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Outline:

- What is 5G?
- Drivers, goals, and challenges of 5G
- Enabling technologies
- CR in 5G
- Broadening the CR concept
- Dynamic Spectrum Access
- Challenges on CR Implementation
- Future Research Directions
- Conclusion

What drives 5G?

Mobile data demand will continue to increase.

Growth of existing applications.

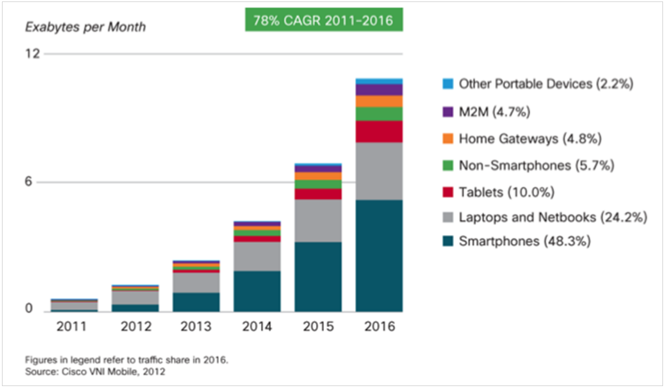
- e-mail,
- file transfer,
- real-time audio (VoIP),
- Video streaming,
- IP traffic,

What drives 5G?

New applications and new ways of doing things .

- Instant Messaging (IM) with big files: lots of short connections, high data rates.
- Internet-of-Things (IoT) and Machine-to-Machine (M2M): massive numbers of devices and connections, little data more than 50 billions of connected devices in 2020.
- Critical applications - e.g., health, safety and security, traffic systems: guaranteed QoS.

Ciscos traffic prediction



Multiple challenges

Exploding traffic volume

- Mobile data traffic growth more than 24-fold between 2010 and 2015, more than 500-fold between 2010 and 2020.

Random and diverse traffic

- Uneven distribution of traffic across space and time
- Peak-to-mean traffic in fixed Internet up to 100:1; greater ratios expected for mobile broadband
- Diversity of applications with very different QoS requirements

Control plane load (IoT, IoE)

Low cost

Energy efficiency

Goals in 5G

- Data Rates
- Capacity
- Spectrum
- Energy
- Latency
- Reliability
- Coverage
- Devices per area

5G TECHNOLOGIES

Dense Heterogeneous Networks (HetNets)

- **Macro cells combined with Small cells**: picocells and femtocells Increase of spectral efficiency, improved coverage, reduction of transmit power.
- **Separation of data and control planes** Connectivity with two BS: macro for control, small cell for transport
- **Multiple radio-access technologies** Including unlicensed and licensed shared access
- **Device-to-device communication (D2D)** Increase energy efficiency, decrease interference, increase coverage

5G TECHNOLOGIES

Self-Organizing Networks (SONs)

- Self-configuration: neighbor discovery , coordinated selection of parameters, e.g., cell identity, Tx-power, time-frequency resource sharing
- Saving of OPEX by reducing human interventions
- SON needed for small cells where the number of deployed nodes could be very high

5G TECHNOLOGIES

Software Defined (Cellular) Networks

- Directly programmable architecture
- Simplified network management and control
- Simplified introduction of new services or configuration changes
- Fine-grained resource control

5G TECHNOLOGIES

Indoor positioning

- Additional information can help in resource allocation, and service improvement
- Enabler of new applications

5G TECHNOLOGIES

Intelligent user-device assistance

- Sensing, relaying.
- Machine learning.
- Intelligent Transport System paradigm.

COGNITIVE RADIO IN 5G

What will be the role of CR in 5G?

- Will CR in 5G be a key technology or a nice-to-have feature?
- Wouldnt 5G loose its edge if CR spectrum access became dynamic and without guarantees?
- Do we need to extend the concept of CR beyond spectrum?

Meaning of Cognitive Radio

It is an intelligent wireless communication system that is aware of its surrounding environment (i.e., outside world), and uses the methodology of understanding by building to learn from the environment and adapt its internal states to statistical variations in the incoming RF stimuli by making corresponding changes in certain operating parameters (e.g., transmit power, carrier frequency and modulation strategy) in real-time, with two primary objectives in mind: highly reliable communications whenever and wherever needed; and efficient utilization of the radio spectrum.

The Motivation behind Cognitive Radio

Significant underutilization of the radio spectrum.
The Cognitive Radio solution to the spectrum underutilization problem:

- Sense the radio environment to detect spectrum holes (i.e., underutilized subbands of the radio spectrum).
- Make the spectrum holes available for employment by secondary users efficiently, subject to the constraint that the received power in each spectrum hole does not exceed a prescribed limit (set by the legacy user).

How it works

The cognitive radio network is a complex multiuser wireless communication system capable of emergent behaviour.
It embodies the following functions:

- To perceive the radio environment (i.e., outside world) by empowering each users receiver to sense the environment on a continuous-time basis;
- To learn from the environment and adapt the performance of each transceiver (transmitter-receiver) to statistical variations in the incoming RF stimuli;

How it works cont..

- To facilitate communication between multiple users through cooperation in a self-organized manner;
- To control the communication processes among competing users through the proper allocation of available resources;
- To create the experience of intention and self-awareness.

Primary objectives

- To provide highly reliable communication for all users of the network.
- To facilitate efficient utilization of the radio spectrum in a fair-minded way.

Why may CR be interesting for 5G?

- Some bands are significantly underutilized
- Cost of dynamically leasing spectrum is expected to be much lower than purchasing a licensed band
- Allows expansion of spectrum at a much lower cost
- Coping with overload traffic

Challenge: How to use those complementary resources to optimize system performance?

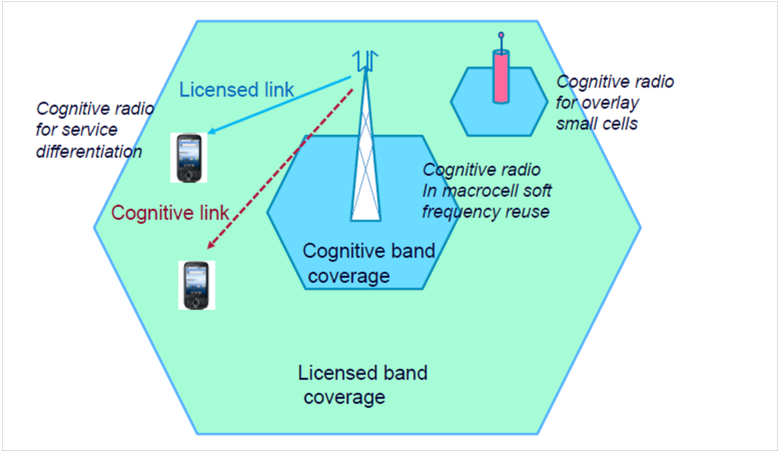
Non-Cooperative Architecture

- Two separated networks at the physical layer
- Integration at upper layers

Cooperative Architecture

- Combined used of licensed and CR resources to form a single integrated network
- Using cooperative communication principles (coordinated relaying by users)
- Major performance gains possible

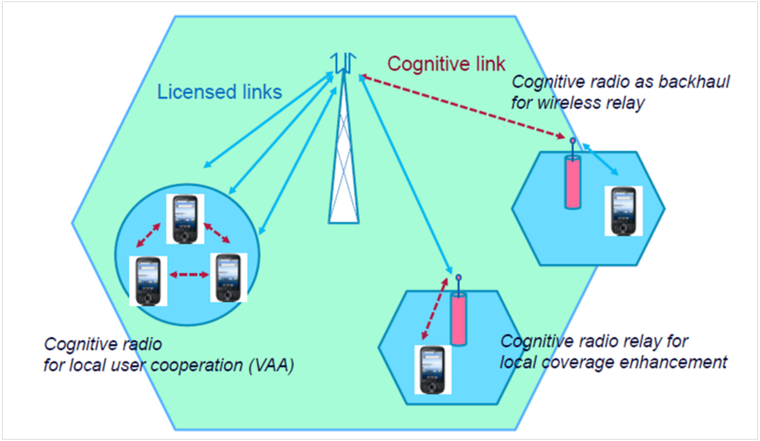
Non-Cooperative Architecture



Usage scenarios

- Power-limited cognitive radio resources for users near the macro-cell; licensed resources for users far away.
- Service differentiation: licensed resources for strict QoS demands and CR for relaxed QoS
- Cognitive small cells (femtocells) using CR to cover traffic hot spots or coverage gaps.

Cooperative Architecture



Usage scenarios

Cognitive relay for capacity enhancement

- Communication to BS with licensed resources; CR for local coverage
- Communication to BS with CR; local coverage with licensed resources: no modification for conventional user devices **Virtual Antenna Array (VAA)**
- Virtual MIMO in licensed band: performance gains

Major Functional Blocks of Cognitive Radio

Function	Objective
Spectrum sensing	Detection of spectrum holes and estimation of their average power contents.
Predictive modeling	Prediction of how long the spectrum hole is likely to remain available for employment by secondary user.
Transmit power control	Maximize the data rate of each user subject to power constraints
Dynamic spectrum management	Distribute the spectrum holes fairly among secondary users, bearing in mind usage costs.
Packet routing	Design a self-organized scheme for routing of packets across the radio network

Main in CR issues

Self Coexistence

- To avoid secondary users to harmfully interfere with primary users.

Accurate sensing

- Sensing aims to determine if a channel is idle or busy in terms of primary user activity.

Optimized spectrum decision

- Secondary users are expected to dynamically choose the best available channels and transmission parameters.

Seamless spectrum handover

- No latency should be noticed by users during mobility.

Main in CR issues cont..

Cross layer design

- Spectrum sensing is restricted only to the PHY and MAC layers, spectrum management (e.g., spectrum handover, decision making and scheduling) can be related to all upper layers, which makes interaction and coordination between the different layers of the protocol stack necessary.

Energy efficiency

- Have limited communication and resource requirements, since most of the devices are battery powered.

Standards

The IEEE 802.22

- It is the first effort for achieving a CR international standard.
- It defines CR techniques that are specifically targeted to enable unlicensed devices to exploit television white spaces in the VHF and UHF bands (54-862 MHz) in a non-interfering basis for the deployment of Wireless Regional Area Networks (WRAN).

Standards

The IEEE SCC41 (Standards Coordinating Committee 41)

- Formerly known as IEEE P1900, addresses the area of Dynamic Spectrum Access Networks (DySPAN) and aims to develop standards for next generation radio and advanced spectrum management.

Learning

Spectrum decision can be performed reactively, as a consequence of an unexpected link failure, or proactively through anticipation. Benefits of proactive spectrum decision are:

- Decrease of time and energy spent to find an idle channel before any transmission, as channels can be prioritized according to their probabilities of availability

Learning cont..

- Decrease in the number of spectrum handovers and service interruption losses, because channels can be prioritized according to their expected durations of availability
- Decrease in terms of interference to primary users, as primary user appearance can be probabilistically determined during transmission.

Dynamic Spectrum Access

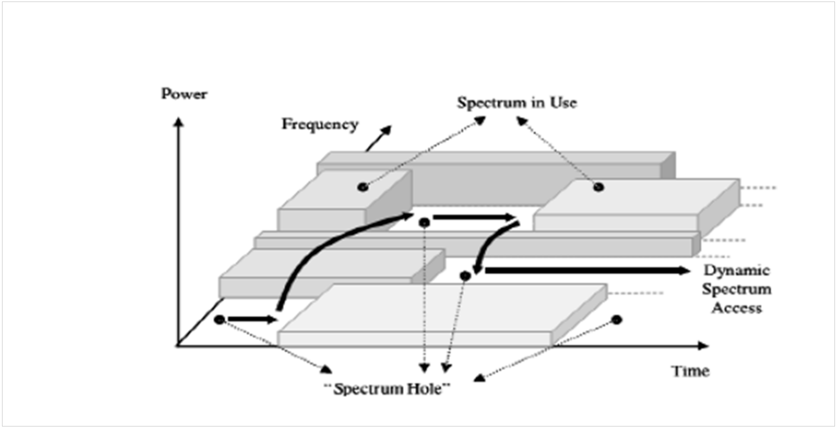
It refers to the method used to detect and to access spectrum holes.
This term is very broad and contains a number of elements like:

- spectrum access
- spectrum allocation
- spectrum pooling
- spectrum management
- regulation activities

Dynamic Spectrum Access...

- The spectrum is allocated opportunistically and the goal is to achieve device-centric interference control and dynamic reuse of the spectrum.

Dynamic Spectrum Access. . .

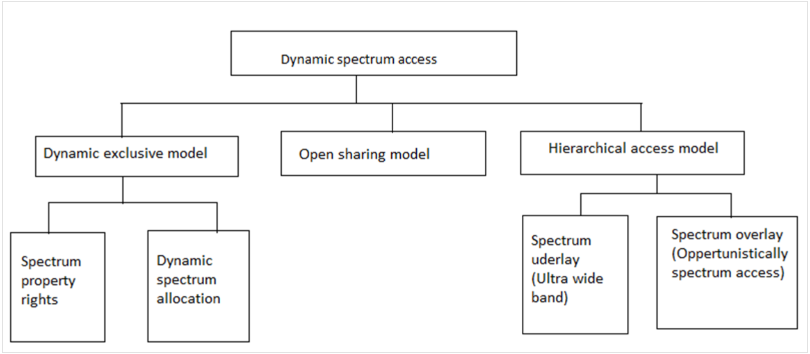


Categories of DSA

There are three general categories of DSA

- Between a licensed primary system and a license-free secondary system, e.g., used to access the digital TV spectrum.
- Within the same primary system (to share the 3G/4G spectrum), with the help of, e.g., femtocells.
- Between two primary systems used at spectrum trading among cellular operators.

Models of Dynamic Spectrum Access



Dynamic exclusive use model

- It maintains the basic structure of the existing policy for spectrum regulation.
- The spectrum is allocated to certain services for exclusive use, at particular times and in particular geographic regions. This approach cannot eliminate the white space in spectrum, which may result from the busty nature of the wireless traffic.

Open sharing model

- It is used by competing peer users to share the available spectrum in a spectral region.
- Different spectrum sharing strategies can be used in this case, e.g., centralized, distributed.
- This model is popular in diverse wireless services operating in industrial, scientific and medical environments.

Open sharing model

Uncontrolled-commons

- This is also referred as open spectrum access. When a spectrum band is managed no entity has exclusive licensed to the spectrum band. It is maximum transmit power constraint.

Managed-commons

- This represents an effort to avoid the tragedy of commons by imposing a limited form of order or structure of spectrum access.

Private-commons

- Spectrum owner specifies technology and protocol for the CR user access. CR user may receive a command from spectrum owner (transmission parameter). CR user may sense and access the spectrum.

Hierarchical access model

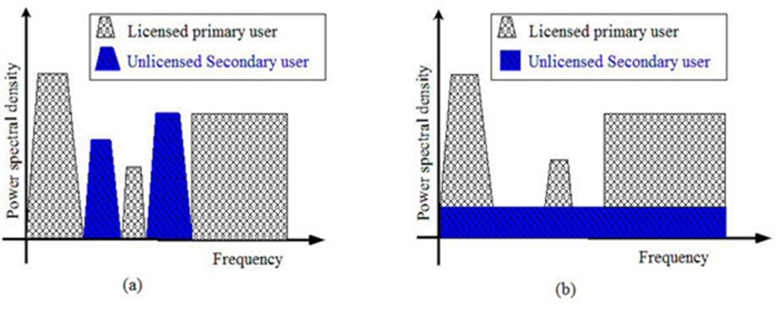
Hierarchical access model

- It is used to the primary and secondary users.
- The basic idea is to open the licensed spectrum to secondary users provided that the interference perceived by the primary (licensees) users is limited.

There are also two types of model

- Spectrum overlay -High noise of Secondary User against Primary User
- Spectrum underlay -Low noise of Secondary User against Primary User

Hierarchical access model



Implementation Challenges

- RF Front-Ends Transceiver Challenges.
- ADC and DAC Challenges.
- Baseband Challenges.
- Spectrum Sensing Algorithm Implementation.

Implementation Challenges

- Seamless spectrum handovers
- Proactive spectrum selection and interference avoidance
- Interdependency between the propagation characteristics of radio signals and the frequency band in usage Energy efficiency
- Validation of CR protocols
  GNU Radio/USRP-based.
  ORBIT (Open Access Research Testbed for Next-Generation Wireless Networks).
- Security

Conclusion

- CRS offers also the possibility of flexibly managing the spectrum in a dynamic manner in heterogeneous radio access networks.
- Through intelligent management mechanisms, frequency bands can be allocated to Radio Access Technologies(RATs) dynamically in a way such that the capacity of each RAT is maximized and interference is minimized
- Network operator may employ different RATs dynamically over time/frequency/location and acquire or exchange the spectrum usage rights.
- The cognitive devices may autonomously and dynamically adapt to the diverse heterogeneous radio access networks.
- CR area, which is still in its infancy and aims to enable an efficient utilization of the radio spectrum.