PerLab

# Dynamic Multipath Scheduling Protocol in SDN

Project Work of “Advanced Network Architectures and Wireless Systems”

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# Used technologies

- VirtualBox 6.1
- Floodlight VM pre-configured with mininet, Open vSwitch, and Floodlight v1.1: for the tests, the VM has been executed with the maximum memory available (3562MB) and 4 processors. Two network adapters have been used: NAT and host-only adapter. https://floodlight.atlassian.net/wiki/spaces/floodlightcontroller/pages/8650780/Floodlight+VM
- Mininet 2.2.1
- Wireshark 2.6.6
- Iperf 2.0.5

# Introduction

- DMSP is based on a multipath enviroment and makes real-time changes to select least congested links for routing data packets. The path selection and monitoring is done by a central SDN controller.
- We modified the java code of the project Floodlight to  adapt it to the DMSP requirements.

S. A. Hussain, S. Akbar and I. Raza, "A dynamic multipath scheduling protocol (DMSP) for full performance isolation of links in software defined networking (SDN)," 2017 2nd Workshop on Recent Trends in Telecommunications Research (RTTR), Palmerston North, 2017, pp. 1-5, doi: 10.1109/RTTR.2017.7887866.

# Topology

- We created the topology with redundant links for multipaths, using Mininet.
- We wrote a python code ("*fat-tree.py*") that implemented a "Fat Tree Topology" and we executed it from command line:

*sudo mn --custom fat-tree.py*
*--controller=remote,ip=192.168.56.109*
*,port=6653 –topo=fat-tree*

# Building Multipaths

- We adapted the original module ***TopologyInstance*** in the package *net.floodlightcontroller.topology*: when calculting dijkstra shortest paths, we managed to store all the next-hops for each source-destination tuple that have minimum cost, instead of stopping at the first one found.
- We used the found next-hops to build all the possible paths and then we stored them in a cache.

# Building Multipaths

The main funcions in the code that we modified for calculating the multhipaths are:

- *getRoute* [l.753-816]: get the possible multi-paths from the cache to the *TopologyManager*
- *dijkstra* [l.496-557]: calculate all the minimum cost next-hops
- *buildroute* [l.655-727]: build all the possible paths from the next-hops of dijkstra

# TopologyInstance

This is an extract of the code, in which we can see how the multiple next-hops are selected.

```
public class TopologyInstance {
    ...
    protected LoadingCache<RouteId, List<Route>> pathcache;
    ...
    protected BroadcastTree dijkstra(Cluster c, DatapathId root,
                                     Map<Link, Integer> linkCost,
                                     boolean isDstRooted) {
       HashMap<DatapathId, List<Link>> nexthoplinks = new HashMap<DatapathId, List<Link>>();
       ...
       if (ndist <= cost.get(neighbor)) {

            if( isLinkCongested(link,isDstRooted) )
                continue;

            cost.put(neighbor, ndist);
            List<Link> templinks = nexthoplinks.get(neighbor);
            if (templinks == null) templinks = new ArrayList<Link>();
            templinks.add(link);
            nexthoplinks.put(neighbor, templinks);
            NodeDist ndTemp = new NodeDist(neighbor, ndist);
            nodeq.remove(ndTemp);
            nodeq.add(ndTemp);
       }
....
```

# Scheduling of multipaths

- We have updated the ***TopologyManager*** module: after receiving the list of possible paths from the *TopologyInstance*, it schedules one for each source-destination host pair, using the Round Robin algorithm.
- The interested functions are:
  - class PathId [l.97-155]
  - getRoute [l.780-802]
  - scheduleNewRoute [l.805-821]
  - checkStatistics [l.370-379]

# TopologyManager

```java
public class TopologyManager implements IFloodlightModule, ITopologyService, IRoutingService, ILinkDiscoveryListener,
IOFMessageListener {

    protected Map<RouteId,Integer> lastScheduledRoutes = new HashMap<RouteId,Integer>();
    protected Map<PathId,Route> scheduledPaths = new HashMap<PathId,Route>();
    .....
    @Override
    public Route getRoute(DatapathId src, OFPort srcPort, DatapathId dst, OFPort dstPort, U64 cookie,
            boolean tunnelEnabled) {
        TopologyInstance ti = getCurrentInstance(tunnelEnabled);
        List<Route> routes = ti.getRoute(null, src, srcPort, dst, dstPort, cookie);
        Route r = null;
        PathId pid = new PathId(src,srcPort,dst,dstPort);
        ....
            if(scheduledPaths.get(pid)!=null && routes.contains(scheduledPaths.get(pid))){
                r = scheduledPaths.get(pid);
                r = ti.getWholeRoute(r, src, srcPort, dst, dstPort);
            }else{
                r = scheduleNewRoute(src,srcPort,dst,dstPort,routes);
                r = ti.getWholeRoute(r, src, srcPort, dst, dstPort);
            }
        }
        return r;
    }

    // scheduling based on round robin
    private Route scheduleNewRoute(DatapathId src, OFPort srcPort, DatapathId dst, OFPort dstPort, List<Route> routes){
        PathId pid = new PathId(src,srcPort,dst,dstPort);
        RouteId rid = new RouteId(src,dst);
        ....
            int last = lastScheduledRoutes.get(rid);
            last = (last+1)%routes.size();
            lastScheduledRoutes.put(rid, last);
            scheduledPaths.put(pid,routes.get(last));
            return routes.get(last);
        }
  .....
```

# Statistics on bandwidth

- Since the DMSP protocol requires congestion control, so that different paths can be scheduled according to link available bandwidth, we included this part.
- We integrated the *statistics* module of a later version (present since 14 Dec 2015) of Floodlight to our system, which periodically collects statistics about link bandwidth.
- This service is exploited by the *TopologyInstance*: congested links do not contribute to path building.

# Statistics on bandwidth

We added several classes in a new package net.floodlightcontroller.statistics:

- ***IStatisticsService***: interface of the service
- ***StatisticsCollector***: implements the interface and contains the threads that collect the bandwidth statistics
- ***SwitchPortBandwidth***: utility class to store statistics for each port
- The other classes in the package are for the Rest API service

# Use of StatisticsCollector

The congested links are not considered in the computing of the possible paths by *TopologyInstance*.

```
public class TopologyInstance {

    protected IStatisticsService statisticsCollectorService;
    ...

    protected BroadcastTree dijkstra(Cluster c, DatapathId root, Map<Link, Integer> linkCost, boolean isDstRooted) {
        ....
        if( isLinkCongested(link,isDstRooted) )
                        continue;
        .....
    }

    protected boolean isLinkCongested(Link link, boolean isDstRooted){
        if(this.statisticsCollectorService != null){
            SwitchPortBandwidth spb = null;
            if(isDstRooted){
                spb = statisticsCollectorService.getBandwidthConsumption(link.getSrc(),link.getSrcPort());
            }else{
                spb = statisticsCollectorService.getBandwidthConsumption(link.getDst(),link.getDstPort());
            }
            // Check threshold;
            if (spb != null && spb.getBitsPerSecondTx().compareTo(statisticsCollectorService.getTxThreshold()) > 0){
                log.info(link+": TxBitsPerSec: "+spb.getBitsPerSecondTx()+", over threshold;");
                return true;
            }
        }
        return false;
    }
```

# Alternative choice

We developed an alternative version to calculate the shortest paths, modifying the *dijkstra* code (class *TopologyInstance*): insteaod of setting the link weights all to 1, we use the traffic load on the link. So the computed paths will be the ones with less load on them.

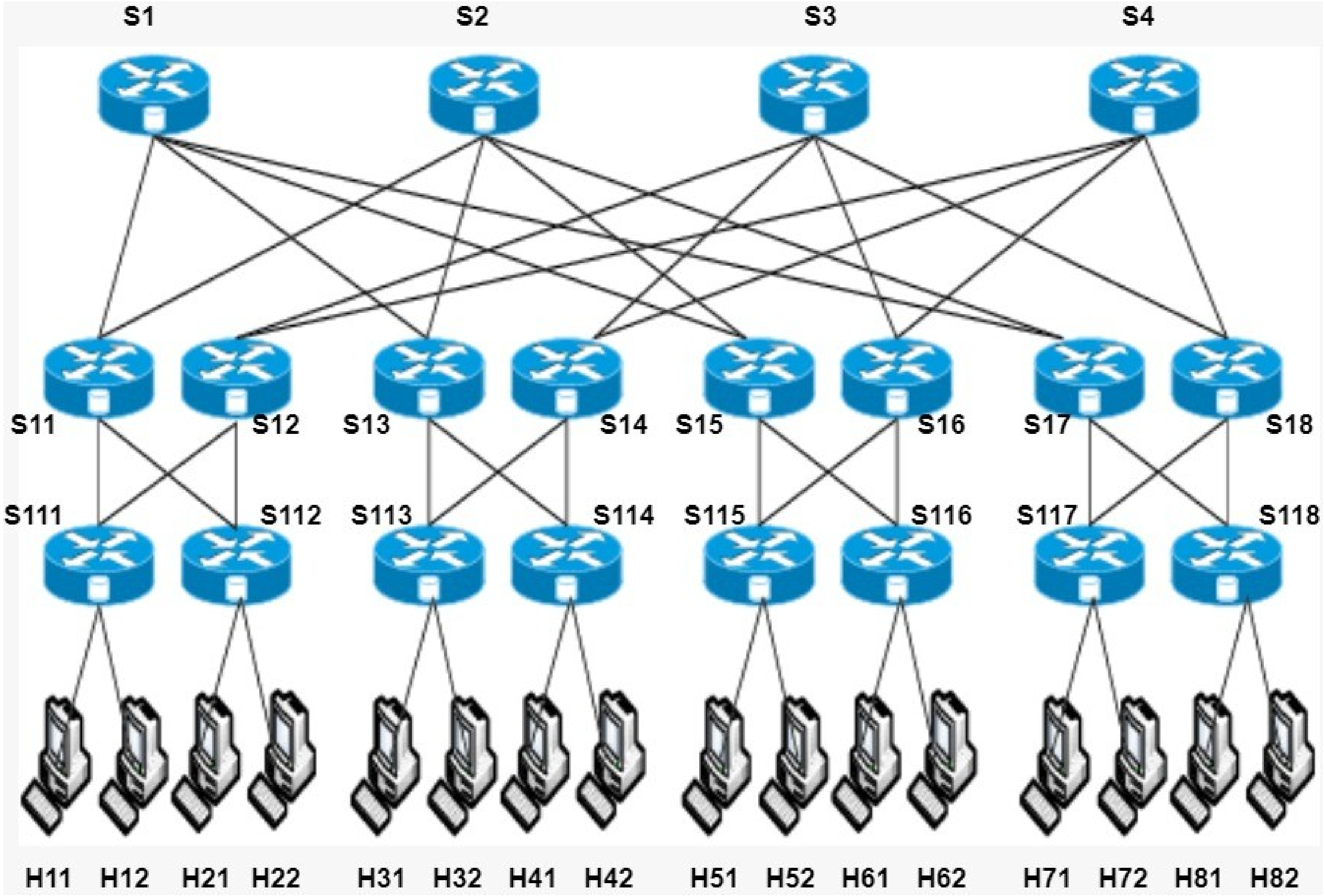
To exploit this altervative, the code is:

```
protected BroadcastTree dijkstra(Cluster c, DatapathId root,Map<Link, Integer> linkCost,boolean isDstRooted) {
    ....
    for (Link link: c.links.get(cnode)) {
            DatapathId neighbor;
        ....
        weight += getTrafficLoad(link);

        int ndist = cdist + weight; // the weight of the link
        if (ndist <= cost.get(neighbor)) {

            cost.put(neighbor, ndist);
            List<Link> templinks = nexthoplinks.get(neighbor);
            if (templinks == null) templinks = new ArrayList<Link>();
            templinks.add(link);
            nexthoplinks.put(neighbor, templinks);
            NodeDist ndTemp = new NodeDist(neighbor, ndist);
            nodeq.remove(ndTemp);
            nodeq.add(ndTemp);
        }
    }
}
```

# Topology



S1
S2
S3
S4
S11
S12
S13
S14
S15
S16
S17
S18
S111
S112
S113
S114
S115
S116
S117
S118
H11
H12
H21
H22
H31
H32
H41
H42
H51
H52
H61
H62
H71
H72
H81
H82

# Test on multipath

```
mininet> h11 ping -c 1 h41
PING 10.0.0.7 (10.0.0.7) 56(84) bytes of data.
64 bytes from 10.0.0.7: icmp_seq=1 ttl=64 time=20.7 ms

--- 10.0.0.7 ping statistics ---
1 packets transmitted, 1 received, 0% packet loss, time 0ms
rtt min/avg/max/mdev = 20.792/20.792/20.792/0.000 ms
mininet> h11 ping -c 1 h42
PING 10.0.0.8 (10.0.0.8) 56(84) bytes of data.
64 bytes from 10.0.0.8: icmp_seq=1 ttl=64 time=27.0 ms

--- 10.0.0.8 ping statistics ---
1 packets transmitted, 1 received, 0% packet loss, time 0ms
rtt min/avg/max/mdev = 27.043/27.043/27.043/0.000 ms
```

Two consecutive pings between hosts connected to the same switches go on different paths.

| No. | Time | Source | Destination | Protocol | Length | Info | Interface id |
|---|---|---|---|---|---|---|---|
| 5 | -0.015173730 | 10.0.0.1 | 10.0.0.7 | ICMP | 98 | Echo (ping) request … | s111-eth1 |
| 7 | -0.003014273 | 10.0.0.1 | 10.0.0.7 | ICMP | 98 | Echo (ping) request … | s111-eth4 |
| 9 | -0.003007870 | 10.0.0.1 | 10.0.0.7 | ICMP | 98 | Echo (ping) request … | s11-eth4 |
| 11 | -0.000128085 | 10.0.0.1 | 10.0.0.7 | ICMP | 98 | Echo (ping) request … | s11-eth1 |
| 13 | -0.000123214 | 10.0.0.1 | 10.0.0.7 | ICMP | 98 | Echo (ping) request … | s1-eth1 |
| 15 | -0.000061989 | 10.0.0.1 | 10.0.0.7 | ICMP | 98 | Echo (ping) request … | s1-eth2 |
| 17 | -0.000057418 | 10.0.0.1 | 10.0.0.7 | ICMP | 98 | Echo (ping) request … | s13-eth1 |
| 19 | -0.000003400 | 10.0.0.1 | 10.0.0.7 | ICMP | 98 | Echo (ping) request … | s13-eth3 |
| 1 | 0.000000000 | 10.0.0.1 | 10.0.0.7 | ICMP | 98 | Echo (ping) request … | s114-eth4 |
| 3 | 0.000049787 | 10.0.0.1 | 10.0.0.7 | ICMP | 98 | Echo (ping) request … | s114-eth1 |
| 4 | 0.000068082 | 10.0.0.7 | 10.0.0.1 | ICMP | 98 | Echo (ping) reply … | s114-eth1 |
| 2 | 0.005410383 | 10.0.0.7 | 10.0.0.1 | ICMP | 98 | Echo (ping) reply … | s114-eth4 |
| 20 | 0.005415825 | 10.0.0.7 | 10.0.0.1 | ICMP | 98 | Echo (ping) reply … | s13-eth3 |
| 18 | 0.005462957 | 10.0.0.7 | 10.0.0.1 | ICMP | 98 | Echo (ping) reply … | s13-eth1 |
| 16 | 0.005466405 | 10.0.0.7 | 10.0.0.1 | ICMP | 98 | Echo (ping) reply … | s1-eth2 |
| 14 | 0.005528212 | 10.0.0.7 | 10.0.0.1 | ICMP | 98 | Echo (ping) reply … | s1-eth1 |
| 12 | 0.005531807 | 10.0.0.7 | 10.0.0.1 | ICMP | 98 | Echo (ping) reply … | s11-eth1 |
| 10 | 0.005562314 | 10.0.0.7 | 10.0.0.1 | ICMP | 98 | Echo (ping) reply … | s11-eth4 |
| 8 | 0.005564621 | 10.0.0.7 | 10.0.0.1 | ICMP | 98 | Echo (ping) reply … | s111-eth4 |
| 6 | 0.005591334 | 10.0.0.7 | 10.0.0.1 | ICMP | 98 | Echo (ping) reply … | s111-eth1 |
| 28 | 9.025874915 | 10.0.0.1 | 10.0.0.8 | ICMP | 98 | Echo (ping) request … | s111-eth1 |
| 30 | 9.031446361 | 10.0.0.1 | 10.0.0.8 | ICMP | 98 | Echo (ping) request … | s111-eth3 |
| 21 | 9.031455877 | 10.0.0.1 | 10.0.0.8 | ICMP | 98 | Echo (ping) request … | s12-eth4 |
| 24 | 9.035961265 | 10.0.0.1 | 10.0.0.8 | ICMP | 98 | Echo (ping) request … | s12-eth2 |
| 32 | 9.035966330 | 10.0.0.1 | 10.0.0.8 | ICMP | 98 | Echo (ping) request … | s4-eth1 |
| 34 | 9.036013873 | 10.0.0.1 | 10.0.0.8 | ICMP | 98 | Echo (ping) request … | s4-eth2 |
| 22 | 9.036016628 | 10.0.0.1 | 10.0.0.8 | ICMP | 98 | Echo (ping) request … | s14-eth2 |
| 26 | 9.036057355 | 10.0.0.1 | 10.0.0.8 | ICMP | 98 | Echo (ping) request … | s14-eth3 |
| 36 | 9.036060245 | 10.0.0.1 | 10.0.0.8 | ICMP | 98 | Echo (ping) request … | s114-eth3 |
| 38 | 9.036088265 | 10.0.0.1 | 10.0.0.8 | ICMP | 98 | Echo (ping) request … | s114-eth2 |
| 39 | 9.036103994 | 10.0.0.8 | 10.0.0.1 | ICMP | 98 | Echo (ping) reply … | s114-eth2 |
| 37 | 9.037833543 | 10.0.0.8 | 10.0.0.1 | ICMP | 98 | Echo (ping) reply … | s114-eth3 |
| 27 | 9.037837627 | 10.0.0.8 | 10.0.0.1 | ICMP | 98 | Echo (ping) reply … | s14-eth3 |
| 23 | 9.037878038 | 10.0.0.8 | 10.0.0.1 | ICMP | 98 | Echo (ping) reply … | s14-eth2 |
| 35 | 9.037880917 | 10.0.0.8 | 10.0.0.1 | ICMP | 98 | Echo (ping) reply … | s4-eth2 |
| 33 | 9.042136762 | 10.0.0.8 | 10.0.0.1 | ICMP | 98 | Echo (ping) reply … | s4-eth1 |
| 25 | 9.042143530 | 10.0.0.8 | 10.0.0.1 | ICMP | 98 | Echo (ping) reply … | s12-eth2 |
| 40 | 9.052784038 | 10.0.0.8 | 10.0.0.1 | ICMP | 98 | Echo (ping) reply … | s12-eth4 |
| 31 | 9.052789344 | 10.0.0.8 | 10.0.0.1 | ICMP | 98 | Echo (ping) reply … | s111-eth3 |
| 29 | 9.052887863 | 10.0.0.8 | 10.0.0.1 | ICMP | 98 | Echo (ping) reply … | s111-eth1 |

# Test on congestion

Two consecutive pings between the same hosts go on the same path.

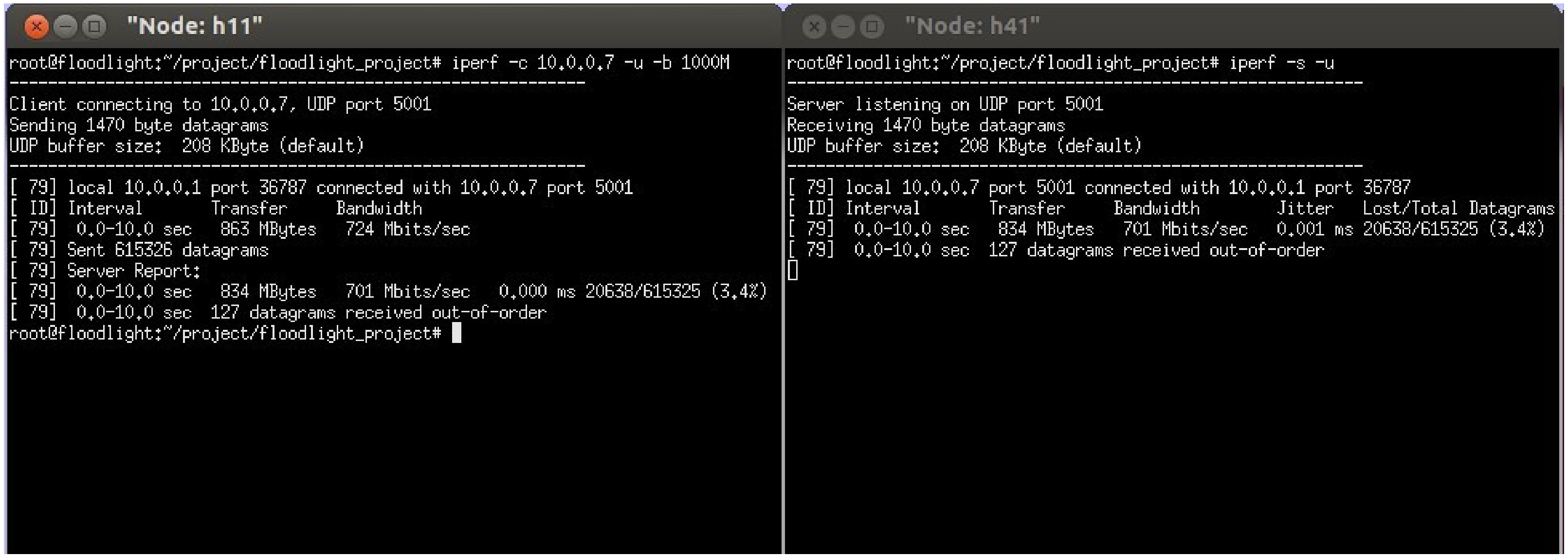
```
mininet> h11 ping -c 1 h41
PING 10.0.0.7 (10.0.0.7) 56(84) bytes of data.
64 bytes from 10.0.0.7: icmp_seq=1 ttl=64 time=22.3 ms

--- 10.0.0.7 ping statistics ---
1 packets transmitted, 1 received, 0% packet loss, time 0ms
rtt min/avg/max/mdev = 22.318/22.318/22.318/0.000 ms
mininet> h11 ping -c 1 h41
PING 10.0.0.7 (10.0.0.7) 56(84) bytes of data.
64 bytes from 10.0.0.7: icmp_seq=1 ttl=64 time=10.6 ms

--- 10.0.0.7 ping statistics ---
1 packets transmitted, 1 received, 0% packet loss, time 0ms
rtt min/avg/max/mdev = 10.695/10.695/10.695/0.000 ms
mininet>
```

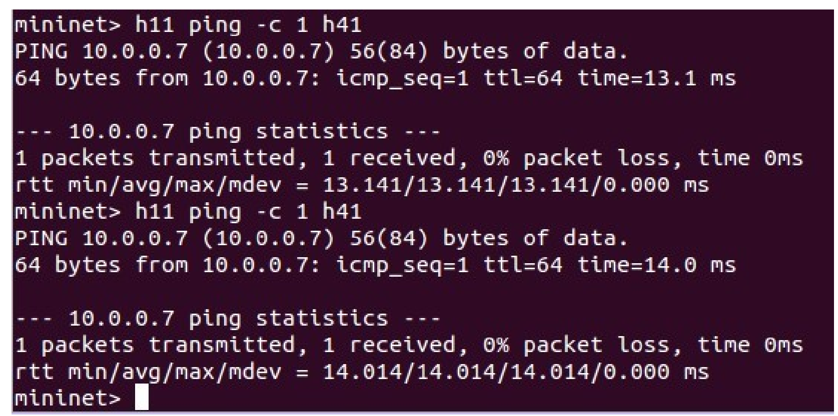
| No. | Time | Source | Destination | Protocol | Length | Info | Interface id |
|---|---|---|---|---|---|---|---|
| 1 | 0.000000000 | 10.0.0.1 | 10.0.0.7 | ICMP | 98 | Echo (ping) request … | s111-eth1 |
| 3 | 0.009411146 | 10.0.0.1 | 10.0.0.7 | ICMP | 98 | Echo (ping) request … | s111-eth4 |
| 5 | 0.009416482 | 10.0.0.1 | 10.0.0.7 | ICMP | 98 | Echo (ping) request … | s11-eth4 |
| 11 | 0.012970510 | 10.0.0.1 | 10.0.0.7 | ICMP | 98 | Echo (ping) request … | s11-eth1 |
| 17 | 0.012973333 | 10.0.0.1 | 10.0.0.7 | ICMP | 98 | Echo (ping) request … | s1-eth1 |
| 9 | 0.013048574 | 10.0.0.1 | 10.0.0.7 | ICMP | 98 | Echo (ping) request … | s1-eth2 |
| 15 | 0.013051999 | 10.0.0.1 | 10.0.0.7 | ICMP | 98 | Echo (ping) request … | s13-eth1 |
| 19 | 0.013104538 | 10.0.0.1 | 10.0.0.7 | ICMP | 98 | Echo (ping) request … | s13-eth3 |
| 7 | 0.013107947 | 10.0.0.1 | 10.0.0.7 | ICMP | 98 | Echo (ping) request … | s114-eth4 |
| 13 | 0.013142874 | 10.0.0.1 | 10.0.0.7 | ICMP | 98 | Echo (ping) request … | s114-eth1 |
| 14 | 0.013164574 | 10.0.0.7 | 10.0.0.1 | ICMP | 98 | Echo (ping) reply … | s114-eth1 |
| 8 | 0.022139925 | 10.0.0.7 | 10.0.0.1 | ICMP | 98 | Echo (ping) reply … | s114-eth4 |
| 20 | 0.022145679 | 10.0.0.7 | 10.0.0.1 | ICMP | 98 | Echo (ping) reply … | s13-eth3 |
| 16 | 0.022192290 | 10.0.0.7 | 10.0.0.1 | ICMP | 98 | Echo (ping) reply … | s13-eth1 |
| 10 | 0.022201353 | 10.0.0.7 | 10.0.0.1 | ICMP | 98 | Echo (ping) reply … | s1-eth2 |
| 18 | 0.022233785 | 10.0.0.7 | 10.0.0.1 | ICMP | 98 | Echo (ping) reply … | s1-eth1 |
| 12 | 0.022236415 | 10.0.0.7 | 10.0.0.1 | ICMP | 98 | Echo (ping) reply … | s11-eth1 |
| 6 | 0.022262533 | 10.0.0.7 | 10.0.0.1 | ICMP | 98 | Echo (ping) reply … | s11-eth4 |
| 4 | 0.022265124 | 10.0.0.7 | 10.0.0.1 | ICMP | 98 | Echo (ping) reply … | s111-eth4 |
| 2 | 0.022294743 | 10.0.0.7 | 10.0.0.1 | ICMP | 98 | Echo (ping) reply … | s111-eth1 |
| 25 | 3.732317601 | 10.0.0.1 | 10.0.0.7 | ICMP | 98 | Echo (ping) request … | s111-eth1 |
| 27 | 3.740094534 | 10.0.0.1 | 10.0.0.7 | ICMP | 98 | Echo (ping) request … | s111-eth4 |
| 29 | 3.740099209 | 10.0.0.1 | 10.0.0.7 | ICMP | 98 | Echo (ping) request … | s11-eth4 |
| 31 | 3.740149703 | 10.0.0.1 | 10.0.0.7 | ICMP | 98 | Echo (ping) request … | s11-eth1 |
| 21 | 3.740152736 | 10.0.0.1 | 10.0.0.7 | ICMP | 98 | Echo (ping) request … | s1-eth1 |
| 23 | 3.740187009 | 10.0.0.1 | 10.0.0.7 | ICMP | 98 | Echo (ping) request … | s1-eth2 |
| 33 | 3.740189689 | 10.0.0.1 | 10.0.0.7 | ICMP | 98 | Echo (ping) request … | s13-eth1 |
| 35 | 3.740216859 | 10.0.0.1 | 10.0.0.7 | ICMP | 98 | Echo (ping) request … | s13-eth3 |
| 37 | 3.740219551 | 10.0.0.1 | 10.0.0.7 | ICMP | 98 | Echo (ping) request … | s114-eth4 |
| 39 | 3.740244542 | 10.0.0.1 | 10.0.0.7 | ICMP | 98 | Echo (ping) request … | s114-eth1 |
| 40 | 3.740259471 | 10.0.0.7 | 10.0.0.1 | ICMP | 98 | Echo (ping) reply … | s114-eth1 |
| 38 | 3.742834521 | 10.0.0.7 | 10.0.0.1 | ICMP | 98 | Echo (ping) reply … | s114-eth4 |
| 36 | 3.742840013 | 10.0.0.7 | 10.0.0.1 | ICMP | 98 | Echo (ping) reply … | s13-eth3 |
| 34 | 3.742892054 | 10.0.0.7 | 10.0.0.1 | ICMP | 98 | Echo (ping) reply … | s13-eth1 |
| 24 | 3.742895173 | 10.0.0.7 | 10.0.0.1 | ICMP | 98 | Echo (ping) reply … | s1-eth2 |
| 22 | 3.742926495 | 10.0.0.7 | 10.0.0.1 | ICMP | 98 | Echo (ping) reply … | s1-eth1 |
| 32 | 3.742928988 | 10.0.0.7 | 10.0.0.1 | ICMP | 98 | Echo (ping) reply … | s11-eth1 |
| 30 | 3.742955196 | 10.0.0.7 | 10.0.0.1 | ICMP | 98 | Echo (ping) reply … | s11-eth4 |
| 28 | 3.742957595 | 10.0.0.7 | 10.0.0.1 | ICMP | 98 | Echo (ping) reply … | s111-eth4 |
| 26 | 3.742990196 | 10.0.0.7 | 10.0.0.1 | ICMP | 98 | Echo (ping) reply … | s111-eth1 |

# Test on congestion




We congest the path between h11 and h41 with the command *iperf*.

The controller will detect the congestion on the links and compute a different path for the hosts comunication.



# Test on congestion

| No. | Time | Source | Destination | Protocol | Length | Info | Interface id |
|---|---|---|---|---|---|---|---|
| 2 | -0.067705264 | 10.0.0.1 | 10.0.0.7 | ICMP | 98 | Echo (ping) request … | s111-eth1 |
| 6 | -0.002210492 | 10.0.0.1 | 10.0.0.7 | ICMP | 98 | Echo (ping) request … | s111-eth4 |
| 16 | -0.002203960 | 10.0.0.1 | 10.0.0.7 | ICMP | 98 | Echo (ping) request … | s11-eth4 |
| 18 | -0.000806475 | 10.0.0.1 | 10.0.0.7 | ICMP | 98 | Echo (ping) request … | s11-eth1 |
| 14 | -0.000800061 | 10.0.0.1 | 10.0.0.7 | ICMP | 98 | Echo (ping) request … | s1-eth1 |
| 8 | -0.000009296 | 10.0.0.1 | 10.0.0.7 | ICMP | 98 | Echo (ping) request … | s1-eth2 |
| 1 | 0.000000000 | 10.0.0.1 | 10.0.0.7 | ICMP | 98 | Echo (ping) request … | s13-eth1 |
| 4 | 0.000041933 | 10.0.0.1 | 10.0.0.7 | ICMP | 98 | Echo (ping) request … | s13-eth3 |
| 12 | 0.000047434 | 10.0.0.1 | 10.0.0.7 | ICMP | 98 | Echo (ping) request … | s114-eth4 |
| 10 | 0.000083282 | 10.0.0.1 | 10.0.0.7 | ICMP | 98 | Echo (ping) request … | s114-eth1 |
| 11 | 0.000111036 | 10.0.0.7 | 10.0.0.1 | ICMP | 98 | Echo (ping) reply … | s114-eth1 |
| 13 | 0.003600459 | 10.0.0.7 | 10.0.0.1 | ICMP | 98 | Echo (ping) reply … | s114-eth4 |
| 5 | 0.003609796 | 10.0.0.7 | 10.0.0.1 | ICMP | 98 | Echo (ping) reply … | s13-eth3 |
| 20 | 0.095849187 | 10.0.0.7 | 10.0.0.1 | ICMP | 98 | Echo (ping) reply … | s13-eth1 |
| 9 | 0.095855913 | 10.0.0.7 | 10.0.0.1 | ICMP | 98 | Echo (ping) reply … | s1-eth2 |
| 15 | 0.096130884 | 10.0.0.7 | 10.0.0.1 | ICMP | 98 | Echo (ping) reply … | s1-eth1 |
| 19 | 0.096139848 | 10.0.0.7 | 10.0.0.1 | ICMP | 98 | Echo (ping) reply … | s11-eth1 |
| 17 | 0.096198366 | 10.0.0.7 | 10.0.0.1 | ICMP | 98 | Echo (ping) reply … | s11-eth4 |
| 7 | 0.096203820 | 10.0.0.7 | 10.0.0.1 | ICMP | 98 | Echo (ping) reply … | s111-eth4 |
| 3 | 0.096268148 | 10.0.0.7 | 10.0.0.1 | ICMP | 98 | Echo (ping) reply … | s111-eth1 |
| 21 | 179.2681528… | 10.0.0.1 | 10.0.0.7 | ICMP | 98 | Echo (ping) request … | s111-eth1 |
| 22 | 179.2725070… | 10.0.0.1 | 10.0.0.7 | ICMP | 98 | Echo (ping) request … | s111-eth4 |
| 31 | 179.2725119… | 10.0.0.1 | 10.0.0.7 | ICMP | 98 | Echo (ping) request … | s11-eth4 |
| 25 | 179.2770466… | 10.0.0.1 | 10.0.0.7 | ICMP | 98 | Echo (ping) request … | s11-eth2 |
| 38 | 179.2770520… | 10.0.0.1 | 10.0.0.7 | ICMP | 98 | Echo (ping) request … | s2-eth1 |
| 37 | 179.2771008… | 10.0.0.1 | 10.0.0.7 | ICMP | 98 | Echo (ping) request … | s2-eth2 |
| 33 | 179.2771037… | 10.0.0.1 | 10.0.0.7 | ICMP | 98 | Echo (ping) request … | s13-eth2 |
| 32 | 179.2771716… | 10.0.0.1 | 10.0.0.7 | ICMP | 98 | Echo (ping) request … | s13-eth3 |
| 27 | 179.2771746… | 10.0.0.1 | 10.0.0.7 | ICMP | 98 | Echo (ping) request … | s114-eth4 |
| 23 | 179.2772022… | 10.0.0.1 | 10.0.0.7 | ICMP | 98 | Echo (ping) request … | s114-eth1 |
| 24 | 179.2772168… | 10.0.0.7 | 10.0.0.1 | ICMP | 98 | Echo (ping) reply … | s114-eth1 |
| 28 | 179.2780081… | 10.0.0.7 | 10.0.0.1 | ICMP | 98 | Echo (ping) reply … | s114-eth3 |
| 34 | 179.2780120… | 10.0.0.7 | 10.0.0.1 | ICMP | 98 | Echo (ping) reply … | s14-eth3 |
| 35 | 179.2803867… | 10.0.0.7 | 10.0.0.1 | ICMP | 98 | Echo (ping) reply … | s14-eth1 |
| 39 | 179.2803915… | 10.0.0.7 | 10.0.0.1 | ICMP | 98 | Echo (ping) reply … | s3-eth2 |
| 40 | 179.2808016… | 10.0.0.7 | 10.0.0.1 | ICMP | 98 | Echo (ping) reply … | s3-eth1 |
| 30 | 179.2808054… | 10.0.0.7 | 10.0.0.1 | ICMP | 98 | Echo (ping) reply … | s12-eth1 |
| 29 | 179.2812245… | 10.0.0.7 | 10.0.0.1 | ICMP | 98 | Echo (ping) reply … | s12-eth4 |
| 26 | 179.2812280… | 10.0.0.7 | 10.0.0.1 | ICMP | 98 | Echo (ping) reply … | s111-eth3 |
| 36 | 179.2812689… | 10.0.0.7 | 10.0.0.1 | ICMP | 98 | Echo (ping) reply … | s111-eth1 |

Before the congestion

After the congestion

# Pingall comparision

We executed the *pingall* command for the three versions of the project:

1. Scheduling with <u>*dijkstra*</u> the first shortest path available

2. Scheduling multipaths with *Round Robin*, discarding <u>congested links</u>

3. Scheduling multhipaths with *dijkstra*, considering as cost measure the <u>traffic load</u> on each link

# Pingall comparision

These are the results in term of number of packets captured at each switch's interfaces.

| pingall | DIJKSTRA | CONGESTEDLINKS | TRAFFICLOAD |
|---|---|---|---|
| switch | pkts | pkts | pkts |
| *s1* | 768 | 151 | 208 |
| *s2* | - | 204 | 192 |
| *s3* | - | 196 | 196 |
| *s4* | - | 166 | 172 |
| *s11* | 416 | 212 | 216 |
| *s12* | - | 204 | 200 |
| *s13* | 416 | 220 | 216 |
| *s14* | - | 196 | 200 |
| *s15* | 416 | 222 | 216 |
| *s16* | - | 194 | 200 |
| *s17* | 416 | 222 | 216 |
| *s18* | - | 194 | 200 |
| *s111* | 232 | 232 | 232 |
| *s112* | 232 | 232 | 232 |
| *s113* | 232 | 232 | 232 |
| *s114* | 232 | 232 | 232 |
| *s115* | 232 | 232 | 232 |
| *s116* | 232 | 232 | 232 |
| *s117* | 232 | 232 | 232 |
| *s118* | 232 | 232 | 232 |

# Parameters

To study better the network we could modify some parameters:

- Add the option *–link tc,bw=10* to the mininet command, to limit the bandwidth of the links
- Change consequently the TX_THRESHOLD of the interface *IstatisticsService*
- Change the FLOWMOD_DEFAULT_IDLE_TIMEOUT in the *ForwardingBase* class, to alterate the timeout of the flow table entries
- Change the *expireAfterWrite* timeout of the *PathCache* in the *TopologyInstance* class.