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Towards an Efficient Path Selection for Tactile Internet Traffic via Multi-Plane Routing

Deni Lumbantoruan, Mohammad Farhoudi, Andrej Mihailovic, and A. Hamid Aghvami

Centre for Telecommunications Research, Faculty of Natural and Mathematical Sciences, Kings College London, UK
Email: (deni.lumbantoruan, mohammad.farhoudi, andrej.mihailovic, hamid.aghvami)@kcl.ac.uk

***Abstract*—This paper presents a foundation study of the routing support in scoped IP access networks towards early investigations and conclusions on provisioning the tactile traffic class in related networks. A specification for a type of traffic for tactile/haptic communications is derived and applied in the paper and tested in network scenarios alongside with best effort traffic and varying traffic load conditions. To better facilitate the experiments conducted, we have explicitly chosen and applied the most fitting routing solution in IP access network that enables balancing of the variations of performance criteria and costs typically encountered in packet communications, hence serving as the practical optimum for using the whole of the network routing resources. This specific routing scheme is a multipath routing solution; already tested and proven to combine multitude of performance benefits under practical deployment considerations. This protocol solution termed Multi-Plane Routing is accordingly adopted and applied in the analysis and experiment to expedite the various tactile traffic requirements and most importantly the packet loss and delay while ensuring maximization of the packet delivery throughput. The results indicate the performance margins in early but routing-dedicated study of the possibilities for supporting such novel and stringent traffic requirements inherent in the tactile traffic class.**

Keywords*—*Tactile, Multi-Plane, Routing, Best-Effort, Traffic

I. Introduction

Internet technology retains and increases its popularity as it keeps on evolving to meet various human needs. In the early days of it Internet was known as a tool for fixed-communications invented essentially for helping people to be connected globally despite their geographical location in this wide world. Yet, a significant change happened when mobile and wireless Internet emerged and triggered drastic evolutionary changes in communication. This mobile Internet, nowadays, remarkably connects an additional massive number of smart phones and laptops. The development of Internet further continues to evolve as it is moving into a new direction known as the Internet of things (IoT). It can be claimed that IoT is the third generation of Internet which requires that everything should have their own destination address (i.e. IP address) to enable mutual communication. Then, the fourth generation of Internet was born by the emergence and progression of the Tactile Internet in data communication. The International Telecommunication Union (ITU) defines that Tactile Internet characteristics are networks with extremely low latency in combination with high availability, reliability and security. These characteristics enable haptic communications where humans can communicate to/with machines remotely through real-time interactive systems [1-3].

If the fixed and mobile Internet provide various types of services such as voice services, messaging, video streams, video conferencing and web, the IoT adds a new service for monitoring and controlling the systems. Hence, this also means that the paradigm of the tactile Internet will change compared to the previous generations. Furthermore, while there were transfers of content in the older technology, the tactile Internet enables transfers of skills or knowledge such as remote surgery by using robots, remote monitoring, remote driving, remote education and remote control for industry applications.

The study in [4] describes some potential benefits of the tactile Internet in which the application of tactile Internet will have a significant leverage for community and business. The proposed applications can be applied in various areas such as: remote health-care and medical intervention; assisted driving and transport services; content delivery and gaming; and, industry automation in the sector of entertainment industry. For example, the presence of the tactile Internet will enable people to acquire remote health-care and precision medicine with the use of bio-connectivity and remote intervention with the use of remote robotic surgery. Meanwhile, in transport industry, this technology will facilitate automated driving. This automated driving technology will increase the level of automation through driver assistance applications, self-driving cars and traffic management. In addition, in the field of industry automation, some of its application will use tactile Internet environment such as IoT networks/Wireless Sensor Networks (WSNs) which interconnect a number of intelligent sensors to perform sensing, monitoring and remote controlling of robotic operations like collaborative robots in closed-loop control systems. Overall, the possibility of tactile Internet contributes to the livelihood enhancement for the wide community. A study stated their prediction that the market value for the tactile Internet could potentially exceed 20 trillion dollars worldwide amounting to approximately 20 percent of the worldwide GDP [5].

Since the Tactile Internet will be implemented as a very critical aspect of application, it will need a series of strict criteria such as ultra-minimum delay and very low packet losses and jitters. According to [4], the application in the automotive industry needs end-to-end delays around 10 ms for safety reason while the applications in robotic tele-operations require feed-backs for haptic information with latencies below 10ms. Meanwhile, for entertainment industry, the augmented and virtual reality use cases require a lower latency; round trip latency as low as 7 ms to provide a smooth action-reaction and offer a full immersive experience. Furthermore, for industry automation, the time-critical operations for remote control of factory equipment may go below 1 ms.

There are two main components of latency in tactile Internet: wireless radio access network latency and fixed-line core network/Internet latency. There are many ongoing studies proposing some specific ideas and solutions for addressing the stringent requirements for tactile Internet. Study in [6] proposed a method to predict motion and force information in Haptic media so it would alleviate the network effects such as delay, jitters and packet loss.

In [1], the study highlighted the physical packet length in the wireless transmission medium by proposing that the duration of packets should not be more than 33μs so it could achieve a delay lower than 1ms. The paper further showed the importance of designing a new modulation technique for tactile Internet since the technique that was used by LTE was not feasible because the OFDM symbol operation was in the order of 70μs. Combined implementation of Software Defined Networks (SDN) and network coding were proposed in [7] to reduce latency and packet re-transmissions. Nevertheless, the findings of the study are limited to a simple multi-hop network topology and do not include diversities of traffic types.

In core network communications, the most significant portion of the latency comes from packets being queued due to congestion in the nodes or links. Other latency factors such as transmission and processing related latencies can implicitly be associated with queuing delays or are often negligible or accounted for a small percentage. In simple terms, the queuing delays occur when a network node or link is carrying more data than it can smoothly handle. To fulfill the strict requirements in tactile networks, traffic engineering is one solution in core network that can be implemented to overcome the congestion problem [8] that bottles up the queues in the Internet and applies the best-effort and mostly the shortest-path routing. The objective of traffic engineering is to balance the traffic load and to optimize the overall networks packet routing performance by finding suitable routing and traffic allocation schemes.

II. Related Works

Herein we discuss some main properties of traffic engineering solutions in routing protocols for conventional (core) internet networks (e.g. intradomain networks). In the study, we focus on the possibilities of meeting the tactile traffic requirement in these networks of interest (i.e. campus or metropolitan size networks) using the traffic engineering solutions associated with routing protocols. Solutions such as reservation methods, e.g. IntServ or DiffServ although highly viable deterministic methods, are outside of the scope of this study. A widely used method for implementing traffic engineering uses installations of a flow-based connection-oriented multi-protocol like Multi-Protocol Label Switching (MPLS). MPLS suitably applies traffic engineering since it allows explicit routing and arbitrary splitting of traffic between source-destination pairs in networks via managing Label Switched Paths (LSPs). Nevertheless, complexity and overhead associated with generating and preserving LSPs caused scalability and robustness issues in MPLS [8]. Open Shortest Path First (OSPF) [9] as a destination-based hop-by-hop routing protocol was a widely used IP intra-domain dynamic link-state routing solution. OSPF has some practical benefits for its simplicity, robustness and high scalability. However, it does not accommodate explicit routing and arbitrary splitting of traffic. Moreover, OSPF tends to lead to a high congestion because it is based on the shortest paths only.

Equal Cost Multi-Path (ECMP) protocol [10] is a protocol extension of OSPF that can be used for expediting the traffic engineering purpose. By setting link weights properly the traffic can be effectively split over multiple paths with equal path weights, thus allowing a load balancing in OSPF. However, the ECMP only facilitates even traffic splitting over equal cost paths. This characteristic makes ECMP inappropriate to achieve the general optimal results like in MPLS.

Therefore, it is necessary to design a better engineering traffic in OSPF network without using the ECMP concept but leveraging on OSPFs simplicity and widespread use. Numerous studies have investigated further Internet traffic engineering solutions based on OSPF. Study in [11] optimized the OSPF weights setting based on the projected demands. Meanwhile, multipath routing protocol for delay-sensitive traffic was proposed in [12]. Edge-based traffic engineering for OSPF network was implemented in [13] proposing an edge-based approach, which was called k-set traffic engineering method by partitioning traffic into uneven k-traffic sets. Study in [14], DaVinci (Dynamically Adaptive Virtual Networks for Customized Internet) architecture proposed to support multiple traffic classes by implementing a virtual network on top of a physical topology. Each virtual network shared bandwidth based on a provisioning from a per-link bandwidth coordinator and ran customized traffic-management protocols. Multi-Plane Routing (MPR) was initially investigated in our department in [15] and thoroughly investigated in [16] for emerging converged IP access networks of campus/metropolitan area sizes. The study in [16] gave a comprehensive set of performance improvements of MPR over MPLS and OSPF by practically optimizing and utilizing the whole network topology. MPR is a multipath routing protocol based on Multi-Topology OSPF (MT-OSPF) principle. Path diversity in access network topologies can be maximized by constructing multiple logical Routing Planes (RPs) that represents instances of OSPF. Therefore, by creating the multiple routing planes, multiple routing paths between source and destination pairs in the network are instantiated in the network with a simple protocol overhead is required to run multiple instances of OSPF in the routing/forwarding tables in routers.

The haptic communication packet does not necessarily need a high data rate because the rate of haptic packet transmission is relatively small compared to some other services; assuming that there are 10 points of haptic sensor and every point sends a 3D coordinate for the next position. For instance, if one Cartesian coordinate has 3 numbers, and every number is represented by 8bits then every coordinate needs 24bits. In total, for 10 points of sensors it will need 240bits. As the tactile traffic frequency for sending consecutive packets is around 1000Hz, hence, the tactile packet data rate will be 240kbits for every second. By using IP Packet header, with the overhead of 256bits, the data rate of tactile packets will still be around 241kbps.

Even though a high data rate is not required for haptic packets, it still needs an ultra-reliable end-to-end connection and a sufficient capacity between source and destination pairs.

Therefore, providing reliable and efficient paths for tactile traffic in the existing networks is highly important and presents a novel challenge.

In this work, we will apply MPR protocol as the basis for enabling multipath routing in tactile Internet. Apart from the original goal of MPR, our objective is traffic load balancing through routing planes in the network with tactile traffic as one of the traffic types supported in the network. We will investigate how every single edge/ingress node allocates tactile and best effort packets in the network ensuring the specific requirement of tactile packets are fulfilled and the network can maximize the number of tactile and best-effort flows. This will be realized by developing an optimization framework to support multi-service networks based on the multi traffic class paradigm.

III. System Model

The idea is to find a suitable routing strategy for multicommodity flows consisting of tactile packet and best effort (BE) packets. This routing will ensure that the QoS requirements for tactile packet are met while maximize the total flow in the network and minimize the routing cost simultaneously. Consequently, such objectives require a backbone network for fast provisioning of bandwidth guaranteed paths. The proposed scheme is intended to handle requests for every single demand and satisfy as many potential future demands as possible while prioritizing the tactile packets/flows.

As stated in the previous section, we use MPR as the underlying routing protocol to implement multipath routing for the purpose of load balancing. One example of base topology where source S sends the traffic to destination D through many intermediate nodes is shown in Figure 1. From the topology, it can be seen that there are many possible paths existent for the source-destination pair (S-D pair).

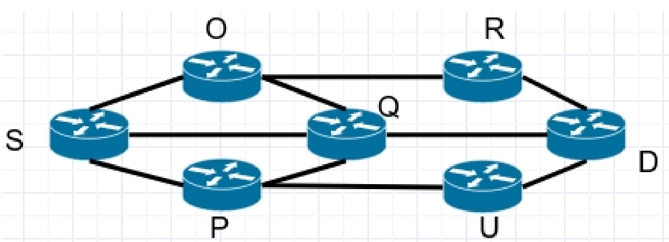

Fig. 1. Topology with many paths between S-D pair nodes

In the MPR, some virtual topologies will be constructed from base topology and such a virtual topology is called a routing plane. Every routing plane which is constructed from the base topology is an instance of the OSPF routing protocol. Therefore, every plane will follow the rules of OSPF when trying to construct the routing and sending the traffic such as sending LSA and following the shortest path algorithm. Figure 2 shows three routing planes that can be constructed from the base topology. Topology contains many possible paths between S-D pair nodes. Each plane has a different link weights of composition. Therefore, each plane will have their own shortest path for traversing traffic from S to D. As from Figure 2, it can be shown that the green routing plane will choose the S-O-R-D path while the orange routing plane will choose S-P-U-D path, and, the red routing plane will choose S-Q-D path.

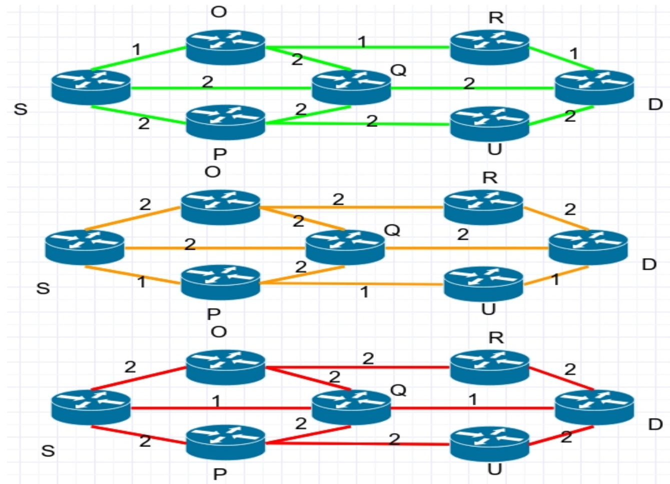

Fig. 2. The example of 3 planes routing

In the edge/ingress node, there will be two important tasks for managing the traffic in the network:

1. Packet classification. Packets are classified based on the applications requirement. Node needs to isolate different classes or types of traffic based on the information loaded in the packet. Afterwards, depending on the class of traffic, a suitable action will be applied. In our work, we classify the packet based on two categories of demand, i.e. inelastic demand and elastic demand. Inelastic demand is a delay sensitive traffic such as tactile packet while elastic demand is a throughput-sensitive traffic such as web, voice and video. In this work, we call these traffics as best-effort traffic.

2. Packet allocation. Edge/ingress node will map tactile and best effort traffic flow(s) to specific routing plane(s), and forward these traffics over them.

For this case, the edge node is assumed to have a global view of the network traffic dynamics and statuses for every node/router in the network. In addition, it is also assumed that the edge nodes have a capability to do complex tasks of signalling to attain the global view information, packet classication, packet mapping and packet allocation.

IV. Routing Plane Selection

In the network, as multiple commodities are considered, there are multiple flow demands associated with different edge/Ingress and Egress nodes for each plane. As a flow demand relates to an IP session, for the transmit duration of every session the used routing plane remains unchanged.

A. Optimization Problem Formulation

MPR offline algorithm presented in [16] facilitates an objective of achieving a practical maximum use of diverse network topological configurations via the deployed routing planes. Unlike in [16], this work was more concerned about the online algorithm of MPR, that was, finding a suitable path/RP for each demand for each ingress-egress pair. The algorithm will now consider the existence of tactile packets specifically in relation to the requirements for tactile flows. The routing scheme should be able to guarantee that every single tactile session can be served in the network without losing much of its best effort packets.

Let the backbone Internet network be represented as an undirected graph $G(V,E)$, where V refer to set of routers and E refers to set of links ($|V| = N$), ($|E| = L$) .

With N nodes in a network, there are $N(N-1)/2$ demand pairs possible considering unidirectional demands, or $N(N-1)$ demand pairs possible when considering bidirectional demands. In a practical network, not all nodes in the network are sources or sinks for external traffic; there are often transit nodes used solely for the purpose of routing. In this case, the traffic sources only come from Gateway (GW) and Access Routers (AR). Meanwhile, the other ones will act as a transit/intermediate nodes.

Consider K is the number of demand pairs with positive demand volume and h_k denotes a demand volume of demand index $k = 1, 2, ..., K$. Candidate paths can be indexed $p = 1, 2, ..., P_k$ for each demand identifier k, where P_k is the total number of candidate paths for demand k. Let x_{kp} denote amount of flows on path p for demand k. By using summation notation, the total flow of a certain demand for every path can be written as:

$$\sum_{p=1}^{P_k} x_{kp} = h_k, \quad k = 1, 2, ..., K \tag{1}$$

δ_{kpe} is defined as binary factor which is 1 if path p for demand pair k uses the edge e; 0, otherwise. By using summation over all demands $k = 1, 2, ..., K$ through all paths that passes edge e, so edge-flow variable for edge e can be written as:

$$\sum_{k=1}^{K}\sum_{p=1}^{P_k} \delta_{kpe} x_{kp} \leq c_e, \quad e = 1, 2, ..., L \tag{2}$$

where c_e is capacity of link $e = 1, 2, ..., L$. If ξ_{kp} is the unit cost of path p for demand pair k, then the general formulation for the minimum cost of routing problem can be written as

$$\textbf{Min} \quad \sum_{k=1}^{K}\sum_{p=1}^{P_k} \xi_{kp} x_{kp} \tag{3}$$

s.t.

Eq. (1) and Eq. (2)

$x_{kp} \geq 0, \qquad p = 1, 2, ..., P_k, k = 1, 2, ..., K$

Model of multi-commodity flow as shown in Eq.(1), Eq(2), and Eq(3) is used to described our problem in using MPR for multipath routing implementation. Let the set of Routing Planes (RPs) be denoted as $n = 1, 2, ..., N$. Every RP consists of $\rho_n^{\mu} : m = 1, 2, ..., M$ set of shortest paths, where m is the number of sources node of traffic. ρ_n^{μ} combines the demand-set κ for $\{\mathrm{P}_n^k\}_{k=1}^K$ in RP n for all the ARs and GW. Hence, there are $\{\mathrm{P}_n^k\}_{k=1}^K \subset \rho_n^{\mu}$ shortest paths for RP n. An VxE matrix R^k represents the link usage, where $R_{eP_n^k}^k = 1$ if path P_n of demand pair k uses link e and $R_{eP_n^k}^k = 0$ otherwise. By considering traffic flow as a session based q, where $q = 1, 2, ..., Q$, it is known that a single demand k will be summation of session q.

A plane selection mechanism is applied by MPR to guarantee a regulated and optimal traffic flow in the network. This mechanism is carried out by the sources; GW and ARs. The cost of RPs is determined by the available capacity which means the greater the link utilization, the higher the cost metric will be. The cost function for any path P_n^k is represented as a summation of real time costs of each link in the path:

$$\phi(p_n^k) = \quad \sum_{e \in P_n^k} R_{eP_n^k}^k \left(\frac{x_{kp}}{b(p_n^k) - x_{kp}}\right) \tag{4}$$

where $b(p_n^k)$ represent the available bandwidth on path p_n^k. The available bandwidth in the links is calculated by considering the minimum bandwidth on every path at various instances

$$b(p_n^k) = min_{(e_{uv,n}) \in p_n^k} \qquad b((e_{uv,n})) \tag{5}$$

By considering the existence of different types of traffic, that is tactile packet and best-effort traffic, the formulation of cost function in MPR-based routing can be written as a combination of cost function of tactile packet Φ_T and best-effort packet Φ_B:

$$\Phi_T(p_n^k) = \sum_{k=1}^K \sum_{n=1}^N \sum_{e \in P_n^k} R_{eP_n^k}^k \left(\frac{x_{kn}^t}{b(p_n^k) - x_{kn}^t}\right) \tag{6}$$

$$\Phi_B(p_n^k) = \sum_{k=1}^K \sum_{n=1}^N \sum_{e \in P_n^k} R_{eP_n^k}^k \left(\frac{x_{kn}^b}{b(p_n^k) - x_{kn}^b - x_{kn}^t}\right) \tag{7}$$

where x_{kn}^t is amount of tactile flow and x_{kn}^b is amount of best effort flow. Based on configuration between tactile packet and best effort packet, so the global formulation can be written as:

$$Min \qquad J := \alpha\Phi_T + \Phi_B \tag{8}$$

s.t.

$\sum_{n=1}^N x_{kn} = h_k, \quad k = 1, 2, ..., K \quad (a)$

$\sum_{k=1}^K \sum_{n=1}^N \delta_{kne} x_{kn} \leq c_e, \quad e = 1, 2, ..., L \quad (b)$

$\sum_{n=1}^N \delta_{nq} = 1, \quad q = 1, 2, ..., Q \quad (c)$

$x_{kn} \geq 0, \qquad n = 1, 2, ..., N, \quad k = 1, 2, .., K$

and α is a big number.

Constraint (a) states that the total flow of a certain demand for every plane is equal to demand volume of the demand. Constraint (b) ensures that the total flow of tactile and best-effort traffic from every plane in a link will be less than or equal to the link capacity. Meanwhile, constraint (c) ensures that every demand flow should go through one plane (1 path).

B. Plane-Set Selection

Based on the optimization problem that is described in part IV-A, procedures for traffic allocation in every single routing plane in the network can be written as:

1. Constructing the planes based on the offline algorithm implemented in [16]. The number of planes to be constructed should consider the optimal number of paths per source-destination pair because an excessive number of paths will increase complexity, memory use and computation power [17].

2. For every source-destination, compute the width of path of every plane. The widths of paths are calculated based on link

state information that carries the average residual bandwidth of each link.

3. Allocate the tactile traffic to the plane which has the largest residual bandwidth.

4. Allocate the best-effort traffic to the other candidate plane proportionally.

V. Performance Evaluation

In this section, we describe the performance evaluation of the proposed traffic allocation in MPR. Firstly, we describe the simulation environment, then, we observe the performance of the proposed traffic allocation in MPR. Eventually, we compare the performance of MPR with OSPF and ECMP routing protocol.

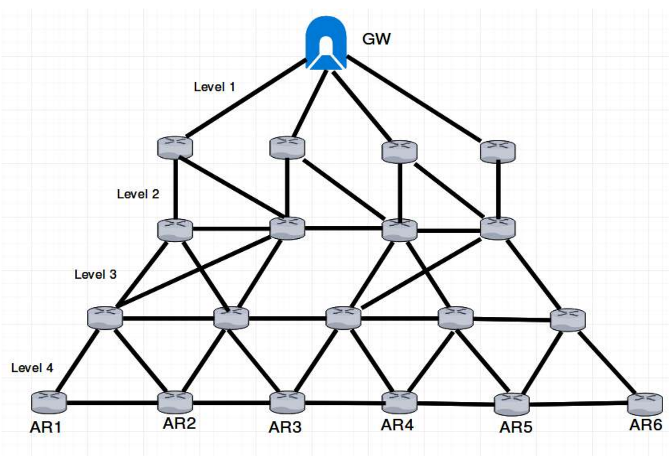

Fig. 3. The Topology Used for Performance Evaluation

A. Simulation Environment

A packet-level NS-3 simulations was conducted to analyse and present the results. Firstly, as input, we took the Routing Planes which were created by using the MPR's offline algorithm [16]. Subsequently, NS-3 was applied to generate and allocate the traffic for each source-destination pair over each plane.

Figure 3 shows the topology used in this study. This topology represents an autonomous system (AS) which can be either a campus or metropolitan IP access network. The network topology consists of Access Routers (AR) as edge/ingress node, routers as intermediate/transit nodes and a single gateway (GW) towards the big Internet. The mesh-tree model in this topology refers to topology used in [16] and types of model (i.e. fat tree) explained in [18]. Nodes are connected by wired network links.

There are 6 ARs acting as aggregation points in the network. Link capacities are defined based on the level where the links belong to each level as shown in the network. For four different levels, we set up link capacities as: 2, 3, 4, 6 Mbps respectively (values used for normalization). Every AR is connected to 4 traffic sources, where 1 source is assumed to generate tactile traffic and the other 3 sources are treated as the generators of the best effort traffic.

The simulations occur for 9 seconds in real time where we record the results for each total volume of demand. For this experiment, the data rates of tactile and best effort traffics are similar. The demands are injected gradually into the network in an increasing manner to demonstrate full network utilization and significant congestion in the links. We set overall the demand data volumes to 14.24MB, 21.38MB, 28.5MB, 35.63MB, and 42.77MB respectively.

B. Performance of online algorithm in MPR

For the first evaluation, we demonstrate the advantage of the effective traffic allocation in MPR, especially for tactile traffic. Figure 4-6 show the performance of tactile traffic when compared to the best effort traffic. Figure 4 shows the packet delivery ratio (PDR) of tactile packet and the best effort packet for different overall demand. When the demand is increased, the PDR will decrease because of the packet congestion. The tactile traffics are only slightly decreased yet the best effort traffics are sharply decreased. From the graph it can be shown that when the overall demand is around 42.77MB, the gap between tactile and the best effort traffic is around 32.6%. The reason for this result is because tactile traffic flows are allocated to higher residual bandwidth paths (i.e. planes) meanwhile best effort traffic are injected to the remaining paths randomly.

Figure 5 and Figure 6 also show the performance of tactile traffics in terms of throughput and that the average delay outperforms the best effort traffic. The reason is similar with the case of PDR performance in which more residual bandwidth in the links enable less possibility for traffic congestion. Eventually, this will enable more traffics to arrive in the destination with less delay.

Fig. 4. Packet Delivery Ratio for Tactile and BE

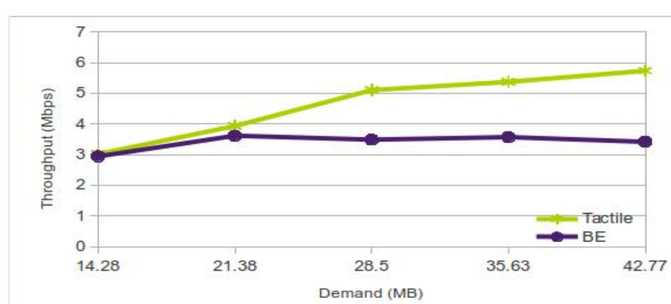

Fig. 5. Throughput for Tactile and BE

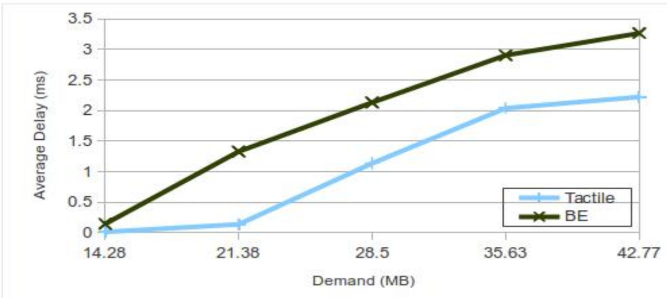

Fig. 6. Average Delay for Tactile and BE

Furthermore, we performed experiments to compare the performance of MPR routing protocol with OLSR and ECMP routing when they are steering tactile traffic in the network. Figure 7 and 8 show that MPR performance outperforms OSPF and ECMP. The reason for this is because MPR exploits the multi planes routing between source-destination pairs. In this case, 4 planes for each peer is constructed: 1 premium plane, with the highest residual bandwidth, is allocated for tactile traffic and the other 3 planes are used for the best effort traffic. OSPF routing has the lowest performance because it only utilizes 1 (one) shortest path for each source-destination peer. Meanwhile, the performance of ECMP routing is between MPR and OSPF because it uses more than 1 path. However, the number of available paths is less than in MPR and there is no traffic classification.

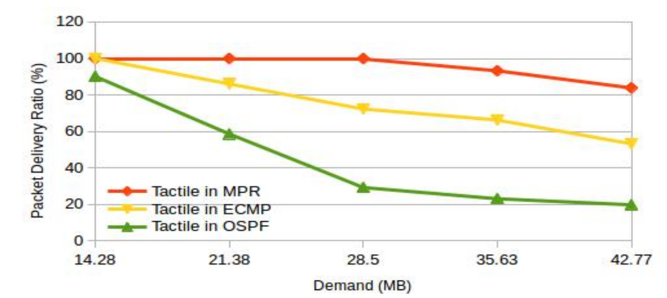

Fig. 7. PDR of Tactile traffic for different routing protocols

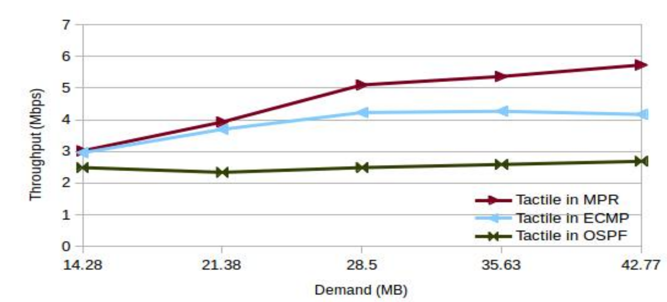

Fig. 8. Throughput of Tactile traffic for different routing protocols

VI. Conclusions

In this paper, a policy for obtaining reliable paths for Tactile Internet traffic through multi-path routing solution (Multi-Plane Routing) has been presented. An IP access network topology which represents an autonomous system (AS) (can be either campus or metropolitan access network) has been investigated by using a realistic traffic scenario with varying overall traffic demands. The results show that our proposed policy provides a better service for Tactile traffic and it outperforms the best effort traffic in terms of PDR, Average Delay and Throughput. Moreover, the results show our proposed multipath routing solution outperforms traditional OSPF routing and ECMP multipath routing. For future work, extended traffic models for Tactile Internet traffic will be investigated. In addition, combinations of multi-plane routing and utilization of specific queuing models for tactile traffic will also be investigated.

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