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OFDM-CFO and Resource Scheduling Algorithm Using Fuzzy Linear-CFO

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Abstract: Orthogonal Frequency-Division Multiplexing (OFDM) is the form of a digital system and a way of encoding digital data across multiple frequency components that are used in telecommunication services. Carrier Frequency Offset (CFO) inaccuracy is a major disadvantage of OFDM. This paper proposed a feasible and elegant fuzzy-based resource allocation technique, that overcomes the constraints of the CFO. The suggested Fuzzy linear CFO estimation (FL-CFO) not only estimates the CFO with increased precision but also allocates resources effectively, and achieves maximum utilization of dynamic resources. The suggested FL-CFO error estimation algorithm in OFDM systems employing 1-bit Quadrate errors ADC (1-bit QE) is utilized to extract the precise CFO. Additionally, the base station (BS) manages the Resource Units (RU), which could be used to distribute resources in such a manner that the user requests are met. To assign resources to a certain job, fuzzy rules are devised. When the residence duration exceeds the resource requirement time then the particular resources are provided to the highest-priority jobs. As a result, the job performance will not be halted due to a lack of allocated resources. Performance metrics such as utilization, rate of failure, and life span, as well as energy consumption, are used to assess the proposed FL-CFO.

Keywords: Orthogonal frequency division multiplexing (OFDM); carrier frequency offset (CFO); fuzzy linear CFO estimation (FL-CFO); resource units (RU); base station (BS); 1-bit quadrate errors ADC (1-bit QE)

1 Introduction

Wireless sensor networks (WSNs) are a network of strategically scattered and specialized systems that detect and capture environmental variables and send the information to the control point. Temperatures, noise, levels of pollution, moisture, and air are the things that WSNs can detect [1,2]. These networks are identical to wireless *ad hoc* networks in the sense that depend on wireless networking and spontaneous system creation to carry sensing data wirelessly. Temperature, noise, and force are the types of active or environmental factors that WSNs detect. Wireless systems are bidirectional; They gather information and allow sensor activities in a controlled manner. The use of surveillance systems by the Army stimulated the improvement of such systems. Industrial and commercial activities include commercial process controlling and device health management employs such networks [3,4]. A WSN is made up of nodes, which can range from a few to hundreds or thousands, each of which is interconnected to additional sensors. A wireless transmitter and receiver with just an internal antenna or a link to an external antenna, a microprocessor, an electrical circuit for communicating with the sensor, and a power supply, typically a battery or an integrated kind of power generation, are the common components of such nodes. Sensor node prices vary widely, that is varying from several dollars to hundreds or thousands of dollars, based on the complexity of the network.

The interconnection of these sensors is similarly crucial when some sensor nodes are placed in a large region to jointly examine the external conditions. Fig. 1 shows a sensor node in a WSN, it uses wireless communication techniques mostly with neighboring sensors and with a Base Station (BS). The base station sends commands to the sensors, and the sensors work together to complete the assignment. When the sensors have gathered all the necessary data, they send it back to the BS [5,6]. A base station can also connect to other systems via the network. A base station receives data from the sensors and provides limited data computation before sending the revised user's information through the network. The sensor nodes collect analog information from the environment, which is then converted into digital data by an ADC. The central processing unit, which is commonly a processor or a controller, processes and manipulates data intelligently.

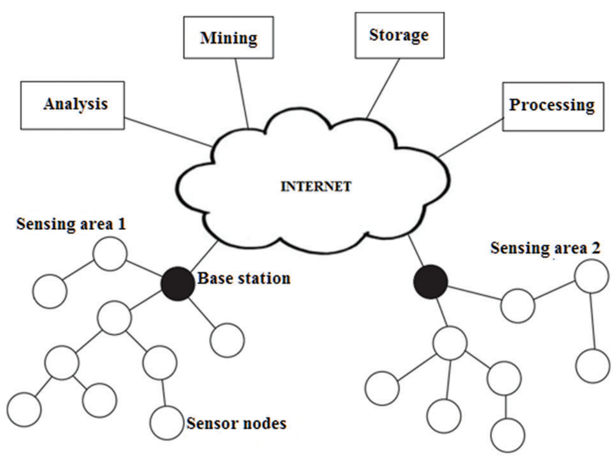


Figure 1: Basic wireless sensor networks with sensor nodes

In multi-carrier modulation techniques, the OFDM system is widely used. All sub-carriers in this transmission are orthogonal to one another, increasing the system's bandwidth. OFDM is highly sensitive to frequencies and synchronization. CFO is one of the most well-known OFDM disruptions. Inter-carrier interference (ICI) is generated, which reduces OFDM efficiency. CFO is one of a series of aspects that might alter the structure of a baseband recipient. [7]. This phenomenon occurs when the wavelength discrepancy in the transmitters and reception oscillation, as well as the Doppler impact as the transmitters or receivers moves. The suggested FL-CFO not only estimates the CFO with increased precision but also allocates resources effectively, achieving maximum utilization of dynamic resources. The BS should efficiently allocate resources to support the sensor node requirements from the RU. The suggested FL-CFO error estimation algorithm in OFDM systems employing 1-bit Quadrate errors ADC (1-bit QE) is utilized to extract the precise CFO. Because of the larger bandwidth, the sampling frequency of the ADC can be raised, resulting in higher energy consumption and technical complexity. As a result, 1-bit QE is the ultimate result of low precision ADCs and can be considered a low-power alternative. Performance metrics such as utilization, rate of failure, and makespan, as well as energy consumption, are used to assess the proposed FL-CFO.

The remainder of this work will be organized as follows: Section 2 will explain the literature survey conducted, Section 3 will discuss the suggested FL-CFO technique, Section 4 will discuss the results and analysis, and Section 5 will address the conclusion.

2 Related Works

In recent years, several researchers have focused on wireless sensor networks, which have issues in terms of high-speed communication, expensive, efficiency, user data privacy, malevolent users, and erroneous information. In this section, we glanced at how the CFO affects the overall system and resource allocation, as well as a few other factors. Some of the most important proposals in CFO and allocating resources are highlighted, as mentioned in the literature.

In 2020, Huang et al. [8] proposed the dependability improvement of sensor networks which is handled by the suggested ISSO method. This method creates a new credibility-based fuzzy model for a series-parallel redundancy allocation problem's limits (RAP). The discussed strategies, including the legitimacy theory and the suggested ISSO algorithm, could be applied to new areas of research in the upcoming years by advancing the RAP to a more practical setting, such as the Internet of Things (IoT), process automation, and transportation networks, or the reliability redundancy allocation problem (RRAP).

In 2013, Brante et al. [9] offer a new fuzzy logic-based relay selection technique that aimed at both system longevity and final performance. When compared to both proactive and randomized selection, techniques, the suggested scheme can broadcast more data even during the system lifespan, boosting system utilization. In terms of energy efficiency, the suggested method outperforms opportunist broadcasting in terms of network lifetime, reaching that of randomization.

In 2014, Li et al. [10] devised a Resource allocation for SC-FDMA-based upstream relay networks. The suggested framing partitioning, resource block distribution, transmission power, and modulator selections are combined to increase network performance. We suggested an adaptive resource scheduling mechanism when the clients are commonly recognized as wireless sensors by demonstrating the NP-hardness of the resources scheduling issue. In the future, we'll expand our effort to include diverse endpoints.

In 2017, Yousaf et al. [11] designed an opportunistic relay to present an online fuzzy logic-based power allocation (FPA) system for a collaborative and delay-constrained EH wireless sensor network (EHWSN). At the intermediate nodes, an EHWSN model is created with limited power and transmission storage limitations. There are several steps for incorporating energy cooperation among nodes to avoid power overflowing due to poor battery storage are some of the upcoming initiatives.

In 2018, Tadayon et al. [12] designed a stochastic gradient method, which is a high-resolution yet low-complexity strategy. The Networks with significant Doppler distortions examined differently coherent detection of sonic OFDM signals and targeted frequency offsets using two approaches, the HT and SG algorithms. This method promotes frequency-domain synchronization while also making effective use of the spectrum to achieve large data rates.

In 2015, Kalwar et al. [13] demonstrates how the influence of the CFO on the efficiency of the LTE upstream network. One of the most difficult aspects of upstream transmission is that each message sent by multiple users travels along a different route and encounters a distinct multipath situation. As a result, upstream synchronization is considered challenging. As a multiple access approach, LTE upstream utilizes a single channel FDMA (Frequency-Division Multiple Access). Users transfer information to a central Node using an LTE upstream SC-FDMA network.

In 2015, Pareyani et al. [14] coined an improved form of the ICI auto cancelation technique with a new and efficient method to suppress the influence of different frequencies on OFDM systems. In the AWGN channel, the suggested ICI self-cancellation approach outperformed the neighboring and symmetrical conjugated auto cancelation methods in terms of BER performance. For high frequencies offsets, the suggested methodology improves CIR (Carrier to Interference Ratio) significantly. As a result, the suggested approach almost eliminates the effect of different frequencies on the OFDM system.

However, various related studies were conducted to provide CFO in a different environment and the resource allocation in the network. The suggested FL-CFO is employed to allocate the resources among the sensor nodes and thereby reducing the CFO error and thus improving the energy consumed, utilization rate in the network. In comparison, the proposed strategy yields better outcomes.

3 Proposed FL-CFO Using 1-bit QE ADC

WSNs are frequently decentralized systems in which sensors may resolve issues on their own, comparable to Multi-Agent Systems. Carrier frequency is the rate of a carrier signal that is modified to send signals and calculated in cycles per second or Hertz. For effective transmitters and receivers, a carrier frequency is employed to shorten the wavelengths. Whenever the phase difference signals for back in the recipient don't synchronize with both the carrier frequency included in the receiver end, carrier frequency offset occurs. The disruption caused in OFDM is carrier frequency offset (CFO). Inter-carrier interference (ICI) is generated, which reduces OFDM efficiency. The suggested FL-CFO error estimation algorithm employing 1-bit QE ADC is utilized in OFDM systems to overcome CFO errors among sensor nodes during transmission and to allocate resources among nodes. However, the available information is limited to the quantized received signal, we allocate resources using a priority-based mechanism with variable intervals. This strategy allows comparing the phasing of each subcarrier to subsequent symbols, as well as the phase difference in signal owing to the carrier frequency offset, to estimate CFO using FL-CFO. In FL-CFO using the QE-ADC approach, two separate estimating methods are used for CFO estimation: acquisitions and monitoring phase. In acquisition mode, a broad range of CFOs is calculated, whereas, in the monitoring phase, just the fine CFO is calculated.

Fig. 2 depicts how the FL-CFO is used to estimate the CFO, and the 1-bit QE ADC is used to identify the accuracy of the CFO values. The RU is used to allocate resources among the sensor nodes and is controlled by the BS, which might be used to distribute resources in such a way that user requests are fulfilled. The various details are calculated as follows:

- The quantity of RUs that must be allocated is determined by the BS.
- The transmitting energy needed is determined by the characteristics of the received signals.
- The CFO inaccuracy has an impact on the preferred RU to be assigned.
- The amount of CFO inaccuracy on the RU has a big impact on its allocatability.

3.1 1–bit QE ADC for CFO Estimation

During the process of synchronization, a CFO of σ as an outcome, a process shift occurs of $2\Pi n\sigma/N$ in the signal received. The transfer function between both the sensor devices and the associated rear portion of an OFDM is equal to the transfer function between the sensor devices and the equivalent rear portion of an OFDM under the hypothesis of minimal channel effect is $2\Pi N\sigma / N = 2\Pi\sigma$. The goal of the FL-CFO is to be capable of determining the CFO precisely matching the relationship utilizing the QE-ADC at adjustable durations. By reviewing the QE-ADC and analyzing the possibilities for the CFO estimation, the final CFO assessment for the partial CFO ranges can be determined. The CFO can now be calculated using the product's phase shift as well as the appropriate rear component of an OFDM signal [15]. Fig. 3 demonstrates the process of calculating the CFO. The received signal is tested for CFO error, and if one is found, the QE-ADC is set up to provide the precise CFO. A phase shift proportionate to frequency offsets is used to change the signals in almost the same manner. As a result, even though the offsetting has become too big for efficient information decoding, reliable estimates can be obtained if offset E is predicted via observations.

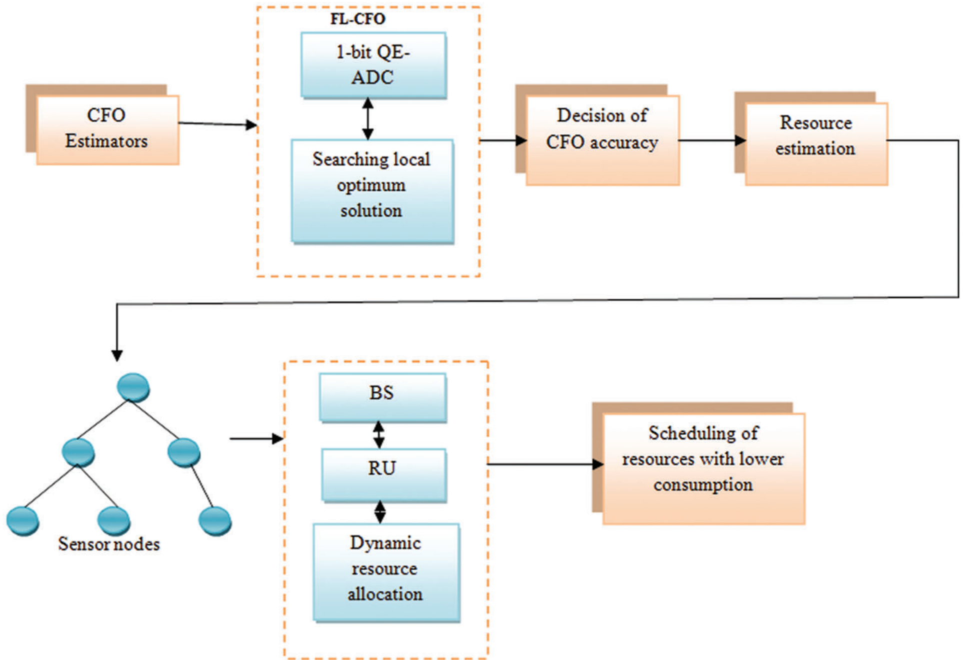


Figure 2: Architecture of the proposed FL-CFO using 1-bit QE ADC

The CFO's estimate is,

$$\sigma' = \left(\frac{1}{2\Pi}\right) \arg\{x_m * [n]\, x_m\, [\mathrm{n} + \mathrm{N}]\} \tag{1}$$

where n = –1, –2, ……- N_a. The mean of the data at an arbitrary interval can be used to minimize the noise impact.

$$\sigma' = \left(\frac{1}{2\Pi}\right) \arg\{\sum_{n=-N_a}^{-1} x_m * [\mathrm{n}]\, x_m[\mathrm{n} + \mathrm{N}]\} \tag{2}$$

Arg () calculates the tan^{-1} () and the CFO's assessment limit varies from [–0.5 + 0.5] and 1-bit QE is carried out by σ' - σ. Two identical signals are sent out in a row, and the matching signals with a CFO are linked together. The 2N Point pattern is for an OFDM transmitted signal placed at a single recipient with the expectation of no distortion.

$$r_n = \frac{1}{N}\sum_{i=0}^{N} H_i X_i e^{\frac{2\Pi y(i+\sigma)}{N}} \tag{3}$$

where n = 0, 1,….. N

$$R_{1i} = \sum_{n=0}^{N} r_n e^{\frac{-2\Pi yni}{N}} \tag{4}$$

where i = 0,1,…..N. The second half of the sequence is,

$$R_{2i} = \sum_{n=0}^{N} r_n + \mathrm{N}\, e^{\frac{-2\Pi yni}{N}} \tag{5}$$

$$r_{n+N} = r_n\, e^{2\Pi\sigma} \tag{6}$$

$$R_{2i} = R_{1i}\, e^{2\Pi\sigma} \tag{7}$$

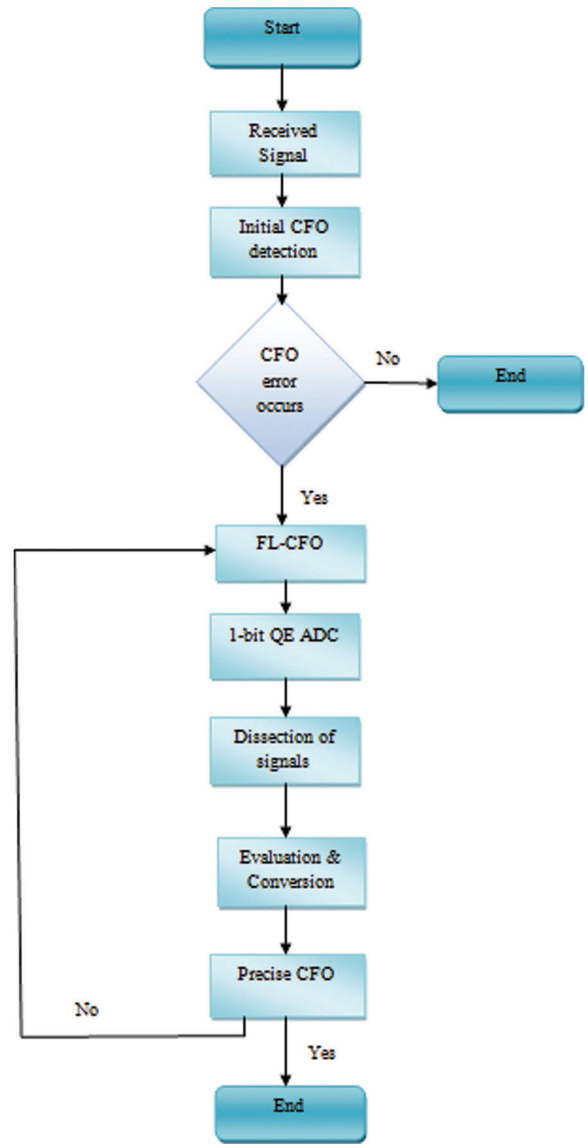


Figure 3: Flowchart depicting the CFO detection process

After getting repeated frequency signals, the recipient can estimate CFO as follows:

$$\sigma' = \left(\frac{RS}{2\Pi}\right)\arg\left\{\sum_{n=0}^{N/RS} x_m*\,[\mathrm{n}]x_m\left[\mathrm{n}\;+\;\frac{N}{RS}\;\right]\right\} \tag{8}$$

By calculating the mean of the assessments with repeating patterns of the shorter period, the 1-bit QE ADC efficiency can be enhanced by estimating the ranges of the CFO. As QE-ADCs are used in OFDM systems, just one data accessible is the signal level indication. As a result of the distortion phasing discrepancies from received data, CFO determination in the OFDM recipient with QE- ADCs is challenging.

3.2 Fuzzy Based Resource Allocation Process

The resource allocation issue for a multi-cellular wireless connection falls into the category of the multi-objective non-linear scheduling problem, which is considered NP-hard to solve. As a result, to deal with these problems, heuristics for localized and independent resource management is essential. An FL (Fuzzy Linear) approach would be a viable approach to gain information about their transmissions conditions over a period, but it is also difficult to implement without the availability of a training phase. As a result, we use fuzzy logic as our heuristics to include "expertise" in the RU distribution selection procedure.

The allocability of each RU is established by integrating the similarity score of the sources using various rules. The report is also "fuzzy," showing how acceptable or unsuited an RU is without requiring a definitive yes/no vote. The FL assigns the most appropriate RUs to each sensors node in each time frame, and transmission of data takes place. The BS adjusts its data based on the acquired signal levels from the primary user and competing sensor nodes to better reflect the long-term interruption and fading conditions of its cell [16,17]. This new data is used in the following time frame to repeat the allocation of resources process. The same technique is followed in all sensor nodes, and RU allocations are constantly refined until the system corresponds to a steady solution to achieve the needs of its users for each unit.

For assigning dynamic resources to the nodes, we offer a fuzzy-based simple and effective allocation of resources methodology. The nodes are prioritized since they are deemed stable. Let, the sensor node be S_n. $0 \leq n \leq N_w - 1$ where N_w is the number of sensor nodes queuing to be prioritized higher in the RU [18,19]. Each node has its priority level P_n. P_n ε (P_{min}, P_{max}) and it requires the resources R_{xy}. $0 \leq x \leq N_{rn} - 1$ where N_{rn} is the resources required by the nth sensor node. Here, the job with a priority level P_{min} is considered as the high priority job, while, the job with a priority level P_{max} is considered as the low priority job. The suggested resource scheduling methodology consists of three stages: resource evaluation, fuzzy logic-based synthesis, and fuzzified rule-based allocation of resources shown in Fig. 4.

3.2.1 Resource Evaluation

The resources are categorized in the first phase depending on how long they have been on the RU and are defined as $R_y^{(t)}$ and are available out from RU. The $R_y^{(t)}$ be the RU's resources during the tth duration, where each timeframe is made up of p time intervals. As a result, $R_y^{(t)}$ the evaluation of the resources has three types such as, stable, semi-permanent, and intermittent. Stable resources are those that are available in the RU for the duration of the period, whereas semi-permanent resources are those that are present in the RU for a longer-term [20,21]. The intermittent resources are a sort of resource whose presence and residence duration are unpredictably erratic.

3.2.2 Fuzzy Logic-Based Synthesis

The most important objective in the suggested technique is to generate fuzzy rules, which determine which type of resources should be deployed for the activity [22]. The fuzzy rules are created using dual input parameters, a1 and a2, and corresponding output, b, using the if-then instructions. The a1 and a2 represent the precedence of the tasks and the resource's residual timeframe, respectively. The score used to assign the resources to the task that was requested is referred to as output b. Priorities and residual time are divided into two categories: low and high is shown in Tab. 1

If the priority is low and the residual time is short, the allocation of resources output is low and resources are used sparingly.

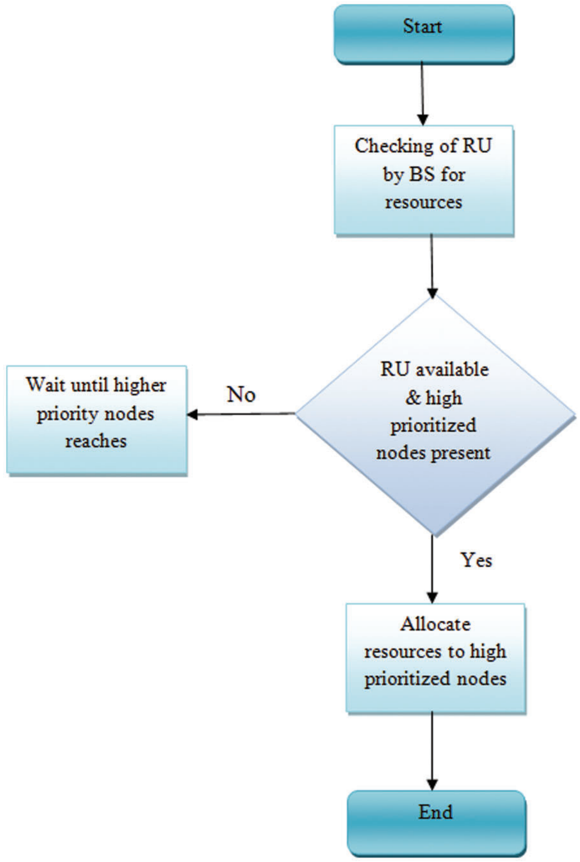


Figure 4: Flowchart depicting resource allocation process

Table 1: Fuzzy rule generation utilizing the two input parameters

SI. No	Fuzzy rules
1	If a1 = low and a2 = low, then b = low
2	If a1 = low and a2 = high, then b = high
3	If a1 = high and a2 = low, then b = low
4	If a1 = high and a2 = high, then b = high

3.2.3 Fuzzified Rule-Based Allocation of Resources

The resources are assigned using fuzzy rules, with the type of resource that is most appropriate for the nodes that have requested the resources being chosen. The completed requests, their priority, the resource requirements, and the time of demand are all kept in a system.

Let us consider

$$R_{xy} = \{r_0\ ,\ r_1\ ,\ \ldots\ldots,\ r_{xy}\} \tag{9}$$

$$RT = \{rt_0,\ rt_2,\ \ldots\ldots,\ rt_{xy}\} \tag{10}$$

where R_{xy} and RT denotes the set of requests and the resources.

$$M = \{m_0, m_1, \ldots\ldots, m_i\} \tag{11}$$

where M consist of i attributes.

$$\text{Rule} = \{FL_1, FL_2, \ldots\ldots, FL_n\} \tag{12}$$

It consists of a set of fuzzy if …. then rules. The consequence of the fuzzy output O'_{FLi} is the image of

$$I_{FLi}(\text{M}) -> O_{FLi}(\text{cost}) \text{ on } I'_{FLi} \tag{13}$$

$$O'_{FLi} = I'_{FLi} \text{ o } FL_i \tag{14}$$

$$O = \text{Agg}\ (O_{FL1}, O_{FL2}, \ldots\ldots\ldots O_{FLn}) \tag{15}$$

where Agg() is the aggregating function, which is determined depending on the requirement of a specific resource allocation problem. The operations summation and maximal are the most regularly utilized. The aggregated resource value from the fuzzy output is

$$r_{xy} = \text{defuzzifier}\ (O) \tag{16}$$

Almost all allocation of resources has its primary purpose of the improvement of service levels. Because of their dynamic frequency accessibility, fuzzy sets are used in the methodology to allocate semi-permanent and intermittent resources. The threat of assigning these resources to low-priority nodes is efficiently handled with the help of fuzzy rules.

4 Results and Discussions

In OFDM systems, we monitor the accuracy of the CFO estimating algorithm which is based on the 1-bit QE-ADC. Performance metrics such as utilization, rate of failure, and life span, as well as energy consumption, are used to assess the proposed FL-CFO. The amount of OFDM signals is used to evaluate the sum of squared deviations of QE-ADC and conventional methodology.

Only a sampling of nodes and services are listed in Tabs. 2 and 3. Tab. 4 lists the system performance for 3 distinct node sets. The obtained results show that the proposed resource provisioning methodology is effective in dynamically allocating resources from the RU to the nominated nodes while maintaining constant node durability.

Table 2: Representation of nodes, prioritization, demanded resources, and the required time

Nodes	Prioritization	Resources on-demand in RU	Time required
N1	1	D1	3
		D3	2
		D5	1
N2	2	D4	4
		D6	3
		D2	10
N3	3	D8	14
		D7	6
		D3	5

Table 3: Evaluation of resources based on Stable, semi-permanent, and Intermittent

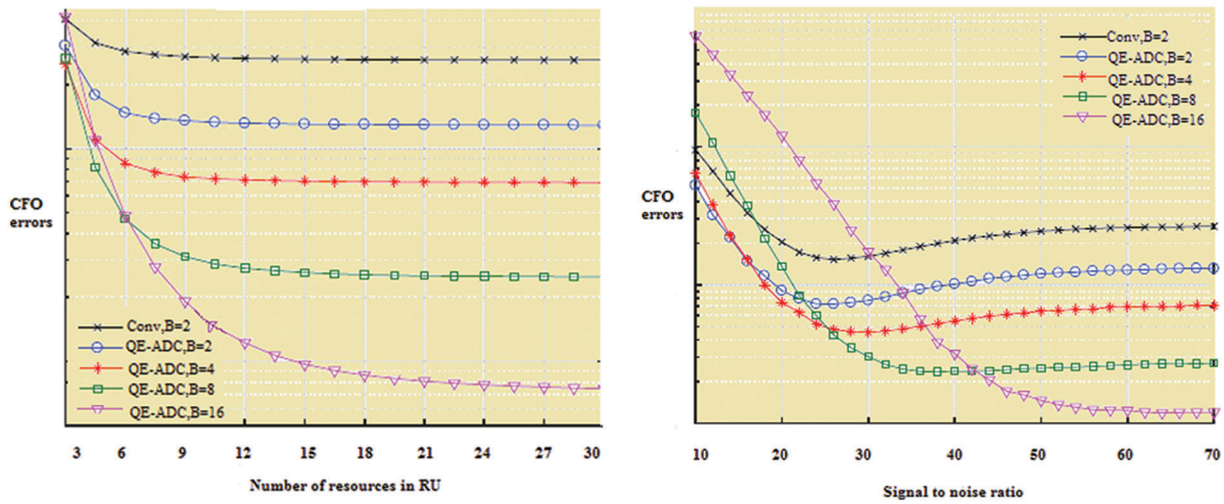
Stable		Semi-permanent		Intermittent	
Resources	Residual time in s	Resources	Residual time in s	Resources	Residual time in s
D8	12	D5	10	D1	12
D7	11	D6	10	D2	14
D1	10	D1	10	D5	15
D4	7	D2	5	D9	16
D2	5	D8	2	D8	10
D5	10	D3	7	D4	12
D3	4	D7	9	D7	12
D9	3	D5	15	D3	12
D6	8	D2	12	D6	7

Table 4: Evaluation of the resources based on the allocation of time

Nodes	Resources on-demand in RU	Resources evaluation	Time required
N1	D2	Intermittent	3
	D3	Stable	3
	D9	Intermittent	1
N2	D6	Semi-permanent	1
	D7	Semi-permanent	2
	D1	Semi-permanent	5
N3	D5	Stable	1
	D8	Intermittent	2
	D4	Intermittent	2

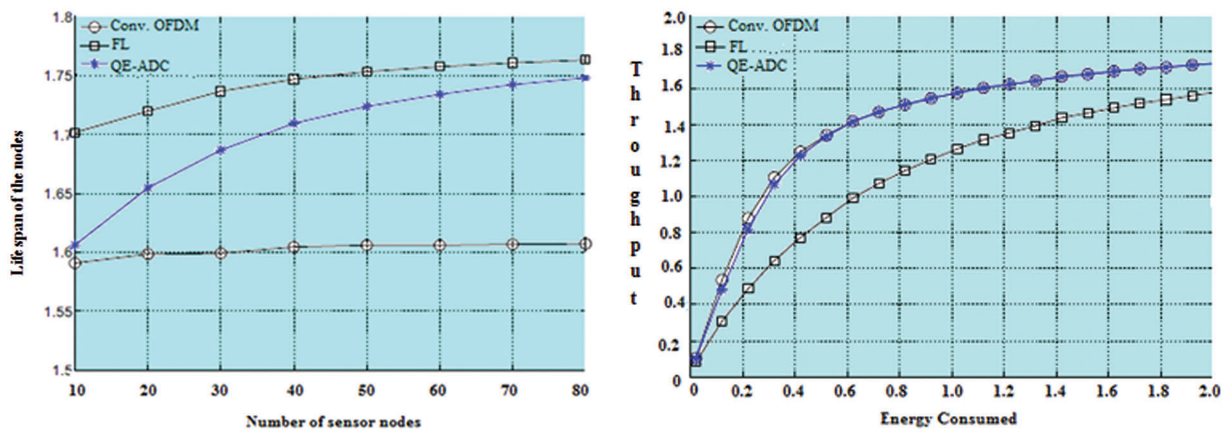
In Fig. 5b the SNR = 30 dB, the CFO errors of QE-ADC are 23.31% less than those of the traditional process for B = 16. The CFO errors in the SNR area around SNR = 8 dB are marginally lower than that of the saturating CFO errors at SNR = 30 in the cases of traditional process and QE-ADC with B = 2 and B = 4.

The parameters used in the estimation are the life span of the sensor nodes, the throughput of all the nodes, and the resource scheduling for the sensor nodes. The network span when the number of sensor nodes varies from 10 to 80 is shown in Fig. 6a. The required energy level of every node is considered to be 12 J. Fig. 6b depicts the performance difference between the FL, 1-bit QE-ADC and traditional OFDM is relatively modest. In most cases, this is sufficient to achieve maximum throughput. Furthermore, the traditional OFDM approach does not take advantage of the increased variety provided by the various resources, resulting in a substantially lower performance than FL and the 1-bit QE-ADC. Figs. 6c and 6d shows the resource usage for 300 and 500 sensor nodes, respectively. With minimum energy consumption, the resource utilization of QE-ADC is greater.

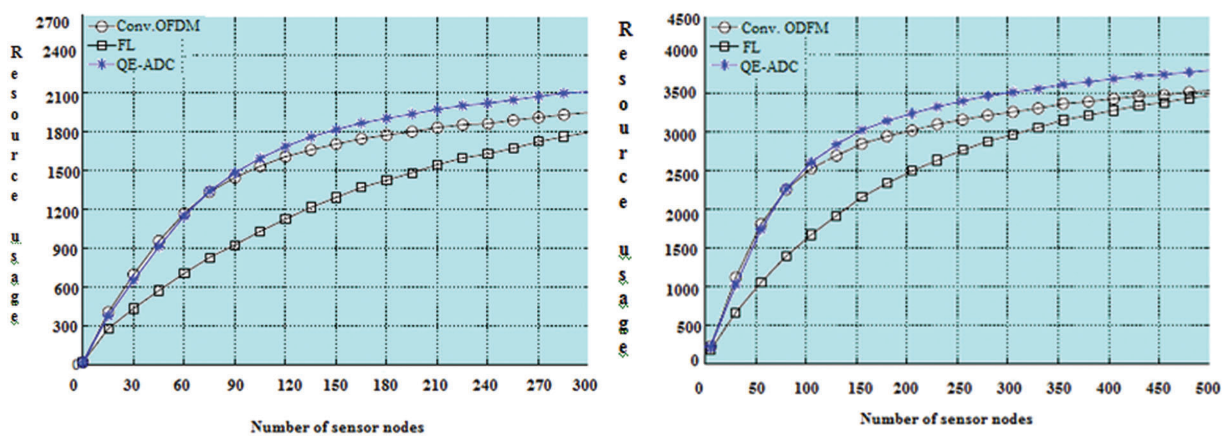


(a) (b)

Figure 5: (a) Estimation of CFO error based on resource availability (b) estimation of CFO errors based on SNR values



(a) (b)



(c) (d)

Figure 6: (a) Life span of the nodes (b) achieved throughput (c) resource utilization for nodes = 300 (d) resource utilization for nodes = 500

5 Conclusion

In a dynamic setting, we suggested a widely applicable fuzzy-based resource scheduling strategy for avoiding CFO errors. The proposed Fuzzy linear CFO estimation (FL-CFO) not only estimates the CFO with greater precision but also effectively allocates resources, providing the most efficient use of dynamic resources. To obtain the accurate CFO, the FL-CFO error estimate algorithm is used in OFDM systems with 1-bit Quadrate errors ADC (1-bit QE). The results show that the proposed technique effectively allocates dynamic resources to the specified nodes in terms of resource appraisal. It has been observed that the methodology searches for a feasible and appropriate resource to distribute to the nodes for each session. The proposed FL-CFO is evaluated and the performance measures such as usage, rate of failures, life span, as well as power consumption are achieved.

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