Data Offloading for Dynamic Point Selection in Cloud Radio Access Networks (C-RAN)

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***Abstract*—For next generation mobile communications, *Cloud-RAN (C-RAN)* is an emerging network architecture to provide broadband services. C-RAN separates computation entities, i.e., *Baseband Units (BBUs)*, from *base stations (BSs)* and puts BBUs in a cloud located in a centralized network. With C-RAN, UEs can receive data from multiple collaborative cells and thus can leverage the *dynamic point selection (DPS)* technology to improve network efficiency. When *user equipments (UEs)* enter a hotspot and can not be served due to congestion, data offloading from the hotspot to its neighboring cells may take place to balance heterogeneous cells' loads. This work shows how to integrate such DPS offloading with the *Discontinuous Reception (DRX)* mechanism, which allows UEs to turn off their radio interfaces in a periodical manner. We address the resource allocation problem in heterogeneously-loaded C-RAN by optimizing UEs' energy consumption based on DRX while reserving sufficient bandwidths for UEs considering their *quality-of-service (QoS)* through DPS. We propose an offloading-based DPS scheduling scheme by exploiting not only maximal instantaneous throughputs but also minimal energy cost. Simulation results show that our scheme can improve throughput, resource utilization, and energy consumption as compared to existing schemes.**

***Index Terms*—3GPP, LTE-A, C-RAN, DPS, DRX, power saving, data offloading.**

I. Introduction

With the growing number of mobile users, network loads may become heterogeneous more frequently. In such scenarios, data offloading is an effective way to balance cells' loads. Through *Cloud Radio Access Networks (C-RAN)*, data offloading becomes more convenient. With a centralized network architecture, C-RAN separates *Baseband Units (BBUs)* from the *Base Stations (BSs)*, puts BBUs in a cloud *BBU pool*, and leaves *Remote Radio Heads (RRHs)* at cell sites. Thus, it can centrally manage the radio resources of different RRHs and collaborate with multiple cells to improve network efficiency by the *dynamic point selection (DPS)* technology [1]. On the other hand, *3GPP LTE-A (Long Term Evolution-Advanced)* has defined the *Discontinuous Reception (DRX)* mechanism [2], [3] to allow UEs to turn off their radio interfaces and go to sleep when an *evolved Node B (eNB)* has no data for them. In this paper, we address the DRX optimization problem under UEs' QoS constraints in a heterogeneously-loaded C-RAN. When UEs have diverse QoS requirements, the objective is to minimize UEs' wake-up periods to save their energy while satisfying their QoS requirements in terms of data rate and packet delay. We propose an offloading-based DPS scheduling scheme to solve this problem. The key idea is to relocate UEs' resource demands from hotspots to cold cells based on their offloading potential. Simulation results will show that our scheme can improve throughput, resource utilization, and maintain lower energy consumption as compared to existing schemes.

The rest of this paper is organized as follows. Related work is discussed in Section II. Preliminaries are given in Section III. Section IV presents our scheme. Simulation results are shown in Section V. Conclusions are drawn in Section VI.

II. Related Work

In the literature, the work [4] develops a cell-selection scheme to maximize network capacity. The study [5] proposes two cell-loading-based DPS schemes to improve cell-edge performance. The reference [6] proposes a joint cell assignment and scheduling scheme for downlink throughput maximization. However, these works do not consider UEs' energy efficiency and load balancing of networks simultaneously. Recently, the work [7] proposes a cross-layer resource allocation scheme for C-RAN to minimize system energy consumption. The work [8] proposes a traffic-density-based RRH selection scheme to reduce energy consumption of C-RAN. The work [9] proposes a minimal-serving-ratio scheme to reduce UEs' energy consumption. Except for [9], the above studies [7], [8] do not address the DRX mechanism to save UEs' energy. However, the work [9] schedules data statically without offloading data when the networks are overloaded. This may limit the network performance.

III. Preliminaries

In this section, we first introduce C-RAN architecture, followed by the concept of data offloading with DPS, and the DRX mechanism. Then, we formally define our DRX optimization problem.

A. C-RAN

C-RAN is a promising architecture for mobile networks to support collaborative transmissions, as shown in Fig. 1. C-RAN separates a traditional base station into two parts: digital function unit known as *Baseband Unit (BBU)* and radio function unit known as *Remote Radio Head (RRH)*. BBUs are placed in the BBU pool in the cloud and connect with RRHs via optical fibers. It thus centralizes control. In C-RAN, *Dynamic Point Selection (DPS)* is a way to realize collaborative transmissions, enhance data rate of UEs, and balance the traffic load of RRHs. When a UE locates in the borders of multiple cells, DPS can allocate multiple RRHs to serve it.

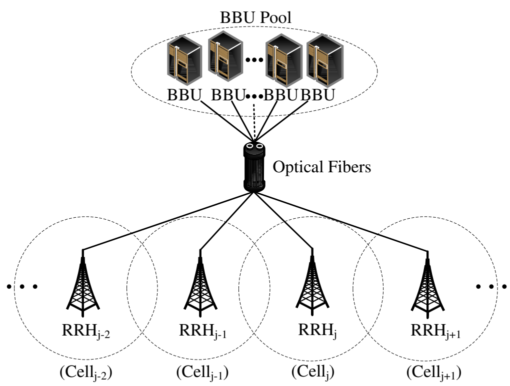


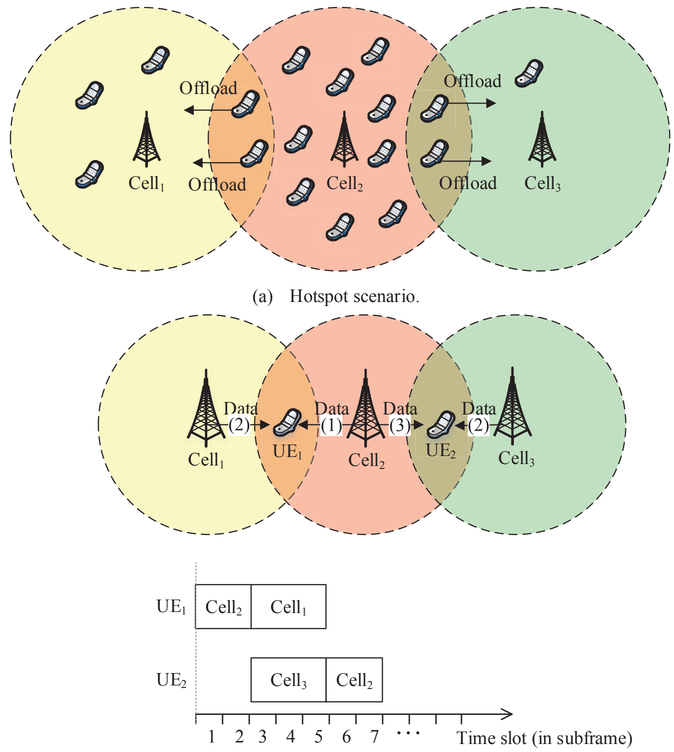
Fig. 1. C-RAN architecture.

B. Data offloading with DPS

Hotspots appear when users gather in small areas. With data offloading, users' resource demands can be relocated to other cells to reduce hotspot effect. An example is shown in Fig. 2(a), where $Cell_2$ is an overloaded hotspot. With DPS, UEs in cell intersections can dynamically construct its links to other candidate cells. In this example, two UEs' data can be offloaded to each of $Cell_1$ and $Cell_3$ with DPS. In the example in Fig. 2(b), cells $Cell_1$ and $Cell_2$ serve UE_1 collaboratively, while cells $Cell_2$ and $Cell_3$ serve UE_2 collaboratively. UE_1 receives data from $Cell_2$ at time slots $1 \sim 2$ and switches to $Cell_1$ at time slots $3 \sim 5$; UE_2 receives data from $Cell_3$ at time slots $3 \sim 5$ and switches to $Cell_2$ at time slots $6 \sim 7$. Here, $Cell_1$ and $Cell_3$ can transmit data at the same time slots due to interference free, which can increase resource efficiency.

C. DRX mechanism

The DRX mechanism is designed to monitor downlink transmission to save UEs' energy. The DRX configurations are UE-specific and configured by eNB. When DRX is activated, a UE performs wake-up/sleep operations in a periodic cycle. An example is shown in Fig. 3. The basic unit is a subframe (with the length of 1 ms). There are short and long cycles. We focus on short cycles only in this paper. When DRX is enabled, four parameters are defined: 1) *DRX-cycle-length*, 2) *DRX-start-offset*, 3) *on-duration*, and 4) *InactivityTimer*. The *DRX-cycle-length* is the period of the UE to receive data from the eNB. The *DRX-start-offset* is the starting subframe of DRX-cycle-length. The *on-duration* is the time when the UE has to stay awake to monitor any data delivered from the eNB. If any data is received, the UE starts *InactivityTimer* and stays awake before the timer expires. If any data is received, it resets the



(a) Hotspot scenario.

(b) An example of DPS.

Fig. 2. A data offloading example with DPS.

timer. When InactivityTimer expires, the UE goes to sleep and turns off its radio interface to save energy. During the UE's sleep period, any data for the UE will be buffered at the eNB until the next on-duration arrives.

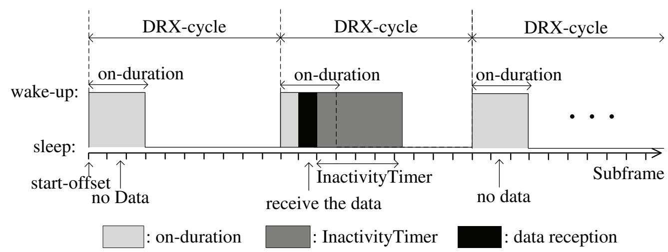


Fig. 3. An example of the DRX mechanism.

D. DPS and data offloading

This paper investigates how to apply DRX to DPS with data offloading in C-RAN. We give an example in Fig. 4(a), where there are 3 cells ($Cell_1 \sim Cell_3$) to serve 5 UEs ($UE_1 \sim UE_5$) and $Cell_1$ covers $\{UE_1, UE_3\}$, $Cell_2$ covers $\{UE_1, UE_2, UE_4, UE_5\}$, and $Cell_3$ covers $\{UE_2\}$. Suppose that UE_1 needs to receive one data subframe from $Cell_1$ and two data subframes from $Cell_2$; UE_2 needs to receive one subframe from $Cell_2$ and two subframes from $Cell_3$; UE_3 needs to receive two subframes from $Cell_1$; UE_4 needs to receive two subframes from $Cell_2$; UE_5 needs to receive one subframe from $Cell_2$. Let DRX-cycle-length of all UEs be 20 subframes. We illustrate the effect of different data offloading strategies in the following. Fig. 4(b) shows the DPS without data offloading, which needs 9 subframes to serve all UEs and takes 5 extra subframes for UEs to stay awake per cycle due to interference. Fig. 4(c) shows a poor data offloading strategy, where two data subframes of UE_1 are offloaded from $Cell_2$ to $Cell_1$, and one data subframe of UE_2 is offloaded from $Cell_3$ to $Cell_2$; it needs 8 subframes to serve all UEs per cycle but no extra wake-up period is incurred. Fig. 4(d) shows a better data offloading strategy, where one data subframe of UE_1 is offloaded from $Cell_2$ to $Cell_1$, and one data subframe of UE_2 is offloaded from $Cell_2$ to $Cell_3$; it takes only 7 subframes to serve all UEs per cycle without extra wake-up period. Note that even if we have reserved a wake-up period for a UE, its '*actual*' data reception time may vary (shorter or longer than the reserved period) due to channel rate changes. Our design will also consider this factor.

E. Problem Definition

We consider downlink transmission in a heterogeneously-loaded C-RAN with TDD mode. There are M RRHs (or *cells*) and N UEs with DPS capability. Each UE_i, $i = 1..N$, is covered by one or multiple cells, denoted by serving cell set $Cell_i^{set}$, and has an admitted data rate of $R_i \geq 0$ (bits/ms) and a delay constraint of D_i (ms). Note that R_i can be offloaded to the serving $Cell_j \in Cell_i^{set}$ as $R_{i,j}$, if ensuring $\sum_{j \in Cell_i^{set}} R_{i,j} \geq R_i$. The subframe duration is 1 ms. The actual data bits that can be delivered depends on channel quality. Let $C_{i,j}$ (bits/ms) be UE_i's channel rate in $Cell_j$, where $C_{i,j} > 0$ if $Cell_j \in Cell_i^{set}$; otherwise, $C_{i,j} = 0$. Our goal is to schedule the data transmission from these M cells to N UEs and choose proper DRX parameters for each UE_i, including DRX-cycle-length (T_i), DRX-start-offset (Z_i), on-duration (O_i) and InactivityTimer (I_i), such that as many UEs can be served as possible without violating their delay constraint D_i and perceived data rate R_i while the total number of wake-up subframes of UEs is minimal.

IV. PROPOSED SCHEME

In this section, we present our offloading-based DPS scheduling algorithm for cooperative RRHs. In this algorithm, we will determine each UE_i's serving time in its serving cells and its corresponding DRX parameters T_i, Z_i, O_i, and I_i. Our scheme maintains three key properties about system throughput and energy efficiency. First, we offload UEs' demands from hotspots to other cells based on their offloading potential to improve system throughput. Second, we make all UEs' DRX-cycle-length an integer multiple of others to reduce unnecessary wake-up time of UEs due to resource competition. Third, UEs' on-duration and InactivityTimer are optimized by their expected wake-up ratios. The scheme works in three phases.

A. Phase 1: Determining DRX-cycle-length (T_i)

When deciding T_i of each UE_i, we first sort the delay requirement of each UE_i. Without loss of generality, let

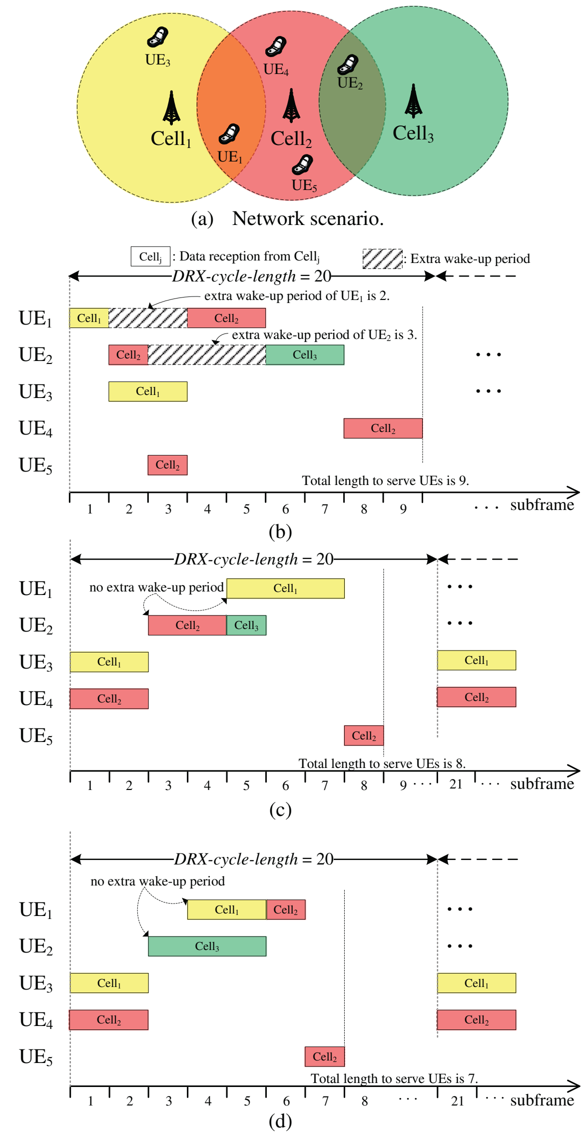


Fig. 4. An example of DRX with DPS and data offloading.

$D_1 \leq D_2 \leq ... \leq D_N$. Then, we set $T_1 = D_1$ and determine T_i, $i = 2..N$, as follows:

$$T_i = \left\lfloor \frac{D_i}{T_{i-1}} \right\rfloor \times T_{i-1}. \tag{1}$$

Eq. (1) implies $T_i \leq D_i$ for each $UE_i, i = 1..N$. This guarantees the receiving data to meet the delay constraint. Meanwhile, Eq. (1) makes T_i an integer multiple of T_{i-1}, for $i = 2..N$. This can help UEs to interleave their wake-up periods to avoid resource competition. Note that the allocation results will repeat after T_N/T_1 cycles.

Based on the above results, we then classify the UEs with the same DRX-cycle-length and sort them according to their cycle-lengths in an ascending order. Without loss of generality, we have X classes of UEs, denoted by $class_x$, $x = 1..X$, with cycle-length denoted as L_x. These classes of UEs will be scheduled sequentially in phase 2.

B. Phase 2: Determining Data Scheduling with Offloading and DRX-start-offset (Z_i)

The main idea of this phase is to offload the demands of UEs in the cell intersections of hotspots to other cold cells based on their offloading potential. In this way, resources are better utilized, potentially increasing the number of served UEs and also decreasing the wake-up intervals incurred by others. Let f_j^{cur} be the subframe index of $Cell_j$ which is available to serve UEs; initially $f_j^{cur} = 1, j = 1..M$. Then, we use f^{cur} as the current subframe index to allocate resource to UEs, where $f^{cur} = min_j\{f_j^{cur}|j = 1..M\}$. Also, let $InfCell_{f^{cur}}$ be the cells that will cause interference to the current allocation at subframe f^{cur}; initially, $InfCell_{f^{cur}} = \phi$. We also define $subframe_{i,j}^{Start}$ as the start subframe number of $Cell_j$ to allocate resource to UE_i; initially, $subframe_{i,j}^{Start} = 0$ for all i, j. In addition, let $remain_j^{sf}$ be the remaining subframes of $Cell_j$; initially, $remain_j^{sf} = T_N$ for all j. Let UE_j^{UnServ} be the set of UEs that have not been served by $Cell_j$; initially, $UE_j^{UnServ} = \{UE_i|UE_i \in class_x, Cell_j \in Cell_i^{set}\}$, for $j = 1..M$. Let $UE_{j,j'}^{UnServ}$ be the set of UEs that locate in the cell intersections of both $Cell_j$ and $Cell_{j'}$ and have not been served; initially, $UE_{j,j'}^{UnServ} = UE_j^{UnServ} \cap UE_{j'}^{UnServ}$. Then, we let S_i^{Alloc} be the number of subframes that have been allocated to UE_i and $S_{i,j} = \left\lceil \frac{R_{i,j} \times T_i}{\overline{C_{i,j}} - 3\sigma_{i,j}} \right\rceil$ be an estimated serving time (in subframe), where $R_{i,j} = R_i \times \frac{\overline{C_{i,j}}}{\sum_{j \in Cell_i^{set}} \overline{C_{i,j}}}$ is a temporal data rate and $R_{i,j} \times T_i$ is the total data bits which will arrive from $Cell_j$ during UE_i's cycle T_i. Note that $\overline{C_{i,j}} - 3\sigma_{i,j}$ is the worst channel rate which is acquired from historical information. Then, let UE^{off} and $Cell^{off}$ be sets of the offloaded UEs and cells. Initially, $UE^{off} = \phi$ and $Cell^{off} = \phi$. In the following, we will determine the data scheduling of UEs and their DRX parameters in this phase. The details are depicted as follows.

Step 1: For each $Cell_j$, $j = 1..M$, we find the UEs in the cell center which can not be served by other cells, i.e.,

$$UE_j^{Center} = \{UE_i|Cell_i^{set} = \{Cell_j\}, i = 1..N\}. \quad (2)$$

These center-UEs can be scheduled without causing interference to other cells'.

Step 2: From UE_j^{Center}, $j = 1..M$, we iteratively schedule the UE_{i^*} with the shortest serving time to $Cell_j$ if $S_{i^*,j} \times \frac{T_N}{T_{i^*}} < remain_j^{sf}$ until no center-UE can be found, where

$$UE_{i^*} = argmin_i\{S_{i,j}|UE_i \in (UE_j^{Center} \cap UE_j^{UnServ})\}, \quad (3)$$

and T_N/T_{i^*} is the cyclic feature of DRX scheduling. Specifically, we iteratively allocate $S_{i^*,j}$ (subframes) at subframe f_j^{cur}, and update the interfering cell set $InfCell_{f_j^{cur}+\Delta+y \cdot L_x} = InfCell_{f_j^{cur}+\Delta+y \cdot L_x} \cup Cell_{i^*}^{set}$, for $\Delta = 0..(S_{i^*,j} - 1)$, $y = 0..(L_X/L_x - 1)$ due to the cyclic repetition. Also, mark the start point of data allocation by $subframe_{i^*,j}^{Start} = f_j^{cur}$, update the total allocated subframes by $S_{i^*}^{Alloc} = S_{i^*,j}$, remove UE_{i^*} from UE_j^{UnServ}, and update the current available subframe index $f_j^{cur} = f_j^{cur} + S_{i^*,j}$, and the remaining subframes $remain_j^{sf} = remain_j^{sf} - (S_{i^*,j} \times \frac{T_N}{T_{i^*}})$, respectively.

After that, most of the center-UEs, which cannot be offloaded, are scheduled in their corresponding cells.

Step 3: Now, considering those overloaded cells, we find the one with the maximal traffic load requested by the UEs in the cell intersections, i.e., $Cell_{j^*} = argmax_{Cell_j \notin Cell^{off}}\{(\sum_{\forall i:|Cell_i^{set}|>1} S_{i,j} \times \frac{T_N}{T_i}) > remain_j^{sf}\}$. Note that $> remain_j^{sf}$ means that $Cell_j$ is overloaded and $Cell_j \notin Cell^{off}$ means that it not yet offloaded before.

Then, for those UEs in the cell intersection of $Cell_{j^*}$ and not yet offloaded before, i.e., $UE_{j^*}^{IntsCell} = \{UE_i|UE_i \in (UE_{j^*}^{UnServ} - UE^{off}), |Cell_i^{set}| > 1\}$, we offload their data from $Cell_{j^*}$ to $Cell_{j'}$ ($j' \in (Cell_i^{set} - Cell_{j^*})$) as follows.

1) Proportional increasing their serving time to its neighboring $Cell_{j'}$ by $S_{i,j'} = S_{i,j'} + \Delta S_{i,j'}$, where

$$\Delta S_{i,j'} = \left\lfloor S_{i,j^*} \times \frac{remain_{j'}^{sf}}{\sum_{i' \in UE_{j^*}^{IntsCell}} (S_{i',j^*} \times \frac{T_N}{T_{i'}})} \right\rfloor. \quad (4)$$

2) Decreasing their serving time from $Cell_{j^*}$ by

$$S_{i,j^*} = S_{i,j^*} - \left\lfloor \Delta S_{i,j'} \times \frac{C_{i,j^*}}{C_{i,j'}} \right\rfloor. \quad (5)$$

Then, update $UE^{off} = UE^{off} \cup UE_i$ and $Cell^{off} = Cell^{off} \cup Cell_{j^*}$ to avoid offloading-looping. This step is repeated until no cell is matched.

Step 4: Now, at the current available subframe f^{cur}, we find the higher-loaded cells that have available subframes and can schedule UEs without causing interference, i.e., $Cell^{Infree} = \{Cell_j|Cell_j \in (Cell^H - InfCell_{f^{cur}}), remain_j^{sf} > 0\}$, where $Cell^H$ is the set of higher-loaded cells.

Then, we find the maximal set of UEs locating in the intersections of those cells in $Cell^{Infree}$ that have not been served, i.e.,

$$UE^{Max} = argmax_{\forall j,j' \in Cell^{Infree}}\{|UE_{j,j'}^{UnServ}|\}. \quad (6)$$

Next, we use a metric function, called *internal cost* $IC_{i,j}$, to evaluate the number of extra wake-up subframes that will be incurred when we schedule $S_{i,j}$, i.e.,

$$IC_{i,j} = |UE^{IC}| \times S_{i,j}, \quad (7)$$

where $UE^{IC} = \{UE_{i'}|i' \in (UE_j^{UnServ} - UE_i), S_{i'}^{Alloc} > 0\}$ is the set of UEs which have been scheduled parts of their serving time (this will be clear later on).

Then, we calculate the *internal cost* $IC_{i,j}$ for each $UE_i \in UE^{Max}$, and $Cell_j \in Cell^{Infree}$, and find the pair $(Cell_{j^*}, UE_{i^*})$ with the minimal internal cost IC_{i^*,j^*}, i.e., $(Cell_{j^*}, UE_{i^*}) = argmin_{i,j}\{IC_{i,j}|UE_i \in UE^{Max}, Cell_j \in Cell^{Infree}\}$. Here, if there are more than one pair matching, we can easily choose the UE that has been scheduled before, thus satisfying its whole demands. Finally, go to step 5 for data allocation.

Step 5: Now, we allocate S_{i^*,j^*} (subframes) for the pair ($Cell_{j^*}$, UE_{i^*}) at subframe f^{cur}, and the interfering cell set $InfCell_k$, for $k = f^{cur} + \Delta + y \cdot L_x$ where $\Delta = 0..(S_{i^*,j^*} - 1)$, $y = 0..(L_X/L_x - 1)$. Similarly, mark the start point $subframe^{Start}_{i^*,j^*} = f^{cur}$, remove UE_{i^*} from $UE^{UnServ}_{j^*}$, and update the current available subframe index $f^{cur}_{j^*}$, the remaining subframes $remain^{sf}_{j^*}$ and total allocated subframes $S^{Alloc}_{i^*}$ accordingly. Finally, go back to step 4 to find the next candidate pair until no pair can be found or no sufficient subframe can be allocated. Then, go to step 6.

Step 6: Based on above results, we set the DRX-start-offset Z_i for each UE_i, $i = 1..N$, by

$$Z_i = min\{subframe^{Start}_{i,j} | Cell_j \in Cell^{set}_i\}. \qquad (8)$$

After that, we have determined the scheduling results of UEs and their DRX-start-offsets.

C. Phase 3: Optimizing DRX parameters (I_i and O_i)

The goal of this phase is to determine the best on-duration O_i and InactivityTimer I_i for each UE_i, $i = 1..N$, to reduce the unnecessary wake-up periods. Recall that $subframe^{Start}_{i,j}$ is the start subframe determined in phase 2. Below, we calculate the wake-up ratio for each UE_i's I_i and O_i based on $subframe^{Start}_{i,j}$. Specifically, we first define $ExpectRatio^{WakeUp}_i$ to represent the expected wake-up ratio of UE_i with its I_i and O_i. Then, we consider two cases for determining their values. Finally, we choose the best pair which incurs the minimal expected wake-up ratio for each UE_i. The details are as follows.

First, we define $ExpectRatio^{WakeUp}_i$ by calculating the expected number of wake-up subframes over the DRX-cycle-length T_i for UE_i, i.e., $ExpectRatio^{WakeUp}_i = \frac{max\left\{(max\{ExpectEPO_{i,j} | Cell_j \in Cell^{set}_i\} - Z_i), O_i\right\} + I_i}{T_i}$, where $ExpectEPO_{i,j} = (subframe^{Start}_{i,j} + \left\lceil \frac{R_{i,j} \times T_i}{E(C_{i,j})} \right\rceil)$ is the expected end subframe for the pair $(Cell_j, UE_i)$ and $\left\lceil \frac{R_{i,j} \times T_i}{E(C_{i,j})} \right\rceil$ is the expected data reception time (in subframe). Note that $E(C_{i,j})$ is the expected channel rate for $Cell_j$ serving UE_i.

Second, we consider the following two cases to find feasible pair (I_i, O_i). Then, we choose the best pair which has the minimal expected wake-up subframes.

- **Case 1:** Set $I_i = 0$ and $O_i = max\{subframe^{Start}_{i,j} + S_{i,j} | Cell_j \in Cell^{set}_i\} - Z_i$.
- **Case 2:** Set $I_i = max\{h_{i,k}\} + 1$ and $O_i = min\{subframe^{Start}_{i,j} + S_{i,j} | Cell_j \in Cell^{set}_i\} - Z_i$, where $h_{i,k}$ is the k-th idle period of UE_i.

Note that Case 1 favors shorter InactivityTimer with longer on-duration and Case 2 ensures UEs to get all data from separated wake-up periods. Based on these cases, we can evaluate the expected wake-up ratio and choose the best pair with the minimal expected wake-up ratio.

V. SIMULATION RESULTS

In this section, we develop a simulator in C++ language to verify the effectiveness of our scheme. The system parameters are listed below [10]. The frame duration is 10 ms. The channel bandwidth is 20 MHz. The cell radius is 500 m. The BS Tx power is 23 dBm. The thermal noise is -174 dBm/Hz. The antenna gain of UEs and cells are 0 dBi and 14 dBi, respectively. Three types of traffic are adopted in the simulation, including VoIP (64 Kbps, 100 ms), IPTV (128 Kbps, 300 ms), and HTTP/FTP (256 Kbps, 300 ms) [11]. The number of cells and UEs is $M = 25$ and $N = 300 \sim 3000$, respectively. Note that the environment is a heterogeneously-loaded network and UEs apply random walk with the speed of 1.4 m/s.

In the simulation, we compare our scheme against ***profit-based cell-selection scheme (PB-CS)*** [4], ***current-load-based DPS (CL-DPS)*** and ***compromise-fairness-based DPS (CF-DPS) schemes*** [5], and ***energy-efficient DPS scheme (EE-DPS)*** [9]. We consider three performance metrics: (i) system throughput: the total number of data bits received by the satisfied UEs per cell during the experiment period; (ii) resource utilization: the allocated resource over the total available resources; (iii) energy consumption: the average consumed energy per subframe, where the power model is referred to [12]. Note that each simulation result is averaged by at least 2000 experiments.

A. System Throughput

First, we investigate the effects of the number of requested UEs on system throughput. As shown in Fig. 5, **CL-DPS** and **CF-DPS** have the lowest throughput because they pair all UEs with cells individually. **PB-CS** has higher throughput because it considers the remaining resource of cells and pairs UEs appropriately to improve performance. **EE-DPS** has higher throughput than **PB-CS** because it chooses the cells with more unsatisfied UEs and schedules them according to the serving ratio. Our scheme outperforms others because it disperses the traffic from high-loaded cells to low-loaded ones and thus can increase the total throughput.

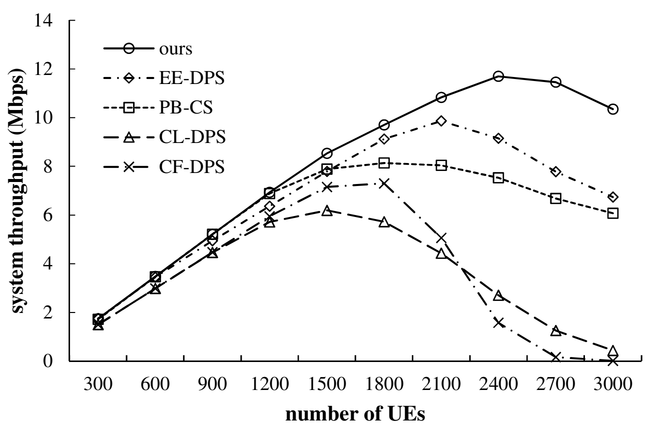


Fig. 5. Comparisons on system throughput.

B. Resource Utilization

Then, we investigate the effects of the number of requested UEs on resource utilization. As shown in Fig. 6, **EE-DPS** has the lowest resource utilization because it always chooses the UEs with minimal serving ratio without considering the interference. Therefore, many resources may not be utilized due to interference. **CL-DPS**, **CF-DPS** and **PB-CS** have better performance because they pair UEs with cells sequentially to mitigate the interference. Our scheme has the best resource utilization because it can well offload the traffic to lower-loaded cells and schedule the UEs without interference, thus further utilizing the resource.

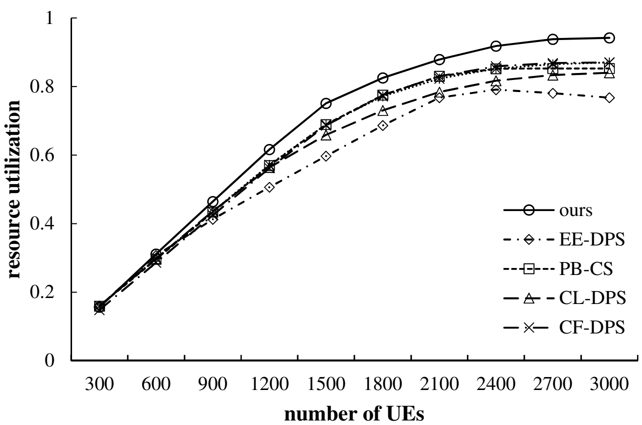


Fig. 6. Comparisons on resource utilization.

C. Energy Consumption

Finally, we investigate the effects of the number of UEs on energy consumption. As shown in Fig. 7, our scheme has lower energy consumption as compared to most of the existing schemes because our scheme well schedules the offloaded data and optimizes the DRX parameters to reduce UEs' wake-up periods. Although **EE-DPS** has similar energy consumption to ours, our scheme can have better system throughput.

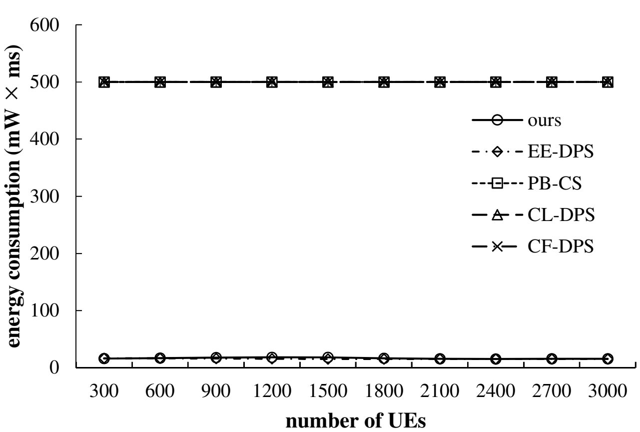


Fig. 7. Comparisons on energy consumption.

VI. Conclusions

In this paper, we have addressed the DPS offloading and DRX optimization problem by considering UEs' QoS requirements in heterogeneously-loaded C-RAN. We have developed an offloading-based DPS scheme, which includes three phases: the first phase determines the DRX cycle to avoid resource competition and reduce unnecessary wake-up periods; the second phase determines the data offloading based on cells' potential; the third phase adopts two special cases to further optimize the DRX parameters. Simulation results have verified that our scheme can improve system throughput, resource utilization, and save UEs' energy.

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