HealthQoS : A Dynamic Meter selection scheme for effective QoS for Healthcare 4.0 in a Software-defined Fog environment

Priyanka Bardalai, *Student Member*, IEEE, Nabajyoti Medhi, *Member*, IEEE, Dilip Kumar Saikia, *Senior Member*, IEEE

***Abstract*—In this paper, we propose a Quality of Service (QoS) enabled Meter band selection scheme for a Software-Defined Fog architecture based Internet of Medical Things (IoMT) based healthcare network. In our proposed scheme, Health-Qos, network statistics is collected through Openflow-enabled fog nodes and switches and appropriate meter rates are assigned to the incoming flows with respect to different QoS constraints. The proposed solution is implemented in a Mininet emulator and RYU controller. By means of simulation under various environments, we verify that the proposed scheme provides a near-optimal results w.r.t some wellknown QoS metrics. Health-Qos offers substantial efficiency of zzzzz over other approaches for PDR, PLR, Average Delay and Average Jitter metrics respectively.**

***Index Terms* - IoMT, SDN, NC.**

I. Introduction

With variety of classes of traffic generated by numerous sensor devices, QoS provisioning of every class of traffic is important. For example, for a sensor based hospital network, appropriate bandwidth should be allocated to sensor data as well and tele-monitoring and robotics related video data. To support this flexibility of network management, Software-Defined Network is used along with fog computing which enables for data to be processed and stored near the sensors or in the hospital premises thereby bringing in very low latency to the system. Therefore it is extremely important to provide sufficient amount of adequate bandwidth, throughput to different classes of traffic data on a per flow basis. The architecture (Fig 1) consists of several IoMT sensors connected to gateway devices and OpenFlow-enabled switches acting as fog devices.

A. Motivation

Therefore, a QoS aware Optimized Meter band selection approach is proposed for a Software-Defined Fog environment. Health-QoS helps to achieve per flow maximum throughput while satisfying its QoS requirements.

B. Contributions

To summarize, the main contributions of the work are as follows :

1) A QoS aware meter rate selection scheme is proposed for a Software-Defined Fog environment to improve throughput of priority flows in a Healthcare environment, called Health-QoS.
2) To guarantee QoS to various time-critical healthcare services, we design and implement a meter band selection algorithm. The algorithm divides incoming traffic at the fog nodes into multiple priorities based on their latency and throughput requirements and selects an optimal meter band for it.
3) We further validate the model based on the case studies under different experiments and scenarios.
4) We show that the model is general and flexible, thus can be applied in various networking systems. We also discuss the factors that may affect the delay and throughput.
5) We implement the proposed framework in a real testbed, and the achieved results are compared to existing state-of-the art solutions.

The rest of the paper is organized as follows. Section II we introduce our system model and give a detailed description of the proposed SDN control environment. Experimental results and analysis are presented in Section III. Conclusion remarks are given in Section IV.

II. The Proposed Architecture and Problem Formulation

Proposed model visualizes the underlying Software-Defined Fog Environment in the form of a graph (G), consisting of multiple Openflow-enabled switch nodes (V), and communication links (E). The proposed architecture and respective problem formulation are detailed in the following subsection.

A. The System Model

A model of the Software-Defined Fog architecture for healthcare and the traffic flow queuing model with priorities is illustrated in Fig 1. It shows N number of IoMT sensors connected through a gateway device which sends data to Openflow enabled fog devices which are in turn connected to a centralized SDN controller. We classify IoMT sensor data into three priorities based on their delay tolerance and latency requirements, i.e. emergency service, real-time streaming and patient monitoring, with priority high to low as shown in Fig 1. High priority means the corresponding service requires least delay and latency to meet its QoS requirements. The scheduler uses a pre-emptive First-In-First-Out (FIFO) policy to schedule the incoming flows so that when a high priority flow request is received, it interrupts the computing of the current flow with a low priority flow. Each traffic flow is generated by the IoMT sensors which are processed in the fog nodes which maintains a constant processing rate of R bits/sec.

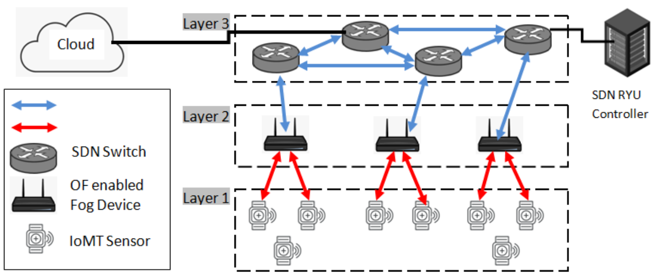


Fig. 1. Architecture

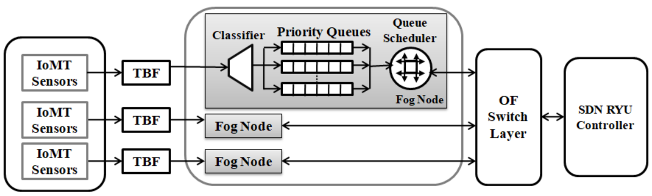


Fig. 2. Traffic queuing model to schedule arrival flows and then calculate an optimal path to satisfy the delay bounds

B. Problem Definition

Problem to select appropriate meter band of an incoming traffic. Meter bands will be selected based on priority of the traffic and how selecting the meter band will in turn maximize the throughput of the network.

Given a network G = $\{V, E\}$ where each link $e \in E$ has a limited capacity $c(e) \in^{+}$. We denote set of flows **N** $= \{0, ..., N\}$ and set of meter bands **M** $= \{0, ..., M\}$. We use a tuple $\{s_i, d_i, p_i\}$ to represent flow i, for $i \in \mathbf{N}$ in which s_i is the source address, d_i is the destination address, and p_i is the priority weight factor for a flow . Each flow priority is assigned as a normalized fractional weight to signify its importance with respect to the other flows. All weights should sum up to an exact 1, i.e. $\sum_{i=1}^{N}$ .The priority of flows is associated with a corresponding rate requirement $[r_{\min}, r_{\max}]$, where $r_{\min}$ denotes minimum required rate(e.g. back office patient records) and $r_{\max}$ represents maximum data rate(e.g. robotic surgery). In the following, we assume that the priority of flow is known before any execution. Moreover, N independent flows are partitioned into M + 1 disjoint sets, where each set is considered as a batch, i.e., a "large" flow. The problem is to select an appropriate meter band to each flow. We leverage an indicator $x_{ik}, \forall i \in N, \forall k \in M$, to represent the meter allocation, i.e.,

$$x_{ik} = \begin{cases} 1, & \text{if flow i is assigned to meter k,} \\ 0, & \text{otherwise.} \end{cases}$$

We denote $\mathbf{X} = \{x_{ik}\} \in \{0,1\}^{N\times(M+1)}$ the meter allocation matrix, and $\mathbf{x}_k = [x_0^T, x_1^T, ..., x_k^T, ..., x_M^T]^T$, where $x_k = [x_{1k}, x_{2k}, ..., x_{Nk}]^T$, the column vector correspond to **X**.

Let P_{ik}, TQT_{ik} be the processing time of flow i, transmission and queuing time before flow i is assigned to meter k. ST_{ik} is the start time of the processing of flow i by meter k. The processing time of each flow is equal to the flow size (in packets) divided by the resource processing power (in packets per second). Let Q_i denote the size of flow i and P_k denote the processing power of meter band k, then the processing time is given by $PT_{ik} = Q_i/P_k$. The transmission and queuing time of flow i from its source node to the meter band k in the fog node, is given by $TQT_{ik} = \sum_{i=1}^{k} \overline{\theta}$ where $\overline{\theta} = \theta_{tr} + \overline{\theta}_q$. θ_{tr} is the deterministic transmission delay that can be calculated beforehand for fixed packet lengths and link transmission rate, and, $\overline{\theta}_q$ is the average value of the queuing delay.

Each fog node when receives an incoming flow assigns a meter $k \in M$ to the flow, process the incoming flows, and return the result to the SDN controller in sequence. Flows are serviced on the basis of its priority. We assume that the network capacity is sufficient to support the minimum required rates of all flows.

TABLE I
DIFFERENT SENSOR NETWORK SCENARIOS

Scenario Number	Topology Name	Nodes	Edges	Controller Node(s)
1	AttMpls	24	57	1
2	Goodnet	17	31	1

TABLE II
PRIORITY TABLE FOR THE PROPOSED METHOD

Traffic Type	Q_ID	DSCP
Compressed and full motion video	3	EF(46)
Tele-surgery	3	EF(46)
Digital audio stethoscope, Mammogram	2	AF(10)
Digital blood pressure monitor	2	AF(10)
Scanned X-ray	2	AF(10)
Ultrasound, cardiology, radiology	2	AF(10)
Electronic Health Records	1	BE(0)

C. Maximum Throughput Optimization

It is important to optimize the maximum throughput of the network to improve network performance. The objective is to maximize the per flow throughput as detailed in Eq X. This helps in . The related mathematical optimization formulation is detailed below :

The throughput of a flow is mainly contributed by number of payload bits per second received correctly.

$$T_k = \sum_{i\in N} x_{ik} \frac{B_i}{S_i} = \sum_{i\in N} x_{ik} Y_{ik}$$

where, $Y_{ik} = (\frac{B_i}{S_i})$. Here, T_k denotes the total throughput of the network.

Hence, the final objective of the overall mathematical formulation is detailed in the form of Overall Utilization (OU) and is defined in Eq. X1.

Thus, the overall objective of the MILP problem of this work is described in the form of Eq. X2. It is subjected to the fulfillment of all above mentioned constraints.

Maximize : OU

$$t(\mathbf{X}, k) = \max_{k \in M} T_k$$

III. Proposed optimization of meter band selection with greedy heuristics

This work discusses the QoS aware throughput optimization to improve the over QoS in a Software-Defined Fog environment. The The Openflow enabled Fog nodes and switches update the controller about their dynamic statistics periodically, the controller offers the QoS aware control instructions to the fog nodes based on the collected network statistics. An optimal meter band allocation decision that maximizes the throughput is proposed.

Algorithm 1: DyMSS (G,T)

Input: G,T
Output: $Max\_Throughput$
Cur_Th = X; $Opti\_Th = Cur\_Th$;
for *each iteration time* **do**
    $Cur\_Th = Opti\_Th(G,T)$;
    if $Cur\_Th < Opti\_Th$ **then**
        $Opti\_Th = Cur\_Th$;
$Max\_Throughput = Opti\_Th$

Algorithm 2: Opti_Th (G,T)

Input: G,T
Output: Cur_Th
$Formal\_Expr$ = MeterAssign(G,T);
Cur_Th = $Solve(Formal\_Expr)$;
return Cur_Th

Algorithm 3: MeterAssign (G,T)

Input: G,T
Output: $Meter$
for *each flow* $f_i \in F$ **do**
    Check priority p_i of flow i
    Assign meter m_i

Algorithm 1 accepts the network topology (*G*) and Traffic matrix (*T*), and returns the Maximum Throughput (*Max_Throughput*). It calls for two sub procedures $Opti\_Th()$ and $Meter\_Assign()$ to calculate the network throughput (Cur_Th) and assign meters to incoming flows based on DSCP values, detailed in the form of Algorithm 2 and

Algorithm 4: Initial Discovery

if *new flow f arrived,* **then**
    Get $DSCP_{value}(f)$
    for *each* f_i *in* F **do**
        if $DSCP_{value} == DSCP_{match}$ **then**
            Set p_i
        Call Algorithm 1
        $F_{install}$
    if *network state change,* **then**
        Remove old rules
        Install New rules

3.Initially, Cur_Th is assumed as the Maximum Throughput (*Max_Throughput*). Subsequently, the values are updated periodically based on network changes. Additionally, flow rules are installed with a hard-timeout so that once obsolete it can be removed. Algorithm 2 returns normalized current throughput (Cur_Th) of the network based on meter bands being assigned to the incoming flows. Algorithm 3 accepts network topology and traffic matrix as inputs and returns meter rates assigned to each flow. It checks each incoming flow for its priority and based on its value it assigns a meter band rate to it.

IV. Experimental Results and Analysis

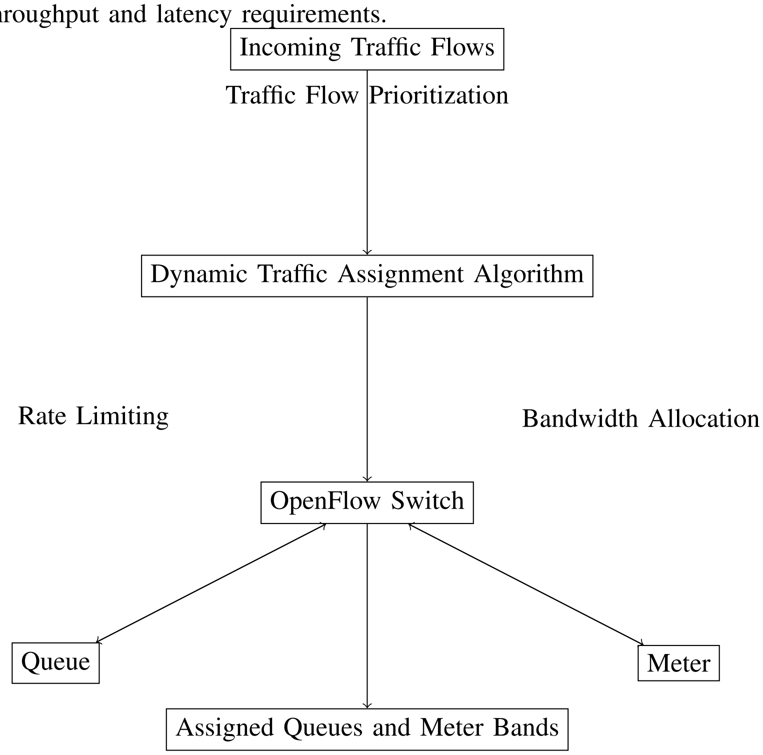
To evaluate the performance of HealthQos, we use Ryu SDN Controller and Mininet emulator. CPLEX is used to validate the proposed mathematical optimization formulation. The ibjective function values for Non-Optimized (traditional) and Optimized (proposed) cases have been depicted in Figure 3. To consider the topological connection, we contemplated AttMpls and Goodnet topology borrowed from the Internet Topology Zoo. The link capacity is limited to 10Mbps. Besides that, to generate the IoT traffic flow, we considered the D-ITG traffic generator [1] from the real-time traces as discussed in [2] .

A smart healthcare network may range from small to large-scale orchestration, different solutions are proposed accordingly. This work focuses on a smart hospital network scenario where there are different units such as ICU ward, general ward, patient consultation etc. Different network simulations and the parameters have been listed in the form of a Table. Based on existing works, HealthQos is compared against some state-of-the art approaches namely, with respect to end-to-end latency of each type of traffic, Packet Delivery Ratio (PDR), Packet Loss Ratio (PLR), Average Delay (AD) and Average Jitter (AJ). In contrast to the xxxx and zzzz, HealthQoS, decides the meter band selection intelligently based on the Algorithms 1, 2 and 3.

As per Figure 4, HealthQoS obtains an average PDR improvement of xxx%, against other approaches w.r.t. various topologies respectively. Similarly, Figure 5, shows PLR improvement of xxx%, against other approaches. Figure 6 shows AD improvement of yyy% and Figure 7 shows AJ improvement of zzz% against all other approaches. Thus, HealthQoS offers an overall average efficiency of www% over other approaches for PDR, PLR, AD and AJ respectively.

V. Conclusion and Future work

In this work, we proposed an dynamic meter selection based QoS provisioning mechanism for an SDN based Fog Architecture for Healthcare called HealthQoS. The proposed solutions are implemented in a Mininet Emulator using RYU Controller. OpenFlow Meter are used on the data plane devices to isolate and classify different traffics in terms of their throughput and latency requirements.



Acknowledgement

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