P4-enabled Network Slicing and 5G User Plane Function

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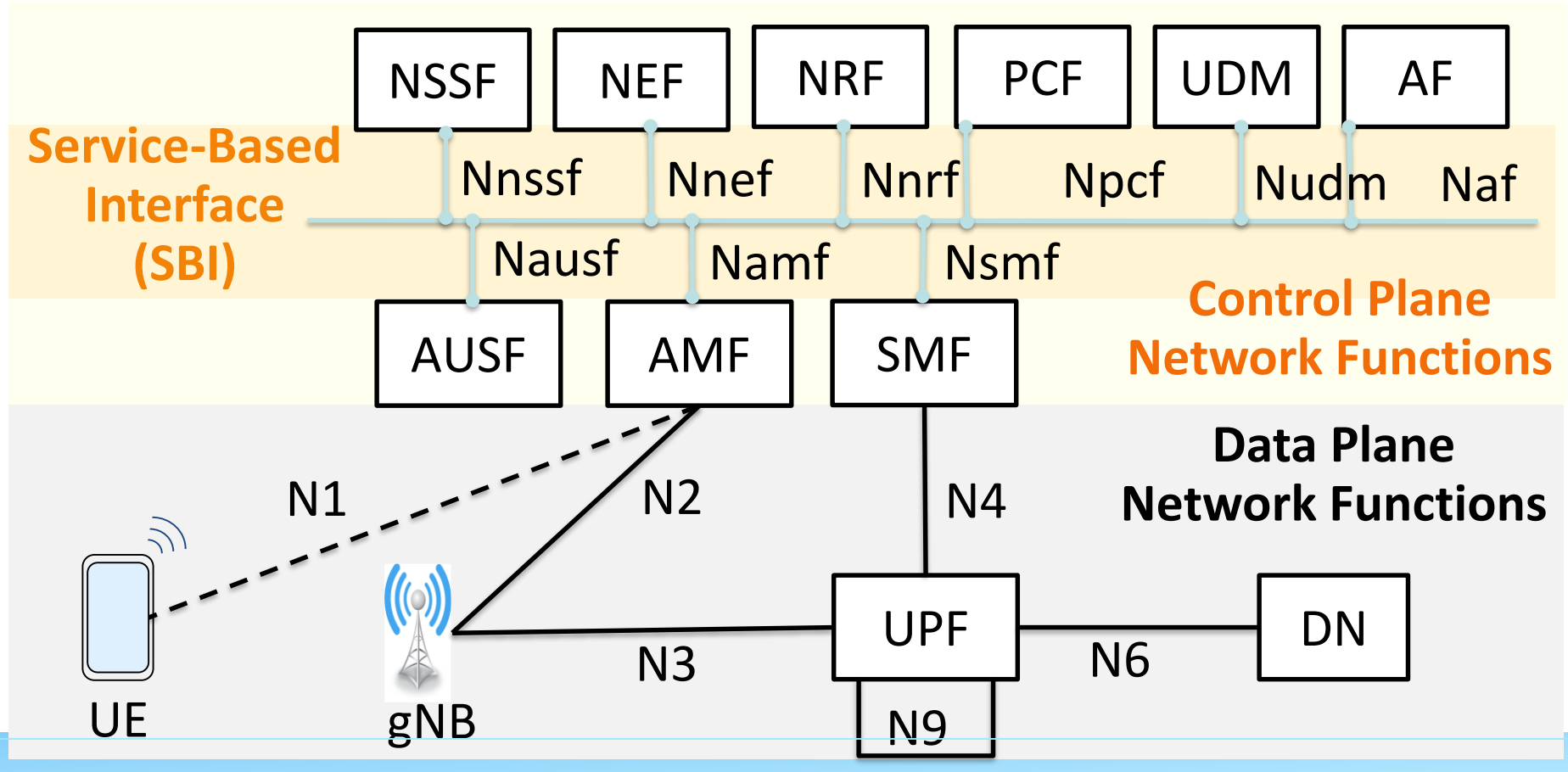
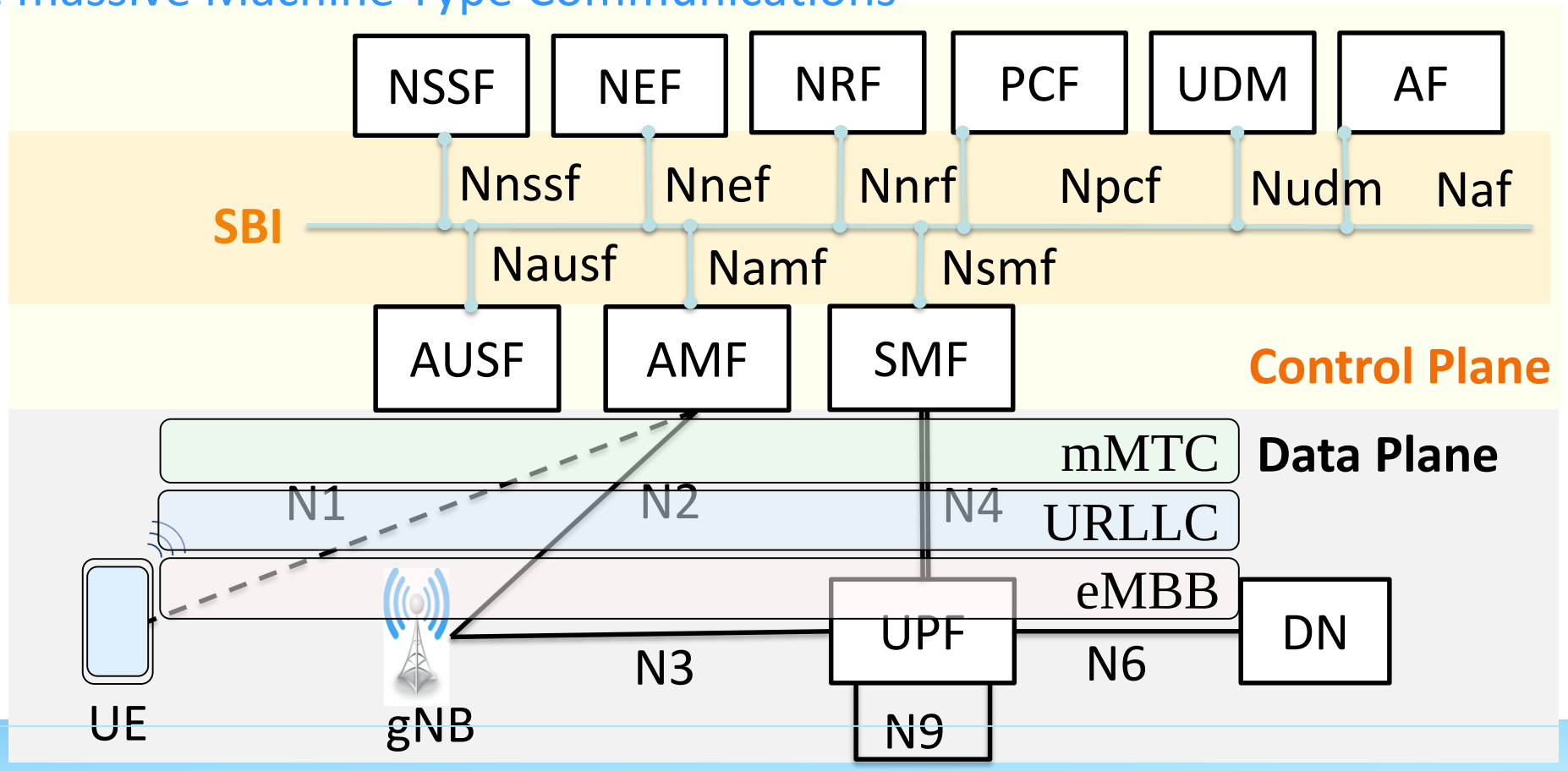
5G Service Based Architecture

- From monolithic to modular **architecture**
  - A set of Network Functions (NFs) provide services to other authorized NFs.
  - New NFs can be rolled out without impacting existing ones.



5G Network Slicing

- To support services with different requirements
  - eMBB: enhanced Mobile Broadband
  - URLLC: Ultra Reliable Low Latency Communications
  - mMTC: massive Machine Type Communications

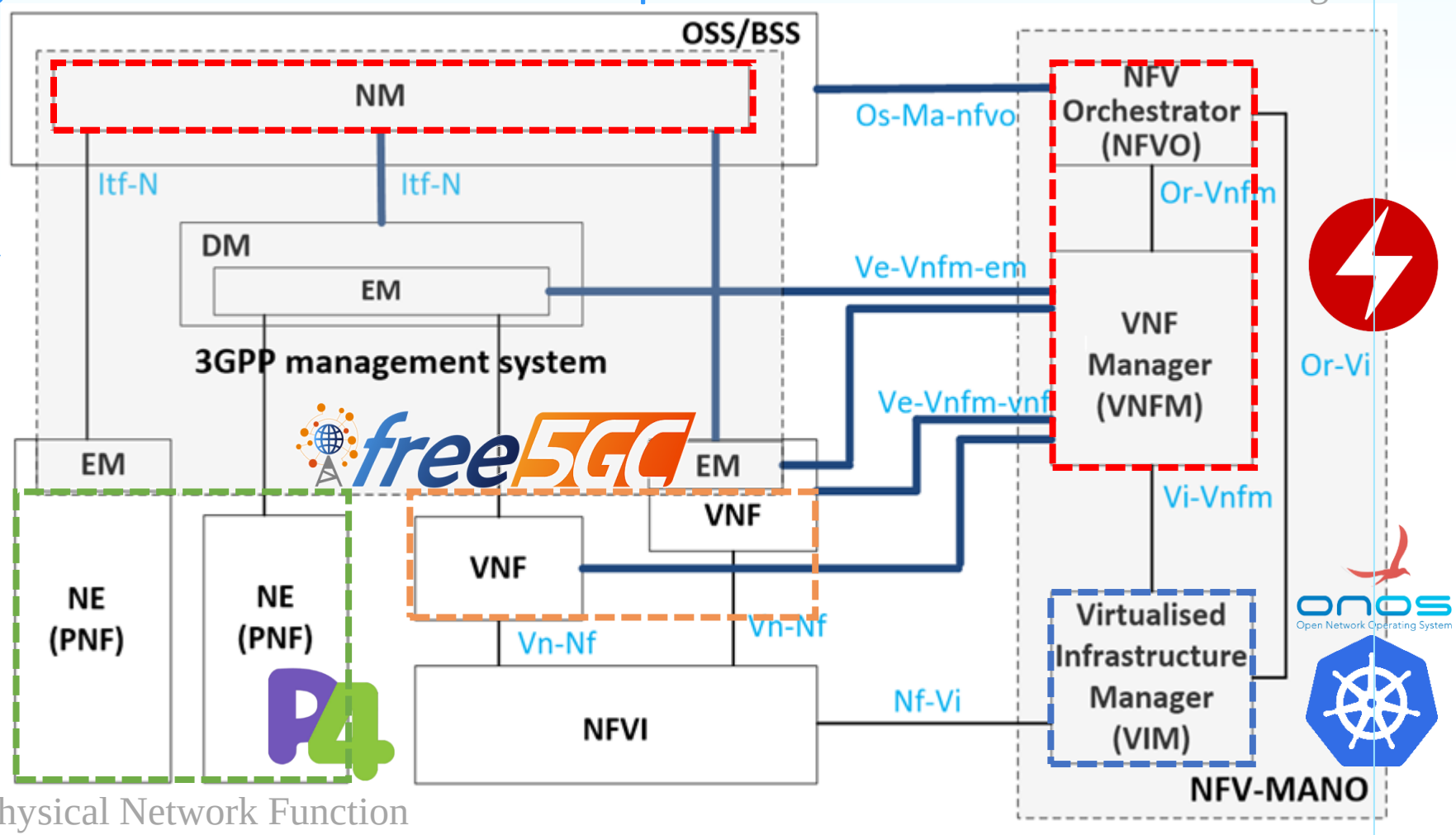


A Cloud Native Management and Orchestration Framework

for 5G End-to-end Network Slicing

- Follows 3GPP Management and ETSI NFV-MANO Specification
- All open sources
- NFVO/VNFM: Operator framework
- VIM:
  - Kubernetes (Computing:
  - ONOS (Networking)
- VNF:
  - free5GC

DM: Domain Management
EM: Element Management

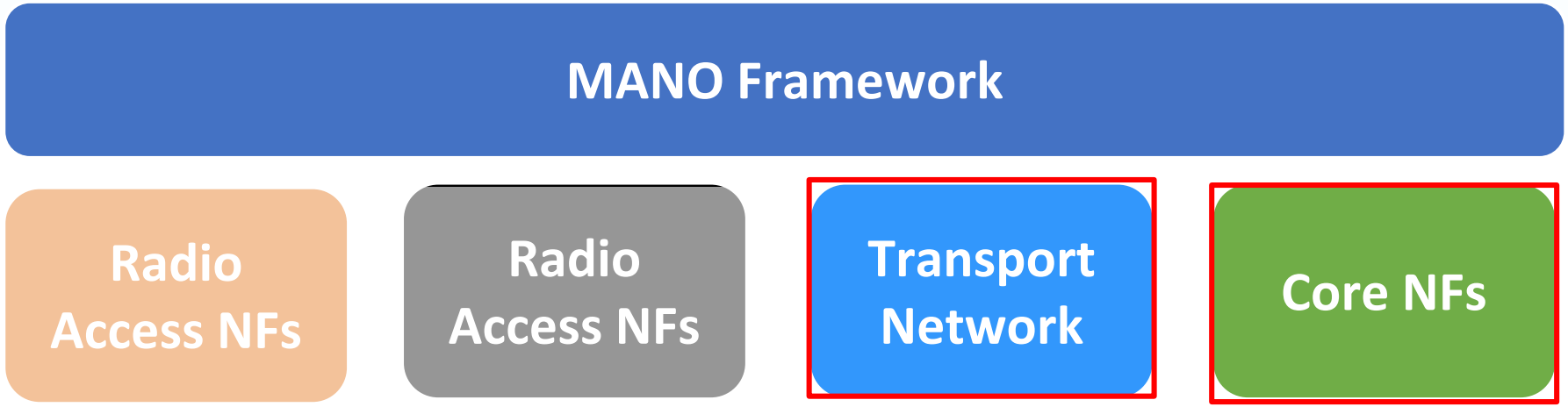


NE: Network Element, PNF: Physical Network Function
NFVI: Network Function Virtualization Infrastructure

Ref. 3GPP TS 28.500 V15.0.0

Management and Orchestration (MANO) Framework

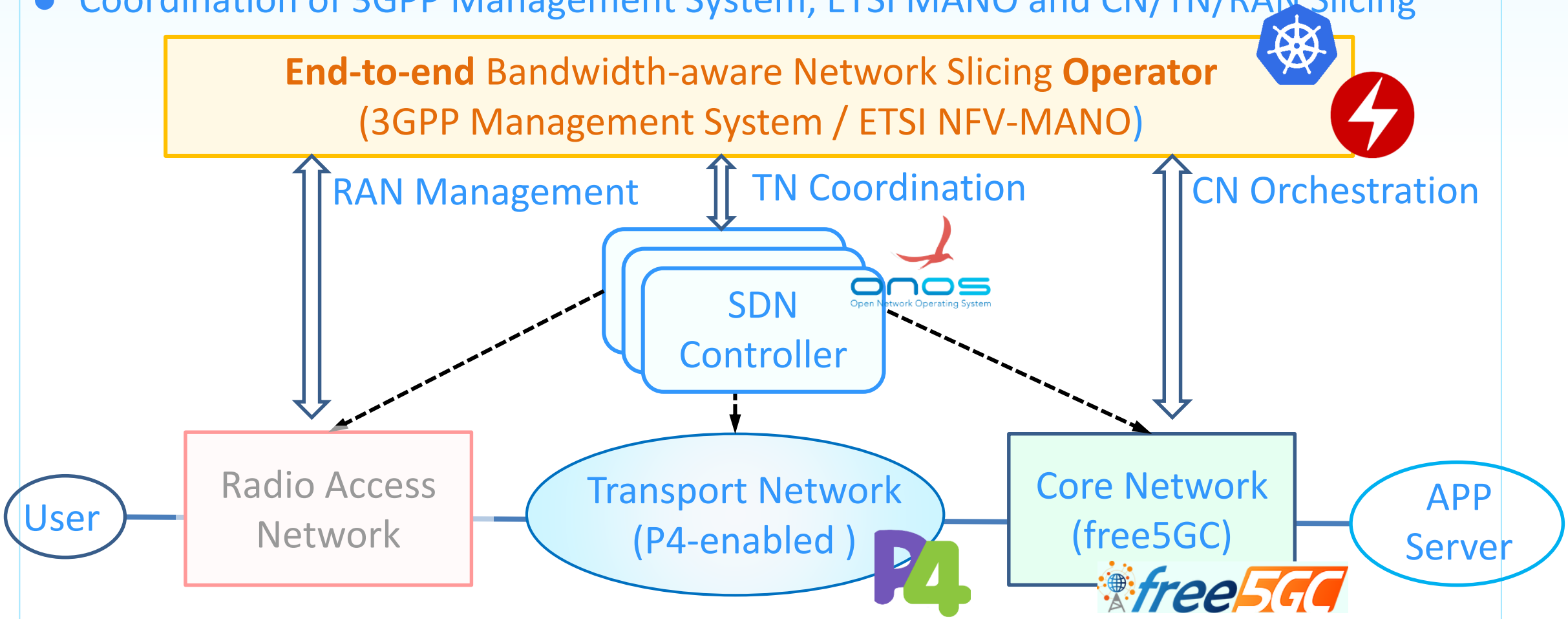
- Automatically deploy and run 5G end-to-end network slices in cloud environments
  - All based on open source, vendor-neutral projects



- Integrate with *P4-Enabled Bandwidth Management and UPF*
  - On **Transport Network** to enforce bandwidth policies
    - Bandwidth Guarantee and Bandwidth Limiting
    - ➢ Service Latency Guarantee
  - On 5G **User Plane Function** (UPF)

5G End-to-End Network Slicing with Bandwidth Control

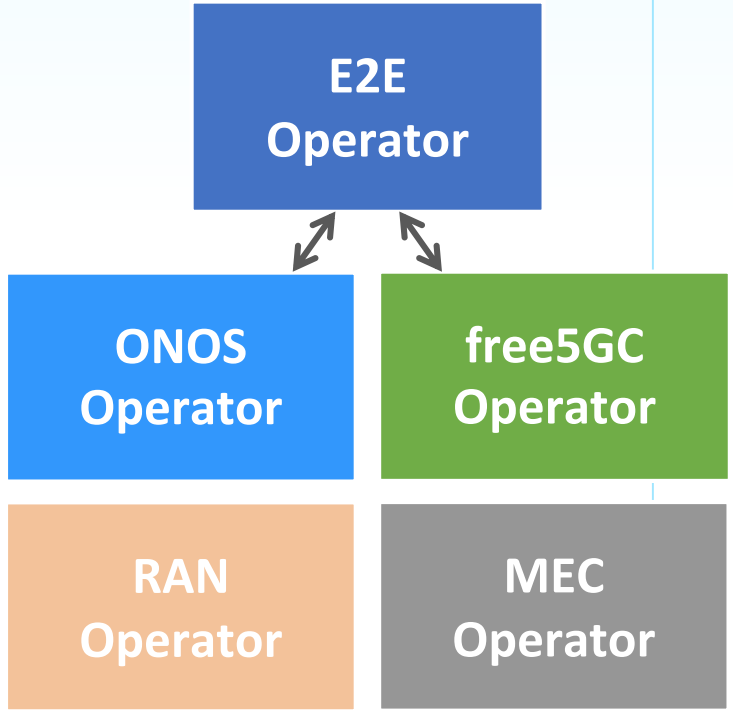
- Coordination of 3GPP Management System, ETSI MANO and CN/TN/RAN Slicing



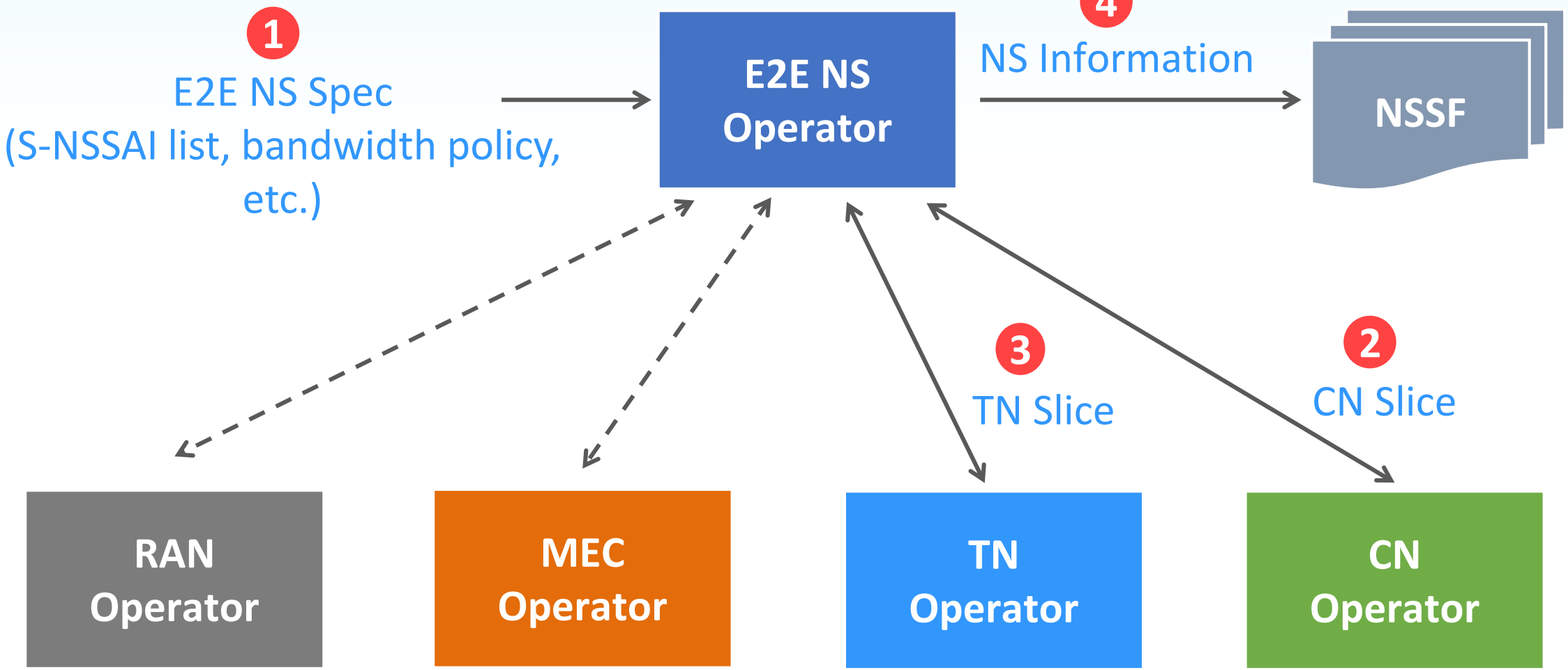
- ONF 2020 5G Transformation with Open Source Spotlight:
  Cloud Native Management and Orchestration Framework for 5G End-to-End Network Slicing - Yi-Sung Chiu

Operators in MANO Framework

- E2E Operator
  - Receive and validate BANS allocation requests
  - Orchestrate free5GC Operator and ONOS Operator
  - Update network slice selection information on NSSFs
- free5GC Operator
  - Create core functions when receiving CN slice requests
- ONOS Operator
  - Configure transport network when receiving TN slice requests



Management and Orchestration (MANO)

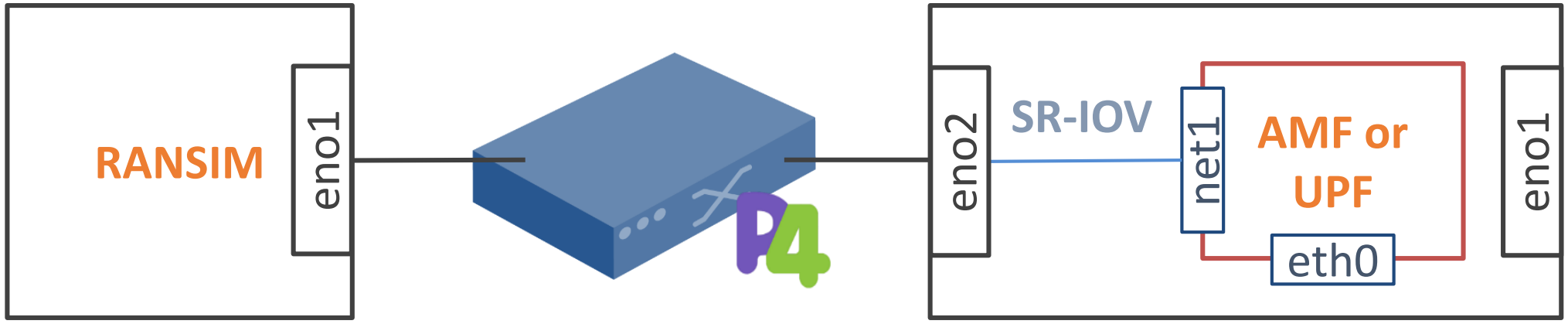


S-NSSAI: Single Network Slice Selection Assistance Information

E2E NS-5GC with P4 Fabric

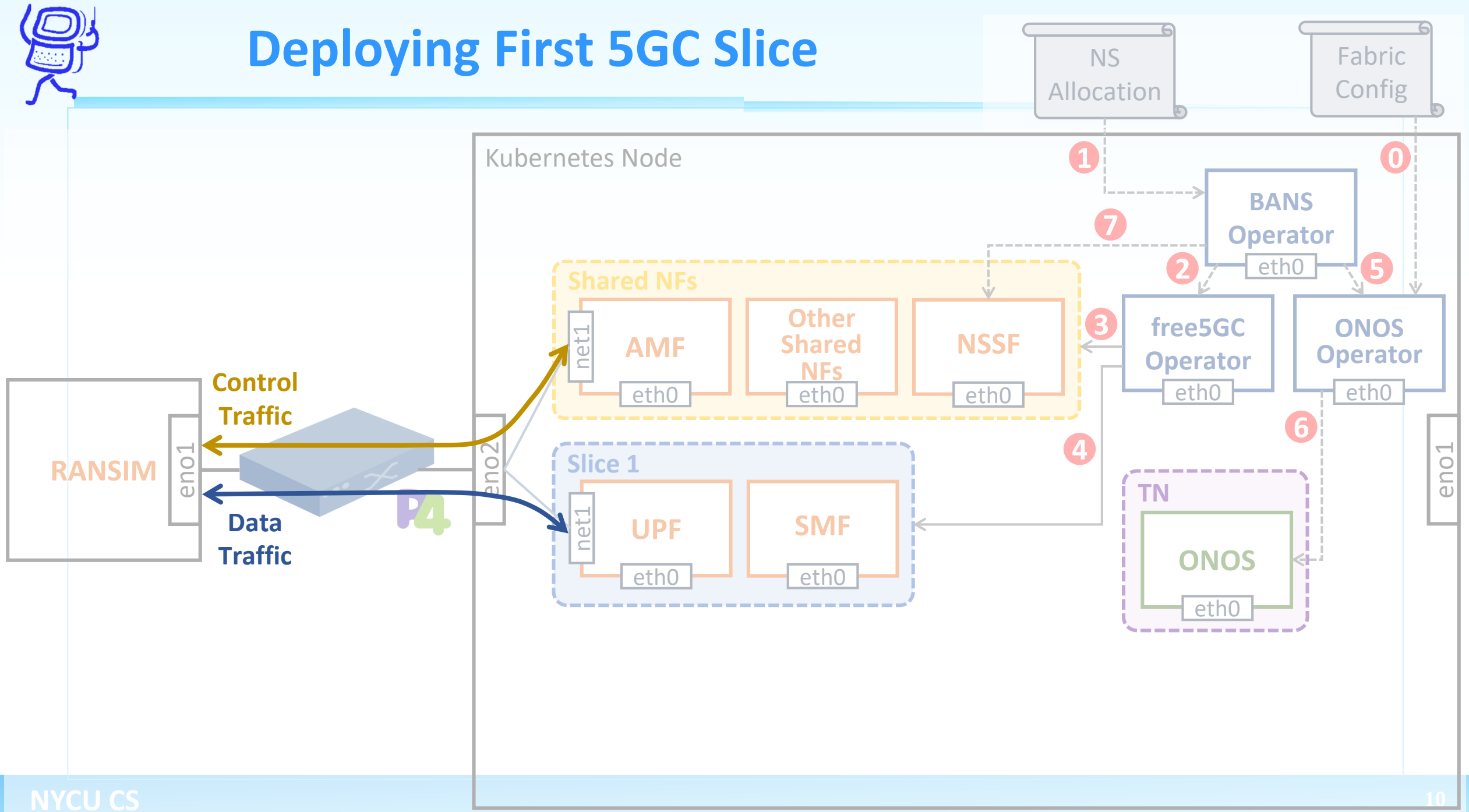
- P4 Fabric Switch
  - Place between RANSIM server and Kubernetes node of core NFs
  - Require fabric configuration on ONOS Bandwidth Operator

- Leverage SR-IOV on interfaces toward RANSIM for core NFs, e.g. AMF and UPF
  - Hardware acceleration

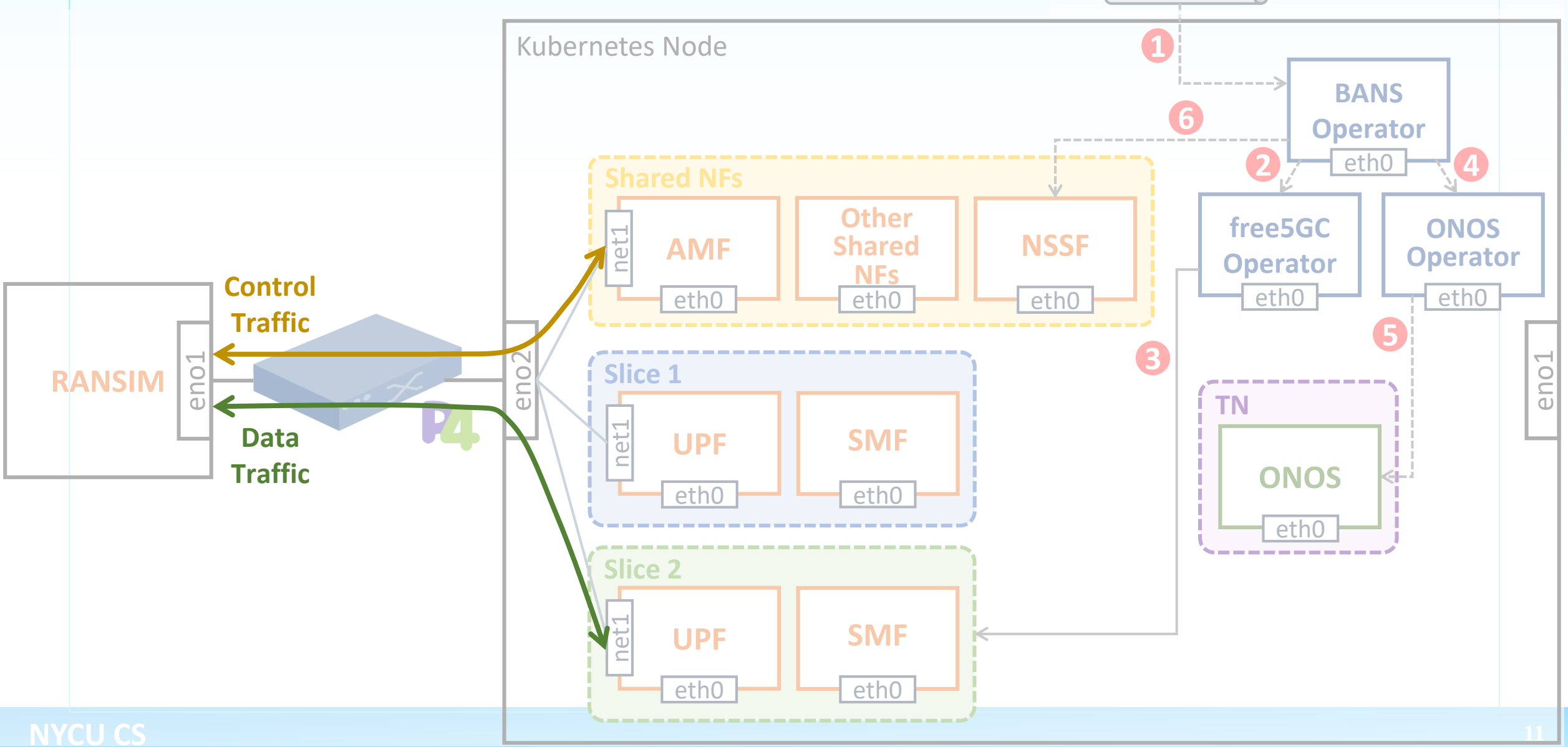


SR-IOV (Single-Root Input/Output Virtualization)

Deploying First 5GC Slice

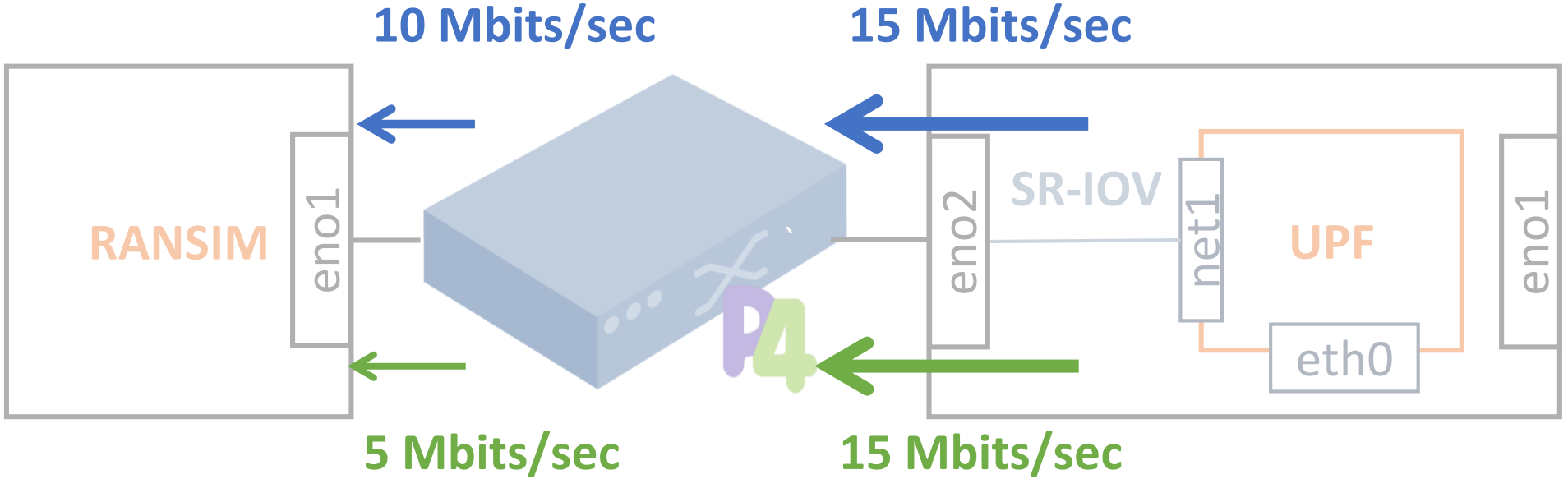


Deploying Subsequent 5GC Slice

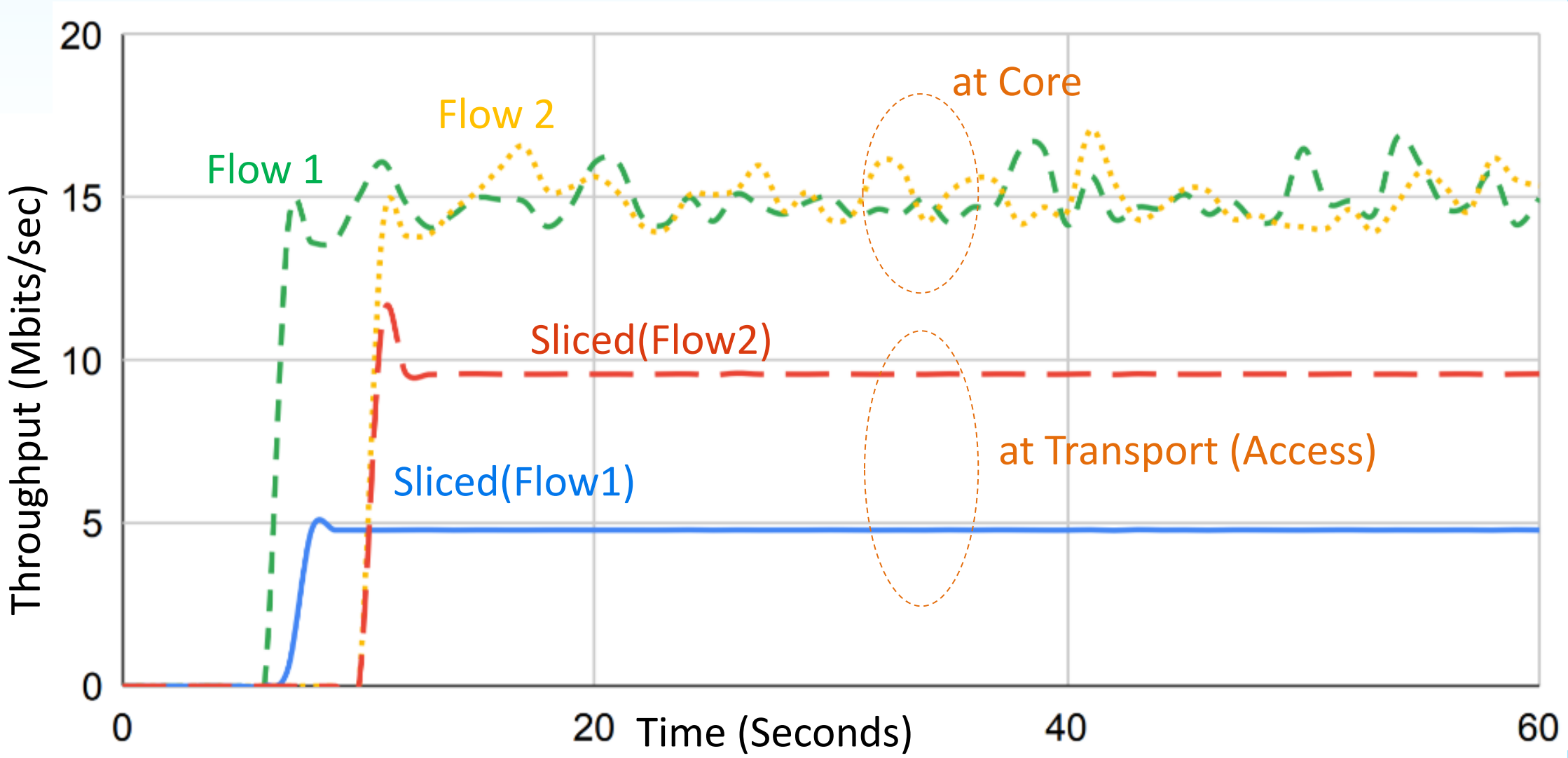


Transport Network Slicing on P4 Fabric

- Two flows (Flow1 and Flow2): send ICMP packets continuously
  - Transmission Rate: around 15 Mbits/sec
- Bandwidth Limitation on TN slices
  - Downlink bandwidth limiting,
    - Sliced(Flow1): 5 Mbits/sec
    - Sliced(Flow2): 10 Mbits/sec



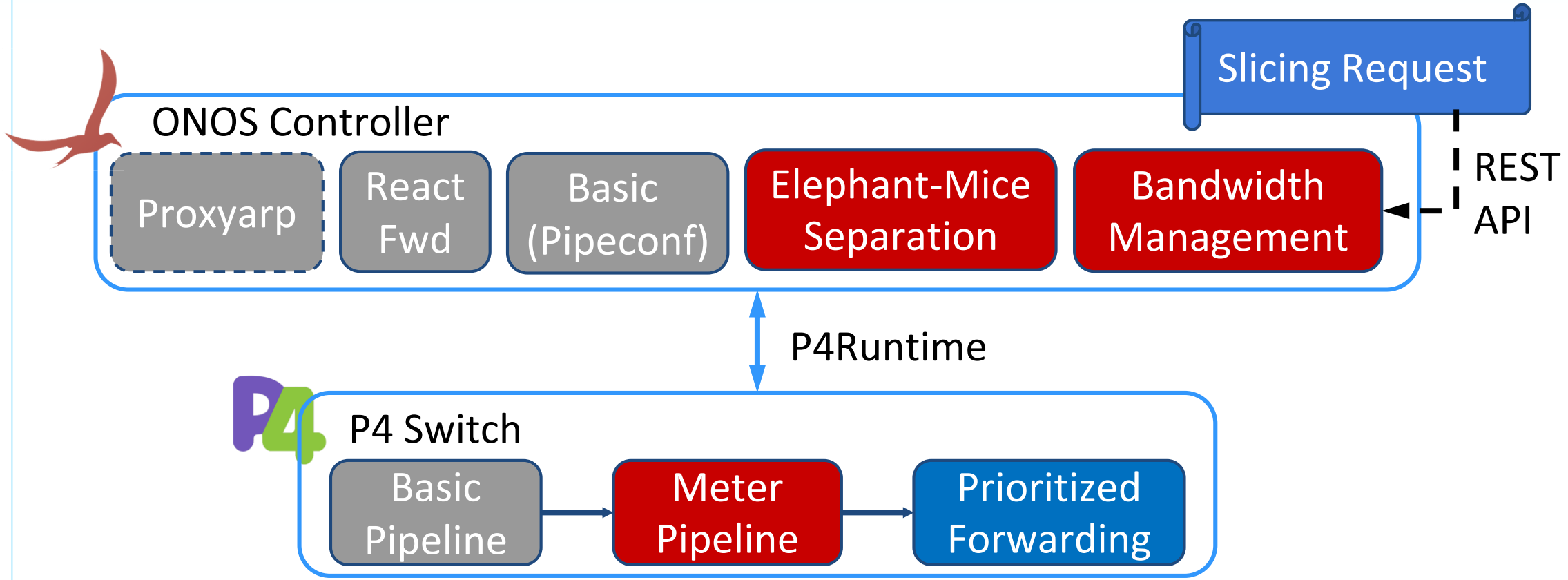
Downlink Throughput of Two Slices



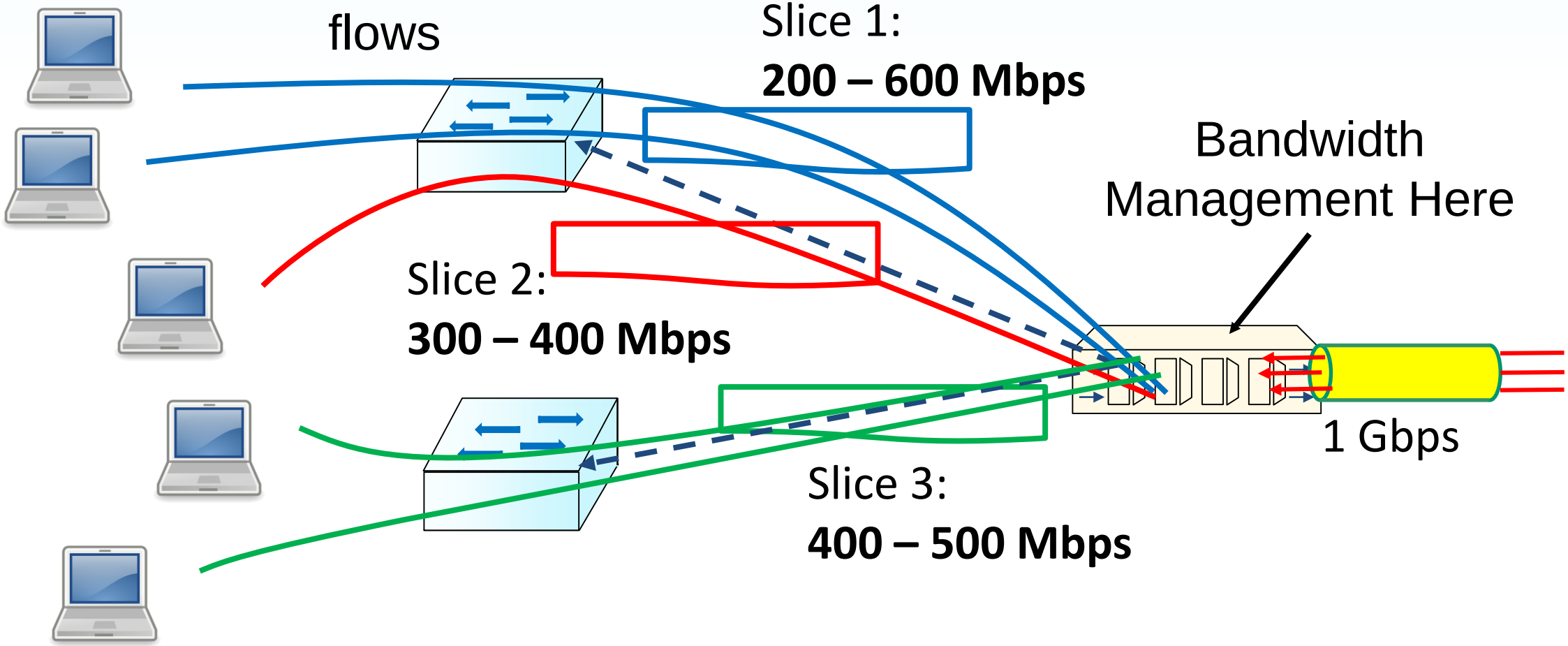
P4-TINS: P4-enabled Traffic Isolation for Network Slicing

with Flow-based Bandwidth Guarantee and Management

- Control Plane: Two P4-TINS applications on ONOS
- Data Plane: P4 switch with Meter pipeline and Prioritized Forwarding
- Protocol: P4Runtime



- Slices with different bandwidth guarantees and limitings



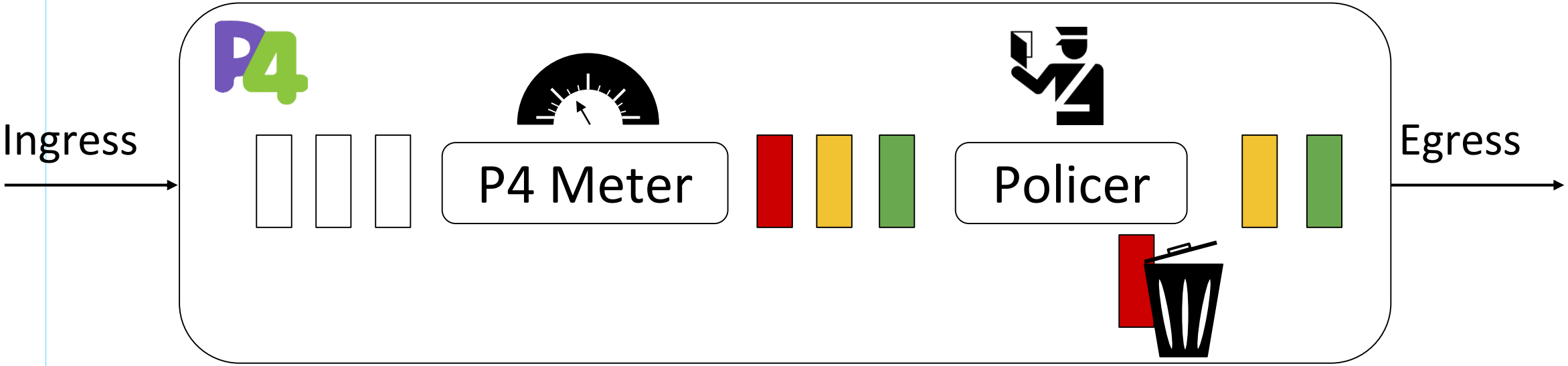
P4 Meter

trTCM: Two Rate Three Color Marker

CIR: Committed Information Rate

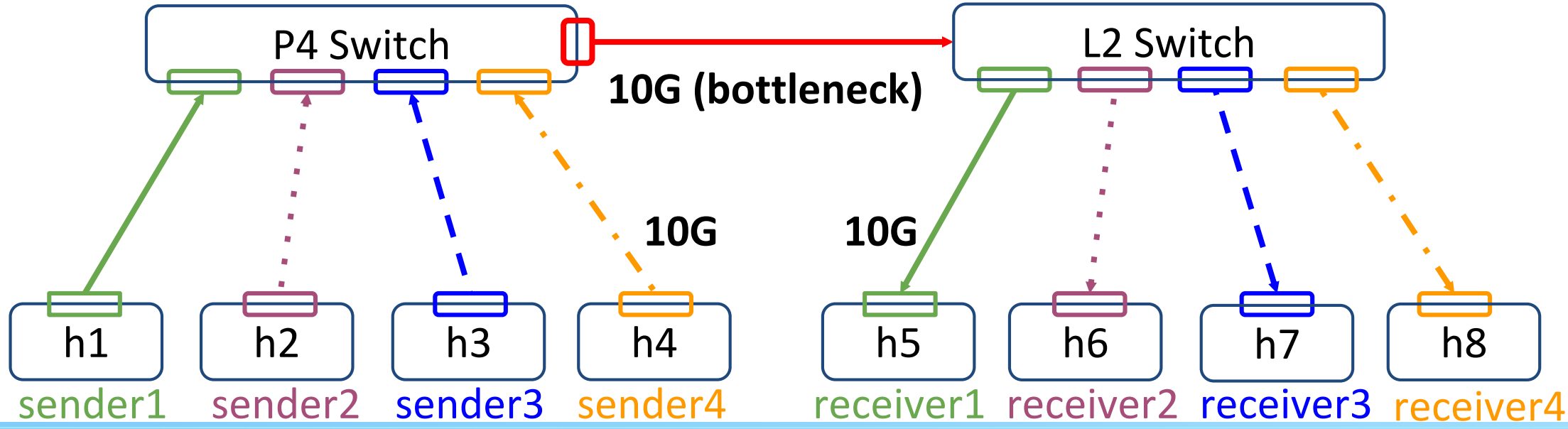
PIR: Peak Information Rate

- Mechanism for measuring data rate
  - Line-rate QoS classifier
  - Managed through P4 Extern Library
- Using RFC 2698-trTCM to classify packets into three groups
  - Green
  - Yellow
  - Red



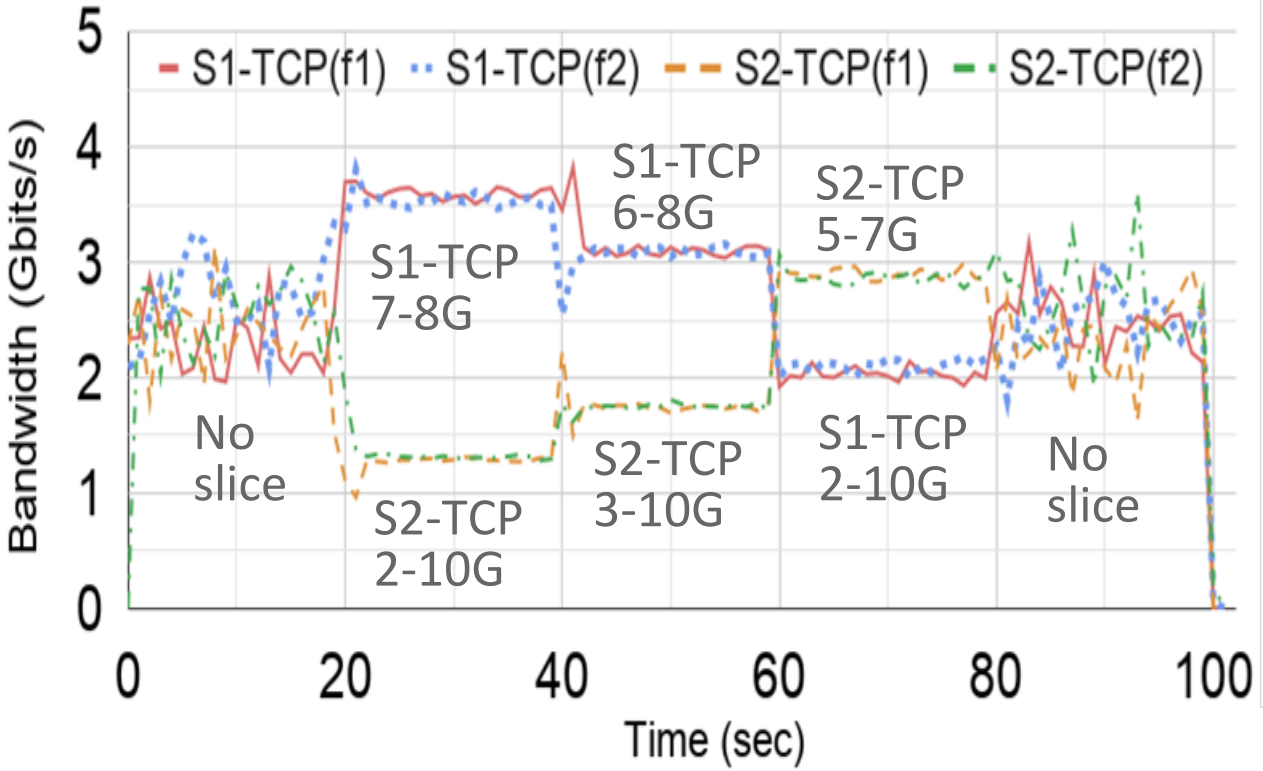
Experiment Environment and Scenario

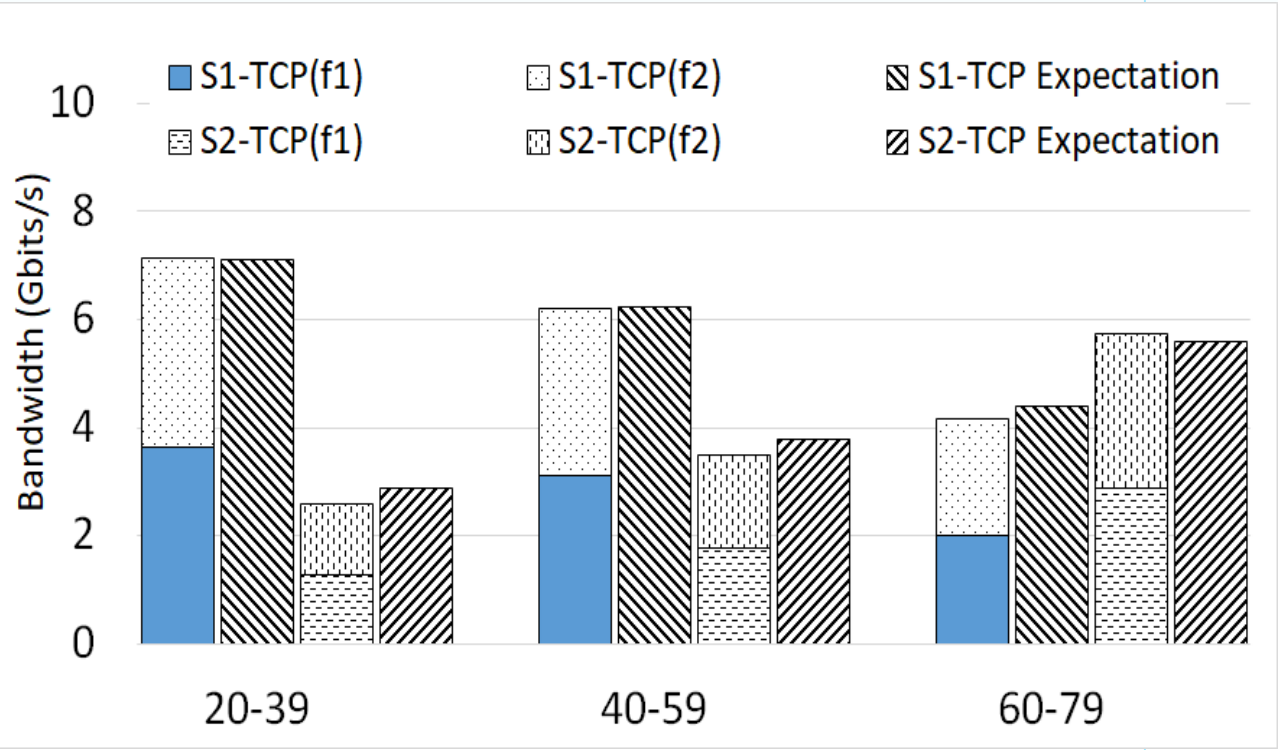
- Testbed
  - Inventec P4 switch (D10056 - Gulmohar2.0T/Intel D-1527/8G)
  - A L2 Switch for traffic measurement
  - Servers (Intel E5-2630/128G/Intel-X710 10GbE) for traffic generation
- Iperf for TCP/UDP flows,
- Http request for Mice TCP flows



Two Slices: Two TCPs in each Slice

- Slice 1: Two TCPs, S1-TCP(f1), S1-TCP(f2),
- Slice 2: Two TCPs, S2-TCP(f1), S2-TCP(f2)

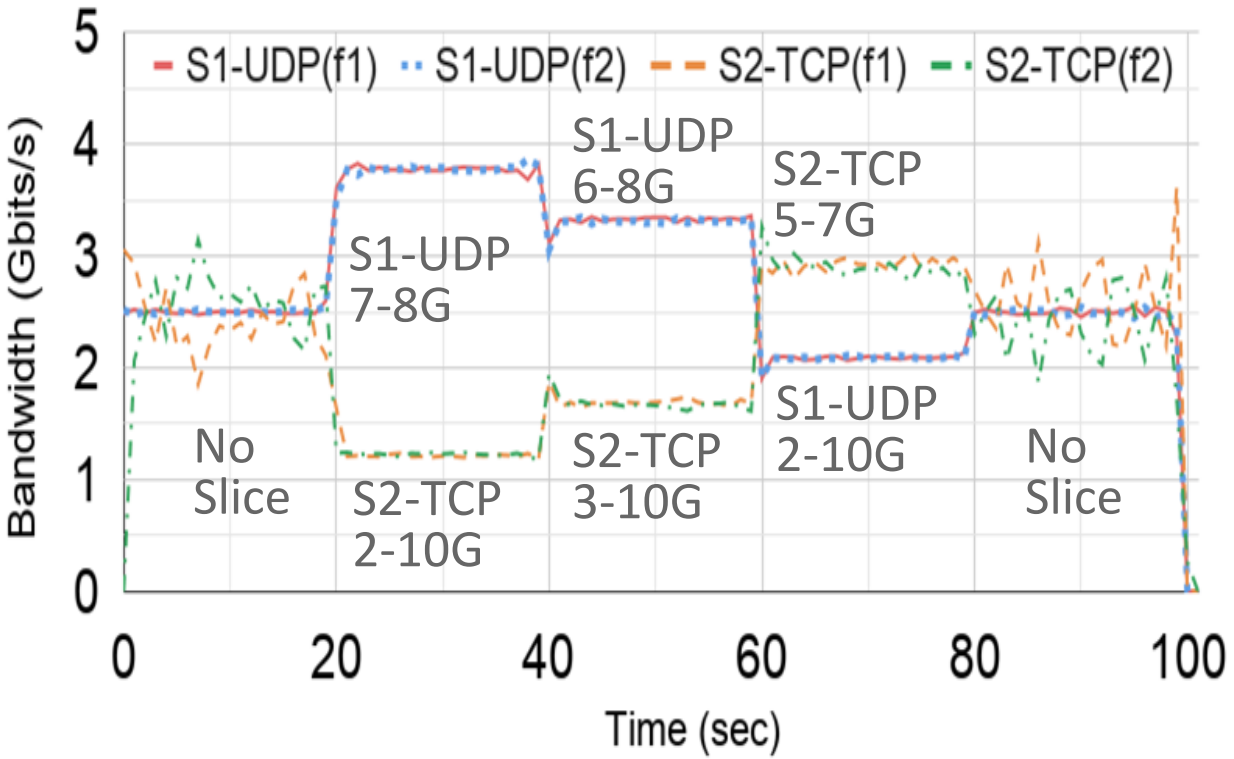


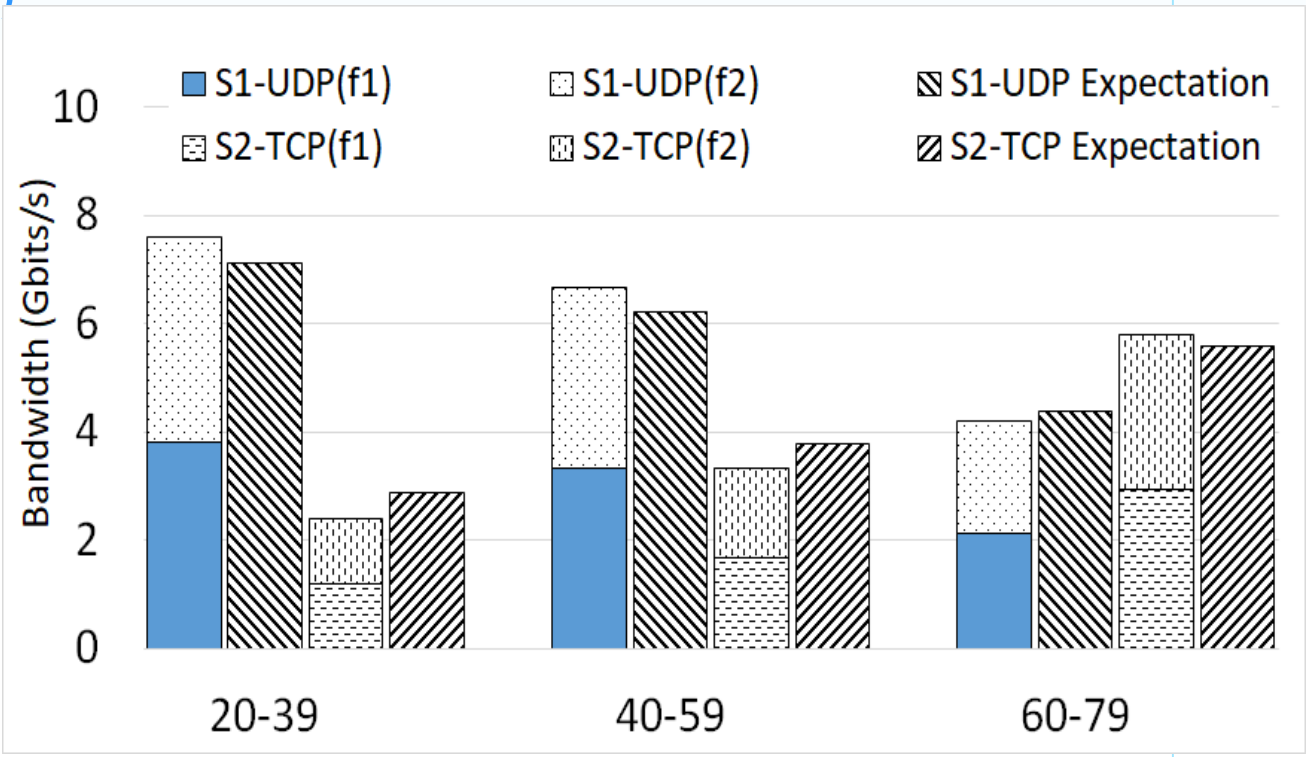


- Flows in same slice fair share sliced bandwidth
- Slices share residual bandwidth proportionally

Two TCPs in One Slice and Two UDPs in the Other

- Slice 1: Two UDPs, S1-UDP(f1), S1-UDP(f2),
- Slice 2: Two TCPs, S2-TCP(f1), S2-TCP(f2)



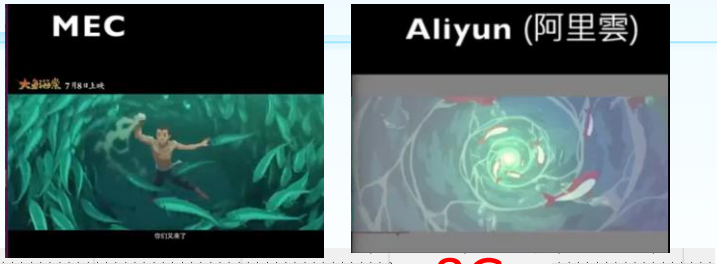


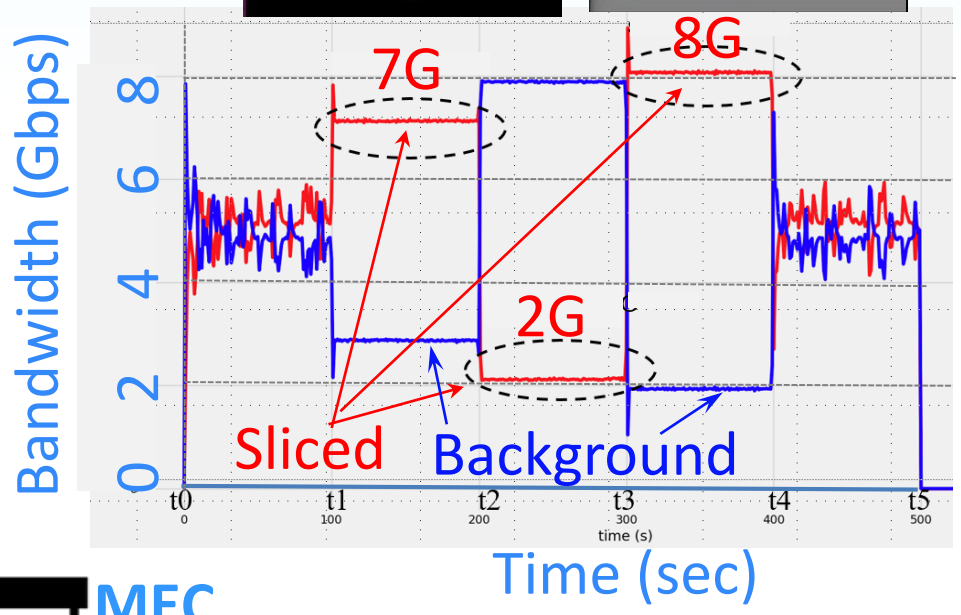
- Flows in same slice share sliced bandwidth fairly
- Slices share residual bandwidth proportionally

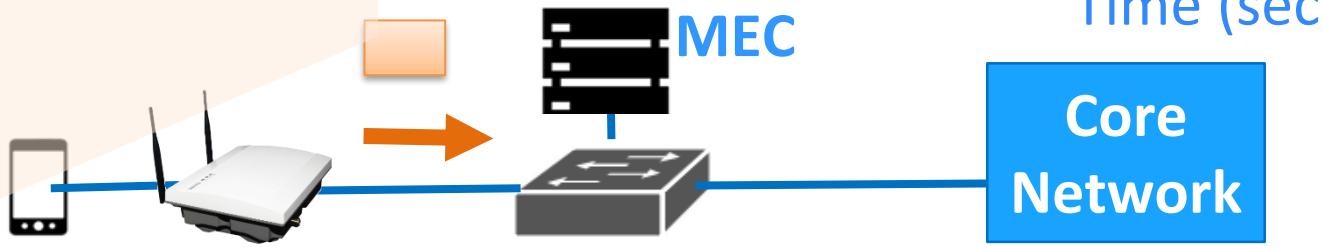
P4-enabled Network Slicing and MEC Services

- Bandwidth Management for Transport Network Slices
- P4-enabled 4G User Plane for MEC
  - GTP-U De-cap/encap Hardware Offloading

Ethernet
IP
UDP
GTP-U(TEID=XXX)
IP
TCP/UDP
Payload

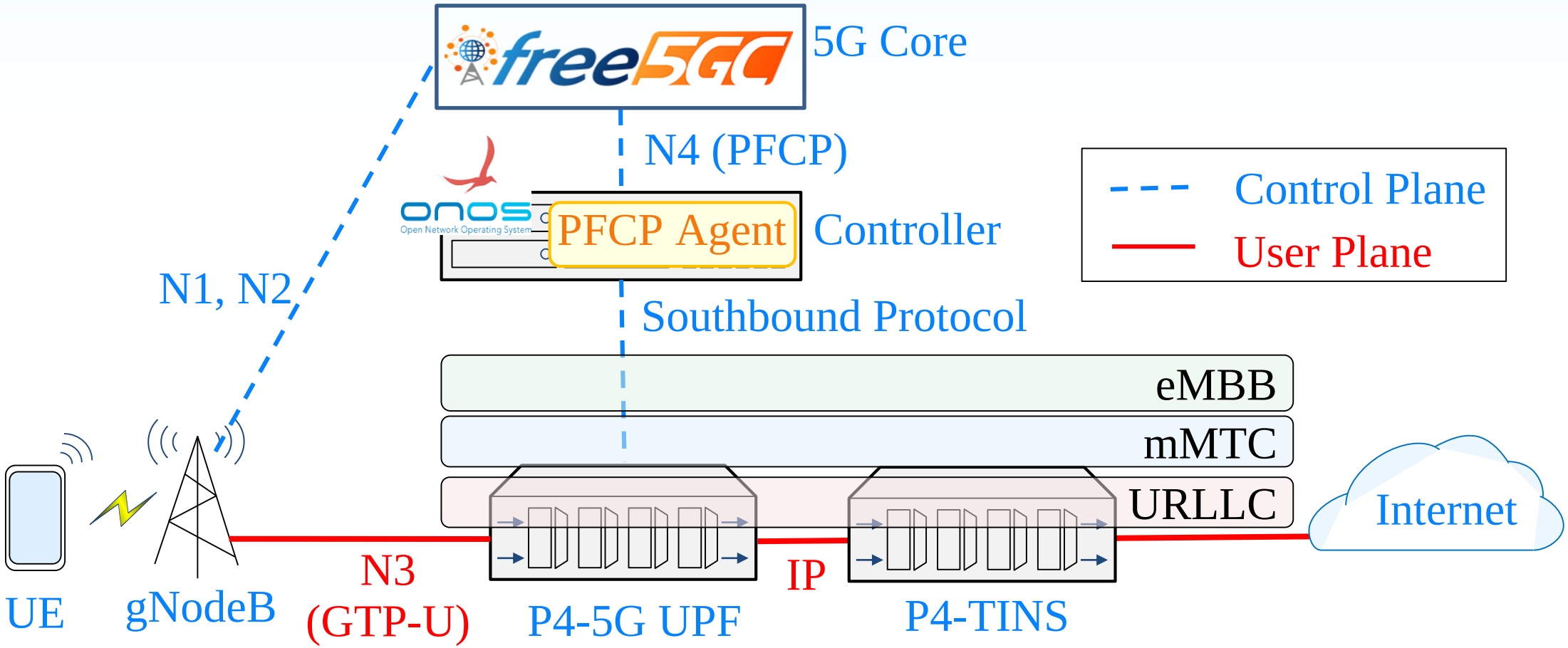






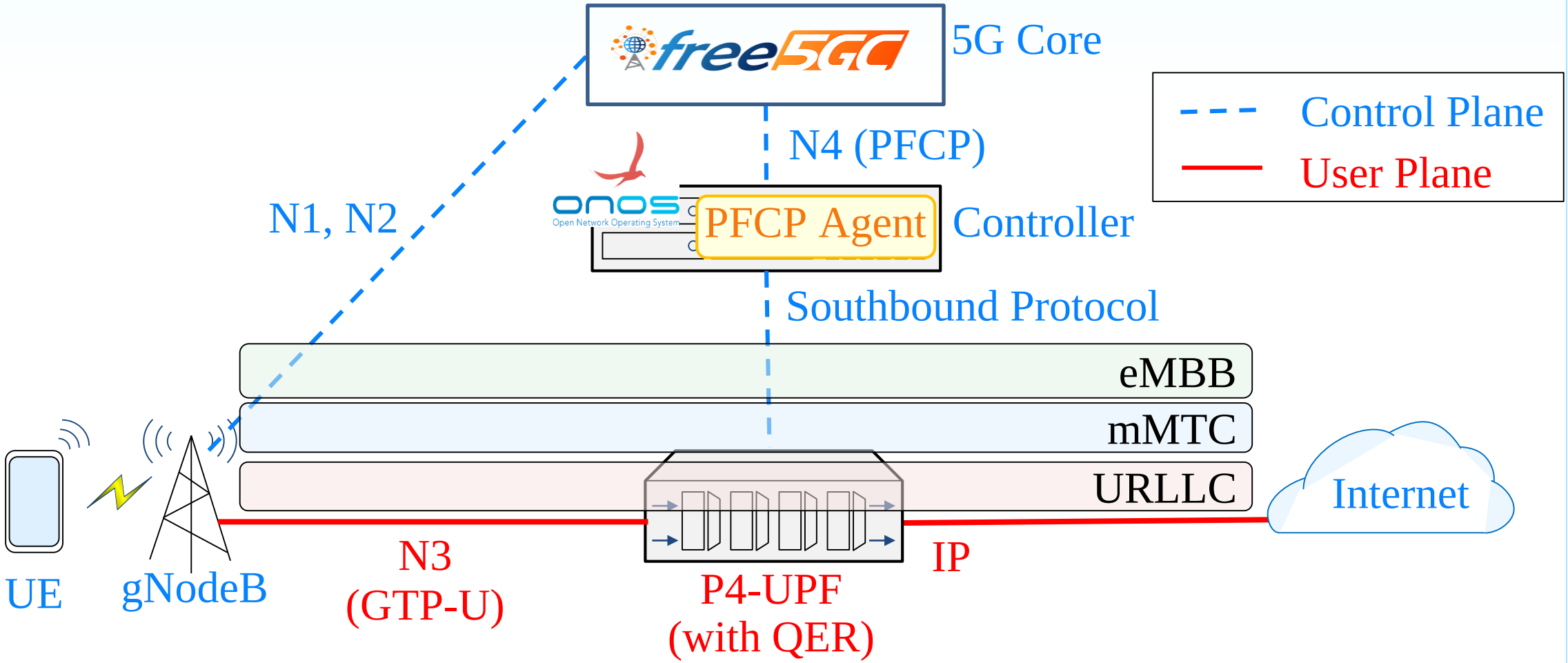
- Presented at ONF Connect 2019

P4-enabled 5G UPF with Network Slicing



P4-enabled UPF with QoS Enforcement Rules

- Next



Q & A

Evaluation

Resource Usage and Bandwidth Policies on TN Slices

Environment Setup

- Software
  - Ubuntu 16.04
  - free5GC Stage 2 Release

- Hardware
  - Quanta D51B-1U server
    - CPU 40 cores
    - RAM 128 Gigabytes
  - Inventec D10056 P4 switch

Details of MANO Framework and BANSs

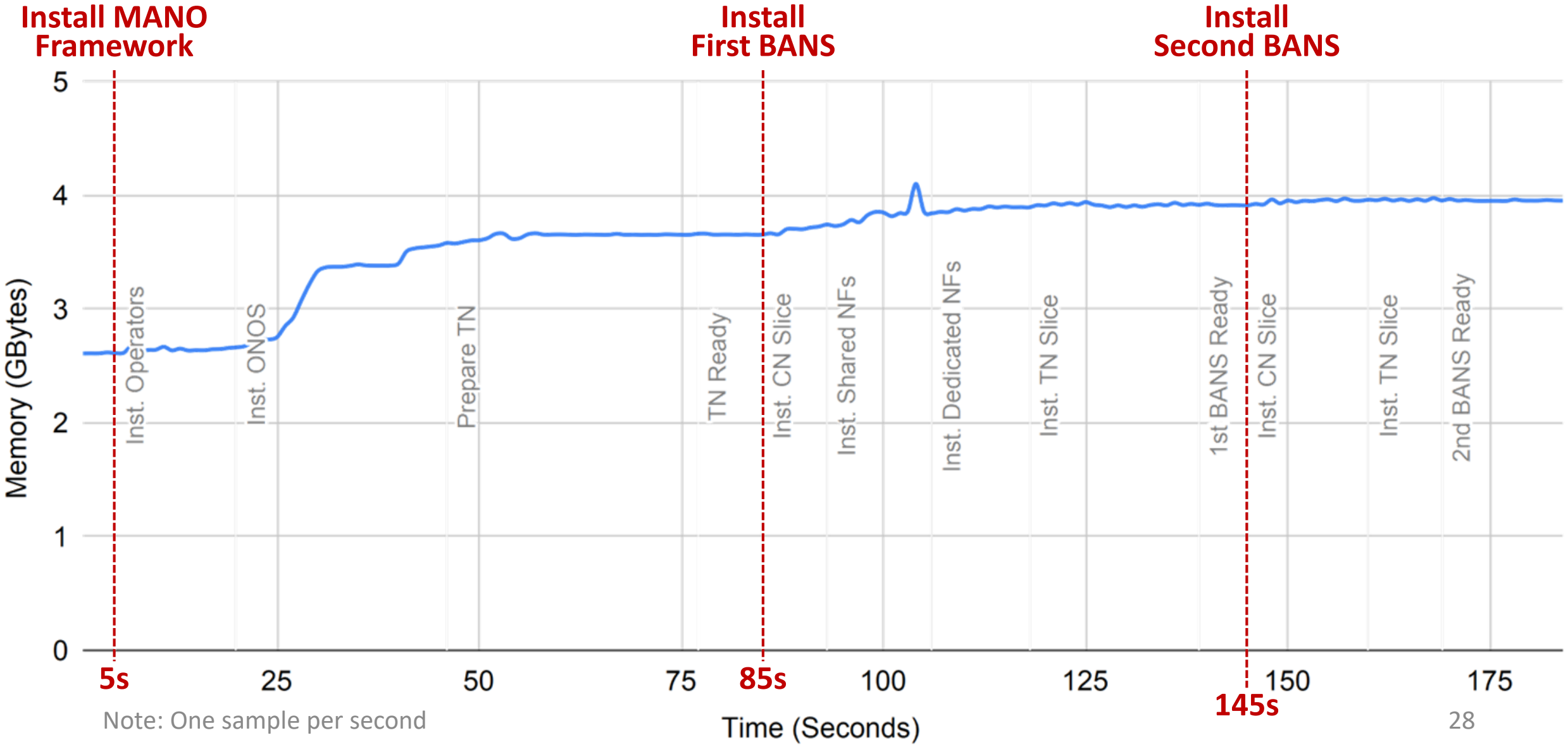
Deployment Object		BANS-5GC with P4 Fabric
MANO Framework		• Creation of three Operators • Preparation of TN environment
First BANS	5G CN Slice	• Creation of shared slice • Creation of dedicated slice
	TN Slice	• Configuration of bandwidth slice
Subsequent BANS	5G CN Slice	• Creation of dedicated slice
	TN Slice	• Configuration of bandwidth slice

Deployment Time of MANO Framework and BANSs

Deployment Time (sec.)		BANS-5GC with P4 Fabric	
MANO Framework		71.02	
First BANS	5G CN Slice	52.15	32.7 (62.7%)
	TN Slice		18 (34.52%)
Subsequent BANS	5G CN Slice	33.21	13.2 (39.75%)
	TN Slice		18.9 (56.91%)

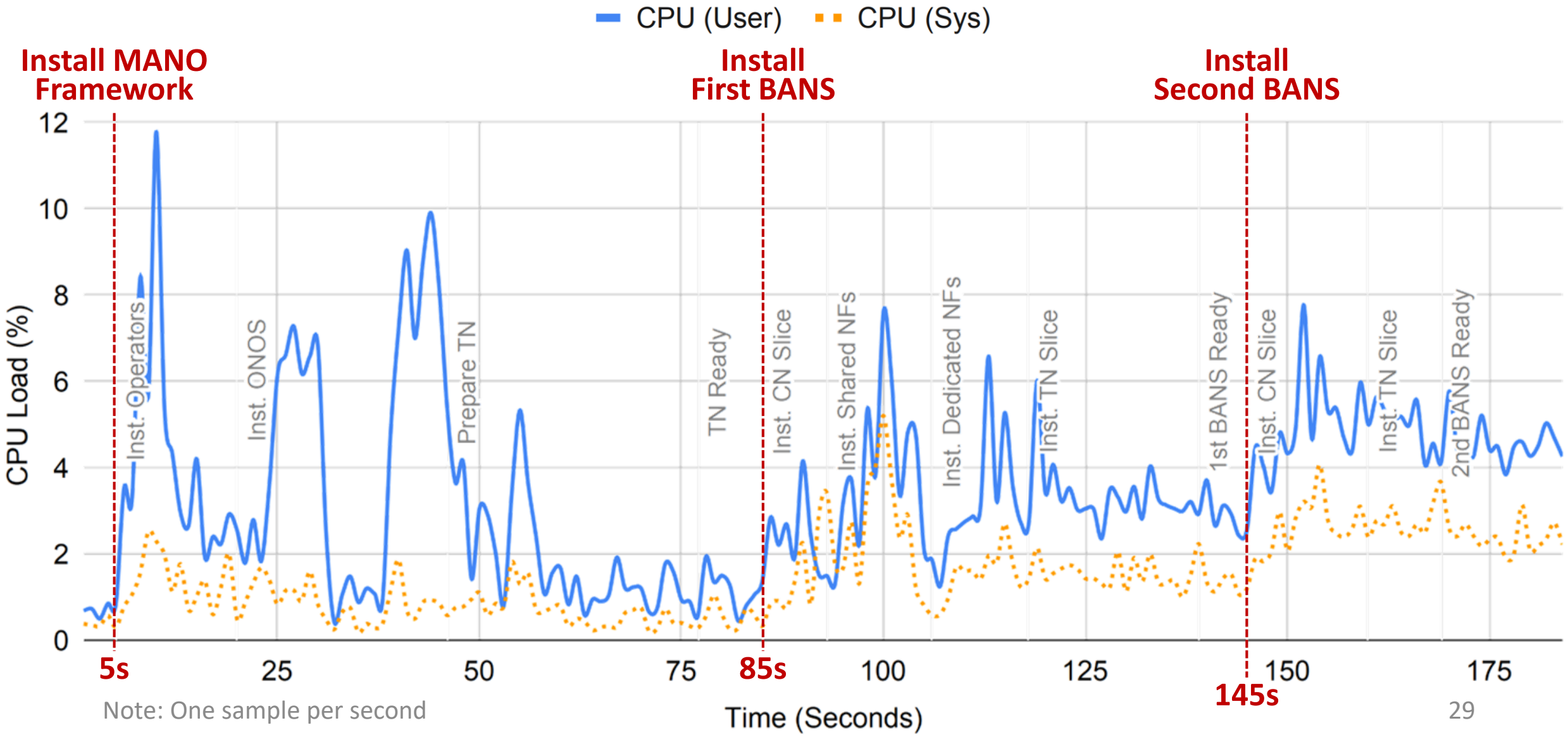
Note: Average of ten times of deployment

Memory Usage of MANO Framework and BANSs



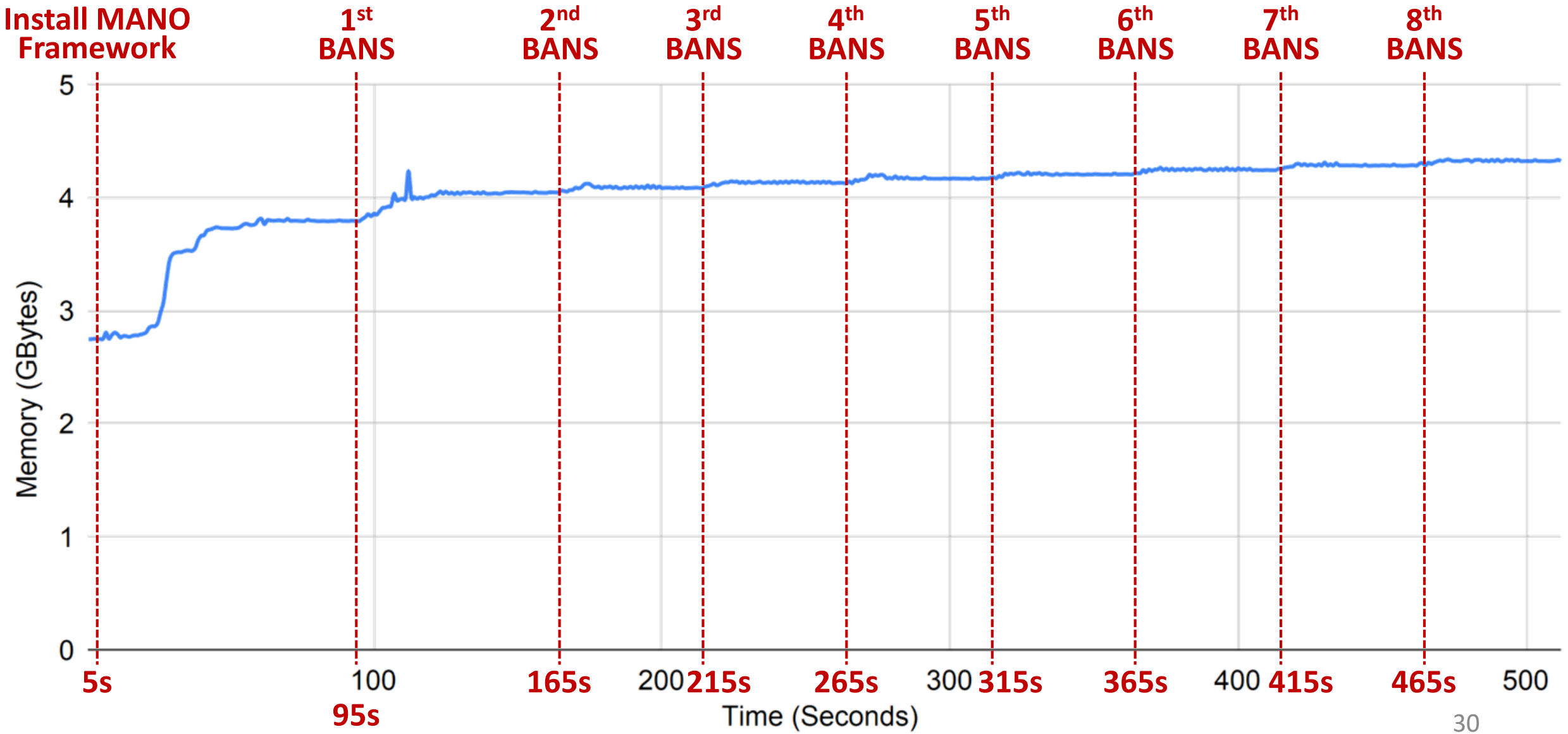
Note: One sample per second

CPU Load of MANO Framework and BANSs

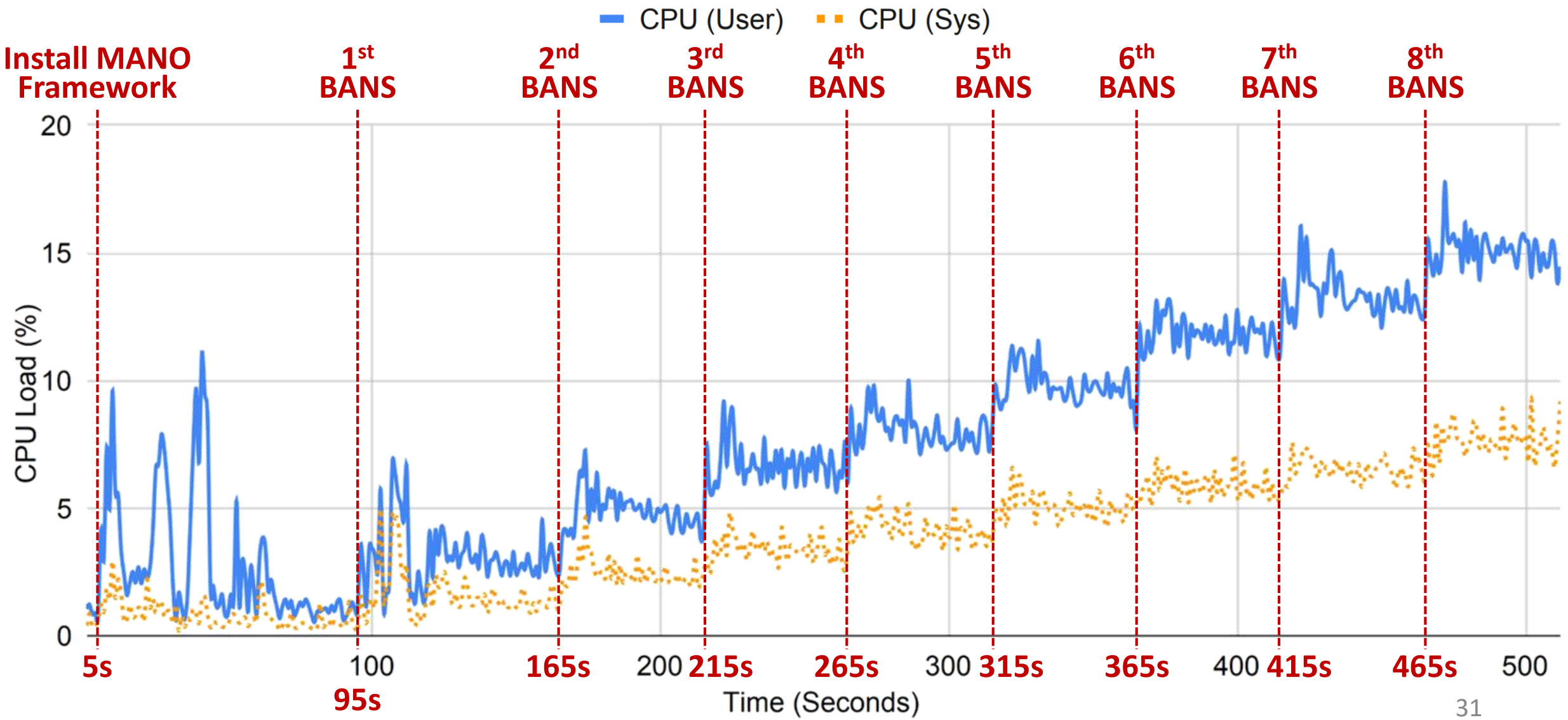


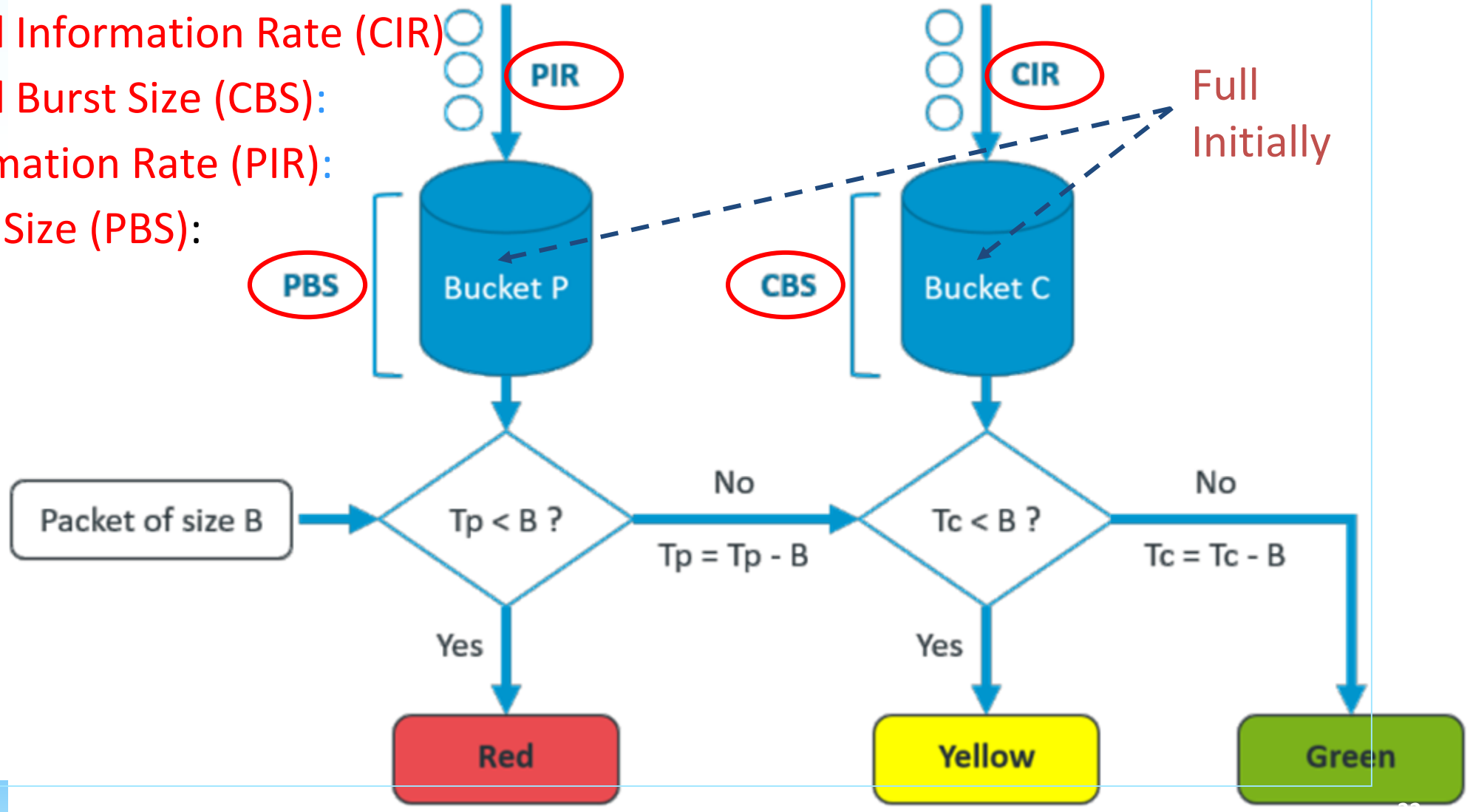
Note: One sample per second

Memory Usage of Deploying Numerous Slices



CPU Load of Deploying Numerous Slices



Packet Classification of trTCM

- Two Rate Three Color Marker (trTCM):
  - Committed Information Rate (CIR)
  - Committed Burst Size (CBS):
  - Peak Information Rate (PIR):
  - Peak Burst Size (PBS):