Performance Improvements in Software-defined and Virtualized Wireless Networks

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Outline

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  - Integration of new networking technologies

- Background on Theoretical Tools

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  - Robust Admission Control of VNs
  - Enhancing QoE-aware Caching in SDWNs
  - Enhancing Video Rate Adaptation in SDWNs

- Conclusions and Future Works
Motivations and Challenges

• 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)

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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

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

[Diagram showing virtual networks and physical resources, with labels for SPs, MVNO, InPs, and their interactions through provides and leases.]
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

- **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 an 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

- **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

• 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

• **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
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
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

• 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


Pullications

**Conference**


**Patent application**

Thank you!