

Development of Performance of OSPF Network by Using SDN Concepts

Hasanein Hasan

Electronic and Computer Engineering
Brunel University London
London, United Kingdom
eepghah@brunel.ac.uk

John Cosmas

Electronic and Computer Engineering
Brunel University London
London, United Kingdom
John.cosmas@brunel.ac.uk

Zaharias Zaharis

Electrical and Computer Engineering
Aristotle University of Thessaloniki
Thessaloniki, Greece
zaharis@auth.gr

Pavlos Lazaridis

Engineering and Technology
University of Huddersfield
Huddersfield, United Kingdom
p.lazaridis@hud.ac.uk

Sinan Khwandah

Maritime, Science and Engineering
Southampton Solent University
Southampton, United Kingdom
sinan.khwandah@solent.ac.uk

Abstract—The aim of this research is to enhance the performance of a traditional Open Shortest Path First (OSPF) routing protocol network by adding some features of the Software Defined Networking (SDN) in a modified approach to improve some network's performance metrics like link congestion and bandwidth utilization. The improvement of those metrics leads to an improvement in the total throughput of the network. This approach results in a network that contains an intelligent dynamic controller, which is capable of detecting the location of a congestion that may take place before or at the brink of its occurrence and dealing with selected flows on selected routers across the network in a way that prevents the congestion by using a smart heuristic Flows Distribution Algorithm (FDA).

Keywords—Dynamic Controller; FDA; Flow Table; OSPF; Routing Table; SDN

I. INTRODUCTION

THE OSPF is one of the Interior Gateway Routing Protocols (IGP). It is used to route the Internet Protocol (IP) packets. Furthermore, OSPF is a link state routing protocol that uses the Dijkstra algorithm to build a routing table by constructing a shortest path tree and then populating the routing table with the resulting best paths [1].

OSPF is a fast converging routing protocol. It can divide a routing domain into separate routing areas. OSPF also supports load-sharing traffic over equal cost multi-paths (ECMP) to the same destination (if required). OSPF uses a link cost parameter as the basis to calculate the shortest path. A reference bandwidth of 100 Mbps is used for cost calculation [2].

The OSPF uses the same path to forward packets between source and destination and only switches to another path during the event of link or node failure [3], [4].

In SDN, the control plane is separated from the data plane. There is a central controller that is responsible of performing all complex tasks, including naming, routing, policy declaration, and security checks. The controller populates a flow table for each switch. Switches use the flow tables to

manage and forward flows. SDN can be applied over Ethernet switches (Layer 2) and internet routers (Layer 3) [5]. SDN provides central flows management. Therefore, SDN-Openflow has been proposed to be used in load balancing of data centers [6].

A. Problems and Challenges

Network congestion is considered as one of the major reasons of quality degradation; it can be caused by uneven distribution of traffic or lack of network resources. Unfortunately, the existing routing algorithms only count shortest paths between sources and destinations. Furthermore, there is a lack of cooperation between routing and congestion control [3].

The effect of congestion increases queueing delay which increases Packet Delay Variation (PDV), Latency (end to end delay), packet drop possibility and error rate. Pre-detection or very early detection of the occurrence and the location of congestion provide a solution for better load balancing by preventing a congestion event or at least reducing its effects as much as possible.

From above discussion, two main problems are identified:

- The link congestion problem.
- The inefficient bandwidth utilization problem.

B. Contributions

Our contribution is a real time dynamic monitoring controller with supervision and intervention mechanisms which is capable of predicting the location of congestion before or at the beginning of its occurrence and removing or mitigating its effect by re-forwarding the flows causing it over other paths.

The controller only deals with the congestion issue, as it has not much effect on low traffic applied load. Our approach combines the practical side of the traditional routing protocols with the intelligence of SDN. It develops the traditional OSPF network (layer 3) to adopt a methodology similar in many aspects to that used in SDN (layer 2) networks (the existence

of the controller and the messaging system between it and the routers).

II. RELATED WORK

Many studies have been conducted to develop the performance of the OSPF protocol.

In [3], Al-Shabibi et al. suggest a congestion aware multi-path routing protocol in a multi-route network, where there is no central controller to manage the traffic and the rate of traffic assigned to each path is determined by each router in response to the congestion signals received from routers along the path. Every router sends its updated information to the neighboring routers when there is any significant change detected. This algorithm provides a high level of independence to the routers however many updating messages directed to other routers may consume significant portion of the available bandwidth.

In [7], Oki et al. propose the Smart Open Shortest Path First (S-OSPF) load balance algorithm based on a model where the traffic is split only at source edge nodes and distributed to the neighbor nodes with optimum ratios. From the neighbor nodes, the traffic is routed according to the OSPF protocol. The optimal traffic distribution is obtained through Linear Programming (LP) by using decision variables like network congestion ratio and traffic portion from parameters of traffic demand and link capacity. However, the algorithm proposed in our study is more flexible because it can divert the traffic from the source edge node as well as from any intermediate node.

The Cost Adaptive OSPF (CA-OSPF) has been proposed in [8]. Haijun et al. suggest that the interface's cost is dynamically adjusted according to the utilization ratio of the interface's bandwidth. CA-OSPF sets two thresholds for the interface: upper limit and lower limit. When the interface bandwidth utilization ratio exceeds the upper limit, the router will increase the interface's cost and when the interface bandwidth utilization ratio falls below the lower limit, the router will reduce the interface's cost. For both cases, the router generates Link State Advertisement messages (OSPF-LSA) to inform other routers within its area to update their routing tables.

The average residual bandwidth in the path as a localized QoS routing metric is proposed in the bandwidth-based routing (BBR) scheme [9]. The quality of the path is measured by calculating the average residual bandwidth for each candidate path. The path with the highest average residual bandwidth is used to route the incoming flow. BBR is applied at the source node which uses a setup message to travel along the selected path with each connection request. Each intermediate node tests the outgoing link residual bandwidth to verify the ability of the link to satisfy the requested bandwidth. If there is sufficient bandwidth on the outgoing link, the requested bandwidth is reserved for that connection and the message is sent to the next hop. If any link along the path does not support the requested bandwidth, a failure message occurs. Our algorithm provides a central controller that efficiently estimates the residual bandwidth of all links.

III. NETWORK MODEL FEATURES

This section presents the network design. The network has been designed by using OMNeT++ simulator and the development of its Inet project.

A. Network Model and Network Messages

Our project examines an OSPF routing network consisting of 9 routers and 9 hosts which are presented in Fig. 2. The network only employs the concept of the SDN networks (existence of controller). None of the SDN protocols or devices is used.

The types of messages that travel across the network are as follows:

- Information messages issued by routers and directed to the controller. The information messages carry the network information such as router address, routing tables of each router and its links bandwidth.
- Real time flow status updating messages issued by routers and directed to the controller. The flow status updating messages carry the flow current information like flow source, flow destination and flow data rate.
- Control messages issued by the controller and directed to specific routers to create or remove flow tables.
- OSPF standard messages.
- Data packets issued only by hosts and directed to other hosts. Data messages represent the flows.

B. The Router Behavior

The router design represents the standard OSPF router of the Inet-OMNeT project. It is also developed with modifications in code and several extra added models to be compatible with the network requirements.

1) Router forwarding mechanisms

Similar to any OSPF router, the router builds its OSPF routing table by exchanging OSPF messages with its neighbors and it also responds to the commands of the controller in terms of IP forwarding mechanism. The router either uses OSPF routing table or flow table to forward the IP routed flows.

2) Flow table model inside the router

The flow table model is an additional model added to the network layer. The flow table is temporary and has higher priority than the OSPF routing table as it substitutes the routing table in forwarding specific flows.

C. The Controller Behaviour

The controller is the device that has the responsibility of monitoring the traffic across the network and deals with any congestion problem. It is connected to some routers. The routers that are not directly connected to the controller use the OSPF routing tables to contact the controller and vice versa. The controller has three main features:

1) Knowledge

At the beginning of the simulation, the controller receives all the information related to the network like topology, channel bandwidths and OSPF routing tables of all routers to

all destinations. According to this information, the controller internally constructs the network topology and it can predict the behaviour of the routers (forwarding decision) when they deal with applied flows. The controller calculates all paths from all sources to all destinations then sorts them in a list from the shortest to the longest regarding the OSPF path obtained from each router. This operation is done once inside the controller unless there is a topology change.

2) Flows Distribution Algorithm (FDA)

The controller is provided with a heuristic traffic management Flows Distribution Algorithm (FDA), which is used to solve the congestion problem. FDA inside the controller deals with IP routed flows according to one of three actions:

- *Diverting the flow of high data rate.*
- *Diverting the non-high data rate flow.*
- *Re-diverting the previously diverted flow.*

3) Ability to affect the network

According to FDA decision, the controller issues limited control messages that affect the network layer of some routers by creating a temporary flow table.

IV. SIMULATION RESULTS

For every new flow or obvious change in the data rate of an existing flow (more or less than 8 % of the previously recorded value), the head-end router will normally deal with the flow by sending a flow updating status message that contains the flow information to the controller.

When the controller receives the flow status message of the head-end router, it internally examines the flow distribution over the network by starting an internal mathematical operation to model the network behavior on dealing with the flow and notices if there is a congestion that may occur at any link due to this flow. If there is no congestion, the controller stores the flow and its distribution path (to be used later if necessary) in its data base and sends an approval control message to the head-end router to confirm its OSPF forwarding decision.

In the situation of congestion, the controller activates its FDA. The FDA deals with congestion according to one of three steps that are applied sequentially:

A. Diverting the Flow of High Data Rate

The first step is to examine flow distribution via all other available paths taking in consideration the **residual bandwidth** and the **path length**.

For the **flow with high data rate**, if there is any **bypass path** with:

Residual bandwidth > Flow data rate

Path length ≤ OSPF path length

The controller assigns this **bypass path** to carry the packets of the **flow of high data rate** to their destination.

The controller informs the head-end router and routers along the bypass path to carry the flow packets to their destination. The controller order is represented by the control message of

the form shown in Fig. 1. The head-end router compares flow forwarding decision, the next flow forwarding hop of the control message flow table, with its peer according to the existing OSPF routing table. If different, it constructs the flow table that takes the place of the routing table related to the flow forwarding.

Flow Source	Flow Destination	Flow Table Path: $N_1 N_2 N_3 N_4 \dots \dots \dots N_k$	Establish/ Remove
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Fig. 1. The contents of the control message.

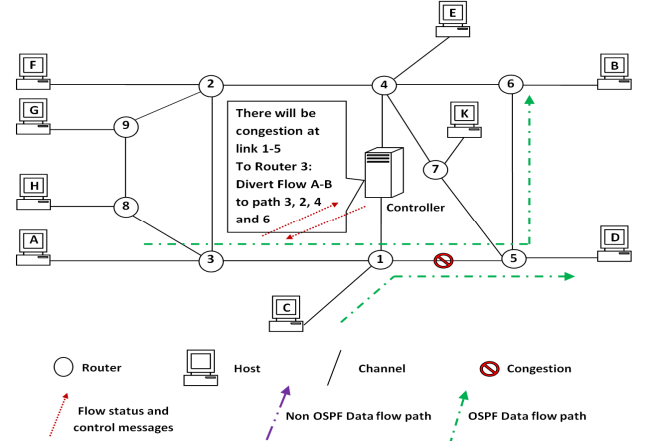


Fig. 2. Flows distribution via the OSPF paths.

The head-end router, N_1 , forwards the control message to the next router, N_2 , over the flow path. The next router repeats the same operation until reaching the tail-end router, N_k , which contacts the controller to confirm the completion of the flow table constructing operation.

Example: the network of Fig. 2. Flow A-B is distributed over the OSPF path passing through routers 3-1-5-6. Flow C-D is also distributed over OSPF path passing through routers 1-5. Both flow A-B and flow C-D share link 1-5. The data rate of flow A-B increases. The head-end router, router 3, informs the controller about the rise in flow A-B data rate. The controller internally examines the current distribution of flow A-B over the OSPF path and finds that congestion starts at link 1-5.

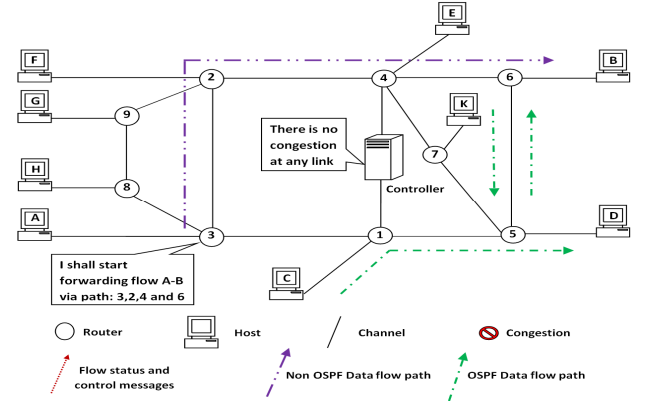


Fig. 3. Flow A-B distribution over the new path.

The controller diverts flow A-B over a new path 3-2-4-6. The new path handles flow A-B without congestion and its length is no longer than the original OSPF path length. The controller informs the involved routers to apply its order. Flow

A-B starts using path 3-2-4-6 as shown in Fig. 3. The latency of flow A-B concerning the same applied load is shown in Fig. 4. After flow A-B data rate returns to its normal value, the controller sends a removal control message to remove the flow table A-B from routers where it exists. This returns forwarding flow A-B via its original OSPF path as in Fig. 2.

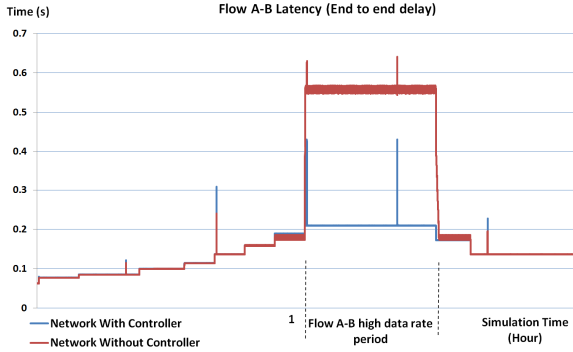


Fig. 4. Flow A-B latency of step 1 with and without controller.

B. Diverting the Non-High Data Rate Flow

If the previous step condition cannot be achieved on the high data rate flow, the controller examines all the flows passing over the congested links and applies flow diversion over any other flow.

For **any flow with moderate data rate passing through the congested links**, if there is any **bypass path** with:

Residual bandwidth > Flow data rate

Path length ≤ OSPF path length

The controller assigns this **bypass path** to carry the packets of the **flow of moderate data rate** to their destination. In the network of Fig. 2, both flow A-B and flow C-D are distributed over the OSPF paths and they share link 1-5. The data rate of flow C-D increases. The head-end router of flow C-D, router 1, informs the controller about the rise in flow C-D data rate. The controller internally examines the current distribution of flow C-D over the OSPF path and finds that congestion starts at link 1-5. There are several bypass paths to divert flow C-D to avoid congestion:

- 1-3-2-4-6-5.
- 1-3-2-4-7-5.
- 1-3-8-9-2-4-6-5.
- 1-3-8-9-2-4-7-5.

By examining the length of any of these detours, it is obvious that all of them are much longer than the OSPF path 1-5. The controller examines all the flows over the congested link 1-5. The only flow that can be diverted over a non OSPF path that is no longer than the OSPF path is flow A-B. Therefore, the controller diverts flow A-B via non OSPF path to avoid the congestion. The controller informs the head-end router of flow A-B, router 3, to divert flow A-B. Flow A-B starts using path 3-2-4-6 as shown in Fig. 3. The latency of flow C-D concerning the same applied load is shown in Fig. 5. Packet Delay Variation (PDV) of flow C-D of simulation with controller is as shown in Fig. 6 while that of the simulation without controller is as shown in Fig. 7.

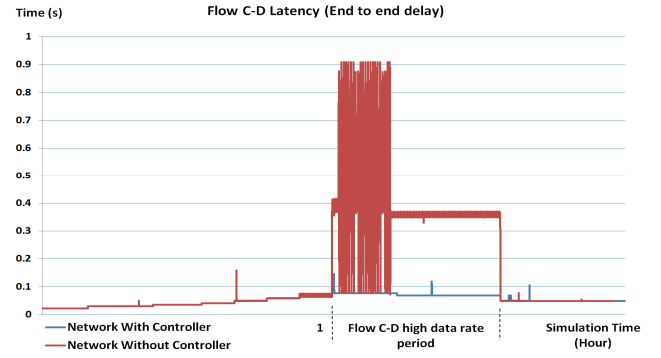


Fig. 5. Flow C-D latency of step 2 with and without controller.

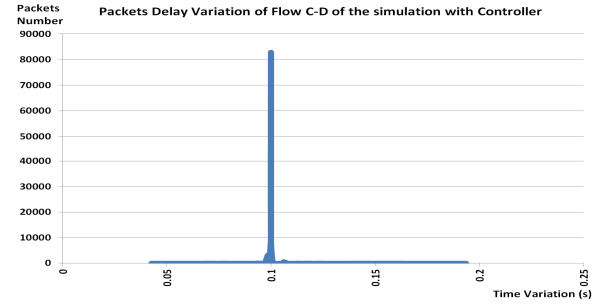


Fig. 6. Packet Delay Variation of flow C-D of step 2 with controller.

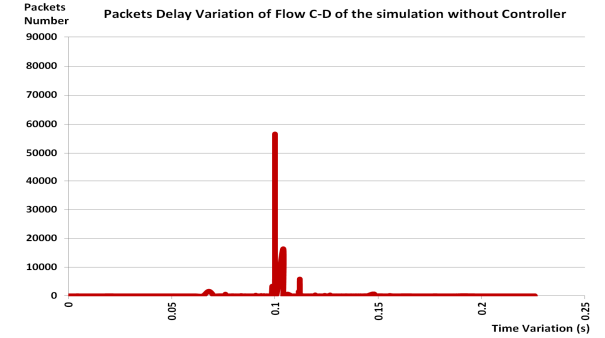


Fig. 7. Packet Delay Variation of flow C-D of step 2 without controller.

C. Re-Diverting the Previously Diverted Flow

If none of the previous steps could solve the problem, the controller investigates if there is any previously diverted flow that currently passes through the congested links. The controller examines the possibility of returning the diverted flow to its original OSPF path without congestion. If this possibility exists, then the controller applies it. If it does not exist, the controller re-diverts the previously diverted flow by considering the **residual bandwidth** factor only.

For **any previously diverted flow passing through the congested links**, if there is any **bypass path** with:

Residual bandwidth > Flow data rate

The controller assigns this **bypass path** to carry the packets of the **previously diverted flow** to their destination.

In the network of Fig. 3, flow A-B is previously diverted over a non OSPF path 3-2-4-6 to avoid congestion at link 1-5 caused by flow C-D. Flow E-B passes through path 4-6 shares link 4-6 with flow A-B. Flow E-B data rate obviously increases. The head-end router, router 4, informs the controller of the rise in flow E-B data rate value.

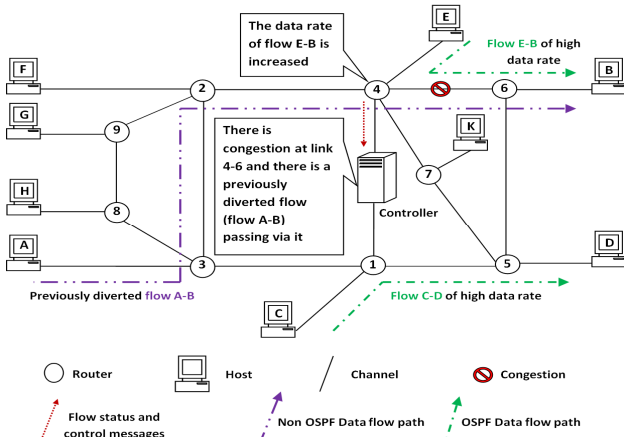


Fig. 8. The process of allocating the previously diverted flow.

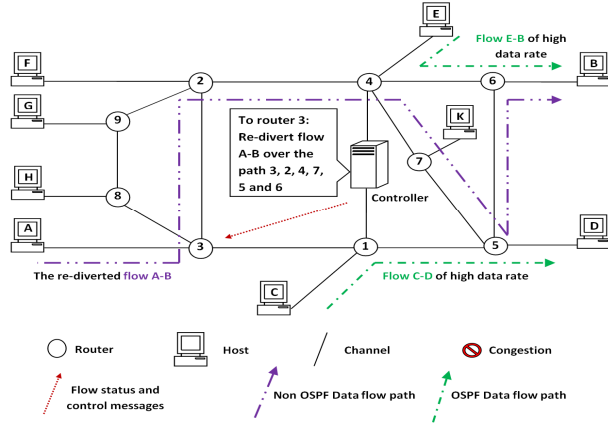


Fig. 9. Flow A-B re-distribution over the new path.

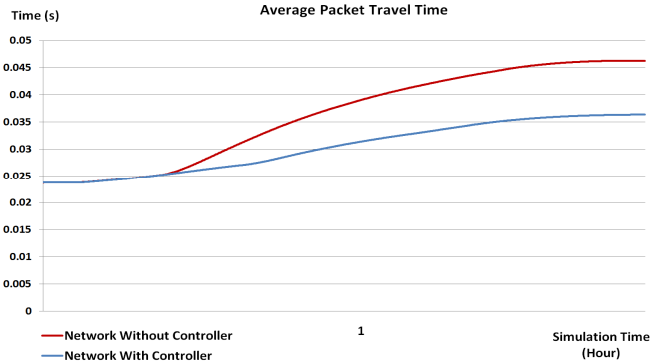


Fig. 10. Network average packet travel time of step 3.

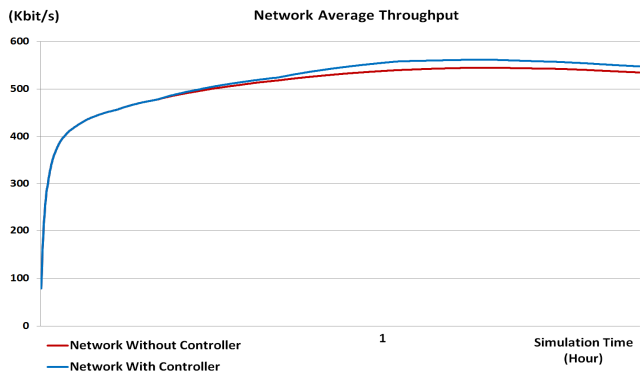


Fig. 11. Average throughput of the network of step 3.

The controller notices that congestion starts over link 4-6. It allocates flow A-B as a flow that was previously diverted as shown in Fig. 8. The controller finds that it is not possible to return flow A-B to be forwarded over the OSPF path 3-1-5-6 as there will be congestion at link 1-5. The controller decides to re-divert flow A-B over a longer path 3-2-4-7-5-6 to avoid congestion at both links 4-6 and 1-5. Flow A-B re-distribution is as shown in Fig. 9. The gain of last case, step 3, of FDA is illustrated by the average packet travel time shown in Fig. 10, and the average throughput of the network shown in Fig. 11.

Concerning the simulation results, every case is investigated twice with the same applied load. Firstly by using a controller with FDA and secondly by using standard OSPF. All factors used to measure the Quality of Service (QoS) show that the network with controller performs better than its version without a controller during higher applied traffic. In all FDA steps, higher average throughput is recorded with less number of dropped packets, less average packet travelling time, less latency and less packet delay variation (PDV). As FDA tries to divert the flow over the shortest bypass path, there is a possibility that the bypass path shares one link or more with the original OSPF path.

V. CONCLUSION

The semi-central management of the controller solved most of the problems discussed in the introduction section. The congestion problem was solved by the central controller using its FDA to selectively manage flows, which also results in better bandwidth utilization. FDA has been also applied on other network topologies and showed promising results.

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