# Effects of Optical Network Unit Placement Schemes for Multi-Channel Hybrid Wireless-Optical Broadband-Access Networks

Amitangshu Pal and Asis Nasipuri
Electrical & Computer Engineering, The University of North Carolina at Charlotte, Charlotte, NC 28223-0001
E-mail:{apal,anasipur}@uncc.edu

*Abstract-* **In this paper, we propose a heuristic to solve the problem of optical network units (ONUs) placement in an WOBAN. We compare the performance of the proposed heuristic with the random ONU deployment scheme, along with the effect of routing and channel assignment on top of the ONU placement schemes.**

## I. Introduction

The present growing demands for bandwidth-intensive services and at the same time the flexibility (anytime-anywhere service) of the users are accelerating the research on efficient and cost-effective access infrastructures where optical-wireless combinations are seen as a promising approach. The wireless-optical broadband-access network (WOBAN) is a novel hybrid access network paradigm with the combination of high-capacity optical backhaul and highly flexible wireless front-end that can provide higher bandwidth in a cost effective manner. The placement of ONUs in the network plays an important role for the better performance of the network. Given the location of the mesh routers, our objective is to place the ONUs optimally throughout the network to minimize some cost metric. We propose a *cluster-based* scheme for ONU placement where ONUs are the cluster-heads and cost metric is the average distance between the mesh routers and their corresponding ONUs. Extensive simulation results verify that our proposed clustering scheme performs better than uniform-random ONU placement scheme. At the same time the planning of an WOBAN requires fiber deployment from OLT to the ONUs to form the optical backend. In this paper we consider the schemes for laying out fiber for tree and ring PON topologies and evaluate their cost comparison.

## II. ONU Placement Scheme

As mentioned earlier, the network performance highly depends on the placement of ONUs. Our objective is to place the ONUs in a geographic area (such as in a college campus or in a residential area) with the assumption that the location of the wireless mesh routers $(MR_1, MR_2, ..., MR_V)$ are known. Let us assume that the locations of the ONUs are given by $(X_i, Y_i)$ $(i \in (1, 2, ..., U)$ and locations of all the routers are given by $(x_j, y_j)$ $(j \in (1, 2, ..., V))$. We develop a clustering scheme for ONU placement which is described as follows.

First, we need to find how many ONUs are required to satisfy the demands of all users. If the peak demand of the whole network is $D$ and each ONU can serve a demand of $d$ then the number of ONU required is $U = \frac{D}{d}$. Now, we propose a greedy algorithm to place these $U$ ONUs based on *k-means clustering* technique. At first, an initial set of $U$ locations are generate randomly, these points are denoted by $m_1^{(1)}, m_2^{(1)}, ..., m_U^{(1)}$ (the superscripts (1) corresponds to initial position). The algorithm consists of three steps:

*Assignment phase:* In this phase, the routers are assigned to their closest ONUs, i.e. an ONU and its corresponding routers are in one cluster (this is basically partition the routers according to the *Voronoi diagram* generated by the ONUs. Mathematically, if a router $V_j$ (the position of $V_j$ is denoted by vector $x_j$) is in cluster $S_i^{(t)}$ in the $t$-th iteration then $S_i^{(t)} = \{x_j : \|x_j - m_i^{(t)}\| \leq \|x_j - m_{i^*}^{(t)}\| \ \ \forall i^* = 1, 2, ..., U\}$.

*Update phase:* In this stage, the new ONU position of cluster $i$ are calculated by taking the mean of all the router-positions, i.e. $m_i^{(t+1)} = \frac{1}{|S_i^{(t)}|} \sum_{x_j \in S_i^{(t)}} x_j$. The *Assignment* and *Update* phase is repeated until the solution converged, i.e. the coordinates of the ONUs no longer change.

*Refinement phase:* In this phase each routers are individually reassigned to other clusters and then ONU positions are again calculated by taking the means. The new assignment is accepted if doing so improves the solution. The algorithm is repeated a large number of times with different random ONU positions and the best solution is taken at last.

*Laying out fiber from OLT to the ONUs:* After the positions of the ONUs are identified, the OLT and the ONUs need to be connected using optical fiber. Depending on the network planning, in the optical backend the OLT and the ONUs can be connected using a tree topology or a ring topology. In case of a tree topology, a *minimum spanning tree (MST)* is constructed to connect the OLT and the ONUs. In case of a ring architecture, the laying out of fiber with minimum length can be modeled as a *travelling salesman problem (TSP)*. The reason behind using the MST or TSP is to minimize the length of the fiber needed, thus the deployment cost is minimized.

## III. Performance Study

In this section we compare the performance of our ONU placement scheme along with the random placement scheme using *network simulator–2 (ns2)* with IEEE 802.11 MAC, with substantial modifications in the physical and the MAC layers, to model the cumulative interference calculations and also include the physical carrier sensing based on cumulative received power at the transmitter. We also compare the effects of these ONU placement schemes on minimum hop-count routing in the upstream direction of the WOBAN. The effects and benefits of using multiple channels are also explored. The amount of total fiber required for designing the PON backend is also calculated. We distribute the mesh routers uniformly in an area of 1000×1000 square meters as shown in Fig. 1-Fig. 2. All the mesh routes generate traffic at a rate of 15 KBps which are carried to the ONUs using multi-hop communications based on shortest hop-count routes.

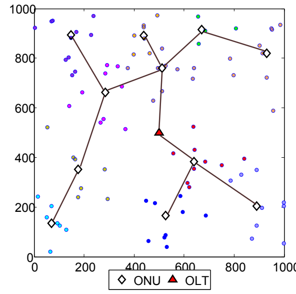


Fig. 1. Tree PON architecture.

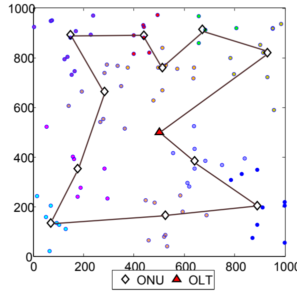


Fig. 2. Ring PON architecture.

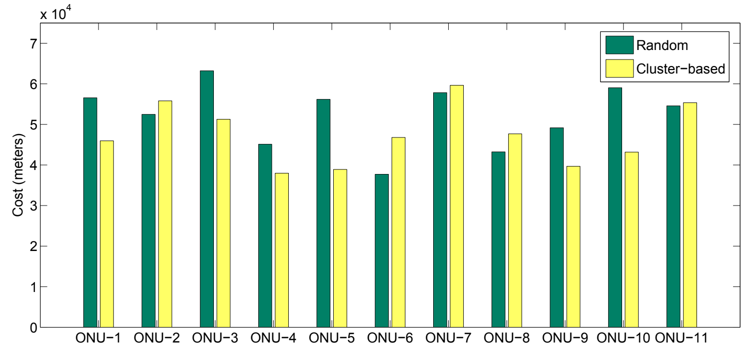


Fig. 3. Costs of different ONUs for random placement and clustering-based schemes.

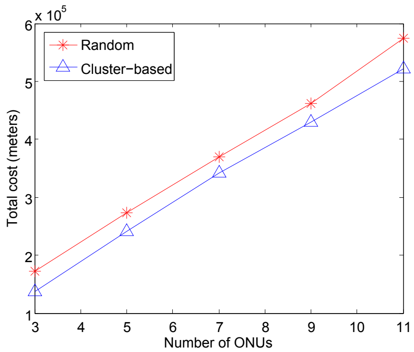


Fig. 4. Comparison of overall cost.

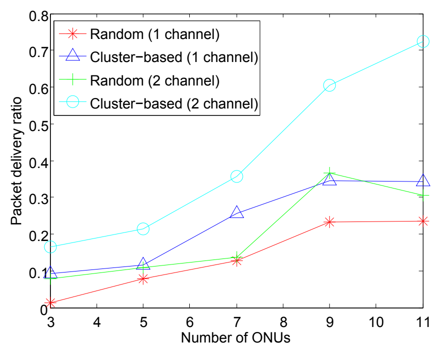


Fig. 5. Comparison of delivery ratio.

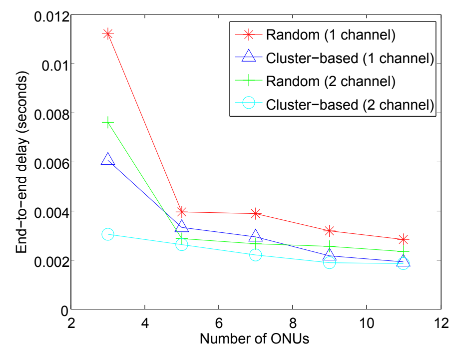


Fig. 6. Comparison of end-to-end delay.

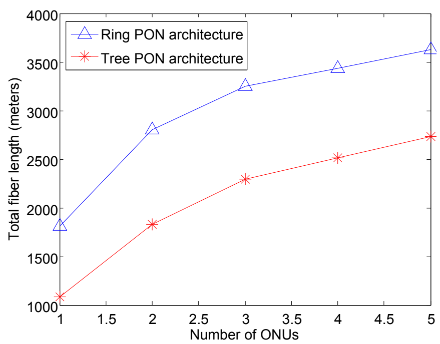


Fig. 7. Comparison of total fiber length.

Fig. 1 shows the placement of eleven ONUs in a geographic area where the mesh routers are distributed uniformly across the network area. Fig. 3 shows the costs of the ONUs in case of random (uniformly) ONU placement scheme and clustering scheme. The cost of the ONU$_i$ is defined as $\sum_{j=1}^{V} \sqrt{(X_i - x_j)^2 + (Y_i - y_j)^2}$. Fig. 4 shows the variation of overall cost with the number of ONUs. From these figures we can observe that the clustering scheme improves the cost by a good margin compared to the random placement scheme.

We also compare the effects of ONU placement on routing with multiple orthogonal channels. Here we consider routing in upstream direction, i.e. from the mesh router to any one of the ONUs (anycast routing). We consider minimum hop-count based routing to the nearest ONU. After the routes are decided, the channels are assigned to the links as follows. The links are sorted in the decreasing order of their interfering load. Then channels are assigned to the links one-by-one as the least used channel in their interfering neighborhood.

Fig. 5 shows the variation of packet delivery ratio with the number of ONUs. From this figure we can observe that the delivery ratio increases with the increase in number of ONUs. This is because the increase in ONUs results in reduced route length as well as traffic load on each link, which results in better route quality as well as delivery ratio. Fig. 6 shows variation of end-to-end delay with the number of ONUs. We can observe that the delay decreases with the increase in ONUs due to reduced route length and less channel access delay due to less traffic load on each link. We can also observe that the clustering scheme performs better compared to the random ONU placement scheme, which shows the effectiveness of our proposed scheme. Also we can observe that the delivery ratio is improved in case of two channels because of reduced interference due to the presence of multiple channels, whereas the reduction in delay is mainly due to reduction in channel access delay from using multiple channels in neighbouring transmitting nodes.

Depending on how the OLT and the ONUs are connected using optical fiber, the required fiber length will be different as well as the total deployment cost. Fig. 1 shows the network topology for uniform distribution of mesh routers respectively, where the minimum spanning tree is constructed joining the OLT and the ONUs to ensure the minimum fiber cost. The position of the OLT is assumed to be (500, 500). Fig. 2 depicts the case of a ring topology where the fiber layout is done by solving the travelling salesman problem. Fig. 7 shows the total fiber required for both tree and ring topology with different distribution of mesh routers. These figures clearly show the amount of extra fiber required for the ring topology compared to the tree PON architecture.

## IV. Conclusion

In this paper, we propose a clustering technique to solve the problem of ONU placement and compare its benefits compared to the random ONU placement scheme in improving the network quality. We also studied the effects of routing and multiple channels on the overall network packet delivery ratio and end-to-end packet delay. We also explain different fiber layout schemes along with their deployment cost comparison.