Lecture 2: Cognitive Radio Systems

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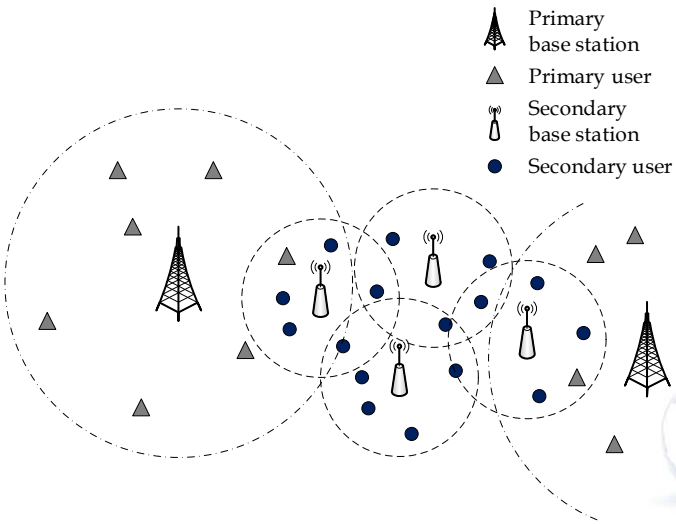
Cognitive Radio Systems

- Cognitive radio users, who are are unlicensed users, attempt to harness spectrum that is assigned to licensed users, but is not being fully utilized at a specific place or time.
- On the condition that unlicensed users do not cause interference to licensed users.
- Devices in a cognitive radio network have to sense the spectrum around them for unused portions and then dynamically utilize empty spectrum bands they can find.
- Spectrum sensing, spectrum management, spectrum optimization, frequency switching, and communication overhead make the system quite complex.

Terminology

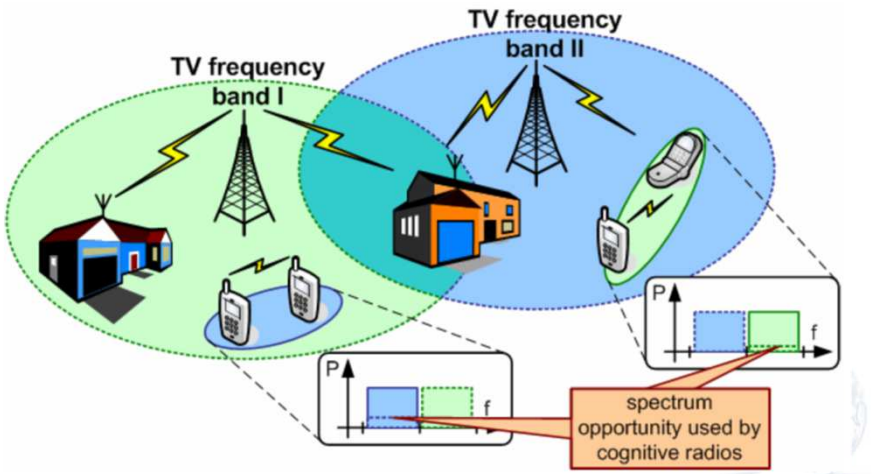
- Primary Users (PUs): The main license-holders of the spectrum. Such devices are typically not cognitive, and do not have any functionality for sharing the spectrum with others, as they have priority access to the spectrum by law.
- Secondary Users (SUs): Allowed opportunistic access to the licensed spectrum of the PUs, but only temporarily and with less priority.
- An SU uses its cognitive abilities to communicate over the available spectrum bands, while concurrently minimizing interference with PUs.

Intelligent Operations



Spectrum Sharing Techniques

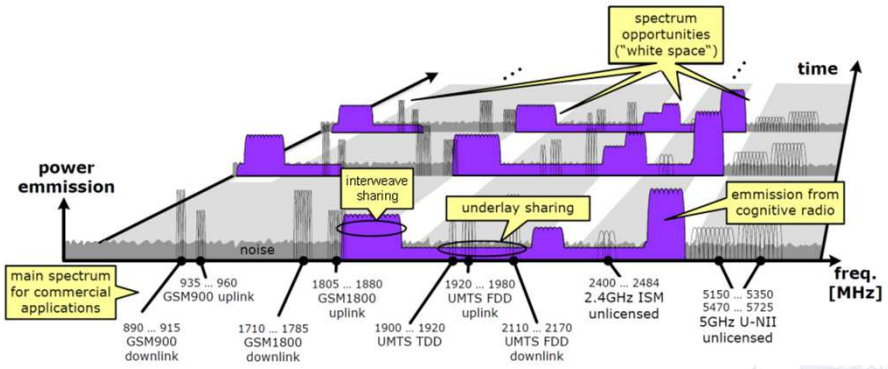
- **Interweave** approach: SUs occupy the spectrum space that has been left vacant by PUs.
- The surrounding environment should be observed to estimate the state of each portion of the frequency spectrum.
- Spectrum that is empty may be accessed by secondary users as long as the primary activity remains idle.
- Hence, spectrum opportunities should be actively identified and monitored.



Spectrum Sharing Techniques

- **Underlay** approach: Simultaneous SU and PU transmissions are allowed as long as the interference level at the primary user side remains acceptable.
- Exceeding the predefined tolerable interference threshold (temperature) may degrade dramatically the primary signal.
- Recently, extra advanced signal processing techniques have been proposed for interference avoidance and mitigation.

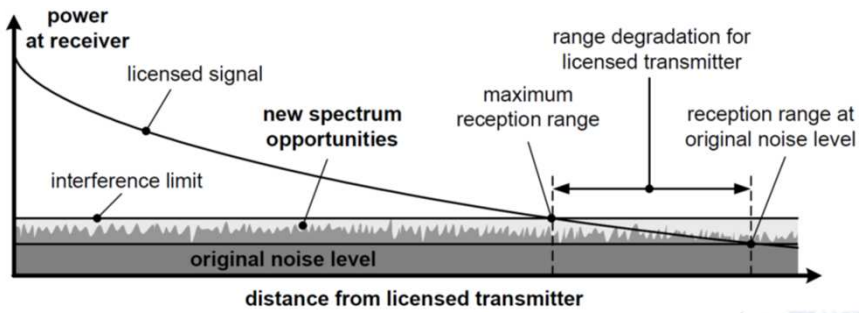
Interweave vs Underlay



Underlay: Interference Mitigation!

- **Limiting power** of the SU transmission to keep the interference level at the primary side bounded, albeit restricting the SU to short range communications.
- **Beamforming**: Exploit the superposition concept of radio waves to guide the signal toward a specific receiver using multiple antennas. Also, constructive or destructive interference is triggered at the intended location to lessen the interference.
- **Spread spectrum** techniques: The SU signal is multiplied by a spreading code to obtain a weaker signal with wider band. The resulting spread signal causes less interference at PUs. The original SU signal is recovered at the receiver side by orthogonality.

Interference Temperature Concept



Spectrum Sharing Techniques

- **Overlay** approach: Here, PUs share knowledge of their signal codebooks and messages with the SUs.
- Thus, the SUs may assist the PU transmission rather than vying for spectrum access.
- More precisely, SUs overhear the messages sent by PUs and use these messages either to eliminate the interference generated by the PU communication at the cognitive receiver side or to improve the performance of the PU transmission through relaying the accumulated messages to the primary receiver.
- The latter case allows SUs to transmit at the same time as the PU provided that its overall transmit power covers the energy needs of its own communication as well as its relaying operation.
- A trade-off should be achieved between extra interference induced on the PU and the improvement brought to it by the SU.

Spectrum Sharing Techniques

- **Hybrid** schemes using a combination of the Underlay, Overlay and Interweave paradigms are possible.
- Some hybrid schemes can improve the efficiency of spectrum sharing on the expense of a more complex algorithm and hardware.
- The benefit of such schemes is that the secondary users can maximize their transmission rate once a spectrum opportunity is detected.

Cognitive Radio Standards

- IEEE 802.22 Wireless Regional Area Network (WRAN) standard to exploit the UHF/VHF TV bands.
- TV frequency bands have favorable wireless propagation characteristics, allowing longer distance communications.
- IEEE 802.16h standard (now part of IEEE 802.16-2012 standard) adds cognitive radio to WiMAX networks.
- IEEE 802.11af standard allows Wi-Fi operation in TV white space in VHF and UHF bands using cognitive radio.
- European Computer Manufacturers Association ECMA-392 standard.
- European Telecommunications Standards Institute ETSI TS 102 946 standard for cognitive radio in TV whitespace.