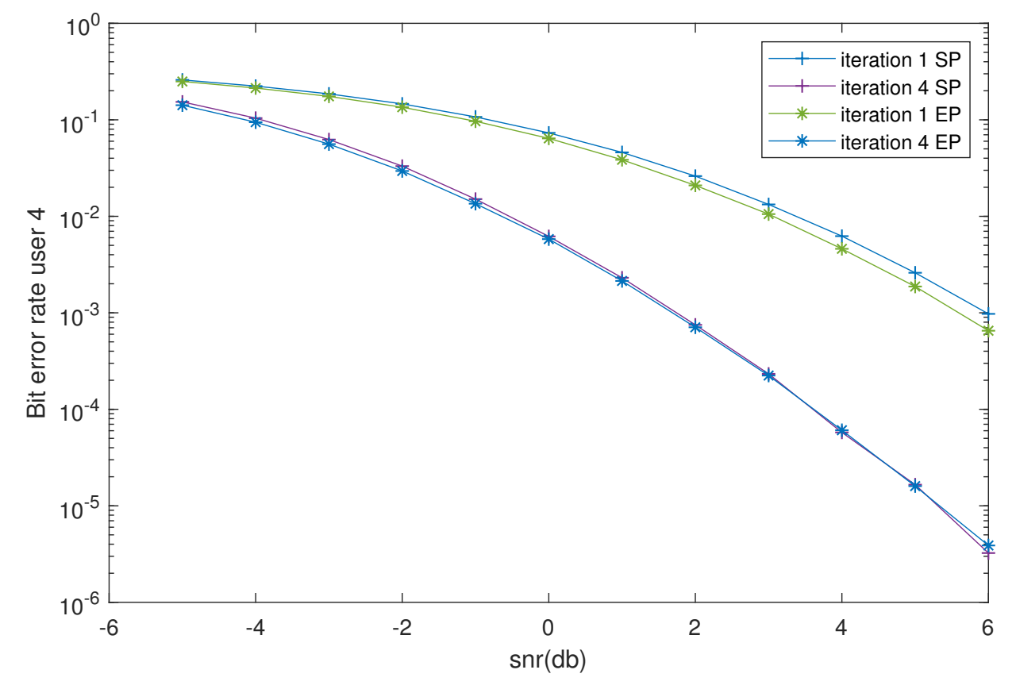

Fig. 3: Bit error rate of user 4

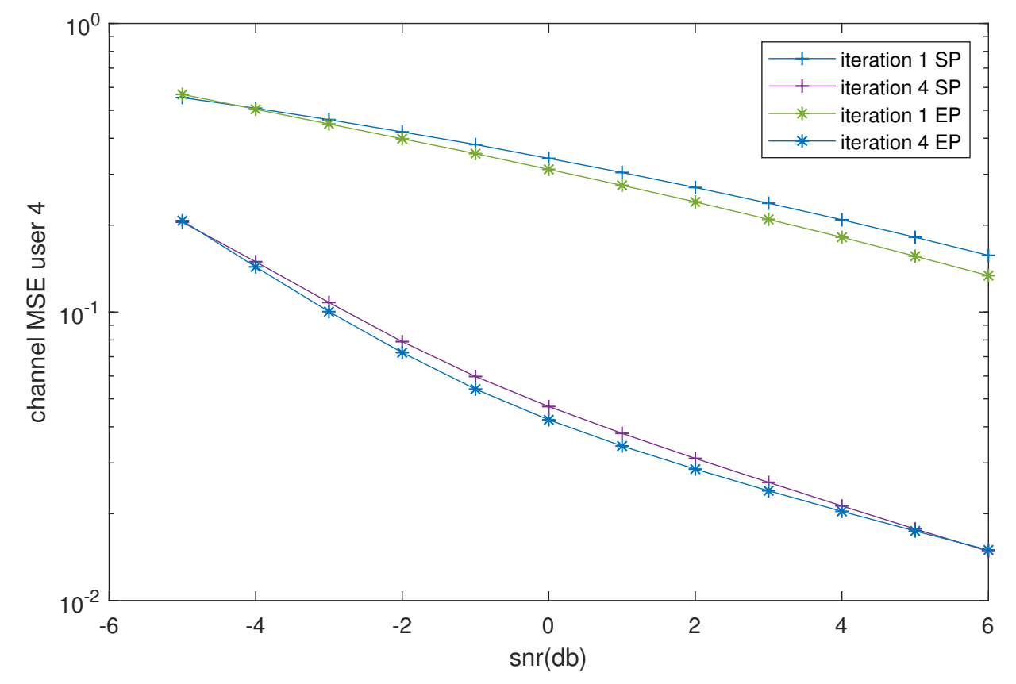

Fig. 4: Bit error rate of user 4

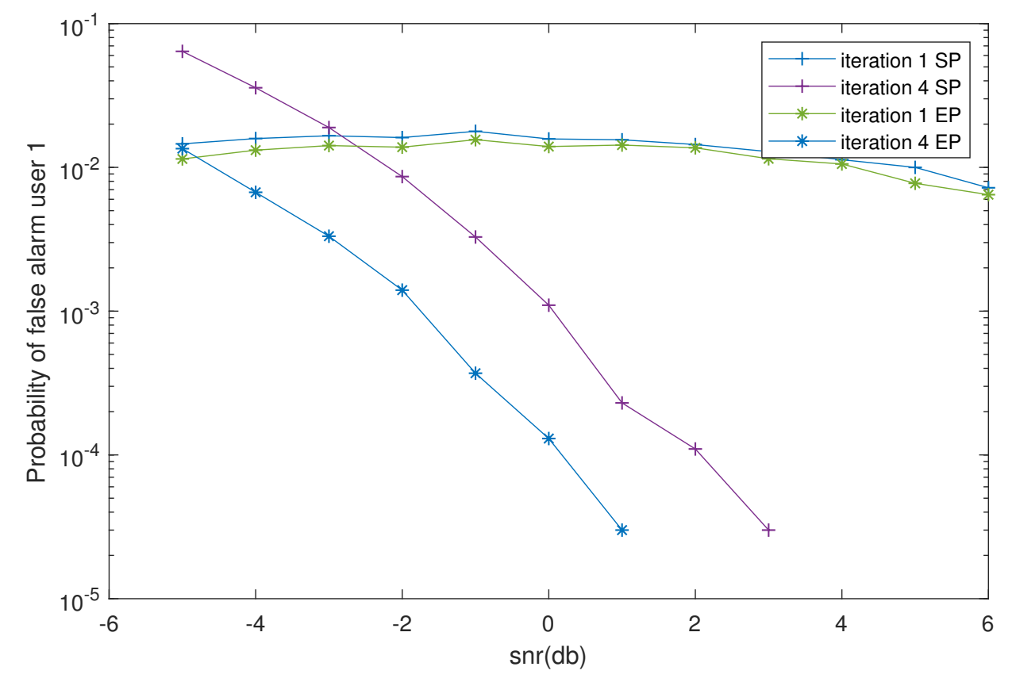

Fig. 5: Bit error rate of user 4

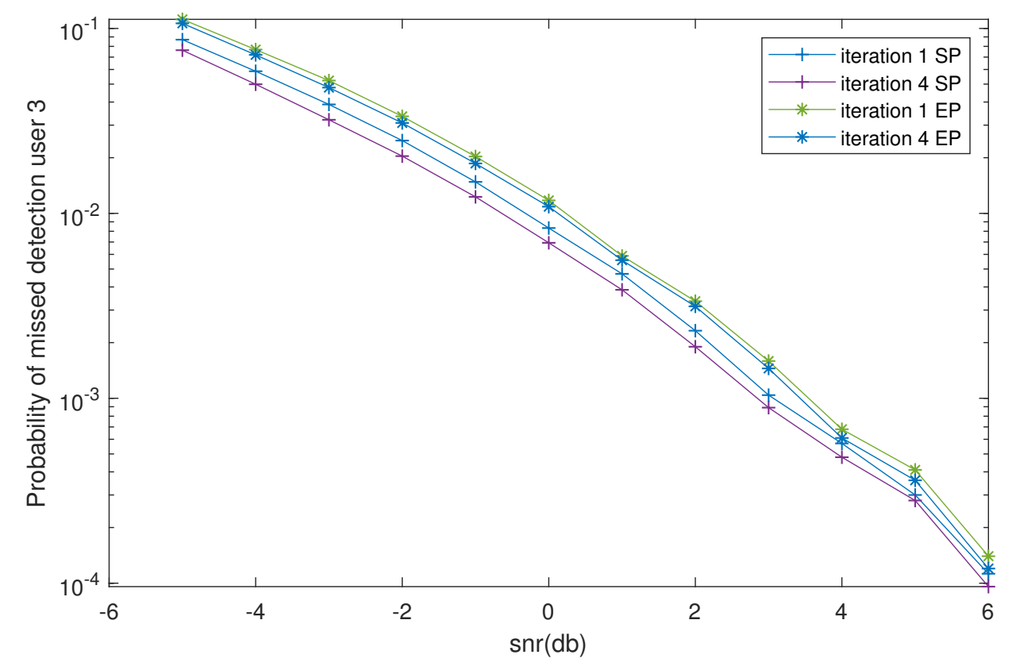

Fig. 6: Bit error rate of user 4

Future work

In future, I will implement other graphical model based algorithms like approximate passing applied on the same problem and compare their performances with each

References

Lehmann, Frederic. "Joint User Activity Detection, Channel Estimation, and Decoding for Multiuser/Multiantenna OFDM Systems." IEEE Vehicular Technology, vol. 67, no. 9, 2018, pp. 8263–8275., doi:10.1109/tvt.2018.2841190.

Zou, Qiuyun, et al. "Concise Derivation for Generalized Approximate Message Passing Using Expectation Propagation." IEEE Signal Process