Cognitive Radio Networks

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Information technology - information networks

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Brief history

The term cognitive radio was coined by Mitola in an article he wrote with Maguire in 1999

and refers to a smart radio that has the ability to sense the external environment, learn from the history and make intelligent decisions to adjust its transmission parameters according

to the current state of the environment.

Introduction

The radio spectrum is divided into licensed and unlicensed frequencies.

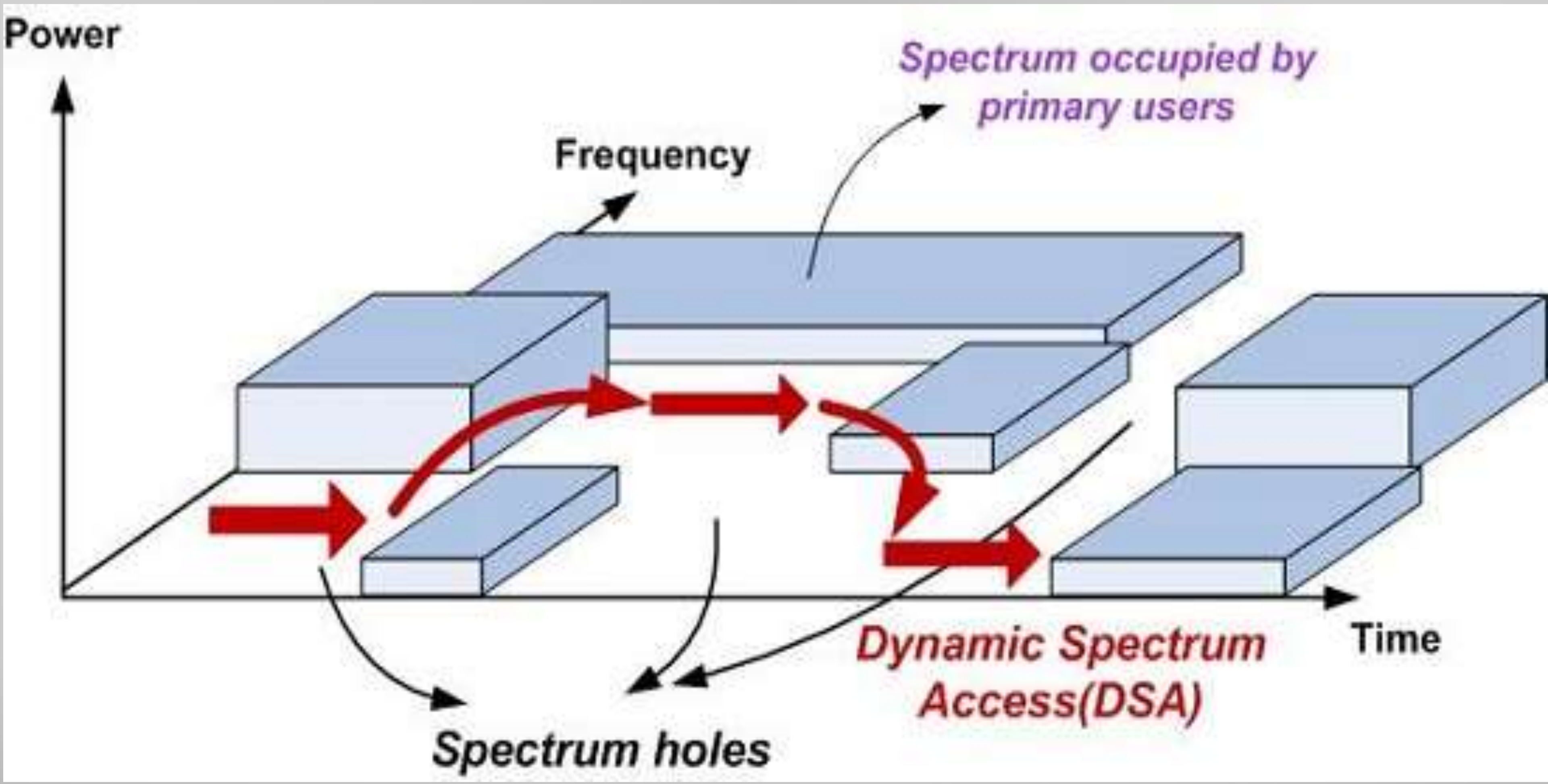
The licensed spectrum is for the exclusive use of designated users. For instance, it includes the UHF/VHF TV frequency bands.

The unlicensed spectrum can be freely accessed by any user, following certain rules (e.g., not exceeding a defined limit for transmission power). It includes, for instance, the ISM (Industrial, Scientific and Medical) and U-NII (Unlicensed National Information Infrastructure) frequency bands. ISM is shared by technologies such as IEEE 802.11 for wireless local area networks (WLANs), Bluetooth .

Introduction

The key enabling technology of dynamic spectrum access is cognitive radio (CR) has emerged as one of the keys that can help addressing the inefficient usage of the radio spectrum. It exploits unused licensed radio frequencies, often designated as spectrum holes see (Figure 1). or white spaces. CR aims to enable secondary users to autonomously access spectrum holes in the entire spectrum to increase performance, as long as they do not harmfully interfere with primary users. Basically, at a given time and location.

Introduction



(Figure 1) spectrum holes.

Introduction

In order to share the spectrum with licensed users without disturbing them, and meet the diverse quality of service requirement of applications, each CR user in a CRN must:

*** Determine the portion of spectrum that is available, which is known as Spectrum sensing.**

*** Select the best available channel, which is called Spectrum decision.**

*** Coordinate access to this channel with other users, which is known as Spectrum sharing.**

*** Vacate the channel when a licensed user is detected, which is referred as Spectrum mobility.**

See figure (1) Cognitive Cycle .

Introduction

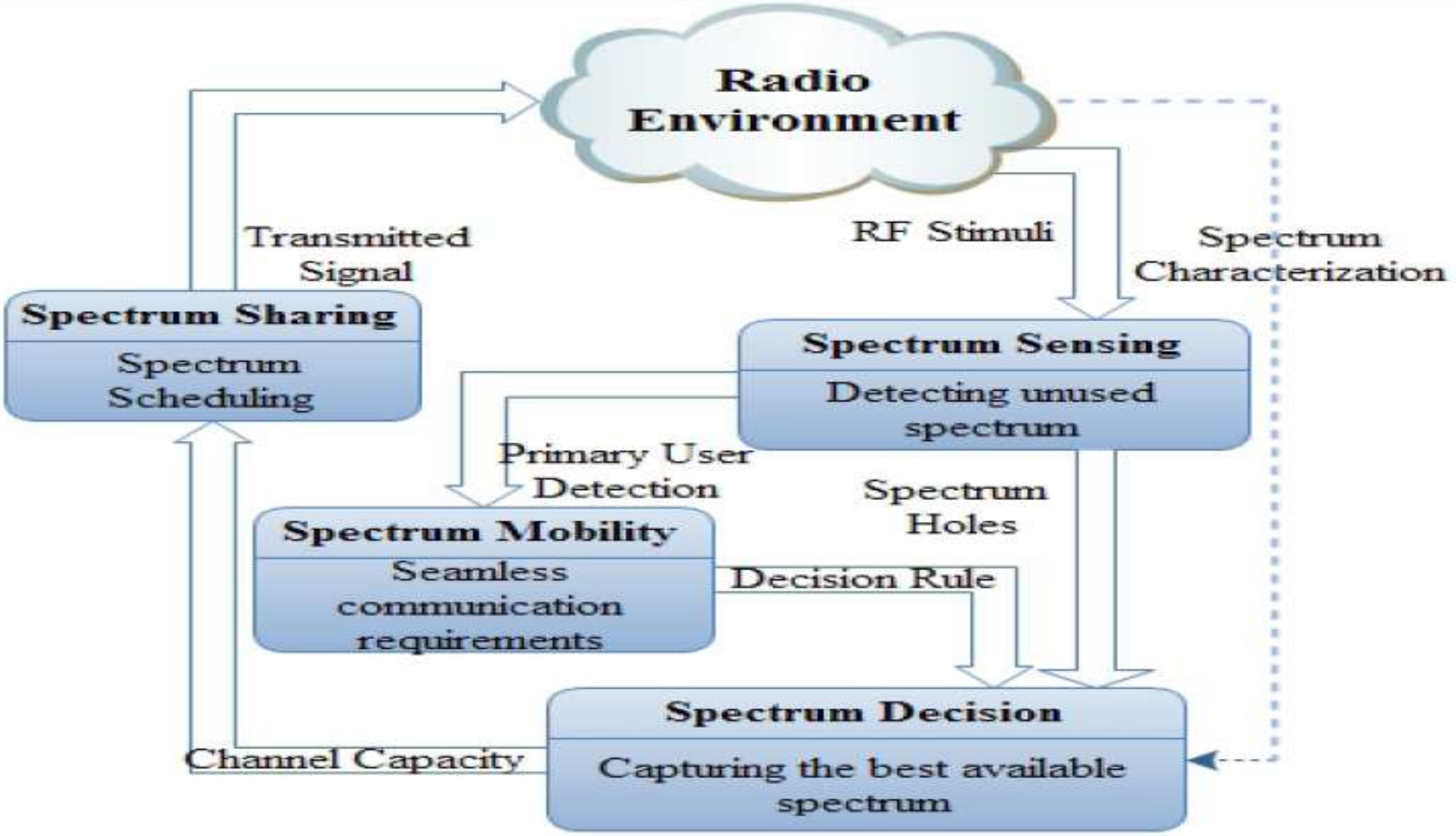


figure (1) Cognitive Cycle

Characteristics of Cognitive Radio

cognitive Radio have main characteristics :

1- Cognitive capability

2- Reconfigurable Capability

3- self-organized capability

We can summarize 1- Cognitive capability as follows:

Spectrum sensing

Location identification

Network/system discovery

Service discovery

Characteristics of Cognitive Radio

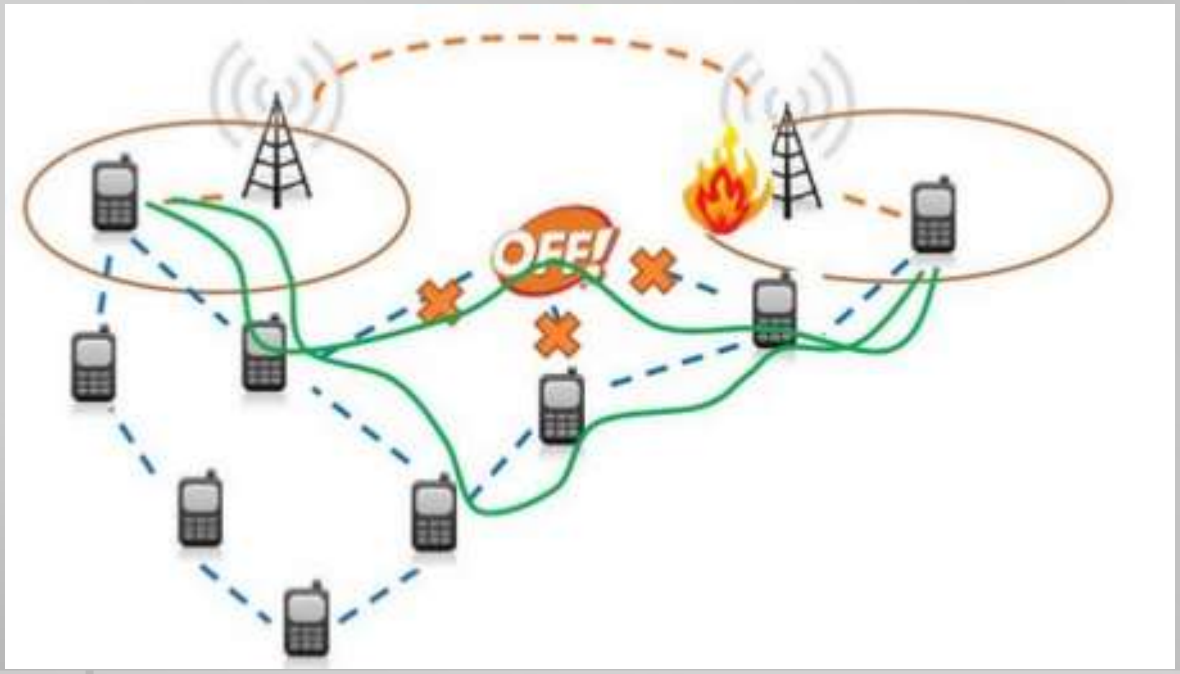
2- Reconfigurable Capability :

- Frequency agility
- Dynamic frequency selection
- Adaptive modulation/coding (AMC)
- Transmit power control (TPC)
- Dynamic system/network access

Characteristics of Cognitive Radio

3- self-organized capability

With more intelligence to communication terminal devices, CRs should be able to self-organize their communication based on sensing and reconfigurable functions . see figure (3.S) below



Cognitive Radio Networks Architecture

The basic components of CRNs are the mobile station (MS), base station/access point (BSs/APs) and backbone/core networks. These three basic components compose three kinds of network architectures in CRNs:

1- Network architectures

2- Links in CRN

3- IP Mobility Management in CRN

Cognitive Radio Networks Architecture

Here only explain network architectures in CRNs:

1- Network architectures

A- Infrastructure-Based

B- Ad-hoc Architecture

C- Mesh Architecture

Cognitive Radio Networks Architecture

1- Infrastructure-Based

In the Infrastructure architecture (Figure 1.1), a MS can only access a BS/AP in the one-hop manner. MSs under the transmission range of the same BS/AP shall communicate with each other through the BS/AP. Communications between different cells are routed through backbone/core networks. The BS/ AP may be able to run one or multiple communication standards/protocols to fulfil different demands from MSs. A cognitive radio terminal can also access various kinds of communication systems through their BS/AP.

Cognitive Radio Networks Architecture

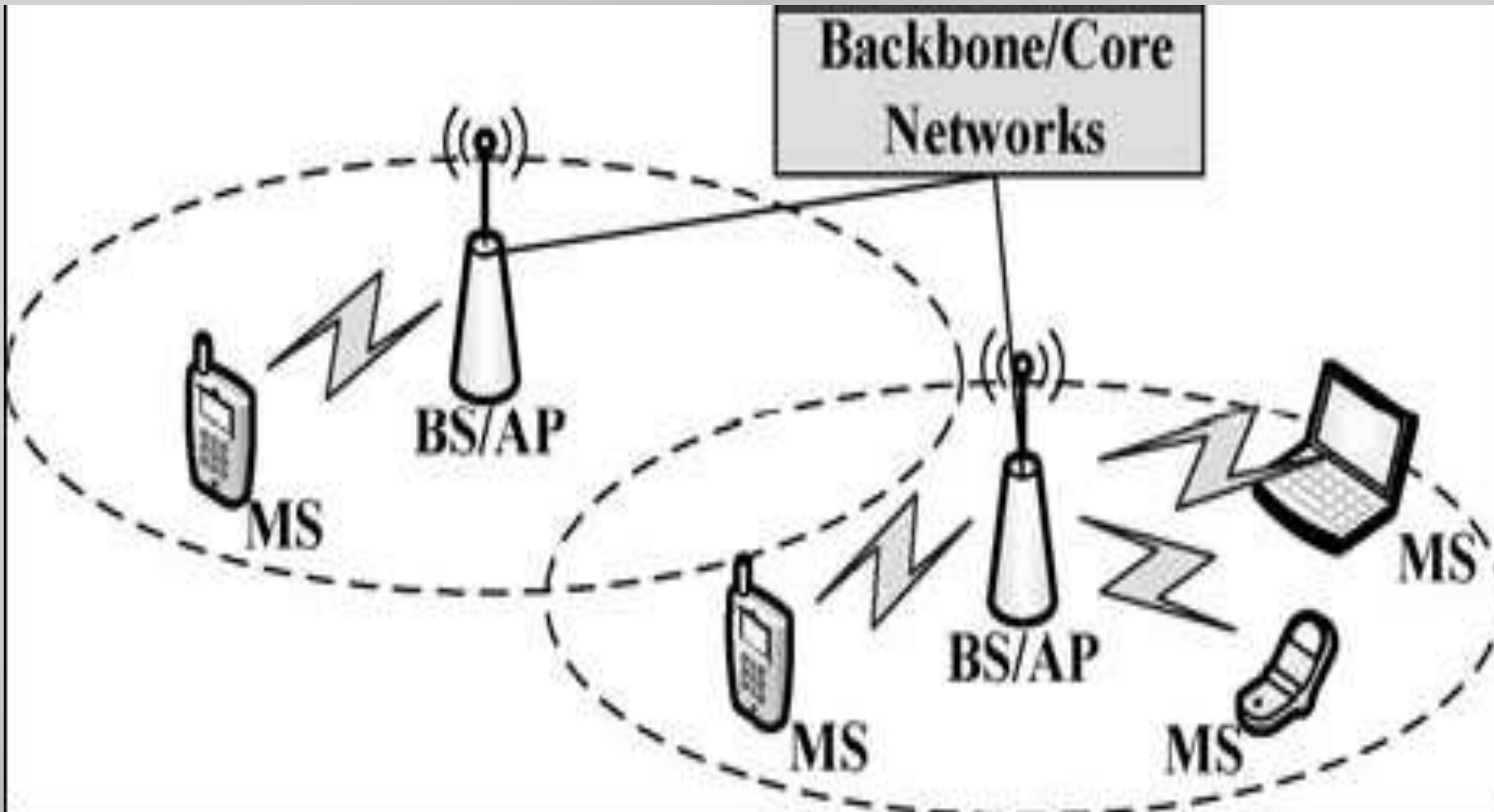


Figure 1.1 Infrastructure architecture of a CRN

Cognitive Radio Networks Architecture

2- Ad-hoc Architecture

There is no infrastructure support in ad-hoc architecture (Figure 2.1). The network is set up on the fly. If a MS recognizes that there are some other MSs nearby and they are connectable through certain communication standards/protocols, they can set up a link and thus form an ad-hoc network. Note that these links between nodes may be set up by different communication technologies. In addition, two cognitive radio terminals can either communicate with each other by using existing communication protocols (e.g., WiFi, Bluetooth) or dynamically using spectrum holes .

Cognitive Radio Networks Architecture

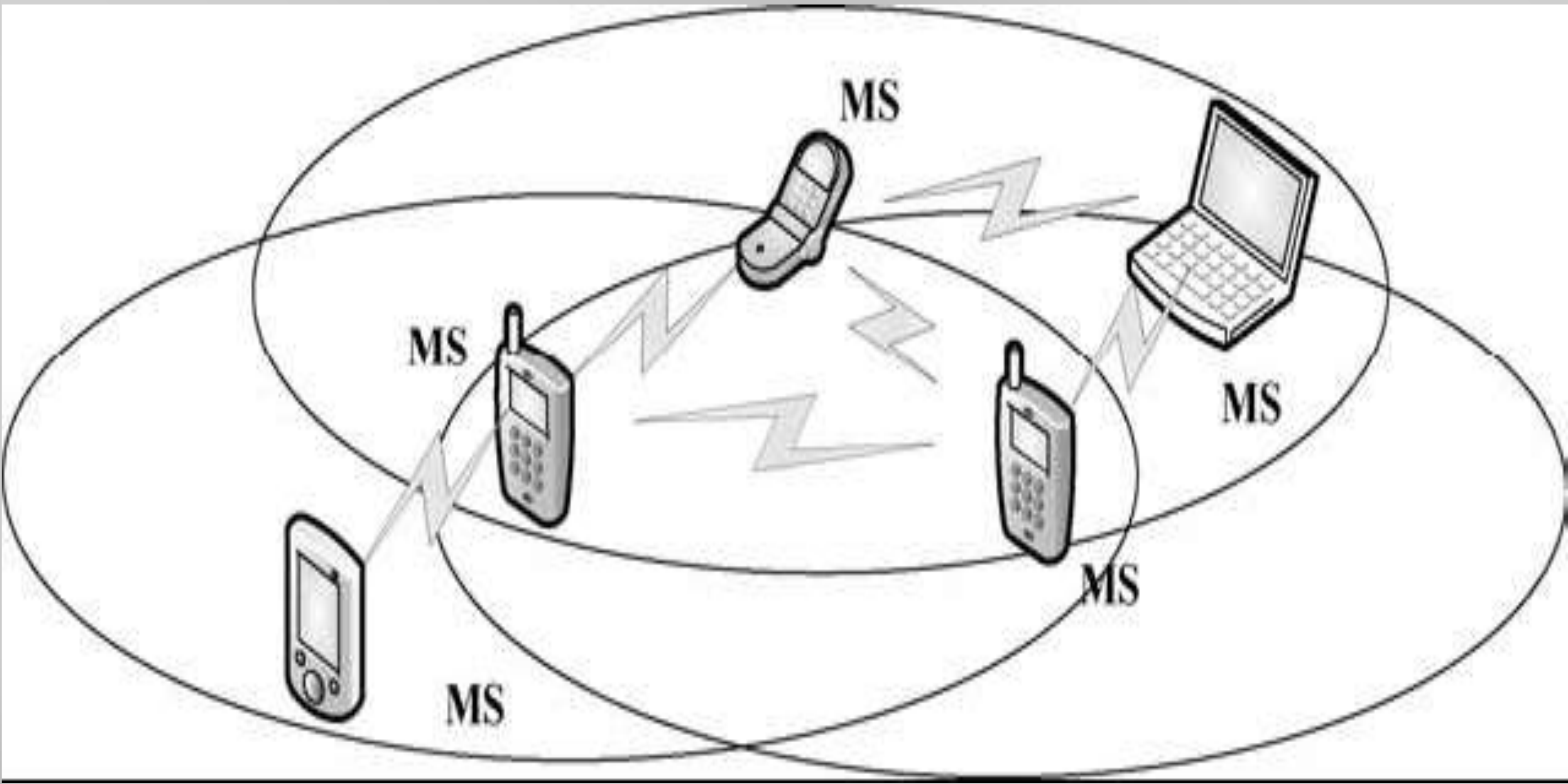


Figure 2.1 Ad-hoc architecture of a CRN

Cognitive Radio Networks Architecture

3- Mesh Architecture

This architecture is a combination of the infrastructure and ad-hoc architectures plus enabling the wireless connections between the BSs/APs (Figure 3.1).

This network architecture is similar to the Hybrid Wireless Mesh Networks.

the BSs/APs work as wireless routers and form wireless backbones.

MSs can either access the BSs/APs directly or use other MSs as multi-hop relay nodes.

Some BSs/APs may connect to the wired backbone/core networks and function as gateways.

. If the BSs/APs have cognitive radio capabilities, they may use spectrum holes to communicate with each other

Cognitive Radio Networks Architecture

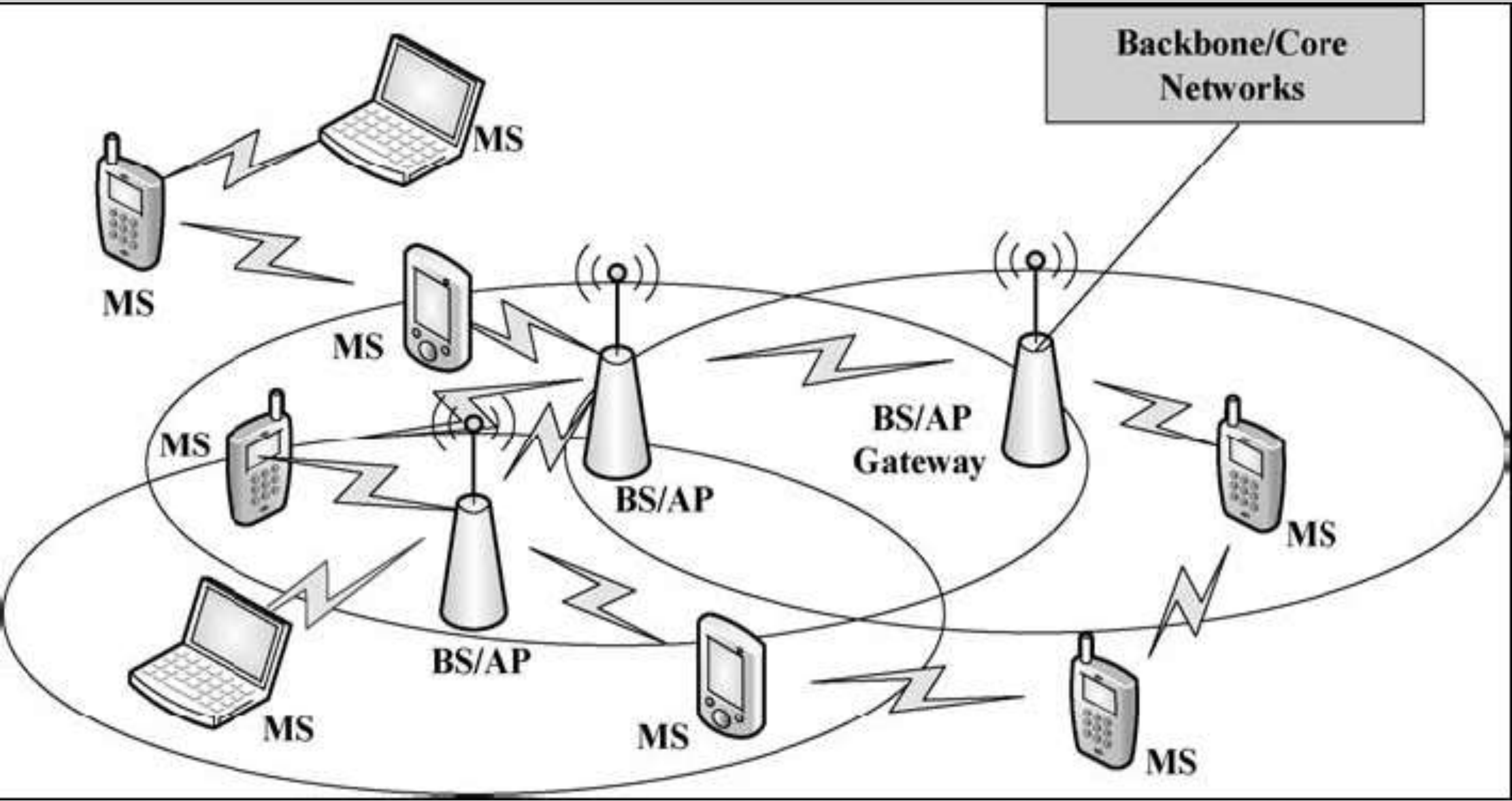
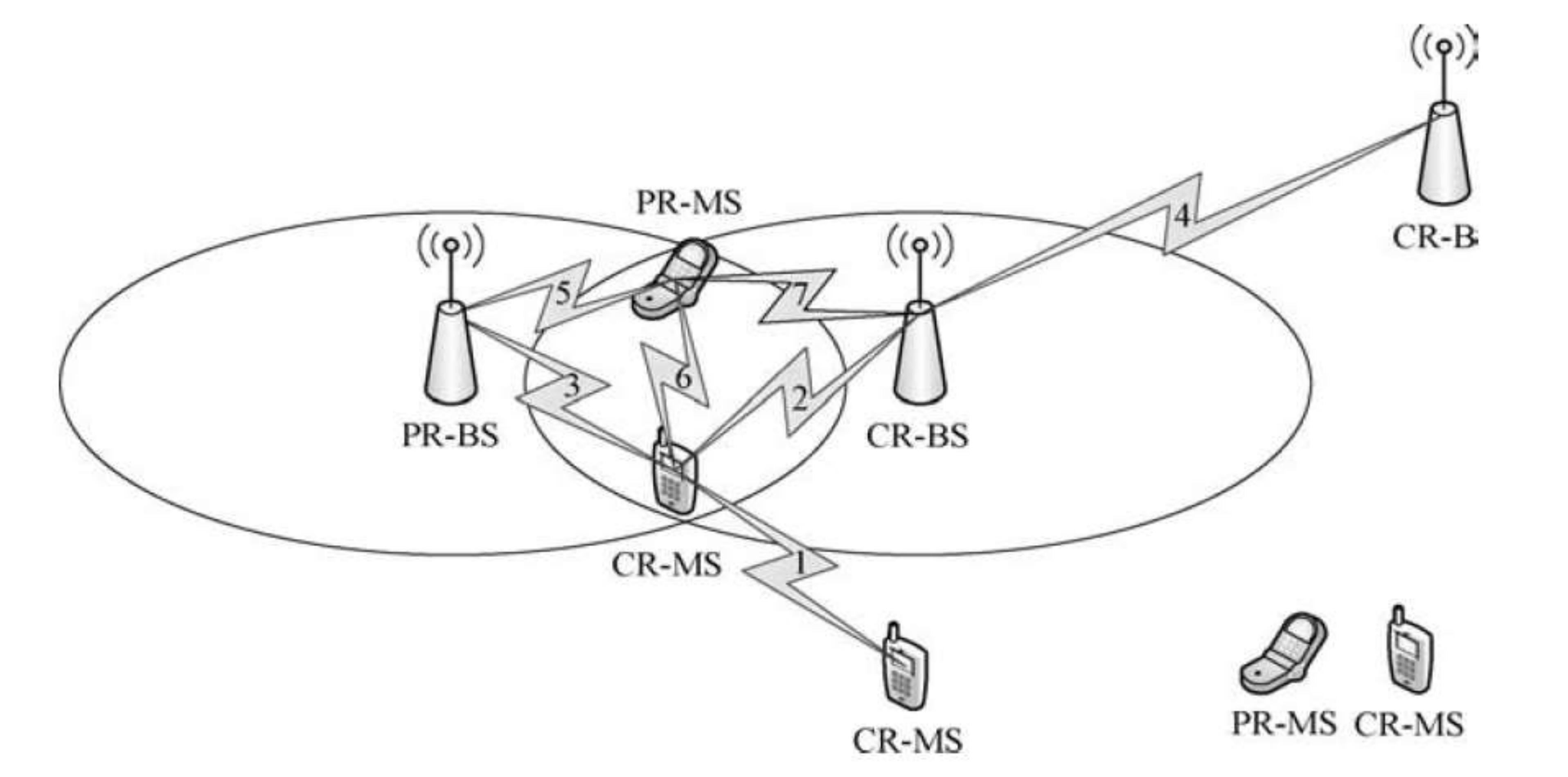


Figure 3.1 Mesh architecture of a CRN

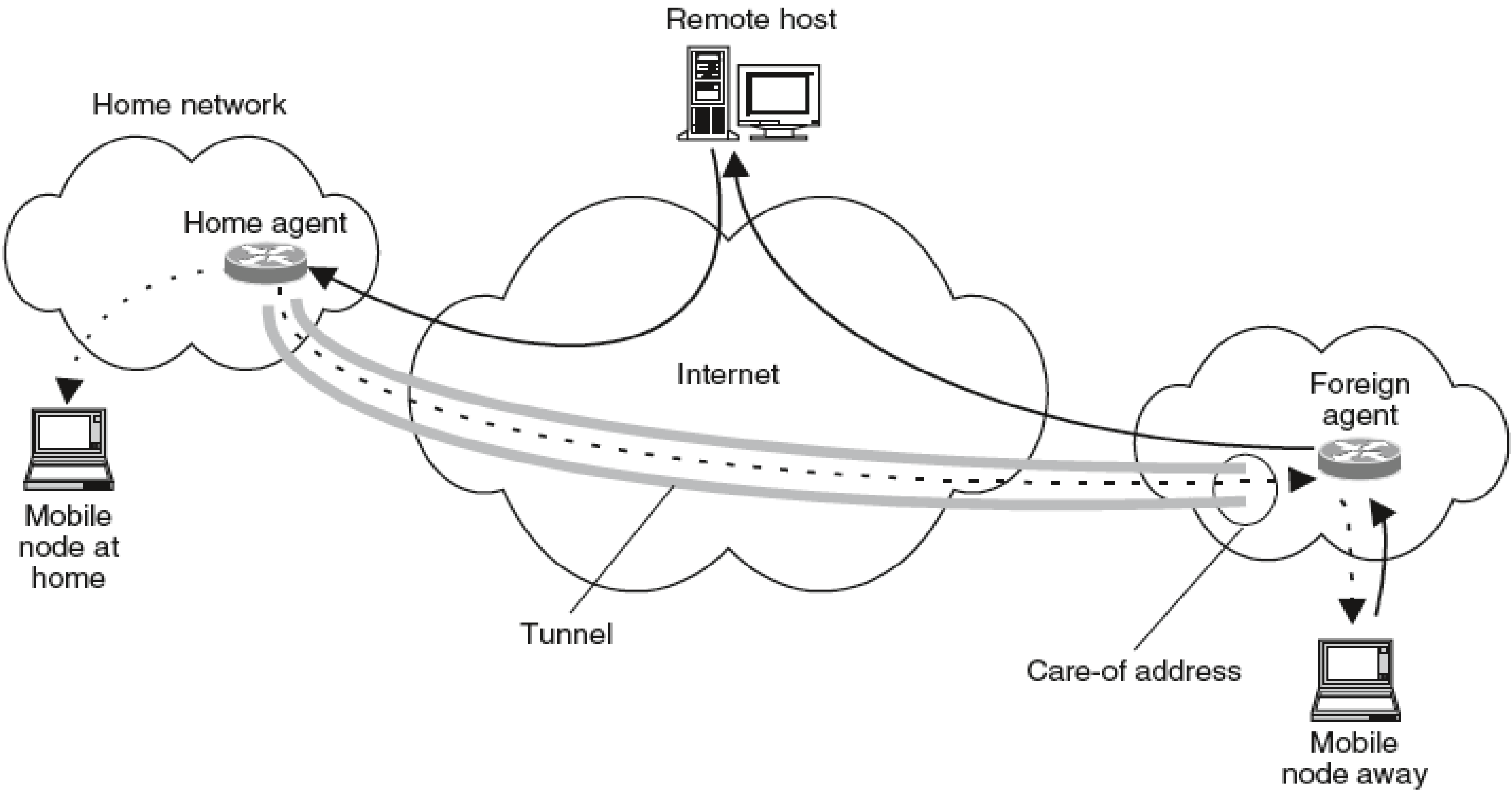
Cognitive Radio Networks Architecture

2- Links in CRN



Cognitive Radio Networks Architecture

3- IP Mobility Management in CRN



Security Issues

The question is how to protect the licensed spectrum and users and also how to avoid unlicensed users from causing interference with existing licensed users or use of special reserved frequencies like, e.g., for emergency services.

Other possible security risks are involuntary downloading of malicious software, licensed user emulation

Attacks on Cognitive Networks

We define an attack on cognitive networks as any activity that results in :

(a) unacceptable interference to the licensed primary users

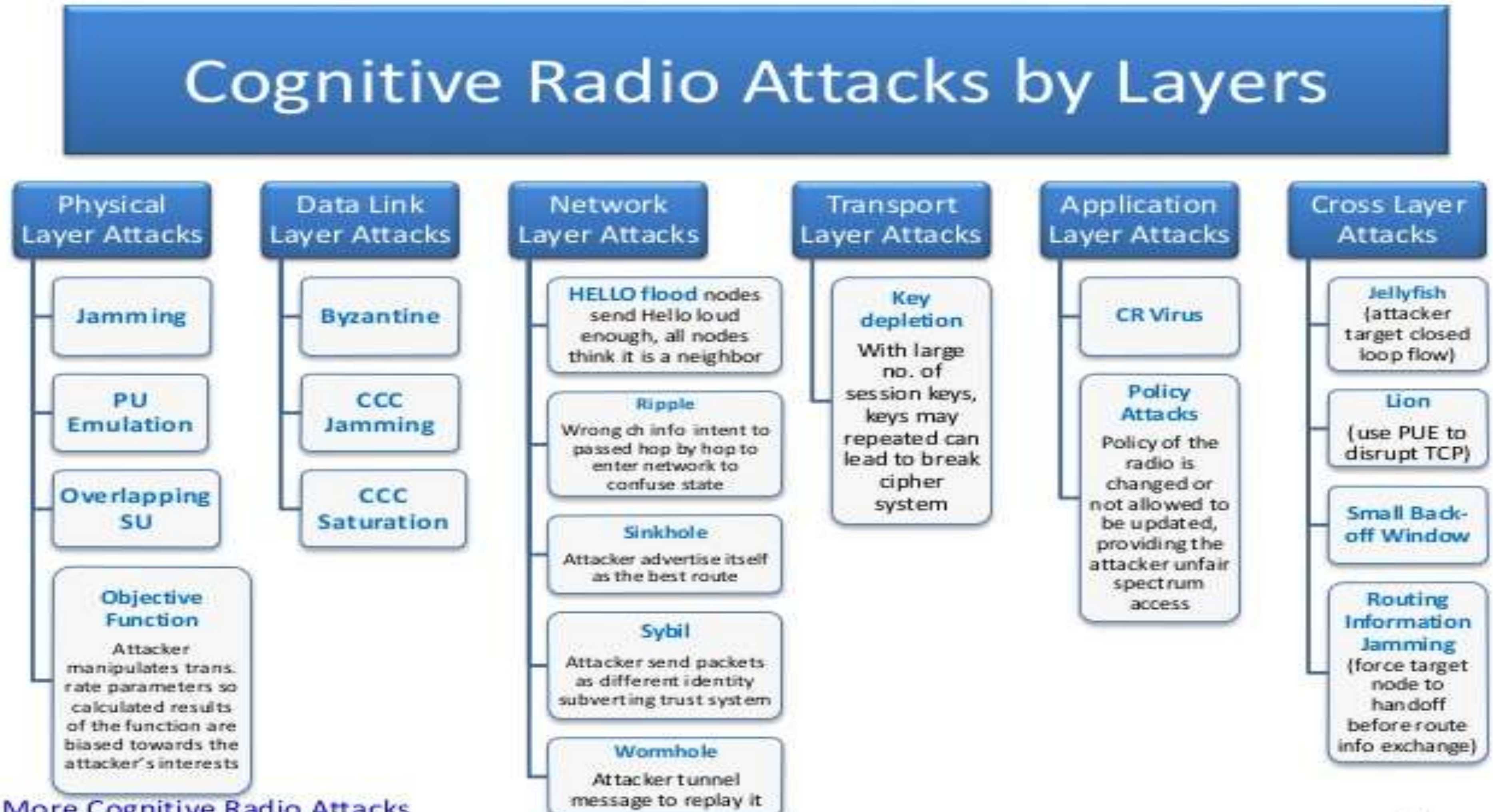
Or

(b) missed opportunities for secondary users.

An attack is considered strong if it involves a minimal number of adversaries performing minimal operations but causing maximum damage/loss to the primary and or secondary users in the network.

See figure (A.1) explain Layer Attacks :

Attacks on Cognitive Networks



More Cognitive Radio Attacks

Source: Deanna Hlavacek, J. Morris Chang, "A layered approach to cognitive radio network security: A survey", Journal of Computer Networks, 2014. http://dx.doi.org/10.1016/j.comnet.2014.10.001

figure (A.1)

Cognitive Radio Network Applications

Cognitive Radio Networking and Opportunistic Spectrum Access can be used in different applications:

1- Cognitive Mesh Networks

2- Public Safety Networks

3- Disaster Relief and Emergency Networks

4- Battlefield Military Networks

5- Leased Networks

Cognitive Radio Network Applications

1- Cognitive Mesh Networks

Multi-hop wireless mesh networks have recently gained significant popularity as a cost-effective solution for last-mile Internet access. Traditional wireless mesh network are challenged by the scarcity of the wireless bandwidth needed to meet the high-speed requirements of existing wireless applications.

by allowing the mesh nodes to dynamically explore any available

spectral opportunities. Such cognitive mesh networks are meant be used to provide broadband access to rural, tribal, and other under-resourced regions.

See figure (1.C) explain Cognitive Mesh Networks

Cognitive Radio Network Applications

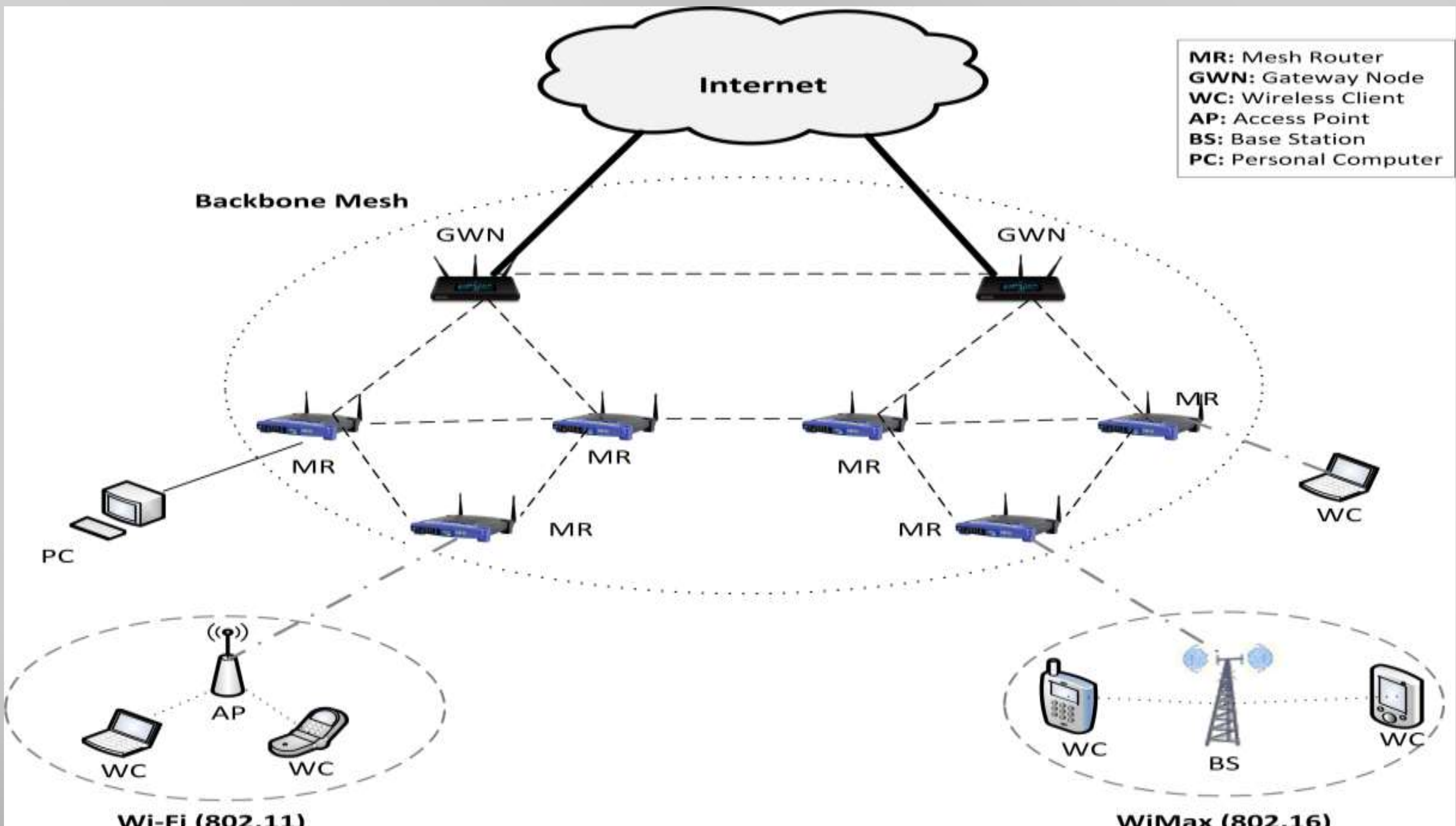


figure (1.C) Cognitive Mesh Networks

Cognitive Radio Network Applications

2- Public Safety Networks

Public safety networks are used for communications among police officers and fire and paramedic personnel. Such networks are also challenged by the limited amount of allocated spectrum. Even with the recent extensions of the allocated public safety spectrum bands, the public safety personnel do not have the technology to dynamically operate across the different spectrum segments. Recall that public safety licensees have a wide variety of bands available (VHF-Low, VHFHi,220MHz, UHF below 800, UHF-800, etc.). The cognitive radio technology can offer public safety networks more bandwidth through Opportunistic Spectrum Access. Furthermore, a public safety CRN can provide a substantial communication improvement by allowing the interpretability across different public safety services while smartly adapting to the high peak-to-average nature of the traffic carried out by such networks. See figure (2.P)

Cognitive Radio Network Applications

figure (2.P) Public Safety Networks

Cognitive Radio Network Applications

3- Disaster Relief and Emergency Networks

Natural disasters such as hurricanes, earthquakes, wild fires, or other unpredictable phenomena usually cause the communications infrastructure to collapse. For example, some base stations of cellular networks can fall, the connectivity between sensor nodes and the sink node in static wireless sensor networks can be lost, existing Wireless Local Area Networks (WLANs) can be damaged, etc. This results in a set of partially or fully damaged coexistent networks that were previously deployed and then became disconnected. Meanwhile, there is an urgent need for a means of communications to help the rescue teams to facilitate organized help, rehabilitation efforts, and to locate the disaster survivors. CRNs can be used for such emergency networks.

provide a significant amount of bandwidth that can handle the expected huge amount of voice, video, and other critical and time-sensitive traffic

See figure (3.D)

Cognitive Radio Network Applications

figure (3.D) Disaster Relief and Emergency Networks

Cognitive Radio Network Applications

4- Battlefield Military Networks

Unfortunately, the recent advances in wireless technologies made the job of communication jamming and/or hacking much easier. Consequently, achieving reliable and secure communications in modern battlefields has become a more challenging task. Recall that a battlefield communication network provides the only means of communications between soldiers, armed vehicles, and other units in the battlefield amongst themselves as well as with the headquarters. This implies that such networks do not only require significant amount of bandwidth, but also mandate secure and reliable communications to carry vital information. The cognitive radio is the key enabling technology for realizing such densely deployed networks which use distributed Opportunistic Spectrum Access strategies to fulfill the bandwidth and reliability needs . see figure (4.B)

Cognitive Radio Network Applications

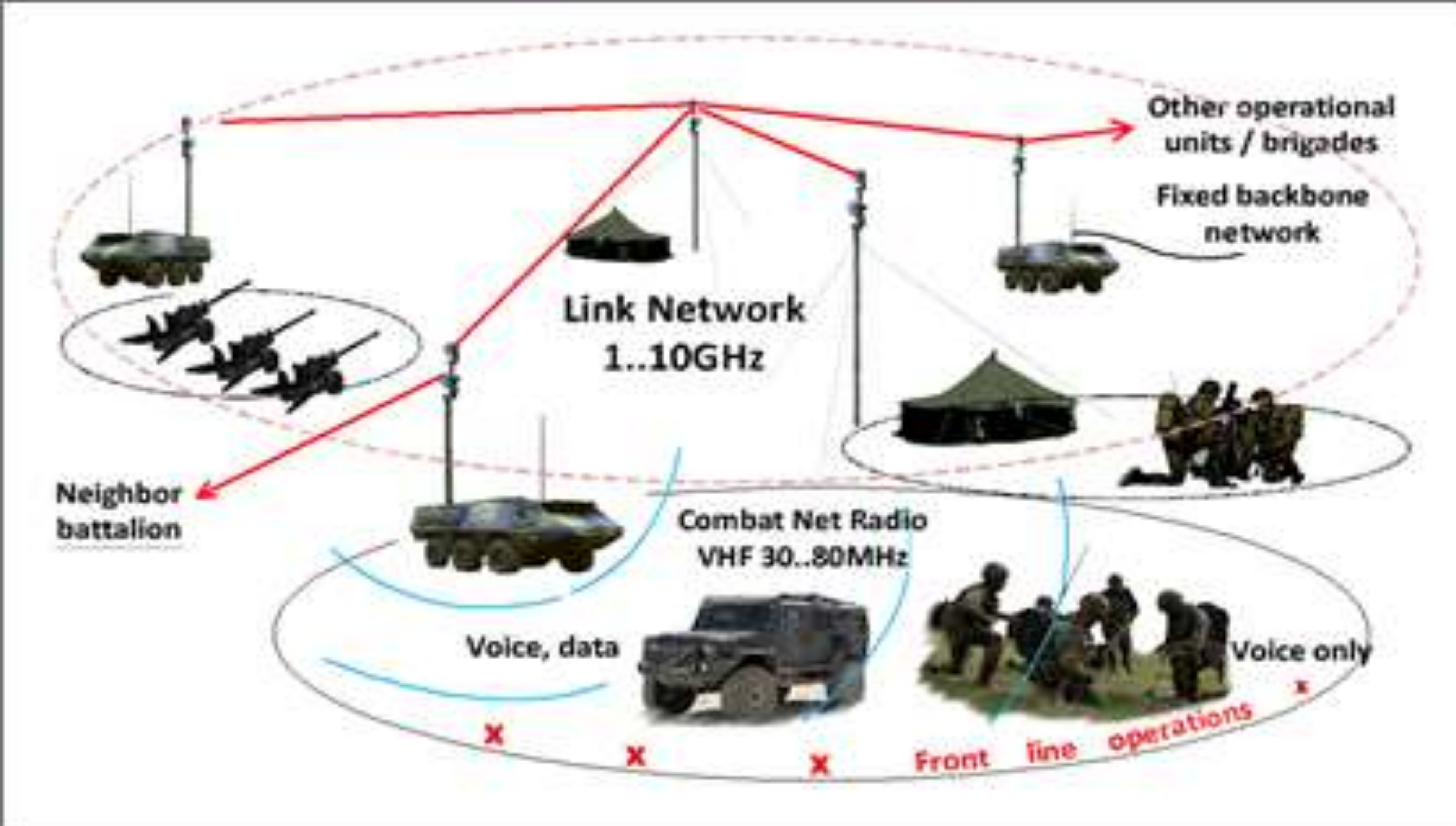


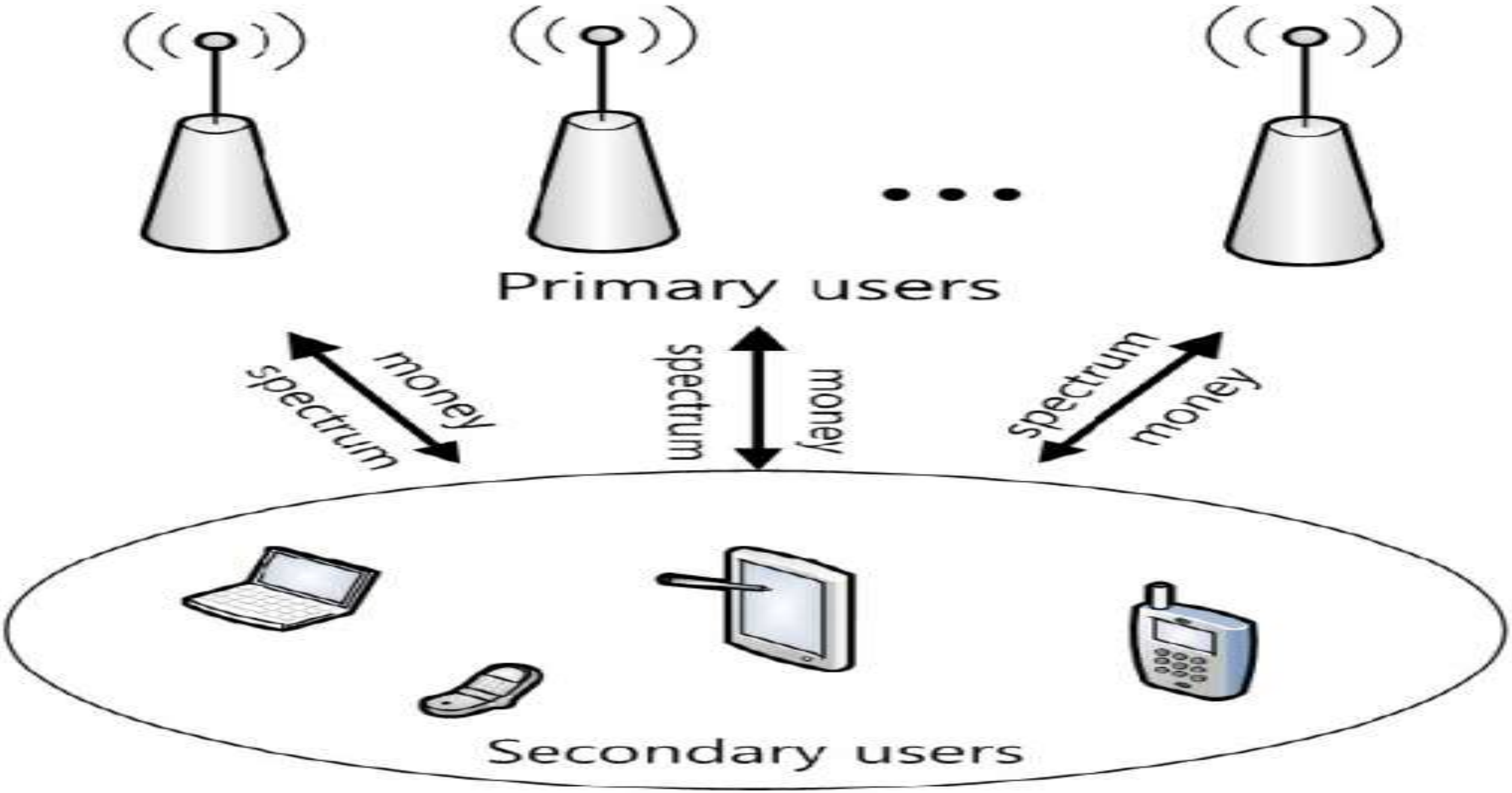
figure (4.B) Battlefield Military Networks

Cognitive Radio Network Applications

5- Leased Networks

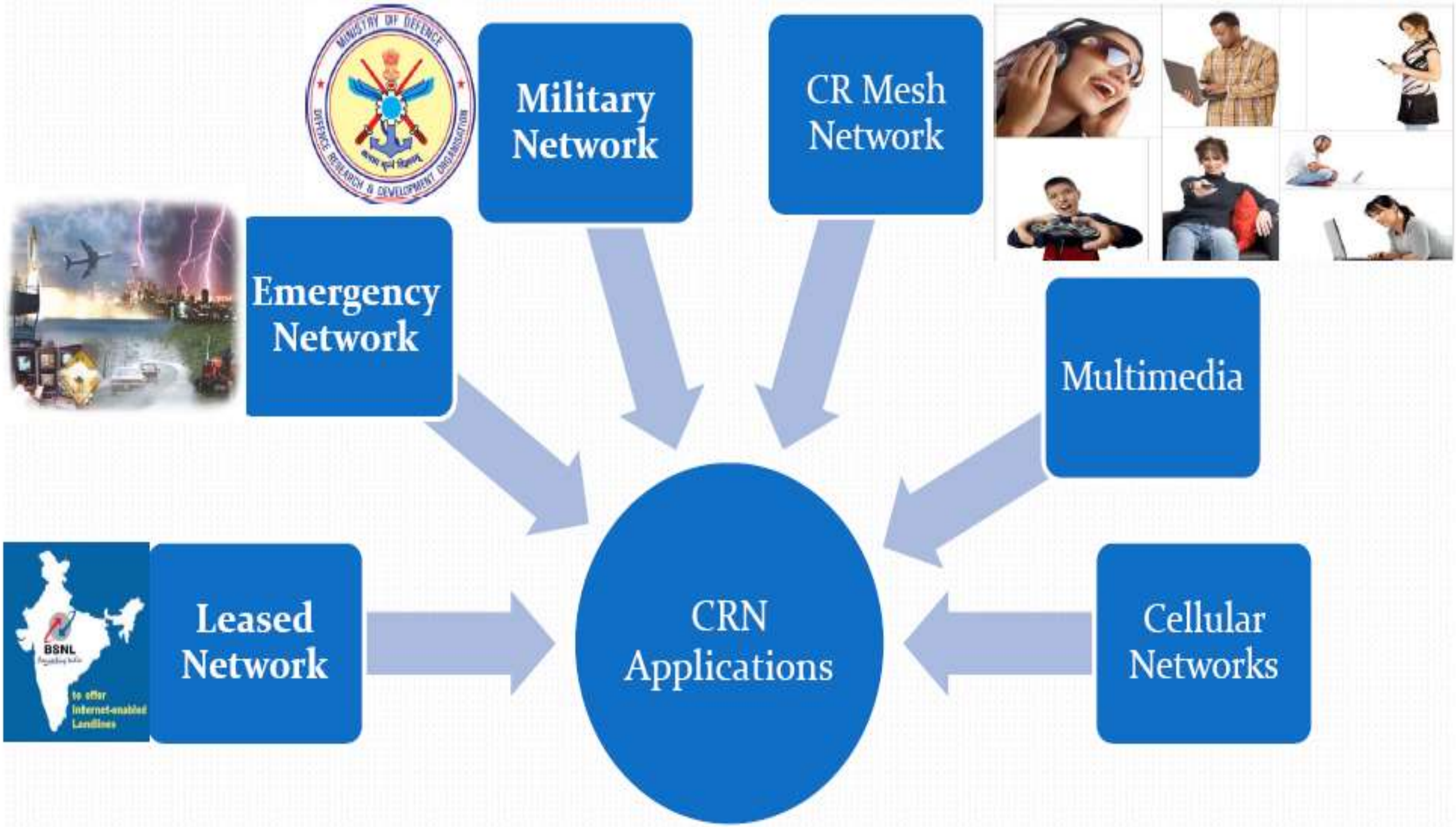
All of the aforementioned CRN applications have the secondary users exploiting the resources of the primary networks without being beneficial to the primary networks in any way. However, a primary network can benefit from leasing a fraction of its licensed spectrum to secondary operators adopting cognitive radio technology to opportunistically access the spectrum. The entrance of the secondary operator to the market of the incumbent primary network can increase the revenue of the primary licensed operator. See figure(5.L)

Cognitive Radio Network Applications



figure(5.L) Leased Networks

Cognitive Radio Network Applications



Popular Cognition Techniques

A list of popular cognition techniques that can be used in CF for the control of CRNs :

Bayesian signal processing

Dynamic programming

Learning machines with feedback

Game theory

Dynamic frequency management

Software defined radio

Cross-layer protocol design

future research direction

A. Seamless spectrum handovers

B. Proactive spectrum selection and interference avoidance

C. Interdependency between the propagation characteristics of radio signals and the frequency band in usage

D. Alternatives to the common channel

E. Energy efficiency

F. Validation of CR protocols

Conclusions

1- The radio spectrum is statically allocated and divided between licensed and unlicensed frequencies.

2- Cognitive Radio is a recent network paradigm that enables a more flexible and efficient usage of the radio spectrum.

3- The status of a wireless channel can change due to several reasons in CR, such as node mobility, operating frequency, neighbor interference, transmission power and primary user appearance.

4-The architecture of CR networks can either be centralized or distributed.

5- The capabilities of cognitive radios as nodes of CRN can be classified according to their functionalities based on the definition of cognitive radio.

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