

NetFPGA 플랫폼 기반 OpenFlow Switched Network 의 가상화 및 QoS 지원

2011. 8. 10, Future Internet Testbed W/G

충남대학교 데이터 통신 연구실
이재용, 김병철, 민석홍, 정회진

{jyl, byckim, minsh, wjjung}@cnu.ac.kr



목차

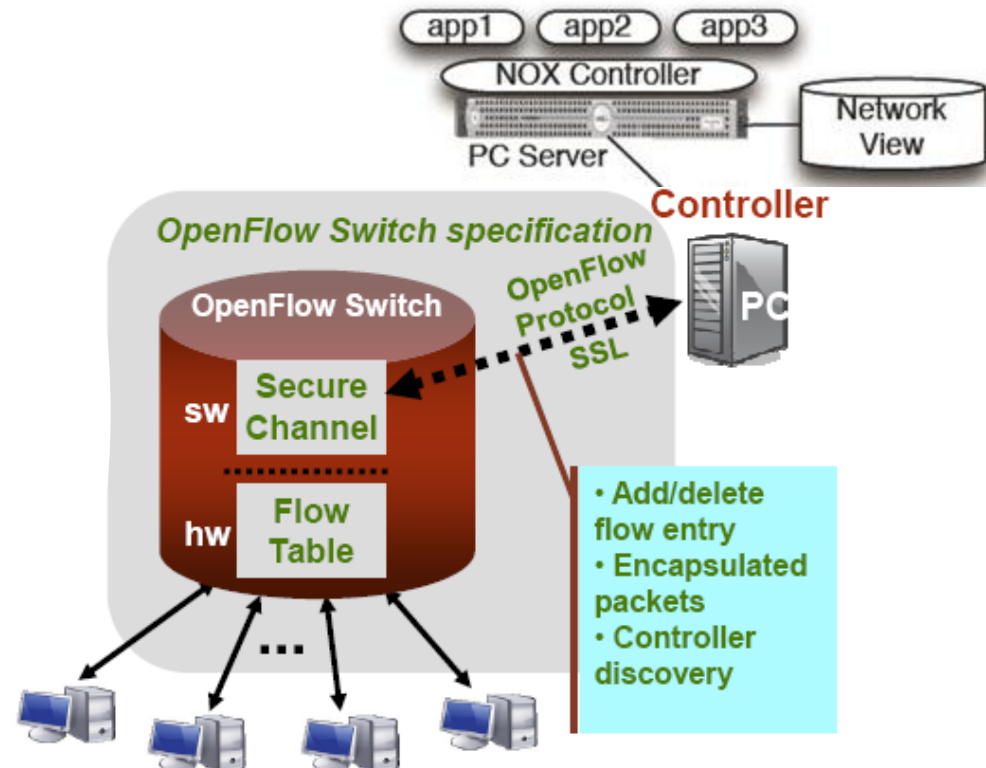
- ❖ NetFPGA & OpenFlow overview
 - NetFPGA Network Emulator
 - NetFPGA Capsulator
 - NetOpen Capsulator Software (FiRST@PC)
 - NetOpen Switching Software (FiRST@PC)

- ❖ Implementation of NetFPGA platform-based OpenFlow Testbed on KOREN/KREONET (FiRST@PC)
 - NetOpen RA Alpha
 - Network Virtualization with QoS support



OpenFlow components

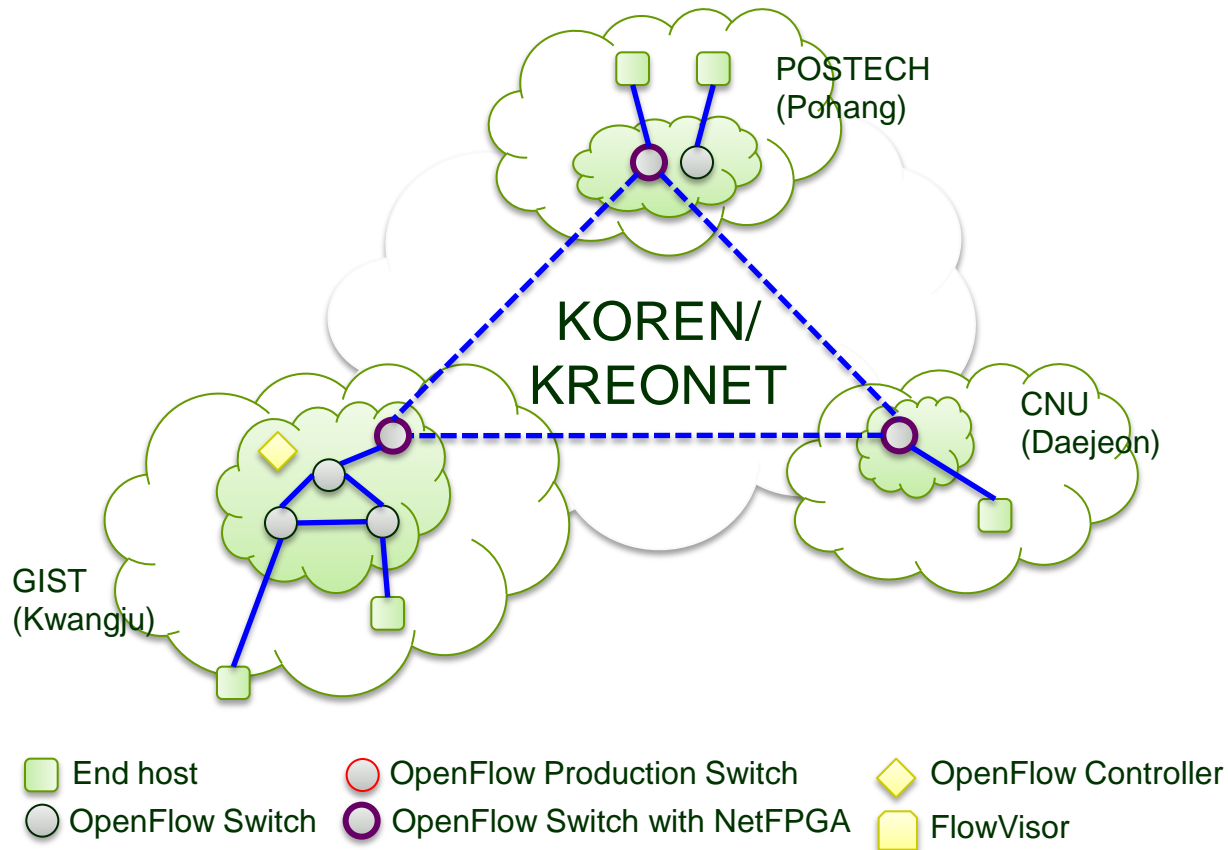
- ❖ OpenFlow Controller
 - Network operating system with centralized programming model
- ❖ OpenFlow protocol
 - OF switch ↔ controller
- ❖ Secure channel
- ❖ Flow Table
 - Ingress port
 - Ethernet src/dst addresses
 - Ethernet type
 - VLAN tag
 - IP src/dst addresses
 - IP protocol
 - TCP/UDP src/dst ports



NetOpen Capsulator S/W **Fi**RST@PC

Future Internet Research for Sustainable Testbed

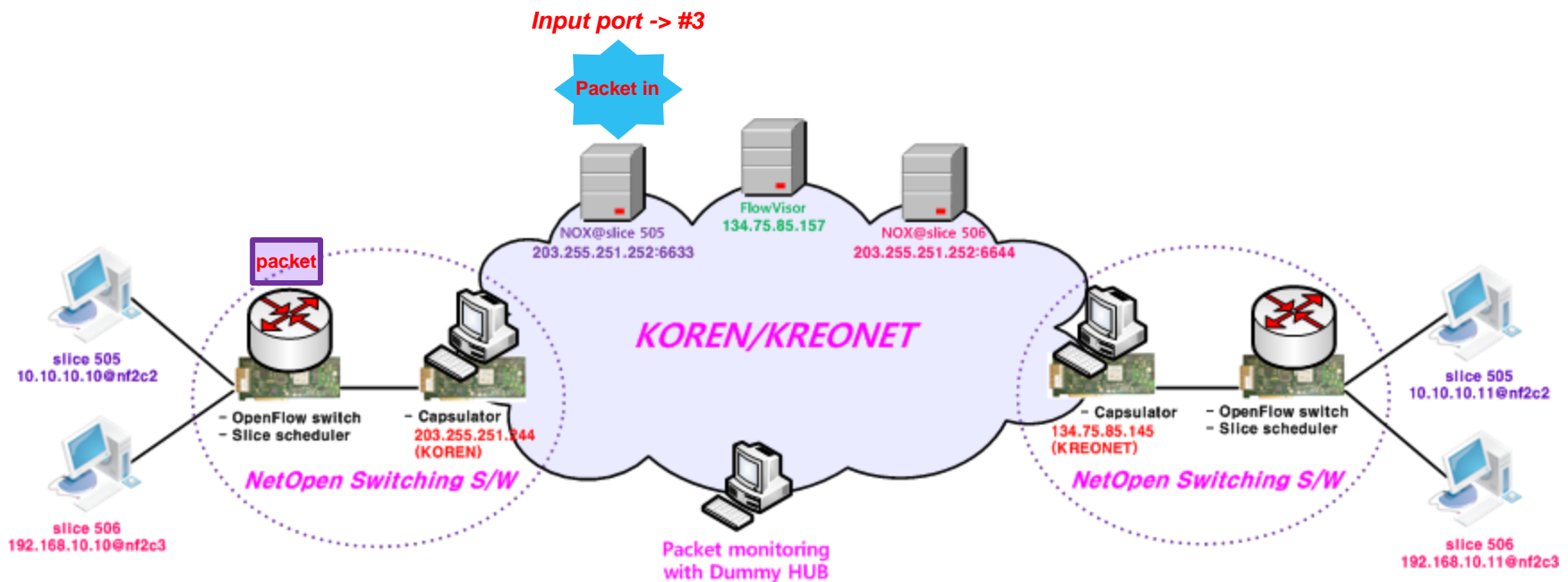
❖ NetOpen RA Alpha (NetFPGA platform-based Future Internet Testbed)



Local Testbed for Network Virtualization

❖ KOREN ↔ KREONET

- Testbed slicing and mapping to controller(NOX) by FlowVisor
- VLAN tagging @end-hosts (IEEE 802.1q)
- VLAN tagging @switch by NOX

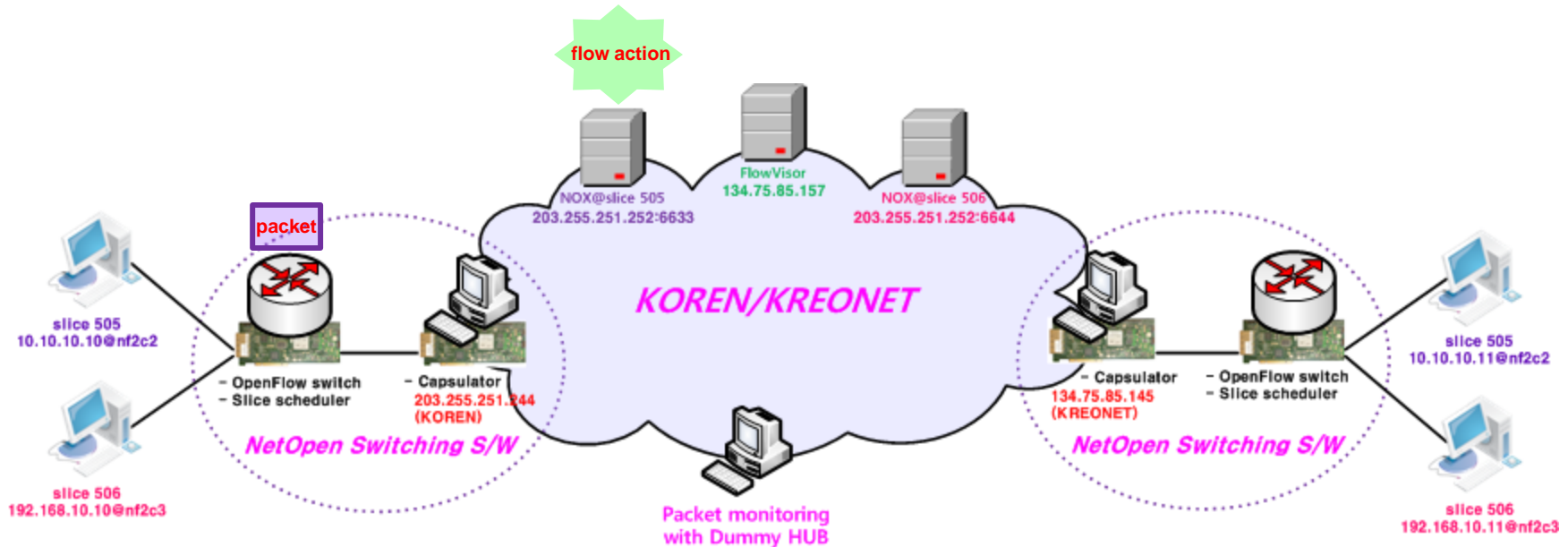


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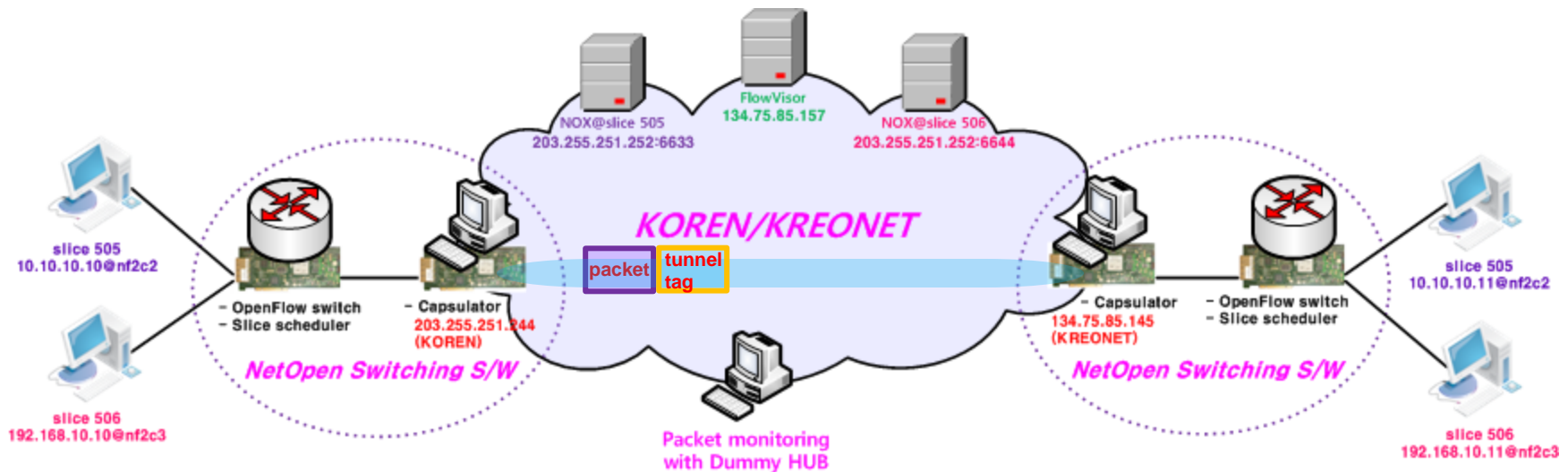
VLAN TAGGING -> VLAN ID 505, PCP 6



Local Testbed for Network Virtualization

❖ KOREN ↔ KREONET

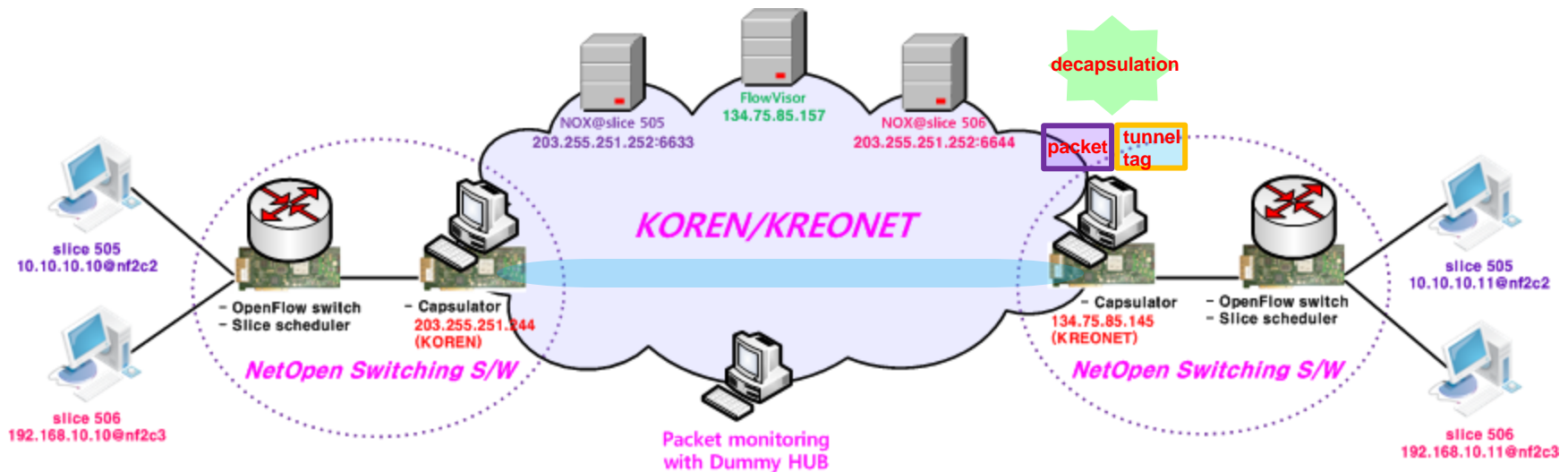
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Local Testbed for Network Virtualization

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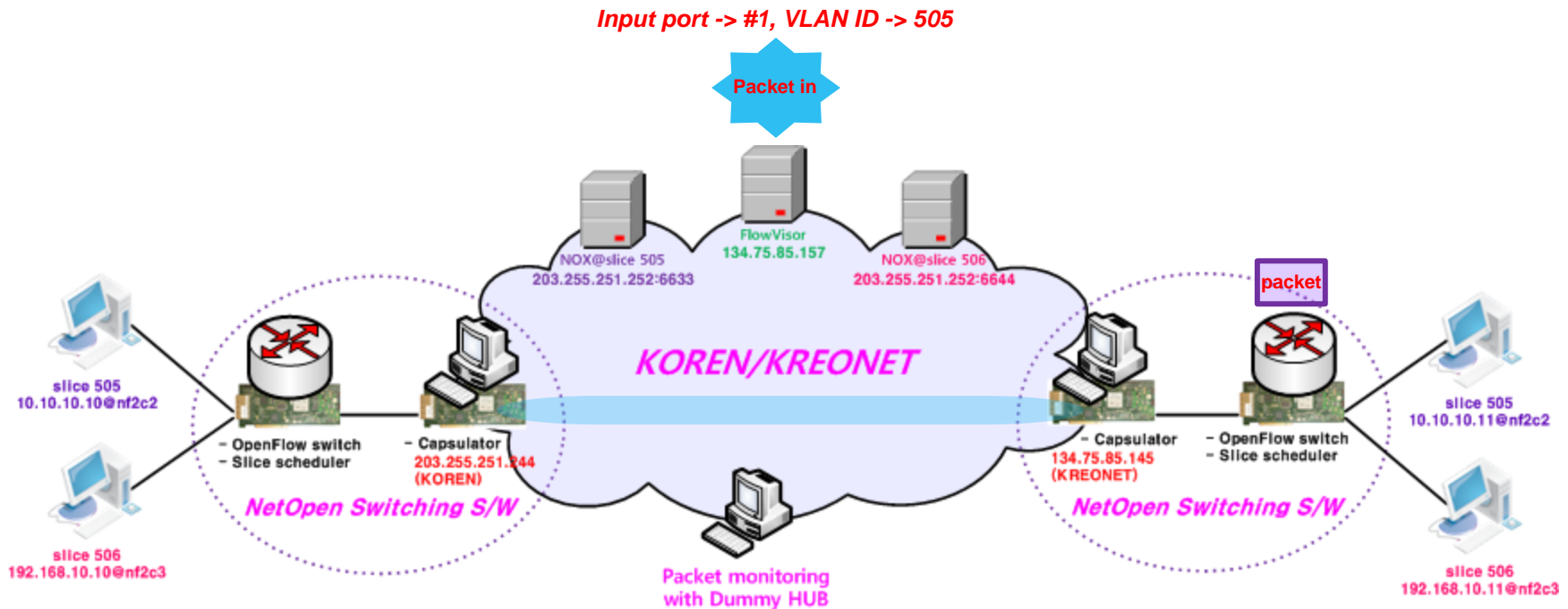
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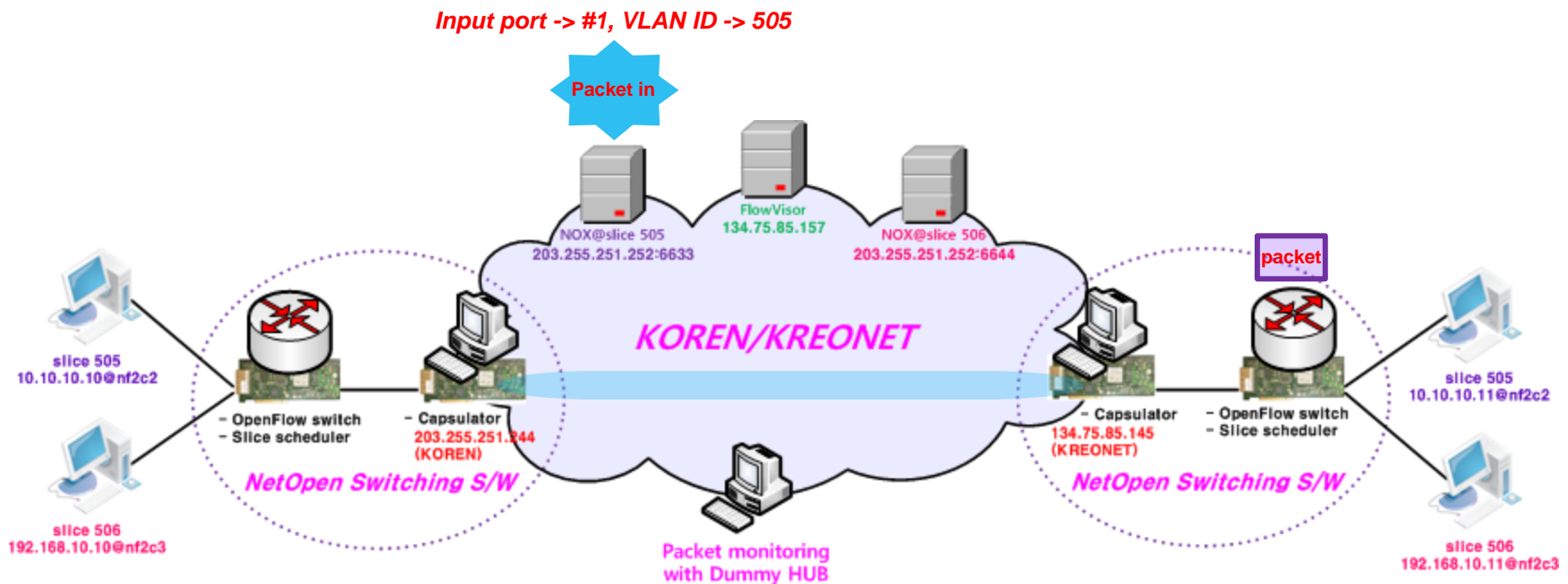
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Local Testbed for Network Virtualization

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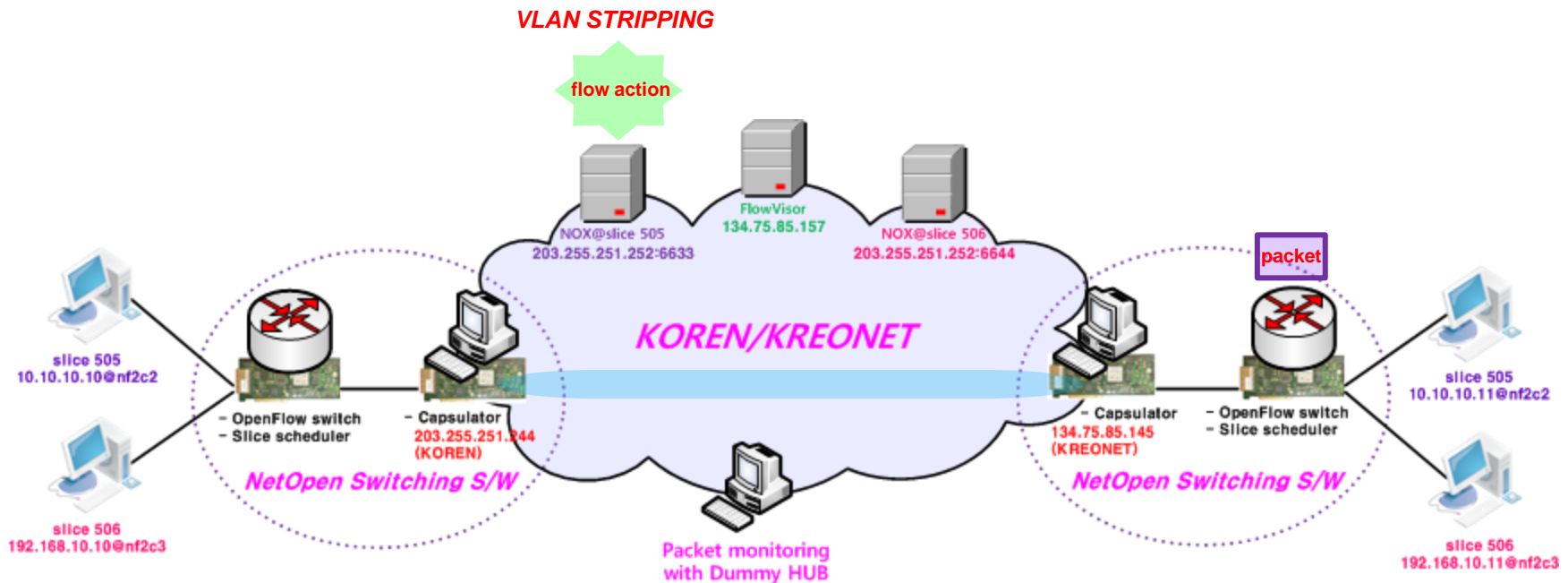
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Local Testbed for Network Virtualization

❖ KOREN ↔ KREONET

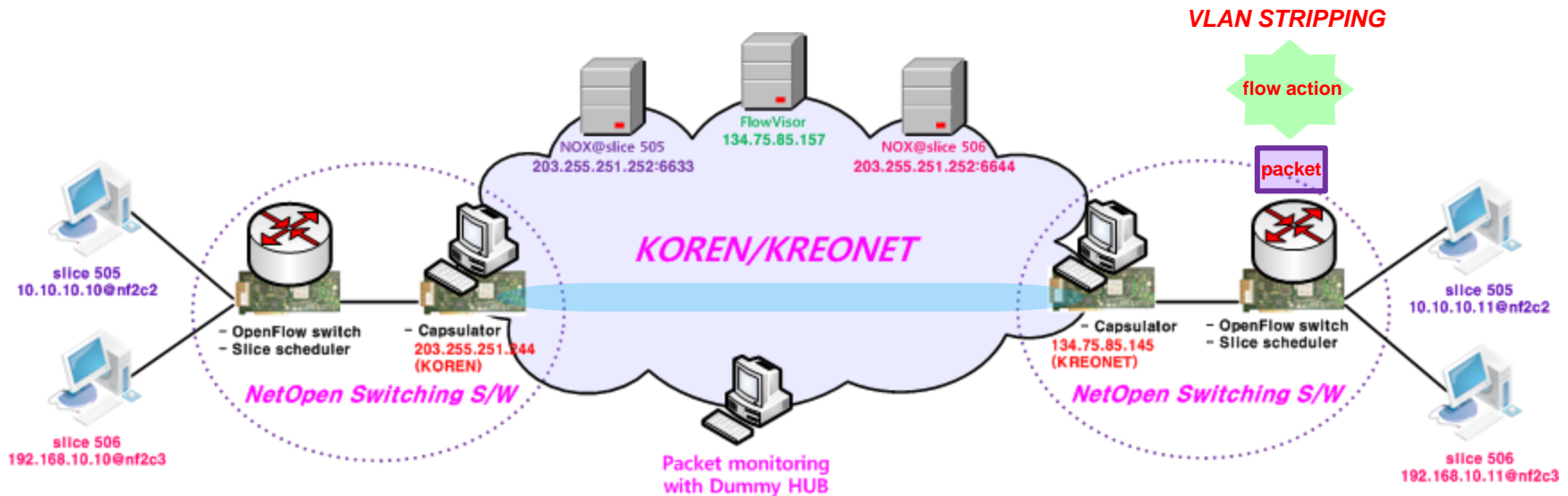
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❖ KOREN ↔ KREONET

- Testbed slicing and mapping to controller(NOX) by FlowVisor
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- VLAN tagging @switch by NOX

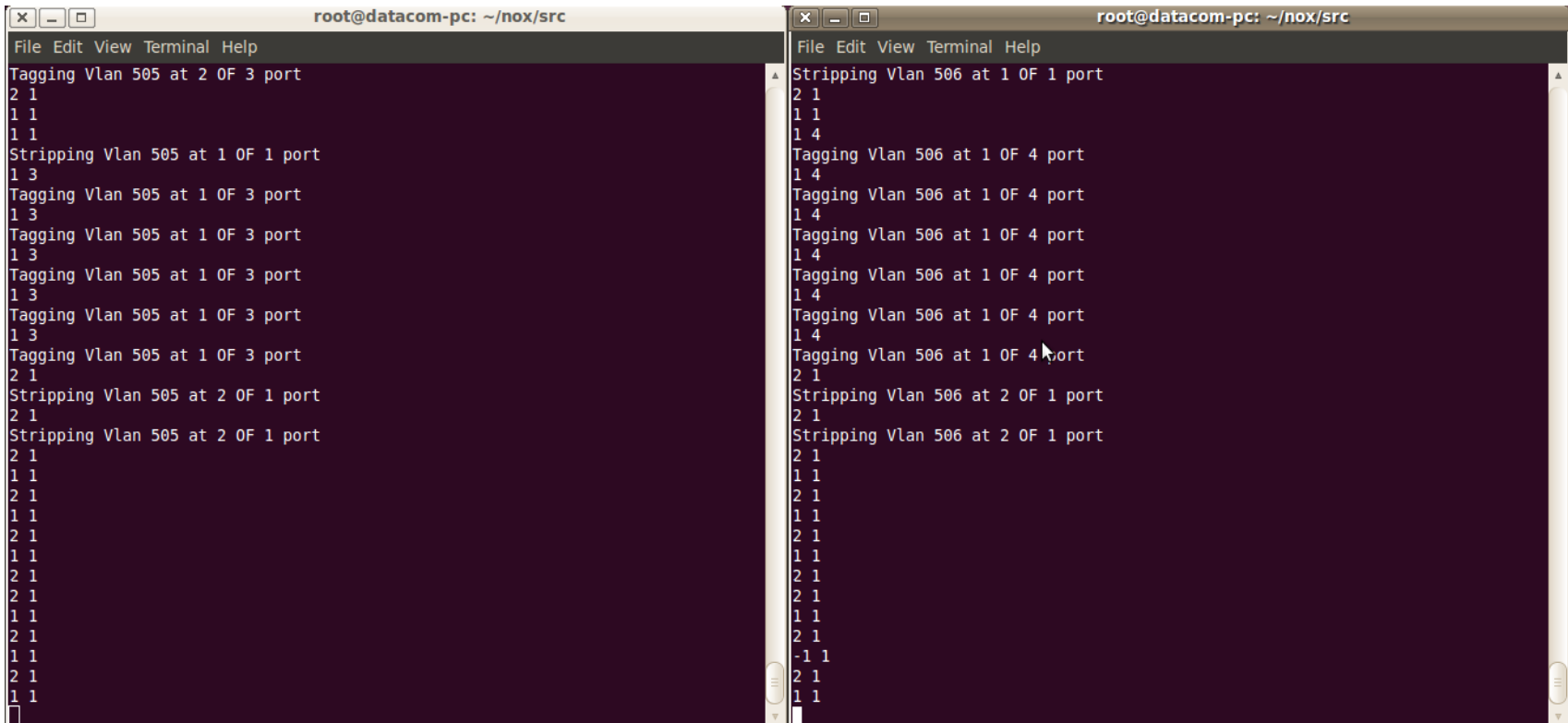


Experimental Setup

❖ NOX

**Slice: DATACOM-A
VLAN 505**

**Slice: DATACOM-B
VLAN 506**



```
root@datacom-pc: ~/nox/src
File Edit View Terminal Help
Tagging Vlan 505 at 2 OF 3 port
2 1
1 1
1 1
Stripping Vlan 505 at 1 OF 1 port
1 3
Tagging Vlan 505 at 1 OF 3 port
1 3
Tagging Vlan 505 at 1 OF 3 port
1 3
Tagging Vlan 505 at 1 OF 3 port
1 3
Tagging Vlan 505 at 1 OF 3 port
1 3
Tagging Vlan 505 at 1 OF 3 port
2 1
Stripping Vlan 505 at 2 OF 1 port
2 1
Stripping Vlan 505 at 2 OF 1 port
2 1
1 1
2 1
1 1
2 1
2 1
1 1
2 1
1 1
2 1
1 1
2 1
1 1

root@datacom-pc: ~/nox/src
File Edit View Terminal Help
Stripping Vlan 506 at 1 OF 1 port
2 1
1 1
1 4
Tagging Vlan 506 at 1 OF 4 port
1 4
Tagging Vlan 506 at 1 OF 4 port
1 4
Tagging Vlan 506 at 1 OF 4 port
1 4
Tagging Vlan 506 at 1 OF 4 port
1 4
Tagging Vlan 506 at 1 OF 4 port
1 4
Tagging Vlan 506 at 1 OF 4 port
2 1
Stripping Vlan 506 at 2 OF 1 port
2 1
Stripping Vlan 506 at 2 OF 1 port
2 1
1 1
2 1
2 1
2 1
1 1
2 1
2 1
-1 1
2 1
1 1
```



Experimental Setup

❖ FlowVisor

```
shmin@shminpc: ~  
File Edit View Search Terminal Help  
  
[list Slices]  
Slice 0: fvadmin  
Slice 1: Datacom-B  
Slice 2: Datacom-A  
  
[list Slice info] Datacom-A  
Got reply:  
connection_2=00:00:00:00:00:00:02-->/134.75.85.157:45935-->/203.255.251.252:6633  
connection_1=00:00:00:00:00:00:01-->/134.75.85.157:45934-->/203.255.251.252:6633  
contact_email=minsh@cnu.ac.kr  
controller_hostname=203.255.251.252  
controller_port=6633  
creator=fvadmin  
  
[list Slice info] Datacom-B  
Got reply:  
connection_2=00:00:00:00:00:00:02-->/134.75.85.157:37669-->/203.255.251.252:6644  
connection_1=00:00:00:00:00:00:01-->/134.75.85.157:37668-->/203.255.251.252:6644  
contact_email=minsh@cnu.ac.kr  
controller_hostname=203.255.251.252  
controller_port=6644  
creator=fvadmin  
  
[list FlowSpaces] Datacom-A, B  
Got reply:  
rule 0: FlowEntry[dpid=[all_dpids],ruleMatch=[OFMatch[dl_vlan=0x1f9]],actionsList=[Slice:Datacom-A=4],id=[350373],priority=[1],]  
rule 1: FlowEntry[dpid=[all_dpids],ruleMatch=[OFMatch[dl_vlan=0x1fa]],actionsList=[Slice:Datacom-B=4],id=[379921],priority=[1],]  
rule 2: FlowEntry[dpid=[all_dpids],ruleMatch=[OFMatch[in_port=3]],actionsList=[Slice:Datacom-A=4],id=[337575],priority=[0],]  
rule 3: FlowEntry[dpid=[all_dpids],ruleMatch=[OFMatch[in_port=4]],actionsList=[Slice:Datacom-B=4],id=[372375],priority=[0],]  
  
shmin@shminpc:~$ ~]
```



Experimental Result (capsulator)

- ❖ Performance test: single flow (iperf, UDP, datagram size: 1420 bytes)

**Slice: DATACOM-A
VLAN 505**

```
root@datacom-nf0:~  
File Edit View Terminal Tabs Help  
[ ID] Interval      Transfer      Bandwidth     Jitter      Lost/Total Datagrams  
[ 3] 25.0-26.0 sec    109 MBytes    917 Mbits/sec 0.015 ms    2586/83325 (3.1%)  
[ ID] Interval      Transfer      Bandwidth     Jitter      Lost/Total Datagrams  
[ 3] 26.0-27.0 sec    109 MBytes    918 Mbits/sec 0.014 ms    2523/83342 (3%)  
[ ID] Interval      Transfer      Bandwidth     Jitter      Lost/Total Datagrams  
[ 3] 27.0-28.0 sec    109 MBytes    917 Mbits/sec 0.016 ms    2560/83321 (3.1%)  
[ ID] Interval      Transfer      Bandwidth     Jitter      Lost/Total Datagrams  
[ 3] 28.0-29.0 sec    109 MBytes    915 Mbits/sec 0.015 ms    2791/83341 (3.3%)  
[ ID] Interval      Transfer      Bandwidth     Jitter      Lost/Total Datagrams  
[ 3] 29.0-30.0 sec    109 MBytes    917 Mbits/sec 0.015 ms    2579/83321 (3.1%)  
[ ID] Interval      Transfer      Bandwidth     Jitter      Lost/Total Datagrams  
[ 3] 0.0-30.0 sec    3.21 GBytes    917 Mbits/sec 0.084 ms    76066/2499626 (3%)
```

**Slice: DATACOM-B
VLAN 506**

```
root@datacom-pc: ~  
File Edit View Terminal Tabs Help  
[ 4] 18.0-19.0 sec    93.0 MBytes    780 Mbits/sec 0.014 ms    14259/82940 (17%)  
[ 4] 19.0-20.0 sec    92.8 MBytes    778 Mbits/sec 0.020 ms    14264/82766 (17%)  
[ 4] 20.0-21.0 sec    93.0 MBytes    780 Mbits/sec 0.014 ms    14415/83111 (17%)  
[ 4] 21.0-22.0 sec    93.0 MBytes    781 Mbits/sec 0.014 ms    14238/82944 (17%)  
[ 4] 22.0-23.0 sec    92.7 MBytes    778 Mbits/sec 0.017 ms    14091/82551 (17%)  
[ 4] 23.0-24.0 sec    93.0 MBytes    780 Mbits/sec 0.014 ms    14389/83073 (17%)  
[ 4] 24.0-25.0 sec    92.8 MBytes    779 Mbits/sec 0.014 ms    14419/82982 (17%)  
[ 4] 25.0-26.0 sec    92.5 MBytes    776 Mbits/sec 0.014 ms    14587/82920 (18%)  
[ 4] 26.0-27.0 sec    92.8 MBytes    778 Mbits/sec 0.014 ms    14428/82953 (17%)  
[ 4] 27.0-28.0 sec    92.8 MBytes    779 Mbits/sec 0.020 ms    14255/82802 (17%)  
[ 4] 28.0-29.0 sec    93.0 MBytes    780 Mbits/sec 0.014 ms    14414/83073 (17%)  
[ 4] 29.0-30.0 sec    93.0 MBytes    780 Mbits/sec 0.021 ms    14038/82720 (17%)  
[ 4] 0.0-30.0 sec    2.72 GBytes    778 Mbits/sec 0.020 ms    429182/2484829 (17%)
```



Experimental Result (scheduler)

- ❖ Performance test: PQ (iperf, UDP, datagram size: 1420 bytes)

**Slice: DATACOM-A
VLAN 505
Priority: LOW**

```
root@datacom-nf0:~  
File Edit View Terminal Tabs Help  
[ 4] 1750.0-1751.0 sec 749 KBytes 6.13 Mbits/sec 0.104 ms 82893/83433 (99%)  
[ ID] Interval Transfer Bandwidth Jitter Lost/Total Datagrams  
[ 4] 1751.0-1752.0 sec 749 KBytes 6.13 Mbits/sec 0.123 ms 82809/83349 (99%)  
[ ID] Interval Transfer Bandwidth Jitter Lost/Total Datagrams  
[ 4] 1752.0-1753.0 sec 741 KBytes 6.07 Mbits/sec 0.293 ms 82768/83302 (99%)  
[ ID] Interval Transfer Bandwidth Jitter Lost/Total Datagrams  
[ 4] 1753.0-1754.0 sec 757 KBytes 6.20 Mbits/sec 0.103 ms 82825/83371 (99%)  
[ ID] Interval Transfer Bandwidth Jitter Lost/Total Datagrams  
[ 4] 1754.0-1755.0 sec 754 KBytes 6.18 Mbits/sec 0.089 ms 82743/83287 (99%)  
[ ID] Interval Transfer Bandwidth Jitter Lost/Total Datagrams  
[ 4] 1755.0-1756.0 sec 756 KBytes 6.19 Mbits/sec 0.103 ms 82741/83286 (99%)  
[ ID] Interval Transfer Bandwidth Jitter Lost/Total Datagrams  
[ 4] 1756.0-1757.0 sec 738 KBytes 6.04 Mbits/sec 0.112 ms 82754/83286 (99%)  
[ ID] Interval Transfer Bandwidth Jitter Lost/Total Datagrams  
[ 4] 1757.0-1758.0 sec 745 KBytes 6.10 Mbits/sec 0.053 ms 82898/83435 (99%)  
[ ID] Interval Transfer Bandwidth Jitter Lost/Total Datagrams  
[ 4] 1758.0-1759.0 sec 746 KBytes 6.11 Mbits/sec 0.214 ms 82753/83291 (99%)  
[ ID] Interval Transfer Bandwidth Jitter Lost/Total Datagrams  
[ 4] 1759.0-1760.0 sec 743 KBytes 6.09 Mbits/sec 0.262 ms 82595/83131 (99%)
```

**Slice: DATACOM-B
VLAN 506
Priority: HIGH**

```
root@datacom-pc: ~  
File Edit View Terminal Tabs Help  
[ 4] 1708.0-1709.0 sec 92.7 MBytes 778 Mbits/sec 0.018 ms 14700/83174 (18%)  
[ 4] 1709.0-1710.0 sec 92.9 MBytes 779 Mbits/sec 0.014 ms 14875/83488 (18%)  
[ 4] 1710.0-1711.0 sec 93.0 MBytes 780 Mbits/sec 0.014 ms 14692/83333 (18%)  
[ 4] 1711.0-1712.0 sec 92.9 MBytes 780 Mbits/sec 0.013 ms 14709/83335 (18%)  
[ 4] 1712.0-1713.0 sec 92.8 MBytes 778 Mbits/sec 0.014 ms 14703/83194 (18%)  
[ 4] 1713.0-1714.0 sec 92.9 MBytes 780 Mbits/sec 0.014 ms 14800/83430 (18%)  
[ 4] 1714.0-1715.0 sec 93.0 MBytes 780 Mbits/sec 0.015 ms 14697/83341 (18%)  
[ 4] 1715.0-1716.0 sec 92.5 MBytes 776 Mbits/sec 0.019 ms 14515/82849 (18%)  
[ 4] 1716.0-1717.0 sec 92.9 MBytes 779 Mbits/sec 0.014 ms 14855/83444 (18%)  
[ 4] 1717.0-1718.0 sec 93.0 MBytes 780 Mbits/sec 0.014 ms 14698/83341 (18%)  
[ 4] 1718.0-1719.0 sec 93.0 MBytes 780 Mbits/sec 0.014 ms 14687/83337 (18%)  
[ 4] 1719.0-1720.0 sec 92.8 MBytes 778 Mbits/sec 0.039 ms 14816/83333 (18%)  
[ 4] 1720.0-1721.0 sec 93.0 MBytes 780 Mbits/sec 0.014 ms 14660/83326 (18%)  
[ 4] 1721.0-1722.0 sec 92.9 MBytes 780 Mbits/sec 0.014 ms 14711/83335 (18%)  
[ 4] 1722.0-1723.0 sec 92.8 MBytes 779 Mbits/sec 0.021 ms 14673/83209 (18%)  
[ 4] 1723.0-1724.0 sec 92.9 MBytes 780 Mbits/sec 0.013 ms 14825/83453 (18%)  
[ 4] 1724.0-1725.0 sec 93.0 MBytes 780 Mbits/sec 0.014 ms 14693/83340 (18%)  
[ 4] 1725.0-1726.0 sec 92.9 MBytes 780 Mbits/sec 0.018 ms 14664/83299 (18%)  
[ 4] 1726.0-1727.0 sec 92.9 MBytes 779 Mbits/sec 0.014 ms 14780/83366 (18%)  
[ 4] 1727.0-1728.0 sec 93.0 MBytes 780 Mbits/sec 0.014 ms 14654/83325 (18%)
```



Experimental Result (scheduler)

- ❖ Performance test: DRR (iperf, UDP, datagram size: 1420 bytes)

**Slice: DATACOM-A
VLAN 505
Quantumn: 1000**

```
root@datacom-nf0:~  
File Edit View Terminal Tabs Help  
[ ID] Interval      Transfer      Bandwidth      Jitter      Lost/Total Datagrams  
[ 3] 127.0-128.0 sec  54.7 MBytes   459 Mbits/sec  0.035 ms  42901/83328 (51%)  
[ ID] Interval      Transfer      Bandwidth      Jitter      Lost/Total Datagrams  
[ 3] 128.0-129.0 sec  54.8 MBytes   460 Mbits/sec  0.037 ms  42856/83345 (51%)  
[ ID] Interval      Transfer      Bandwidth      Jitter      Lost/Total Datagrams  
[ 3] 129.0-130.0 sec  54.7 MBytes   459 Mbits/sec  0.038 ms  42913/83317 (52%)  
[ ID] Interval      Transfer      Bandwidth      Jitter      Lost/Total Datagrams  
[ 3] 130.0-131.0 sec  54.8 MBytes   460 Mbits/sec  0.037 ms  42873/83342 (51%)  
[ ID] Interval      Transfer      Bandwidth      Jitter      Lost/Total Datagrams  
[ 3] 131.0-132.0 sec  55.1 MBytes   462 Mbits/sec  0.038 ms  42629/83321 (51%)  
[ ID] Interval      Transfer      Bandwidth      Jitter      Lost/Total Datagrams  
[ 3] 132.0-133.0 sec  54.8 MBytes   460 Mbits/sec  0.036 ms  42876/83335 (51%)  
[ ]
```

**Slice: DATACOM-B
VLAN 506
Quantumn: 1000**

```
root@datacom-pc: ~  
File Edit View Terminal Tabs Help  
[ 4] 113.0-114.0 sec  54.6 MBytes   458 Mbits/sec  0.033 ms  42578/82903 (51%)  
[ 4] 114.0-115.0 sec  54.6 MBytes   458 Mbits/sec  0.041 ms  42609/82951 (51%)  
[ 4] 115.0-116.0 sec  54.6 MBytes   458 Mbits/sec  0.035 ms  42595/82936 (51%)  
[ 4] 116.0-117.0 sec  54.6 MBytes   458 Mbits/sec  0.033 ms  42491/82781 (51%)  
[ 4] 117.0-118.0 sec  54.6 MBytes   458 Mbits/sec  0.034 ms  42603/82932 (51%)  
[ 4] 118.0-119.0 sec  54.6 MBytes   458 Mbits/sec  0.034 ms  42596/82938 (51%)  
[ 4] 119.0-120.0 sec  54.5 MBytes   457 Mbits/sec  0.034 ms  42468/82694 (51%)  
[ 4] 120.0-121.0 sec  54.7 MBytes   459 Mbits/sec  0.035 ms  42569/82935 (51%)  
[ 4] 121.0-122.0 sec  54.7 MBytes   459 Mbits/sec  0.034 ms  42570/82951 (51%)  
[ 4] 122.0-123.0 sec  54.6 MBytes   458 Mbits/sec  0.034 ms  42604/82947 (51%)  
[ 4] 123.0-124.0 sec  54.6 MBytes   458 Mbits/sec  0.036 ms  42579/82930 (51%)  
[ 4] 124.0-125.0 sec  54.6 MBytes   458 Mbits/sec  0.033 ms  42592/82945 (51%)  
[ 4] 125.0-126.0 sec  54.6 MBytes   458 Mbits/sec  0.039 ms  42589/82936 (51%)  
[ ]
```



Experimental Result (scheduler)

- ❖ Performance test: DRR (iperf, UDP, datagram size: 1420 bytes)

**Slice: DATACOM-A
VLAN 505
Quantumn: 4000**

```
root@datacom-nf0:~  
File Edit View Terminal Tabs Help  
[ ID] Interval      Transfer      Bandwidth      Jitter      Lost/Total Datagrams  
[ 3] 390.0-391.0 sec  87.3 MBytes   732 Mbits/sec  0.021 ms 18861/83334 (23%)  
[ ID] Interval      Transfer      Bandwidth      Jitter      Lost/Total Datagrams  
[ 3] 391.0-392.0 sec  87.2 MBytes   732 Mbits/sec  0.020 ms 18907/83316 (23%)  
[ ID] Interval      Transfer      Bandwidth      Jitter      Lost/Total Datagrams  
[ 3] 392.0-393.0 sec  87.4 MBytes   733 Mbits/sec  0.020 ms 18819/83341 (23%)  
[ ID] Interval      Transfer      Bandwidth      Jitter      Lost/Total Datagrams  
[ 3] 393.0-394.0 sec  87.3 MBytes   732 Mbits/sec  0.019 ms 18881/83323 (23%)  
[ ID] Interval      Transfer      Bandwidth      Jitter      Lost/Total Datagrams  
[ 3] 394.0-395.0 sec  87.3 MBytes   732 Mbits/sec  0.019 ms 18896/83342 (23%)  
[ ID] Interval      Transfer      Bandwidth      Jitter      Lost/Total Datagrams  
[ 3] 395.0-396.0 sec  87.2 MBytes   732 Mbits/sec  0.021 ms 18909/83320 (23%)
```

**Slice: DATACOM-B
VLAN 506
Quantumn: 1000**

```
root@datacom-pc: ~  
File Edit View Terminal Tabs Help  
[ 4] 377.0-378.0 sec  21.8 MBytes   183 Mbits/sec  0.011 ms 66636/82769 (81%)  
[ 4] 378.0-379.0 sec  21.8 MBytes   183 Mbits/sec  0.012 ms 66368/82483 (80%)  
[ 4] 379.0-380.0 sec  21.9 MBytes   183 Mbits/sec  0.010 ms 66619/82765 (80%)  
[ 4] 380.0-381.0 sec  21.9 MBytes   184 Mbits/sec  0.014 ms 66605/82767 (80%)  
[ 4] 381.0-382.0 sec  21.8 MBytes   183 Mbits/sec  0.014 ms 66639/82772 (81%)  
[ 4] 382.0-383.0 sec  21.9 MBytes   183 Mbits/sec  0.018 ms 66677/82823 (81%)  
[ 4] 383.0-384.0 sec  21.8 MBytes   183 Mbits/sec  0.014 ms 66795/82919 (81%)  
[ 4] 384.0-385.0 sec  21.8 MBytes   183 Mbits/sec  0.016 ms 66804/82932 (81%)  
[ 4] 385.0-386.0 sec  21.8 MBytes   183 Mbits/sec  0.016 ms 66599/82692 (81%)  
[ 4] 386.0-387.0 sec  21.8 MBytes   183 Mbits/sec  0.016 ms 66804/82929 (81%)  
[ 4] 387.0-388.0 sec  21.9 MBytes   183 Mbits/sec  0.013 ms 66796/82944 (81%)  
[ 4] 388.0-389.0 sec  21.9 MBytes   183 Mbits/sec  0.012 ms 66763/82913 (81%)  
[ 4] 389.0-390.0 sec  21.8 MBytes   183 Mbits/sec  0.010 ms 66803/82936 (81%)
```

