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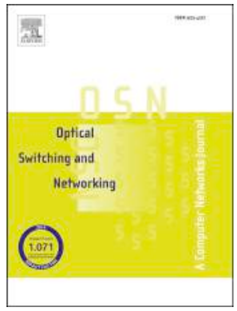

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SNA based Resource Optimization in Optical Network using Fog and Cloud Computing

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Abstract

Optical transmission has emerged as the most cost-effective technology to implement high-bandwidth based communications and to transmit the huge volume of data with low latency. Fog computing extends cloud computing to improve efficiency and reduces the amount of data to be transferred to the cloud for data processing, analysis, and storage etc. In this paper, a new fog layer among optical elements is proposed that utilizes the resources of the optical network. It uses passive optical network (PON), optical line terminals (OLTs) and optical network units (ONUs) to deliver cloud-based services more effectively with minimum latency. A large number of jobs and limited resources in fog layer lead to the deadlock that affects the Quality of Service (QoS) and reliability in heterogeneous fog and cloud environment. Therefore, Social Network Analysis (SNA) based deadlock manager is proposed with a new concept of Free Resource Fog (FRF) that helps to remove deadlock by collecting available free resources from all running jobs. In order to utilize resources and minimize the response time of the submitted job, a rule-based algorithm is proposed that assigns priorities to the jobs and provides resources accordingly from fog and cloud. In addition, energy consumption and latency measure are presented those reflects the QoS as well as reliability to end users. Gephi is used for the implementation of SNA based deadlock management whereas Cloudsim is used to evaluate the utilization of fog and cloud computing resources using Resource Pool Manager (RPM). Finally, we conclude that optimum resource utilization and latency measures can enable future computing with optical fog systems.

Keywords:

Optical Network, Fog Computing, Cloud Computing, Social Network Analysis, Deadlock Management, Optical Fog layer.

1. Introduction

The optical technology has emerged as fast and reliable backbone network in computing paradigm. It can extend fog and cloud computing concepts by using its fundamental

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processing elements laying across the network. The passive optical network (PON) is an inexpensive, scalable and simple technology that can provide a most promising solution for cloud computing environment. It provides the on-demand capability, multi-layer oriented network management and optimization of computing resources of both cloud and underlying network [1]. For delivering cloud-based services (Infrastructure, Platform, and Software), PONs are considered as most effective and cost-efficient cloud-ready network due to their elasticity and on-demand bandwidth availability. Presently, they are more widely used by mobile 3/4/5G wireless networks to access cloud-based applications with minimum latency and less network congestion. In the rapidly growing use of cloud-based applications, fourth-generation, fifth-generation, future-ready sixth-generation and seventh-generation wireless technologies will play tremendous role to provide heterogeneous connectivity, device-to-device, and machine-to-machine communication etc.

Fog computing is a promising approach that brings cloud computing, storage, and networking services closer to the end user. It is rapidly benefiting many industries such as manufacturing, e-health, education, oil and gas, smart cities, smart homes, and smart grids. It processes data as well as real-time applications at the edge to reduce latency as compared to cloud computing which requires high bandwidth and remote processing. Fog computing nodes aggregate the computing resources at the edge. The critical data-sensitive computations to be processed on this layer and analysis part is sent to the cloud for further processing due to restricted storage and computing power of fog nodes. Even cloud and fog offer similar resources and services but fog computing is characterized by low latency with a wider dispersed and geographically distributed nodes [2].

In particular, fog computing infrastructure requires extensive research to solve many challenges such as Quality of Service (QoS), efficient resource utilization, deadlock, task scheduling and dynamic resource management [3]. Deadlock seems impossible in the cloud environment but is a more concerned issue in fog computing. Thus, deadlock in fog environment is always expected due to over demand of resources. Since traditional deadlock detection and prevention algorithms are not so efficient because the number of jobs and resources are highly dynamic and large in numbers in optical fog environment. Even the popular banker's algorithm also fails to maintain resource allocation metrics effectively in fog environment.

In this paper, a new fog layer in the optical network is proposed to improve fog computing capabilities. For optimum utilization of fog resources, Social Network Analysis (SNA) based deadlock manager is proposed that draws and maintains resource allocation graph for making essential decisions. Further, a concept of Free Resource Fog (FRF) is introduced at fog layer where un-utilized resources corresponding to currently running jobs are merged and can be utilized for new arriving jobs. In case, deadlock is identified, the Heterogeneous Service Manager (HSM) reallocates job that causes deadlock. In order to manage resource efficiency, a rule-based algorithm for resource pool manager (RPM) is also presented. Results indicate the effectiveness of proposed framework by using more efficient knowledge discovery to make smart decision for resource allocation.

This paper is organized as follows. Section 2 summarizes related work related to the use of the optical network in cloud computing, management of optical resources and concept of deadlock detection in heterogeneous fog and cloud computing. Section 3 describes proposed optical fog layer and SNA based deadlock manager for management of resources by introducing a new concept of Free Resource Fog. A rule-based algorithm is also proposed for RPM supported by HSM. Experimental evaluation is explained in Section 4. Performance analysis using energy consumption and latency measure is presented in Section 5. Finally, Section 6 concludes the paper. The acronyms used in this paper are defined in Table 1.

Table 1: List of Acronyms

PON	Passive Optical Network
OLT	Optical Line Terminal
ONU	Optical Network Unit
QoS	Quality of Service
FRF	Free Resource Fog
SNA	Social Network Analysis
RPM	Resource Pool Manager
HSM	Heterogeneous Service Manager
VPC	Virtual Private Cloud
MPCP	Multi Point Control Protocol
MAC	Media Access Control

2. Related Work

In today's computing paradigm, most of the research in optical network technology have a vital contribution in realizing cost-effective interconnection of multiple resources over cloud computing environment, especially managing network resources. In addition, latest trends in research are giving more attention to fog computing. Even though it is hard to find research work related to fog computing in the optical network and there is no research document on deadlock detection in fog layer of the optical network in Scopus database. So, different dimensions of fog computing in optical network and deadlock management are discussed in context of distributed and cloud computing.

Luo et al. [4] explored various resource management approaches in the passive optical network to handle the bottleneck in the network. The state-of-the-art schemes over time-division multiplexing are evaluated and analyzed by using a unified state space model. Zervas et al. [5] identified the operations between cloud service and network using a gateway to map service requests. They also provided a survey on resource allocation schemes and algorithms used in optical networking. To detect deadlock in the cloud environment, Lim et al. [6] proposed fault-tolerant, scalable and efficient deadlock detection algorithm based on a gossip protocol. This algorithm analyzes the behavior of constituent nodes and has significant advantages over previous deadlock detection algorithms. Contreras et al. [7] discussed a cloud-ready network architecture to support cloud services hosted in data centers. They highlighted the different issues in present transport networks and described the architecture. Their model is best suited for service delivery models where resources such as CPU or storage capacity are pooled dynamically using virtualization technology. Klinkowski and Walkowiak [8] proposed an efficient and cost-effective architecture for provisioning of cloud computing traffic using the elastic optical network. In contrast to traditional wavelength switched optical networks, this architecture is capable to provide both scalable bandwidth provisioning and flexible resource allocation for clouds.

Peng et al. [9] invented the role of optical network virtualization in cloud computing environments. They proposed an architecture to deliver Data-center as-a-service for future cloud computing using virtualization of the optical network. In addition, they provided guidelines for both the optical network and cloud providers for provisioning virtual infrastructure services. Wang et al. [10] proposed an architecture that guarantees minimum resource usage, early detection, and removal of deadlock with low complexity. They combined wavelength assignment method and a deadlock-free routing algorithm and achieved high throughput and low latency with respect to other packet switching techniques. Alyatama et al. [11] explored the importance of routing and spectrum allocation in the optical network and proposed an adaptive RSA algorithm. Their results showed the validity and robustness of proposed algorithm under multiple call type distributions, varying from light to heavy load traffic conditions.

Ofek [12] provided an algorithm for deadlock avoidance in optical hypergraph flow control for preventing deadlock. The optical hypergraph is similar to a centralized switching network where switching nodes are kept in the center location, and external nodes are distributed around switching nodes. Finally, a flow control protocol is presented for an arbitrary traffic pattern, that includes the algorithm to prevent overflow with maximum switching capability of the switching nodes. Bhatam et al. [13] proposed efficient resource provisioning in multi-domain optical networks using traffic balancing approach. A heuristic algorithm was designed for time-aware routing and wavelength assignment. Extensive simulated experiments were performed in MATLAB and results were compared with the existing ordering policies. None of the researchers has sighted into the utilization of optical network in fog computing as well as deadlock problem in fog environment.

3. Proposed Model

3.1. Fog computing over Optical Network

In order to handle real-time and bandwidth-intensive applications, new fog layer is proposed that leverages the computing resources of the optical network rather than cloud resources. Figure 1 shows the architecture of fog layers in the computing paradigm. The first fog layer is called Edge-Fog layer and the second layer is referred as Optical-Fog layer.

Optical-Fog layer utilizes PONs, optical line terminals (OLTs) and especially optical network units (ONUs) in the middle-ware of cloud computing environment. In an optical network, PON is connected to multiple OLTs and each OLT is connected to several ONUs varies from 16 to 256. These ONUs have their own processing, storage and interconnection capabilities those are used to design Optical-Fog layer.

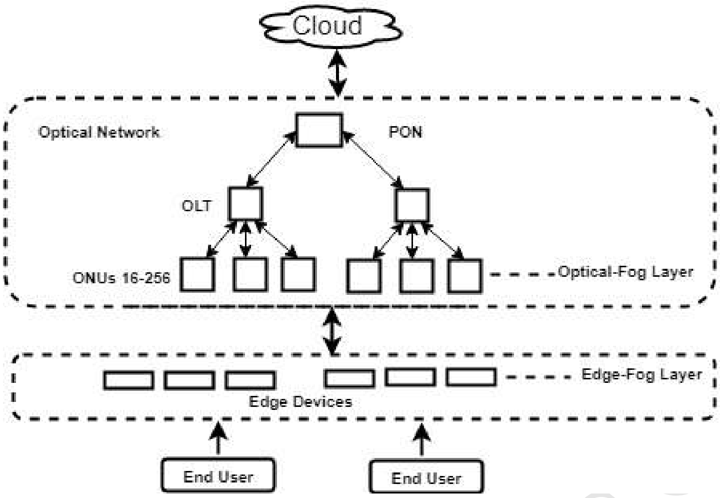


Figure 1: Fog layers in computing paradigm.

3.2. Proposed framework for SNA based Deadlock Manager

The proposed framework for SNA based deadlock manager is shown in Figure 2. It consists of two fog layers, rule-based RPM supported by HSM, and FRF for both layers. Each new non-bandwidth intensive job is processed at Edge-Fog layer and the jobs those require more computation and higher bandwidth are directly send to Optical-Fog layer. The SNA based deadlock manager updates resource allocation graph dynamically whenever a new job is added, removed, requests or releases resources. In case, a deadlock is detected at Edge-Fog layer or Optical-Fog layer, the required resources are borrowed from Free Resource Fog i.e. FRF_{Edge} or $FRF_{Optical}$ respectively to remove deadlock. The FRF collects the available free resources from already allocated jobs. If FRF_{Edge} fails to remove deadlock, the deadlocked job is shifted to Optical-Fog layer that follows the same process. This layer has high configurable computing resources such as ONUs those have more resources to process jobs in deadlock-free environment. In case, a deadlock is found at Optical-Fog layer, the particular job that causes deadlock will be shifted to VPC or public cloud. The rule-based RPM uses HSM to manage resources, remove deadlock and resource allocation in heterogeneous fog environment. The components of the proposed framework are explained in following sections.

3.2.1. SNA Based Deadlock Detection

Traditional techniques for generating resource allocation graphs to detect deadlock are not effective due to large, dynamic nature of requests and resource requirements of different end users. Therefore, SNA based technique is used that allows both nodes and edges to be added or removed at any instance of time using growth model. Consequently, deadlock can be easily detected even if it happens only for a fraction of time. The effectiveness of graph requires regular and dynamic updations with time which is provided by SNA [14].

In Figure 3a, resource allocation to multiple jobs at Edge-Fog layer is depicted. Since this layer has restricted resources and closer to the end user, the probability of consuming

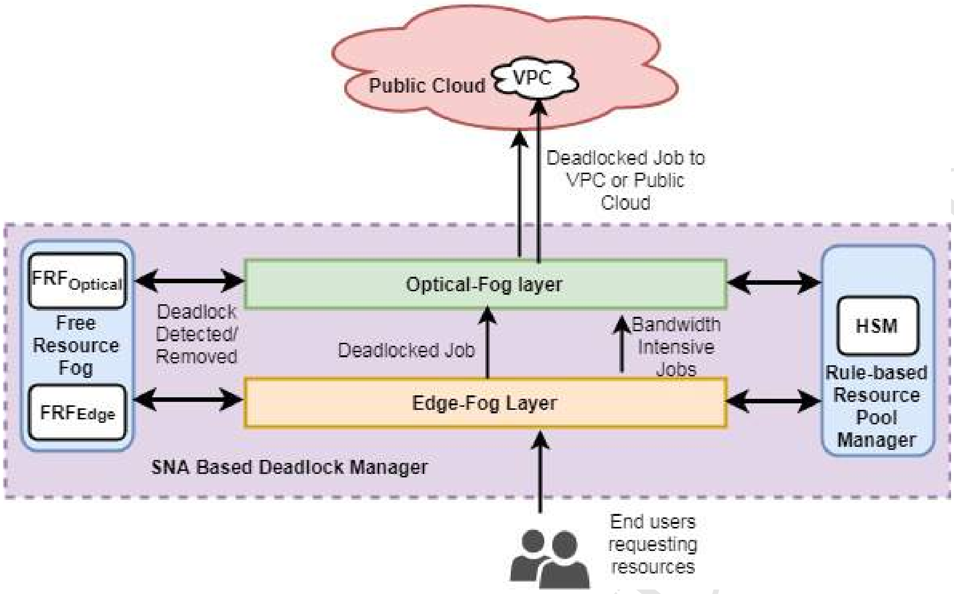


Figure 2: Proposed framework for SNA based Deadlock Manager.

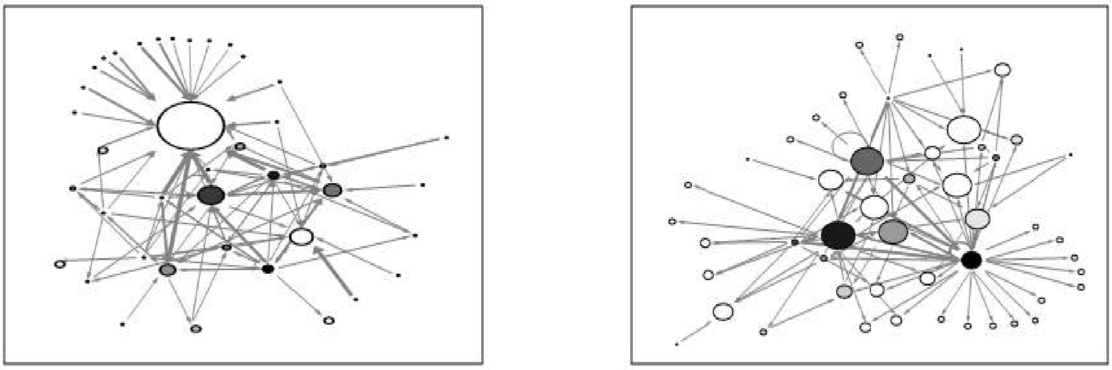
more resources by a single job is high. This situation leads to the occurrence of deadlock. On the other hand, Figure 3b represents the equal allocation of resources to multiple jobs at Optical-Fog layer where jobs consume resources with all most equal probability. The varying size of a circular node represents the number of resources used whereas the color intensity of node represents the number of resources requested by a particular job. Here, white color represents lowest and black represents the highest number of requests for resource.

For experimental setup, Gephi software [15] is used to model resource allocation graph. It is an open source software used for network exploration and manipulation. To model resource allocation graph for Optical-Fog layer, resources such as computation cycles (CPU), memory, storage space, and bandwidth are considered. Figure 4 shows the simulated resource allocation graph for deadlock detection in Optical-Fog layer where multiple color scheme is used to depict different jobs and resources. Whenever a cycle is identified between jobs and resources in the resource allocation graph, the counter of deadlock is increased by one. It is noted that all edges are directed in this simulation.

In case, a deadlock is detected, the node forming the cycle with the highest usage of resources is removed based on rule-based algorithm explained in the section ahead. Results indicate the usefulness of SNA in the detection of deadlock.

3.2.2. Free Resource Fog

The optimum utilization of fog affected when a deadlock occurs. It restricts multiple jobs from their execution at each layer. In order to remove deadlock, a novel concept of Free Resource Fog (FRF) is proposed that fulfills the requests of a particular job that causes deadlock. Jobs running at different fog layers have some free resources. The free resources of already allocated jobs are collected at each layer and merged to form a new fog known as



(a) Resource allocation at Edge-Fog layer. (b) Resource allocation at Optical-Fog layer.

Figure 3: SNA-based resource allocation diagrams by Deadlock Manager.

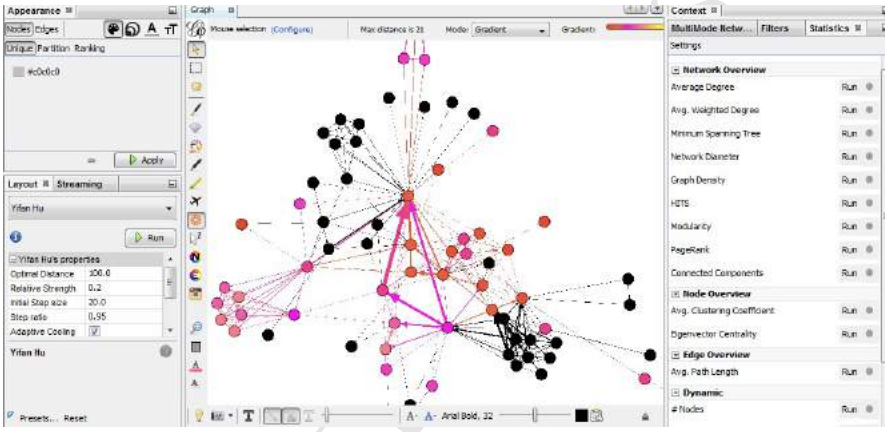


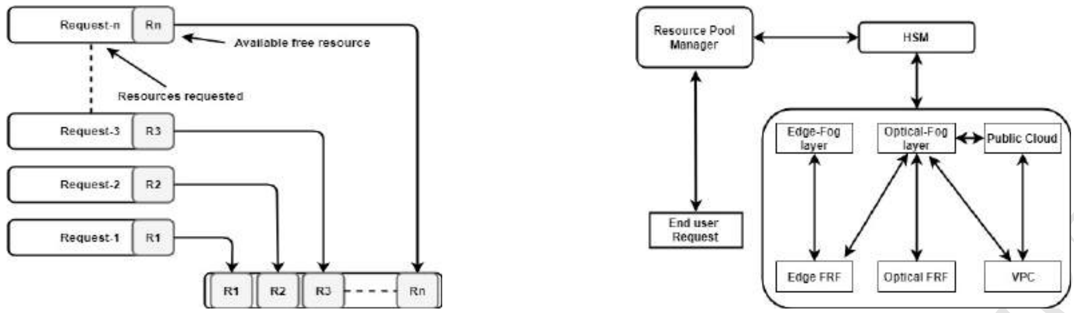
Figure 4: SNA based Deadlock Management in Gephi Tool.

FRF at their respective layers. The formation of FRF is depicted in Figure 5a. In this figure, $Request_i$ are the requests for resources raised by the currently running jobs. Similarly, R_i are the available free resources those are merged to create FRF. This FRF can serve new request to remove deadlock with minimum latency and without reallocating already running jobs.

The FRF_{Edge} and $FRF_{Optical}$ are computed whenever a deadlock is detected. It is noted here that if $Request_i$ requires resources which are already been allocated to FRF then $Request_i$ has to request resources freshly from the RPM using algorithm explained in the next section.

3.2.3. Rule-Based Algorithm

Initially, each job is submitted to RPM as shown in Figure 5b. On the basis of resource requirements (such as processing power, bandwidth, and acceptable security level), each job is categorized as High-priority or Bandwidth-intensive or Low-priority job. If the requested processing power or acceptable security level is high, the job is categorized as a High-priority job. Whereas real-time applications those require high priority along with higher bandwidth



(a) Free Resource Fog (b) Resource Pool Manager

Figure 5: Free Resource Fog and RPM of proposed resource utilization model.

are labeled as Bandwidth-intensive. All the other requests, as well as general routine tasks, are classified as Low-priority jobs. In HSM, Edge-Fog layer, FRF_{Edge}, Optical-Fog layer, $FRF_{Optical}$, public cloud and VPC interact with each other.

A rule-based algorithm is proposed for RPM to manage resources as well as the deadlock over resource allocation in heterogeneous fog environment. The security aspect of vital application and data is effectively handled during the processing. This proposed algorithm leads to optimize resource utilization of fog layers. Hence, desired reliability and QoS can be provided especially by Optical-Fog layer. Decisions to reallocate resources are taken on the basis of the following Algorithm 1.

- New represents new users request for VM comprising of memory, computing, storage and bandwidth resources.
- FRF represents new fog created by collecting free resources from already allocated jobs on fog layers.
- Virtual Private Cloud is used for a private cloud created within a public cloud with dedicated IP and resources where Public Cloud is any third party public cloud.
- $Avail_{Edge}$ and $Avail_{Optical}$ are available resources at Edge-Fog layer and Optical-Fog layer respectively.
- $Avail_{FRF_{Edge}}$ and $Avail_{FRF_{Optical}}$ are free available resources in respective FRF.
- $High\_priority$ request performs security sensitive data analysis and demands better response time.
- $Bandwidth\_intensive$ request is real-time or similar to $High\_priority$ requests that require higher bandwidth.
- $Low\_priority$ request jobs perform general routine tasks.

In the proposed rule-based algorithm, resources required by each new job (New) are evaluated. All new Non-Bandwidth-intensive jobs are executed at Edge-Fog layer. A new job can be executed on FRF_{Edge} in case resources in one go are not available in Edge-Fog layer. If the resources of FRF_{Edge} are already occupied, New is allocated to Optical-Fog layer that also executes the job in the same manner. In case, $FRF_{Optical}$ resources are also occupied, RPM has two options to execute the job on the basis of job's priority. If the requested new job is of Low-priority, it is allocated to the public cloud directly. Otherwise, High-priority job can be executed as shown ahead.

Algorithm 1: Rule-based Algorithm

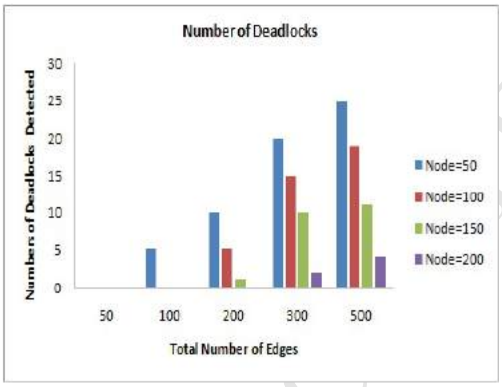
```
Data: New
if (New < Avail_Edge AND New = (!Bandwidth_intensive)) then
 |  Call Fog_Edge();
else
 |  Call Fog_Optical();
end

 Fog_Edge()
{
Allocate New on Edge-Fog layer ;
if (!Avail_Edge) then
    Allocate New on FRF of Edge-Fog layer ;
    if (!Avail_FRF_Edge) then
     |  Call Fog_Optical();
    end
end
}
 Fog_Optical()
{
Allocate New on Optical-Fog layer ;
if (!Avail_Optical) then
    Allocate New on FRF of Optical-Fog layer ;
    if (!Avail_FRF_Optical) then
        if New = (Low_priority) then
         |  Allocate New on Public cloud;
        else
            Choose p such that (p > New AND p=Low_priority);
            if (!NULL) then
                Allocate p on Public cloud;
                Allocate New on Optical-Fog layer;
            else
             |  Allocate New on Virtual Private Cloud;
            end
        end
    end
end
}
```

First, a Low-priority already running job which is using more resources in Optical-Fog layer or in $FRF_{Optical}$ than the requirement of the new High-priority job is shifted to the public cloud. Then the new High-priority job is allocated to the current Optical-Fog layer or $FRF_{Optical}$. Second, if no such Low-priority job is running on Optical-Fog layer or $FRF_{Optical}$, the new High priority job is allocated on a virtual private cloud. However, each fog layer or respective FRF resources are to be allocated first, if available. Subsequently, these resources have to be utilized to maximum extend.

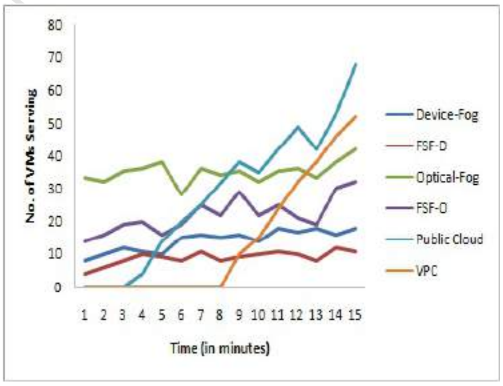
The proposed framework also considers switching of Virtual Machine (VM) between fog and cloud on the basis of (i) resource availability in each fog layer and (ii) priority of users requests. Such VM switching is also used by commercial clouds such as Amazon EC2.

4. Experimental Evaluation

In order to evaluate the proposed framework for fog layers and cloud environment, a large infrastructure is required. Subsequently, comparison with other existing models is also very difficult in real large scale environment. So, CloudSim v3.0.0 is used to simulate the proposed model. This framework uses the cloud on a single computer that provides consistent support for modeling and experimentation. Simulated data center comprises of fog layers as private clouds with 50 nodes for Edge-Fog layer and 100 nodes for Optical-Fog nodes respectively. In addition, a public cloud, and VPC are created with 150 and 200 heterogeneous nodes respectively. The node configuration for Optical-Fog layer is kept higher with additional bandwidth capability. Figure 6a shows a number of deadlocks with a different number of process nodes and connecting edges detected by SNA modeling using Gephi as discussed in the previous section. Resources are kept constant because resources for fog layers do not change with time. Simulation is carried out for 15 minutes with the arrival of 50 jobs per



(a) Total Numbers of Deadlock Detected.

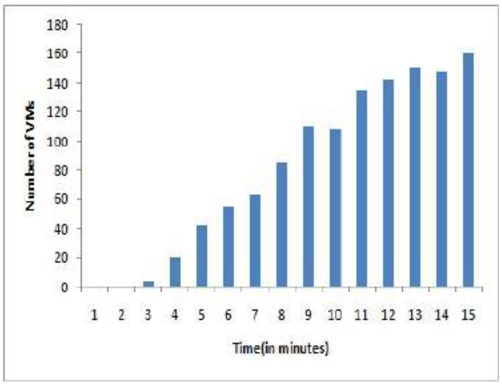


(b) Number of jobs submitted in proposed framework.

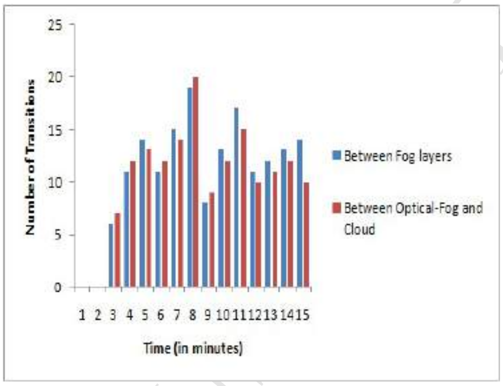
Figure 6: Number of Deadlocks detected and Jobs submitted in Simulated Environment.

minute of all High-priority, Bandwidth-intensive and Low-priority jobs. A rand() function of FreeMat [16] which is an open source software used to generate uniform and randomly distributed priorities of jobs. For comparing results, two fog layers are created as a private cloud with 50 and 100 heterogeneous nodes respectively and different jobs are submitted for 15 minutes. Simulation is done for equal number of combinations of priorities for end users jobs for both proposed (Rule-based) and non rule-based approaches.

Figure 6b shows the total number of jobs served during the simulation. Maximum numbers of virtual machines are created by fog layers or free resource fog to utilize its resources to the maximum extent. The number of virtual machines on VPC or public cloud increases when there are no available resources in fog layers.



(a) Waiting Queue in non rule-based Approach



(b) Number of Transitions between fog layers and between Optical-Fog and cloud.

Figure 7: Results for non rule-based approach v/s rule-based approach.

Figure 7a shows the waiting queue of the simulation above for the non rule-based approach. In this experimental setup, live migration of requests is considered. Job shifting time can be calculated on the basis of job's size and the bandwidth of the channel. A transition happens when job shifts from Edge-Fog layer to Optical-Fog layer or Optical-Fog to cloud. Figure 7b shows number of transitions with respect to time in simulated environment.

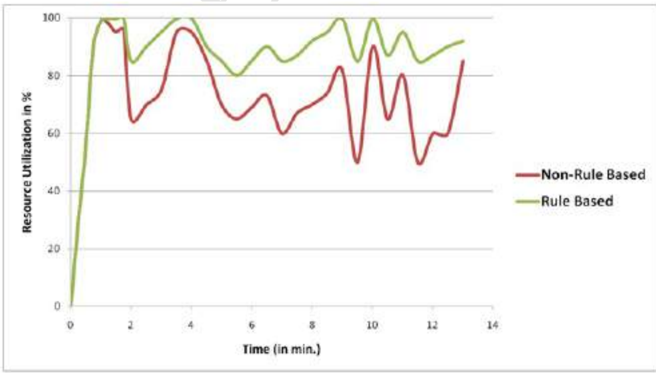


Figure 8: Resource Utilization

In the simulation, resource utilization of only computational resources is considered. The resource utilization for both rule-based and non rule-based approach is shown in Figure 8. In rule-based approach, Edge-Fog layer reaches its maximum number of requests it can serve after 3 minutes but due to the concept of FRF, extra resources can be used which in turn increases utilization of this fog layer. Similarly, Bandwidth-intensive request is more efficiently handled by Optical-Fog layer due to its higher configuration of nodes as compared to Edge-Fog layer.

It is observed from the results that average resource utilization in fog using non rule-based approach is 72% whereas rule-based approach leads to achieve 92% optimum utilization of fog resources. Furthermore, the proposed approach increases security for confidential data because it only permits the confidential information to store on VPC rather to an open public cloud.

5. Performance Analysis

The delay-sensitive traffic such as real-time voice and video requires higher bandwidth with minimum delay. The proposed Optical-fog layer can solve the problem related to large bandwidth demands of end users. In addition, the QoS is improved by evaluating energy consumption and latency measure which are concerning issues in the cloud as well as fog computing.

5.1. Energy Consumption Analysis

In order to evaluate the energy consumption of the proposed framework in the heterogeneous computing environment, the energy consumed by each layer is computed. At Edge-Fog layer all edge devices whereas PON, OLTs and ONUs are taken into account at Optical-Fog layer. Similarly, VPC and public cloud are also considered. The energy consumption by the proposed framework is shown by the following equation:

$$\Delta E = E_{Edge-Fog} + E_{Optical-Fog} + E_{VPC} + E_{Public} \tag{1}$$

- $E_{Edge-Fog} = \Sigma(E_{Edge-devices})$ is the energy consumed by all edge devices in Edge-Fog layer.
- $E_{Optical-Fog} = \Sigma(E_{ONU} + E_{OLT} + E_{PON})$ is the energy consumed by optical elements in Optical-Fog layer.
- E_{VPC} and E_{Public} are the energy consumed by virtual private cloud and public cloud respectively.

The computations performed only on cloud increases the energy consumption. On the other hand, our proposed framework performs most of the computations at Edge-Fog layer and Optical-Fog layer that leads to less overhead on the cloud and improves QoS.

5.2. Latency Measure

In ONU-OLT communication, Multi Point Control Protocol (MPCP) is being used. MPCP is a frame based protocol that uses five MAC control messages called REGISTER_REQ, REGISTER, REGISTER_ACK, GATE, and REPORT. Latency measure in the context of delay is considered as the most concerning issue to improve QoS performance [17].

Our rule-based framework reduces delay especially when Optical-Fog layer is being utilized. In the standard signaling scenario of PON, GATE and REPORT messages are exchanged between OLT and ONU. The latency measure or delay is defined for a request as the time between the arrival of its last bit at ONU and the arrival of its last bit at OLT in the optical network. In other words, it is the time duration when respective REPORT message completely arrives at OLT (or equivalent queue status update). Thus, the delay $tD(f_i)$ for request's frame is the sum of three basic components represented by the following equation as:

$$tD(f_i) = \gamma_i + t_p + T_R \tag{2}$$

where γ_i is the one-way propagation time of ONU_i, tp is the time between the request arriving at ONU_i and the start of next REPORT message (or equivalent queue status update) and T_R is the time duration of REPORT message [18]. The Optical-Fog layer processes more cloud-based applications those require low-latency performance and achieve efficient QoS requirements.

6. Conclusion

In this paper, two fog layers are proposed that reduce latency and optimize the resource utilization in fog and cloud computing environment by utilizing edge devices and optical elements such as PONs, OLTs, and ONUs in the optical network. The proposed framework uses SNA based deadlock manager that resolves deadlock effectively in the heterogeneous computing environment. RPM uses HSM that allocates jobs based on the availability of resources. It provides an effective solution to detect deadlock as well as for efficient resource allocation. Henceforth, it provides enhanced resource availability in the heterogeneous environment. The new concept of FRF and the rule-based algorithm used in RPM enhance the resource utilization up to 92%. The virtual private cloud is created within a public cloud to accommodate High-priority jobs only if fog layers or FRF are already pre-occupied. In this way, most of the jobs are served by fog layers those increase their resource utilization. The maximum usage of Optical-Fog layer provides energy efficient, cost efficient and low latency computing environment. Therefore, the proposal of Edge-Fog layer and Optical-Fog layer, free resource fog, SNA based deadlock manager and rule-based algorithm for RPM enables flexibility for secure and bandwidth-intensive applications with low latency and guaranteed QoS.

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