Collaborative base station sleeping solution design in heterogeneous cellular network

Lijin Li,Weixiao Meng
Harbin Institute of Technology, Harbin, 150001 China
Emails: {llj1955741312@163.com; wxmeng@hit.edu.cn }

***Abstract*—Green and energy-saving heterogeneous cellular networks are the trend of future mobile communication networks, and there are also a series of problems such as resource allocation, load balancing, and energy-saving design. As an important component of energy consumption in cellular networks, base stations have the characteristics of regularity and periodicity of services, so the introduction of base station dormancy technology can effectively save energy while ensuring the quality of service for users. Aiming at the sleep problem of base stations in heterogeneous cellular networks in urban areas, this paper analyzes the sleep probability and power consumption model of distance-aware micro base stations in sleep mode. Aiming at minimizing system power consumption, a sleep scheme in which macro base station and micro base station cooperate horizontally is designed. For the multi-constraint problem of user transfer in horizontal cooperation, a heuristic algorithm is proposed. The results show that the proposed cooperative scheme can save a lot of energy when the user SINR loss is small .**

Keywords—heterogeneous cellular networks, base station sleeping, Collaborative sleeping

I. Introduction

With the rapid growth of mobile communications, there has been an explosion of traffic data. Studies show that the traffic load in cellular networks is expected to grow by thousands of times over the next decade, making it an urgent problem for the next generation of mobile networks to handle the exponential growth in traffic load. In addition, 5G mobile communication systems also present a range of communication metrics requirements including millisecond end-to-end latency, millions of service users per square kilometer, and 10 Gbps peak data rates [1]. One way to address these issues is to deploy ultra-dense low-power small base stations, which together with conventional macro base stations providing large area coverage, form a heterogeneous communications network.

The mobile communications industry is also facing an energy crisis and a carbon burden. As shown by studies, the ICT industry accounts for approximately 2% of global carbon emissions, with the mobile communications sector accounting for 15-20% of this [2]..As people's awareness of environmental protection increases, they are also paying more attention to the irreversible harm caused by carbon emissions to the atmosphere. With thousands of base stations deployed in heterogeneous networks, which inevitably generate a large amount of energy consumption, how to establish a green heterogeneous mobile communication network has become an environmental concern.

In cellular systems, nearly 60% of the system energy consumption is related to the base station equipment[3]. Therefore, energy saving techniques for base station equipment have become a hot topic of research, and base station sleeping techniques are receiving more and more attention. Base station sleeping technology is designed as an algorithm to control the change of the switching state of base stations in heterogeneous networks, so as to achieve the goal of reducing the energy consumption of base stations and achieving green communication.

A traffic-aware base station sleeping management scheme is proposed in [4] to reduce the energy consumption of the system by exchanging user arrival information to determine the hotspot areas and switching the base stations in low-load areas to sleeping mode. A distance-based optimal micro-base station shutdown algorithm is proposed in [5] for heterogeneous networks, where the micro-base stations operate in a mode that decides whether to switch off or activate based on their distance from macro-base stations. In [6], the authors describe the base station sleeping optimization problem as a noncooperative game optimization problem in a satisfactory form that is able to maintain the user QoS while minimizing the energy consumption.

In sum, the above existing work only addresses the problem of when and the sleeping mode of individual micro-base stations in heterogeneous networks, and does not consider the transfer of users served by sleeping base stations. To address this problem, this paper proposes a joint macro-base station and micro-base station collaborative sleeping scheme based on the distance-aware sleeping mode of micro-base stations. The scheme aims at minimizing power consumption and ensuring that all users are served. The simulation results show that the scheme effectively reduces the system energy consumption while ensuring the user quality.

II. System Model

The system model is shown in Fig. 1.In a T-layer heterogeneous cellular network, the first layer is a macro-cellular network and the other T-1 layers are small cell (micro-cell, femtocell, etc.) networks, with varying base station densities and transmitting powers in the different layers. This paper focuses on the downlink transmission system at T=2, where the first layer is a macro cellular cell and the second layer is a micro cellular cell.

For the heterogeneous network model, base stations are divided into macro base stations and micro base stations. The cellular network protocol structure is divided into a control plane and a service plane, where the control plane is mainly taken over by the macro base stations, while the micro base stations are responsible for the service plane by the macro base stations. For the control plane, the macro base station will act as a control cell to manage multiple micro base stations and mobile users within its coverage area. As the macro base station also has service capability for subscriber services, it can also act as a service cell. A macro base station or a macro cell is always in a working state, and only base stations of other layers, such as a micro base station, can sleep.

Users in the system select which service base station provides services according to the user association algorithm, including macro base stations and micro base stations.

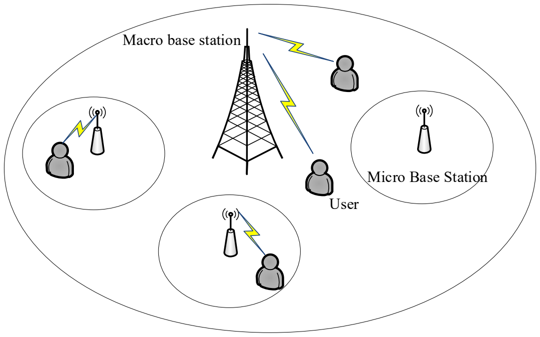

Fig. 1. Heterogeneous cellular network model when T=2.

A. Power Consumption Model

The power consumption model of the micro base station is

$$P_k^t = \begin{cases} P_{\mathrm{A}}, & \text{if BS is working} \\ P_{\mathrm{SL}}, & \text{if BS is sleeping} \end{cases} \tag{1}$$

where P_{A} represents the power when the micro base station is working, and P_{SL} represents the power consumption when the micro base station is sleeping.

The power consumption of the macro base station is modeled as

$$P_m = P_0 + \frac{A}{K} \cdot P_{TR} \tag{2}$$

where A represents the users served by the macro base station, P_0 is the power consumption of the macro base station when it is not loaded, P_{TR} is the slope of the power consumption of the macro base station increasing with the load, and K is the maximum number of users that the macro base station can accommodate, mainly related to bandwidth.

In the base station power consumption model, the power consumption of the base station does not remain at the maximum load at all times, but changes according to the real-time service load of the base station. ln a macro base station, the power consumption of the power amplifier accounts for a major part of the total system energy consumption. As the service load decreases, the power consumption of the PA also decreases. While for the base band processor, the power fluctuation is not much related to the service load variation, the power consumption of the small-signal RF transceiver is almost independent of the service traffic.

B. Small Base Station Sleeping Model

The sleep scheme based on distance threshold is adopted. When sleeping, the distance between the micro base station and the macro base station is mainly considered, and the micro base station that is closer to the macro base station is given priority to sleep.

If the distance threshold is A, since the distribution of micro base stations obeys Poisson point process (PPP) distribution, the location distribution of micro base stations obeys uniform distribution，that is

$$f(x) = \frac{1}{a}, -\frac{a}{2} \le x \le \frac{a}{2} \tag{3}$$

$$f(y) = \frac{1}{a}, -\frac{a}{2} \le y \le \frac{a}{2} \tag{4}$$

Here, (x , y) is the position coordinate of the micro base station, which is distributed in the square area of ($-\frac{a}{2}$, $\frac{a}{2}$).

The distance between the micro base station and the macro base station is

$$d = (x - x_M)^2 + (y - y_M)^2 \tag{5}$$

where (x_M , y_M)is the position coordinates of the macro base station.

When the distance between the base station and the macro base station is less than the threshold L_t , the sleep probability is

$$p_s = P\left(d < L_t\right) \tag{6}$$

Taking the macro base station as the center of the circle and the distance threshold as the radius, draw a circle, then the sleep probability can be converted into the probability that the micro base station is distributed in the circle. For the sake of simplicity, let the position of the macro base station be the origin, and let $z = x^2 + y^2$, Then p_s can be obtained by obtaining the probability distribution function of z .

The probability density function of z can be obtained as

$$f(z) = \begin{cases} \frac{\pi}{a^2} & 0 \le z \le \frac{a^2}{4} \\ \frac{2}{a^2}(\arcsin(\frac{a}{2\sqrt{z}}) - \arcsin(\sqrt{1 - \frac{a^2}{4z}})) & \frac{a^2}{4} < z \le \frac{a^2}{2} \\ 0 & \text{otherwise} \end{cases} \tag{7}$$

From the probability density function of z , p_s is

$$\begin{aligned} P\left(d < L_t\right) &= F(L_t) \\ &= \int_0^{L_t^2} f(z)dz \end{aligned} \tag{8}$$

The sleeping probability is the cumulative distribution function of z . From the probability density function of z , the sleeping probability can be obtained by piecewise integration.

When $L_t \ge \frac{a}{\sqrt{2}}$, p_s is 1. At this time, all micro base stations are in the sleeping range.

When $0 \le L_t \le \frac{a}{2}$, p_s is

$$\begin{aligned} \int_0^{L_t^2} f(z)dz &= \int_0^{L_t^2} \frac{\pi}{a^2} dz \\ &= \frac{\pi}{a^2} L_t^2 \end{aligned} \tag{9}$$

At this time, the sleeping probability is the ratio of the sleeping circular area to the base station distribution square area.

When $\frac{a}{2} < L_t < \frac{a}{\sqrt{2}}$, p_s is

$$\begin{aligned}&\int_0^{L_t^2} f(z)dz \\ &= \int_0^{\frac{a^2}{4}} \frac{\pi}{a^2}dz + \int_{\frac{a^2}{4}}^{L_t^2} \frac{2}{a^2}\left(\arcsin\left(\frac{a}{2\sqrt{z}}\right) - \arcsin\left(\sqrt{1-\frac{a^2}{4z}}\right)\right)dz \\ &= \frac{\pi}{4} + \frac{2}{a^2}\left(\int_{\frac{a^2}{4}}^{L_t^2} \arcsin\left(\frac{a}{2\sqrt{z}}\right)dz - \int_{\frac{a^2}{4}}^{L_t^2} \arcsin\left(\sqrt{1-\frac{a^2}{4z}}\right)dz\right) \\ &= \frac{2}{a^2}L_t^2\cdot\left(\arcsin\left(\frac{a}{2L_t}\right) - \arcsin\left(\sqrt{1-\frac{a^2}{4L_t^2}}\right)\right) \\ &\quad + \frac{2}{a}L_t\sqrt{1-\frac{a^2}{4L_t^2}}\end{aligned} \tag{10}$$

C. User Association Model

The user association model is that the user associates with the base station with the largest received power, the maximum RSRP association policy, that is

$$j^* = \arg\max_M RSRP_{ij} \tag{11}$$

Where, j^* is the base station that the user selects to associate with, M is the set of base stations, $RSRP_{ij}$ is the received power received by user i from base station j.

D. Collaborative Base Station Sleeping Model

The cooperative sleep scheme is that when the micro base station enters the sleep mode, in order to ensure the user service quality, the users originally served by the sleep base station are transferred to the adjacent micro base station or macro base station.

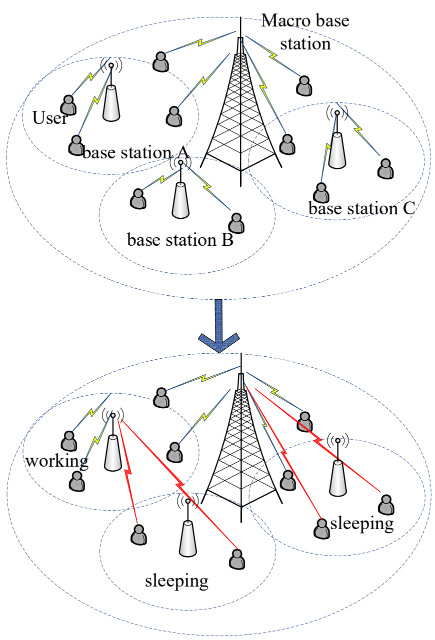

Fig. 2. Schematic diagram of user transfer under collaborative sleep.

As shown in Fig. 2. , when the micro base station B enters the dormant state, the users it serves are transferred to the neighboring base station A. After the micro base station C enters the dormant state, its only adjacent micro base station is also in the dormant state, so the users it serves will be transferred to the macro base station. The cooperative dormancy is to preferentially offload the users served by the dormant micro base station to the available micro base station, and if there is no available micro base station, offload to the macro base station. The available micro base station refers to the micro base station that is in working state, has not reached the maximum number of serving users, and is adjacent to the dormant micro base station.

III. Problem Formulation

The total power consumption of the system is the power consumption of all micro base stations and macro base stations in the system, that is

$$\begin{aligned}P_{total} &= (P_{SL}\cdot p_s + P_A\cdot(1-p_s))M + P_0 + \frac{N_{trans-m}+N_m}{K}\cdot P_{TR} \\ &= p_s(P_{SL}-P_A)M + P_0 + (N_{trans-m}+N_m)/K\cdot P_{TR} + P_A M\end{aligned} \tag{12}$$

The power consumption is linearly related to the sleep probability. The greater the sleep probability, the smaller the power consumption. Therefore minimizing power consumption is equivalent to maximizing sleep probability. So the problem can be modeled as:

$$\begin{aligned}&\max p_s \\ &s.t. \sum_i^{N_{trans-m}+N_m} B_i < W_m \\ &\quad \sum_j^{N_{trans-f1}+N_1} B_j < W_1 \\ &\quad \sum_j^{N_{trans-f2}+N_2} B_j < W_2 \\ &\quad \ldots \\ &\quad \sum_j^{N_{trans-fM}+N_M} B_j < W_M\end{aligned} \tag{13}$$

where $N_{trans-m}, N_{trans-f1}, N_{trans-f2}, \ldots N_{trans-fM}$ represents the number of users transferred to macro base stations, micro base stations 1,2,....M respectively, $N_m, N_1, N_2, \ldots N_M$ represents the number of users of macro base stations, micro base stations 1,2,...M originally respectively.

It is a variant of the box packing problem and is an NP-Hard problem.

IV. Proposed Heuristic Sleeping Scheme

This paper proposes a heuristic algorithm to solve this multi-constrained NP-Hard problem. The problem is decomposed into multiple single base station dormancy transfer problems, and each dormancy problem is interrelated and non-independent, so the base stations will be dormant in a certain order.

For the communication network that has been constructed or laid out, the position of each base station is determined, so the adjacency matrix D between the micro base stations in the heterogeneous network can be obtained, D_{ij} in the adjacency matrix represents the adjacency of micro base station i and micro base station j.

$$D_{ij} = \begin{cases} 1 & i \text{ and } j \text{ are adjacent base stations} \\ 0 & else \end{cases} \tag{14}$$

Assuming the user association number matrix of the micro base station is $N=\{N_1,N_2,N_3,...N_M\}$, $N_1,N_2,N_3,...N_M$ is the number of users served by the 1st to M micro base stations before sleep, and the order of the micro base stations is in positive order according to their distance from the macro base station.

A. Single Base Station User transfer scheme

For a single base station k that reaches the sleep threshold, its original service user transfer situation has the following three situations according to the adjacency matrix of the base station.

1) The dormant base station has no available adjacent micro base stations, and its service users can only be transferred to the macro base station after the base station is dormant.

2) The dormant base station has only one available adjacent micro base station. At this time, its service users should be preferentially transferred to the only adjacent micro base station, and redundant overflow users should be transferred to the macro base station.

3) There are multiple available adjacent micro base stations in the dormant base station. At this time, there are various transfer schemes. The service users should be transferred to the available micro base stations first, and the overflow users should be transferred to the macro base station. The adjacency and transfer situation of other dormant micro base stations should be considered, and the transfer plan should be obtained through unified planning.

If conditions 1) and 2) are satisfied, there is only one transition scheme, and if condition 3) is satisfied, there are multiple transition schemes. We therefore propose the Single Base Station User Transfer (SBSUF) algorithm, the pseudo-code for which is given in Algorithm 1

Algorithm 1 SBSUF Algorithm

```
Denote that there are O available neighbor base stations, denote cur is the number of untransferred users of the current base station
for i=1:O
    while cur!=0 do
        Transfer users to neighboring available micro base stations, update cur
    end while
end for
```

Through this algorithm, the user transfer scheme $T_i=\{T_{i1},T_{i2},T_{i3},...T_{in}\}$ of the base station i to be dormant can be obtained.

B. Cooperative Sleep of Multiple Micro Base Stations

On the basis of the single base station transfer scheme, the multi-user cooperative sleep scheme can be obtained through a Depth-First Search Collaborative Sleeping (DFSCS) algorithm, which is given in Algorithm 2.

Algorithm 2 DFSCS Algorithm

```
Denote dp is the search depth, denote dt is the number of micro base stations to sleep, denote Nm is the current number of users served by the macro base station, and Nm* is the threshold, denote T_i^t is the set of schemes tried by the base station i.
while dp!= dt do
    if Nm> Nm*
        dp= dp-1, T_dp* ∈ {T_dp1, T_dp2, T_dp3, ...T_dpn}, T_dp* ∉ T_dp^t
    else
        dp= dp+1, T_dp* ∈ {T_dp1, T_dp2, T_dp3, ...T_dpn}, T_dp* ∉ T_dp^t
    end if
end while
```

V. SIMULATIONS

Simulations are set up as follows. The macro base station is deployed in the center of the simulation area and the deployment of micro base stations and users obeys a Poisson point process. When sleeping there are only sniffers on in the micro base station. The algorithm parameters are shown in TABLE I.

TABLE I SIMULATION PARAMETERS

Symbol	Parameter Value
Macro base station transmitting power	46 dBm
Micro base station transmitting power	30dBm
Macro base station coverage radius	500m
Bandwidth	10MHz
Density of users	500/km^2
Density of Micro base stations	10/ km^2

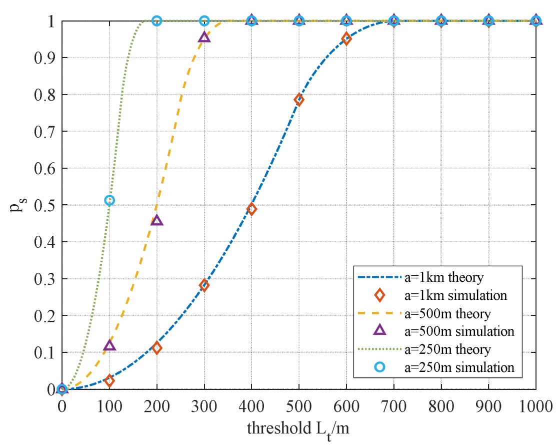

Fig. 3. The sleep probability of micro base station varies with distance threshold.

Fig. 3.shows the relationship between the sleep probability and the distance threshold, where a represents the boundary value of the simulation area. It can be seen from the simulation results that when the area range increases, the distance threshold corresponding to the same dormancy probability also decreases proportionally, and the main factor affecting the dormancy probability is the ratio of the distance threshold to the boundary. When the size of the area is constant, as the distance threshold increases, the dormancy probability also increases. After increasing to a certain value, the sleep probability is 1. The accuracy of the theoretically derived dormancy probability with respect to the closed expression of the distance threshold is verified.

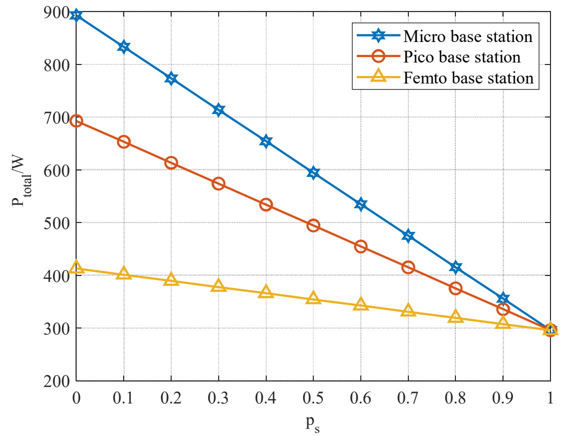

Fig. 4. Changes of system power consumption with sleeping probability under different types of base stations.

Fig. 4. compares the impact of base station type and sleeping probability on power savings after sleep in a heterogeneous cellular network. Micro-base stations can save more power compared to the other two types of base stations. As the sleeping probability increases, the power saving increases. When the sleeping probability is 0.2, the three types of base stations save 14.4%, 11.6% and 2.5% of power respectively. The micro-base station saves 27.8% power when the sleeping probability is 0.4 and 41.1% when the sleeping probability is 0.6.

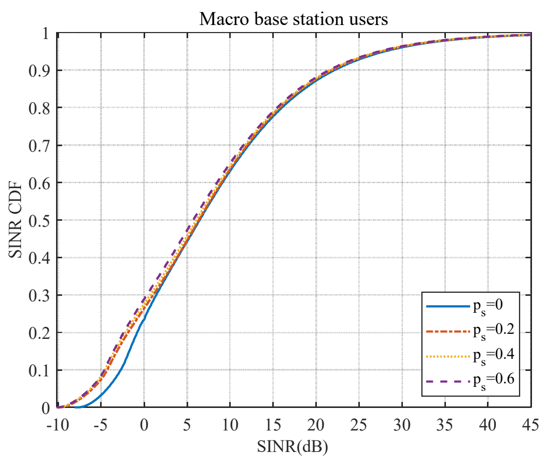

Fig. 5. SINR of macro base station users under different sleeping probabilities.

Fig. 5. and Fig. 6. compare the cumulative distribution of signal-to-noise ratios for macro and micro base station users with sleeping probabilities of 0, 0.2, 0.4 and 0.6 respectively. In the simulation, as the sleeping probability increases, the SINR of macro base station users is affected in the region of less than 0dB, while the median SINR value is not much different. It is mainly the micro-base station users that are affected, with the difference in the median SINR values of 1.5dB, 3.5dB and 6dB for 0.2, 0.4 and 0.6 sleeping probabilities respectively. Thus, with a sleeping probability of 0.2, a power saving of 14.4% is achieved when the SINR drops by only 1.5 dB

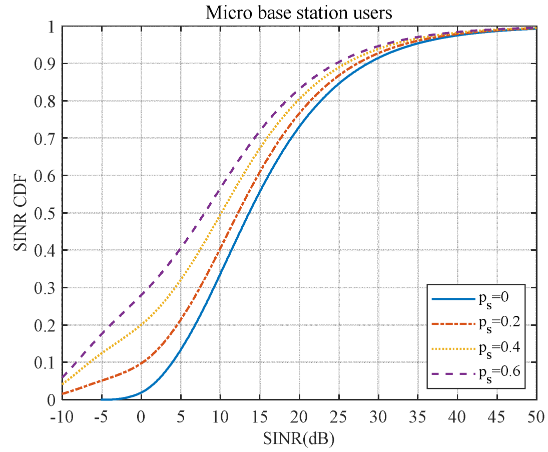

Fig. 6. SINR of micro base station users under different sleeping probabilities.

VI. CONCLUTION

This paper proposes a cooperative sleeping scheme for base stations in heterogeneous cellular networks. The micro base station adopts a distance-aware sleep mode, designs a horizontal cooperative sleep scheme, and proposes a heuristic sleeping scheme. The results show that this scheme can effectively save energy consumption with low user SINR loss, and the SINR loss of macro base station and micro base station users is about 0 when saving about 12% of energy consumption. When saving about 28% of energy consumption, the SINR loss of micro base station users is only 1dB, and the SINR loss of macro base station users is about 0.

ACKNOWLEDGMENT

This work was supported by National Nature Science Foundation of China (No. 61871155)

REFERENCES

[1] Wu J , Zhang Y , Zukerman M , et al. Energy-Efficient Base-Stations Sleep-Mode Techniques in Green Cellular Networks: A Survey[J]. IEEE Communications Surveys & Tutorials. 2015, 17(2): 1-24.

[2] Han C , Harrold T , Armour S , et al. Green radio: radio techniques to enable energy-efficient wireless networks[J]. IEEE Communications Magazine. 2011, 49(6): 46-54.

[3] Rao J B , Fapojuwo A O . A Survey of Energy Efficient Resource Management Techniques for Multicell Cellular Networks[J]. IEEE Communications Surveys & Tutorials. 2014, 16(1): 154-180.

[4] Z. Li, D. Grace and P. Mitchell, "Traffic-Aware Cell Management for Green Ultradense Small-Cell Networks," in IEEE Transactions on Vehicular Technology, vol. 66, no. 3, pp. 2600-2614, March 2017, doi : 10.1109/TVT.2016.2576404.

[5] A. Ebrahim and E. Alsusa, "Interference and Resource Management Through Sleep Mode Selection in Heterogeneous Networks," in IEEE Transactions on Communications, vol. 65, no. 1, pp. 257-269, Jan. 2017, doi : 10.1109/TCOMM.2016.2623614.

[6] A. H. Arani, M. J. Omidi, A. Mehbodniya and F. Adachi, "A Distributed Satisfactory Sleep Mode Scheme for Self-Organizing Heterogeneous Networks," Electrical Engineering (ICEE), Iranian Conference on, 2018, pp. 476-481, doi : 10.1109/ICEE.2018.8472421.