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Efficient resource allocation for passive optical fronthaul-based coordinated multipoint transmission

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Abstract

The centralized processing in cloud radio access network enables cooperation between baseband processing units (BBUs) like inter-cell interference (ICI) cancellation on the basis of coordinated multipoint (CoMP). Large amounts of the sharing data will be transmitted through fronthaul transport network. In the paper, both integer non-linear programming (INLP) optimization model and adaptive genetic algorithm (GA) are explored to release the capacity pressure of the fronthaul transport network when CoMP is introduced. We also consider the resource allocation problem of the passive optical fronthaul network. The proposed algorithm tries to reduce the downlink bandwidth and improve the optical resource allocation efficiency of the optical fronthaul with minimal influence on the fronthaul topology. During the simulations, three critical factors are considered: (1) the number of cell edge users, (2) the average traffic demand of cell edge users, (3) the size of cell cluster used to enable the CoMP. The simulation results show that the most efficient bandwidth saving and optical resource allocation can be achieved with INLP, while the proposed adaptive GA nearly has the same performance with low computational complexity and fast convergence, which is more applicable for the large-scale fronthaul network. Furthermore, the load difference of the fronthaul transport network can be further reduced.

Keywords: Network optimization, INLP, Coordinated multipoint, Adaptive genetic algorithm, TWDM-PON-enabled fronthaul

1 Introduction

Network densification using small cells is emerging as a critical technology to enhance the resource management of next-generation wireless network [1, 2]. However, the received signal quality of cell edge users can be sharply degraded by the transmission of neighboring cells. Thus, the signal-to-noise ratio is badly influenced (particularly near the cell edge), as well as the downlink capacity of the mobile network. Inter-cell interference (ICI) has been a bottleneck to improve the mobile network capacity and the quality of service (QoS) of the mobile users that located at cell edge [3]. To face this challenge, coordinated multipoint (CoMP) was proposed [4, 5]. Multiple base stations (BSs) are connected and exchange information for cooperation via backhaul links to reduce ICI. And prediction algorithms can be used to estimate the movement of mobile equipment [6, 7]. Techniques enabling coordinated transmission are explored to migrate the inter-cell interference and increase the system capacity [8–16]. Spectral efficiency (SE)-oriented CoMP techniques have been investigated [8–10]. In [8, 9], CoMP precoders have been explored to improve the spectral efficiency and network capacity. And both spectral efficiency and fairness were considered in CoMP systems [10]. Besides, energy efficiency (EE)-oriented CoMP techniques have also been studied [11–14]. In CoMP-enabled mobile network, the authors investigated the downlink transmit power optimization problem with QoS constraint and limited cell coordination (max-min EE for CoMP systems) [11]. Considering the individual data rate requirement and transmit power of each BS, energy-efficient CoMP precoding was proposed [12]. And EE-oriented resource allocation algorithm was also proposed in CoMP-enabled heterogeneous network, considering of

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the backhaul power consumption [13]. Semi-smart antenna-based coordinated multipoint technique has been studied to reduce the transmit power of orthogonal frequency division multiplexing (OFDMA) networks [14]. Furthermore, the methods to acquire channel state information were discussed in [5]. Limited feedback CoMP system was reviewed in [15]. Moreover, in [16], the authors took the non-ideal backhaul into consideration, and the spectrum allocation scheme was proposed in heterogeneous network for coordinated multipoint transmission. And cooperation between base stations in the downlink of heterogeneous network has been studied [17]. In [18], CoMP downlink transmission design for cloud radio access network (C-RAN) was studied.

C-RAN is emerging as a potential architecture for the next-generation wireless network [19]. In C-RAN, baseband units (BBUs) are migrated and centralized into a BBU central server retaining only distributed remote radio units (RRUs) at remote cells [20]. The fiber technique-based network used to forwarding signals between BBUs and RRUs is called fronthaul [21]. This novel architecture opens up opportunities for a better management of resource of the mobile network.

CoMP can benefit from the centralized processing in C-RAN. However, large amounts of sharing data need to be transmitted in the fronthaul transport network when CoMP is introduced in C-RAN. Considering the limited bandwidth and optical resource of the fronthaul, to release the capacity pressure and improve the optical resource efficiency of the fronthaul is significantly important when CoMP technique is introduced in next-generation radio access network. However, as far as we know, little attention has been focused on the influence on fronthaul when CoMP technique is introduced in C-RAN. In previous works, recent advances like key technologies and system architectures in fronthaul-constrained C-RAN have been discussed in [22]. Advanced techniques were explored to enhance the utilization efficiency and transfer capability of the optical fronthaul [23–29]. Digital signal processing (DSP)-based channel aggregating technique was researched [23]. To ensure a reasonable fronthaul transmission rate, subcarrier multiplexing technique was investigated [24]. In [25], microwave-photonics techniques were introduced for integrated optical-wireless access network. Besides, topology-reconfigurable fronthaul transport network has been proposed [26]. CoMP and device-to-device (D2D) connectivity can benefit from this architecture and network measurement schemes [30] in the 5G mobile networking era. And different models of optical fronthaul for C-RAN were discussed [27]. Furthermore, to simplify the RRU, fully passive RRU and self-tuning colorless optical network unit (ONU) transmitter was proposed and demonstrated for short-range wireless network [28]. Data and energy are jointly transmitted through optical fronthaul. Moreover, in C-RAN with non-ideal fronthaul network, delay-sensitive services can benefit from the efficient strategy proposed in [29]. And multicore fiber media (MCF) has been investigated for the future optical fronthaul [31].

However, little work has been done to solve CoMP-oriented resource allocation problem in the fronthaul transport. In the paper, we try to release the capacity pressure and improve the optical resource allocation efficiency of the fronthaul with minimal influence on the fronthaul topology. We present two CoMP-oriented resource allocation schemes for the fronthaul transport network. Both integer non-linear programming (INLP) model and adaptive genetic algorithm (GA) are explored.

In this paper, we formulate the INLP model in Section 2, and Section 3 discusses the adaptive GA. Meanwhile, in Section 4, the performance of numerical simulations are described. Finally, we summarize the paper in Section 5.

2 INLP model formulation for CoMP-oriented fronthaul

In subsequent subsections, we present the CoMP-oriented C-RAN architecture and develop the INLP model to release the capacity pressure and improve the optical resource allocation efficiency of the time and wavelength division multiplexing (TWDM) passive optical network (PON)-enabled fronthaul transport network.

2.1 CoMP-oriented C-RAN architecture

Figure 1 illustrates the CoMP-oriented C-RAN architecture. Recently, large-scale deployment of PONs significantly releases the capacity pressure of the access network [32, 33]. TWDM-PON is emerging as a potential candidate to transfer data between centralized BBUs and distributed RRUs with strong ability of transmission [34]. As shown in Fig. 1, optical line terminal is deployed at BBU pool, and ONUs with tunable lasers are placed with cost and power efficient RRUs. Virtualization technology has been widely investigated [35, 36]. In TWDM-PON-enabled fronthaul, a virtual PON is formed when a group of ONUs transfer data using the same wavelength. As shown in [27], based on the software defined network (SDN) technique, different transport abstractions can be achieved in the centralized controller, which results in better performance of the C-RAN. Besides, we also take common public radio interface (CPRI) compression techniques [37–39] into consideration, since the typical CPRI physical link rate is fixed [19]. Compared to the typical CPRI, compression technique-based bitrate-variable CPRI is a potential efficient radio interface to face the challenge of overwhelming data stream in the 5G.

2.2 INLP model formulation

In [8–16], different challenges of CoMP technique have been investigated, such as SE/EE-oriented precoder, the

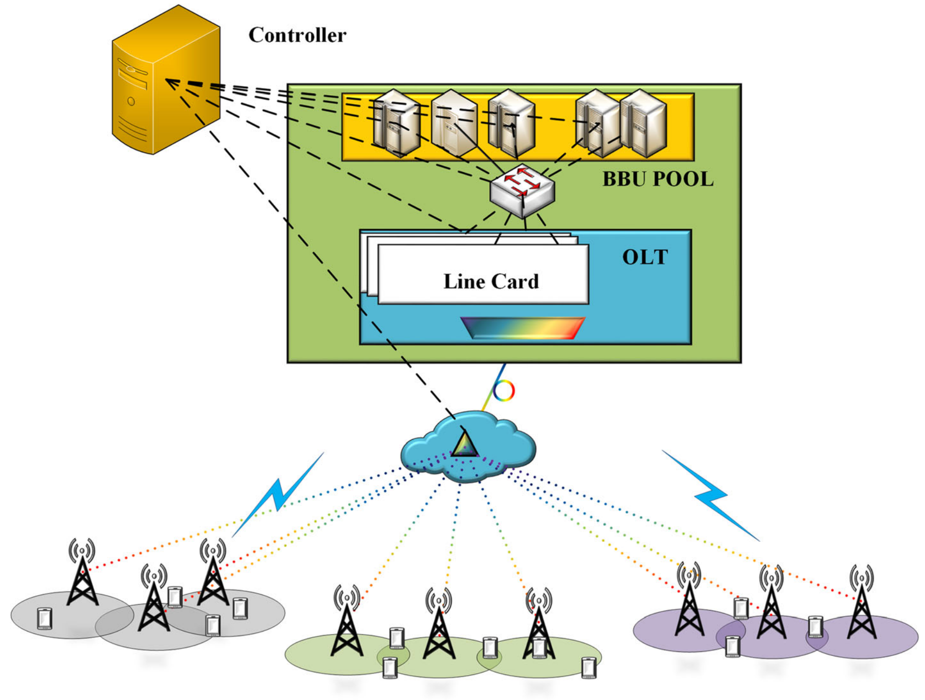

Fig. 1 CoMP-oriented C-RAN architecture

influence of the limited feedback. However, little attention has been focused on the influence on fronthaul when CoMP technique is introduced in C-RAN. Considering that large sharing data needs to be transmitted in the fronthaul transport network when CoMP technique is introduced, we focus on releasing the capacity pressure and improving the optical resource allocation efficiency of the fronthaul with minimal influence on the fronthaul topology. The proposed INLP model considers CoMP technique and broadcast characteristic of the TWDM-PON. The transmission of sharing data can benefit greatly from the broadcast characteristic of the TWDM-PON.

Notations:

- W: The set of optical wavelength resources used in the TWDM-PON-enabled fronthaul transport network.
- C: The set of cells served by the TWDM-PON-enabled C-RAN.
- O: The set of distributed ONUs at cell sites co-located with simplified RRUs.
- T: A series of discrete time slots.
- I: The set of mobile terminals located at the small cells.
- I*e*: The set of cell edge mobile terminals, $\mathrm{I}e \subset \mathrm{I}$.
- C*i*: The small-cell cluster enabling CoMP for cell edge mobile terminal $i, i \in \mathrm{I}e, \mathrm{C}i \in \mathrm{C}$.
- *Cv*: The maximum bandwidth of a single-wavelength. In current TWDM-PON system, $Cv = 10Gb/s$.
- *vc*: CPRI fixed link rate [19].
- *ni*: The size of small cell cluster enabling CoMP for cell edge mobile terminal $i, i \in \mathrm{I}e$.
- *bi*: The bandwidth requirement of mobile terminal $i,\ i \in \mathrm{I}$.
- $\beta^t_{c,o}$: Load fluctuation-based compression ratio of typical CPRI for cell c served by ONU o at time t, $c \in \mathrm{C}$, $o \in \mathrm{O}$.
- $\mathrm{Q}^t_{c,o} = \{i|i{\in}\mathrm{I}\ i \text{ is in cell } c \text{ at time } t\}$: The set of mobile terminals that is located in the small cell c is served by the corresponding ONU o.
- $\mathrm{R}w, oj = \{w|w \in \mathrm{W}j, \mathrm{W}j \subseteq \mathrm{W}\}$: The wavelength tuning range of ONU oj, $oj \in \mathrm{O}$.
- $\Omega^t_{w,o}$: The topology of current TWDM-PON-enabled fronthaul at time t.

Variable:

$$\lambda^t_w = \begin{cases} 1, & \text{if wavelength } w \in \mathbf{W} \text{ is used for data transmission} \\ & \text{at time } t \\ 0, & \text{otherwise} \end{cases}$$

$$\mathbf{\Omega}_{w,o}{}^t = \begin{cases} 1, & \text{if wavelength } w \in \mathbf{W} \text{ is used to establish a} \\ & \text{lightpath for ONU } o \in \mathbf{O} \text{ at time } t \\ 0, & \text{otherwise} \end{cases}$$

σ^t_i : The number of wavelength used for cell cluster $\mathbf{C}i$ enabling CoMP at time t.

Objective:

Maximize the fronthaul transport network bandwidth allocation efficiency η:

$$\eta = \frac{\sum\limits_{c\in\mathbf{C}}\sum\limits_{i\in\mathbf{I}e\cap\mathbf{Q}_{c,o}^{t}} nibi - \sum\limits_{c\in\mathbf{C}}\sum\limits_{i\in\mathbf{I}e\cap\mathbf{Q}_{c,o}^{t}} \sigma_i^t bi}{\sum\limits_{c\in\mathbf{C}}\sum\limits_{i\in\mathbf{I}e\cap\mathbf{Q}_{c,o}^{t}} nibi + \sum\limits_{c\in\mathbf{C}}\sum\limits_{i\in(\mathbf{I}-\mathbf{I}e)\cap\mathbf{Q}_{c,o}^{t}} bi} \tag{1}$$

In addition, improving the optical resource allocation efficiency of the fronthaul plays a critical role for CoMP-oriented optimization. Three sub-objectives are also considered during the optimization:

$$\min \quad \zeta = (\zeta 1, \zeta 2, \zeta 3) \tag{2}$$

where:

$$\zeta 1 = \sum_{w\in\mathbf{W}} \lambda_w^t \tag{3}$$

$$\zeta 2 = \frac{\sum\limits_{w\in\mathbf{W}}\left(\lambda_w^t\left(\sum\limits_{o\in\mathbf{O}}\left(\Omega_{w,o}^t\cdot vc\cdot\beta_{c,o}^t\right) - \sum\limits_{o\in\mathbf{O}} vc\cdot\beta_{c,o}^t / \sum\limits_{w\in\mathbf{W}}\lambda_w^t\right)^2\right)}{\sum\limits_{w\in\mathbf{W}}\lambda_w^t} \tag{4}$$

$$\zeta 3 = \left(\sum_{w\in\mathbf{W}}\sum_{o\in\mathbf{O}}\left(\left(\Omega_{w,o}^t - \Omega_{w,o}^{t-1}\right)^2\cdot\sum_{i\in\mathbf{Q}_{c,o}^t} bi\right)\right)/2 \tag{5}$$

Subject to

$$\lambda_w^t \in \{0,1\}, \Omega_{w,o}^t \in \{0,1\} \qquad \forall w\in\mathbf{W}, \forall o\in\mathbf{O} \tag{6}$$

$$\sum_{w\in\mathbf{W}} \Omega_{w,o}^t = 1 \qquad \forall o\in\mathbf{O} \tag{7}$$

$$\sum_{w\in\mathbf{W}} \lambda_w^t \le |\mathbf{W}| \tag{8}$$

$$\sum_{o\in\mathbf{O}} \Omega_{w,o}^t \cdot vc\cdot\beta_{c,o}^t \le Cv \quad \forall w\in\mathbf{W} \tag{9}$$

$$w = \left\{w \middle| \Omega_{w,o}^t = 1, w\in\mathbf{W}\right\} \in \mathbf{R}w, o \ \ \forall o\in\mathbf{O} \tag{10}$$

The three sub-objectives of the INLP are as follows: (1) minimize the used optical resource, (2) balance out the traffic load served by the activated wavelengths, and (3) minimize the migrated load due to fronthaul topology adjustment. Equation (6) indicates the reasonable integer value of variable λ_w^t and $\Omega_{w,o}^t$, $\forall w\in\mathbf{W}, \forall o\in\mathbf{O}$. Equation (7) states that each ONU co-located with the RRU at small cell can only be allocated one wavelength at time *t*. Equation (8) limits the maximum feasible wavelengths of fronthaul at time *t*. Equation (9) limits the maximum load served by each single-wavelength w ($\forall w\in\mathbf{W}$) at time *t*. Equation (10) ensures that the wavelength assigned to ONU *o* ($o\in\mathbf{O}$) is within the tuning range at time *t*.

3 Adaptive genetic algorithm for CoMP-oriented resource allocation

The complexity of INLP is exponentially increasing with the growing of network scale. To reduce the time complexity, an adaptive GA is proposed to solve the CoMP-oriented capacity and resource allocation problems of the fronthaul network. We will introduce the modified genetic encoding scheme, corresponding fitness function, and adaptive genetic operations for the proposed GA as follows.

3.1 Genetic encoding and the fitness function

GA is an efficient search heuristic method on the basis of principles of natural evolution in the real world [40]. A reasonable chromosome (or an individual) is encoded as a group of genes. For the CoMP-oriented resource allocation, we encode each gene as $\{\xi(oj, wj), oj\in\mathbf{O}, wj\in\mathbf{R}w, oj\}$, where $\xi(oj, wj)$ indicates that wavelength *wj* is allocated to ONU *oj*. For each distributed ONU *oj*, a wavelength *wj* is randomly selected for its data transmission according to the traffic in the corresponding small cell *cj*. The lightpath is built up for data transmission between ONU *oj* and OLT. We apply this process for all ONUs to obtain an individual *I*. We can form a different individual by choosing different optical resource for some of genes. We randomly repeat *P* times to generate more individuals and form the population *I* by grouping different individuals together. In order to release the capacity pressure of the fronthaul when CoMP technique is introduced, we need to enhance the bandwidth efficiency of the optical fronthaul based on the broadcast characteristic of the TWDM-PON. In addition, improving the optical resource allocation efficiency of the fronthaul is also playing a significant role. Furthermore, we also need to pay attention to load balancing of the fronthaul and the influenced traffic load during ONU migration. Finally, each of the individual's fitness is assigned as $(\rho 1, \rho 2, \rho 3, \rho 4)(\eta, \zeta)'$, where $\rho 1$, $\rho 2$, $\rho 3$, and $\rho 4$ are the weights allocated to the optimization objectives described in Section 2.2, respectively. Better individuals survive and reproduce themselves more often than the worse ones. In each iteration, we update the fittest individual on the basis of each individual's fitness. The GA can obtain a good result when it converges [41].

3.2 Adaptive genetic operations

Algorithm 1 illustrates the procedure of the proposed adaptive GA. The initial population **I** of constant size

P is generated randomly based on the gene generation principle mentioned above. Then the population $\mathbf{I}$ goes into the following adaptive genetic operations. The tournament selection [42] is adopted for the selection operation. We randomly select s individuals from population $\mathbf{I}$ and implement tournament selection by holding a tournament among s competitors, where s is the tournament size. When all tournaments are finished, we select the winner of each competing group for crossover, on the basis of each individual's fitness among competitors.

In crossover phase, we implement multipoint gene level crossover to generate the offspring. We randomly select two individuals paired as parent for crossover. In each crossover operation, on the basis of crossover rate pc, $|\mathbf{O}| \cdot pc$ genes are randomly picked out from the parent and swapped at random positions of the individuals. Then P individuals are selected based on their fitness to go into mutation phase. During the evolution, the population size is constant.

In the mutation phase, on the basis of mutation rate pm, $|\mathbf{O}| \cdot pm$ genes of the individuals will be randomly modified to generate new genes. And we modify a gene $\xi(oj, wj)$ by replacing its optical resource wj with another feasible one. Based on the fitness of each individual, P individuals are selected to form a new population. During crossover and mutation phases, in order to limit the maximum traffic load served by each single-wavelength and ensure that the ONU tuning range is legal, a penalty function is used during each genetic operation.

In the evolution phase, pc and pm vary with the fitness value of the initial population of each iteration. We define Fj as the fitness of individual Ij. We have $F\max = \max j(Fj),\ \ j \in \mathbf{I}$, $F\text{mean} = \left(\sum_j Fj\right)/P$, and $F' = \max(Fj1, Fj2)$. Then pc and pm are obtained by Eqn. (11) and Eqn. (12) [43], where βc and βm are fixed parameters.

$$pc = \begin{cases} \dfrac{F\max - F'}{F\max - F\text{mean}}, & F' \leq F\text{mean} \\ \beta c, & \text{otherwise} \end{cases}, \tag{11}$$

$$pm = \begin{cases} \dfrac{F\max - Fj}{F\max - F\text{mean}}, & Fp \leq F\text{mean} \\ \beta m, & \text{otherwise} \end{cases}, \tag{12}$$

We define GA's degree of diversity as Eqn. (13) [44]. $d(j1, j2)$ indicates the differences between two individuals $Ij1$ and $Ij2$. The GA stopped when its convergence reaches a preset threshold [41].

Algorithm 1 CoMP Oriented Genetic Algorithm for Passive Optical Fronthaul

```
I =Null set;
{Stage 1: Randomly Initialize the First Generation Population I of Constant Size P }
while |I| is less than P do
    I =Null set;
    {Generate an Individual I }
    for each distributed ONU $oj \in \mathbf{O}$ do
        randomly choose a reasonable wavelength $wj$ ;
        generate a gene $\{\xi(oj, wj), oj \in \mathbf{O}, wj \in \mathbf{R}_{w,o_j}\}$ ;
        put gene $\{\xi(oj, wj), oj \in \mathbf{O}, wj \in \mathbf{R}_{w,o_j}\}$ in I ;
    end for
    check the individual I ;
    if I is a reasonable individual then
        put I in I ;
end while
{Stage 2: Adaptive Genetic Operations based Evolution}
$I_{best}$ =Null set;
```

Algorithm 1 CoMP Oriented Genetic Algorithm for Passive Optical Fronthaul

```
while the proposed adaptive GA is not converged do
    calculate the fitness value $(\rho_1, \rho_2, \rho_3, \rho_4)(\eta, \zeta)'$ for each individual;
    while number of tournaments is less than P do
        randomly select s individuals from current population;
        select the winner of the competing group;
    end while;
    select the winner of each competing group for crossover, on the basis of each individual's fitness among competitors;
    choose P fittest individuals based on their fitness to go into mutation phase;
    $I_{best} \leftarrow$ the fittest individual in I on the basis of fitness $(\rho_1, \rho_2, \rho_3, \rho_4)(\eta, \zeta)'$;
    adjust $p_c$ and $p_m$ ;
    update the $D_p$ for I ;
end while
```

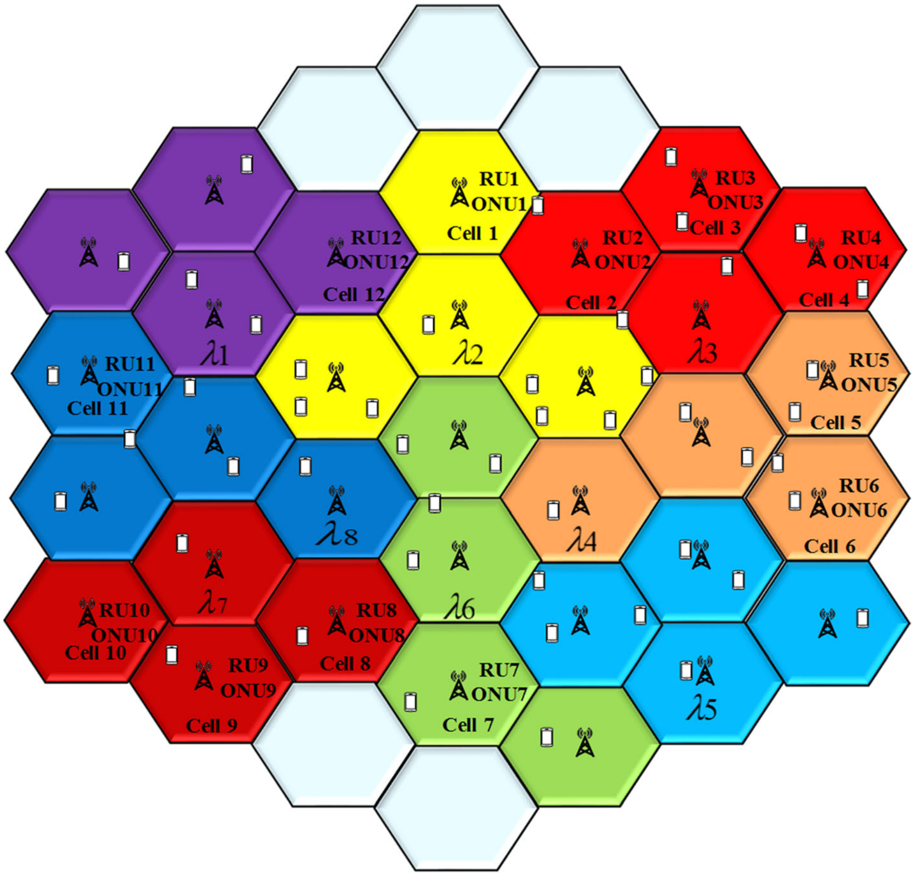

Fig. 2 The 32-cell topology for simulations

$$Dp = \frac{2}{P(P-1)} \sum_{j1=1}^{P-1} \sum_{j2=j1+1}^{P} \frac{d(j1,j2)}{|I|} \tag{13}$$

4 Performance evaluations

Numerical simulations are conducted based on the proposed INLP model and adaptive GA for CoMP-oriented optical resource optimization. In the simulations, a 32-cell physical topology (shown in Fig. 2) is used, and the number of used wavelengths in the TWDM-PON-enabled fronthaul is set as eight. We assume that each distributed RRU is assigned only one ONU with tunable lasers, and compression technique-based bitrate-variable CPRI is adopted in TWDM-PON-enabled fronthaul. Besides, we also assume that time is divided into discrete time periods. Table 1 illustrates the parameters used in our simulations.

In the simulations, different scenarios are considered: (1) typical C-RAN without CoMP-oriented optimization; (2) C-RAN with CoMP-oriented INLP optimization; 3) C-RAN with CoMP-oriented GA. We also consider the influence of the tuning range of the ONUs. With the traffic fluctuation, we try to release the capacity pressure and improve the resource allocation efficiency of the fronthaul when CoMP technique is introduced in C-RAN. Besides, the migrated traffic due to topology change is also considered in our formulations.

Figure 3 represents the converging condition of the proposed adaptive GA with the *Dp* defined in Eqn. (13). It is obviously that the proposed GA converges when the number of iterations exceed 50, if the threshold of the

Table 1 Simulation parameters

Cv, the maximum bandwidth of a single-wavelength	10 Gbits/s
Bandwidth requirement of a mobile terminal	0–20 Mbits/s
vc, fixed physical link rate of typical CPRI [19]	2.5 Gbits/s
$\beta^{t}_{c,o}$, load fluctuation-based compression ratio of typical CPRI for cell *c* served by ONU *o*	0.2–1
The number of the distributed optical network units (ONUs)	32
P, the constant size of the initial population	60
The number of the mobile terminals	100
ni, the size of the cell cluster enabling the CoMP	2 or 3
Dp, preset convergence threshold of the proposed adaptive GA	0.15

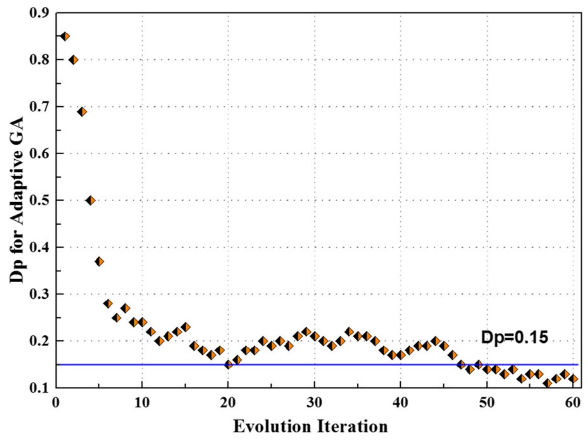

Fig. 3 Convergence performance of the adaptive GA

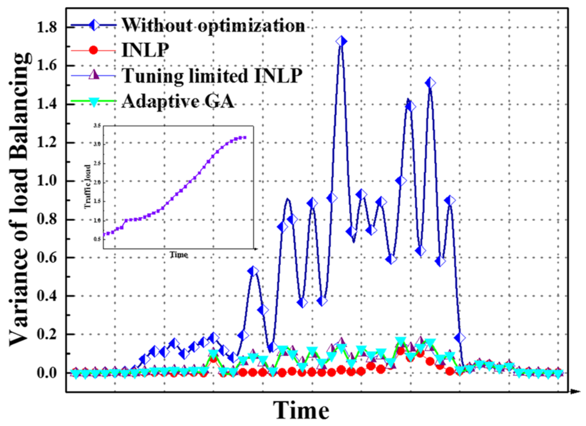

Fig. 5 Load balancing simulation results with different methods

Dp is set at 0.15. Besides, compared to the INLP method, the computation time of the proposed GA is much lower within 1.68 s.

Figure 4 illustrates the optical resource allocation performance comparison of the INLP to the proposed adaptive GA. The limited tuning range of each ONU is also considered. It is known that the traffic flow varies with the time in the fronthaul. Compared to the scenario without CoMP-oriented optimization, better optical resource allocation performance can be obtained with INLP. Specifically, in light traffic load time slot, nearly 70 % wavelengths can be saved by using INLP. However, in typical C-RAN, wavelength resource allocation is fixed regardless of load variation. It is known that the complexity of INLP is exponentially increasing with the growing of network scale. As we can see, the proposed GA nearly has the same resource allocation performance with the INLP based on the load fluctuation. Compared to the INLP, the computation time of the adaptive GA is much lower within 1.68 s. Besides, compared to the tuning limited INLP, better performance can be obtained with full-spectrum tunable lasers, which is more expensive. Furthermore, as shown in Eqn. (4) and Eqn. (5), the load imbalance and the migrated traffic due to topology adjustment are also considered during the optimization. In traditional C-RAN, considering that the traffic served by each wavelength resource has a big difference, the load imbalance is clearly in the TWDM-PON-enabled fronthaul. As shown in Fig. 5, the variance of the traffic load fluctuation is further reduced, while the migrated traffic load due to topology change is very light by using INLP and the proposed adaptive GA.

Figures 6, 7, 8, and 9 show the CoMP-oriented downlink bandwidth optimization simulation results with different methods. When the number of mobile users that located near the small cell edge is small, little sharing data is needed to be transmitted through fronthaul transport network. The performance of the proposed algorithms is not obvious. However, with the growth of mobile users that is near the cell edge, the sharing data is getting large. As shown in the Fig. 6, the most efficient bandwidth saving can be achieved by using INLP. Compared with INLP,

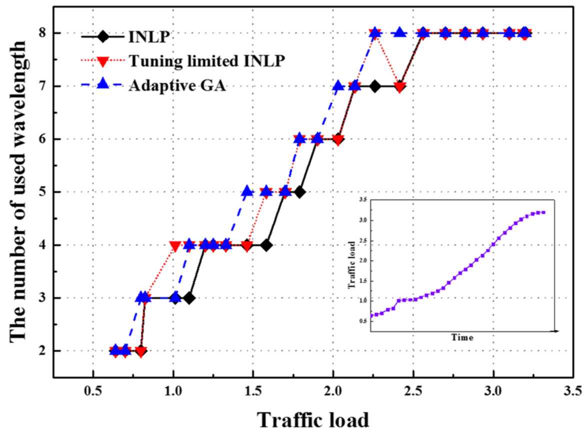

Fig. 4 Utilization of wavelength with different methods

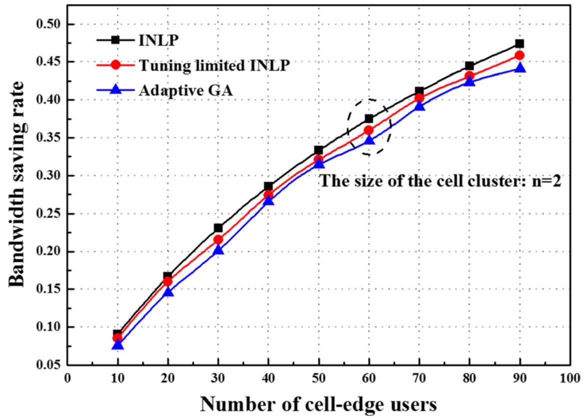

Fig. 6 Bandwidth saving rate considering the number of cell edge users with different methods ($n = 2$)

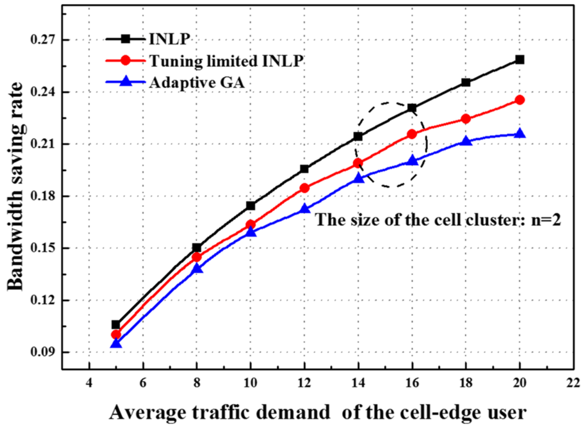

Fig. 7 Bandwidth saving rate considering the average traffic demand of cell edge users with different methods (*n* = 2)

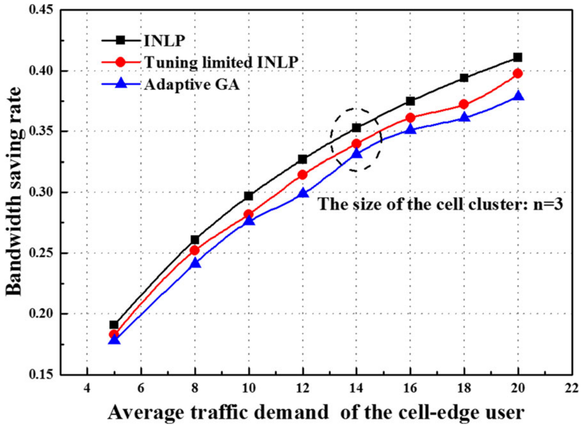

Fig. 9 Bandwidth saving rate considering the average traffic demand of cell edge users with different methods (*n* = 3)

similar trends can be observed by using the proposed adaptive GA with lower computational complexity. The limited tuning range of the ONU is also considered. Better performance can be obtained with full-spectrum tunable lasers. Besides, Fig. 7 represents the influence of the average traffic demand on the optimization. When the bandwidth demand of the cell edge users increases, the total demand of the downlink bandwidth is increasing including the bandwidth allocated to the sharing data. By using the proposed method, the capacity pressure of the fronthaul is released. Furthermore, the size of the cell cluster used to enable the CoMP also plays a critical role in the optimization. As shown in Figs. 8 and 9, the larger the size of the cell cluster, the better performance can be achieved. Finally, the significant bandwidth saving is attributed to the broadcast characteristic of the TWDM-PON, wavelength assignment provided by the INLP and proposed GA, and the SDN technique.

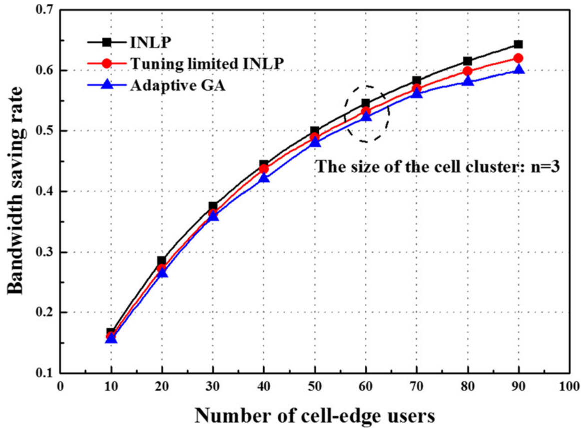

Fig. 8 Bandwidth saving rate considering the number of cell edge users with different methods (*n* = 3)

5 Conclusions

Both INLP model and adaptive GA were explored to release the capacity pressure of the fronthaul, when CoMP technique is introduced in C-RAN. The proposed algorithm offered an efficient way to face the capacity pressure of the fronthaul. Besides, optical resource allocation problem was also considered. The results from the simulations of the proposed algorithm in the 32-cell topology indicated that good performance could be achieved by using the INLP and the proposed adaptive GA. The significant performance was attributed to the broadcast characteristic of the TWDM-PON, wavelength assignment provided by the INLP and the GA, and the SDN technique used in the C-RAN.

Abbreviations

BBU: Baseband unit; BS: Base station; CoMP: Coordinated multipoint; CPRI: Common public radio interface; C-RAN: Cloud radio access network; D2D: Device-to-device; EE: Energy efficiency; GA: Genetic algorithm; ICI: Inter-cell interference; INLP: Integer non-linear programming; OFDMA: Orthogonal frequency division multiplexing; OLT: Optical line terminal; ONU: Optical network unit; RRU: Remote radio unit; SE: Spectral efficiency; TWDM-PON: Time wavelength division multiplexing passive optical network; SDN: Software defined network; SE: Spectral efficiency

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Competing interests

The authors declare that they have no competing interests.

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