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Abstract. Energy efficiency and physical layer security are important features in future wireless communication networks. A secure point to point communication is established by using a symbol decomposition method where higher order modulation symbols are decomposed into bits or smaller symbols as separate components and then transmitted to the receiver through multiple amplifiers on the same channel. One of the main challenges in symbol decomposition is accurate channel knowledge for the case of non-static transmitter and receiver position, which necessitates employing a robust and accurate channel estimation with this technique. To improve the accuracy of the channel estimate, an iterative block decision feedback equalizer (IB-DFE) is used at the receiver for joint channel and information estimation. In this paper, we study the symbol decomposition method along with the channel estimation technique and analyze the performance of the system model by using bit error rate parameter and results showcase the effectiveness of IB-DFE receiver.

Keywords: Channel estimation, efficient power amplification, low complexity detection.

1 Introduction

In this work, the massive multiple-input multiple-output (mMIMO) system model is adopted with secure point to point communication based on symbol decomposition. Massive MIMO has several advantages over the single input single output model due to its high spectral efficiency [1]. The idea of maximizing the spectral efficiency of mMIMO by using higher order modulation symbols can lead to high peak-to-average power ratio (PAPR), which can lead to distortion and reduce amplification efficiency [2]. Naturally, higher order modulation signals have amplitude difference in the multilevel constellation points to high envelope fluctuations. Alternatively, higher order modulation symbols can be decomposed into low order modulation symbols to experience low envelope fluctuations which results in improved amplification efficiency over signal with high envelope fluctuations. In this method, we decompose sixteen Quadrature Amplitude Modulation (16-QAM) symbol into four Binary Phase Shift Keying (BPSK) symbols and amplify all the four components in four transmitting antenna and beamforms all the components simultaneously through a single channel. The receiver receives all the components as a single 16-QAM symbol [3]. In this paper, we decompose 16-QAM symbol into four BPSK symbols instead of 2 QPSK symbols, since using BPSK will have low envelop as compared to using QPSK. Also, based on the results from [3] in terms of security aspects, we use BPSK.

This method involves multi-layer system: a multi-branch amplification circuit forms the first layer; each branch is connected in parallel to an antenna array forming the second layer; the third layer is composed of a spatial multiplexing circuit. This multi-layer approach can create complex channel matrix and self-interference in the received signal. Therefore, this requires Iterative Block Decision Feedback Equalization (IB-DFE) to reduce the self-interference in the signal detection block [4]. IB-DFE is a low complexity receiving technique because it does not require matrix inversion unlike mMIMO conventional receivers, improving estimation and the information estimate with each iteration [5],[6].

We consider that both the transmitter and receiver positions are dynamic and, in this condition, the communication channel will also be dynamic, thus it is imperative to estimate channel information at the receiver. If receiver does not know accurate channel knowledge, then the symbol components will for distorted higher order modulation symbols. A robust channel estimation technique is employed in his system model, in which, we superimpose pilot symbol for every single data symbol and estimate at the receiver [7], [8]. This technique is robust and gives accurate estimates but consumes higher energy as compared to other techniques and this excess energy can be harvested from the superimposed signal at the receiver by using power splitting based simultaneous wireless power and information transmission technique (PS-SWIPT) with an power splitting circuit [9], [10]. The physical layer security aspects of the decomposition-based transmitter were already explained in [3]. Thus, in this paper we focus on energy efficiency and channel estimation technique with IB-DFE receiver.

The paper is organized as follows: Section 2 describes the system model. Section 3 describes joint information and channel estimation technique. The performance analysis is illustrated with simulation results in section 4. Conclusion and future works are given in section 5.

1.1 Technological Innovation and Contribution for Life Improvement

From autonomous cars to health monitoring systems, many real time mobile applications depend on the resilience of the communication system. The presented system combines energy efficiency, information security and improved channel estimation for non-static channels. It means that the overall communication will be more robust compared with classic schemes, thus providing a solid based for the development of more and better products for life improvement. This paper also adopts green communication technology SWIPT to improve energy efficiency and opportunistically use the available excess energy from RF signals and thereby this system model is suitable for sustainable wireless communication system.

2 System Model

In this system model, a 16-QAM signal is decomposed to four BPSK polar components and transmitted over Rayleigh frequency selective fading channel, which is denoted as H_k. Single-carrier frequency-division multiple access (SC-FDMA) transmission scheme is used for transmitting all the symbol components over H_k. The 16-QAM symbols are converted to its corresponding bits [5]. The modulated symbol set is given as $\mathcal{S} = \{s_0, s_1, ..., s_{N-1}\}$, where N is the total number of symbols, where $s_n \in \mathbb{C}$ and $\mathbb{C}$ denotes constellation. To each constellation point i.e. s_n is associated to a set of bits, the total number bits in constellation points is denoted as μ, $\mu = \log_2(M)$. The bits in polar form for each symbol is given as $\mathcal{B} = \{b_n^0, b_n^1, ..., b_n^{(\mu-1)}\}$, with $b_n^{(i)} = \pm 1 = 2\beta_n^{(i)} - 1, \beta_n^{(i)} = 0$ or 1. The set of 4 bits can be decomposed from each 16-QAM constellation points and the bit subsets of the transmitted signal is given as $\mathcal{B}_m$, $m = 0,1,\ldots,M-1$, where M is the total number of constellation points. The bits of 16-QAM signal can be written as

$$s_n = \sum_{m=0}^{M-1} g_m \prod_{b_n^{(i)} \in \mathcal{B}_m} b_n^{(i)}; n = 0,1,\ldots,M-1\,; \tag{1}$$

and this forms a system of M equations for each constellation points in $\mathcal{S}$ and g_m is the unknown variable. Without loss of generality, m is associated with its corresponding μ bits and then m is given as, $m = (\gamma_{(\mu-1,m)}, \gamma_{(\mu-2,m)}, \ldots, \gamma_{(1,m)}, \gamma_{(0,m)})$, This defines $\mathcal{B}_m$ as the set of bits, where $b_n^{(i)}$ is included if $\gamma_{(i,m)}$ is 1.

Then, s_n can be written as

$$s_n = \sum_{m=0}^{M-1} g_m \prod_{i=0}^{\mu-1} (b_n^{(i)})^{\gamma(i,m)}\,. \tag{2}$$

The transmitter has 3 layers, in the 1^{st} layer, the symbols is decomposed into 4 BPSK polar components. In the 2^{nd} layer, all the 4 polar components amplified by 4 parallel non-linear amplifiers and these amplifiers are connected to 4 parallel antennas. This 4 parallel antennas denoted as N_m, where $m = 1,2,3,4$. In the 3^{rd} layer, to reduce the complexity in channel estimation, N_m is combined and connected to only 1 transmitting antenna as in [11] and therefore this system model is similar to single input and multiple output antenna model.

Due to amplification of low envelop BPSK components, the power efficiency improves with the decrease in amplifier distortion and lower PAPR of smaller components, it is possible to use non-linear amplifier in transmitter with negligible distortion [12]. All the 4 components are beamformed by using an angle Θ to a desired direction towards the receiver like conventional beamforming mMIMO and here all the components are transmitted in a single communication channel. The total number of receiving antennas are denoted as R.

As in [3, Fig. 1], all the four antennas with the BPSK components have a uniform distance d between them, this d can create time delay of the transmitted components at the receiver. The difference between each component at the receiver due to d and angle θ can be compensated by using phase shift in the transmitter. The antennas R receives this signal at a time delay Δt between each antenna due to the angle θ and this time delay is assumed to be uniform, which is due to multiple receiving antennas. θ is originally meant for transmitting all the components in a uni-direction, however due to multiple receiving antenna, there is space d between each antenna is similar to transmitting antenna. In practice, Δt is common in all beamforming mMIMO systems and it can be compensated.

3 Joint Channel and Information Estimation

The joint channel estimation and signal detection method by using IB-DFE receiver as shown in Fig. 1, which is presented in this section. The received signal at R is given as

$$Y_{k,l,i} = (1-\alpha)\big(H_{k,l}\big(\sqrt{P_x}X_{k,l} + \sqrt{P_q}Q_{k,l}\big) + N_l\big) + N_{e,l}\,, \tag{3}$$

where $X_{k,l}$ and $Q_{k,l}$ are the data and pilot symbols and k is the frequency of block l, then $k = 0,1,\ldots,K-1$ and $l = 0,1,\ldots,L-1$. $X_{k,l}$ =DFT$\{X_{n,l}\}$ and $Q_{k,l} = DFT\{q_{n,l}\}$ are the information and pilot signals converted from time to frequency domain, respectively. N_l is additive Gaussian white noise (AWGN) due to signal transmission and $N_{e,l}$ is due to power allocation at power splitting circuit. $(1-\alpha)$ is power allocated for information and α is the power allocated for energy harvesting.

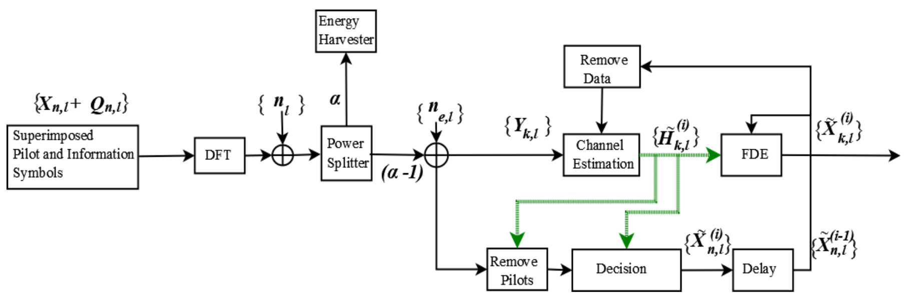

Fig. 1. Block diagram of IB-DFE receiver with joint channel and information estimate.

To perform joint channel and information estimation; the average channel estimate $\widetilde{H}^{avg}_{k,l}$ without using IB-DFE receiver is estimated over a set of signal block. By using received $\widetilde{H}^{avg}_{k,l}$ in IB-DFE, the information estimate $X^{(i)}_{k,l}$ and new channel estimates $\widetilde{H}^{(i)}_{k,l}$ are estimated, where i is the number of IB-DFE iterations. In each iteration, the accuracy of estimate improves, and the final information estimate is denoted as $X^{(i)}_{k,l,F}$.

The channel can be estimated by using the received signal and pilot signal, which is given as

$$\begin{aligned}\widetilde{H}_{k,l} &= \frac{Y_{k,l,i}}{P_q Q_{k,l}} \\ &= (1-\alpha)\left(\frac{H_{k,l}\sqrt{P_X}X_{k,l}+N_l}{\sqrt{P_q}Q_{k,l}}\right) + (1-\alpha)H_{k,l} + \frac{N_{e,l}}{P_q Q_{k,l}} = (1-\alpha)H_{k,l} + eH_{k,l}\,; \end{aligned} \quad \textbf{(4)}$$

$$eH_{k,l} = (1-\alpha)\left(\frac{H_{k,l}\sqrt{P_X}X_{k,l}+N_l}{\sqrt{P_q}Q_{k,l}}\right) + \frac{N_{e,l}}{P_q Q_{k,l}}\ , \quad \textbf{(5)}$$

where $eH_{k,l}$ is the channel estimation error. $eH_{k,l}$ depends on the power of the information, noise and pilot signal. The frame structure has N sub carriers per block and it is modelled as in [7]. The expected value of $H_{k,l}$, N_l, N_e, $X_{k,l}$ and $Q_{k,l}$, respectively is given as

$$\mathbb{E}[H_{k,l}] = 2\sigma_{h,k,l}^2\,;\ \ \mathbb{E}[N_l] = 2\sigma_{n,l}^2\,;\ \ \mathbb{E}[N_{e,l}] = 2\sigma_{n,e}^2\,;$$
$$\mathbb{E}[X_{k,l}] = N\mathbb{E}[X_{n,l}^2] = 2\sigma_{X,k,l}^2\,;$$
$$\mathbb{E}[Q_{k,l}] = N\mathbb{E}[q_{n,l}^2] = 2\sigma_{Q,k,l}^2\,, \tag{6}$$

then applying (6) in (5) gives

$$\mathbb{E}[eH_{k,l}] = (1-\alpha)\left(\frac{\sigma_{X,k,l}^2+\sigma_{n,l}^2}{\sigma_{Q,k,l}^2}\right) + \frac{\sigma_{n,e}^2}{\sigma_{Q,k,l}^2}\,. \tag{7}$$

Even though channel fades with the change in frequency but remains constant for the respective frequency of a set of transmitted signals. Therefore, (7) can be is written as

$$eH_{k,l}^{avg} = \frac{1}{l}\sum_0^{L-1}\left(\mathbb{E}[eH_{k,l}]\right),\quad l = 0,1,\ldots,L-1\,; \tag{8}$$

$$\widetilde{H}_{k,l}^{avg} = (1-\alpha)\left(H_{k,l} + eH_{k,l}^{avg}\right), \tag{9}$$

Where $eH_{k,l}^{avg}$ and $\widetilde{H}_{k,l}^{avg}$ are the average of channel estimation error and channel estimate over l blocks, respectively. The information estimated from the received signal by using channel estimate $\widetilde{H}_{k,l}^{avg}$ and $Q_{k,l}$ is given as

$$X_{k,l}^{hd} = \frac{Y_{k,l,i}}{\widetilde{H}_{k,l}^{avg}} - (1-\alpha)\sqrt{P_q}Q_{k,l}$$
$$= \frac{(1-\alpha)(H_{k,l}(\sqrt{P_X}X_{k,l} + \sqrt{P_q}Q_{k,l}) + N_l) + N_{e,l}}{(1-\alpha)(H_{k,l} + eH_{k,l}^{avg})} - (1-\alpha)\sqrt{P_q}Q_{k,l} \tag{10}$$

The information estimate by using IB-DFE is written as

$$X_{k,l}^{(i)} = \left(Y_{k,l,i} - (1-\alpha)\sqrt{P_q}Q_{k,l}\widetilde{H}_{k,l}^{(i)}\right)F_{k,l}^{(i)} - X_{k,l}^{(i-1)}B_{k,l}^{(i)}\,, \tag{11}$$

where i is the number of iterations with $i = 0,1,\ldots,n$. In the first iteration, $\widetilde{H}_{k,l}^{(0)} = \widetilde{H}_{k,l}^{avg}$, then, the feed forward coefficient $F_{k,l}^{(i)}$ is given as

$$F_{k,l}^{(i)} = \frac{F_{k,l}^{(i)}}{\frac{1}{N}\sum_{k=0}^{N-1}(F_{k,l}^{(i)}\widetilde{H}_{k,l}^{(i)})}\ , \quad \textbf{(12)}$$

where $F_{k,l}^{(i)}$ is given as

$$F_{k,l}^{(i)} = \frac{\widetilde{H}_{k,l}^{(i)}}{(\frac{\sigma_{n,k,l}^2}{\sigma_{x,k,l}^2}) + |\widetilde{H}_{k,l}^{(i)}|^2(1-(Cr^{(i-1)})^2)} \quad \textbf{(13)}$$

and the correlation factor $Cr^{(i-1)} = \frac{\mathbb{E}[X_{n,l}^{(i)}X_{n,l}^{*}]}{\mathbb{E}[|X_{n,l}^{2}|]}$. The feedback co-efficient $B_{k,l}^{(i)}$ is given as

$$B_{k,l}^{(i)} = F_{k,l}^{(i)}\widetilde{H}_{k,l}^{(i)} - 1\,. \quad \textbf{(14)}$$

By using $X_{k,l}^{(i)}$ and $Q_{k,l}$ in (4), the improved channel estimates is given as

$$\widetilde{H}_{k,l}^{(i)} = (1-\alpha)\left(\frac{H_{k,l}\left(\sqrt{P_X}\left(X_{k,l}^{(i)}\right)+\sqrt{P_q}Q_{k,l}\right)+N_l}{\sqrt{P_X}X_{k,l}^{(i)}+\sqrt{P_q}Q_{k,l}}\right) + \frac{N_{e,l}}{\sqrt{P_X}X_{k,l}^{(i)}+\sqrt{P_q}Q_{k,l}}\,. \quad \textbf{(15)}$$

Here, two channel estimate obtained from this receiver, they are:

- The channel estimate i.e. (9), obtained without by using IB-DFE.
- The channel estimate i.e. (15), obtained by using IB-DFE block. Here, estimate accuracy improves with each IB-DFE iteration until a saturation point.

Applying (15) instead of (9) in (11) gives information estimates than the previous estimates, which is denoted as $X_{k,l,F}^{(i)}$. Here, three information estimates obtained from this receiver, they are:

- The information estimate obtained by using $\widetilde{H}_{k,l}^{avg}$.
- The information estimate i.e. (11), obtained by using $\widetilde{H}_{k,l}^{avg}$ and by using IB-DFE.
- The information estimate i.e. $X_{k,l,F}^{(i)}$, obtained by using improved channel estimate obtained with the help of IB-DFE i.e. (15) and by using IB-DFE.

4 Results

The performance of the system model is analyzed by using Monte Carlo simulations. Bit error rate (BER) analysis is considered as the performance metric for this model. For all the simulation results $R = 32$ and $K = 256$, while $l = 2; 3$. The power ratio between pilot signal and the data symbols at the transmitter is denoted as β. To analyze the impact of channel estimation, energy harvesting power allocation α is considered zero except Fig. 4.

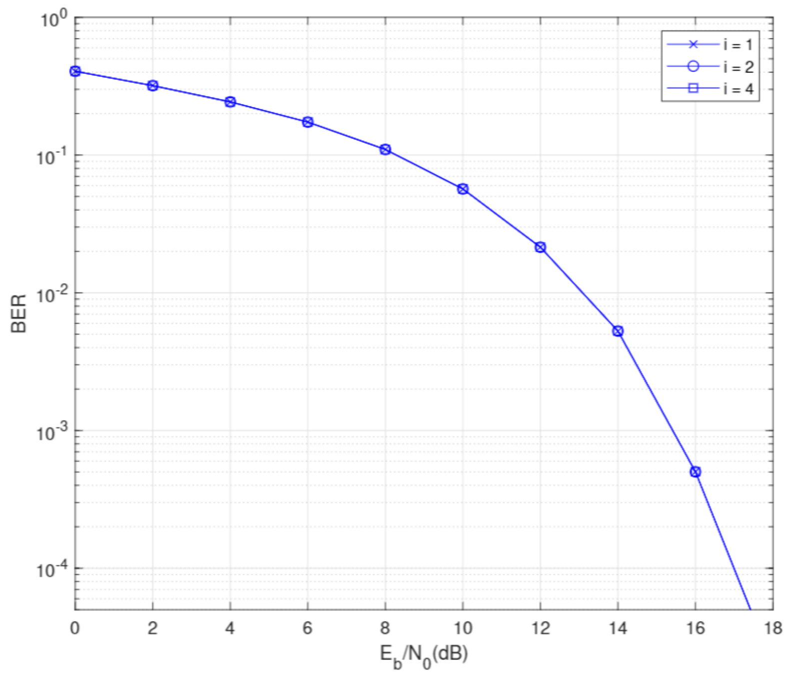

Fig. 2. BER performance of the system model with perfect channel, where i is the IB-DFE receiver iteration and $\alpha = 0$.

Fig. 2 illustrates the BER performance of the system model with IB-DFE, where irrespective of number of iterations, the BER does not improves with iteration due to high diversity provided by R. The results demonstrate that, under high order diversity, BER reaches its saturation point and there is no scope of improvement. Therefore, this simulation model is can be used in imperfect channel model condition, to understand the impact of IB-DFE receiver on the channel estimation technique.

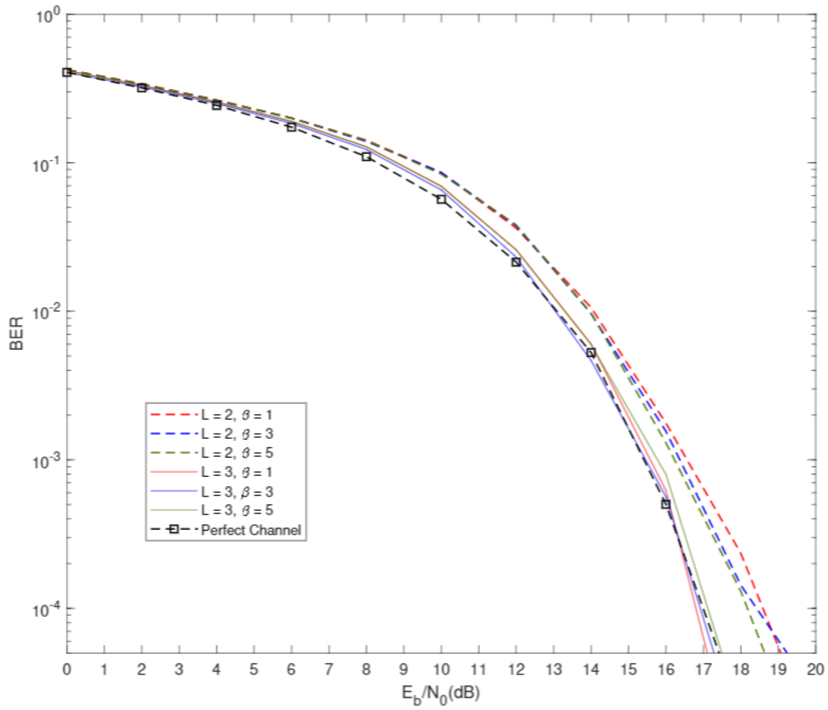

Fig. 3. BER performance of the system model with IB-DFE receiver for an imperfect channel. Here, IB-DFE receiver iteration $i = 4$ for all the curves and $\alpha = 0$.

Fig. 3 illustrates the BER performance of the system model with IB-DFE receiver for an imperfect channel. Here, we compare the results based on the block size $L = 2{,}3$ and $\beta = 1{,}3{,}5$. The results shows that error rate performance improves with the increase in block size, while there is not much difference with β value, but results on the basis that $\beta = 1$, shows that BER performance is slightly better at $L = 3$, because the information estimate suffers due high power of pilot signal. This pattern shows the results of [8]. Thus, we consider $L = 3$ and $\beta = 1$ as an optimum configuration for this simulation.

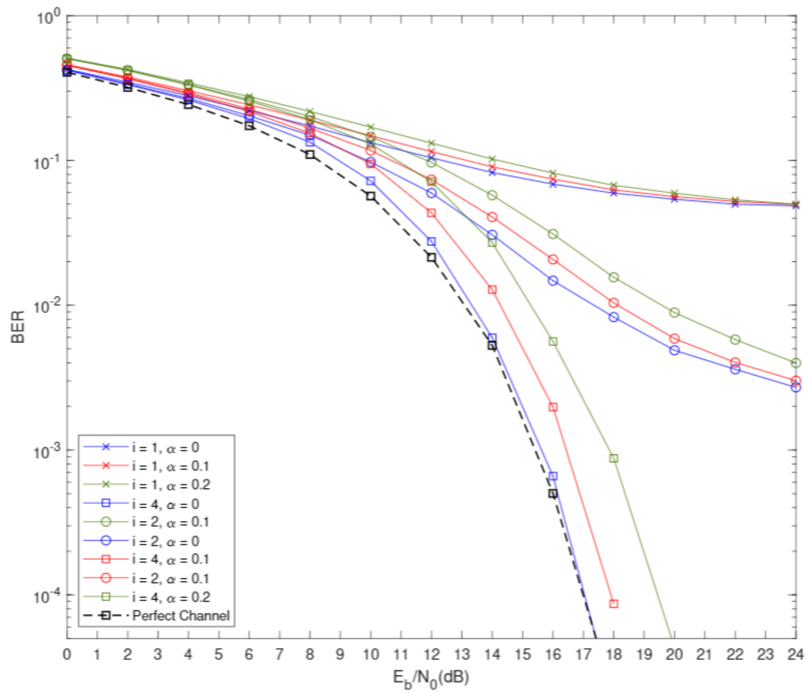

Fig. 4. BER performance the system model with imperfect channel condition, where $\alpha = \{0, 0.1, 0.2\}$, $L = 3$ and $\beta = 1$.

Fig. 4 illustrates BER performance under imperfect channel condition and, the BER performance improves with increase IB-DFE iterations. The impact of power loss due to energy harvesting increases with increase in α value. Thereby, IB-DFE incorporation with this channel estimate technique helps to achieve better performance as similar to system with perfect channel condition and helps in improving BER performance under energy harvesting condition. This simulation analysis explicitly demonstrates the advantage of using IB-DFE receiver for allowing rectenna to harvest 10% of the total energy of the received signal with the loss of 1 dBm SNR.

5 Conclusions

In this paper, we have analyzed the efficiency of IB-DFE receiver for joint channel and information estimation. The results show the improvement of error rate performance under the imperfect channel condition proves that IB-DFE receiver is perfect choice for employing SWIPT, which results in less one dBm SNR loss for using up to 10% of power for energy harvesting. Also employing efficient power amplifier with less distortion due to signal low envelop makes this system model energy efficient at both transmitter and receiver. For the future, this work can be extended to multiple channel estimation for multi-user scenarios.

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