Hot Topics in Networking

16/03/2023

Prof. Christian Rothenberg (FEEC/UNICAMP)

https://intrig.dca.fee.unicamp.br/

UNICAMP

INTRIG INFORMATION & NETWORKING TECHNOLOGIES RESEARCH & INNOVATION GROUP

Agenda

- Motivation, Objectives & Disclaimers [5’]
- Hot Topics in Networking [30’]
  - Methodology
  - Overview of key Concepts and Sample Publications
- Current Best Practices & Trends in Scientific Events [10’]
- Q&A [5’]

Motivation & Objectives

Following the **state of the art** is paramount for

- **sound** and **impact** scientific practices
- informed **strategic R&D** decisions

This talk seeks two main contributions:

- 10,000 foot view of **10 selected hot topics** in networking
  - incl. methodology for hot topic identification!
- Overview of **recent practices in scientific events**

From my side, this talk has one main expectation:

- Each of the attendees (largely diversified group!) will get at least one valuable take-away for future actions / time investments

Disclaimers

- What is a hot topic in networking?
  - ???
- What is not a hot topic but...
  - A core, relevant, critical (traditional, fundamental) topic (e.g., routing, security, etc.)

- This talk is a personal, subjective (certainly biased) view on a non-exhaustive list of potential current hot topics and evolving practices in scientific events in the area of networking and distributing systems.
- The views presented here do not correspond those of my employers, collaborators, or funders of the INTRIG research group (e.g. RNP, Ericsson, Padtec, etc.)

Hot Topics in Networking

Methodology (by INTRIG / FEEC)

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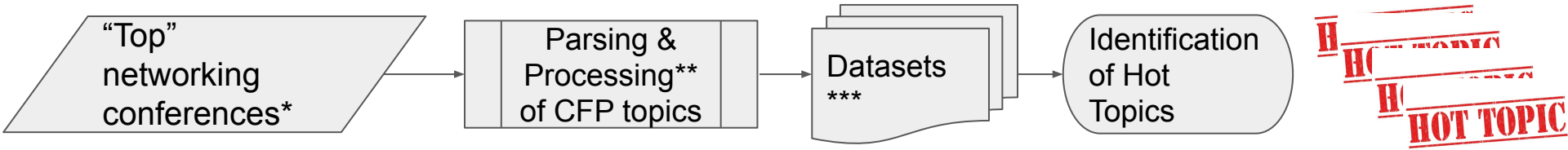
INFORMATION & NETWORKING TECHNOLOGIES RESEARCH & INNOVATION GROUP



* Demanda para CE-ReSD (Alberto Egon Schaeffer et al.)
https://docs.google.com/spreadsheets/d/15F9CE1ou_jyMvw7g3AerfV1uxvqO2888woHrw0h0w5o/edit#gid=2122635417

** Shell scripts by PhD candidate Rossano Pablo Pinto: https://github.com/rossanx/hottopics

***
https://docs.google.com/spreadsheets/d/1QTi58zVWPVe8m2QXvoQ5PP4EgjvfyjJEEsuqZcQnfeo/edit#gid=2059275233

Curious about Networking Conferences Statistics (#submissions, %acceptance rate, etc.) ?
https://sites.cs.ucsb.edu/~almeroth/conf/stats/

Selected Hot Topics
(In no specific order but slightly grouped)

1. **Intent-based Networking** (Closed-loop operations, Self-Driving Networking, Intent-based Management, Smart Networks)
2. **ZTM** (Zero-Touch Management)
3. **Digital Twins** (Networking for Digital Twins & Network Digital Twins)
4. **Metaverse**
5. **Blockchain Networking**
6. **AI/ML** (Network protocols meet AI/ML, Machine Learning for Networking)
7. **High precision networking** (Industrial Networks, TSN, precision telemetry)
8. **Quantum** Communications & Computing
9. **6G** (Beyond 5G)
10. **OpenRAN**

HotNets 2022:

Twenty-First ACM Workshop on Hot Topics in Networks

November 14-15, 2022 — Austin, Texas, USA

HotNets 2022: Highlights

- CFP: 6-page submissions (must be blind)
  - https://conferences.sigcomm.org/hotnets/2022/cfp.html

... "*We invite researchers and practitioners to submit short position papers. We encourage papers that identify fundamental open questions, advocate a new approach, offer a constructive critique of the state of networking research, re-frame or debunk existing work, report unexpected early results from a deployment, report on promising but unproven ideas, or propose new evaluation methods.*
Novel ideas need not be supported by full evaluations; well-reasoned arguments or preliminary evaluations can support the possibility of the paper's claims.
...
We seek early-stage work, where the authors can benefit from community feedback. An ideal submission has the potential to open a line of inquiry for the community that results in multiple conference papers in related venues (SIGCOMM, NSDI, CoNEXT, SOSP, OSDI, MobiCom, MobiSys, etc.), rather than a single follow-on conference paper. The program committee will explicitly favor early work and papers likely to stimulate reflection and discussion over "conference papers in miniature" "...

HotNets 2022: Highlights

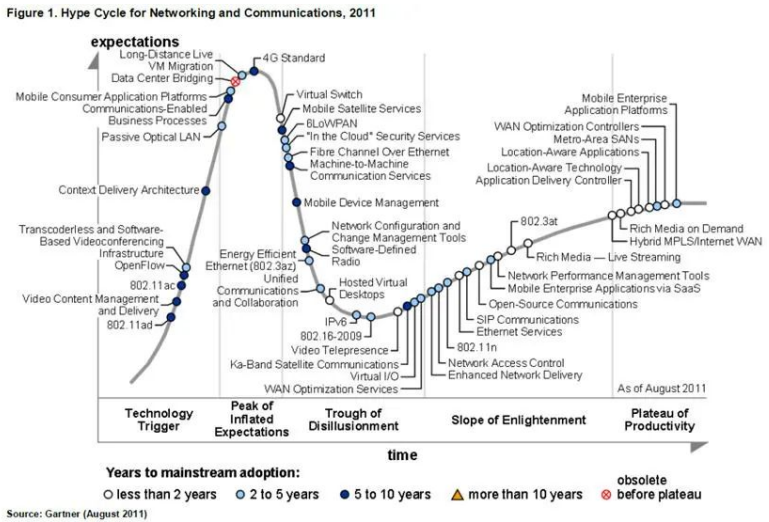
- Program: https://conferences.sigcomm.org/hotnets/2022/program.html
- Position papers: Mixed Academy & Industry collaborations

- ❏ Session 1: Web Next - decentralized, privacy-preserving, and resilient
- ❏ Session 2: Rethinking the Internet
- ❏ Session 3: Demystifying the network - the theory, models & testing
- ❏ Session 4: Digital Twinning the Network - can we perfect it?
- ❏ Session 5: ML for networking – can “transformers” transform networks?
- ❏ Session 6: Programming Networks at Scale
- ❏ Session 7: Towards NextG Wireless and Cellular Systems
- ❏ Session 8: Cloud Networks 2.0
- ❏ Session 9: Keeping up with ever-increasing performance demands

Hot Topics

Aka. Hype topics or “State-of-the art Radar”

Gartner



CPQD

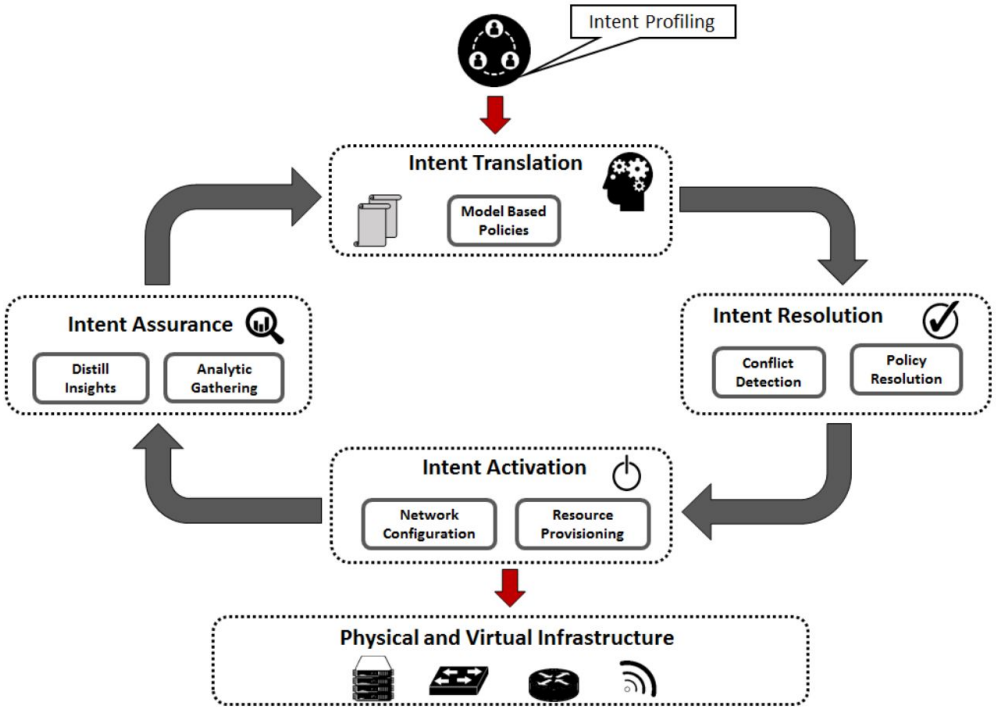
https://ia377-feec-unicamp.github.io/seminars/2023/03/23/Seminar-2-Radar-CPQD.html

IBN: Intent-based Networking

IBN: Intent-based Networking

Concept Overview

- “Evolution” of SDN
- Control loop architecture
- Automation
- High-level declarative Language
- Model-based Networking



Intent-based Networking
Selected Publication

A. Leivadeas and M. Falkner, "A Survey on Intent Based Networking," in IEEE Communications Surveys & Tutorials, 2022, doi: 10.1109/COMST.2022.3215919.

A Survey on Intent Based Networking

Aris Leivadeas, *Senior Member, IEEE,* Matthias Falkner

***Abstract*—Current and future network services and applications are expected to revolutionize our society and lifestyle. At the same time, the abundant possibilities that new network technologies offer to end users, network operators and administrators have created a cumbersome network configuration process to accommodate all different stakeholders and applications. Thus, lately, there is a need to simplify the management and configuration of the network, through possibly an autonomic and automatic way. Intent Based Networking (IBN) is such a paradigm that envisions flexible, agile, and simplified network configuration with minimal external intervention. This paper provides a detailed survey of how the IBN concept works and what are the main components to guarantee a fully autonomous IBN system (IBNS). Particular emphasis is given on the intent expression, intent translation, intent resolution, intent activation and intent assurance components, which form the closed loop automation system of an IBNS. The survey concludes with identifying open challenges and future directions of the problem at hand.**

***Index Terms*—Intent Based Networking, Network Policies, Network assurance, Network Automation**

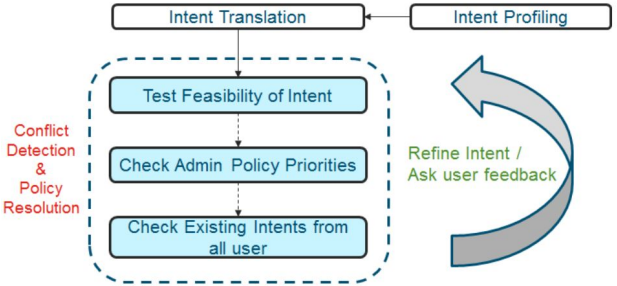
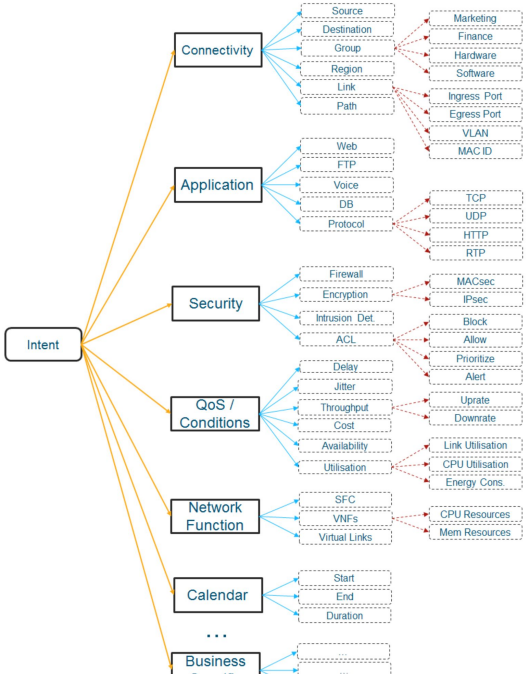


Fig. 12: Policy's Closed Loop Automation

behavior [2]? Is the expressed intent tightly coupled to the author's experience (e.g. expert level operator vs. novice first level support)?

Second, assuming the intent has been captured in an acceptable form, how can multiple intent expressions be disambiguated? Intent authors with different skill sets or experience



Intent-based Networking
Selected Standardization work

C. Li
China Telecom
O. Havel
A. Olariu
Huawei Technologies
P. Martinez-Julia
NICT
J. Nobre
UFRGS
D. Lopez
Telefonica, I+D
October 2022

RFC 9315 (Informational), October 2022

Intent-Based Networking - Concepts and Definitions

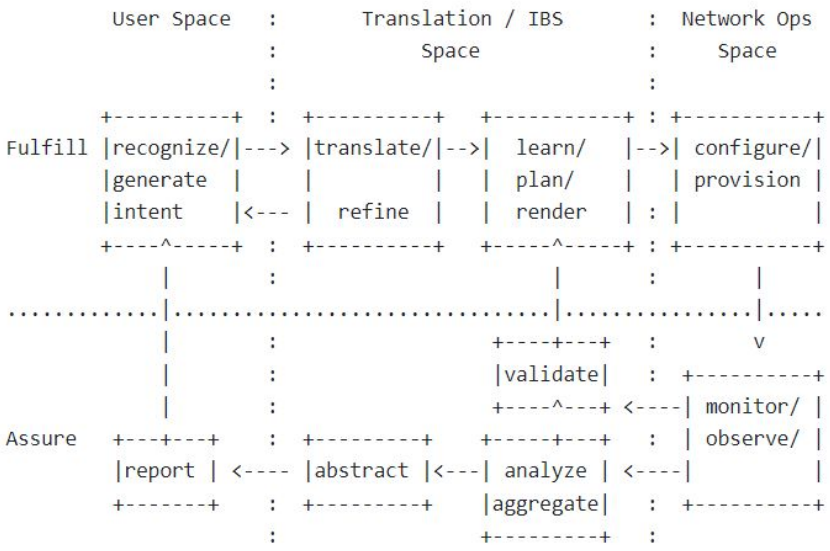


Figure 1: Intent Life Cycle

Source: https://datatracker.ietf.org/doc/rfc9315/

RFC 9316 (Informational), October 2022

Intent Classification

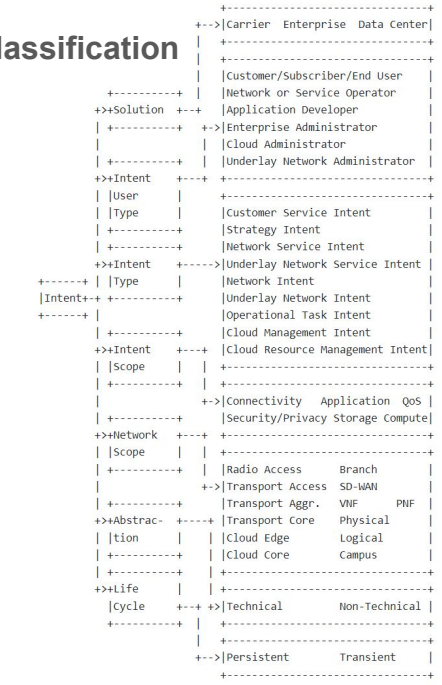


Figure 2: Intent Taxonomy

https://datatracker.ietf.org/doc/rfc9316/

ZTM - Zero Touch Management

Zero Touch Management
Selected Publication

E. Coronado et al., "Zero Touch Management: A Survey of Network Automation Solutions for 5G and 6G Networks," in IEEE Communications Surveys & Tutorials, vol. 24, no. 4, pp. 2535-2578, Fourthquarter 2022, doi: 10.1109/COMST.2022.3212586.

Zero Touch Management: A Survey of Network Automation Solutions for 5G and 6G Networks

Estefanía Coronado, *Member, IEEE*, Rasoul Behravesh, Tejas Subramanya, Adriana Fernàndez-Fernàndez, Muhammad Shuaib Siddiqui, Xavier Costa-Pérez, and Roberto Riggio, *Senior Member, IEEE*

***Abstract*—Mobile networks are facing an unprecedented demand for high-speed connectivity originating from novel mobile applications and services and, in general, from the adoption curve of mobile devices. However, coping with the service requirements imposed by current and future applications and services is very difficult since mobile networks are becoming progressively more heterogeneous and more complex. In this context, a promising approach is the adoption of novel network automa-**

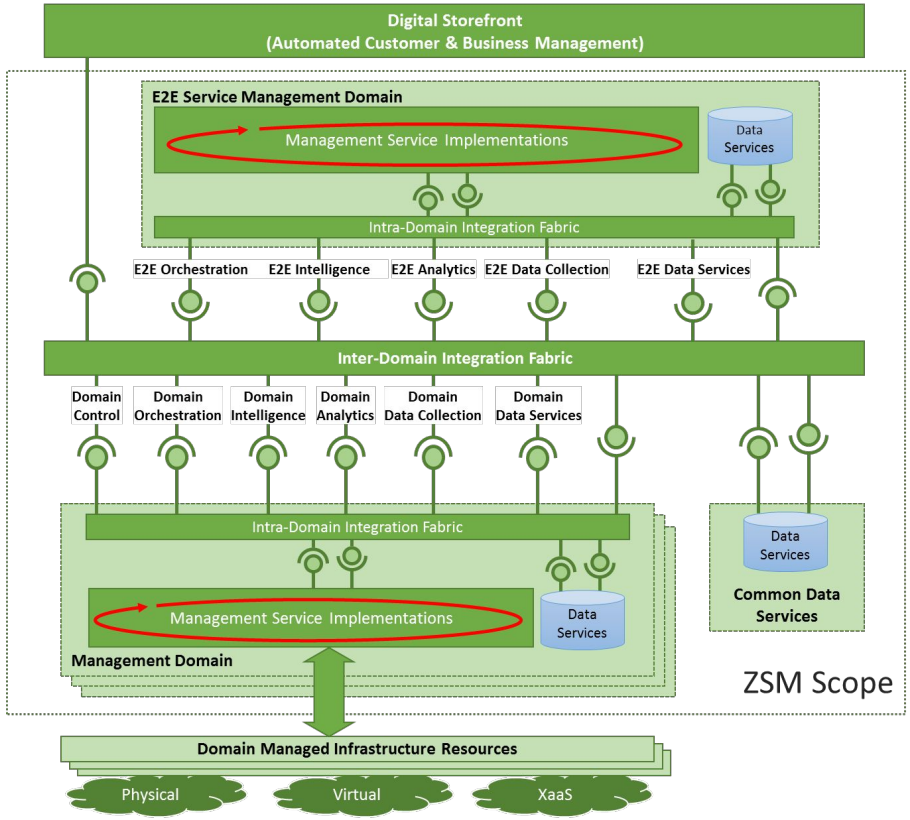
I. Introduction

THE CURRENT Internet is a marvelous piece of engineering, connecting billions of people around the world. It is a gigantic feat and consists of many complex, interacting pieces of hardware and software, from the optical links, switches, routers, radio base stations, hosts, and the hundreds of other

Zero Touch Management

Selected Standardization work

ETSI Zero touch network & Service Management (ZSM)



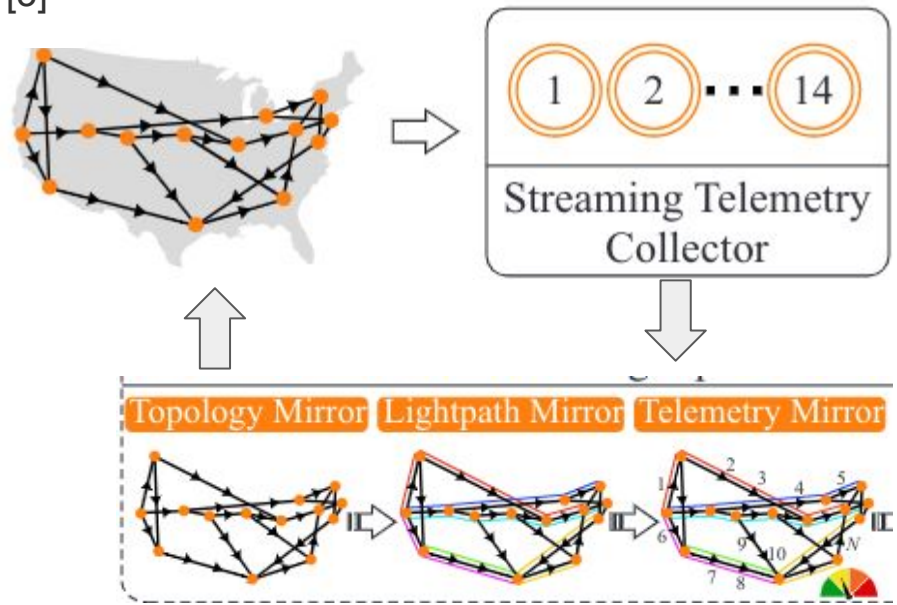
Source: https://www.etsi.org/technologies/zero-touch-network-service-management

(Network) Digital Twins - NDT

Network Digital Twins
Concept Overview

- **Digital mirror of the network**
- Virtual instance of a physical system that is continually updated throughout the physical system's life cycle with:
  - the latter's performance
  - maintenance
  - health status [1]
- Realizes co-evolution between physical and virtual spaces through:
  - DT modeling
  - communication
  - computing/data processing technologies [2]

[3]



[1] Digital Twin Network: Concepts and Reference Architecture - https://www.ietf.org/id/draft-irtf-nmrg-network-digital-twin-arch-02.html
[2] Digital Twin Networks: A Survey - https://ieeexplore.ieee.org/document/9429703
[3] ML-based soft-failure localization with partial SDN telemetry - https://opg.optica.org/jocn/abstract.cfm?URI=jocn-13-10-e122

Network Digital Twins

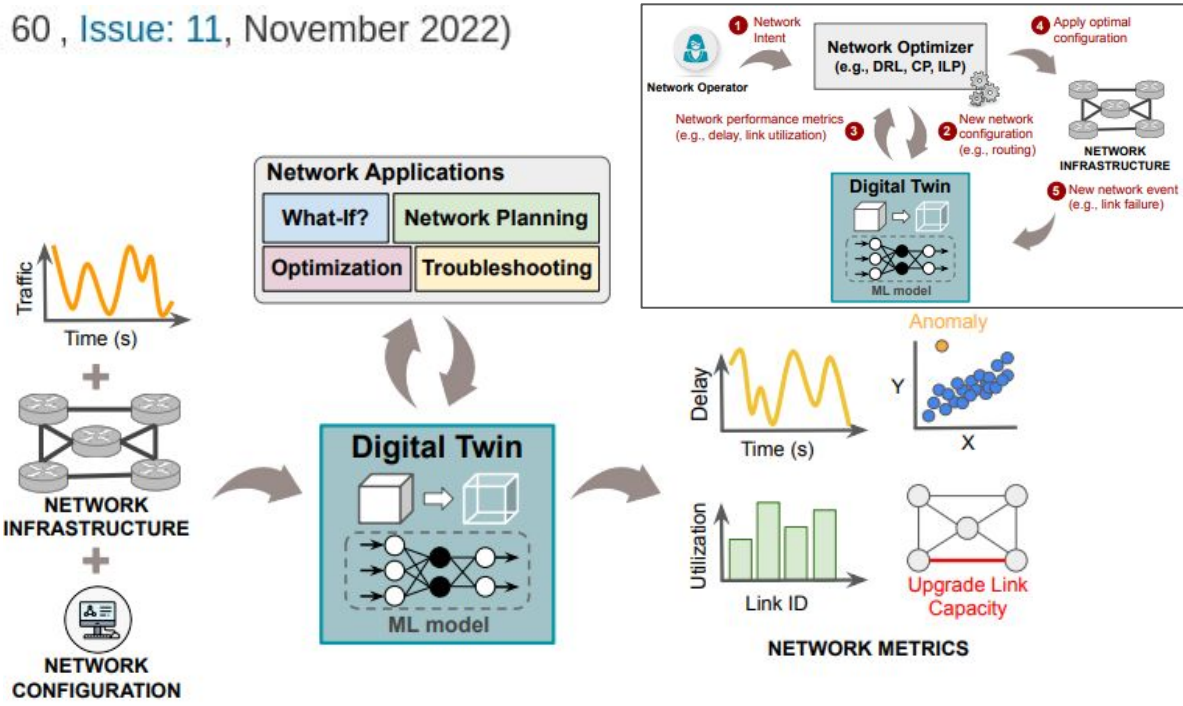
Selected Publication

Network Digital Twin: Context, Enabling Technologies and Opportunities

Paul Almasan, Miquel Ferriol-Galmés, Jordi Paillisse, José Suárez-Varela, Diego Perino, Diego López, Antonio Agustin Pastor Perales, Paul Harvey, Laurent Ciavaglia, Leon Wong, Vishnu Ram, Shihan Xiao, Xiang Shi, Xiangle Cheng, Albert Cabellos-Aparicio, Pere Barlet-Ros

IEEE Communications Magazine (Volume: 60 , Issue: 11, November 2022)

***Abstract*—The proliferation of emergent network applications (e.g., telesurgery, metaverse) is increasing the difficulty of managing modern communication networks. These applications entail stringent network requirements (e.g., ultra-low deterministic latency), which hinders network operators to manage their resources efficiently. In this article, we introduce the network digital twin (NDT), a renovated concept of classical network modeling tools whose goal is to build accurate data-driven network models that can operate in real-time. We describe the general architecture of the NDT and argue that modern machine learning (ML) technologies enable building some of its core components. Then, we present a case study that leverages a ML-based NDT for network performance evaluation and apply it to routing optimization in a QoS-aware use case. Lastly, we describe some key open challenges and research opportunities yet to be explored to achieve effective deployment of NDTs in real-world networks.**



Network Digital Twins

Selected Standardization work

Workgroup: Internet Research Task Force
Internet-Draft: draft-irtf-nmrg-network-digital-twin-arch-02
Published: 24 October 2022
Intended Status: Informational
Expires: 27 April 2023

Authors:

C. Zhou, *China Mobile*
H. Yang, *China Mobile*
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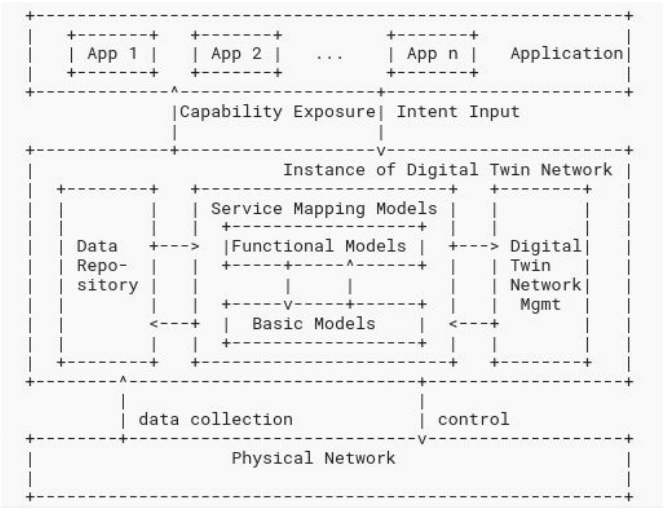
D. Lopez, *Telefonica I+D*
A. Pastor, *Telefonica I+D*
Q. Wu, *Huawei*
M. Boucadair, *Orange*
C. Jacquenet, *Orange*



Digital Twin Network: Concepts and Reference Architecture

Abstract

Digital Twin technology has been seen as a rapid adoption technology in Industry 4.0. The application of Digital Twin technology in the networking field is meant to develop various rich network applications and realize efficient and cost effective data driven network management and accelerate network innovation.

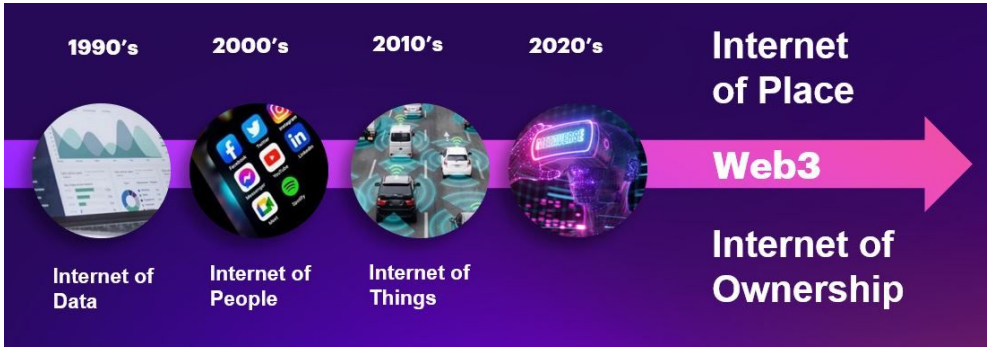
This document presents an overview of the concepts of Digital Twin Network, provides the basic definitions and a reference architecture, lists a set of application scenarios, and discusses the benefits and key challenges of such technology.

Metaverse

Metaverse: “The Future of Internet”

Concept Overview

- Fully immersive virtual world space;
  - Regarded as Web 3.0 Internet evolution
- Term first used by Neal Stephenson in his science fiction novel “*Snow Crash*” in 1992;
- Integrates multiple emerging technologies:
  - Digital twin: mimic real world;
  - VR/AR/MR: immersive 3D experience;
  - B5G: ultra-high reliable, ultra-low latency;
  - Wearable sensors: avatar interaction;
  - AI/ML: metaverse creation and rendering;
  - Blockchain/NFT: authentic rights;
- New metaverse business models
  - Marketing, Avatar, Digital goods / lands, NFTs, Tourism, Business Services, etc.
- Examples:
  - Meta - Facebook;
  - Microsoft mesh - Microsoft;
  - Omniverse - NVIDIA;
  - Games - Second Life, Roblox, VRChat;



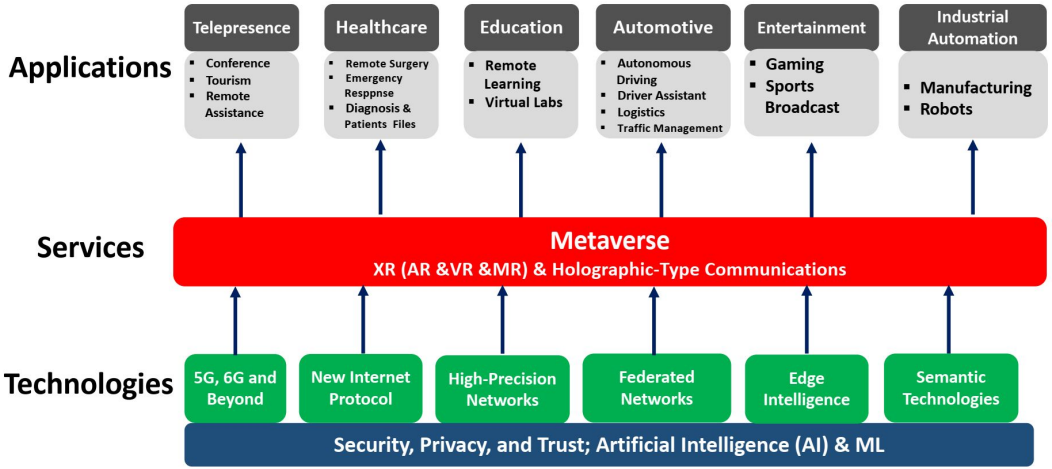


Image (Top): https://www.accenture.com/us-en/blogs/accenture-research/want-to-demystify-the-metaverse-hype-think-of-it-as-an-internet-evolution
Image (Bottom) :I.F. AKYILDIZ. “METAVERSE: Challenges for Extended Reality and Holographic-Type Communication in the Next Decade”

Metaverse

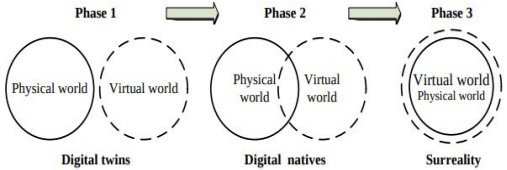
Selected Publication

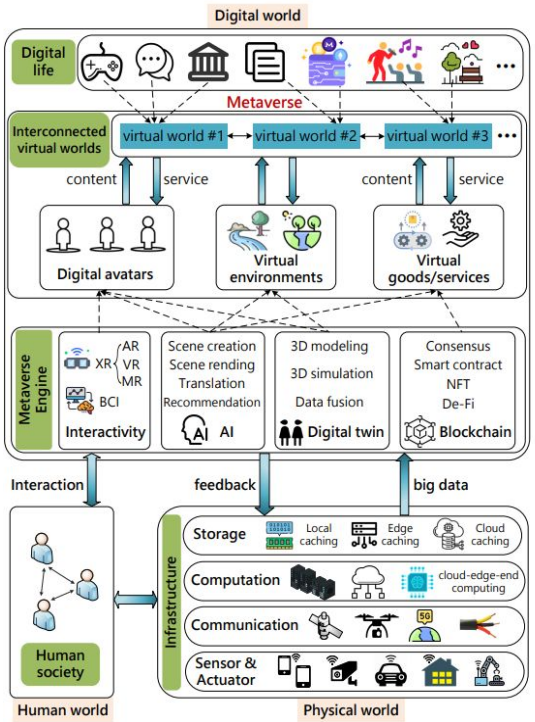
Wang, Yuntao, et al. "A survey on metaverse: Fundamentals, security, and privacy." IEEE Communications Surveys & Tutorials (2022).

A Survey on Metaverse: Fundamentals, Security, and Privacy

Yuntao Wang[†], Zhou Su[†*], Ning Zhang[‡], Rui Xing[†], Dongxiao Liu[§], Tom H. Luan[†], and Xuemin Shen[§]
[†]School of Cyber Science and Engineering, Xi'an Jiaotong University, Xi'an, China
[‡]Department of Electrical and Computer Engineering, University of Windsor, Windsor, ON, Canada
[§]Department of Electrical and Computer Engineering, University of Waterloo, Waterloo, ON, Canada
*Corresponding author: Zhou Su (zhousu@ieee.org)

***Abstract*—Metaverse, as an evolving paradigm of the next-generation Internet, aims to build a fully immersive, hyper spatiotemporal, and self-sustaining virtual shared space for humans to play, work, and socialize. Driven by recent advances in emerging technologies such as extended reality, artificial intelligence, and blockchain, metaverse is stepping from science fiction to an upcoming reality. However, severe privacy invasions and security breaches (inherited from underlying technologies or emerged in the new digital ecology) of metaverse can impede its wide deployment. At the same time, a series of fundamental challenges (e.g., scalability and interoperability) can arise in metaverse security provisioning owing to the intrinsic characteristics of metaverse, such as immersive realism, hyper spatiotemporality, sustainability, and heterogeneity. In this paper, we present a comprehensive survey of the fundamentals, security, and privacy of metaverse. Specifically, we first investigate a novel distributed metaverse architecture and its key characteristics with ternary-world interactions. Then, we discuss the security and privacy threats, present the critical challenges of metaverse systems, and review the state-of-the-art countermeasures. Finally, we draw open research directions for building future metaverse systems.**





Metaverse

Further relevant activities

IEEE International Conference on Metaverse Computing, Networking and Applications (IEEE MetaCom 2023)

https://www.ieee-metacom.org/2023/

IEEE SIG on Metaverse

https://www.ieee-metacom.org/sigmeta/

ACM SIG on Computer-Human Interaction (CHI)

https://doi.org/10.1145/3491101.3516399

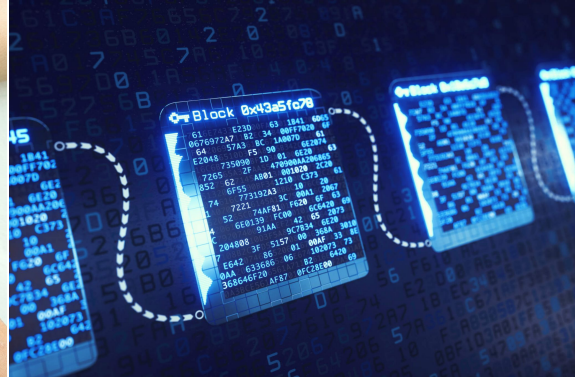
Telefonica Metaverse Days

https://metaverseday.telefonica.com/en

Blockchain Networks

Blockchains Networks

Concept Overview



- Based on P2P Networks;
- Creates a distributive ledger;
- Base of cryptocurrency;
- Works with consensus protocols;
- Blocks are immutable;
- General different network requirements than traditional networks:
    - Routing, Performance, Security, Topology;

Blockchain (Networking):

- Research in BC enablers / core components
- Application of BC to other systems (e.g. Metaverse, Network-Cloud Slicing Marketplaces, etc. etc)

Read more / Follow-up:

- RNP CT-Blockchain https://wiki.rnp.br/display/blockchain/CT-Blockchain

Blockchain Networks
Selected Publication

Maya Dotan, Yvonne-Anne Pignolet, Stefan Schmid, Saar Tochner, and Aviv Zohar. 2021. **Survey on Blockchain Networking: Context, State-of-the-Art, Challenges**. ACM Comput. Surv. 54, 5, Article 107 (June 2022), 34 pages. https://dl.acm.org/doi/10.1145/3453161

Survey on Blockchain Networking: Context, State-of-the-Art, Challenges

MAYA DOTAN, Hebrew University, Israel
YVONNE-ANNE PIGNOLET, DFINITY, Switzerland
STEFAN SCHMID, Faculty of Computer Science, University of Vienna, Austria
SAAR TOCHNER, Hebrew University, Israel
AVIV ZOHAR, Hebrew University, Israel

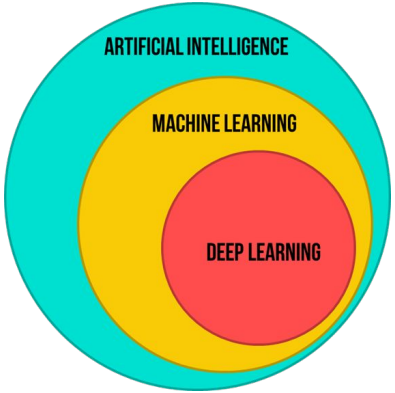
Blockchains in general and cryptocurrencies such as Bitcoin in particular are realized using distributed systems and hence critically rely on the performance and security of the interconnecting network. The requirements on these networks and their usage, however can differ significantly from traditional communication networks, with implications on all layers of the protocol stack. This paper is motivated by these differences, and in particular by the observation that many fundamental design aspects of these networks are not well-understood today. In order to support the networking community to contribute to this emerging application domain, we present a structured overview of the field, from topology and neighbor discovery, over block and transaction propagation, to sharding and off-chain networks, also reviewing existing empirical results from different measurement studies. In particular, for each of these domains, we provide the context, highlighting differences and commonalities with traditional networks, review the state-of-the-art, and identify open research challenges. Our paper can hence also be seen as a call-to-arms to improve the foundation on top of which blockchains are built.

HOT TOPIC

AI/ML

Network protocols meet AI/ML
Machine Learning for Networking
Networking for AI/ML (distributed) workloads

AI vs ML !



Machine Learning for Networking
Concept Overview

- Contribute to solving complex networking problems
- Allows systems to learn automatically
- Provides predictions or solutions based on experience
- Trends in prediction, intrusion detection, route and path assignment, Quality of Service improvement, and resource management, etc. etc.,
- ML Models have superior classification and optimization performance
- Remarkable Impact activities on “all” **Standardization** tracks
    - E.g., ITU, 3GPP, ETSI ENI, O-RAN, etc...
- Learn more:
    - Boutaba, R., Salahuddin, M.A., Limam, N. et al. A comprehensive survey on machine learning for networking: evolution, applications and research opportunities.JISA, 16 (2018). https://doi.org/10.1186/s13174-018-0087-2
    - RNP CT Comitê Técnico de Ciência de Dados e Inteligência Artificial

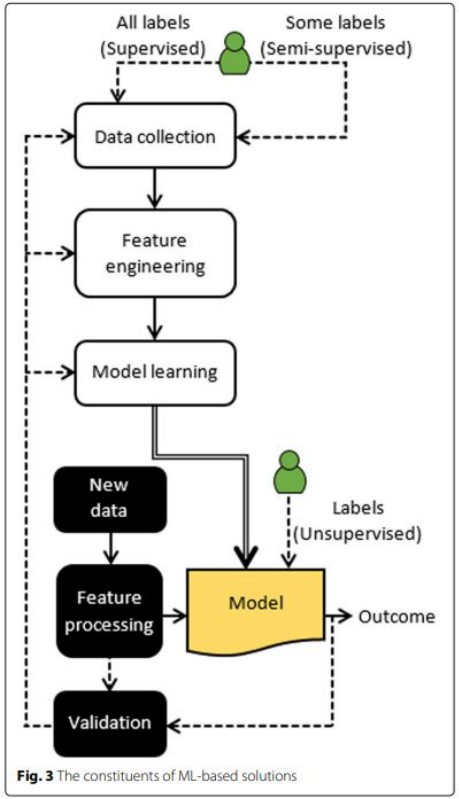


Fig. 3 The constituents of ML-based solutions

Machine Learning for Networking

Selected Publication

Applications of Machine Learning in Networking: A Survey of Current Issues and Future Challenges

M. A. RIDWAN[1], N. A. M. RADZI[2], (Senior Member, IEEE), F. ABDULLAH[2], (Senior Member, IEEE), AND Y. E. JALIL[2]

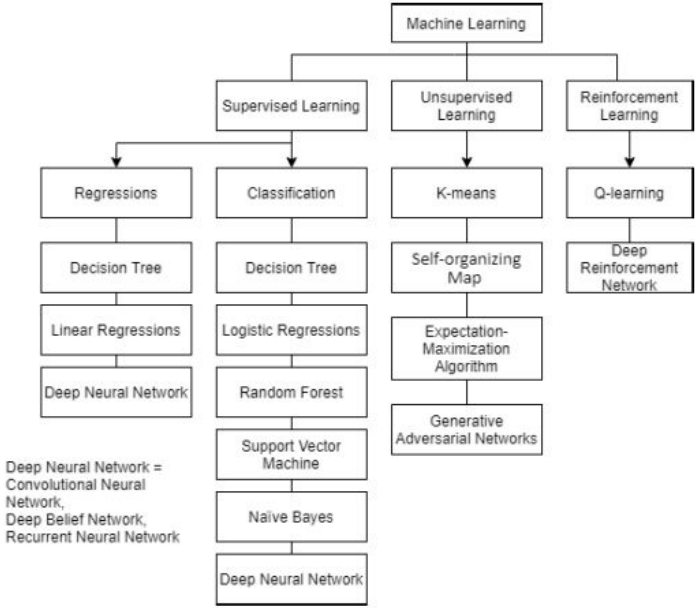
[1]Institute of Power Engineering, Universiti Tenaga Nasional, Kajang 43000, Malaysia
[2]Department of Electrical and Electronics Engineering, College of Engineering, Universiti Tenaga Nasional, Kajang 43000, Malaysia

Corresponding author: M. A. Ridwan (asyikin@uniten.edu.my)

This work was supported by the Universiti Tenaga Nasional Internal Grant RJO10517844057.

ABSTRACT Communication networks are expanding rapidly and becoming increasingly complex. As a consequence, the conventional rule-based algorithms or protocols may no longer perform at their best efficiencies in these networks. Machine learning (ML) has recently been applied to solve complex problems in many fields, including finance, health care, and business. ML algorithms can offer computational models that can solve complex communication network problems and consequently improve performance. This paper reviews the recent trends in the application of ML models in communication networks for prediction, intrusion detection, route and path assignment, Quality of Service improvement, and resource management. A review of the recent literature reveals extensive opportunities for researchers to exploit the advantages of ML in solving complex performance issues in a network, especially with the advancement of software-defined networks and 5G.

INDEX TERMS Machine learning algorithms, communication network, intrusion detection, routing, quality of service.

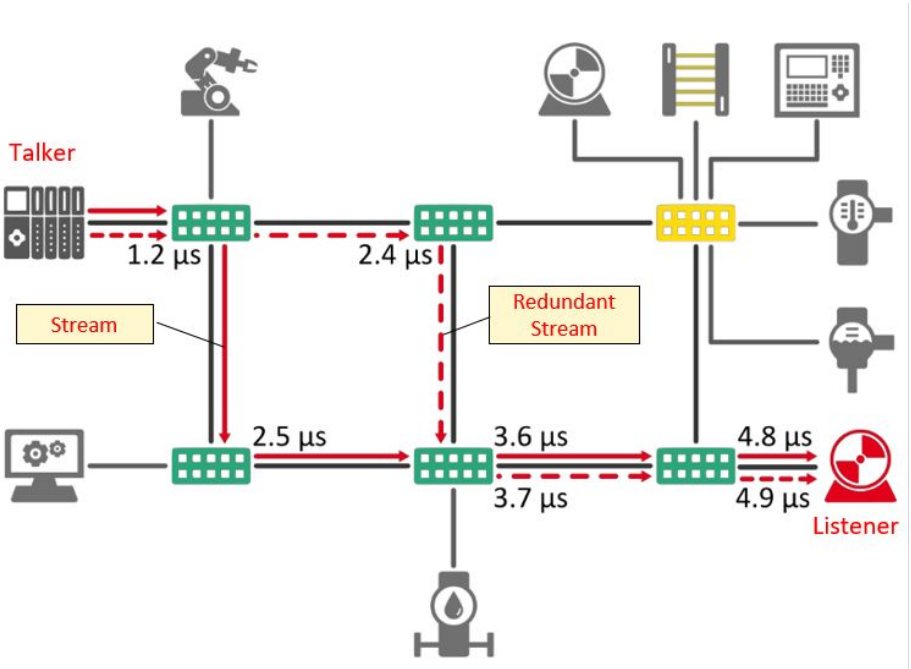


M. A. Ridwan, N. A. M. Radzi, F. Abdullah and Y. E. Jalil, "Applications of Machine Learning in Networking: A Survey of Current Issues and Future Challenges," in IEEE Access, vol. 9, pp. 52523-52556, 2021, doi: 10.1109/ACCESS.2021.3069210. https://ieeexplore.ieee.org/document/9388670

High Precision Networking

High Precision Networking
Concept Overview

- Near-deterministic and ultra-low end-to-end latency;
- Precise synchronization, coordination and phase-alignments;
- Low lost rate and High accuracy
- Applications with Low tolerance for degradations in service levels
- Standardization
  - IETF DetNet
  - IEEE TSN



High Precision Networking
Selected Publication

Alexander Clemm, “High Precision Networking Services: Problems, Approaches and Opportunities”, 2022, DOI 10.1109/TNSM.2022.3201435

High-Precision Networking Services: Problems, Approaches, and Opportunities

Alexander Clemm
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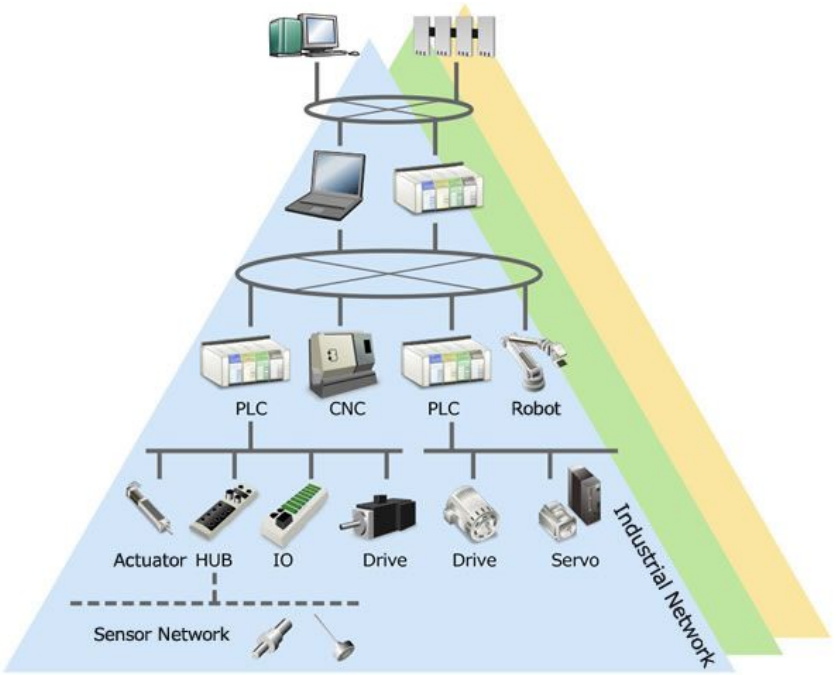
alex@futurewei.com

***Abstract*—One of the next waves of networking innovation is expected to be driven by the needs of applications that require communication services with stringent service level guarantees, for example near-deterministic and ultra-low end-to-end latency. Providing such services is riddled with challenges due to limitations with existing QoS mechanisms and application characteristics that are not tolerant of even slight degradation. In addition, to be deployable in practice, advances in accounting technology to be able to verify compliance of services with their guarantees will also be sorely needed, resulting in a separate set of challenges. This industry vision paper provides an overview of the problems, highlights some solution approaches, and articulates a set of very practical research challenges that, when successfully addressed, will have significant practical impact.**

***Index Terms*—High-Precision Communications, Accounting Management, QoS, Service Level Guarantees, Performance**

area where many opportunities lurk [4]. I
networking applications will become only
conjunction with networks that are able to suppo
precision services.

Examples of such high-precision networking
abound. Industrial Technology for factory floo
involves precision industrial controllers that rec
precisely timed control signals and actions that m
adjusted using feedback control loops. Placing su
logic into remote clouds connected via the Inter
desirable but remains elusive [5]. Telehaptics ma
operate equipment and machinery remotely
operators. To provide haptic feedback that provi
with a sense of touch necessary to operate th
confidently, strict latency bounds must be obse
which the ability for operation is not only degrad

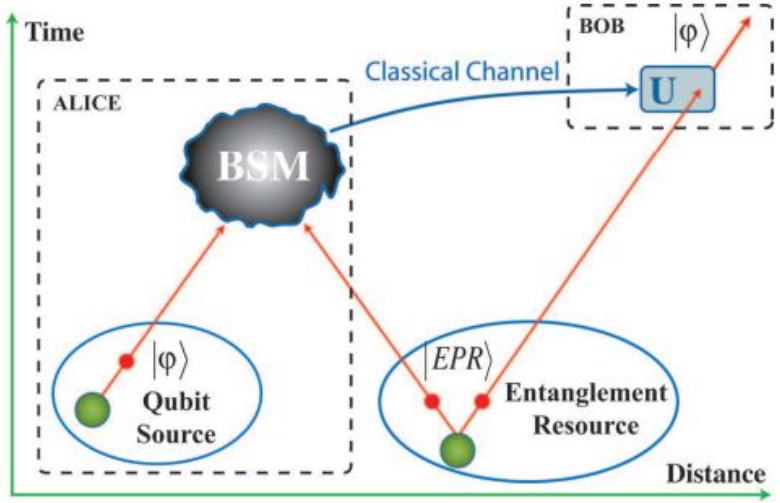


Quantum Communications

Quantum Communications

Concept Overview

- Uses quantum particles for communication;
- Based on quantum mechanics;
- Based on quantum computing and photonics;
- Uses quantum entanglement and teleportation for transmission;
- Low bandwidth but higher distance;
- Can be used for deep-space communication;
- Useful for cryptographic key distribution.



Quantum Communications

Selected Publication

A. Singh, K. Dev, H. Siljak, H. D. Joshi and M. Magarini, "Quantum Internet—Applications, Functionalities, Enabling Technologies, Challenges, and Research Directions," in IEEE Communications Surveys & Tutorials, vol. 23, no. 4, pp. 2218-2247, Fourthquarter 2021, doi: 10.1109/COMST.2021.3109944.

TABLE I
COMPARISON OF THIS SURVEY WITH OTHER RELATED SURVEYS

Topics	Basics of Quantum Mechanics	Qubit Technologies	Quantum entanglement	Quantum Teleportation	Quantum Repeaters	Quantum Channels	Quantum Memories	QKD	End Nodes	Quantum error correction
Laszlo Gyongyosi and Sandor Imre (2019) [44]	√						√			√
Stephanie Wehner (2018) *et al.* [2]			√	√	√	√	√	√	√	√
Robert Bedington (2017) *et al.* [52]			√	√	√			√		√
Valerio Scarani *et al.* (2009) [50]			√	√	√	√		√		√
Angela Sara Cacciapuoti *et al.* (2020) [47]	√		√	√	√		√	√		√
Stefano Pirandola *et al.* (2015) [46]		√	√	√	√			√		
Gerardo Adesso and Fabrizio Illuminati (2007) [51]	√		√	√	√			√		
Hoi-Kwong Lo *et al.* (2014) [54]			√	√				√		√
Laszlo Gyongyosi *et al.* (2018) [48]	√		√			√		√		√
Feihu Xu *et al.* (2020) [49]			√		√	√	√	√	√	√
Stefano Pirandola *et al.* (2020) [55]			√			√		√	√	√
Zunaira Babar *et al.* (2018) [56]	√		√							√
Nedasadat Hosseinidehaj *et al.* (2019) [53]	√		√			√	√	√	√	√
This Survey	√	√	√	√	√	√	√	√	√	√

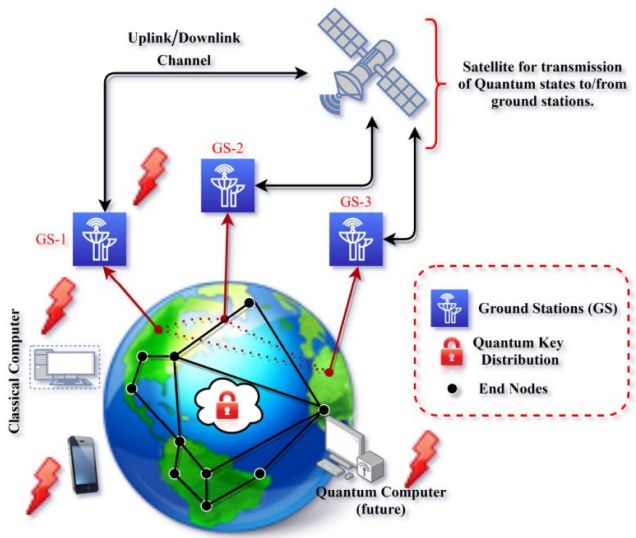


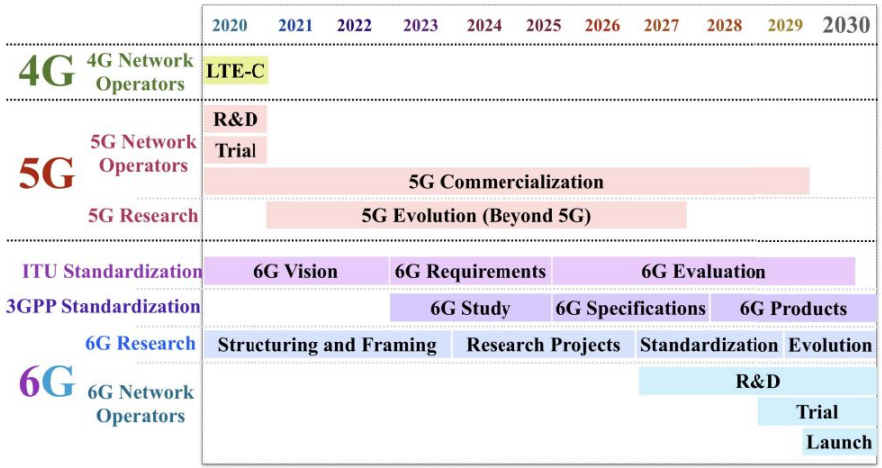
Fig. 2. Vision of future quantum Internet working in synergy with classical Internet.

6G
(B5G)

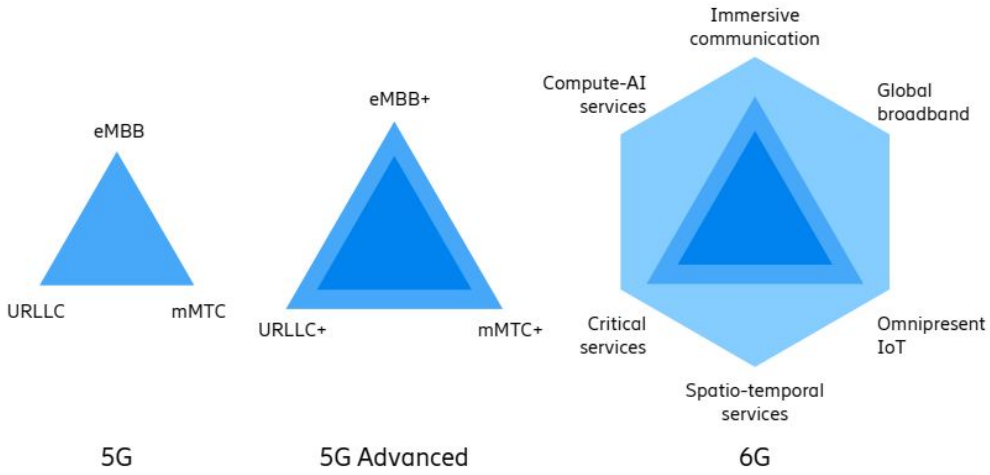
6G (Beyond 5G)
Concept Overview

6G is still a vision, no architecture or specifications yet (exp. 2025 - 2030).

Also referred to as Beyond 5G (B5G)...



Source: ALWIS et al.: SURVEY ON 6G FRONTIERS:



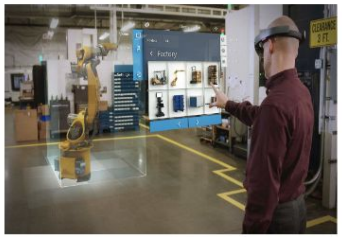
Source: Ericsson

6G

Use Cases

- Entertainment, sports, health care, tourism, education and e-commerce, etc.
- Automotive
- Manufacturing → e.g., training of personnel
- Education
- Gaming
- Remote health care
- Tourism; Real Estate
- Customer can try clothes or beauty products before buying
- How a piece of furniture looks in their living room
- Virtual Home Theater

IFA'2022



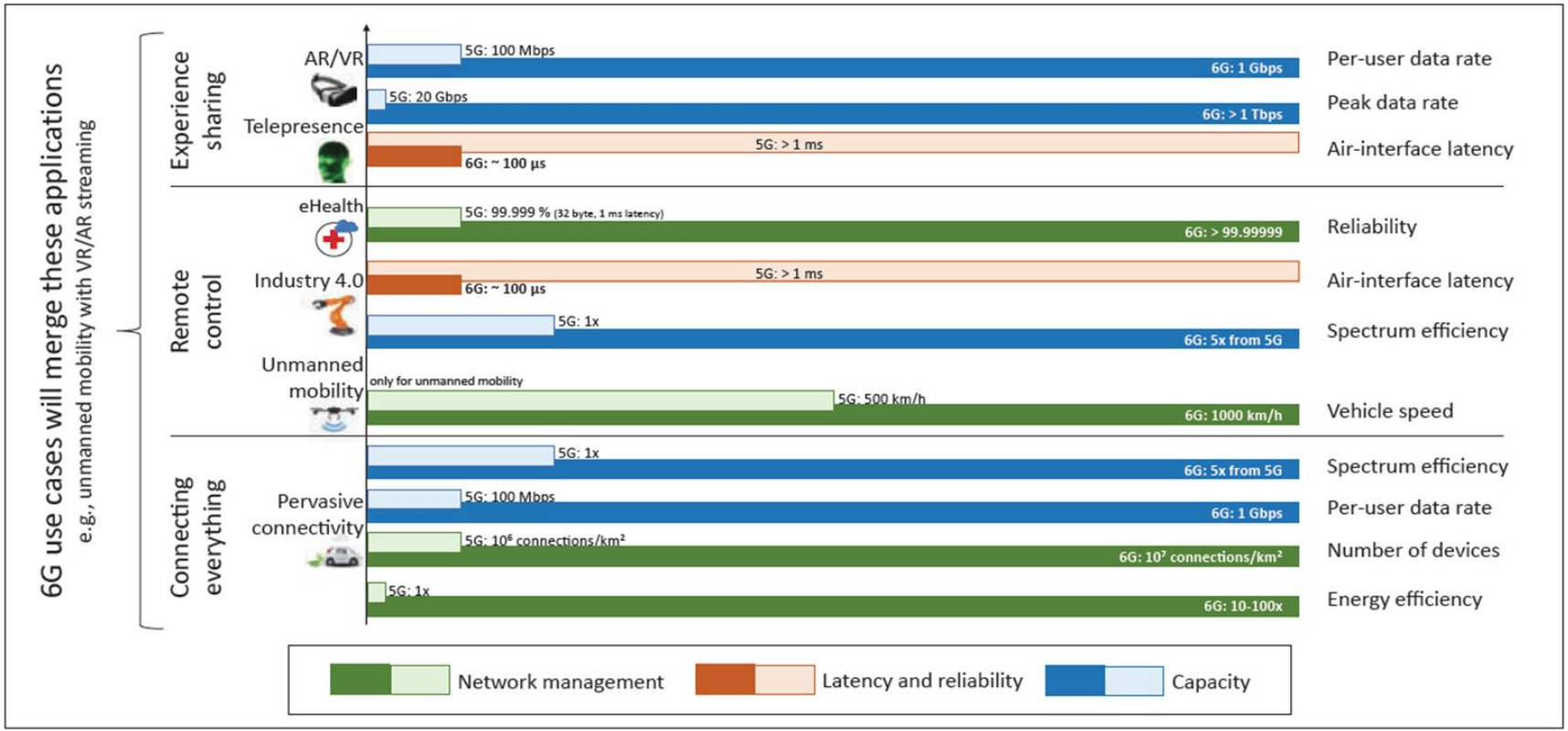




Source: Ian Akyildiz

6G

KPIs

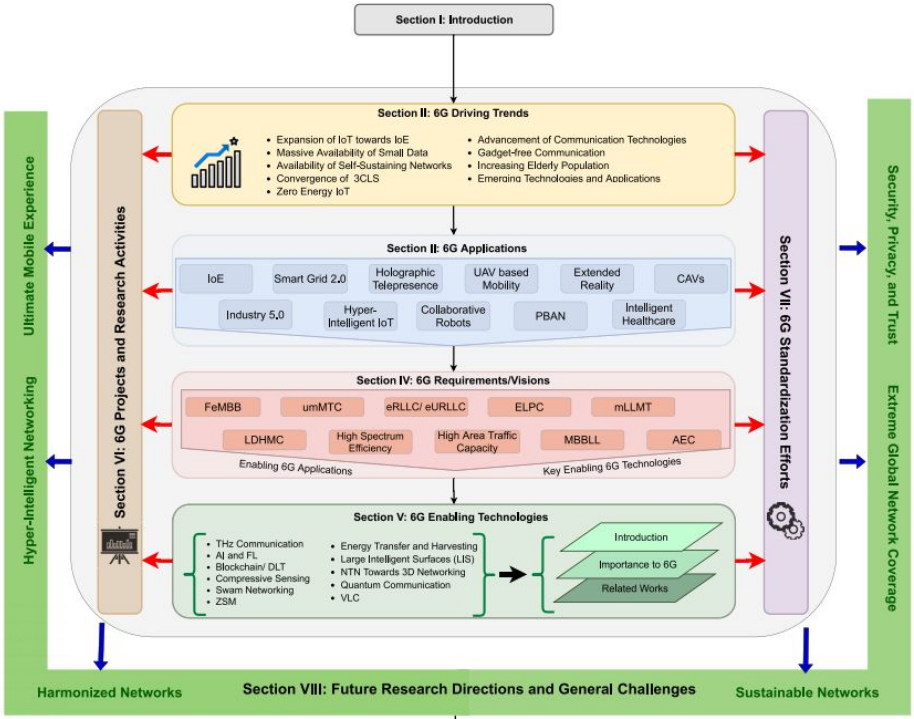


Source: M. Giordani, et al., "Toward 6G Networks:Use Cases and Technologies", IEEE Communications Magazine , March 2020

6G

Further Reading & Relevant Activities

- De Alwis, C., Kalla, A., Pham, Q. V., Kumar, P., Dev, K., Hwang, W. J., & Liyanage, M. (2021). Survey on 6G frontiers: Trends, applications, requirements, technologies and future research. IEEE Open Journal of the Communications Society, 2, 836-886. https://doi.org/10.1109/OJCOMS.2021.3071496
- 6G Flagship
  https://www.6gflagship.com/
- EU 6G SNS
  https://5g-ppp.eu/europe-scales-up-6g-research-investments-and-launches-35-new-projects-worth-e250-million/
- Brasil 6G (Inatel, RNP, MCTI)
  https://inatel.br/brasil6g/
- FAPESP-ERICSSON SMARTNESS 2030
  https://smartness2030.tech/



Open RAN

Open RAN (Concept Overview)

- Open RAN Movement (#oRAN):
  - Disaggregation;
  - Open Ecosystem;
  - Open Interface;
  - Decouple HW from SW;
  - Vendor diversity;
- O-RAN ALLIANCE (#O-RAN):
  - Foundation 2018;
  - Define specifications and standards;
  - 3GPP NR 7.2split as baseline;
  - Includes RAN intelligent controller (RIC);
- O-RAN Software Community (OSC):
  - O-RAN Alliance and Linux Foundation;
  - Provide open source software for RAN;
- ONF/SD-RAN (3rd Party):
  - Develop open source nRT-RIC;

Read more / Follow-up:

- OpenRAN Brasil
  https://www.rnp.br/projetos/openranbrasil

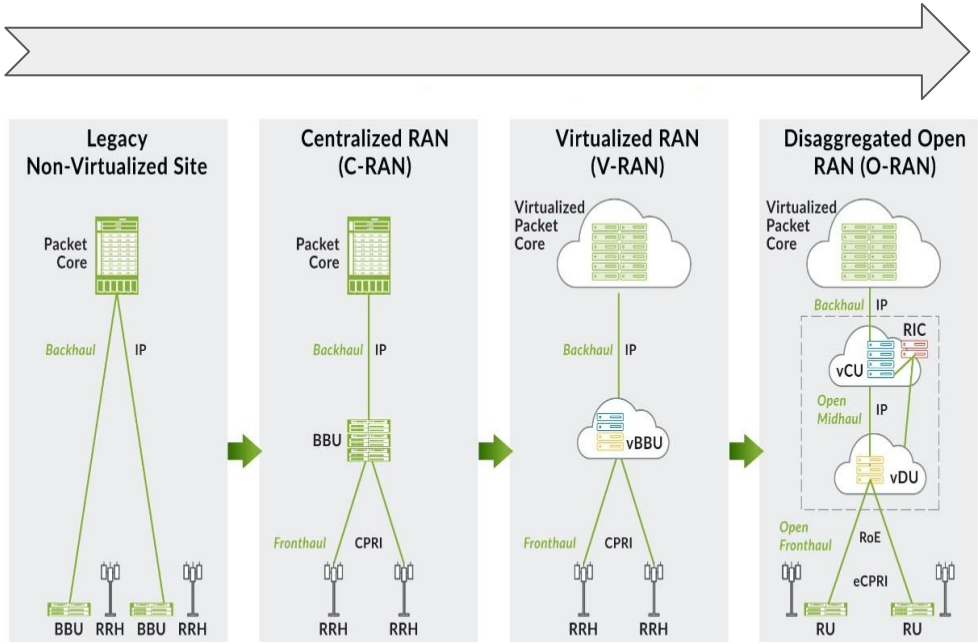
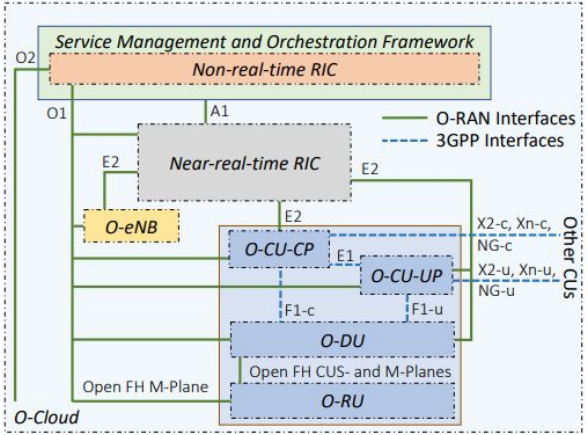


Image credit: https://www.juniper.net/br/pt/research-topics/what-is-open-ran.html

Open RAN
Selected Publication

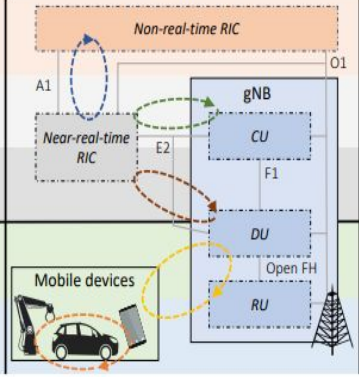
Polese, Michele, et al. "**Understanding O-RAN: Architecture, interfaces, algorithms, security, and research challenges**." arXiv preprint arXiv:2202.01032 (2022).



Understanding O-RAN: Architecture, Interfaces, Algorithms, Security, and Research Challenges

Michele Polese, Leonardo Bonati, Salvatore D'Oro, Stefano Basagni, Tommaso Melodia

***Abstract*—The Open Radio Access Network (RAN) and its embodiment through the O-RAN Alliance specifications are poised to revolutionize the telecom ecosystem. O-RAN promotes virtualized RANs where disaggregated components are connected via open interfaces and optimized by intelligent controllers. The result is a new paradigm for the RAN design, deployment, and operations: O-RAN networks can be built with multi-vendor, interoperable components, and can be programmatically optimized through a centralized abstraction layer and data-driven closed-loop control. Therefore, understanding O-RAN, its architecture, its interfaces, and workflows is key for researchers and practitioners in the wireless community. In this article, we present the first detailed tutorial on O-RAN. We also discuss the main research challenges and review early research results. We provide a deep dive of the O-RAN specifications, describing its architecture, design principles, and the O-RAN interfaces. We then describe how the O-RAN RAN Intelligent Controllers (RICs) can be used to effectively control and manage 3GPP-defined RANs. Based on this, we discuss innovations and challenges of O-RAN networks, including the Artificial Intelligence (AI) and Machine Learning (ML) workflows that the architecture and interfaces enable, security and standardization issues. Finally, we review experimental research platforms that can be used to design and test O-RAN networks, along with recent research**

Control and learning objective	Scale (devices)	Input data	Timescale	Architecture	Challenges and limitations	
Policies, models, slicing	> 1000	Infrastructure KPMs	Non-real-time > 1 s		Orchestration of large-scale deployments	Supported by O-RAN
User Session Management e.g., load balancing, handover	> 100	CU KPMs e.g., number of sessions, PDCP traffic	Near-real-time 10-1000 ms		Process streams from multiple CUs and sessions	
Medium Access Management e.g., scheduling policy, RAN slicing	> 100	MAC KPMs e.g., PRB utilization, buffering	Near-real-time 10-1000 ms		Small time scales, control many DUs/UEs	
Radio Management e.g., scheduling, beamforming	~10	MAC/PHY KPMs e.g., PRB utilization, channel estimation	Real-time < 10 ms		Custom real-time loops not supported	For further study
Device DL/UL Management e.g., modulation	1	I/Q samples	Real-time < 1 ms		Device- and RU-level standardization	

Further Hot Topics in Networking?

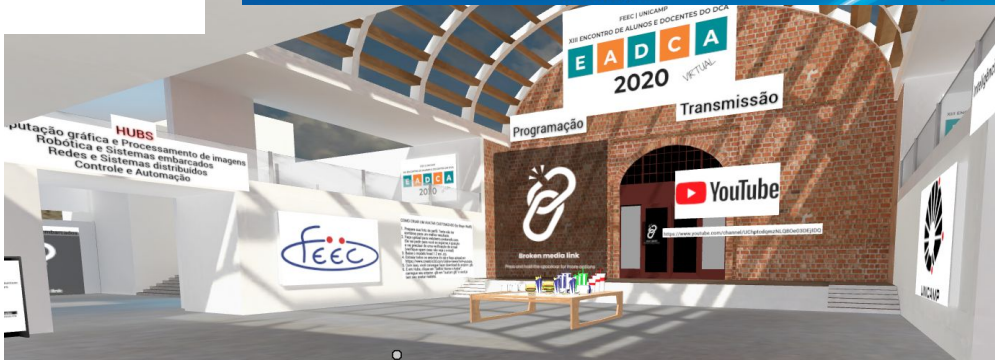
Further (candidate/actual?) Hot Topics in Networking

- ChatGPT / OpenAI
  - Applied to IBN? As a co-author?
- Evolving Programmable Infrastructures
  - IPDK, P4, Tofino, eBPF, SmartNICs, ...
- Cloud Network Slicing (Deep Slicing, Slicing 2.0)
  - EU-BR NECOS https://www.h2020-necos.eu/
- Cloud-Scale Data Center Networking
  - Disaggregated Servers / DCS, Network SW/HW Stacks, etc.
- Optical
  - SDM, 3D Optical Network-on-Chip. Virtual MIMO Optic Network.
  - Wireless Optical Networks, Light Fidelity (Li-Fi), Visible Light Communication (VLC)
  - Free-Space Optical Communication (FSOC)
- Wireless
  - RIS: Reconfigurable Intelligent Surfaces and Metamaterials
  - Semantic Communications
  - Aerial Communications / Non-Terrestrial-Networks
- More? <share-your-suggested-hot-topic>

Some Best Practices
& Trends in Scientific Events

Event Digitalization

- Positive lessons from COVID-19
- Valuable Offline-only experiences
- True, immersive Hybrid Events
- Digital-only events
- Towards Metaverse-like conferences?
- But humans like to travel and meet in person!



https://hubs.mozilla.com/xNUcx2e/recepcao-eadca-2020

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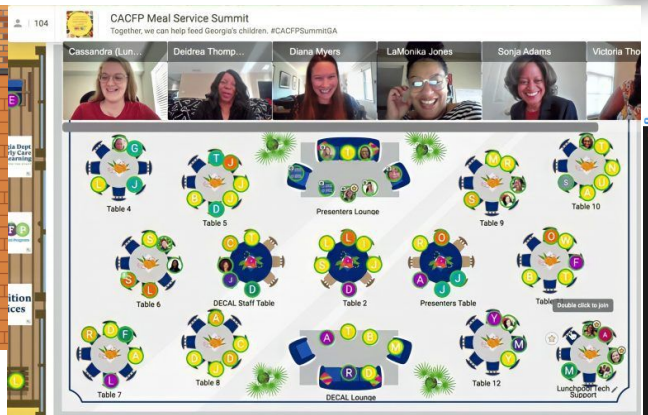
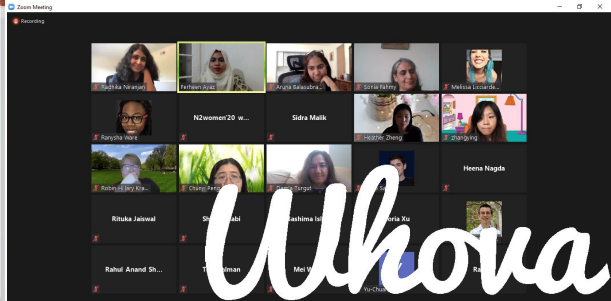




Gather https://www.gather.town/

Submission deadlines revisited

Currently, single 01 deadline (hard or “fixed” with pre-agreed / expected extensions)

Submission deadlines revisited towards more continuous submissions

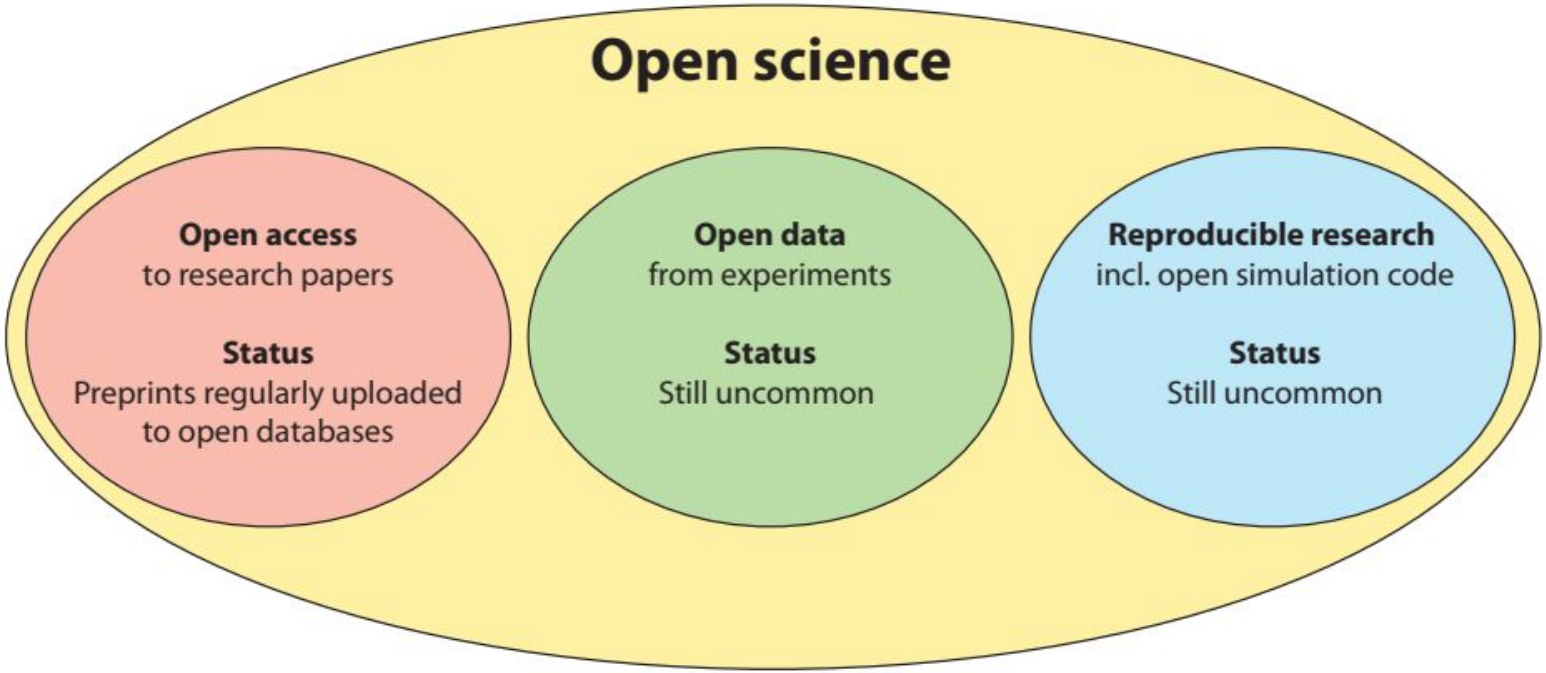
Some changes to conference submission processes:

- Multiple (two, three, ?) submission deadlines spread over the year (e.g. ACM SIGPLAN ASPLOS’22, EICS PACM)
- Possibility for papers near acceptance to be revised and resubmitted, e.g. one-shot “major” revision (e.g. ACM CoNEXT’23 - two deadlines)
- Early reject notification (ACM CoNEXT’23)

Read more:

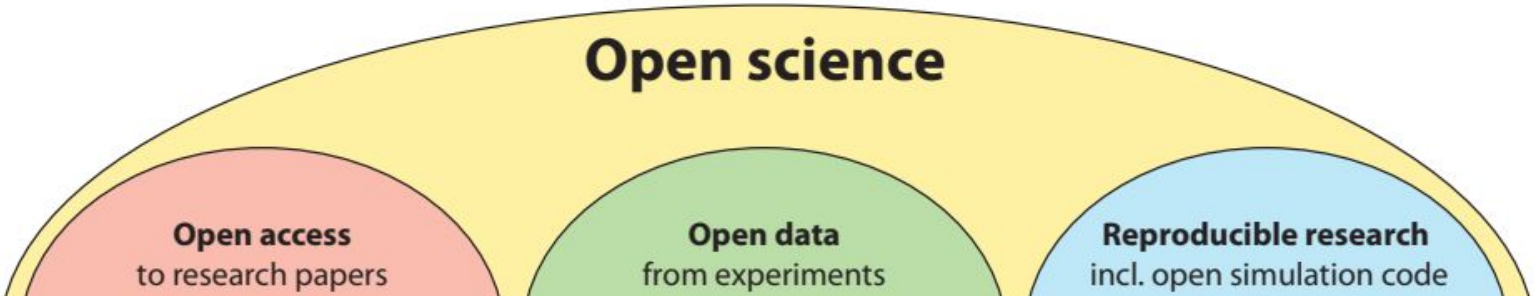
- https://blog.sigplan.org/2021/11/30/a-new-asplos-conference-submission-process/

Open Science



Source: E. Bjornson, "Reproducible Research: Best Practices and Potential Misuse [Perspectives]," in IEEE Signal Processing Magazine, vol. 36, no. 3, pp. 106-123, May 2019, doi: 10.1109/MSP.2019.2898421.

Open Science



- Open Access Policies
  - EU
  - FAPESP
- Arxiv
- TechRxiv™

- IEEE DataPort™
- Zenodo
- kaggle
- FAPESP (Planos de Gestão de Dados, Repositórios) https://www.fapesp.br/openscience/

- “Executable papers”
- Interactive Jupyter Notebooks
- Google Colab notebooks
- IEEE Code Ocean
- CodaLab
- Artifact Badges
- ...

Read more:

- Lasser, J. Creating an executable paper is a journey through Open Science. Commun Phys 3, 143 (2020). https://doi.org/10.1038/s42005-020-00403-4
- https://www.openaire.eu/
- CNPq Consórcio Nacional Para Ciência Aberta - CoNCienciA, 2022

Artifact Review Badging

A number of ACM conferences and journals have already instituted formal processes for artifact review.

Terminology

- Repeatability (Same team, same experimental setup)
- Reproducibility (Different team, same experimental setup)
- Replicability (Different team, different experimental setup)

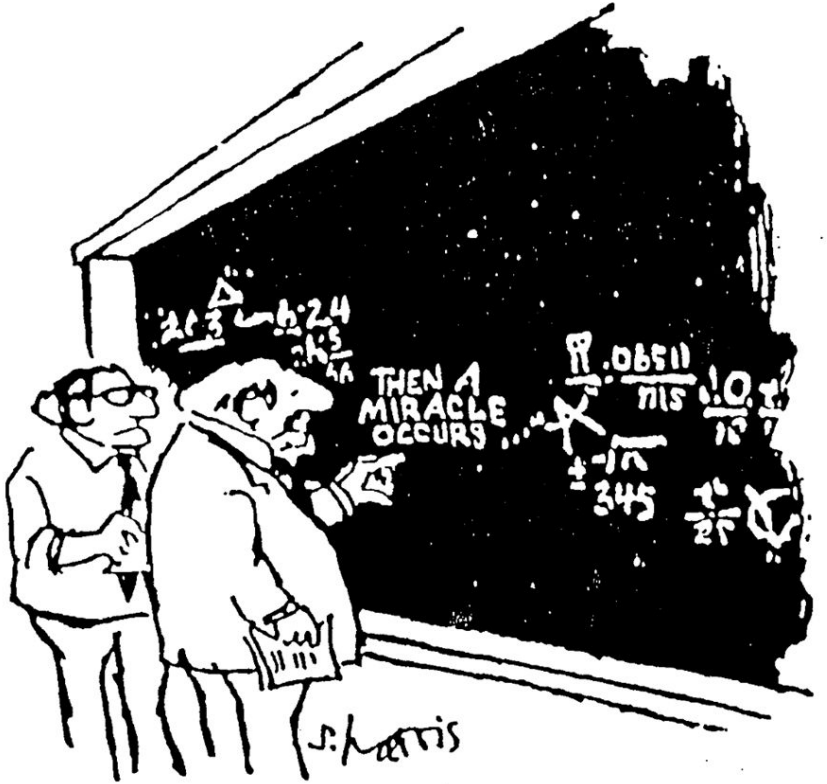
Read more:

- https://www.acm.org/publications/policies/artifact-review-and-badging-current
- A Badging System for Reproducibility and Replicability in Remote Sensing Research: https://doi.org/10.1109/JSTARS.2020.3019418
- Repeatability in computer systems research https://doi.org/10.1145/2812803
  - http://reproducibility.cs.arizona.edu/
- cTuning foundation: Artifact Evaluation for Systems/AI/ML Publications
  - https://ctuning.org/

Conclusions

- Networking is hot
  - again or still?
- Keeping the scientific radar up to date is challenging
  - Many events...
  - needle in a haystack
- Open Science practices are here to stay
  - Impact
  - Research integrity
  - Be ready and start adopting!
  - Req.: Cultural changes in scientific experimentation
  - Req.: Researcher-friendly cutting-edge experimental facilities

Thanks! Q&A + Acknowledgements



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- Arthur
- Rodrigo
- Kleber
- Alan

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