Recent Advances in SDN, Virtualization, and Caching for 5G and Beyond

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Outline

Outline

When will 5G be available? - Timeline

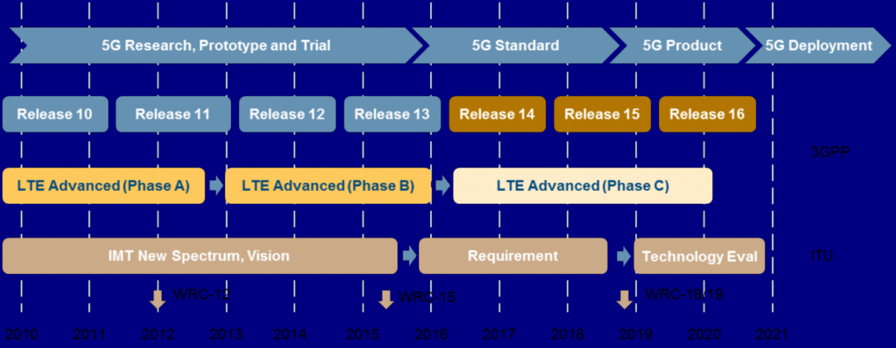

Figure 1: 5G roadmap and timeline[1]

[1] Huawei. *5G: A Technology Vision*. 2015. URL: www.huawei.com/5gwhitepaper/.

Outline

Where can we find 5G? - Use cases

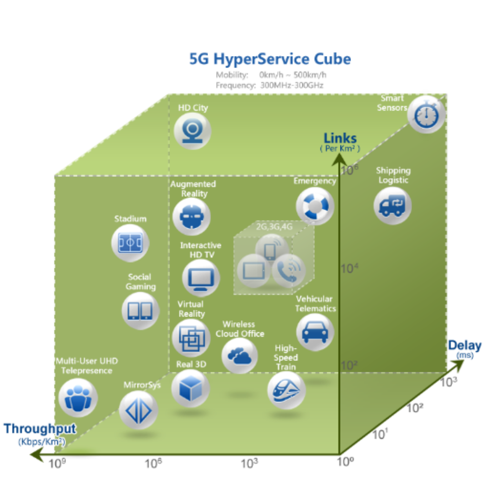

Figure 2: 5G service and scenario requirements[2]

[2] Huawei. *5G: A Technology Vision*. 2015. URL: www.huawei.com/5gwhitepaper/.

What are differences in 5G? - Requirements

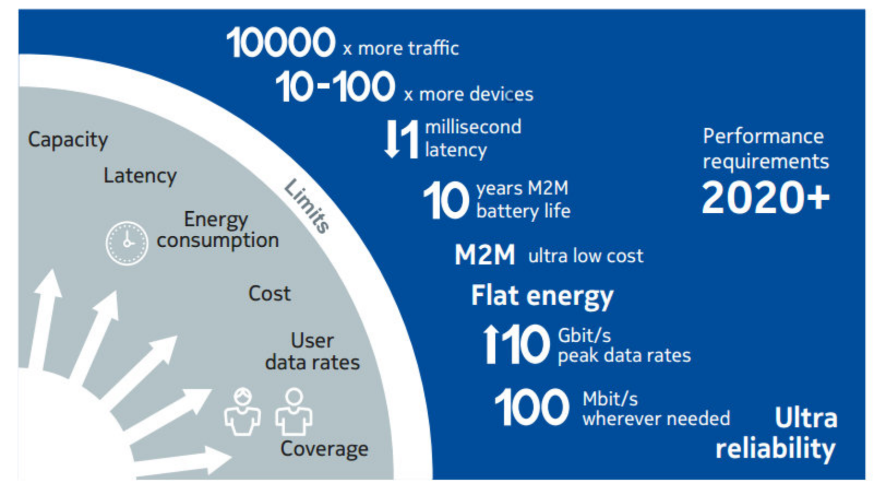

Figure 3: The summary of key requirements for 5G[3]

[3]Nokia. *5G Use Cases and Requirements White Paper*. Tech. rep. Nokia, 2015.

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What are new in 5G? - Networks

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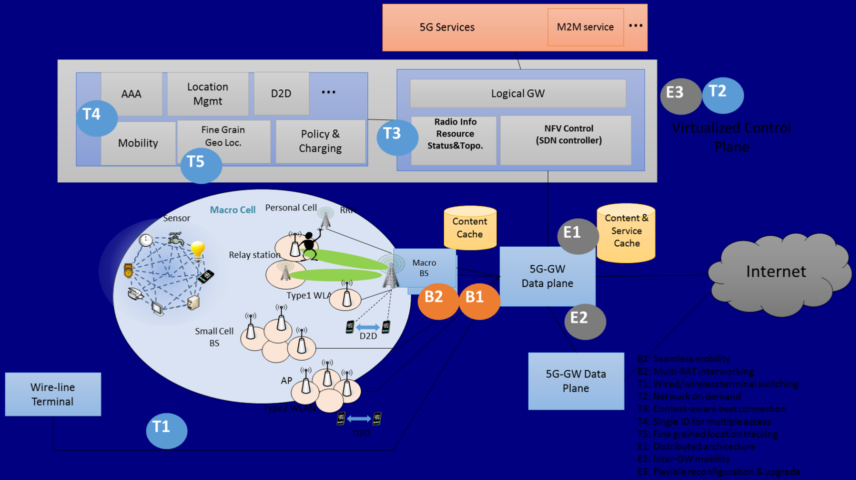

Figure 4: The summary of key enabling technology of 5G networks[4]

[4] Youngnam Han. *IMT2020 5G Forum Korea.* 2015. URL: https://www.itu.int/en/ITU-T/gsc/19/Documents/201507/GSC-19_304_5_5_5G%20Forum.pptx.

What are new in 5G? - Radio

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Category	Enabling Technologies		5G RAN Requirements									
			R1	R2	R3	R4	R5	R6	R7	R8	R9	R10
Wide and Flexible Bandwidth Technology	Millimeter-wave Band Communication		✓	✓		✓						
	Spectrum Integration	Integrated Tx/Rx with WLAN and WPAN							✓	✓		
	Cognitive radio and spectrum sharing		✓						✓	✓		
Advanced Transmission Technology	Modulation	Advanced modulation: FQAM	✓		✓							
	Waveform	FBMC	✓		✓							
		GFMC										
	Duplexing	In-band full duplexing	✓			✓			✓			
	Multiple Access	NOMA	✓		✓							
		SCMA										
	Large-scale Antenna	Large-scale antenna below 6GHz	✓	✓	✓							
		Large-scale antenna above 6GHz	✓	✓	✓							✓
	Advanced Interference Management		✓		✓							
Access Architecture-related Technology	Advanced Dense Small Cell								✓	✓		✓
	Virtualized RAN				✓	✓			✓			
	Enhanced Wireless Backhaul				✓				✓			
	Advanced Relay		✓		✓							
	Moving Network				✓				✓			
	Device-to-Device (D2D) communication								✓	✓		
	Massive Connectivity					✓			✓	✓	✓	

R1: Cell Spectral Efficiency
R2: Peak Data Rate
R3: Cell Edge User Data Rate
R4: Latency
R5: Mobility
R6: Handover Interruption Time
R7: Areal Capacity
R8: Energy Efficiency
R9: Connectivity
R10: Positioning

Figure 5: The summary of key enabling technology of radio for 5G[5]

[5] Youngnam Han. *IMT2020 5G Forum Korea*. 2015. URL: https://www.itu.int/en/ITU-T/gsc/19/Documents/201507/GSC-19_304_5_5_5G%20Forum.pptx.

Outline

A High-Level view on 5G Architecture

◇ Current, the existing *one-size-fits-all* mobile network architecture was designed to meet requirements for voice and conventional MBB services. It worked well for single-service subscriber networks with predictable traffic and growth.

◇ In 5G, the essential driving force behind the network architecture transformation is *service-orientation (an as-a-service basis)* which can enable flexibly and efficiently meet diversified mobile service requirements.

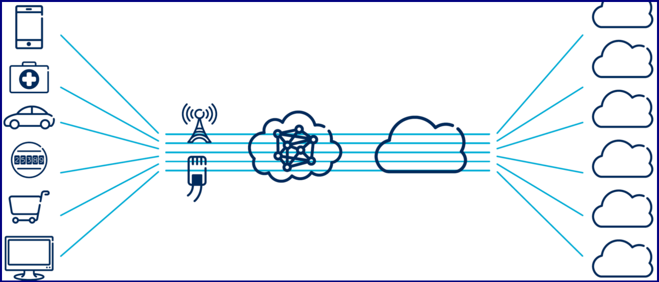

Figure 6: The service-driven 5G network architecture.[6]

[6] Ericsson. *5G systems enabling industry and society transformation*. Tech. rep. Ericsson, 2015.

Multiple industries on one physical NET

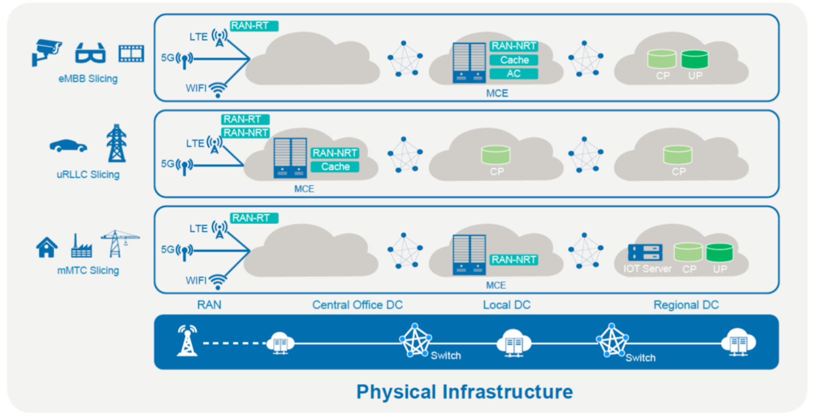

Figure 7: End-to-end network slicings[7]

[7] Huawei. *5G Network Architecture A High-Level Perspective.* Tech. rep. Huawei, 2016.

Key enablers

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Figure 8: Software-Defined Networking (SDN) and Network Functions Virtualization (NFV) make the network different

Outline

2. SDN, virtualization, and caching in mobile networks
   - Software-defined mobile networks and NFV
   - In network caching in 5G

Outline

2 SDN, virtualization, and caching in mobile networks

- Software-defined mobile networks and NFV
- In network caching in 5G

SDN Architecture

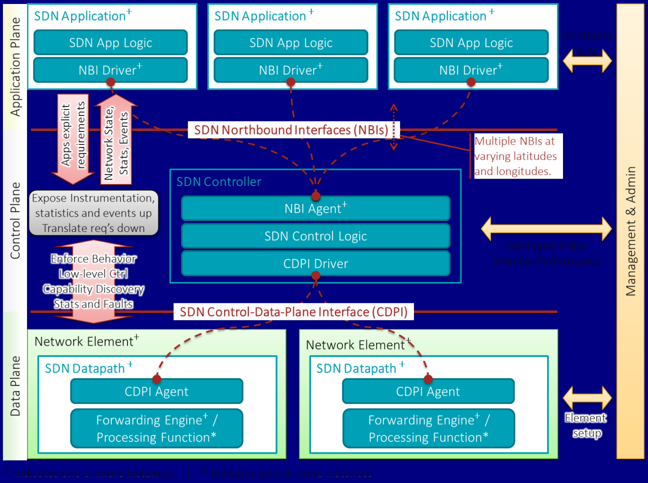

Figure 9: Overview of SDN Architecture[8]

[8]ONF. *ONF White Paper: SDN Architecture Overview.* Tech. rep. ONF, 2013.

NFV Architecture

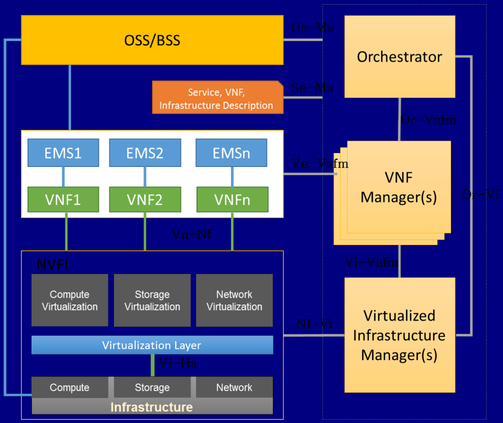

Figure 10: NFV Architectural Framework[9]

[9]ETSI. *Network Functions Virtualisation (NFV): Network Operator Perspectives on Industry Progress*. Tech. rep. 2013001. 2013.

Why SDN and NFV?[10]

- ◇ **Virtualization & Multi-tenancy**
- ◇ **Orchestration & Dynamic Scaling**
- ◇ **Programmable & Service Integration & Automation**
- ◇ **Visibility & Performance**
- ◇ **Openness**

[10] Raj Jain. *Introduction to Software Defined Networking (SDN)*. 2013. URL: http://www.cse.wustl.edu/~jain/cse570-13/.

SDNizing mobile networks[11]

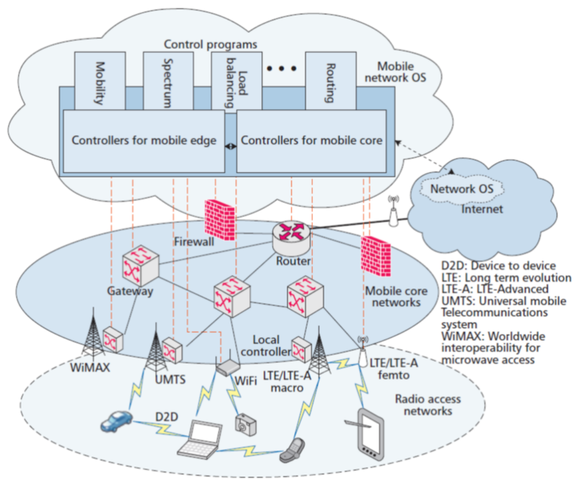

Figure 11: Illustration of software-defined mobile network

[11] Tao Chen et al. "Software defined mobile networks: concept, survey, and research directions". In: *IEEE Commun. Mag.* 53.11 (2015), pp. 126–133.

SDNizing mobile networks[12]

	Software-defined design at RAN	Software-defined design at CN
E2E services	Network awareness to improve QoS, support services with network reality	Traffic steering, QoS support
Heterogeneous network integration	Open control interfaces, network awareness, joint network configuration	Traffic steering to improve network resource utilization
Spectrum management	High level spectrum provision, network awareness, facilitate SAS and LSA	Traffic load awareness for spectrum allocation
Mobility	Network awareness, resource reservation, mobility prediction	Logic centralized control, reduce mobility overhead
RAN cooperation	Programmable SON, open cooperation interface	Traffic steering to better support CoMP and other cooperative techniques

Figure 12: Benefits of SDMN for service support and network function implementation.

[12] Tao Chen et al. "Software defined mobile networks: concept, survey, and research directions". In: *IEEE Commun. Mag.* 53.11 (2015), pp. 126–133.

Virtualizing mobile networks

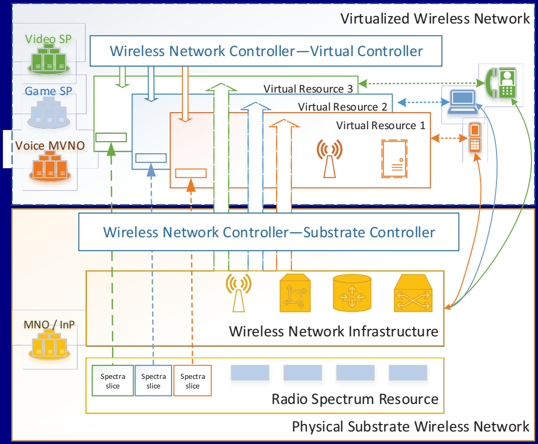

Figure 13: A framework of wireless network virtualization[13]

[13] C. Liang and F. R. Yu. "Wireless Network Virtualization: A Survey, Some Research Issues and Challenges". In: *IEEE Commun. Surveys Tutorials* 17.1 (2015), pp. 358–380.

Virtualizing mobile networks

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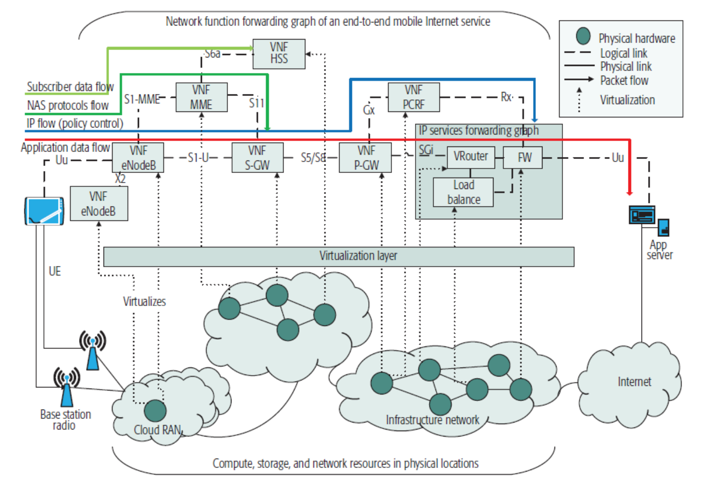

Figure 14: NFV in 5G[14]

[14] Sherif Abdelwahab et al. "Network function virtualization in 5G". In: *IEEE Comm. Mag.* 54.4 (2016), pp. 84–91.

Virtualizing mobile networks

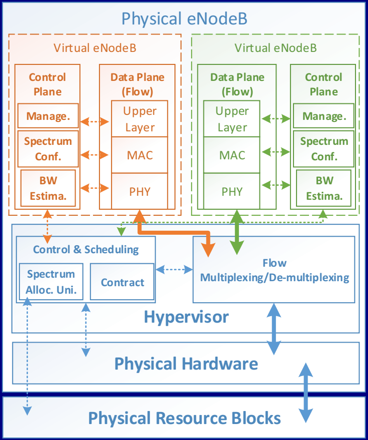

Figure 15: An example of LTE virtualization[15]

[15]Yasir Zaki et al. "LTE mobile network virtualization". In: *Mobile Net. & Applications* 16.4 (2011), pp. 424–432, C. Liang and F. R. Yu. "Wireless Network Virtualization: A Survey, Some Research Issues and Challenges". In: *IEEE Commun. Surveys Tutorials* 17.1 (2015).

Outline

2 SDN, virtualization, and caching in mobile networks

- Software-defined mobile networks and NFV
- In network caching in 5G

In network caching

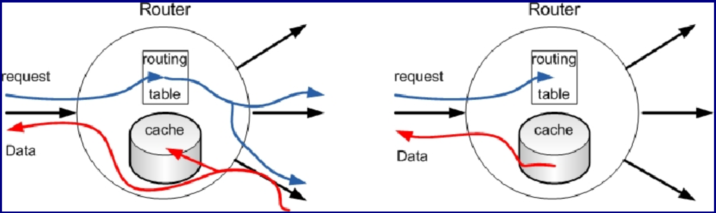

Figure 16: An example of in-network caching[16]

[16] McGill Computer Networks Research Group. *Mobile Content-Centric Networking (CCN)*. URL: http://networks.ece.mcgill.ca/node/177.

Why caching?

- **Latency reduction**
  - Avoid slow links (e.g., low bandwidth, congested).
  - Shorten transmission length (e.g., backhaul).
- **Traffic offloading**
  - Avoid traffic between RANs and CN or CN and the Internet.
  - Avoid traffic on content servers.
- **Efficiency improvement**
  - Avoid duplicated transmissions on popular contents.
  - Realizing cooperations between network elements.

Caching in the mobile edge

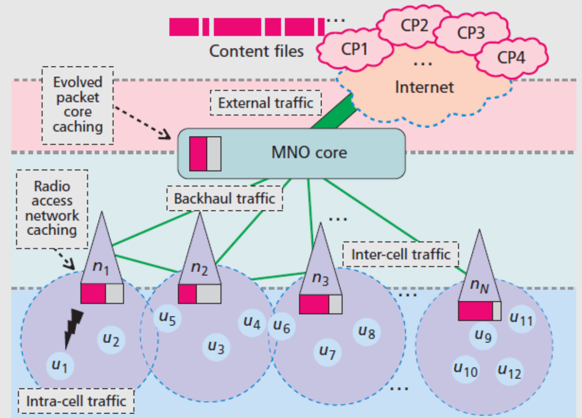

Figure 17: Cache in the air: content caching for 5G system[17]

[17] Xiaofei Wang et al. "Cache in the air: exploiting content caching and delivery techniques for 5G systems". In: *IEEE Commun. Mag.* 52.2 (2014), pp. 131–139.

Outline

3. Recent research on SDN, NFV and caching in Carleton
   - Virtual Mobile Network Admission Control
   - To enable cache virtualization
   - Dynamic caching in SDN-enabled mobile networks

Outline

3 Recent research on SDN, NFV and caching in Carleton

- Virtual Mobile Network Admission Control
- To enable cache virtualization
- Dynamic caching in SDN-enabled mobile networks

Business model for VN service slice[18]

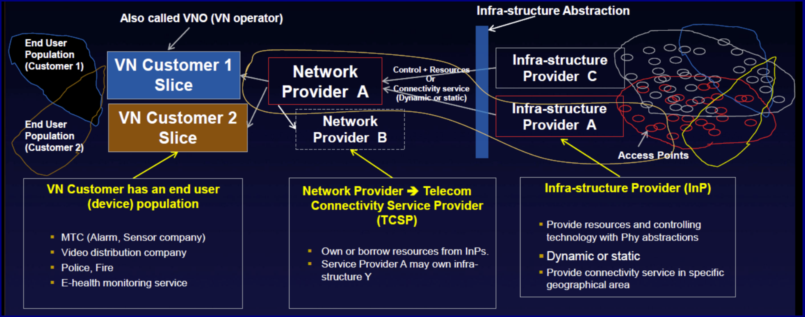

Figure 18

[18] Huawei. *5G Vision and Key Access and Networking Technologies.* 2015. URL: https://www.winlab.rutgers.edu/iab/2015-02/Slides/04.pdf.

Motivations

◇ **Traditional admission control**

· Limiting the number of UEs entering the network

· Guaranteeing the QoS of users.

· Maximizing the network utilization.

◇ **Virtual mobile network admission control**

· Limiting the number of mobile virtual networks (MVNs) embedded in the physical network.

· Guaranteeing the QoS requirments of embedded MVNs.

· Maximizing the utilization of physical network.

System model

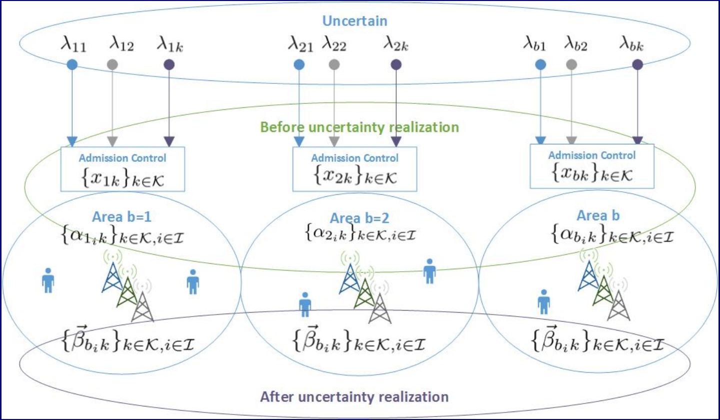

Figure 19

Problem statement

- **Objective**
  - Maximizing the total utility of the network.
- **Constraints**
  - Available physical resources.
  - QoS.
  - Stability.

MVN embedding mechanism

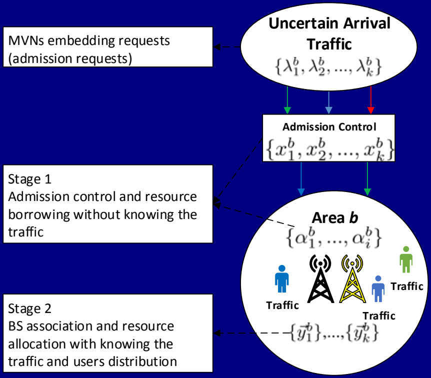

Figure 20: A two-stage MVN embedding mechanism including admission control, resource borrowing and resource allocation

· In the 1st stage, without knowing the exact traffic load request from MVNs, the InP conducts AC and resource leasing based on the estimated arrival traffic that are uncertain and provided by MVNs. Therefore, in the 1st stage, the system has to be able to tolerate this variance. Thus, we use the robust optimization technique to transfer the problem in the 1st stage to a convex problem that can be solved efficiently.

· In the second stage, the InPs will perform a traditional resource allocation. This stage can be considered as an extended stage of 1st stage after traffic arriving. As we consider multiple InPs in our model, this resource allocation includes radio resource allocation and BS association.

Implementation of MVNs admission control

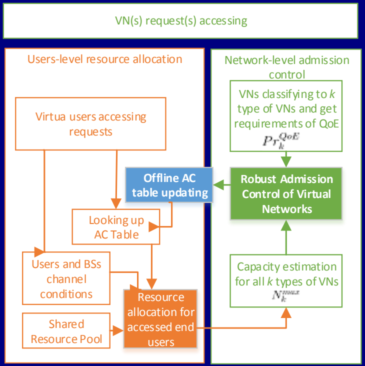

Figure 21

Simulation results

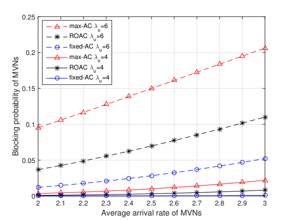

Figure 22: Blocking probability

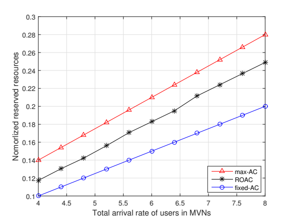

Figure 23: Resource efficiency

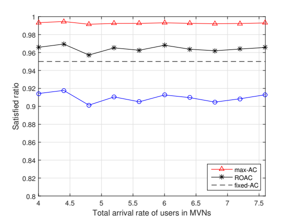

Figure 24: QoS

Outline

3 Recent research on SDN, NFV and caching in Carleton
- Virtual Mobile Network Admission Control
- To enable cache virtualization
- Dynamic caching in SDN-enabled mobile networks

Motivations

◇ On one hand, wireless network virtualization enables the sharing of not only the infrastructure, but also the content, among different service providers. Consequently, the capital expenses (CapEx) and operation expenses (OpEx) of content delivery, wireless access networks, as well as core networks, can be significantly reduced.

◇ On the other hand, virtual resource allocation (e.g., which nodes, links and resources should be selected and optimized) is a significant challenge of wireless network virtualization. As content retrieval (instead of other traditional parameters, such as spectrum efficiency) is put as a high priority in caching, the processes in wireless network virtualization (e.g., virtual resource abstracting, slicing, sharing, and control) will be significantly affected by in-network caching.

◇ Therefore, integrating wireless network virtualization with the in-network caching technique can significantly improve the end-to-end network performance.

Framework for cache virtualization

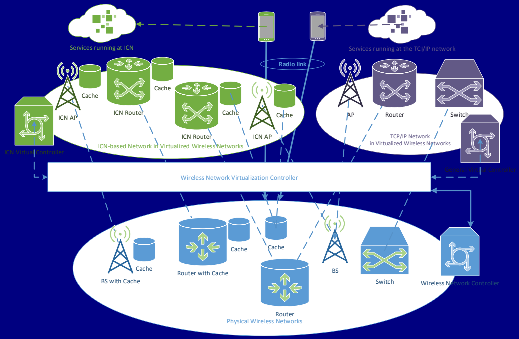

Figure 25: The architecture of our proposed cache-enabled wireless network virtualization. Here, the substrate physical wireless networks are virtualized into two virtual networks. One is running cache-enabled, while the other is based on traditional networks.

Cache slicing

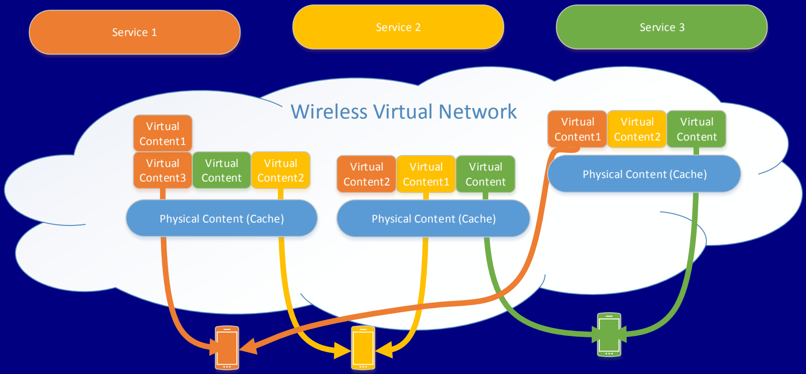

Figure 26: The framework of our proposed content-level slicing. Here, the physical content (cache) is sliced into virtual contents, which can be shared by different services dynamically.

Problem statement

We can formulate the virtual resource allocation and in-network caching strategy as the following joint optimization problem:

$$\max_{x_{ki}, y_{ki}, z_{kj}} \left\{ \sum_{k \in \mathcal{K},\, i \in \mathcal{I}} U_v \left(\mathbb{E} \left[Gain_{virtualization} \right] \right) + \sum_{k \in \mathcal{K},\, j \in \mathcal{J}} U_c \left(\mathbb{E} \left[Gain_{caching} \right] \right) \right\} \quad (1)$$

$$\begin{aligned} s.t. \quad & C1: \quad \textit{All the control variables } (x_{ki},\ y_{ki},\ \textit{and } z_{kj}) \textit{ are feasible} \\ & C2: \quad \textit{All users satisfy the requirements demanded by virtual resources} \end{aligned}$$

Simulation results

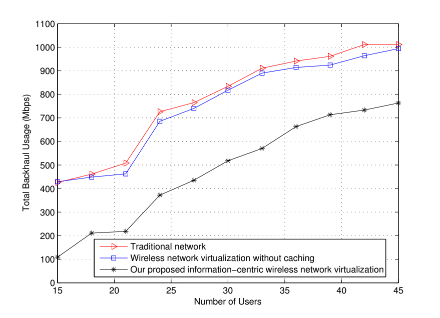

Figure 27: The backhaul usage in different schemes.

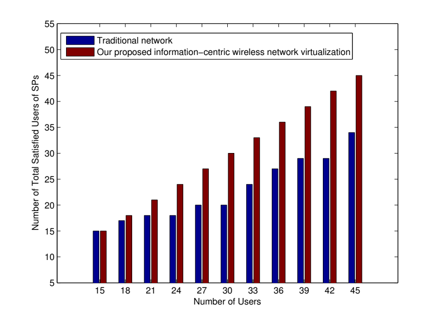

Figure 28: The number of total satisfied users of SPs.

Outline

3 Recent research on SDN, NFV and caching in Carleton
- Virtual Mobile Network Admission Control
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Background

◇ Future mobile networks (e.g., 5G) can benefit from *software-defined networking* (SDN) and *information-centric networking* (ICN).

◇ *Software-defined Mobile Networks* (SDMNs) in conjunction with the in-network caching shows great potential in future mobile networks.

◇ It is desirable for the network to follow the users, i.e., adapts its resource allocation to fulfill user demands (e.g., QoE).

◇ Effective utilization of the scarce resources (spectrum, APs, and cache).

Prior Art

Table 1: Video deliver and resource allocation on SDN and caching in mobile networks.

Resource allocation			Dynamic caching	Video deliver
Radio resource	SDN	ICN		
Yes	Yes	Null	Null	Null
Yes	Yes	Null	Null	Yes
Yes	Null	Yes	Null	Null
Null	Null	Yes	Yes	Null
Yes	Null	Yes	Yes	Null
Null	Yes	Yes	Null	Yes
Yes	Null	Yes	Null	Yes

Motivations

◇ Most of current research on the deployment of in-network caching in mobile networks assumes that the data distribution is static and fixed during research time.

◇ Few developed content distribution (caching strategies) algorithms take the real-time mobile network and traffic status into account

◇ Wireless acess points (APs) in RANs, such as macro base stations (MBSs), Pico BSs (PBSs) and small BSs (SBSs) may only have limited storage capacity.

◇ In order to achieve efficient utilization of caches, a traffic-user-aware mechanism is necessary to dynamically prefetch data in caches of APs received from the SDN controller.

Network elements

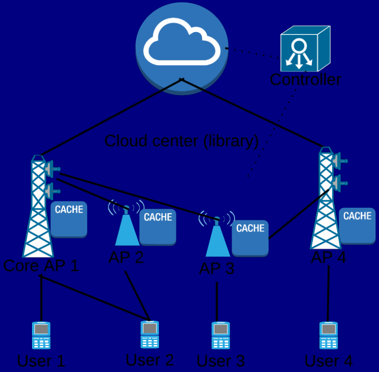


Figure 29: Network architecture of the cache-enabled SDMN.

Problem Statement I

◇ **Assumptions**

· A HetNet with N cache-enabled BSs and the central SDN controller.

· The backhaul deploys wired links.

· U users request video flows with required data rate.

· The central controller stores S_0 contents.

· Each node n stores S_n piece of contents.

· The probability that the user u is served by the node n after a certain time period δ is known.

◇ **Objective**

· Maximizing a weighted sum of the hitting rates.

· Maximizing a log-based weighted sum of the hitting rates.

◇ **Variables**

· Data rates (source,routes)

· Dynamic caching indicator

· Video resolution indicator

Problem Statement II

Table 2: vMOS of video resolutions.

q	resolution	Required data rate v_q	resolution vMOS g_q
1	4k or more	25 Mbps	4.9
2	2k	12 Mbps	4.8
3	1080p	10 Mbps	4.5
4	720p	5 Mbps	4
5	480p	2 Mbps	3.6
6	360p	1.5 Mbps	2.8

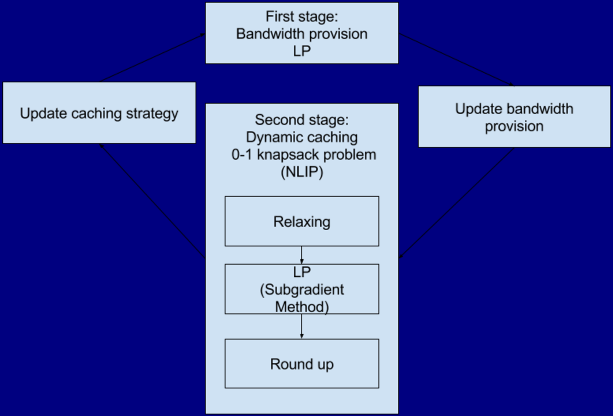
Problem Statement III

- **Constraints**
  - The flow conservation law (traffic engineering).
  - Backhaul limitations.
  - Spectrum limitations.
  - The minimum data requirement.
  - Cache storage limitations.
  - Non-negativity of variables.
  - Binary variables.
- **Difficulties**
  - Non-convex.
  - NP-hard.
  - Large scale.

Description of the proposed scheme I

- **Dual decomposition**
  - The bandwidth provisioning can be separated from the dynamic cache placing.
  - **An iterative two-stage algorithm**.
- **Bandwidth provisioning with video resolution adaptation**.
  - A linear integer problem.
- **Dynamic cache placing**.
  - 0-1 knapsack problem.
  - Non-linear integer problem (NLIP).

Description of the proposed scheme II



Description of the proposed scheme III

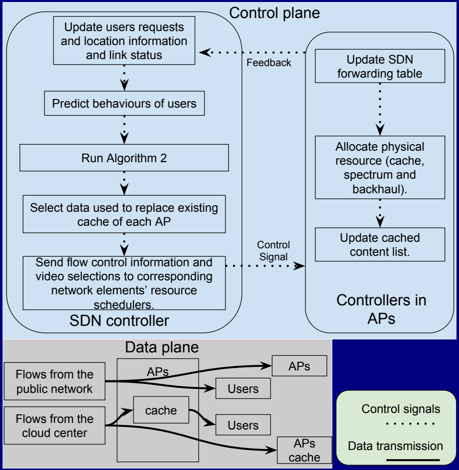


Figure 30: Flow diagram approach to proposed cache-enable flow control in SDMN.

Description of the proposed scheme IV

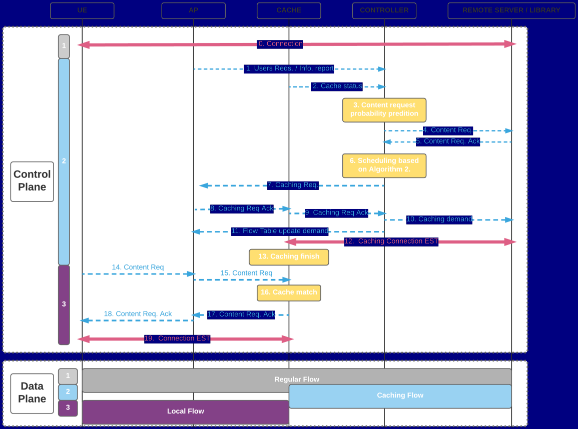
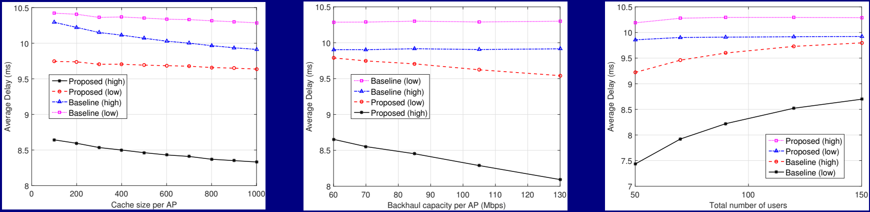


Figure 31: Dynamic caching signaling



(a) Cache capacity (b) Backhaul bandwidth (c) Network load

Figure 32: Impacts of network parameters on delay.

Outline

Challenges

◇ **Isolation**

◇ **Control signaling**

◇ **Resource discovery and allocation**

◇ **Mobility management**

◇ **Network management**

◇ **Security**

◇ **etc.**

Broader Perspectives

◇ **Cognitive radio**

◇ **Energy efficiency**

◇ **Cloud computing**

◇ **Mobile edge computing**

◇ **V2X networking**

◇ **etc.**

Q & A

Thank you

SDNizing mobile networks

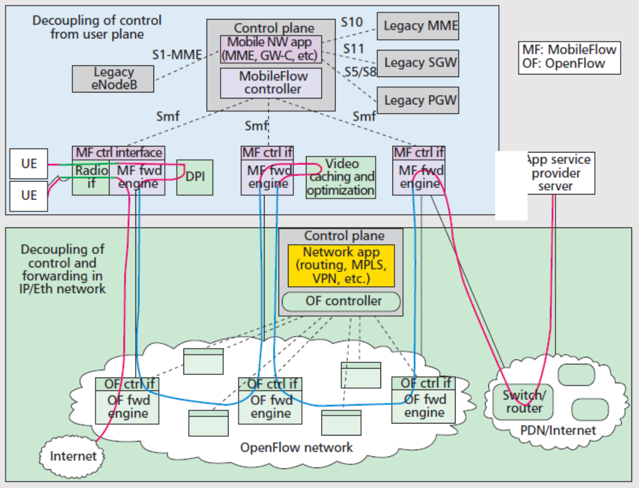


Figure 33: Software-defined mobile network at Huawei[19]

[19] K. Pentikousis, Wang Yan, and Hu Weihua. "Mobileflow: Toward software-defined mobile networks". In: *IEEE Commun. Mag.* 51.7 (2013), pp. 44 –53.