Chapter

Role of Optical Network in Cloud/Fog Computing

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Abstract

This chapter is a study of exploring the role of the optical network in the cloud/fog computing environment. With the growing network issues, unified and cost-effective computing services and efficient utilization of optical resources are required for building smart applications. Fog computing provides the foundation platform for implementing cyber-physical system (CPS) applications which require ultra-low latency. Also, the digital revolution of fog/cloud computing using optical resources has upgraded the education system by intertwined VR using the fog nodes. Presently, the current technologies face many challenges such as ultra-low delay, optimum bandwidth, and minimum energy consumption to promote virtual reality (VR)-based and electroencephalogram (EEG)-based gaming applications. Ultra-low delay, optimum bandwidth, and minimum energy consumption. Therefore, an Optical-Fog layer is introduced to provide a novel, secure, highly distributed, and ultra-dense fog computing infrastructure. Also, for optimum utilization of optical resources, a novel concept of *OpticalFogNode* is introduced that provides computation and storage capabilities at the Optical-Fog layer in the software defined networking (SDN)-based optical network. It efficiently facilitates the dynamic deployment of new distributed SDN-based *OpticalFogNode* which supports low-latency services with minimum energy as well as bandwidth usage. Therefore, an EEG-based VR framework is also introduced that uses the resources of the optical network in the cloud/fog computing environment.

Keywords: cloud/fog computing, optical resources, virtual reality, cyber physical system, electroencephalogram (EEG)

1. Introduction

Optical transmission is the most cost-effective technology to implement high-bandwidth-based communication in the fog/cloud computing environment. The passive optical network (PON) uses optical line terminals (OLT) and optical network units (ONU) for delivering fog/cloud-based services effectively [1]. Introducing this technology with the present information technology, Internet of Things (IoT), cloud computing, 5G wireless networking, and embedded artificial intelligence have tremendous potential to assist the development of smart applications that demand a large amount of data to be processed locally and operate on-premise with minimum latency and network congestion [2]. Optical technology has supported IoT-based applications for transferring massive information in a virtual frictionless fashion by using the optical network elements. It has provided new ways for various business applications to move over the latest technologies such as big data analytics, machine learning, etc. in the era of the 5G network.

Fog computing is a new distributed architecture which brings computing, storage, and networking services closer to the proximity of the end user [3]. As compared to the traditional cloud computing techniques, it processes real-time applications and data at the edge with minimum latency, minimum network congestion, and lower energy consumption which are the key demand of many industries such as manufacturing, e-health, education, oil and gas, smart cities, smart homes, and smart grids [4]. Fog nodes aggregate the computing resources of edge devices to perform the critical data-sensitive computations where the data of analysis part is directly sent to the cloud for further processing because traditional fog nodes have limited storage and computing power.

The integration of fog computing and PON is an inexpensive, scalable, and simple technology to provide a most promising solution for building e-learning-based smart educational applications [5]. The dynamic capabilities of SDN combined with the state-of-the-art optical technologies have the ability to modernize the optical transport network through its primary feature, i.e., programmability [6]. The purpose of this chapter is to explore efficient techniques to combine SDN-based optical technology at different levels of design and development of smart VR-based applications.

2. Utilization of optical resources in cloud/fog computing environment

In order to handle real-time and bandwidth-intensive applications, fog leverages the computing resources of the SDN-based optical network. **Figure 1** shows that the Optical-Fog layer [7] uses ONUs in the middleware of the cloud and IoT layer. In a typical PON channel with multiple OLTs, each OLT is connected with multiple ONUs (16–256) [8]. The Optical-Fog layer is designed by using their residual processing, storage, and interconnection capabilities. It can enable fast service provisioning, dynamic service restoration, network automation, and network optimization at different layers of the underlying network infrastructure. It makes optical network

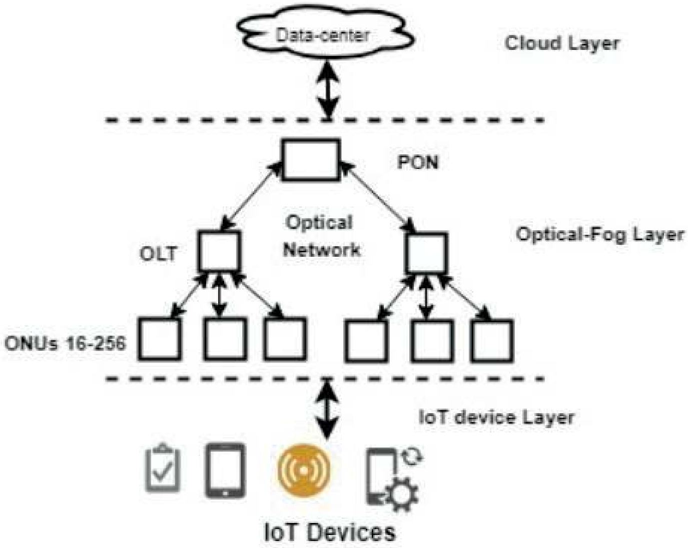


Figure 1.
Utilization of optical resources in cloud/fog computing environment.

centralized, intelligent, and controlled (real time) which can serve application-level services efficiently in the heterogeneous IoT, machine learning, big data, and cloud computing paradigms. The acronyms used in this paper are defined in **Table 1**.

2.1 SDN-based optical network

Presently, SDN is supporting wide area network to deal with many more technologies for delivering several benefits. It has adopted a hierarchical approach in which domain controllers collect information and delegate the control (real time) over the network layers and geographic clusters to support applications and provide higher levels of service orchestrations. Initially, SDN was used in data centers for separating the data plane, control plane, and management plane from each other [9]. The interface like OpenFlow is used by the centralized controller to deliver computing infrastructure for making better communication. While applying this concept to the optical network, optical domain controller (ODC) plays an important role. As shown in **Figure 2**, it provides a more programmatic and abstract view of the underlying optical network through the northbound interface [10]. The programming feature of SDN makes it capable of fulfilling customized demands for manipulating network infrastructure. To handle real-time, bandwidth-intensive applications, fog uses the computing resources of the SDN-based optical network.

The SDN-based optical network infrastructure fulfills the demand of increasingly high-performance and network-based applications with flexibility and efficiency. The key security issues in fog/cloud computing over optical network lies at both downstream and upstream channels of PON. PON uses broadcasting in the downstream channel which is prone to eavesdropping attacks where an attacker can modify the behavior of ONUs at its media access control (MAC) layer. On the other hand, the traffic in the upstream channel is only visible to the OLT rather than other ONUs that can also be exploited for attacks. In PON network, OLT uses time division multiplexing access (TDMA) that provides sharing of the upstream channel among

PON	Passive optical network
OLT	Optical line terminal
ONU	Optical network unit
CPS	Cyber physical systems
VR	Virtual reality
EEG	Electroencephalogram
QoE	Quality of experience
QoS	Quality of service
ONV	Optical network virtualization
SDN	Social-defined network
FAR	Free available resource
TDMA	Time division multiplexing access
MPCP	Multipoint control protocol
ODC	Optical domain controller
MAC	Media access control

Table 1.
List of acronyms.

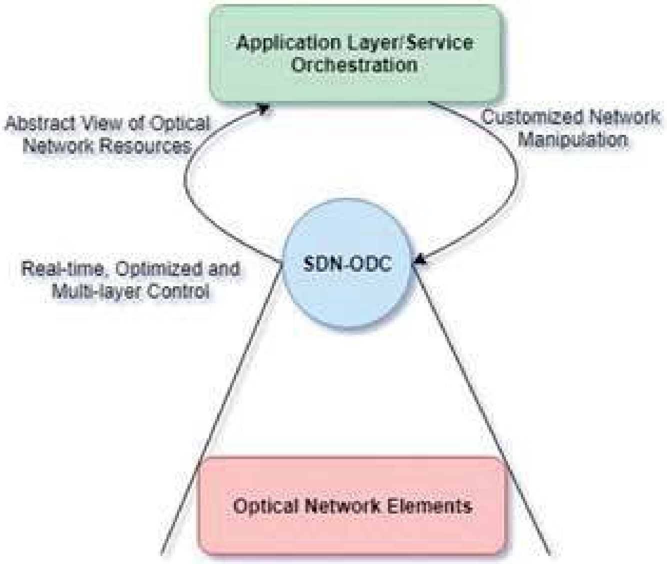


Figure 2.
SDN-based optical network.

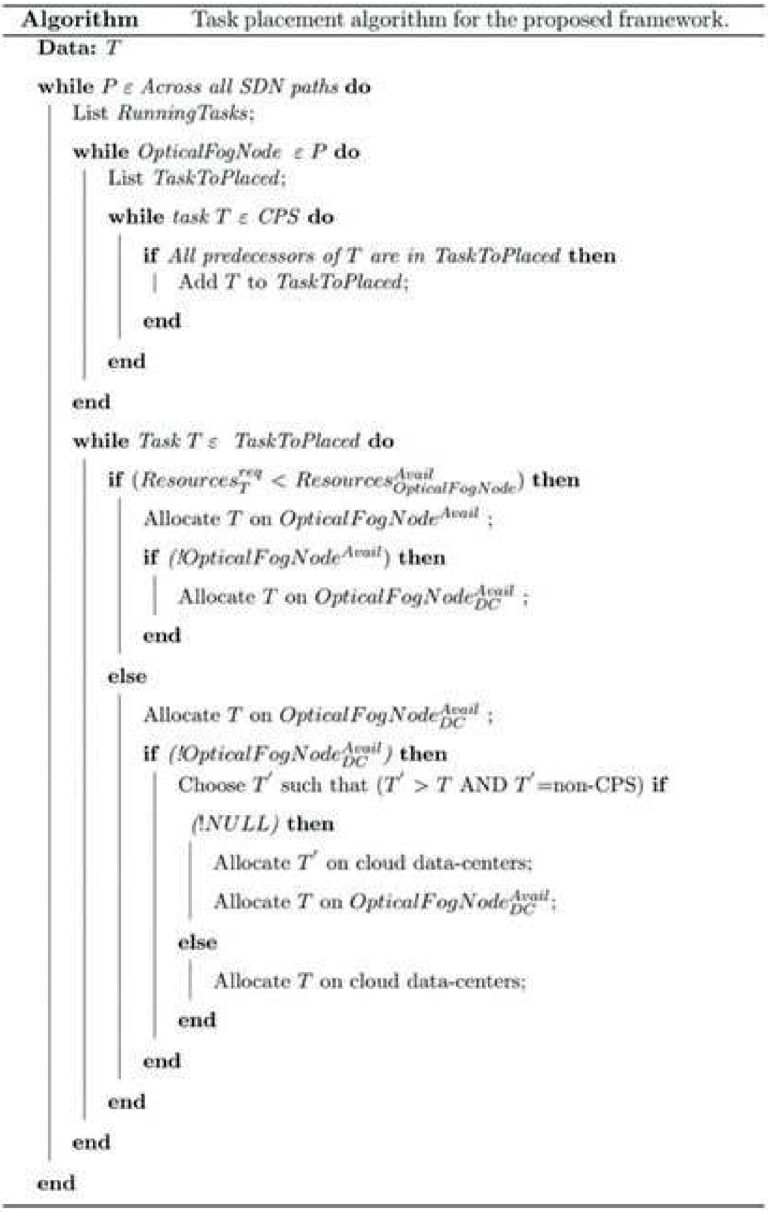
ONUs [11]. It assigns static or dynamic nonoverlapping time slots to connected ONUs. Here, OLT and all connected ONUs are well synchronized that result in the collision-free transmission of the traffic or data frames. In the security aspects of PON, more research work is required that can restrict the ONUs to send data frames outside of their preassigned time-slots. In case if a malicious ONU intends to send data frames outside its preassigned time slot, the collision can encounter with the data-frames of other ONUs that degrade the quality of service (QoS) of the optical channel.

To ensure QoS and quality of experience (QoE) to the end-user for various real-time CPS-based applications, Optical-Fog layer is utilized. To handle real-time processing, this layer uses the optical network resources by creating *OpticalFogNode*. The optical network can effectively realize the interconnected optical resources (PON, OLTs, and ONUs) across the 5G network. It provides ultralow delay and less energy consumption for IoT devices and uses the majority of the computing resources of the optical layer rather than the cloud layer.

2.2 *OpticalFogNode* for implementing CPS system

CPS enables the integration of cyber components such as sensors, computational and control units, and network devices into the physical components (such as objects, end-users, and infrastructures) by connecting them to the Internet and each other. It also has shown tremendous progress in many fields like communication, healthcare, education, manufacturing, robotics, transportation, military, etc. It has also encouraged many innovative and ever-growing projects in the application domain of cloud and fog computing. CPS requires a novel, highly distributed, secure fog computing infrastructure in the heterogeneous network for strengthening its position for the mobile and wireless network in the new 5G era [12]. It can provide unified and cost-effective computing services for smart cities, vertical industries, and IoTs at the extreme edge of the new 5G network.

Further, the concept of an *OpticalFogNode* is proposed that supports low-cost and on-demand access to the computing infrastructure of the Optical-Fog layer in the 5G network. The main challenge is to run the CPS-based applications on the *OpticalFogNode*. The optical network virtualization (ONV) and SDN provide a novel solution to deploy *OpticalFogNode* at the edge of the network. All free available resources (FARs) of the optical elements are grouped together to form an *OpticalFogNode* with the computing capabilities like processor, memory, and bandwidth. ONV converts the free available physical resources of the optical network elements into the virtual resources as infrastructure-as-a-service (IaaS) model. Initially, each submitted task is categorized as CBS-based or non-CPS-based task on the basis of requested resources in terms of processing power, storage, bandwidth, acceptable security level, etc. The Optical-Fog manager can dynamically reconfigure the *OpticalFogNode* which provides the desired reliability and QoS for the CPS. An algorithm is proposed that identify all possible created *OpticalFogNode* on the SDN path and assign them CPS-based tasks for further processing. The non-CPS-based tasks are directly sent to the cloud layer only if the resources of *OpticalFogNode* are not free.



```
Algorithm   Task placement algorithm for the proposed framework.
 Data: $T$
 while $P \varepsilon$ Across all SDN paths do
     List RunningTasks;
     while OpticalFogNode $\varepsilon$ $P$ do
         List TaskToPlaced;
         while task $T \varepsilon$ CPS do
             if All predecessors of $T$ are in TaskToPlaced then
                 Add $T$ to TaskToPlaced;
             end
         end
     end
     while Task $T \varepsilon$ TaskToPlaced do
         if $(Resources_T^{req} < Resources_{OpticalFogNode}^{Avail})$ then
             Allocate $T$ on $OpticalFogNode^{Avail}$ ;
             if $(!OpticalFogNode^{Avail})$ then
                 Allocate $T$ on $OpticalFogNode_{DC}^{Avail}$ ;
             end
         else
             Allocate $T$ on $OpticalFogNode_{DC}^{Avail}$ ;
             if $(!OpticalFogNode_{DC}^{Avail})$ then
                 Choose $T'$ such that ($T' > T$ AND $T'$=non-CPS) if
                   $(!NULL)$ then
                     Allocate $T'$ on cloud data-centers;
                     Allocate $T$ on $OpticalFogNode_{DC}^{Avail}$;
                 else
                     Allocate $T$ on cloud data-centers;
                 end
             end
         end
     end
 end
```

In the proposed algorithm, the resources required by the new task are evaluated and then allocated on the *OpticalFogNode.* This node is scalable to provide the required computing resources dynamically by using the concept of ONV.

If the computing resources of *OpticalFogNode* are already occupied, then there are two options to execute the task on the basis of its preference. If the requested new task is a non-CPS task, it can be directly allocated to the cloud. Otherwise, CPS-centric task can be executed.

- *T* represents the requirements of submitted task for the framework along with its category as CPS-based or non-CPS-based task.

- *RunningTask* represents the already running tasks.

- *OpticalFogNode* is virtual and a dynamically configurable smart node using the concept of ONV at the Optical-Fog layer.

- *TaskToPlaced* all coming task to be allocated to the *OpticalFogNode* for further processing.

- $OpticalFogNodeNode^{Avail}$ is a free available resource at the OpticalFog.

- $OpticalFogNode_{DC}^{Avail}$ is a free available resource at the dynamically configured *OpticalFogNode.*

Further, this layer uses the SDN-based controller for optimizing the distribution of the flow among various redundant paths. In order to increase the QoS, the shortest path is chosen that minimizes the delay. In the optical network in the 5G environment, the *OpticalFogNode* has a flow table which is used to match the routing information of the received packet in the path. If there is no entry found in the flow table, the received packet is forwarded to the SDN controller for finding the shortest path so that the particular packet can be forwarded. Thus, a new entry is added (once the path is chosen) in the flow table of the *OpticalFogNode* for the coming future packets. Hence, the proposed SDN controller identifies the shortest path with the least congestion among all possible paths.

2.2.1 Architecture of OpticalFogNode

In SDN-based Optical-Fog/cloud network, the key challenge with the deployment of a fog node is to make it secure from the attackers. However, attackers are capable to create malicious programs with the ability to detect and evade their targets in distributed computing environments. **Figure 3** shows that optical network virtualization provides a novel solution to deploy *OpticalFogNode* in the middleware of IoT devices and the cloud rather than deploying at cloud data centers.

SDN technology combined with optical network virtualization allows for running the control logic of each tenant on a virtual SDN controller rather deploying and running at the cloud data centers.

The resources to the proposed *OpticalFogNode* can be provisioned on demand from geographically distributed optical elements specially ONUs. The architecture of *OpticalFogNode* is shown in **Figure 4** where it can be deployed and configured virtually. The architecture has southbound and northbound interface along with SDN controllers which belong to different tenants of *OpticalFogNode* to emulate them for different IoT applications. It has the capability to control optical network elements for processing the configuring demand of different *OpticalFogNode* tenants such as computing resources, topology, address scheme, node mapping options, etc. Hence, virtual *OpticalFogNode* can be created in the form of infrastructure-as-a-service for providing real-time control to each *OpticalFogNode* tenant over its virtual

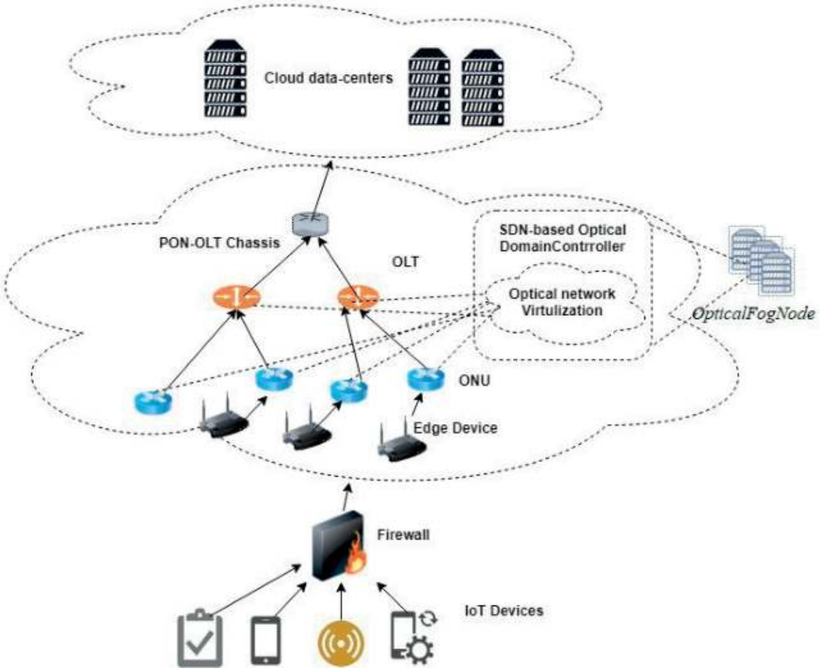


Figure 3.
Deployment scenario of OpticalFogNode at Optical-Fog layer.

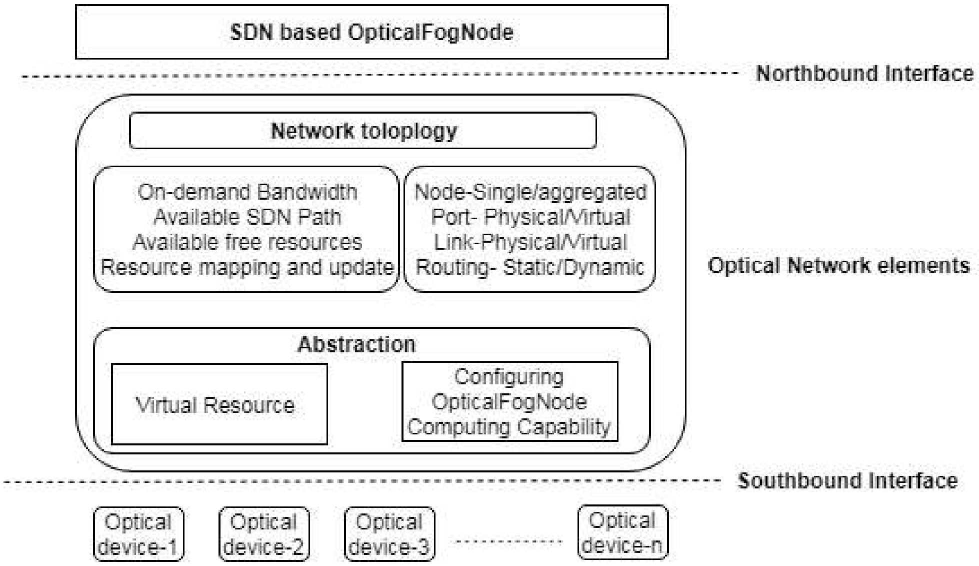


Figure 4.
SDN-based OpticalFogNode architecture.

network. In order to form virtual infrastructure, a free-available-resource concept is proposed which uses the freely available resources of the optical network elements that lie at the Optical-Fog layer. Since routers and switches have limited resources, only optical elements such as optical network units and optical line terminals are taken into account for implementing FAR. Optical elements like ONUs and OLTs have their own processing, storage, and interconnection capabilities that are not fully utilized by the present network scenario. Thus, as shown in **Figure 5**, each optical element has some amount of running resources as well as FAR. Our proposed *OpticalFogNode* aggregates those FARs for facilitating the computing capability to each *OpticalFogNode* tenant.

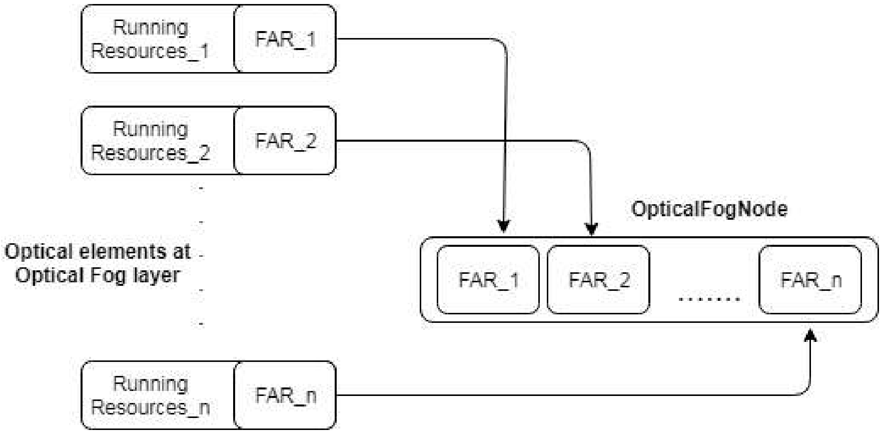


Figure 5.
Free available resource.

Hence, all FARs of optical network are grouped together to form virtual data centers with computing resources such as processor, memory, and bandwidth. ONV converts the physical resources of optical network elements into the virtual resources as infrastructure-as-a-service (IaaS) model to build virtual honeypots that prevents vulnerability and its identity from the attacker.

2.3 EEG-based VR gaming applications

SDN-based Optical-Fog network introduced as shown in **Figure 3** provides optimum bandwidth and ultralow delay for EEG-based VR gaming applications. The Edge-Fog layer and Optical-Fog layer provide rich gaming experience and QoE for EEG-based VR gaming applications by utilizing the optical resources than the cloud resources [13]. The Optical-Fog layer executes the game logic where the VR scenes can be encoded and streamed at the Edge-Fog layer. SDN-based controller improves the QoE and supports the playing of a game across the distributed geo-locations with minimum delay. It optimizes the flow distribution among the various redundant paths inside the Optical-Fog network to reduce the delay. In contrast to a traditional controller, the proposed SDN controller provides the shortest path with the least congestion among all possible paths

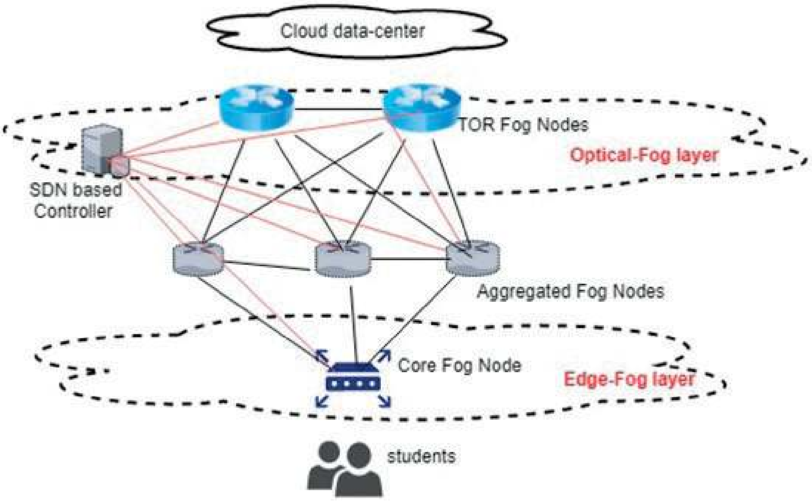


Figure 6.
SDN-based Optical-Fog network.

from the requesting Core Fog nodes to the Top of Rack (TOR) Fog nodes in the optical network which is shown in **Figure 6**. It uses an open-loop congestion control mechanism to employ congestion aware direct routing. Each node of the SDN network keeps the estimation cost $C_n^c(t)$ for delivering packets to their destination node c [14]. It helps to find the shortest path with least congestion by using the historical knowledge of the connection to node c and the waiting time of packets to c in the node n's queue. It is assumed that all nodes broadcast a request for the cost frequently to their neighbors. Also, all neighbor nodes keep updating their cost table on the basis of the received request for the cost. To find the shortest path with the least congestion, the node with minimum delivery cost is selected as shown in **Figure 7**. The convoluted parameters are referred to as *Proximity Measure* $\Theta_n^c(t)$ and *Net Destination Queue Waiting Time* $\Omega_n^c(t)$ are used to compute the delivery cost [13].

$$\Theta_n^c(t) = \frac{Q_n^c(t)}{T_n^c(t)} \tag{1}$$

The value of $\Theta_n^c(t)$ lies between 0 and 1. The value 1 indicates the connection between n and c, whereas 0 shows that they were never connected. Here, $T_n^c(t)$ is the time increment, and $Q_n^c(t)$ is the time duration while c and n remains connected.

2.3.1 Net destination queue waiting time

$$\Omega_n^c(t) = \sum_{i=0}^{N}\left(\tau - a_{n,i}^c\right) \tag{2}$$

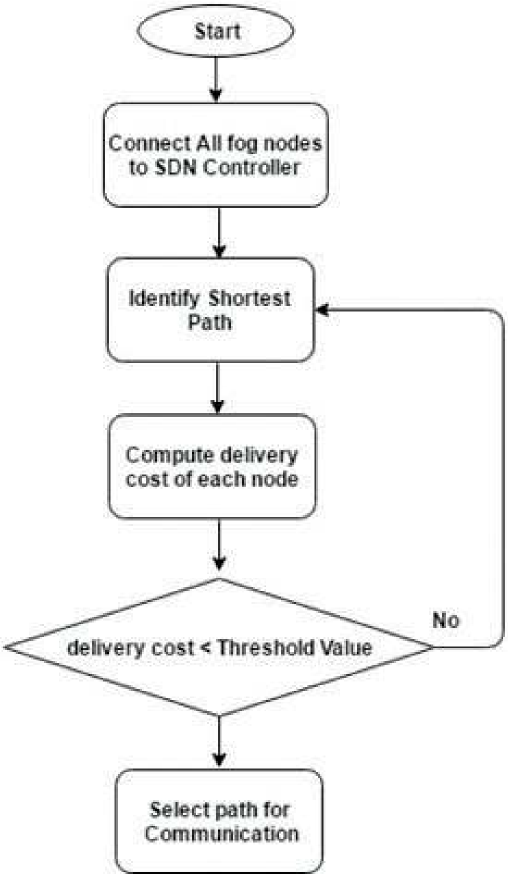


Figure 7.
Workflow to find the shortest path.

Here, τ id the present time and $a_{n,i}^{c}$ is the arrival time of packets i. Since the queue waiting time is used to predict the congestion, delivery cost can be considered as an exponentially increasing function. Hence, the delivery cost to c via n is computed as:

$$C_n^c(t) = \Omega_n^c(t).\left[1 - \Theta_n^c(t)\right] + C_n^c(t-1) \tag{3}$$

Thus, the shortest path with least congestion is identified by pulling packets toward the neighbors that have the smallest queue. It helps the SDN controller to set the threshold value for decision making.

2.3.2 Modules placement strategy in the Optical-Fog network

In order to deploy gaming modules, an algorithm is proposed that utilizes the Edge-Fog layer and Optical-Fog layer in the Optical-Fog network. The proposed algorithm places gaming modules using the SDN topology and iterates over all paths. Here, it places modules on the devices in incremental fashion starts from edge devices d_{Edge} to the optical devices $d_{Optical}$ and to the cloud data-centers. The modules that can be placed for each fog device in the path $\varepsilon\, d_{Edge} \cup d_{Optical}$ are identified by computing the processing requirement against the available capacity of fog devices.

A module M is placed on a fog device d_{Edge} or $d_{Optical}$ only if all other modules are already placed in the bottom-up path.

Algorithm Optical-Fog-based gaming modules placement

```
Data: $M$
while $P \varepsilon$ Across all SDN paths do
    List PlacedModules;
    while Fog devices $(d_{Edge} \cup d_{Optical}) \varepsilon P$ do
        List ModulesToPlaced;                    /* Bottom-up traversal*/
        while module $g \varepsilon$ GammingApp do
            if All predecessors of $g$ are in PlacedModules then
                Add $g$ to ModulesToPlaced;
            end
        end
    end
    while module $M \varepsilon$ ModulesToPlace do
        if $(CPU_M^{req} < CPU_{d_{Edge}}^{Avail})$ then
            Allocate $M$ on $d_{Edge}$ ;
            if $(!CPU_{d_{Edge}}^{Avail})$ then
                Allocate $M$ on $d_{Optical}$ ;
            end
        else
            Allocate $M$ on $d_{Optical}$ ;
            if $(!CPU_{d_{Optical}}^{Avail}))$ then
                Choose $M'$ such that $(M' > M$ AND $M'$=Less-Delay-Sensitive) if $(!NULL)$ then
                    Allocate $M'$ on cloud data-centers;
                    Allocate $M$ on $d_{Optical}$;
                else
                    Allocate $M$ on cloud data-centers;
                end
            end
        end
    end
end
```

3. Performance analysis

The real-time gaming applications and CPS systems require ultralow latency, minimum energy consumption, and optimum bandwidth. The proposed Optical-Fog layer provides the desired QoE by evaluating the following parameters such as latency measure, energy consumption and bandwidth usage in contrast to the traditional cloud computing.

3.1 Latency measure

The proposed system utilizes the Optical-Fog layer that reduces the delay and improves QoE. The latency measured in the context of delay is the most concerning issue. The communication between ONU and OLT is supported by the multi-point control protocol (MPCP) which is a frame-based protocol [15]. Here, only GATE and REPORT messages are exchanged between OLT and ONU. So, in the Optical-Fog network, the delay is measured as the time between the arrival of its last bit at ONU and the arrival of its last bit at OLT. The delay $tD(f_i)$ is the computation of adding three basic components shown as:

$$tD(f_i) = \Gamma_i + t_p + T_R \tag{4}$$

Alternatively, it is the time during which the respective REPORT message reaches at the OLT completely, where Γ_i represents the one-way propagation time of ONU_i, tp represents the time between the request arriving at ONU_i and the start of the next REPORT message, and T_R represents the time duration of REPORT message [16]. Thus, the Optical-Fog layer processes more smart applications which require ultralow delay as well as efficient QoS requirements.

3.2 Energy consumption analysis

For computing energy consumption, only the edge devices of the network is a concerning issue because energy consumption by the PON channel is negligible. Thus, the total energy consumption is computed as:

$$\Delta E = E_{Edge-Fog} + E_{Optical-Fog} + E_{cloud} \tag{5}$$

- $E_{Edge-Fog} = \Sigma(E_{Edge-devices})$ represents the energy consumed by all edge devices.
- $E_{Optical-Fog} = \Sigma(E_{ONU} + E_{OLT} + E_{PON})$ represents the energy consumed by the optical elements which is negligible.
- E_{cloud} is the energy consumption of cloud data centers.

The proposed framework computes most of the computations at the Optical-Fog layer which reduces the overhead on the cloud data centers. Thus, QoE is improved by minimizing the overall energy consumption.

3.3 Bandwidth measure

Real-time applications require more bandwidth to process the extraordinarily huge volume of data. Thus, the traditional cloud system increases the overhead on communication bandwidth which results in increasing delay and poor QoE. To compute the communication bandwidth constraint, the traffic rate is assumed to be dispatched from the fog node i located at Edge-Fog layer to the server j located at cloud data center through the transmission path [17]. There is a limitation $\lambda_{i,j}^{max}$ on the bandwidth capacity of each path which is computed as:

$$0 \le \lambda_{i,j} \;\le\; \lambda_{i,j}^{max}\; \forall_i \epsilon N_{fog} \text{ and} \forall_i \epsilon M_{cloud} \tag{6}$$

Here, N_{fog} represents the set of fog devices where M_{cloud} is the set of cloud data center servers. The optimum utilization of Optical-Fog network is more effective than the traditional cloud.

4. Conclusion

The utilization of optical resources provides several benefits such as high scalability, optimum bandwidth capacity, ultralow delay, and very less energy consumption. A novel concept of FRF and ONV is used to create *OpticalFogNode* in SDN-based optical network technology. In the realization of the SDN-based optical network in fog/cloud environment, the optical network uses SDN controller efficiently to identify the shortest path (with the least congestion) to minimize delay. Also, the proposed framework effectively enhances the QoE by using the proposed module placement algorithm which enhances the QoE and makes applications more entertaining. The realization of CPS-based tasks requires optimum placement strategy which is one of the concerning issues. The proposed algorithm efficiently finds the shortest path by utilizing the concept of SDN over the optical network. The novel concept of configuring *OpticalFogNode* successfully implemented to fulfill the requirements of the CPS system. Further, the performance of the proposed system is evaluated by effectively interpreting the delay measure, bandwidth usage, and energy consumption. Finally, Optical-Fog-based deployment provides an effective platform which enhances the QoE for smart applications.

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