Green Virtual Network Embedding Framework based on Zooming Small Cells in Fiber-Wireless Access Network for 5G

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ABSTRACT

The converged Fiber-Wireless (FiWi) access network that can provide service to users with a high capacity, flexibility and reliability has become a promising “last mile” solution for the Fifth Generation (5G). Network virtualization is capable of shielding the heterogeneous features of physical networks and facing the emergence of Over the top (OTT) content, which is consistent with the vision of 5G, where energy efficiency is one of the key issues. This paper concerns the green virtual network embedding scheme in virtualized FiWi access network for 5G, where the zooming small cell is designed. On one hand, the energy can be saved by decreasing the transmitting power of Small cell Base Stations (SBSs) reasonably. On the other hand, the virtual node embedding can be optimized through zooming the coverage of small cells and the zero-loaded SBSs can be switched into sleep state for energy-saving.

Keywords: Fiber-Wireless access network, 5G, zooming small cell, virtual network embedding, energy-saving

1. INTRODUCTION

The Fifth Generation (5G) foreseeing 1000-fold gains in capacity, extremely high data rates reaching 10Gbps and connections for at least 100 billion devices [1] is expected to be a paradigm shift of current network [2]. The cost-saving fiber infrastructure is considered to be a promising candidate for small cell backhaul, that is Fibre-Wireless (FiWi) enhanced 5G network [1]. However, the massive deployment of wireless base stations resulting from meeting the tremendous growth in number of wireless users leads to a high energy consumption, accounting for 70-80% of total energy consumption in cellular network [3], which poses a huge challenge for the green 5G network design. Besides, facing the emergence of Over the top (OTT) content, network virtualization is capable of shielding the heterogeneous features of Physical Networks (PNs) and providing customized service to Virtual Networks (VNs) through Virtual Network Embedding (VNE) [4]. There exist several zooming small cell paradigms where transmission powers of Small cell Base Stations (SBSs) are adjusted to optimize the coverage of small cells [2-3]. Nevertheless, an insight into the VNE problem upon infrastructure of scalable small cells, that is zooming small cells, needs to be promoted. This paper focuses on the green VNE design of FiWi access network for 5G. Taking small cell with scalable nature into account, the VNE can be optimized through zooming the coverage of small cells. More specifically, energy can be conserved by not only reducing the transmitting power of SBSs reasonably but also switching the zero-loaded SBSs into sleep state. The Integer Liner Programming (ILP) model is formulated investigating specific objective and constraints of FiWi enhanced 5G network to obtain the maximum Infrastructure Provider (InP) profit while consuming the least energy.

2. NETWORK MODEL AND PROBLEM STATEMENT

VNE by definition is a process of resource allocation from InP to VNs in Service Providers (SPs) while meeting their resource demands. After that, a SP will implement customized network protocols to support users with specific service requirements. The illusion of VNE in FiWi access network for 5G is shown as Fig. 1.

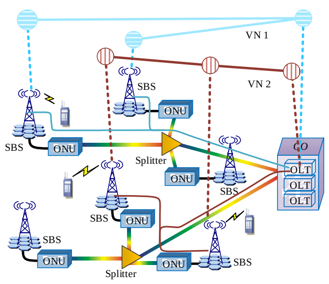

Figure 1. Illusion of VNE in FiWi access network for 5G

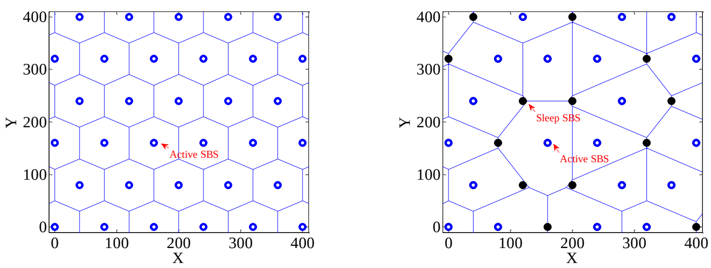

Figure 2. Small cell network layout. Traditional layout on the left, 5G layout on the right.

2.1 Network model

In the VN set G^V, The k th VN $G_k^V = (N_k^V, L_k^V)$ whose duration is $T_k(G^V)$ consists of sets of virtual nodes N_k^V and virtual links L_k^V. Total number of virtual nodes and links in G_k^V are represented by m_k and n_k respectively. Each virtual node $n_{k,i}^V$ is related with a CPU demand $c_{k,i}^V$, a node type $t_{k,i}^V$, a location $lct_{k,i}^V$ and a maximum embedding location offset demand $\Delta lct_{k,i}$. Note that node type is either O for Optical Line Terminal (OLT) or S for SBSs, that is, $t^V_{k,i} \in \{O, S\}$. Each virtual link $l^V_{k,j}$ has a transmission rate demand $r^V_{k,j}$.

In PN, the OLT located in CO handle the SBSs located at the remote site through broadcasting signals from splitter to Optical Network Units (ONUs) over the fibers [5]. Therefore, the substrate network can be represented by $G^S = (N^S, L^S)$, where N^S indicates the set of physical nodes and L^S is the set of physical links. With the total number of physical nodes and links represented by X and Y respectively, the x th physical node n^S_x is equipped with CPU capacity c^S_x, CPU load f^S_x, node type t^S_x, location lct^S_x, power P^S_x and power state z^S_x and the y th physical link l^S_y has a transmission rate r^S_y and a load f^S_y. As for node type, we can get $t^S_x \in \{OLT, ONU, SBS\}$ with each element representing a kind of physical nodes. Moreover, each SBS has a sleep mode by which it can reduce energy consumption by turning down specific modules and active SBSs will enlarge their coverage area to cover the coverage hole as shown in Fig. 2.

2.2 SBS power model

In this paper, we considered only the energy-saving power mode of SBSs while keeping other physical devices active. Note, however, that other devices (e.g. Optical Network Unit (ONU)) can also be set into sleep state which is studied in our prior work [6]. The total power of SBS can be formulated as Eq. (1):

$$P^S_x = z^S_x \cdot \left[p^{S\_static\_active}_x + \sum_{u=1}^{U^S_x} (\eta_{x,u} \cdot p^{S\_tran}_{x,u}) \right] + (1 - z^S_x) \cdot p^{S\_static\_sleep}_x, \text{ if } t^S_x = SBS \tag{1}$$

where P^S_x denotes the total power of SBS taking the power state z^S_x into account. Specifically, while SBS is in sleep state ($z^S_x = 0$), its power is $p^{S\_static\_sleep}_x$. While SBS is active ($z^S_x = 1$), P^S_x covers the static power consumption $p^{S\_static\_active}_x$ when SBS is in idle mode and the sum of transmission power of users where U^S_x denotes total users number, $p^{S\_tran}_{x,u}$ denotes the transmission power at full load from SBS to u th user and $\eta_{x,u}$ is the load occupation ratio of u th user on SBS. $p^{S\_tran}_{x,u}$ can be calculated using Eq. (2) according to Shannon's formula, where b^H denotes the occupied bandwidth, N_0 indicates the noise power spectral density and $G^S_{x,u}$ is the corresponding channel gain related with path-loss factor α, path-loss exponent β and the close-in distance d_0 as shown in Eq. (3). $d^S_{x,u}$ is the distance between from SBS x to user u.

$$p^{S\_tran}_{x,u} = \frac{b^H N_0}{G^S_{x,u}} (2^{\frac{r^S_x}{b^H}} - 1) \tag{2}$$

$$G^S_{x,u} = \alpha \left(\frac{d_0}{d^S_{x,u}} \right)^{\beta} \tag{3}$$

Comprehensively analyse Eqs. (2)-(3), it can been concluded that transmission power of SBS lies on the distance from SBS to designated user under the specific settings of path-loss coefficients (α, β), b^H and N_0. Therefore, there is an opportunity for SBSs to zoom their coverage through adjusting their transmission power. Importantly, power consumption will be reduced by zooming out SBS coverage according to distribution of users instead of transmitting signals using maximum allowed power $p^{S\_tran\_max}_x$ and more SBSs can be turned into sleep state to save energy if we zooming in the coverage of a proportion of SBSs achieving the full coverage of users. Note that the transmission power $p^{S\_tran}_{x,u}$ is constrained by $p^{S\_tran\_max}_x$.

2.3 Virtual network embedding

Based on above network models and network devices power models, the green VNE problem in FiWi access network for 5G is to construct a logical network using appropriate physical resources leasing from InP and intend to obtain maximum InP profit as shown in Eq. (4):

$$R(G^V_k) = T(G^V_k)^*\{\gamma_1 \left[\rho^n \sum_{i=1}^{m_k} c^V_{k,i} + \rho^l \sum_{j=1}^{n_k} r^V_{k,j} \right] - \gamma_2 \left[\rho^n \sum_{i=1}^{m_k} c^V_{k,i} + \rho^l \sum_{j=1}^{n_k} (r^V_{k,j} \cdot len^S_{k,j}) \right] - \gamma_3 \sum_{x=1}^{X} (p^S_x)\} \tag{4}$$

where γ_1 and γ_2 represent the revenue and cost of each unit of resource respectively and γ_3 is the cost of each unit of power. Besides, ρ^n and ρ^l are the weighs of node and link resources and $len^S_{k,j}$ denotes the embedding path length of $l^V_{k,j}$. We can conclude from Eq. (4) that InP profit equals the residual revenue with minus cost of both resource and power and is related with time duration of VNs. In addition, when it comes to VNE, meanwhile satisfying the resource demand of VNs, there are some general constraints of VNE and specific constraints in green VNE in FiWi enhanced 5G network. General constraints include the all-different node embedding constraint (different nodes from same VN should be embedded onto different substrate nodes), flow conservation requirement and disjoint link embedding constraint (each virtual link should be embedded on one consecutive path) etc.. As for specific constraints, it is specified that virtual nodes whose types are O and S should be embedded on OLT and SBSs respectively. Moreover, transmission power of SBSs and power state of devices should also be constrained which will be described in section 3 in detail.

3. GREEN VNE PROBLEM FORMULATION

In this section, we formulate the green VNE problem in FiWi enhanced 5G network in terms of ILP based on our prior work [7] where general constraints are proposed. The objective and specific constraints are as follows. The objective in Eq. (5) aims at maximizing the total InP profit from embedding VNs where ξ_k indicates the binary variable identifying if G_k^V is embedded successfully. Constraints (6)-(7) elaborate the node type constraints with $\chi_{k,i}^x$ donating if $n_{k,i}^V$ is embedded on n_x^S . Eq. (6) states that virtual node whose type is O should be embedded on OLT and Eq. (7) expresses the inevitable embedding relationship between virtual node with $t_{k,i}^V = S$ and SBSs. Eq. (8) elaborates the power state constraint in sense that a sleep SBS will not accept any virtual node. And constraints of transmission power and total power of SBSs are shown as Eqs. (9) and (10) respectively where $p_{k,i}^x$ denotes the transmission power at certain load and can be formulated as Eq. (11). $I_{k,i}^V$ and I_x^S are the sets of instream links of $n_{k,i}^V$ and n_x^S , and $dis(lct_{k,i}^V, lct_x^S)$ denotes the Euclidean distance between two locations.

$$\text{Maximize}: \sum_{k \in G^V} R(G_k^V) \cdot \xi_k \tag{5}$$

$$\chi_{k,i}^x = \xi_k, \text{ if } t_{k,i}^V = O \text{ and } t_x^S = OLT, \forall k \in G^V, i \in N_k^V, x \in N^S \tag{6}$$

$$\chi_{k,i}^x = 0, \text{ if } t_{k,i}^V = S \text{ and } (t_x^S = OLT \text{ or } t_x^S = ONU), \forall k \in G^V, i \in N_k^V, x \in N^S \tag{7}$$

$$z_x^S \ge \chi_{k,i}^x, \text{ if } t_x^S = SBS, \forall k \in G^V, i \in N_k^V, x \in N^S \tag{8}$$

$$0 \le \chi_{k,i}^x \cdot p_{k,i}^x \le p_x^{S\_trans\_max}, \text{ if } t_x^S = SBS, \forall k \in G^V, i \in N_k^V, x \in N^S \tag{9}$$

$$p_x^S \ge z_x^S \cdot p_x^{S\_static\_active} + \sum_{k \in G^V} \sum_{i \in N_k^V} (\chi_{k,i}^x \cdot p_{k,i}^x) + (1 - z_x^S) \cdot p_x^{S\_static\_sleep}, \text{ if } t_x^S = SBS, \forall x \in N^S \tag{10}$$

$$p_{k,i}^x = \sum_{j \in I_{k,i}^V} r_{k,j}^V \Big/ \sum_{y \in I_x^S} r_y^S \cdot \frac{b^H N_0}{\alpha d_0^{\beta}} \cdot (2^{\sum_{y \in I_x^S} r_y^S / b^H} - 1) \cdot dis(lct_{k,i}^V, lct_x^S)^{\beta}, \text{ if } t_x^S = SBS, \forall k \in G^V, i \in N_k^V, x \in N^S \tag{11}$$

4. SIMULATION RESULTS AND DISCUSSIONS

Table 1. Key simulation parameter settings.

Parameter	Symbol	Value
path-loss factor	α	-31.45 dB
path-loss exponent	β	2
occupied bandwidth	b^H	20 MHz
power of OLT	p_{OLT}	20 W
power of ONU	p_{ONU}	2 W
basic power of active SBS	$p_x^{S\_static\_active}$	4.8W
power of sleep SBS	$p_x^{S\_static\_sleep}$	2.9W
SBS maximum transmission power	$p_x^{S\_tran\_max}$	0.05W

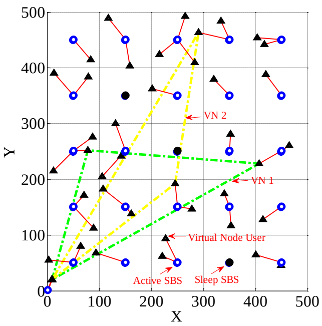

Figure 3. Node embedding result of VNE-B under fixed PN topology.

In the simulation, we deploy 1 OLT, 25 ONUs and 25 SBSs randomly in an area of 500m*500m. The node CPU capacity ranges uniformly from 200 to 500 and link transmission rate between ONU to SBS is set to 20Mpbs. Each VN has average 3 virtual nodes equipping their CPU demand ranging from 10 to 20 and link transmission rate demand is 1 Mbps. The probability of link existing between two virtual nodes is 0.5. Some key simulation parameter settings can be seen in Table. 1. Other parameter settings include $N_0 = -174\ dBm/Hz$ [3], $d_0 = 3$, $\gamma_1 = 10, \gamma_2 = 1, \gamma_3 = 1$ and $\rho^n = \rho^l = 0.5$. We evaluate our green VNE mechanism (VNE-G) in comparison with basic VNE method (VNE-B) where virtual nodes are embedded onto the nearest optional physical nodes and the zero-loaded SBSs are switched into sleep state for energy-saving.

The virtual node embedding results are displayed in Figs. 3-6 where not only fixed but also random PN topologies are considered. In the scenario of fixed PN topology deploying 25 SBSs in a regular mesh fashion, VNE-B brings about little sleep SBSs due to the mapping mechanism of choosing nearest nodes. However, it can be seen from Fig. 4 that virtual nodes are gathered to embed on a proportion of SBSs. Thus, more SBSs in VNE-G will be switched into sleep state for energy-saving. Similar phenomenon can be found in scenario of random PN topology comparing Fig. 5 with Fig. 6. Moreover, we mark two VNs in Figs. 3-6 to convince the effectiveness of all-different node embedding constraints. Figures 7-9 summarize the performance of SBS active rate, network power consumption and InP profit respectively. SBS active rate is the ratio that active SBSs accounting for all SBSs. In Fig. 7, SBS active rate of VNE-G is obviously lower than that of VNE-B leading to the same result in the comparison of network power consumption in Fig. 8. Note that the jitter of SBS active rate of VNE-B attributes to the randomness of virtual node distribution. So does the network power consumption of

VNE-B in Fig. 8. In contrast to VNE-B, both SBS active rate and network power consumption in VNE-G rise smoothly while VN number increases. In addition, InP profit of both VNE-B and VNE-G in Fig. 9 grow up with the increase of VN number and InP profit of VNE-G is slightly higher that of VNE-B. Meanwhile, resulting from high power consumption while VN number grows higher than 16, InP profit encounters a reduction. In conclusion, there is as much as 12% of energy can be save compared with VNE-B while guaranteeing InP profit.

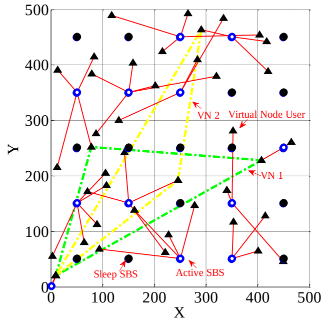

Figure 4. Node embedding result of VNE-G under fixed PN topology.

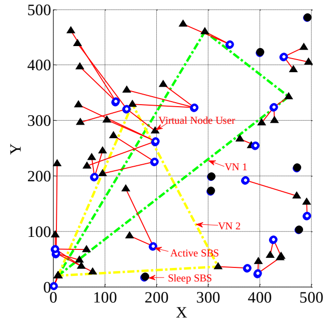

Figure 5. Node embedding result of VNE-B under random PN topology.

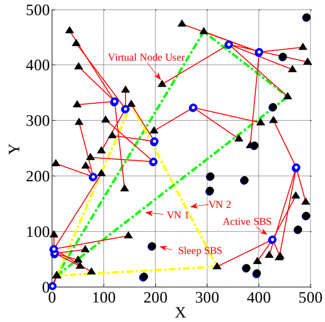

Figure 6. Node embedding result of VNE-G under random PN topology.

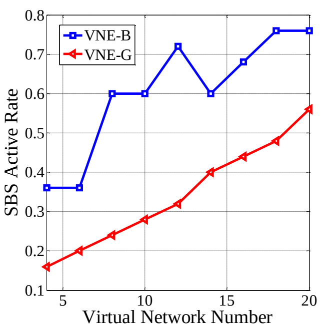

Figure 7. SBS active rate

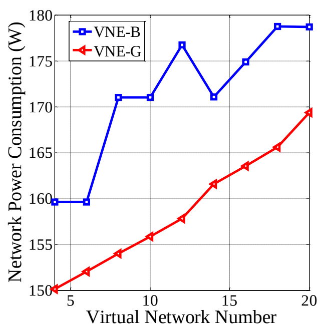

Figure 8. Network power consumption

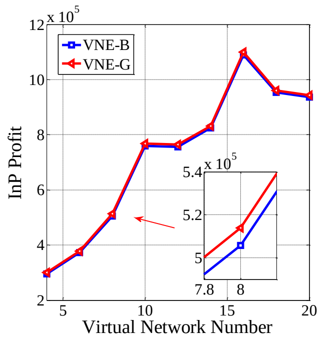

Figure 9. InP profit

5. CONCLUSIONS

This paper emphasizes on the energy-saving VNE mechanism in FiWi access network for 5G. The transmission power of SBS is allowed to adjust to facilitate the implementation of zooming small cell. Moreover, the specific objective and constraints of the problem are formulated to be more practical. Simulation results demonstrate that the proposed mechanism can significantly reduce the power consumption while guaranteeing the InP profit. Further researches will concentrate on the low power state of other network devices such ONUs and a time-saving heuristic algorithm will be designed for network devices power state scheduling.

ACKNOWLEDGEMENTS

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