



Development of a Modified Adaptive Independent Component Analysis Scheme to Improve CSI in M-MIMO

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ABSTRACT

A lot of techniques had been developed to obtain near perfect Channel State Information (CSI) in Massive Multiple Input Multiple Output (M-MIMO). Adaptive Independent Component Analysis (AICA) was another scheme developed with the limitation of having the same performance with conventional Independent Component Analysis (ICA). AICA had same performance with conventional Independent Component Analysis (ICA) with reduced computational time (run time), thus there was need to improve the performance in terms of reduced channel estimation error. This research focused on blind channel estimation technique based on AICA through normalizing the covariance matrix and modifying the Gram-Schmidt as a de-correlation algorithm instead of the classical Gram-Schmidt used in AICA. Hence, it was termed Modified Adaptive Independent Component Analysis (MAICA). The modified technique was implemented in a Graphical User Interface (GUI) using MATLAB R2019a incorporated with COST2100 channel model. Simulation results showed that the developed MAICA provided a better CSI estimate using Root Mean Square Error (RMSE) as performance metrics compared to AICA. The average RMSE was also found to reduce from $1.69e - 5$ to $1.33e - 5$ which translated to 17.4% reduction in error. In conclusion, the developed scheme had a better performance as compared to the work of Peken et al., (2017) but became inefficient as the number of symbols increased.

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INTRODUCTION

The increasing demand for higher data rates in wireless mobile communication systems and the emergence of services like Internet of Things (IoT), Machine to Machine (M2M) communication, virtual reality, etc. have prompted the need for new technologies that are capable of providing higher capacity compared to the existing cellular network technologies (Olakunle et al., 2016). This upcoming new cellular network is termed fifth generation (5G). This magnificent network is capable of improving network performance in terms of capacity, energy and spectral efficiency, latency, network security and robustness (Zerihun and Wondie, 2018). 5G is expected to encompass some key technologies such as Massive Multiple Input Multiple Output (M-MIMO), Mobile femtocell, Cognitive radio, Visible light communication, Green Communications, Spatial Modulation etc., (Wand et al., 2014). The Mobile and wireless

communication Enablers for the 2020 Information Society (METIS) identified Massive Multiple Input Multiple Out (M-MIMO) as a prime technology in the upcoming 5G wireless communication to counter the demand for high data rate because of its exceptional gains in spectral and energy efficiency as well as robustness to hardware failures and impairments (Fodoor et al., 2017). Thus, there is need to exploit these gains and one way to do so is by achieving near perfect channel gain between the User Terminal and the base station, this channel gain is called Channel State Information (CSI).

Although, a lot of dissertation has been published on how to get a better CSI estimate, the following contribution was uniquely made:

- i. A Modified technique based on modified Gram Schmidt and normalized covariance matrix was developed to reduce the RMSE and give a better CSI estimate.

- ii. The RMSE of the developed technique was reduced by 28.33% as compared to Peken et al., (2017) scheme.

The rest of this paper is organised as follows: section II discusses a selected number of literatures that are crucial to understanding the state-of-the-art and tools required for this research. The detailed procedure and materials used to achieve the target aim and objective are discussed in section III. Section IV discusses the results of this paper, while section V concludes this paper.

REVIEW OF SIMILAR WORKS

The review was carried-out to understand the general concept of the subject matter. This review is vital because it gave the lead way to this research contribution here in leading to a better result as compared to the existing techniques.

The following are reviewed literatures related to the selected area of research:

Liu et al., (2015) proposed a novel decoding scheme based on the systematic combination of Principal Independent Analysis (PCA), Independent Component analysis (ICA) and few pilot signals. The technique presented PCA to reduce the size by extracting the main components of the received signals from both intra-cell and Inter-cell, while the ICA was used to separate the signals at receiving end. The ambiguity associated with ICA, where the order of the independent component could not be determined, was solved by employing the properties of few training sequence. Though, the decoding technique had mitigated both intra-cell and inter-cell interference, the introduction of two phases of extraction and separation by entirely different technique with different computations increases the computational time.

Though, the decoding technique has mitigate both intra-cell and inter-cell interference but the introduction of two phases of extraction and separation by entirely different increases the computational time.

Uddin et al., (2016) presented MIMO UD-transceiver system to improve the static or quasi-static property of the ICA technique particularly for time varying nature of the wireless environment. The proposed scheme transmitted the smaller data block and increases the sampling rate at the receiving end to the mixed data block so as to increase the length of the data

block for further processing. The authors further developed Optimal Value System (OVS) to select the up-sample signals parameter and used ICA to separate it by down- sampling the signal in order to obtain the original data block. To evaluate the performance of the technique, the Fastlca algorithm performance was used as benchmark using SIR and BER as performance metric.

The aim was achieved, but as the number of transmitting antennas increased exponentially, the technique becomes challenging to use because of random number of source signals.

Akbar et al., (2016) developed a new location aware pilot allocation scheme which reduced the effect of PC in a full-dimension Multiple Input Multiple Out (MIMO) networks. In this technique, the channels were modelled as Rician fading type such that the location information of each user can be obtained and utilized to trigger the allocation of pilot in the network. The information obtained will clearly state the Line of Sight (LOS) interference between the required signal and the interfering signal. The location-aware algorithm returns the User Equipment (UE) assignment matrix which identified the UEs that can share same pilot sequence to improve the system performance. Similarly, the analyses carried out established that the LOS interference tends to zero as the number of antennas increases toward infinity. For finite number of antennas LOS interference depends on the assignment strategy employed. With the idea stated above, the training sequence are assigned to UE such that LOS interference is minimized in a defined number of antennas scenario. Numerical analyses showed that this technique outperformed previous schemes in particular random pilot assignment in-terms of high uplink sum rate performance for some values of Rician k-factor. The technique, focused only on LOS component that caused interference is not satisfactory because there are other sources of interference such as scatterers that can cause Non-Line of Sight (NLOS) interference in a multipath propagation environment.

Peken et al., (2017) carried out comparative analysis based on accuracy and computational complexity between pilot-based, semi blind and blind channel estimation method in Massive Multiple Input Multiple Output (M-

MIMO) and the author further proposed a new blind adaptive channel estimation method based on Independent Component Analysis (ICA) algorithm to obtain the Channel State Information (CSI). Simulation result using MATLAB shows that least square(Ls) use for channel estimation in pilot-based scenario and Singular value decomposition(SVD) in semi-blind are less effective in terms of performance as compared to conventional ICA and the adaptive ICA blind estimation method in both interference and non-interference scenario. The technique was able to curb pilot contamination completely but computational complexity still remains a setback and also the performance remain the same for both the conventional ICA and Adaptive ICA.

Mehrotra and Chaubey, (2017) investigated an extensive study on Pilot Contamination (PC) and other likely sources. Literature related to the effect of PC on the performance of massive multiple input multiple output (M-MIMO) systems were examined. The authors also discussed pilot pattern design where zero pilot symbols are inserted into the pilot sequence to minimize PC effect on uplink channels estimation and bit error performance. The forward link achievable rate and spectral efficiency with maximum ratio and zero forcing precoding schemes were also assessed. The performance of simple Least Square (LS) channel estimator and that of the minimum Mean Square Estimate (MMSE) channel estimator having high complexity were examined. Issues related to mitigation techniques based on the current Long-Term Evolution (LTE) measurement, Open Loop Power Control (OLPC) and pilot sequence reuse schemes that prevent PC within a cluster of cells was carried out. The article offered a wide review of the idea of PC, its sources, effects, estimation techniques, mitigation techniques and finally, open issues related to training overhead, computational complexity and cost, it did not provide solution on how to tackle the issues and this leaves a huge research gap.

Lousha et al., (2018) proposed a novel training sequence designed to reduce the effect of Pilot Contamination (PC) and went further to present an analog combiner which maps the high number of sensors to the low number of RF chains, which in turns decrease the computational complexity and hardware cost. Furthermore, a statistical model in which the channel covariance obeyed

the Kronecker structure, considered two scenarios which were fully- and partially-separable correlations. It was proven that with the aid of these models, the analog combiner could be designed independent of the training sequence. A closed-form expression was derived based on the proposed analog combiner for PC in the fully-separable case while a Greedy Sum of Ratio Traces Maximization (GSRTM) method was suggested for partially separable case. The scheme was able to mitigate PC but at the expense of high overheads and wastage of bandwidth.

In summary, most of the papers reviewed used pilots to obtain the Channel State Information (CSI), thereby giving rise to issues like pilot contamination, high overhead and consumption of bandwidth. In order to combat the problems of pilot contamination, high overhead, and consumption of bandwidth, the blind way of channel estimation technique is proposed. This proposal will be an improvement of the works of Peken et al., (2017) which employed adaptive Independent Component Analyses (ICA) to estimate the channel. The work will be compared with Peken et al., (2017) for validation purpose

MATERIALS AND METHOD

This section is written such that it is made up of the detailed procedure and materials used to achieve the target aim and objectives. MATLAB 2019 is used as a simulation tool to develop and implement Modified Adaptive Independent Component Analysis (MAICA).

Materials

The materials used to achieve this work are MATLAB 2019a Simulation tool, Visio 2013, HP EliteBook and work of Peken et al.,(2017).

Development of Modified Adaptive Independent Component Analysis (MAICA)

MAICA is a technique developed based on blind channel estimation in M-MIMO systems. Blind channel estimation is an estimation technique in M-MIMO systems which was established in reviewed literatures to be free from PC, high overhead and bandwidth consumption which makes it a good candidate to estimate radio channels. MAICA is established

through normalizing the covariance matrix and Modifying the Gram-Schmidt algorithm.

Normalizing the Covariance Matrix

In modifying the covariance matrix to maintain the computational time, the covariance matrix was normalized. The normalized covariance matrix was obtained after dividing the covariance matrix by a number say u . In this case, the u is the maximum number among the element of the Covariance Matrix. Each element of the matrix is divided by the number of maximum number. This was achieved using the equation (1):

$$NCov(y_{i1}, y_{i2}) = \frac{1}{u(n-1)} \sum_{i=1}^n (y_{i1} - \mu_i)(y_{i2} - \mu_i) \quad (1)$$

Where:

u is the maximum number in a given set of elements of the covariance matrix.

The covariance matrix which is part of the algorithm shows the relationship between variables pair (in this case vectors representing channels within the considered radio environment) to reduce the number of computations during the application of the fastICA algorithm is modified in the equation (1), when the elements of the matrix become normalized.

A. Modifying Gram-Schmidt Algorithm

Similarly, the conventional Gram-Schmidt was modified to improve its numerical instability. It was achieved through settling the previous orthonormal vector by subtracting the projection of it from other vectors in time. The modification was achieved using equation (2) and (3):

$$W_p(k) = w_p^{p-1}(k) - \sum_{i=1}^p Proj_{w_{p-1}(k)} w_p^{p-1}(k) \quad (2)$$

$$w_p(k) = \frac{w_p(k)}{\sqrt{(w_p(k))^T w_p(k)}} \quad (3)$$

Step by Step Modified Gram Schmidt Approach

Modified Gram-Schmidt was developed to improve on the numerical instability of the Conventional GS. It is achieved through settling the previous orthonormal vector by subtracting the projection of it from other vectors in time. The operation count for MGS is same

with that of GS but when working with individual vectors allows for level one BLAS kernel, on like GS which requires level two BLAS kernel (Stathopoulos & Wu, 2000). Due to this instability issue, the MGS will be employed in place of CGS in Adaptive Independent Component Analysis (AICA) technique to improve its performance which in turns improves the Channel State Information (CSI) estimate.

If there was a set of linearly independent vectors $V_1, V_2, V_3, \dots, V_n$. Applying Modified Gram-Schmidt (MGS) the process results to orthonormal vectors $Q_1, Q_2, Q_3, \dots, Q_n$ is stated mathematically as follows (Roy, 2018):

For the first vector V_1 , let
 The orthogonal vector:

$$U_1 = V_1 \quad (4)$$

Then, the orthonormal vector

$$Q_1 = \frac{U_1}{\|U_1\|} \quad (5)$$

For the second vector V_2 , let replace V_2 with $V_2^{(2)}$,

$$V_2^{(2)} = V_2 - Proj_{Q_1}(V_2) = V_2 - (Q_1^T V_2) Q_1 \quad (6)$$

And replace V_3 with $V_3^{(2)}$,

$$V_3^{(2)} = V_3 - Proj_{Q_1}(V_3) = V_3 - (Q_1^T V_3) Q_1 \quad (7)$$

$$V_k^{(2)} = V_k - Proj_{Q_1}(V_k) = V_k - (Q_1^T V_k) Q_1, \text{ for } (2 \leq k \leq n) \quad (8)$$

Then, let $U_2 = V_2^{(2)}$
 Therefore, the orthonormal vector is:

$$Q_2 = \frac{U_2}{\|U_2\|} \quad (9)$$

For the third vector V_3 ,

$$V_3^{(3)} = V_3^{(2)} - Proj_{Q_2}(V_3^{(2)}) = V_3^{(2)} - (Q_2^T V_3^{(2)}) Q_2 \quad (10)$$

Replacing V_4 with $V_4^{(3)}$,

$$V_4^{(3)} = V_4^{(2)} - Proj_{Q_2}(V_4^{(2)}) = V_4^{(2)} - (Q_2^T V_4^{(2)}) Q_2 \quad (11)$$

$$V_K^{(3)} = V_K^{(2)} - Proj_{Q_2}(V_K^{(2)})$$

$$= \mathbf{V}_K^{(2)} - (\mathbf{Q}_2^T \mathbf{V}_K^{(2)}) \mathbf{Q}_2, \text{ for } (3 \leq k \leq n). \quad (12)$$

Then, let $\mathbf{U}_3 = \mathbf{V}_3^{(2)}$ and therefore, the orthonormal vector is:

$$\text{Vector } \mathbf{Q}_2 = \frac{\mathbf{U}_3}{\|\mathbf{U}_3\|} \quad (13)$$

In general, the orthogonal vector is given in equation (14):

$$\mathbf{U}_K = \mathbf{V}_K^{(K)} = \mathbf{V}_K^{(K-1)} - \sum_{i=1}^{k-1} \text{Proj}_{\mathbf{Q}_{K-1}^{(i)}} \mathbf{V}_K^{(K-1)} \quad (14)$$

And the orthonormal vector is given in equation (15):

$$\mathbf{Q}_K = \frac{\mathbf{U}_K}{\|\mathbf{U}_K\|} \quad (15)$$

In the developed MAICA, modified Gram-Schmidt Algorithm will be applied to de-correlate the output of the estimates as stated in equations (17) and (18) (Roy, 2018):

$$\mathbf{W}_p(k) = \mathbf{w}_p^{p-1}(k) - \sum_{i=1}^p \text{Proj}_{\mathbf{w}_{p-1}^{(i)}(k)} \mathbf{w}_p^{p-1}(k) \quad (17)$$

where:

$\mathbf{w}_p(k)$ is the estimates of the pth column at kth iteration

$\mathbf{w}_{p-1}(k)$ is the de-correlated estimate of the previous estimate

p is the selected column of the orthogonal matrix W

$$\mathbf{w}_p(k) = \frac{\mathbf{w}_p(k)}{\sqrt{(\mathbf{w}_p(k))^T \mathbf{w}_p(k)}} \quad (18)$$

where:

$\mathbf{w}_p(k)$ is the estimates of the pth column at kth iteration

p is the selected column of the orthogonal matrix W

The Gram Schmidt algorithm which contributes enormously to the technique represented by the equations (14) and (15) is also modified by immediately settling the orthonormal vector through removing the projection of it from other vectors as in equations (2) and (3) which solves the issue of convergence during estimation.

$$\mathbf{w}_p(k) = \mathbf{w}_p(k) - \sum_j^p \text{Proj}_{\mathbf{w}_j(k)} \mathbf{w}_p(k) \quad (14)$$

$$\mathbf{w}_p(k) = \frac{\mathbf{w}_p(k)}{\sqrt{(\mathbf{w}_p(k))^T \mathbf{w}_p(k)}} \quad (15)$$

where:

$\mathbf{w}_p(k)$ is the estimates of the pth column at kth iteration

$\mathbf{w}_j(k)$ is the decorrelated estimate of the previous estimate

p is the selected column of the orthogonal matrix W

Evaluation and Comparison in-terms of performance

The modified technique was implemented in a Graphical User Interface (GUI) using MATLAB R2019a incorporated with COST2100 channel model. Simulation results showed that the developed MAICA provided a better CSI estimate using Root Mean Square Error (RMSE) as the performance metric compared to AICA.

The MAICA technique was developed based on the limitation of the existing technique called AICA which had high computational time and maintain same performance with conventional ICA. This implies that there is need to maintain the computational time and improve the performance of the technique.

From the flowchart (Figure 1) of this research work, the performance of the AICA was improved by employing Modified Gram-Schmidt algorithm (MGS) in place of the Classical Gram-Schmidt (CGS) which is highlighted with a red broken line. This MGS have less numerical instability as compared CGS as a result of accumulation of rounding-off errors there by rendering the orthogonality of the resulting vector ineffective. This modification in MAICA will hence give a better representation of the behavior within wireless radio channels; this is called the Channels State Information (CSI). The CSI will allow the BS to identify users within its coverage and also allow for better adaptation of data by using signal demodulation, equalization and decoding techniques that best suit the channel. Figure 1 shows where modifications are made to form the developed MAICA.

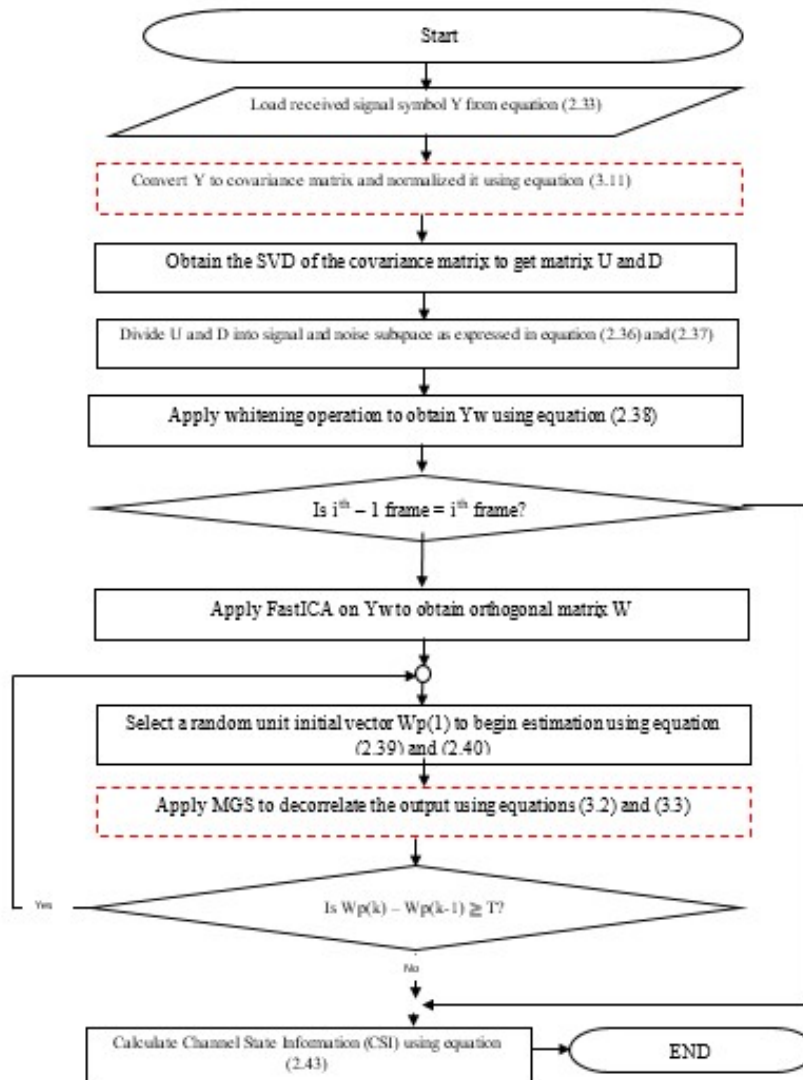


Figure 1: Flow-Chart of the Developed MAICA

Channel Model and Parameters

A multi-cellular Massive MIMO environment was designed using Rayleigh fading channel incorporated with COST2100 Model. The environment has L hexagonal cells with M number of antennas and N User Terminals such that $M < N$.

The Base Station (BS) parameter adopted is arranged such that the BS antenna type is an ideal dipole antenna numbered 100 and the data length is 50 symbols. MMSE is used to

equalize the data at the receiving end. The User Terminal (UT) parameter is having single antenna with velocity of less than 1m/s.

Performance Metrics

In order to prove that this dissertation is valid, the metrics used to validate the work with that of Peken et al., 2017 are RMSE and RT. This comparison proves beyond reasonable doubt that Modified technique outperforms the previous technique.

Root Mean Square Error (RMSE)

RMSE is the calculated difference between forecasted value and the actual value observed from the modelled environment. This implies that the difference is less as the performance of the technique is improved. The RMSE is defined in equation (16) (Peken et al., 2017) as:

$$RMSE = \sqrt{\frac{1}{MN} \sum_{i=0}^M \sum_{j=0}^N (h_{ij} - \hat{h}_{ij})^2} \quad (16)$$

RESULTS AND DISCUSSION

This section presents the result obtained and the explicit explanation on the performance of the technique during the estimation of the channel. Evaluation and comparison was made between the developed MAICA and AICA based on the estimation. The result obtained was used to validate the work using Root Mean Square Error (RMSE) as the performance metric.

The result obtained for each plot of RMSE and RT based on the simulation setup for MAICA and AICA was represented by the red coloured line while black coloured line was for the work of Peken et al., (2017).

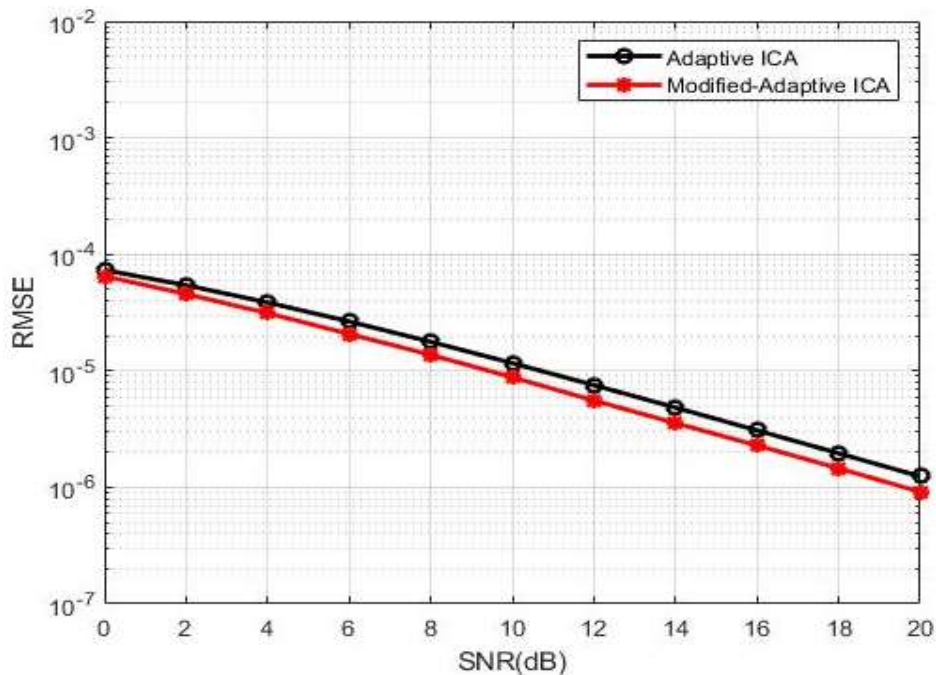


Figure 2: RMSE against SNR for the Two Techniques

The graph of Figure 2 relates AICA with the developed MAICA in terms of performance based on RMSE and SNR. Equation (16) was used to calculate the value of RMSE for both AICA and MAICA. The AICA has an average RMSE of 1.69×10^{-5} while the developed MAICA has an average RMSE of 1.30×10^{-5} which implies that there is a 28.33% reduction in RMSE. This is so because AICA uses the classical Gram Schmidt as a de-correlation algorithm but it had proven less effective because it does not immediately settle the obtained vectors (channels), thereby correlating

with other vectors (channels) and making it inefficient. The Modified AICA (MAICA) addresses the issue of settling the obtained orthonormal vector immediately by subtracting the projection of it from other vectors instantly.

The graph of Figure 2 obeys inverse proportionality based on equation (16) as the SNR increase the RMSE reduces. This proves that the amount of error encountered during the estimation as a result of correlation between the estimated output has been reduced drastically leading to a better CSI estimate.



CONCLUSION

CSI is one of the most crucial aspect of communications because it determines the reliability of a communication link based on the gravity of fading, scattering effect, power delay, etc. affecting the channel. These make it very vital to obtain the near perfect channel estimate in order to adapt the signals to the nature of the radio environment. CSI estimate obtained using pilot based or semi-blind are largely affected by PC, high overhead, and bandwidth consumption. Hence, the choice of blind technique termed Adaptive Independent Component Analysis (AICA) was employed to deal with those effects, but the technique is also affected by high computational complexity and needed improving in terms of performance. The gap of the technique led to the development of the Modified Adaptive Independent Component Analysis (MAICA) to bridge this gap by effectively reducing the correlation of the channel estimate and quantifying the achievement using the performance metric of RMSE. The RMSE was found to be reduced from 1.69×10^{-5} to 1.33×10^{-5} which implies that there is a 28.33% reduction in RMSE. This is so because AICA uses the classical Gram Schmidt as a de-correlation algorithm but it had proven less effective because it does not immediately settle the obtained vectors (channels), thereby correlating with other vectors (channels) and making it inefficient.

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