Energy-saving Strategy Based on an Immunization Algorithm for Network Traffic

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Abstract

The rapid development of both communication traffic and increasing optical network sizes has increased energy consumption. Traditional algorithms and strategies don't apply to controlling the expanded network. Immunization algorithms originated from the complex system theory are feasible for large-scale systems based on a scale-free network model. This paper proposes the immunization strategy for complex systems which includes random and targeted immunizations to solve energy consumption issues and uses traffic to judge the energy savings from the node immunization. The simulation results verify the effectiveness of the proposed strategy. Furthermore, this paper provides a possibility for saving energy with optical transmission networks.

Keywords: random immunization, targeted immunization, energy consumption, traffic, complex system

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1. Introduction

The rapid development of global information technology has caused optical transmission networks to be increasingly utilized. The accompanying energy issues are prominent and will consume significant resources. For instance, data centers account for 2% of the electricity consumed in the U.S., and this amount is growing at a rate of 12% [1]. Furthermore, optical networks contain numerous layers, sub-areas, and nodes that must be supported; therefore, their energy requirements become more prominent. Reducing this energy consumption to achieve green communication is being emphasized in research.

The green network concept was first proposed by Gupta et al. [2] and interests numerous researchers. Generally, energy consumption of data network equipment in the Internet is unknown although they use a substantial amount of energy. In this area, there is a lack of deeper related studies with a special focus on wired networking and it still remains to be many challenges to flexible and reliable technology, which has begun to be researched [3]. Chiaraviglio et al. proposed a novel approach for switch-off network nodes and links while still guaranteeing full connectivity and maximum link utilization [4]. Zhang et al. introduced the fundamentals and current progress for existing cognitive radio and self-organization techniques. They also survey critical cognitive radio issues (including common control channel management, cooperative spectrum sensing, bioinspired spectrum sharing, network scalability and adaptive routing)and their self-organization features while identifying new directions and open problems with cognitive radio networks [5], such as the increased network architecture complexity, high configuration and management costs for large-scale networks, spectral fluctuations, diverse QoS requirements for various applications, and increasing difficulties for centralized control. Li et al. proposed a new power saving mechanism called the sleep-transmit mode (STM), which enabled optical network units (ONUs) on the customers' premises to transmit upstream data during sleep periods without turning on the receiver, which conserved energy and improved the upstream transmission delay. These advantages were achieved by pre-allocating bandwidth for upstream transmission using the ONU before entering the sleep state [6]. Ji et al. researched energy consumption problem from the perspective of components and modules, node equipment, and network levels, different enabling technologies, but they didn't consider the controlling algorithm into the control architecture for energy-efficient all optical switching networks [7]. However, we still need to deal with the problem of energy consumption based on the complex-giant-system theory to the complex and increasingly large networks rather than only sleep devices or a single mechanism. Especially, we hope that the strategy is feasible and could facilitate to judge data or control system performance on ASON/WSON (Automatically Switched Optical Network/ Wavelength Switched Optical Network).

Immunizing complex systems from the theory of complex giant system is actively researched. Liu et al. were concerned with designing a flexible immune algorithm suitable for most optical multicast networks and modified a fitness function to reflect the level of individual excellence and protect the links. Increasing the individual concentration function reflected the network coding link probability, increased the alternative coding link diversity and simplified the immunization process by adopting an elitist reservation strategy for the selected encoding links [8]. Shams et al. proposed a new immunization strategy based on a stochastic hill-climbing algorithm to create a subset of nodes whose immunization efficiently reduced the network vulnerability to worst-case epidemics [9]. Keramati et al. presented a risk factor to evaluate their framework. This factor multiplied the likelihood an attack path by its impact on the security factors (confidentiality, integrity, and availability). Their framework was previously applied to a well-known network example to determine its performance [10]. In recent years, immunization strategies have improved the information-processing capabilities and system intelligence. Therefore, the immunization strategy becomes a new direction for researching intelligent controllers [11-15]. In this paper, we propose an immunization algorithm to solve energy consumption in optical networks, which is easier and more convenient than the past iterative algorithm and strategies. The solution will facilitate to both energy saving and global information processing in the optical network.

2. Node immunization technology

The immunization algorithm is based on the immune system of human. **Table 1** is the comparison to the immunization algorithm and immune system.

Table 1. The comparison to the immunization algorithm and immune system

Immune system	Immunization algorithm
Antigen	The problem
Antibody	The best answer
Antigen recognition	Problem recognition
Produce antibody memory cell	Associate the best answer before
Lymphocyte differentiation	Keep the better answer
T-cell suppression	Eliminate the rest answer
Cell clone(Antibody increasing)	Produce the new antibody using GA operator

The immunization algorithm is defined by simulating the recognition and combination between the antigen and antibody, and simulating the process of producing antibody. This kind of immunization algorithm is widely used. It can combine with the other algorithm just as the genetic algorithm. On the premise of reserving the original algorithm with good properties, we could restrain the degenerating phenomenon with some information or knowledge characteristics during the process of optimization.

Network devices can't act like monitors and other equipment which can switch into a power-saving mode to reduce energy consumption when idle. Therefore, such networks consume significant energy. Internet-saving algorithms can be applied to ASON/WSON as follows:

(1) Set two states, active and immunized, for the network device. The device rests when idle to reduce energy consumption.

(2) Aggregate run routes to a few devices at the network level to reduce energy consumption when the network traffic load is low.

(3) Change the network protocol in the control plane for the optical links, which flexibly adjusts devices. Run devices when the load is high, and make the appropriate equipment sleep when the load is low to reduce energy consumption.

Both random and targeted immunization algorithms can reduce the power consumption, and this paper compares the different effects.

3. Immunization strategy

We can use an immunization strategy to solve the energy consumption problems in optical networks, on which we can immunize nodes with low traffic on the optical networks layer to save energy. This paper uses random and targeted immunizations to solve this problem. The nodes were divided into gateway and interior nodes. The gateway node energies are much larger than for the interior nodes; therefore, we use the gateway nodes for this strategy as shown in **Fig. 1**.

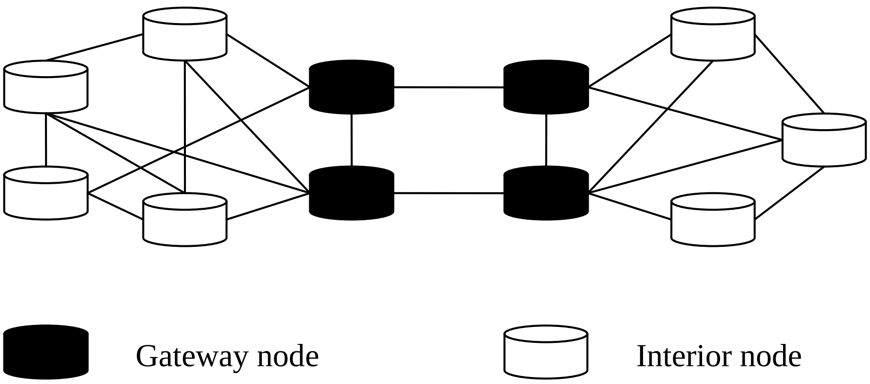

Fig. 1. Gateway and interior nodes in the routing domain

3.1 Random immunization strategy

The random immunization strategy randomly selects immunized nodes in the network. Nodes with large or small degrees are treated equally. The immune node density, g, yields the following immune critical value for random immunization to gain the steady state infection, g_c:

$$g_c = \lambda / \lambda_c \tag{1}$$

The steady state infection (high energy consumption) density, ρ_g, is:

$$\begin{cases} \rho_g = 0 & g > g_c \\ \rho_g = (g_c - g)/(1-g) & g \le g_c \end{cases} \tag{2}$$

We obtain the immune critical value, g_c [16], from λ_c, the epidemic threshold for a scale-free network:

$$g_c = 1 - (1/\lambda)(\langle k \rangle / \langle k^2 \rangle) \tag{3}$$

where k is the degree for some nodes related to traffic interlinkage, which is ascending with the increase of traffic. λ is the effective propagation rate. Thus, as $\langle k \rangle \to \infty$, the critical value λ_c tends to zero with the unlimited network growth, and the immune critical value, g_c, tends to 1.

3.2 Targeted immunization strategy

Using the uniform characteristics from a scale-free network, we can make the objective immune selective; therefore, we choose nodes with small degrees to immune. Once these nodes are immune, the side they are connected to can be wiped, which greatly reduces the possibility for spreading energy. We define this network as a BA scale-free network; therefore, the immune critical value for targeted immunization is:

$$g_c \propto e^{-2/m\lambda} \tag{4}$$

where λ is the effective propagation rate to yield the immune value and m is the number of connections at some node. The selectively targeted immunization in the scale-free network provides an accurate critical value, on which we can gain the steady state infection to judge and select the immunized node.

The traffic is chosen based on its degree, and we obtain the critical value and choose an operator based on the traffic size. The aim is to save energy without affecting the network transmission. The function to count the traffic probability of each node is $P_i = F_i / \sum_{i=1}^{n} F_i$, and F_i is a traffic function; however, for the immunization strategy, f means the degree.

$$f_{ij} == \sum_{s=1}^{N} \sum_{d=1}^{N} f_{L_{ij}}^{sd} \quad \forall i,j \tag{5}$$

In this formula, f_{ij} is the traffic, L_{ij} shows the link [17] between node i and node j, t^{sd} is the average traffic intensity for node *s* (*s=1, 2，…，N*) to node *d* (*d=1, 2，…, N*), $\{t^{sd}\}$ refers to the traffic requirements, $f_{L_{ij}}^{sd} \epsilon [0, t^{sd}]$ is the flow produced when the traffic t^{sd} route goes through the link, and $f_{L_{ij}}$ is the traffic flow for link L_{ij}.

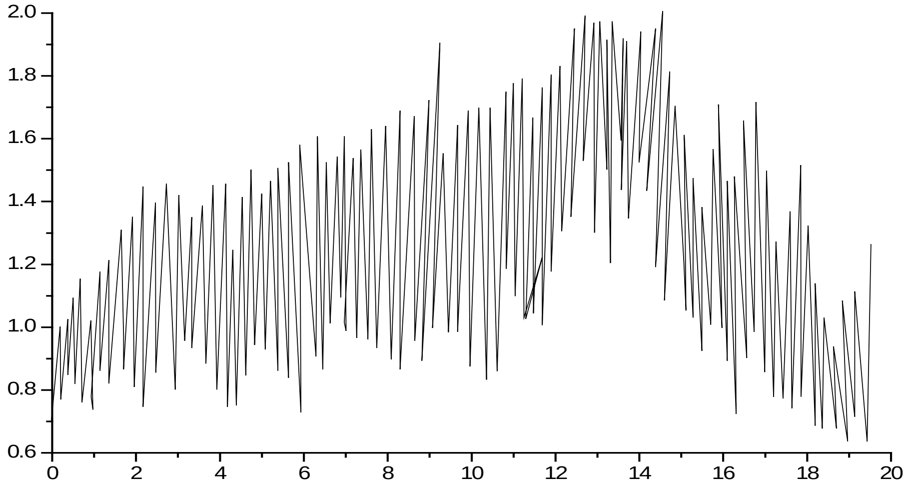

Fig. 2. Daily traffic status

We compare the steady state infection density and traffic probability to judge immunized nodes.

The network traffic changes through the daily status [2] as shown in **Fig. 2**. **Fig. 2** shows the daily network traffic overtime in the US, which begins to rise at 8 in the morning and peaks during 12:00 to 14:00. Afterwards, it begins to decrease to a minimum at 20:00. To ensure the algorithm accuracy, we test it at every time interval. We set up a time variable, *t*, between 8 am and 2 pm to detect the nodes for the remaining time. The test is divided into two sections, which could not only ensure the normal network operation but also maximize the saving effect for different network traffic.

Selecting the individual is an important detail to this strategy. Using a traversal algorithm may increase the difficulty. We draw on experience to set the edge node selection strategy to the minimum degree nodes and use the priority selection strategy to reduce the difficulty and time.

3.3 Immunization strategy for saving energy

The energy-saving control based on immunization strategy includes the following steps:
(1) Initialize traffic, giving the values of the traffic probability, setting the value of λ, etc.
(2) Compute g_c.
(3) Adjust the parameters of the immunization strategies according to the Eq. (2).
(4) Compare the output of the step (2-3).
(5) Compare the steady state infection density and traffic probability.
(6) Adjust immunized nodes according to the steady state infection density.
(7) Compute saving-energy results.

4. Simulation

4.1 Random immunization

This algorithm uses the traffic volume as a reference to set the parameters based on the traffic or traffic probability. Defining λ as the effect of a node on other nodes and λ_c as the highest traffic probability capable of disturbing the transfer yield a g_c based on the formula $g_c = 1 - \lambda_c/\lambda$, which is 0.164.

The data used are based on the paper by Lifang Zhang[18]and Peng Ren[19], and the traffic load is shown in **Table 2**. Immune algorithm of this paper is based on the traffic of the nodes, manages the nodes not to meet the sleep conditions and carries through energy saving. The data 1, data 2 and data 3 are the energy saving results. Because the core of the algorithm is traffic, we choose the node to sleep based on it. And we provide seven consecutive nodes for the simulation.

Table 2. Original data

node / traffic	1	2	3	4	5	6	7
data1	90	150	110	120	180	200	270
data2	150	210	200	100	270	170	110
data3	60	120	180	240	260	280	400

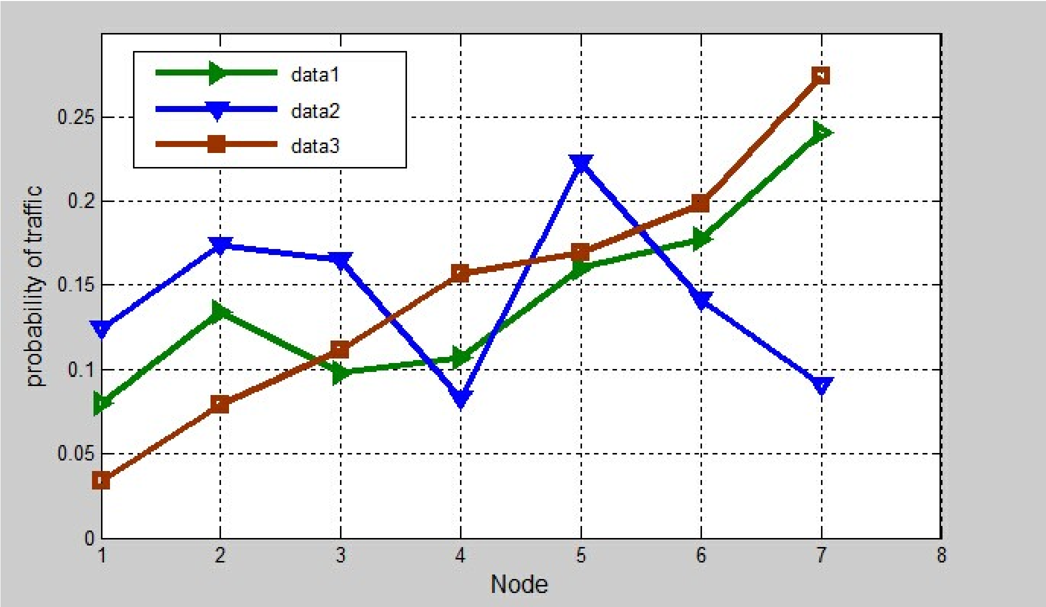

Fig. 3. Traffic probability

We obtain the traffic probability P_i based on **Table 2** in **Fig. 3**. The immunized nodes exhibit a density on **Fig. 3** according to Eq. (2) as shown in **Fig. 4**:

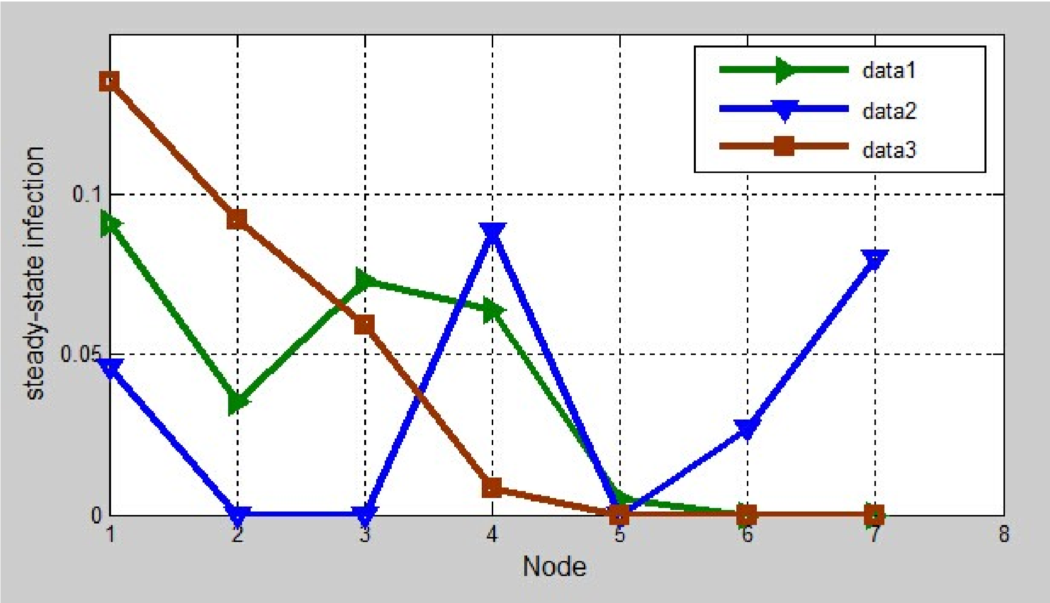

Fig. 4. Steady state density for random immunization

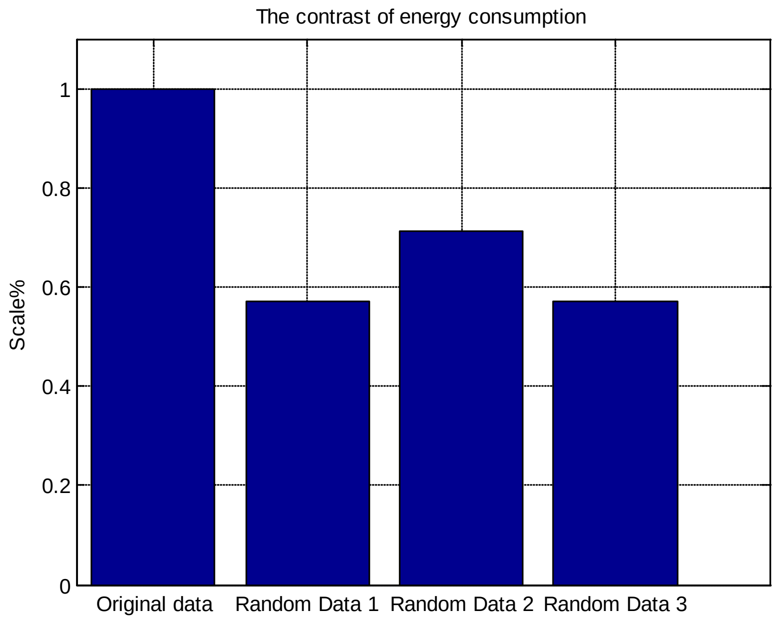

Fig. 5. The contrast of energy consumption

We determine the sleep nodes on the steady state infection density. **Fig. 5** shows the energy usage before and after the random immunization and compares the original data and random data. We can see that the random immunization is feasible and yield good results.

4.2 Targeted immunization

The immune critical value for the targeted immunization is different from the random immunization and is $g_c \propto e^{-2/m\lambda}$, where m [19] is the minimum number of connections, and λ is set to 1. Therefore, g_c is 0.141. According to **Table 2** and **Fig. 3**, the immunized nodes to the density are shown in **Fig. 6**:

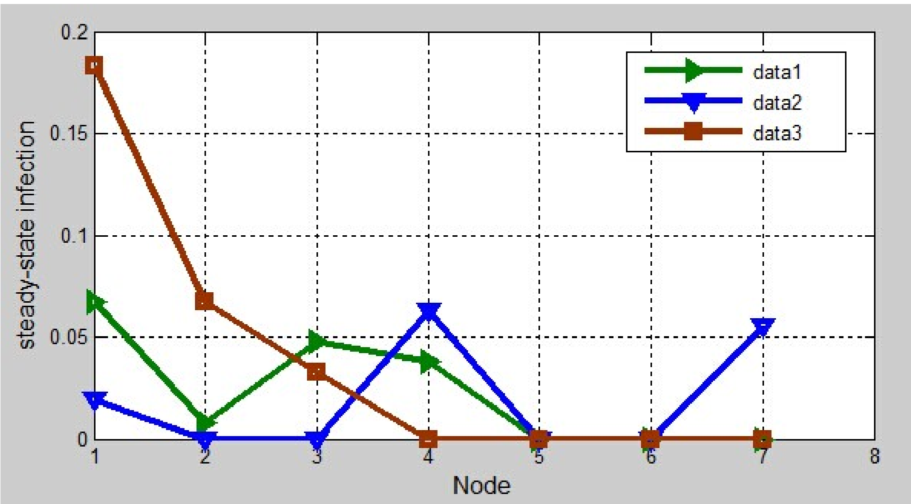

Fig. 6. Steady state density for targeted immunization

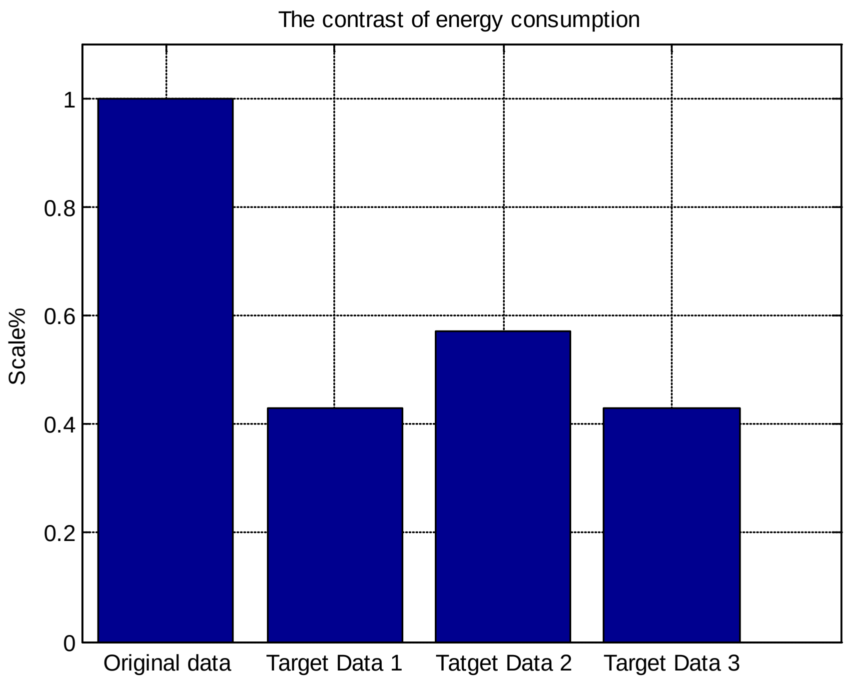

Fig. 7. Energy consumption contrast

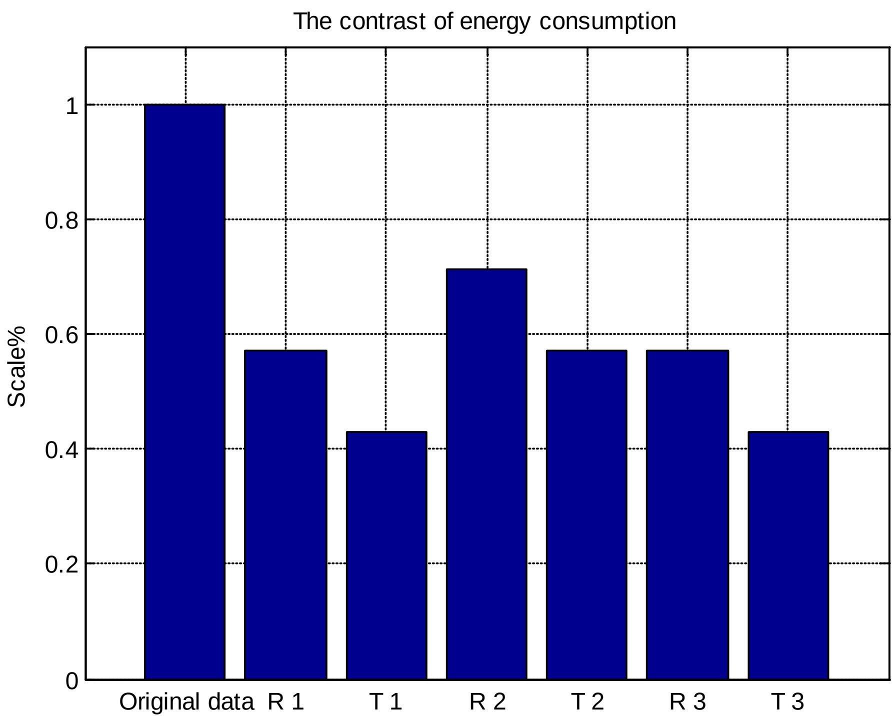

Fig. 8. Energy consumption contrast

We determine the sleep nodes on the steady state infection density from **Fig. 6**. We assume the original energy consumption is 1. **Fig. 7** compares the energy data before and after the targeted immunization. Energy consumption of three sets of data are decreased through targeted immunization. Because of the difference of energy consumption of each node, energy saved is different through immunization algorithms based on differfent traffic. In general, energy consumption of the three sets have been reduced, which verifies the effectiveness of the proposed strategy. The targeted immunization is also feasible and could yield good results.

From the **Fig. 5** and **Fig. 7**, we can know the two immunization strategies can all save the energy, but the results are different because the steady state infection density in **Fig. 6** are more accurate than random immunization. **Fig. 8** clearly exhibits the original energy data for the random, *R*, and targeted, *T*, immunizations. We can know that energy consumption of the nodes have declined after targeted immunization or random immunization. The targeted immunization can yield better results than random immunization.

5. Conclusion

The immunization strategy can be used with optical networks to save energy and divided into random and targeted immunizations. These two strategies can save energy for an optical network. However, the targeted immunization exhibits better targeting and veracity than random immunization; the targeted immunization can yield better saving energy results for large-scale networks. In the future, we intend to consider more complex systems and algorithms, and plan to draw into game theory setting sleep nodes based on our research to increase the network performance for green communication.

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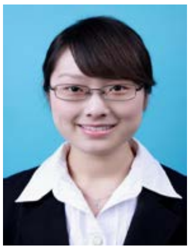

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