Towards Wireless Infrastructure-as -a-Service (WIaaS) for 5G Software-Defined Cellular Systems

Albert Gran, Shih-Chun Lin, and Ian F. Akyildiz

Broadband Wireless Networking Laboratory
School of Electrical and Computer Engineering
Georgia Institute of Technology

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Outline

- Motivation
- Wireless Infrastructure-as-a-Service (WIaaS) as a key enabler for Next Generation 5G Cellular Systems
- Architecture Definition and Problem Statement
- Implementing WIaaS: Resource efficient Scheduling with Fairness support
- Performance Evaluation
- Conclusions and Future Challenges

Motivation

The forthcoming next generation 5G of cellular systems is envisioned to provide:

1. Higher data rates
2. Lower end-to-end latencies
3. Enhanced quality of service (QoS) for end users
4. Exponential growth of multimedia applications, service diversity and RATs

- **Software-Defined Networking as the new paradigm:** Achieving more scalable, resilient and flexible architectures to face these challenges.

Cloudification and Virtualization key technologies in that change

However,

- **Wireless virtualization** still has an **enormous potential** to be exploited
  - Powerful framework for high-level resource utilization
  - Optimizing resource scheduling taking advantage of SDN-centralized network view
  - Can consider multiple radio access technologies
  - Reduces CAPEX and OPEX, and facilitates new technology development

Proposing Wireless Infrastructure-as-a-Service

Active and dynamic sharing of wireless resources in which **service providers lease the wireless infrastructure:**

- According to the **instantaneous demands of their subscribed users**
- Wireless hardware infrastructure **offered as a service rather than a physical asset**
- Ability to control, optimize and customize the underlying resources
- **Paying only for resources used. No need to predict usage**. Cost-efficient operations

"Network" deciding and assigning resources to the leasers for the best performance of the whole network considering:

- QoS requirements for all service providers globally optimized without interfering each other's operations and performance
- Different network capabilities integrated and deployed over the same network infrastructure
- Maximizing utilization of limited resources of the network

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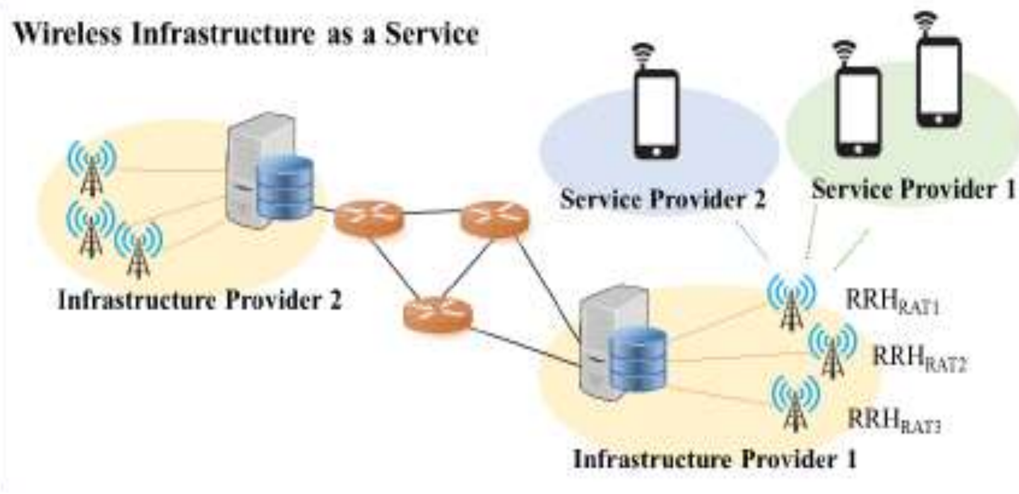
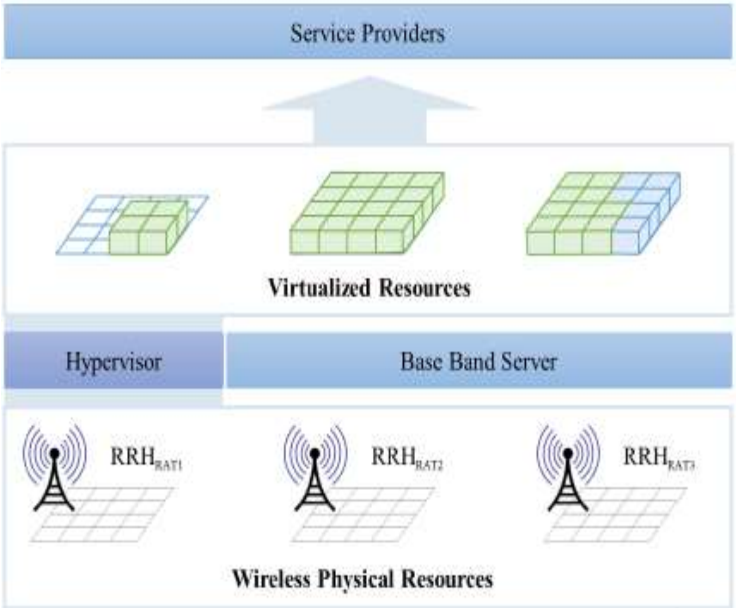
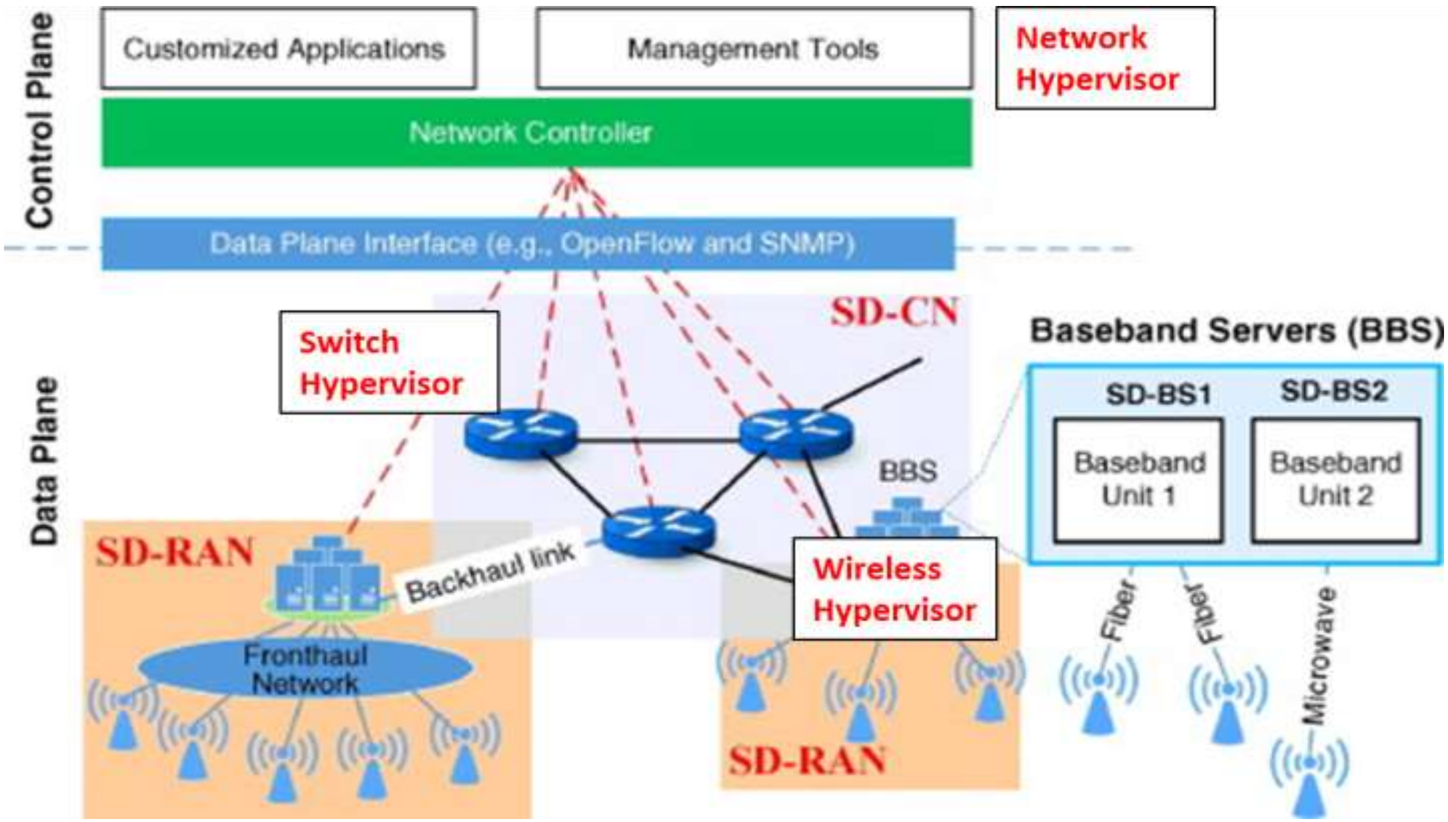




System Model

End-to-End virtualization through SoftAir: Software-Defined Networking for 5G Cellular Systems



SoftAir: A software defined networking architecture for 5G wireless systems. *Computer Networks*, *85*, 1-18
Akyildiz, I. F., Wang, P., & Lin, S. C. (2015).

System Model

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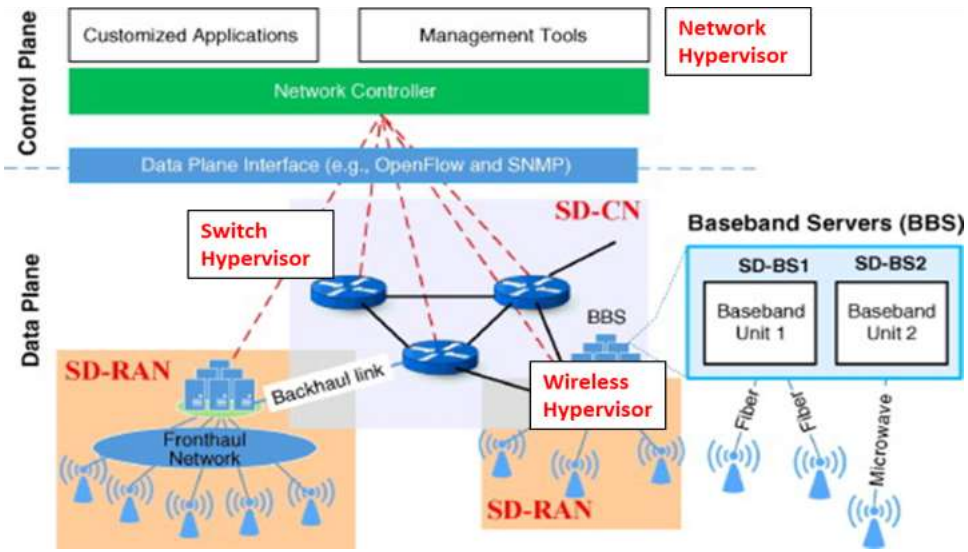


The **Network Hypervisor** determines the optimal resource allocation at each moment taking advantage of the whole view of the network, not only for the wired core network but also for the physical wireless infrastructure.

The **Wireless Hypervisor** is a low-level resource scheduler in the SD-BSs, which:

- Executes the policies of the network hypervisor
- Dynamically virtualizing the physical network, assigning wireless resources to the service providers

Problem Statement

- **Objective:** Optimize the allocation of non-conflicting network resource blocks among virtual network operators based on their demands and maximizing the global resource utilization.

- **Considered Scenario (1 SD-BS, Downlink):**

Implementing WIaaS: Resource efficient Scheduling with Fairness support

Every flow can transmit more or less information in the same RB depending on the instantaneous channel condition of its user

- **Profit:**
  - Throughput required: That each flow needs to transmit satisfying the specified QoS
  - Throughput provided by the channel: Depends on the channel conditions of the users

$$R_f = Arrival\_rate_f \cdot TTI;$$

$$Th\_required_f = \frac{R_f}{QoSDelay_{max,f}},$$

Assuming instantaneous CQI reports:

$$Th\_provided_f \cdot TTI = \sum_{r=1}^{RB} i_{r,f} \cdot Data\_provided_{r,f}$$

$$\text{s.t.} \quad \sum_{f \in F} \sum_{r \in RB} i_{r,f} \leq RB\_BW,$$

$$PF_f\,(\%) = \begin{cases} \frac{Th\_required_f}{Th\_provided_f} \cdot 100 \\ 0 \ \text{ if } \sum_{r=1}^{RB} i_{r,f} = 0 \end{cases}.$$

$$\max_{i_{r,f}} \ \frac{1}{F} \sum_{f \in F} PF_f$$

$$\text{s.t.} \quad PF_f \leq 100, \quad \forall f \in F.$$

Best allocation is **the one mapping the RB's to the flows taking the most profit from the channel limited resources at each moment**.

Maximizes resource-efficiency and satisfies data rate requirements of the flows.

Implementing WIaaS: Resource efficient Scheduling with Fairness support

One of the main requirements of wireless virtualization is isolation: Changes in one virtual network does not affect behavior of neighbors.

- **Fairness Index:**
  - Historical record of the profit obtained by each flow, stored and updated at each scheduling decision
  - Controlling the impact of each instance on the network: Giving priority to flows with low fairness-index.
  - Extended to user and slice (virtual network) level. What if paying more?

$$FI_f(d) = \frac{FI_f(d-1) \cdot D_{d-1} \; + \; PF_f(d)}{D_d},$$

$$\begin{aligned} \max_{t_{r,f}} \quad & \sum_{f \in F} PF_f \\ \text{s.t.} \quad & PF_f \leq 100 \quad \forall f \\ & \varphi_1 \leq FI_{u,f,s} \leq \varphi_2 \quad \forall u, f, s \end{aligned}$$

- **Power:**
  - Current cellular systems distribute power uniformly among used resources.
  - Power should be another variable to take into account when optimizing
  - Throughput depends on power and power on throughput: 2-steps iteration

Implementing WIaaS: Resource efficient Scheduling with Fairness support

- **Power 2-steps iteration:**
  - Using the channel conditions, data rate requirements and power available of the base-station.
  - Re-distributing power for the satisfaction of not only data rate, but also SNR requirements.

Performance Evaluation

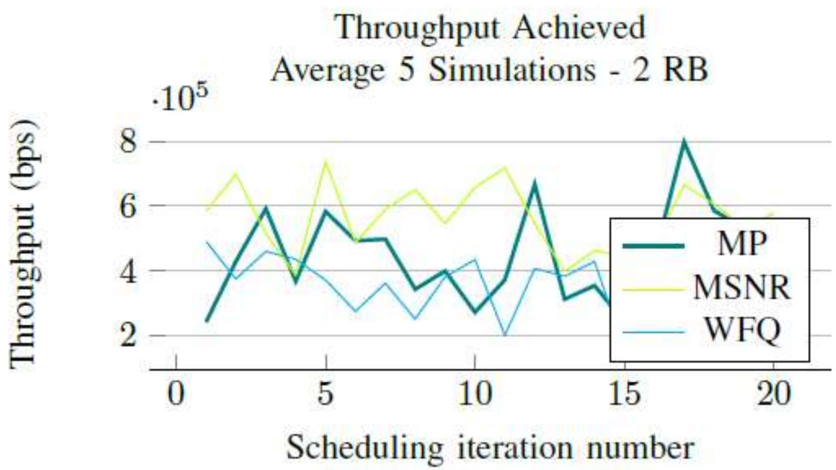
Throughput-efficiency Assessment

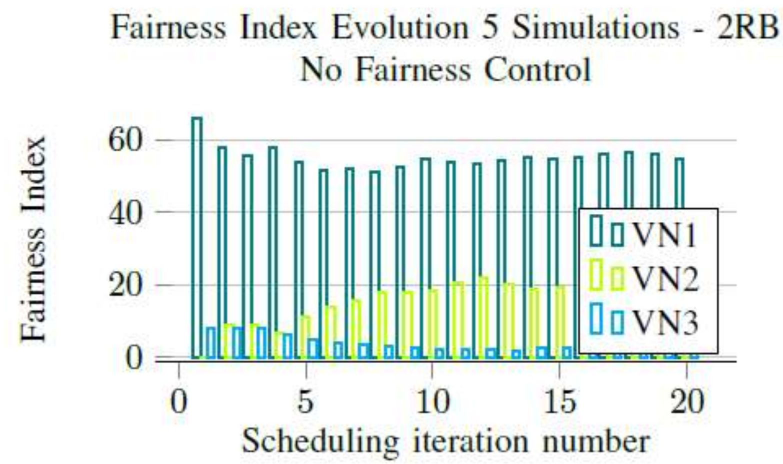
- Comparing it to existing designs which user Maximum SNR and WFQ
- Non of them still adapted to wireless flow-level granularity
  - MSNR: The flow combination with best channel conditions
  - WFQ: Fraction relating flow throughput required with sum of all throughput demands. Progressive recursion to match RBs size

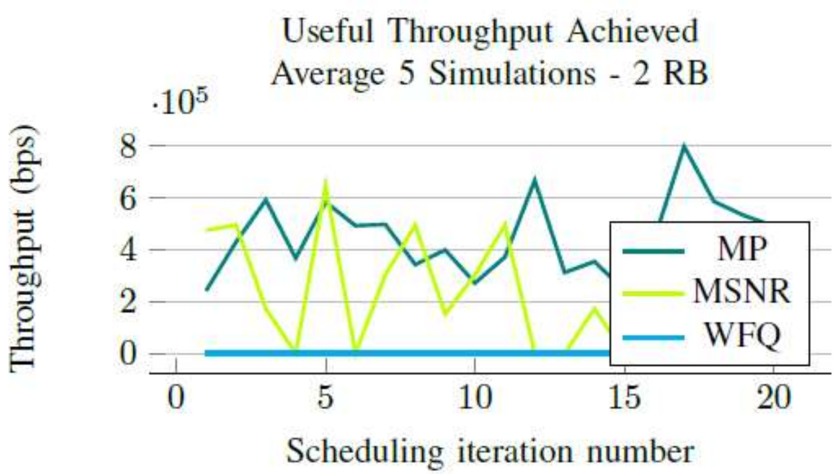
Parameters analyzed

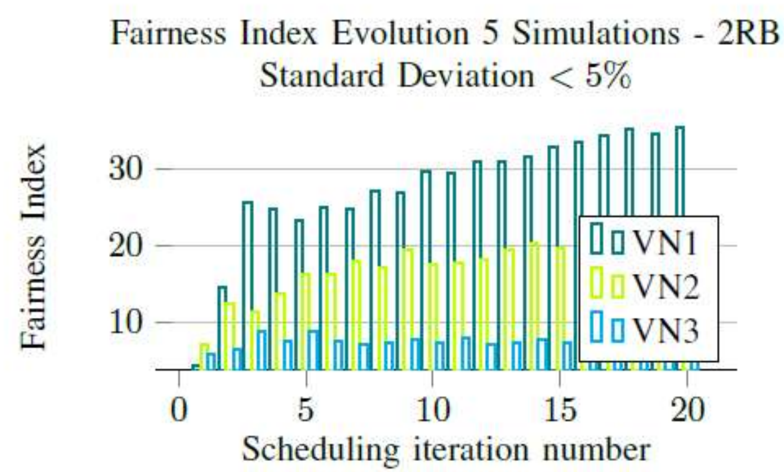
- Total throughput achieved for the total amount of data transmitted
- Useful throughput achieved = Throughput achieved > Throughput required
- Fairness Index Evolution: To see if the network impact can be easily controlled

Performance Evaluation









Performance Evaluation

Simulation results and observations:

- **Improved behavior** with respect to traditional algorithms (WFQ and MSNR), specially in **real-time data**, where QoS is a MUST.
- When we want to strictly satisfy QoS requirements, traditional algorithms are not a good alternative.
- With our optimization, we can achieve **high levels of profit (around 90%)** when good channel and **strictly satisfying* QoS**.

  *Assuming CQI immediate and accurate
- Performance **enhanced when higher diversity of flows**: Easier to find a combination of flows completely filling current RB size.
- Adaptive **fairness-control** by using standard deviation: **Easy monitoring of the virtual networks impact** on the infrastructure.

Wireless Infrastructure-as -a-Service: Conclusions and Future Challenges

- **WIaaS offers promising opportunities for the next generation cellular systems.**
  - We have set the path with our proposal but there is still a long way to investigate:
- **New horizons for the research community:**
  - Achieving algorithm-optimality, reducing computational complexity and achieving fast convergence
    - Relaxing optimality of results
    - Clustering, pattern recognition and specific bottle-necks
  - Power-control, uplink-downlink and collaborative inter-BS techniques
  - New non-orthogonal medium access techniques (NOMA), mmWaves transmissions, massiveMIMO and beamforming could also be virtualized
  - Exploiting carrier aggregation flexibility

Thank You for Your Attention!