An Energy-Aware Data Offloading Scheme in Cloud Radio Access Networks

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***Abstract*—Mobile data offloading has become an important issue for mobile cellular network in recent years. Existing energy-aware data offloading scheme for mobile cellular network makes the offloading decision only according to the current local information of the user equipment (UE) and thus the UE cannot switch to a more efficient way to offload even other UEs have released their transmission resources later on. Hence, in this paper, a centralized offloading scheme based on cloud radio access networks (C-RAN) is proposed so as to make the offloading more efficient. The C-RAN based centralized offloading scheme considers all the situation of UEs of a baseband unit (BBU) at the same time and thus the BBU can do a better offloading decision for those UEs. At the beginning, each UE, who needs offloading, sends an offloading request to the BBU. When there is any UE released the transmission resource, the corresponding BBU will try to fulfill the pending offloading requests of the UEs. The corresponding BBU considers the pending UEs' transmission rate and energy consumption of the cellular network as well as the Wi-Fi network, and then makes offloading decisions for those UEs so as to save more energy and achieve higher throughput at the macroscopic level. Extensive simulations have been conducted to illustrate that the proposed energy-aware data offloading scheme can reduce the energy consumption and turnaround time, and enhance the transmission throughput.**

***Index Terms*—C-RAN, offloading, heterogeneous network, energy-aware algorithm, energy-saving.**

I. Introduction

With the increasing of global mobile data traffic, mobile data offloading has become an important issue. According to the forecast data by Cisco [1], more than half of the traffic from mobile-connected devices (almost 17 exabytes/month) will be offloaded to the fixed network by means of Wi-Fi devices and femtocells.

Recently, cloud radio access network (C-RAN) has been proposed in this direction by China Mobile [2]. C-RAN is a natural evolution of the distributed Baseband Transceiver Station (BTS), which is composed of the baseband unit (BBU) and the remote radio heads (RRHs). Because of C-RAN's unified open platform, C-RAN can support heterogeneous network. This cannot only make operators upgrade their mobile communication technology standards, but also can make offloading become more efficient. Besides, C-RAN is not a new mobile radio standard to replace 3G/4G/B4G standard. C-RAN aims to provide a low cost and high performance green architecture and can be easily deployed on any mobile network.

Some existing data offloading schemes [4][5] consider the transmission quality issue; some consider the energy efficiency issue [6][7] but are designed for delay tolerant applications. The data offloading scheme [8], which considers the energy efficiency issue for smartphones, makes the offloading decision only according to the current local information of the user equipment (UE) that the UE cannot switch to a more efficient way to offload because it cannot realize and make full use of the situation when some UEs have released their transmission resources later on.

In this paper, an energy-aware data offloading scheme for C-RAN is proposed that the BBU can make a better decision by considering the global situations of UEs and access networks within the BBU, and the UE can realize its power consumption according to the scheme proposed in [3] . When several UEs request for offloading, the BBU will schedule the offloading according to the global situations so as to raise energy efficiency and achieve higher throughput. The proposed centralized offloading scheme not only can improve energy and transmission efficiency of the UEs, but also can reduce the average turnaround time of each UE and thus the operator can serve more UEs at a certain period of time.

The rest of the paper is organized as follows. In section II, related work is described. Section III describes the system model, problem formulation, and basic idea of our approach. Section IV describes the proposed energy-aware offloading scheme in Cloud Radio Access Network. Simulation results are presented in section V. Section VI concludes this paper.

II. Related Works

Mobile data offloading has become an important and popular issue in the cellular network. Most researches talk about transmission quality for mobile equipments [4][5]. Some other studies concern more issues, like offloading to Wi-Fi access point (AP) for power saving on delay-tolerant applications [6][7] and real time-data applications.

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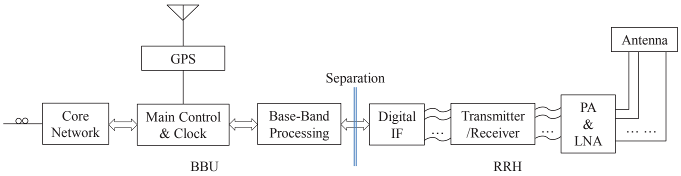


Fig. 1. The separation of the BTS functions.

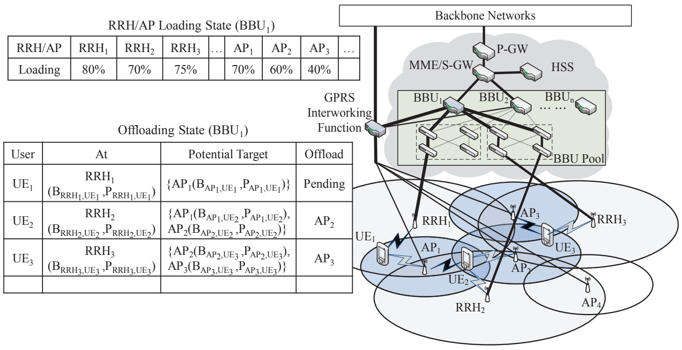


Fig. 2. The energy-aware data offloading scheme in C-RAN.

Two enhanced offloading methods that guarantee session continuity for non-seamless wireless local area network (WLAN) offloading is proposed in [4]. How to maintain IP sessions in the dynamics of available radios is also described in this paper. Amani *et al.* [5] propose a policy based offloading framework for cellular network which is based on a cost function approach by discussing user centric (signal power and access fee), network centric (utilization and load), and hybrid policies. Balasubramanian *et al.* [6] develop an energy consumption model of network activity for each technology. Using this model, Balasubramanian *et al.* develop a protocol that reduces energy consumption of mobile applications with small-delay-tolerant. Youngbin *et al.* [7] schedules multiple data streams of delay-tolerant applications with varying size and delay tolerance, onto networks with varying coverage and bandwidth, in order to minimize cellular data usage. Ding *et al.* [8] intelligently aggregate the collaborative power of cellular operators, Wi-Fi service providers and end-users. An energy-aware algorithm for energy-constrained devices is designed to assist the offloading decision. The goal of energy-aware offloading is to improve the data transmission quality and reduce the transmission power consumption of smartphone. [8] present a collaborative Wi-Fi-based mobile data offloading architecture - MADNet. This scheme first considers whether the UE is feasible to offload data traffic to Wi-Fi networks [9][10] and then check whether the performance of AP is good enough for smartphone offloading. After that, the UE calculates the energy consumption for all APs and 3G networks and find out the most energy-saving way of transmission.

In MADNet, most of the offloading decisions are made by the UE itself. The UE can only consider the situation around itself and hence the UE may not know what happened not around itself. The main objective of this paper is to design an energy-aware offloading scheme in C-RAN. With the centralized characteristic of C-RAN, the BBU can consider all APs' and RRUs' load changing which the UE cannot detect. After the BBU realizes the situations of all the access networks, the BBU can make a better decision for more UEs to offload and achieve energy efficient transmission at the same time.

III. Preliminaries

A. System Model

Based on C-RAN White Paper [2], a traditional base transmission station (BTS) like eNB can be divided into a baseband unit (BBU) and remote radio heads (RRHs) as shown in Fig. 1. The basic idea of C-RAN is to separate the BBUs form eNB, and centralize those BBUs to the BBU pool with the high-performance programmable processors and real-time virtualization technology. With the characteristic of flexibility, C-RAN has better capability for supporting multi-standard operation, and can be easily deployed with heterogeneous network in many ways.

Salkintzis *et al.* [11] talk about how to use GPRS interworking function (GIF) to combine WLANs and cellular data networks into integrated wireless data environments. Fig. 2 illustrates the C-RAN architecture with GPRS interworking function (GIF). GIF connect to BBUs with tight coupling instead of connecting to S-GW in [11]. In this architecture, GIF not only can transmit data with BBUs but also can connect to internet directly. GIF can transmit data with BBUs for reducing offloading delay time by pre-fetching data from BBUs, and can connect to internet for offloading data from core network. BBUs can manage the traffic load of all access networks and detect signal strength between UEs and APs or RRHs. In this scheme, APs are binding with the most related RRH. If this AP located at the RRH's range, the AP will bind with this RRH. Based on the BBU-RRH separating characteristic of C-RAN, when RRH is mapping to different BBU, those APs binding with this RRH will also managed by the BBU. As for the power consumption model, the one proposed in [3] is adopted.

B. Basic Idea

The basic idea of this work is to use the centralized characteristic of C-RAN to schedule the offloading for each UE so that the UE can achieve better transmission quality and energy consumption efficiency.

The BBU can assign UEs to connect to RRH or offload data from RRH to a Wi-Fi AP which can let the UE satisfy the bandwidth requirement and have a better energy efficiency. Also, the BBU can assign the offloading of a UE form an AP to another AP so as to achieve better efficiency or release this AP's resource for other UEs. This paper calls it indirect offloading. When all of the APs are busy, the traffic of the UEs cannot be offloaded and the offloading is pending. Whenever enough resource is released, the BBU will make the best offloading decision so as to improve the transmission and energy efficiency of the pending offloading UEs.

There are two main mechanisms in this paper : First, BBU will consider which AP can offload data traffic and whether any other nearby AP also need this resource. Second, BBU will calculate which UE can use this resource with the best power efficiency.

IV. The Proposed Energy-Aware Data Offloading Scheme in C-RAN

This section presents the energy-aware data offloading scheme in C-RAN. The main objective of the energy-aware data offloading scheme is to reduce the energy consumption of an UE for extending the UE's battery lifetime and also enhance the offloading data traffic for better wireless transmission quality. An UE can connect to an RRH or an AP. All APs and RRHs are managed by BBUs. The BBU also can assign an UE to connect to one of those APs and RRHs. There are three phases in this scheme, including resource estimation and request transmission phase, neighbor offloading AP/RRH detection phase, and serving AP/RRU selection phase.

A. Phase I: Resource estimation and request transmission

This phase talks about how to estimate every information for offloading requests. After an UE estimate those needed information, the UE will generate a data offloading request packet and send the request to the BBU. The offloading request packet is shown as bellow: $Request_{UE_i}(C_w, E_T, E_{oo}, RRH_w(B_{RRH_w,UE_i}, P_{RRH_w,UE_i}), ..., AP_y(B_{AP_y,UE_i}, P_{AP_y,UE_i}), ...)$, where C_w is the offloading capacity of a UE, E_T is the cellular radio state transition overhead (in terms of energy) including head and tail, E_{oo} is the Wi-Fi offloading overhead including turning on or off Wi-Fi radio, B_{RRH_w,UE_i} is the bandwidth between RRH$_w$ and UE$_i$, B_{AP_y,UE_i} is the bandwidth between AP$_y$ and UE$_i$, P_{RRH_y,UE_i} is the transmission power consumption per second between RRH$_y$ and UE$_i$, and P_{AP_y,UE_i} is the transmission power consumption per second between AP$_y$ and UE$_i$.

The UE can detect which APs and RRHs that the UE can connect with. In the $Request_{UE}$ packet, there are two categories of data. One category of data is relating to the UE itself, like C_w, E_T, E_{oo}. The other category of data is relating to the connection between the UE and the access network, including the bandwidth and the power consumption when the UE connects to the AP/RRH. The algorithm of this phase is shown as follows.

S1: When UE_i wants to request some content from the Internet, UE_i detect whether UE_i can contact to any AP. If so, UE estimate its offloading data size C_w by predicting Wi-Fi connectivity [10]. If the offloading data size C_w is not zero, it means that UE_i is capable to offload data traffic to Wi-Fi networks.

S2: UE_i estimate its cellular radio interface overhead and the Wi-Fi interface offloading overhead, E_T and E_{oo}.

S3: UE_i detects which AP/RRH can be contacted with, estimates the bandwidths B_{RRH,UE_i},B_{AP,UE_i} [12] and power consumptions [3] P_{RRH,UE_i},P_{AP,UE_i} for all AP/RRH which UE_i can contact with.

S4: UE_i generates the offloading request packet $Request_{UE_i}$ and sends the packet to the BBU through the RRH which UE_i is connecting to. The BBU updates the offloading state table according to this packet.

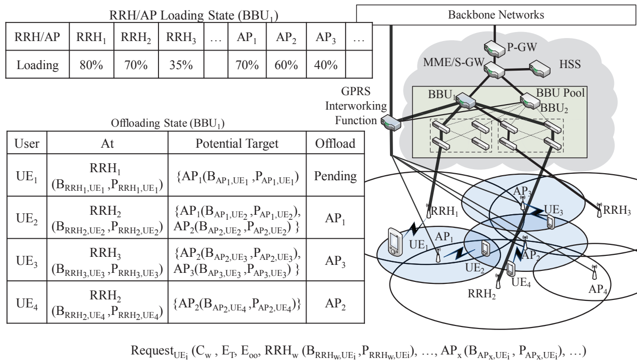


Fig. 3. Phase I: Resource estimation and request transmission.

An example of the resource estimation and request transmission phase is given in Figure 3 to illustrate the scenario of the UE_1 sending the offloading request packet. UE_1 wants to request some data or content from Internet. First, UE_1 detects that it can connect to AP_1, and predicts the offloading data size C_w. After checking that it is possible to connect to AP_1 and the C_w is larger than 0, UE_1 estimates the transmission overhead E_T and E_{oo} for helping the BBU doing offloading decision. Because UE_1 can detect RRH_1 and AP_1, UE_1 predicts B_{RRH_1,UE_1}, P_{RRH_1,UE_1} and B_{AP_1,UE_1}, P_{AP_1,UE_1}. After getting all the needed information for offloading, UE_1 generates an offloading request packet

B. Phase II: Neighbor Offloading AP/RRH Detection

One of the characteristics of this energy-aware offloading scheme is sharing the transmission resource to the busiest and needed AP or RRH. That means when an AP's resource is released, the BBU will try to assign this AP's resource to an already offloaded UE for releasing resource of another more busy AP. In some cases, this offloading also can reduce the load of other busy RRHs. This neighbor offloading AP/RRH detection phase aims to detect the neighboring APs and find out which one of those neighboring APs is the busiest AP. The algorithm of this phase is shown as follows.

S1: When an UE is end of the transmission, the UE release the resource of the AP or RRH. If the UE connects to a Wi-Fi AP, the UE will also turn off it's Wi-Fi radio interface for saving power, and the AP will send a notice to the BBU and change the loading state table in the BBU. If the UE connects to the cellular network RRH, the BBU will also get the notice that the resource block is released.

S2: When the BBU gets the resource released notice, the BBU checks the loading state from the loading state table to see if this AP_w/RRH_w has the free resource. If this AP_w/RRH_w is capable of offloading more UEs,

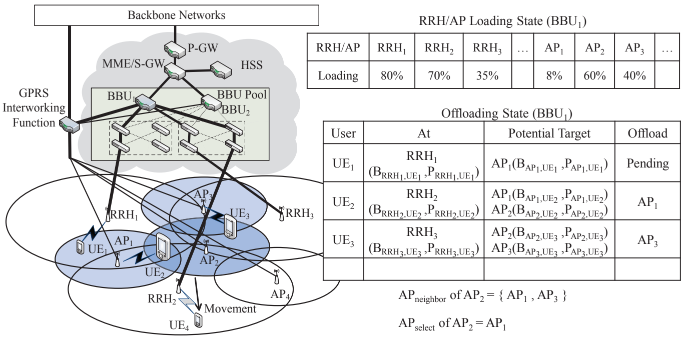


Fig. 4. Phase II: Neighbor offloading AP/RRH detection.

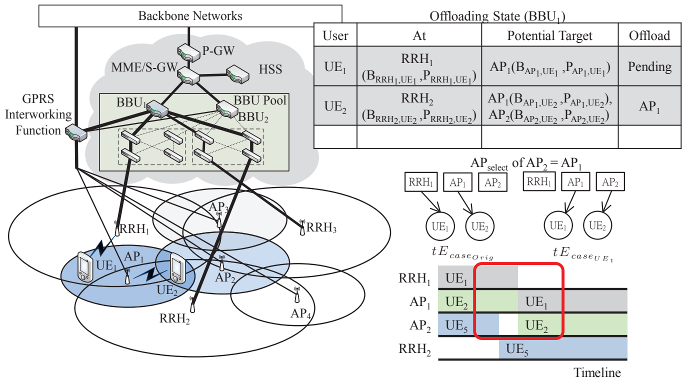


Fig. 5. Serving AP selection with indirect offloading.

the BBU find out the set of neighboring APs $AP_{neighbor}$, for considering whether to share its resource to those APs. If an UE, which can contact to AP_x, finds the other APs which this UE can contact with from the offloading state table, the BBU adds those APs to the set $AP_{neighbor}$ of AP_w, where $AP_{neighbor}$ of $AP_w = \{AP_x,\ AP_y,\ \dots\dots\}$

S3: If the set $AP_{neighbor}$ is not null, the BBU find out the busiest area from $AP_{neighbor}$. The busiest AP covering area can be decided by the numbers of pending offloading request. The busiest AP covering area has the most offloading requests, and have the most UEs needed to be offloading. The BBU saves this AP as AP_{select}.

S4: If the resource is released by AP_w, the BBU checks whether there is any pending offloading UE who also needs AP_w's resources, and the BBU compares the amount of pending offloading UEs of AP_w and the amount of pending offloading UEs of AP_{select} to realize which AP is the busiest. More pending offloading requests for an AP indicates this AP's coverage area is the busiest area. If the AP_w is busier, save this AP_w as AP_{select}.

An example of the neighbor offloading AP/RRH detection phase is given in Figure 4 to illustrate the scenario of the UE_4 released the resource of AP_2, and BBU_1 finds the $AP_{neighbor}$ set of AP_2 from the offloading table. After UE_4 released the resource of AP_2, AP_2 sends a notice to BBU_1 for updating the RRH/AP loading state table. When BBU_1 notice that the loading of AP_2 is low, BBU_1 try to find the $AP_{neighbor}$ set of AP_2, AP_1 and AP_3. AP_4 has no UE that can contact with AP_2 and AP_4, AP_4 is not in $AP_{neighbor}$. After checking $AP_{neighbor}$ is not null, BBU_1 compares the pending offloading request amounts of all elements in $AP_{neighbor}$, and chooses AP_2 as the AP_{select}. BBU_1 compares the pending offloading request amounts of AP_1 and AP_2 and indicates that the AP_{select}, AP_1, is the busiest AP. If the AP_2 has more requests than the AP_1, BBU_1 marks AP_2 as the AP_{select}.

C. Phase III: Serving AP/RRH selection

The serving AP/RRH selection phase aims to decide which UE can offload the traffic flow. In other words, the BBU selects an AP/RRH for satisfying the pending offloading request with the most appropriate UE. The serving AP/RRH selection phase is classified into two cases: (1) Serving AP selection and (2) Serving RRH selection.

1) Case 1: Serving AP selection: In Case 1, the released resource comes from AP_w, the BBU try to find the UE which can help the indirect offloading if needed, and choose an UE which can get this resource directly or indirectly. The algorithm is shown as follows.

S1: If AP_w and AP_{select} are the same AP, the BBU goes to S3 for direct offloading. If not, the BBU try to find UE_j which can help the indirect offloading. The BBU calculates the energy consumption of all UEs which can both connect to AP_w and AP_{select}, and finds UE_j for helping by checking if $(ECR_{AP_{select},UE_j} - ECR_{AP_w,UE_j})$ is the maximum and larger than zero, and makes sure that the transmission quality of UE_j will not became worse. If not, the BBU does not use the AP_{select} and set AP_w as AP_{select} and goes to S3.

S2: The BBU decides which UE the BBU will assign the resource to for indirect offloading. For each available UE's request for offloading to AP_{select} as an option. An option is a set of mapping pair between the UE and the RRU or between the UE and the Wi-Fi AP. The BBU calculates the total energy consumption tE_{Option_a} with all related UEs who connects to AP_{select}.

S3: If AP_w and AP_{select} are the same AP, the resource of AP_w can directly assign to the UEs who is waiting for AP_w's resource. AP_w and AP_{select} are the same AP means that AP_w area is the busiest AP area. Just like S2, for each available offloading UE's request as an option, calculates the tE_{Option_a} for all related UEs.

S4: The BBU finds the option which has the minimum energy consumption as the final decision. In other word, the BBU calculates the energy consumption (tE_{Option_a}) for each option, choose the option with the minimum value, and use it as the decision.

An example of the serving AP selection with indirect offloading is given in Figure 5 to illustrate the scenario of the resource of AP_2 is released. According to phase 2, BBU_1 can realize that the AP_{select} is AP_1. BBU_1 finds out some UEs from offloading state table, and those UEs not only are

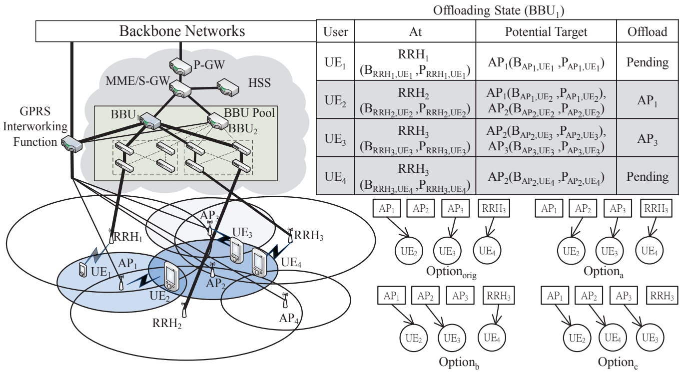


Fig. 6. Serving AP selection with direct offloading.

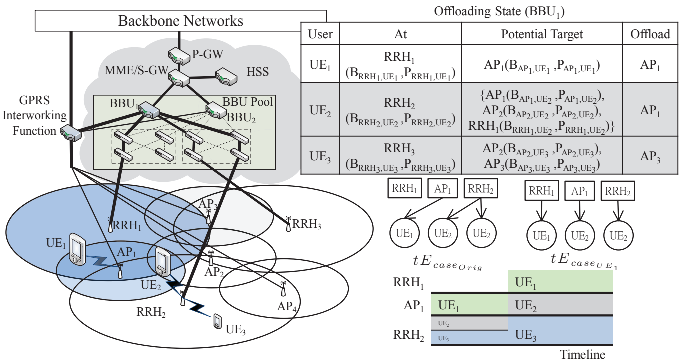


Fig. 7. Phase III: Phase III: Serving AP/RRH selection.

offloading to AP_1 and also can contact with AP_2. Because tE_{Option_1} is smaller, BBU_1 choose option 1 as the decision.

Another example of serving AP selection with direct offloading is given in Figure 6 to illustrate the scenario of that there are more pending request for AP_2 than AP_1 or there is no UE can help indirect offloading when the resource of AP_2 is released. When BBU_1 cannot find any UE for helping indirect offloading, BBU_1 set AP_2 as AP_{select}.

2) Case 2: Serving RRH selection: The released resource comes from RRH_w, the BBU chooses an UE to get this resource directly for reducing the load of AP or other RRH. This case aims to make an UE switch its load to an RRH for release an AP's resource and the AP's released resource can reduce the load of other RRH. The algorithm is shown as follows:

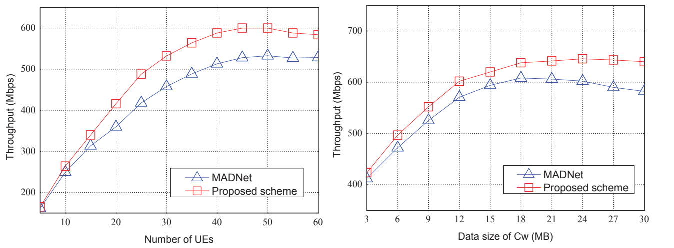
S1: Just like case1, the BBU try to find UE_j who can switch its load to RRH_w and can help the offloading.

S2: The BBU decides to assign the resource to UE_a for reduceing another RRH's loading. The BBU calculates the total energy consumption tE_{Option_a} with all related UEs for each options.

S3: The BBU finds the option which saves the most energy as the final decision. THe BBU calculates the saved energy $(tE_{Option_a} - tE_{Option_{orig}})$ for each option and chooses the option with the maximum value.

An example of the serving RRH selection is given in Figure 7 to illustrate the scenario of the resource of RRH_1 is released. According phase 2, BBU_1 can realize that the AP_{select} is AP_1. BBU_1 find out some UEs from the offloading state table, and those UEs not only are offloading to AP_1 but also can contact with RRH_1. The BBU calculates $(ECR_{AP_1,UE} - ECR_{RRH_1,UE})$ for those UE and check if this result is the maximum and lager than zero form all UEs which are offloading to AP_1 and also can contact with RRH_1.

After BBU_1 checks that UE_1 can help indirect offloading, the BBU finds out UE_2 which is pending for AP_1 from offloading state table. BBU_1 can find two options : $Option_{orig}$ and $Option_2$. BBU_1 calculates the total energy consumption (tE_{Option}) for each option: $tE_{Option_{orgi}}$ and tE_{Option_2}. Because tE_{Option_2} is the smaller one, BBU choose $Option_2$ as the decision.



(a) (b)

Fig. 8. (a) Throughput v.s. number of UEs. (b) Throughput v.s. size of C_w.

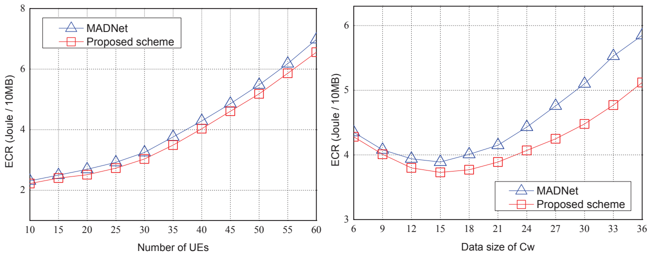
V. Simulation Results

To evaluate the offloading scheme of Ding *et al.* [8] (denotes as MADNet) and the proposed energy-aware offloading scheme, this section provides simulations with the Network Simulator-2 (NS2). The network size is 400×400 m, the peak data rate of RRH is 42Mbps, the peak data rate of AP is 54Mbps, the UE's moving speed is $5 \sim 15$ km/hr, the number of RRHs is 4, the number of Wi-Fi APs is 12, the transmission range of RRHs is 100m, and the transmission range of APs is 35m. The performance metrics to be observed in the simulations are shown as follows:

- *Average throughput* (AT): the transmission rate of this mobile data network system, including the cellular traffic and Wi-Fi AP traffic.
- *Average energy consumption ratio* (ECR): the ratio of average energy consumption to average data size.
- *Average turnaround time* (TAT): The average turnaround time of each connection of an UE. This value also indicates the transmission time of each connection.

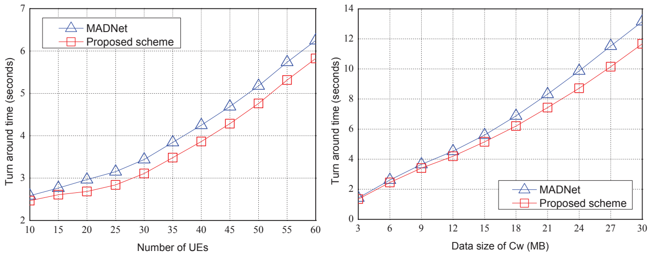
A. Average Throughput (AT)

Fig. 8 shows the simulation results of the throughput under the number of UEs (ranging from 5 to 60) and the size of C_w (ranging from 3 to 30). With the help of centralized and energy-aware offloading decision, the proposed scheme can achieve a higher throughput. The proposed scheme can make the transmission more efficient because it can make a better usage of the resources by centralized offloading decision.



(a) (b)

Fig. 9. (a) ECR v.s. number of UEs. (b) ECR v.s. size of C_w.



(a) (b)

Fig. 10. (a) Turnaround time v.s. number of UEs. (b) Turnaround time v.s. size of C_w.

B. Average Energy Consumption Ratio (ECR)

Fig. 9 shows the simulation results of the ECR under the number of UEs (ranging from 10 to 60) and the size of C_w (ranging from 3 to 30). We can observe that the proposed energy-aware offloading scheme can make the UE consume less energy. Fig. 9 (b) illustrates a result of high ECR when the data size is small. The reason is that an UE sends the data through the RRH when the data size is small and the UE cannot contact any Wi-Fi AP. The ECR of those UEs makes the average ECR become higher. When the size of C_w is larger than 15 MB, the ECR of the proposed scheme becomes much lower than that of MADNet. The reason is that MADNet will not change the connection of the UE until the UE cannot contact the AP or base station. But the proposed scheme can still make the UE transmit through other AP or RRH.

C. Average turnaround time (TAT)

Fig. 10 shows the simulation result of the average turnaround time under the number of UEs (ranging from 10 to 60) and the size of C_w (ranging from 3 to 30). Fig. 10 illustrates that this scheme can reduce the average turnaround time of each connection of the UE. In Fig. 10 (a), when there are few UEs in the system, the difference between the two schemes are not great. When there are more and more UEs in the system, the difference between the two schemes becomes larger. Same as the Fig. 10 (a), when the data size is small, the results of the two schemes in Fig. 10 (b) are close. When the data size becomes larger, the difference between the two schemes becomes lager.

VI. Conclusion

This paper has proposed a scheme with pending offloading and energy-aware offloading to make the offloading more efficient. With the help of the proposed pending offloading request, the proposed scheme can make the best usage of the available bandwidth so as to relieve the traffic load of the busy area. The results show that this scheme can reduce the energy consumption and average turnaround time of UEs and improve the network throughputs of C-RAN with heterogeneous networks and thus the operator can serve more UEs at a certain period of time.

VII. Acknowledgements

This research was supported by the Ministry of Science and Technology of the ROC under Grants MOST-103-2221-E-305-005-MY3.

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