PhD Thesis Defense

Performance Improvements in Software-defined and Virtualized Wireless Networks

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Outline

- Motivations and Challenges
  - Network transformation in next generation wireless networks
  - Integration of new networking technologies
- Background on Theoretical Tools
- Completed Works
  - Virtual Resource Allocation and Caching
  - Robust Admission Control of VNs
  - Enhancing QoE-aware Caching in SDWNs
  - Enhancing Video Rate Adaptation in SDWNs
- Conclusions and Future Works

Motivations and Challenges

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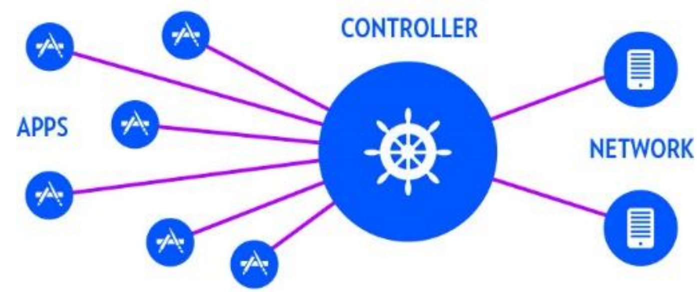
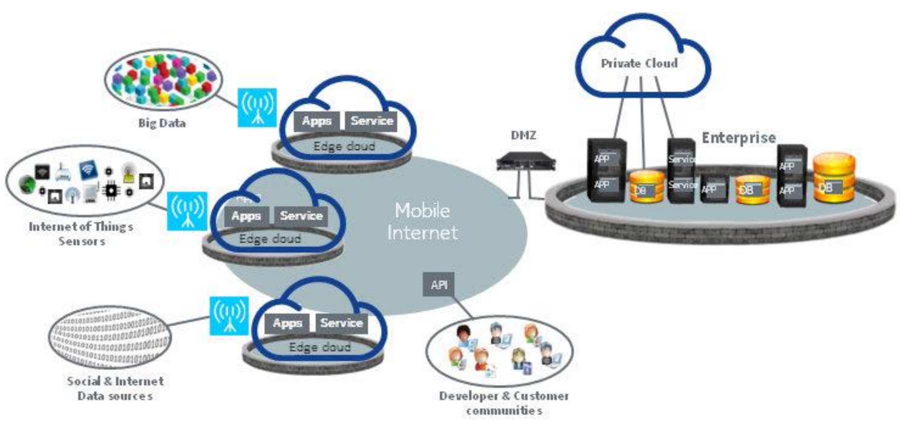
- Network transformation in next generation wireless networks

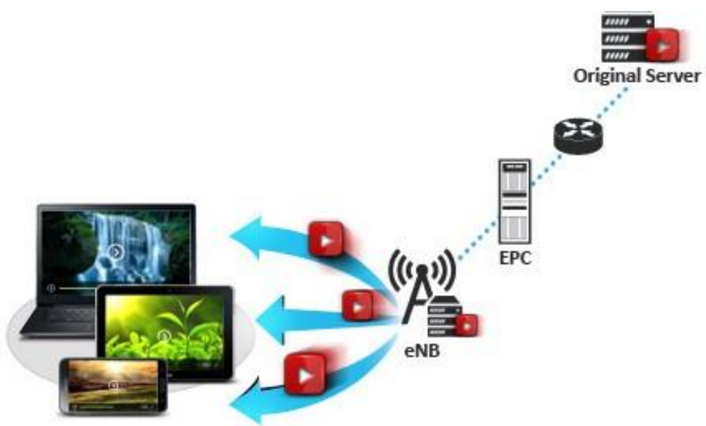
Wireless network virtualization



Software-defined wireless network



Mobile edge computing



In-network caching

Motivations and Challenges

- Enhance performance of delivering content by integrating of Caching and Computing with Virtualization and SDN
  - Efficiency of network resources
    - Spectrum
    - Backhaul
    - Cache
    - Computing
  - Utility of network operator
  - QoS of VNs (admission control)
  - QoE (Quality and latency)

In-network Caching

	Virtual Networks	SDWN	MEC
Caching strategies	Chapter 2	Chapter 4	Chapter 5
Spectrum allocation	Chapter 2	Chapter 4	Chapter 5
Backhaul allocation	Chapter 2	Chapter 4	Chapter 5
Traffic engineering	Chapter 3	Chapter 4	Chapter 5
Admission control	Chapter 3		
Data rate	Chapter 2, 3		
Operator Utility	Chapter 2, 3		
QoE-aware		Chapter 4	Chapter 5

Background on Theoretical Tools

- Summaries on theoretical tools
  - Effective algorithms
    - **Convex optimization**
  - Distributed
    - Large scale networks
    - **Alternating Direction Method of Multipliers (ADMM)**
    - Chapters 2 and 5
  - Uncertainty
    - Arrival rate of virtual networks and traffic are not fixed
    - **Robust optimization (RO)**
    - Chapter 3
  - Decomposition
    - Caching strategies, computing scheduling and bandwidth provisioning are hard to be controlled at the same time.
    - **Dual-decomposition**
    - Chapters 4 and 5

Virtual Resource Allocation and Caching

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Select the physical resource to satisfy virtual network requests and cache resource to save backhaul resource.

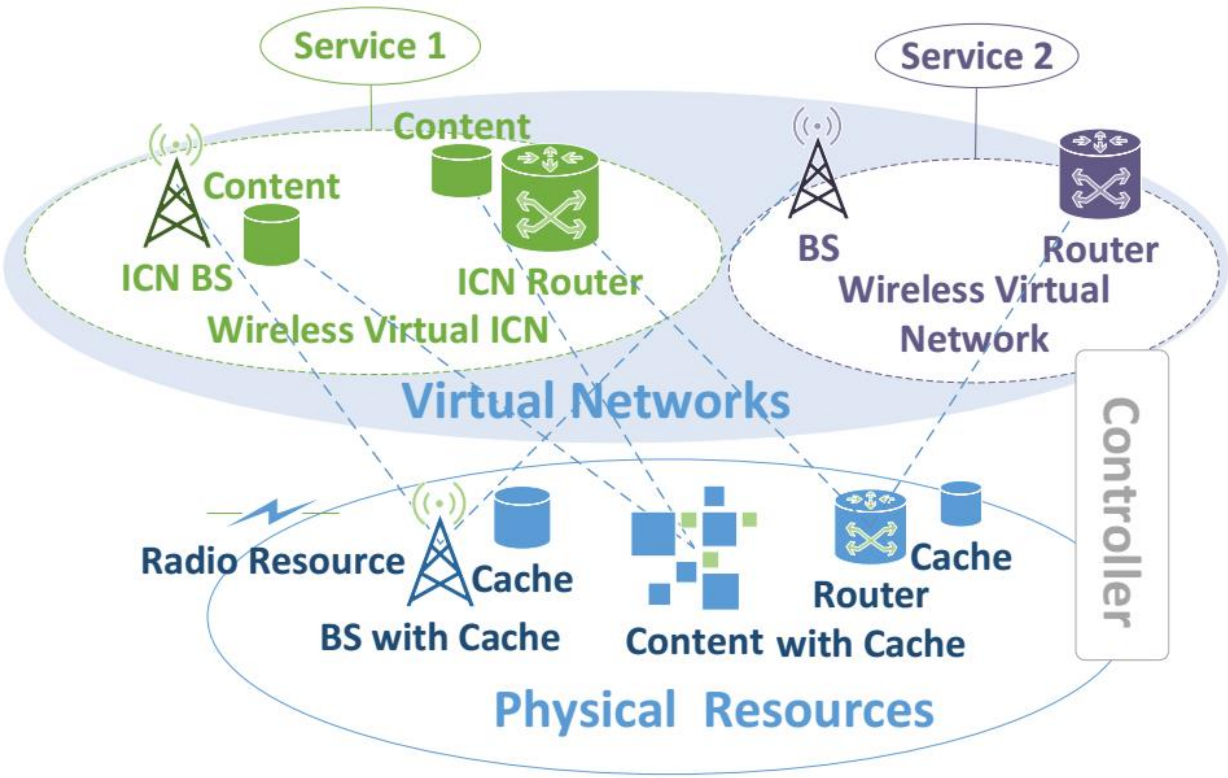
- Virtualization in wireless networks
  - Embed a virtual wireless network on physical networks
    - Selecting node, links, resources
    - Satisfying requirements of virtual networks (VNs)
  - Cross infrastructure providers
  - Large scale networks
  - Multiple criterions

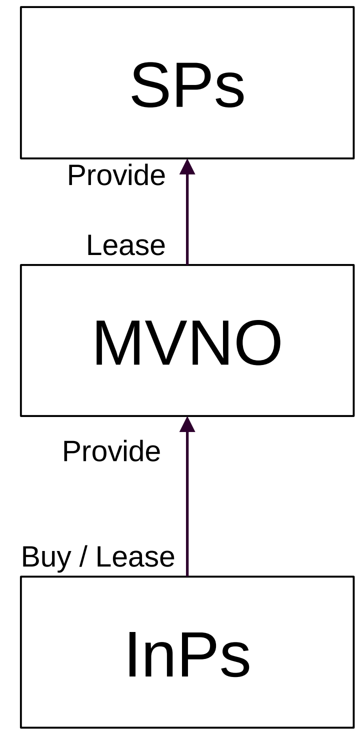
- In-network caching in wireless networks
  - Where to cache: Node selection
  - What to cache: Content selection

- Most of current works address them separately

Virtual Resource Allocation and Caching

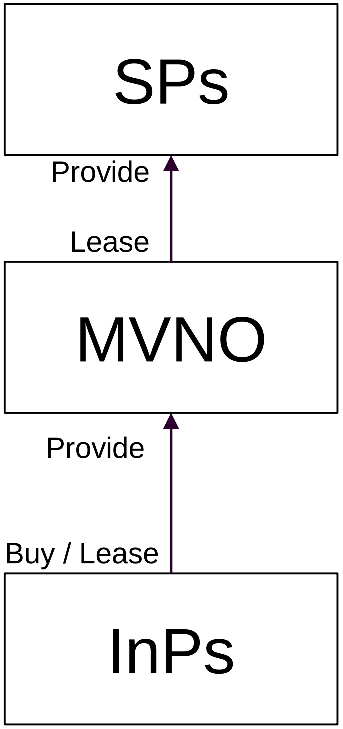
- Framework





Virtual Resource Allocation and Caching

- Problem
  - Objective: Maximizing the utility of mobile virtual network operators (revenue from SP- cost from leasing infrastructure).
  - Variables:
    - Base stations association
    - Spectrum and backhaul
    - Cache strategy indicator
      - Decided to cache the content or not.
  - Constraints:
    - Physical resource limitations (local)
    - Single association (global)
    - SP-wise data rate requirements (local)



Virtual Resource Allocation and Caching

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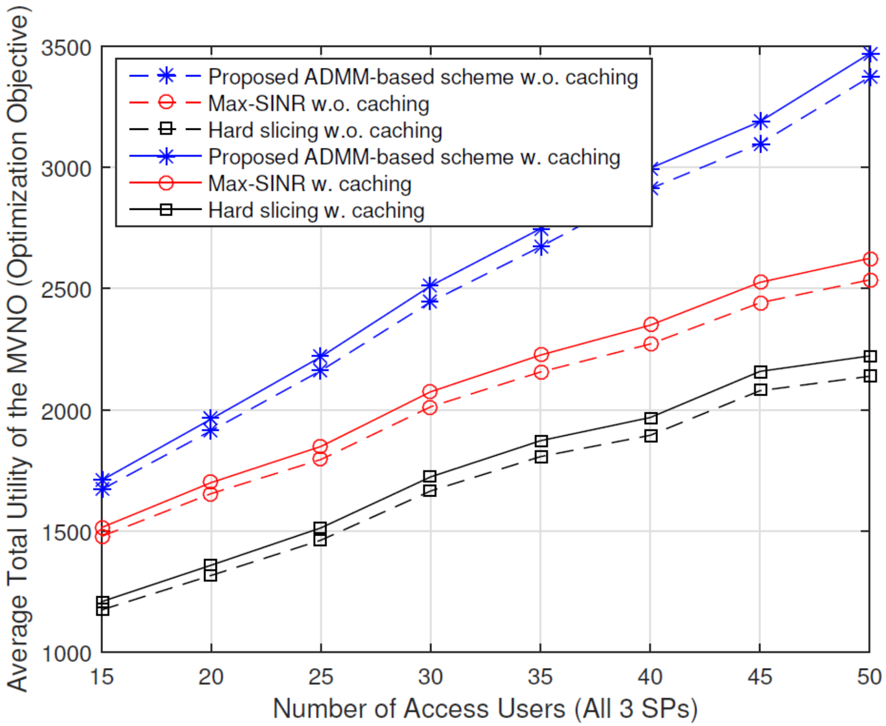
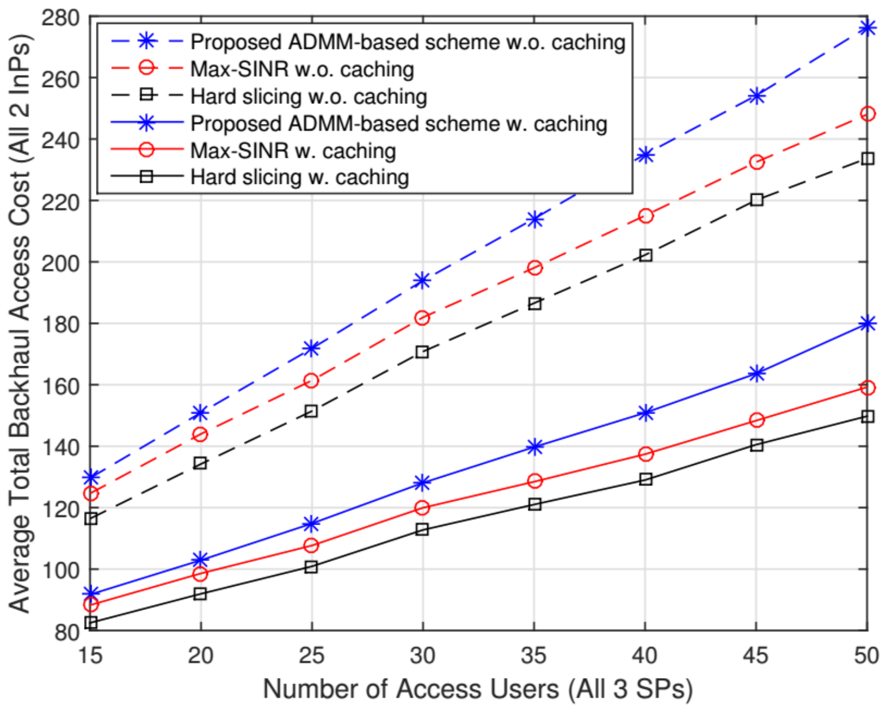
- Challenges and Solutions:
  - Caching benefits
    - Define caching benefits as potential saved backhaul (congestion, latency)
  - Non-convex feasible sets and objective function
    - Relaxing the binary variables to real numbers => round-up => small gap.
    - Transfer the problem to a equivalent convex optimization problem
  - Large number of nodes => centralized method is impossible
    - Deploy ADMM to distributed solve problem in each BS.
    - ADMM = Decomposition method + Augmented Lagrange method
      - Fast convergence, accurate and easy

Decoupling the problem to sub-problems => solving local variables => giving opinion of global variables => solving global variable (minimize differences).

Information exchange only includes BS association, which is just binary sequence.

Virtual Resource Allocation and Caching





Robust Admission Control of VNs

Limiting the number of VNs embedded in the physical network

- Admission control of VNs
  - Guarantee QoS
  - Maximize the utilization
  - Uncertain traffic
  - Resource reservation
  - Uncertain demand

- VN admission control has not been well studied in the literature

Robust Admission Control of VNs

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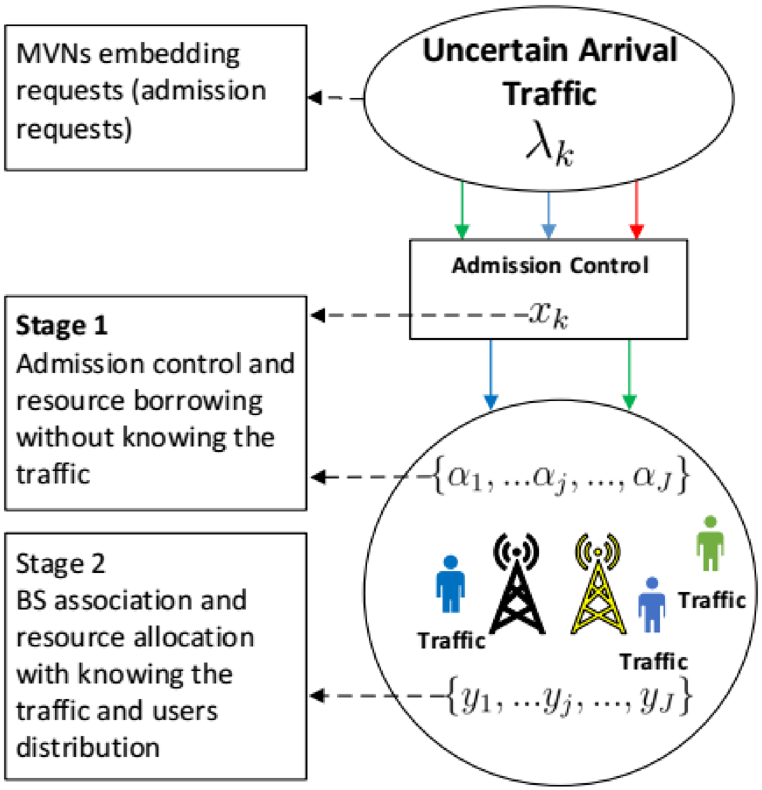
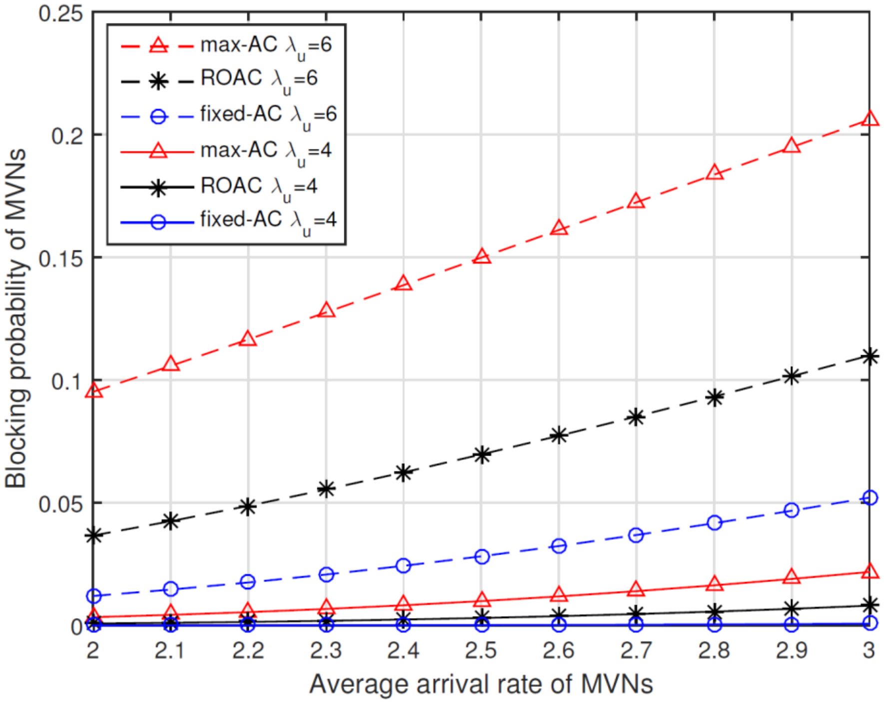
- Problem
  - Objective: Maximizing the utility of mobile virtual network operators (revenue from SP- cost from leasing infrastructure).
  - Variables:
    - Large scale:
      - Admission control (AC)
      - Resource leasing (RL)
    - Small scale:
      - Bandwidth provisioning
  - Constraints:
    - Physical resource limitations
    - Data rate requirements
    - Stability

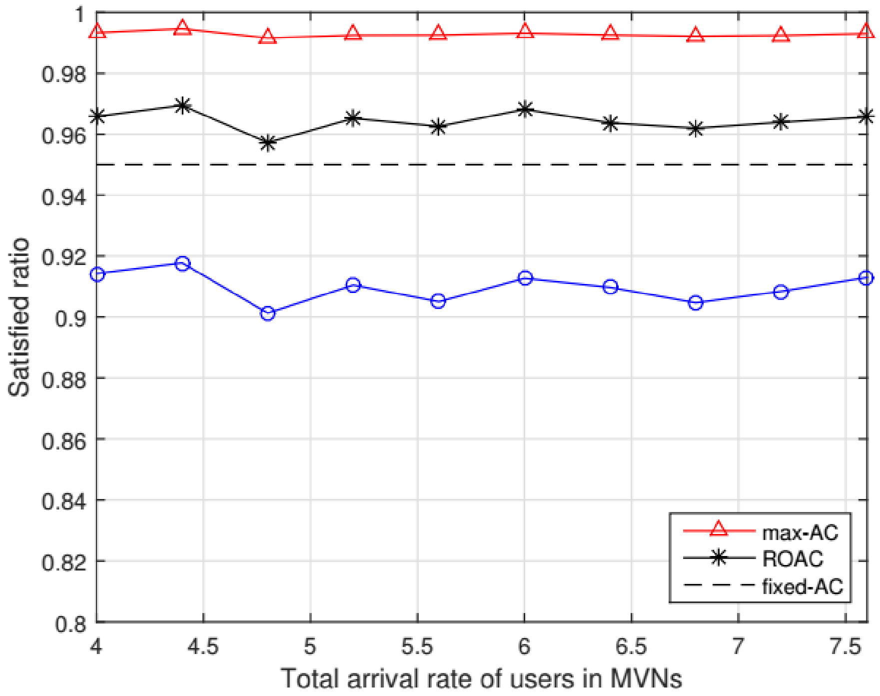
Robust Admission Control of VNs

- Challenges and Solutions:
  - Different optimization levels
    - 2-stage control with the feedback adjustment
      - 1st stage: AC and resource leasing (reservation)
      - 2nd stage: bandwidth provisioning and resource allocation
  - Uncertain traffic and demand
    - 1. hard guarantee (worst case) => waste resource
    - 2. soft guarantee => how to tolerate the uncertainty => Non-convex
    - Robust optimization => safe reservation => convex optimization problem



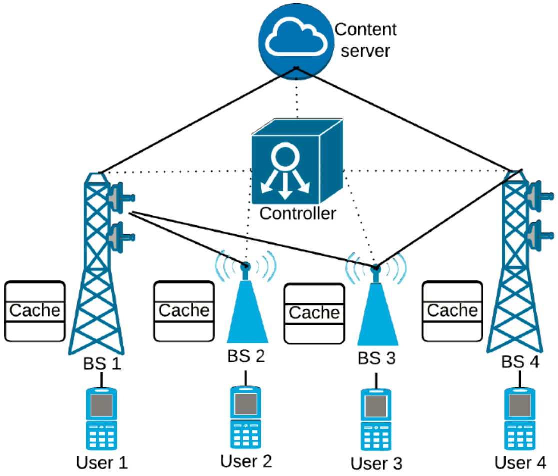
Robust Admission Control of VNs





Enhancing QoE-aware Caching in SDWNs

Cache the most appropriate content to BSs to increase the hitting rate and reduce the access delay.



- Dynamic in-network caching
  - Users mobility: a predicted pattern
  - Limited backhaul
- SDWNs
  - Directs traffic easily
    - Traffic engineering
      - Bandwidth provisioning
- QoE of Video
  - Buffer management
  - Resolution selections
- Most of current works address them separately

Enhancing QoE-aware Caching in SDWNs

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- Problem
  - Objective: Maximizing the average utility of caching content in BSs based on predicted mobility of users.
    - We assume that we know the probability of that a user will be served by a BS.
  - Variables:
    - Caching strategies
    - Bandwidth provisioning
    - Video resolution
  - Constraints:
    - Physical resource limitations (spectrum and backhaul)
    - Average QoE requirement

Enhancing QoE-aware Caching in SDWNs

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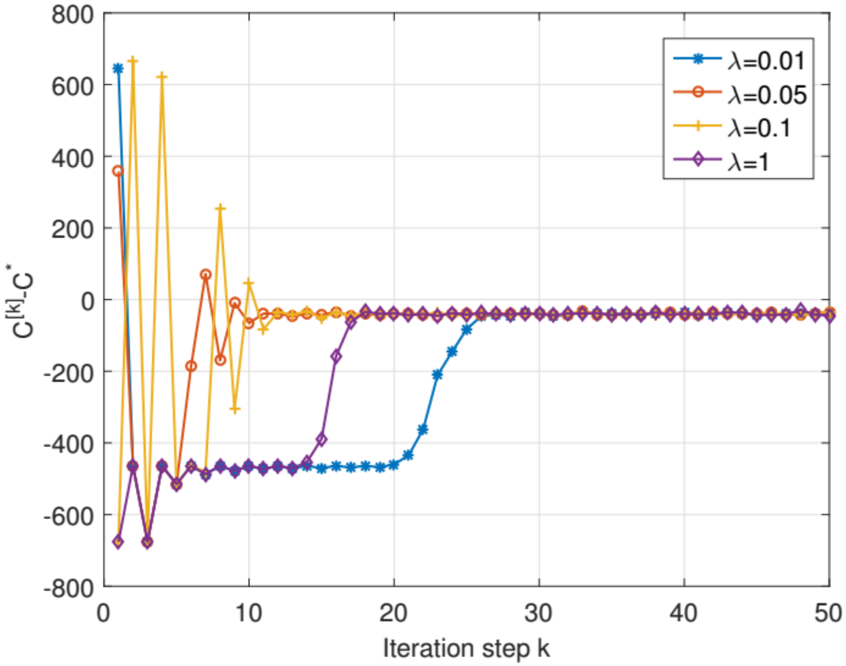
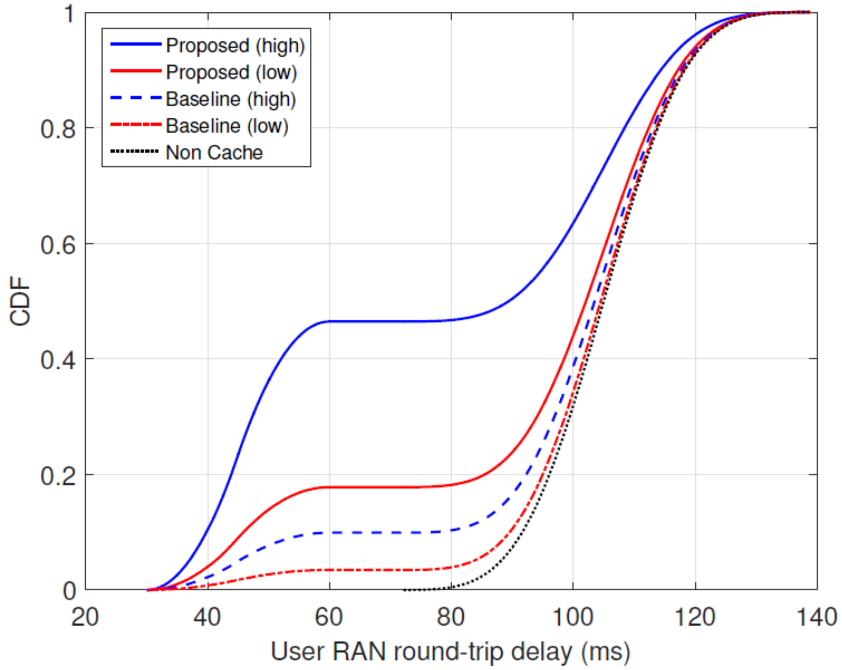
- Challenges and Solutions:
  - Cache, video rate, flows bandwidth are decided by different layers and perform in different time scales.
  - Dual-decomposition to decouple cache from other two variables
    - Joint optimization of video rate are flows bandwidth are traditional cross-layer design.
  - A low complexity algorithm to solve the dynamic caching problem
    - a non-convex problem =>
    - Relax it to convex problem =>
    - Closed-form by using Lagrange method (KKT conditions) =>
    - Rounding Methods Based on Marginal Benefits
    - Small gap

Enhancing QoE-aware Caching in SDWNs

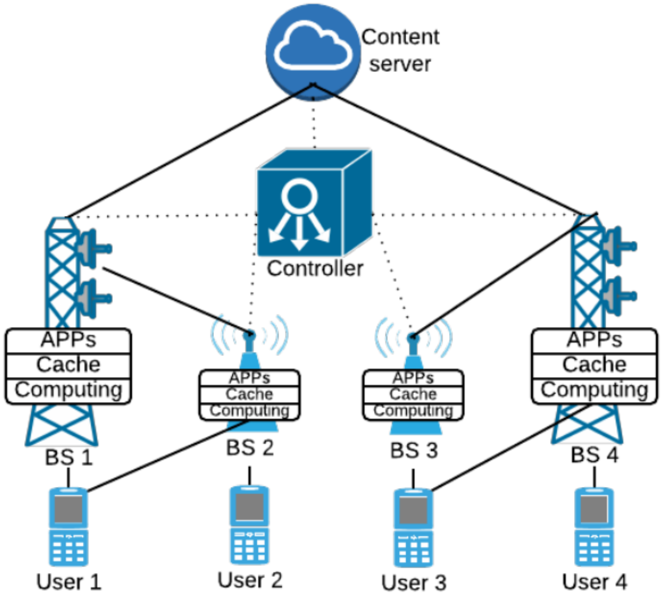




Enhancing Video Rate Adaptation in SDWNs

Let the network help to select the content and deliver method

- Get the content?
  - Caching
  - Source servers
  - BSs
- Get the preferred version of content?
  - MEC to process
  - Get it from server
- SDWNs
  - Traffic engineering
  - Bandwidth provisioning
  - Multiple source

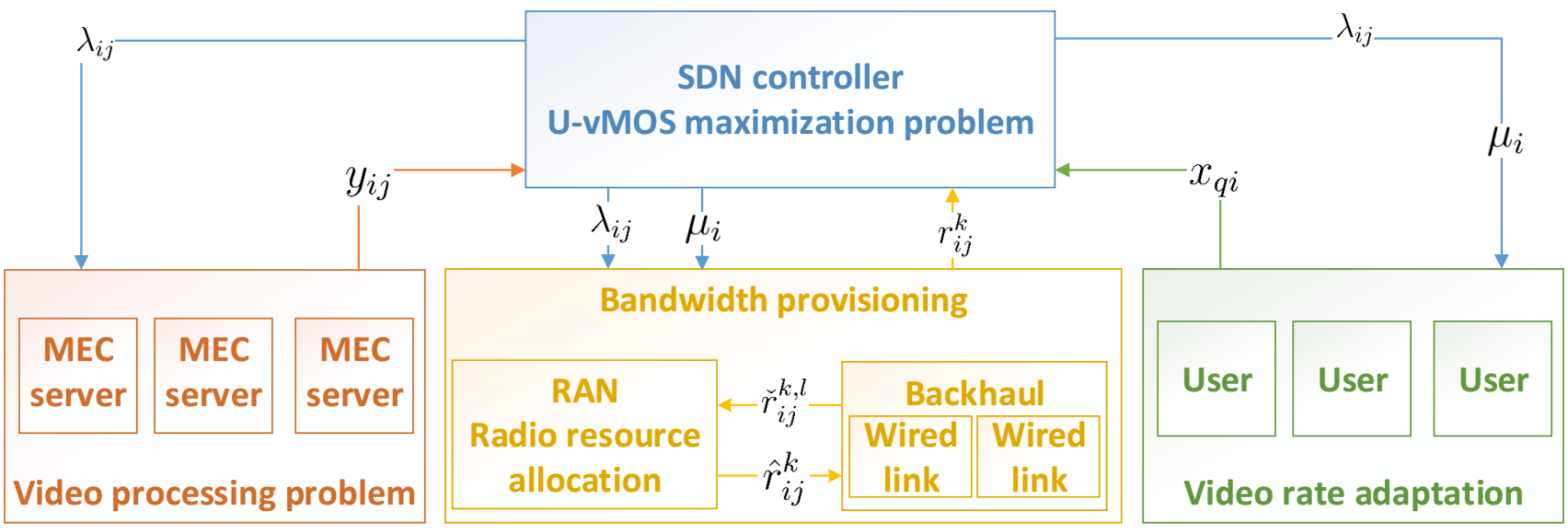


Enhancing Video Rate Adaptation in SDWNs

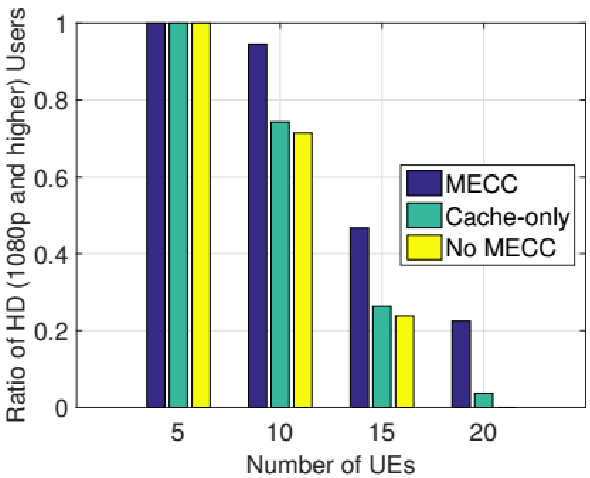
- Problem
  - Objective: Maximizing the average U-vMOS (video resolution) of the network
    - U-vMOS is a modified mean opinion score
  - Variables:
    - Source selection
    - Bandwidth provisioning
    - Video resolution
  - Constraints:
    - Physical resource limitations (computing, spectrum and backhaul)
    - Average QoE requirement

Enhancing Video Rate Adaptation in SDWNs

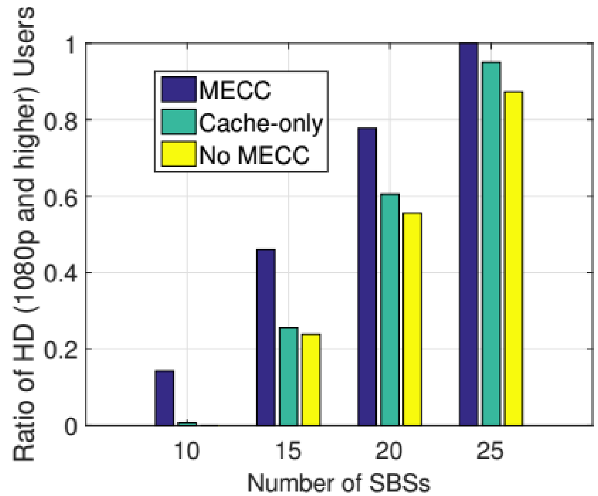
- Challenges and Solutions:
  - Computing, video rate, flows bandwidth are decided by different layers and perform in different time scales.
    - Dual-decomposition to decouple all of them.
  - Low complexity algorithm
    - Distributed by ADMM



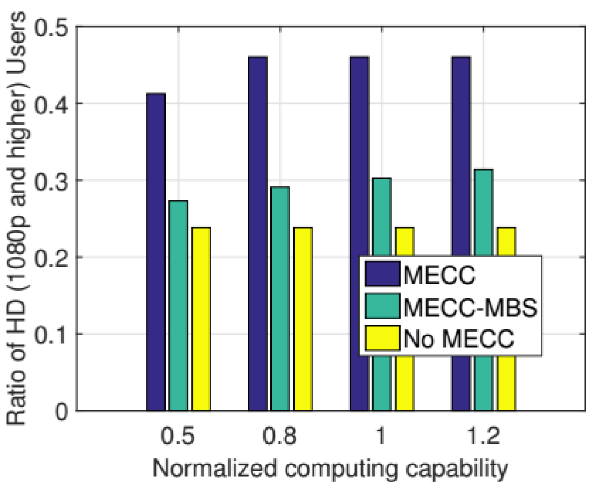
Enhancing Video Rate Adaptation in SDWNs



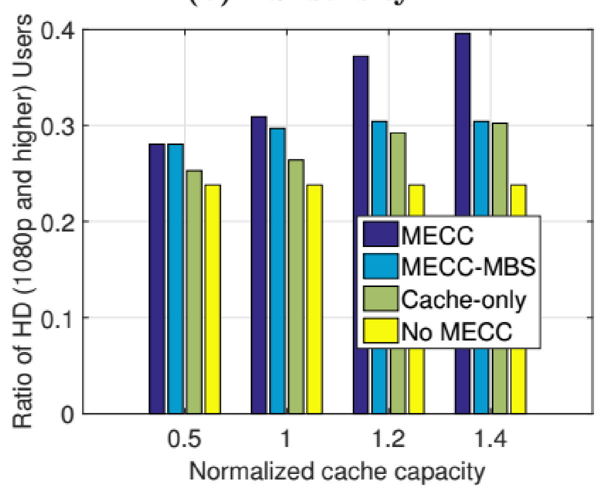
(a) Network load



(b) BS density



(c) Computing resource



(d) Cache storage capacity

Conclusions and Future Works

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- In this dissertation, we investigate performance improvements in software-defined and virtualized wireless networks with advanced convex optimization techniques

- Future works
  - Energy-efficient techniques
  - Advanced power allocation schemes and massive MIMO
  - Ultra-reliable low latency communication
  - Leverage telecommunications with AI

Pulications

- **Journal**

1. C. Liang and F. R. Yu. Enhancing QoE-aware mobile edge caching with bandwidth provisioning in software-defined mobile networks. *Submitted to IEEE Transactions on Wireless Communications*, 2016..

2. C. Liang, F. Yu, H. Yao, and Z. Han. Virtual resource allocation in information-centric wireless virtual networks. *IEEE Transactions on Vehicular Technology*, PP(99):1–1, 2016.

3. Y. Cai, F. R. Yu, C. Liang, B. Sun, and Q. Yan. Software-defined device-to-device (D2D) communications in virtual wireless networks with imperfect network state information (NSI). *IEEE Transactions on Vehicular Technology*, 65(9):7349–7360, Sept. 2016..

4. C. Liang and F. R. Yu. Wireless network virtualization: A survey, some research issues and challenges*.* *IEEE Communications Surveys Tutorials*, 17(1):358–380, Firstquarter 2015.

5. C. Liang and F. R. Yu. Wireless virtualization for next generation mobile cellular networks. *IEEE Wireless Communications*, 22(1):61–69, Feb. 2015..

6. C. Liang, F. R. Yu, and X. Zhang. Information-centric network function virtualization over 5G mobile wireless networks*.* *IEEE Network*, 29(3):68–74, May 2015.

Pulications

- **Conference**

    1. C. Liang and F. R. Yu. Enhancing qoe-aware mobile edge caching with bandwidth provisioning in software-defined mobile networks. Submitted to *2017 IEEE International Conference on Communications (ICC)*, 2016.
    2. C. Liang and F. R. Yu. Bandwidth provisioning in cache-enabled software-defined mobile networks: A robust optimization approach. In *Proc. IEEE 84rd Vehicular Technology Conference (VTC Fall)*, pages 1–5, Sept. 2016.
    3. C. Liang and F. R. Yu. Mobile virtual network admission control and resource allocation for wireless network virtualization: A robust optimization approach. In *Proc. IEEE Global Communications Conference (GLOBECOM)*, pages 1–6, Dec. 2015.
    4. C. Liang and F. R. Yu. Virtual resource allocation in information-centric wireless virtual networks. In *Proc. IEEE International Conference on Communications (ICC)*, pages 3915–3920, June 2015
    5. C. Liang and F. R. Yu. Distributed resource allocation in virtualized wireless cellular networks based on ADMM. In *Proc. IEEE Conference on Computer Communications Workshops (INFOCOM WKSHPS)*, pages 360–365, Apr. 2015.
    6. Y. Cai, F. R. Yu, and C. Liang. Resource sharing for software defined D2D communications in virtual wireless networks with imperfect NSI. In *Proc. IEEE Global Communications Conference (GLOBECOM)*, pages 4448–4453, Dec. 2014.

- **Patent application**

    1. Chengchao Liang, F. Richard Yu, Ngoc Dao, Senarath Gamini and Hamid Farmanbar, “Data prefetching in mobile networks”, Filed by Huawei, Canada, *US provisional patent application no: 85194217US01*, application date: 30 Nov. 2016.

Thank you!