5CM510 – Network System development
Lecture 17: Green Networks

Lecture Outline

- Green and Soft Networks: Background
- Why Green and Soft?
- Rethinking Network design: Green and Soft 5G
- Energy-Efficient Communications and Green networks
- Greener networks: Software Defined Air Interface (SDAI)

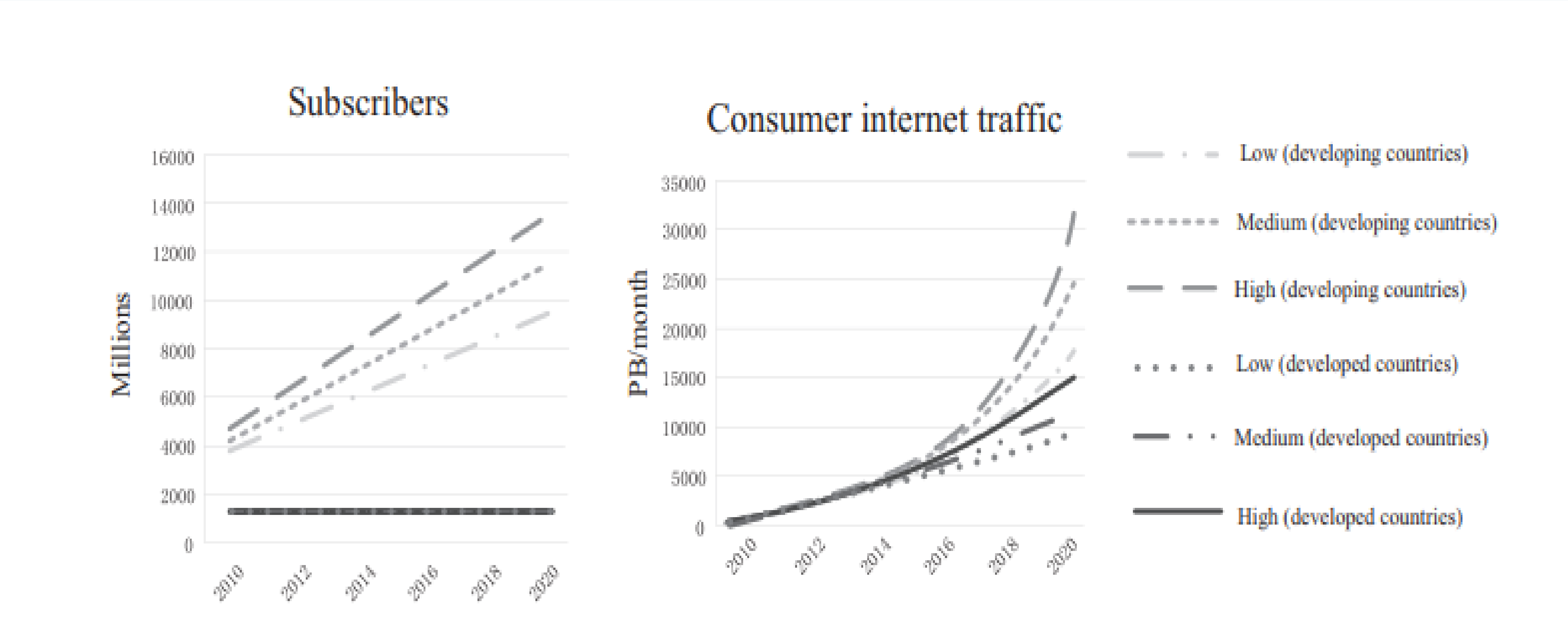
Sensitivity: Internal

Green and Soft Networks: Background

- For the past forty years, mobile communication systems have been undergoing a revolutionary change from the first-generation (1G) analog cellular systems to the fourth generation (4G) long-term evolution (LTE) systems.
- 4G could provide high-speed data service, including internet access, high-definition video broadcasts, and so on. With the development of mobile internet and service diversity, wireless traffic is growing rapidly, especially in developing countries.
- we can predict that the data explosion will continue in the future, driven by the vigorous development of mobile internet and internet of things (IoT). More and more mobile internet applications have emerged to meet the diverse demands of subscribers.
- The fifth-generation (5G) wireless networks will touch many aspects of our daily life in the future, such as home, work, leisure, and transportation. Consequently, a consistent service experience should be supported in various scenarios, including dense residential areas, office buildings, stadiums, open-air gatherings, subways, highways, high-speed trains, and wide-area coverage scenarios.

Sensitivity: Internal

Subscriber and Consumer Internet traffic



Sensitivity: Internal

Why Green and Soft?

- In addition to the technical requirements on 5G, the operators are also faced with the requirement of taking social responsibilities when deploying the 5G networks. The first one is how to tackle the global warming issue. As it is becoming more and more serious, the impact of wireless communication networks on the environment has drawn extensive concerns.
- 5G mobile networks should be more energy-efficient than ever before to reduce both the operational costs and carbon dioxide emission. Motivated by this, network operators, regulatory bodies, such as the 3rd Generation Partnership Project (3GPP) and ITU, have conducted several research activities aiming at improving the **network energy efficiency** (EE).
- Is there a possibility that such generation transition can be conveniently and efficiently achieved via **software upgrade**, without abandoning old hardware or replacing it with newly manufactured equipment?
- The 5G network is therefore, motivated to be reconfigurable with **software-defined networking** (SDN) and air interface agility in implementation.

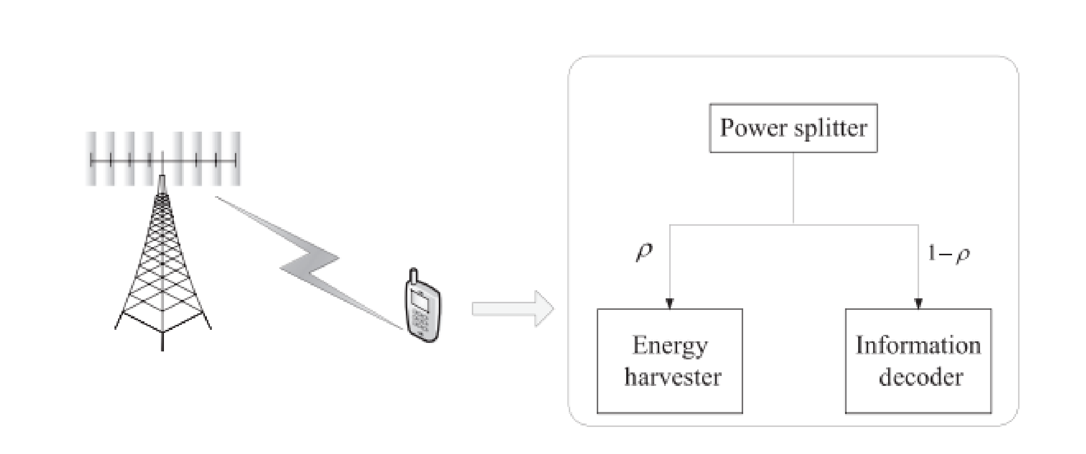
Sensitivity: Internal

Green: From User terminal side to Infrastructure

- Reducing carbon emissions and operating expenditure (OPEX) costs are important goals for wireless cellular networks. The profound meaning of green is to heighten efficiency in utilization of any resources supporting wireless communications from the network side to the user terminal (UE) side.
- For the UE side, the required energy in the UE’s battery is increasing with the development of mobile internet. How to optimize the battery life of mobile users is still a challenging task.
- Power-saving mode (PSM), such as discontinuous reception (DRX) mechanism, has been introduced in LTE for power saving at the UE. DRX enables the UE to switch from an active state to a short or long sleep state without sacrificing the quality of service (QoS).
- To cope with the limited battery energy problem, radio frequency (RF) energy harvesting technology has garnered extensive attention.
- Since the RF signals radiated by transmitter carry both information and power at the same time, it is natural to think that the devices can be powered by the energy from the received electromagnetic waves.

Energy harvesting: SWIPT

- An example of a simultaneous wireless information and power transfer (SWIPT) system.
- In this system, the UE intends to decode the information and harvest energy from the received signal simultaneously.
- The power of the received signal at the UE is split into two parts, for decoding the information and for energy harvesting.
- With the energy-harvesting mechanism, the UE is expected to be not only environmentally friendly but also self-sustainable.

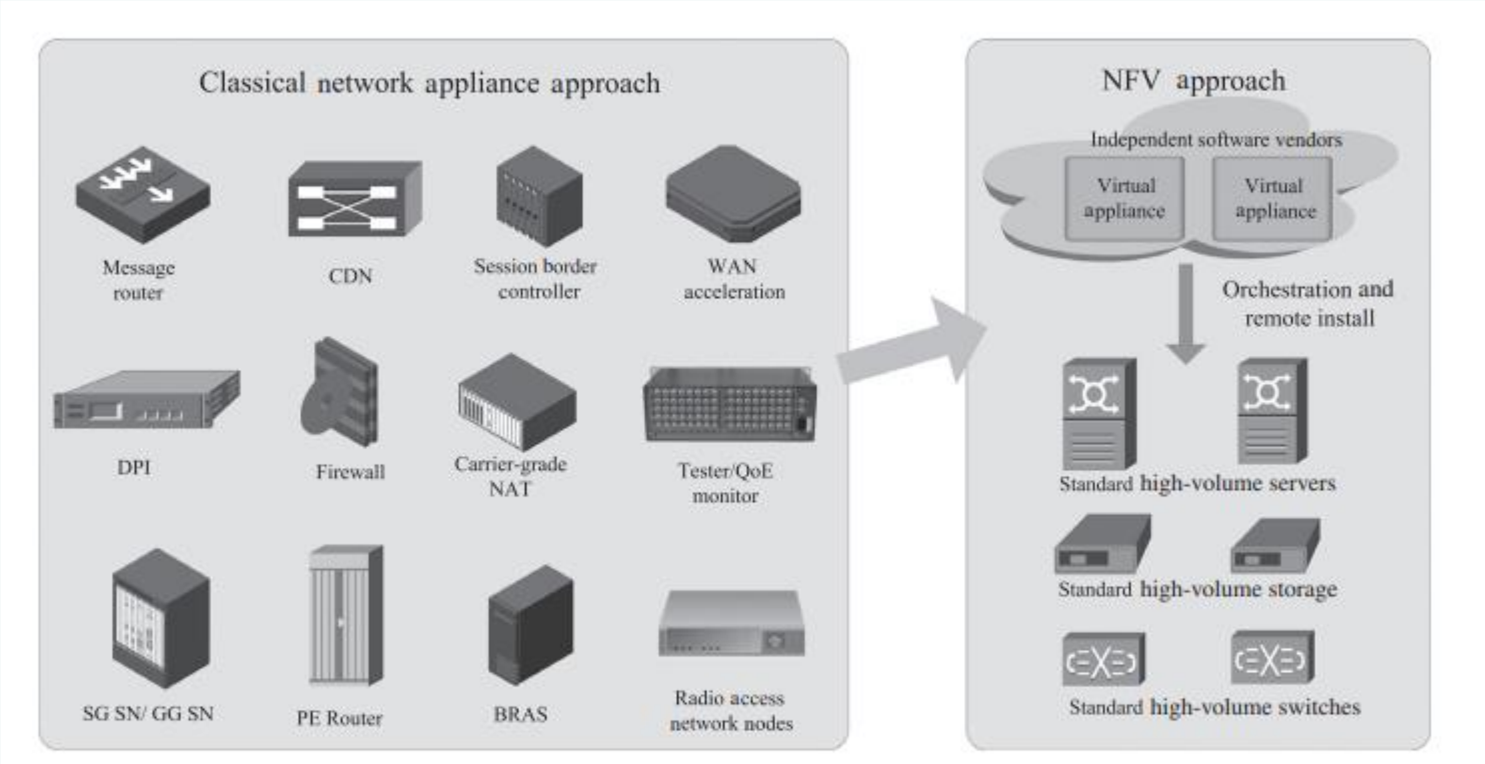


Sensitivity: Internal

From Core Networks to SDR: Soft Design

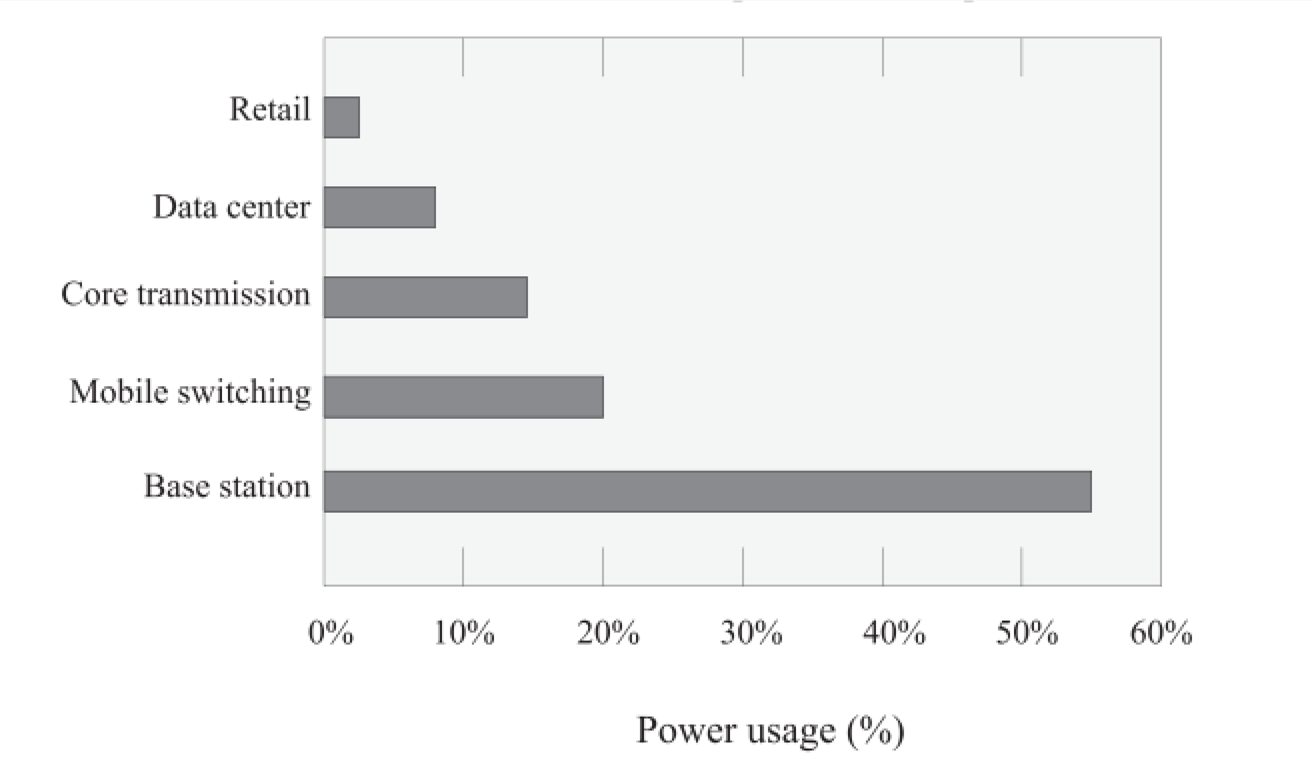
- It usually takes a long time to evolve to a new communication system, since the launch cycle of new standards is long, and new equipment needs to be developed and integrated. Therefore, it is necessary to make the network more flexible and reconfigurable.
- Soft design is the key to achieve these goals, and it will bring agility to the implementation of network elements from both core networks and access networks, as well as the building blocks of air interface. In a soft network, computing, storage, and radio resources are virtualized and centralized to reach dynamic and user-centric resource management.
- The soft idea in communication networks can be traced back to the 1990s. In early 1990, the communication industry realized that it was difficult to define a unique standard for future mobile systems, and hence software-defined radio (SDR) emerged.
- Some components of radio systems are implemented using software on a programmable platform instead of implementing on the hardware, such as modulation, coding scheme.

NFV Vision



Classical network appliance approach
Message router
CDN
Session border controller
WAN acceleration
DPI
Firewall
Carrier-grade NAT
Tester/QoE monitor
SG SN/ GG SN
PE Router
BRAS
Radio access network nodes
NFV approach
Independent software vendors
Virtual appliance
Virtual appliance
Orchestration and remote install
Standard high-volume servers
Standard high-volume storage
Standard high-volume switches

Cellular Network: Base Station Power consumption



Sensitivity: Internal

Energy-Efficient Communications and Green Networks: Motivation

- Traditional designs in cellular networks focuses on spectrum efficiency, which is defined as the amount of bits transmitted by each unit of bandwidth.
- Since the first-generation cellular system, spectrum efficiency improvement, along with network coverage enhancement, has been the most important issue in network design.
- Many appealing technologies, such as orthogonal frequency-division multiplexing (OFDM), multiple input multiple-output (MIMO), small-cell networking, and full-duplex communications, have been proposed in this regard.
- With the explosion of wireless data applications in recent years, energy consumption of wireless networks has aroused much interest in the 5G era.
- The motivation of so-called energy-efficient communications or green networks is to **save the energy consumption of the whole cellular network**.

Sensitivity: Internal

Energy-Efficient Communications and Green Networks: Challenges

- What are the biggest challenges in making 5G networks energy-efficient?”
- “How can software-defined networking (SDN) help in reducing power consumption?”

Sensitivity: Internal

Energy Efficient Base Stations: Ericsson

- midband 5G radio, featuring 64 transmitters and receivers.
- Weighs only 20 kilograms, a reduction of up to 45%.
- Energy consumption is down 15% to 20% compared with older equipment, says the company.

Sensitivity: Internal

Rethinking Green and Soft 5G Network Design

- Toward a “Green and Soft” 5G, eight innovative 5G research and development themes have been proposed by China Mobile, including:
- Rethinking Shannon to start a green journey on wireless systems;
- Rethinking Ring and Young for no more “cells”;
- Rethinking signalling and control to make network applications- and load-aware;
- Rethinking antennas to make BSs invisible via SmarTiles;
- Rethinking **spectrum and air interface** to enable wireless signals to “dress for the occasion”
- Rethinking fronthaul to enable soft RAN via next-generation fronthaul interface (NGFI);
- Rethinking the protocol stack for flexible configurations of diversified access points and optimal baseband function split between the BBU pool and the remote radio systems;
- Rethinking big data (BD) analytics in wireless communication systems to facilitate globally optimized resource allocation and scheduling via big-data-enabled network architecture and signalling procedure.

Sensitivity: Internal

Green Radio Metrics: Definitions

- There are various definitions of metrics for Green radio, which can be roughly classified as two kinds: energy efficiency (EE) metrics and energy consumption metrics.
- These metrics can be viewed from the link level, access level, and network level.
- **Link Level:** The energy consumption of a point-to-point communication link presents the required energy for transmitting one bit information (Joules/bit). Minimizing the energy consumption has been considered for a long time. Radio resource allocation aims to minimize the average required transmit power for a given average data rate requirement.
- Link-level energy efficiency largely depends on the data rate of communication channels and the energy consumption in the transmitter and the receiver. Therefore, for a wireless channel, link-level energy efficiency is greatly impacted by the channel fading, such as path loss, shadowing, and fast fading.
- **Access Level:** The point-to-point link-level metric can be extended into a multiple-user link, e.g., multiple access network, multiuser interference, and device-to-device communications. In these scenarios, each communication node/user has its own energy efficiency, which should be considered for the EE metric. There are mainly three well-established metrics to aggregate the different EEs:

Green Radio Metrics: Definitions

  - **Global energy efficiency (GEE)** represents the ratio between the overall amount of bit and the overall energy consumption, and thus can be interpreted as the benefit–cost ratio of the entire network.
  - **The weighted sum energy efficiency (WSEE)** and the weighted minimum energy efficiency (WMEE) can characterise the complete Pareto-optimal EE region of users, as it can prioritize individual EE by varying some weight value ωk.
- **Network level:** the area energy consumption (AEC) is defined as the average network power consumption divided by the network coverage (W/m2). This metric considers all network power consumptions, including radio transmission power, fixed circuit power related to the operation system, cooling system, etc. Thus, it is more related to carbon dioxide emissions and the carbon footprint.
- A counterpart area energy efficiency (AEE) metric can be defined as the average network coverage per consumed power (m2/W).
- With the densification of 5G small-cell base stations where the number of access points could be comparable to that of the associated users, the average power consumption per user becomes an important metric related to the operation cost, particularly the electricity bill, of cellular operators.
- In the urban environment where the network is capacity-limited, a more useful metric defined as the number of supported users per power unit can be used, which has a unit of users/W or W/user.

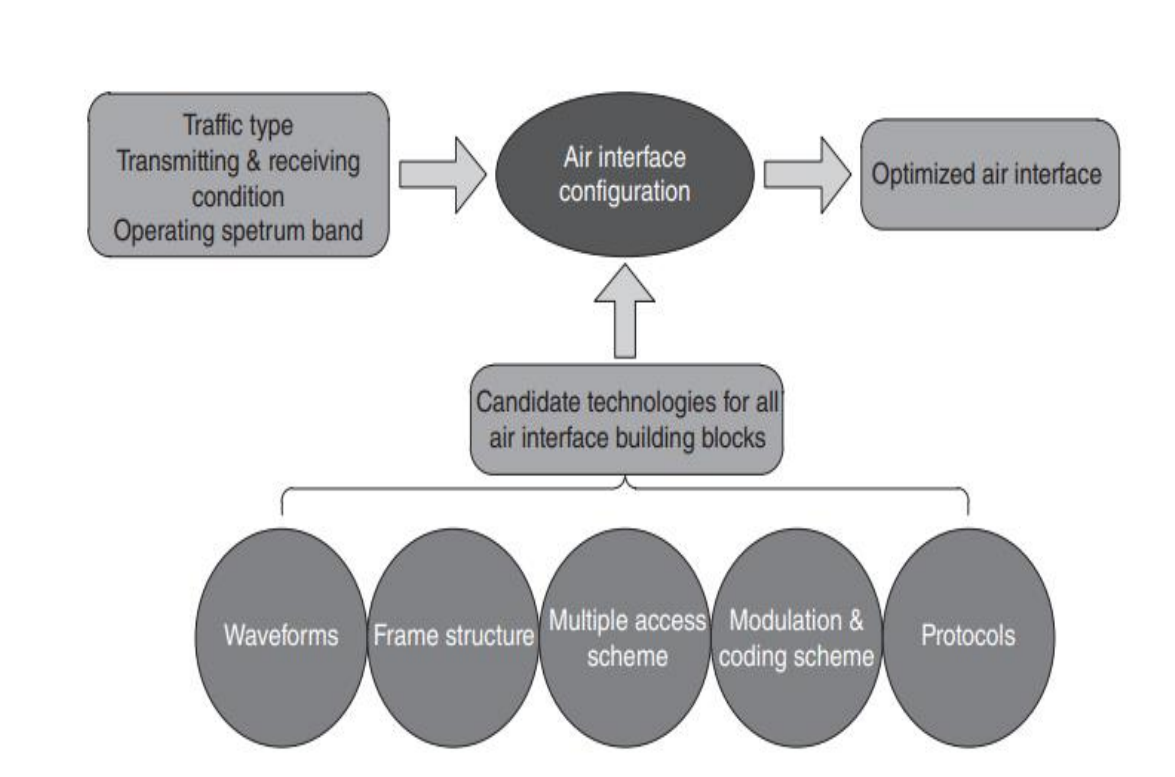
Green metrics for different levels

	Energy efficiency	Energy consumption
Link level	b/Joule; b/s/W; b/s/W; $(b \cdot m)$/s/Hz/W	Joule/bit
Access level	GEE; WSEE; WMEE	
Network level	m^2/W; user/W	W/m^2 W/user

Sensitivity: Internal

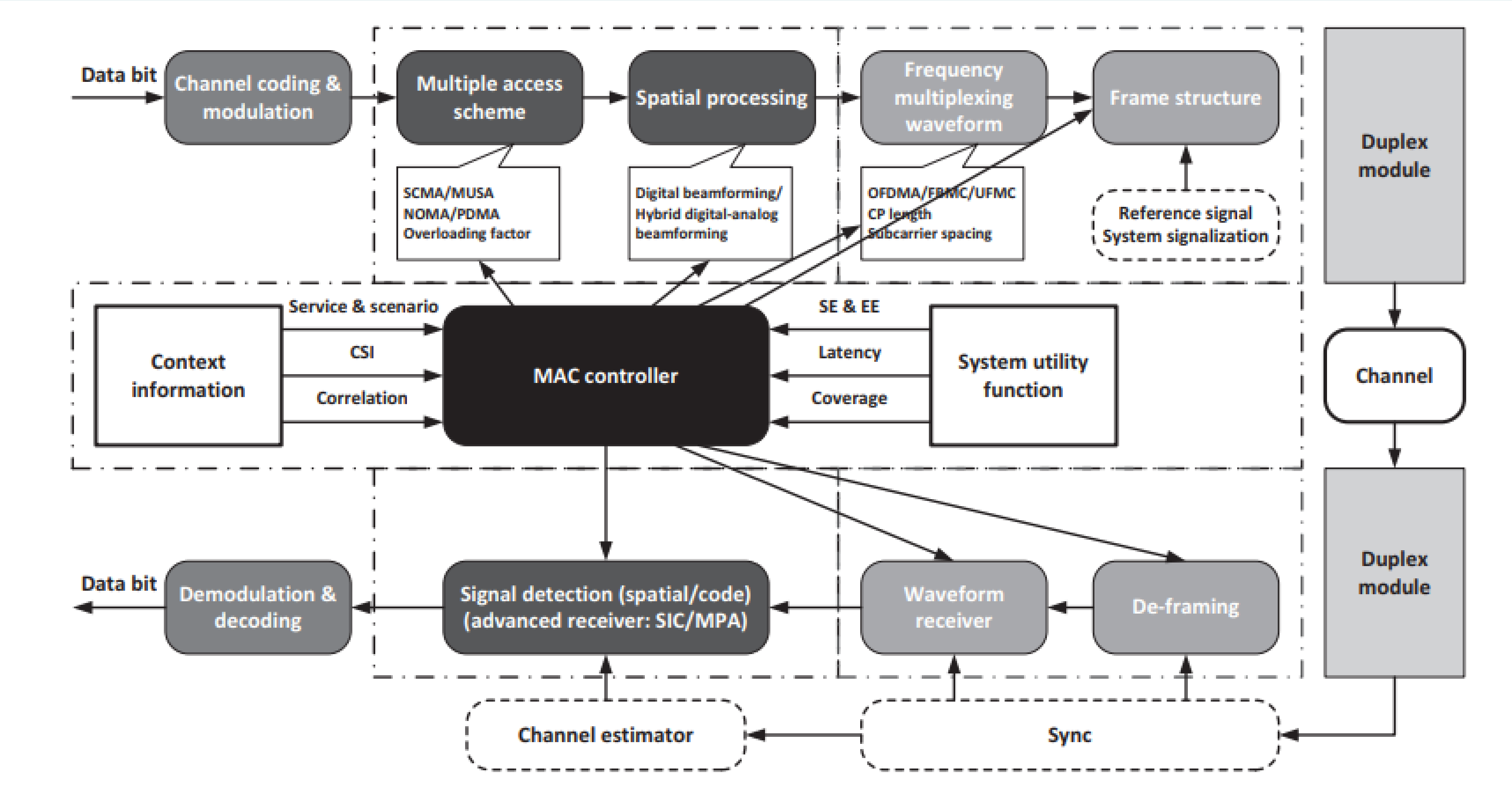
Greener Networks using SDAI

- SDAI extends the concept of “soft design” to the air interface in communication networks.
- Instead of a global optimized air interface, which is the trade-off among many factors, SDAI is highly motivated to meet the massive connections and diverse demands by reconfiguration and combination of multiple physical-layer building blocks, including frame structure, duplex mode, waveforms, MA scheme, modulation and coding, a MIMO transmission scheme, etc.



Sensitivity: Internal

Structure of SDAI



Sensitivity: Internal

The Intelligent Centralised(MAC) Controller

- Since there are diverse deployment scenarios and use cases emerging, or soon to emerge in future 5G networks, it is very important and beneficial for operators to deploy one network to support all use scenarios and use cases.
- To implement this, it is critical to adopt one unified and flexible air interface framework like SDAI to meet the diverse requirements of diversified usage scenarios.
- the core of SDAI structure is an intelligent central controller. The controller can receive, sense, even predict the context information of the network, including service types and requirements, traffic volume, channel state information, etc.
- Given the goal of optimizing specific system utility functions like spectrum efficiency, energy efficiency (EE), latency, coverage, and user QoE, the controller could select and configure the building blocks.

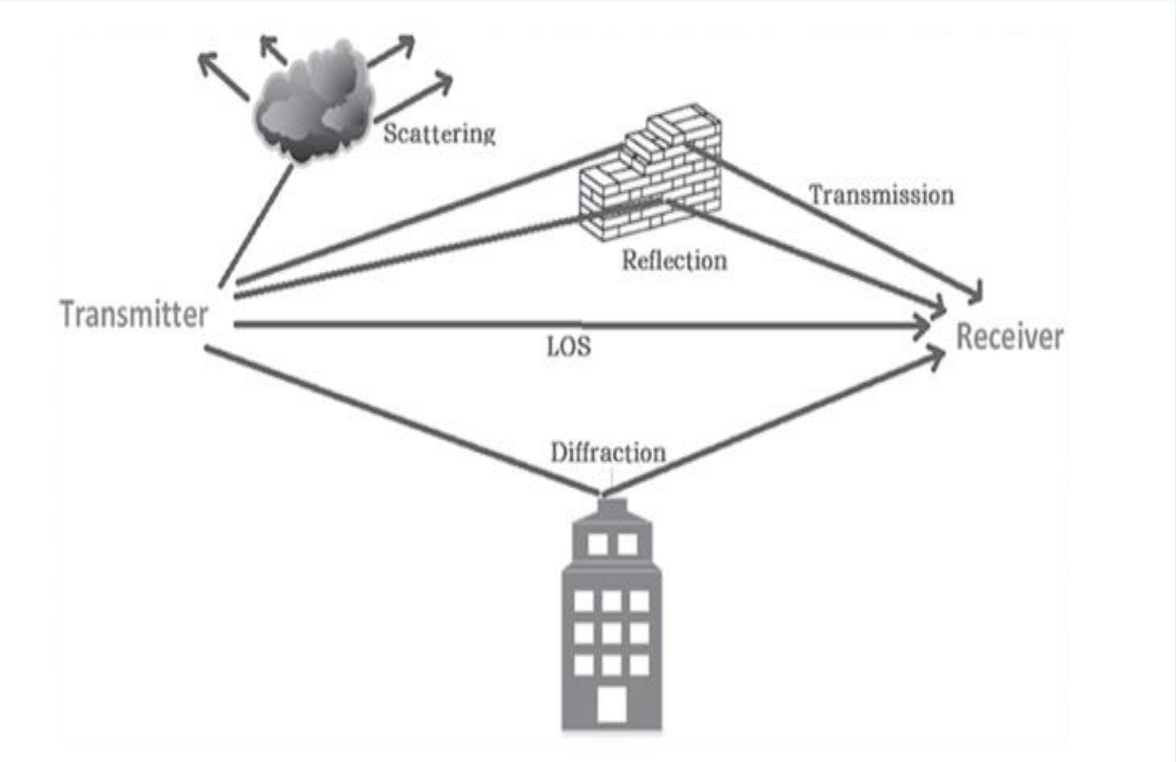
Propagation Channels

- The propagation channels dominate the actual performance of any practical system, since physical law, described by Shannon's capacity equation, dictates the amount of information that can be carried through the wireless media.
- To evaluate the performance of a wireless system, one could rely on software simulation, which is probably the most cost-effective and time-saving evaluation method.
- It offers a mathematically tractable process and can be used to predict trends and average performance reasonably and accurately.
- Channel behaviors are well understood at traditional cellular frequency bands. However, in the realm of 5G, we see high frequency bands (i.e., mmWave bands with wide bandwidth), and high mobility scenarios (e.g., 500km/hr for high-speed railway [HSR]) are considered for mobile access.

Sensitivity: Internal

Channel Modelling Principles

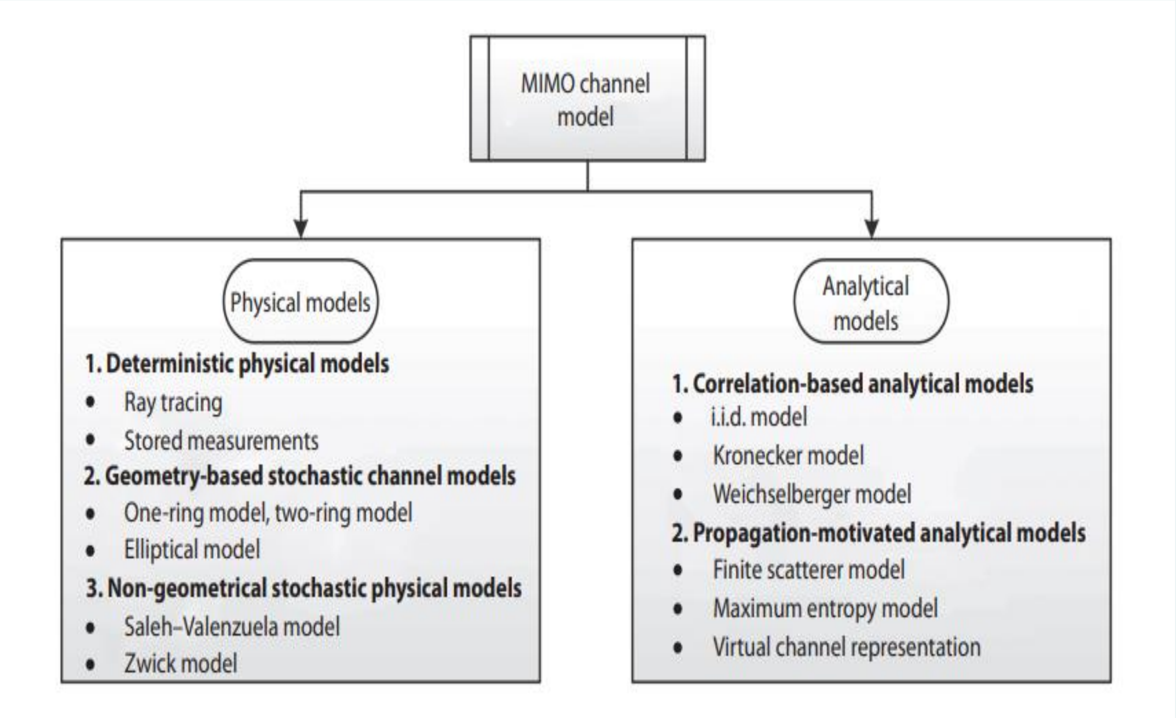
- Channel models used to be only in two dimension, however it is increasingly obvious that the elevation domain and the azimuth domain both have huge impacts on radio propagation, hence wireless performance. There are four basic propagation mechanisms: reflection, diffraction, scattering, and transmission (penetration).
- Propagation in the cellular and WLANs scenarios is more complex. In many cases, the receiver is placed in non-line-of-sight (NLOS) of the base station (BS) or access point (AP).
- The transmitted signal usually reflects off surfaces, diffracts around object edges, or transmits through obstacles, following different paths before reaching the receiver.
- This results in the multipath effect, where reflections, diffractions, and transmissions all attenuate the signal power.



Sensitivity: Internal

Channel Model Classification

- The state-of-the-art channel models can be classified as physical and analytical channel models.
- The physical channel models concern the physical propagation environment, thus modelling signal parameters such as AOA, AOD, complex power, and time of flight.
- They can be further divided into deterministic channel models (e.g., ray-tracing and measurement-based models), geometry-based (e.g., one/two-ring and elliptical models), and non-geometry stochastic channel models (e.g., Saleh-Valenzuela and Zwick models). Physical channel models can be in 2D or 3D.



Sensitivity: Internal

Exercise

- Discuss an example of a company using SDN, NFV, or SWIPT for sustainability.
- "Green Tech Pitch" : Propose an innovative energy-saving solution for any telecom provider.

Sensitivity: Internal

Summary

- Green networking is crucial for sustainable 5G – energy consumption challenges in 5G.
- Software-defined solutions play a key role in efficiency – e.g. dynamic resource allocation.
- Future networks must balance performance, cost, and sustainability.
- Case Study: Google's carbon-neutral data centres, AT&T's energy-efficient 5G infrastructure.

Sensitivity: Internal

Sensitivity: Internal