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Research Article

Utility-Based Joint Power Control and Resource Allocation Algorithm for Heterogeneous Cloud Radio Access Network (H-CRAN)

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The high density of H-CRAN associated with frequent UE handover may degrade the throughput. The infrastructure equipment like RRHs and BBUs consumes more energy to reduce UE energy consumptions. In this paper, we propose a utility-based joint power control and resource allocation (UJPCRA) algorithm for heterogeneous cloud radio access network (H-CRAN). In this framework, the power consumption of baseband units (BBUs), remote radio heads (RRHs), and macrocell base station (MBS) are estimated by predicting their dynamic loads. The data rate achievable for UE associated with each RRH and MBS on resource block RB_k is then estimated. The user wishing to connect to a RRH or MBS then checks the corresponding utility with minimum expected energy consumption and the maximum expected data rate. If any UE with high priority traffic connected to MBS could not achieve its desired data rate requirements, then it can cooperatively seek the assistance of any RRH for assigning the balance RBs. The throughput may be enhanced by the high density of H-CRAN and frequent UE handover. Inter- and intracell interference causes the H-CRAN macrocells' improved data rate to diminish. To lower UE energy consumption, infrastructure devices like RRHs and BBUs need more energy. As a result, there is a trade-off between operators and UE energy conservation. It is possible to determine the power consumption of BBUs, RRHs, and MBS using predictions of their dynamic loads. The UE may then forecast the data rate for each RRH and MBS on the resource block. When a user wishes to connect to an RRH or MBS, they look at the utility with the highest expected data rate and the least predicted energy usage first. A UE with high priority traffic connected to the MBS can cooperatively ask any RRH for assistance in allocating the remaining RBs if it is unable to achieve its intended data rate needs. Experimental results have shown that the proposed JRAUA algorithm achieves higher throughput, resource utilization, and energy efficiency with reduced packet loss ratio, when compared to the existing techniques.

1. Introduction

High-capacity services are anticipated to be provided by cellular networks in light of the rapid increase in mobile data traffic. Cellular networks have been examined, and a slew of network designs have been devised to satisfy the demands. Much design has been examined for future 5G cellular networks in order to increase the system's bandwidth and performance. Taking into account the rising demand for energy, researchers are conducting studies to find ways to reduce the amount of energy used. Representative designs include heterogeneous networks (HetNet), cloud radio access networks (CRAN), and heterogeneous CRANs (H-CRANs) [1]. By enabling interference reduction, scalability, and radio resource control, H-CRAN inherits the attractive advantages of heterogeneous networks (HetNet) and cloud computing.

C-RAN is a centralized design that isolates the RF processing subsystem from the base station processing section of various base stations (BSs) [2]. A CRAN is made up of remote radio heads (RRHs) and a pool of baseband units (BBUs). These RRHs are linked to the BBU pool via fronthaul connections. The RRHs are frequently used as RF transmitters and receivers, while the BBU pool is used for baseband signal processing and upper layer functions.

H-CRAN refers to a situation in which a CRAN and a macrocell base station (MBS) coexist. The MBS transmits control signals to the mobile users via the H-CRAN, making it easier to manage small-cell networks' mobility [3]. For 5G networks, researchers believe that the H-CRAN is a potential solution to meet the need for broadband and energy savings. BBU management may definitely be used to better coordinate transmit power across the network and minimize system energy usage [4].

The H-CRAN design incorporates both centralized processing and BS densification. A shorter distance between the BS and the end-users results in higher data speeds and more efficient spectrum utilization. A 5G-ready design confronts substantial problems because to the strict 5G requirements, such as large capacity growth and significant energy reductions [5, 6].

Designing energy efficient is a difficult and unexplored area of study: H-CRAN. The BBU pool in H-CRAN partly implements the baseband signal processing operations. Consequently, the H-energy CRAN's consumption model is substantially different from typical cellular networks. This means that current energy-efficient networking solutions cannot be directly applied to H-CRAN because of the differences. H-CRAN has been demonstrated to outperform CRANs and regular HetNets in terms of performance. Cooperative signal processing and radio resource allocation remain a hard design challenge, however [7].

1.1. Problem Identification and Proposed Solution. The high density of H-CRAN associated with frequent UE handover may degrade the throughput. Improved data rate provided by macrocells of H-CRAN degrades due to intra- and intercell interference. The infrastructure equipment like RRHs and BBUs consumes more energy to reduce UE energy consumptions. Hence, there is a tradeoff between energy conservation of operators and UEs [8]. Using predictions of their dynamic loads, the power consumption of BBUs, RRHs, and MBS is calculated. The data rate that the UE can achieve for each RRH and MBS on the resource block is then predicted. When a user wants to connect to an RRH or MBS, they first examine the utility with the lowest predicted energy usage and highest expected data rate. When a UE with high priority traffic connected to the MBS is unable to meet its intended data rate needs, it can collaboratively ask any RRH for help in allocating the remaining RBs.

2. Related Works

For heterogeneous C-RANs, Lee and his colleagues [3] have developed a new combined remote radio head (RRH) activation, user-RRH pairing, and resource allocation strategy (H-CRANs). In the beginning, they came up with an optimization problem for H-CRANs that would maximize their energy efficiency. This is followed by the formation of a low-complexity, suboptimal solution. Three main operations make up our mechanism proposition: (1) RRH activation is based on greedy RRH selection; (2) user-RRH pairing is based on channel quality; and (3) dual decomposition is used to solve the resource allocation problem.

In a situation with two cloudlet servers, Rodrigues et al. [9] have provided a solution for reducing service delay. Virtual machine migration and transmission power control are two of the method's key goals. The proposed approach is compared to two existing conventional methods using a mathematical model of the problem. These methods have a single focus and only seek to improve transmission delay or processing delay, but not both. In order to combat edge cloud computing's service delay problem, researchers recommend a dual emphasis strategy.

A contract-based interference coordination system has been presented by Peng et al. [10], which includes three scheduling schemes and divides the downlink transmission interval into three phases correspondingly. When it comes to contracting with an MBS, an individual rational constraint is used to determine whether or not a contract should be accepted from the BBU pool of all RRHs, which is picked as the principal that would provide an agreement. When both the principal and the agent have perfect channel state information (CSI), an optimum contract design that maximizes rate-based utility may be found. Even in cases where only a limited amount of channel estimate data is available, contract optimization is handled. These findings are corroborated by Monte Carlo simulations which demonstrate that the proposed framework may greatly boost transmission data rates above baselines, proving the efficiency of our contract-based method.

SDN and SDWN approaches have been proposed by Marotta et al. [8] for the construction of flexible, programmable, and sustainable H-CRAN infrastructures for the incoming next-generation cellular networks to reach the area throughput objective Moreover, they discussed how SDWN may be used in combination with H-CRAN in order to achieve a comprehensive SDWN-enabled cellular network. They also conducted a case study for H-CRAN, where an SDWN controller assigns and distributes RRH channels depending on UE handovers.

EE performance may be measured using an average weighted metric, as described by Peng et al. [11]. It has been suggested that, using the Lyapunov optimization framework, a dynamic network-wide beam former design method be developed, which takes into account the average and instantaneous power limits as well as the interference requirements.

Network-wide beam former design technique can be used to solve the nonconvex average-weighted EE performance optimization problem with this general weighted minimum mean square error approach.

3. Proposed Solution

3.1. Overview. In this paper, we propose a utility-based joint power control and resource allocation algorithm for H-CRAN. The CRAN (cloud radio access network) is a radio access network (RAN) architecture based on centralized cloud computing that supports collaborative radio technology support and real-time virtualization. It provides large-scale deployment, collaborative radio technology support, and real-time virtualization capabilities. In this framework, the power consumption of BBUs, RRHs, and MBS are estimated by predicting their dynamic loads [12–14]. The data rate achievable for UE associated with each RRH and MBS on resource block is then estimated. The user wishing to connect to a RRH or MBS then checks the corresponding utility with minimum expected energy consumption and the maximum expected data rate. If any UE with high priority traffic connected to MBS could not achieve its desired data rate requirements, then it can cooperatively seek the assistance of any RRH for assigning the balance RBs [15, 16].

3.2. System Model. The proposed framework consists of a number of remote radio heads (RRHs) which are connected to a centralized baseband unit (BBU) pool, via fronthaul links. The BBU pool is interfaced to various macrobase stations (MBSs) through backhaul links. Figure 1 shows the architecture of H-CRAN. Figure 2 shows the operations of H-CRAN.

3.3. Estimation of Power Consumption. In this framework, the power consumption of BBUs, RRHs, and MBS are estimated by predicting their dynamic loads, i.e., the number of UEs connected with RRHs and MBS [17–19].

Let H_{RU} be the past resource utilization of VM.

Let z be the size of workloads.

The workloads on the assigned virtual machines (VMs) in cloud environments are predicted by monitoring the past resource utilizations and the size of the workloads [20].

$$\mathrm{WLBBU} = \left[\frac{d}{p}\right] * z, \tag{1}$$

where d is resource utilization's mean value and p is resource utilization peak value

$$d = \frac{(VM1 + VM1 + VM1 \cdots + VM1)}{T}, \tag{2}$$

$$p = \max\ (VMt). \tag{3}$$

The dynamic power required on each BBU unit is estimated based on the predicted work load:

$$\mathrm{PBBU} = \sum \mathrm{WL}_{\mathrm{BBU}}. \tag{4}$$

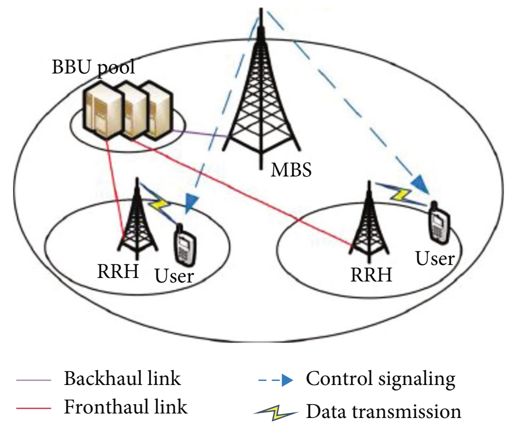

Figure 1: Architecture of H-CRAN.

Similarly, the power consumption of each RRHs and the MBSs are estimated as follows:

$$\mathrm{PRRH} = \sum \mathrm{WL}_{\mathrm{RRH}}, \tag{5}$$

$$\mathrm{PMBS} = \sum \mathrm{WL}_{\mathrm{MBS}}. \tag{6}$$

3.4. Data Rate Achievable for UE. The data rate achievable for UE associated with each RRH on resource block RB_k is then estimated [3].

$$\mathrm{DRRRH} = \mathrm{BW}\ \log 2 \left(1 + \frac{QR}{\sum_{i\in S\backslash\{s\}} a_i QiRiu + x0}\right), \tag{7}$$

where BW is the bandwidth of a subchannel, Q is a nonnegative transmission power of RRH s on a subchannel, R is the downlink channel gain between the RRH and user u on a subchannel, and x_0 is the additive white Gaussian noise.

Similarly, the data rate achievable for each UE associated with MBS is also estimated.

$$\mathrm{DRMBS} = \mathrm{BW}\ \log 2 \left(1 + \frac{QR}{\sum_{i\in S\backslash\{s\}} a_i QiRiu + x0}\right). \tag{8}$$

3.5. Expected Data Rate. For each UE associated with RRH or MBS, its expected data rate is estimated based on the traffic type (real-time or nonreal-time). Table 1 shows the types of traffic arrival pattern.

Prediction accuracy is estimated using the following equation:

$$\frac{1}{K * x} \sum_{K=0}^{K-1} \sum_{i=0}^{X} \frac{\left|tlp_{k+1}^{t} - tl(i/k+1)\right|}{tl_{\max}^{i}}, \tag{9}$$

where K denotes the total number of considered time slots and $tl_{\max}$ denotes the maximum traffic loads of switch i; Expected Date Rate $\mathrm{EDR}_{\mathrm{UE}} = \mathrm{BW}\ \log_2 (\mathrm{DR}_n)$.

3.6. Resource Allocation. Utility function U_{RRH} is derived for each RRH in terms of expected energy consumption (energy

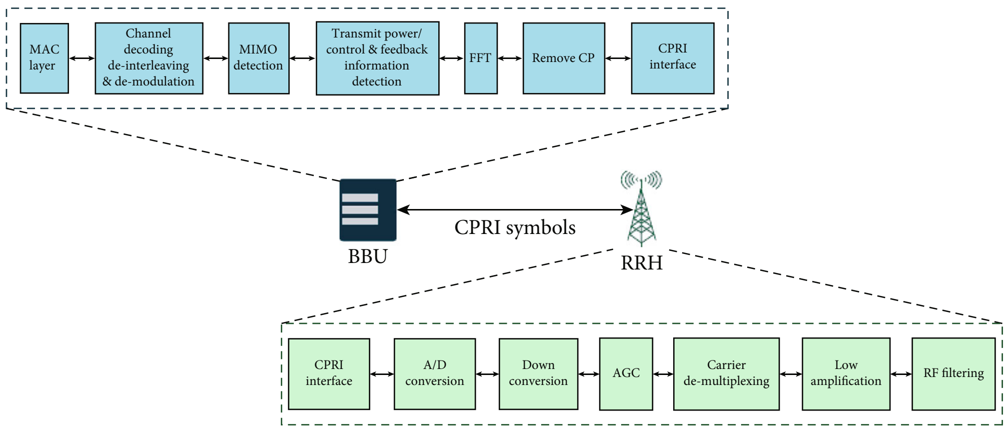

Figure 2: Operations of H-CRAN.

Table 1: Types of traffic arrival patterns.

Traffic arrival pattern	Data rate	Traffic type
Bursty	DR1	Real-time voice
Periodic	DR2	IoT
Constant	DR3	Best effort

consumption of RRH and BBU) and the expected data rate for each RB as follows:

$$\mathrm{URRH} = \sum \{P_{\mathrm{RRH}} + \mathrm{EDR}_{\mathrm{RB}}\}. \quad (10)$$

Similarly, a utility function UMBS is derived for each MBS in terms of expected energy consumption of MBS and the expected data rate for each RB as follows:

$$\mathrm{UMBS} = \sum \{P_{\mathrm{MBS}} + \mathrm{EDR}_{\mathrm{RB}}\}. \quad (11)$$

If the user wishes to connect to a RRH or MBS, then the corresponding utility ($\mathrm{UE}_{\mathrm{RRH}}$ and $\mathrm{UE}_{\mathrm{MBS}}$) needs to be checked. Then, a utility that satisfies the following constraints needs to be selected:

(i) The expected energy consumption should be minimum

(ii) The expected data rate should be maximum

If any UE with high priority traffic connected to MBS could not achieve its desired data rate requirements, then it can cooperatively seek the assistance of any RRH for assigning the balance RBs.

4. Experimental Results

4.1. Experimental Settings. The proposed UJPCRA algorithm is implemented in OpenAirInterface (OAI) 5G–RAN platform [21] which is an open-source software that implements the 5G networks completely encompassing the 3GPP standard protocol. The L2 simulation framework uses actual radios and offers the possibility of connecting the OAI UE with the gNB in 5G through the nFAPI interface defined by the Small Cells Forum [12] [22–24].

Table 2: Simulation parameters.

Simulation parameter	Value
Number of subchannels	100
Channel bandwidth	100 MHz
Channel model	Rayleigh fading
Noise power spectral density	-174 (dBm/Hz)
SINR threshold	0 dB
Maximum outage probability	0.05
Number of resource blocks	20
RRH maximum transmission power	30 dBm
Constant power of alive RRH	6.8 Watts
RRH sleep power	4.3 Watts
Constant power of backhaul link	13.25 W^3
Constant power of fronthaul link	13 W
Minimum required data rate of UE	512 kbps
Radius of macrocell	500 m
Number of RRHs	5 - 20
Number of UEs in each cell	20-100

In this work, a single-cell H-CRAN network, which consists of a macrocell BS of radius 500 m and 5 femto cell RRHs with various set of UEs is considered. The RRHs are randomly deployed within the macrocell and the small cells are deployed at random locations. All the users are uniformly distributed within the network. Table 2 shows the simulation parameters.

4.2. Results and Discussion. The proposed UJPCRA algorithm is compared with joint resource allocation and user association (JRAUA) [3] and H-CRAN energy-efficient radio resource management (HERM) [25] techniques. The performance is evaluated in terms of expected throughput, resource utilization, packet loss ratio, and energy efficiency.

4.2.1. Varying the UEs in RRH. In this section, experiments are conducted by varying the number of UEs in each RRH

Table 3: Results of throughput.

No. of UEs	JRA-UA (Mb)	UJPCRA (Mb)	HERM (Mb)
20	84.7	91	87.2
40	87.1	92.4	89.1
60	88.1	96.2	91.7
80	90.1	98.3	93.4
100	92.2	98.5	96.7

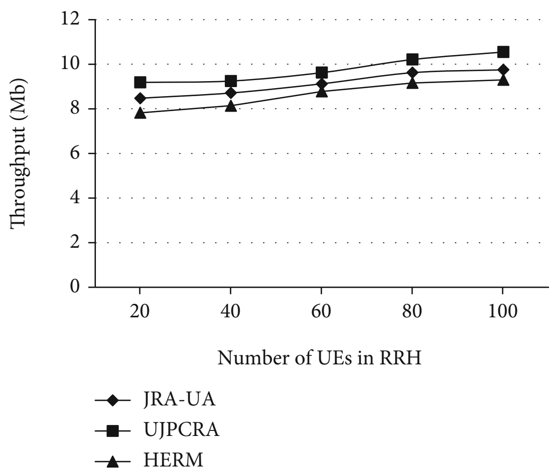

Figure 3: Throughput for varying UEs.

Table 4: Results of packet loss ratio.

No. of UEs	JRA-UA	UJPCRA	HERM
20	5.00	3.00	4.00
40	6.00	3.30	5.00
60	6.00	4.00	5.50
80	6.30	4.50	5.70
100	7.00	5.00	6.50

as 20, 40, 60, 80, and 100. Table 3 shows the results of expected throughput.

Figure 3 shows the results of throughput for different numbers of UEs. It can be observed that the throughput of UJPCRA was 6% higher than JRAUA and 12% higher than HERM. Table 4 shows the results of the packet loss ratio.

Figure 4 shows the results of packet loss ratio for different numbers of UEs. It can be observed that the packet loss ratio of UJPCRA was 35% lesser than JRAUA and 26% lesser than HERM. Table 5 shows the results of resource utilization.

Figure 5 shows the results of resource utilization for different numbers of UEs. It can be observed that the resource utilization of UJPCRA was 7% higher than JRAUA and 4% higher than HERM. Table 6 shows the results of energy efficiency.

Figure 6 shows the results of energy efficiency for different numbers of UEs. It can be observed that the energy efficiency of UJPCRA was 59% higher than JRAUA and 21% higher than HERM.

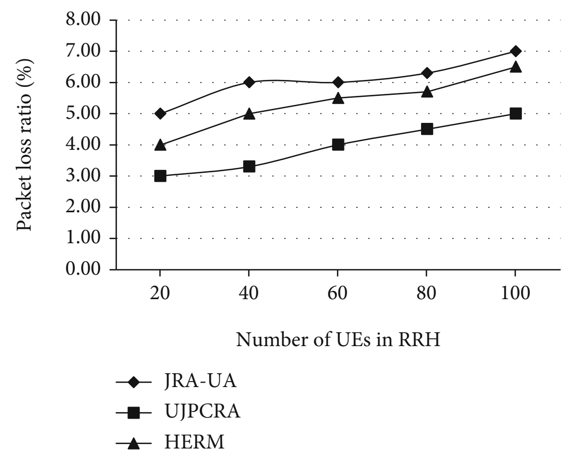

Figure 4: Packet loss ratio for varying UEs.

Table 5: Results of resource utilization.

No. of UEs	JRA-UA (%)	UJPCRA (%)	HERM (%)
20	84.7	91	87.2
40	87.1	92.4	89.1
60	88.1	96.2	91.7
80	90.1	98.3	93.4
100	92.2	98.5	96.7

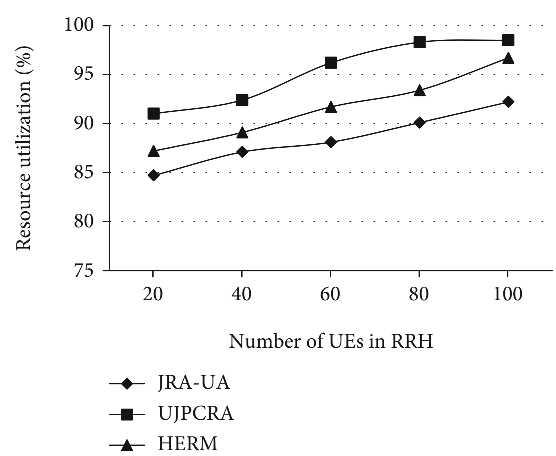

Figure 5: Resource utilization for varying UEs.

Table 6: Results of Energy Efficiency.

No of UEs	JRA-UA (Mb/Joules)	UJPCRA (Mb/Joules)	HERM (Mb/Joules)
20	0.06	0.32	0.25
40	0.15	0.35	0.28
60	0.18	0.41	0.33
80	0.22	0.44	0.36
100	0.26	0.51	0.38

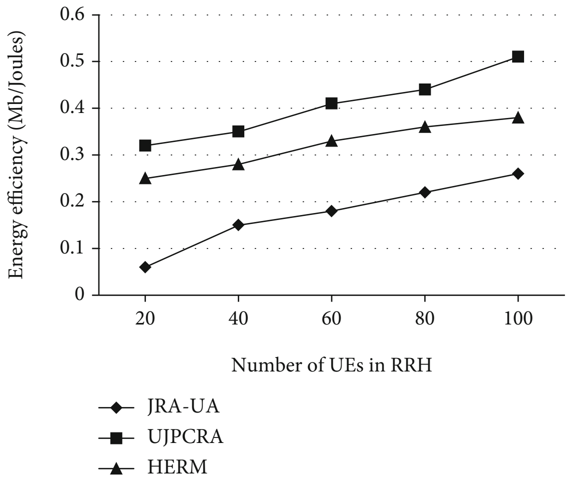

Figure 6: Energy efficiency for varying UEs.

Table 7: Results for throughput.

No of RRHs	JRA-UA (Mb)	UJPCRA (Mb)	HERM (Mb)
5	8.47	9.18	7.82
10	12.71	16.24	10.14
15	19.12	26.62	16.78
20	22.62	29.20	20.15

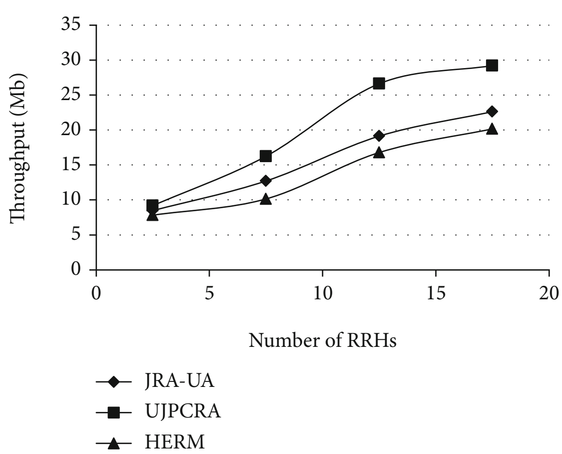

Figure 7: Throughput for varying RRHs.

4.2.2. Varying the RRH. In this section, experiments are conducted by varying the number of RRHs in the macrocell as 5, 10, 15, and 200 with 20 UEs. Table 7 shows the results of expected throughput.

Figure 7 shows the results of throughput for different numbers of RRHs. It can be observed that the throughput of UJPCRA has 20% higher than JRAUA and 30% higher than HERM. Table 8 shows the results of energy efficiency.

Figure 8 shows the results of energy efficiency for different numbers of RRHs. It can be observed that the energy efficiency of UJPCRA was 50% higher than JRAUA and 19% higher than HERM.

Table 8: Results of energy efficiency.

No. of RRHs	JRA-UA (Mb/Joules)	UJPCRA (Mb/Joules)	HERM (Mb/Joules)
5	0.06	0.32	0.25
10	0.21	0.39	0.32
15	0.27	0.46	0.37
20	0.34	0.5	0.41

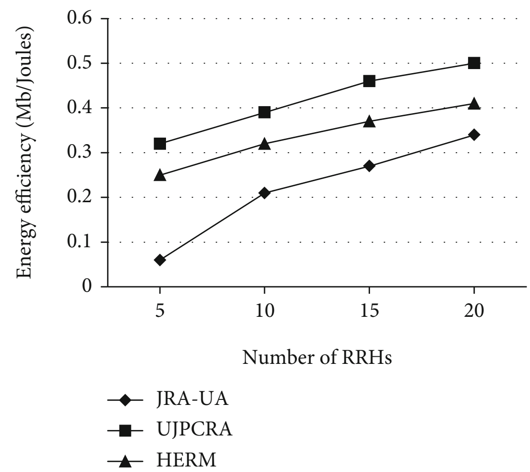

Figure 8: No. of RRHs vs. energy efficiency.

5. Conclusion

In this paper, we have proposed a utility-based joint power control and resource allocation algorithm for heterogeneous cloud radio access network (H-CRAN). In this framework, the power consumption of BBUs, RRHs, and MBS are estimated by predicting their dynamic loads. The data rate achievable for UE associated with each RRH and MBS on resource block is then estimated. The user wishing to connect to a RRH or MBS then checks the corresponding utility with minimum expected energy consumption and the maximum expected data rate. If any UE with high priority traffic connected to MBS could not achieve its desired data rate requirements, then it can cooperatively seek the assistance of any RRH for assigning the balance RBs. Experimental results have shown that the proposed JRAUA algorithm achieves higher throughput, resource utilization, and energy efficiency with reduced packet loss ratio, when compared to the existing techniques. Throughput results for different numbers of UEs show that UJPCRA has 6% higher throughput than JRAUA and 12% higher throughput than HERM; packet loss ratio results for different numbers of UEs show that UJPCRA has 35% less packet loss than JRAUA and 26% less packet loss than HERM; resource utilization results for different numbers of UEs show that UJPCRA has 7% higher throughput than JRAUA and 4% higher throughput than HERM; and for the energy efficiency for various numbers of RRH, UJPCRA is 50% more efficient than JRAUA and 19% more efficient than HERM.

Data Availability

The datasets used and/or analyzed during the current study are available from the corresponding author on reasonable request.

Conflicts of Interest

The authors declare that they have no conflicts of interest.

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