A Hybrid Wavelength Allocation Framework for Fiber-Wireless Based Vehicle-to-Infrastructure Communication Network

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***Abstract*—In order to facilitate low latency vehicle-to-infrastructure (V2I) communication, latency sensitive solutions for resource allocation should be explored. In our paper, we propose a novel wavelength allocation algorithm for a fiber-wireless (FiWi) based V2I communication network. Specifically, we propose a novel approach for wavelength allocation in a time and wavelength division multiplexed passive optical network (TWDM-PON) by utilizing a first-fit bin packing algorithm. The TWDN-PON forms the optical backhaul of our FiWi network. The proposed algorithm is hybrid in nature, i.e., it utilizes both static and dynamic wavelength allocation. Further, the proposed algorithm enables an hourly allocation of wavelength to each optical network unit (ONU), connected to a roadside unit (RSU), whilst reducing the switching between the wavelengths and hence, consequently reducing the latency in the optical link. The proposed bin packing algorithm has been compared with conventional first-fit bin packing algorithm. It has been shown that by utilizing the proposed algorithm, the total number of wavelength switches reduces by 65 in 12 hours duration as well as the latency of the optical network reduces by 40% per ONU when compared with the conventional bin packing algorithm.**

***Index Terms*—Fiber-wireless (FiWi), Vehicle-to-infrastructure (V2I), Wavelength switching, Road side units (RSU), Delay.**

I. Introduction

Intelligent transportation system (ITS) has gained considerable prominence in the field of vehicular commutation for applications like real-time traffic management, emergency vehicle notification systems, collision avoidance systems [1] and many more. Moreover, the advent of Internet of vehicles has facilitated new modes of vehicular communication such as vehicle-to-vehicle (V2V) and vehicle-to-infrastructure (V2I) [2]. V2I communication connects several vehicles with road side units (RSUs) to help manage and supervise the traffic in an efficient manner. Significant literature has been devoted to provide reliable and low latency services through V2I communication. However, one of the key challenges in V2I communication is fast and secure handovers when the vehicle is commuting between the RSUs. For high density and high mobility scenarios, the authors in [3] proposed an extension of the trustful space-time protocol (TSTP) which is capable of performing handovers among roadside gateways with low roaming latency of about 14 msec. In [4], performance of a low latency V2I system was enhanced by using cooperative relay V2V communication. The data transmission between a distant vehicle and the base station was done by relaying data to the nearest vehicle. This enhanced throughput for the distant vehicle also helped in avoiding re-transmissions. In order to build an information-theoretic foundation and provide practical transmission schemes for 6G-enabled V2V traffic the authors in [5] studied the sum-secure degree of freedom of multiple input multiple output (MIMO) interference channel. The authors proposed two novel transmission schemes, i.e., the interference decoding scheme and the interference alignment scheme, and thus established a sum-SDoF lower bound.

Many different communication architecture has been proposed in literature to facilitate V2I communication. One such architecture is a FiWi network which exploits the high capacity and low latency characteristics of an optical network along with the flexibility and mobility of the wireless network [2]. The authors in [2] used such a model for FiWi based V2I communication for task offloading in vehicular edge computing networks (VECN). The authors tried to minimize the computational delay of FiWi enhanced VECNs by employing a remote server for computationally intensive tasks whose performance is enhanced by a software-defined networking (SDN) based load-balancing task offloading solution which provides support to the centralized network for information handling and management. The authors in [2] showed that the SDN based load-balancing scheme can achieve improved performance in terms of processing delay by employing the edge servers' computation resources more efficiently.

Management of resources, both for the wireless and the optical part of a FiWi system is a major requirement for optimal V2I transmissions. The authors in [6] focused on wireless resource allocation for latency sensitive applications in V2I transmissions. They designed a low latency resource pre-allocation algorithm which consisted of two parts, one for the prediction of wireless resource requests and another part for resource allocation. For the resource allocation in optical network based on TWDM-PON architecture, the authors in [7] used first-fit bin packing algorithm for dynamic bandwidth and wavelength allocation (DBWA) to obtain improved energy efficiency. TWDM-PON architecture comes with the provision of allocating wavelengths to all tunable optical network units

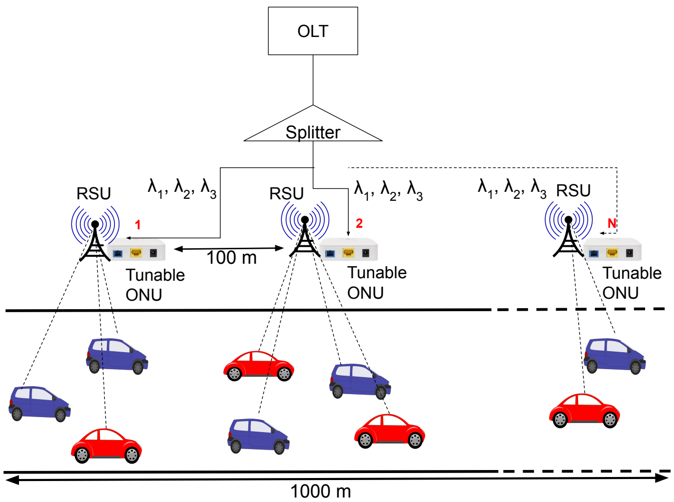

Fig. 1. System Architecture for the considered FiWi-V2I network

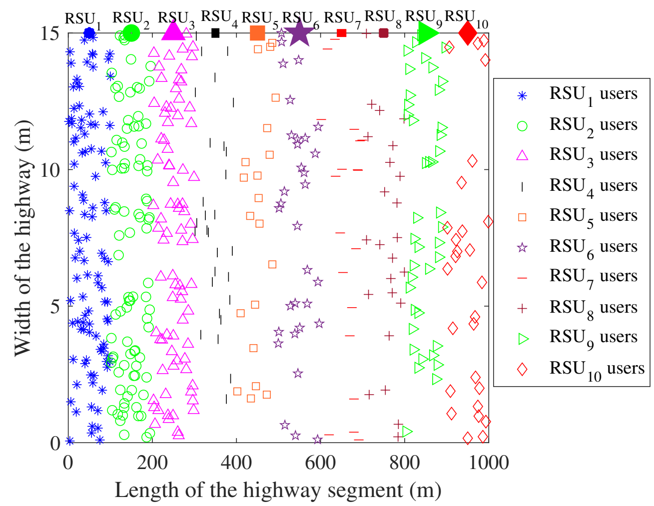

Fig. 2. Association of vehicles with RSUs based on throughput

(ONUs) at the optical line terminal (OLT) [8]. In [7], the proposed best-fit bin packing sleep mode aware (BP-SMA) algorithm showed an improved delay performance in comparison to the state-of-art DBWA and hybrid sleep mode aware algorithm [9].

Motivated by the above, we propose a novel wavelength allocation algorithm to optimally allocate wavelengths to ONUs for a TWDM-PON based V2I network. The major contributions of our work are summarized below:

1) We propose a throughput based hybrid (static as well as dynamic) wavelength allocation algorithm using an updated first-fit bin packing approach for a TWDM-PON system which reduces the hourly switching of wavelengths at each ONU.
2) We compare the wavelength switching delay of the proposed algorithm with the conventional first-fit bin packing algorithm. The results presented illustrate that the delay at an ONU reduces by 81% using the proposed approach when compared with the conventional approach.
3) The end-to-end (e2e) delay analysis is performed for the proposed optical backhaul network of the FiWi based V2I system. The delay analysis showed a reduction of 40% latency in V2I transmissions using the proposed approach.

Using the proposed algorithm we are able to show that the number of wavelength switches reduces from 78 to 13 over twelve hours duration. Moreover, due to the reduced wavelength switching, the average e2e delay per ONU is reduced from 1.335 msec to 0.802 msec compared to conventional first-fit bin packing. This reduction in delay is very significant for delay sensitive vehicular applications such as cooperative sensing and cooperative maneuvers that requires an end-to-end delay of less than 3 msec [10].

Rest of the paper is organized as follows. In Section II, we provide the architecture of the FiWi based V2I network. The proposed bin packing algorithm and its comparison with the first-bit bin packing algorithm is explained in Section III. The simulation environment and parameters considered for the FiWi based V2I network is mentioned in Section IV. The comparative results of the proposed bin packing and first-fit bin packing algorithm are shown in Section V. Finally, Section VI concludes the paper.

II. System Description

The FiWi based V2I system architecture is shown in Fig. 1. The FiWi network consists of a TWDM-PON as the back-end network and IEEE 802.11p based V2I network as the front-end [2]. Our system model consists of an OLT located at the central office (CO) which communicates with ten ONUs placed along the highway through a 1:16 splitter [11]. The ONUs are connected to the RSUs which in turn communicate with the end users that are vehicles. The passive splitter centralizes the communication between OLT and various users. Wavelength allocation is facilitated at the OLT based on the load served by each ONU which is the aggregate throughput of vehicles handled by them. The hourly traffic volume considered the Interstate (IS)-94 highway between Minneapolis and Saint Paul and is taken from [12]. The vehicles are associated with ONUs based on the maximum throughput from the ONUs. Fig. 2 shows the association of vehicles with RSUs along the IS-94 highway segment at 9 AM. We consider a scenario with ten RSUs, each RSU is connected to an ONU. The distance between the RSUs is 100 m. For V2I communication to be possible, each vehicle has to be connected to any one of the ten ONUs. A throughput based association of vehicle is considered where a vehicle is associated with the ONU that provides maximum throughput. It can be seen from Fig. 2 that for each vehicle, the nearest ONU provides the highest throughput to the users.

Considering the road near ONU_1, ONU_2 and ONU_3 to have congestion, load in terms of traffic at these ONUs is considered to be higher compared to the other ONUs. This is shown in

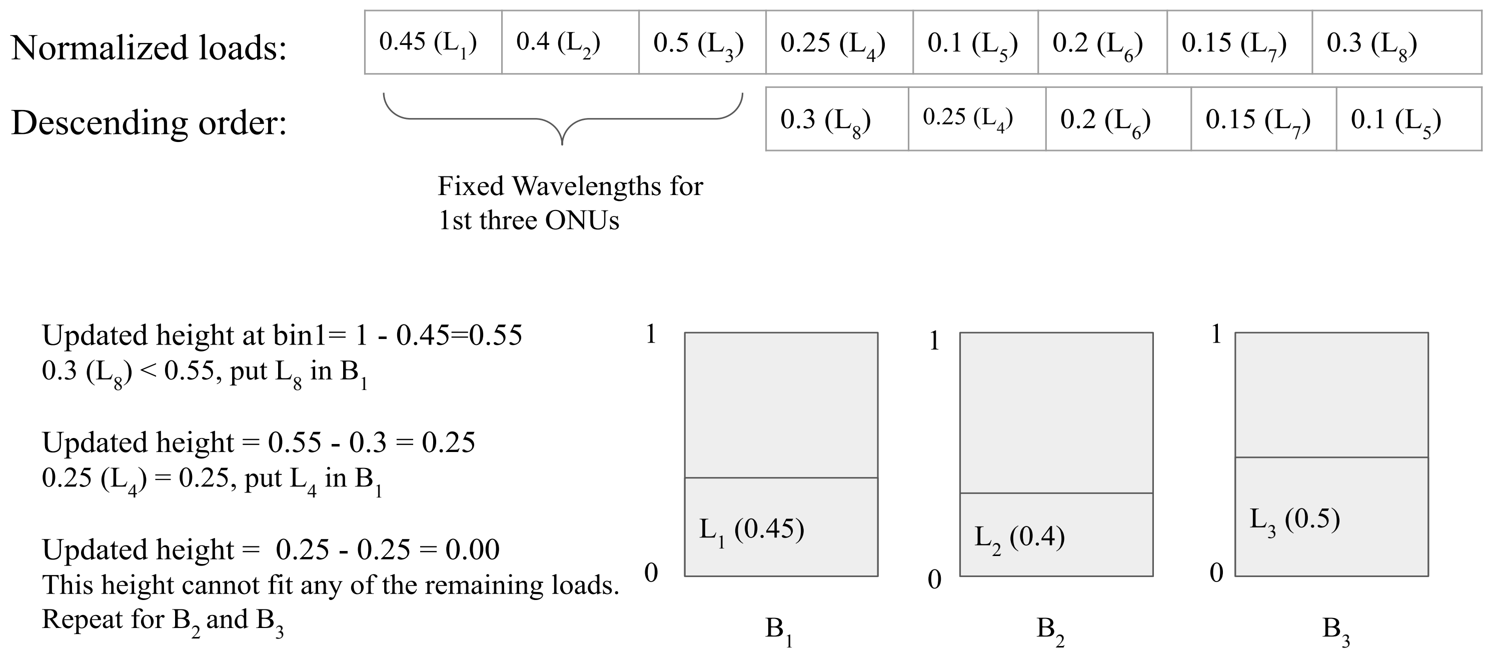

Fig. 3. Proposed bin packing framework

Fig. 2 by association of higher number of vehicles to these ONUs compared to other ONUs. Based on the aggregated throughput of the ONUs, the wavelength allocation by the OLT is done. Wavelength allocations using both conventional first-fit bin packing and proposed bin packing algorithms is described in detail in Section III.

III. Wavelength allocation Algorithms

In this section we present the conventional first-fit bin packing algorithm [7] and the proposed hybrid bin packing algorithm.

1) First-fit Bin Packing Algorithm: Considering the number of wavelengths to be allocated to the ONUs be N_W, i.e., we have N_W bins, where the height of each bin $(B_i; i \in [0, N_W])$ represents the normalized capacity of each wavelength. Let, the total number of ONUs in the network be N_{ONU} and each ONU has a load size of L_n, where $n \in [1, N_{\text{ONU}}]$. In conventional first-fit bin packing, after sorting all the loads at ONUs in descending order, the normalized capacity of bins (B_i) is computed. The wavelength assignment for each ONU is then done based on Algorithm 1. According to Algorithm 1, initially, the loads at different ONUs are sorted in descending order. At each hour, wavelength of the ONU is switched based on the load of the ONU. Thus, the algorithm is dynamic in nature. Moreover, the dynamic nature of the algorithm, i.e., the hourly switching also contributes to an increase in tuning

Algorithm 1 First-fit bin packing algorithm

Input:
Total number of Loads: L_T
Load size of n^{th} ONU (ONU$_n$): L_n
Total number of ONUs in the network: N_{ONU}
Normalized capacity of wavelength bin, j = B_j
Number of wavelengths to be allocated to the ONUs: N_W
Assumption:
Let the load of ONU$_1$ $>$ ONU$_2$ $>$ ONU$_3$ $>$ ... $>$ ONU$_{N_{\text{ONU}}}$, i.e., $L_1 > L_2 > L_3 > \ldots > L_{N_{\text{ONU}}}$

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for j = 1 to N_W do
    for m = L_1 to L_{N_ONU} do
        if (B_j ≥ L_m) then
            Assign B_j to L_m
            B_j=B_j- L_m
        end if
    end for
end for
```

delay of the ONU. The complexity of the Algorithm 1 is $\mathcal{O}(N_W \times N_{ONU})$, where $\mathcal{O}$ is the Big-O notation.

2) Proposed hybrid bin packing algorithm: In the first-fit bin packing, all loads were fitted into the bins dynamically. As mentioned earlier, the dynamic wavelength allocation increases the delay of the network, therefore in order to reduce the wavelength switching, we propose a hybrid wavelength allocation algorithm. The wavelength is allocated such that the largest N_W loads are allocated to N_W separate bins, or in other words, the ONUs with the highest throughput are allocated N_W different fixed wavelength bins. The heavily loaded ONUs are chosen based on the 24×7 load at the ONUs, i.e., the ONUs where the traffic congestion is high are considered as heavily loaded. In order to obtain the minimum number of switches in the whole system, we fix the ONU with the largest load at fixed wavelengths and then dynamically allocate wavelengths to the rest of the ONUs as shown in Algorithm 2. It is evident that the proposed algorithm uses static and dynamic wavelength allocation algorithms and hence, is hybrid in nature. The complexity of the Algorithm 2 is $\mathcal{O}(N_W + N_W \times (N_{ONU} - N_W)) = \mathcal{O}(N_W N_{ONU} - N_W^2 + N_W))$. As, $N_W > 0$, thus the complexity of the proposed bin-packing algorithm is lesser that the first-fit bin packing algorithm.

Algorithm 2 Proposed bin packing algorithm

Input:
Total number of Loads: L_T
Load size of n^{th} ONU (ONU$_n$): L_n
Total number of ONUs in the network: N_{ONU}
Normalized capacity of wavelength bin, j = B_j
Number of wavelengths to be allocated to the ONUs: N_W
Assumption:
Let the {load of ONU$_1$, ONU$_2$, ..., ONU$_{N_W}$} > load of other ONUs , i.e., $\{L_1, L_2, ..., L_{N_W}\} > \{L_{N_{\text{ONU}}-N_W}, L_{N_{\text{ONU}}-N_W+1}, L_{N_{\text{ONU}}-N_W+2}, ..., L_{N_{\text{ONU}}}\}$

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Place L_1 in B_1, L_2 in B_2, ..., L_{N_W} in B_{N_W}.
Sort the remaining loads in descending order.
Update the heights of each bin:
for j = 1 : N_W do
    B_j = B_j − L_j
end for
for j = 1 to N_W do
    for m = L_{N_W} to L_{N_ONU} do
        if (B_j ≥ L_m) then
            Assign B_j to L_m
            B_j = B_j - L_m
        end if
    end for
end for
```

Consider the following example as shown in Fig. 3, where eight loads need to be fitted into three bins. In our case, three bins represent three wavelengths to be allocated to the ONUs. Let the eight ONU loads be: $L_1 = 0.45$, $L_2 = 0.4$, $L_3 = 0.5$, $L_4 = 0.25$, $L_5 = 0.1$, $L_6 = 0.2$, $L_7 = 0.15$ and $L_8 = 0.3$. The first step is to place the first three loads which are the largest in the three separate bins, i.e., $L_1 \rightarrow B_1, L_2 \rightarrow B_2$ and $L_3 \rightarrow B_3$. Now, sort the rest of the loads in descending order as $L_8 > L_4 > L_6 > L_7 > L_5$ and first compare them with the height of the first bin (B_1). Updated height of the first bin after placing the first load will be 0.55. As $L_8 = 0.3 < 0.55$ hence, L_8 it will also be placed in the B_1. After computing the updated height, compare the next largest load which is L_4, with the updated height of the bin B_1. As the value of L_4 is same as the updated height of the B_1, place it in B_1 and update the height of the bin B_1 as $0.25 - 0.25 = 0$. Now the next largest load, L_6 will be compared with the height of the next bin which is B_2. Similarly, the remaining bins will be packed with loads as was done for B_1. The wavelength allocation for the above example has been shown Fig. 4.

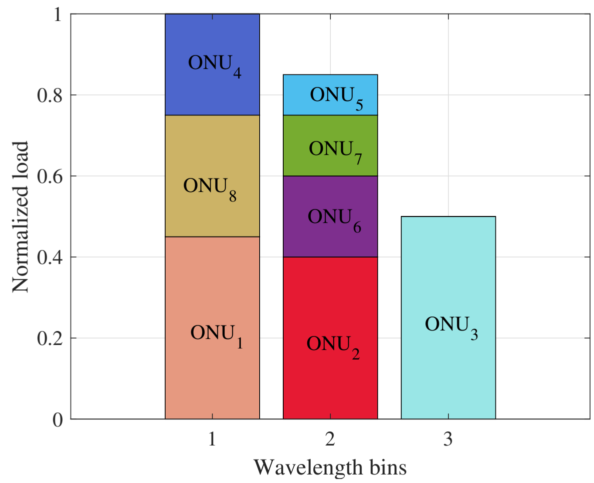


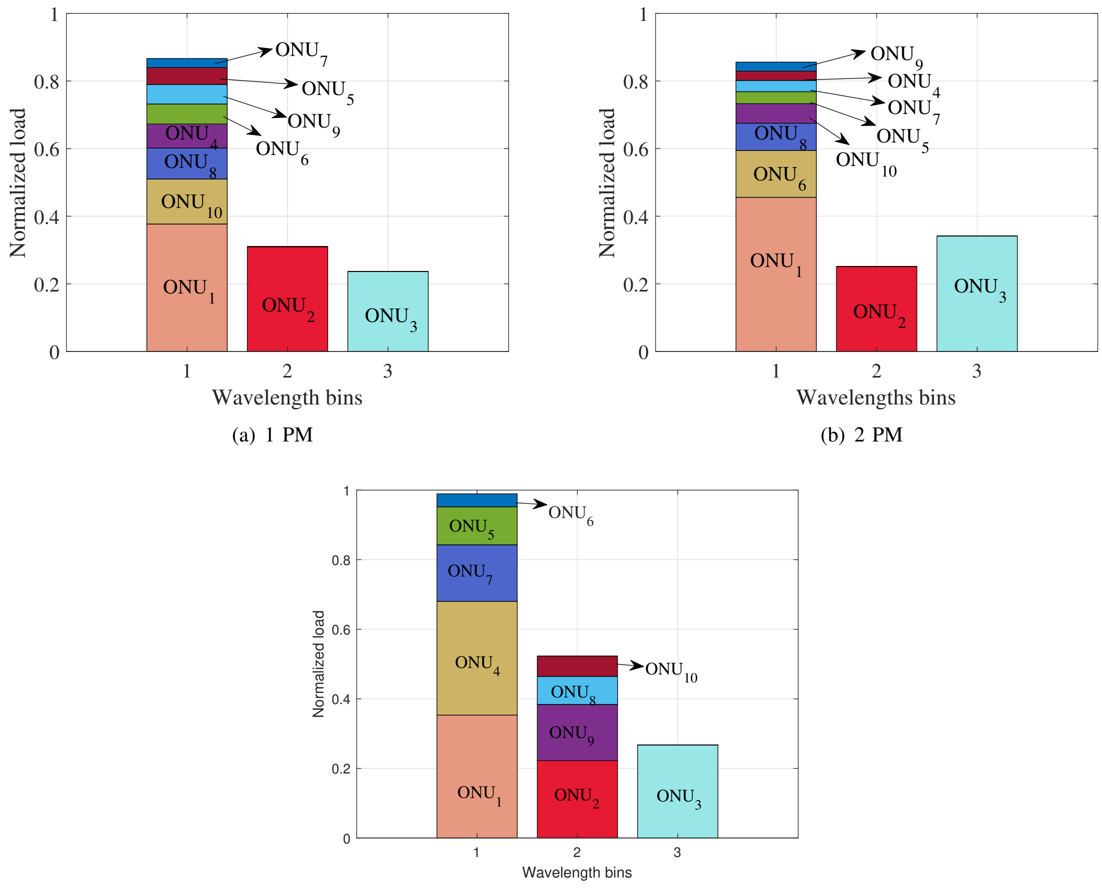
Fig. 4. Wavelength Allocation using proposed bin packing

TABLE I
PARAMETERS FOR SIMULATION [13]

Parameter	Definition	Value
$D_{o,s}$	OLT-splitter distance	2.2 km
$D_{s,ONU}$	Splitter-ONU distance	2 km
t_{FiWi}	Constraint on e2e FiWi network delay	10 ms
t_T	Transport delay/Propagation delay	5 μs
t_Q	Queueing delay at ONUs	60 μs
t_P	Processing delay at OLT	200 μs
t_{maxonu}	Max delay from each ONU to OLT achieved	0.31 ms

IV. SIMULATION ENVIRONMENT

For the simulation of FiWi assisted V2I network, we have considered a 1000 m $\times$ 15 m segment of IS-94 highway. The same has been simulated in MATLAB R2020b where an area of 1000×15 units on a cartesian plane is used to represent the highway segment in consideration. Each unit represents one meter of the distance on the highway. The ten ONUs, which are considered to be placed on the roadside are represented on the cartesian plane by the points (50,15), (150, 15), (250, 15), (350, 15), (450, 15), (550, 15), (650, 15), (750, 15), (850, 15) and (950, 15). The positions of the vehicles for each hour is randomly determined, with more vehicles around the points which represent the first three ONUs, i.e., (50, 15), (150, 15) and (250, 15). The hourly traffic data from



(a) 1 PM

(b) 2 PM

(c) 3 PM

the Minnesota Department of Transportation (MnDOT) dataset determines the vehicles in the considered area per hour [12]. We consider an upstream traffic flow, where the RSUs are collocated with tunable ONUs. The tunable ONUs have the capability to switch between N_W wavelengths available to each ONU. The parameters for simulation are summarized in Table I which are taken considering the same network architecture for the placement of various optical transmission nodes such as splitter and the ONUs as in [13]. The delay at nth ONU in 12 hours is calculated as [14]:

$$\begin{aligned} d_{\mathrm{ONU}_n} &= \sum_{t=1}^{12} d_{\mathrm{ONU}(t)_n} \\ &= \sum_{t=1}^{12} (T_{overhead} + T_{tuning}(t))//(1 - \Lambda_{\mathrm{ONU}(t)_n}) \end{aligned} \quad (1)$$

where $T_{overhead}$ is the delay due to overheads at the ONU, T_{tuning} is the tuning time from one wavelength to the next. $T_{tuning}(t) = 0$ if there is no wavelength switching at the hour t, else $T_{tuning}(t) = 50\ \mu s$ [14] and $\Lambda_{\mathrm{ONU}(t)_n}$ is the normalized load of ONU$_n$ on a wavelength at time t. The overhead delay are taken as 16 μs [14].

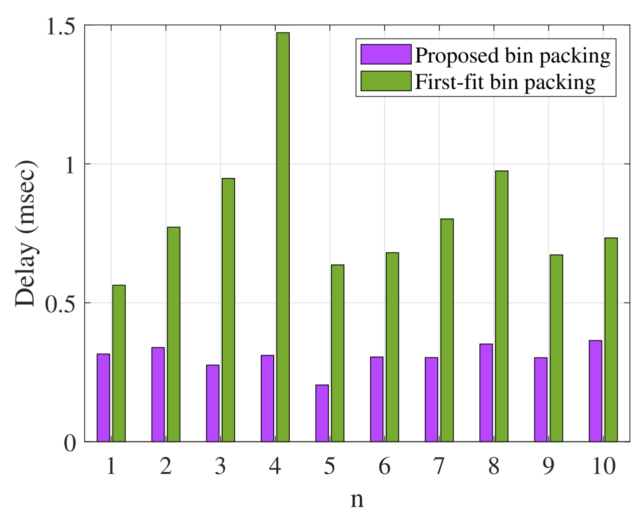


Fig. 5. Delay at ONU$_n$ after switching minimization

The e2e delay for the optical link, i.e., between ONU and OLT at the n^{th} ONU (ONU$_n$) is calculated as [13]:

$$d_{e2e_n} = d_{\mathrm{ONU}_n} + t_T(D_{o,s} + D_{s,ONU}) + t_Q + t_P \quad (2)$$

TABLE II
WAVELENGTH ALLOCATION AT DIFFERENT ONUS FROM 12 NOON TO 5 PM

First-fit bin packing algorithm										
Time	ONU_1	ONU_2	ONU_3	ONU_4	ONU_5	ONU_6	ONU_7	ONU_8	ONU_9	ONU_{10}
9 AM	λ_1	λ_2	λ_2	λ_2	λ_3	λ_2	λ_3	λ_2	λ_2	λ_1
10 AM	λ_1	λ_1	λ_1	λ_2	λ_1	λ_2	λ_2	λ_1	λ_2	λ_2
11 AM	λ_1	λ_1	λ_2	λ_1	λ_2	λ_1	λ_2	λ_2	λ_1	λ_1
12 noon	λ_1	λ_2	λ_2	λ_1	λ_1	λ_2	λ_2	λ_2	λ_2	λ_1
1 PM	λ_1	λ_2	λ_1	λ_2	λ_1	λ_1	λ_2	λ_1	λ_2	λ_1
2 PM	λ_2	λ_3	λ_3	λ_2	λ_3	λ_1	λ_1	λ_2	λ_2	λ_1
3 PM	λ_2	λ_1	λ_2	λ_1	λ_2	λ_3	λ_2	λ_2	λ_3	λ_3
4 PM	λ_3	λ_3	λ_3	λ_3	λ_1	λ_3	λ_2	λ_3	λ_2	λ_1
5 PM	λ_2	λ_3	λ_1	λ_2	λ_2	λ_2	λ_3	λ_3	λ_1	λ_3
6 PM	λ_1	λ_1	λ_2	λ_1	λ_2	λ_2	λ_1	λ_1	λ_2	λ_1
7 PM	λ_2	λ_1	λ_1	λ_1	λ_1	λ_1	λ_1	λ_1	λ_1	λ_1
8 PM	λ_1	λ_2	λ_1	λ_2	λ_2	λ_2	λ_2	λ_2	λ_1	λ_1
Total switches	6	7	8	8	8	9	8	7	8	9

Proposed hybrid bin packing algorithm										
Time	ONU_1	ONU_2	ONU_3	ONU_4	ONU_5	ONU_6	ONU_7	ONU_8	ONU_9	ONU_{10}
9 AM	λ_1	λ_2	λ_3	λ_2	λ_1	λ_1	λ_2	λ_1	λ_1	λ_1
10 AM	λ_1	λ_2	λ_3	λ_2	λ_1	λ_1	λ_2	λ_1	λ_1	λ_1
11 AM	λ_1	λ_2	λ_3	λ_2	λ_1	λ_1	λ_2	λ_1	λ_1	λ_1
12 noon	λ_1	λ_2	λ_3	λ_1	λ_1	λ_1	λ_1	λ_1	λ_1	λ_1
1 PM	λ_1	λ_2	λ_3	λ_1	λ_1	λ_1	λ_1	λ_1	λ_1	λ_1
2 PM	λ_1	λ_2	λ_3	λ_1	λ_1	λ_1	λ_1	λ_1	λ_1	λ_1
3 PM	λ_1	λ_2	λ_3	λ_1	λ_1	λ_1	λ_1	λ_2	λ_2	λ_2
4 PM	λ_1	λ_2	λ_3	λ_1	λ_2	λ_2	λ_2	λ_3	λ_2	λ_1
5 PM	λ_1	λ_2	λ_3	λ_2	λ_2	λ_2	λ_2	λ_3	λ_1	λ_3
6 PM	λ_1	λ_2	λ_3	λ_2	λ_2	λ_2	λ_2	λ_2	λ_1	λ_3
7 PM	λ_1	λ_2	λ_3	λ_2	λ_2	λ_2	λ_2	λ_3	λ_1	λ_3
8 PM	λ_1	λ_2	λ_3	λ_2	λ_2	λ_2	λ_2	λ_3	λ_1	λ_3
Total switches	0	0	0	2	1	1	2	4	2	3

where $d_{\mathrm{ONU}n}$ is calculated from (1) and t_T, t_Q, t_P, $D_{o,s}$, and $D_{s,ONU}$ are propagation delay, queueing delay, processing delay, OLT-splitter distance, and splitter-ONU distance, respectively, as mentioned in Table I.

V. RESULTS

In this section, the performance of the proposed bin packing algorithm is evaluated and compared to the performance of the conventional algorithm for a kilometer of the IS-94 highway between Minneapolis and St. Paul. For a system of ten ONUs, the wavelength allocation for different ONUs is evaluated for 12 hours, i.e., from 9 AM to 8 PM. For simulations, we consider $N_W = 3$ wavelength bins. We consider a total of 10 ONUs in the network, i.e., $N_{\mathrm{ONU}} = 10$. An hourly analysis of bin packing algorithm is discussed where the wavelength assignment for each ONU is done at hourly basis. The wavelength allocation using proposed bin packing algorithm for different ONUs from 1 PM to 3 PM is shown in Fig. III-2.

It is evident that for all the three hours, the first wavelength bin (B_1) is occupied more compared to the other bins. This is because according to the proposed bin packing algorithm the wavelength assignment is dynamic after the first three allocations. Further, it can be seen that ONU_1, ONU_2, and ONU_3 have static wavelength allocation and therefore, occupy wavelength bins B_1, B_2, and B_3, respectively at all the hours. For the other ONUs the wavelength bins are assigned dynamically based on their load. This hybrid (static as well as dynamic) allocation of wavelength by the proposed algorithm ensures zero switching for at least three ONUs with highest throughput and reduces the switching of wavelengths at the rest of the ONUs. The hourly wavelength switching at each

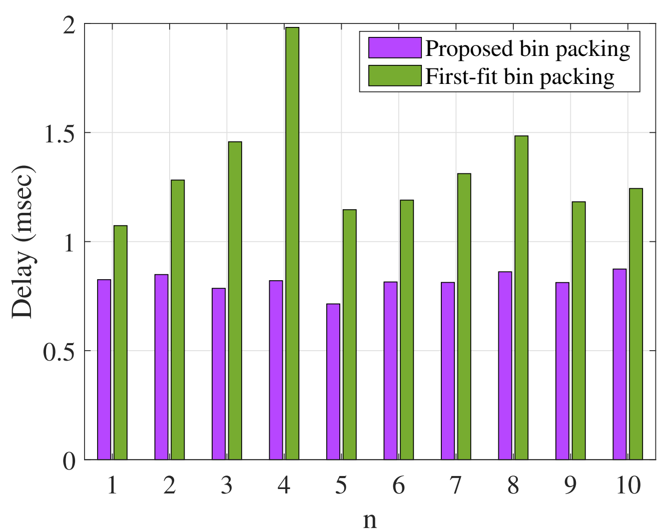


Fig. 6. E2E delay for optical network at ONU_n

ONU is summarized in Table II. In Table II, we compare the number of wavelength switches by using the two algorithms i.e., conventional bin packing algorithm and the proposed hybrid bin packing algorithm. As the time delay at each ONU depends on the time taken to switch from one wavelength to another, hence, lesser number of wavelength switches are desired for reduction in the delay. Table II summarizes the hourly switching of wavelengths at the ten ONUs for a period of twelve hours. It can be observed that using the conventional bin packing algorithm, the wavelength at ONU_1 switches six times from 9 AM to 8 PM, but using the proposed hybrid bin packing algorithm, the number of wavelength switches during the same period of time is reduced to zero. Similarly for ONU_2 and ONU_3, the number of wavelength switches are reduced from seven and eight switches, respectively, in twelve hours using the conventional algorithm to zero switches in twelve hours using the proposed algorithm. Similarly, for ONU_5, the number of wavelength switches reduces from eight switches to one switch in twelve hours using the proposed hybrid bin packing algorithm. Similarly, the number of wavelength switches at all other ONUs are also reduced. Furthermore, it can be observed that the proposed hybrid bin packing algorithm reduces the wavelength switching at ONUs from an average of eight switches per ONU to an average of two switches per ONU over a twelve hours duration. This reduction in number of wavelength switches has led to a reduction in time delay at the ONUs as shown in Fig. 5.

From Fig. 5 it can be observed that the delay for the 4^{th} (ONU_4) is 1.5 msec, which is the highest for first-fit bin packing. If we use the proposed bin packing algorithm, the delay for ONU_4 reduces to 0.2 msec. Moreover, it can be observed that the average delay for all the ONUs using first-fit bin packing is 1.05 msec, while for proposed bin packing algorithm the average delay is 0.275 msec. The maximum delay at an ONU is reduced from 1.5 msec to 0.6 msec and the minimum delay has reduced from 0.35 msec to 0.2 msec using our proposed approach as compared to the first-fit bin packing algorithm.

The e2e delay for optical network is shown in Fig. 6. It can be observed that using first-fit bin packing the e2e optical delay for ONU_4 is the highest. With the use of proposed bin packing algorithm, the delay for ONU_4 reduces by 1.25 msec. Further, a significant reduction in e2e optical delay is observed from a maximum of 1.98 msec to 0.87 msec and from a minimum of 1.1 msec to 0.71 msec. Further, the average e2e optical delay is reduced from 1.335 msec to 0.802 msec per ONU using proposed hybrid bin packing algorithm as compared to first fit bin packing. This reduction in delay is very significant for delay sensitive vehicular applications such as cooperative sensing and cooperative maneuvers that requires an end-to-end delay of less than 3 msec [10].

VI. Conclusion

A hybrid bin packing algorithm to facilitate the wavelength allocation of ONUs for a FiWi based V2I network is proposed. The proposed algorithm has been shown to minimize the number of wavelength switches at each ONU. It also has been shown that the proposed algorithm reduces the delay of the optical backend of a FiWi network. This FiWi network considered for V2I communication provides a strong optical backhaul in terms of latency and high capacity. An hourly vehicular traffic is considered and it is able to achieve reduction in the number of wavelength switches per ONU from 8 to 2 switches in 12 hours. The reduction in number of wavelength switches at each ONU in turn reduces the ONU delay by 81% and hence the end-to-end delay of the whole optical fiber link by 40%. In future, we plan to extend this work by incorporating deep learning techniques to predict the dynamic nature of vehicular traffic.

References

[1] M. Shawki and M. S. Darweesh, "Collision probability computation for road intersections based on vehicle to infrastructure communication," in *2020 32nd International Conference on Microelectronics (ICM)*, 2020, pp. 1–4.

[2] J. Zhang, H. Guo, J. Liu, and Y. Zhang, "Task offloading in vehicular edge computing networks: A load-balancing solution," *IEEE Transactions on Vehicular Technology*, vol. 69, no. 2, pp. 2092–2104, 2020.

[3] C. Huegel Richa and A. A. Fröhlich, "Low-latency secure roaming in V2I networks," in *2018 VIII Brazilian Symposium on Computing Systems Engineering (SBESC)*, 2018, pp. 31–37.

[4] E. Okamoto, H. Okada, Y. Ishii, and S. Makido, "Performance improvement of low-latency V2I uplink using superposed cooperative V2V transmission," in *2017 IEEE 86th Vehicular Technology Conference (VTC-Fall)*, 2017, pp. 1–5.

[5] T. Zhang, Y. Xu, S. Wang, M. Wen, and R. Wang, "On secure degrees of freedom of the MIMO interference channel with local output feedback," *IEEE Internet of Things Journal*, vol. 8, no. 20, pp. 15 334–15 348, 2021.

[6] M. Zhang, J. Zhang, X. Tang, and Y. Tang, "Wireless resource pre-allocation for cellular V2I low-latency communications," in *2020 IEEE 91st Vehicular Technology Conference (VTC2020-Spring)*, 2020, pp. 1–5.

[7] S. Garg and A. Dixit, "Novel dynamic bandwidth and wavelength allocation algorithm for energy efficiency in TWDM-PON," in *2019 21st International Conference on Transparent Optical Networks (ICTON)*, 2019, pp. 1–4.

[8] "ITU-T PON standards - progress and recent activities," 2020. [Online]. Available: https://www.itu.int/en/ITU-T/studygroups/2017-2020/15/Documents/OFC2018-2-Q2_v5.pdf

[9] S. Garg and A. Dixit, "Models for evaluating power saving techniques in flexible optical access networks," in *2018 20th International Conference on Transparent Optical Networks (ICTON)*, 2018, pp. 1–4.

[10] M. Boban, A. Kousaridas, K. Manolakis, J. Eichinger, and W. Xu, "Connected roads of the future: Use cases, requirements, and design considerations for vehicle-to-everything communications," *IEEE Vehicular Technology Magazine*, vol. 13, no. 3, pp. 110–123, 2018.

[11] R. Kaur, A. Gupta, A. Srivastava, B. C. Chatterjee, A. Mitra, B. Ramamurthy, and V. A. Bohara, "Resource allocation and QoS guarantees for real world IP traffic in integrated XG-PON and IEEE802.11e EDCA networks," *IEEE Access*, vol. 8, pp. 124 883–124 893, 2020.

[12] "Metro interstate traffic volume data set," 2018. [Online]. Available: https://archive.ics.uci.edu/ml/datasets/Metro+Interstate+Traffic+Volumel

[13] Y. Yu, C. Ranaweera, C. Lim, L. Guo, Y. Liu, A. Nirmalathas, and E. Wong, "Hybrid fiber-wireless network: an optimization framework for survivable deployment," *IEEE/OSA Journal of Optical Communications and Networking*, vol. 9, no. 6, pp. 466–478, 2017.

[14] A. Dixit, B. Lannoo, D. Colle, M. Pickavet, and P. Demeester, "Dynamic bandwidth allocation with optimal wavelength switching in TWDM-PONs," in *2013 15th International Conference on Transparent Optical Networks (ICTON)*, 2013, pp. 1–4.