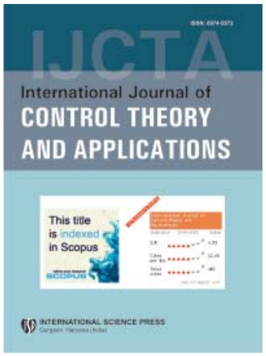

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Bandwidth-Delay Constrained Flow Assignment in Hybrid IP/SDN

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Abstract: Software defined networking is a state-of-the-art network paradigm designed to present network service providers a centralized view of the network enabling them to manage the data plane effectively by specifying their network policies in the control plane. Since the data plane and control plane are combined together in the network devices operating in Internet Protocol/ Multi Protocol Label Switch networks, the complexity of managing such networks has significantly increased due to an influx of a variety of protocols. Software defined networking architecture can accommodate the scalability and efficiency of these networks concurrently with relative simplicity. This simplification enables service providers to propose more flexible and efficient routing algorithms. Multiple network constraints like latency, bandwidth and throughput, can be taken into account for assigning flows to paths and thereby routing more efficiently. This paper proposes a solution to reduce the complexity of Multiprotocol Label Switch - Traffic Engineering algorithm in the control plane using Software defined networking controller. The proposed system guarantees quality of service to the applications by allocating a maximum number of flows to the shortest path computed with bandwidth and delay constraints. The bandwidth-delay constrained routing paths are translated to segment routing paths to provide dynamic traffic engineering solution guaranteeing faster routing, making the network more flexible by accommodating multiple types of traffic.

Keywords: *Traffic Engineering, SDN, Bandwidth-delay Constrained Shortest Path, Flow Assignment.*

1. INTRODUCTION

Traffic Engineering (TE) in IP/MPLS networks improves the performance of networks by offering the best possible services to users in terms of bandwidth and delay. Multiprotocol Label Switching (MPLS) technology had been introduced as a better solution for traffic engineering mechanism in IP network by overcoming the drawback of traditional packet forwarding. MPLS is a Layer 2 switching technology based on label switching launched to provide quality of service by prioritizing different traffic[12][13]. Due to the tight linkage of many layers of protocols in the data plane of IP/MPLS networks, the complexity of the data plane increases and its core routers become quite expensive. The shortcomings that arise due to increased network complexity can be overcome by integrating it with SDN as it offers a global view of the entire network. On migrating IP provider networks to SDN raises the need for the coexistence of IP and SDN services [10]. The Layer 3 routing in traditional IP network interacts with the Layer 2 SDN switches using the Open Source Hybrid IP/SDN (OSHI) [5] nodes in a single provider domain. Segment Routing (SR) [9], a source routing paradigm built for SDN further enhances the packet forwarding behavior.

Segment routing paths are computed from the traffic engineered bandwidth-delay constrained shortest paths. The bandwidth-delay path computations in [2] selects the best path from source to destination based on the QoS parameters such as bandwidth and delay with minimized average network delay of the network as well as improve the overall network performance. This approach is used to provide delay and bandwidth guarantee in applications like Video on demand and Voice over IP (VoIP). Much work has been done to choose the MPLS paths that satisfy the bandwidth requirements of applications and optimized network performance. However, for these multimedia applications to operate seamlessly with multiple parameters like bandwidth and delay as constraints the computed optimal constrained shortest paths has to accommodate maximum number flows that guarantee a delay threshold and a maximum bandwidth capacity. A generic bandwidth-delay approach involves finding the least delay path for an application's traffic flow only when the path satisfies the constraints imposed by the flow on parameters like bandwidth and delay. It keeps on pruning the entire network until it finds the best path which satisfies the predefined constraint.

This paper focuses on enhancing the Quality of Service (QoS) by dynamically assigning a specified amount of bandwidth for different types of traffic and routing the traffic via paths with least delay. The proposed system is completely based on flow assignment problem with bandwidth-delay constrained routing as a dynamic traffic engineering application launched by SDN controller (Ryu) to optimize the network performance. The flow allocation is accomplished based on path containing critical links. Here, the paths identification is handled by converting the bandwidth a concave constraint to additive weight metric along with the delay. The allocated partial flows are further reassigned paths to minimize the total average delay of the network. The traffic engineered paths are translated to the segmenting routing paths as in [1].

The flow assignment and flow reassignment problem encompasses two approaches 1) Traffic flow assignment with bandwidth-delay constrained routing. Here, the initial allocation is carried out through the delay constrained least weight path and the traffic is routed through the computed path. 2) Flow reassignment is carried out based on a specific heuristic taken as weight attribute consisting of propagation delay so as to minimize the average delay of the entire network. For each flow allocation, the heuristic approach checks for the existing average delay of the network with the previously computed delay. This process is repeated until there is no further scope for decreasing the delay and assigning more flows to the path. When further flows are assigned to the path exceeding its threshold capacity, the QoS guarantees are no longer met. Thus, the flow allocation process stops when the path has been utilized to its maximum extent. While computing the path with least delay and while checking if there is sufficient link capacity to allocate the new flow to a particular path, the algorithm rejects the path for that particular flow from a given source to destination and computes an alternative path to which the flow can be assigned. This process continues till the best possible path is chosen.

The rest of the paper is organized as follows: Section II provides the related works on OSHI environment and the existing TE algorithms, Section III gives the architecture and problem definition, Section IV discusses the flow allocation algorithm, Section V elaborates the topology, list of flows with bandwidth-delay requirements, and the observation of the experiment and Section VI concludes the paper.

2. RELATED WORK

2.1. OSHI Hybrid IP/SDN Node

An open source Hybrid IP/SDN node [5] has been designed by integrating the OpenFlow Capable Switches (OFCS), an IP forwarding engine and IP routing demon. The open flow capable switches are connected to a set of physical interfaces that belongs to the IP/SDN network and IP forwarding engine is connected to a set of OFCS virtual port. In this OSHI node architecture, OFCS is implemented using Open vSwitch. The IP forwarding engine is the Linux kernel and Quagga [11] act as routing daemon. An Open vSwitch is able to handle both IP based and SDN based traffic simultaneously, whereas IP routing engine is only capable of handling IP based traffic and it maintains the flow table of traffic entries. The OFCS differentiates among regular IP packets and packets belonging to SDN Based Paths. By default, it forwards the regular IP packets from the physical ports to the virtual ports, so that they can be processed by the IP forwarding engine, controlled by the IP routing daemon. An SDN capable switch contains both physical and virtual ports. IP routing engine is incorporated with Open vSwitch(OvS) through the virtual ports and physical port is connected to a central controller and segment routing daemon. Thus, SDN capable switch has an ability to differentiate the IP packet and SDN based packet, and forwarded to corresponding routing engine. Controller will interact with the OvS, and install dynamic routing policies using open flow protocol. Controller will take care of flow table and topology update. Controller generates the traffic across the network. In the given topology core router will acts as an OSHI node which is capable of routing the SDN and IP based traffic.

2.2. TE/SR in OSHI Network

The TE approach [1] defines a flow assignment problem classified into two phase Initial flow assignment Flow reassignment. In the first phase, initial flow allocation is realized based on the capacity of each link. In the second phase, reallocation of each admitted flows are accomplished to reduce the average delay of the network. The flow assignment problem is considered as a NP-complete problem [1] [4] with a heuristic approach to minimize the average crossing time of the network. The TE algorithm computes the best available path for each flow from source to destination by calculating the constrained shortest path using the weight parameter which is inversely proportional to residual capacity.

The flow assignment is a multi commodity (MC) flow problem [4] with a particular QoS constrained. The average number of flows is considered as multi commodity flow which satisfies a specific routing policy. Each flow is referred as single commodity and individually satisfies the bandwidth and delay constrained. For each flow, calculate the average crossing time and compare with previously computed delay. During each allocation of flow, it try to minimize the average delay of the network .So there exists number of local minima out of which feasible one is considered as the best solution for the given problem.

The Segment Routing (SR) is a source based routing approach which provides enhanced packet forwarding without maintaining the per-flow state in the network [1]. It classify the network into different segment with unique identifier and establishes a tunnel between ingress and egress node. The traffic engineering approach in [1] focuses on incorporating the SR with hybrid IP/SDN to provide an efficient routing mechanism by establishing a source based routing. The segment identifier (SID) is classified into two types, prefix SID and adjacency SID [9]. Prefix SID represents the identity of each node in the segment. The prefix SID is unique in a particular SR domain. An Adjacency ID represents the identity of a node segment which is adjacent to another node.

An SR daemon [1] is introduced as a routing engine to provide SR based forwarding and update the flow table of OvS. The flow table is updated to manage the SID encoded into MPLS label. The SR daemon set the open flow table to manage the SID to forward the packet in the SR domain. The SR daemon is incorporated with IP routing daemon and establish a communication between them using Quagga.

2.3. Bandwidth-Delay Constrained Routing

The bandwidth–delay constrained routing [2] is considered as one of the QoS routing problem defined to optimize the performance of the network satisfying the bandwidth and delay constrained. It is also a type of link-constrained and path-constrained routing [13] where a list of QoS constrained is assigned to each link of the network. The routing is completely based on bandwidth and delay constraints, and eliminates the entire link from the path which does not satisfy the given constraints. The bandwidth-delay constrained routing computes the least delay path from a source to destination pair based on the QoS constraints bandwidth and delay taken as weight delay weighted capacity [1] (DWC). Routing a request through the critical link in the path resulted lowest DWC value, which means link delay become relatively highest among the path. The algorithm identifies and eliminates all critical links between sources to destination pair to reduce the delay of the network. Extended Dijkstra's Shortest Path (EDSP) algorithm has been applied to achieve two–additive-constrained problem [2].

3. PROBLEM DEFINITION

The Fig.1 depicts the system architecture as in [1], where topology converter converts the topology GraphML to JSON format. The topology parser can acquire the topology information from REST API of Ryu controller. The flow generator is used to generate random flow from a particular source to destination with bandwidth-delay constrained. The TE algorithm takes the Link.json and Node.json file as an input argument to the main java module and process the request from a particular source to destination. TE algorithm performs flow assignment based on bandwidth-delay constrained shortest path. The result of the algorithm is a list of TE path which satisfy the bandwidth and delay constraints. The segment routing algorithm as in [1] maps the TE paths to SR paths to establish a source based routing between ingress and egress node. SR algorithm generates a list of SR path with minimum path length from source to destination for a particular flow. The SR pusher maintains the list of flows Vs path and pushes it into the SR data plane. The Ryu controller is responsible for launching the TE and SR algorithm to the Open Flow switches.

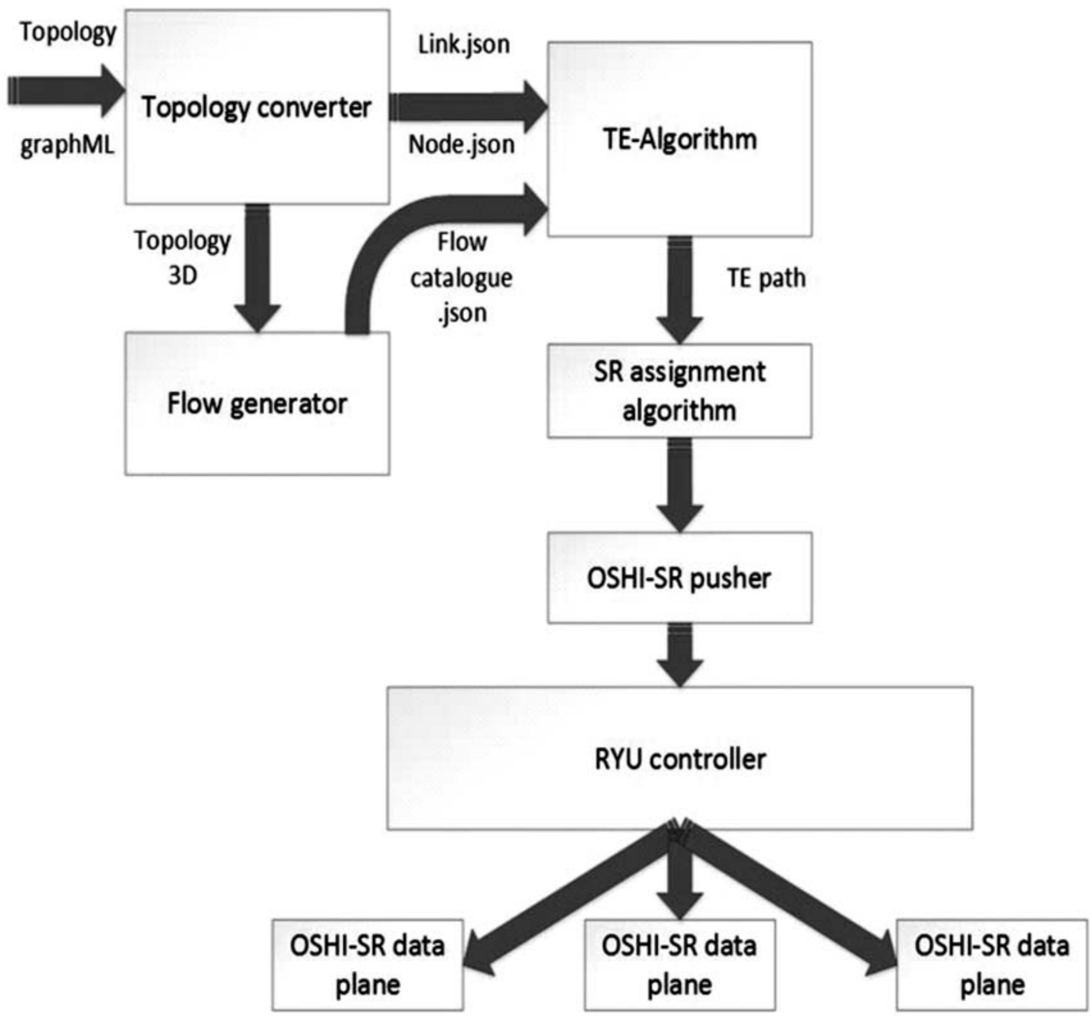

Figure 1: System Architecture

Our main contribution is the design of the bandwidth-delay constrained shortest path algorithm for maximum flow allocation. The route computation problem aims at minimizing the average network delay T subject to bandwidth-delay constraints. The problem formulation as follows:

Table 1
Design Parameters

Given	Topology Channel capacity (C_i) Channel delay (D_i) Traffic flows F = (f_1, f_2…. f_n) where fi represented as (source, destination, bit rate, minimum delay), $f_i = (s_i, t_i, b_i, d_i)$ $1 \leq s_i, t_i \leq n$
Objective Function	Minimize T
Design variable	$pf = (pf_1, pf_2 \ldots\ldots pf_k)$ $k \leq n$ where pf = List of partial flows
Subject to	$pf_i(c) \leq r_i$ $pf_i(d) \leq d_i$

The hybrid IP/SDN network is a graph G with three tuples (V, E, P), where V is the set of *n* hybrid IP/SDN switches, E is the set of links with residual capacity and delay and P is a known subset of these switches acts as ingress-egress switches and change roles frequently. The link delay is measured between two switches S1 and S2 using the OpenFlow messages (controller to switch and vice versa) and the Link Layer Discovery Protocol (LLDP) packets (switch to switch), similar to discovering links and checking device status. The link delay consists of propagation delay and queuing delay.

4. FLOW ASSIGNMENT ALGORITHM

The flow assignment problem is an optimization problem that minimizes the average network delay T to provide bandwidth and delay service guarantee. The flow assignment problem increases the performance by providing congestion control by assigning flows with low delays. This is a NP Complete problem which can be solved using heuristic approach similar to [1].

4.1. Initial Flow Assignment

In this phase, the flow allocation is based on the dynamic ratio of bandwidth and delay which is represented as the weights on critical links [2]. The Extended Dijkstra's Shortest Path (EDSP) algorithm further computes the least weight path that satisfies the capacity constraints. Before allocating the flows on a specific path from the source to destination, it ensures that the path has enough residual capacity to meet the flow bandwidth requirement. If the capacity constraint is not satisfied for a specific flow, the given path is rejected and searching for another best path to allocate the flow. Fig.2 illustrates the bandwidth-delay constrained routing algorithm which determines the least delay path and selects the set of feasible flows that can be allocated.

It considers both bandwidth and delay QoS constraint to compute the Least Delay Path (LDP) for each source to destination pair in the network. Dijkstra algorithm [2] is used to find the least delay path based on Bandwidth-Delay Ratio (BDR) [2].

$$\text{BDR} = +\sum_{\text{LDP}\ i} \frac{B_i}{D_i} \quad (1)$$

Where,

B_i Residual bandwidth

D_i End to end delay of LP

The BDR of a source to destination pair is considered as performance measure to determine the best paths in the set of least delay path. For each least delay path (LDP), identify the bottleneck link which has minimum bandwidth ratio among the LDP. Once all the bottleneck links are identified, calculate their link weight. The bottleneck links are removed for the further flow allocation as it indicates the overloaded path.

To establish multi-constrained routing satisfying both delay and bandwidth constraint for the particular path in the network, introduce an EDSP algorithm [2] which will compute the least weight path from source to destination. So EDSP provides the best available path with respect to both bandwidth and delay. It also ensures that a particular delay bound for each link of the path on which the flows are allocated.

The bandwidth-delay constrained routing determines the best path with least delay and high bandwidth availability based on delay and bandwidth constraint.

1. Initialize the link weight (LW) to 0 in the given graph/topology **Inner**.
2. For each flows f_i, $1 \le i \le n$
    a. For each source to destination, compute the **BDR** value.
        i. Create working graph **InnerTemp** as a copy of the given graph **Inner.**
        ii. If any path(s) exist between source and destination then compute the least delay path.
        iii. Identify the critical link for the least delay path.
        iv. Compute the weight of the critical link in the least delay path as LW = LW + (1/link delay)
        v. Remove the critical link.
    b. Remove the edges of **Inner** graph with the residual bandwidth less than flow bandwidth.
    c. Compute least weight path based on delay and bandwidth constrained using **EDSP**.
    d. Assign the request from source to destination through the least weight path and set the residual bandwidth of the network.

Figure 2: Bandwidth-delay constrained routing

4.2. Flow Reassignment

In this phase reallocation of flow is accomplished using the flow deviation method, and each time average delay of the network is calculated [1]. It is considered as a NP complete problem which is used to minimize the average delay of the network.

$$T = \frac{1}{\gamma} + \sum_{i=1}^{b} \frac{F_i}{cp_i - F_i} \tag{2}$$

Where,

T Average delay which consist of both queuing and transmission delay,

γ Total delay of traffic,

F_i Average bit rate in the channel I,

cp_i Average capacity in the channel I

In addition to average delay T, propagation delay PR_i is also added.

$$T = \frac{1}{\gamma} + \sum_{i=1}^{b} \frac{1}{\lambda_i}(T_i + PR_i) \tag{3}$$

Where,

PR_i Propagation delay in the channel I,

λ_i Average flow rate.

Initially, an average delay of the network is computed and stored to a variable **T first**. On flow reallocation, average delay of the network is computed as **T final** and is compared with the previously computed delay **T first**. The process is repeated multiple time until no improvement is achieved (**T first = T final**).

Since the feasible paths are allocated for particular flows, the algorithm check for current average delay time with previously computed one and the process will be repeated until there is no variation in the average delay. It keep on pruning the edges that does not support the current flow to find best path.

The flow assignment is a multi commodity flow problem with multiple constraints such as bandwidth and delay. So there exists number of local minima out of which feasible one should be considered as the best solution for the given problem.

5. PERFORMANCE EVALUATION AND RESULTS

To evaluate working condition of proposed algorithm, comparatively a large possible topology is considered. The Colt-153 topology is taken as the input. The topology Colt-153 is represented in json format with same capacity. A list of 750 flows is generated with random bit rate and delay using random flow generator from a source to destination. Each flow has a specific bit rate, size and id. Flow-id is used to identify the flows from a particular source to destination. The delay of the link is randomly taken from 62 to 80ms.

The segment routing paths are computed using the TE to SR mapping algorithm in [1]. The mean SR path length shows minimal increase even of the network is heavily loaded.

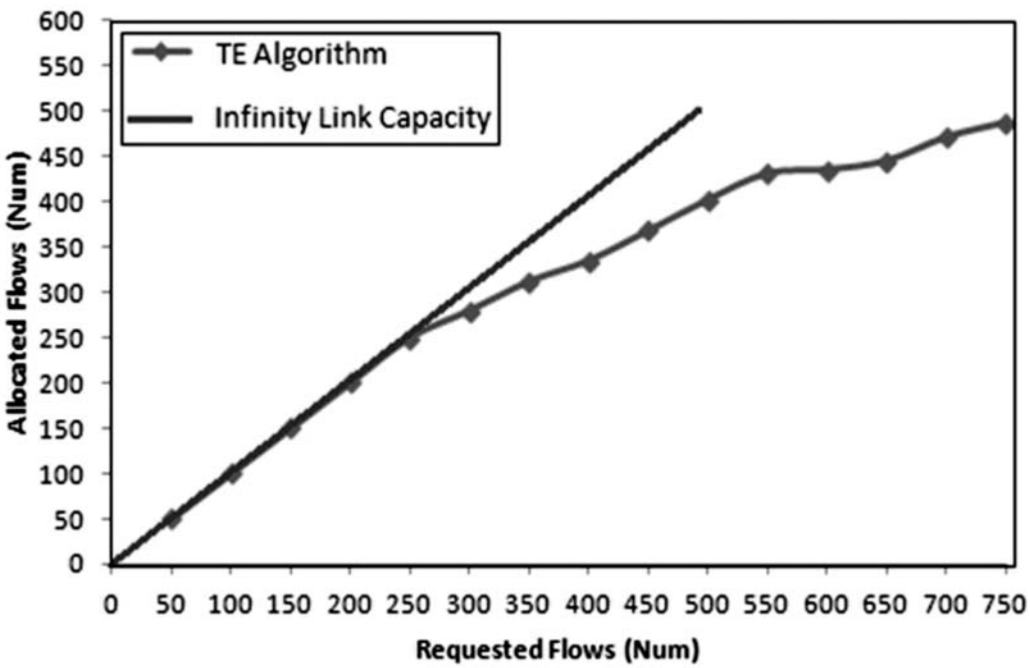

Figure 3: Allocated flow vs. Requested flows

In this experiment, a list of 50 flows is considered initially and the length of the TE path, natural path and SR path are examined. It is observed that initially all the 50 flows are allocated into the colt topology of 150 nodes. This algorithm computed the best feasible path for the 50 flows generated from ingress node to egress node. Further, the number of flows was continuously increased by 50 each time till 750 flows. Thus, the flow allocation is accomplished based on the capacity of each link in the colt network.

The dip in the QoS provided is measured by the number of allocated flows versus the number of requested flows. The deviation the rejection ratio as the flow size increases is shown in the Fig. 3. The objective is to minimize the call blocking ratio [14] of network and maximize the number of allocated flows in the network.

Fig. 4 shows that the length of the TE path is greater than the shortest natural paths computed with no constraints as expected. However using the segment routing the path length does not exceed two nodes. The SR path length is relatively shorter than the Natural path and TE path in the list of 750 flows.

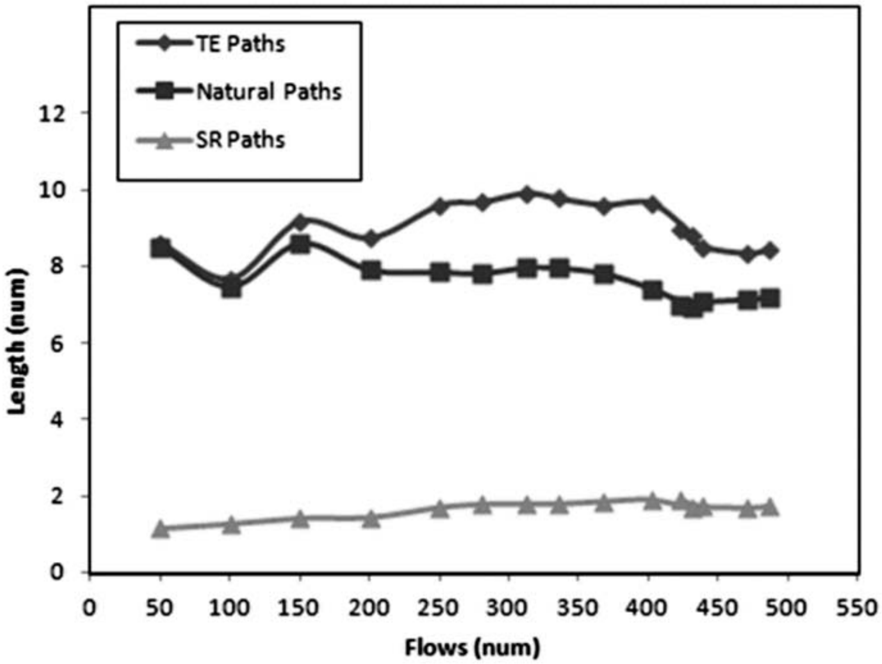

Figure 4: Mean length of TE path, Natural path and SR path

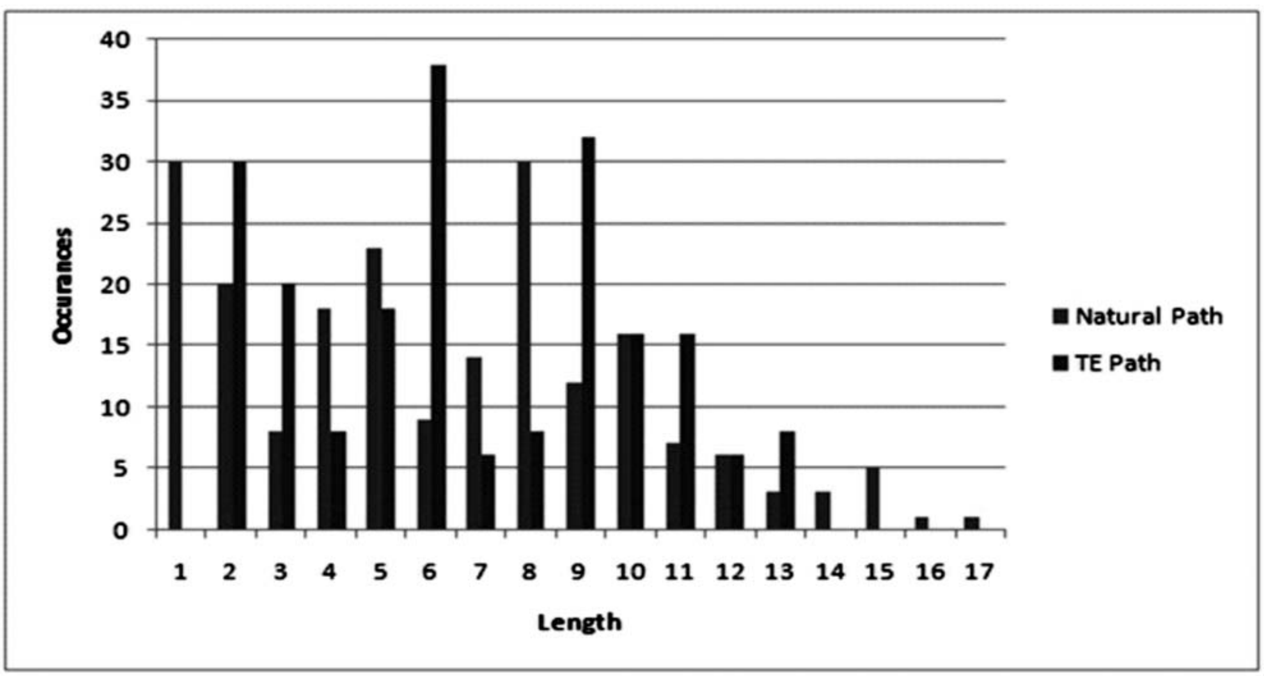

Figure 5: Distribution of path length for TE path, Natural path

The Fig. 5 represents the distribution of path length for TE path and natural path. As natural path do not satisfy the QoS constraint, the path length is relatively shorter than TE path. TE algorithm computes the optimal path between source to destination based on bandwidth and delay parameter. The flow assignment heuristic algorithm takes more iteration to converge than the segmenting routing algorithm.

6. CONCULSION

In this paper a new flow assignment algorithm is introduced to optimize the overall network performance by satisfying the QoS requirement and to minimize the average delay. Thus TE algorithm is implemented using SDN paradigm and reduces the overhead of storing the per-flow information in hybrid IP/SDN. The TE algorithm minimizes the average delay and call rejection rate by satisfying bandwidth and delay constraints. The TE algorithm with multi constraints performs in a better way, when compared to a regular traffic engineering approach. It determines the best possible path for a particular traffic flow from source to destination considering both bandwidth and delay constraints and thereby reducing the average delay. Thus proposed algorithm focuses on providing a faster routing and making the network more flexible by satisfying the QoS requirements.

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