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RESEARCH ARTICLE

Spectrum-Efficient User and Qos-Aware Resource Allocation With Enhanced Uplink Transmission in U-LTE Networks Co-Occurrence With Wi-Fi by CRN

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ABSTRACT Unlicensed Long-Term Evolution (U-LTE) is one of the few scientific fields that allow illegitimate access to the 5GHz band to boost data transmission throughput. However, the overall client-perceived Quality-of-Service (QoS) was not improved. This has an impact on the scheduling process since scheduling allows clients to be assigned channels or subframes based on their QoS requirements. To solve this issue, a Desirable U-LTE-Wi-Fi with QoS-aware Based Resource Allocation (D-U-LTE-Wi-Fi-QBRA) has been designed. It allocates the necessary resources and ensures the QoS of the Primary User (PU) and Secondary User (SU) in 3GPP-LTE-Cognitive Radio Network (CRN). But, from the Primary Network's (PN) perspective, it does not prevent the interference generated by SUs. Similarly, from the Secondary Networks (SNs) perspective, there was a need to allocate PNs to SUs to minimize the total interference. This article dwells on how the coexistence of Wi-Fi and LTE networks using Cognitive Radio (CR) is enhanced by introducing the Flower Pollination optimization Algorithm (FPA). The main aim of this framework is to enable SUs with a high QoS using reasonable cost and data rate according to the interruption limits of all accessible networks with inactive systems. First, an optimization dilemma is devised to reduce the interruption experienced by the authorized clients and the price that SUs must spend to utilize the PNs. Then, this dilemma is rectified using the FPA. This improved the cost and SE for the co-occurrence of Wi-Fi and LTE networks using CR. Further, the modeling outcomes reveal that the proposed model achieved better Spectrum Efficiency (SE) than the usual models.

INDEX TERMS Cognitive radio network, D-U-LTE-Wi-Fi-QBRA, spectrum efficiency, QoS, interference, flower pollination algorithm.

I. INTRODUCTION

Fourth-generation (4G) communication systems, commonly referred to as LTE networks, have largely emerged with the goal of transmitting massive amounts of information through digital platforms. Cell miniaturization is a direct response to customer queries. Miniaturization also necessitated additional system resources. The provision of uncertified bands with certified bands to meet their consumers' bandwidth demands is a great prospect for LTE facilities. The 3GPP has assisted in the implementation of LTE to address remarkably higher data transfer limitations in upcoming broadcasting techniques [1]. To facilitate authorization insights, 3GPP LTE-A provides specified cooperation of certified and uncertified bands in micro-cells [2], [3], [4]. However, broadband providers remain restricted by the allocation of certified frequency bands.

According to these restrictions, LTE is permitted to perform on the uncertified frequency bands shared by Wi-Fi/IoT technologies [5]. In any sort of communication in a wireless

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environment, energy efficient data collection process and optimal speed factors should be considered [6], [7], [8]. As 5GHz has hundreds of MHz of spectral efficiency, U-LTE might be promoted to enable 5GHz Industrial, Scientific, and Medical (ISM) services [9]. The objective of U-LTE is to leverage characteristics from the most popular LTE 3GPP standards and adapt them for uncertified implementation in advanced nations that do not support Listen-Before-Talk (LBT). It often encourages unsecured information exchange in the 5150-5250MHz and 5725-5850MHz frequency bands, with the 5250-5725MHz band, favored for long-term deployment [10], [11], [12]. The main concern with using such bands was that some Wi-Fi/IoT technologies promote the deployment of LBT. So, U-LTE is enhanced,and the CRN-LBT standards for acceptable 5GHz spectrum usage. The U-LTE-LBT dealt with requirements and improve their cooperation with Wi-Fi/IoT customers by lowering the Wi-Fi back-off restriction in a non-interference situation. Additionally, U-LTE's major features for novel spectrum accessibility and the collaboration of auxiliary customers with permitted customers have been rebuilt by exploiting the core concept of spectrum sensing and allocation. Heuristic algorithms adjust the sensing range with the overlapping sensing area without affecting the high degree of coverage [13]. A low-complexity algorithm is developed in [14] for intercell interference coordination with the use of cognitive radio when single and multi-UAVs are deployed in a cellular environment to facilitate URLLC services. Originally, the License Assisted Access (LAA) approach had been established to encourage the LBT process. The LTE duty cycle may be used to simplify the spectrum control procedure in complicated implementation circumstances. In addition, a Low Amplitude Stream Injection (LASI) approach for simultaneous Wi-Fi-LTE access management on a distributed band and information recovery after conflicts have been developed [12].

Similarly, an improved Cell ON/OFF method was presented, which may considerably increase system throughput and expand web access through advancing LTE to inappropriate frequency ranges. A study on UAV-assisted communications to improve secrecy for URLLC systems under the finite blocklength regime is reported in [15]. As a consequence, the SE and reliability have been increased, when the Transmission Delay (TD) has been reduced. Conversely, the predicted UT throughput on the unapproved frequencies has been severely impacted by eNodeB (eNB) and User Equipment (UE) dual LBT restrictions. Further, efficiency loss occurred as a consequence of a decline in the UE's channel access capability. As a result, D-U-LTE-Wi-Fi [16] was created as an upgrade to UT in E-U-LTE-Wi-Fi/IoT networks. To increase upstream throughput for LTE in prohibited bandwidth using Grant-less Multiple Subframe Scheduled Uplink (GMSSUL) transmission, a novel UT model has been proposed that does not use the eNB distribution technique. To guarantee good collaboration, the UE used Cat4.5LBT-based channel recognition in accordance with upstream data. Following that, a preamble sign has been required ahead of data exchange to recognize the Uplink Burst (UB) at an anchor eNB was made mandatory. Similarly, a reservation sign was made mandatory to preserve the preset level.

After that, the UE evaluated at the absolute Highest Channel Possession Time (HCPT) to share data, and the eNB received feedback information for the Amalgam Automatic Repeat Request (AARQ). In addition, Multi-Subframe Scheduling (MSS) has been designed to enhance the upstream frame by allowing the UE to take advantage of numerous network recognition possibilities and constantly communicate data to many subbands. Even if it improves the UT on all certified and uncertified frequencies, the average client-perceived QoS has not been improved. This has an impact on the RA process because allocation allows for the availability of bands or subframes to customers based on their QoS requirements. So, D-U-LTE-Wi-Fi-QBRA was created to allocate the necessary resources for 3GPP-LTE-CRN [19]. Its goal was indeed to ensure entry to prohibited eNBs while ignoring the QoS compromise for authorized eNBs. From this perspective, a two-stage method was included: 1) spectrum resources could be provided to the allowed eNBs in the initial stage to improve QoS for certified customers, and 2) additional service capability of the main bandwidth was distributed among prohibited eNBs in the second stage to improve QoS for fraudulent customers. But it does not consider the data rate to ensure the SE and QoS of LTE-CRN systems.

For this purpose, the co-occurrence of Wi-Fi and LTE systems utilizing CR is improved in this study by implementing the FPA. The main contribution of this paper is summarized as follows:

- To deliver good QoS to SUs at a cheaper cost while constrained by the interference restrictions of all available networks with idle channels. The data rate is taken into account to improve the SE of both uplink and downlink broadcasts.
- The optimization problem is modeled to decrease the amount of interference experienced by licensed users as well as the cost that SUs must pay to utilize the PNs
- To achieve high QoS at a reasonable cost and increase the SE of coexisting Wi-Fi and LTE networks using CR, the optimization algorithm FPA is employed.
- Simulations are carried out in MATLAB and the results are compared with some of the existing algorithms to prove the efficiency of the proposed work in terms of Spectrum efficiency, throughput, transmission delay, SINR, and interference.

The remaining portions of this manuscript are prepared in the following form: Section II discusses the research associated with the machine learning-based co-occurrence of U-LTE and Wi-Fi/IoT networks. Section III explains the proposed model and Section IV shows its performance. Section V concludes the research work and discusses the performance enhancement in the proposed model.

II. LITERATURE SURVEY

Ghalut et al. [17] presented a new hybrid method using Genetic Algorithm (GA) and Random Neural Networks (RNN) for optimizing the Quality-of-Experience (QoE) of multimedia stream downlink allocation. In this method, the allocation of accessible system resources was optimized among many customers to increase the mean opinion score and fairness. Also, the LTE downlink was modelled by the RNN for learning a sophisticated non-linear map of QoE and GA was used to explore the overall finest via a certain parametric area. But it needs to optimize the uplink allocation for increasing the system throughput. Hasan et al. [18] presented a network choice and channel assignment method for increasing profits by admitting additional SUs and responding to their demands. An optimization dilemma was devised for reducing the cumulative interruption experienced by authorized clients and the rate that SUs must spend to utilize the PNs. The objective was to enable SUs with a particular QoS at a competitive cost, according to the interruption limits of all accessible networks containing inactive streams. Particle Swarm Optimization (PSO) and a customized GA were utilized for solving the optimization dilemma. But it had a low convergence rate in the iterative process and was time-consuming.

Abdulghafoor et al. [19] developed a challenge of RA in OFDM-based downstream CRN. The main aim was to reduce the time overhead of the RAscheme for downstream CRNin relation to the interruption limit of the major system. It was achieved using a pricing method for designing the RA method. Though it optimizes the RA, the computational burden was not minimized effectively. Thakur et al. [20] developed two RA methods for femtocell networks that effectively distribute resources, namely spectrum and transfer energy amid hostile portable clients in the LTE and Wi-Fi bands. For the LTE spectrum, the utilization of the distribution-based band and RA was developed and the network efficiency was modelled by a non-cooperative game-theoretic model. Also, a Q-learning-based RA was applied for enhancing the coexistence efficiency of small networks functioning in the Wi-Fi. Still, the energy usage and computation burden were high.

Gu et al. [21] addressed the issue of the dynamic band and RA in LAA-facilitated femtocells and Wi-Fi systems. In the model of Lyapunov optimization, the sophisticated stochastic dilemma was analyzed as a customized Hungarian model and as a variance of two convex algorithms. Manzoor et al. [22] addressed the challenge of unauthorized band distribution amid Wi-Fi and LTE-U systems. Also, a fair time distribution framework was developed depending on the ruin theory for distributing unwanted resources from the unauthorized spectrum with LTE-U systems. The theory of chance of degradation was used to guarantee equality amid Wi-Fi and LTE-U. But, it must increase the efficacy of channel usage and system throughput. Alsenwi et al. [23] developed a new method depending on NN for the co-occurrence of an LTE-U base station in the unauthorized band together with Wi-Fi. In this method, the issue in co-occurrence was modelled as a 2D Hopfield NN (2D-HNN)-based dilemma which strives to ensure equality by taking into consideration the LTE-U speed and QoS demands of Wi-Fi. Also, the issue of unauthorized RA to LTE-U clients was devised as a 2D-HNN and its power factor was contributed to RA to LTE-U clients depending on their stream conditions. But the efficiency was reduced while increasing the percentage of Wi-Fi clients. Tian et al. [24] presented a Radio Frequency (RF) power system-based underlay CRN architecture in which a supplementary transceiver gathered power from RF communication. Also, the least demand of throughput limit was imposed on the secondary transmitter in the task of energy-efficiency maximization for ensuring the QoS.

Ostovar et al. [25] presented a wireless multi-access media utility for establishing the PU's occurrence and the average energy-efficiency dilemma of the CRN with mathematical structure computation applications. The goal was to reduce the power usage of SUs when increasing the overall energy efficiency, and maintaining the precise sensing by increasing the sensing time identification subject to SU energy restraints and the least data rate. But it needs to optimize the spectrum and power assignment for minimizing power usage which maximizes the overall energy efficiency. Zaharia et al. [26] dealt with providing an absolute offloading solution depending on the greedy mechanism, multi-objective optimization, and the GA. It was intended for various goals: preserving the energy, obtaining the highest data rate, and providing a simulator that regenerates the characteristics of the network. Initially, the simulator was constructed depending on machine learning for estimating Wi-Fi and cellular broadband signal strengths. Also, it was used to compute the energy usage and expected data rate. But its efficiency depended on the parameters utilized in the GA. Alonso et al. [27] presented a new wireless network optimization method for CRN depending on a cloud-sharing decision scheme. In this method, different major evaluation metrics such as spectrum utilization, energy usage, and exposure were optimized. However, it was observed that the energy usage was increased, and it needed to characterize the data rate to minimize the interference in CRN.

III. PROPOSED METHODOLOGY

In this section, the D-U-LTE-Wi-Fi-QBRA-FPA model is explained briefly. First, authenticated and unauthenticated users originated by communicating UEs with Wi-Fi access points and eNB, correspondingly, with the help of an unlicensed spectrum. Then, the uplink communication was developed by Cat.4 LBT, which ensured effective co-occurrence amid Wi-Fi and U-LTE clients. The resources and service rates were precisely shared by the 2-step procedure and this improved the QoS of all users. Furthermore, the interference caused by SUs was prevented by choosing the network and channel using FPA-based optimization. The processes in this D-U-LTE-Wi-Fi-QBRA-FPA are described below.

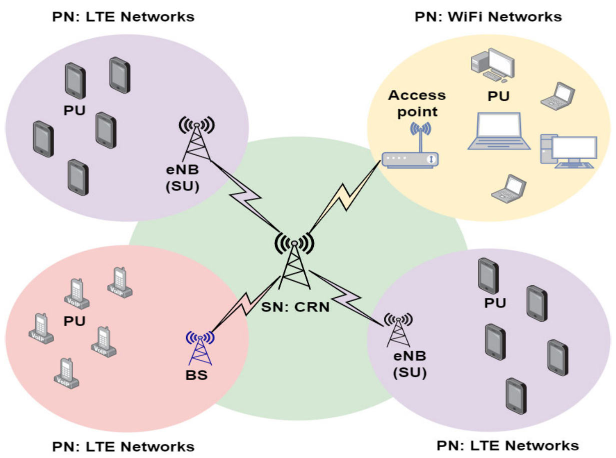

FIGURE 1. Illustration of CRN-based LTE-Wi-Fi network.

A. PROBLEM FORMATION

Consider a U-LTE-Wi-Fi/IoT network consisting of NPNs (i.e., Wi-Fi/IoT) where each PN can have any number of PUs. Each PU had the highest number of channels represented by p_n, but the number of channels accessible for SUs (eNBs) transmission depended on the PUs behavior. For all certain PUs, the PU behavior is modeled using the Poisson task with 2 states, i.e., the ON-OFF state framework. The highest probable rate of transfer on c^{th} channel of n^{th} network is r_{cn}^{max}. The range of r^{th} depended on c^{th} channel state in network n. It is considered that there was a CRN (i.e. SN) that controlled each incoming SUs and gathered the network status data of each accessible PN as illustrated in Fig. 1.

If s^{th} SU entered the system, it characterized its least data rate demand γ_s and the highest cost p_s that it was willing to pay to the CRN. Assume $U = \{u_1, u_2, \ldots, u_n\}$ is the collection of MSUs competing for access. When s^{th} SU is assigned a certain channel c in a network n, it is considered that SU generates a unit interference represented by ξ_{sn} with the PUs. The amount of interference relied on the channel state. It is desired to constrain the highest interference to the PUs of n^{th} with the PUs. It is desired to constrain the highest interference to the PUs of the network below a particular threshold ϵ_n.

Consider that a price η_n is related to each n^{th} network; this defines when s^{th} SU joins n^{th} PN, the cost η_{sn} will be charged. The goal is to reduce the total price and interference caused by allocating SUs to various networks, subject to the restraints of each network. So, the objective function for the optimization is defined as

$$\left.\begin{aligned} \min Q(\tau) &= \sum_{s=1}^{M}\sum_{n=1}^{N}(\xi_{sn}+\eta_{sn})\,T_{sn} \\ \text{s.t. } \textstyle\sum_{n=1}^{N}\tau_{sn} &= 1, \forall s = 1, 2, \ldots, M \\ \sum_{s=1}^{M}\xi_{sn}\tau_{sn} &\le \varepsilon_n, \forall s = 1, 2, \ldots, N \\ \gamma_s\tau_{sn} &\le \gamma_{en}, \forall c, s, n \\ p_s\tau_{sn} &\le \eta_n, \forall s, n, \tau_{nn} \in \{0, 1\} \end{aligned}\right\} \quad (1)$$

In (1), $Q(\tau)$ is the objective function that accumulates the interference incurred by PUs in the network and the cost which SUs must spend to utilize the PNs. The major restraint defines that all SUs can be allocated only one channel among each channel in the networks at a given interval. When the binary decision variable τ_{sn} is 1, the user is allocated to the n^{th} network and vice versa. The subsequent restraints depend on the PN resources accessible for SUs and the network policy. The second restraint guarantees that the overall interference caused by each SU allocated to a certain network n will not exceed the highest tolerable interference ϵ_n. The third and fourth restraints show that the allocated channel should be appropriate for the SU regarding bandwidth and price demands, correspondingly. This optimization dilemma is resolved by using the FPA to assign the SUs in certain PNs at high QoS and low prices. There are different optimization algorithms used like GA, PSO, etc. But they have their limitations. For example, the limitations of the GA are: the entire population is changed with the consecutive generation chromosomes. The optimum solution was only obtained from the global optimum and so the outcome is not stable. Similarly, the limitations of PSO are: it is mostly dependent on global optimum location, i.e. other particles can become trapped in a local optimum due to the influence of global optimum location. Also, the number of learning variables is high which impacts the outcome. Accordingly, FPA outperforms both GA and PSO. It is highly effective and the convergence rate is exponential.

B. FLOWER POLLINATION ALGORITHM

Let the x number of flowers/stamen gametes wherein each has a complete solution for SUs, PNs and channels. It considers the k^{th} stamen in a hunting space of a vector for the problem of MSUs and NPNs, each consisting of p_{sn} channels. To select the network and channel, the FPA is adopted in U-LTE-Wi-Fi/IoT networks. This algorithm comprises many traits like associating flower stamens into the different PNs and channels (called encoding of flowers), determining the fitness value of a flower, updating solutions, and applying the repair procedure for all infeasible SU allocations.

1) ENCODING OF FLOWERS

Each flower must consist of a full solution for SUs, PNs, and channels. Consider that each m^{th} network has a similar channel represented by ρ. The stamen of a flower is represented by multi-dimensional vectors whose entries belong to a collection of $\{1, 2, \ldots, M\ x\rho N\}$.

The M-dimensional stamen of the k^{th} flower is represented as $S_k = (S_{k1}, \ldots, S_{kM})$, where s_{kl} is the l^{th} dimension of the k^{th} flower, which indirectly provides the assigned network and channel for the l^{th} SU. The above-mentioned encoding of the flowers is simply extended to a dilemma with n^{th} network having a different number of channels represented by p_n. In this scenario, the range of ρ will be a maximum of i.e., $\rho = max\ p_n$. It defines that it is supposed that all networks have similar ρ channels. For any network n having the number of channels $p_n < \rho$, a range 1 is added in all the slots other than p_n, which defines that $\rho - p_n$ slots of network n are already occupied. The network and channel corresponding to an element of a flower are determined as:

$$Network = \left[\frac{s_{kl} - (l-1) \times N \times \rho}{\rho}\right]. \quad (2)$$

$$Channel = s_{kl} - \rho\left[\frac{s_{kl}}{\rho}\right]. \quad (3)$$

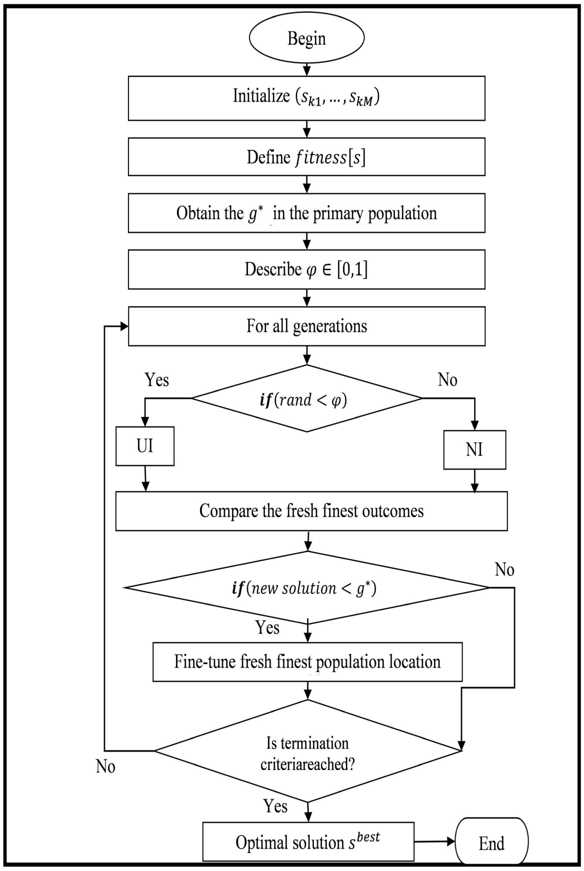

FIGURE 2. Flow diagram of flower pollination algorithm for network and channel selection in U-LTE-Wi-Fi network.

2) FITNESS VALUE

The total interference incurred by SUs and the total price SUs have to pay ($Q(\tau)$) is utilized for analyzing the algorithm efficiency. In this study, the fitness value is the inverse of $Q(\tau)$ which indicates a solution with higher accumulative interference and subscription prices will have a lesser fitness range. The fitness range of all solutions is measured as:

$$fitness[s] = (Q(\tau))^{-1}. \quad (4)$$

3) UPDATE SOLUTIONS

The FPA performs two processes: Universal Insemination (UI) and Neighborhood Insemination (NI). In the UI process, flower stamens are transported by the bees and the stamens will travel a great range since bees may regularly migrate a greater distance.

It guarantees the insemination and procreation of the best fitness value which is represented by g^*. In this algorithm, the flower constancy may be considered, as the procreation chance is relative to the resemblance of the 2 flowers engaged in the insemination process. Also, both UI and NI are guided by a transition possibility $\phi \in [0, 1]$. Based on these constraints, the following update process is performed:

$$s_k^{t+1} = s_k^t + L(s_k^t - g^*). \quad (5)$$

In (5), s_k^t refers to the stamen k or result vector s_k at iteration t and g^* refers to the present optimum outcome obtained amid each outcome at the present t. The parameter L refers to the confidence of the insemination or step length. As bees can fly a great range in varied L, a Levy flight is employed to effectively simulate this ability. Therefore, $L > 0$ is obtained from a Levy distribution.

$$L \sim \frac{\lambda\Gamma(\lambda)sin(\frac{\pi\lambda}{2})}{\pi}\frac{1}{a^{1+\lambda}}, \ (a \gg a_0 > 0, \ \lambda = 1.5). \quad (6)$$

In (6), $\Gamma(\lambda)$ refers to the gamma function of levy exponent λ and this distribution is applicable for $a > 0$. Similarly, flower constancy for NI is described as the following update function:

$$s_k^{t+1} = s_k^t + \epsilon(s_l^t - s_q^t). \quad (7)$$

In (7), s_l^t and s_q^t are stamens from various flowers of matching crops. Basically, it simulates the flower fidelity in narrow vicinity. When both s_l^t and s_q^t are decided from the matching species, a confined arbitrary walk is achieved with $\varepsilon \in [0, 1]$ i.e., a uniform distribution. Practically, adjacent flowers in the not-so-distant vicinity are highly probable to be inseminated through neighboring flower stamens that those distant.

In this case, ϕ is applied to shift amid usual UI to efficient NI. This process is continued until the highest t and the current best solution. The processes in FPA are illustrated in Fig. 2 and the FPA parameters are presented in Table. 1.

4) REPAIR PROCEDURE

The algorithm begins to randomly create several possible solutions to the dilemma as the size of the initial population of the FPA. Every dimension of the flower vector defines a channel as well as the network allocated to a SU. The assignment of a network and a channel to SUs are executed sequentially until all SUs are allocated to the PNs and channels. All flowers denote a full solution that guarantees that each assignment should satisfy the restraints given in (1).

The repair procedure is adopted for fine-tuning the locations of SUs to meet the restraints. The initial step is to detect infeasible types like 2 SU's conflict based on their assignment, SU's requirement is greater than the capability of the allocated channel, a SU cannot be allocated to this network since it is not willing to pay the price of this network and the network cannot accommodate any further allocated SUs since its interference tolerance limit has been reached. The second step is to reproduce the new velocity of the SU to detect the new slot for reassignment. If the newly produced slot satisfies each restraint, the SU's location is updated. Or else, the second step is continued until a slot is obtained that satisfies each restraint.

Algorithm 1

Input:MSUs, NPNs and p_n channels
Output: Suitable network and channel
Initialize a population of n flowers/stamens (number of SU) with random results (suitable network and channel for each SU);
Define the objective, fitness[s];
Obtain g^* in the primary population;
Describe $\phi \in [0, 1]$;
while ($t < Max\_generation$)
for(k = 1:n)
  if(rand < ϕ)
  Get L that follows a Levy distribution;
    UI using $s_k^{t+1} = s_k^t + L(s_l^t - g^*)$.
  else
    Get ϵ from a regular distribution in [0,1];
    Select l and q amid each result;
    Perform NI using $s_k^{t+1} = s_k^t + \epsilon(s_l^t - s_q^t)$.
  end if
  Compare fresh results;
  When fresh results are superior, fine-tune them in the population;
  end for
Obtain g^*;
end while

TABLE 1. FPA parameters.

Parameters	Range
Number of flowers	25
Maximum generation	2100
Φ	0.8
A	0.01
λ	1.5

IV. SIMULATION RESULTS

In this portion, the efficiency of the proposed D-U-LTE-Wi-Fi-QBRA-FPA algorithm is analyzed by simulating it in MATLAB. Also, its efficiency is compared with the existing optimization algorithms such as D-U-LTE-Wi-Fi-QBRA-PSO, D-U-LTE-Wi-Fi-QBRA-GA and D-U-LTE-Wi-Fi-QBRA [22]. The comparative analysis is carried out regarding the Spectral Efficiency (SE), throughput, Average Transmission Number (ATN), Transmission Delay (TD), Interference, and Signal-to-Interference Ratio (SINR). This model is simulated by using the parameters mentioned in [20].

A. SPECTRUM EFFICIENCY

SE stands for the ratio of transfer rate to spectrum throughput, and it is depicted as follows:

$$SE = \frac{Transmission\ rate}{Spectrum\ throughput} \tag{8}$$

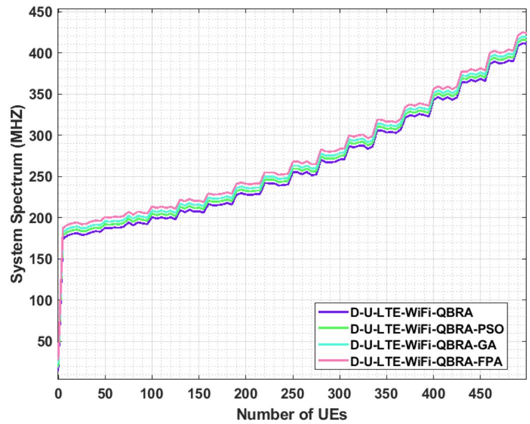

FIGURE 3. SE vs. No. of UEs.

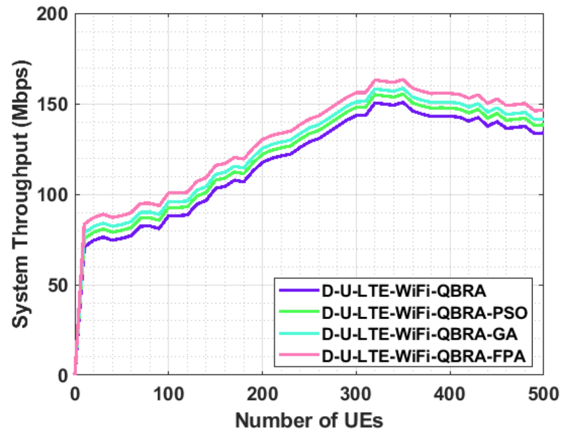

FIGURE 4. Throughput vs. No. of UEs.

Table. 2 gives the values of SE obtained by the D-U-LTE-Wi-Fi-QBRA with different optimization models. It signifies that the mean SE of D-U-LTE-Wi-Fi-QBRA-FPA is 290.53 MHz, whereas the mean SE of D-U-LTE-Wi-Fi-QBRA-GA, D-U-LTE-Wi-Fi-QBRA-PSO, and D-U-LTE-Wi-Fi-QBRA is 285.53 MHz, 281.83 MHz, and 277.53 MHz, correspondingly.

Fig. 3 illustrates the SE (in MHz) obtained by the D-U-LTE-Wi-Fi-QBRA, D-U-LTE-Wi-Fi-QBRA-PSO, D-U-LTE-Wi-Fi-QBRA-GA, and D-U-LTE-Wi-Fi-QBRA-FPA. If 250 UEs exist in the network, then the SE of D-U-LTE-Wi-Fi-QBRA-FPA is 5.1% larger than the D-U-LTE-Wi-Fi-QBRA, 3.4% larger than the D-U-LTE-Wi-Fi-QBRA-PSO and 1.9% larger than the D-U-LTE-Wi-Fi-QBRA-GA. This indicates that the proposed algorithm D-U-LTE-Wi-Fi-QBRA-FPA realizes the maximum SE of all other models.

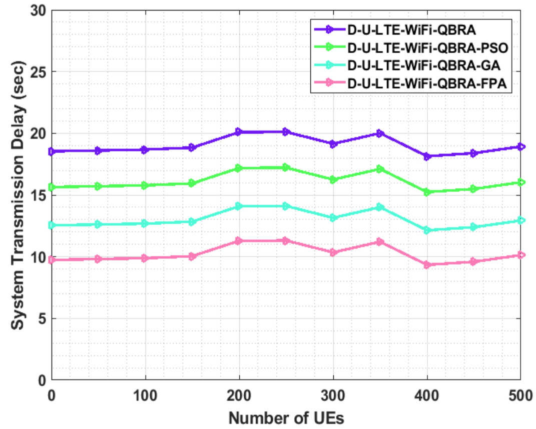

FIGURE 5. System TD vs. No. of UEs.

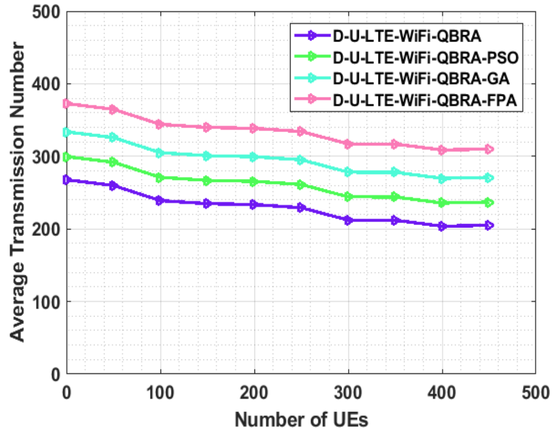

FIGURE 6. ATN vs. No. of UEs.

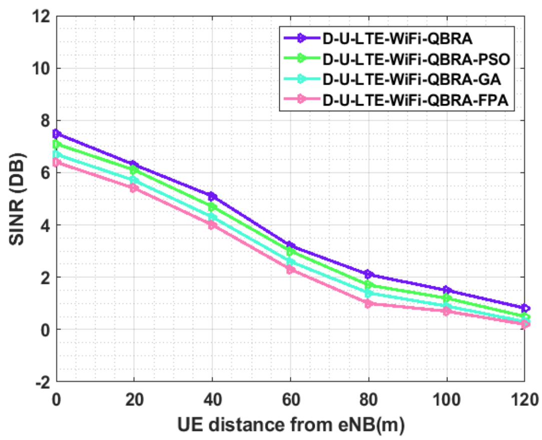

FIGURE 7. SINR vs. UE distance from eNB.

B. THROUGHPUT

Throughput refers to the amount of data sent via wireless channels in a given amount of time. Table. 3 gives the values of throughput attained by the proposed D-U-LTE-Wi-Fi-QBRA-FPA algorithm compared with different optimization algorithms. It addresses that the mean throughput of D-U-LTE-Wi-Fi-QBRA-FPA is 135.08 Mbps

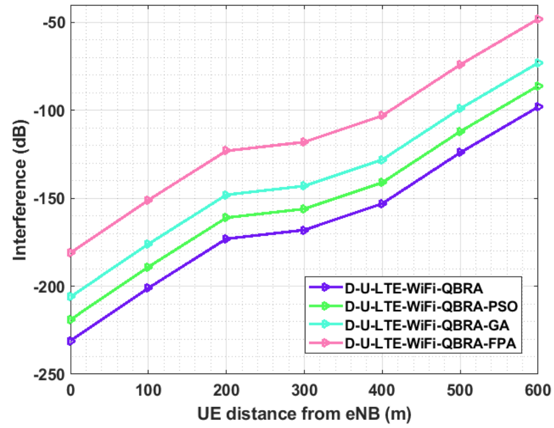

FIGURE 8. SINR vs. UE distance from eNB.

TABLE 2. Evaluation of SE.

No. of UEs	SE (MHz)			
	D-U-LTE-Wi-Fi-QBRA	D-U-LTE-Wi-Fi-QBRA-PSO	D-U-LTE-Wi-Fi-QBRA-GA	Proposed D-U-LTE-Wi-Fi-QBRA-FPA
50	187.72	192.02	195.72	200.72
100	200.65	204.95	208.65	213.65
150	207.79	212.09	215.79	220.79
200	228.16	232.46	236.16	241.16
250	254.99	259.29	262.99	267.99
300	270.44	274.74	278.44	283.44
350	303.31	307.61	311.31	316.31
400	343.05	347.35	351.05	356.05
450	368.31	372.61	376.31	381.31
500	410.84	415.14	418.84	423.84

whereas the mean throughput of D-U-LTE-Wi-Fi-QBRA-GA, D-U-LTE-Wi-Fi-QBRA-PSO, and D-U-LTE-Wi-Fi-QBRA is 130.18 Mbps, 126.98 Mbps, and 122.48 Mbps, correspondingly.

Fig. 4 exhibits the throughput (in Mbps) attained by the proposed D-U-LTE-Wi-Fi-QBRA, D-U-LTE-Wi-Fi-QBRA-PSO, D-U-LTE-Wi-Fi-QBRA-GA, and the proposed D-U-LTE-Wi-Fi-QBRA-FPA. For 500 UEs, the throughput of D-U-LTE-Wi-Fi-QBRA-FPA is 9.8% larger than the D-U-LTE-Wi-Fi-QBRA, 6.1% larger than the D-U-LTE-Wi-Fi-QBRA-PSO, and 3.6% larger than the D-U-LTE-Wi-Fi-QBRA-GA. So, this indicates that the proposed D-U-LTE-Wi-Fi-QBRA-FPA model achieved the maximum throughput of all other models.

C. TRANSMISSION DELAY

The time used to convey data is referred to as the system TD. Table. 4 gives the values of system TD attained by the D-U-LTE-Wi-Fi-QBRA with different

TABLE 3. Evaluation of throughput.

No. of UEs	Throughput (Mbps)			
	D-U-LTE-Wi-Fi-QBRA	D-U-LTE-Wi-Fi-QBRA-PSO	D-U-LTE-Wi-Fi-QBRA-GA	Proposed D-U-LTE-Wi-Fi-QBRA-FPA
50	75.58	80.08	83.28	88.18
100	88.17	92.67	95.87	100.77
150	103.25	107.75	110.95	115.85
200	117.59	122.09	125.29	130.19
250	128.92	133.42	136.62	141.52
300	143.43	147.93	151.13	156.03
350	150.80	155.30	158.50	163.40
400	143.09	147.59	150.79	155.69
450	140.09	144.59	147.79	152.69
500	133.87	138.37	141.57	146.47

TABLE 4. Evaluation of system TD.

No. of UEs	System TD (sec)			
	D-U-LTE-Wi-Fi-QBRA	D-U-LTE-Wi-Fi-QBRA-PSO	D-U-LTE-Wi-Fi-QBRA-GA	Proposed D-U-LTE-Wi-Fi-QBRA-FPA
50	18.54	15.64	12.54	9.74
100	18.61	15.71	12.61	9.81
150	18.68	15.78	12.68	9.88
200	18.84	15.94	12.84	10.04
250	20.09	17.19	14.09	11.29
300	20.11	17.21	14.11	11.31
350	19.15	16.25	13.15	10.35
400	20.01	17.11	14.01	11.21
450	18.14	15.24	12.14	9.34
500	18.39	15.49	12.39	9.59

optimization algorithms. It observes that the mean system TD of proposed D-U-LTE-Wi-Fi-QBRA-FPA is 10.26 sec whereas the mean system TD of D-U-LTE-Wi-Fi-QBRA-GA, D-U-LTE-Wi-Fi-QBRA-PSO and D-U-LTE-Wi-Fi-QBRA is 13.06 sec, 16.16 sec and 19.06 sec, correspondingly.

Fig. 5 displays the system TD (in sec) obtained by the D-U-LTE-Wi-Fi-QBRA, D-U-LTE-Wi-Fi-QBRA-PSO, D-U-LTE-Wi-Fi-QBRA-GA and the proposed D-U-LTE-Wi-Fi-QBRA-FPA. When 250 UEs are taken in the network, the TD of D-U-LTE-Wi-Fi-QBRA-FPA is 43.8% smaller than the D-U-LTE-Wi-Fi-QBRA, 34.3% smaller than the D-U-LTE-Wi-Fi-QBRA-PSO and 19.9% smaller than the D-U-LTE-Wi-Fi-QBRA-GA. Thus, this realizes that the D-U-LTE-Wi-Fi-QBRA-FPA algorithm achieves a reduced TD than all other models.

TABLE 5. Evaluation of ATN.

No. of UEs	ATN			
	D-U-LTE-Wi-Fi-QBRA	D-U-LTE-Wi-Fi-QBRA-PSO	D-U-LTE-Wi-Fi-QBRA-GA	Proposed D-U-LTE-Wi-Fi-QBRA-FPA
50	267.72	299.72	333.72	372.72
100	259.84	291.84	325.84	364.84
150	239.04	271.04	305.04	344.04
200	234.84	266.84	300.84	339.84
250	233.54	265.54	299.54	338.54
300	229.20	261.20	295.20	334.20
350	212.19	244.19	278.19	317.19
400	212.00	244.00	278.00	317.00
450	203.72	235.72	269.72	308.72

TABLE 6. Evaluation of SINR.

UE Distance from eNB (m)	SINR (dB)			
	D-U-LTE-Wi-Fi-QBRA	D-U-LTE-Wi-Fi-QBRA-PSO	D-U-LTE-Wi-Fi-QBRA-GA	Proposed D-U-LTE-Wi-Fi-QBRA-FPA
5	7.5	7.1	6.7	6.4
20	6.3	6.1	5.7	5.4
40	5.1	4.7	4.3	4.0
60	3.2	3.0	2.6	2.3
80	2.1	1.7	1.4	1.0
100	1.5	1.2	0.9	0.7
120	0.82	0.5	0.3	0.2

TABLE 7. Evaluation of Interference.

UE Distance from eNB (m)	Interference (dB)			
	D-U-LTE-Wi-Fi-QBRA	D-U-LTE-Wi-Fi-QBRA-PSO	D-U-LTE-Wi-Fi-QBRA-GA	Proposed D-U-LTE-Wi-Fi-QBRA-FPA
0	-231	-219	-206	-181
20	-201	-189	-176	-151
40	-173	-161	-148	-123
60	-168	-156	-143	-118
80	-153	-141	-128	-103
100	-124	-112	-99	-74
120	-98	-86	-73	-48

D. AVERAGE TRANSMISSION NUMBER

The ATN stands for the amount of data that will be transmitted per second/connection.

$$ATN = \sum_{i=1}^{n} TN_i + \sum_{j=1}^{m} TN_j. \tag{9}$$

Here, n is the number of WiFi connections, m is the amount of LTE connections, TN_i and TN_j are the broadcast integers of Wi-Fi link i and LTE link j, correspondingly. The values of ATN achieved by the D-U-LTE-Wi-Fi-QBRA with different optimization models are given in Table. 5. It defines that the mean ATN of the proposed D-U-LTE-Wi-Fi-QBRA-FPA is 337.45, whereas the mean ATN of D-U-LTE-Wi-Fi-QBRA-GA, D-U-LTE-Wi-Fi-QBRA-PSO, and D-U-LTE-Wi-Fi-QBRA is 298.45, 264.45, and 232.45, correspondingly.

Fig. 6 shows the ATN achieved by the D-U-LTE-Wi-Fi-QBRA, D-U-LTE-Wi-Fi-QBRA-PSO, D-U-LTE-Wi-Fi-QBRA-GA, and the proposed D-U-LTE-Wi-Fi-QBRA-FPA algorithms. If there are 250 UEs in the network, the ATN of D-U-LTE-Wi-Fi-QBRA-FPA will be 44.96% higher than the D-U-LTE-Wi-Fi-QBRA, 27.49% higher than the D-U-LTE-Wi-Fi-QBRA-PSO, and 13.02% higher than the D-U-LTE-Wi-Fi-QBRA-GA. This proves that the D-U-LTE-Wi-Fi-QBRA-FPA accomplished the highest average number of transmissions of all other models.

E. SINR

The SINR for a client in the D-U-LTE-WiFi-QBRA-FPA the setting is calculated as

$$SINR_i = \frac{p_D - U - LTE - WiFi - RA, i \times G_{D-U-LTE-WiFi-RA}}{I_D - U - LTE - \text{WiFi-RA}\ network}. \tag{10}$$

Here, $P_{D-U-LTU-WiFi-RA,I}$ is the total power at eNB from UE i, $G_{D-U-LTU-WiFi-RA,I}$ refer to the channel gain involving U-LTE and Wi-Fi, and lD-U-LTU-WiFi-RA network is the total interferences in the D-U-LTE-Wi-Fi-QBRA-FPA. The values of SINR for D-U-LTE-Wi-Fi-QBRA with different optimization algorithms are given in Table. 6. It showed that the mean SINR of D-U-LTE-Wi-Fi-QBRA-FPA was 2.86 dB, whereas the mean SINR of D-U-LTE-Wi-Fi-QBRA-GA, D-U-LTE-Wi-Fi-QBRA-PSO, and D-U-LTE-Wi-Fi-QBRA is 3.13 dB, 3.47 dB and 3.79 dB, correspondingly.

Fig. 7 portrays the SINR (in dB) obtained by the D-U-LTE-Wi-Fi-QBRA, D-U-LTE-Wi-Fi-QBRA-PSO, D-U-LTE-Wi-Fi-QBRA-GA and the proposed D-U-LTE-Wi-Fi-QBRA-FPA models. For 120m distance of UEs from eNB, the SINR of D-U-LTE-Wi-Fi-QBRA-FPA was 75.6% less than the D-U-LTE-Wi-Fi-QBRA, 60% less than the D-U-LTE-Wi-Fi-QBRA-PSO, and 33.3% less than the D-U-LTE-Wi-Fi-QBRA-GA. This reveals that the D-U-LTE-Wi-Fi-QBRA-FPA algorithm achieves the minimum SINR of all other models by selecting the proper network and channel for SU assignment.

F. INTERFERENCE

It is the total interferences caused by the U-LTE-Wi-Fi networks. Table. 7 gives the values of interference that occurred by the D-U-LTE-Wi-Fi-QBRA with different optimization models. It indicated that the mean interference of the proposed D-U-LTE-Wi-Fi-QBRA-FPA was −114 dB whereas the mean interference of D-U-LTE-Wi-Fi-QBRA-GA, D-U-LTE-Wi-Fi-QBRA-PSO, and D-U-LTE-Wi-Fi-QBRA is −139 dB, −152 dB, and −164 dB, correspondingly.

Fig. 8 shows the interference (in dB) caused by the D-U-LTE-Wi-Fi-QBRA, D-U-LTE-Wi-Fi-QBRA-PSO, D-U-LTE-Wi-Fi-QBRA-GA and the proposed D-U-LTE-Wi-Fi-QBRA-FPA algorithms. If the distance between UEs and eNB is 120m, then the interference caused by D-U-LTE-Wi-Fi-QBRA-FPA was -48dB which was smaller than the interference caused by all other models. This realizes that the proposed D-U-LTE-Wi-Fi-QBRA-FPA algorithm minimizes the total interference caused by the SU in the network by allocating proper resources, service rate capacities for all users, networks and channel during the interaction.

V. CONCLUSION

In this article, the network and channel selection problem in U-LTE networks has been investigated. The proposed D-U-LTE-Wi-Fi-QBRA-FPA algorithm was developed for network and channel selection for SU allocation. At first, an optimization problem for network and channel selection was modeled. This reduced the interference to PNs and the cost paid by SUs. After that, the optimization problem was solved by the FPA to obtain a near-optimal solution, i.e. the appropriate network and channel for SU allocation. Based on this model, the co-occurrence of Wi-Fi/IoT and LTE networks can be improved using the least cost that SUs have to pay to utilize the PN. At last, the simulation outcomes prove that the FPA attained a greater fitness value with less iteration in terms of both interference reduction and SU cost demands. Also, it proves that the proposed D-U-LTE-Wi-Fi-QBRA-FPA achieved a higher throughput and lesser transmission delay compared to the other classical models.

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