Panel:

Advances in Communications Technologies

(communication software, technologies -sdn, 5g, 6g, cyber -, control, sensing, data)

SoftNet 2020

October 18, 2020 to October 22, 2020 - Porto, Portugal

Panel:
Advances in Communications Technologies
(communication software, technologies -sdn, 5g, 6g, cyber -, control, sensing, data)

SoftNet 2020

Chair

Jorge A. Cobb, The University of Texas at Dallas, USA

Panelists

Zhaobo Zhang, Futurewei Technologies, USA

Rony Kumer Saha, KDDI Research, Inc., Japan

Eugen Borcoci, University POLITEHNICA Bucharest, Romania

Jorge A. Cobb, The University of Texas at Dallas, USA

Points to Ponder

- Are there limits to where machine learning can be applied (in the context of new communication technologies)? Will machine learning be effective in configuring new network technologies, or will it cause more problems than it solves due to its lack of certainty?
- With the advent of 5G, 6G, etc, are there limits to the wireless bandwidth that will be available to users? When can we expect that ``wall'' to be encountered?
- With the increase in bandwidth and as more data is being collected, are we creating so much data that the security and privacy of users are at risk? (Especially in light of data mining and machine learning).
- Is SDN applicable everywhere (home, office, ISPs, data centers, etc.)? Will its management and programmability be simple and efficient enough to use in all these environments? Will there be enough skilled personnel to deploy and manage it?
- With the increase in wireless bandwidth and the natural increase in the size of the IoT, will SDN offer a solution to the challenges of the IoT?

Points from the panelists

Zhaobo Zhang, Futurewei Technologies, USA

- Deep Reinforcement Learning can be used for the optimization of new communication infrastructures, such as cloud services, data centers, and network function virtualization.

Rony Kumer Saha, KDDI Research, Inc., Japan

- Spectrum utilization-centric networks (SUCN) have an impact on network capacity and spectral efficiency by employing several techniques such as spectrum sharing, spectrum trading, and spectrum reusing. This is effective for in-building small cells and can also be investigated for the outdoor environments.

Eugen Borcoci, University POLITEHNICA Bucharest, Romania

- Fifth generation (5G) wireless networks is currently a hot topic both in research and in commercial development. It offer significant advances, however it is unable to meet the full demands of the future digital society. This short panel-type overview presents some major trends and potential challenges of the future 6G technology.

Jorge A. Cobb, The University of Texas at Dallas

- Software Defined Networking (SDN) offers great flexibility in the delivery of network services. New models are being proposed that transfer different degrees of intelligence from the SDN controller to the switches. Will these models provide a significant boost to SDN efficiency and programmability, or will they quickly be forgotten?

Panellist Position

Steering the Next-Generation Infrastructure with Deep Reinforcement Learning

Zhaobo Zhang, Futurewei Technologies, USA zzhang1@futurewei.com

- Next level of intelligence, dynamic decision-making
- Label (instructive)-> Reward (evaluative)
- Cloud-native architecture
- Autonomous infrastructure

→ Cloud-native infrastructure provides an interactive environment with observability and actionable APIs

→ Deep reinforcement learning is designed for finding the optimal policy, a perfect fit for control optimization

→If a machine receives negative feedback, it should act differently next time

Panel:

Advances in Communications Technologies

(communication software, technologies -sdn, 5g, 6g, cyber -, control, sensing, data)

SoftNet 2020

Panellist Position

Evolution Toward Spectrum Utilization-Centric Network: Addressing High Capacity with Limited Spectrum Bandwidth

Rony Kumer Saha, KDDI Research, Inc., Japan, ro-saha@kddi-research.jp

Abstract: Over the past years, due to the scarcity of the available radio spectrum, mobile networks have been evolved toward improving spectrum utilization to address the ever increasing high network capacity and data rate demands. Numerous techniques have been developed to improve the spectrum utilization by exploiting time, frequency, power and space domains.

In this panel position, the evolution toward spectrum utilization-centric networks (SUCN) is discussed. By exploiting time, frequency, and space domains, the impact of SUCN on increasing the network capacity and spectral efficiency by employing several spectrum utilization improvement techniques, namely spectrum sharing, spectrum trading, and spectrum reusing, is shown for in-building small cells operating on the 28 GHz bands.

Presentation Outline

- Evolution (concerning SUCN)
- Example spectrum usage
- Techniques to improve spectrum utilization
- Architecture, assumption and parameter
- Impact of SUCN Next level of intelligence, dynamic decision-making

Panellist Position

6G – perspectives and challenges

Eugen Borcoci, University POLITEHNICA Bucharest, Romania eugen.borcoci@elcom.pub.ro

Why 6G?

What business and societal drivers ?

6G use cases- examples

Spectrum, physical layer

6G Architectural aspects

Note: The 6G concepts, architecture and technologies are open research issues. This panel position will only present a summary of some 6G trends and challenging topics and research domains, compiled from the public papers and documents (see References)

Panel:

Advances in Communications Technologies

(communication software, technologies -sdn, 5g, 6g, cyber -, control, sensing, data)

SoftNet 2020

Panellist Position

Next Generation SDN Execution Models, a Necessity for Future Growth or a Let Down?

Jorge A. Cobb, The University of Texas, USA jcobb@utdallas.edu

Presentation Outline

- SDN Basics
- Advantages / Disadvanatges
- Semantics Extensions
- Execution Model Extensions
- Future Prospects

SoftNet 2020 Congress, Panel: Advances in Communications Technologies

Steering the Next-Generation Infrastructure with Deep Reinforcement Learning

Zhaobo Zhang
Futurewei Technologies
zzhang1@futurewei.com
Oct. 2020

Advances in Communications

- Driven by new application requirements
  - AR/VR, Hologram, IoT, autonomous cars
  - Internet usage surge in pandemic (video conferencing/streaming, etc.)
- Current 5G characteristics
  - Throughput, latency, mobility, connections density, spectrum efficiency, Intelligence
- Enhanced by Cloud, AI
  - Cloud-native (microservice, API-driven) architecture, scalable, resilient, agile
  - Detailed observability and executable actions enable AI-based control

Network Intelligence

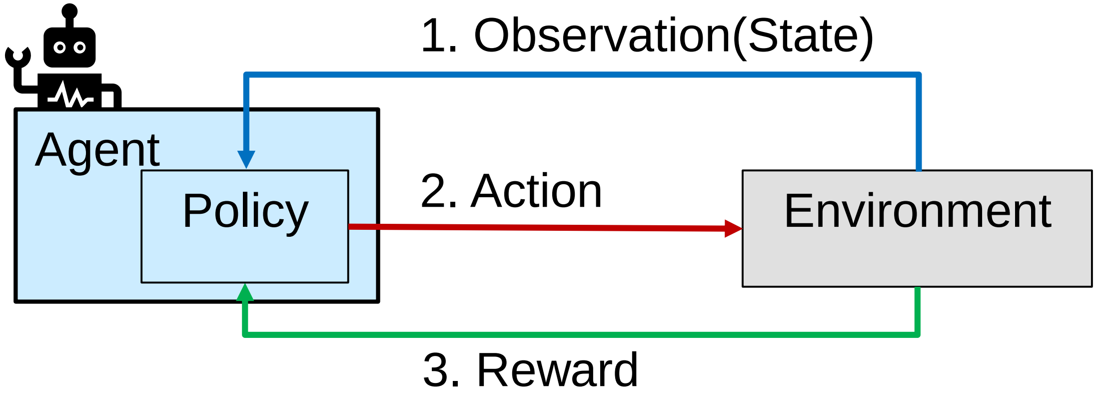
- Mature Machine Learning Application
  - Traffic prediction/classification
  - Fault diagnosis
  - Intrusion/Anomaly detection

Supervised, Unsupervised → Reinforcement, Nature Language Processing

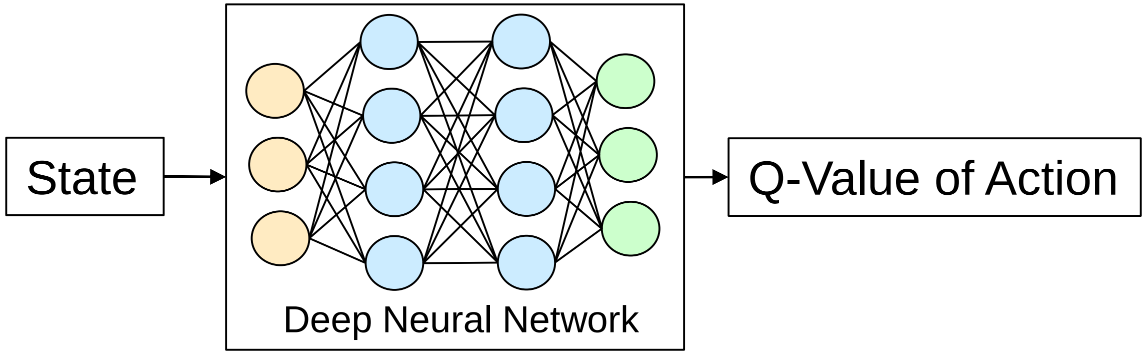
- Trending
  - AIOps, Virtual Assistance
  - Full-stack (from infra to app) observability and correlation
  - Closed-loop Control

✓ One step → Interactive
✓ Silo → multiple domain
✓ Analysis → Action

Deep Reinforcement Learning (DRL) for Real-time Decision Making



RL control loop



Deep Q Learning Algorithm

- MDP: discrete-time stochastic control process, a mathematical framework for modeling decision making
- Policy: a mapping from state to action
- Agent goal: find the optimal policy to maximize the reward, long-term cumulative return
- Two popular reinforcement learning algorithms
  - Q-Learning (value-based) vs Policy gradient (policy-based)

VNF Orchestration Example: State, Action and Reward

- Dynamic resource (VNF/CNF, bandwidth) orchestration in 5G ecosystem to provide cost-effective services with better performance
- Deep reinforcement learning model
  - Agent: network orchestrator
  - State Space: VNF requests, VNF availability
  - Action Space: VNF allocation options
  - Reward function: function of request processing time and VNF costs
- Reward function design
- Environment design (state transition)

More Application References

Ref	Problem Category	Agent	States	Actions	Reward
[1]	Routing Optimization (Traffic Engineering)	Network Controller	Link load, switch load (queue depth)	Assign weight value of links	Max-link-utilization
[2]	Adaptive Rate Control (Congestion Control)	Traffic Sender	Sent packet interval, packet, loss, average delay, set bytes, last action	Decide sending rate	Throughput, delay, packet loss rate
[3]	Job scheduling (Resource Management)	Cluster Controller	Available resource, job required resource (CPU, Memory, I/O)	Schedule a job at a certain time slot	Average Job slowdown
[4]	Spectrum Allocation (Network Slicing)	Base station	No. of arrived packets in each slice	Allocate bandwidth to each slice	Spectrum efficiency, Quality of Experience
[5]	Computation offloading (Mobile Edge Computing)	User device	Remained energy of device, connection condition, channel power gain between user device and base station, task info	Decide if offload tasks, decide CPU frequency and transmit power	Task completion latency, energy consumption

[1] Q. Li, et al., "Data-driven Routing Optimization based on Programmable Data Plane," *2020 ICCCN*
[2] L. Zhang, et al., "Reinforcement Learning Based Congestion Control in a Real Environment," 2020 ICCCN
[3] H. Mao, et al., "Resource Management with Deep Reinforcement Learning," 2016 HotNets
[4] [1] R. Li *et al.*, "Deep Reinforcement Learning for Resource Management in Network Slicing," in *IEEE Access*, vol. 6, 2018
[5] Y. Zhang, et al., "A Deep Reinforcement Learning Approach for online computation offloading in Mobile Edge Computing," 2020 IWQoS

Industry Research and Adoption of DRL

- Microsoft, finding the optimal cloud configuration for DNN inference workload [1]
- Google, optimizing chip layout with RL agent [2]
- VMware, continuous performance tuning for data center infrastructure [3]

[1] Y. Li, et al., "Automating Cloud Deployment for Deep Learning Inference of Real-time Online Services," IEEE INFOCOM 2020
[2] https://ai.googleblog.com/2020/04/chip-design-with-deep-reinforcement.html
[3] https://blogs.vmware.com/management/2019/08/tech-preview-project-magna.html

Takeaways

- Challenges
  - Real environment, to provide continuous trigger and feedback to the agent
  - Reward function design, to guide the agent to the real goal
  - Action space design, scalable
  - Interpretability, trusted AI actions
- Mission Possible
  - Modern architecture: structured data, microservice, orchestrator
  - Strength of DRL on continuous optimization in a dynamic environment

Westworld Dolores

THANK YOU

Evolution Toward Spectrum Utilization-Centric Network: Addressing High Capacity with Limited Spectrum Bandwidth

Rony Kumer Saha

Presented by
Rony Kumer Saha, Ph.D.
Radio and Spectrum Laboratory
KDDI Research, Inc. JAPAN
2-1-15 Ohara, Fujimino-shi, Saitama, 356-8502
Email: ro-saha@kddi-research.jp

KDDI Research

IARIA

Resume of the Panelist

RONY KUMER SAHA (Postdoc, PhD, MEng, BSc Engg) received the B.Sc. degree in electrical and electronic engineering from the Khulna University of Engineering and Technology, KUET, in 2004, the M.Eng. degree in information and communications technologies from the Asian Institute of Technology (AIT), Thailand, in 2011, and the Ph.D. degree in electrical engineering from Chulalongkorn University, Thailand, in 2017. Since 2017, he has been working as a Postdoctoral Fellow/Research Engineer with the Radio and Spectrum Laboratory, KDDI Research, Inc., Japan.

He worked as a Lecturer and later promoted to an Assistant Professor with American International University-Bangladesh, Bangladesh, AIUB, from January 2005 to August 2013. From September 2013 to July 2014, he was with East West University, Bangladesh. His current research interests include 5G and beyond ultra-dense HetNets, spectrum sharing, policy, and management in multiple communication systems, and millimeter-wave communications. He has research experiences on mobile wireless communications in universities and industries for more than ten years. He has authored about 50 peer-reviewed, reputed, and highly recognized international journal and conference papers. He also filed an international patent.

Dr. Saha served as a member of the Fronthaul Working Group, xRAN Forum, USA. He also served as a TPC member of the 2020 ICSNC and 2018 IEEE Global Communications Conference Workshops. Furthermore, he also served as the Session Chair for two sessions, namely Radio Resource Management and Aerial Networks at 2019 IEEE VTC-Fall, Hawaii, USA, as well as the 2019 IEEE International Symposium on Dynamic Spectrum Access Networks Newark, NJ, USA, for the session Spectrum Sharing in 5G. Since early 2019, he has been serving as an Associate Editor of the Engineering Journal, Thailand. He served as a Reviewer of a number of recognized journals, including IEEE Transactions on Vehicular Technology, IEEE Access, Elsevier Physical Communication, Wiley International Journal of Communication Systems, MDPI Sensors Journal, MDPI Symmetry Journal, Hindawi Mobile Information Systems, and MDPI Sustainability Journal.

Topics of Research Interests

- Millimeter wave communications
- Dynamic spectrum sharing and policy for 5G and beyond mobile networks
- Cognitive radio networks and spectrum sensing techniques
- Co-channel interference analysis, mitigation, avoidance, and cancellation strategies
- In-building small cell network planning, design and deployment
- Planning, design and development of spectrum sharing algorithm for homogeneous (mobile networks) and heterogeneous networks (mobile networks and satellite networks)
- Radio resource allocation and scheduling policy and algorithm
- Mobile MAC layer and Physical layer issues
- Proof-of-concept evaluation of virtualization and Slicing of 5G radio access network (RAN)
- Cloud RAN (CRAN) in 5G era
- Fronthaul design for CRAN

Evolution (Concerning Spectrum Utilization-Centric Networks)

- The demand for **high network capacity and user data rate are ever increasing** from one generation to another in mobile networks.
- For example, the sixth-generation (6G) mobile network is expected to be further upgraded and expanded from the fifth-generation (5G) network to achieve **10 to 100 times higher data rate, higher system capacity, and higher spectrum efficiency [1].**
- According to **Shannon's capacity** formula, the achievable capacity is directly proportional to the available radio spectrum bandwidth.
- However, the radio spectrum allocated to a Mobile Network Operator (MNO) is **limited** and **expensive.**

[**1**] S. Chen, Y. Liang, S. Sun, S. Kang, W. Cheng, and M. Peng, "Vision, Requirements, and Technology Trend of 6G: How to Tackle the Challenges of System Coverage, Capacity, User Data-Rate and Movement Speed," IEEE Wireless Communications, vol. 27, Apr. 2020, pp. 218-228, doi: 10.1109/MWC.001.1900333.

Evolution (Concerning Spectrum Utilization-Centric Networks)-Cont'd

- Hence, the **traditional approach** to increase the capacity by aggregating spectrum bandwidths of a number of bands (**Figure 1**) is no more considered sufficient.

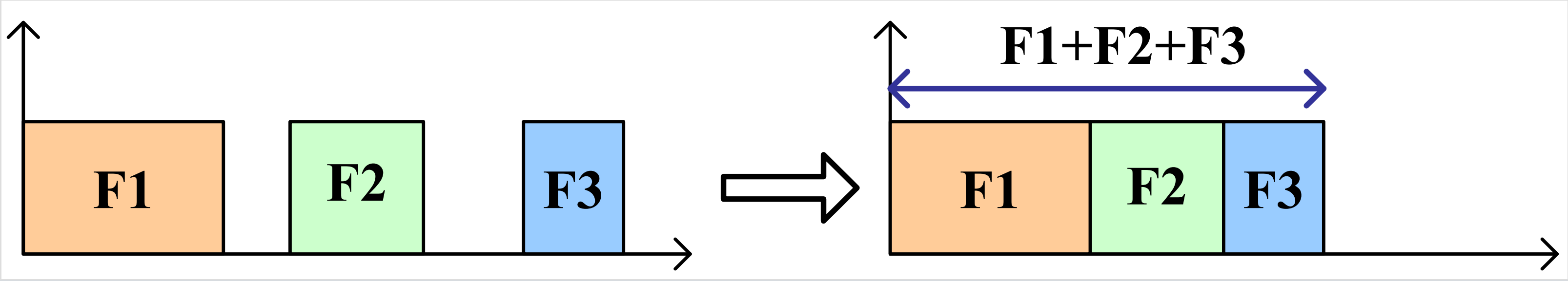


Figure 1. Spectrum aggregation.

So, how to address the high capacity and data rate demands with a limited spectrum bandwidth allocated to an MNO has become a major issue in mobile communications.

- Since radio spectrum can't be increased, a potential approach to increase network capacity is to **improve the utilization of the radio spectrum** allocated to an MNO.

Hence, **spectrum utilization** has become a **major design approach** to address the ever-increasing capacity and data rate demands of mobile networks.

Example Spectrum Usage

Spectrum utilization can be improved by **exploiting** (see **Figure 2 below**):

- **Time-domain**
- **Frequency-domain**

- **Space-domain**
- **Power-domain**

User traffic demands of different MNOs **vary differently** in time and space (**Figure 2**).

Accordingly, a great portion of the allocated spectrum of an MNO may be left **unused** (**spectrum holes** in **Figure 2**) in time, frequency, and space .

This causes an MNO to be **suffered** from the scarcity of the required spectrum and another MNO to have the **excessive** amount of the spectrum in any time at a given area.

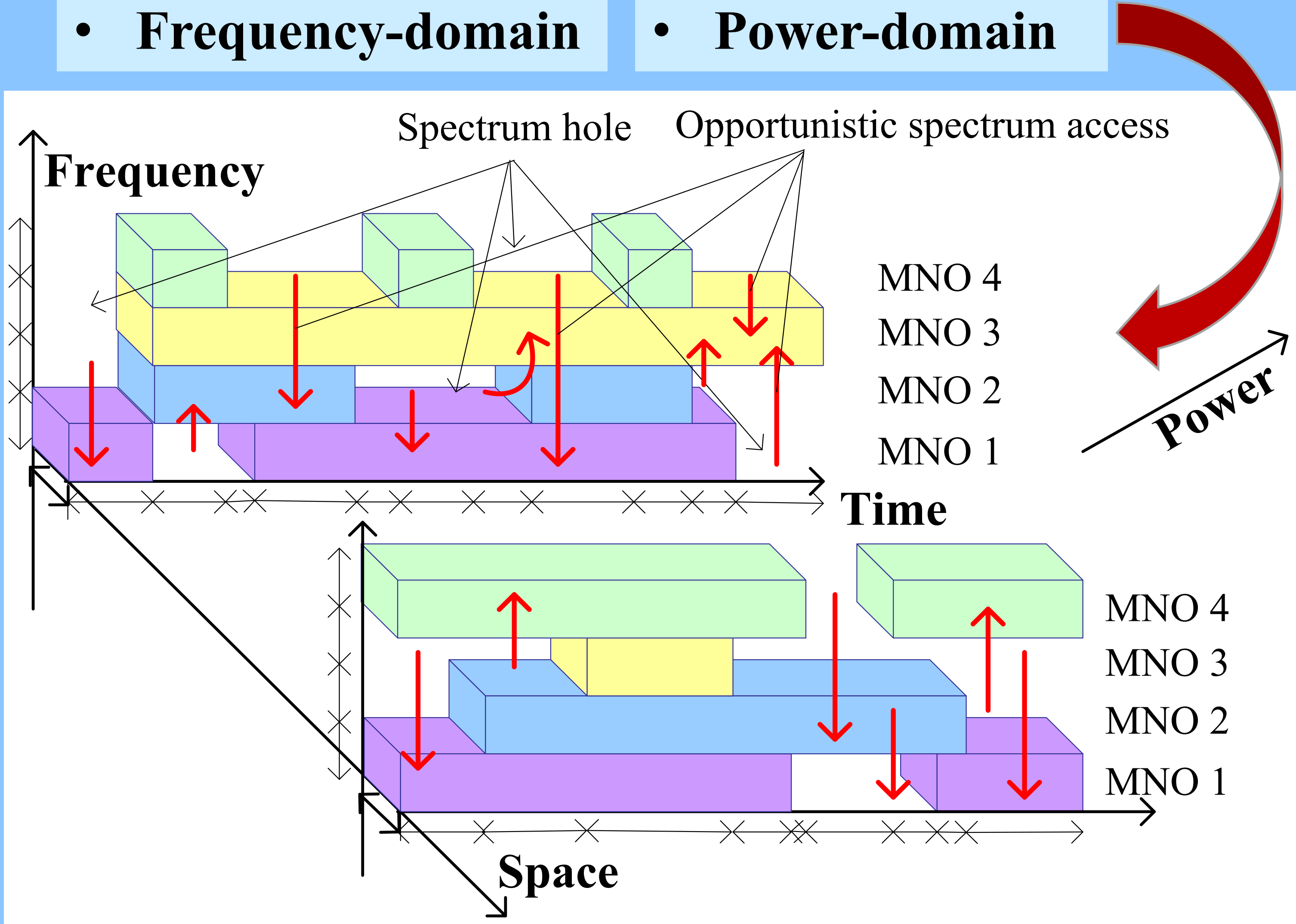


Figure 2. An example spectrum usage of four MNOs in a country.

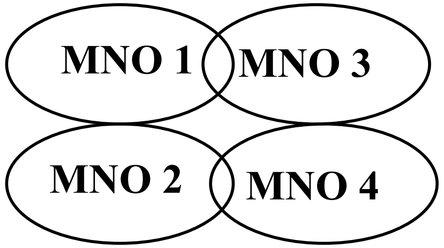
Techniques to Improve Spectrum Utilization

Several techniques have been proposed to improve spectrum utilization by exploiting these aforementioned domains, e.g., **spectrum sharing, spectrum trading, and spectrum reusing**.

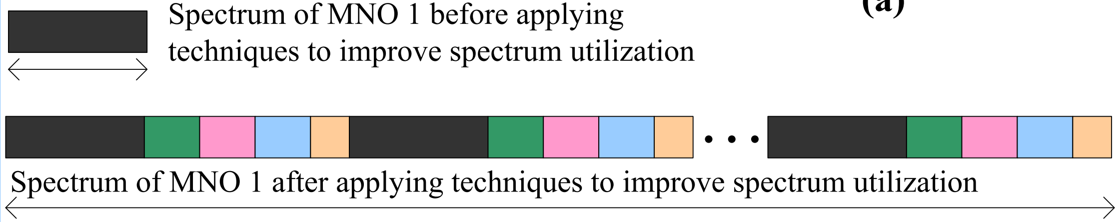
1) In **spectrum sharing**, the same spectrum can be shared among multiple MNOs subject to avoiding co-channel interference (CCI) by exploiting the time, frequency, and power domains.

2) In **spectrum trading**, an MNO with a shortage of spectrum can lease from other MNOs, each having unused or under-utilized spectra, in the secondary-level by exploiting the frequency-domain.

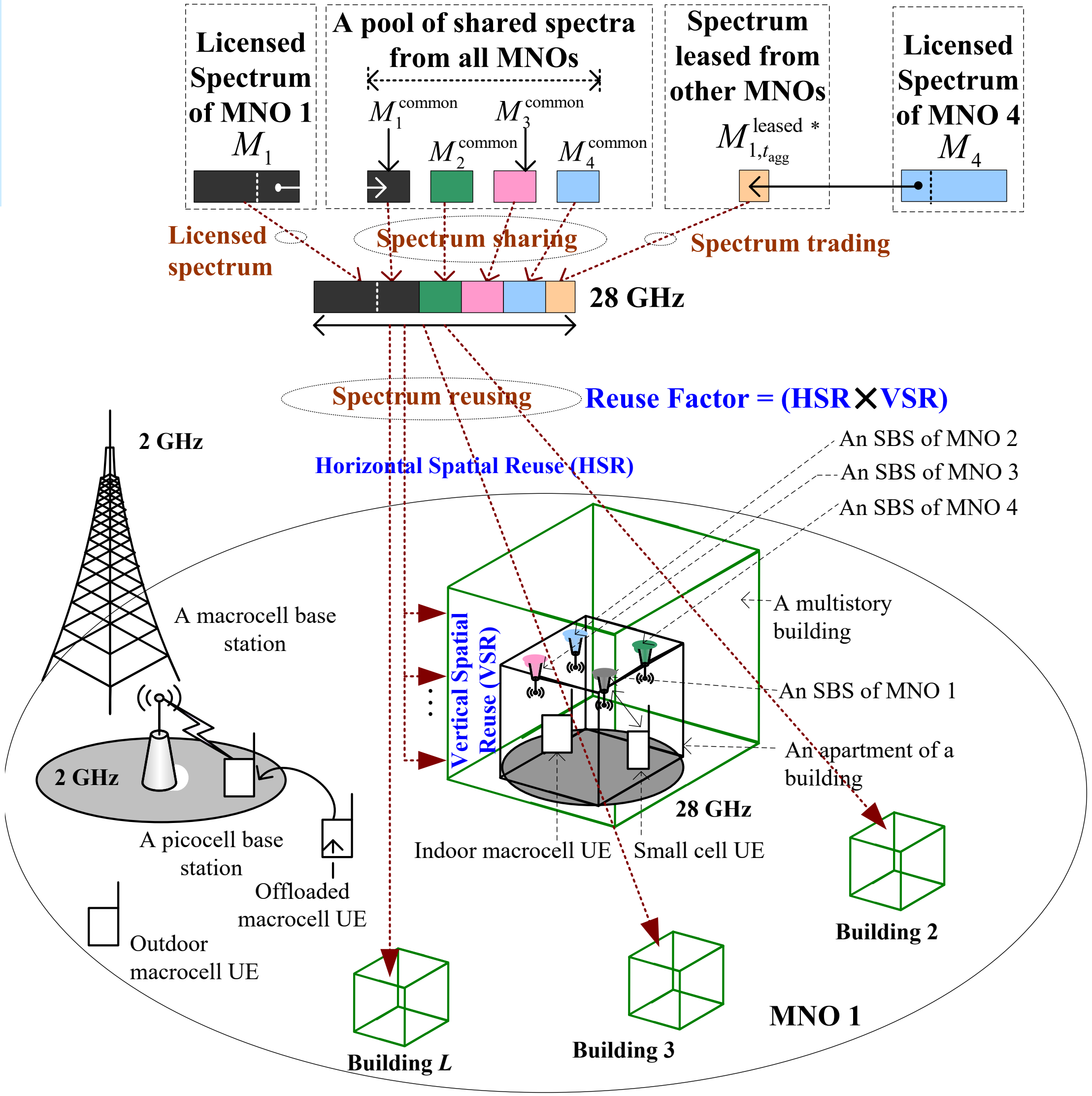
3) In **spectrum reusing**, the same spectrum of an MNO can be reused in space subject to satisfying CCI by exploiting the space-domain.



(a)



(c)



(b)

[2] R.K. Saha, "On Application and Evaluation of Millimeter-Wave Spectrum Sharing, Trading and Reusing for Small Cells Toward Spectral and Energy Efficiencies of 6G," in Proc. WPMC, IEEE Press, Oct. 2020, pp. 1-6.

Figure 3. System architecture and the application of spectrum utilization improvement techniques to an MNO (MNO 1) in a country.

Architecture, Assumption and Parameter

System Architecture

- **Four MNOs** (i.e., MNO 1, MNO 2, MNO 3, and MNO 4) are operating in a country **Figure 3(a).**
- Each MNO has a **similar system architecture** consisting of three types of Base Stations (BSs), namely Macrocell BSs (MBSs), Picocell BSs (PBSs), and Small Cell BSs (SBSs).
- For simplicity, the detailed architecture of only one MNO (i.e., MNO 1) is shown in **Figure 3(b)#.**
- All SBSs are deployed only within **3-Dimensional (3D)** multistory buildings each serving one user equipment (UE) at a time.

Table 1. Default simulation parameters and assumptions#.

Parameters and Assumptions	Value
Number of MNOs countrywide	4
Total licensed 28 GHz millimeter-wave spectrum and reserved spectrum for MNO 1	50 MHz and 10 MHz
E-UTRA simulation case	3GPP case 3
Cellular layout, inter-site distance (ISD) , transmit direction	Hexagonal grid, dense urban, 3 sectors per macrocell site, 1732 m, downlink
Carrier frequency	Licensed 2 GHz non-line-of-sight (NLOS) microwave spectrum band for macrocells and picocells, licensed 28 GHz line-of-sight (LOS) mmWave spectrum band for all small cells
Number of cells	1 macrocell, 2 picocells, 48 small cells per building
3D multistory building and SBS models (square-grid apartments): number of buildings, number of floors per building, number of apartments per floor, number of SBSs per apartment, number of SBSs per building, area of an apartment	*L*, 6, 8, 1, 48, 10×10 m^2
Scheduler and traffic model	Proportional Fair (PF) and full buffer
Type of SBSs	Closed Subscriber Group (CSG) femtocell BSs

#Taken from [2]. The detailed simulation parameters and assumptions can be found in [2].

Result (Impact of Spectrum Utilization-Centric Networks)

The **spectrum reusing** technique **outperforms** the spectrum sharing and spectrum trading techniques significantly (see **Figure 4**) since in spectrum reusing, the **whole spectrum for the data traffic of MNO 1 itself can be reused** to its small cells on-demand basis.

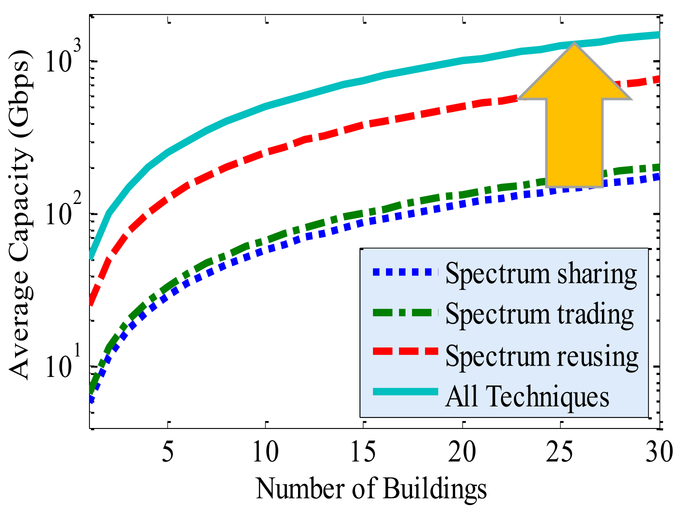


Figure 4. (Taken **from** [2]) Capacity response of spectrum sharing, trading, and reusing techniques.

It is expected that the future 6G mobile networks can achieve **10 times** average SE (i.e., **270-370 bps/Hz**), as well as **10 times average EE** (i.e., **0.3×10^{-6} Joules/bit**), of 5G mobile networks [3].

- Using **Figure 5**, the **number of buildings of small cells L** required by spectrum sharing, spectrum trading, spectrum reusing techniques are respectively **23, 30, and 6**.
- However, when employing all three techniques to small cells per building, the number of buildings of small cells L required is **only 4**.
- Hence, **employing all three techniques to improve spectrum utilization jointly can satisfy both SE and EE** by reusing the 28 GHz spectrum to small cells for the least number of times.

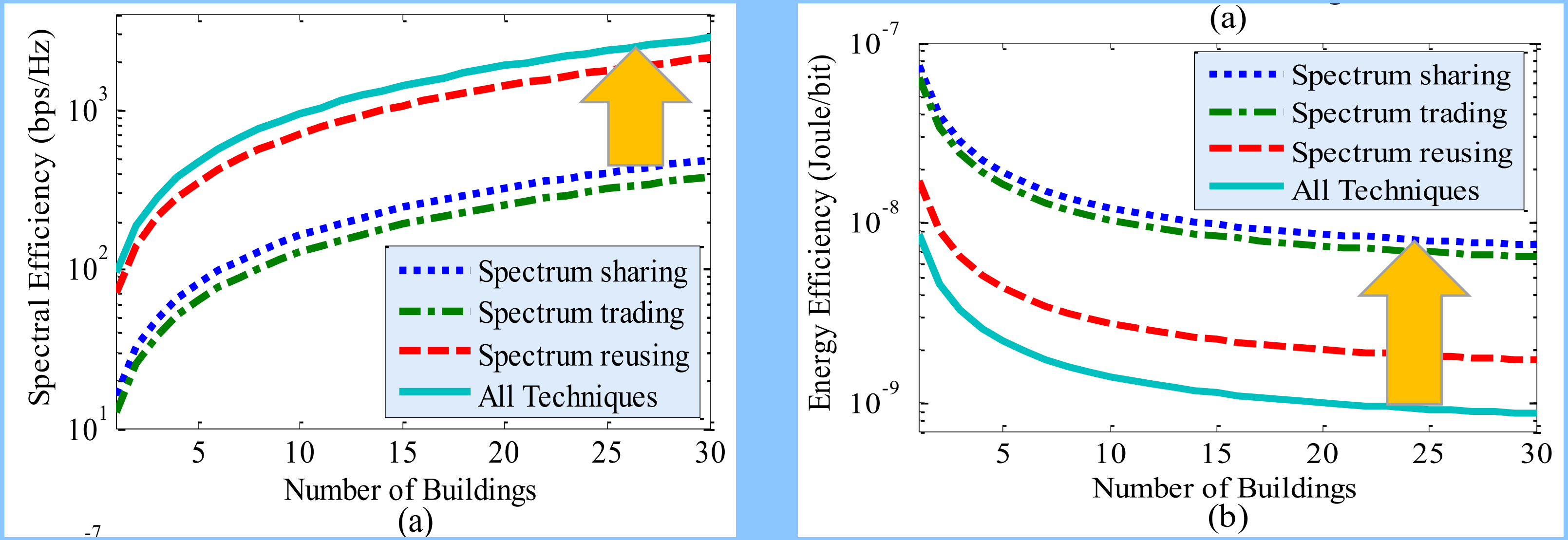


Figure 5. (Taken **from** [2]) Capacity and spectral efficiency responses of spectrum sharing, trading, and reusing techniques.

[3] Z. Zhang et al., "6G Wireless Networks: Vision, Requirements, Architecture, and Key Technologies," IEEE Vehicular Technology Magazine, vol. 14, Sept. 2019, pp. 28-41, doi: 10.1109/MVT.2019.2921208.

Conclusion and Further Work

Over the past years, **mobile networks have evolved toward improving the spectrum utilization** to address the ever increasing high network capacity and data rate demands due to the scarcity of the available radio spectrum. Numerous techniques have been developed to improve the spectrum utilization by exploiting time, frequency, power and space domains.

In this panel position, by exploiting time, frequency, and space domains, the impact of a number of spectrum utilization improvement techniques, **namely spectrum sharing, spectrum trading, and spectrum reusing,** have been shown for in-building small cells operating at the 28 GHz millimeter-wave bands.

- **Likewise**, by exploiting the power-domain, and using the **Cognitive Radio Technology,** the spectrum utilization improvement techniques can be developed.
- Since the **distance-dependent path loss,** floor and wall penetration losses vary with the operating frequency indoors, the above techniques can be investigated further for other millimeter-wave bands (for example, 38 GHz, 60 GHz, and above 70 GHz) and Terahertz frequencies.
- Since the propagation characteristics of millimeter-wave frequencies outdoors differ from that indoors, **the above spectrum utilization improvement techniques can also be investigated for the outdoor environments.**

End of the Presentation

Thank You …

Rony Kumer Saha, Japan

Panel:
Advances in Communications Technologies
(communication software, technologies -sdn, 5g, 6g, cyber -, control, sensing, data)

SoftNet 2020

6G – perspectives and challenges

Eugen Borcoci, University POLITEHNICA Bucharest, Romania
eugen.borcoci@elcom.pub.ro

Why 6G?

- **5G is becoming mature - towards a global standard; however it has limitations w.r.t. future needs**
- ***6G Vision for 2030: the society will be data driven, served by near instant, unlimited wireless connectivity***
  - key aspects: connectivity will be: intelligent, deep, holographic and ubiquitous
- **Research community started to study beyond-5G solutions , i.e. 6G. (vision towards 2030 era)**
- **It is not clear yet what 6G will entail**

  - relevant technologies considered too immature for the current scope of 5G

  - e.g., the way to in which data is collect, process, transmit and consume data

  - while wireless network will be a key driver for 6G – which technology development is necessary ?
- **6G challenges**

  Business and services

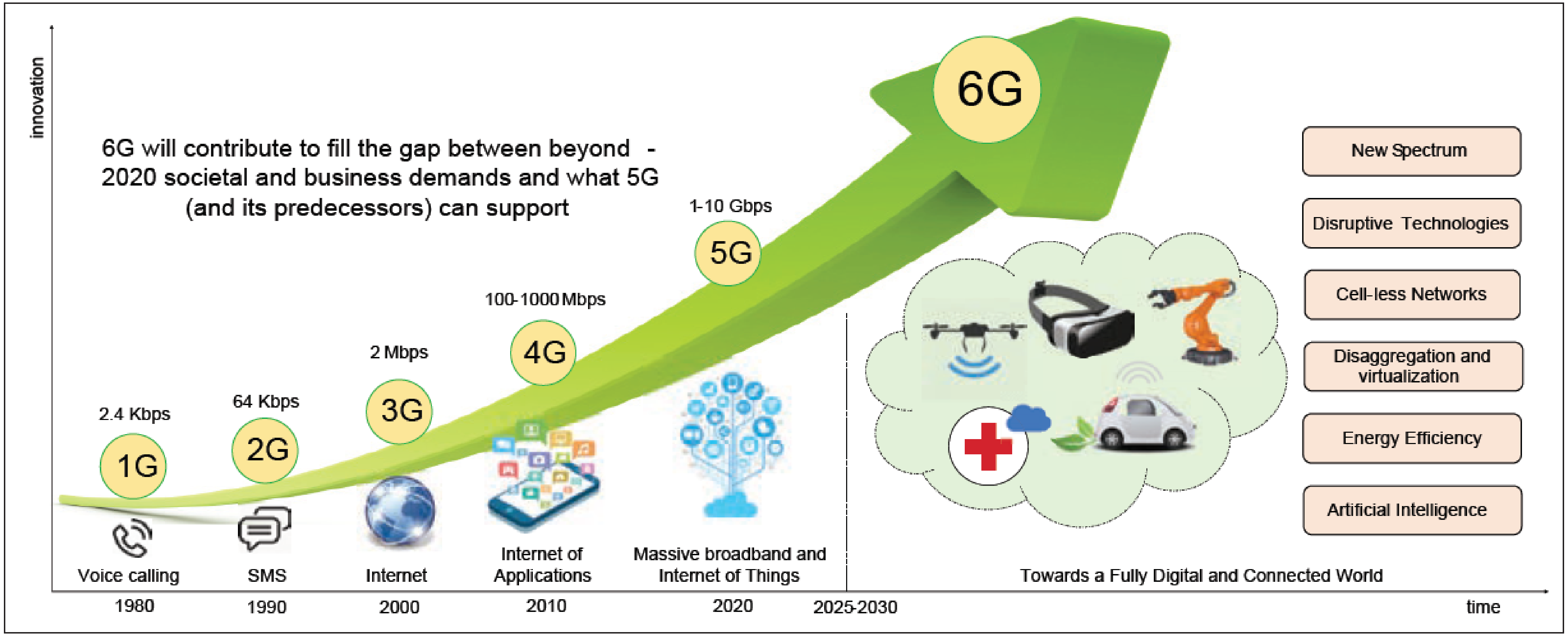
  Verticals Driving Development; New Value Chains; Huge number of users/terminals

  Architecture and technologies

  Flexible Network Architectures; Autonomous Wireless Systems; Hardware and physical layers technologies

6G – perspectives and challenges: Why 6G? (cont'd)

Source: M. Giordani, et al., "Toward 6G Networks:Use Cases and Technologies", IEEE Communications Magazine , March 2020

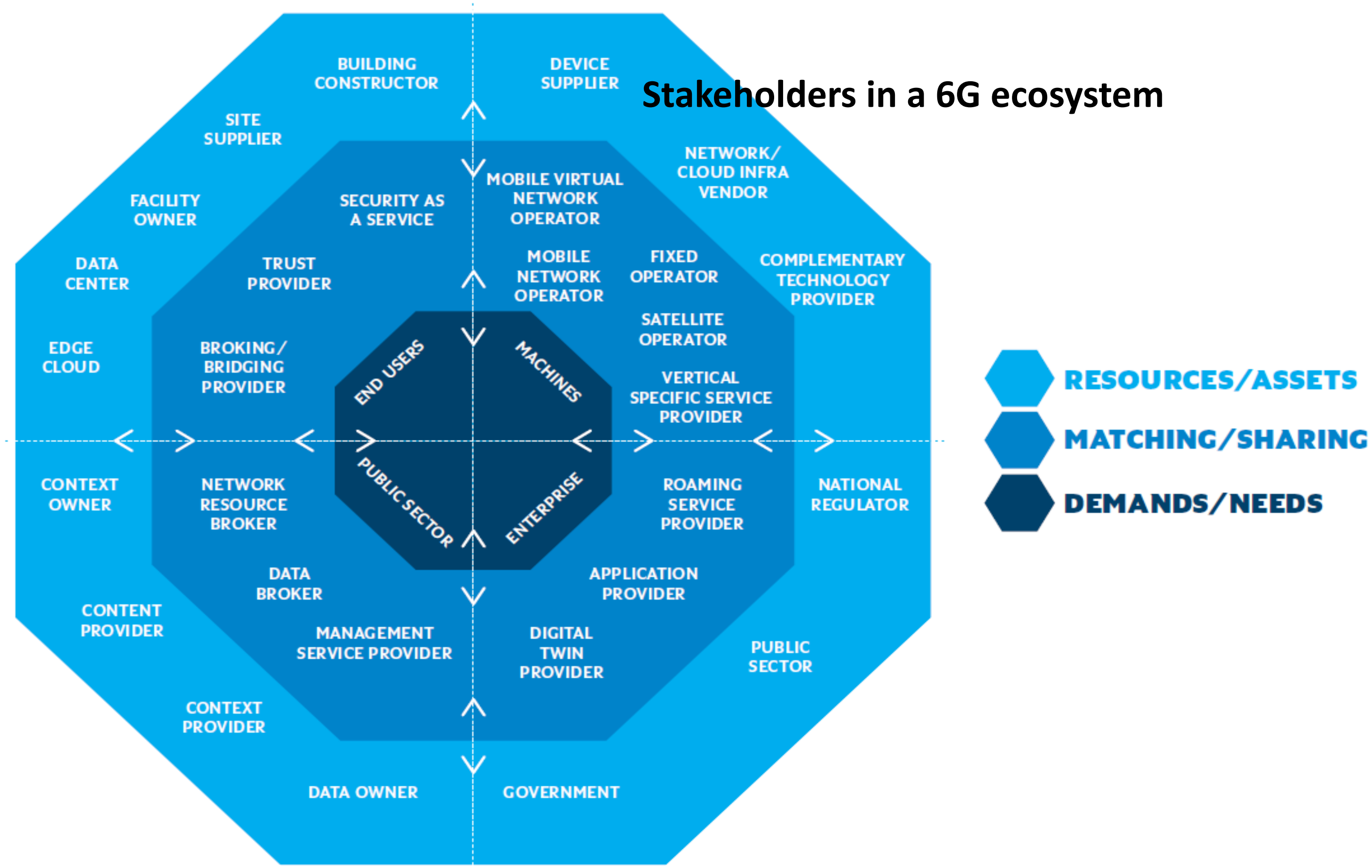


6G – perspectives and challenges

What business and societal drivers ?

- business and societal drivers → 6G development, including
  - ***political, economic, social, technological, legal and environmental (PESTLE)*** drivers
  - 6G will require a holistic approach
    - to identify future communication needs
    - to serve much wider community with a large variety of services
  - Need to identify
    - the trends, future society demands and challenges to avoid merely commercially driven system definitions

Stakeholders in a 6G ecosystem



Source: B.Aazhang, P.Ahokangas, et al., "Key drivers and research challenges for 6G ubiquitous wireless intelligence (white paper)", https://www.researchgate.net/publication/336000008_Key_drivers_and_research_challenges_for_6G_ubiquitous_wireless_intelligence_white_paper

6G – perspectives and challenges

6G Use cases- examples

- 6G, will meet network demands (e.g., ultra-high reliability, capacity, efficiency, and low latency) in a holistic fashion, in considering the foreseen economic, social, technological, and environmental context of the 2030 era
  - Augmented reality and Virtual reality
  - Holographic telepresence (teleportation)
  - eHealth
  - Pervasive connectivity
  - Industry 4.0 and Robotics
  - Unmanned mobility
  - Smart phones are likely to be replaced by pervasive XR experiences through lightweight glasses delivering unprecedented resolution, frame rates, and dynamic range
  - Telepresence -high resolution imaging and sensing, wearable displays, mobile robots and drones, specialized processors, and next-generation
  - Autonomous vehicles for ecologically sustainable transport and logistics based on advances in wireless networks and in distributed AI and sensing wireless networks

Panel:

Advances in Communications Technologies

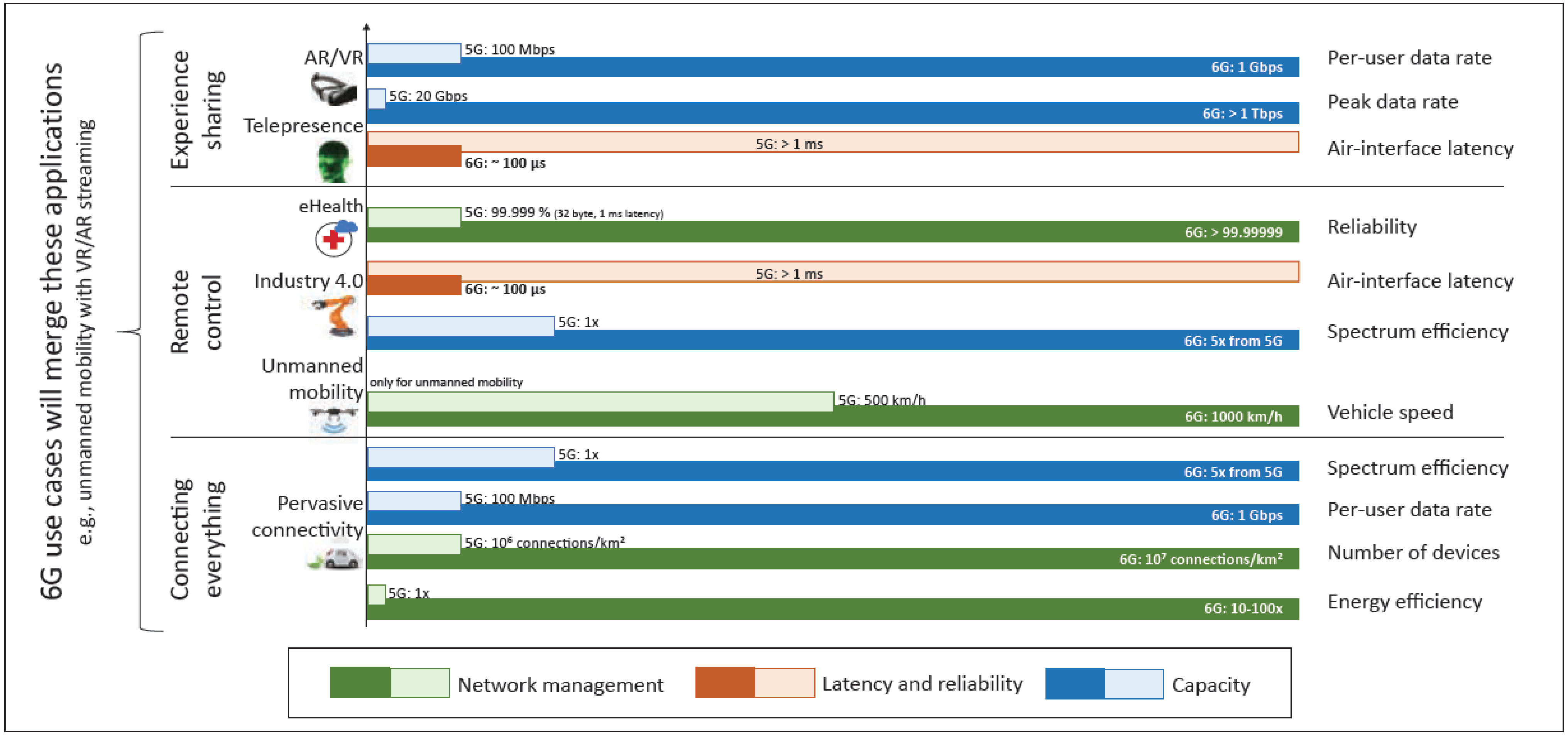
(communication software, technologies -sdn, 5g, 6g, cyber -, control, sensing, data)

SoftNet 2020

Multiple KPIs of 6G use cases; improvements with respect to 5G

6G – perspectives and challenges

6G Use cases- examples

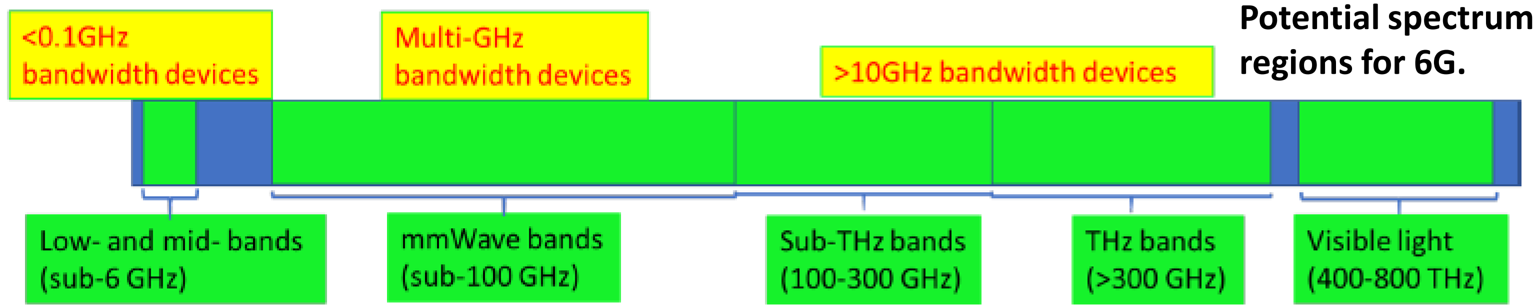


Source: M. Giordani, et al., "Toward 6G Networks:Use Cases and Technologies", IEEE Communications Magazine , March 2020

6G – perspectives and challenges

6G Spectrum, physical layer features

- 5G defines separately operations for sub-6 GHz and 24.25 to 52.6 GHz
- 6G: enhancements w.r.t. 5G spectrum, and expansion to potential new bands from low-bands to low THz and visible light region



Potential spectrum regions for 6G.

Performant PHY layer :
6G enhanced KPI versus 5G

KPI	5G	6G
Peak data rate	20 Gb/s	1 Tb/s
Experienced data rate	0.1 Gb/s	1 Gb/s
Peak spectral efficiency	30 b/s/Hz	60 b/s/Hz
Experienced spectral efficiency	0.3 b/s/Hz	3 b/s/Hz
Maximum bandwidth	1 GHz	100 GHz
Area traffic capacity	10 Mb/s/m^2	1 Gb/s/m^2
Connection density	10^6 devices/km^2	10^7 devices/km^2
Energy efficiency	not specified	1 Tb/J
Latency	1 ms	100 μs
Reliability	1-10^{-5}	1-10^{-9}
Jitter	not specified	1 μs
Mobility	500 km/h	1000 km/h

Source: N.Rajatheva et al., "White Paper on Broadband Connectivity in 6G-Research Visions", https://arxiv.org/pdf/2004.14247.pdf

6G – perspectives and challenges

Spectrum, physical layer(cont'd)

- **Enablers at the Infrastructure Level**
  - Ultra-Massive MIMO and Holographic Radio
    - Beamforming beyond the Beam-Space Paradigm
    - Holographic Radio
  - Intelligent Reacting Surfaces
  - User-Centric and Scalable Cell-Free Networking
    - Cell-Free Initial Access
    - Implementation Challenges
  - Integrated Access and Backhaul
  - Integrated Space and Terrestrial Networks
  - Integrated Broadcast and Multicast Networks

Source: N.Rajatheva et al., "White Paper on Broadband Connectivity in 6G- Research Visions",
https://arxiv.org/pdf/2004.14247.pdf

6G – perspectives and challenges: Architectural aspects

Enabling Technology	Potential	Challenges	Use cases
Innovative Network Architectures			
Multi-connectivity and cell-less architecture	Seamless mobility and integration of different kinds of links	Scheduling, need for new network design	Pervasive connectivity, unmanned mobility, holographic telepresence, eHealth
3D network architecture	Ubiquitous 3D coverage, seamless service	Modeling, topology optimization and energy efficiency	Pervasive connectivity, eHealth, unmanned mobility
Disaggregation and virtualization	Lower costs for operators for massively-dense deployments	High performance for PHY and MAC processing	Pervasive connectivity, holographic telepresence, industry 4.0, unmanned mobility
Advanced access-backhaul integration	Flexible deployment options, outdoor-to-indoor relaying	Scalability, scheduling and interference	Pervasive connectivity, eHealth
Energy-harvesting and low-power operations	Energy-efficient network operations, resiliency	Need to integrate energy source characteristics in protocols	Pervasive connectivity, eHealth
Intelligence in the network			
Learning for value of information assessment	Intelligent and autonomous selection of the information to transmit	Complexity, unsupervised learning	Pervasive connectivity, eHealth, holographic telepresence, industry 4.0, unmanned mobility
Knowledge sharing	Speed up learning in new scenarios	Need to design novel sharing mechanisms	Pervasive connectivity, unmanned mobility
User-centric network architecture	Distributed intelligence to the end-points of the network	Real-time and energy-efficient processing	Pervasive connectivity, eHealth, industry 4.0
Not considered in 5G		With new features/capabilities in 6G	

6G proposes significant innovative architectures versus 5G

Source: M. Giordani, et al., "Toward 6G Networks:Use Cases and Technologies", IEEE Communications Magazine , March 2020

THANK YOU !

References

1. H.Saarnisaari, "Overview of 6G activities", SaT5G demo event Feb 6, 2020, Zodiac Aerospace, Wessling, Germany, https://www.sat5g-project.eu/wp-content/uploads/2020/02/2020.02.06_Sat5G-workshop-Oulu.pdf
2. M. Giordani,et al., "Toward 6G Networks:Use Cases and Technologies", IEEE Communications Magazine, March 2020
3. N.Rajatheva et al., "White Paper on Broadband Connectivity in 6G- Research Visions", https://arxiv.org/pdf/2004.14247.pdf
4. Matti Latva-aho, Kari Leppänen, "KEY DRIVERSAND RESEARCH CHALLENGES FOR 6G UBIQUITOUS WIRELESS INTELLIGENCE", 2019, http://jultika.oulu.fi/files/isbn9789526223544.pdf
5. M.H. Alsharif et al., "Sixth Generation (6G)Wireless Networks:Vision, Research Activities, Challenges and Potential Solutions", https://www.mdpi.com/2073-8994/12/4/676
6. K.B. Letaief, et al., "The Roadmap to 6G:AI Empowered Wireless Networks", IEEE Communications Magazine , August 2019
7. B.Aazhang, P.Ahokangas, et al., "Key drivers and research challenges for 6G ubiquitous wireless intelligence (white paper)", https://www.researchgate.net/publication/336000008_Key_drivers_and_research_challenges_for_6G_ubiquitous_wireless_intelligence_white_paper
8. Seppo Yrjölä et al., (Ed) " WHITE PAPER ON BUSINESS OF 6G- 6G Research Visions", No. 3June 2020, https://arxiv.org/ftp/arxiv/papers/2005/2005.06400.pdf

SoftNet 2020

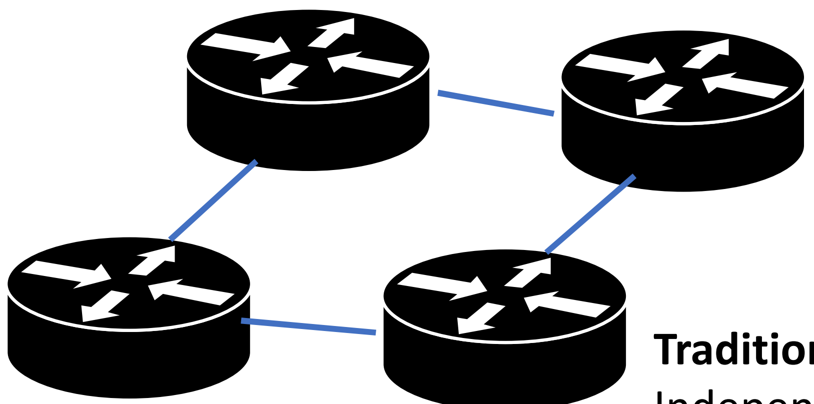
Next Generation SDN Execution Models, a Necessity for Future Growth or a Let Down?

Jorge A. Cobb
The University of Texas at Dallas, USA
jcobb@utdallas.edu

Traditional vs. Software Defined Networks

SoftNet 2020

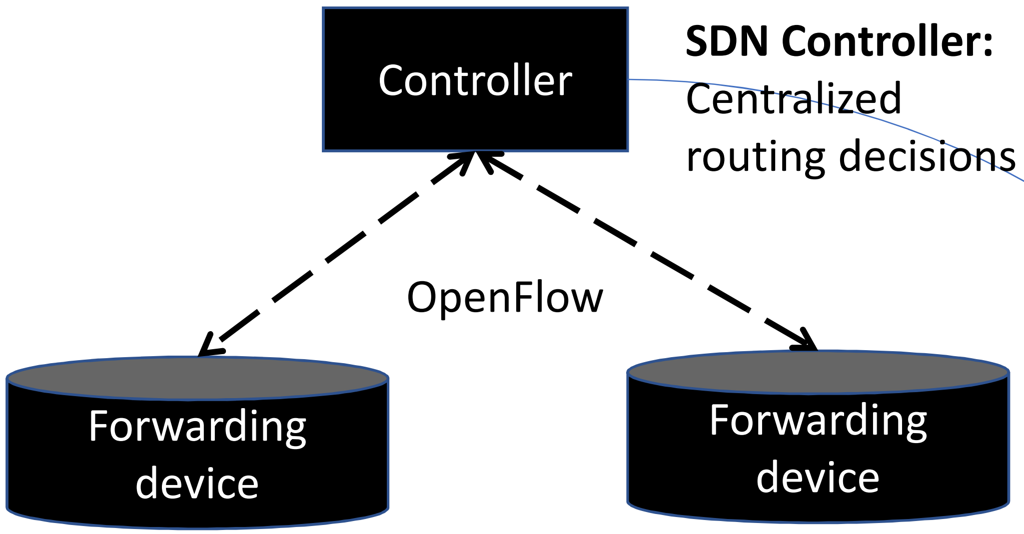
- Traditional networks:
  - Each router is independent
  - Routes are determined via a global distributed routing algorithm
  - Routing algorithms are typically vendor-specific
  - The routing algorithms are generic
    - Detailed specific needs of users are not taken into consideration.



Traditional Router: Independent, distributed routing decisions

Traditional vs. Software Defined Networks (SDN)

- SDN decouples the brain of the router from its forwarding capabilities



Forwarding Table

Match Fields	Actions	Priorities
In_port 2 and IP addr = X	Forward to Out_port 3	1

Flow entries

- Forwarding devices are "dumb"
  - They have a simple table of rules
  - If a packet's fields matches the values of the rule then the action is taken.
- If a packet does not match a rule?
  - Send a message to the controller asking for help
  - Controller returns a rule to be added to the forwarding table of the device.
- The controller sets up forwarding rules at each device in order to:
  - Balance traffic
  - Enforce security restrictions
  - Etc.

Software Defined Networks Issues

- Consistency
  - If rules are defined by system programmers, and are complex, the rules can be inconsistent with each other.
  - Algorithms and methodologies are needed to check for this consistency.
- Atomicity of action
  - If a new set of rules is deployed, it should be deployed in an atomic way
    - Packet atomicity: if a packet enters the network via a forwarding device with the old set of rules, it should be processed by the old rules along its entire path. If the packet enters the network via a device with the new set of rules, it should be processed by the new rules along its entire path.
    - Flow atomicity: all the packets of a flow should be treated the same: all by the old rules, or all by the new rules.
- Programmability
  - Defining rules for each forwarding device is difficult and error prone.
    - Skilled personnel is difficult to find.
  - Programming models and languages are necessary to define *what* is desired, and let the system *automatically* generate the rules.

Blurring the line between controller and forwarding devices

SoftNet 2020

- Typically the controller has all the intelligence.
- However, the line can be drawn in multiple places
  - A greater degree of intelligence can be given to the forwarding device
  - The controller is still totally in charge.
  - This offloads some of the computation required at the controller.
- One enhancement is adding a finite state machine per flow
  - When a flow first arrives, the controller downloads a finite state machine to be added to the rule tables of the forwarding device
  - Using the finite state machine, the flow can be treated differently at different stages of its lifetime, without the need to involve the controller.
- Useful for, among many others:
  - Firewalls, port knocking
  - Throttling of flows
  - Reacting to security attack patterns

IARIA

Points to ponder …

- What is the right balance between flexibility and control?
  - How much power should we add to the forwarding device?
  - Too much power makes the hardware slower but reduces load on the controller.
- Programming SDN switches is hard enough as it is
  - Will increasing the power of the forwarding device make it more difficult to manage/program ?
  - Will it become undecidable?
- Can hybrid systems interact well together?
  - Part of the network may be a legacy network, other parts normal SDN, and other parts enhanced SDN.
- Can machine learning play a role? (it is used practically everywhere nowadays …)
  - Can we enforce consistency/sanity of the rules and state-machines if we allow machine learning to help in SDN programming?

A few references …

- Salvatore Pontarelli et. al., "FlowBlaze: Stateful Packet Processing in Hardware", *USENIX Symposium on Networked Systems Design and Implementation (NSDI '19)*
- Maurantonio Caprolu, Simone Raponi, and Roberto Di Pietro, "FORTRESS: An efficient and distributed firewall for stateful data plane SDN", *Security and Communication Networks*, Feb. 2019.
- Arashloo, Yaron Koral, Michael Greenberg, Jennifer Rexford, and David Walker, "SNAP: Stateful Network-Wide Abstractions for Packet Processing", *SIGCOMM '16.*
- Masoud Moshref, Apoorv Bhargava, Adhip Gupta, Minlan Yu, Ramesh Govindan, "Flow-level State Transition as a New Switch Primitive for SDN", *HotSDN'14.*