Load Balanced Optical-Network-Unit (ONU) Placement Algorithm in Wireless-Optical Broadband Access Networks

Bing Li, Yejun Liu, and Lei Guo

Abstract—**With the broadband services increasing, such as video conference, interactive games and multimedia applications, the broadband access network is experiencing a rapid development. Compared with traditional access technologies, Wireless-Optical Broadband-Access Networks (WOBAN) can provide larger bandwidth, flexible access and better support for the emerging multimedia applications so as to better meet the users' requirements. Therefore, WOBAN is a promising solution for the "last mile" access networks and it has become a hot issue in recent years. In WOBAN, the placement of Optical Network Units (ONUs) is one of the key issues for the network deployment since the ONU acts as the interface between wireless front-end and optical back-end. To address the existing problems in ONU placement in WOBAN, we propose a novel ONU placement algorithm called Load Balanced ONU Placement (LBOP) in this paper, aiming to minimize the number of required ONUs under the constraints of hop number and load balancing. According to the LBOP, the procedure is divided into two stages: ONU placement and load transfer. First, the greedy algorithm is adopted to determine the minimum number of ONUs and the location of each ONU under the constraint of hops number. Second, given the traffic load of each router and the location of each ONU, the traffic load is transferred strategically among different ONUs with the purpose of load balancing. If the load balancing constraint is not yet satisfied after the load transfer, we will place new ONUs into the network according to the ONU placement stage and repeat the load transferring. Simulation results demonstrate that the proposed LBOP algorithm requires fewer ONUs than the previous works, while maintaining better load balancing.**

***Index Terms*—Wireless-optical broadband-access networks, onu placement, load balancing, greedy algorithm.**

I. Introduction

Optical access networks aim to provide long distance, high-bandwidth communication, while wireless access networks aim to provide ubiquitous, flexible communications mainly in community areas. In view of complementary features of both optical and wireless access networks, Wireless-Optical Broadband Access Networks (WOBAN) has been proposed to integrate the Passive Optical Network (PON) and the Wireless Mesh Network (WMN) to provide the high bandwidth, cost-efficient and ubiquitous last mile Internet access [1]. A typical architecture of WOBAN is shown in Fig. 1. In WOBAN, the optical sub-network (i.e., PON) consists of an Optical Line Terminal (OLT) at the central office, a Remote Node (RN), and a group of Optical-Network-Units (ONUs). The wireless sub-network (i.e., WMN) is responsible to support ubiquitous and flexible access for the users in premises. Generally, the WMN consists of multiple gateways connected to the Internet, a group of wireless mesh routers that provide multi-hop wireless communication and a group of wireless mesh clients whose traffic will be aggregated into mesh routers.

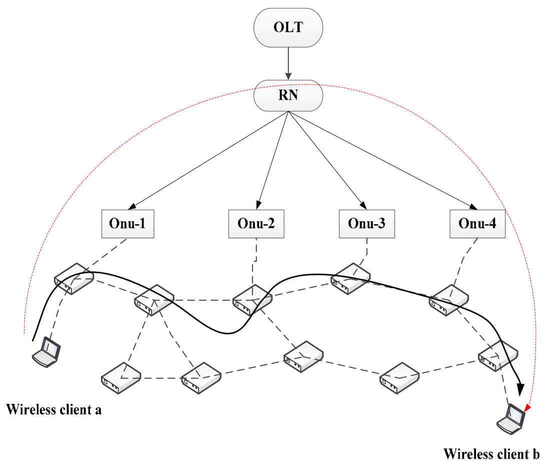


Fig. 1. The architecture of WOBAN

In WOBAN, the network traffic is divided into two parts: traffic to the Internet and peer-to-peer traffic [2], [3]. When a wireless client wants to communicate with another wireless client, such peer-to-peer traffic in WOBAN has two alternative routes. It could be routed either through the multi-hop wireless path within the wireless sub-network or through the wireless-optical-wireless mode. Specifically, in the wireless-optical-wireless mode, the wireless client *a* first routes its traffic to the closest ONU (i.e., ONU-1), which will send traffic to the OLT, OLT then broadcasts the traffic back to all ONUs. When receiving the broadcast traffic from the OLT, each ONU will determine either to drop or to forward the traffic according to the destination address of the wireless client. Then, the ONU closest to the wireless client *b* (i.e., ONU-4) will send traffic to *b*. It is worth noting that the wireless-optical-wireless mode helps reduce the interference among different traffic flows in WMN. Therefore, the network is able to carry more traffic from wireless clients to the Internet, which contributes to the network throughput improvement.

It is well known that ONU placement plays an important role in improving the performance of WOBAN [4]. Recently, it becomes a very hot topic. In order to find the optimal

Manuscript received September 18, 2012; revised October 26, 2012.
The authors are with the College of Information Science and Engineering, Northeastern University, Shenyang, 110819, P. R. China (e-mail: haveball@gmail.com)

DOI: 10.7763/IJFCC.2013.V2.131

ONUs placement in WOBAN, the reconfiguration of PON structure and getaway placement scheme in WMN play significant roles. Related work on this aspect will be introduced in the following. [5] proposed algorithms for gateway placement under different wireless models and also accounted for the traffic load variance from users. [6] proposed an analytical model for optimal placement of base stations (BSs) and ONUs so that the WOBAN deployment cost is minimized. [7] intended to place K gateways to maximize the overall network throughput. [8] applied an intelligence optimization algorithm: Simulated Annealing (SA) algorithm to minimize the average euclidian distance of any wireless mesh router to its neighborhood ONU in WOBAN. All above works just focused on the traffic to the Internet and did not consider any peer-to-peer communication. [9] proposed a TaBu Reach algorithm with the objective of minimizing the wireless hop number from wireless routers to ONUs while considering both Internet traffic and peer-to-peer traffic. But it did not consider the issue of minimizing the ONU number. Furthermore, all the works above did not consider the load balancing between different ONUs. To keep the load balancing between different ONUs is a efficient way to decrease the blocking rate and increase the throughput of WOBAN.

In this paper, we focus on the study of ONU placement in WOBAN with the consideration of load balancing among ONUs which is a problem less mentioned in related works. Besides the traffic to Internet, we consider the peer-to-peer traffic between different wireless clients simultaneously. To address the existing problems about ONU placement in WOBAN, we propose a novel ONU placement algorithm called Load Balanced ONU Placement (LBOP) in this paper, aiming to minimize the number of required ONU under the constraints of hop number and load balancing. We formulate such ONU placement problem as a single objective linear programming model. According to LBOP, we can obtain the solution to the ONU placement as the following steps. First, the greedy algorithm is adopted to determine the minimum number of ONUs and the location of each ONU under the constraint of hop number. Then, given the traffic load of each router and the location of each ONU, the traffic load is transferred strategically among different ONUs with the purpose of load balancing. If the load balancing constraint is not yet satisfied after load transferring, it is necessary to place new ONUs into the network until the load balancing constraint is satisfied.

The remainder of this paper is organized as follows. In Section II, we describe the optimization problem of ONU placement. To solve such an optimization problem with less complexity, we propose the LBOP algorithm in Section III. The simulation results are shown in Section IV. Finally, we conclude this paper in Section V.

II. Problem Description

The proposed WOBAN is modeled as a directed graph G=(N,E) where N is composed of the OLT denoted as u_0, a group of ONUs denoted as N_G and a group of wireless mesh routers denoted as N_M. Particularly, we denote

$$\begin{cases} N_G = \{G_i\}, i \in [1, K] \\ N_M = \{M_j\}. j \in [1, M] \end{cases} \tag{1}$$

where G_i denotes the ith ONU, K is the number of required ONU, M_j denotes the jth router and M is the number of routers.

Let L_{Gg} denote the load of ONU, L_{Gmax} denote the maximum load of ONU and L_{Gmin} denote the minimum load of ONU. In our work, we apply a grid with $n\times n$ size to cover the WOBAN area and take all $n\times n$ cross points on this grid as the set of potential locations for ONU placement. For simplicity of presentation, we denote $P = \{P_i\}, i \in [1, n\times n]$ as the $n\times n$ grid, where P_i denotes the ith grid coordinate. We try to find the minimum K locations in P to place ONUs so as to minimize the number of required ONU under the constraints of hop number and load balancing.

We define F as the traffic flow vector in the network. The flow f in vector F is represented by s_f, d_f and r_f which denote the source node, the destination node and the traffic demand of f respectively. The network traffic is divided into two parts:

$$F = F_{\text{inter}} \cup F_{\text{p2p}} \tag{2}$$

where F_{inter} denotes the traffic to the Internet, F_{p2p} denotes the peer-to-peer traffic.

Given the traffic flow vector F in WOBAN, we denote $H_{s_f}^{d_f}$ as the wireless hop number of the flow f from the source node s_f to the destination node d_f. We also denote h_{uv} as the hop number of the wireless shortest path between node u and node v within the wireless subnetwork. In WOBAN, each wireless router should be reachable to at least one ONU for the Internet access. Once the locations of K ONUs is fixed, each wireless router will calculate the shortest path to each ONU within the wireless subnetwork and selects the ONU to which the hop number of the path is minimum as the primary ONU. Each wireless router will transmit the traffic to its primary ONU for the Internet access. We denote the primary ONU of node M_j as $G(M_j)$.

For any flow $f \in F_{\text{Inter}}$, the wireless hop number from s_f to d_f is

$$H_{s_f}^{d_f} = h_{s_f G(s_f)} \tag{3}$$

For any flow $f \in F_{\text{p2p}}$, its traffic could either go through the wireless shortest path within the wireless subnetwork or through the wireless-optical-wireless mode. Since the bandwidth in the optical subnetwork is much higher than that in the wireless subnetwork, we assume that the available throughput provided by the wireless-optical-wireless mode is only determined by the transmission in the wireless subnetwok. Thus, we choose the path with less wireless hop number for the peer-to-peer traffic routing so that

$$H_{s_f}^{d_f} = \min\{h_{s_f d_f}, h_{s_f G(s_f)} + h_{d_f G(d_f)}\} \tag{4}$$

In this paper, we address the problem about ONU placement in WOBAN. We focus on optimizing the placement of ONUs, such that each wireless router can connect to the unique primary ONU under the constraints of hop number and load balancing. We aim to minimize the number of required ONUs under the constraints of hop number and load balancing, thus reducing the cost for network deployment and maintenance. We formulate such ONU placement problem as a single objective linear program model as follows.

Objective:

$$\min \{K\} \tag{5}$$

Constraints:

$$h_{s_f G(s_f)} <= A \tag{6}$$

$$\min\{h_{s_f d_f}, h_{s_f G(s_f)} + h_{d_f G(d_f)}\} <= B \tag{7}$$

$$L_{G\max} - L_{G\min} <= C \tag{8}$$

The constraint in Eq. (6) ensures that the wireless hop number of the traffic to Internet should be bounded by A. The constraint in Eq. (7) ensures that the wireless hop number of peer-to-peer traffic should be bounded by B. The constraint in Eq. (8) ensures that the difference between maximum and minimum ONU load (i.e., max-min load difference) should be bounded by C.

III. Algorithm Description

When deploying the ONU, apply a grid with $n \times n$ size in wireless sub-network means the alternative locations of ONUs are the intersection of the grid. The optimal solution of this problem can be obtained through the Brute-force search. In the worst case, the brute-force reach totally results $2^{n \times n} - 1$ choice, the number of results of the Brute force reach algorithm can be very large. Although the Brute force reach algorithm is very simple and easy to operate, its complexity suffers from exponential growth. Thus, it is impractical when n increases, and it is not suitable for practical application.

To reduce the computational complexity, we propose a heuristic algorithm called LBOP to obtain a suboptimal solution to the ONU placement problem. According to the LBOP, the procedure is divided into two parts: ONU placement and load transfer. First, the greedy algorithm is adopted to determine the minimum number of ONUs and the location of each ONU under the constraint of hops number. It is guaranteed in the first stage that all wireless routers can connect to at least one ONU under the constraints of hops number. So, we can calculate the traffic load of each ONU. Second, given the traffic load of each router and the location of each ONU, the traffic load is transferred strategically among different ONUs with the purpose of load balancing. If the load balancing constraint is not yet satisfied after load transferring, it is necessary to place new ONUs into the network until the load balancing constraint is satisfied.

The procedure of the LBOP algorithm is described as follow:

A. ONU Placement

In the first stage of LBOP, we use a greedy algorithm to determine the minimum number of ONUs and the location of each ONU under the constraint of hops number. The best location should guarantee that all wireless routers can connect to at least one ONU.

Step 1: According to the original network topology, record the location of each router. We introduce a binary variable to each router as its flag. When the binary variable turns 1from 0, it means this router can connect to at least one ONU existing in the network under the constraints of hops number.

Step 2: Calculate the hop number of M routers to $n \times n$ grid points. To the ith grid point, compute the set of candidate subordinate wireless routers that can connect to it under the constraints of hop number and record the number of eligible router. The routers which can connect to two or more ONUs will be tagged as the overlap routers.

Step 3: Choose the grid point that contains the most eligible routers with flag 0 as the location of ONU, then turn these routers' flag from 0 to 1. This means that these wireless routers have already found their primary ONU.

Step 4: Repeat step 3, in such a way, we iteratively place the ONUs into the network one-by-one and determine the best location for each ONU until all wireless routers in the network can connect to the primary ONUs under the constraints of hops number.

After the above steps, each router can connect to at least one ONU, and we can obtain the subordinate wireless routers for each ONU. Therefore, we can calculate the traffic load of each ONU. Without loss of generality, we calculate the difference between maximum and minimum ONU traffic loads. If the load balancing constraint is satisfied, that $L_{G\max} - L_{G\min} <= C$, end the LBOP algorithm, otherwise we will implement the load transferring among different ONUs by coordinating the sets of their subordinate wireless routers, transfer the traffic load of the overlap routers to the minimum-load ONU.

B. Load transferring

In the load transferring stage, the LBOP algorithm aims to encourage the ONUs in the network to satisfy the load balancing constraint. According to the output of the ONU placement stage, we can obtain the set of candidate subordinate wireless routers for each ONU and the set of candidate primary ONUs for each wireless router. We can see that different ONUs may have the common candidate subordinate wireless routers, the overlap routers, which enable the load transferring. Thus we can transfer the overlap routers between the sets of subordinate wireless routers of ONUs in order to satisfy the load balancing constraint. For any overlap wireless router, we can transfer it to more alternative ONUs if it has more candidate primary ONUs. Thus we always select the wireless router which has the least candidate primary ONUs when executing the load balancing. We iteratively select the minimum-loaded ONU and transfer the traffic load to it by adding new subordinate wireless routers.

Step 1: Calculate the traffic load of each ONU, then we can calculate the difference between maximum and minimum ONU traffic loads.

Step 2: According to the set of candidate primary ONU for each wireless router, it is preferable to transfer the overlap wireless router which has the at least candidate primary

ONUs to the minimum-load ONU during the subsequent load transferring.

Step 3: Iteratively transfer the traffic load to the minimum-load ONUs until the load balancing constraint is satisfied or there is no any overlap wireless routers for the minimum-load ONU.

If the load balancing constraint is not yet satisfied after the load transfer, we will place new ONUs into the network according to the ONU placement stage and repeat the load transferring.

IV. Simulation Results

In the simulation, we set a WOBAN including 20 routers uniformly distributed in a 100km×100km square area. The network area is divided into $n \times n$ grids, where *n* takes value within $\{5,6,7\}$ in different cases. We place ONUs at the intersection of the grids. The transmission range of routers and ONUs R_T is 30m. There are available wireless links between any pair of wireless nodes if they are in the transmission range of each other. The wireless topology ensures that any pair of wireless nodes can communicate with each other through the wireless multi-hop path between them. The wireless routers are randomly assigned the traffic load taking value within $\{10,20,30\}$.

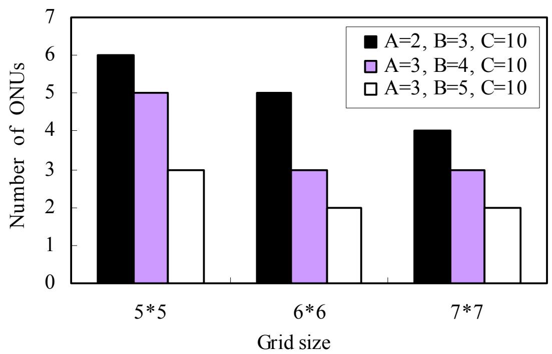


Fig. 2. Number of ONUs with different *A* and *B*

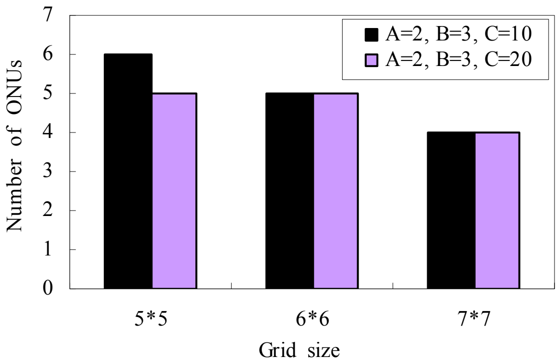


Fig. 3. Number of ONUs with different *C*

In Fig. 2, given a fixed topology, the number of required ONU gradually decreases with the grid size increasing. The larger grid size indicates the larger number of potential locations for ONUs placement and also the larger solution space for the ONU placement problem, which may results better solution to the ONU placement problem, so the number of ONUs is decreasing. Also, we can see that when the load balancing constraint *C* is fixed, the number of required ONU decreases with the wireless hop number constraints *A* and *B* increasing.

Fig. 3 illustrates that the number of required ONU also decreases with the load balancing constraint *C* increasing. This is because when the load balancing constraint is lager, each ONU will support more wireless routers, then the number of ONUs will decrease.

In Fig. 4, we make a comparison between the LBOP algorithm and the Tabu Search algorithm [9] in terms of number of eligible routers which meet the constraints of hop number and load balancing. We can see that in any case the LBOP algorithm has 20 eligible routers. For the Tabu Search algorithm, when we apply the 7×7 grid, the number of eligible routers is 18. Thus, the LBOP algorithm has better performance than the Tabu Search algorithm.

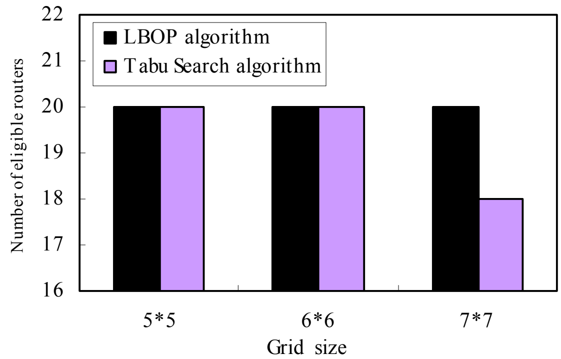


Fig. 4. LBOP *vs*. Tabu Search in number of eligible routers

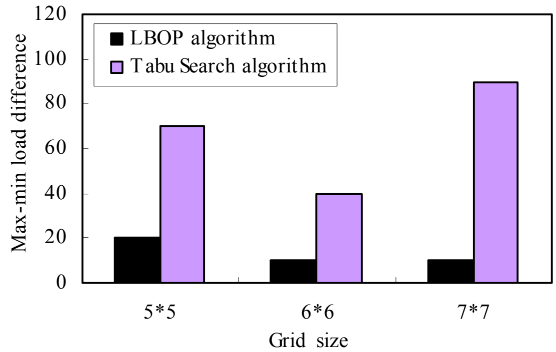


Fig. 5. LBOP *vs*. Tabu search in max-min load difference

Fig. 5 clearly illustrates that the LBOP algorithm outperforms the Tabu Search algorithm in terms of load balancing. When we apply the 7×7 grid, the max-min load difference of the LBOP algorithm has 80% reduction compared with the Tabu Search algorithm.

V. Conclusion

In this paper, we study ONU placement problem in WOBAN which aims to minimize the number of required ONU under the constraints of hop number and load balancing considering peer-to-peer communication. We propose a novel ONU placement algorithm called LBOP to solve the problem. The simulation results show that the applied network size, the constraint of hop number and load balancing all have great impact on performance of the algorithm .The simulation results also demonstrate that the proposed LBOP algorithm can maintain better load balancing than the previous works, while requiring fewer ONUs (i.e., lower cost for network deployment and maintenance). Thus, the LBOP algorithm is a cost-efficient solution for the load-balanced ONU placement in WOBAN.

ACKNOWLEDGEMENTS

This work was supported in part by the National Natural Science Foundation of China (61172051, 61071124), the Fok Ying Tung Education Foundation (121065), the Program for New Century Excellent Talents in University (11-0075), the Fundamental Research Funds for the Central Universities (N110204001, N110604008), and the Specialized Research Fund for the Doctoral Program of Higher Education (20110042110023, 20110042120035).

REFERENCES

[1] M. Mirahmadi and A. Shami, "Traffic-prediction-assisted dynamic bandwidth assignment for hybrid optical wireless networks," *Computer Networks*, vol. 56, pp. 244-259, Jan. 2012.

[2] Z. Y. Zheng, J. P. Wang, and X. Wang, "ONU Placement in Fiber-Wireless (FiWi) Networks Considering Peer-to-Peer Communications," *IEEE Globcom*, 2009, pp. 1-6.

[3] S. Li, J. P. Wang, and C. M. Qiao, "Mitigating packet reordering in FiWi networks," *Journal of Optical Communications and Networking*, vol. 3, no. 2, pp. 134-144, Feb. 2011.

[4] N. Ghazisaidi and M. Maier, "Fiber-wireless (FiWi) access networks: challenges and opportunities," *IEEE Network*, vol. 25, no. 1, pp. 36-42, Jan. 2011.

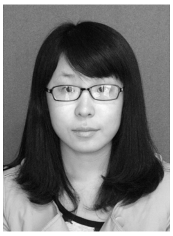
[5] R. Chandra, L. Qiu, K. Jain, and M. Mahdian, "Optimizing the placement of integration Points in Multi-hop Wireless Networks," in *Proc. ICNP conf.,* 2004, pp. 271-282

[6] S. Sarkar, "Hybrid Wireless –Optical Broadband Access Network (WOBAN): Network Planning Using Lagrangean Relaxation," *IEEE/ACM Transactions on Networking,* vol. 17, no. 4, Aug 2009.

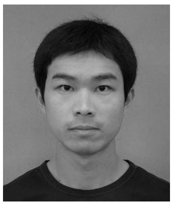
[7] F. Li, Y. Wang and X. Y. Li, "Gateway placement for Throughput Optimization in Wireless Mesh Network," in *Proc. ICC conf.*, pp. 4855-4960, 2007.

[8] S. Sarkar, B. Mukherjee, and S. Dixit, "Towards global optimization of multiple ONUs placement in hybrid optical-wireless broadband access networks," in *Proc. COIN conf.*, pp. 65-67, Jul 2006.

[9] Z. Zheng, J. Wang, C. M. Qiao, and A. Gumaste, "ONU placement in fiber-wireless (FiWi) networks considering peer-to-peer communications," *IEEE GLOBECOM*, pp. 1-7, Nov 2009



Bing Li received the B.S degree in communication engineering from Northeastern University, Shenyang, China, in 2012. She is currently pursuing the M.S. degree in the same university. Her research interests include the green algorithms in Fiber-Wireless (FiWi) access networks.



Yejun Liu received the B.S. degree in communication engineering from Shenyang Ligong University, Shenyang, China, in 2008, and the M.S. degree in communication and information systems from Northeastern University, Shenyang, China, in 2010. He is currently pursuing the Ph.D. degree in the same university. His research interests include the survivability and green algorithms in Fiber-Wireless (FiWi) access networks.

Lei Guo received the Ph.D. degree in communication and information systems from University of Electronic Science and Technology of China, Chengdu, China, in 2006. He is currently a professor in Northeastern University, Shenyang, China. His research interests include optical networks, access networks and wireless multi-hop networks. He has published over 100 technical papers in the above areas. Dr. Guo is a member of IEEE and OSA. He was the recipient of the Best Paper Award from the International Conference on Communications, Circuits and Systems (ICCCAS'04).