

Precoding Aided Data Correlation Scheme for Channel Estimation Technique in MIMO-OFDM System

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Abstract: Channel estimation is considered as an important phase in Multiple Input Multiple Output – Orthogonal Frequency Division Multiplexing (MIMO-OFDM) networks which can enhance the performance significantly. Channel estimation is widely classified as pilot based, blind and semi-blind channel estimation. The pilot-based channel estimation decreases the data transmission rate and spectral efficiency. To overcome these issues of existing schemes, we present a novel blind channel estimation technique. According to the proposed scheme, we transmit the data in a block-wise manner. The proposed scheme uses precoding technique to establish the correlation between these blocks. Further, we use channel correlation to solve the diagonal uncertainty of the correlation matrix which helps to improve the system performance. We present a comparative analysis study which shows that the proposed approach can achieve better performance in terms of Normalized Mean Square Error (NMSE) and Mean Square Error (MSE) when compared with existing techniques.

Keywords: Systems Theory, Multiple Input Multiple Output – Orthogonal Frequency Division Multiplexing (MIMO-OFDM), Normalized Mean Square Error, Systems Engineering

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1. Introduction

Orthogonal Frequency Division Multiplexing (OFDM) system is immensely endorsed in various wireless communication standards like WiMAX, IEEE 802.16, and Long-Term Evaluation (LTE). The main reason behind OFDM's popularity is that it divides wideband into smaller sub bands which are used to convert the frequency selective channel into flat fading. The OFDM technique is preferred for Digital Audio Broadcast (DAB) [1], Digital Video Broadcasting (DVB) [2] and 5GHz broadband

networks (HIPERLAN/2 and IEEE802.11a) [3]. Moreover, this technique is also embraced for

both uplink and downlink communication in 5G systems. Similarly, Multiple-Input Multiple-Output (MIMO) is also deliberated as a favorable technique for 4G and 5G wireless communication systems [4]. Zreikat et al. [24] evaluated the performance of 5G systems where the cell is divided into two zones to represent the WiFi-6 and 5G technology.

More spectrum efficiency and efficient multipath fading resistance capability are available for the OFDM systems. The cyclic prefix is used to decrease the inter-symbol (ISI) and inter-carrier (ICI) interference in this. Similarly, OFDM utilizes multipath fading channel time delay characteristics to simplify the configuration of the equalizer.

However, the OFDM and MIMO technologies can be combined to increase the channel capability [5]. In OFDM systems, the wireless channel plays an important role, but it suffers from various difficult problems, such as when information is passed through the wireless fading channel, the signal is corrupted due to Additive White Gaussian Noise (AWGN), which affects the output of the system. Similarly, employing many antennas at the base station can improve the spectral efficiency performance when compared to the current multi-antenna LTE systems. However, this gain can be ensued if the Base Station (BS) has the accurate knowledge of Channel State Information (CSI) [6]. Moreover, CSI plays important role for signal detection, channel allocation, resource allocation, beam forming and signal detection. Thus, channel estimation is considered as important phase in MIMO-OFDM systems. Below given Figure 1 shows the general process of channel estimation

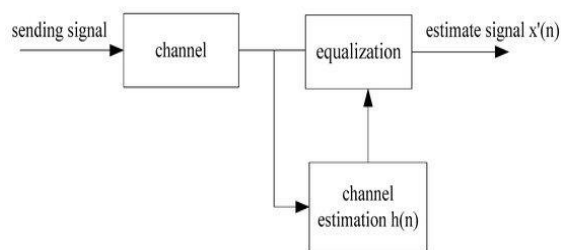


Fig.1: Channel Estimation Procedure

1.1. Channel Estimation Techniques

For channel estimation in MIMO-OFDM systems, various techniques have been presented. These techniques can be divided into three major groups, such as preparation, blind and semi-blind channel estimation, or pilot-based approaches.

The pilot tones are inserted into each OFDM symbol or can be inserted into all subcarriers with a particular timeline according to the pilot-based methods. This method of pilot insertion is further known as the pilot insertion process of block type and comb type. Block-type pilot channel estimation: under the slow fading channel, the pilot insertion is assumed in this mechanism. The channel estimation is based on Least Square MMSE for this type of pilot arrangement. When the channel is changing in

each OFDM block, the comb-type pilot channel estimation is introduced for equalization. Such techniques use methods of interpolation. The techniques of blind channel estimation are focused on the exploitation of statistical knowledge from symbols obtained. In terms of saving bandwidth, this scheme is useful.

2. Literature survey

This section presents the literature review study about recent techniques of channel estimation in MIMO-OFDM systems. Ma et al. [16] developed channel estimation technique for multi-antenna system for high-mobility scenarios. This work abstracts the channel responses into three domains to report the doubly selective property. The OFDM systems uses time and frequency domains pilots. Initially, time domain training is analyzed to obtain the common support for channel. Later, genetic algorithm-based optimization is implemented for pilot location optimization which helps to construct the compressive sensing structure and recovers the channel. A novel adaptive compressing sensing algorithm is also presented. In [17] Uwaechia et al. considered doubly selective channel and presented a new technique for channel estimation, pilot power allocation and pilot placement. Initially, it exploits the spatial structure of attained response vectors and scarcity of multipath signal components, thus, developed a modified spatial basis expansion model. The complex exponential and modified Complex Exponential Spatial Basis Exponential Model (CE-SBEM) can be used to represent the downlink communication. Moreover, a joint pilot power and pilot placement strategy is presented for channel estimation.

Mishra et al. [18] presented sparse Bayesian learning scheme for channel estimation in an Orthogonal - STBC, MIMO- OFDM wireless system. A combination of maximum likelihood symbol detection is incorporated in expectation maximization (EM) for ill-posed MIMO-OFDM system. Thus, this scheme performs jointly channel estimation and symbol detection. Some relevant studies about 5G and wireless communication can be found in [24] and [25]. Hayder et al. [19]

focused on the issue of pilot contamination proposed a novel approach for channel estimation for MIMO systems. This scheme is based on the sparse Bayesian learning and pattern coupled Gaussian framework. Jeya et al. [20] proposed Optimized Semi-Blind Sparse channel estimation for MIMO-OFDM systems. In this approach, Quadrature Phase Shift Keying (QPSK) modulation and Pulse shaping algorithms are implemented at the receiver end for modulation and mitigating the ISI (Inter-Symbol Interferences), respectively. Hansen et al. [21] designed a novel receiver architecture to exchange the information channel estimation and decoding stages. In this receiver, the sparsity based parametric channel estimation is incorporated. The conventional methods restrict the multipath delays however this approach avoids this and reduces leakage effect.

Qin et al. [22] considered time varying channels and presented sparse channel estimation technique for massive MIMO-OFDM systems. Generally, channel estimation of downlink data transmission in MIMO-OFDM is a tedious task because of numerous channel coefficient estimation. Abdzadeh-Ziabari et al. [23] presented a preamble-aided scheme for joint estimation which is used to jointly estimate the time, carrier frequency offset and channel for OFDM systems which are operated in high mobility scenarios. Moreover, this scheme uses Basic Expansion Modeling (BEM) to analyze the time variations which helps to reduce the unknown channel parameters. The BEM coefficients, timing and frequency offset parameters are obtained through the maximum likelihood approach. Below given table 1 presents a comparative analysis of these schemes.

Table.1. Comparative analysis of existing schemes

Reference	Technique	Objective
[16]	Genetic algorithm	Channel estimation optimization using genetic algorithm for high-mobility networks
[17]	Spatial Basis Exponential Model	Main objective is to improve channel estimation, pilot power allocation and pilot placement for downlink communication.
[18]	Bayesian learning	A joint channel estimation and symbol detection scheme using maximum likelihood and expectation maximization

[19]	Bayesian learning	Channel estimation with Bayesian learning
[20]	QPSK modulation and Pulse shaping algorithms	The interference cancellation schemes are combined to perform the semi-blind channel estimation
[21]	Sparsity based module	New receiver architecture is designed for channel estimation
[23]	Basic Expansion Modeling	jointly estimate the time, carrier frequency offset and channel

3. Proposed Model

This section describes the proposed solution for channel estimation in MIMO-OFDM systems. First of all, we present a MIMO-OFDM system model multiple number of transmitter and receiver antennas using different carriers. Later, a channel estimation solution is presented to improve the estimation accuracy. Let us consider a MIMO-OFDM system which is equipped with N number of transmitter antennas and M number of receiver antennas with K number of subcarriers. During transmission, the information bits b_i , coded bits c_i and symbol for i^{th} stream are transmitted on the i^{th} antenna on k^{th} subcarrier. These transmitted symbols are combined and arranged in a vector as $x(k) = [x_1(k), \dots, x_N(k)]^T$.

The communication channel between each transmitter and receiver antenna is demonstrated using a conventional digital tapped delay line which contains L taps which are arranged at the OFDM symbol rate. Here, channel coefficient is the important parameter which is used to extract the channel information. The channel coefficient between specific n^{th} transmitter and m^{th} receiver is denoted as $L \times 1$ in the vector form as $\mathbf{h}_{mn} = [h_{mn}(0), h_{mn}(1), \dots, h_{mn}(L-1)]^T$. Thus, the collection of channel coefficients for each pair of transmitter and receiver is expressed as:

$$h = [[h_{11}^T, \dots, h_{M1}^T], \dots, [h_{1N}^T, \dots, h_{MN}^T]] \quad (1)$$

Here, we assume that channel coefficient $h_{mn}(l)$ for all, m, n and $l = 0, \dots, L-1$ are independent. Further, we apply Fourier Transform to obtain the channel coefficients in frequency domain for K

subcarrier. We present a DFT matrix D as $K \times L$ where k and l^{th} element is denoted as $d_{kl} = e^{-\frac{j2\pi kl}{K}}$. Thus, the frequency domain channel coefficients are given as:

$$\tilde{h}_{mn}(k) = \sum_{l=0}^{L-1} h_{mn}(l)d_{kl} \quad (2)$$

for all $n = 1, \dots, N$, $m = 1, \dots, M$ and $k = 0, \dots, K - 1$. The channel matrix for $M \times N$ MIMO system for k^{th} subcarrier is given as

$$\tilde{H}(k) = \begin{bmatrix} \tilde{h}_{11}(k) & \tilde{h}_{12}(k) & \dots & \tilde{h}_{1N}(k) \\ \tilde{h}_{21}(k) & \tilde{h}_{22}(k) & \dots & \tilde{h}_{2N}(k) \\ \vdots & \vdots & \ddots & \vdots \\ \tilde{h}_{M1}(k) & \dots & \dots & \tilde{h}_{MN}(k) \end{bmatrix} \quad (3)$$

With the help of this, the $M \times 1$ received signal vector for k^{th} subcarrier is given by:

$$y(k) = \tilde{H}(k)x(k) + w(k) \quad \forall k = 0, 1, \dots, K - 1 \quad (4)$$

Where $w(k)$ is a noise vector of size $M \times 1$ which is a symmetric complex Gaussian random variable. Each antenna contributes some noise in the received signal. The noise variance for each antenna is denoted by γ^{-1} . Similarly, the scalar form of the received signal is given as:

$$y_m(k) = \sum_{n=1}^N x_n(k) \sum_{l=0}^{L-1} h_{mn}(l)d_{kl} + w_m(k) \quad (5)$$

Where y_m and w_m represent the m^{th} element of $y(k)$ and $w(k)$ respectively. Final received signal and channel matrix are given as

$$y = [y(0)^T, \dots, y(K-1)^T]^T$$

$$\tilde{H} = [\tilde{H}(0)^T, \dots, \tilde{H}(K-1)^T]^T \quad (6)$$

In this work, our aim is to estimate the accurate value of channel matrix and its coefficients to improve the performance of MIMO-OFDM system.

In order to achieve this, let us consider that i^{th} block of symbol of p^{th} user is given as $d_p^i \triangleq [d_p^i(0) \dots d_p^i(N-1)]^T$ without considering any precoding. In this i^{th} block, the symbol of p^{th} user

are transmitted over carrier k . These symbols are generated in a vector form as $N \times 1$ as a code vector which can be expressed as:

$$s_p^i(k) \triangleq w_p^H(k; i)d_p^i \quad (7)$$

Similarly, we perform the precoding on i^{th} block of p^{th} user which is given as:

$$s_p^i(k) \triangleq [s_p^i(0), \dots, s_p^i(N-1)]^T$$

$$= [w_p(0; i), w_p(1; i), \dots, w_p(N-1; i)]^H d_p^i$$

$$= W_p^i d_p^i \quad (8)$$

During the transmission of these data blocks, the noise deteriorates the quality and also signals suffer from the interference. Hence, the main of this precoding is to introduce correlation between transmitted blocks. Moreover, a diversity also can be introduced which helps to estimate the channel matrix. This diversity is incorporated by changing the coding matrix.

On the other hand, let us consider that i^{th} block is received by the receiver antenna. The symbol of all users on carrier k are arranged in a vector form $y^i(k)$. This can be expressed as:

$$y^i(k) \triangleq [y_0^i(k) \dots y_{MR-1}^i(k)]^T = H(k)s^i(k) + n(k) \quad (9)$$

Where $s^i(k) \triangleq [s_0^i(k) \dots s_{MT-1}^i(k)]^T$. With help of Eq. (7) and (9), the received signal vector can be rewritten as:

$$y^i(k) = H(k)\psi^i(k)d^i + n(k) \quad (10)$$

Where

$$\psi^i(k) \triangleq \begin{bmatrix} w_0^H(k; i) & 0 & \dots & 0 \\ 0 & w_1^H(k; i) & \dots & 0 \\ \vdots & \vdots & \ddots & \vdots \\ 0 & 0 & \dots & w_{MT-1}^H(k; i) \end{bmatrix}$$

$$\text{And } d^i \triangleq [(d_0^i)^T, (d_1^i)^T, \dots, (d_M^i)^T]^T$$

In general, estimating $H(k)$ for fixed k is a common MIMO channel estimation problem. However, we

focus on varying k and estimating the channels for received blocks. Let \tilde{y}^i denotes the received symbol sequence which starts at block i and spaced apart by M blocks. This sequence is expressed as:

$$\tilde{y}^i(k) = \{y^i(k), y^{i+M}(k), y^{i+2M}(k), \dots\} \quad (11)$$

The correlation matrix of received sequence is presented as:

$$R_{kl}^i = \{y^i(k), y^{i+M}(k), y^{i+2M}(k), \dots\} \quad (12)$$

With the help of Eq. (12), the correlation can be rewritten as:

$$R_{kl}^i = \sigma^2 H(k) \text{Diag}(w_{kl}^i) H^H(l) + \delta_{k,l} \sigma_n^2 I_{M_r}, \quad i = 0, \dots, M-1 \quad (13)$$

In order to extract the u^{th} column of R_{kl}^i , we multiply R_{kl}^i with column selection vector e_u . Based on Eq. (13), it can be given as:

$$R_{kl}^i e_u = \sigma^2 H(k) \text{Diag}[H^H(l) e_u] w_{kl}^i + \delta_{k,l} \sigma_n^2 e_u \quad (14)$$

Thus the matrix C_{ukl} can be constructed based on the u^{th} column of matrices $R_{kl}^0, R_{kl}^1, \dots, R_{kl}^{M_T-1}$. This is expressed as:

$$C_{ukl} = \frac{1}{\sigma^2} [R_{kl}^0 e_u, R_{kl}^1 e_u, \dots, R_{kl}^{M_T-1} e_u] = H(k) \text{Diag}[H^H(l) e_u] U_{kl} + \delta_{k,l} \frac{\sigma_n^2}{\sigma^2} e_u \quad (15)$$

At this phase, we can transmit the pilots using l^{th} carrier based on which we estimate the value of $H(l)$. However, we precoding is applied then it is not feasible to transmit pilots hence we will construct a set of indices as $\{p_1, p_2, p_3, \dots, p_K\}$ which will not be precoded. Based on these blocks the estimation can be presented as:

$$\hat{H}(l) \approx [y^{p_1}(l), y^{p_2}(l), \dots, y^{p_K}(l)] [s^{p_1}(l), s^{p_2}(l), \dots, s^{p_K}(l)]$$

4. Results and Discussion

In this section, we discussed the experimental analysis using proposed method and investigated and compared the outcome of proposed scheme with

various existing techniques. The complete experimental study is performed using MATLAB simulation tool on PC which has Intel core i5 CPU, 3.2 GHZ with 16GB memory and 8 GB of GPU memory. The simulation parameters considered in this work are presented in below given table 2.

Table.2. Simulation Parameter

Simulation Parameter Name	Used Parameter value
Number of transmitter antennas	64
Number of receiver antennas	64
Modulation	QPSK
Number of subcarriers	2048
Length of cyclic prefix	256
Number of taps	90

We consider a MIMO-OFDM system with 64 transmitter and receiver antennas. The data transmission is performed using QPSK modulation system with the help of 2048 number of subcarriers. This system uses 256 as a cyclic prefix and 90 as the number of taps. The performance of system is calculated in terms of MSE, NMSE and BER. The signal to noise ratio per transmitter antenna is expressed as

$$SNR = \frac{\sigma_h^2(L+1)}{\sigma_e^2} \quad (17)$$

Where L denotes the fading, σ_h^2 is the variance of the channel taps and σ_e^2 denotes the noise variance. Similarly, we compute the NMSE as follows:

$$NMSE = \frac{1}{R} \sum_{r=0}^{R-1} \frac{\|\hat{h}^{(r)} - h^{(r)}\|^2}{(L+1)N_T N_R \sigma_h^2} \quad (18)$$

where R represents the total number of simulations runs, N_T represents the number of transmitter and N_R denotes the number of receivers

Further, we compare the efficiency of proposed method with existing techniques for varied number of pilots and SNRs. First, we consider fixed pilot numbers as 8 and 16 with varied SNR. Later, we have varied the number of pilots and fixed the SNR

as 15 dB to present the comparative analysis. Below given figure 2 shows a comparative study in terms of MSE for varied SNR. The obtained outcome is compared with Deep low-SNR [18], Deep high-SNR [18], and CAE-Channel Net [18].

Figure 2 shows that proposed approach achieves better performance by reducing the mean squared error at the receiver end. Initially, the low SNR values produce more error due to less correlation between the data. As the SNR is increasing, error also reduces.

The existing scheme seems to obtain the saturated point for MSE reduction at the 20 dB of SNR level whereas proposed approach further improves the performance. This study shows that the average MSE is obtained as 0.0753, 0.093, 0.1778 and 0.2084 using proposed approach, CAE channel net, Deep high SNR and Deep Low SNR respectively.

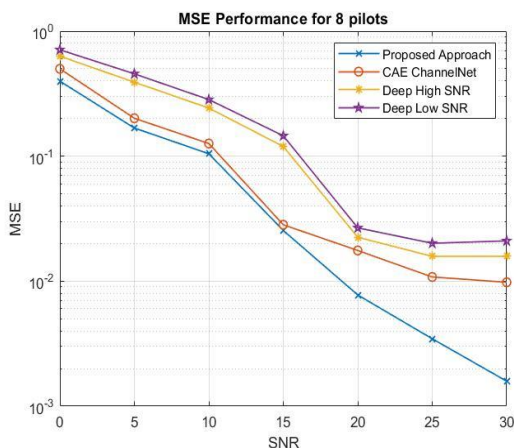


Fig.2: MSE Performance for 8 Pilot Scenario

In next experiment, we perform the experiment for 16 number of pilots for varied number of SNRs. Below given Figure 3 shows the outcome of this experiment

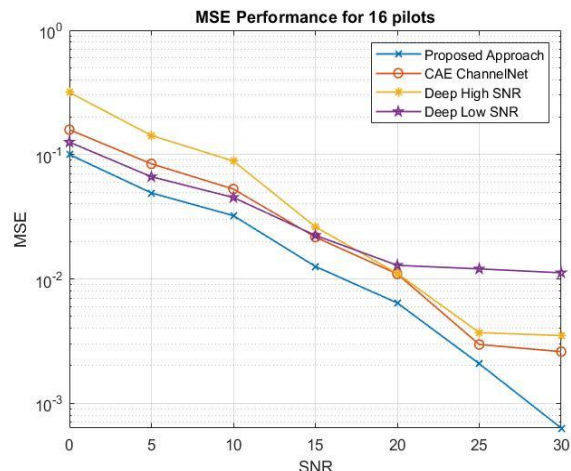


Fig.3: MSE Performance for 16 Pilots

In this experiment we obtain the average the average performance as 0.0234, 0.0356, 0.0385 and 0.0644 by using proposed approach, Deep Low SNR, CAE Channel Net and Deep High SNR, respectively. The existing scheme are not suitable to achieve the high SNR values because after achieving the certain SNR, it doesn't improve further.

In next experiment, we fix the SNR at 15 dB and varied the number of pilots from 10 to 50. The obtained performance is depicted and compared in below given Figure 4.

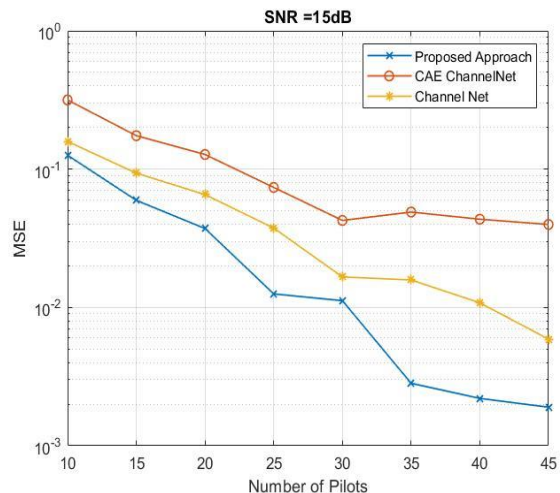


Fig.4.: MSE performance for varied pilots

According to this experiment, we obtain that the proposed approach achieves better performance as number of pilots are increasing. The experiment shows that MSE of Channel Net and CAE-Channel

Net follows the uniform for convergence whereas proposed approach maintains the reliable performance. Hence, selection of number of pilots is an important task when low number of pilots are used. Similarly, we measure the performance in terms of NMSE and compare with existing techniques such as DF method [19], LS method [19], and Haar wavelet method [19]. Below given Figure 5 shows the comparative performance for varied SNR. This comparative analysis shows that proposed approach meets better performance when compared with conventional techniques. The average NMSE is obtained as 0.2778, 0.0521, 0.1107 and 0.0320 using DF, Haar, LS and proposed approach respectively. This comparison shows that performance of proposed approach is improved by 88.48%, 81.25%, and 60.15% when compared with DF, Haar, and LS algorithms. The proposed precoding and correlation techniques helps to minimize the symbol contamination and improves the channel estimation which mitigates the performance related issues of proposed approach.

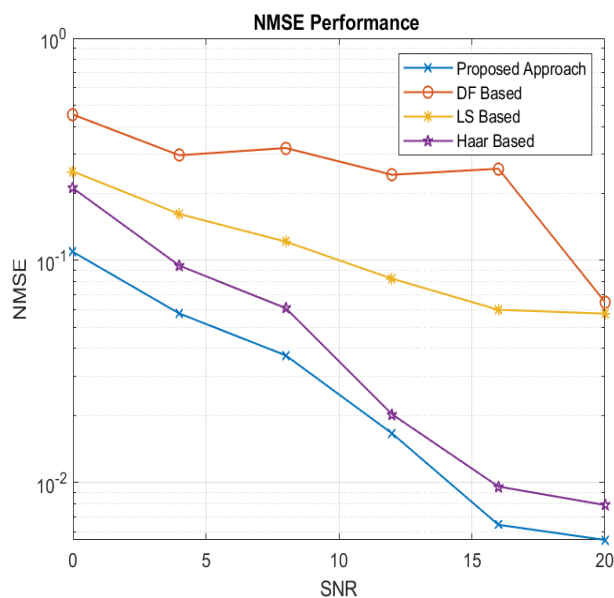


Fig.5: NMSE Performance

5. Conclusion

Demand of wireless cellular communication is increasing rapidly hence providing efficient resources and maintaining network in such a way

that it can meet requirements, is a tedious task. Currently, MIMO-OFDM technique has gained more attraction from research community and industries due to their vital role in cellular communication. However, channel estimation is an ambitious task in these systems which degrades the system performance. In this work, we focused on channel estimation and presented a novel approach. The proposed approach uses precoding to establish the correlation between transmitted blocks. Further, a novel mechanism is described to obtain the channel coefficients. These coefficients suffer from diagonal uncertainty issues hence precoding correlation is used to solve this problem. Experimental results shows that proposed approach achieves the better performance with respect to MSE and NMSE. In future, this work can be extended by incorporating deep learning schemes for channel estimation and interference cancellation for massive MIMO systems.

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Contribution of individual authors to the creation of a scientific article (ghostwriting policy)

Sidramayya S M: Has conceived the presented idea, methodology, implementation, writing, reviewing, and editing.

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