Cost function for delay (CFD) in software defined network with fog computing and associated IoT application

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Abstract. Fog Computing become an emerging technology and majorly adapted to IoT networks. In the IoT network Fog nodes interact directly with edge devices and create easy communication with reliable data transmission to store in cloud data centers. In this paper we proposed a Cost Function for Delay (CFD) in transmission of data from end devices to cloud data centers by passing through fog devices and other network devices in a multi hop based network. The total data transmission time included with many parameters including delay which occupies small amount of time in total data transmission time. The CFD evaluated for every local device on reach by each hop and at fog device where task offload dynamically. In our proposal we considered the greedy heuristic based approach to derive the solution effectively.

Keywords: Fog Computing, Cloud data centers, Cost Function for Delay.

1. Introduction

IoT is an emerging technology in the present days which can implement in all platforms in the world. The expansion of the IoT network with smart cities, V2V, Fog Computing and medical sectors leads to increase the number of devices, volume of data and traffic. IoT created trend with Fog computing for self managed areas and become new research. The expansion of the network and technology of IoT need some alternate for easy control with low cost for users. There are many challenges are there in the IoT like scalability, load balance, inter node latency, discoverability, routing, and traffic inter communication authentication. Many researches providing different kinds of solutions for different challenges. These is an alternate technology to overcome the challenges little more is Software Defined Networking (SDN)[1]. The SDN improves the network performance in association of virtualization. The main key aspect behind the SDN is Network Functions Virtualization (NFV). The research of NFV to virtualizes the network devices and topologies and whatever which are dedicated hardware. Here the network functions are decoupled from hardware of the network for them NVF provided flexible provisioning of the network with control of software[2][3]. With the motivation of the NVF the network development leads to Software Defined Network with more abstraction with data plane and control plane. The data plane of SDN in the southbound of architecture creates the device communications and topological
communication and interaction of the end devices. These topological structures fall into virtualization with the help of cloud computing or fog computing which leads to efficient network with less network components. By decoupling the network functions from SDN results in improved network performance in terms of network management, control and data handling. SDN is a best solution for present computing networks and it created more convivance to cloud computing. With dealing with individual devices the administrator can able to control the dataflow, routing and communication with helps of central control that is control plane. Control plane also provides the data of arbitrary change in the network, routing tables, control information and group information. SDN also less expensive because controlling and managing of network totally handle in a virtual manner and data forwarding devices in the network embedded with OpenFlow protocol which enables the SDN features in all devices and software. In the edge networks the Fog computing act as cloud to perform the concept of virtualization, storage and analytics. Most of the attributes of Fog computing are similar to the Cloud computing. It has many mechanisms and attributes in common with Cloud Computing. However, Fog can be distinguished from Cloud by its architecture, data processing, number of nodes, latency, connectivity and security. Fog nodes are decentralized in the network and created interface between edge networks to cloud storage or data centers. Fog computing directly provided the services to users devices and reduce network imbalance and traffic. Fog Computing can handle the different kinds of network devices such as such routers, gateways, bridges, and hubs and provides reliable communication with access points. As research analysis of experts voice, these devices can also handle by Cloud services but they are on centralized manner with all local networks. The decentralization of computing nature provide reliable services in all corners of the network. Based on this consequence Fog Computing included in smart cities, data center network and SDN. The nodes in the fog are virtualized with communication interfaces and infrastructure resources like routers, switches, access point and end devices. The data collected by end devices or IoT devices will not send their data to nearby fog nodes then process after that will forward to cloud. The data received by the fog node will filter and process then send to cloud to store permanently. Fog computing extends the Quality of Services of virtualization of large IoT applications and reduces the significant bandwidth and traffic. Consequently, the OpenFlow switches to handle aspects of node level decision taking optimally, fog node selection by access points and transmission path selection in the data transmission. In this entire architecture including end devices, SDN controllers, Virtualized servers, routers, access points, Fog technology and cloud technology. The virtualized node in the fog and cloud computing geospatially distributed in the network. The Fog nodes run with API for resources management and control. These APIs help in accessing of hypervisors, remote monitoring of physical devices and services on physical machines.

2. Related work
In the recent days SDN becomes the management of edge computing and IoT with association of virtualization. SDN with fog middleware which provides abstractions to the heterogeneous fog infrastructure and enables orchestration of fog services while considering end-to-end QoS requirements. Hakiri et al. [8] was discussed about software-defined wireless fog architecture towards how to reduce the time delay and load balance and routing optimization. Here SDN controller collects the signal to noise ratio (SNR) from each wireless device to manage the traffic among the fog devices. Chang et al. [9] discussed the energy-efficient task offloading scheme for fog computing. The author interpreted the process of queuing analysis, task offloading into fog nodes and queues at end devices and servers. Yousefpour et al. [10] discussed about task offloading in the virtual architecture. The author also explained about inter-fog communication and load balancing and minimization process of overall delay. The system did not considered the dynamic network situation with presence of IoT [18-20]. Here data can receive by the fog nodes and access points in the networks. However while receiving the data from one device to other the responsibility of SDN is to provide optimal paths in the routing, selection of fog node for decentralized pat of network and correct decisions when task computing. These all things should be happen dynamically at every time and dynamic task offloading efficiency calculated based on the Integer Linear Program (ILP) and greedy heuristic.
The SDN controller calculated the current network scenario with help of OpenFlow switches in a virtual nodes based on some parameters like IoT total traffic, transit traffic, traffic access type, times delay and state of OpenFlow switches[11]. The SDN controller transmits data of IoT passed to core network with help of Fog nodes. Finally the OpenFlow switches synchronize the transmission of IoT device data with cloud storage with association of fog node and access points.

Figure 1. Software defined network with fog computing and associated IoT application.

In the IoT it is the combination of network nodes with access point. Figure 1 illustrate the concept of how the edge devices interact with nearby roadside devices or access points in wireless communication and consequently the access points connect to the decentralized fog nodes. These access points and fog nodes also will come under the SDN controller [12][13]. The Figure 1 interprets the actual implementation of the SDN controller and cloud virtualization in IoT. Under on access point there are many nodes are communicate and also utilize the cloud resources. These devices are under the data plane of SDN architecture where nodes are available and communicate. Here the OpenFlow based switch manager used to communicate the network with associated of topology manager. The IoT generate the huge data in the network which leads create the more traffic [14].

3. Problem formulation
Here we proposed the Cost Function for Delay (CFD) model for Software Defined Network with Fog computing in association of IoT application. We considered the task execution in local node, data offloading decision, access point choice for selecting fog node, fog node decision for offloading, queuing, pre-processing of data and path to fog node in presence of SDN are considered as parameters for our proposal. Figure 2, illustrated concept queuing at fog nodes and selection of access points by edge devices and decentralized fog node communication with access points. The main contributions of my works identifying of delay model in data transmission and here we considered the greedy heuristic based approach to derive the solution.
3.1. A Cost function for delay (CFD) model:

The software-defined fog network included with set of access points, \( A \), set of fog nodes, \( F \), and set of IoT devices, \( D \). The set of links \( L \) establishes dynamically among the nodes to transmit and access the data. The relationship between the access point, fog nodes and edge devices represented with directed as \( G = (A \cup F, L) \). Here \( A \cup F \) defines the union of access point nodes and fog nodes in the relation of link \( L \). The characteristic of fog nodes will be the physical servers or virtualized devices and they are provisioning and de-provisioning on the access points [1][15]. Here the provisioning of devices create the more availability but increase the cost of network, let’s consider the total number of fog nodes less than number of AP nodes i.e., \( |F| < |A| \). The computational task in the network of each IoT devices \( k \) which executes in any node of IoT devices \( D \) at given time \( t_k \). A task \( t_k \) depends upon size of input data \( s_k \), segments \( s_{g_k} \), total CPU cycles need for execution \( w_k \). Then \( t_k \) given as: \( t_k := (s_k, s_{g_k}, w_k) \). The IoT devices connected to fog computing based on multi hop communication network with access points. The task offloading request received from IoT devices to fog nodes in a multi-hop communication. The role of SDN controller will be taking of optimal decision on each task offloading request to fog nodes with respect to that SDN enables the access points. The data generated at end device and propagate in the network and finally store in the cloud by crossing the many devices, model and integrated technologies. In the total propagation time also occupies the some delay. Here a variable \( z_k \) where \( k \in D \). If the task computed locally then the \( z_k \) will zero that is \( z_k = 0 \).If the task offloaded in the fog related devices then we define \( z_k \) as one that is \( z_k = 1 \). The task \( t_k \) total execution time in locally calculated based on the preprocessing and execution of the task at each node.

The time taken for pre-processing:
\[
\delta_k^{\text{pre}} = \frac{s_k}{f_k} + \sum_{i=1}^{m} \frac{s_{i,m}}{f_k} \quad (1)
\]

The time taken for execution:
\[
\delta_k^{\text{exe}} = \frac{w_k}{f_k} \quad (2)
\]

Total execution of a task \( t_k \) at a node will be \( \delta_k^{\text{loc}} = \sum_k (\delta_k^{\text{pre}} + \delta_k^{\text{exe}}) \quad (3) \)

Where \( f_k \) represents the CPU frequency of device \( k \in D \) and \( m \) denotes numbers of segments. If task \( t_k \) offloaded to the fog devices then the delay will defined based on a)Transmission time of \( s_k \) to nearby access point. b) Total propagation delay from access point to fog node. c) Total queuing delay at a fog node d)Pre-processing of data at each node e)Execution time of a task \( t_k \) at fog node. We consider a long-distance path-loss model with log-normal shadowing given: \( PL_{[\text{dB}]} = 140.7 + 36.7\log_{10} d_{[\text{km}]} + N [16] \). As per the Shannon’s the maximum data rate between device and access point given as:
\[
r_{kd} = B \log_2 \left( 1 + \frac{p_k^{[\text{dB}]} - PL_{kd}}{\delta^2} \right). \quad (4)
\]
Where $p_{g_k}^x$ is transmission signal power of device $k$, and $\delta^2$ represents the noise power.

The IoT device $k \in D$ can access the network by associating with access point $i \in A$, using existing association policies $X$ such that $X(k) = i$.

Based in the above scenario the offloading time for $sk$ from the device $k$ given as:

$$\delta_k^{tx} = \frac{sk}{r_k x(k)}$$  \hspace{1cm} (5)

To describe the state of a link is using for offloading the task $tk$ or not will described by a binary variable $x_{ij} \in L$. Here the link $(i,j) \in L$ between two points. The transmission of the data from access point to fog node on a link $(i,j)$ creates small amount of delay called as propagation delay for offloading the task $tk$ given as:

$$\delta_k^{prp} = \sum x_{ij} x_{ij}^k.$$  \hspace{1cm} (6)

Kleinrock independence approximation [17], the task arrival at a particular fog node $j \in F$ may be approximated as a Poisson process, and task arrival rate given as:

$$\lambda_j = \sum_{i} x_{ij} x_{ij}^k.$$  \hspace{1cm} (7)

In the each node the task execution follows the multithreading model. Based on that when task arrives, it should be wait in the queue until it fetch for process. The queuing delay at the fog node $j \in F$ is given as:

$$\delta_j^{que} = \frac{1}{\mu_j - \lambda_j}.$$  \hspace{1cm} (8)

Where $\mu_j$ denotes the service rate. The task offloading state verified for a fog node denoted by a binary variable $y_j \forall k \in D$. If $y_j^k = 1$ then the corresponding fog node selected for task execution. The execution time taken for task in the fog node given as:

$$\delta_k^{fog} = \sum_{j} \frac{w_k}{\tau_j} y_j^k.$$  \hspace{1cm} (9)

In the multi hop network data process and execution done at each node. Therefore time delay calculated from source device to cloud storage which may contains $n$ number of hops. The Cost Function for Delay(CFD) in the multi hop network given as:

$$J(x,y,z) := \sum_n \left( \sum_k [(1 - z_k) \delta_k^{loc} + z_k (\delta_k^{tx} + \delta_k^{prp} + \delta_k^{fog})] + \sum_j \delta_j^{que} \right).$$  \hspace{1cm} (10)

Misra. [1] explained the total transmission time in the network including delay. The CFD the delay model slide difference with delay calculated by Mistra. The proposed CFD model considered the data preprocessing and evaluated for $n$ number of hops.

4. CFD Model result and discussion

The total delay calculated for each node and it depended on number of hops from source to destination. Here hop count included with fog nodes. So that if we create the network with more number of fog nodes leads to decrease the number of hop counts because of more availability for data offloading[18]. Consequently average delay time increase with respect to number of fog nodes. In the result explained with comparative analysis among CFD model, Delay Aware Greedy-Path(DAGP) and Random-Offloading Random-Path (RORP) model to show the differences. The RORP generally goes on random optimal path selection but RORP during the offloading process the path selection will not be considered as major aspect for RORP. This leads to increase the delay compared to normal situation. On the other hand the DAGP identify the shortest path based on the greedy method but it will not be considered the major issues as one parameter that is bandwidth utilization. In the path selection RORP goes on more hops compared to DAGP. So obviously according to hop count the delay time will be higher in RORP then DAGP. But delay not only calculated by number of hops but also other parameters like bandwidth. According to bandwidth utilization DAGP created more delay. Figure 3, presented the delay differences among RORP, DAGP and CFD. The graph result showed the optimality by
implementation of CFD in Fog based IoT. In this below comparative study the all three algorithms are well performed in their circumferences and environment and our research wants to identify perfect delay model for Software Defined Network with Fog Computing and associated IoT application. Each model effectively worked with their concerned parameters and network environment but not works well in all kinds of conditions. In this paper all issues of each algorithm not presented. Our research and study presented only delay process while data transmission in the network. So that here presented result interprets differences in delay among the three models. Misra. [1] explained the total transmission time in the network including delay with below parameters.CFD the delay model slide difference with delay calculated by Mistra and accordingly result scenario also change. The sample parameters for network construction included with fog and IoT devices showed in Table 1. The Figure 3 showed the sample output of delay deference with respect to number of fog nodes. Number of tasks uploading into the network of fog nodes the offloading and delay differences presented in the Figure 4. Our goal to reduce the delay and delay differences even the network uploaded with more number of task.

| Parameters                  | Value                      |
|-----------------------------|----------------------------|
| Number of vehicles          | 20–100                     |
| Number of Access Points     | 15                         |
| Area                        | 1200 m × 1200 m            |
| Number of Tasks             | 100–1000                   |
| Number of Fog Nodes         | 5                          |
| Simulation time             | 300 s                      |
| Average Task Size           | 450KB                      |
| Transmission range          | 450 m                      |
| Vehicles speed (min)        | 0–4 m/s                    |
| Vehicles speed (Max)        | 5–25 m/s                   |
| Wireless Channel Bandwidth  | 20MHz                      |
| Receiver sensitivity        | −71.65 dBm                 |
| Traffic type                | User datagram protocol     |
| Antenna type                | Omni-directional           |
| Simulation scenario         | roads with various intersections |
Figure 3: Delay difference with respect to number of fog nodes.

Figure 4: Delay reduction with respect to number of tasks.

5. Conclusion
In this paper we presented Cost Function for Delay model for Software Defined Network with Fog computing and associated IoT application. Our research concentrated only on finding of average delay from generating source point to destination point while crossing the many other nodes including fog devices. Finally we calculated a delay model for multi hops based network. In the future our research continues with energy consumption, transmission time, path selection and link utilization in the SDN based Fog Computing.

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