Application-Driven Network Softwarization

Aki Nakao
Professor, The University of Tokyo
Chairman, 5GMF Network Architecture Committee
2016/6/8
Smart building with 1500 sensors embedded

APIs for admission control, light switches, elevators

Software Defined Building...

My labs (faculty office, students, staffs)
Research Interest in NakaoLab@UTokyo

- Network Softwarization
- SDN
- NFV
- MEC
- IoT
- App
- Machine Learning
  - “Thinking Network”
- 5G
5G Mobile Network Promotion Forum

76 Industry Members
14 Individual Members
30 Advisory Members
3 Special Members

General Assembly

Advisory Board

Strategy & Planning Committee
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NTT DOCOMO

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GEO NETWORKS

Network Architecture Committee
Chairman
Akihiro Nakao,
Univ of Tokyo
Acting chairman
Ryutaro Kawamura,
NTT

• Strategy & Planning of 5G mobile and develop outcomes from this forum
• Contact, coordinate and confer with suitable organizations in and outside Japan
• Coordinate among the various committees of this forum

• Study technology and frequency requirements for 5G mobile
• Contact, coordinate and confer with international standards organizations and overseas organizations regarding technologies

• Study mobile applications for the 2020’s

• Study overall network architecture for 5G mobile
• Study requirements and technologies for network infrastructure

Chairman of 5GMF
Susumu Yoshida, Kyoto Univ.
Vice chairmen of 5GMF
Masao Sakauchi, NICT
Hiromichi Shinohara, NTT

Industry Members
14 Individual Members
30 Advisory Members
3 Special Members
Whitepaper has been published!

- 30 May 2016  5GMF White Paper “5G Mobile Communications Systems for 2020 and beyond”, Ver. 1.0
- 30 May 2016  Executive Summary of 5GMF White Paper Ver. 1.0

Network Softwarization view of 5G mobile

Goal: End-to-End Quality and Extreme Flexibility to Accommodate Various Applications & Services with various requirements (M2M/IoT, Content delivery, Tactile)

Virtualized networks/platform

Slice Control

API

App-Driven API

Management Orchestration

Network management and orchestration

Network Softwarization

Physical infrastructure (network, computing and storage resources)

UE/Device

Computation and storage resources

Data Centers

Mobile Edge Computing

RAT(s)

Network resources

MFH

MBH

Transport

Fronthaul Backhaul
Network softwarization is an overall transformation trend for designing, implementing, deploying, managing and maintaining network equipment and network components by software programming, exploiting characteristics of software such as flexibility and rapidity of design, development and deployment throughout the lifecycle of network equipment and components,

Draft Contribution at FG IMT-2020 as of 2015/11/6
ITU-T FG IMT-2020 Phase2

FG IMT-2020
ITU-T Focus Group on IMT-2020

Meeting in Focus
6 September (2 PM) - 9 September 2016, Palo Alto, United States, hosted by PARC
- Announcement (incl. phone numbers)
- Registration
- Documents

Future Meetings
November 2016, ITU, Geneva, Switzerland
Details coming soon

Past Meetings
1. 8-9 June 2015, San Diego, United States: Announcement - Participants - Report
3. 21-24 September 2015, Turin, Italy: Announcement - Participants - Report
4. 27-30 October 2015, Beijing, China: Announcement - Participants - Report
5. 8-11 March 2016, Seoul, Korea: Announcement - Participants - Report
6. 17-20 May 2016, Beijing, China: Announcement - Participants - Report

Tools
- Terms of Reference (2016); (2015)
- Recommendation ITU-T A.7: "Focus groups: Establishment and working procedures"
- ITU-T basic document template
- Manual for rapporteurs and editors
- Author's guide for drafting ITU-T Recommendations
- Quick guide for remote meeting attendees (GoToMeeting)
- Mailing list subscription
- Mailing list archive

Contact
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- ITU secretariat: Mr. Martin Adolph; E-mail: tbsfgimt-2020@itu.int; Tel: +41 22 730 6828
ITU-T SG13 FG IMT-2020 From Phase1 To Phase2

- FG (Focus Group) IMT-2020 was formed under ITU-T SG13 in Apr. 2015.
- FG IMT-2020 (phase-1) studied gap analysis of existing technologies against the requirements of IMT-2020, and delivered its report in Dec. 2015.
- Based on the outcome of phase-1, FG IMT-2020 (phase-2) has been started with the goal being to compile recommendations on enabling technologies for IMT-2020, targeted at the end of 2016.

**Gap Analysis**

**Network Softwarization (SDN/NFV)**
- Fronthaul/Backhaul
- E2E Management Architecture
- Emerging Technologies (ICN)

**FG IMT-2020 (phase-1)**

- #1 meeting (2015.6)
- #2 meeting (2015.7)
- #3 meeting (2015.9)
- #4 meeting (2015.10)

**FG IMT-2020 (phase-2)**

- #1 meeting (2016.3)
- #2 meeting (2016.5)
- #3 meeting (2016.8/9)
- #4 meeting (2016.11/12)

Gap Analysis of existing technologies, such as NFV/SDN, ICN/CCN, Fronthaul/Backhaul, and so forth.

Compiling recommendations on enabling technologies
- Prototyping, Showcases, Use of open source is also planned.
FG IMT-2020 Network Softwarization Activity Plan

Further analysis of gaps of interest
- Technical gaps
- SDOs’ coverage

Draft recommendations to SG
- Aligned with other groups? Such as “Requirements”/Framework etc.
- Output document should be brought to SG

Create a catalogue of open source software
- Including Impact, applicability and maturity for 5G development
- Mapping open source software in end-to-end slicing (e.g., ODL, ONOS, OPNFV, Docker, OpenStack, etc)
- To what extent, the existing software need to be extended for 5G (gap analysis).
- Successful outcome: Suggest extensions for 5G mobile network to open source community

Explore various prototyping activities
- Interaction among multiple open source softwares
6 → Network Softwarization for IMT-2020

6.1 → Standardization activities for network softwarization

[Editor's note: we must include discussion on 1. description of work programs, and 2. Relevance to network softwarization.]

6.1.1 → Standardization activities at 3GPP SA2

The “Study on Architecture for Next Generation System” was started at SA2#112 meeting and officially approved as 3GPP TR 23.799 at the 3GPP TSG SA#70 plenary in December 2015. After that, the TR 23.799 has been updated through three more meeting including one adhoc meeting. The latest version of the TR can be found on the following links; the latest version is version 0.4.0 at the time of this writing, early May 2016.

- → http://www.3gpp.org/ftp/3gpp/Specs/TS_23.799

The objective of the study is to design a system architecture for “5G”, which is called as the next generation mobile network or NextGen aiming to support at least the new RAT(s), the evolved LTE, non-3GPP accesses with minimum access dependencies.

The study is being done based on the following studies on the requirements for the next generation mobile networks which has been carried in 3GPP SA1; the latest version of all of them is version 1.0 as of now.

- → 3GPP·TR·22.861 (FS_SMARTEm - massive Internet of Things)
- → 3GPP·TR·22.862 (Feasibility Study on New Markets and Technology Enablers - Critical Communications; Stage 1"
- → 3GPP·TR·22.863 (FS_SMARTEm - enhanced Mobile Broadband)
- → 3GPP·TR·22.864 (Feasibility Study on New Services and Markets Technology Enablers - Network Operation)
The basic concept of the Network Softwarization is “Slicing” as defined in [ITU-T Y.3011], [ITU-T Y.3012]. Slicing allows logically isolated network partitions (LINP) with a slice being considered as a unit of programmable resources such as network, computation and storage.
Definitions of (Network) Slicing

“…a slice is defined as an isolated set of computational and network resources allocated and deployed across the entire network”

Akihiro Nakao, “Network Virtualization as Foundation for Enabling New Network Architectures and Applications” IEICE TRANS.COMMUN., VOL. E93-B. No3 March 2010

“Slice = a set of resources reserved across multiple network domains”

Akihiro Nakao, “deeply programmable network”, ITU-T Kareidoscope 2013, Kyoto, Japan

“Since 2008, we have conducted our research on continuously evolve-able network virtualization infrastructure, proposing the concept of “slice”, i.e., a set of isolated programmable resources so as to implement new generation network protocols and services.”

A Brief History of “Slicing”

<table>
<thead>
<tr>
<th>JP</th>
<th>US/EU/BR</th>
<th>Worldwide</th>
</tr>
</thead>
<tbody>
<tr>
<td>2005- PlanetLab JP</td>
<td>2002- PlanetLab (US)</td>
<td></td>
</tr>
<tr>
<td>2008 VNode Project (NICT/Utkyo/NTT/NEC/Hitachi/Fujitsu)</td>
<td>2005- PlanetLab EU (EU)</td>
<td></td>
</tr>
<tr>
<td>2011 VNode/FLARE Project (Utkyo/NTT/NEC/Hitachi/Fujitsu/KDDI)</td>
<td>2006- OneLab (EU)</td>
<td></td>
</tr>
<tr>
<td>2014 O3 Project (NTT/NEC/Hitachi/Fujitsu)</td>
<td>2008- OneLab2 (EU)</td>
<td></td>
</tr>
<tr>
<td>2016</td>
<td>2008 GENI Kick Off (US)</td>
<td></td>
</tr>
<tr>
<td>2016</td>
<td>2012 OpenLab(EU)</td>
<td></td>
</tr>
<tr>
<td>2016</td>
<td>Fed4Fire (EU)</td>
<td></td>
</tr>
<tr>
<td>2016</td>
<td>FIBRE(EU/BR)</td>
<td></td>
</tr>
<tr>
<td>2016</td>
<td>24 GEC’s</td>
<td></td>
</tr>
</tbody>
</table>

Network Softwarization view of 5G mobile

Goal: End-to-End Quality and Extreme Flexibility to Accommodate Various Applications & Services with various requirements (M2M/IoT, Content delivery, Tactile)

Virtualized networks/platform

- Slice Control
- UE/Device
- Radio access network (RAN)
- Mobile packet core
- Cloud

API

App-Driven API

Management Orchestration

Network management and orchestration

Network Softwarization

Physical infrastructure (network, computing and storage resources)

- UE/Device
- Computation and storage resources
- Data Centers

- Mobile Edge Computing
- Network resources
- RAT(s)
- MFH
- MBH
- Transport

Fronthaul Backhaul
Application Driven Network Softwarization Network Slicing

Why do we need slicing from applications point of view?
“White screen of Death”
Pulling Necessary Files Out of Broken Mac
Only Option for Reinstalling “El Captain” is Network Install

That took 5 hours !!
OS upgrade via network is a “Killer” app for operators in a difference sense!
Network Softwarization view of 5G mobile

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Data Centers

Mobile Edge Computing

Network resources

RAT(s)

MFH

MBH

Transport

Fronthaul Backhaul
Gap B.6.2.1: Efficient accommodation of various applications

Priority: High

Description: It is envisioned that such an infrastructure that efficiently supports a diversified set of application requirements across end-to-end paths, ranging from M2M communication, to autonomous and collaborative driving, virtual reality and video streaming, etc. Network softwarization technologies including SDN, NFV and their extensions for supporting IMT-2020 mobile networks are expected to provide slicing capability both in wired and wireless parts of communication infrastructure, so that each slice provides an isolated environment to efficiently accommodate individual applications meeting specific requirements. The slice should be capable of dynamically adjusting resources to meet the application requirements. The network infrastructure is expected to provide extreme flexibility to support those different capabilities with reasonable cost.

Related work: ITU-T Y.3011, Y.3012, Y.3300, ETSI ISG NFV, Network Functions Virtualization, 3GPP, IEEE SDN
End-to-End Slicing and RAN Slicing

1. Overall Architecture

<table>
<thead>
<tr>
<th>Platform/Middleware Applications</th>
<th>Core</th>
<th>FH/BH</th>
<th>UE</th>
</tr>
</thead>
<tbody>
<tr>
<td>4. Edge Computing</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>5. Softwarized Data Plane (in support of e.g. ICN)</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Slicing</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>3. Horizontal Extension of Slicing</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Infrastructure</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>2. Vertical Extension of Slicing</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

O3

FG IMT-2020 Phase 2   I-156 Contribution
Virtualized (SLICE) MFH/MBH using wavelength

To ensure reliability and quality required for each service requires a mechanism that can be controlled independently of the resources. For example, if MFH/MBH is virtualization (SLICE), classification can be implemented in the entire network (EtoE).

Note: Resource (SLICE) control has been discussed in “7 Network Softwarization”.
RAN (Backhaul) Slicing (Elastic OADM Ring)
RAN (Fronthaul) Slicing (Dynamic Resource Allocation for Small Cells)
RAN (Midhaul:BBU) Slicing (Virtual BBU)
Network Slicing

In Preparation for 5G Mobile Networks
Software-defined 5G System
Software Defined Radio

Software Defined LTE/5G Network!

Programmable SIM

sysmocom
systems for mobile communications GmbH

Visit us at http://sysmocom.de/
- First-hand expertise in protocol E2E from A-bits to RAN/Network
- Support, training and development for OpenBSC, OpenBTS
- Low-cost GSM picowell platforms sysmowells
- B2B, B2C-style automation GSM networks
Application Specific LTE Network Slicing

A mobile virtual network operator (MVNO), or mobile other licensed operator (MOLO), is a wireless communications services provider that does not own the wireless network infrastructure over which the MVNO provides services to its customers.

NakaoLab is running SDN/NFV/MEC on top of several MVNOs

Mobile Network

MNO

MVNO

The Internet

https://en.wikipedia.org/wiki/Mobile_virtual_network_operator
App-Specific Slicing Traffic Control
Smartphones/wearables attach the information of applications and devices at the trailers of TCP SYNs. FLARE detects the information and creates mapping between flows and the information on applications and/or devices.
Topology

1) Classify reverse traffic to VLAN
2) DHCPD and SNAT

Attach app to packet trailer

Classify packets by app to VLAN

vNODE

SLICE_VLAN301 (HTTP Cache)
SLICE_VLAN302 (Pass through)
SLICE_VLAN303 (BW control)
SLICE_VLAN304 (VNF4)
SLICE_VLAN305 (VNF5)
Flow Characteristics of Popular App

<table>
<thead>
<tr>
<th>Apps</th>
<th>Avg Size (KBytes)</th>
<th>Avg duration (s)</th>
<th>Avg Rate (Kbps)</th>
</tr>
</thead>
<tbody>
<tr>
<td>YouTube</td>
<td>4000</td>
<td>107</td>
<td>396</td>
</tr>
<tr>
<td>Tethering</td>
<td>560</td>
<td>151</td>
<td>48</td>
</tr>
<tr>
<td>Google Maps</td>
<td>330</td>
<td>815</td>
<td>57</td>
</tr>
<tr>
<td>Instagram</td>
<td>192</td>
<td>496</td>
<td>71</td>
</tr>
<tr>
<td>Twitter</td>
<td>143</td>
<td>361</td>
<td>45</td>
</tr>
<tr>
<td>Facebook</td>
<td>40</td>
<td>438</td>
<td>3</td>
</tr>
<tr>
<td>Chrome</td>
<td>35</td>
<td>164</td>
<td>28</td>
</tr>
<tr>
<td>LINE</td>
<td>16</td>
<td>273</td>
<td>12</td>
</tr>
<tr>
<td>Gmail</td>
<td>11</td>
<td>8.7</td>
<td>56</td>
</tr>
</tbody>
</table>

• Observations:
  – YouTube traffic (396Kbps) is much higher than other applications (<100Kbps)
  – The average TCP rate of Tethering flow is not so large.
  – The average rate of Facebook is even smaller than that of Gmail
App Specific QoS via custom Southbound Interface

NakaoLab UTokyo MVNO

List of current rules:

<table>
<thead>
<tr>
<th>App name</th>
<th>Action</th>
</tr>
</thead>
<tbody>
<tr>
<td>com.facebook.katana</td>
<td>Pass</td>
</tr>
<tr>
<td>com.android.browser</td>
<td>200kbps</td>
</tr>
<tr>
<td>jp.naver.line.android</td>
<td>Pass</td>
</tr>
<tr>
<td>org.mozilla.firefox</td>
<td>Pass</td>
</tr>
<tr>
<td>com.android.chrome</td>
<td>Pass</td>
</tr>
<tr>
<td>com.google.android.youtube</td>
<td>1Mbps</td>
</tr>
<tr>
<td>com.skype.raider</td>
<td>Pass</td>
</tr>
<tr>
<td>mediaserver</td>
<td>1Mbps</td>
</tr>
</tbody>
</table>

Powered by FLARE@UTokyo

- chrome: unlimited
- Youtube (mediaserver): 1Mbps
- android.browser: 200kbps
Edge Computing Experiment with FLARE x MVNO

1. ISP A
   - Period: since 2014/11/20 up to present
   - UE: 59 Android Phones (Nexus)
   - End Users: Students/Staffs
   - Service Availability: 99.8% (0.2% downtime due to scheduled blackout)
   - Total traffic amount: about 1.7 TB (4.2GB per day on average)

2. ISP B
   - Period: since 2015/9/18 up to present
   - UE: 262 IoT Gateways (Intel Edision + WiFi + 3G + BLE)
   - End Users: Limousine Bus (public transportation)
   - Service Availability: 100% (by far)
   - Total traffic amount: about 1.7 TB (4.2GB per day on average)

3. ISPs C, D are in preparation for field trials
Application Specific Traffic Breakdown

- Chrome
- Total
- Facebook
- Tethering
- YouTube
Software Defined Data Plane

Applications

Network Applications

North-Bound Interface (NBI)

Control Plane

Control-Plane Elements

Publish API

Data Plane

Programmable Data-Plane Elements

ML
CCN
DPI
DTN
Application Identification by Machine Learning
Application Inference Accuracy vs. Learning Period

After 5 days of learning we can achieve 90+% accuracy of inferring applications.
Gap : Deep Data Plane Programmability

Gap B.6.6.3: Vertical extension: Deep data plane programmability (Data Plane Enhancement)

Priority: High

Description: The current SDN technology primarily focuses on the programmability of the control plane, and only recently the extension of programmability to the data plane is being discussed both in the research community and in ITU-T SG13 but without well-defined use cases. For IMT-2020 mobile networking, there are several use cases for driving invention and introduction of new protocols and architectures especially at the edge of the network. For instance, the need for redundancy elimination and low latency access to contents in content distribution drives ICN at mobile backhaul networks.

Protocol agnostic forwarding methods such as Protocol Oblivious Forwarding (POF) discuss the extension to SDN addressing forwarding with new protocols. In addition, protocols requiring a large cache storage such as ICN needs new enhancement.

A few academic research projects such as P4 [b-P4] and FLARE [b-FLARE] discuss the possibility of deeply programmable data planes that could implement new protocols such as ICN, but there is no standardization activity to cover such new protocols to sufficient extent.
FLARE: Sliceable Software Defined Data Planes

Applications

Network Applications

North-Bound Interface (NBI)

Control Plane

Control-Plane Elements

Data Plane

Programmable Data-Plane Elements

Slices
Commercial FLARE Node

- 72 core EZ-Chip Network processor
- GbE: 24 ports and 10GbE SFP+: 2 ports
- Up to 128GB memory / 1TB SSD
- Redundant Power supply
Slice Architecture on NPU

LXC: Linux Container on Zero Overhead Linux (ZOL)

Packet Forwarding Path

To X86
Or
To GPGPU

LXC Data Plane Slice

LXC Slicer Slice

LXC Data Plane Slice

Flexible I/O

MiCA

DDR3 Controller

DDR3 Controller

Network I/O
Research Interest in NakaoLab@UTokyo

SDN

NFV

MEC

App

IoT

Machine Learning

“Thinking Network”

5G
Mobile Edge Computing provides **IT and cloud-computing capabilities within the Radio Access Network (RAN)** in close proximity to mobile subscribers.

- On-Premises
- Proximity
- Lower Latency
- Location Awareness
- Network Context Information

http://www.etsi.org/technologies-clusters/technologies/mobile-edge-computing

MEC Introductory Technical White Paper
"Vehicle Control System Coordinated Between Cloud and Mobile Edge Computing” Kengo Sasaki*, Naoya Suzuki, Satoshi Makido, Akihiro Nakao (To Appear in IEEE SICE 2016)
Deviation From the Center of the Road

Fig. 8 Evaluation method of the vehicle path the stability
Cloud MEC Cooperative Driving PoC (Toyota&UTokyo)

With 100msec delay from UE to Cloud
Cloud MEC Cooperative Driving PoC (Toyota&UTokyo)

With 150msec delay from UE to Cloud

40% of the trajectory is out of the course
Edge Server Achieves Better Control

(a) Edge Server (0ms)
Wireless Performance Requirement in 5G

ITU-R IMT Vision (IMT2020)
Breakdown of E2E Delay

One way latency defined in 5G: $\text{②} + \text{③} + \text{④} + \text{⑤}$
EU-Japan Collaboration Project Proposal

5G!Pagoda
“A network slice for every service”


Call:
EUJ1-2016 - 5G - Next Generation Communication Networks

Coordinators:
Tarik Taleb and Akihiro Nakao

E-mails:
tarik.taleb@aalto.fi and nakao@nakao-lab.org

Phone:
+358-50-435-2325 and +81-3-5841-2384
5G!Pagoda Abstract

5G!Pagoda represents network softwarization enhancing NFV, SDN and aimes at 5G network evolution. The top objectives of 5G!Pagoda are i) the development of a scalable 5G slicing architecture towards supporting specialized network slices composed on multi-vendor network functions, through the development of ii) a scalable network slice management and orchestration framework for distributed, edge dominated network infrastructures, and convergent software functionality) lightweight control plane and iv) data plane programmability and their integration, customization, composition and run-time management towards different markets. 5G!Pagoda will develop a coherent architecture enabling research and standardization coordination between Europe and Japan.