

ONU Placement in Fiber-Wireless (FiWi) Networks

Uma Rathore Bhatt*, Nitin Chouhan

Department of Electronics & Telecommunication Engineering, Institute of Engineering & Technology
Devi Ahilya University, Indore -452017, India

*Corresponding author- umarathore@rediffmail.com

Abstract— In recent years, there is an explosive growth in internet users which require a broadband access network with high capacity and better flexibility and gets service in “anywhere-anytime” manner. The solution is a FIWI technology which proving itself a main tool in the field of telecommunication by its own merits over the other existing technologies. Fiber-Wireless (FiWi) Network is a combination of Passive Optical Network(PON) and Wireless Mesh Network(WMN). It provides large bandwidth capacity and high stability in optical network and lower cost in wireless network. Therefore, FiWi gives users to broadband access service in an “anywhere-anytime” way. In this paper, the main focus is on the ONU placement in FiWi network to make a cost-efficient network. The key issue in FiWi network is the placement of optical network unit (ONU) since ONU gives interface between the optical network and wireless network. The placement of ONU plays also an important role in network throughput. In FiWi network, placement of ONU such that it supports both types of traffic i.e. Internet traffic and peer-to-peer (P2P) traffic. Internet traffic means traffic from the wireless client to internet and peer-to-peer traffic means traffic from one wireless client to another wireless client. In this paper, the related work done in ONU placement to support both types of traffic and to minimize the numbers of ONU in a FiWi network is studied. In this paper, how to save energy in ONU in case of low-load or zero-load is also discussed. This is the review paper for enlightening the trends of ONU placement in a FIWI access networks.

Index Terms— Fiber-Wireless (FiWi), Passive Optical Network (PON), Wireless Mesh Network (WMN), ONU placement.

ACRONYMS

Abbreviations	Full meaning
Fi-Wi	Fiber-wireless
Wi-Fi	Wireless fidelity
PON	Passive optical networks
OLT	Optical line terminal
CO	Central Office
ONU	Optical network units
RN	Remote node
WMN	Wireless mesh network
AWG	Array Waveguide Grating
TDM	Time Division Multiplexing
WDM	Wavelength Division Multiplexing
P2P	Peer to Peer Communication

I. INTRODUCTION

In past year there is an explosive growth in the field of broadband access technologies which basically required higher bandwidth, better flexibility and lower cost access network and enable users to access internet in a flexible manner. The networks which are providing services for the internet are optical access networks and wireless networks. The PON gives higher bandwidth capacity and stability for accessing the internet but it fails to provide service to user in “AnyTime AnyWhere” manner and it also requires higher cost due to the usage of optical devices. On the other hand the wireless access network such as WIFI or WiMax are now mostly used as they are providing services at lower cost and also serves better flexibility to the user. However, interference and lower bandwidth limits its reliability.

So, on integrating the technical merits of both the technologies a FiWi broadband access network [1]-[3] was proposed to enable user to access internet at lower cost and higher bandwidth and also providing better speed. FiWi architecture generally consists of a PON at a back-end and WMN at a front-end. A wireless Gateway is combined to a ONU through a wire to act as an interface between PON and WMN. The ONU has a capability of transmitting and receiving both wireless and optical signal as well as wireless-optical signal conversion. ONU is responsible to collect traffic from front-end and send to OLT. Thus, placement of ONU in such a way that it increases the network performance and makes a cost-efficient network.

In general, two types of traffic are considered in the network i.e. internet traffic and p2p traffic[4]. Internet traffic originates from user and goes to an internet backbone. Firstly the traffic goes to a wireless router, the router will send to its primary ONU via multi-hop wireless path. The ONU forwards the internet traffic to an OLT where they will be injected to an internet backbone. It should be noted that the end-to-end delay in internet traffic is dependent on transmission in wireless front-end only since optical back-end has higher data rate than front-end.

p2p traffic originates from a wireless client and goes to another wireless client. It has two routes either through the pure wireless path or through the wireless-optical-wireless path as shown in fig.1. In wireless, the traffic will go through a wireless router and be received at the destination. In wireless-optical-wireless mode the traffic will firstly go to a wireless router. Then the router sends it to a primary ONU through wireless multi-hop way. The ONU

send traffic to a OLT, then OLT send this traffic to all the ONUs in the segment. The ONUs will determine either to drop the packet or to forward according to a destination address. Lastly the ONU which is a primary ONU of the destination wireless client send the traffic to a client through a wireless multi-hop way.

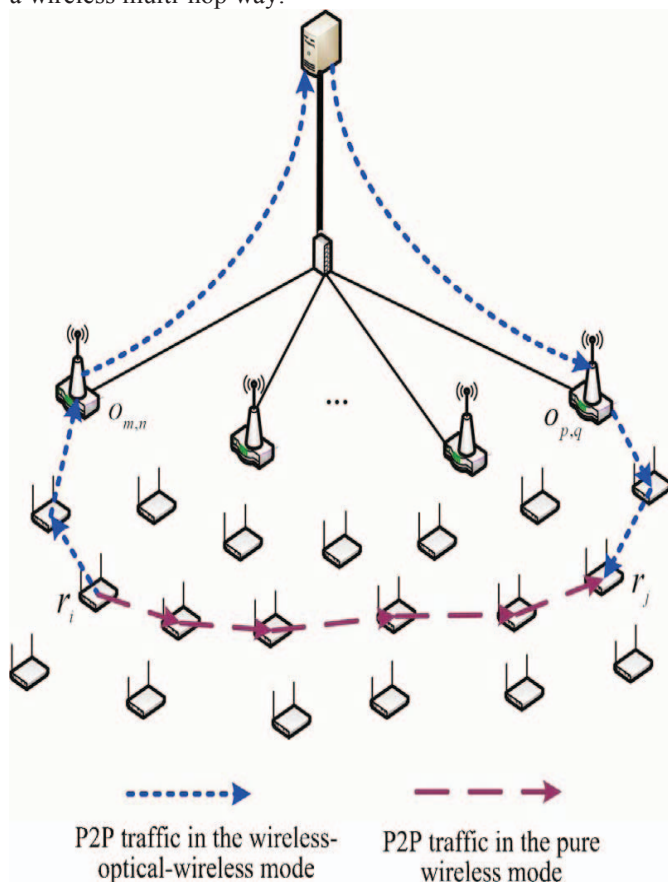


Fig. 1. Illustration of routing for P2P traffic [4]

From fig.1. it is clear that if a router r_i want to communicate with a router r_j in complete wireless mode, it requires a 5 wireless hops while in wireless-optical-wireless it only requires a 4 wireless hops. Also due to large bandwidth in optical back-end, the wireless-optical-wireless mode can reduce the end-to-end delay of the p2p traffic and also increases the network throughput. The network throughput will be further improved in p2p communication by direct inter-ONU communication. We also discuss about the energy saving in ONUs. When there is a low-load or zero-load on the ONU, then ONU will transfer its traffic to different ONU and get into the sleeping mode. In this way, we save energy in FiWi network.

The rest of the paper is organized as follows. Section II described the broadband access technologies include optical access technology, wireless access technology and the FiWi technology. Section III include the literature survey based on the ONU placement in FiWi network. Finally, we conclude this paper in section IV.

II. BACKGROUND

1) Optical Access Network

PON is widely considered as the preferable solution for broadband access due to its excellence in bandwidth capacity, lower transmission loss and better tolerance to interference than any other wired technology available for the users such as Digital Subscriber Line (DSL) and Cable Modem (CM). Basically PON has tree topology, in which OLT in CO connected with multiple ONUs via RN, feeder fiber and distribution fiber.

PON will be categorized as TDM-PON, WDM-PON and Hybrid TDM/WDM-PON[5]-[8]. In TDM-PON, there is a separate wavelength channel for both upstream (ONU To OLT) and downstream (OLT To ONU) services. All the ONU share same wavelength channel for upstream and downstream as per TDM method. Thus, TDM-PON provides Point-to-Multipoint (P2MP) communication. Whereas WDM-PON has separate wavelength channel for each ONU on the same feeder fiber i.e. each ONU has a separate wavelength channel for upstream and downstream services. Therefore it provides point to point communication and gives larger bandwidth capacity than TDM-PON. Therefore its advantage make it possible to use in NG-PON technology. One another method which is widely used in PON technology is hybrid TDM/WDM-PON which is integration of above two technologies. The hybrid TDM/WDM-PON can be achieved in four different ways as[2]: (1) TDM technology supports upstream services and WDM supports downstream services. (2) TDM supports downstream services and WDM supports upstream services. (3) The multiple TDM-PONs on distributed fiber side shares same feeder fiber through WDM technology. (4) The multiple WDM-PONs on distributed fiber side shares same feeder fiber via TDM Technology.

Hence, from above discussion its is clear that PON provides larger bandwidth and better stability but it fails to support mobile services and usually requires longer fiber cables to provide services to user which increases the overall cost.

2) Wireless Access Network

For accessing internet, another technology which gains attention due its lower cost and better flexibility is Wireless Access Networks. It is classified as :-

(a) WIFI – In these technology user can communicate with each other in a local area network (LAN) by Access Points (AP) which acts as a intermediate among the user. It will be operated in Infrastructure mode and Adhoc mode. In Infrastructure mode, there is Access Point(AP) through which users will communicate. In Adhoc mode Users can communicate directly to each other for a short period of time. The existing WIFI standards approved are IEEE 802.11 a/b/g/n can support the data rate of 54/11/54/300 mbps respectively in a range of 100m.

(b) WiMax - WiMax (Worldwide Interoperability for Microwave Access)[9]-[10] is a standards-based technology enabling the delivery of last mile wireless broadband access as an alternative to cable and DSL. WiMAX is provides

fixed, portable and eventually, mobile wireless broadband connectivity without the need for direct line-of-sight (LOS) with a base station. Mobile network deployments are expected to provide up to 15 Mbps of capacity within a typical cell radius deployment of up to three kilometers. WiMax Standards are shown below:-

- IEEE 802.16
 - Single carrier PHY layer and TDM MAC layer
- IEEE 802.16a
 - Include NLOS application
 - OFDM PHY layer and OFDMA MAC layer
- IEEE 802.16d
 - “Fixed WiMAX”
 - Combine previous versions
- IEEE 802.16e
 - “Mobile WiMAX”
 - Add mobility support
 - Scalable OFDM PHY layer and Scalable OFDMA MAC layer

(c) Cellular Technology – It is widely used in mobile communication, in which a base station in each cell is used to communicate between two different users and also support voice and low rate data application. The advancement in cellular mobile technology are termed as Generations and presently four generations are revealed till date and they are described below in shortly:

- 1G :- The first generation of public wireless telecom. Analog. Voice only. Since 1980s. Examples: AMPS, NMT, TACS. Frequency: various, 150MH.
- 2G :- The second generation of public wireless telecom. Digital, encrypted. Digital data transmission, voice as data; slow data services (SMS text messages). TDMA: GSM, PDC(Japan), iDEN, D-AMPS(IS-136). CDMA: cdmaOne(IS-95). In US, 2G is also called PCS (Personal Communications Service). Higher capacity. 800-2000MHz.
- 3G (third generation) – high-speed voice-oriented systems integrated with data services; ex.: General Packet Radio Service (GPRS), Code Division Multiple Access (CDMA)
- 4G (fourth generation) – still experimental, not deployed yet; based on Internet protocol networks and will provide voice, data and multimedia service to subscribers.

3) Fiber- Wireless Access Network

This technology is the integration of Optical and Wireless access technology providing the advantages of both the technologies i.e. larger bandwidth capacity, high stability and low deployment cost. Therefore FiWi enables user to access internet in an “Anywhere Anytime manner”[1,11].

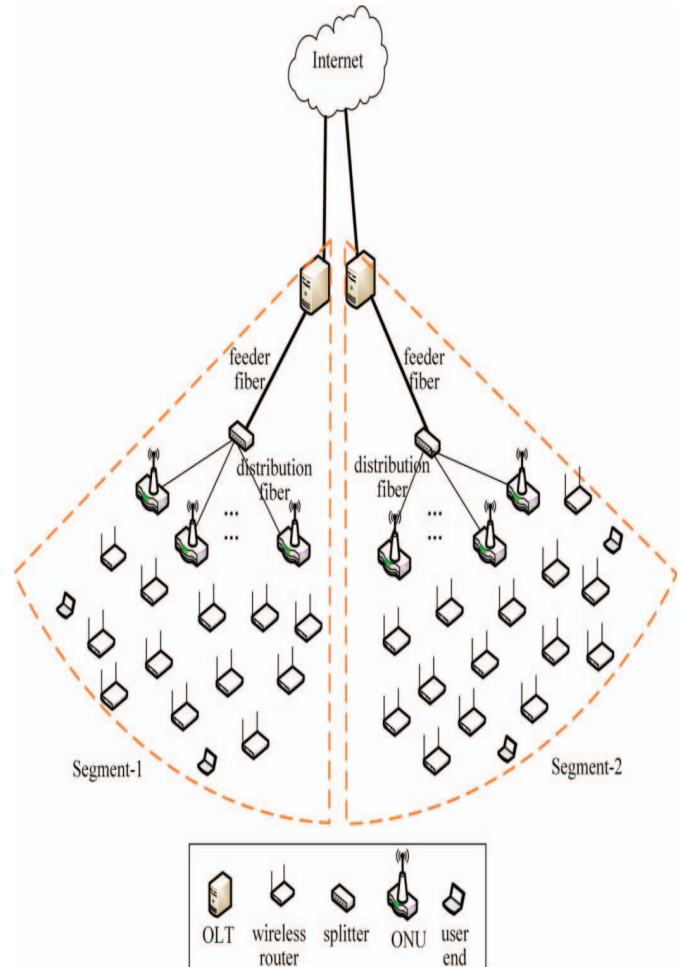


Fig. 2. An architecture of FiWi access network including two segment [12]

FiWi has a Tree- Mesh architecture as shown in fig.2. It has two ends named as Front End and Back End. Front End consist WMN which has Mesh Topology whereas Back end consist of PON which has tree topology. In each segment ONU is responsible to interface between front end and back end. The function of ONU is to convert Optical signal into wireless signal and vice-versa. From each ONU a Wireless Gateway is connected through a wire. The user ends are located at the residential buildings and can be connected to internet through wireless devices and Optical devices. If a User wants to access the internet, first he has to sends the packet to its nearby wireless router, then router sends the packet to its primary ONU through a multi hop wireless path via wireless gateway. Now this packet arrives to the OLT through the fiber cable and then this packet is injected into the internet back bone. Then internet gives service to the user in the reverse fashion.

The advantages of FIWI Access network are:

- (1) Compared to wireless networks, FIWI provides larger bandwidth and better stability, so reduces packet loss rate and traffic blocking rate.

(2) Compared to optical network FiWi provides wider coverage and more flexible access which shorter the fiber length and reduces the network cost.

III. LITERATURE REVIEW

FiWi network recently attracted much attention due to their potential to become a broadband access network. However, FiWi face some technical challenges i.e. the placement of ONU is such that it maximize the network throughput and minimize the number of ONUs in a network. Related work on those aspect are as follows:

Suman Sarkar et. al.[13]-[17] proposes various algorithm for ONU placement includes random approach, deterministic approach, greedy algorithm and Simulated Annealing(SA) algorithm. In random approach, after dividing the network in multiple non-overlapping region, ONUs are placed randomly in each region. This scheme may not ensure proper connectivity because in some part of the network ONU may be in bunch and other part may be void. In deterministic approach, after dividing the network into multiple non-overlapping region, placed ONU at the center of each region. This approach works well in a symmetric network and much lower processing required. But this scheme does not fit well for a non-uniform distribution of users.

In greedy algorithm, first divide the network into a multiple region according to users and then placing the ONUs at the center of each region. Then we find the distance of all ONUs with the users. According to minimum distance from the user, we identify the primary ONU of all the users. After identifying the primary ONUs, we try to minimize the average distance between the ONU and the user. The Greedy Algorithm is a heuristic, which performs local optimization of an individual ONU after the identification of premium users for that ONU, but this solution is not globally optimal. The purpose of global optimization is to find the minimum average cost for all the users with respect to multiple ONUs. The next algorithm is to optimize the ONUs placement globally by means of combinatorial-optimization technique namely Simulated Annealing (SA) algorithm.

The Simulated Annealing algorithm has five phases: (1) Initialization, (2) Perturbation, (3) Cost Calculation, (4) Acceptance and (5) Update. In Initialization phase of SA, the initial placement of ONU is obtained by greedy algorithm. In Perturbation phase SA relocates the ONUs with a small random amount. In Cost Calculation phase, the algorithm calculate the new cost of ONU placement and observed the new cost changes with respect to old cost. In Acceptance phase, if the new cost of ONU deployment is lower SA accept the relocation of ONUs else it remains with the old cost. In Update phase, SA iterates the same process until no further cost improvement occur. If no more perturbation will reduce the cost of deployment then algorithm is said to be in 'equilibrium state'. From analysis, it conclude that greedy algorithm perform well at slightly higher cost than SA but at much lower processing requirement.

Suman Sarkar also proposes a primal model for the ONU placement[17]. In the primal model, they considered more constraint including user assignment, capacity and interference. They take a Lagrangean relaxation method used to solve the primal model for the lower bound and the upper bound of the optimization problem. All the above work done only in internet traffic i.e. traffic from user end to internet and not in P2P traffic i.e. one user to another user. The P2P traffic should be considered into ONU placement especially in the wireless-optical-wireless mode.

Zeyu Zheng et. al.[18,19] considering both internet traffic and p2p traffic and give an algorithm for ONU placement in a FiWi network. Firstly find the optimal K ONUs placement so that overall wireless hop counts will be minimized in network. For solving this tabu search algorithm is applied. But this work will remain untouched in how to minimize the number of ONUs in a network and also the load balancing between the different ONUs.

In [4] author proposed a load balance ONU placement (LBOP) algorithm for both type of traffic to minimize the numbers of ONUs and load balancing among ONUs. The LBOP algorithm consist of two stages ONU placement and load balancing. In first stage, firstly place the ONU in a network in greedy manner one-by-one, then find best location for everyone such that the required number of ONU is minimized and all the wireless router will connect to ONU under a wireless multihop way. In second stage, given traffic load to each ONU according to their subordinate wireless router. Then implement the load transferring among different ONU until it satisfy the load balancing condition. From this algorithm the required number of ONU is minimized and therefore we get a cost efficient FiWi network. But this algorithm is underperform as compared to Tabu search algorithm.

The network throughput can be improved by direct inter-ONU communication. Yan Li et. al. [20] gives a novel hybrid WDM/TDM PON architecture supporting direct inter-ONU and a corresponding dynamic bandwidth allocation (DBA) protocol. The WDM/TDM PON architecture supporting direct inter-ONU communication based on novel arrayed waveguide grating (AWG). The DBA protocol determines which ONU can send/receive data on bandwidth shared by other ONUs. For this a decentralized DBA protocol algorithm proposes which can maximize the network throughput and provide fairness among ONUs.

In case when there is low-load or zero-load on ONU, then ONU will transfer its load to other ONUs and get into sleeping mode. In this way we save energy in ONU. In [2] author proposes an Energy Saving algorithm[8,21,22] based on Sleeping Low-load ONUs (EASLO) for saving energy in ONU. The DEA is used to aggregate the traffic as much as possible to high-load ONUs to increase the number of low-load and zero-load ONUs. Then TRR reroute the traffic into a ONUs which have enough capacity to handle the traffic.

TABLE-I COMAPRISON OF VARIOUS ONU PLACEMENT ALGORITHMS

ONU Placement Algorithm	Solution Quality	Advantage	Limitation	Ref.
Random	Worse	Simple	Not ensure proper connectivity. Considering only internet traffic.	[7]
Deterministic	Better	Work well in symmetric N/w.	Not fit well for a non-uniform distribution of users. Considering only internet traffic.	[7]
Greedy	Good	Required low processing.	Not globally optimal. Considering only internet traffic.	[5]
Simulated Annealing	Improved over greedy.	Combinatorial Optimizer	Not converge for discontinuous model. Considering only internet traffic.	[5]
Primal model	Optimal	Considered several constraint	Complex analytical solution. Considering only internet traffic.	[9]
Tabu Search	Optimal in most cases.	Better performance. Considered both internet and p2p traffic.	Untouched in minimizing the number of ONUs in the network.	[10]
LBOP	Better	Minimise the number of ONUs in the network. Load balancing among ONUs. Considered both internet and p2p traffic.	Not perform well as compared to Tabu Search algorithm.	[1]

The SAS examine the traffic in ONU, if the traffic is lower than sleeping threshold than ONU put into the sleeping mode and if traffic suddenly increases then ONU in awakening state. We summarize the comparison of various ONU placement algorithms in Table 1.

IV. CONCLUSION

In this paper, firstly the broadband access technology including optical access technology, wireless access technology and FiWi technology is discussed. The placement of ONU is such that it support the internet traffic as well as p2p traffic. For that a different ONU placement algorithms considering both internet traffic and p2p traffic is studied. For ONU placement in internet traffic we study random, greedy and SA algorithm. From literature survey it is examined that

greedy algorithm performs very well but at higher deployment cost than SA. The LBOP algorithm discussed in the literature

considered both internet traffic and p2p traffic which minimizes the number of ONUs required in the network. From literature it is examined that the performance of LBOP algorithm is less than Tabu search algorithm but LBOP algorithm is cost efficient.

REFERENCES

- [1] Navid Ghazisaidi, Martin Maier, Chasi M. Assi, "Fiber-wireless (FiWi) access networks: A survey", *IEEE Communications Magazine*, Vol.47, No.2. 2009, pp. 160-167.
- [2] N. Ghazisaidi, M. Maier, Fiber-wireless (FiWi) access networks: challenges and opportunities, *IEEE Network* 25 (January (1)) (2011) 36-42.
- [3] M. Maier, N. Ghazisaidi, and M. Reisslein, "The audacity of fiber-wireless (FiWi) networks (invited paper)," in *Proc. ICST Int. Conf. Access Networks*, Oct. 2008, pp. 16-35.
- [4] Y. Liu, et al., Load balanced optical network unit (ONU) placement in cost-efficient fiber-wireless (FiWi) access network, *Optik - Int. J. Light Electron Opt.* (2013).
- [5] J. Zhang, N. Ansari, Scheduling hybrid WDM/TDM passive optical networks with nonzero laser tuning time, *IEEE/ACM Trans. Networking* 19 (2011) 1014-1027.
- [6] F. Aurzada, M. Scheutzow, M. Reisslein, et al., *IEEE Trans. Commun.* 59 (2011) 1378-1388.
- [7] J. Kani, Enabling technologies for future scalable, flexible WDM-PON, WDM/TDM-PON systems, *IEEE J. Sel. Top. Quantum Electron.* 16 (2010) 1290-1297.
- [8] Y. Liu, et al., Green Survivability in FiWi Access Network, *Optical Fiber Technology* 18 (2012) 68-80.
- [9] D. Pareit, B. Lannoo, I. Moerman, The history of WiMAX: a complete survey of the evolution in certification and standardization for IEEE 802.16 and WiMAX, *IEEE Commun. Surv. Tutorials* (2011) 1-29.
- [10] L. Yi, K. Miao, A. Liu, A comparative study of WiMAX and LTE as the next generation mobile enterprise network, in: *Proc. ICACT*, 2011, pp. 654-658.
- [11] P. Chowdhury, B. Mukherjee, S. Sarkar, Hybrid wireless-optical broadband access network (WOBAN): prototype development and research challenges, *IEEE Network* 23 (2009) 41-48.
- [12] Yejun Liu, et al., Optimizing Backup Optical-Network-Units Selection and Backup Fibers Deployment in Survivable Hybrid Wireless-Optical Broadband Access Networks, *Journal Of Lightwave Technology*, Vol. 30, No. 10, (2012).

- [13] S. Sarkar, B. Mukherjee, S. Dixit, Towards global optimization of multiple ONU placement in hybrid optical-wireless broadband access networks, in: Proceedings of COINNGNCON, July 2006, 2006, pp. 65–67.
- [14] S. Sarkar, S. Dixit, B. Mukherjee, Hybrid wireless-optical broadband-access network (WOBAN): a review of relevant challenges, *J. Lightw. Technol.* 25(November (11)) (2007) 3329–3340.
- [15] S. Sarkar, H. Yen, S. Dixit, et al., Hybrid wireless-optical broadband access network (WOBAN): network planning and setup, *IEEE J. Sel. Areas Commun.* 26(August (6)) (2008) 12–21.
- [16] S. Sarkar, H. Yen, S. Dixit, B. Mukherjee, A mixed integer programming model for optimum placement of base stations and optical network units in a hybrid wireless-optical broadband access network (WOBAN), in: Proceedings of WCNC, March 2007, 2007, pp. 3907–3911.
- [17] S. Sarkar, H. Yen, S. Dixit, et al., Hybrid wireless-optical broadband access network (WOBAN): network planning using Lagrangean relaxation, *IEEE/ACM Trans. Network.* 17 (August (4)) (2009) 1094–1105.
- [18] Z. Zheng, J. Wang, X. Wang, ONU placement in fiber-wireless (FiWi) networks considering peer-to-peer communications, in: Proceedings of GLOBECOM, November 2009, 2009, pp. 1–7.
- [19] Z. Zheng, J. Wang, J. Wang, A study of network throughput gain in optical-wireless (FiWi) networks subject to peer-to-peer communications, in: Proceedings of IEEE ICC, March 2009, 2009, pp. 1–6.
- [20] Li, et al., Integrated FiWi Access Networks supporting Inter-ONU Yan Communications, *Journal of Lightwave Technology*, Vol. 28, No. 5, 2010 pp. 714–724.
- [21] A. Ali, T. Tauqeer, and S. M. H. Zaidi, “Energy aware routing algorithm for FiWi networks (EARF),” in *Proceedings of the High Capacity Optical Networks and Enabling Technologies (HONET '11)*, pp. 89–94, December 2011.
- [22] Xiaoxue et. al, “Dynamic energy-saving algorithm in green hybrid wireless-optical broadband access network” *optik* 124 (2013) 1874–1881.