Joint Optimization of BBU Pool Allocation and Selection for C-RAN Networks

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Abstract: BBU pool allocation and selection are jointly optimized for maximizing wireless traffic capacity while minimizing wavelength resource occupation in optical networks. Numerical results show optimal BBU pool locations under different traffic patterns and network capacities.

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1. Introduction

5G radio access networks (RANs) are expected to increase access capacities by orders of magnitude while decreasing latencies to handle the growing number of connected devices and data rates. Cloud-RAN (C-RAN), which is a promising 5G mobile network architecture, involves the functional separation of traditional base stations (BSs) into two parts: the base-band unit (BBU) which performs baseband signal digital processing together with all upper layer functions, and the remote radio head (RRH) which interfaces with antennas for wireless signal transmission and reception. This functional separation allows BBUs to be geographically separated from RRHs so that they can be centralized into one or several common locations (called BBU pools) to promote consolidation [1]. BBU pooling has advantages for coordinated multipoint (CoMP) transmission/reception and reduces both capital and operating expenses. However, the adoption of C-RAN requires high bandwidth digitized radio-over-fiber (D-RoF) baseband signals to be exchanged at low latency between each BBU-RRH pair, called the fronthaul link. Optical networks are a promising candidate for meeting the demanding bandwidth and latency requirements in metro areas.

When designing the converged wireless and optical networks supporting C-RAN (illustrated in Figure 1), tradeoffs between the number of BBU pools, optical network capacity and fronthaul latency should be carefully considered. The network planning problem can be described as two sub-problems: 1) BBU pool allocation, and 2) BBU pool selection, under a given traffic pattern. The BBU pool allocation problem aims to decide the number of BBU pools in the network and in which optical network nodes to place them, while the BBU pool selection problem determines the best pool to host the BBU of each traffic request [2,3]. These two problems interact with each other, together with the routing and wavelength assignment of each traffic request and the constraint of the C-RAN latency requirements, thus joint optimization of BBU pool allocation and selection is required.

In this work, we propose a constraint programming (CP) based mathematical formulation for joint optimization of the BBU pool allocation and selection problem, and convert it into an integer linear programming (ILP) formulation. Numerical results show the optimal numbers and locations of BBU pools, as well as corresponding optical network performance, under different traffic patterns and network capacities.

2. Problem statements and mathematical formulation for joint optimization

In this network planning problem, we mainly focus on the BBU pool allocation and selection, traffic routing and wavelength assignment in optical networks. As shown in Figure 1, each node in a given optical network topology can be selected to host a BBU pool. Traffic requests can originate from any of the optical network nodes, and each of them is aggregated from the wireless traffic of multiple RRHs. If an optical network node hosts a BBU pool, traffic requests originated from it will be served in this pool, or they will go to other BBU pools through the network. The C-RAN latency constraint should be respected, resulting in a restriction on the maximum length of the routing path [4].

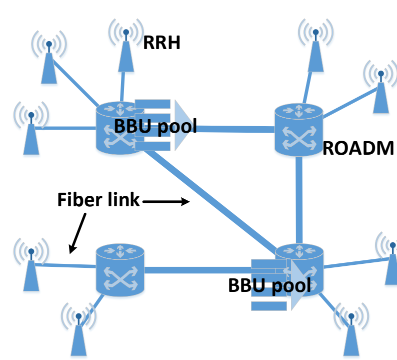

Fig. 1. C-RAN network architecture

The following presents the CP model of the joint optimization planning problem of BBU pool allocation and BBU pool selection under given traffic requests, with the objective of maximizing the traffic acceptance ratio and minimizing network resource usage. For simplicity, we assume that each traffic request has a bandwidth demand of one wavelength channel capacity.

Given:

$G(N,E)$: an undirected graph representing the network topology, where N and E represent the sets of nodes and links respectively.
K : traffic set.
W : wavelength set.
s_k : source of traffic request k .
L_{ij} : length of link (i,j) .
N_i : number of traffic requests whose source is node i .
N_F : maximum fiber number per link.
N_{BBU} : maximum number of BBU pool.
$L_{\max}$: maximum routing path length.
η_1, η_2 : weight parameters for multi-objective optimization.

Variables:

f_{ij}^{kw} : binary decision variable, which takes the value of one if request k uses wavelength w on link (i,j) .
z^{kw} : binary decision variable, which takes the value of one if request k uses wavelength w .
C_i : binary decision variable, which takes the value of one if node i has a BUU pool.
a^k : binary decision variable, which takes the value of one if request k can be accepted.

Optimize: Maximize number of accepted traffic requests, and minimize network resource usage.

$$\text{Maximize: } \eta_1\Big(\sum_{k\in K} a_k + \sum_{i\in N} C_i N_i\Big) - \eta_2 \sum_{(i,j)\in E}\sum_{k\in K}\sum_{w\in W} f_{ij}^{kw} \tag{1}$$

Constraints:

$$(1-C_i)\Big(\sum_{j\in N} f_{ij}^{kw} - \sum_{j\in N} f_{ji}^{kw}\Big) = \begin{cases} 0, i\neq s_k \\ z^{kw}, i = s_k \end{cases} \qquad \forall i\in N, w\in W, k\in K \tag{2}$$

$$\sum_{i\in N} C_i \Big(\sum_{j\in N} f_{ji}^{kw} - \sum_{j\in N} f_{ij}^{kw}\Big) = z^{kw} \qquad \forall w\in W, k\in K \tag{3}$$

$$\sum_{w\in W} z^{kw} = a_k \qquad \forall k\in K \tag{4}$$

$$\sum_{k\in K} f_{ij}^{kw} \le N_F \qquad \forall (i,j)\in E, w\in W \tag{5}$$

$$\sum_{i\in N} C_i \le N_{BBU} \tag{6}$$

$$\sum_{(i,j)\in E}\sum_{w\in W} f_{ij}^{kw} L_{ij} \le L_{\max} \qquad \forall k\in K \tag{7}$$

Equation (1) is the optimization objective function. Equations (2) and (3) account for the routing path of each request. Equation (4) guarantees that each traffic request occupies only one wavelength link resource. Equation (5) guarantees that the required fiber number does not exceed the maximum fiber number per link. Equation (6) ensures that the number of selected BBU pool nodes does not exceed the maximum number of BBU pools. Equation (7) ensures that the length of the routing path of each traffic request is no more than the given maximum routing path length, in order to meet the latency requirement of C-RAN.

It should be noted that Equations (2) and (3) are non-linear constraints, which can be converted to linear constraints since f_{ij}^{kw} and C_i are binary variables. Let $\overline{f}_{ij}^{kw} = C_i f_{ij}^{kw}$, $\hat{f}_{ji}^{kw} = C_i f_{ji}^{kw}$, then:

$$\overline{f}_{ij}^{kw} \le C_i,\ \overline{f}_{ij}^{kw} \le f_{ij}^{kw},\ \overline{f}_{ij}^{kw} \ge C_i + f_{ij}^{kw} - 1 \quad \forall (i,j)\in E, i\in N, k\in K, w\in W \tag{8}$$

$$\hat{f}_{ji}^{kw} \le C_i,\ \hat{f}_{ji}^{kw} \le f_{ji}^{kw},\ \hat{f}_{ji}^{kw} \ge C_i + f_{ji}^{kw} - 1 \quad \forall (i,j)\in E, i\in N, k\in K, w\in W \tag{9}$$

thus Equation (3) and Equation (4) can be converted to the following two linear constraints, and this model is turned into an integer linear programming (ILP) model.

$$\Big(\sum_{j\in N} f_{ij}^{kw} - \sum_{j\in N} f_{ji}^{kw}\Big) - \Big(\sum_{j\in N} \overline{f}_{ij}^{kw} - \sum_{j\in N} \hat{f}_{ji}^{kw}\Big) = \begin{cases} 0, i\neq s_k \\ z^{kw}, i = s_k \end{cases} \qquad \forall i\in N, w\in W, k\in K \tag{10}$$

$$\sum_{(i,j)\in E} \hat{f}_{ji}^{kw} - \sum_{(i,j)\in E} \overline{f}_{ij}^{kw} = z^{kw} \qquad \forall w\in W, k\in K \tag{11}$$

3. Numerical results and analysis

We use CPLEX to solve the optimization problem on the New York regional topology (from zayo.com, shown in Figure 2). The fiber number per physical link is set to 1, and two scenarios of wavelength number per fiber (denoted as N_w) equal to 4 and 8 are investigated, each running at 100 Gbps capacity. The maximum length of the routing path is set to be 30 km in order to meet the latency requirement of C-RAN [4]. Three traffic patterns, i.e. uniform-distributed traffic (*Unif_traf*), daytime traffic (*Day_traf*) and nighttime traffic (*Night_traf*) shown in Figure 3, are tested.

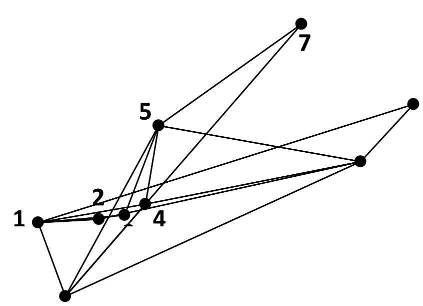

Fig. 2. New York regional topology

Figure 4 shows the traffic acceptance ratio under different maximum numbers of BBU pools (N_{BBU}). We can see that it increases with N_{BBU} , and providing higher network capacity ($N_w = 8$) can increase the acceptance ratio under a given N_{BBU} , achieving a smaller turning point (defined as the smallest N_{BBU} reaching full acceptance). When $N_w = 4$, for traffic pattern of *Day_traf* and *Night_traf*, full acceptance can be reached when $N_{BBU} = 4$; while for *Unif_traf*, traffic requests cannot be fully accepted until N_{BBU} is 5. When $N_w = 8$, full acceptance can be achieved when $N_{BBU} = 3$ for all the traffic patterns.

Similarly, it can be observed from Figure 5 that higher network throughput can be achieved under higher network capacity, and an increase can be observed with the increase of N_{BBU} before reaching the turning point. However, the network throughput is observed to fall when N_{BBU} goes beyond the turning points. This is because when the full acceptance is reached, adding BBU pools will only increase the amount of traffic requests to be processed locally instead of using other BBU pools across the network, therefore decreasing the network throughput. In this sense, it is not necessary to deploy a higher number of BBU pools after the turning point, given that more BBU pools may result in higher cost and power consumption.

Based on this analysis, the optimal number of BBU pools can be determined and their locations are marked red in Table 1. Nodes with high degrees (node 1 and 5) have higher probability to be selected to host BBU pools, and nodes far from other nodes (node 7 and 8) are also likely to be selected since the latency requirement may not be met if these nodes are used in routing traffic to or from other nodes across the network.

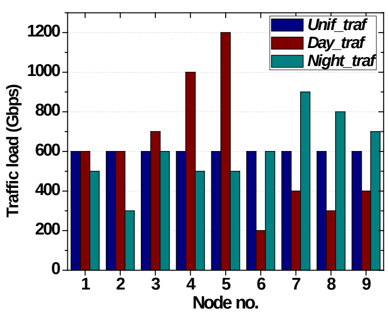

Fig. 3. Traffic patterns

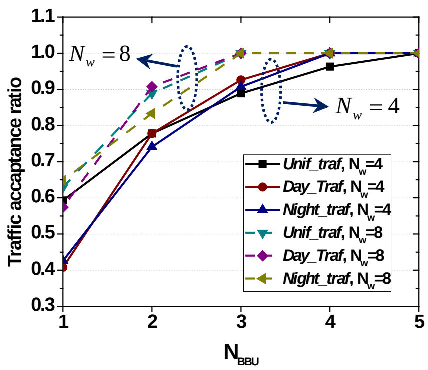

Fig. 4. Acceptance ratio vs. N_{BBU}

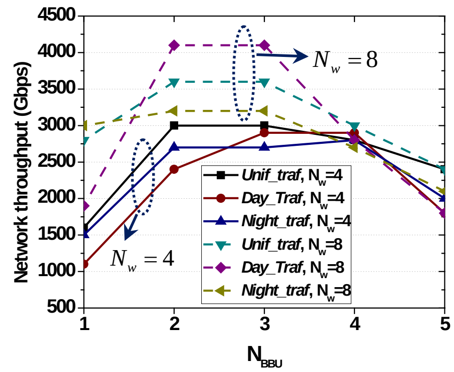

Fig. 5. Throughput vs. N_{BBU}

Tab. 1. Optimal BBU pool locations

N_{BBU}	$N_w = 4$			$N_w = 8$		
	Unif_traf	*Day_traf*	*Night_traf*	*Unif_traf*	*Day_traf*	*Night_traf*
1	1	5	8	1	5	4
2	1,8	1,5	1,8	1,8	1,8	1,8
3	1,7,8	1,5,8	1,7,8	**1,7,8**	**1,7,8**	**1,7,8**
4	1,5,7,9	**1,5,7,8**	**1,5,7,9**	1,5,7,9	1,5,7,9	1,5,7,8
5	**2,5,6,7,9**	3,4,5,7,8	1,5,7,8,9	1,5,6,7,8	1,4,5,9	1,5,6,7,8

4. Conclusions

Joint optimization of BBU pool allocation and selection for C-RAN networks is investigated and its mathematical formulation is proposed. Numerical results show the improvement in traffic acceptance ratio and network throughput with the increase of the number of BBU pools under different traffic patterns and network capacities, based on which the optimal BBU pool numbers and locations are determined. Network nodes with high degree and distant nodes with a large latency penalty are more likely to be selected to host BBU pools.

5. References

[1] A. Pizzinat, et al., "Things you should know about fronthaul," Journal of Lightwave Technology 33.5 (2015): 1077-1083.

[2] F. Musumeci, et al., "Optimal BBU placement for 5G C-RAN deployment over WDM aggregation networks," Journal of Lightwave Technology 34.8 (2016): 1963-1970.

[3] X. Wang, et al., "Joint Allocation of Radio and Optical Resources in Virtualized Cloud RAN with CoMP," Global Communications Conference (GLOBECOM), 2016 IEEE. IEEE, 2016.

[4] A. Nag, et al., "Integrating wireless BBUs with optical OFDM flexible-grid transponders in a C-RAN architecture," Optical Fiber Communications Conference and Exhibition (OFC), 2017. IEEE, 2017.