Network Communication and IoT in Healthcare

Assoc. Prof. Dr. Müge Özçevik,

Software Engineering Department of Manisa Celal Bayar University,
Deputy General Manager of Manisa Technopark TTO
(https://manisatto.com.tr/tto)
Head of SDxRG lab (https://sdxrg.mcbu.edu.tr/)
E-mail: muge.ozcevik@cbu.edu.tr

Outline

- Introduction
  - Network Stack
  - Cellular/Wireless Networks
- Motivation for network infrastructure
- Contributions from current literature
- Network Architecture with SDN & Digital Twin
- System Model for SDN & Digital Twin
  - Optimization algorithms
  - Deep learning algorithms
- Conclusion

According to Ericson's technical report,

- The global mobile data traffic exceeds 80 exabytes per month in the fourth quarter of 2021.
- 5G subscribers are expected to reach 4.4 billion by 2027.
- 85% of them are in eMBB content which requires huge bandwidth with a few end-to-end delay requirements (under 4 milliseconds).
- Augmented/Virtual Reality-based smart city applications, wireless-based offices, online education, etc.
- FWA is expected to offer broadband to 300 million connections projected in 2028.
- Forwarding data over FWA is expected to exceed 19 GB per month for a smartphone.

Background Information

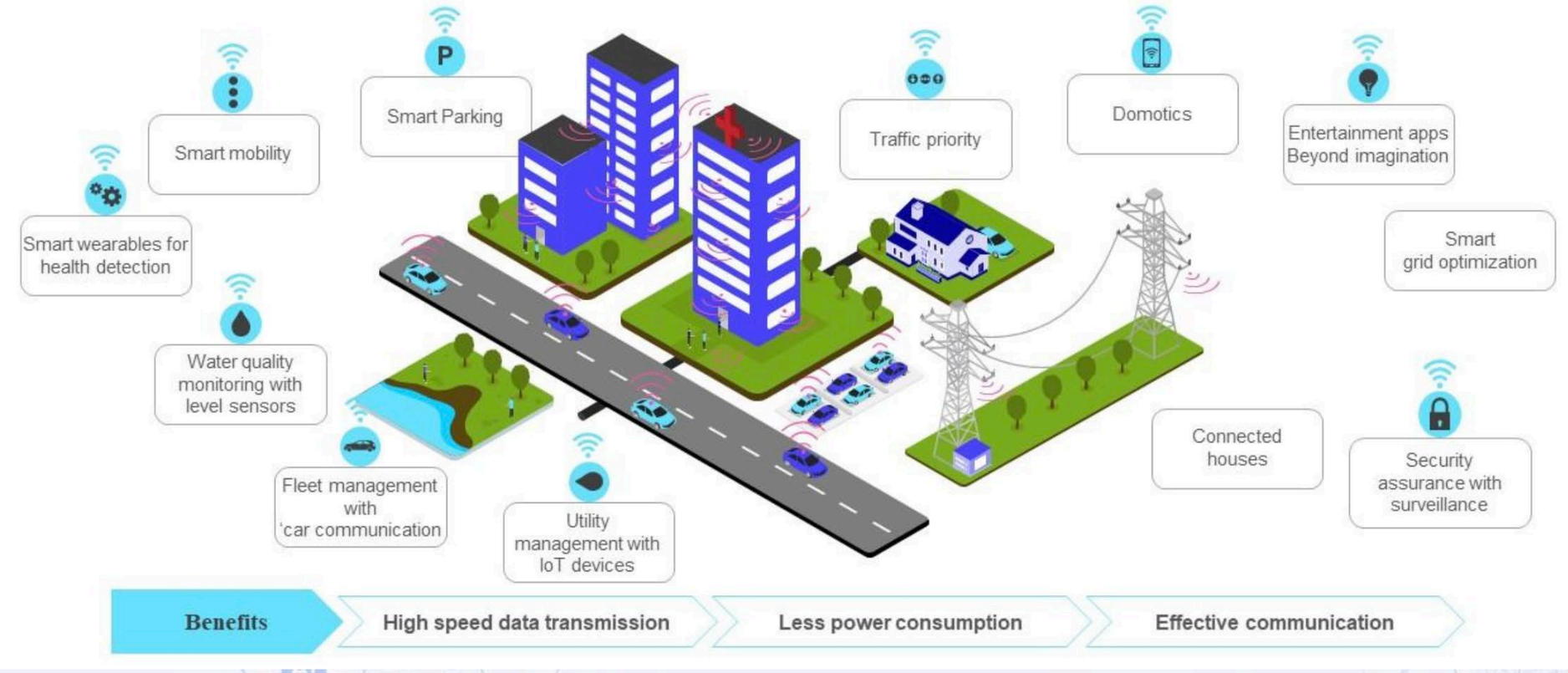
The contents of 5G new radio available in cloud market:

- Enhanced Mobile Broadband (eMBB)
- Ultra-Reliable Low Latency (URLLC)
- Massive Internet of Things/ Massive Machine-Type Communication (mIoT/mMTC)

Technical Metric	eMBB	URLLC	mIoT / mMTC
Primary Design Goal	Maximize throughput & capacity	Minimize latency & maximize reliabili	Massive connections & efficiency
Peak Data Rate	DL: 20 Gbps / UL: 10 Gbps	Low to moderate (1-10 Mbps)	Very low (10-100 Kbps)
User Latency	4 ms	≤ 1 ms	Non-critical (seconds to hours)
Reliability	Standard (~10^-2 BLER)	99.999% to 99.9999%	Standard (app-layer retry)
Connection Density	~2,500 devices / km²	Low to moderate	1,000,000 devices / km²
Mobility Support	Up to 500 km/h	Up to 500 km/h	Low (stationary/pedestrian)
Battery Life Target	Standard optimization	High draw (always-on reliability)	10+ years (PSM / eDRX)
Spectrum Focus	Mid-band (Sub-6) & mmWave	Sub-6 GHz (propagation focus)	Low-band (< 1 GHz)

MANİSA CELAL BAYAR ÜNİVERSİTESİ

SHEng
SMART HEALTHCARE ENGINEERING



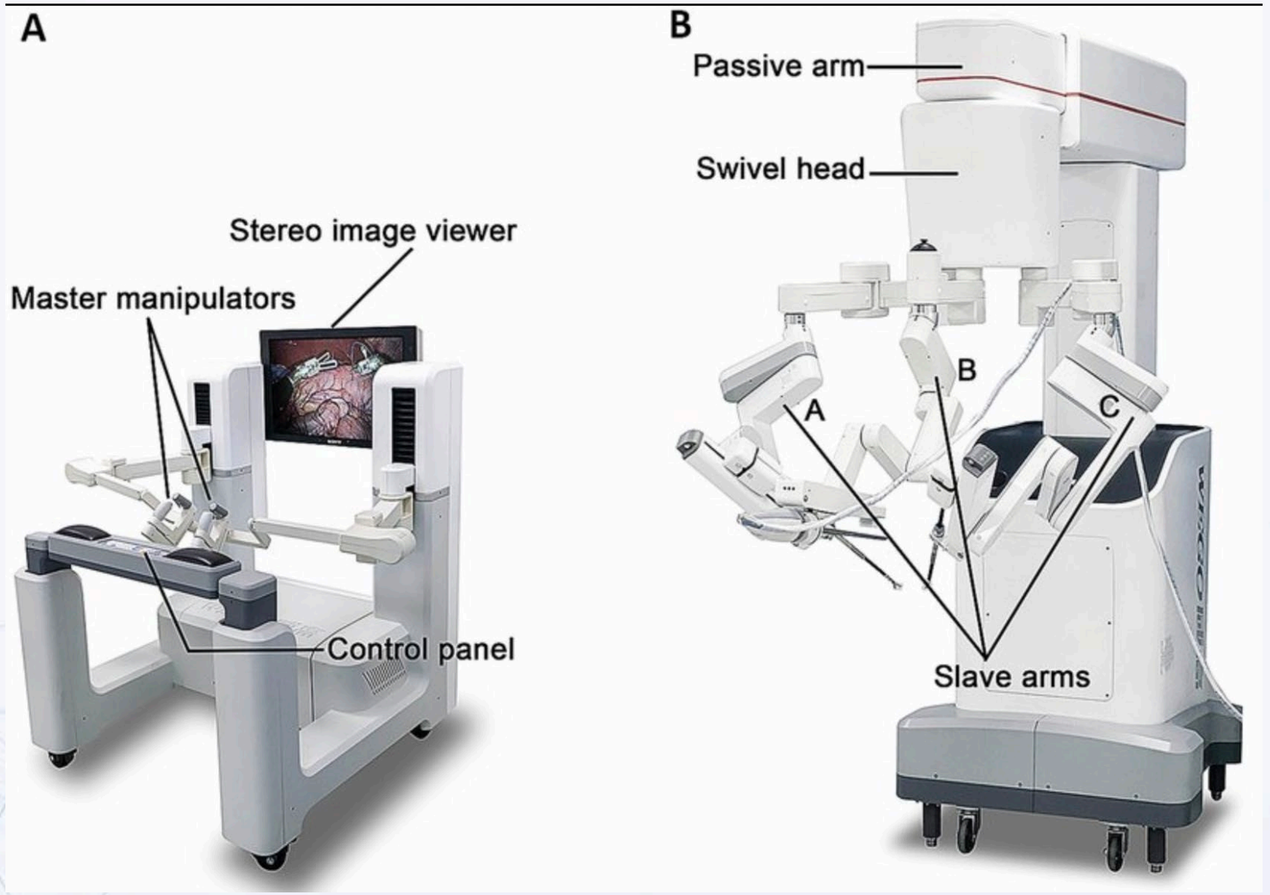
MANİSA CELAL BAYAR ÜNİVERSİTESİ

Universitatea Transilvania din Brașov

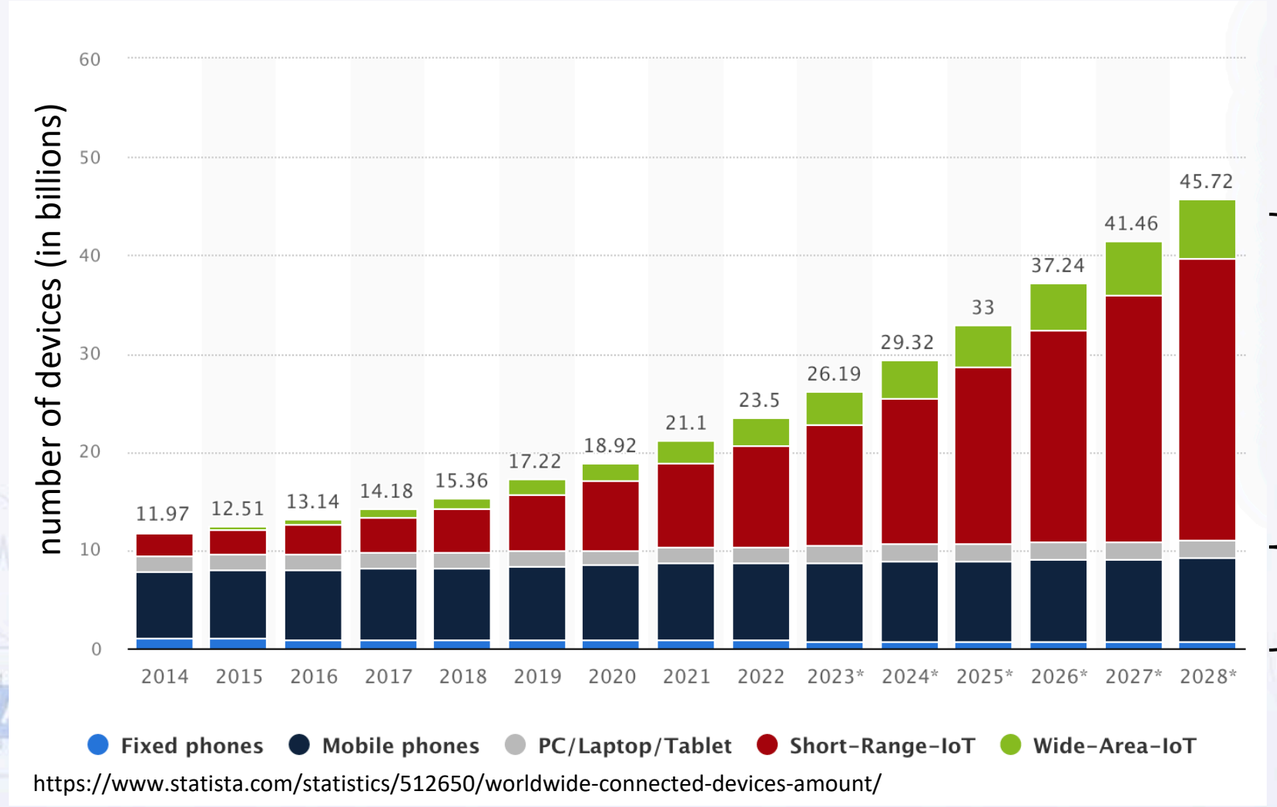
ULPGC Universidad de Las Palmas de Gran Canaria

SPITALUL MUNICIPAL SĂCELE

Servicio Canario de Salud


A
Stereo image viewer
Master manipulators
Control panel
B
Passive arm
Swivel head
A
B
C
Slave arms

Lots of connected IoT devices, and more soon!



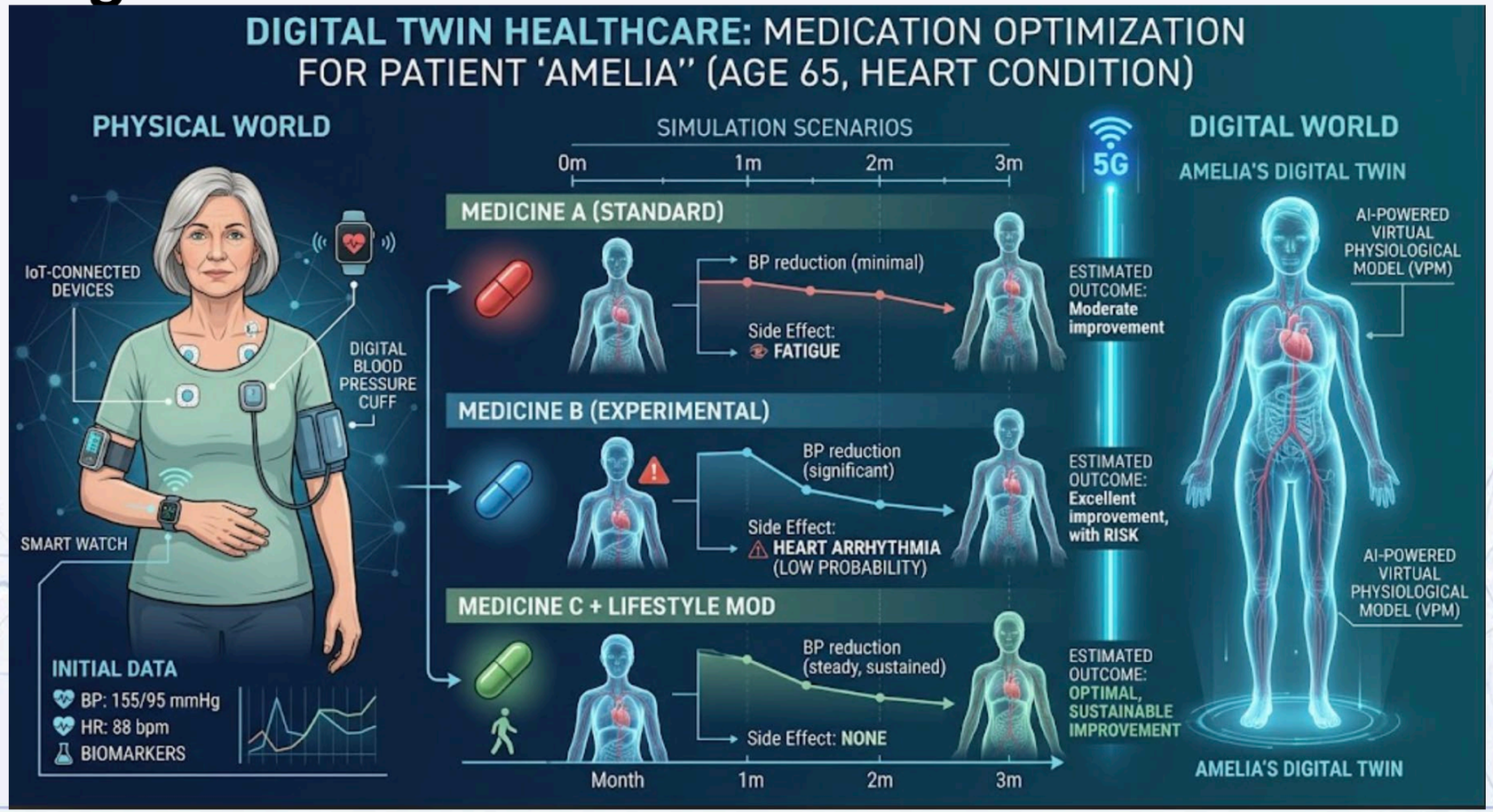
https://www.statista.com/statistics/512650/worldwide-connected-devices-amount/

Digital Twin

is a dynamic, virtual representation of a physical object, process, person, or system that mimics its real-world counterpart in real time.

Unlike a static 3D computer model or CAD drawing, a digital twin relies on a continuous, two-way flow of data to stay perfectly synchronized with its physical twin.

IoT & Digital Twin



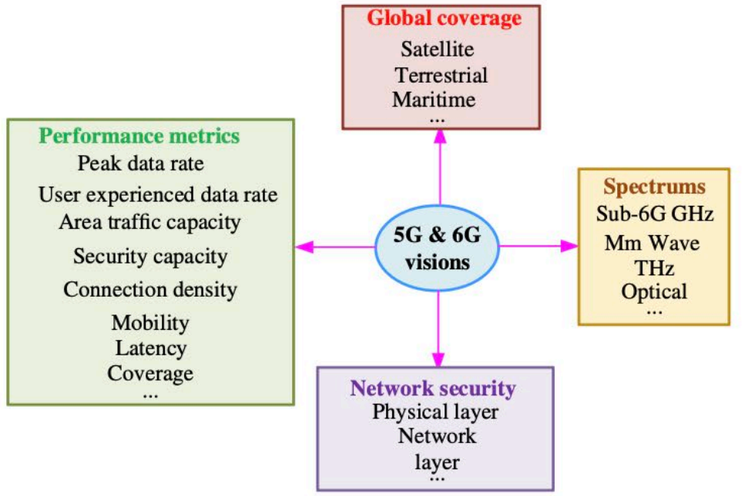
9ō▪ĵĠ▪ ▫ża ▫L’╢é / ▪▩▩ĵ ▬Ĥ’ĂĠ▪

4G LTE

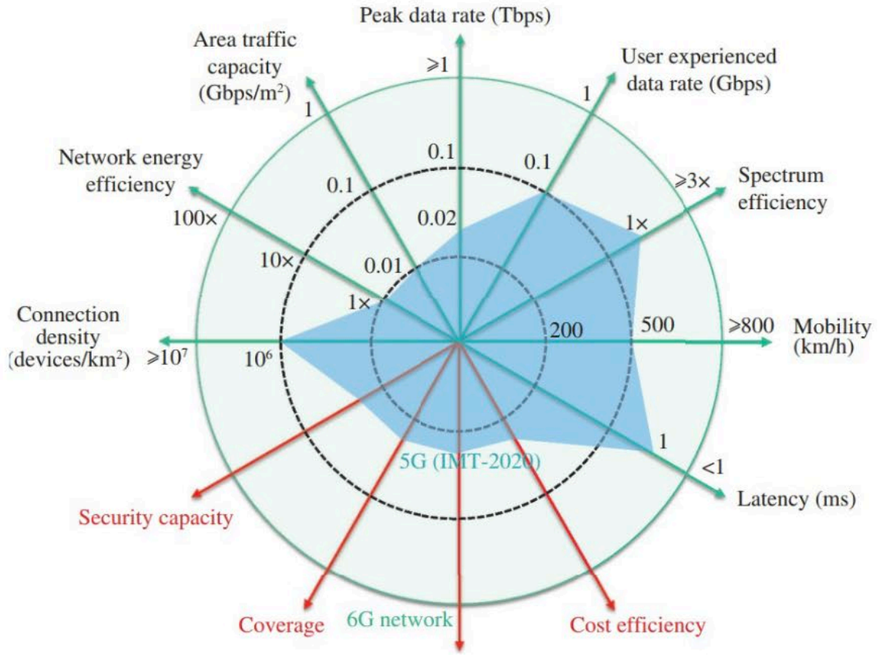
Reduced latency, optimized throughput, and delivered seamless broadband networks.

5G New Radio

Enabled mmWave bands, massive MIMO, ultra-dense networks, and initial IoT support.



(A)



(B)

(A) Various vision of 5G and 6G networks, and (B) performance of 6G networks[62]

Introduction

Billions of connected computing *devices*:

- *hosts = end systems*
- running *network apps* at Internet's "edge"

Packet switches: forward packets (chunks of data)

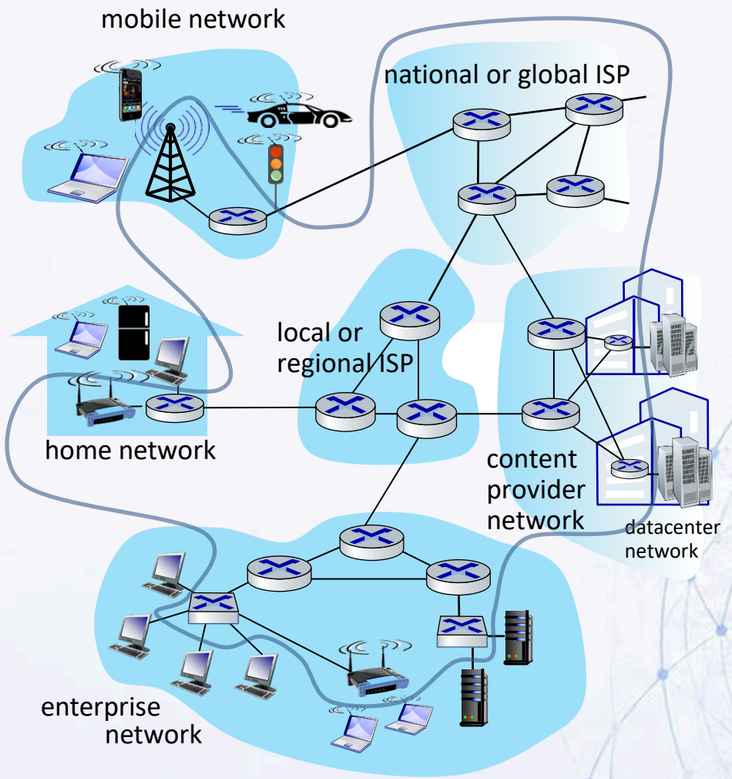
- *routers*, *switches*

Communication links

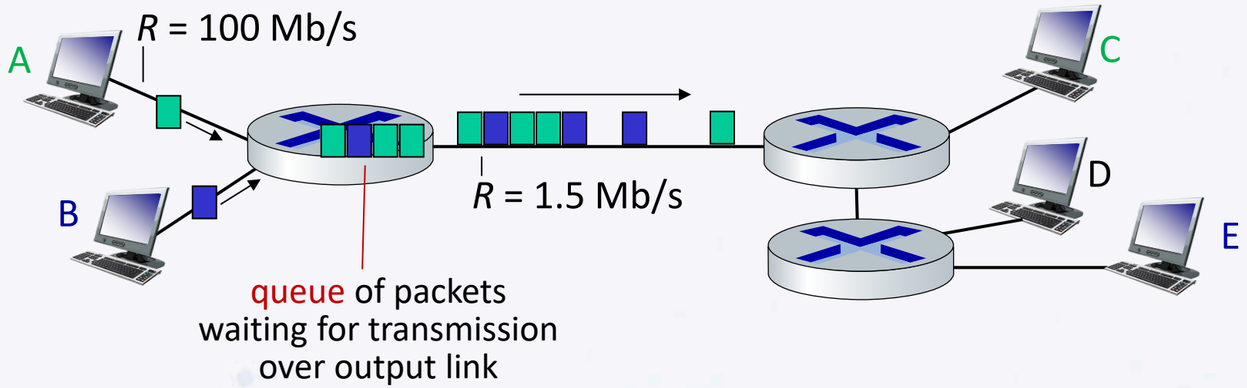
- fiber, copper, radio, satellite
- transmission rate: *bandwidth*

Networks

- collection of devices, routers, links: managed by an organization

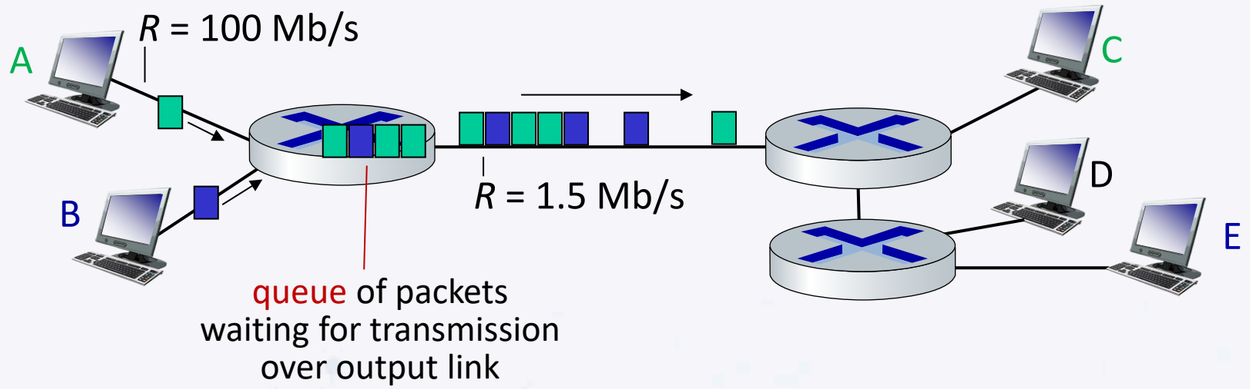


Introduction



Queueing occurs when work arrives faster than it can be serviced:

Introduction



Packet queuing and loss: if arrival rate (in bps) to link exceeds transmission rate (bps) of link for some period of time:

- packets will queue, waiting to be transmitted on output link
- packets can be dropped (lost) if memory (buffer) in router fills up

Protocol “layers” and reference models

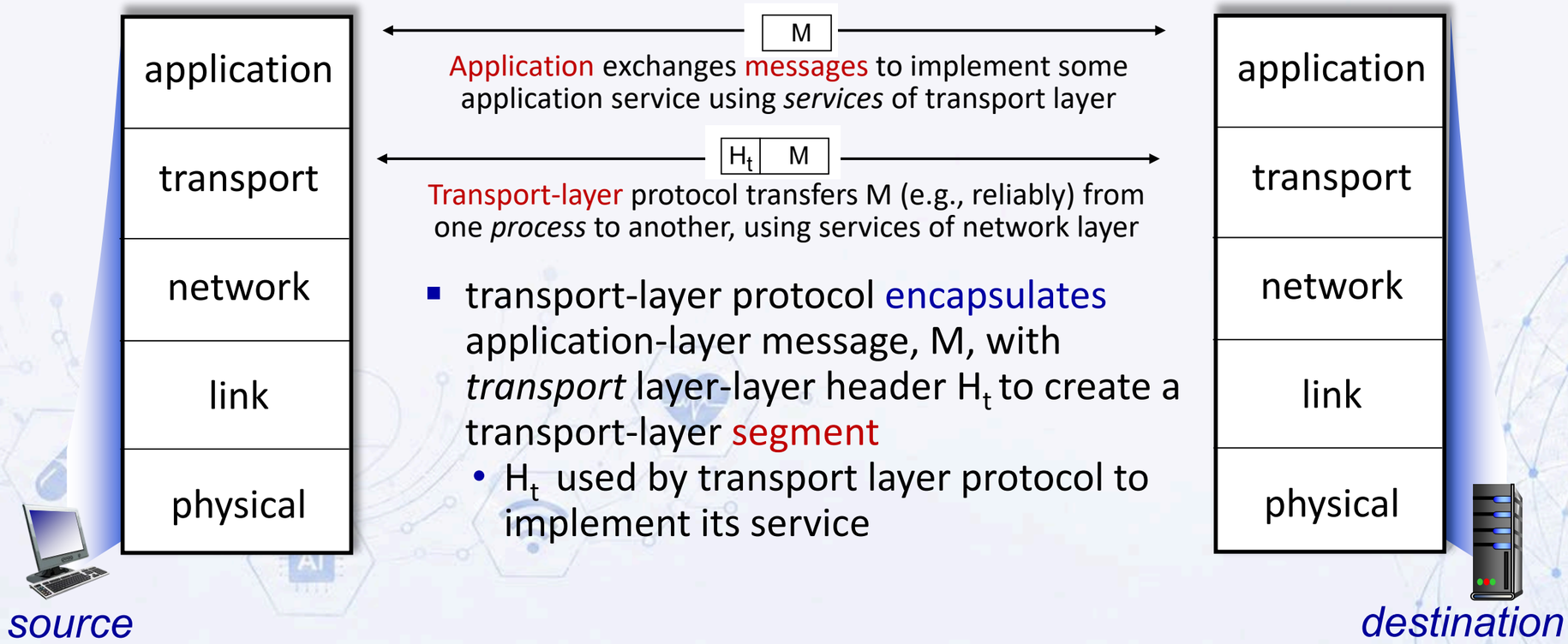
Networks are complex, with many “pieces”:

- hosts
- routers
- links of various media
- applications
- protocols
- hardware, software

Question: is there any hope of *organizing* structure of network?

- and/or our *discussion* of networks?

Services, Layering and Encapsulation



- transport-layer protocol encapsulates application-layer message, M, with *transport* layer-layer header H_t to create a transport-layer segment
  - H_t used by transport layer protocol to implement its service

WiFi spectrum bands

6 GHz range
- most recently added
- more than 250 configurable/selectable WiFi channels of different transmission rates

802.11 ax/be

5 GHz range
- more than 150(configurable/selectable WiFi channels) of different transmission rates

802.11 a/h/n/ac/ax

2.4 GHz
- Divided into 11-14 channels, depending on country

802.11 b/g/n/ax

- other 802.11 WiFi spectrum bands, but not in widespread use

5G spectrum: three spectrum bands*

* No single, well-accepted ranges for “low”, “mid” and “high”

High band frequencies: 25–66 GHz range (aka mmwave)

- 26 GHz, 40 GHz, 50 GHz, 66 GHz bands popular
- short distances (< mile), high speeds (<3 Gbps)
- line of sight transmission: poor penetration of trees, buildings, ...

5G

Mid-band frequencies: 1 - 6 GHz ranges

- balance distances (~5 miles ?) and transmission rates (100–900 Mbps)
- 1.8, 3.3 GHz to 3.8 GHz, 6 GHz bands popular

3.4 - 6 GHz: 5G, 4G

1-2.6 GHz: 5G, 4G, 3G, 2G

Low band frequencies: (< 1 GHz range)

- covers longer distances (10’s of miles), but at lower speeds (50–250 Mbps)

5G, 4G, 3G, 2G

Motivation

- **Overcoming Resource Constraints:** Next-generation communication networks must balance conflicting metrics like latency, power consumption, spectrum efficiency, and terminal transmit power.
- **Centralized RAN & MEC Bottlenecks:** Cloud-based Radio Access Networks (C-RAN) and Mobile Edge Computing (MEC) suffer from serious speed, throughput, and data storage bottlenecks.
- **Highly Dynamic Channels:** Complex channel behaviors, multi-user paths, and high-frequency wave propagation require fast real-time mathematical adjustments.
- **Autonomous Network Management:** Finding optimal operational variables without manual engineering input necessitates intelligent, self-organizing optimizations.

Motivation

Due to persistent economic reasons in a pandemic,

- There is partial recovery instead of full recovery in the physical infrastructure with limited resources.

Moreover, the indispensable goal of 5G is:

- minimizing the risk of physical deployment.

Dynamic Network Slicing

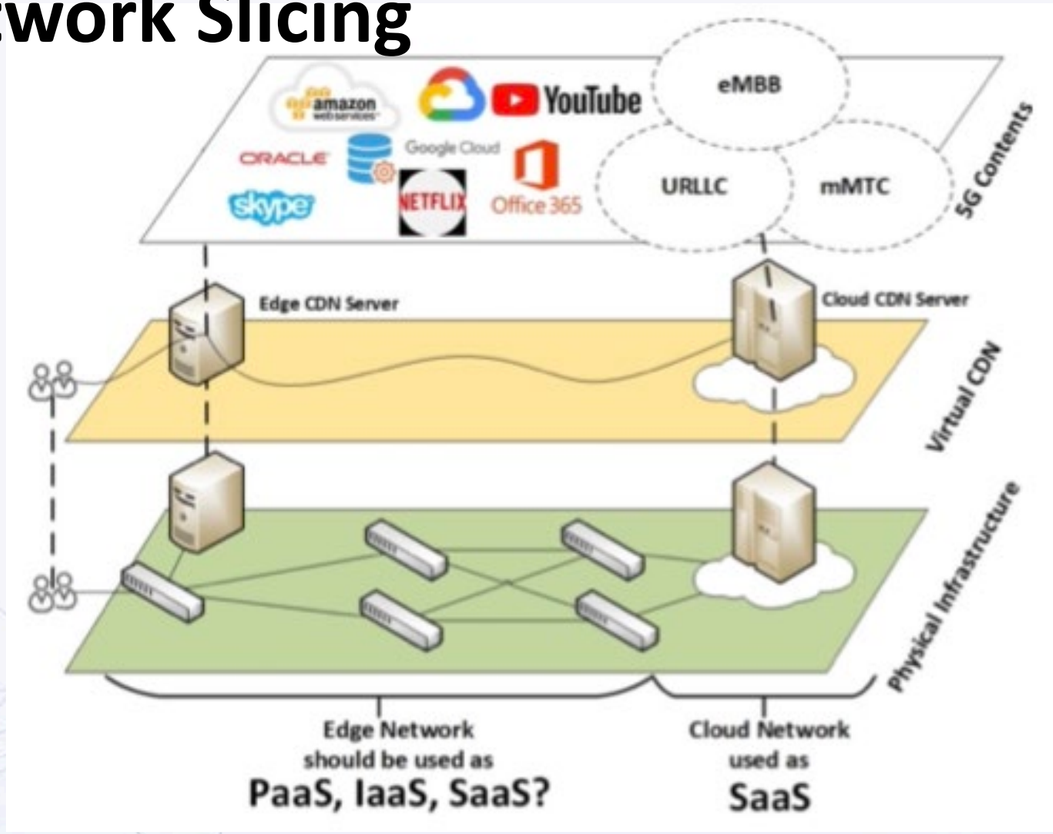


Figure: How should a switch be configured to serve as a service?

Research Question

However, there are also security challenges of dynamic network slicing:

- Network privacy
- Standardization
- Contention between providers
- Computational work in OpenFlow switch

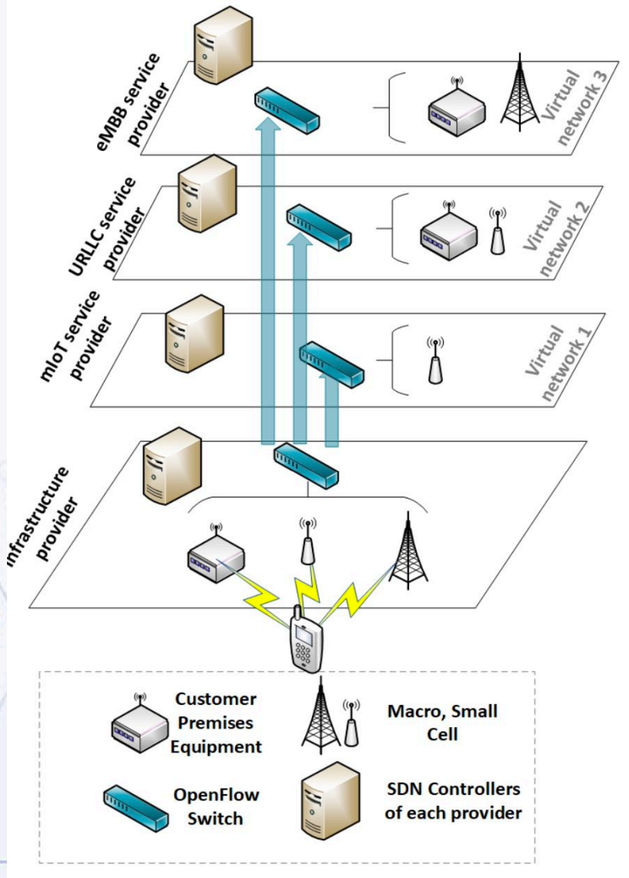
How can the service providers keep their own network ***sustainable*** by using infrastructure in a ***secure***, ***cost-efficient***, and ***conforming the standard*** in **fair** way?

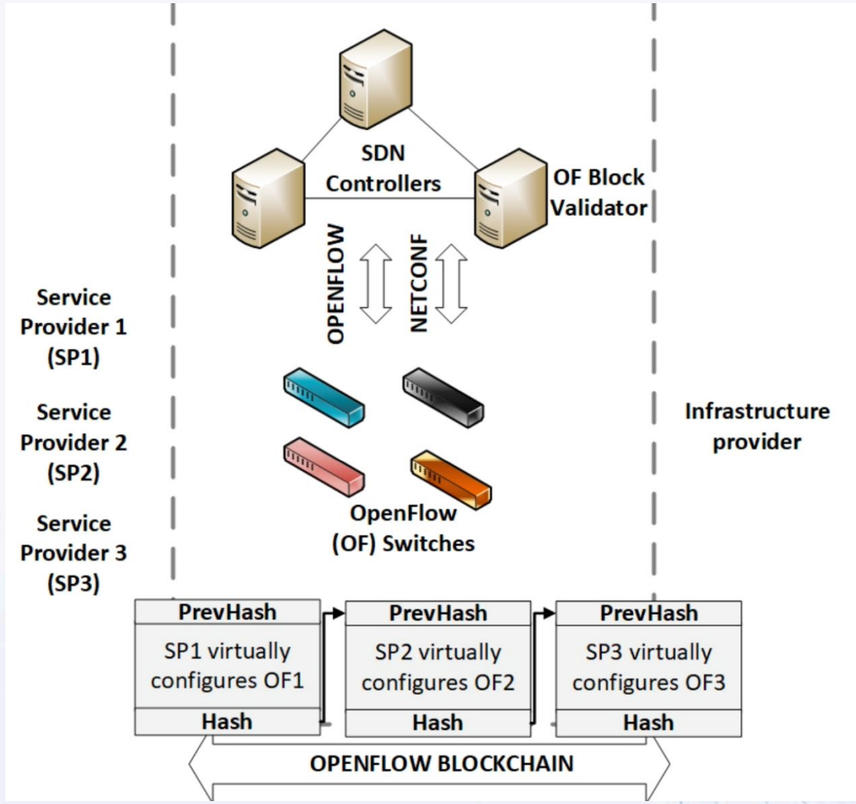
Contribution

Sustainable Fixed Wireless Access (SFWA):

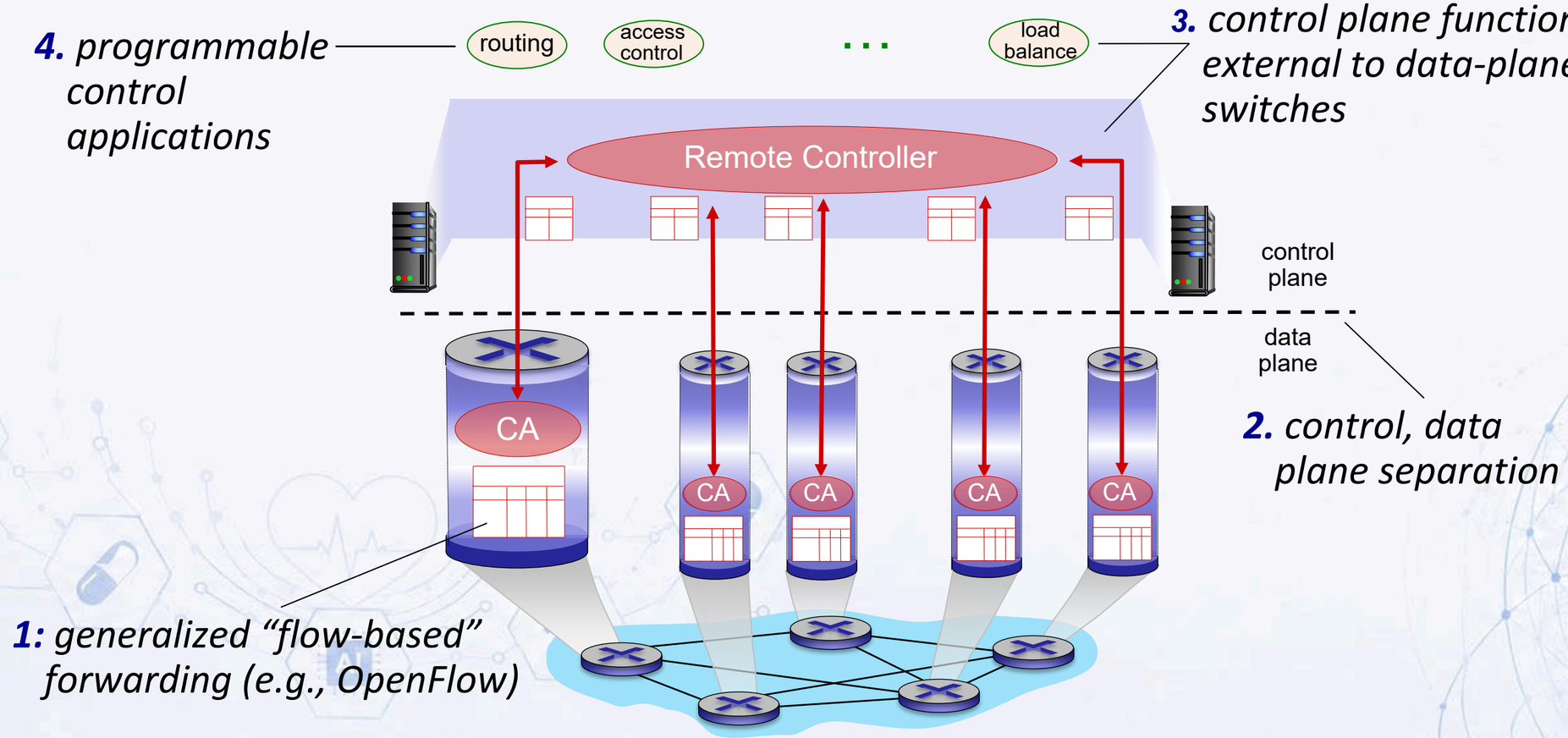
- OpenFlow switches as a service by Software-Defined Network,
- Reduce OPEX/CAPEX by decoupling data and contol planes,
- Having global view on topology,
- Periodic end-to-end configuration.

Network Architecture

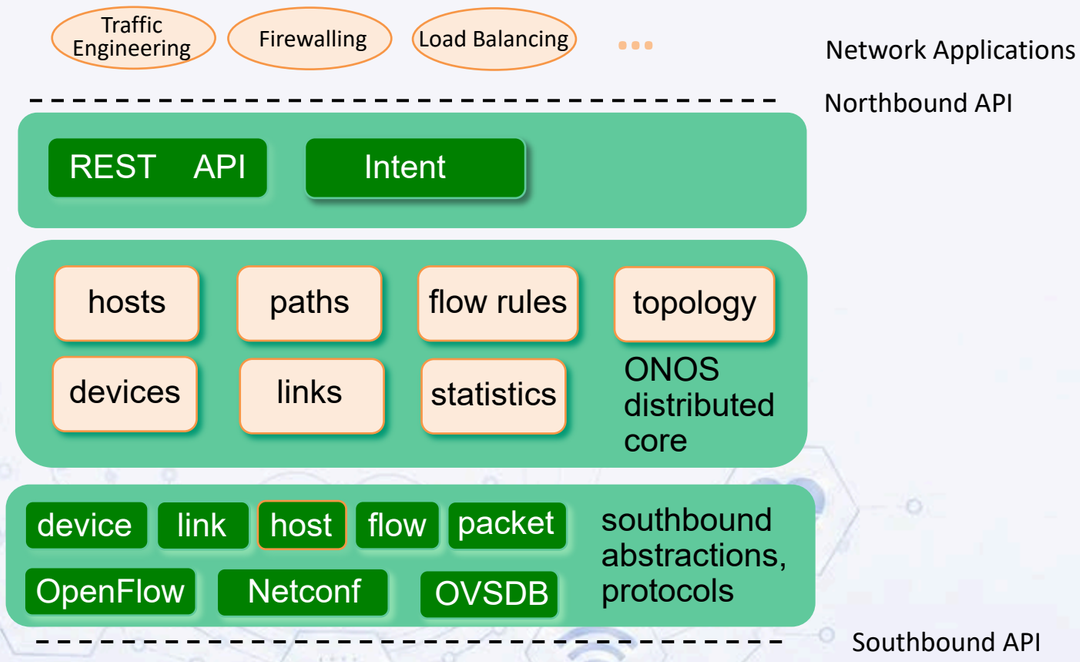




Software defined networking (SDN)



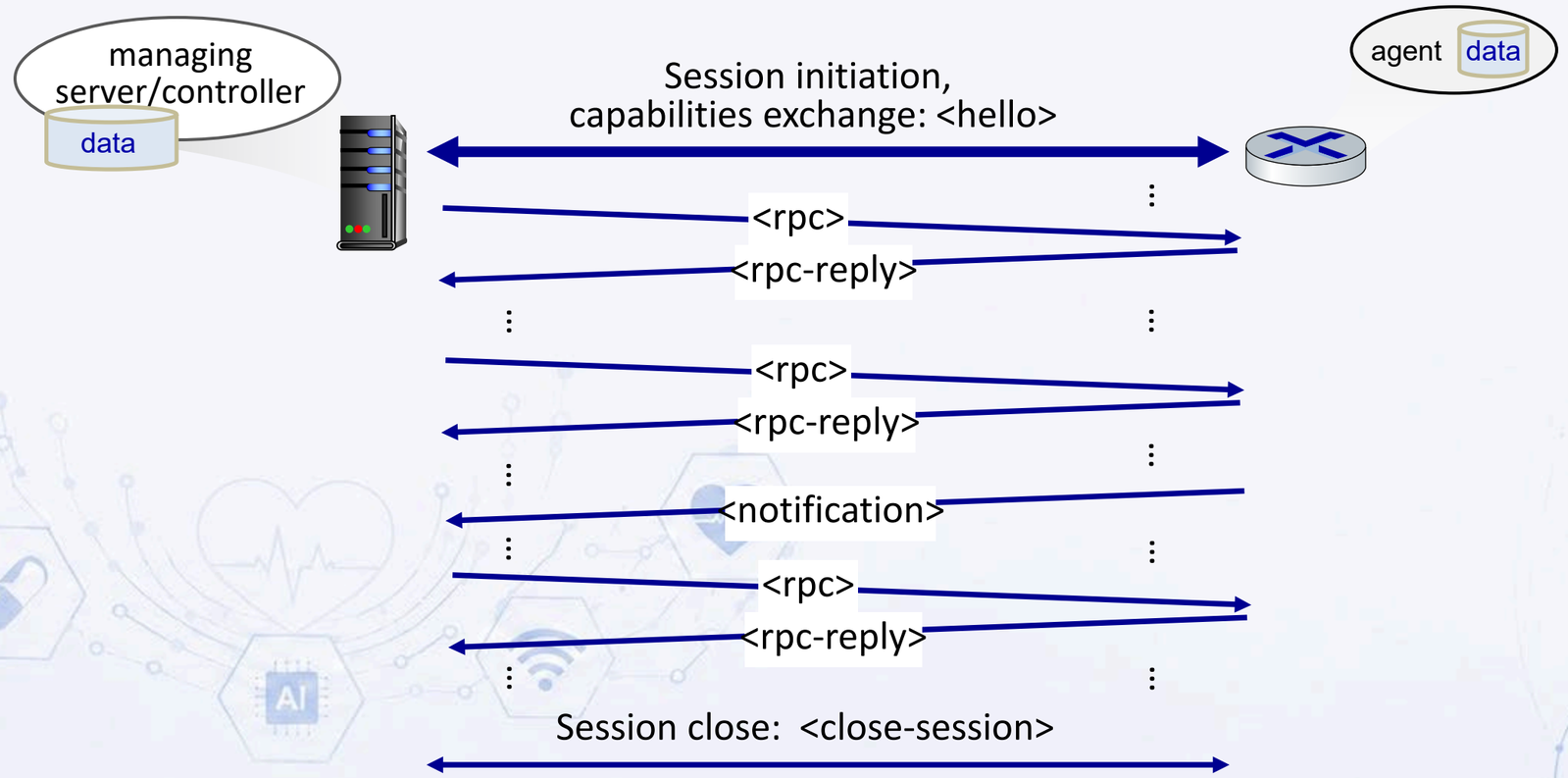
ONOS SDN controller



- control apps separate from controller
- intent framework: high-level specification of service: what rather than how
- considerable emphasis on distributed core: service reliability, replication performance scaling

ONOS: early, influential open-source SDN controller

NETCONF initialization, exchange, close



Selected NETCONF Operations

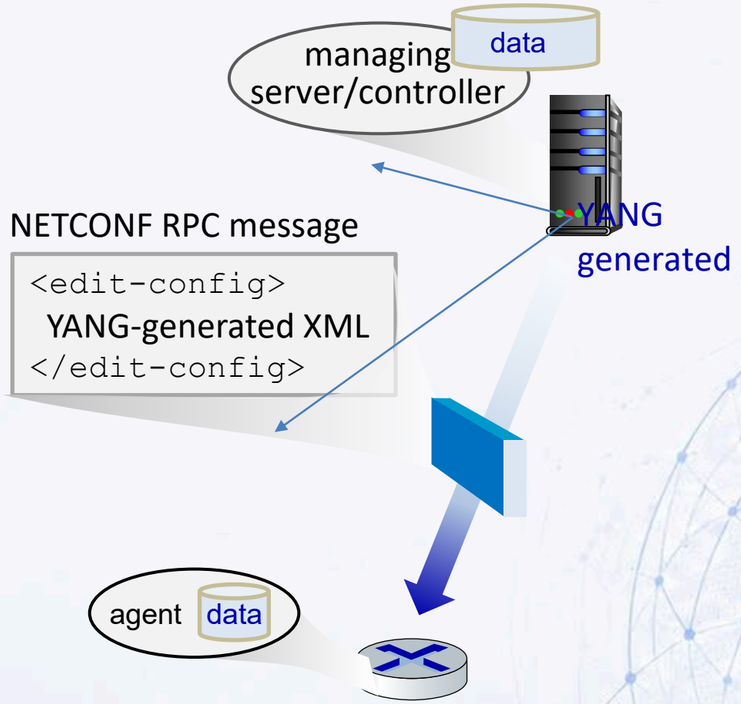
NETCONF	Operation Description
<get-config>	Retrieve all or part of a given configuration. A device may have multiple configurations.
<get>	Retrieve all or part of both configuration state and operational state data.
<edit-config>	Change specified (possibly running) configuration at managed device. Managed device <rpc-reply> contains <ok> or <rpcerror> with rollback.
<lock>, <unlock>	Lock (unlock) configuration datastore at managed device (to lock out NETCONF, SNMP, or CLIs commands from other sources).
<create-subscription>, <notification>	Enable event notification subscription from managed device

Sample NETCONF RPC message

```
01 <?xml version="1.0" encoding="UTF-8"?>
02 <rpc message-id="101"                    note message id
03   xmlns="urn:ietf:params:xml:ns:netconf:base:1.0">
04   <edit-config>                          change a configuration
05     <target>
06       <running/>                         change the running configuration
07     </target>
08     <config>
09       <top xmlns="http://example.com/schema/
         1.2/config">
10         <interface>
11           <name>Ethernet0/0</name>       change MTU of Ethernet 0/0 interface to 1500
12           <mtu>1500</mtu>
13         </interface>
14       </top>
15     </config>
16   </edit-config>
17 </rpc>
```

YANG model of devices

- data modeling language used to specify structure, syntax, semantics of NETCONF network management data
  - built-in data types, like SMI
- XML document describing device, capabilities can be generated from YANG description
- can express constraints among data that must be satisfied by a valid NETCONF configuration
  - ensure NETCONF configurations satisfy correctness, consistency constraints



SDN Demo

System Model

Exact Optimization Methods

These methods mathematically guarantee that the obtained outcome is the absolute **best/optimal solution** for the objective function.

However, they suffer from **high computational complexity** when applied to non-linear, multi-modal, and NP-hard network architecture challenges.

Heuristic Optimization Methods

These methods provide **no formal guarantee** of obtaining the absolute optimal mathematical limits, but find **highly acceptable solutions fast**.

They are widely used in wireless routing, clustering, and spectrum management because they solve complex multi-dimensional problems in seconds.

- Finding the **best solution** through a long period of study would be meaningless according to the **age of information.**
- According to the **age of information**, we should choose the algorithms that yield **the best solutions** within **an acceptable timeframe.**

System Model

Bio-Inspired Models

Algorithms based on collective animal, plant, or insect behaviors. Examples include Particle Swarm, Ant Colony, and Artificial Bee Colony.

Human Treatment Models

Metaheuristic formulations mimicking social human behaviors or creative processes. The key candidate is the Harmony Search Algorithm.

Evolutionary Process

Optimizers modeled on genetic mutation, crossover, and natural selection. Examples include Genetic Algorithms and Differential Evolution.

System Model

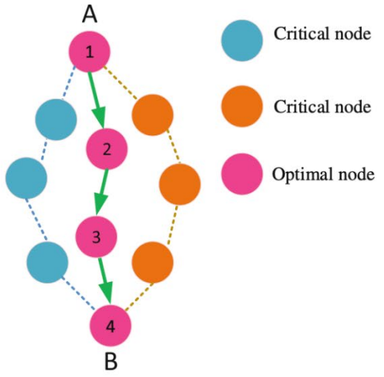


FIGURE 10 Ant colony optimization illustration[96]

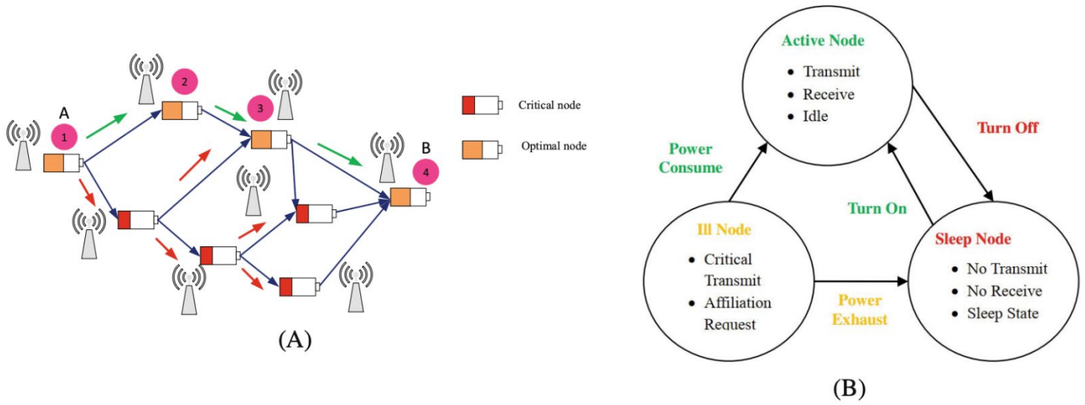


FIGURE 11 Network scenario by using ACO[97]

REFERENCES

M. Erel-Özçevik, Y. Özçevik, E. Bozkaya-Aras, T. Bilen, "6G-Enabled Digital Twin-Based Smart Warehouse for Supply Chain of Things", **Computing**108, 79 (2026). https://doi.org/10.1007/s00607-026-01668-3

M. Gider, M. Erel-Özçevik, "A Novel Triage Management for Digital Twin controlled Healthcare System", **accepted by Sinop Fen Bilimleri Dergisi**, April 2026.

A.Çay, M. Erel-Özçevik, B. Karaman, İ. Baştürk, E. Zeydan, S. Taşkın ,"Proof of Genesis-Supported Blockchain and Resilience Networks for In-Disaster Scenarios", **accepted by IEEE TNSM**, 22 January 2026.

M. Erel-Özçevik, E. Bozkaya-Aras,"Secure Computation Offloading for Data Leakage Prevention in Digital Twin Edge Networks", **accepted by Cluster Computing**, 14 January 2026.

K. A. Baykal, M. Erel-Özçevik, A. Özçift,"Reinforcement Learning-Enhanced Fair Resource Management for eMBB and URLLC Traffic in 5G Networks", **Mus Alparslan University Journal of Science**, 24 December 2025.

M. Erel-Ozcevik, "Token as a Service for Software-Defined Zero Trust Networking", **Journal of Network and Systems Management**, Volume 33, article number 10, 2025.

M. Erel-Özçevik,'Sustainable fixed wireless access with blockchain secured software defined network',**Pervasive and Mobile Computing**,Volume 92,2023,101803,ISSN 1574-1192,https://doi.org/10.1016/j.pmcj.2023.101803.