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# Improved Carrier Frequency Offset Measurement with Reduced Latency and Computational Requirements

Niyaz Othman Ali[1,*], Jalal Jamal Hamad Ameen[2]

[1, 2]Department of Electric Engineering, Salahaddin University-Erbil, Erbil, Kurdistan Region 44001 Iraq

[1]niyaz1969@gmail.com, [2]jalal.hamadameen@su.edu.krd

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## HIGHLIGHTS

- Novel frequency estimation method. Athree steps method combine as order, fast fourier transform(FFT), Candan algorithm, Generized Goertizel filter to enhance the latency and accuracy.
- Enhance real-time data transfer. The higher accuracy of frequency estimation with noticeable reduce of latency lead to apply this technique at telemedicine, remote surgery, and autonomus vehicles.
- Provide a viable solution to improve the performance of telecommunication sector with new emerging application and 5G and beyond.

## ARTICLE HISTORY

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## ABSTRACT

*Over the past four decades, the communication sector has experienced significant economic growth and widespread adoption. Some emerging applications require high data rates, low latency, and must operate efficiently in environments where wireless devices are moving at high speeds. Noise and high device mobility have a considerable impact on received signal frequency, ultimately affecting system performance. So, accurate frequency estimation for received signals is therefore crucial, prompting extensive research. In this paper, we propose a three-step frequency estimation technique. The first stage, termed the coarse stage, employs a few sampling sizes to perform a fast Fourier transform. The second stage utilizes the Candan algorithm to refine the coarse output, while the third stage applies the Generalized Goertzel algorithm for further accuracy. The proposed method offers more precise frequency estimation compared to several well-known techniques, while significantly reducing latency and computational power requirements. Our proposed result enhances the real-time transfer of vital data, such as telemedical information collected by wearable devices, as well as remote surgeries that require extremely low latency. It offers a viable solution for enhancing the performance of the telecommunications sector, particularly in applications like autonomous vehicles and 5G and beyond, which demand stringent latency requirements*

# I. INTRODUCTION

Wireless communications has become one of the most important sectors, enhancing our life quality and fostering economic growth by faster information exchange as well as canceling barriers that obstacle communication. Users of wireless equipment continuously need more and more data rate with mobility especially with emerging new technologies and applications as autonomous vehicles, and smart cities. These developments and applications place higher criteria demands on the wireless communication sector and of course signal processing.

Carrier frequency evaluation of the received signal corrupted by a noise is very important in wireless communication. The correct convertion between radio frequency (RF) received signal to intermediate frequency (IF) to baseband signal need precise value of carrier frequency of the received signal. While local oscillator (LO) output must have precie value according to the arrived signal frequency. Unprecise frequency evaluate destroys the essential properties such as orthognality among subcarrier consisit of the orthogonal frequency division multiplexing (OFDM) system, which leads to the induction of inter-Carrier Interference (ICI)[1]. Although, many methods exist in the literature that try to address these challenges, nevertheless, they have many drawbacks and limitations, like high computational power, sensitivity to noise or latency. Evaluation of received signal frequency need extra researches as well as promote the now days models. They have to be high precies with less time and calculating possess so the match with the critical obstacles of the wireless communication sectores. Frequency evaluation technique mainly divided to:

## A. Time - Domain Technique or Parametric Technique

This method includes “Zero crossing rate, Peak rate and slop event rate”. These techniques have many pros like simplicity and minor caculation but they have severe from the fact that signals rarely have just one status during one signals cycles. Additionally, complex signals contain many harmonics may have several cross as well as peaks throught one cycle of signal. Autocorrelation is also a time-domain technique, the idea of autocorrelation is showing the similarity between received signal and a pattern of it which saved in the receiver. The important cons of this technique is need high computational power as well as if the waveform contains harmonics, its hardly distinguish between large and small values which lead to have uncorrect results.[2].

## B. Frequencies Domain Techniques “ Non-Parametric Technique.”

These technique mainly depend on Fourier transform methods. The main pros of these teckniues they do not have to known beforehand the received signal pattern although, they give accurate frequency caculation of the receiver signal. However, there are cons for these techniques like huge calculation process need and spectral leakage effect [2]-[5].

The discrete Fourier transform (DFT) are consider as one of the most precise technique for determining the frequency of a received signal. However, it’s huge calculation requirements which surely increase latency, making this tecknique impractical for many applications especially real-time. For the beforementions several researches try to find ways to cope this limitation. Some researchers apply DFT by two steps, the first was called “coarse step” which choose small numbers samples as well as small number of DFT points. Consecontly, the second step (are called fine step) do DFT again depending on coarse step output. It is worth noting that, others researchers replace the fine step by invented algorithm to cope the huge calculations [6]-[9]. They have good results, however, its have cons like dependency on enviroments as bandwidth or noise [3].

Authors at [10] apply bootstrap method to find the frequency of a received signal. They used a technique which make the periodic signals to change to rectangular form wave. By calculate time between two positive successive edges the frequency of the signal determined. Many steps done and several thousand iterations as well as a thousand resamples produce for this model and statistical technique for frequency inquire was developed. This method's drawback is high computing process which mean impractical.

While, at [11] use fewer DFT interpolations comparison to (A&M, GAM and HAQSE) estimators' methods. Their proposed technique based on Padé Approximation. Although this approach has good performance, high precision with respect to (A&M, GAM and HAQSE) estimators' but, it still needs high computational power and possesses complexity which leads to unacceptable latency for many communications fields.

Researchers at [12] used capacitance value convert to frequency as another variable. They use capacitance to frequency convert measurement. The main target for them is to make a comparison between many frequency estimation techniques when used capacitance for frequency measurement as well as examine the opportunity to apply capacitance to frequency in those technique. They examine parameter estimation methods," phase locked loop (PLL), discrete Fourier transform (DFT) based frequency" locked loop (FLL) structures. Additionally, they investigated efficient DFT structures through (FLL). This approach shows high accuracy, fast convergence and capability of system-on-chip achieve as well as may be applied to signal not constricted to sinusoidal signals. However, they exhibit challenges in implementation duo to parasitic capacitance influence as well as high complexity.

For [13] researchers try to estimate input signal frequency by analyzing the input data using machine learning. They used new algorithms which learn relevant patterns automatically from input data to increase the reliability of frequency detection, adaptability, and good efficiency. However, they need high latency and data dependency.

Researchers at [14] explored the use of deep learning (DL) to estimate carrier frequency offset (CFO) and detect packets in IEEE 802.11 systems. Their findings highlighted that, in some scenarios, the DL-based method performed on par with or even better than conventional CFO techniques. However, in other cases, its performance lagged behind. They stressed the importance of further research to refine these promising DL-based approaches, especially for more complex systems like multiple-input multiple-output (MIMO). While the method shows potential, it is still in its early stages, Also, requiring significant computational resources and being quite complex.

The researchers in [15] introduce a method for improving nonparametric methods of estimation of received signals. They need just up to two periodic inputs of periodic signal data. The proposed technique used two windowing. One is rectangular to enhance resolution and the others is Hann windowing which deals with the leakage effect. This technique achieves ten times better estimation errors. compared with non-iterative methods. The drawback is the huge computing process reaches 2.1 times of computing process for DFT needs.

The researchers in [16] proposed a method which especially deals with asynchronous samples for a corrupted real sine wave. The researchers mention that negative frequency have heavy impact on frequency estimation particularly with short sampling periods. Their technique primarily calculates the proportion of two rotational spectral neighboring to the crest one and for both the negative as well as the positive frequencies sides. these two DFT-based points called RI2pDFT technique. The simulation shows superior surpasses the cutting-adge methods however, sample records less than one cycle. the drawback of this technique is shows badly behave when the harmonics is existed within examine signal. Noticeably this technique uses rectangular window which suppression of harmonics is poor.

Our paper explains a new method which shows less computational power, less latency and good accuracy with respect to famous methods in the literature. This technique enhance applicable of 5G and beyond because they have restricted small latency.

## II. PROPOSED METHOD

This section outlines the steps involved in the new proposed technique, along with the approach used to establish comparative metrics against other well-known algorithms. *Fig. 1* illustrates the absolute magnitude spectrum of pure exponential signal for S[n]. while *Fig. 2* shows a flow chart demonstrating the proposed technique.

A- Step one of the proposed algorithm, a specific number of (N') points is chosen for the initial coarse step which applies the FFT to (N') point. For our simulation we used eight points (N'=8) for the proposed. While the other comparative algorithms (Quin, Macleod, Jacobsen, Candan) we make it sixty-four points.

B- The Candan algorithm manipulates the previous output of the FFT ( step one) and finds F´, which is the fine step in calculating the earliest signal frequency (F´). we used Candan algorithm because it demonstrates good performance when applied to a small number of FFT points, outperforming many well-known algorithms. As shown in *Fig. 3,* its advantage is noticeable when the FFT size is small, in our simulation we choose N = 8. However, as the number of FFT points increases to N = 64, other algorithms begin to approach the performance of the Candan technique as shown in *Fig. 4*. It is worth noting that, *Fig. 3* and *Fig. 4* used the jargons "bias", which is the mean error in frequency estimation [3]. The signal frequency is (k+ δ´), S[k] is the value of signal at bin index equal to [k], Here, K is the bin index corresponding to the peak of the DFT, and(δ´) is the deference between correct signal frequency value and the K th integer signal frequency, (N) is number of input samples which equal to (number of FFT points). The Candan algorithm is mathematically expressed as:

$$\delta' = \frac{\tan(\frac{\pi}{N})}{(\frac{\pi}{N})} \text{real}\left(\frac{(S[k-1]-S[k+1])}{(2S[k]-S[k-1]-S[k+1])}\right) \quad (1)$$

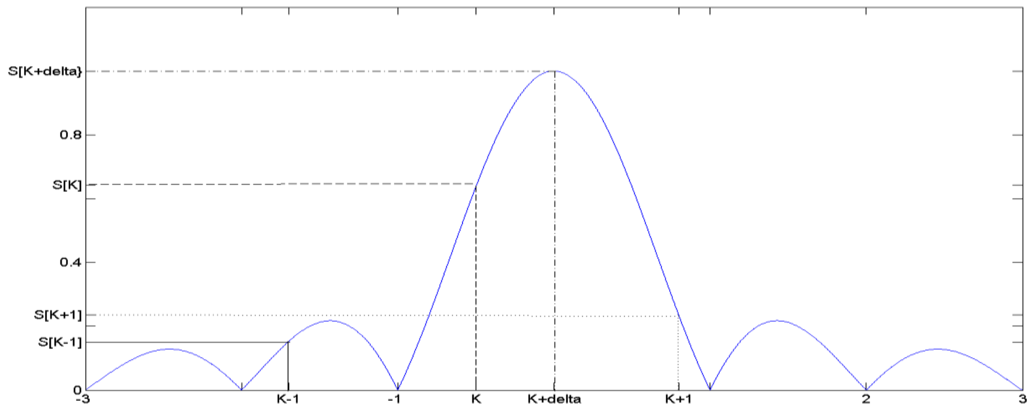


FIG. 1. ILLUSTRATES THE ABSOLUTE MAGNITUDE SPECTRUM OF A PURE EXPONENTIAL SIGNAL WITH (Ω=2π (K + Δ) RADIAN/SAMPLE).

C- The frequency detection result from the previous stage (F´) Hz, it will be used for determine the narrowband for final stage of our technique. The narrowband is determined using a lookup table and is subdivided into (Nn) bins. The Generalized Goertzel Algorithm (GGA) is applied to each bin. GGA has the capability to process data as it arrives, thereby reducing latency. Additionally, unlike traditional DFT methods, GGA supports non-integer multiples of the fundamental frequency without restricting it to integer values. A significant advantage of the GGA is that, in many applications, it eliminates the need to round desired frequencies, resulting in improved accuracy[17]. In this paper we apply simulated using MATLAB software package (R2021a).

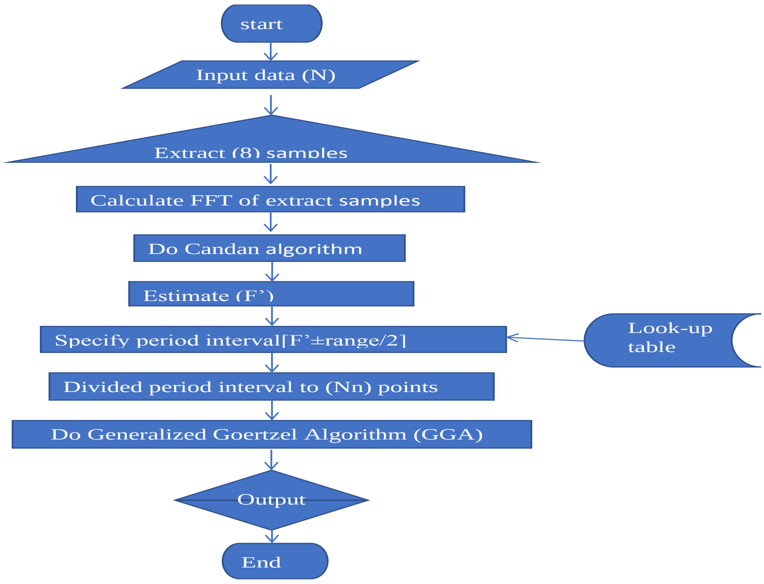


FIG. 2. FLOW CHART OF PROPOSED ALGORITHM.

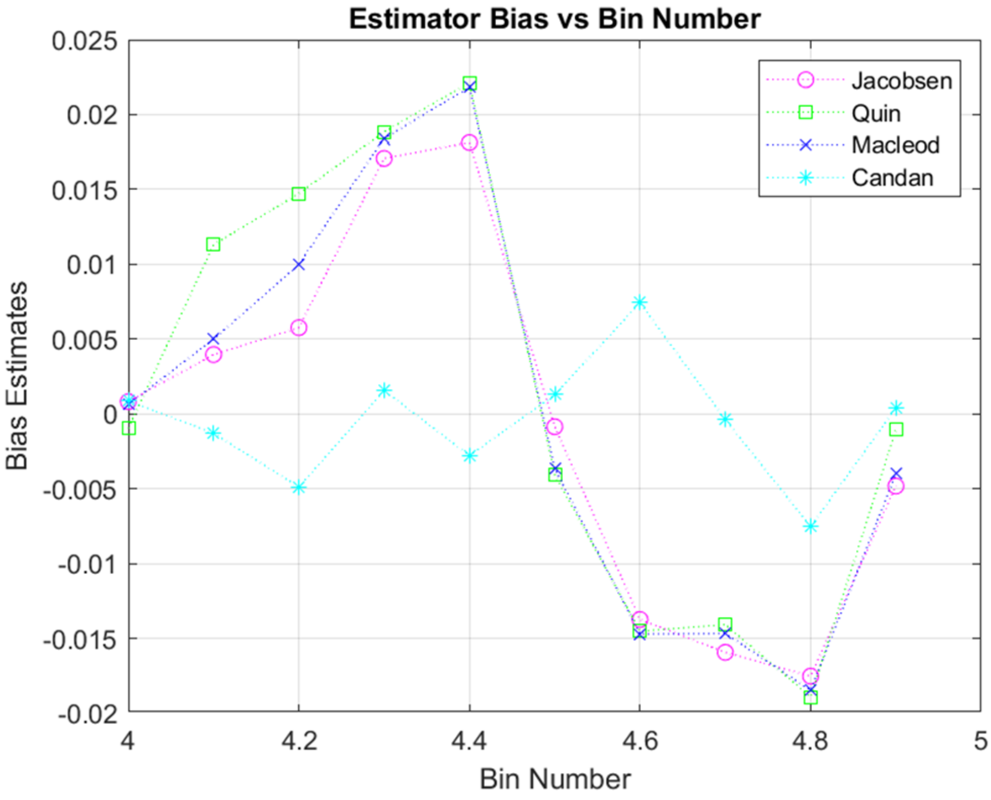


FIG. 3. ESTIMATOR BIAS VERSUS BIN NUMBERS FOR SEVERAL ALGORITHMS. SAMPLES NUMBERS (N=8).

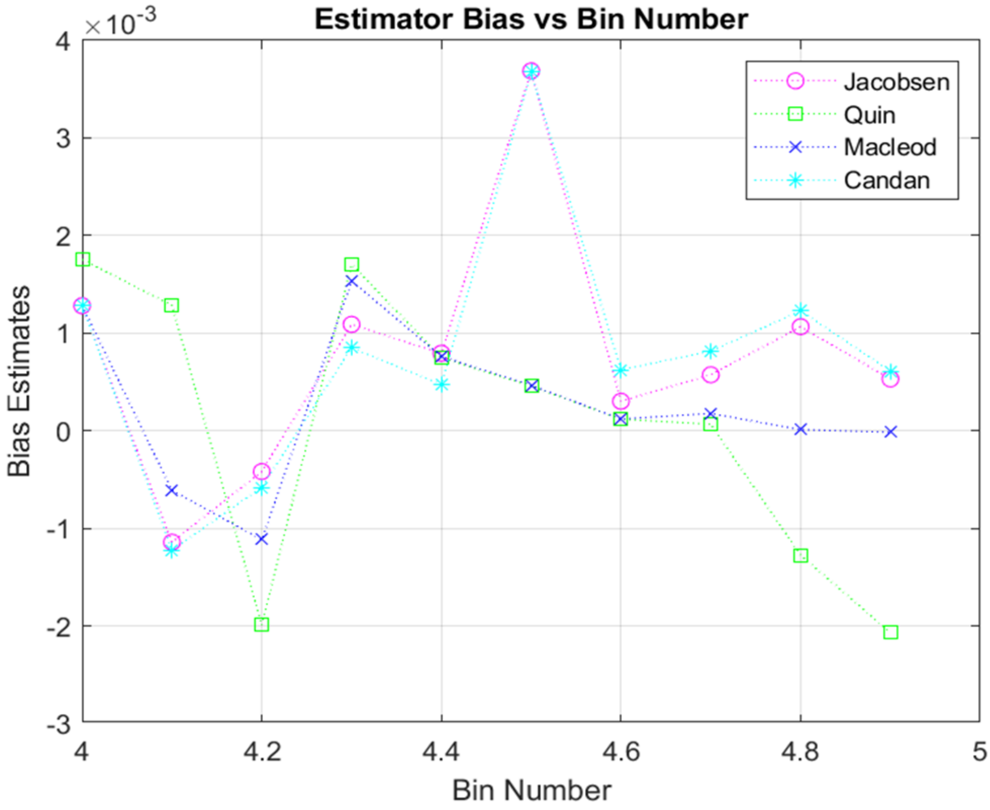


FIG. 4. ESTIMATOR BIAS VERSUS BIN NUMBERS FOR SEVERAL ALGORITHMS. SAMPLES NUMBERS (N=64).

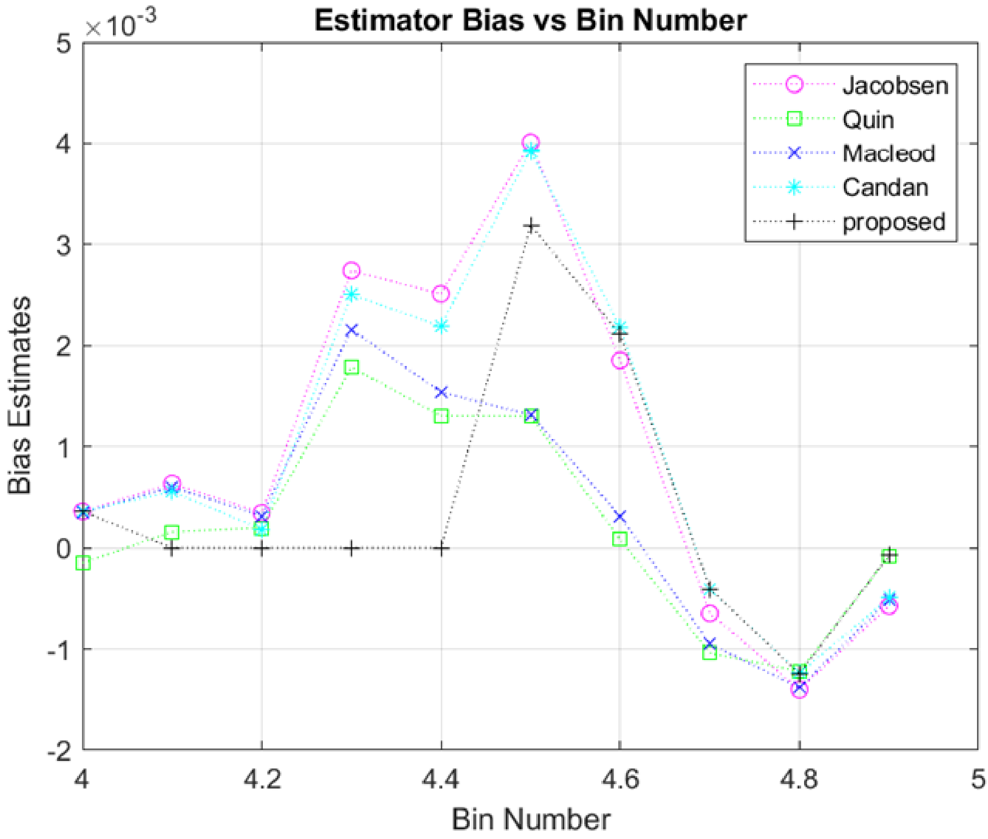


FIG. 5. ESTIMATOR BIAS VERSUS BIN NUMBERS FOR SEVERAL ALGORITHMS AND PROPOSED TECHNIQUE.

## III. RESULTS

*Fig. 5* illustrates that the proposed technique achieves more accurate frequency estimation across most bins, outperforming other methods. Additionally, as detailed in Table I, the computational complexity of the proposed technique is significantly lower compared to alternative algorithms which noticeably leads to reduced latency. It is obvious FFT computation is more complex than other traditional operations like multiplication and addition. Despite this reduction in computational power and latency, our method maintains a high precision of frequency estimation, demonstrating superior performance relative to well-known techniques such as those by Jacobsen, Quin, Macleod, and Candan, as depicted in *Fig. 5*.

Table I demonstrates that the proposed signal has lower latency than other algorithms because of the number of FFT operation is less than other by 16 times. Additionally, the GGA manipulates just eight samples at the time the samples arrived, in contrast to FFT which must receive the entire samples to start the calculation. The noticeable reduction in latency for the proposed technique as demonstrated in Table I makes the proposed technique suitable for latency-sensitive applications, such as autonomous vehicles, remote surgery as well as 5G and beyond, where meeting Stringent latency requirements are critical. Nevertheless, sensitivity to noise and dependence on coarse estimations in the initial step remain challenge as it for the others algorithms. As illustrated in *Fig. 6*, under the same signal-to-noise ratio (SNR), frequency estimations can vary due to of arbitrary noise generated.

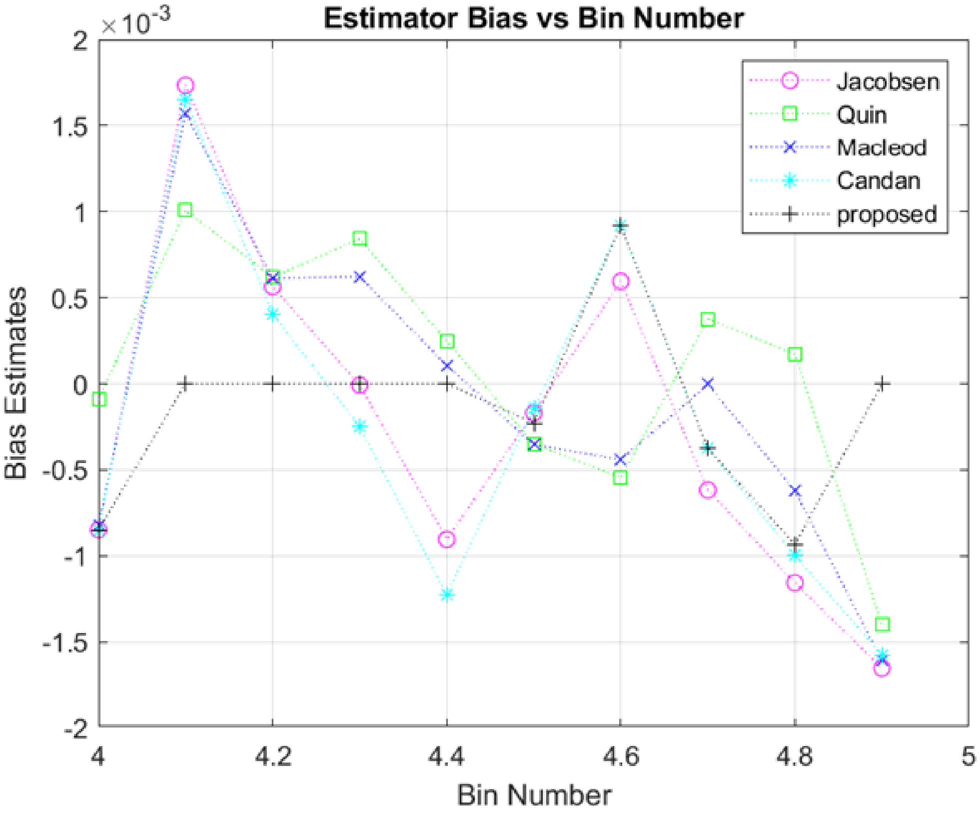


FIG. 6. ESTIMATOR BIAS ACROSS BIN NUMBERS FOR VARIOUS ALGORITHMS AND PROPOSED TECHNIQUE UNDER IDENTICAL SNR CONDITIONS IN A SEPARATE PROGRAM RUN.

TABLE I. COMPUTATIONAL COMPLEXITY COMPARISON

| Type of technique | Number of FFT operations (coarse stage) | Number of Multiplication (fine stage) | Number of Division (fine stage) | Number of Adition (fine stage) | Number of Subtraction (fine stage) | Number of operation (GGA) |
|---|---|---|---|---|---|---|
| **Jacobson** | 576 | 1 | 1 | 0 | 3 | 0 |
| **Quin** | 576 | 12 | 0 | 6 | 0 | 0 |
| **Maclead** | 576 | 12+one root | 2 | 8 | 0 | 0 |
| **Candan** | 576 | 5 | 2 | 2 | 3 | 0 |
| **Proposed method** | 36 | 5 | 2 | 2 | 3 | Multiplication=8<br>Division=1<br>Addition=7 |

## IV. DISCUSION

Our proposed technique demonstrates a significant enhanced process of frequency estimation in spite of high reduction in computational power and latency compared to well-known techniques like Jacobian, Quin, Macleod and Candan. The high reduction of latency of proposed technique leads many applications being feasible, especially for 5G and beyond with their known latency limitations. However, the sensitivity to noise and dependency of the coarse estimation of first step need further investigation. This novel technique enhances performance of communication sectors by enhancing of received signal frequency estimation for present and future application.

## V. CONCLUSIONS

In conclusion, the proposed method shows low computational power and less latency with high precise frequency estimation in comparison with well-known methods. It offers a promising solution to address the limitations of traditional algorithms in terms of computational power and latency. By introducing a novel fine search step, the proposed method achieves competitive accuracy with a lower resource demand, making it highly applicable to modern wireless communication systems like autonomous vehicles, remote surgery, and many other applications which need small latency and accurate received signal frequency.

The result obtain in this study shows significant advance to enhance frequency estimation. Also, addressing critical obstacles with assistance of tool like AI, this technique will pave the way to apply in many communication fields now and in the future.

## CONFLICT OF INTEREST

The Authers affirm that there aren’t any conflicts of interest with regard to the puplication for this research study. Additionally, This study supported by the Electric Engineering Department, Salahaddin University-Erbil, Kurdistan Region, Iraq.

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