

# An Energy Efficient Resource Provisioning Scheme For Joint all Photonic and Wireless Networks

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**Abstract**—Flexible joint all photonic and wireless transport networks are a promising backbone network technological solution to accommodate the various dynamic bandwidth nated applications. In this paper, we mitigate methods aimed at maximizing available resources in a joint-photonic and wireless transport network in an energy-efficient manner. In so doing, we take into account challenges posed by transmission impairments as they tend to degrade signals and reduce their optical reach. We thus propose a state-of-the-art and innovative network architecture that can efficiently process a large amount of data. This architecture is designed to cater for bandwidth-hungry and bandwidth-dynamic applications and services. We further propose a load aware energy efficient resource optimization scheme using LERA algorithm, which couples with related service reconfiguration functions to maximize higher spectral efficiencies and minimal blocking in both optical and wireless sections of the composite network. Performance analysis shows that the proposed architectural scheme based on the LERA algorithm outperforms traditional benchmark techniques in achieving minimal blocking while efficiently maximizing spectral utilization compared to legacy benchmark approaches. Hence this scheme drastically enhances the utilization of the available resources and the overall network throughput.

**Keywords**— joint all photonic, wireless network, throughput, optimized allocation, LERA algorithm, energy efficiency.

## I. INTRODUCTION

The global increase in power consumption in telecommunication networks and the increase in bandwidth-hungry and bandwidth dynamic applications and services has motivated a variety of technologies to be implemented to help alleviate power consumption in telecommunication networks. Current (and future) telecommunication networks are mainly segregated into two domains: optical and wireless access networks [1]. As a result, there is a need for a network architecture flexible enough to cater for ultra-high-speed, massive-capacity, low-delay optical multicast on-demand to provide high-presence and real-time video-distribution services such as 4k and 8k pixels, and further provide guaranteed and secure feedback path with low jitter for mission-critical remote-monitoring and control services in various usage such as e-health, autonomous vehicles, and factory control systems [2]. Therefore, this can be achieved via wireless access terminals with a flexible optical backbone core network. Flexible optical transport networks have gained unprecedented development and are considered the most

efficient in terms of resource allocation and energy efficiency. These optical architectures are flexible because they allow for flexible bandwidth transmission by introducing a variable number of orthogonal subcarriers occupying a bandwidth equivalent to the suitable subcarrier frequency slot [3][4]. Flexibility is introduced by using bandwidth variable transponders (BVTs) and bandwidth variable optical cross connects (BV-OXCs) to support mixed line rates as illustrated in Fig. 1.

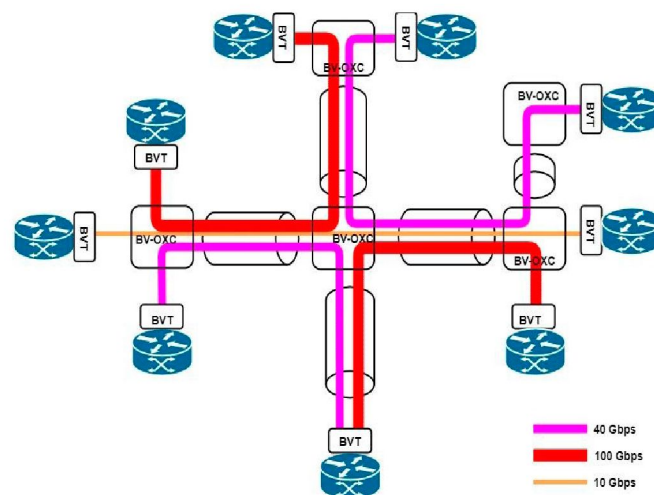


Fig. 1 Flexible optical path network

Emerging technologies such as Software Defined Networking (SDN) and Network Functions Virtualization (NFV) are also considered the favorable solution to provide flexible control on the backbone network by the demarcation of the control plane from the data plane. On the optical network layer, NFV and SDN are revolutionizing the way network resources are managed. Basically, SDN is a paradigm that aims to simplify routing issues in core networks by way of abstracting their intelligence into a centralized SDN controller as a control entity [5], which implies that SDN is more of a communication resources manager. On the other hand, NFV is more of a computational resources manager including the CPU and memory. Essentially this means NFV migrates traditional legacy physical functions from dedicated hardware devices toward software applications referred to as Virtualized Network Functions (VNFs) which can run on general commodity servers. Consequently, reducing OPEX and CAPEX

further plays a significant role in energy efficiency. Moreover, the implementation of SDN and NFV on a backbone network can result in having logically centralized and intelligent management of the entire network. Finally, the centralization approach introduced by SDN promises to utilize network resources and improve network throughput efficiently.

In the wireless network section, densification seems to be a promising solution for a capacity increase to support a higher data rate. Densification is the proliferation of small cell deployment to increase network capacity. Therefore, wireless transport network architectures also require restructuring for them to provide high bandwidth support capacities. Bandwidth enhancements in the wireless sections can be achieved by densifying cells. Furthermore, the communication should provide wireless end-to-end (E2E) access between users for a variety of services. Several approaches have been discussed in the literature to improve data rates transmission on wireless networks efficiently. The Heterogeneous Cloud Radio Access Network (HCRAN) is the most promising approach. HCRAN refers to the concept of consolidating all data at one point from different densified cells or base stations, in a more detailed manner HCRAN can be viewed as a wireless network architecture in which the baseband resources (which were traditionally located at the base station site) are now pooled to a centralized location so that they can be shared between neighboring base stations as illustrated in Fig. 2, consequently improving the provisioning of resources in the network and helps to minimize energy consumption.

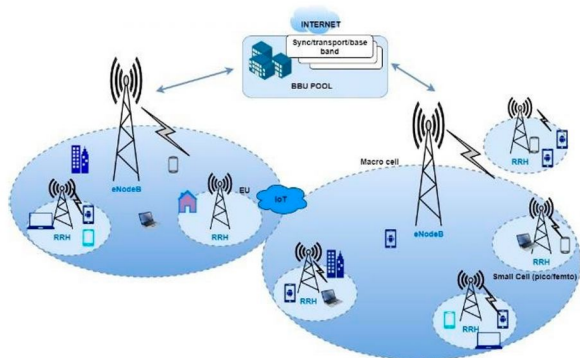


Fig. 2 HCRAN architecture

The advances and strides made by flexible optical transport network, SDN and NFV, as well as HCRAN wireless transport network have emerged an innovative state-of-the-art optical and wireless network approach which comprises of an all-photonic network together with the wireless access network. The joint All-Photonic and Wireless Network (APWN) can be viewed as a highly improved network technique that can efficiently process a large amount of data incomparable with the internet [2]. The main objective of this paper herein would be to consider an architecture-of-architecture for future network operation, which includes high-capacity transmission in the optical/photonic backbone core network as well as dense deployment of cells in the wireless access network. This state-of-the-art architecture-of-architecture would be designed based on energy-efficient operation and resource allocation to achieve a highly improved resources provisioning scheme for a holistic network operation.

The next sections are organized as follows: Section II discusses the previous literature on the related works, Section III proposes and describes a joint all-photonic and wireless network architecture, and section IV describes a load-aware

energy-efficient resources provisioning scheme for an all-photonic and wireless transport network, Section V shows the performance evaluation of the proposed energy-efficient resources provisioning scheme for a joint the all-photonic and wireless network, and finally Section VI concludes the paper.

## II. RELATED WORKS

In [5], the authors examined and proposed a novel approach to efficiently allocate both optical and wireless resources in an SDN/NFV-based combined network architecture. Their approach was more based on slicing the converged network into isolated network slices that can perform and serve different functions. Their approach also employed software-defined networking (SDN) and network functions virtualization (NFV) to create a system model architecture for both wireless and optical networks. This approach proved to be energy efficient while also improving the allocation of resources in the sense that a network slice will only be assigned an adequate number of channels. Furthermore, the network slices were constantly checked in real-time to re-assign new channels if necessary. Hence, it was concluded that a larger number of channels implied a more efficient resource allocation in the overall network. However, their approach was more based on SDN, NFV, and network slicing on an optical-wireless network, the authors did not consider the various dynamic bandwidth-natured applications and services for current and future networks. The authors at [8], proposed an efficient resource provisioning approach for multi-domain optical networks through traffic balancing, they proposed a time-aware routing and wavelength assignment (TA-RWA) algorithm with different policies. This approach looked at time intervals during the day and managed to balance the load throughout the entire day. The authors here proposed a novel approach of adopting three solutions or policies to improve the overall network performance by evenly distributing the load traffic during different time intervals of the day. The observation of the results proved that their proposed policies when used with the TA-RWA outperform the standalone TA-RWA strategy and other existing strategies in terms of improved QoS and improved resource utilization. What can be observed from this approach is that the authors only considered improving the network operation and load balancing only in the optical network and neglected the wireless network. Moreover, the authors at [1], provided an experimental approach to observe the convergence behavior between the optical and wireless networks for 5G networks. This approach provided detailed information from the conducted experiments about the convergence of optical and wireless networks. They discussed the main advantages of incorporating advanced technologies such as SDN/NFV, cloud computing and radio-over-fiber (RoF) into networks such as 5G and beyond. According to their experiments, it showed that adopting these technologies can be highly advantageous for heterogeneous networks such as 5G, because the adoption of SDN results in improved network control, while RoF technology resulted in improved throughput and proved to be suitable for the Internet of things (IoT) data transmissions. Again, this approach was based on showing the advantages of SDN as well NFV in future optical and wireless networks. The authors at [9], leveraged cloud computing technologies using a cloud radio access network (CRAN) to improve on the management of resources in a network. The authors here investigated the energy efficiency as well as the on-demand resource provisioning in CRAN, and their approach was based on using virtualized baseband unit (vBBU) in the cloud infrastructures and assigning those

vBBUs to each radio remote head (RRH) group as well as adopting cooperative beamforming in the RRH. They further proposed an energy-efficient on-demand CRAN virtualization (REACT) algorithm, which leveraged on RRH selection, beamforming, and vBBU provisioning to minimize power consumption while maximizing resource allocation. The resulting performance of their proposed algorithm was observed through simulation which proved that the REACT algorithm greatly reduces the power consumption of the CRAN. While this approach is a promising technique, it does not consider efficiency and resource allocation in the backbone core network. Finally, the authors at [10], looked at NFV in a converged optical and wireless network, they proposed a platform that is based on NFV together with SDN to create an elastic optical and wireless architecture for diverse requirements in telecommunication systems. The proposed platform proved to be superior because it allows for virtualized management of resources which is achieved through fine-grained frequency allocation in the optical and wireless network. Additionally, parameters such as QoS, switching, and data flows are dynamically controlled by the centralized controller which results in an improved and flexible infrastructure utilization as well as an improved quality of transmission. Therefore, in our approach which is motivated by all the shortcomings in literature, we then propose methods that aim to maximize the available resources in a joint photonic and wireless transport network for bandwidth-hungry and bandwidth dynamic services and applications.

### III. A JOINT ALL PHOTONICS AND WIRELESS NETWORK ARCHITECTURE

The combination of flexible optical and densified wireless access networks emerges a network architecture which is an infrastructure-of-infrastructure referred to as a joint All-Photonic Wireless Network architecture. This architecture can serve various types of services such as ultra-high-speed, massive-capacity data transfer services for mobile network backhaul and fronthaul, low jitter mission-critical and high precision services for remote hospital operations, and real-time-high-capacity video distribution services for remote conference meeting and events.

This architecture comprises a flexible mobile convergence core (flexible optical path network) which is made up of optical full mesh topology. The wireless section is made up of a densified cell deployment arranged in a CRAN approach, additionally what gives this architecture an urge over legacy approaches is the use of Radio-over-Fiber (RoF) between wireless nodes and processing units.

Furthermore, to leverage on the advantages of SDN and NFV, the architecture has a multi-orchestrator that functions as a network resource manager or as the overall intelligence of the network as illustrated in Fig. 3. This approach of using a centralized multi-orchestrator improves the network control, manageability, and flexibility while it also promises to reduce power consumption. This architecture promises to provide and serve multiple services, therefore with so many services to accommodate in the same network, the network is further broken down into network slices or Function Dedicated Networks (FDN). FDN can be viewed as a technique for running a logically isolated network based on its function or service type. FDN comprises three transmission services, namely, digital-to-optical transmission, analog-to-optical transmission, and packet framed data-to-optical transmission. This is because in a joint APWN, it is expected that all services

with different network requirements must be able to coexist in the same network, therefore the FDN approach is essential to meet this goal of coexistence in the same network. To further elaborate, packet framed data-to-optical transmissions will be used in data center connections, while digital-to-optical transmissions will be used for services such as real-time-high-presence video distribution, and finally analog-to-optical transmissions will be used for services such as analog RoF.

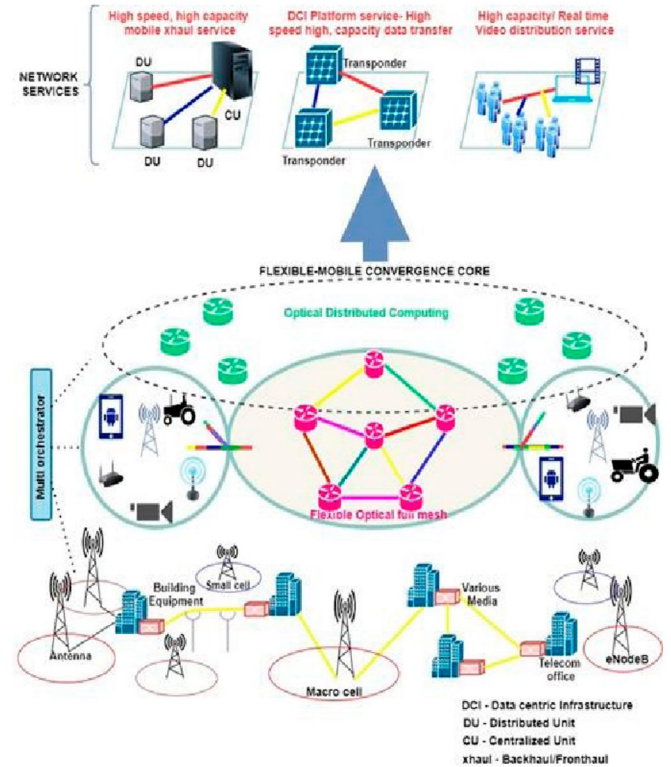


Fig. 3 A joint APWN architecture

The multi-orchestrator comprises of FDN controllers, namely, wireless controller, data centric infrastructure controller, function management controller, and transport resource switching. An FDN model architecture is represented in Fig. 4.

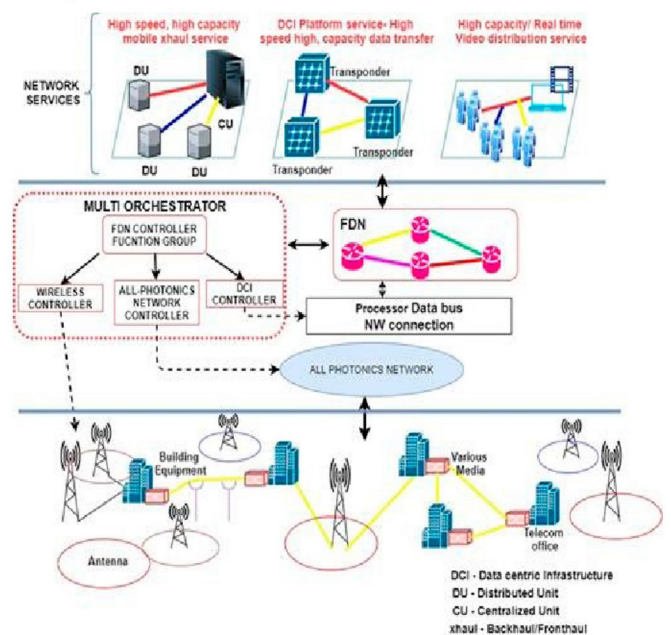


Fig. 4 FDN model architecture

#### IV. LOAD-AWARE ENERGY EFFICIENT RESOURCE OPTIMIZATION FOR A JOINT ALL PHOTONIC AND WIRELESS NETWORK

##### A. Traffic Load Variation

In general, network traffic loads vary according to the time of the day. Hence, peak traffic loads occur during office hours. Therefore, it can be concluded that network resources are underutilized during non-peak hours and over-utilized during peak hours. Consequently, appropriate network resource dimensioning, considering the traffic load variations, is necessary to improve network performance.

##### B. Load-aware energy efficient resources provisioning in a joint all Photonics and wireless network.

Optical networks suffer from linear impairments such as power loss and chromatic dispersion, but this is compensated using EDFA amplifiers and other techniques, on the other hand non-linear impairments such as cross phase modulation and four-wave mixing are difficult to mitigate [6]. We estimate non-linear impairments based on the Gaussian noise model to improve network performance. We further present 5 loading states (LS) of a link represented by 20%, 40%, 60%, 80%, and 100% which is calculated using Gaussian noise model. Therefore, for flexible optical networks we propose a Load-aware Efficient Resources Allocation (LERA) algorithm to support flexible channel allocation and cater for dynamic bandwidth requests.

The LERA algorithm is based on finding k-least congested paths and First-Fit (FF) assignment. To work out the congested weight ( $W$ ) on a link path  $l$ , we use equation (1).

$$W_l = \frac{N_{sp,l}}{1 - \frac{SS_{o,l}}{SS_l}} \quad (1)$$

Where  $N_{sp,l}$  is the number of fiber span of link  $l$ ,  $SS_{o,l}$  is the total number of occupied spectrum slots on a link  $l$ , and  $SS_l$  is the sum of all spectrum slots on link  $l$ .

From source  $s$  to destination  $d$ , it is assumed that each service request  $R$  comprise of traffic demand  $z$  bps. The state of the network ( $S_N$ ) is based on 3 variables for computation, the loading state ( $LS$ ), congestion weight ( $W_l$ ), and spectrum availability of each link on a network. The LERA algorithm is called for each new request  $R_i$ , then k-least congested paths between source  $s_i$  and destination  $d_i$  is evaluated based on the current network state  $S_N$ , and for each evaluated path  $P_k$  the  $SNR_k$  is computed using equation (2). Based on the  $SNR_k$  and the  $LS$ , a suitable modulation format  $MF_k$  is selected, and finally the first available spectrum resource ( $SR_{k,i}$ ) on the evaluated links of the path is assigned to the request.

$$SNR_{RX} = \frac{P_{ch}}{P_{ASE} + P_{NL}} \quad (2)$$

Where  $P_{ch}$  represents the channel power,  $P_{ASE}$  is the amplified spontaneous noise power, and  $P_{NL}$  is the non-linear impairment power of the channel.

To simplify on future requests, the cost of each candidate path is calculated using equation (3).

$$Cost_{k,i} = N_{sr,k}^i \cdot N_{l,k}^i \quad (3)$$

Where  $N_{sr,k}^i$  is the number of required spectrum slots, and  $N_{l,k}^i$  is the number of links on path  $k$ . The cost can represent

the spectrum resource utilization along the path, so if the cost is minimum then the spectrum utilization across the network increases hence efficient utilization of resources is achieved. Additionally, the network spectrum utilization ( $NU$ ) can be calculated using equation (4).

$$NU = \frac{\sum_l SS_{o,l}}{\sum_l SS_l} \quad (4)$$

The uniqueness of the LERA algorithm in comparison with existing network approaches is that:-

- Before any assignment or selection of a light path takes place, the algorithm firstly observes the least congested path from source to destination as compared to locating the shortest path from source to destination, noting that selecting the shortest path does not necessarily mean that path is not congested, so it is much more efficient to select the least congested path.
- The algorithm also calculates the signal-to-noise ratio of all the candidate paths coupled with a further selection of an appropriate modulation format taking into account the prevailing signal-to-noise ratio.
- Finally, the LERA algorithm takes into account the current levels of spectrum utilization across the network before choosing the light path. This is necessary for achieving efficient utilization in the spectrum domain, which can result in improved network throughput.

##### Load-aware Efficient Resource Allocation (LERA) algorithm

**Input :** request  $R_i$ , NS

**Output :** Routing, Mod , Spectrum, Assignment solution for the  $R_i$

1. Find  $K$  least congested paths  $\{P_{k,i}\}$  for  $z_i$  using graph edge weight given in eq. (1), ( $k = 1, 2, \dots, K$ );
2. **for** path  $P_{k,i}$
3. Calculate estimated  $SNR_{k,i}$  based on eq. (2);
4. Apply optimal modulation format  $MF_{k,i}$ ;
5. Based on  $MF_{k,i}$ , search for spectrum resources  $SR_{k,i}$  that can satisfy traffic demand  $z_i$ ;
6. **if** spectrum resources  $SR_{k,i}$  are available;
7. Record  $P_{k,i}$ ,  $SR_{k,i}$  and  $MF_{k,i}$ ;
8. Calculate cost of  $P_{k,i}$ ;
9. **else** set cost of  $P_{k,i}$  to be infinity;
10. **end if**
11. **end for**
12. **if** minimum cost  $Cost_{m,i}$  is not infinity
13. Choose the minimum cost path  $P_{m,i}$ ;
14. **return**  $P_{m,i}$ ,  $MF_{m,i}$ ,  $SR_{m,i}$ ;
15. **else** reject the request  $R_i$ ; **return** fail;
16. **end if**

In the wireless access section of the joint APWN, a feedback strategy between the base station (eNodeB) and the multi-orchestrator is used to monitor and control the traffic load at eNodeB. This technique will achieve load balancing amongst base stations in which overloaded base stations will hand over some of their traffic load to neighbouring base stations, and this process is achieved and controlled by the multi-orchestrator. The traffic load ( $T_L$ ) observed by the multi-

orchestrator for a base station is dependent on the number of attached end-users ( $N_{EU}$ ) and the time duration ( $T_{EU}$ ) at which end users (EU) hold the available channel [7].

$$T_L = N_{EU} \cdot T_{EU} \cdot l_i = \sum_{i \in |N_{EU}|} l_i \quad (5)$$

Where  $l_i$  is the traffic load generated by  $EU_i$  based on the bandwidth utilization ( $B$ ) for a time period  $t$ . Moreover, the multi-orchestrator will define two thresholds, the upper traffic load ( $T_{LU}$ ) and the lower traffic load ( $T_{LL}$ ). An EU request is only accepted if the traffic is below the  $T_{LU}$ , otherwise rejected or handed over to neighbouring base stations. But if the traffic falls below the TLL, the neighbouring base station will hand over some of its load or incoming requests to the under-loaded base station or switch it off if there are no incoming requests. This key algorithm's actions in the wireless section of the overall architecture is summarised in flow chart form in Fig. 5. The illustrated operation in the wireless section is a load-aware base station operation, which proves to be superior compared to existing techniques because it further observes the quality of service (QoS) before switching off any base station., therefore this approach not only improves the utilization of resources but also reduces power consumption while constantly maintaining an acceptable level of the quality of transmission (QoT).

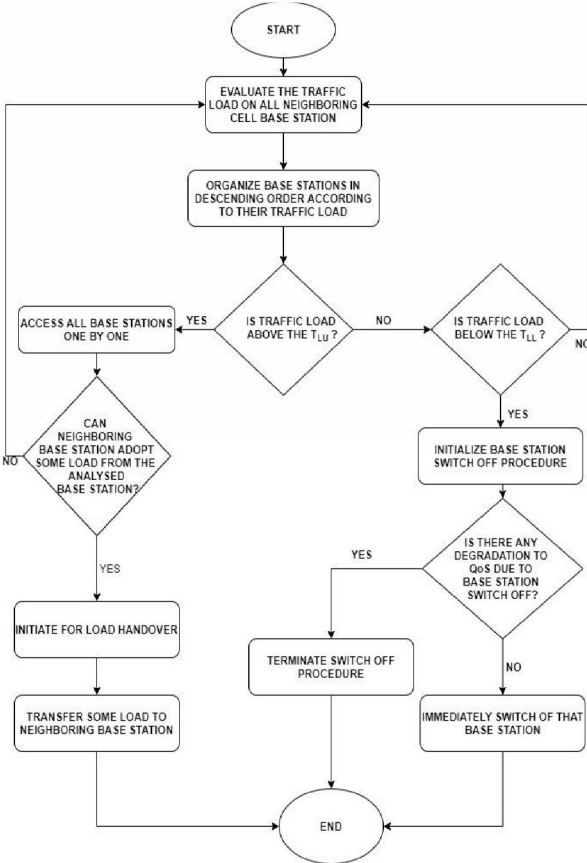


Fig. 5 Load-aware base station operation

## V. PERFORMANCE EVALUATION

This section outlines the evaluation approach of the load-aware efficient resource allocation algorithm in a joint all photonic and wireless network. We further evaluate the blocking Probability and network spectrum utilization for mixed line rate requests, and we observe this at different average holding times. We compare our LERA algorithm with legacy benchmark methods that use the shortest path.

Assuming a network topology with 14 nodes and 21 links with random Poisson distributed traffic requests. From Fig. 6, It is noted that the LERA based network has a much reduced blocking probability compared to the legacy benchmark at different holding times, and additionally, it is also observed that LERA based network outperforms at a shorter holding time as compared to longer durations.

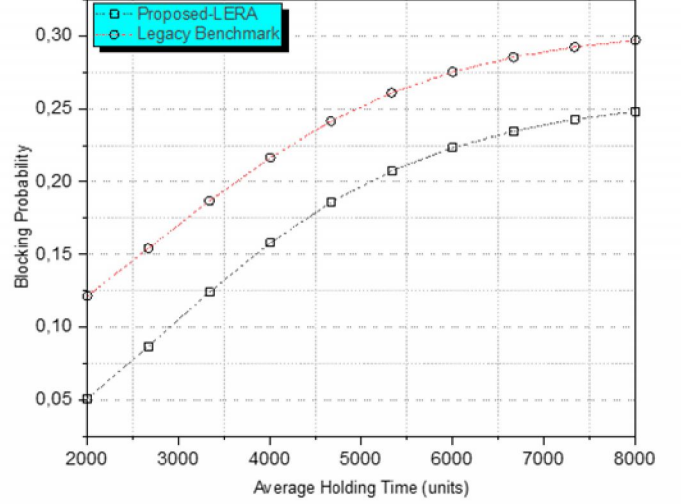


Fig. 6 Blocking Probability at different holding times.

Based on equation (4), we can compare the proposed LERA algorithm with the legacy benchmark for average network utilization. From Fig. 7, it can be clearly observed that the LERA based network is much more efficient in terms of spectrum usage, which is due to choosing the least congested path and load balancing in the wireless access network.

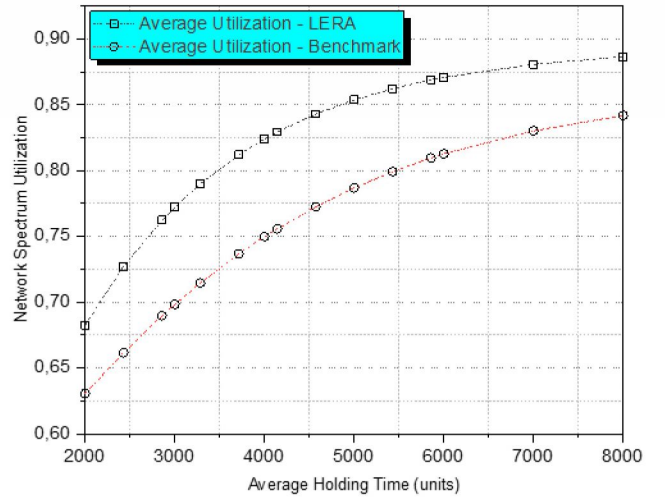


Fig. 7 Average spectrum utilization at different holding time

## VI. CONCLUSION

In this paper, we proposed a state-of-the-art network architecture that can efficiently process a large amount of data effectively, this is a joint all photonic and wireless transport network architecture which is designed to cater for bandwidth-hungry and bandwidth dynamic applications and services. This architecture is based on a Function Dedicated Network (FDN) model to control different functions and services within this network. The proposed network architecture is able

to service high-speed, high capacity mobile fronthaul and backhaul services for current and future networks. Furthermore, it promises to provide low-delay on-demand services to support mission-critical services such as e-health. Moreover, we proposed a Load-aware Efficient Resource Allocation (LERA) algorithm, which is based on locating the K-least congested paths to improve network throughput, and finally, we presented an energy-efficient operation based on load balancing approach as well as base station sleep mode for the wireless access network nodes. The results show that the LERA based network approach outperforms the legacy benchmarks approach for increased throughput (less blocking Probability) and increased spectrum utilization.

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