P4-enabled Network Slicing and 5G User Plane Function

Professor Chien-Chao Tseng

Department of Computer Science
National Yang Ming Chiao Tung University
cctseng@cs.nctu.edu.tw
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

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

**End-to-end** Bandwidth-aware Network Slicing **Operator**

(3GPP Management System / ETSI NFV-MANO)

- 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)

1. E2E NS Spec (S-NSSAI list, bandwidth policy, etc.)
2. CN Slice
3. TN Slice
4. NS Information

RAN Operator
MEC Operator
TN Operator
CN Operator

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
Deploying First 5GC Slice
Deploying Subsequent 5GC Slice

1. NS Allocation
2. BANS Operator
3. Slice 1
   - AMF
   - NSSF
   - UPF
   - SMF
4. free5GC Operator
5. ONOS Operator
6. ONOS

Shared NFs
- AMF
- Other Shared NFs
- NSSF

Slice 1
- net1
- eth0

Slice 2
- net1
- eth0

Control Traffic

Data Traffic
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

Throughput (Mbits/sec)

Flow 1
Flow 2
Sliced(Flow1)
Sliced(Flow2)
at Core
at Transport (Access)

Time (Seconds)
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

- **Slice 1:** 200 – 600 Mbps
- **Slice 2:** 300 – 400 Mbps
- **Slice 3:** 400 – 500 Mbps

Bandwidth Management Here
P4 Meter

- 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

trTCM: Two Rate Three Color Marker
CIR: Committed Information Rate
PIR: Peak Information Rate

Ingress → P4 Meter → Policier → Egress
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

<table>
<thead>
<tr>
<th>Ethernet</th>
<th>IP</th>
<th>UDP</th>
<th>GTP-U(TEID=XXX)</th>
<th>IP</th>
<th>TCP/UDP</th>
<th>Payload</th>
</tr>
</thead>
</table>

![Diagram showing bandwidth and time graph with sliced and background traffic]

- Presented at ONF Connect 2019
P4-enabled 5G UPF with Network Slicing

5G Core

N4 (PFCP)

Controller

Southbound Protocol

N3 (GTP-U)

UE

gNodeB

P4-5G UPF

P4-TINS

Internet

eMBB

mMTC

URLLC

Control Plane

User Plane
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

<table>
<thead>
<tr>
<th>MANO Framework</th>
<th><strong>BANS-5GC with P4 Fabric</strong></th>
</tr>
</thead>
<tbody>
<tr>
<td>Creation of three Operators</td>
<td></td>
</tr>
<tr>
<td>Preparation of TN environment</td>
<td></td>
</tr>
</tbody>
</table>

### First BANS

<table>
<thead>
<tr>
<th>5G CN Slice</th>
<th><strong>BANS-5GC with P4 Fabric</strong></th>
</tr>
</thead>
<tbody>
<tr>
<td>Creation of shared slice</td>
<td></td>
</tr>
<tr>
<td>Creation of dedicated slice</td>
<td></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>TN Slice</th>
<th><strong>BANS-5GC with P4 Fabric</strong></th>
</tr>
</thead>
<tbody>
<tr>
<td>Configuration of bandwidth slice</td>
<td></td>
</tr>
</tbody>
</table>

### Subsequent BANS

<table>
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<tr>
<th>5G CN Slice</th>
<th><strong>BANS-5GC with P4 Fabric</strong></th>
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<tr>
<td>Creation of dedicated slice</td>
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<th>TN Slice</th>
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<tbody>
<tr>
<td>Configuration of bandwidth slice</td>
<td></td>
</tr>
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</table>
## Deployment Time of MANO Framework and BANSs

<table>
<thead>
<tr>
<th>Deployment Time (sec.)</th>
<th>MANO Framework</th>
<th>BANS-5GC with P4 Fabric</th>
</tr>
</thead>
<tbody>
<tr>
<td>First BANS</td>
<td></td>
<td></td>
</tr>
<tr>
<td>5G CN Slice</td>
<td>71.02</td>
<td>32.7 (62.7%)</td>
</tr>
<tr>
<td>TN Slice</td>
<td></td>
<td>18 (34.52%)</td>
</tr>
<tr>
<td>Subsequent BANS</td>
<td></td>
<td></td>
</tr>
<tr>
<td>5G CN Slice</td>
<td>33.21</td>
<td>13.2 (39.75%)</td>
</tr>
<tr>
<td>TN Slice</td>
<td></td>
<td>18.9 (56.91%)</td>
</tr>
</tbody>
</table>

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

- Install MANO Framework
- 1st BANS
- 2nd BANS
- 3rd BANS
- 4th BANS
- 5th BANS
- 6th BANS
- 7th BANS
- 8th BANS

Time (Seconds):
- 5s
- 95s
- 165s
- 200s
- 215s
- 265s
- 300s
- 315s
- 365s
- 400s
- 415s
- 465s
- 500s
CPU Load of Deploying Numerous Slices

Install MANO Framework

<table>
<thead>
<tr>
<th>Install MANO Framework</th>
<th>1st BANS</th>
<th>2nd BANS</th>
<th>3rd BANS</th>
<th>4th BANS</th>
<th>5th BANS</th>
<th>6th BANS</th>
<th>7th BANS</th>
<th>8th BANS</th>
</tr>
</thead>
<tbody>
<tr>
<td>5s</td>
<td>95s</td>
<td>165s</td>
<td>215s</td>
<td>265s</td>
<td>315s</td>
<td>365s</td>
<td>415s</td>
<td>465s</td>
</tr>
</tbody>
</table>

CPU Load (%)

Time (Seconds)

- CPU (User)
- CPU (Sys)
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):

```
Packet of size B
```

```
Tp < B ?
```

```
Tp = Tp - B
```

```
Yes
```

```
Red
```

```
No
```

```
Tc < B ?
```

```
Tc = Tc - B
```

```
Yes
```

```
Yellow
```

```
No
```

```
Initial
```

```
Full
```