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Estimation of channel distortion in orthogonal frequency division multiplexing system using pilot technique

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ABSTRACT

Orthogonal frequency-division multiplexing (OFDM) is resistant to frequency selective fading due to the longer symbol duration. However, mobile applications channel timing fluctuations in one OFDM signal cause intercarrier-interference (ICI), which reduces performance. This research presented the support vector regression (SVR) model-based channel estimation technique for coherent optical communication systems. Due to the coherent optical orthogonal frequency-division-multiplexed (CO-OFDM) system, a channel model is developed that includes linear fibre dispersion effects, noise from optical amplifiers, and inter-carrier interference generated by laser phase noise. As a result, for such a system, an accurate channel estimate is essential. Based on this concept, derivation of channel estimation and phase estimation for the system of CO-OFDM. The proposed method is tested and evaluated using MATLAB software. Computer simulation results for several standard methods such as extreme learning machines (ELM) and artificial neural networks (ANN) validate the feasibility of the suggested methodology. The CO-OFDM system's transmission experiments and computer simulations prove that the support vector machine-based model following pilot-assisted phase estimation gives the optimal performance. Therefore, results depicted that the channel estimation utilizing the SVR model gives good performance than the other methods, thus the proposed model gives an accurate CE process, respectively.

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1. INTRODUCTION

Over polarisation mode and chromatic dispersion, coherent optical orthogonal frequency-division-multiplexed (CO-OFDM) is a promising technology because of its great spectrum efficiency and advantage. High-speed transmission is possible when polarization-division multiplexing (PDM) technology is used in conjunction with a CO-OFDM system [1]. The overall reliability, efficiency and system performance called CO-OFDM are degraded by the phase noise (PN) constitutes is a major impairment [2]. While improving overall efficiency and system performance, it decreases system complexity [3]. Then, a shorter OFDM symbol duration (lower number of subcarriers) is preferable to increase the PN tolerance [4]. Orthogonal frequency-division multiplexing (OFDM) is a sort of digital transmission that uses multiple carrier frequencies to encode digital data that are used in telecommunications. Based on fast Fourier transform algorithms, carry data in parallel Demodulation, transmitted the overlapping spectra, with this the multiple closely spaced orthogonal subcarrier signals are transmitted in OFDM. In the utilization of available bandwidth than FDMA, OFDM offers more benefits economically [5]. Because of its durability, flexibility, and efficiency, coherent optical CO-

OFDM has gotten a lot of attention in recent years. The CO-OFDM has an impact on the system's effectiveness and overall performance, and it is very prone to carrier frequency offset (CFO) [6].

Channel estimation (CE) is basic for an OFDM-based wireless communication receiver [7], [8]. Using wireless channel's frequency or time correlation features, blind methods or those based on adaptive or non-adaptive methods, training pilots, channel estimation can be performed in different ways: with or without the use of a parametric model [9]-[10]. Pilot-aided phase noise is a method of correction that takes into account continuing professional education (CPE) by using OFDM subcarriers as pilots [11], [12]. A pilot-aided, semi-blind adaptive filtering method has been created for COOFDM systems to simultaneously eliminate the impacts of intercarrier-interference (ICI) and CPE [13]. Coherent detection is the best option for high-spectral-efficiency, high-speed, dynamically reconfigurable optical networks for long-distance transmission for these reasons [14]. In all degrees of freedom available in fibre, a coherent receiver allows information symbols to be encoded by recovering the electric field in the two-fibre polarization, resulting in increased power and spectral efficiency [15].

The literature survey is based on the study of channel estimation in the OFDM system using different methods. Then the article presented an Support vector regression (SVR) model-based channel estimation process. For an OFDM-based super-channel transmission system, Deynu *et al*. [16] devised a carrier phase tracking approach similar to low-overhead, low-complexity via OF combs. Through comprehensive simulation, this phase tracking scheme of joint-carriers feasibility was successfully verified. Alhalabi *et al*. [17] propose two modulation approaches that are utilised to mimic a CO-OFDM system: quadrature amplitude modulation (QAM) and phase shift keying (PSK). The CO-OFDM system was modulated with 16-PSK and 64-QAM with the same number of subcarriers to get the best BER performance. An adaptive weighted averaging-based noise suppression CE method for OFDM systems was proposed by Zhang *et al*. [18]. The suggested channel estimation approach provides superior performance to other traditional channel estimation methods and it is effective, which is evaluated based on the simulation findings. A more straightforward PN model for OQAM/OFDM under channel influence is derived by Wang *et al*. [19] by the intrinsic interference-based distribution feature. A feedback loop-based search called modified blind phase has a commercial laser linewidth of 200 kHz time complexity, which is just a third as wide. The offset-QAM OFDM (OQAM-OFDM) modulation is used for the low-overhead equalisation technique for application in an intensity modulation direct detection (IMDD) system, which is proposed by Bi *et al*. [20]. In order to assess the proposed IA-CFAL process' performance from the phases of complexity, time jitter tolerance, bit error rate (BER), mean square error (MSE) performance, and dispersion tolerance, the experimental and numerical simulation is constructed.

A PDM single-sideband optical OFDM (SSB-OOFDM) approach with receivers that can eliminate interference with a signal utilising balanced detection was introduced by Yang *et al*. [21]. Due to the PDM, with the reduced guard band, this system can enhance spectrum efficiency (SE) and double channel capacity. Zhang *et al.* [22] proposed a high-implementation-efficiency cross-correlation technique for the correction of CPE in OFDM systems. It is constrained by the number of pilot constraints in the wireless communication standard so that the classic algorithm PCP performs poorly in terms of BER. Zhang *et al*. [23] developed a special pilot structure for polarization division multiplexed (PDM) CO-OFDM systems to reduce the quadrature and the in-phase transmitter imbalance, channel distortion, and phase noise. This technology not only enhances the system's tolerance to phase noise and IQ imbalance but also increases transmission speed, which is compared to the conventional approach. For the CO-OFDM systems' estimate of CFO and laser phase noise, Balogun *et al*. [24] devised and used a simplified maximum-likelihood (ML) methodology which avoids the necessity for the exhaustive search associated with typical ML approaches. Furthermore, it produces better performance. The optical phase noise with a low-complexity reduction system was proposed by Hu *et al*. [25]. Based on a partition phase correction and radio frequency pilot (RFP). Furthermore, by discussing decision errors, performance degradation is caused, and it is revealed that a modest partition length combined with a limited floating range can ensure sufficient repair quality.

Due to its robustness in contexts with high delay spread, OFDM can do away with the requirement to balance the influence of the delay spread. Time synchronisation, channel estimation, and mobility all affect the OFDM system's performance. OFDM systems are extremely vulnerable to ICI due to the growth of symbol length. In wireless OFDM transmission, the problem of identifying appropriate pilot distributions has been extensively investigated for channel estimation as well as joint CPE and channel estimation. Therefore, this paper presented an SVR model for the channel estimation process in OFDM. Their method also relies on the information of adjacent OFDM symbols for channel estimation, which increases processing delay. One of the important challenges for OFDM systems in high mobility communications is the time-varying channel estimate. The remainder of the work is divided into the following sections: The proposed research methodology is presented in section 2, the experiments and results discussion is portrayed in section 3, and the research conclusion is exposed in section 4 respectively.

2. PROPOSED RESEARCH METHOD

CO-OFDM is considered an advanced technology for future optical communications. Scalability to ever-increasing data rates and transponder adaptability, both of which are crucial in future transmission systems, are two benefits of CO-OFDM. When speed rates reach 100 Gbit/s or greater, the impact of an optical channel is a critical limiting factor in CO-OFDM transmission systems. The coherent optical network is explored in this work for SVR-based channel estimation. Based on the simulated channel response, the channel distortion is estimated using a support vector machine (SVM). Figure 1 represented the workflow diagram of the research.

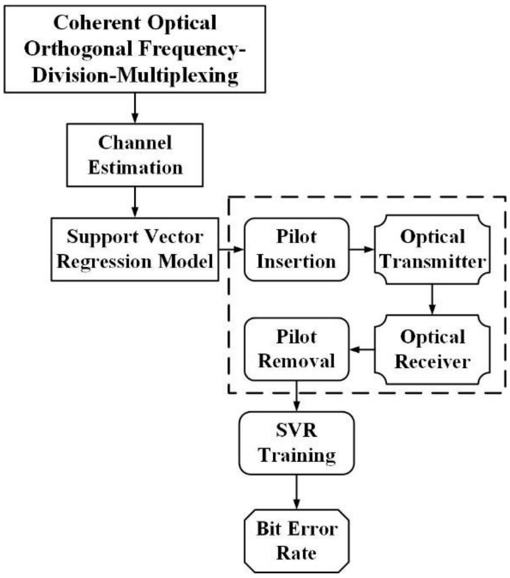


Figure 1. Flow diagram of the research work

The actual optical network distortion is tested using the trained support vector model, and the SVR training phase is performed. In the Software Radio OFDM system, n is the number of subcarriers, among which for transmitting pilot symbol vector $n = s$ subcarriers are used, where t_n is the noted vector. In the receiving end, the CP of the receiving data is removed after that it is known as fast fourier transform (FFT), and in the frequency domain, it receives data $b(q)$.

2.1. System model of OFDM

The transmitting and the receiving side are presented in this proposed method which is portrayed in Figure 2. The converter called decimal to binary is used to convert the source data from the decimal to binary into frames. For processing, demodulate the signal and the pilot data is removed after the CE is performed, for fast fourier transform, the optical channel sends the data to the receiving device.

Figure 2 depicts the OFDM system's baseband equivalent model. Using a Q-point inverse discrete fourier transform (IDFT), the QPSK or QAM constellation sequence $A(l)$ is parsed into blocks of Q symbols and then translated into a time-domain sequence. Over the fading channel, the time-domain $a(q)$ signal can be serially transmitted. $a(q)$can be written as:

$$a(q) = \frac{1}{\sqrt{Q}} \sum_{l=0}^{Q-1} A\,(l)\, e^{j2\pi ql/Q} \tag{1}$$

where, $q = -p, \ldots\ldots, Q-1$, $l = 0,1, \ldots\ldots, Q-1$.

$$b(q) = \sum_{m=0}^{M} k(q,m)\, a(q-m) + w(q) \tag{2}$$

Where, variance σ_q^2 and independence from one another, i.e., $H\left(w(q)w(p)\right) = 0, \forall_q \neq p$ are represented as attributes of additive white Gaussian noise (AWGN) with zero mean. Define the discrete fourier transform (DFT) matrix F, which has an entry $[F]_{q,l} = \left(1/\sqrt{Q}\right) exp(-j2\pi ql/Q)$.

$$B = KA + W \quad (3)$$

Where, $= Fw = [V(0), V(1), \dots, V(Q-1)]^T \in C^Q$, and $B = Fb = [B(0), B(1), \dots, B(Q-1)]^T \in C^Q$, are AWGN vector and RS vector in frequency domain respectively. Therefore, in two parts, it can be categorized, one of which $K_g \in C^{Q \times Q}$ only keeps the main diagonal elements, and the other one $K_q \in C^{Q \times Q}$ is to retain only the off-diagonal elements. Then (3) can be expressed as (4).

$$B = K_g A + K_q A + W = diag(A) K_g + X + W \quad (4)$$

Where the diagonal operators are indicated by $diag(.)$ and the ICI component is $x = K_q A$ and $K'_g \in C^Q$ is a column vector, the element of which is taken from the main diagonal component of K_g.

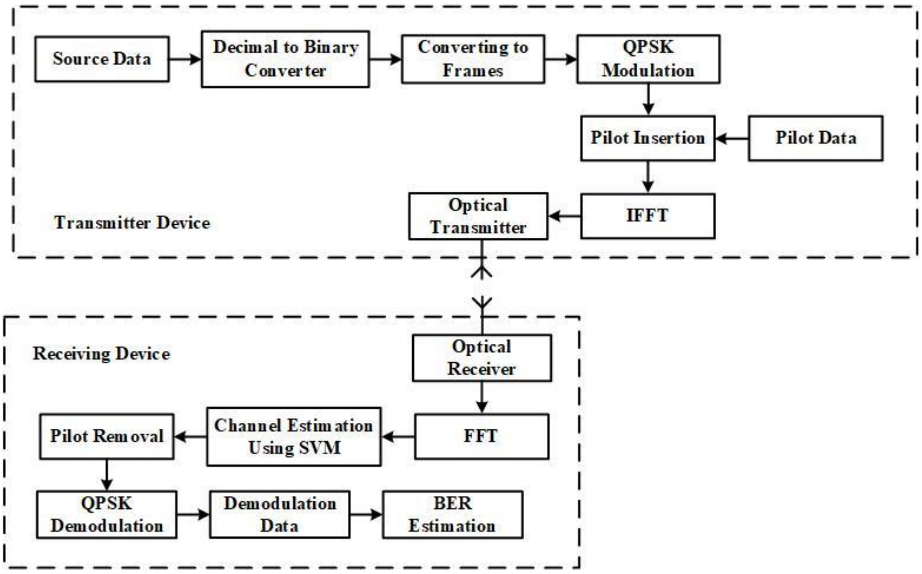


Figure 2. OFDM system model diagram

2.2. CO-OFDM communication system

Alternative symbols are used to modulate each subcarrier when if the subcarriers are used, the OFDM symbol consists of combined alphabet symbols. For a system with S subcarriers, the discrete-time received OFDM signal is described in (5).

$$A_s = \sum_{n=0}^{N-1} T_n U_n e^{j2\pi qs/s} + w_s + d_s\, x_k \quad (5)$$

Before DFT transformation, time-domain samples are $A_s = (n = 0, \dots, N-1)$, at the n-th frequency, the channel's frequency response is U_n, at the n-th subcarrier, the transmitted complex symbol is denoted as T_n, and the complex Gaussian noise process is w_s [26]. A Bernoulli-Gaussian process $f(n)$ is a random process with probability.

$$A_s = \sum_{n=0}^{N-1} T_n U_n e^{j2\pi qs/s} + w_s + o_s \quad (6)$$

As a result, the OFDM system may be written as (7).

$$h(n) = h^t(n) + h^i(n) + u(n) \quad (7)$$

At the s th subcarrier, the data symbol $h^i(n)$ and the complex pilot $h^t(n)$ are transmitted. Every OFDM symbol's pilot insertion in the subcarriers satisfies the requirements of the uniform distribution and sampling theory.

2.2.1. Pilot Insertion in OFDM systems

Pilot symbols are typically included for channel estimation in incoherent OFDM systems. Then, between the information data sequence or within a certain period, pilots will be added to all sub-carriers. Then, using techniques like DFT-based procedures with zero-padding in the TD features, the channel's frequency response can be first estimated over a subset n_t of subcarriers with cardinality $n_t = |N_t|$ and then interpolated over the remaining subcarriers. The OFDM system can be labelled as (8).

$$A_s = \sum_{n\in(n_t)} t_n U_n e^{j2\pi qs/s} + \sum_{n\in(n_t)} I_n U_n e^{j2\pi qs/s}\, u_{(s)} \tag{8}$$

In the n th subcarrier, the data symbol I_n and the complex pilot t_n are transmitted.

2.3. Channel estimation scheme

The block-type pilot insertion model was chosen for the channel estimation, which uses all sub-carriers as pilots and OFDM channel estimate symbols are regularly broadcast. The SVR approach can be utilized to carry out the estimation. Then write $W(s)$ by assuming guard interval drops inter-symbol interference.

$$W = Fz + n \tag{9}$$

Where W is the RS vector, z is the channel attenuation vector, F is a matrix with the diagonal of the transmitted signalling points, zero-mean, and n is a vector of complex, Gaussian noise with variance σ_n^2. For multiple-input multiple-output systems, nonlinear channel estimation based on SVM multi-regression has also been examined. SVM techniques outperform classical methods in all these applications.

2.3.1. Support vector regression model

SVR for regression analysis is a logical extension of classification analysis using large margin kernel methods. While SVR developed from SVM is suitable for regression of nonlinear systems. SVR has evolved into a powerful prediction tool. The following equation is the proposed signal model for SVR.

$$A_s = \sum_{n\in(n_t)} t_n U_n e^{j2\pi qs/s}\, v_s \tag{10}$$

Due to data symbols, v_s contains the residual noise plus the term. By employing SVR algorithms, a regularised cost function of the channel is minimised.

$$R(v_s) = \begin{cases} 0, |v_s| \leq \in \\ (|v_s| \leq \in)^2, \in \leq |v_s| \leq v_c \\ C(|v_s| - \in) - C^2, |v_s| \geq v_c \end{cases} \tag{11}$$

Where, C is the control of the trade-off between regularisation and losses, and v_s is the insensitive parameter. By making zero the primal-dual functional gradient to U_n, we have the following expression for channel estimated values at pilot positions:

$$\widehat{U}_n = \sum_{n=0}^{N-1} \zeta_n t_n \tag{12}$$

where, $\zeta_n = \left(\beta_{Real,n} - \beta_{Real,n}^{+}\right) + j\left(\beta_{Imag,n} - \beta_{Imag,n}^{+}\right)$. For notation, we define the following column vector:

$$\zeta_n(s) = \left[t_n e^{j2\pi qs/s}\right], s \in \{k_t\} \tag{13}$$

The following Gram matrix as $Real(n, v) = \psi_n^U \psi_v$. Now, a compact form of the functional issue that entails maximizing can be given in vector form by incorporating the optimal solution (12) into the primal-dual functional and grouping terms.

$$-\frac{1}{2}\omega^U(Real + \delta Image)\omega + Real(\omega^U\sigma) - \left(\beta_{Real}\beta_{Real}^{+} + \beta_{Image}\beta_{Image}^{+}\right)1 \in \tag{14}$$

Constrained to $0 \leq \{\beta_{Real,n}\}, \{\beta_{Real}^{+}\}, \{\beta_{Image,n}\}, \{\beta_{Image}^{+}\} \leq C$, where, $\omega = [\omega_0, \ldots\ldots, \omega_{N-1}]^T$; the vector containing the associated Lagrange multipliers, with the other subsets being similarly represented; and $\sigma =$

$[\sigma_0, \ldots\ldots, \sigma_{N-1}]^T$, $\mathrm{Im}\, ag,1$ are the identity matrix and the all-ones column vector, respectively. By optimising (14) concerning $\{\beta_{Real,n}\}$, $\{\beta^{+}_{Real}\}$, $\{\beta_{Image,n}\}$, and $\{\beta^{+}_{Image}\}$, the channel values at pilot points (12) can be obtained.

2.3.2. SVR training

The algorithm for the support vector machine's goal is to determine a N dimensional space hyperplane, where N based on the total features that distinguish data points. The margin for linear regression in SVM is shown in Figure 3. Support vectors are closer-to-the-hyperplane data points that have an impact on the orientation and location of the hyperplane.

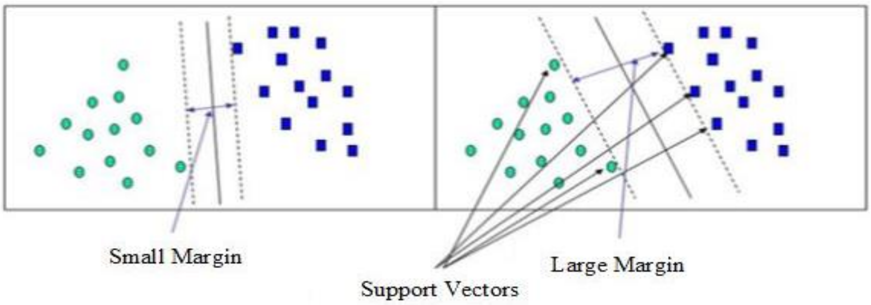


Figure 3. SVM margin for linear regression

The hyperplane position can be altered by eliminating the support vectors. The SVM model is constructed using these data points. By retelling the same process with the roles of x_1 and $x_2$switched, a second such score is then obtained: therefore, a second classification score is obtained using a model learned with x_2 as the positive example is used to classify x_1. The average of these two scores is represented as the symmetric score.

3. EXPERIMENTATION AND RESULT DISCUSSION

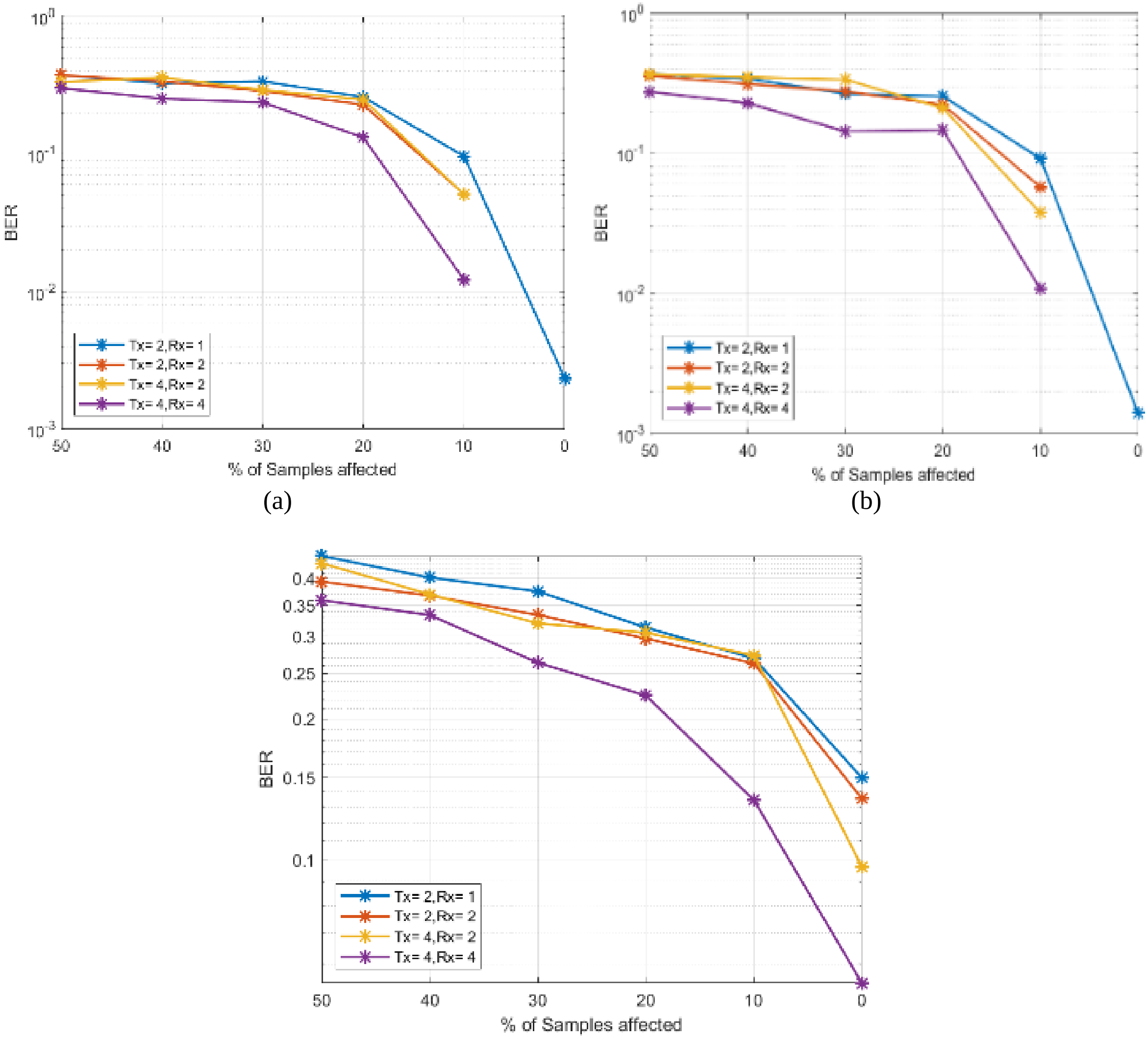
The proposed method is implemented in MATLAB 2020a in an i5 system with 4 GB RAM. The operating system of the proposed work is Windows 10 Home which is depicted in the following Table 1. The performance is increased when using the proposed work SVR network and also the security is very compromising using the same techniques. performance of the system is analyzed based on accuracy.

Table 1. Table of simulation system configuration

Simulation System Configuration	
MATLAB	Version R2020a
Operation System	Windows 10 Home
Memory Capacity	4GB DDR3
Processor	Intel Core i5 @ 3.5GHz

To evaluate the performance, both existing artificial neural networks (ANN) and extreme learning machines (ELM) are compared and the proposed method SVR outperforms both methods. The accuracy graph is plotted as exposed in the following Figures 4 and 5. For both implementations, the same number of users and channels are specified as in the proposed method. The resultant graphs concerning retrieval performance.

Figure 4 illustrates the performance graph for BER using different methods. Figure 4(a) represents the bit error ratio graph for ANN, based on channel estimation, concerning the total samples affected at the receiver end. When the BER is 0.1, the transmitter signals values are 18.5%, 14.5%, 14.4%, and 10%, respectively. Accordingly, Figure 4(b) depicts the BER values using the ELM method, this method is taken as four transmitter and receiver signals. It depicted that BER for affected samples is 0.1, then the % of samples affected are 18%, 16%, 14%, and 10%. Figure 4(c) illustrates the BER graph for the SVR method. This depicts the total affected sample percentage is less than the other two methods. When the BER is 0.05, 0.098, 0.147, and 0.15, % of samples affected reaches 0%. Therefore, the graph represents support vector regression performs greater than the ELM and the ANN techniques. Based on the sample affected and the BER the performance of ANN.



(a) (b) (c)

Figure 4. Performance graph for bit error ratio using different methods, (a) ANN-based channel estimation, (b) ELM-based channel estimation, and (c) SVR-based channel estimation

Figure 5 portrayed the performance graph for BER using different transmitters and different receivers. Figure 5(a) demonstrates the BER graph for the two transmitters and one receiver. This represents CO-ODFM models channel estimation using existing methods, ANN MIMI-DF, ELM, and the SVM methods. This figure depicts that the affected values for ELM are 13% when the BER is 0.1. Figure 5(b) reveals the BER graph for existing methods, ANN, ELM, and SVM. During this BER as 0.1, the total samples affected are 14.4% for ANN and SVM, the percentage is 14.2%. The BER graph for two transmitters and four receivers is shown in Figure 5(c). During the BER is 0.1, for ELM, the % of affected samples is 16%, the % of affected samples for ANN is 14.5%, and the % of affected samples for SVM is 15.2%, respectively. Figure 5(d) illustrates the BER graph for utilizing the four transmitters and the four-receiver sample. It plotted the graph for the Existing method, ANN-MIMI-DF, CO-OFDM-CE-ELM, and CO-OFDM-CE-SVM. The graph gives that all the ANN, ELM and SVM methods values are nearly the same as 18 for the total affected samples when the BER is 0.1, respectively.

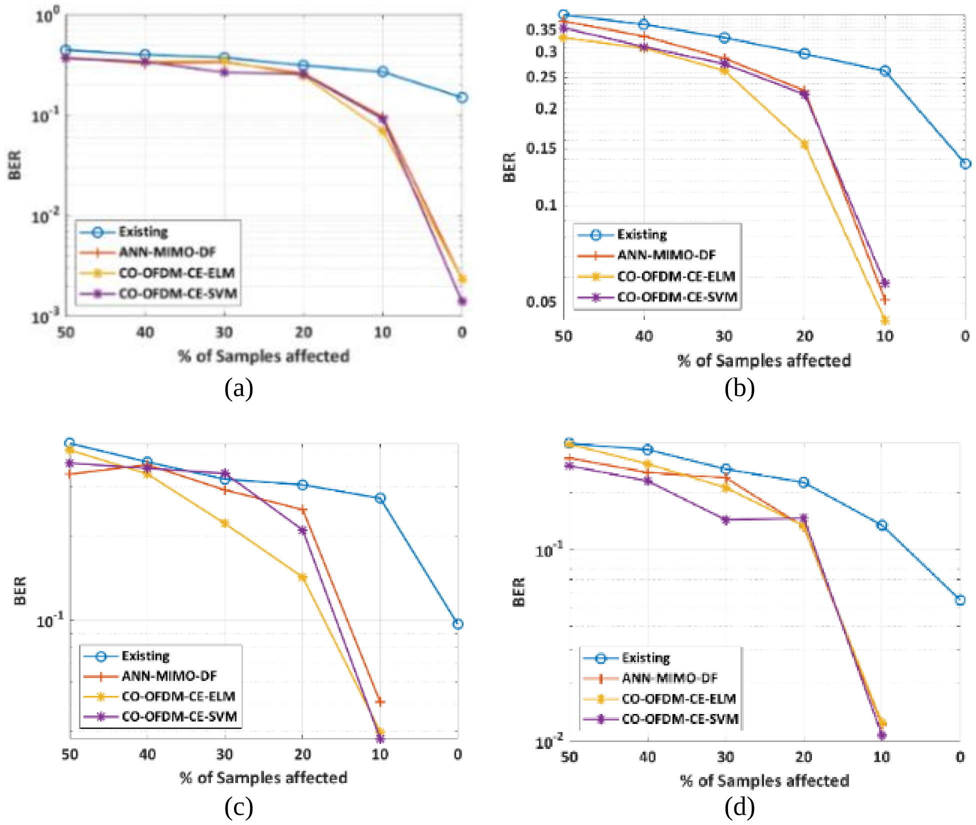


Figure 5. Performance graph for BER using different transmitters and receivers (a) two transmitters and one receiver, (b) two transmitter and two receiver, (c) four receiver and two transmitter, and (d) four transmitter and four receiver

4. CONCLUSION

OFDM is an efficient technique to contest multipath delay spread in high-rate wireless systems, which can transform a frequency-selective fading channel into numerous flat fading parallel sub-channels. An accurate channel estimate is a primary strategy for enhancing system performance in the coherent demodulation of the OFDM system. In this article, an SVR model channel estimation algorithm was proposed for CO-OFDM systems. The proposed algorithm's design was based on channel detection that can minimize the probability of bit error rates out of the channel estimates, thus leading to superior performance. Instead of using a classification method, the suggested formulation is based on a sophisticated regression expression designed specifically for pilot-based OFDM systems. Also, the proposed algorithm was proven to be lower than that of conventional algorithms like artificial neural networks and extreme learning machines. The simulation results further exhibited that the proposed algorithm has better performances in terms of the received constellation BER than the existing conventional algorithms. In future, to enhance the transmission efficiency and reduce the BER rate, a deep learning-based method is proposed which may improve the system performance more than the other methods, respectively.

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