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A Resource Provisioning Framework Overview for a Joint Optical/Wireless Transport Network (JOWTN)

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Abstract— **As data traffic levels surge globally, research is intensifying toward designing high-capacity Data Transport networks that will maximally utilize photonics-electronics convergence. The focus is mainly on defining appropriate architectures and net-work services to accommodate the diverse traffic types with consistent performance objectives such as provisioning ultra-high capacity, high connectivity, and extremely low latencies for critical mission delay-sensitive services. Thus, we define an appropriate modern JOWTN and propose a joint resource allocation scheme considering 5G/7G scenarios. A model for dimensioning the available resources in the wireless and optical domain sections is also overviewed. Finally, the proposed scheme's performance is validated by way of simulation.**

Keywords*— wireless access domain, optical domain, mobile edge computing domain, resource allocation*

I. INTRODUCTION

The advent of increased data volumes globally generated by 5G/ 7G (IoT) services and applications has necessitated a shift towards amalgamating the All-Photonics Network (APN) and wireless loop into a joint optical and wireless Transport Network (JOWTN) infrastructure [1, 2]. In that way, the latter will enable connectivity with ultra-high bandwidth provisioning and reduced end-to-end latencies. As is known, currently, the only sustainable solution for addressing the speed bottlenecks between the wireless peripheral/ access domain and the network core would be a JOWTN. As earlier alluded, the peripheral will directly interface with users; new radio technology connectivity capabilities enable this. The core optical domain will combine the latest transmission capabilities with software-defined networking (SDN) to yield an ultra-high capacity and an efficiently managed next-generation backhaul transport network in the form of a JWOTN [3]. It will then become necessary to dimension the aggregated resource (end to end) optimally to achieve high connectivity coupled with consistent quality of service (QoS) guarantees. In such a new generation transport network, architecture (suited for 5G/7G and beyond optimized resource dimensioning can be realized through the network slicing-based Network Function Virtualization (NFV) coupling with space division multiplexing (SDM), [4, 5]. In that way, heterogeneous traffic types will be accommodated quite efficiently.

Our paper will thus define an appropriate modern JOWTN and propose a joint resource allocation scheme considering 5G/7G scenarios. A model for dimensioning the available resources in the wireless and optical domain sections is also provided. Finally, the proposed scheme's performance is validated by way of simulation. The remainder of this paper is structured as follows: the next section explores an appropriate architecture, followed by a brief exploration of resource allocation approaches in section III. Section IV introduces, models, analyses, and evaluates the proposed scheme. Finally, conclusions are drawn in the last section.

II. RELATED WORKS AND JOWTN OVERVIEW

Overall, future JWOTNs will accommodate various services, including massive machine-type communication (mMTC), Ultra-high data density (uHDD), and Ultra-high-speed with low-latency communications (uHSLLC)) [6]. Such transport networks require high energy efficiency, security, minimal congestion, and end-to-end latency [7]. In addition, the aggregated global traffic volumes are expected to rise exponentially from 2023 to 2035 as 7G is fully rolled out. Hence, future generation transport networks will subscribe to the notion of Volume spectral efficiency (VSE) as opposed to area spectral efficiency (ASE)[8].

To achieve reliable and ubiquitous connectivity, an integrated network incorporating satellite communication will be necessary to provide seamless global coverage. Flexibility, programmability, and reconfigurability will be achieved by implementing network virtualization and softwarization. This implementation will also enhance the sharing of an otherwise small physical infrastructure by billions of devices simultaneously [4].

Artificial intelligence (AI) based enhanced management and control will be introduced for a higher degree of overall network intelligence and atomization. That way, the unimpeded real-time data transfer across the network will be guaranteed and simplified.

Thus, there is a need for a JWOTN to provide an overall infrastructure for providing guaranteed QoS for all connections, as conceptualized in Fig. 1. The figure also illustrates that the access network is wireless, whereas the core is optical.

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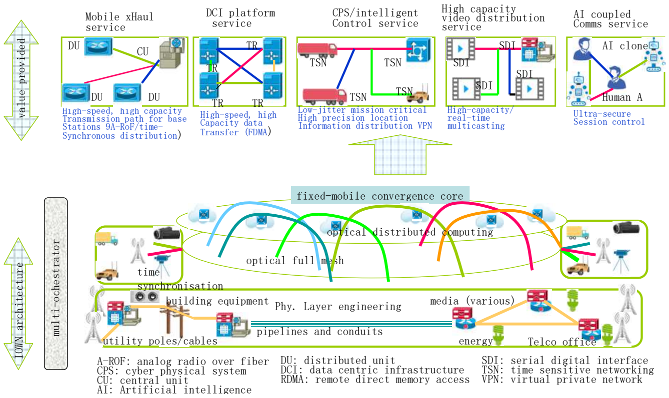

Fig. 1. Conceptualized JWOTN Services functions of the envisaged infrastructure

The bandwidth-constrained access sections provide tributary traffic to the core, which supports ultra-high bandwidths using optical fiber. As a result, the JWOTN will also guarantee low-end-to-end latencies. It will also support a loopback path that guarantees mission-critical remote-control message forwarding from multi-access edge computing located near the user to terminals via wireless access and supports mission-critical remote-monitoring-and-control services in various usage scenarios such as autonomous vehicles and factory-control systems.

Serving as an infrastructure platform for various ICT and networks, the APN will also provide optical transmission services between large-scale data centers and among base stations, wireless control systems, and the mobile core for next-generation mobile communication systems. From the same conceptualized infrastructure, function-dedicated networks (FDNs) are created within the overall infrastructure to support services with diverse network requirements. Their transmission services networks are assumed to exist in varieties such as the following:

- Digital signal transmission (Straight Digital) maps digital signals directly to the optical path.
- Analog signal transmission (Natural) maps analog signals directly to the optical path.
- Packet frame transmission (Framed Digital) frames data into packets and transfers the framed data to the optical path.

We further provide a model architecture of the JOWTN in Fig. 2. As illustrated, the envisaged model combines the wireless and optical sections. The main components in service terms are the access and data-centric infrastructure (DCI) network, dominated by wireless connectivity at the periphery, and the optical domain, which serves as the main transmission and core switching infrastructure. Further, the model incorporates network functions for regulating resource provisioning and the various services and connections between the optical core, wireless access networks, and DCI.

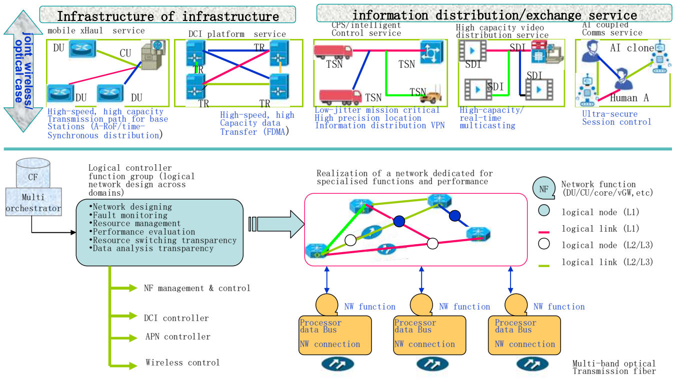

Fig. 2. Envisaged JOWTN Architectural Model

Photonics on-demand, primarily a multipoint connection technology, is expected to be incorporated into the core network [4]. Thus, enabling more simultaneous connections than current technologies can support.

To ensure consistent QoS in wireless access, the extreme network as a service (NaaS) incorporates the JOWTN network infrastructure model illustrated in Fig. 2. The concept ensures that users connected via wireless access systems seamlessly enjoy the same natural grade of service (GoS) when connecting via different technologies. The realization of NaaS requires upgrading and blending various wireless technologies and their peripheral technologies. Including beamforming technology using analog radio-over-fiber (RoF) [5] and Multi- radio Proactive Control Technologies (Cradio$^{\circledR}$) [6]

Note that, in the beamforming technology using analog RoF, the wireless analog signal is transmitted directly into the fiber without digital conversion, reducing the size and cost of antennas deployed. Remote beamforming also enables efficient area deployment of antennas.

Cradio combines various wireless technologies, such as wireless sensing and visualization, wireless-quality prediction and estimation, and wireless-network dynamic design and control in multiple wireless networks, including private and public networks, to meet ever-changing user requirements and radio-wave conditions. By cooperating with various social systems and applications, Cradio also makes it possible to create a natural communication environment in which people do not need to be aware of wireless networks.

The JOWTM will also provision other example services, such as agriculture support. Such a service will require mobility as a service (MaaS) achieved by linking end hosts, cloud infrastructure and the network. This requirement will necessitate the incorporation of a Cooperative Infrastructure Platform [7], whose architecture is exemplified by Fig. 3. By predicting the network's condition utilizing remote-control and monitoring functions, Global Navigation Satellite Systems (GNSSs) can be used to determine the current position and predict the future route and wireless quality on the cloud infrastructure.

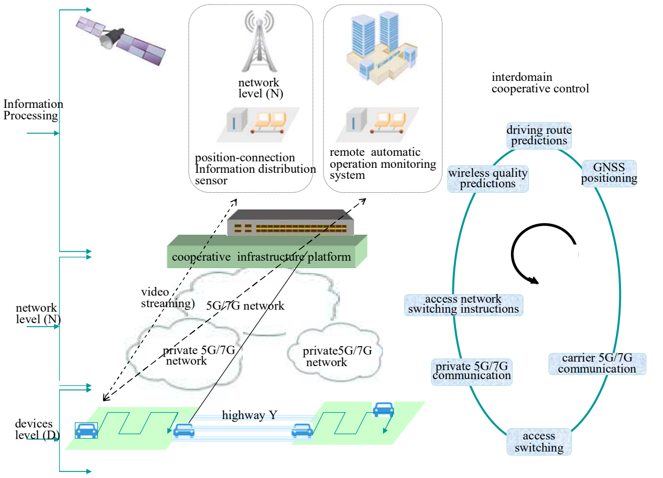

Fig. 3. Cooperative Infrastructure Platform and coordinated information processing, network, and devices operation.

Advantages of the envisaged JWOTN deployment can be summarized as follows:

- Cost-effectiveness in deployment at the end-users side due to the flexible nature of wireless networking architecture.
- The fail-safe nature of wireless architectures makes the overall peripheral network much more robust, resilient, and self-healing. Any failure does not affect connectivity, as traffic can easily be diverted through neighboring wireless mesh routers.
- Better load-balancing capabilities, thus supporting anycast routing. Note that a load-congested gateway switch node in the periphery can easily offload excess traffic to neighboring switches.
- Higher bandwidth capacities compared to wireless network-only architectures, which will help drastically reduce load congestion, blocking probabilities, and end-to-end latencies.

In the next section, we separately look at optimized resource allocation modeling in radio, wireless access, optical in the core, and edge computing domains.

III. OPTIMAL RESOURCES ALLOCATION

In a generalized resource architecture, as illustrated in Fig.4, the end users send resource requests to the resource allocator, and the request is furnished with a resource descriptor. In turn, the allocator will provide the required resources subject to live connections. The resource request descriptor enables the allocator to dynamically assign a virtual machine (VM). Note that each available physical server can host several VMs.

The *RRHs* provide radio resources in the wireless domain. A single RRH casts several beams, converted to communication slots within a radio frame. The bandwidth is subdivided into several subcarriers using OFDMA. Each subcarrier is subsequently partitioned into "best fit" radio allocation units called subchannels. We advocate for RRHs within the C-RAM model as it promotes efficient resource pooling in conformance with the 5G slicing concept. The approach has several advantages: high energy efficiency, low attenuation losses, increased transmission capacities, and dynamic resource allocation. Each end user's request descriptor specifies the minimum requested bandwidth and other critical minimum sustainable QoS-related primitives. The Resources Allocator then assigns appropriate transmission modes to the subchannels by considering both Channel Status Indication (CSI) and Signal Interference and Noise Ratios (SINR). Interference between overlapping beams must also be considered when modeling the radio resource allocation. It is also necessary to identify any interfering subchannels and avoid assigning resources to them simultaneously.

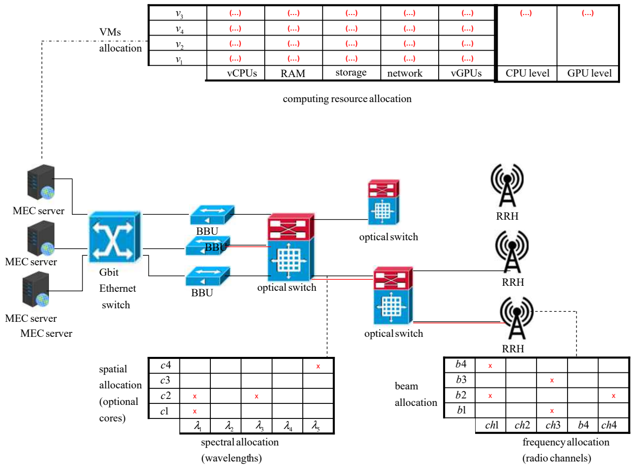

Fig. 4. Generalized Resource Architecture of JWOTN

The allocator assigns light path connections between BBUs and corresponding RRHs in the optical domain. The Optical Distribution Network (ODN) switching elements establish the path. Upon receiving an optical resource demand (opt_dem), the optical resource allocator sets a complete end-to-end lightpath connection across the ODN. The requested lightpath is subsequently established on the available links, each of which avails several wavelengths. The allocation maximizes the number of simultaneous lightpath connections by the allocator identifying an optimal set of nodes and wavelengths that will serve each lightpath connection demand.

A. Optimized Wireless Access Domain Resource Provisioning

As is anticipated, future–generation wireless domain networking concepts are geared towards (5G) provisioning high QoS guarantees. By implementing diversified multi-layer models that include device-to-device (D2D) networks, macro cells, and varying sizes of smaller cells, end users will be guaranteed a consistent desired QoS. The highly "adaptively" cross-layer design concept, where information is shared across different levels, can achieve high throughput rates and efficient utilization bandwidth of available resources in this and neighborhood domains.

This allocation problem can thus be modeled as an Integer Linear programming. [9]. RRH beams' transmission mode can be modeled as an array of binary elements (y) decision variables mapping to the radio allocations (Z_a^r). For each RRH_i beam j and subchannel k , the preoccupied channel slots are denoted by Γ_s^r . We can, therefore, express the following constraint:

$$\sum_{l=1}^{T_{x\_}\text{mod}es} x(i,j,k,l)+\Gamma_s^r(i,j,k,l)\le 1 \tag{1}$$

Each subchannel is restricted to using a single transmission mode at a time, thus ensuring that all its contained subcarriers transmit in the same mode. Thus, once again, for each RRH_i :

$$\sum_{l=1}^{T_{x\_}\text{mod}es} x(i,j,k,l)\le 1 \tag{2}$$

As indicated earlier, subchannels cannot be allocated in interfering beams. We can define a parameter χ that characterizes the extent of interference between frequency channels of beams in a given coverage area. We further define the following constraint relating to each pair of allocation subchannels (i.e., allocation slots):

$$\sum_{l=1}^{T_{x\_}\text{mod}es} x(i,j,k,l)+\sum_{l=1}^{T_{x\_}\text{mod}es} x\left(\tilde{i},\tilde{j},\tilde{k},\tilde{l}\right) + \chi\left(i,j,k,\tilde{i},\tilde{j},\tilde{k}\right)\le 2 \tag{3}$$

As a rule, each subcarrier in each coverage area must allocate bandwidth resources slightly above what was requested. The number of beams in a target area (B) must be identifiable to realize this constraint. Thus, for each coverage area (A) and transmission mode, l we have [9]:

$$\sum_{i=1}^{RRHs}\sum_{j=1}^{beams(i)}\sum_{k=1}^{subch(i,j)} B(i,j,A)\times(i,j,k,l)\times SC_{subchannel} \ge \sum_{s=1}^{services}\left(B(i,j,a)\times\left\lceil\frac{serv\_req\_DR(s,a,l)}{subcarrier\_DR(l)}\right\rceil\right) \tag{4}$$

Equation (4) above $SC_{subchannel}$ represents the number of subcarriers per subchannel.

We recall that the allocation processes in this domain center on provisioning requested resources optimally, fairly, and efficiently, subject to ensuring energy efficiency and computational complicity of the associated allocation algorithm(s). A computational low heuristic algorithm in prioritizing individual RRHs during the allocation is summarized by algorithm 1 and the flow- chart in Fig. 5.

Algorithm I: Prioritization of RRHs in area A

```
1. $set\_area = A_i;$
2. $scan\ all\ RRHs\ within\ (A)$
3. $flag\_RRH_i\_HP\_if\ best\ candidate\ for\ requested\ resources\ accomodating$
4. $flag\_LP\_\ (all\ other\ RRHs)$
5. $flag\_RRH_i\_HP\ if\ already\ flagged\ so\ previously\ in\ A_{i-1}$
6. $flag\_RRH_i\_LP if\ previously\ unprioritised\ in\ A_{i-1}$
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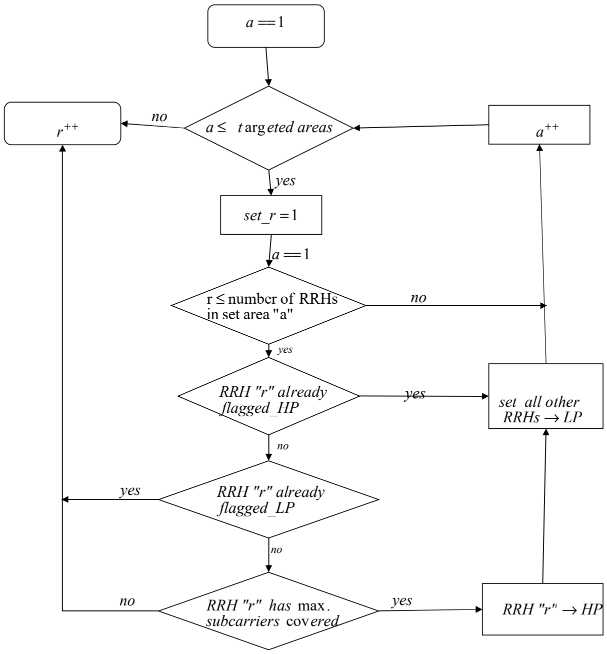

Fig. 5. Summary RRH prioritization heuristic algorithm.

B. Optimized Core Optical Network Domain Resource Provisioning

Typically, the access network aggregates all End-user data before it is distributed to respective destinations by the core optical domain network. Thus, this domain section demands ultra-high bandwidth capacities and can only be achieved through network automation, elasticity, and operational efficiency. It is, therefore, necessary to allocate the available resources optimally to achieve this goal. Once again, the optimization is modeled along an ILP approach. There is a relationship between resource allocation in this domain and that in the radio, in that the first step is to assign $BBUs$ to active $RRHs$' beams. In this regard, we first define a set array of binary elements that will eventually be mapped to allocation optical slots $y\in Z_a^o$.

C. MEC Domain Resource Provisioning

This subsection looks at optimized resource allocation in the mobile edge computing domain. In this case, the allocation must be carried out to minimize the number of active servers and VMs . In this case, a particular service request is allocated to a specific physical server. Finally, in assigning required EC resources, we should keep overall power consumption to a minimum. In this regard, we must use a minimal number of physical servers at any time, which should run for the shortest time possible. In that way, prioritizing physical servers with more processing power capabilities makes sense. In that way, we consider attributes for each physical server such as HDD capacity and type, e.g., solid-state drive (SSD), type and quantity of physical memory(RAM), total number of $vCPUs$ as well as $vGPUs$. These attributes can be used to index each server accordingly to afford optical allocations of new job requests.

IV. EVALUATION

In this section, we evaluate the resource allocation scheme separately in the three domains: wireless access, optical core, and mobile edge computing. Fig. 6 illustrates the evaluation topology that was created in Netsim. This topology is assumed to cover a cluster.

For the wireless access domain section, 40 $RRHs$ are created and randomly spread in the cluster. The cluster has an active end-user population of 15000, each generating traffic averaging $2MBps$. However, each service request requires a data rate capped at an average, $15, 20MBps$ and these are evenly distributed among the active $RRHs$. Other key simulation parameters for this section include setting each beam's bandwidth at $1GHz$ the subcarrier spacing of $0.5MHz$ each accommodating 350 subchannels. Varying transmission modes are adopted, including $16-QAM/QPSK$ and $32-QAM/QPSK$. Beams serve each RRH, and any overlapping of a neighboring's coverage within the cluster is flagged as interfering.

In the evaluation scenario, the number of requests varies from zero to a maximum of 5000. These are generated randomly among the $40\ RRHs$. Resources in the optical section are accordingly proportionally when the number of requests is incremented.

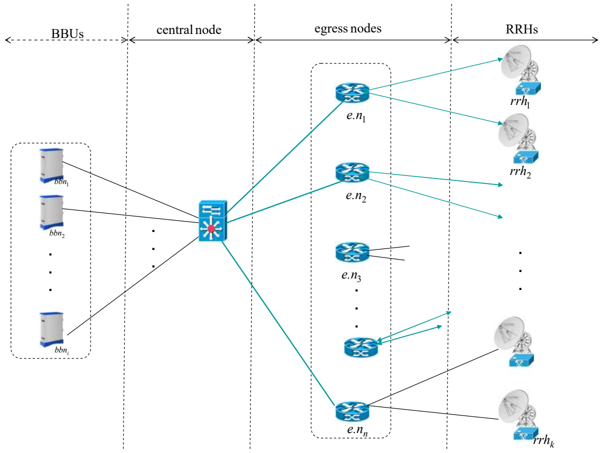

Fig. 6. Network performance evaluation scenario

The plot of Fig 7 partly evidences that the execution times fall within reasonable bounds, thus justifying the scheme's capability to provision the resources optimally within reasonable time scales.

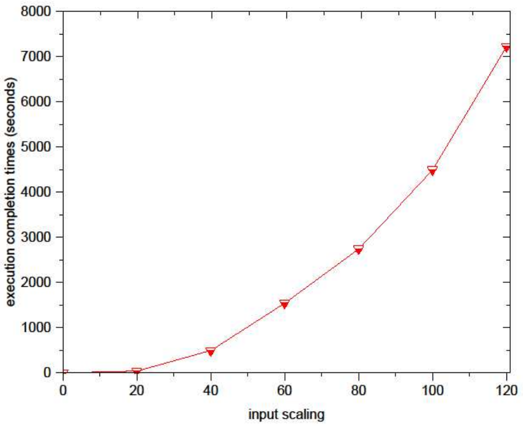

Fig. 7. Execution turnaround times evaluation

Regarding provisioning in the optical network domain, we again incorporate the g modules, such as $RRHs$, $BBUs$, egress (end) and core switches. Provisioning of resources in this domain minimizes power consumption. Thus, fewer components must be in active mode to achieve energy efficiency, as expressed by equation (13) in section II. Simulation parameters for the optical domain section are provided in Table 1.

TABLE I. Simulation parameters for the optical domain section

component	quant	comment
RRH	40	4 x beams, 2 ports link to an egress switch/ 2 core nodes/ $2\times$wavelengths
node(core)	1	complete switching capabilities,/ $4\times$ports linking egress switch/ $4\times x$ wavelengths
egress switxc	10	Complete switching capabilities, dual port to each RRH
BBU unit	80	$2x$ ports to core node/$\times 2$ wavelengths

By maintaining the same input traffic levels (at the wireless access), we present the results plotted in Fig. 8, in which it is observed that a minimal number of optical components are activated. As can be observed, the weighted optimization will result in much fewer optical components and resources being put into active mode. Notably, only about 15% of ports and core nodes are utilized, hence significant power savings.

The parameters in Table 2 are used for simulating resource allocation in the edge computing domain. In this case, we assumed that a group of mobile users together request within the cluster.

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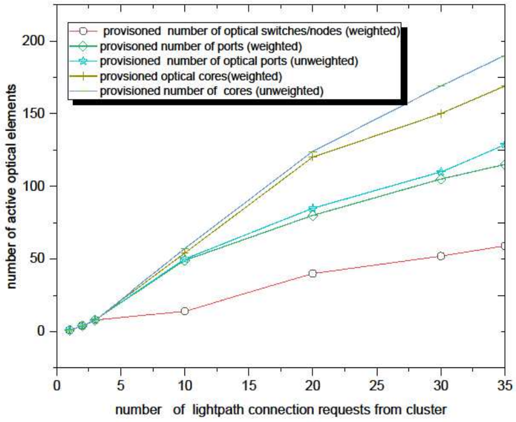

Fig. 8. Number of provisioned elements in the cluster

Table II. Simulation parameters for MEC resources

resource type	quantity
vCPU	61 per physical server
physical servers	60 , @ 50 GB RAM & 100 GB *H*DD
network speed	50 MB per physical server
vGPU	60 per physical server

Plotted in Fig. 9 is the number of physical servers versus allocated VMs. From the same graph, it is observed that weighted optimization will lead to having a lesser number of physical servers in active mode.

On average, the unweighted allocation results in a 15-40% more physical servers being utilized. Overall, a careful analysis of all the results clearly demonstrates that joint allocation is much more effective in optimizing the allocation of available resources in all three domains and significant energy savings

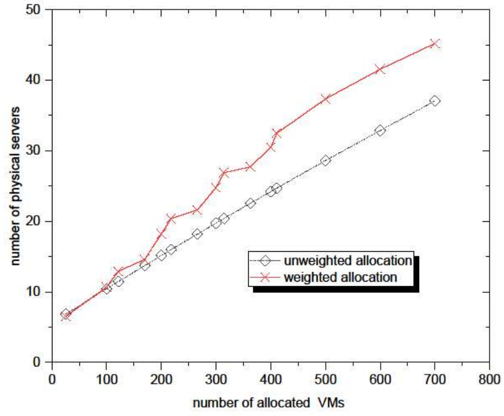

Fig. 9. Total number of allocated VMs in the cluster.

V. CONCLUSION

The work defines and discusses an appropriate modern JOWTN and proposes a joint resource allocation scheme considering 5G/7G scenarios. A model for dimensioning the available resources in the wireless and optical domain sections is also provided. Finally, the proposed scheme's performance is validated by way of simulation. Overall, a careful analysis of all the results clearly demonstrates that joint allocation is much more effective in optimizing the allocation of available resources in all three domains and significant energy savings.

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