Communication Systems based on Software Defined Radio (SDR) (SDR)

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Introduction to Cognitive Radio

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Source: https://www.wipro.com/engineering/cognitive-radio/

History of Cognitive Radio

The need for the development of a cognitive radio has contributed by many factors the major of which being the steady increase in the requirement of radio spectrum with the increase in wireless communication at high communication speeds and stronger signals. In the year 2000, there was a fireworks factory explosion in the Netherlands in which 23 people were killed, injured many people and destroyed a lot of property. During this crisis the emergency hotlines faced serious communication issues and caused further deterioration and destruction. The same problem was faced during 9/11 in the USA in the year 2001. These devastating incidents pushed intellectual and academic societies to work towards the development of a better management system of the scarce resource that is the electromagnetic spectrum. Towards this, the UK stepped up first in 2002 through a report by Professor Cave which detailed the possibility of selling spectrum upon the bandwidth required. Many developments and research has been done in the field of communications. The actual word ‘Cognitive Radio’ was coined by Joseph Mitola in 1999 in a wireless communications seminar on the same at the Royal institute of Technology, Sweden.

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In today's world, use of wireless devices has increased significantly with the advances in wireless technology. In the near future significant growth of connected devices is expected with mass adoption of IoT. Huge amount of spectrum is required to support this increasing number of wireless devices. But the spectrum available is a scarce resource. If we check current spectrum allocation chart, it's very hard to find free spectrum to support upcoming volumes of wireless devices and mobile data traffic.

Cognitive Radio is a concept introduced to attack the upcoming spectrum crunch issue. Cognitive Radio users are unlicensed users who find unused licensed spectrum dynamically for its own use without causing any interference to licensed users.

Some of the existing techniques used in Cognitive Radio include spectrum sensing, spectrum database and pilot channel. These techniques are either complex that requires high computational power to detect unused spectrum or fail to capitalize on spectrum space created in real-time.

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CR Technology

Cognitive radio includes four main functional blocks

- Spectrum Sensing
- Spectrum Management
- Spectrum Sharing and
- Spectrum Mobility

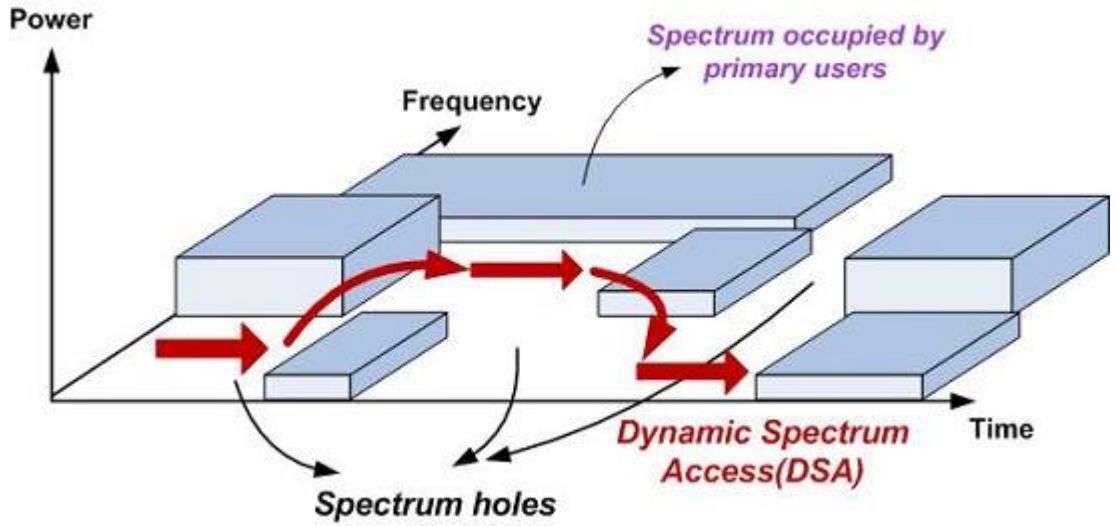

Diagram Explaining Cognitive Radio Concept

Source: https://www.engineersgarage.com/cognitive-radio/

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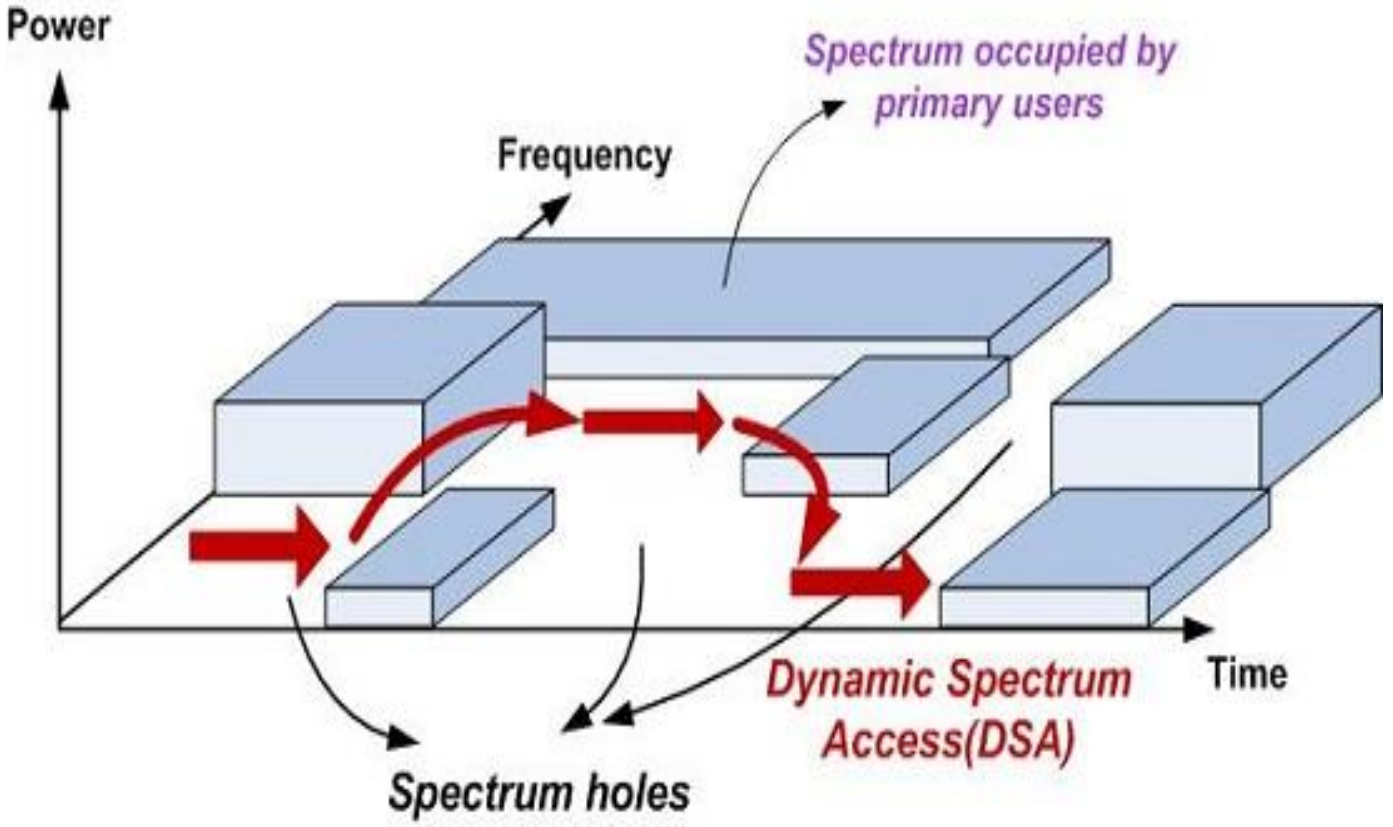

Diagram Explaining Cognitive Radio Concept

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Spectrum Sensing will determine the spectrum availability and the presence of the licensed users (also known as primary users). Spectrum management will predict how long the spectrum holes are going to remain open for use of the unlicensed users (also called the secondary users or CR users). Spectrum Sharing is meant to allocate the spectrum holes equitably among the secondary users bearing in mind the usage cost. Spectrum Mobility is to ensure and maintain the seamless communication requirements during the transition to lighter spectrum. The spectrum sensing function is the most crucial to establish a cognitive radio network.

Source: https://www.engineersgarage.com/cognitive-radio/

There are some techniques used for spectrum sensing, which are; Primary transmitter detection, cooperative detection and interference detection. The reason that spectrum sensing is the most crucial task is that there are many uncertainties connected while picking up the signals to find the holes in the band like Channel Uncertainty, Noise Uncertainty, Sensing Interference Limit, etc. So, these uncertainties need to be addressed while solving the problem that is spectrum sensing in cognitive radio networks.

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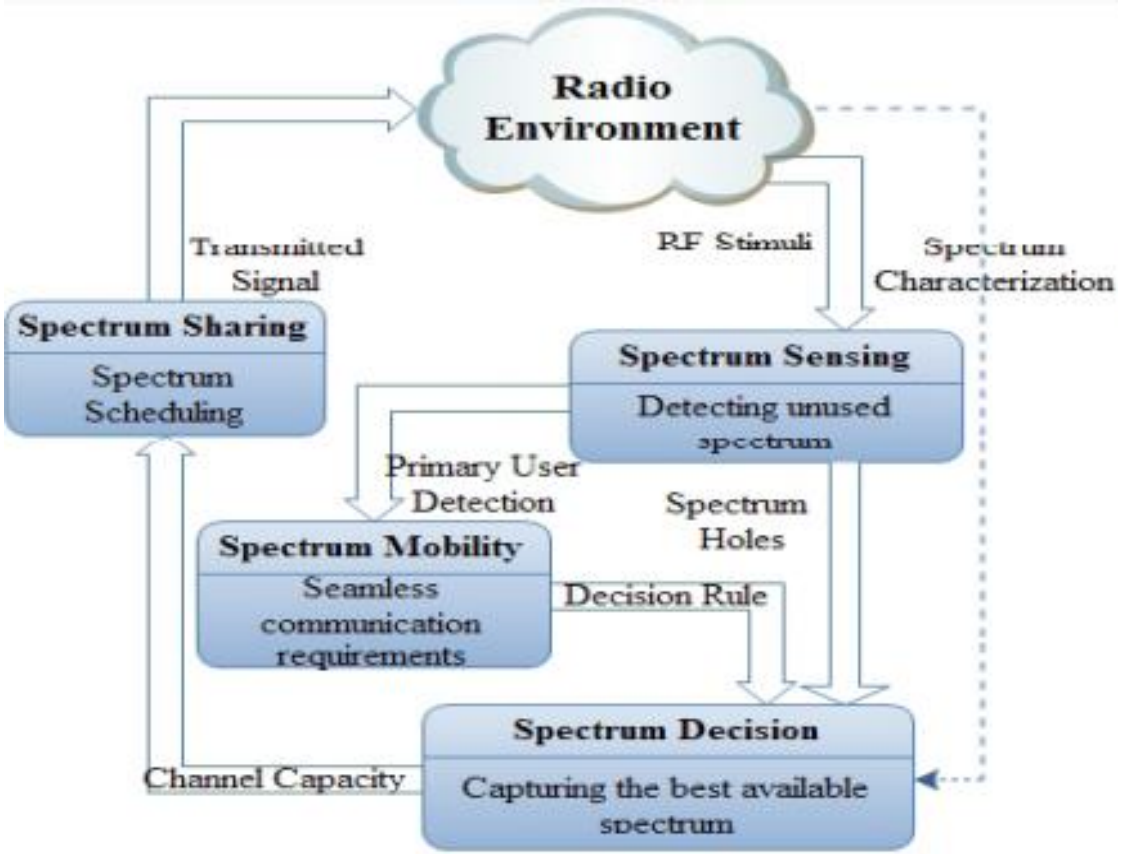

Cognitive Radio Network Cycle

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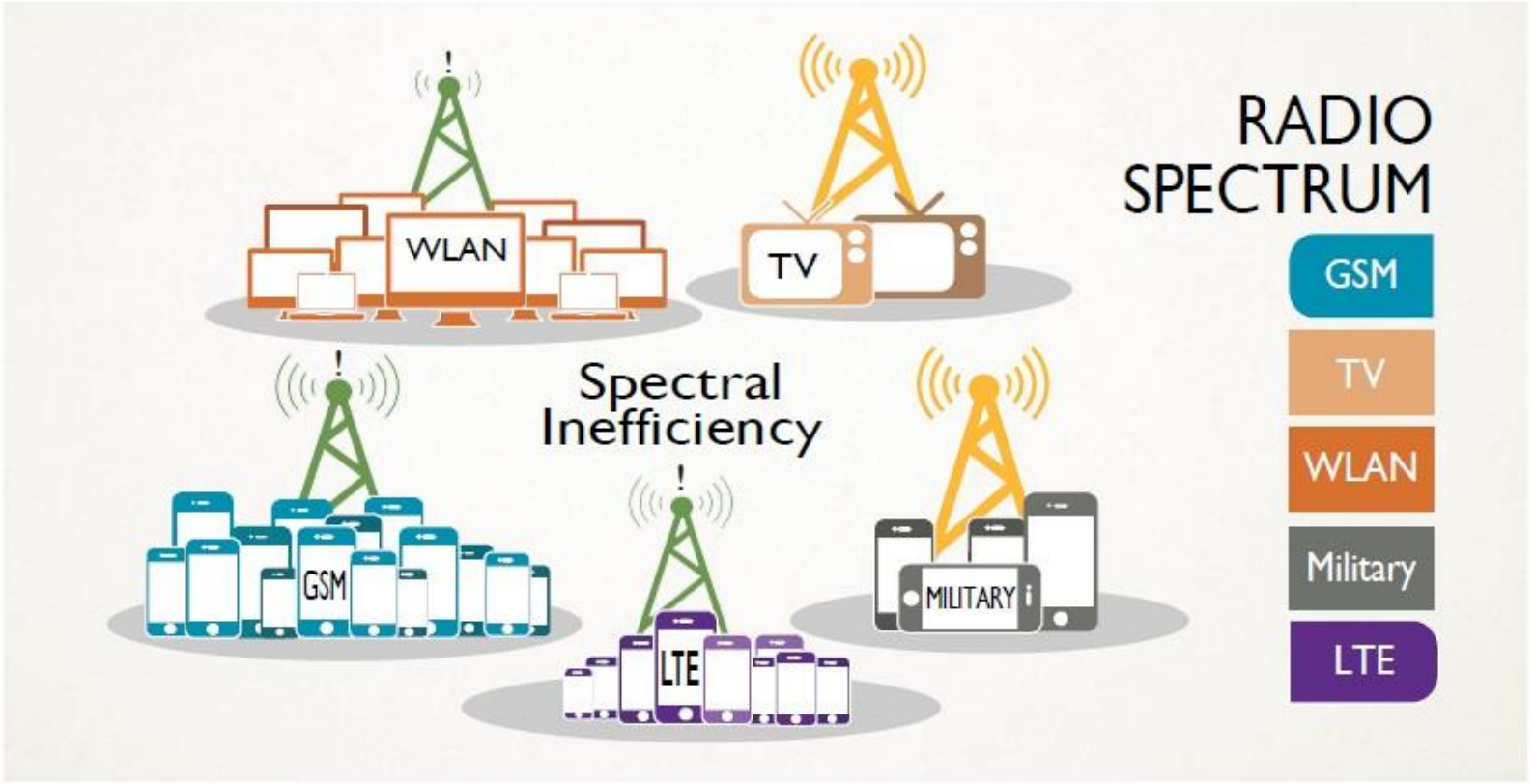
Cognitive Radio Explained

Spectrum allocation typically happens through a licensing process. However, many parts of licensed spectrum are not optimally utilized. Figure 1 shows spectral inefficiency where certain bands are overcrowded while other bands are relatively unused.



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Cognitive radio (CR) is a form of wireless communication in which a transceiver can intelligently detect which communication channels are in use and which are not. It instantly moves into vacant channels while avoiding occupied ones. It does not cause any interference to the licensed user. Figure 2 shows a way of spectrum sharing.

Figure 2: Overutilization and Underutilization of Licenses Spectrum

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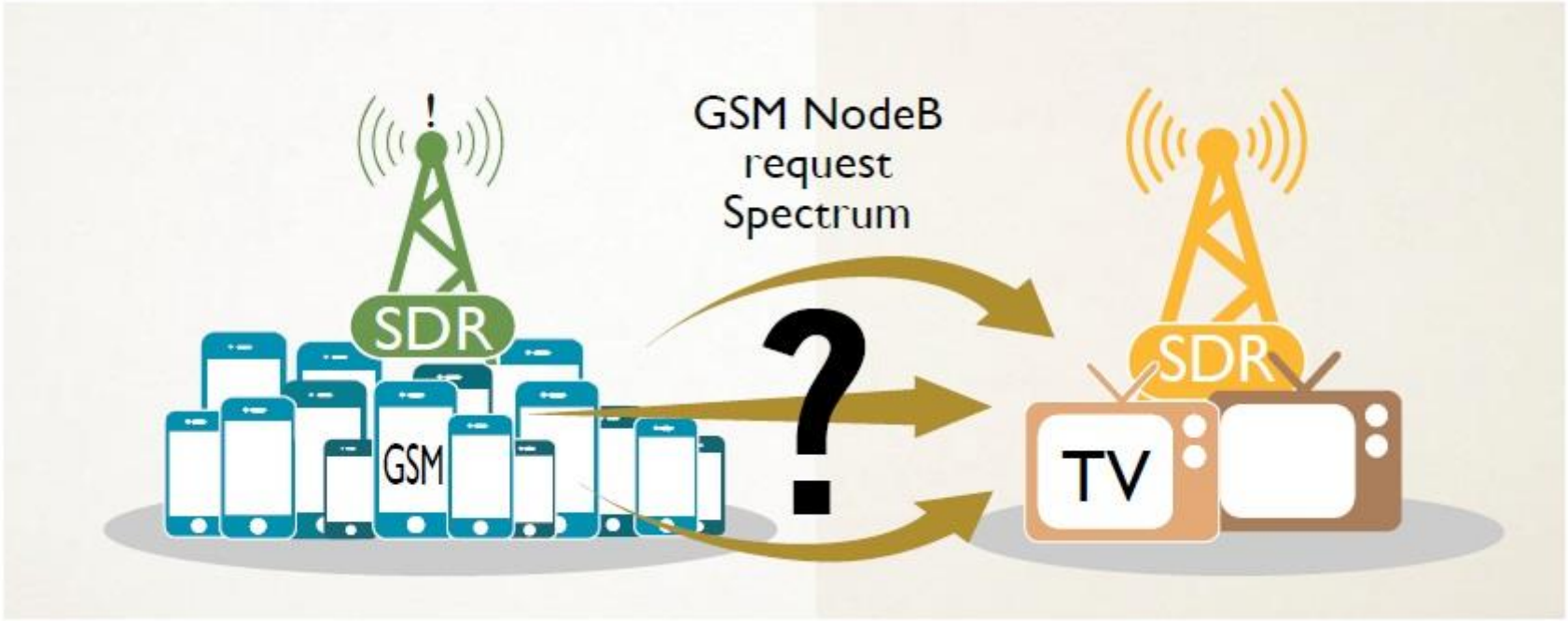

Figure 3: Spectrum Negotiation Between Two Spectrum Bands

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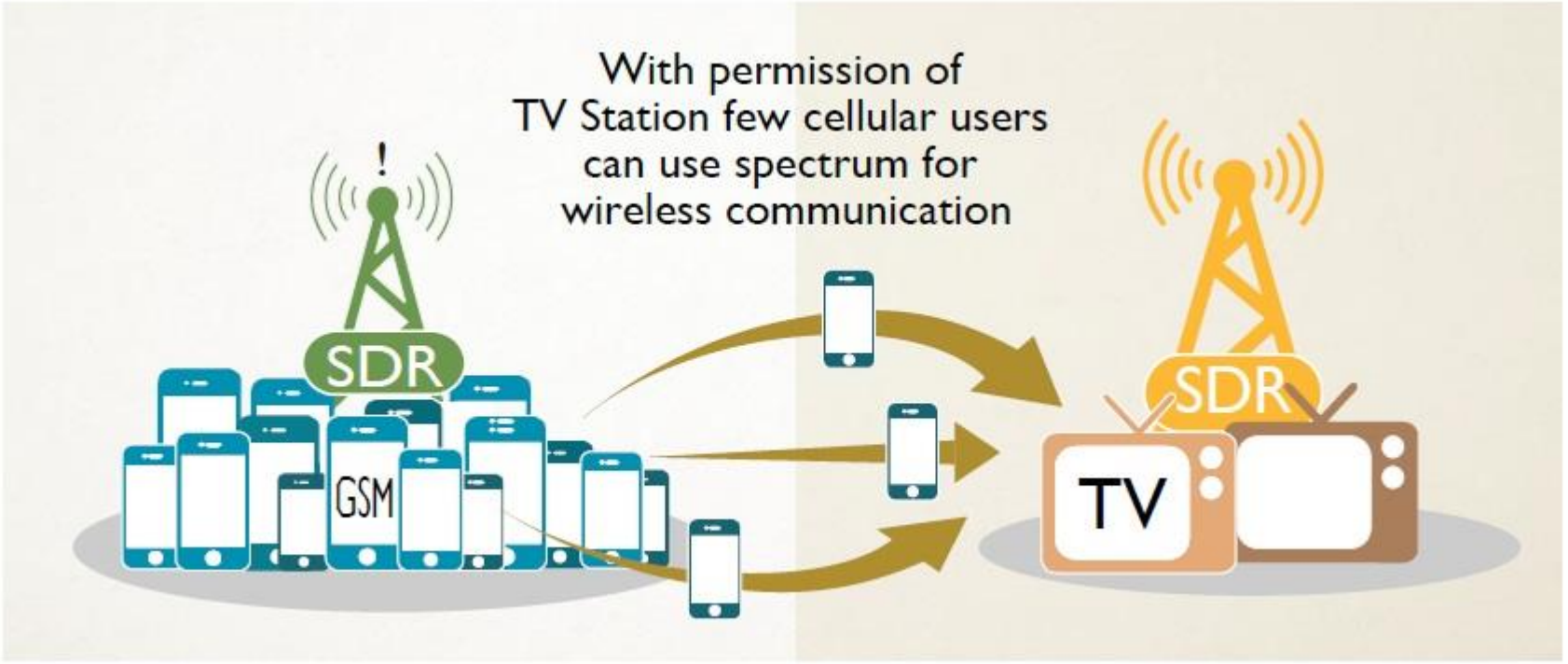

Figure 4: Usage of Underutilized Spectrum by Unlicensed User

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Spectrum-Sensing

Therefore, the major challenge in spectrum sensing is that the secondary users have to detect the presence of the primary users in the licensed spectrum and quit the frequency band as quickly as possible if the corresponding primary radio emerges so that the primary user does not face any interference. This is the first and most important step in implementing the CR system. The Spectrum sensing techniques are classified into 3 main types, Transmitter Detection (Non Cooperative Sensing), Cooperative Sensing and interference based testing. Below are the descriptions of the first two sensing techniques.

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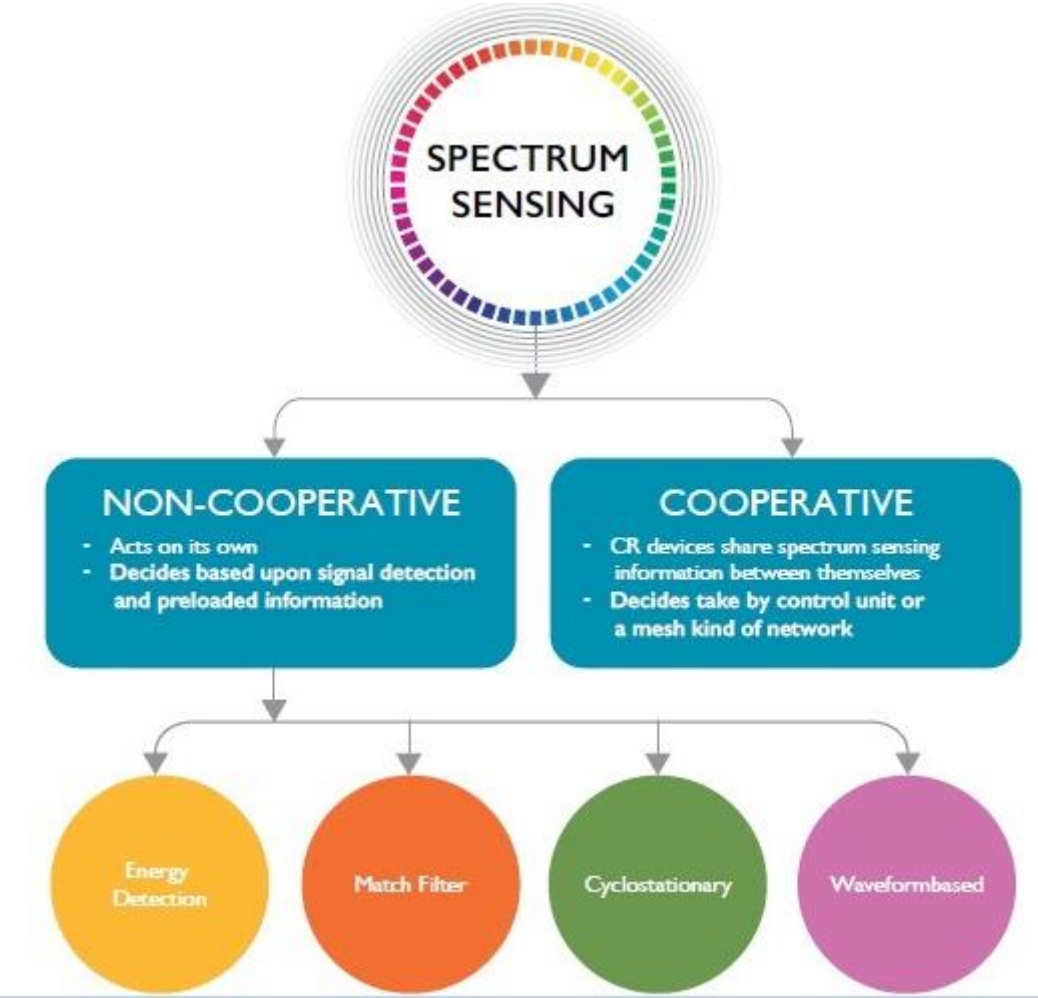
Existing Cognitive Radio Techniques
Here are some existing techniques used in cognitive radio.

Technique 1 - Spectrum Sensing
CR devices closely track all the spectrum bands located in the neighborhood to identify its various primary users and spectrum holes.
Widely used techniques for spectrum sensing are summarized in the below diagram.



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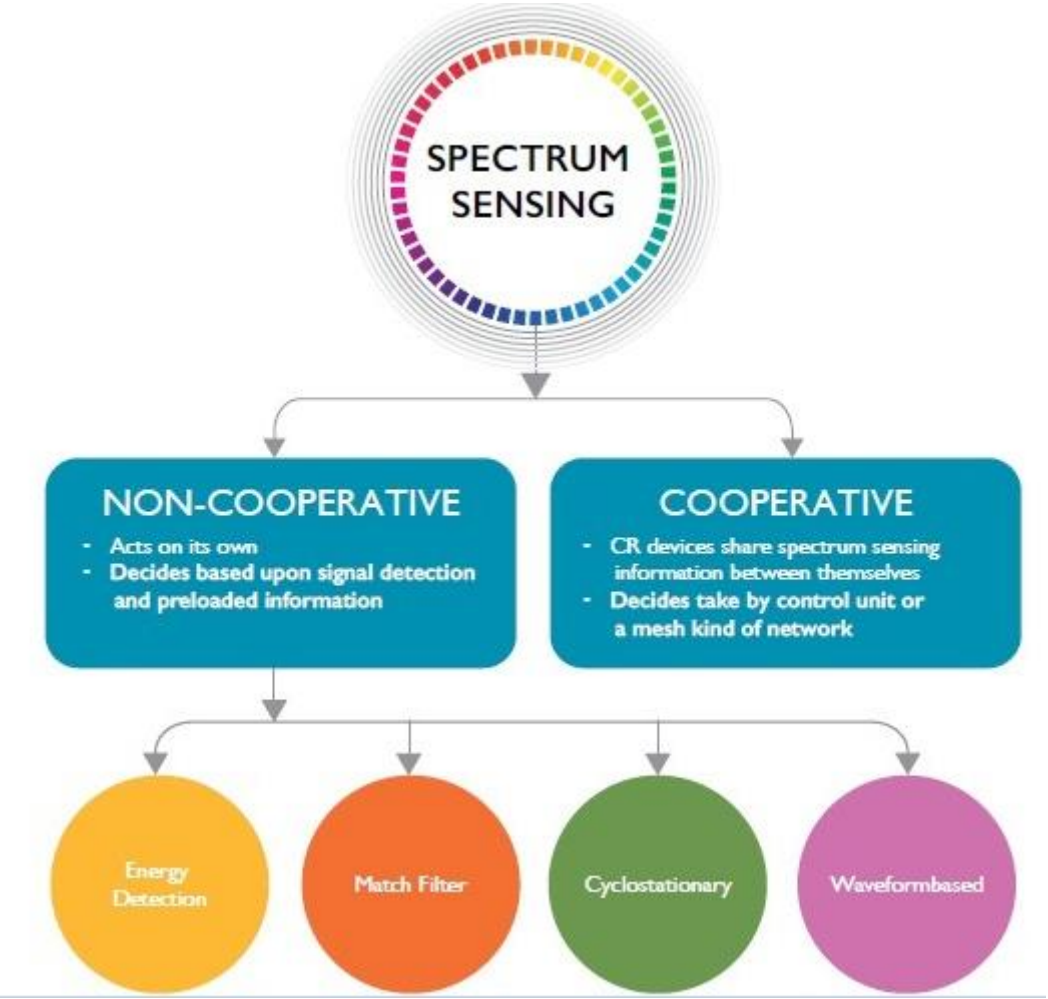
1. Primary users are the users who are licensed to operate in a particular spectrum band.

2. Spectrum holes are space available in a spectrum band that can be utilized by unlicensed users. Spectrum holes are created and removed dynamically in real-time.



Source: https://www.wipro.com/engineering/cognitive-radio/

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Limitations of Spectrum Sensing Techniques: Spectrum Sensing is a best CR solution but it requires a large amount of sensing time. It also requires a complex algorithm to achieve reliability.

Non-cooperative:

- Parallel Sensing

- Hardware Complexity
- High Cost

- **Sequential Sensing**

- Long sensing time as CR devices have to scan the frequencies of primary users one by one to detect availability of spectrum holes

- **Wave Form**

- Requires prior knowledge of synchronization signature of all primary users in various spectrum bands
    - This technique is susceptible to synchronization errors which can cause false detection of primary users

- Match Filter

- Requires prior knowledge of waveform patterns of all primary users in the various spectrum bands
    - Noise variance and uncertainty makes this technique unreliable as CR devices are unable to detect transmitted signal from primary users

- Cyclo Stationary

- High computational complexity

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Limitations of Spectrum Sensing Techniques:

Spectrum Sensing is a best CR solution but it requires a large amount of sensing time. It also requires a complex algorithm to achieve reliability.

Cooperative:

Cooperative sensing technique needzzs to intelligently combine inputs from various CR devices and ascertain the availability of spectrum holes. The accuracy of the algorithm is critical here as incorrect detection can inversely affect the performance of primary users in spectrum bands. Designing such a ‘perfect algorithm’ is a challenge

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Technique 2 - Spectrum Database

Federal Communications Commission (FCC) proposed a spectrum database concept to remove complexity of spectrum sensing technique and to use TV white space. All TV stations need to update their next week usage in database maintained by FCC. CR devices can seek free spectrum information from this database. CR devices will have knowledge about free spectrum for use and can negate the need for complex sensing which requires time and money.

Limitation of Spectrum Database Technique

A significant percentage of spectrum holes are created dynamically for a short duration of time. It is very difficult for a database to update dynamic and real-time activity in spectrum. This presents a massive opportunity loss for CR devices (especially in the IoT ecosystem where several devices need to transmit a small amount of information which can be effectively done on dynamically created spectrum holes).

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Spectrum Management

It captures the best available spectrum to meet the secondary user's requirements, simultaneously not creating an interference to the primary user and then transmit within the spectrum hole which is allocated through the spectrum sensing. Often there are multiple choices presented by the spectrum sensing function but it is the function of the spectrum management system to decide which option is the optimum choice. Spectrum management is carried out in two primary steps

- Spectrum Analysis (Comparing the options)
- Spectrum Decision (Choosing the best option)

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A Consolidated Approach to Drive CR

Efficient use of spectrum is necessary to support the growing number of Massive IOT devices. Unused spectrum can be available in large portions (such as TV white space) or as spectrum holes. Depending on needs and in an opportunistic method both white space and spectrum holes need to be used to satisfy future spectrum requirement. A combined approach could prove ideal for CR solution to meet the massive spectrum demands.
An easy to access local database (maintained in network component) and spectrum sensing technique in CR device can give a better solution for Cognitive Radio. The database should contain below information.
- Primary user's real-time usage (in term of frequency, time, space, transmission characteristics)
- History of primary user's usage pattern in that region in term of frequency, time, power, transmission characteristics

Source: https://www.wipro.com/engineering/cognitive-radio/

Benefits

A. Quick and accurate detection of unused spectrum

Any CR device can start searching spectrum holes which are indicated in the database. If database shows some real-time spectrum holes then CR devices can directly start using it otherwise from the historic information it can understand Primary User's usage pattern in that region and start spectrum sensing to find out the spectrum holes. As the CR device knows about primary signal characteristics in a particular time from database, spectrum sensing can be less complex, accurate and less time consuming.

B. Optimized search and lower battery consumption

By combining information from the database, history of primary user's usage patterns and signal characteristics of primary users, CR devices need not search the entire spectrum for availability but can rather zone in on a particular region. This process will save time and battery consumption.

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Conclusion

The consolidated approach highlighted in this presentaction can help create less complex, cost effective solution. It can drastically reduce operator's investment as CR use unlicensed spectrum. As the IoT phenomenon grows, tens of billions of devices will need to communicate with each other in real-time. The highlighted CR approach will help operators cater to massive spectrum requirements and help build a connected world.

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Future of Cognitive Radio

The success of the unlicensed band to accommodate a wide range of wireless devices and services has inspired the FCC (Federal Communications Commission) in the USA to open up more unlicensed bands. The telecommunications authority in the USA has realized the capability of the CR technology and hopes to open up unlicensed bands which will exploit the inefficiently utilized licensed bands given that the primary users do not undergo interference. An example would be the utilization of radios to operate on TV broadcasting bands. Although TRAI (Telecom Regulatory Authority in India) is yet to utilize the CR networks due to worry over certain security issues such as; Protection against protocol attacks, application attacks, unauthorized user introduction, unauthorized access to system data, Denial of Services (DoS) and Distributed Denial of Service (DDoS) attacks. Yet much research and funding is being directed towards Cognitive Radio to tackle the serious problem of Spectrum overcrowding even more so that India is now becoming a global hub for Information Technology and Services.

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