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Application of Firefly Algorithm to Optimization of Translucent Elastic Optical Networks

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Abstract—In order to achieve global-scale elastic optical networks, it is important to solve a virtualized-elastic-regenerator (VER) placement, and routing and spectrum assignment (VER-PRSA) problem. This study proposes application method of the binary real coded firefly algorithm (BRCFF) for the VER-PRSA problem. BRCFF is used for determining regenerating node candidates where zero or more VER can be installed. We confirm that the proposed method reduce the total number of VERs in comparison with the conventional method.

1. Introduction

The elastic optical network (EON) is scalable optical transport network architecture, and it alleviates the stranded bandwidth issue of current wavelength-routed optical networks. In order to achieve global-scale EONs, a virtualized elastic regenerator (VER) was proposed as a solution for efficiently regenerating various bandwidth superchannels, including tightly aligned Nyquist WDM superchannels as well as inverse-multiplexed discrete superchannels, in translucent EONs [1]. Although VER is absolutely necessary to EON, VER placement and the applicable routing between source-destination nodes are important factors to reduce the total number of VERs, from a viewpoint of installation costs. Furthermore, routing and spectrum assignment in the transparent segment are also important problems to efficient use spectrum resources in each link.

In order to solve the VER placement, and routing and spectrum assignment (VER-PRSA) problem, this study propose a VER placement method using Firefly Algorithm (FA) [3]. FA is one of nature-inspired multi-agent metaheuristic algorithms and is a metaheuristic algorithm inspired by the flashing behavior of fireflies. The primary purpose for a firefly's flash is to act as a signal system to attract other fireflies, and the fireflies of FA search optimal solution with moving toward other brighter fireflies. Because the standard FA is suitable for continuous optimizations, we apply the binary real coded firefly algorithm (BRCFF) to solve VER placement problem. In the proposed algorithm, each position vector of firefly corresponds to regeneration sites. If n th element of the position vector is 1, it denotes that n th node is a candidates of regeneration site and VER can be installed at node n. If n th element of the position vector is 0, VER cannot be installed at the node even if it is necessary. The proposed method is the first application of FA or other multi-agent metaheuristic algorithm to VER-PRSA problem. Even if other problems except of VER placement or routing and spectrum assignment are required to optimize EONs, FA can adapt flexibly by modifying the fitness function. We apply the proposed method using BRCFF to four network models, and we confirm that the proposed method can reduce the total number of VERs in comparison with Shortest-Path and Farthest Node (SP-FN) algorithm [2].

2. Constraint Conditions of VER-PRSA Problem

We explain about the definition of the VER-PRSA problem for a set of static traffic demands in a translucent EON. Note that variables used in this section have no relevance to the variables used in the Section 4.

The following information are given in advance;

- Network graph $\boldsymbol{G} = (\boldsymbol{V}, \boldsymbol{E})$ which comprises a set of nodes $\boldsymbol{V} = 1, 2, \ldots, N$ and a set of links $\boldsymbol{E} \in \boldsymbol{V} \times \boldsymbol{V}$ connecting nodes in $\boldsymbol{V}$. Edge costs between two directly connected nodes.
- An ordered set of frequency-slot units (FSUs) $\boldsymbol{F} = \{f_1, f_2, \ldots, f_{|\boldsymbol{F}|}\}$ for each link
- Optical reach L
- The total number of sub-regenerators in a VER S
- Traffic demand set $\boldsymbol{D} = \{d_1, d_2, \ldots, d_{|\boldsymbol{D}|}\}$

Each demand d is determined by a source node s, a destination node g, and the requested number of contiguous FSUs n_{sg} between source-destination node pair (s, k).

The constraints are follows;

- Regarding the optical path, the length of each transparent segment does not exceed the optical reach L.
- Regarding each transparent segment of the optical path, FSUs allocated to the transparent segment should be contiguous to each other, should be the

same for each link on the transparent segment, and should not overlap with those of other optical paths.
- All subchannels within the superchannel for the optical path should be regenerated using the same VER.

Goal of this optimization is to find an optical path for each demand under the constraints and to minimize the total number of VERs which the whole network needs.

3. Shortest-Path and Farthest Node (SP-FN)

SP-FN algorithm is a one of the simplest algorithms to solve VER-PRSA problem. In SP-FN, the shortest path calculated by Dijkstra method is always adopted as the optical path between source-destination node pair, and the regeneration is performed at the farthest node on the path from the source node (or the previous regenerated node) within the optical reach L. The demand set $\boldsymbol{D}$ is sorted according to the product of the requested number of contiguous FSUs n_{sg} and the shortest distance between each node pair (s, k) in descending order. The required contiguous FSUs are placed according to First-Fit algorithm.

4. Firefly Algorithm (FA)

The FA is inspired by the flashing behavior of fireflies. The M fireflies search the global optima with being attracted to other fireflies according to their attractiveness. The attractiveness is proportional to their brightness, and for any two fireflies, the less brighter one will be attracted by the brighter one. However, the brightness can decrease as their distance increases. If there are no fireflies brighter than a given firefly, it will move randomly. The brightness of a firefly is determined by the objective function.

Let $\boldsymbol{x}_i = (x_{i1}, x_{i2}, \cdots, x_{iN})$ be the position vector for firefly i ($i = 1, 2, \cdots, M$). The initial positions of fireflies are generated at random ($\boldsymbol{x}_i \in [x_{\min}, x_{\max}]^N$).

The movement of a firefly i is attracted to another more attractive firefly j having better solution, is determined by

$$\boldsymbol{x}_i^{\text{new}} = \boldsymbol{x}_i^{\text{old}} + \beta(\boldsymbol{x}_j(t) - \boldsymbol{x}_i^{\text{old}}) + \alpha(t)\boldsymbol{\epsilon}_i, \quad (1)$$

where the second term of Eq. (1) is due to the attraction. The attractiveness β is determined by

$$\beta = \beta_0 e^{\gamma r_{ij}}, \quad (2)$$

where β_0 is the parameter, and an absorption coefficient γ determines the speed of the convergence. Thus, the attractiveness will vary with the distance r_{ij} between firefly i and j;

$$r_{ij} = \|\boldsymbol{x}_i - \boldsymbol{x}_j\| = \sqrt{\Sigma_{d=1}^{D}(x_{in} - x_{jn})^2}. \quad (3)$$

The third term of $\Delta\boldsymbol{x}_i$ is randomization with $\alpha(t)$ being the randomization parameter which increases with time, and $\boldsymbol{\epsilon}_i = (\epsilon_{i1}, \epsilon_{i2}, \cdots, \epsilon_{in})$ is a vector of random numbers;

$$\boldsymbol{\epsilon}_i = (\mathbf{rand} - 0.5)L, \quad (4)$$

where **rand** is a random number generator uniformly distributed in $[0, 1]$, and L is the scale of the problem, $|x_{\max} - x_{\min}|$. The firefly i is attracted to all the brighter fireflies by repeating Eq. (1) if two or more brighter fireflies exist. The brightest firefly i moves randomly according to

$$\boldsymbol{x}_i(t+1) = \boldsymbol{x}_i(t) + \alpha(t)\boldsymbol{\epsilon}_i. \quad (5)$$

5. Binary Real Coded Firefly Algorithm (BRCFF)

In order to select regeneration nodes in VER-PRSA problem, binary numbers 0 and 1 are used. In other words, there are zero or more VERs at a node taking the status 1, and there is no VERs at a node taking the status 0. Due to the normal FA explained in Section 4 is a real-coded algorithm, we use a binary coded FF algorithm. The position vector $\boldsymbol{x}_i$ in Eq.(1) is represented by $\boldsymbol{y}_i = (y_{i1}, y_{i2}, \cdots, y_{iD})$ which takes a value of 0 or 1. The corresponding variation of r_{ij} value varies between -1 to 1, which can be calculated by

$$r_{ij_d} = y_{in} - y_{jn}. \quad (6)$$

When the position of the firefly is updated, δy can be calculated by

$$\boldsymbol{y}_i^{\text{new}} = \boldsymbol{y}_i^{\text{old}} + \beta(\boldsymbol{y}_j(t) - \boldsymbol{y}_i^{\text{old}}) + \boldsymbol{\epsilon_2}_i, \quad (7)$$

where the third term $\boldsymbol{\epsilon_2}$ is the random number generated in the range $(-1, 1)$, and $\boldsymbol{y}_i^{\text{old}}$ and $\boldsymbol{y}_j$ takes a value of 0 or 1. On the other hand, $\boldsymbol{y}_i^{\text{new}}$ varies between -2.180 to 4.3. To code $\boldsymbol{y}$, we set a threshold level th. If $y_{in}^{\text{new}} > th$, then $y_{in} = 1$. If $y_{in}^{\text{new}} \leq th$, then $y_{in} = 0$. In this study, the threshold level is made by a sigmoid function

$$f(y_{in}^{\text{new}}) = \frac{1}{1 + \exp(-y_{in}^{\text{new}})}. \quad (8)$$

6. Application of BRCFF for VER placement

This section explains the algorithm of solving VER-PRSA problem by using BRCFF. BRCFF is used to determine candidates of regeneration nodes and optimizes the number of total VERs installed in whole network.

The proposed algorithm composed of the following steps.

(Step1) Initialize each firefly position $\boldsymbol{y}_i = (y_{i1}, y_{i2}, \ldots, y_{iN})$ randomly in the range $[-1, 1]$. N represents the dimension of search space and is equivalent to the number of nodes in the network.

(Step2) Order demand set $\boldsymbol{D}$ as is the case with SP-FN.

(Step3) Find optical paths for respective demands, install VERs and place required contiguous FSUs, by using each firefly position $\boldsymbol{y}_i$.

(Step3-A) Find k path candidates for each demand d by K shortest path routing algorithm (Yen's algorithm).

(Step3-B) Check whether a path of the candidates is usable. When the length of the transparent segment exceeds the

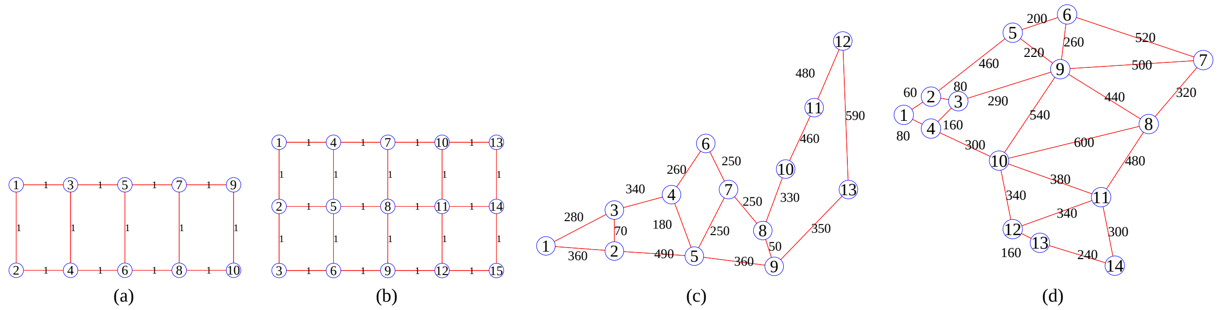

Figure 1: Benchmark network models. (a) 2×5 regular ladder network model. (b) 3×5 regular ladder network model. (c) JP13 network model. (d) DE14 network model.

optical reach, it must be regenerated by VER. The regeneration is performed by the farthest node method, however, VERs can be installed at only nodes n where $y_{in} = 1$. If all the transparent segment is regenerated before the length exceeds the optical reach, the path is adopted as the path for the traffic demand d. If not, check next shortest path. Repeat the Step3-B until the reachable path is found. If all k path candidates are rejected, the fitness $f(\boldsymbol{y}_i)$ of the firefly i is set as ∞, and consider next firefly.
(Step3-C) Repeat the Step3 until all the demand of all the fireflies are considered.
(Step4) Evaluate the fitness of each firefly i by

$$f(\boldsymbol{y}_i) = \#total\_VERs_i, \tag{9}$$

where $\#total\_VERs_i$ denotes the total number of VERs. Therefore, this is a minimum optimization problem.
(Step5) Update $\boldsymbol{y}_i$ of each firefly i by Eq. (7) and Eq. (8).
(Step6) Return to the Step 3 and repeat these steps until the generation step is terminated.
(Step7) With respect to the best firefly needing the least number of VERs, place the required contiguous FSUs according to First-Fit algorithm and calculate the highest FSU-index.

7. Simulation Results

7.1. Networks and Parameters

In order to evaluate the proposed FA-FN, we consider four networks containing 2×5 and 3×5 regular network models and real-world network models: Japan network model JP13 and Germany network model DE14, as shown in Fig. 1. The traffic demand for each node pair was chosen uniformly from 100 Gb/s , 200 Gb/s, 300 Gb/s and 400 Gb/s. For each traffic demand, we assumed the following required number of 25-GHz width FSUs, and subregenerators, expressed as a tuple as (100 Gb/s,2,1), (200 Gb/s,3,2), (300 Gb/s,4,3) and (400 Gb/s,5,4). We carry out 30 simulations with different traffic demand sets.

The parameters of the proposed algorithm using BRCFF are summarized in Table 1. The number of fireflies M is equivalent to the number of network nodes N, namely, 10, 15, 13 or 14. In the same way, the number of dimensions of fireflies is equivalent to N.

Table 1: Parameters that are used in simulations.

Parameter	Symbol	Value
Attractiveness parameter	β_0	0.2
Absorption coefficient	γ	1
Maximum number of evaluations	T	300

7.2. Results

Figure 2 shows comparison results of SP-FN and the proposed method using BRCFF. The node occupancy rate denotes the percentage of the number of nodes where one or more VERs are installed. Regarding the three priorities, the smaller values are better. We can see that on all the optical reach L for all the network models, the proposed method needed less VERs than SP-FN. Furthermore, the node occupancies of the proposed method are smaller than SP-FN. From these results, we can conclude that the proposed method can effectively place VERs.

On the other hand, the highest FSU-index of the proposed methods is bigger than SP-FN. This is because the cost function of BRCFF (Eq. (9)) considers only the total number of VERs. If this function is modified to consider not only the total number of VERs, but also the highest FSU-index, we can expect to obtain better results with a balance between the number of VERs and the highest FSU-index.

8. Conclusions

This study has been proposed a novel VER placement method using BRCFF. BRCFF is used to optimize VER placement problem and reduces the total number of VERs. The simulation results showed that the proposed method can effectively place VERs. Future works include the mod-

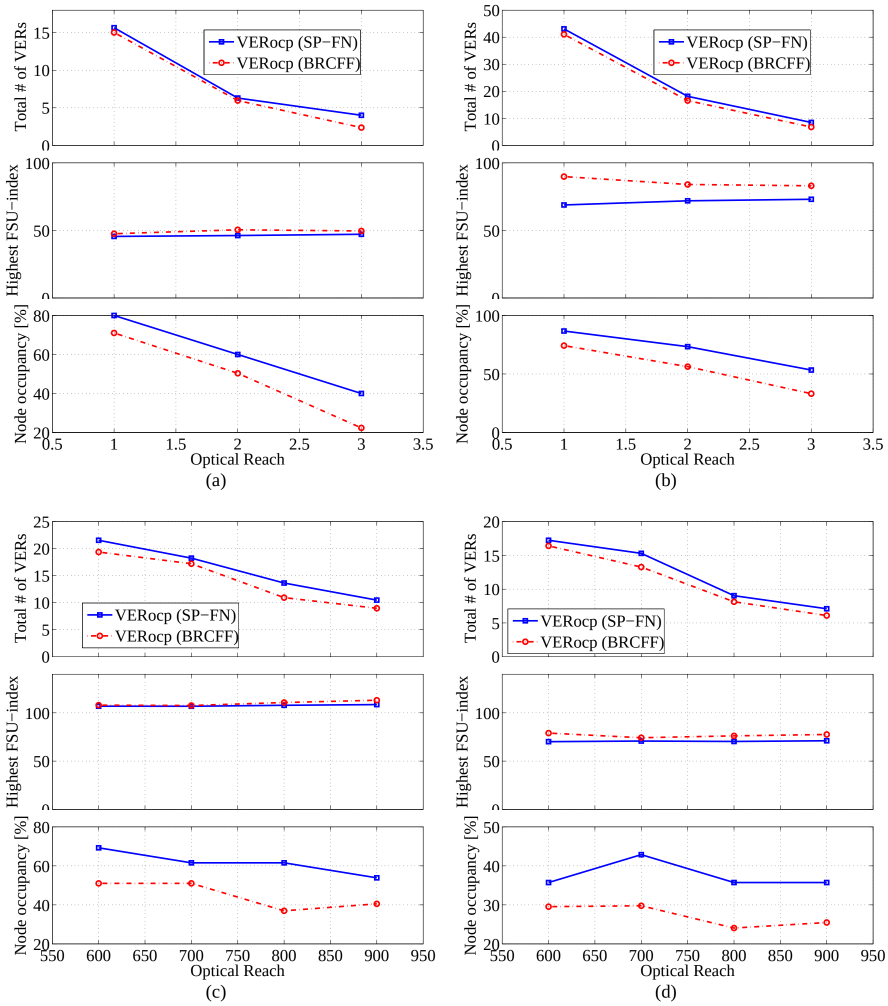

Figure 2: Comparison results of SP-FN and the proposed method in terms of the total number of VERs, the highest FSU-index and the node occupancy rate on VER. (a) 2×5 regular ladder network model. (b) 3×5 regular ladder network model. (c) JP13 network model. (d) DE14 network model.

ification of the fitness function, parameter tuning, path planning and so on.

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