A novel hybrid distributed-routing and SDN solution for Traffic Engineering

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ABSTRACT

Capacity demands and Traffic Engineering (TE) requirements are expected to grow rapidly, and become increasingly challenging. We propose a hybrid approach that combines the benefits of Software-Defined Networking (SDN) solutions of a holistic network view to compute TE paths and resource allocation, with the benefits of distributed routing solutions featuring fast network reactions. TE paths and resource allocations are computed by a controller, then communicated using a link-state routing protocol.

KEYWORDS

TE, PPR, QoS, High-Precision Communication

1 INTRODUCTION

The higher speeds of new access technologies mean capacity demands and TE requirements of transport networks are increasing. TE is commonly used by network providers to support services such as mobile aggregation, corporate VPNs and Data Center Interconnects. With the introduction of more advanced services, such as 5G and beyond, the need for TE will become more important, especially with network slicing where stringent requirements must be met in terms of latency, throughput, packet loss, packet error rate, and traffic steering. Adding to the complexity is the fact that technologically diverse data planes are used, including Ethernet, MPLS, and native IP (IPv4/IPv6). One particular challenge concerns the ability to allocate resources and to compute TE paths in ways that are effective and efficient both from a cost and performance standpoint.

In typical SDN solutions, the calculation of TE paths and the allocation of resources occurs from a conceptually centralized point that has a holistic network view. This allows more effective optimizations than with distributed solutions that either provide only a limited view of the service needs, or that require the continuous replication and synchronization of significant state. Subsequently, paths and resource allocations are communicated individually to nodes. However, this introduces some latency, and makes the solution less resilient against changes or perturbations in network state due to the additional control loop between network node and SDN controller.

We propose a hybrid solution for TE that combines the benefits of centralized SDN control with a holistic view of the network with those of distributed routing that allow network nodes to localize decisions without an external control loop using certain shared state, while avoiding their respective disadvantages. The solution builds on Preferred Path Routing[1], [2]. A central component is used to calculate TE paths and optimize the allocation of resources based on a holistic view of the network. TE path and graph information is communicated using a link-state routing protocol, while packets carry signatures to indicate their association with a particular path. An alternative approach is described in [3].

2 PPR CONCEPT AND FRAMEWORK

PPR is a method of adding explicit paths to a network using a link-state routing protocol. Such a path, which may be a strict or loose and can be any loop-free path between two points in the network. A node makes an on-path check to determine if it is on the path, and, if so, adds a FIB entry with next hop (NH) (computed from the SPF tree) set to next element in the path. The advantages of PPR over alternate methods of creating such paths is described in [1].

The Preferred Path Route Identifier (PPR-ID) in the packet is used to map the packet to the PPR path, and hence to identify resources and the NH. A PPR-ID can be added by encapsulating the packet at ingress, but PPR does not restrict the user to any method. PPR is forwarding plane agnostic, and may be used with any packet technology in which the packet carries an identifier that is unique within the PPR domain. PPR may hence be used to add explicit path and

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resource mapping functionality with inherent TE properties in IPv4, IPv6, MPLS, Ethernet or similar networks [4].

For scalability, a mechanism for building point-to-multipoint (P2MP) or multipoint-to-Multipoint (MP2MP) and their use is described in [5]. In a network of *N* nodes a total *O(N power 2)* unidirectional paths are necessary to establish any-to-any connectivity, and multiple *(k)* such path sets may be desirable if multiple path policies are to be supported (lowest latency, highest throughput etc.). In many solutions and topologies, *N* may be small and/or only a small set of paths need to be preferred paths, for example for high value traffic (e.g DetNet, or some of the 5G slices), in which case a point-to-point path structure specified in [1] [2] can support these deployments.

With no additional IGP (OSPF/IS-IS) extensions other than PPR, graphs can be distributed across the network with a appropriate [5] description. While sufficient in many deployments, for even higher scalability, and faster IGP convergence, this additional information can be restricted to only relevant nodes in the network. This is useful in deployments where the number of paths/graphs required significantly exceeds the total number of routes in that IGP deployment.

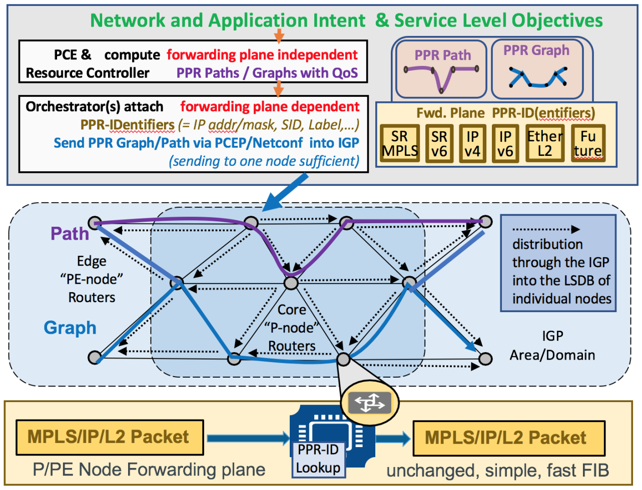

Figure 1: PPR Architecture with PPR Path/Graphs

Figure 1 depicts TE PPR path and graph structures, centrally computed based on operator-provided service level objectives. These structures are associated with the PPR-ID and are injected into the underlying Link State Database (LSDB). This can be done either by directly injecting them into the LSDB of individual nodes or through IGP flooding mechanism. Many of the dynamic capabilities such as the local activation of backup TE paths are derived from introducing the paths/graphs into the LSDB.

The PPR-ID for the data plane is selected by the entity (e.g., a controller as shown, or locally provisioned by the operator), which selects a particular PPR in the network. As the underlying path is abstracted using a forwarding identifier (PPR-ID), this approach is extensible to any underlying data plane as long as the corresponding PPR-ID can be carried in the data packet. The PPR-ID can be an IP address of the terminating PE, or a global SID of an SR [6] [7] node.

The base concept for one IGP (IS-IS) has been implemented in FRR stacks [8] for Native IPv4, Native IPv6 and SR-MPLS data planes. The PPR topologies and related information is available at [9]. A proof of concept is being carried out at Telefonica Labs in Madrid. Different back-haul topologies common in real operations are used to experiment with protocol dynamics and system behavior to assess the potential of PPR technology.

3 CONCLUSION AND FUTURE WORK

We believe that hybrid solutions that combine centralized SDN intelligence with distributed routing show great promise for future TE applications, although more work is needed:

Per-hop policy: It is necessary to apply a number of policies to a packet as it traverses its path, for example to select queuing behaviour or to apply OAM actions such as recording the time at which the packet was seen. A method of encoding actions as part of PPR path/graph specifications is needed.

Path Oriented Flooding: Link state protocols flood link state packets throughout the flooding domain for the topology. However, for reasons of scaling, it is undesirable to flood all of the PPR paths to all of the nodes. The research problem is how to reduce flooding and minimise its scope without compromising the resilience of the network. One way to achieve this is by creating a separate LSDB for PPR information and incrementally computing the PPR next hops when changes in the base topology are detected. Further details specific to IGP will be documented in future publications.

Resilience: The use of PPR to provide different types of Fast Reroute has been described [4]. Of particular interest is the use of graphs. It would be interesting to develop this further including integrating Packet Replication, Elimination, and Ordering Functions (PREOF) [10] into the resiliency.

Byzantine Robustness: The PPR paths are only used for high value traffic and are a prime target for disruption by an attacker. Work has been carried out on constructing link state routing networks with Byzantine robustness [11]. The difficulties of deploying this technology when it was invented have diminished, and the approach should be revisited.

Multi-party Control: The system can obviously be made to work with a single SDN controller and a set of coordinated SDN controllers. The independence needed between the slices needed in a network sliced network makes it interesting to investigate how to develop a distributed approach to PPR path creation.

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