Mailam Engineering College

Mailam, Villupuram (Dt), Pin – 604 304

(Approved by AICTE, New Delhi, Affiliated to Anna University Chennai& Accredited by TCS)

DEPARTMENT OF ELECTRONICS & COMMUNICATION ENGG

Sub Code/Name : EC8071/ COGNITIVE RADIO

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UNIT I

INTRODUCTION TO SOFTWARE-DEFINED RADIO AND COGNITIVE RADIO

Evolution of Software Defined Radio and Cognitive radio: goals, benefits, definitions, architectures, relations with other radios, issues, enabling technologies, radio frequency spectrum and regulations.

Reference Book:

Huseyin Arslan (Ed.), -Cognitive Radio, Software Defined Radio, and Adaptive Wireless Systems, Springer, 2007. (Unit V)

Prepared by

1. Ms.C.JENITHA, Ast.Prof /ECE

Staff i/c	**BC**	**HoD**	**Principal**

Part A

1. Define Software defined radio.

Radio in which some or all of the physical layer functions are software defined"

2. Define Cognitive radio.

Cognitive Radio (CR) is an adaptive, intelligent radio and network technology that can automatically detect available channels in a wireless spectrum and change transmission and reception parameters which enables more communication to run concurrently and also improve radio operating behavior.

3. What are the benefits of SDR?[NOV/DEC2015]

Software Defined Radio - Benefits:

- Reprogrammable units and infrastructure are flexible or reconfigurable.
- Multiband or multimode operation has some reduced obsolescence.
- Different standard scanco-exist due to ubiquitous connectivity.
- Enhances or facilitates experimentation.
- Combines both analog and digital communication.

4. What do you mean by primary users?[NOV2016]

A Users which has highest priority or legacy rights on the usage of specific part of the spectrum.

5. What is unlicensed spectrum.[MAY/JUNE2012]

Based on the IEEE 802.11, 2.4GHz and 5GHz are Unlicensed spectrum band that can be used by unlicensed users like Wi fi users and D2D - U users.

6. What are the issues of SDR?[NOV/DEC2018]

- Wideband radio need,
  - Broad spectrum coverage
  - Dynamic re-configurability
  - Interference mitigation
  - Adaptation of open system architectures.
- Wideband power amplifier has some constraints such as linearity, bandwidth and efficiency.
- Cost to initiate SDR is very high

7. What are the three International communication standards?[NOV/DEC2011]

- International telecommunication union (ITU)
- European conference of postal and telecommunications and administrations (CEPT)
- Inter-American Telecommunication commission (CITEL)

8. What is Adaptive radio? [NOV/DEC2018]

Adaptive radio is a radio in which communication systems has a means of monitoring their own performance and modifying their operating parameters to improve this performance.

9. Compare SDR and CR.[NOV/DEC2017]

SDR provides the wide range of service to provide with the available QOS while CR adjusts the operations to meet QOS for the required application for the signal environment.

10. What are the applications of SDR.[May2015]

Used in Military, Satellite communication, Disaster management and in health monitoring system

11. What is advantages of Software defined radio.[MAY/JUN2018]

- Reprogrammable units and infrastructure are flexible or reconfigurable.
- Multiband or multimode operation has some reduced obsolescence.
- Different standard scanco-exist due to ubiquitous connectivity.
- Enhances or facilitates experimentation.

12. What is Cognitive radio[APR2015]

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.

13. What is Baseband signal?[NOV/DEC2015]

Baseband is a signal that has a near-zero frequency range, i.e. a spectral magnitude that is nonzero only for frequencies in the vicinity of the origin and negligible elsewhere.

14. What do you mean by secondary users?[NOV2016]

A user which has lower priority and therefore exploits the spectrum in such a way that it does not cause interference to primary users.

15. What is licensed spectrum.[MAY/JUNE2012]

The cognitive radio allows the secondary users (SU) to use licensed spectrum when it is not used by the users to which it is actually allocated. The users which are allocated the spectrum have high priority known as primary users (PU)/licensed users.

16. What are the goals of SDR?[NOV/DEC2018]

- Multi-band
- Multi-carrier
- Multi-mode
- Multi-rate
- VariableBandwidth

17. What is RF front end module?[NOV/DEC2011](CO1,K2)

An RF front end is a device or module that incorporates all the circuitry between the antenna and at least one mixing stage of a receiver and possibly the power amplifier of the transmitter.

18. What is Intelligent radio?[NOV/DEC2018]

Intelligent radio is cognitive radio that is capable of machine learning. This allows the cognitive radio to improve the ways in which it adapts to changes in performance and environment to better serve the needs of the end user.

19. Compare Hardware radio & SDR .[NOV/DEC2017]

Hardware radio is a traditional baseband design and SDR is a reconfigurable, and provide provisions for easy upgrades.

20. What are the applications of CR.[May2015](CO1,K2)

There are numerous practical applications for this cognitive research, such as providing help coping with memory disorders, increasing decision-making accuracy, finding ways to help people recover from brain injury, treating learning disorders, and structuring educational curricula to enhance learning.

Part - B

1.What is Software definite radio and illustrates it's various definitions and it's architecture,goals, benefits,issues and it's related technologies.

What is Software Defined Radio

- With the exponential growth in the ways and means by which people need to communicate - data communications, voice communications, video communications, broadcast messaging, command and control communications, emergency response communications, etc. – modifying radio devices easily and cost-effectively has become business critical.

- Software defined radio (SDR) technology brings the flexibility, cost efficiency and power to drive communications forward, with wide-reaching benefits realized by service providers and product developers through to end users.

Software Defined Radio - Definitions:

A number of definitions can be found to describe Software Defined Radio, also known as Software Radio or SDR. The SDR Forum, working in collaboration with the Institute of Electrical and Electronic Engineers (IEEE) P1900.1 group, has worked to establish a definition of SDR that provides consistency and a clear overview of the technology and its associated benefits.

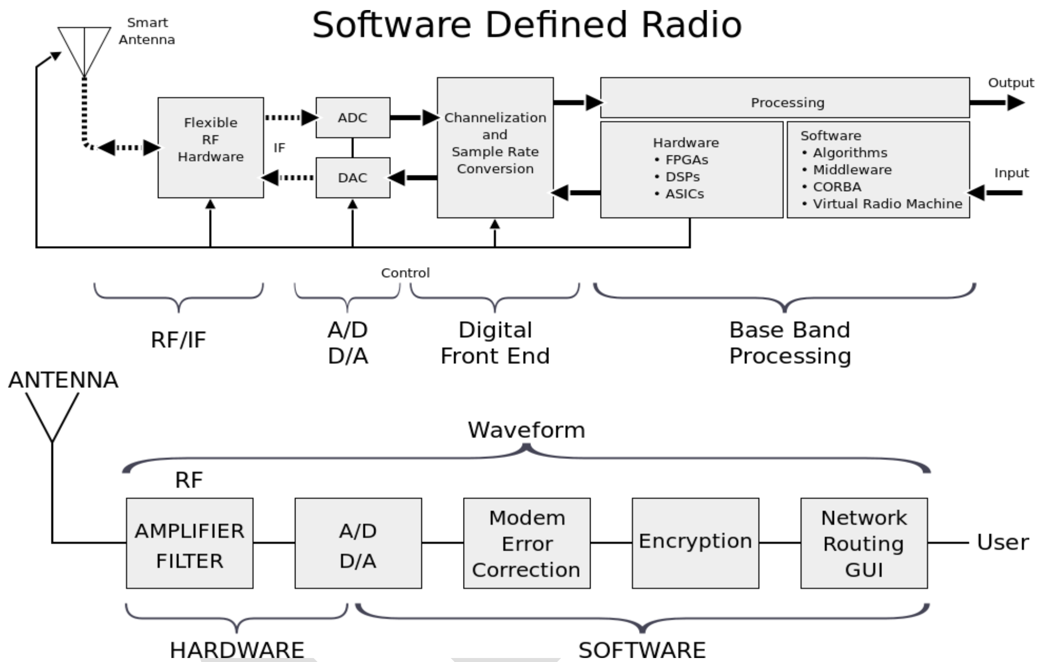
Software Defined Radio is defined as:

- "Radio in which some or all of the physical layer functions are software defined"
- Hardware (e.g. mixers, filters, amplifiers, modulators/demodulators, detectors, etc.)are rather implemented by means of software on a personal computer or embedded system.
- A radio is any kind of device that wirelessly transmits or receives signals in the radio Frequency (RF) part of the electromagnetic spectrum to facilitate the transfer of Information. In today's world, radios exist in a multitude of items such as cell phones, Computers. car door openers, vehicles, and televisions.
- Software radio is introduced to improve the performance of the existing hardware radio.

Goals of SDR:

- Multi-band
- Multi-carrier
- Multi-mode
- Multi-rate
- Variable Bandwidth

SDR Architecture:



- Antenna Section
  - Two basic types:

    1 . Receiving Antenna

    2. Transmitting Antenna
- RF Front End Section
  - Filters
  - LNAs
  - LO
  - Down Conversion Mixers

Converter section

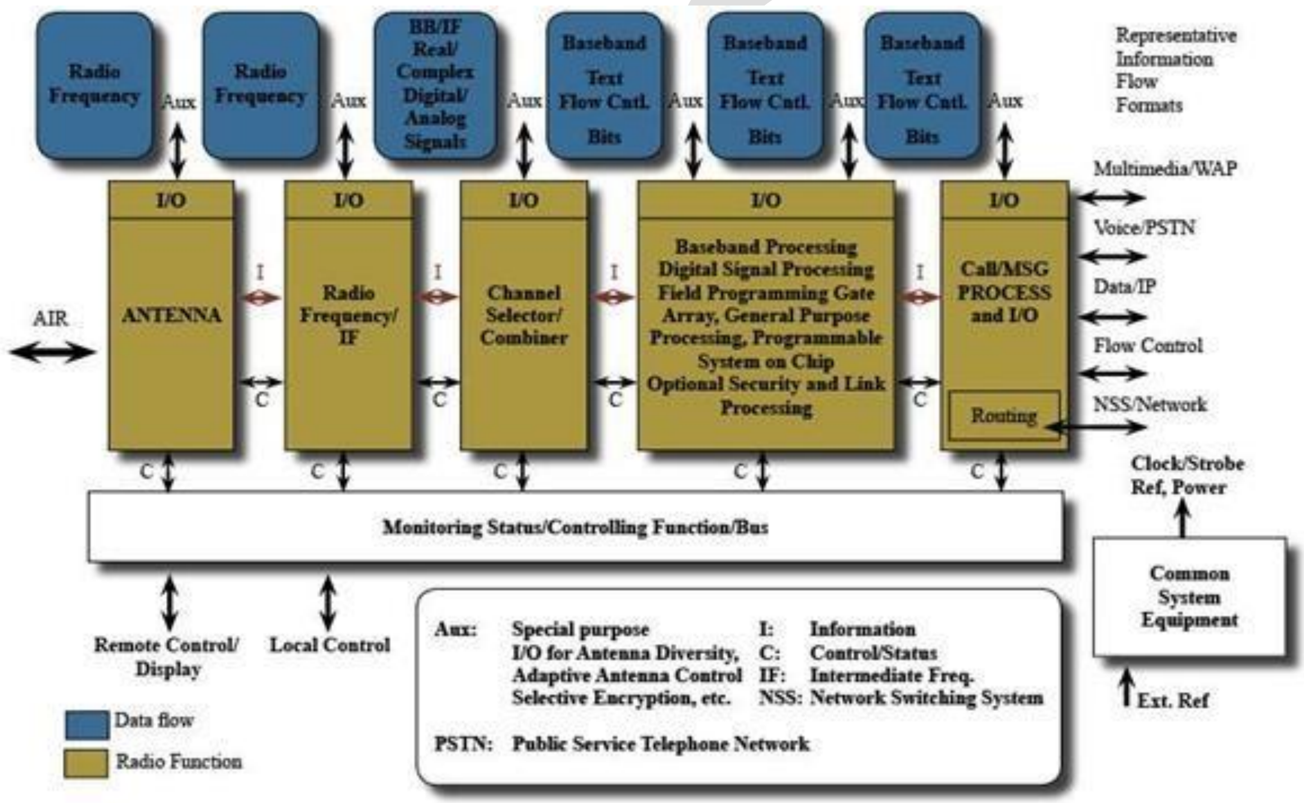
- DUC–Base band signal to IF signal
- DDC–IF signal to baseband signal
- ADC and DAC section

Baseband Section

- Connection setup, Equalization,
- Frequency Hopping, Coding/Decoding
- Correlation, Scrambling
- Modulation, Spreading &Pulse Shaping

SDR Functional Architecture

- Traditional hardware based radio devices limit cross-functionality and can only be modified through physical intervention.
- This results in higher production costs and minimal flexibility in supporting multiple waveform standards.
- By contrast, software defined radio technology provides an efficient and comparatively inexpensive solution to this problem, allowing multi- mode, multi-band and/or multi-functional wireless devices that can be enhanced using software upgrades.



SDR Forum Generalized Functional Architecture

- SDR defines a collection of hardware and software technologies where some or all of the radio’s operating functions are implemented through modifiable software or firmware operating on programmable processing technologies.

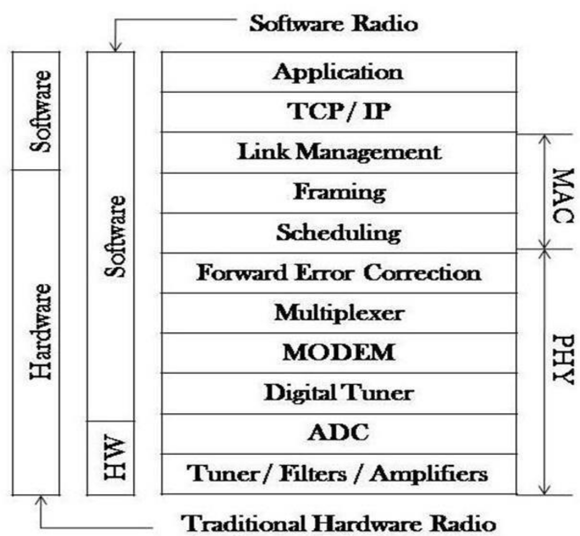
- These devices include field programmable gate arrays (FPGA), digital signal processors (DSP), general purpose processors (GPP), programmable System on Chip (SoC) or other application specific programmable processors.

- The use of these technologies allows new wireless features and capabilities to be added to existing radio systems without requiring newhardware.

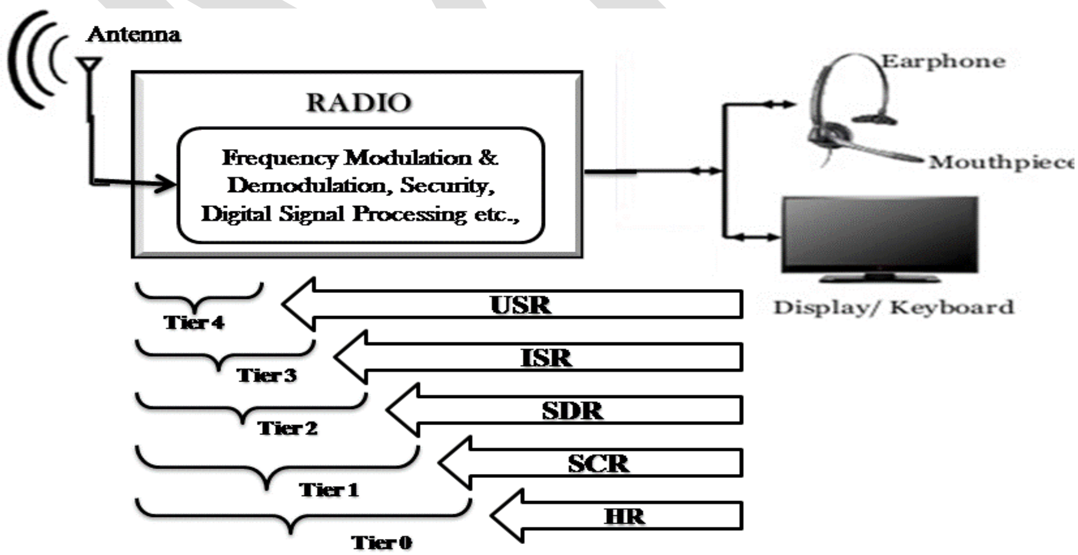
Software Defined Radio - Benefits:

- Reprogrammable units and infrastructure are flexible or reconfigurable.
- Multiband or multimode operation has some reduced obsolescence.
- Different standard scanco-exist due to ubiquitous connectivity.
- Enhances or facilitates experimentation.
- Combines both analog and digital communication.

Hardware vs Software Radio



Software classification:



Tier 0 : Hardware Radio

- The functions of the radio cannot be changed bysoftware.

Tier 1: Software Controlled Radio(SCR)

- SCR Controls limited functions
- Changes of attributes [mode or frequency] cannot be done without changing hardware.

Tier 2 : Software Defined Radio(SDR)

- Performs wideband or narrow band operation.
- Capable of storing large number of waveforms or air interfaces.
- Separate antenna system, Wide band filtering, Amplification and Down conversion
- Digital to Analog Conversion, analog up conversion, filtering and amplification.

Tier 3 : Ideal Software Radio(ISR)

- Provides the capabilities of SDR.
- Eliminates analog amplification and heterodyne

Tier 4 :Ultimate Software Radio(USR)

- Does not require external antenna.
- No restrictions on operating frequency.
- Perform a wide range of adaptive services for user.

Evolution of SDR

From 1984 to 1991

Year	Description
1984	E-System Inc. - term Software Radio. A prototype digital baseband receiver.
1991	First military radio was implemented Its physical layer components in software Example : 1. U.S Military SPEAK easy I & SPEAK easy II radios: ✓ A Compact radio ✓ Fully developed SDR with sufficient DSP resources ✓ Tactical military communications from 2MHz to 2GHz ✓ Interoperability between different air-interface standards. 2. U. S. Navy's Digital Modulator Radio (DMR): ✓ Generate many waveforms and modes which can able to be remotely controlled with an Ethernet interface.

From 1992 to 1999

Year	Description
1992	Joe Mitola published a paper on software radio.
1993	A digital radio - reconfigures which changes the software codes running on it.
1996	Modular Multi-funtion Information Transfer System (MMITS) - First SDR Association
1997 to 1999	✓ SDR was implemented for commercial purpose. ✓ Cellular networks include a general-purpose, more economic hardware platform, future proofing and easier bug fixes through software upgrades.

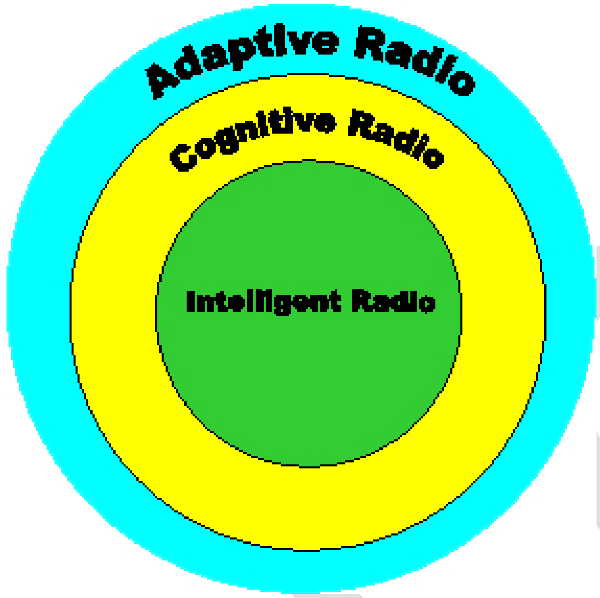
From 2004 to 2010

Year	Description
2004	✓ FCC first time gave approval for commercial SDR. ✓ Vanu Inc. & Anywave BS. ✓ Physical processors - baseband processors running on pico-chip of frequencies.
2006	✓ Texas Instruments and Xilinx ✓ Product was equipped with ARM, DSP, FPGA, Frontend tunable receivers (200MHz to 1GHz).
2009	LIME Microsystems - Commercial Single chip RF Frontend receiver
2010	SDR forum - renamed - wireless innovation forum.

Issues of SDR:

- Wideband radio need,
    - Broad spectrum coverage
    - Dynamic re-configurability
    - Interference mitigation
    - Adaptation of open system architectures.
- Wideband power amplifier has some constraints such as linearity, bandwidth and efficiency.
- Cost to initiate SDR is very high

Software Defined Radio - Related Technologies



Venn diagram illustrating relationship between associated advanced wireless technologies

Adaptive radio

- Adaptive radio is a radio in which communication systems has a means of monitoring their own performanceand modifying their operating parameters toimprove this performance.

Intelligent Radio

Intelligent radio is cognitive radio that is capable of machine learning. This allows the cognitive radio to improve the ways in which it adapts to changes in performance and environment to better serve the needs of the end user.

These types of radio – adaptive radio, cognitive radio and intelligent radio – do not necessarily define a single piece of equipment, but may instead incorporate components that are spread across an entire network.

2. Give a Comparison between Hardware and Software radio

Comparison between Hardware radio, Software radio and Cognitive

Constraint	Conventional Radio	Software Radio	Cognitive Radio
Application	It supports only fixed number of systems	Dynamically supports multiple variable systems, protocols and interfaces	It can create new waveforms on its own
	Reconfiguration can be done only at the time of design	It can interface with diverse systems	It negotiates new interfaces
	It may support multiple services only at the time of design	It provides a wide range of service with available QoS.	It adjusts operations to meet the QoS required by the application for the signal environment
Design	Traditional RF design	More capable than Conventional radio , Software architecture	More capable than SDR, Intelligence
	Traditional Baseband design	Re-configurability, Provide provisions for easy upgrades	Awareness, Learning and Observations

3. What is cognitive radio? Explain it's definitions architecture, evolution standards and it's working.

Definitions:

- Cognitive Radio (CR) is an adaptive, intelligent radio and network technology that can automatically detect available channels in a wireless spectrum and change transmission and reception parameters which enables more communication to run concurrently and also improve radio operating behavior.
- Federal Communications Commission(FCC) defines CR as: “A Cognitive Radio is a radio that can change its transmitter or receiver parameters based on interaction with the environment in which it operates.

  Characteristics of CR
- Reconfigurability
- Intelligent Adaptive Behavior

What is cognitive radio?

Cognitive radio(CR) is a for wireless communication in which a transceiver can intelligently detect which communication channels are in use and which are not. It instantly moves in to vacant channels while avoiding occupied ones. It does not cause any interference to the licensed user.

Goals of CR:

Cognitive-radio networks aim to use the spectrum in a dynamic manner by allowing radio terminals to operate in the best available frequency band, maintaining seamless communication requirements during transitions to better spectrum.

Benefits of CR:

One is related to flexible spectrum usage with the used frequency range, coverage and the backbone network, such as TV white space usage. The other is that cognitive radio improves the next generation cellular network from channel adaptive to be environment aware, as in Self-Optimized Networks (SON). Cognitive radio will make the mobile

Primaryusers:

A Users which has highest priority or legacy rights on the usage of specific part of the spectrum.

Secondary users:

A user which has lower priority and there for exploits the spectrum in such a way that it does not cause interference to primary users.

Licensed spectrum:

Cognitive radio allows the secondary users (SU) to use licensed spectrum when it is not used b the users to which it is actually allocated. The users which are allocated the spectrum have high priority known as primary users(PU)/licensed users.

Unlicensed spectrum:

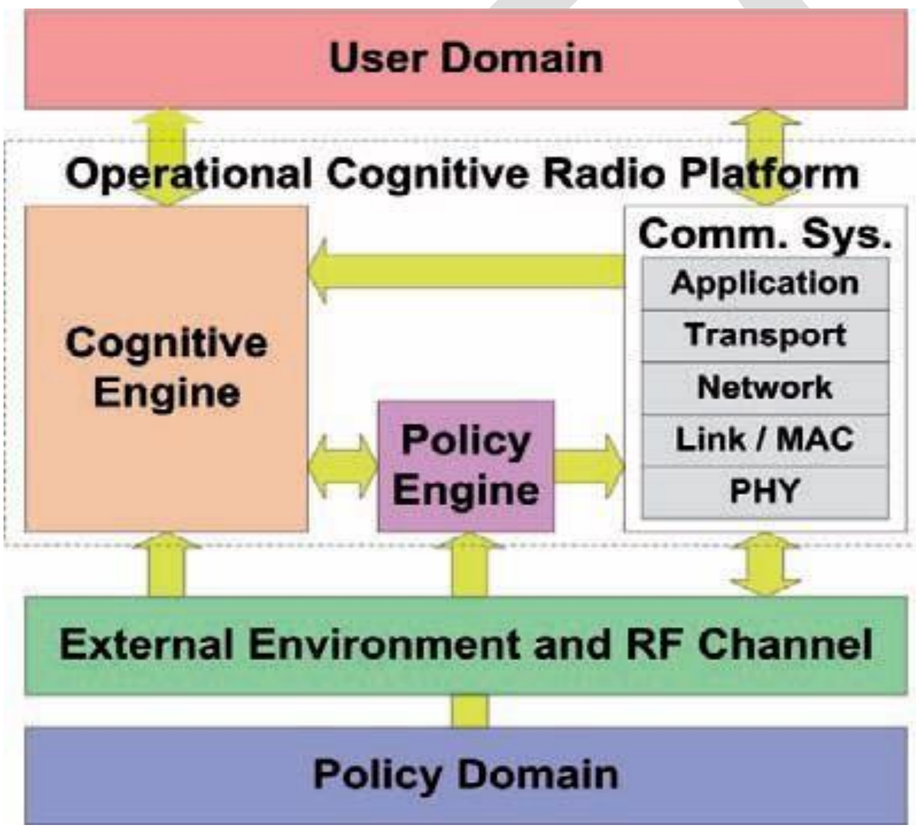
Based on the IEEE802.11, 2.4GHz and 5GHz are Unlicensed spectrum band that can be used by unlicensed users like Wifi users and D2D-Uusers.

CR Architecture:

- There are two major subsystems in a cognitive radio; a cognitive unit that makes decisions based on various inputs and a flexible SDR unit whose operating software provides a range of possible operating modes.
- A separate spectrum sensing subsystem is also often included in the architectural a cognitive radio to measure the signal environment to determine the presence of other services or users.
- It is important to note that these subsystems do not necessarily define a single piece of equipment, but may instead incorporate components that are spread across an entire network.
- As a result, cognitive radio is often referred to as a cognitive radio system or a cognitive network.

- The cognitive unit is further separated into two parts as shown in the block diagram below. The first labeled the “cognitive engine” tries to find a solution or optimize a performance goal based on inputs received defining the radio’s current internal state and operating environment.
- The second engine is the “policy engine” and is used to ensure that the solution provided by the “cognitive engine” is in compliance with regulatory rules and other policies external to the radio.

Cognitive Radio Concept Architecture



Evolution of CR
From 1984 to 2003

Year	Description
1984	Software Defined Radio was implemented by Esystem Inc.,
2000 - 2003	Later on Cognitive Radio research work was started by Mitola and Magurie
	CR research focused fully on DSA.More research projects are done based on this DSA based CR. Example: URA, SPECTRUM, MILTON
	Most important project in spectrum management and policy research was Next Generation (XG) project
	Different working groups on CR and SDR are: IEEE 802.22, SCC41 working groups, ETSI'S re-configurable radio systems technical committee.
	IEEE 802.22 aims to provide DSA to vacant TV spectrum.
	CR started using TVWS for opportunistic access of spectrum bands.

From 2004 to2009

2004	FCC proposed to allow opportunistic access to TV bands.
2008	Adaptrum, I^{2}C, Motorola, Microsoft and Philips were forwarded some demands to FCC for using prototype cognitive radios in TV bands.
	In November, FCC ordered to establish rules to allow the operation of cognitive devices in TVWS on secondary basis.
	U.K.Regulator, Ofcom were proposed FCC to allow license exempt use of interleaved spectrum for cognitive devices.
2009	In February, Ofcom published a new consultation which provides further details of its proposed cognitive access to TVWS.

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UNIT II

COGNITIVE RADIO ARCHITECTURE

Cognition cycle – orient, plan, decide and act phases, Organization, SDR as a platform for Cognitive Radio – Hardware and Software Architectures, Overview of IEEE 802.22 standard for broadband wireless access in TV bands.

Reference Book:

Huseyin Arslan (Ed.), -Cognitive Radio, Software Defined Radio, and Adaptive Wireless Systems, Springer, 2007. (Unit V)

Prepared by

1. Ms.C.JENITHA, Ast.Prof /ECE

Staff i/c **BC** **HoD** **Principal**

PART A

1.Define Ideal Cognitive radio(ICR).

An autonomous agent that perceives the user's situation to proactively assist the user with wireless information services ,particularly if the user is too busy or otherwise occupied, such as when in personal distress.

2. Define Self-aware cognitive radio?

In general, cognitive network is a type of network, wireless or not, that has a capability to think learn and remember. To add , cognitive networks are unique because of its capabilities such as self optimization , self monitoring, self repair, self protection, self adaptation and self healing. In order to optimize network operation, reconfiguration, management, and improving performance, a proposal to introduce self-awareness, self-management, and self-healing properties by bringing "intelligence" into the network.

3. Define are the tasks performed by cognition cycle?

The cognitive process starts with the passive sensing og RF stimuli and culminates with action. Three on-line cognitive tasks:

1.Radio –scene analysis, which encompasses the following:

- Estimation of interference temperature of the radio environment;
- Detection of spectrum holes.

2.Channel identification, which encompasses the following:

- Estimation of channel-state information(CSI);
- Prediction of channel capacity for use by the transmitter.

3. Transmit-power control and dynamic spectrum management.

Tasks (1) and (2) are carried out in the receiver, and tasks (3) is carried out in the transmitter. Through interaction with the RF environment, these three tasks form a cognitive cycle.

4. List capabilities required for the CR Functionality.

- Flexibility and agility
- Sensing
- Learning and adaptability
- Location and environment awarness

5. List some characteristics of Radio Cognitive Tasks?

The major tasks of the cognitive radio include:

- Radio-scene analysis
- Channel identification, and
- Dynamic spectrum management and transmit power control

6. What are the potential impacts areas of cognitive radio?

i. Military
ii. TV white space
iii. Femtocells and cellular agility

7. What are the challenges of cognitive radio networks?

a. Hiden primary user
b. Spectrum primary user can distinguish a spread spectrum transmission from the background is to sample the entire bandwidth, which may impossible for CR, leads to false identification of empty spectrum**.**

8. what are the primary functions of cognition?

The primary radio cognition function consists of:

a. 1.Regconize user communications context
b. 2.Mediate wireless information services as a function of context.

9. what is the objective of cognitive radio architecture?

Architecture for cognitive radio consists of the functions, components and design rules necessary to support the evolution of cognitive radio. The architecture integrates the contribution researchers focusing on the specific disciplines of software radio, network, natural language processing and machine learning. This architecture minimizes the dependence on knowledge-engineering through the integration of machine learning.

10.Define behavior epoch. Mention the modes of behavior .

Cognitive radio support functions include three modes of behavior ; waking, sleeping, and praying. Behavior that lasts for a specific time interval is called a behavioral epoch.

11.What is waking behavior?

The waking behavior is optimized for real-time interaction with the user, isochronous control of software radio assets, and real-time sensing of the environment. The conduct of the waking behavior is informally referred to as the awake –state , although it is not a specific system state ,but a set of behaviors.

12.Define sleeping behavior?

cognitive PDAs detect conditions that permit or require sleep. For example, if the PDA predicts or becomes aware of a long epoch of disuse (eg. overnight), then it PDA may autonomously initiate sleeping behavior .Otherwise, it would request permission to enter sleeping behavior from the waking behavior using non-incremental machine-learning algorithms. These algorithms map current cases and integrated knowledge onto integrated knowledge (b).

13.what is a conflict ?

A conflict is a context where the user overrode a PDA decision about which the PDA had a little or no uncertainity. Map b may resolve the conflict. If not, then it will place the conflict on a list of unresolved conflicts (map g).

14.Define prayer behavior.

Attempts to resolve unresolved conflicts via the mediation of the PDA's home network may be called prayer behavior. The unresolved-conflicts-list is mapped(1) to RKRL XML queries to the PDA's home network expressed in KQML.

15.What are the components of cognitive functions?

Cognition functions implemented via cognition components. These include data structures and related processing components.

16.Define world model.

World Model, S, consists primarily of bindings between a-priori data structures and the current scene. These structrures are also associated with the observe phase.

17.What is the purpose of observe-phase data structures?

The observe phase components match new stimuli to known stimuli. When an exact match is not possible, the components may deliver one or more hypotheses. Hypotheses may consists of best-match, or a prioritized list of partial matches. Bindings may be computed as the interface from the observation phase hierarchy to the orient phase.

18.Define binding in observe-phase data structures?

Binding associates specific stimuli in the <scene/> with related internalized stimulus- experience-response sets that are abstractions of prior scenes. When identical items are bound in a scene, they form conceptual anchors.

19.Define decide-phase components.

The decide-phase selects among alternatives generated by the planning phase. Its knowledges representation depends on the radio procedure components. The decide-phase allocates computational and radio-resources to subordinate software, based on the activation ofa plan.

20.What do you infer from radio procedure knowledge encapsulation?

Radio knowledge may be embodied in components called radio knowledge sources. If so, they are organized as set-theoretic maps among wake-cycle phases (observe, orient, plan. Decide, act).

21.What is the use of plan phase components?

The plan phase represents plans for the control of the software radio personalities. The plan phase may include a plan calculus.

22.How CR can be realized using SDR.

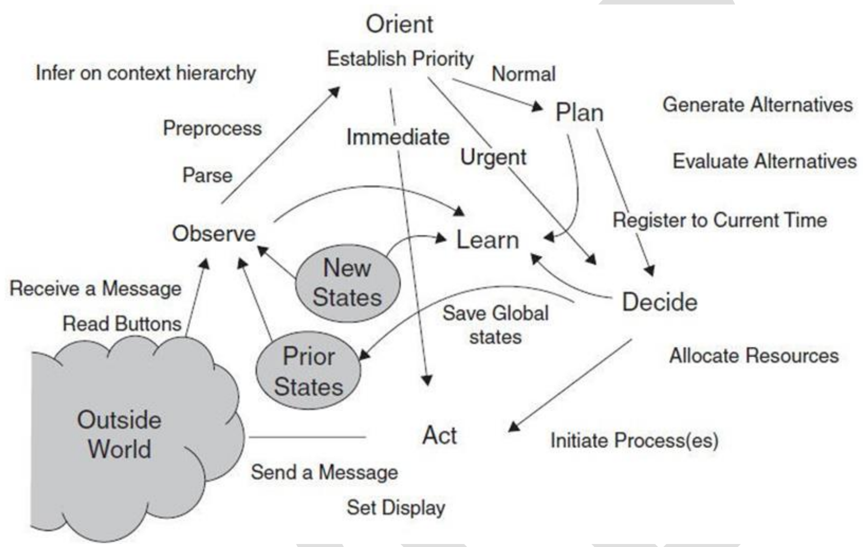
Cognitive radio may be realized via software-defined radio (SDR) with sensory perception, RF autonomy, and integrated machine learning of the self, the user, the environment, and the “situation”.

PART B

1.What is Cognitive cycle? Explain about its different stages of working and its

Capabilities of CR in reactive sequence

- Stimuli enter the cognitive radio as sensory interrupts, dispatched to the cognitive cycle for a response
- Ideal cognitive radio observes the environment, orients itself, creates plan, decides and then acts.



- Wake epoch: The entire process in cognition cycle is called wake epoch, because the primary reasoning activities are reactive to the environment.
- Dream epoch: The process used for performing computationally intensive pattern recognition and learning.
- Prayer epoch: This process used for interacting with a higher authority such as network infrastructure.
- Sleep epoch: The cognition cycle enters sleep mode during power down conditions.

Observe (Sense and perceive):

- The CR observes its environment by parsing incoming information streams.
- In the observation Phase, CR also reads its location, temperature, other parameters.

- The iCR senses and perceives the environment by accepting multiple stimuli in many dimensions simultaneously and by binding these stimuli all together – to prior experience, subsequently detect time-sensitive stimuli and generate plans for action.

Orient:

- The orient phase determines the significance of an observation by binding the observation to a previously known set of stimuli of a scene.

Binding :

- It is a process used to apply the prior experience to current situation, when conditions are met.
- Binding also determines the priority associated with stimuli.

Plan:

- Plan phase enable the synthesis of RF and information access behaviors in a goal-oriented way based on perceptions from the visual, audio, text, and RF domains and previously learned user preferences.
- Open source planning tools enable the planning subsystems into the CRA, enhancing the plan component.

Decide:

- The decide phase selects among the candidate plans.
- The Radio might have the choice to alert the user to an incoming message or to defer the interruption later.

Act:

- Acting initiates the selected processes using effector modules.
- Effectors may access the external world or the CR's internal states.

Learning:

- Learning is a function of perception, Observations, decisions and actions.
- Initial Learning is mediated by the observe phase perception hierarchy.
- Learning also occurs through the introduction of new internal models in response to existing models and case based reasoning bindings.

Self monitoring:

- Self monitoring process used to maintain execution time or various phases and restrict its computations to not consume more resources than the precomputed upper bound.

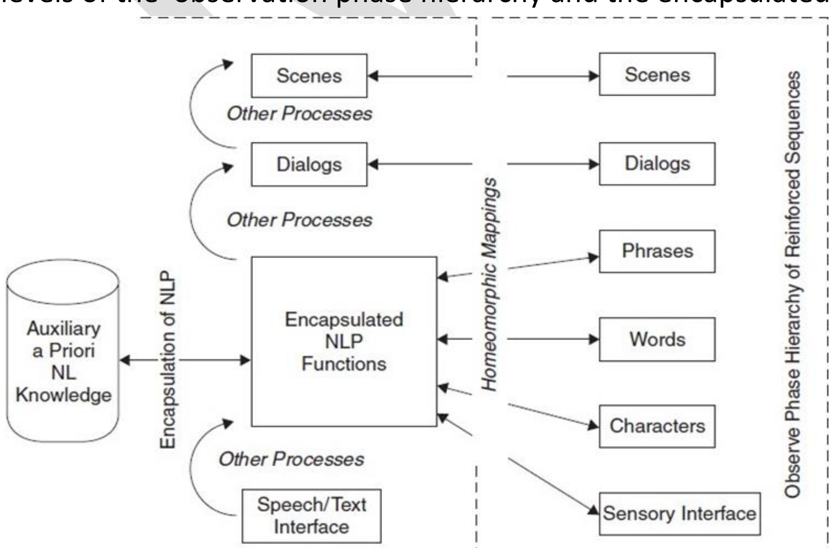
1. **Explain about Inference Hierarchy organization of cognitive radio and its role in organizing data structures**

- The Inference hierarchy is the part of the algorithm architecture that organizes the data structures.
- The Pattern of accumulating elements into sequences begins at the bottom of the hierarchy.

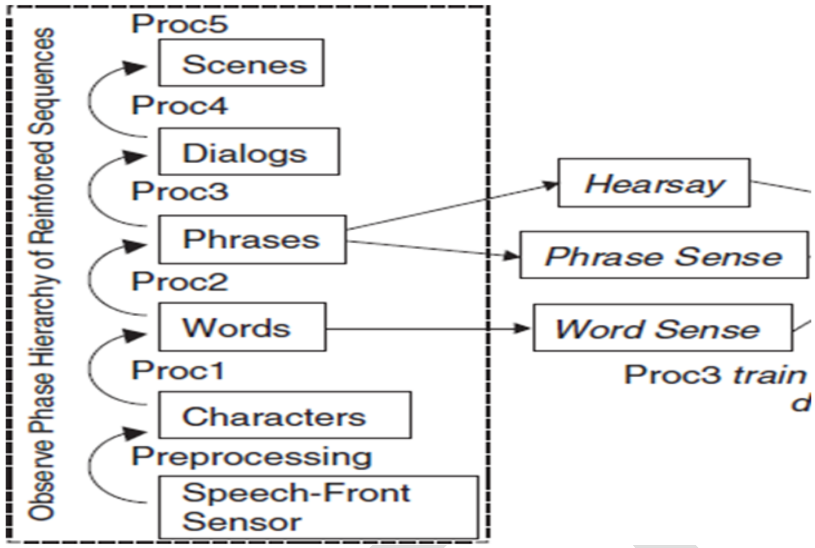
Sequence	***Level of Abstraction***
Context Cluster	***Scenes*** in a Play, Session
Sequence Clusters	***Dialogs***, Paragraphs, Protocol
Basic Sequences	***Phrases***, Video Clip, Message
Primitive Sequences	***Words***, Toke, Image
Atomic Symbols	***Raw Data***, Phoneme, Pixel
Atomic Stimuli	External Phenomena

NL in the Inference Hierarchy:

- NL(Natural language) used to make interactions between computers and human languages.
- Speech and text channels may be processed via such NL facilities with substantial a priori models of language and distance.
- The use of those models entail mapping among the word, Phrase, dialog and scene levels of the observation phase hierarchy and the encapsulated component(s).

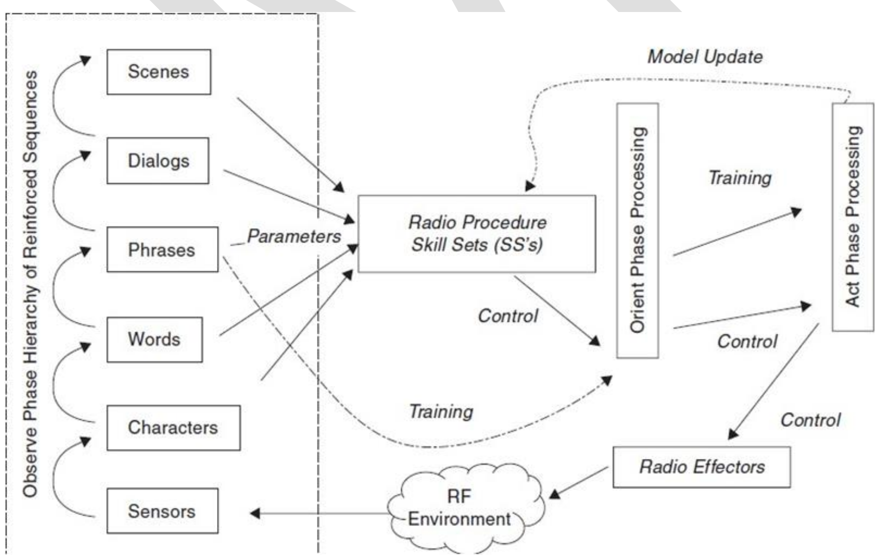


Observe –Orient link for scene interpretation:



- CR may use an algorithm – generating language with which one may define self-similar Inference processes.
- Proc 1: Partitions characters into words.
- Proc 2:Detects novel words and aggregates known words into Phrases.
- Proc 3:Detects novel phrases, aggregates known Phrases into dialogs.
- Proc 4: Aggregates dialogs into scenes.
- Proc 5: Detects known scenes.

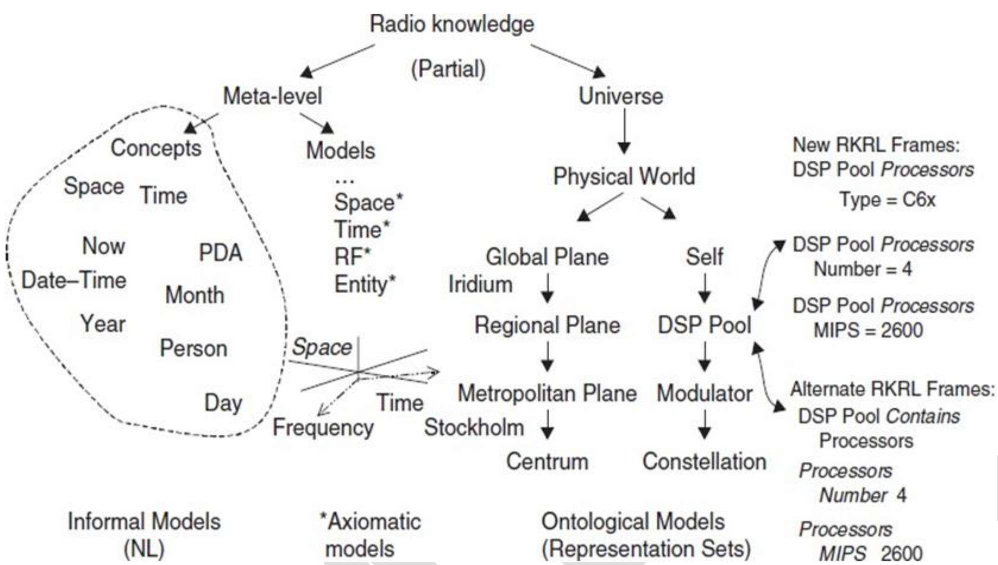
Observe –Orient link for Radio skill sets:



- Radio Knowledge may be embodied in components called radio skills.

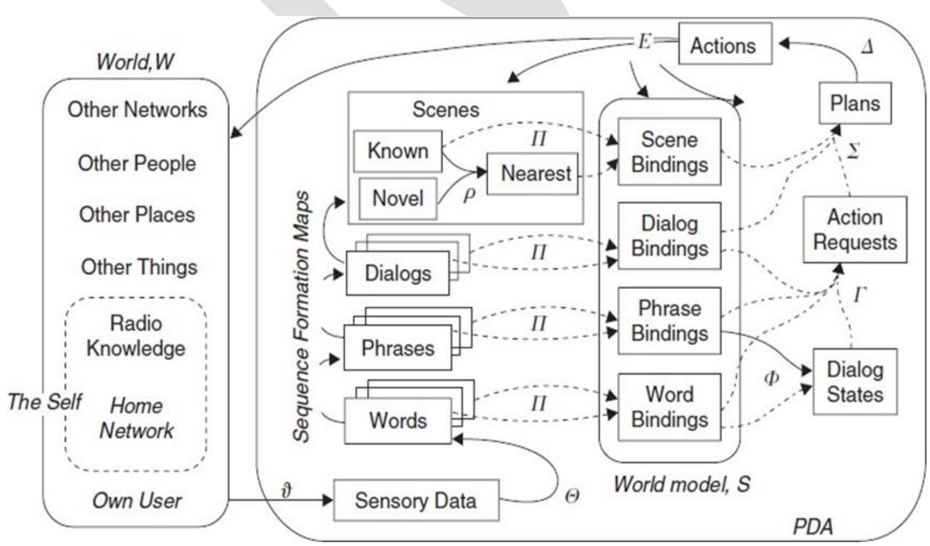
- These skill sets may either be reformatted into serModels directly from the a priori knowledge of an RKRL frame, or they may be acquired from training or sleep/dreaming.
- Each skill set may also save the knowledge it learns into an RKRL frame.

General world knowledge:



- An AACR needs substantial knowledge embedded in the inference hierarchies.
- It needs both external RF knowledge and Internal Radio knowledge.
- Abstractions include informal and formal meta level knowledge from unstructured knowledge of concepts to the more mathematically structured models of space, time, RF and entities that exist in space time.

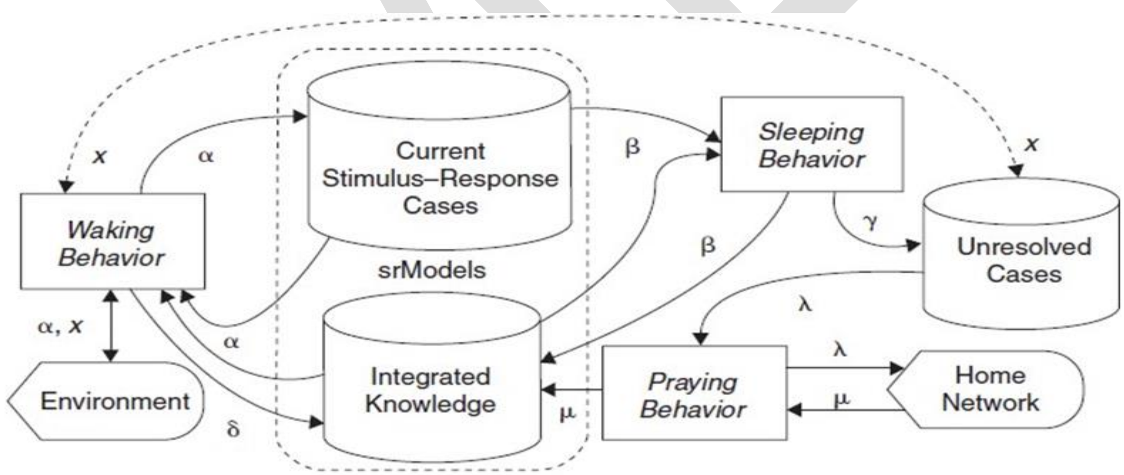
Architecture Maps:



CRA Topological maps:

- The input map consists of components that transform external stimuli to the internal data structure sensory data.
- The Transformation consists of entity recognition (via acoustic, optical and other sensors) ,lower level software radio waveform (SWR) interface components and so forth, that create streams of primitive reinforced sequences.
- Reasoning Components include the map that identifies the best match of known sequences to novel sequences.
- Generalized word-and phrase-level bindings are interpreted by the components to form dialog states.
- The components of create action requests from bindings and dialog states.
- Context-Sensitive plans are created by the component that evaluates action requests in the plan phase.
- The decision phase processing consists of map that maps plans and scene context to actions.
- The map E consists of the effector Components that change the PDA's internal states, change displays, synthesize speech, and transmit information on wireless networks using the SWR personalities.

Behavior in CRA:



α: action cycle; δ: in cremental machnine learning;
β: nonincremental machine learning; γ: learning conflicts;
λ: RKRL/KQML requests for external assistance;
μ: authoritative assistance; x: attempt to resolve problems.

- CRA entails three modes of behavior.
- 1)Waking 2)Sleeping 3) Praying

1) Waking Behavior:

- Waking behavior is optimized for real-time interaction with the user, isochronous control of SWR assets, real time sensing of the environment.

2) Sleeping and Dreaming:

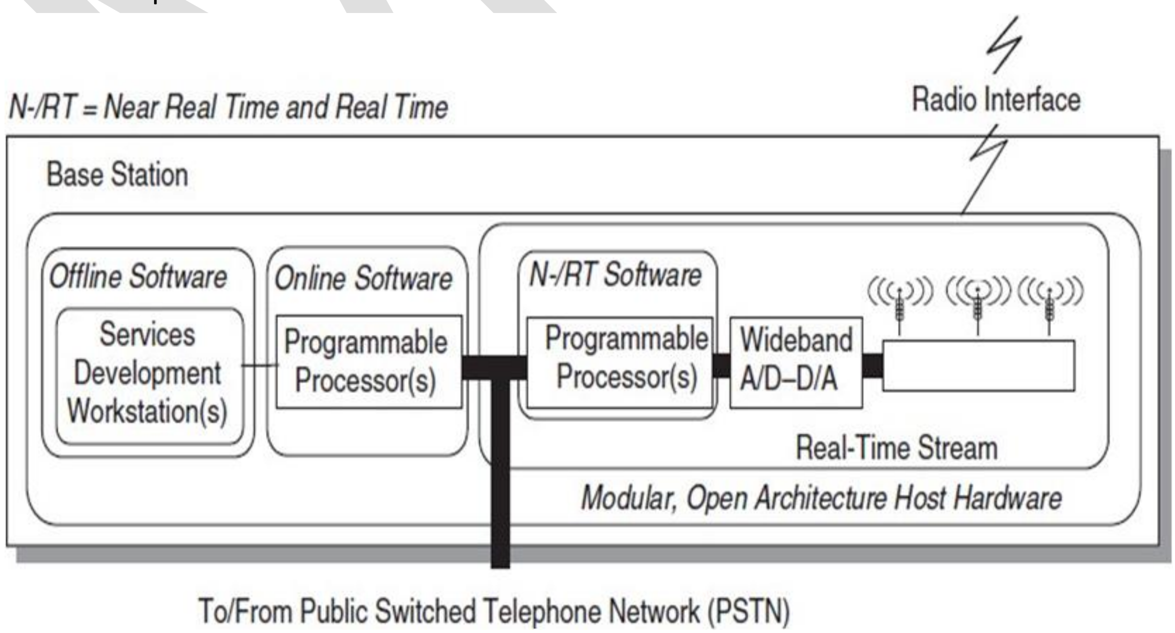
- Cognitive PDAs detect conditions that permit or require sleep and dreaming.
- During the dreaming epochs, The CPDA processes experiences from the waking behavior using non incremental ML algorithms.
- In the CRA all sleep includes dreaming.

3) Prayer Behavior:

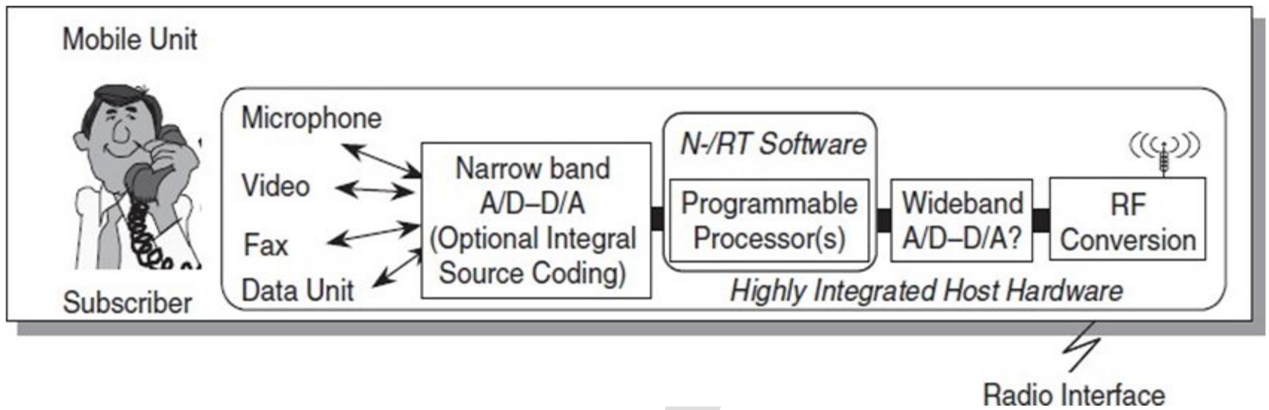
- Attempts to resolve unsolved conflicts via the mediation of the PDA's home network may be called prayer behavior.

2. Explain about building the CRA on SDR Architectures and how SDR act as a platform for Cognitive.

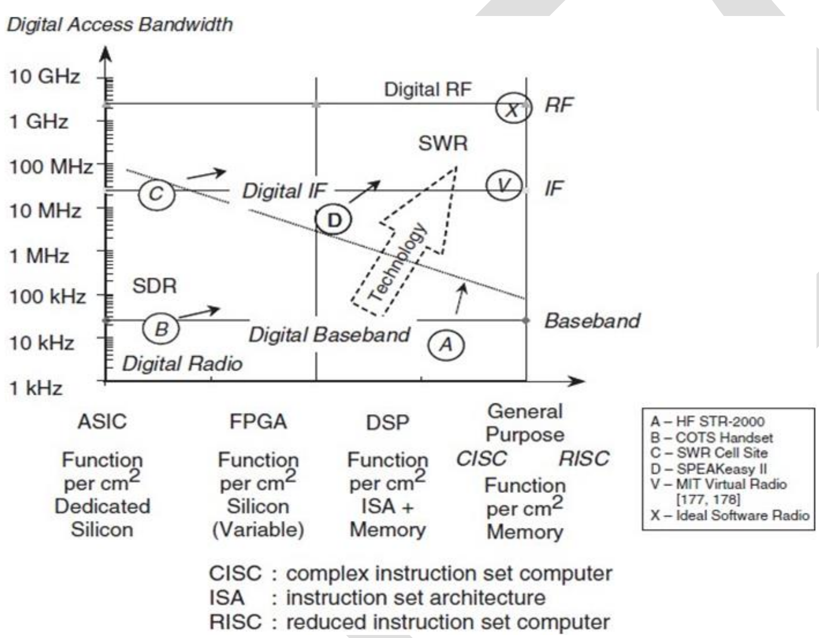
- Software radio(SWR) is the ideal digital radio in which the analog-to-digital converter (ADC) and Digital –to-analog converter(DAC) convert digital signals to and from RF directly, and all RF channel modulation, demodulation, frequency translation and filtering are accomplished digitally.
- The ideal SWR would have essentially no RF conversion , just ADC/DAC blocks accessing the full RF spectrum available to the antenna elements.



SWR Principles:

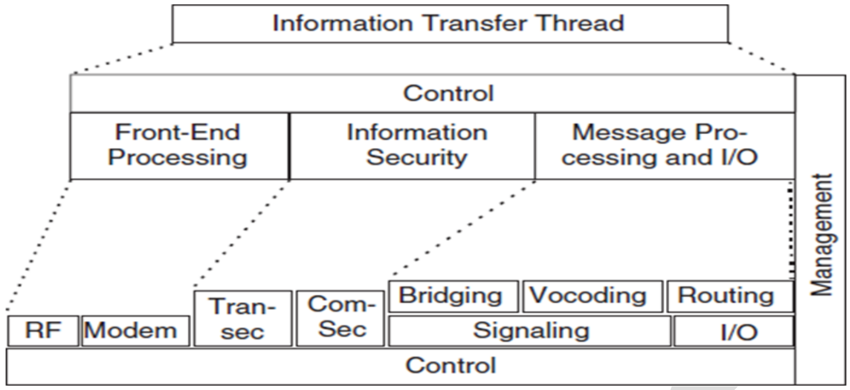


SDR Design space:



- The SDR design space consists of the combination of digital access bandwidth and programmability.
- ASICs Cannot be changed at all, so the functions are dedicated in silicon.
- FPGAs can be changed in the field, but need to upgrade the hardware .
- DSPs are less expensive to program and are more efficient in power use than FPGAs.
- GPPs, RISCs are most effective to change in the field.

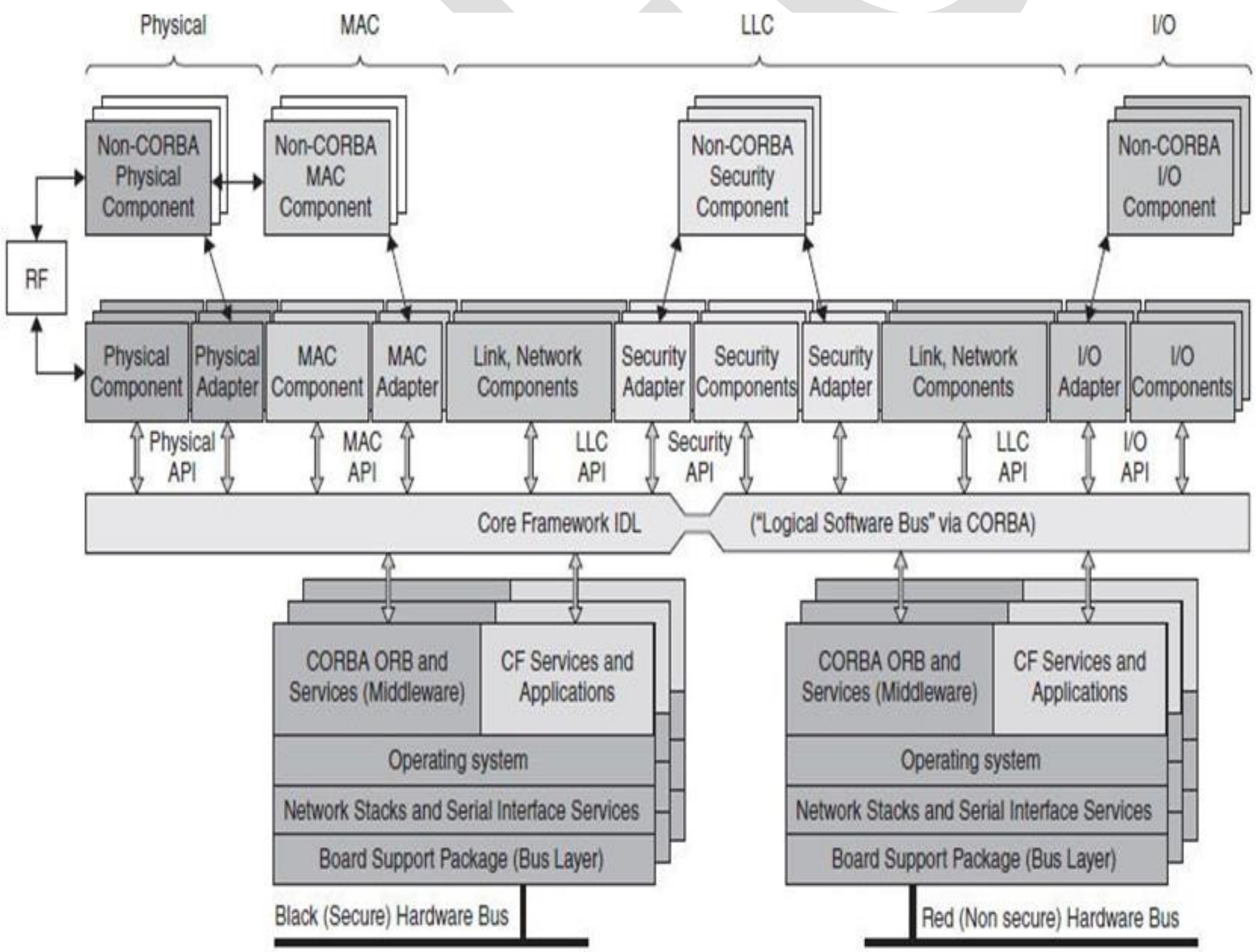
SDR Forum information transfer thread Architecture:



Radio Architecture:

- The SDR Forum defined a very simple, helpful model of radio in 1997.
- This model highlights the relationships among radio functions at the tutorial level.

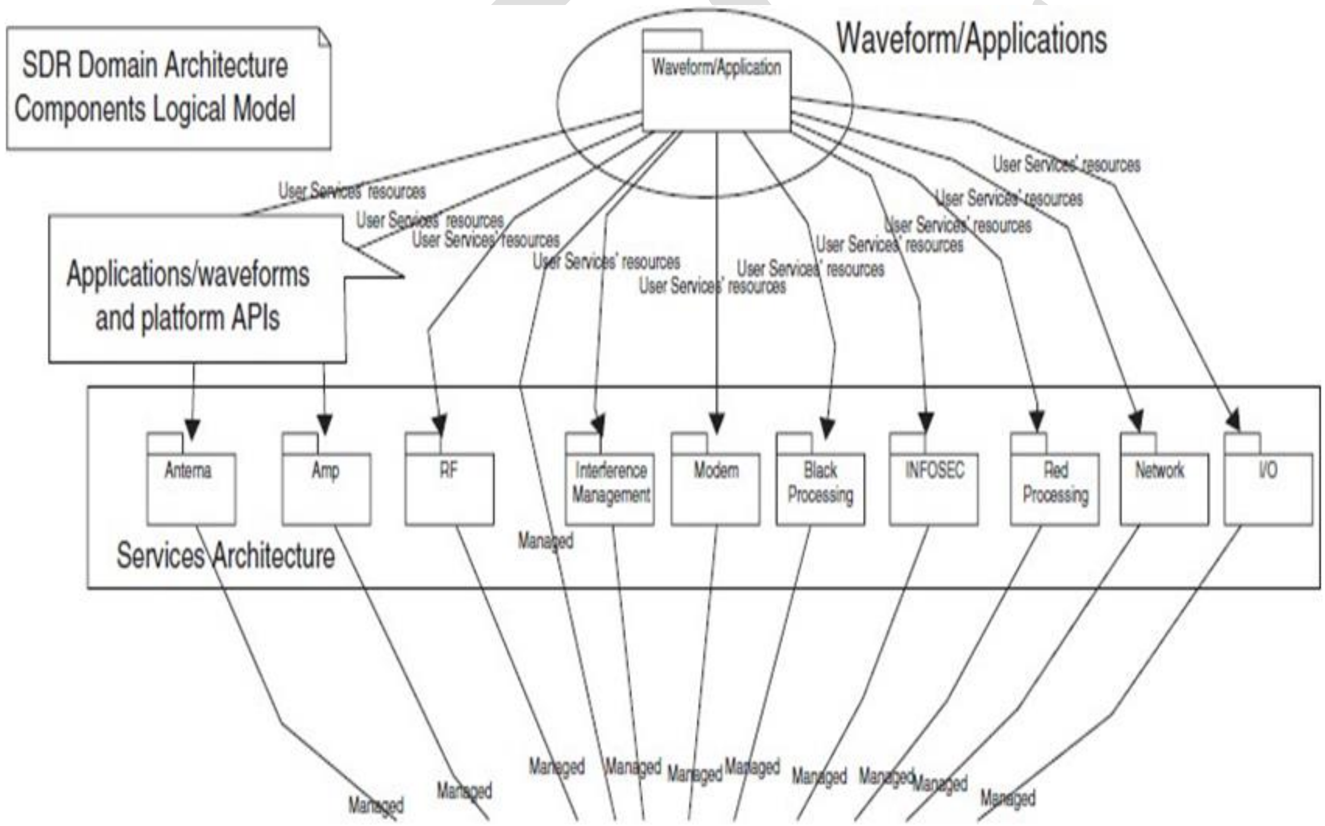
JTRS SCA Version 1.0:



The SCA:

- The US DOD developed the SCA for its Joint Tactical Radio System (JTRS) family of radios.
- The APIs define access to the PHY layer, to the MAC layer, to the LLC layer, to security features, and the I/O of the physical radio device.
- The Physical Components consist of antennas and RF conversion hardware ,that typically lack the ability to describe themselves to the system.
- Most other SCA Components are capable of describing themselves to the system to enable and facilitate plug and play among hardware and software components.
- In addition, the SCA embraces the portable operating system interface(POSIX) and CORBA.

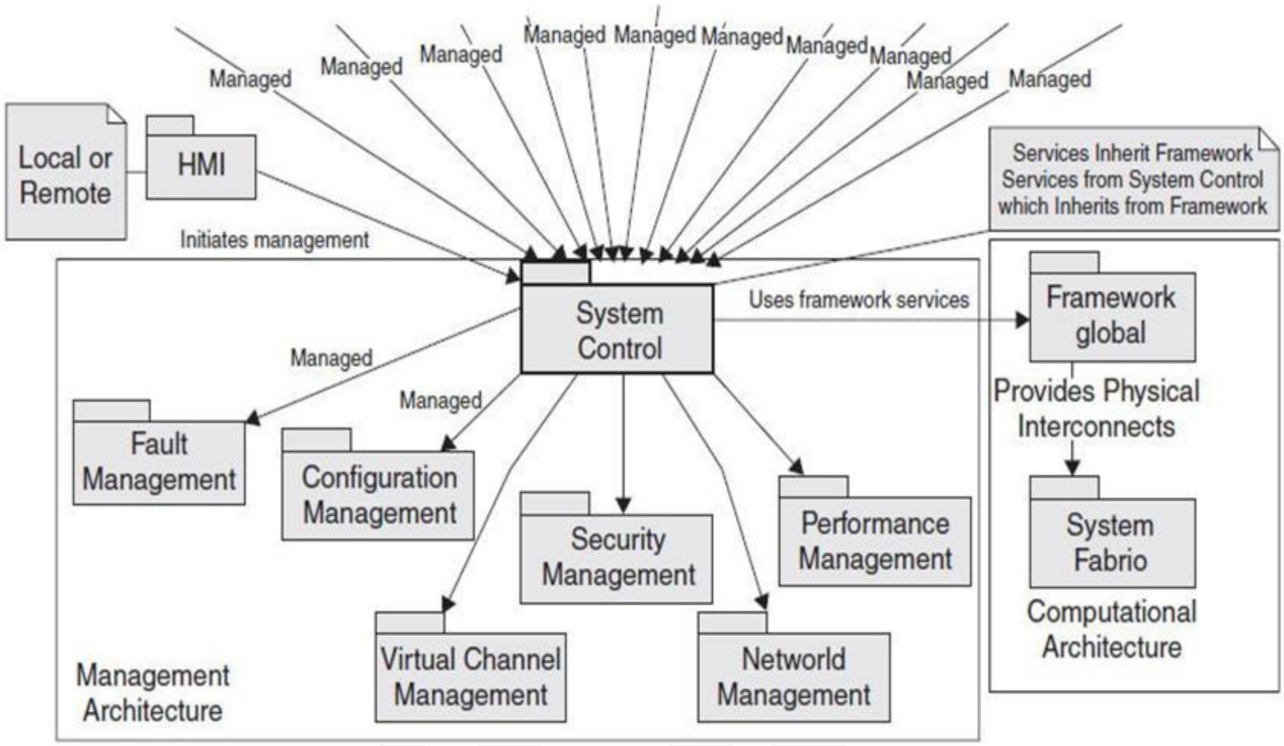
SDR Forum UML Model of radio services:



- UML based object oriented model define Waveforms of different load modules that provides wireless services, so from designer’s perspective the waveform is the key applications in a Radio.
- In the UML model Amp refers to amplication services, RF refers to RF conversion.

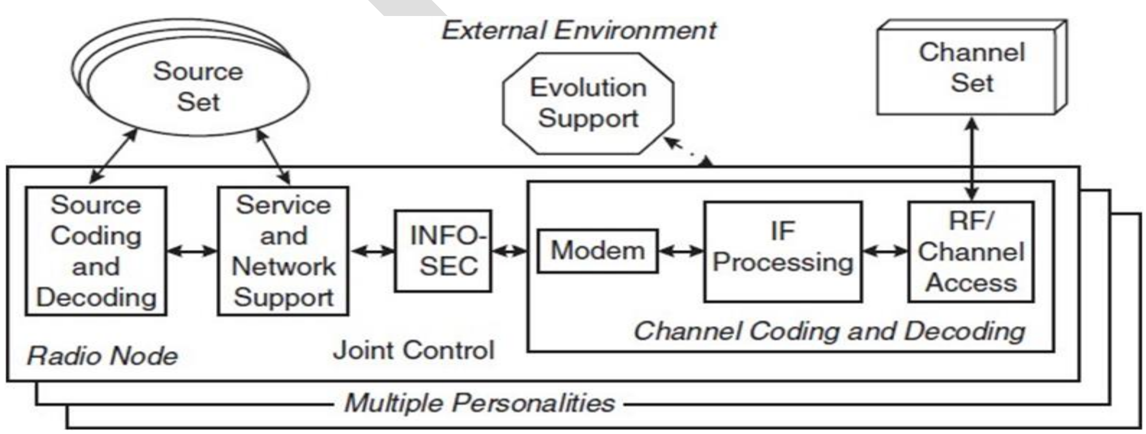
- interface management refers to both avoiding interference and filtering it out of one's band of operation.

SDR Forum UML Management and computational architectures:



- The UML model contains a sophisticated set of management facilities, provides better human- machine Interface and secured communication.
- The CR will direct virtual channel management (VCM) and will learn from the VCM function. What radio bands are available, such as what bands the radio can listen to and transmit on and how many bands it can use at once.

Functions-transforms model of a wireless node:

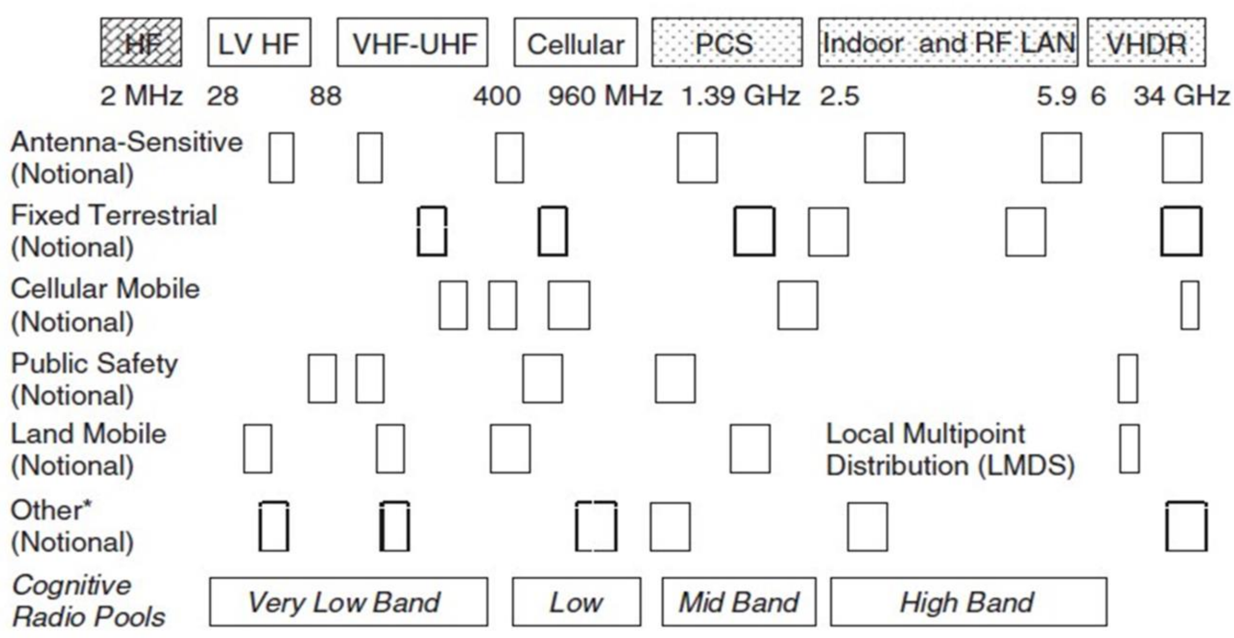


- The CRA uses a self-referential model of a wireless device, the functions-transforms model, to define the RKRL and to train the CRA.
- In this model, Radio knows about sources, source coding, networks, INFOSEC, and the collection of front-end services needed to access RF channels.
- Its knowledge also extends to the idea of multiple channels and their characteristics and the radio part may have many alternative personalities at a given point in time.

Radio Transition towards Cognition:

- For Radio, as the number of bands and modes increases ,the SDR becomes a better candidate for the insertion of Cognition Technology.
- In the future, SDR PDAs could access satellite, Mobile services, Cordless telephone, WLAN,GSM and 3G bands.
- ideal SDR access three bands, 0.4 to 0.96 GHZ,1.3 to 2.5 GHZ,2.5 to 5.9 GHZ.
- When a radio device accesses more RF bands than the host network controls, it is time for CR technology to mediate the dynamic sharing of spectrum

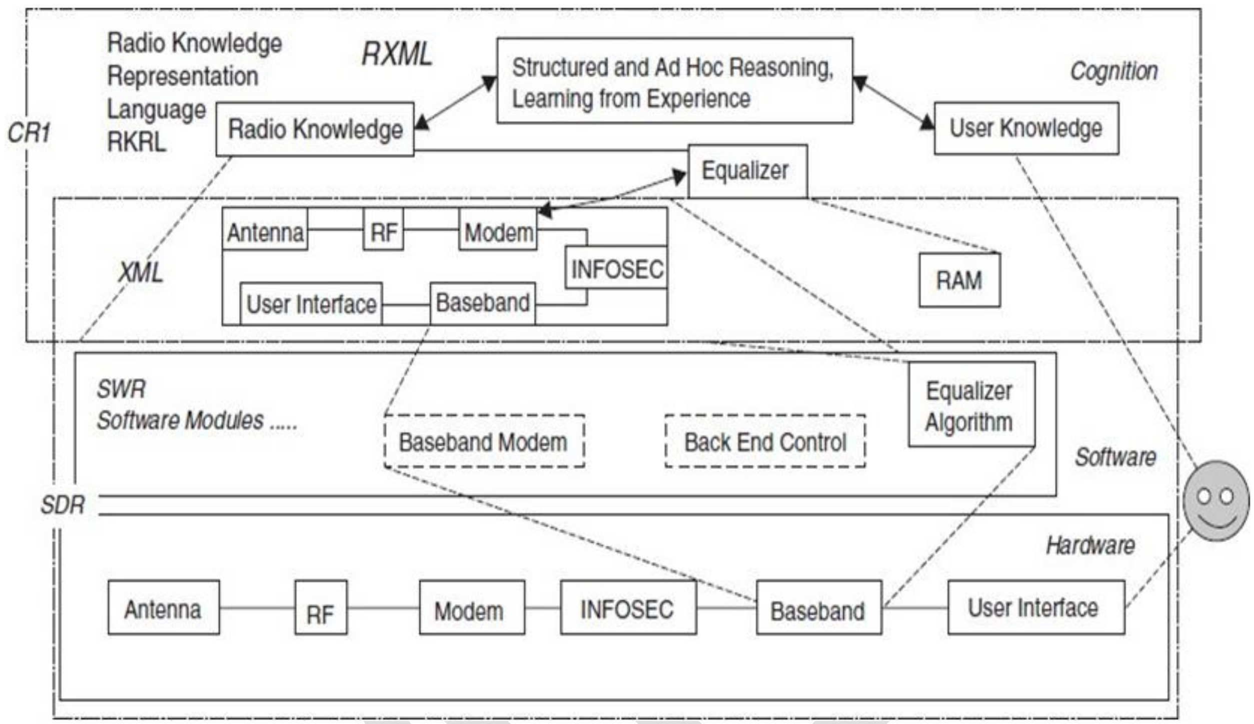
Fixed Spectrum allocations versus pooling with CR:



*Includes broadcast, TV, telemetry, amateur, ISM (Industrial, scientific, medical); VHDR: Very High Data Rate; VHF: very high frequency; UHF: ultra high frequency.

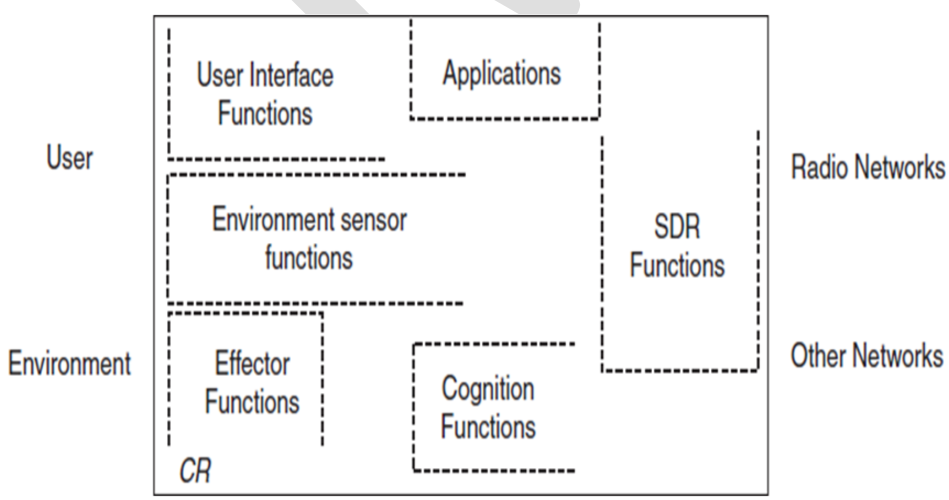
3. **Explain about Hardware and Software Architectures of Cognitive radio and its components.**

Cognitive Radio Components:



- Hardware: Antenna, RF, Modem, INFOSEC, Baseband, User Interface.
- Software: Baseband Modem, Back end control, Equalizer Algorithm.
- Cognition: RXML Language-Defines SDR components.
- RXML Language – includes Priori Radio background, user stereotypes, Knowledge of RF.

AACR Node Functional Components:



Six Functional Components:

- 1)User SP(Sensory Perception) - includes haptic, acoustic, Video sensing and Perception Functions
- 2)Local Environment sensors - location, temperature, accelerometer, compass etc.
- 3)System Applications - media Independent Applications (E.g. Network Games)
- 4)SDR Functions - RF sensing and SDR Applications.
- 5)Cognition Functions - System control, Learning, Planning.
- 6) Local effector Functions - Speech synthesis, text ,graphics and multimedia displays.

Design Rules Include Functional Component Interface:

From\to	User SP	Environment	Sys apps	SDR	Cognition	Effectors
User SP	1	7	13 PA[a]	19	25 PA[b]	31
Environment	2	8	14 SA[a]	20	26 PA[b]	32
Sys apps	3	9	15 SCM[a]	21 SD[a]	27 PDC[a,b]	33 PEM[a]
SDR	4	10	16 PD[a]	22 SD	28 PC[b]	34 SD
Cognition	5 PEC[b]	11 PEC[b]	17 PC[a,b]	23 PAE[b]	29 SC[b]	35 PE[b]
Effectors	6 SC	12	18[a]	24	30 PCD[b]	36

P: primary; A: afferent; E: efferent; C: control; M: multimedia; D: data; S: secondary; others not designated P or S are ancillary.
[a]Information services API; [b]CAPI.

The Cognition Components:

- Radio Knowledge – RXML : RF
- User Knowledge – RXML : User
- The Capacity to Learn

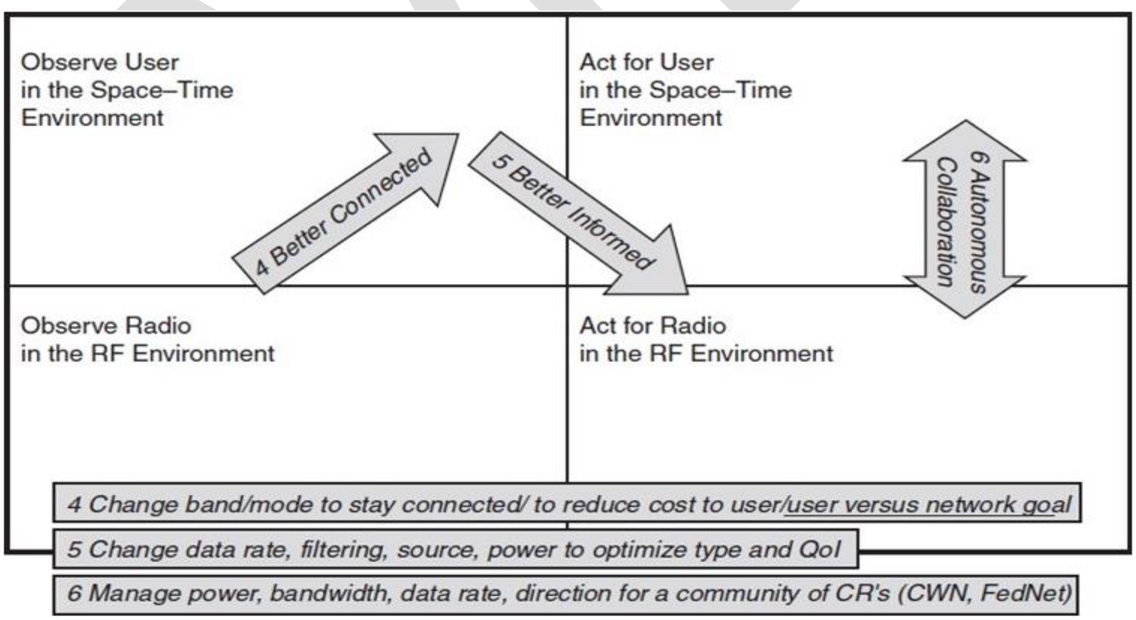
Radio knowledge:

- Radio knowledge is a computationally accessible structured Knowledge about radio.
- RXML language formalize the radio knowledge and enable the structuring of sufficient RF and user world knowledge to build advanced wireless enabled or enhanced information services.
- Radio knowledge must comprehensive, addressing the majority of radio bands.

Radio Knowledge in the Architecture:

Need	*Source knowledge*	*AACR internalization*
Sense RF	RF platform	Calibration of RF, noise floor, antennas, direction
Perceive RF	ITU, ETSI, ARIB, RAs	Location-based table of radio spectrum allocation
Observe RF (sense and perceive)	Unknown RF	RF sensor measurements and knowledge of basic types (AM, FM, simple digital channel symbols, typical TDMA, FDMA, CDMA signal structures)
Orient	XG-like policy	Receive, parse, and interpret policy language
	Known waveform	Measure parameters in RF, space, and time
Plan	Known waveform	Enable SDR for which licensing is current
	Restrictive policy	Optimize transmitted waveform, space–time plan
Decide	Legacy waveform, policy	Defer spectrum use to legacy users per policy
Act	Applications layer	Query for available services (white/yellow pages)
	ITU, ETSI, ... CWN	Obtain new skills encapsulated as download
Learn	Unknown RF	Remember space–time–RF signatures; discover spectrum use norms and exceptions
	ITU, ETSI, ... CWN	Extract relevant aspects such as new feature

User Knowledge in the Architecture:



- User knowledge is defined in RXML with RF knowledge, the capabilities required for an AACR node .
- User Knowledge give the ability to CR to acquire relevant information about services , from its owner and other designated users.

Flexible function of the Component Architecture:

Feature	*Function*	*Examples (RF; vision; speech; location; motion)*
Cognition	Monitor and learn	Get to know user's daily patterns and model the local RF scene over space, time, and situations
Adaptation	Respond to changing environment	Use unused RF, protect owner's data
Awareness	Extract information from sensor domain	Sense or perceive
Perception	Continuously identify knowns, unknowns, and backgrounds in the sensor domain	TV channel; depth of visual scene, identity of objects; location of user, movement and speed of <Self/>
Sensing	Continuously sense and preprocess single-sensor field in single-sensory domain	RF FFT; binary vision; binaural acoustics; GPS; accelerometer; etc.

4. **Give an Overview of IEEE 802.22 standard for broadband wireless access in TV bands and how the channel management is done.**

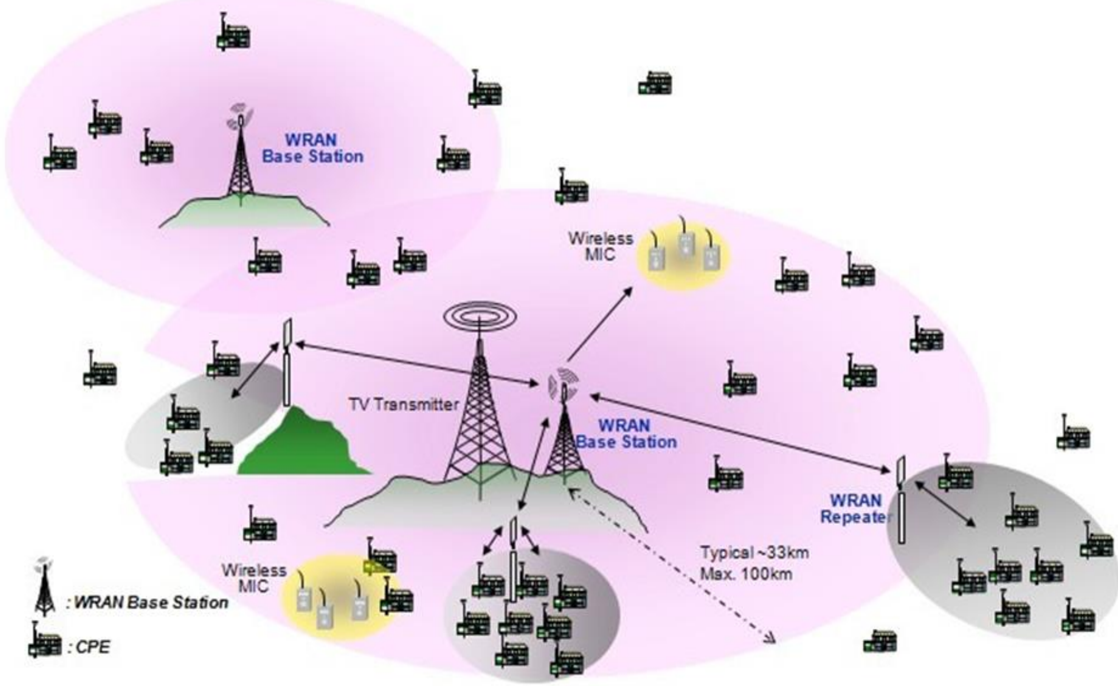
IEEE 802.22:

- Share the geographically unused TV spectrum in a rural environment to provide Broadband access

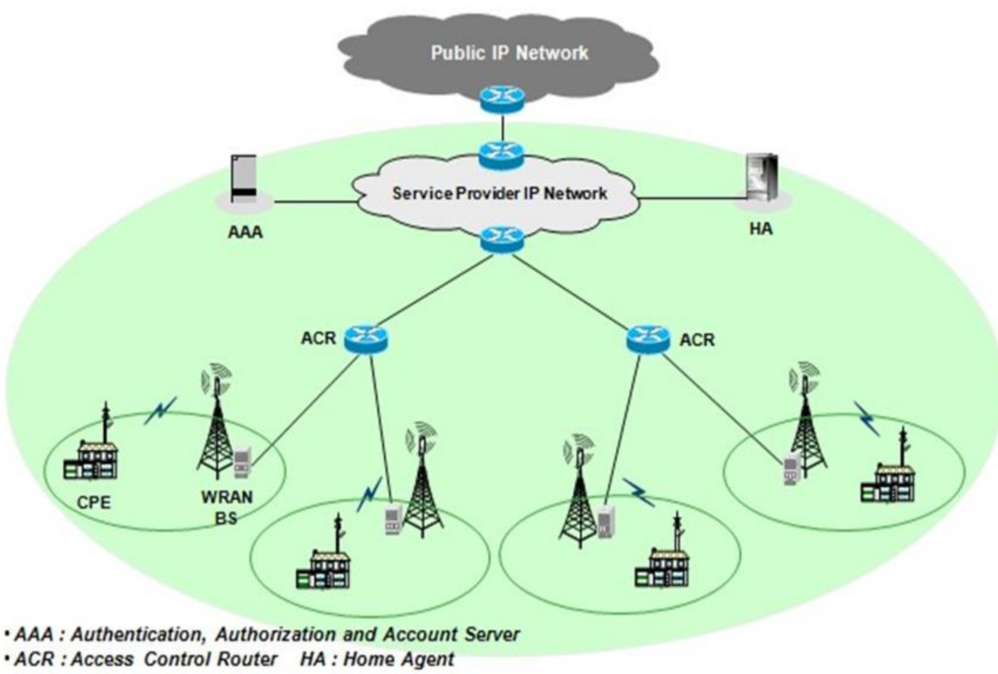
WRAN Standard:

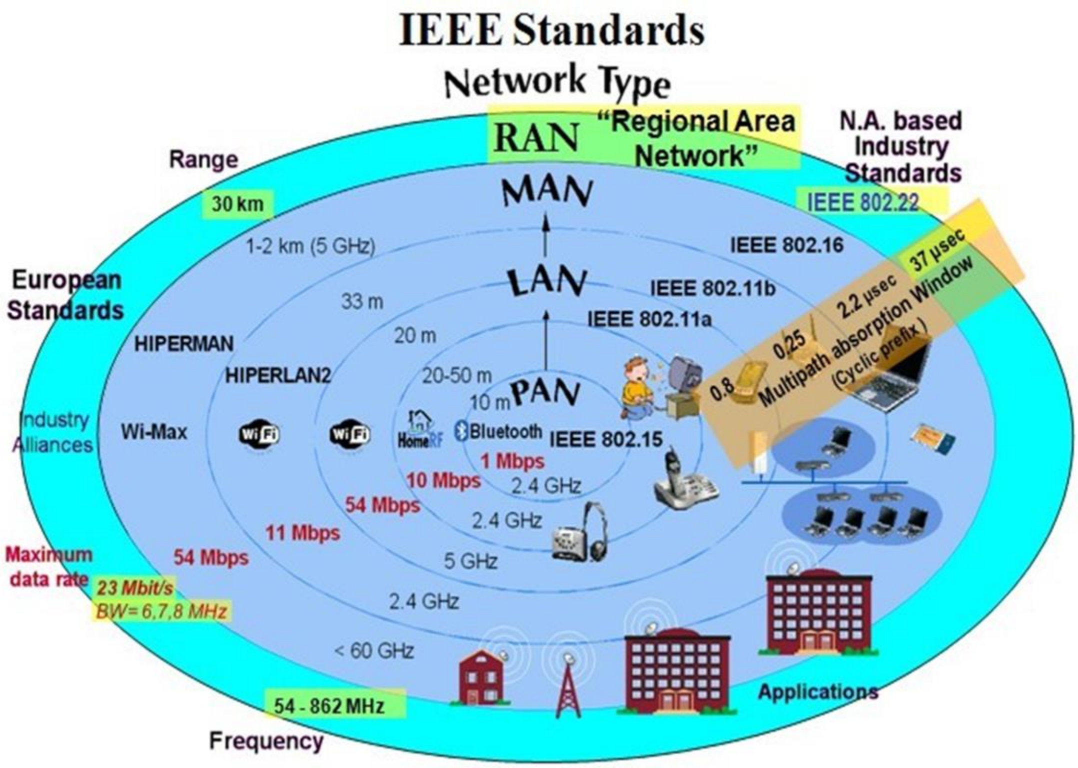
- Specify both PHY & MAC layer functionalities Infrastructure based Broadband access
- BS (base station) controls CPE (consumer premises equipment)
- Operates in TV band
- Dynamic channel management is the key feature

Deployment Scenario



WRAN Hierarchy

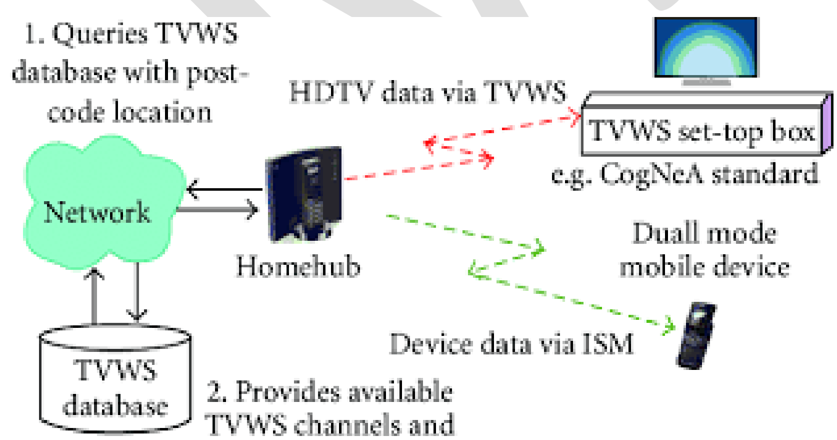




Dynamic channel Management:

- Resource utilization
- QoS (Quality of Service)
- Incumbent monitoring

TVWS Channels:

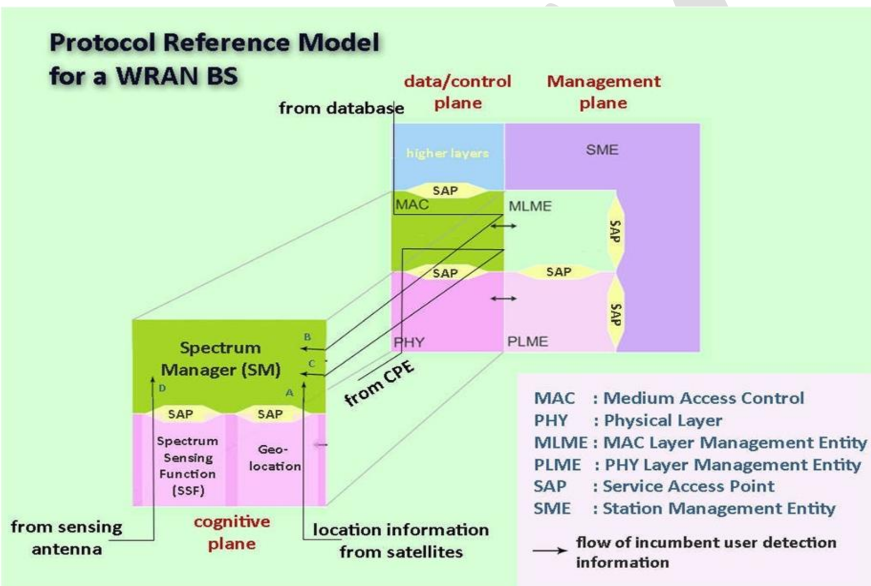


Types of incumbent user operations in TV band:

- Analog TV
- Digital TV
- Wireless microphone
- Guard bands
- User protection rules by Regulatory bodies

Channel information

- Geo-Location Database
- Incumbent Database
- Spectrum Sensing



Geo location:

- The geographic location of the BS and CPE has to be known to determine the permissible channels at a given location
- Devices find their location through Global Positioning System

Incumbent database:

- Maintained by Regulatory bodies in different places to keep information of licensed users
- Should be available at no operational cost

Spectrum sensing:

- To detect presence of incumbent users
- Both BS and CPE scans TV channels independently
- SSF tunes channels & reports to SM

Channel classification procedure:

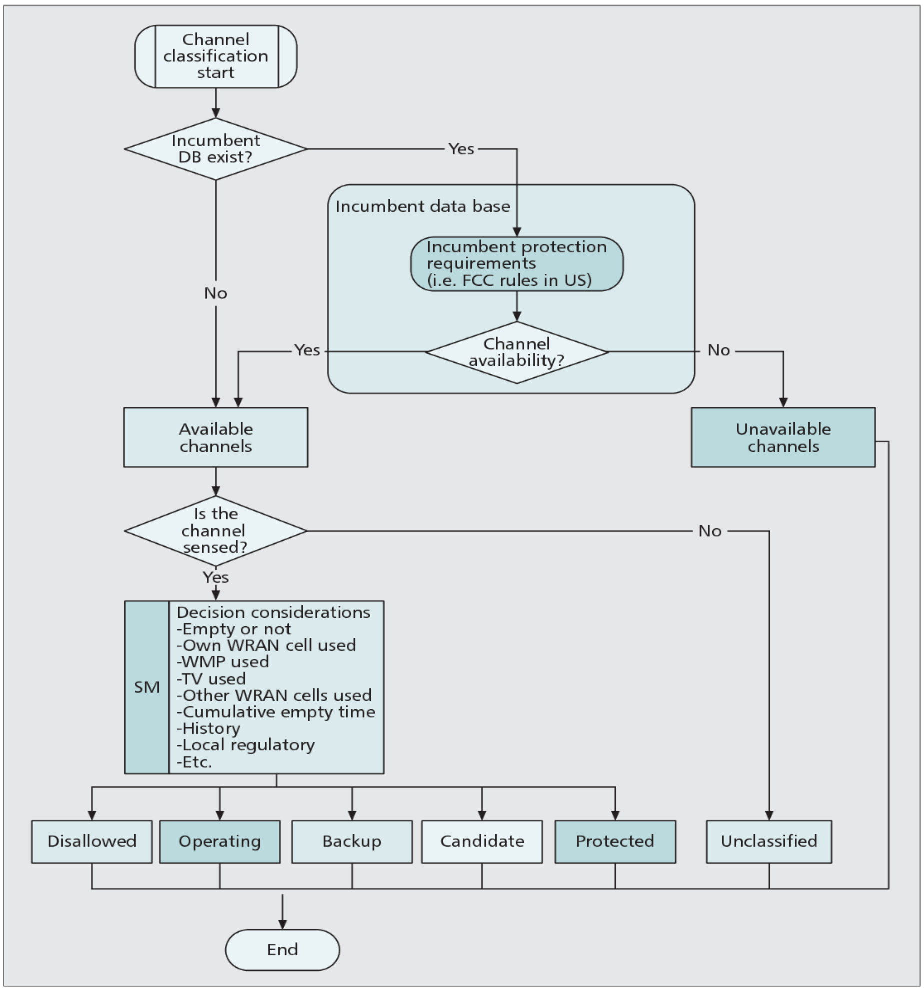


Figure 2. *Two- step channel classification procedure.*

The IEEE 802.22 WRAN standard also supports the spectrum sensing mechanism to detect the possible presence of incumbent users such as analog TV, digital TV, and low power licensed users such as wireless microphone.

Available channels:

Channels	**Characteristics**	**Re-sensing time** **interval**
Protected	channels in which incumbent users or WRAN operations has been detected	**Infrequent**
Operating	The channel currently in operation for WRAN	Every 2s
Back up	channels that have been cleared to become the operating channel	Every 6s
Candidate	channels that are candidates to become a backup channel	Infrequent
Disallowed	Channels precluded by the operator due to operational or local regulatory constraints	Infrequent
Unclassified	Channels that have not yet been sensed	Infrequent

Maintenance of channel information between WRAN Devices:

- The BS and CPE should maintain same list of backup channels
- WRAN system provides various channel list exchange information elements in the form of MAC Management messages

Channel Management modes:

Embedded mode:

- downstream channel descriptor (DCD) message

Explicit mode:

- Channel terminate request/response (CHT-REQ/RSP)
- Channel switch request/response (CHS-REQ/RSP)
- Channel quiet request/response (CHQ-REQ/RSP)

- Channel occupancy update (CHO-UPD)

Between BS

- Using Coexistence Beacon Protocol (CBP)

Conclusions:

- 1st international standard that uses Cognitive Radio technology is IEEE 802.22 WRAN standard, which is used to provide broadband access in rural areas from unused TV bands
- The key features of WRAN are Incumbent protection and Dynamic channel management
- Channel Classification using geo-location information, incumbent database and by spectrum sensing
- For coexistence, channel information should be exchanged & updated between BSs and between BS & CPE

Mailam Engineering College
Mailam, Villupuram (Dt), Pin – 604 304

(Approved by AICTE, New Delhi, Affiliated to Anna University Chennai& Accredited by TCS)

DEPARTMENT OF ELECTRONICS & COMMUNICATION ENGG

Sub Code/Name : EC8071/ COGNITIVE RADIO

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Year/Sem: IV YEAR/7th SEM

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UNIT III

SPECTRUM SENSING AND DYNAMIC SPECTRUM ACCESS

Introduction – Primary user detection techniques – energy detection, feature detection, matched filtering, cooperative detection and other approaches, Fundamental Tradeoffs in spectrum sensing, Spectrum Sharing Models of Dynamic Spectrum Access - Unlicensed and Licensed Spectrum Sharing, Fundamental Limits of Cognitive Radio.

Reference Book:

Huseyin Arslan (Ed.), -Cognitive Radio, Software Defined Radio, and Adaptive Wireless Systems, Springer, 2007. (Unit V)

Prepared by

1. Ms.C.JENITHA, Ast.Prof /ECE

Staff i/c **BC** **HoD** **Principal**

PART A

1.What is spectrum sensing?

spectrum sensing:
A wireless communications technique that is able to pick a free channel for transmission.

2.What is Cooperative spectrum sensing?

Cooperative sensing is a solution to enhance the detection performance, in which secondary users collaborate with each other to sense the spectrum to find the spectrum holes.

3.What is spectrum sharing?

Spectrum sharing is a way to optimize the use of the airwaves, or wireless communications channels, by enabling multiple categories of users to safely share the same frequency bands.

4. What is Dynamic spectrum sharing?

Dynamic spectrum sharing (DSS) allows operators to use the same **spectrum** bands for different radio access technologies. In recent quarters, vendors have positioned it primarily as a way to help operators evolve their 4G networks to support 5G in the face of finite **spectrum** resources.

5.What is Cognitive sensing?

Cognitive sensor networks are based on the deployment of a large number of **sensors** for intelligently and autonomically acquiring localized and situated information of the **sensing** environment. Another example of bio-inspired **sensing** and networking is quorum **sensing**.

6.What is primary user in Cognitive radio?

Cognitive Radio: Definitions. **Primary User**: A **user** who has higher priority or. legacy rights on the usage of a specific part of the. spectrum. Secondary **User**: A **user** who has a lower priority.

7.What antennas are used in cognitive radio?

In cognitive radio networks, two types of antennas are needed: sensing and communicating antennas. The sensing antenna, which is usually an **Ultra Wide Band** (UWB) antenna, is used to sense the spectrum and find the spectrum holes, and the communicating antenna is used to transmit at the frequencies of these holes.

8.What is secondary user?

Secondary user is an unlicensed **user** who either utilizes unlicensed spectrum band or licensed spectrum band of primary **user** when it is idle, i.e., not utilizing by the primary **user** subject to the condition that primary **user** should not be interfered.

9.How does cognitive radio works?

Such a **radio** automatically detects available channels in **wireless** spectrum, then accordingly changes its transmission or reception parameters to allow more concurrent **wireless** communications in a given spectrum band at one location. ... This process is a form of dynamic spectrum management.

10. Compare Primary user and Secondary user.

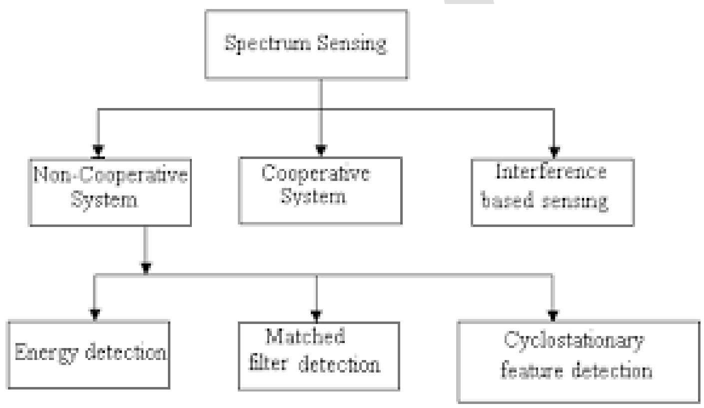
The person who makes the initial application to open an **account** or to apply for credit is referred to as the **primary account holder**. ... These people are known as **secondary account holders** and, **in the** case of credit cards, authorized users are also called additional cardholders.

PART -B

1. Explain about Spectrum sensing Primary user detection techniques and its methodologies.

Spectrum sensing:

- Spectrum sensing is the main task in cognitive cycle and the main challenge to the CRs.
- In spectrum sensing studying the spectrum and find the unused bands and sharing it while avoiding the spectrum that is occupied by PU.
- It can be defined as "*action of a radio measuring signal feature".*
- To enhance the detection probability many spectrum detection techniques can be used, as in below Figure



Transmitter detection (Non-cooperative Detection)

- In transmitter detection each CR must independently have the ability to determine the presence or absence of the PU in a specified spectrum.
- A hypothesized model for transmitter detection is defined that the signal detected by the SU is:

$$\begin{cases} H_0: y(t) = w(t) \\ H_1: y(t) = h.\, x(t) + w(t) \end{cases}$$

where H_O represents the hypothesis corresponding to "no signal transmitted", and H_1 to "signal transmitted", y(t) is received signal, x(t) is transmitted signal, w(t) is an Additive White Gaussian Noise (AWGN) with zero mean and variance a_n^2, and 'h' amplitude of channel gain

Energy detection:

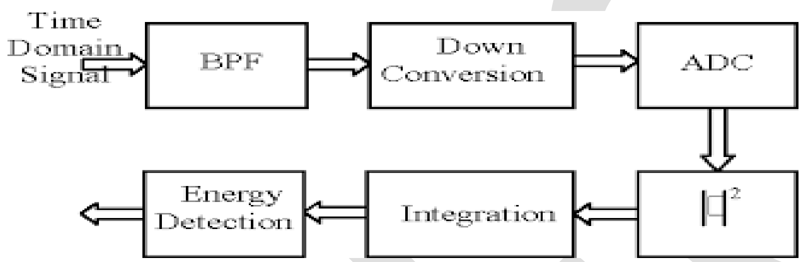
- Energy detection is the most popular signal detection method due to its simple circuit in practical implementation.
- The principle of energy detector is finding the energy of the received signal and

compares that with the threshold.

- In the literature, we come across various algorithms indicating that energy detection can be implemented both in time and also frequency domain using Fast Fourier Transform (FFT).

Time Domain Energy Detection

- The most important preliminary work for the general analysis of energy detector in time domain was presented in the landmark paper, the Urkowitz proposed the model as shown in Figure



- The input signal y(t)is first passed through an ideal BandpassFilter (BPF) with center frequency f_0 and bandwidth W, with transfer function

$$H(f) = \begin{cases} \frac{2}{\sqrt{N_0}} & |f - f_0| \le W \\ 0, & |f - f_0| > W \end{cases}$$

- Where N_0 is the one-sided noise power spectral density, this normalizes it found convenient to compute the false alarm and detection probabilities using the related transfer function.
- After that the signal squared, and integrated in the observation interval T to produce a test statistic, V, is compared to a threshold h.
- The receiver makes a decision that the target signal has been detected if and only if the threshold is exceeded.
- The received signal y(t)of SU under the binary hypotheses testing can represent as

$$\begin{cases} H_0: y(t) = w(t) \\ H_1: y(t) = x(t) + n(t) \end{cases}$$

- Where H_0 represents the hypothesis corresponding to “no signal transmitted”, and H_1 to “signal transmitted”, x(t) is the unknown deterministic transmitted signal, and w(t) assumed to be anAWGN with zero mean and variance a^2 = WN is known a priori. The SNR is denotedas y = ^{c} where a^2 variance of signal and a^2 variance of noise.

- we can obtain the reconstructed noise signal

$$n(t) = \sum_{i=-\infty}^{+\infty} n_i \,\mathrm{sinc}(2Wt - i)$$

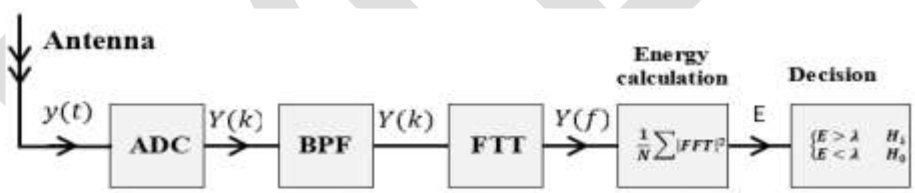
- where P_{on} is the probability of the period used by primary users and P_{off} is the probability of the idle period. From the definition of MAP detection, the P_d and P_{fa} can be expressed as follows

$$P_d = P[V > h| H_1]P_{on}$$

$$\mathbf{P_{fa} = P[V > h| H_O]P_{off}}$$

Frequency Domain Energy Detection:

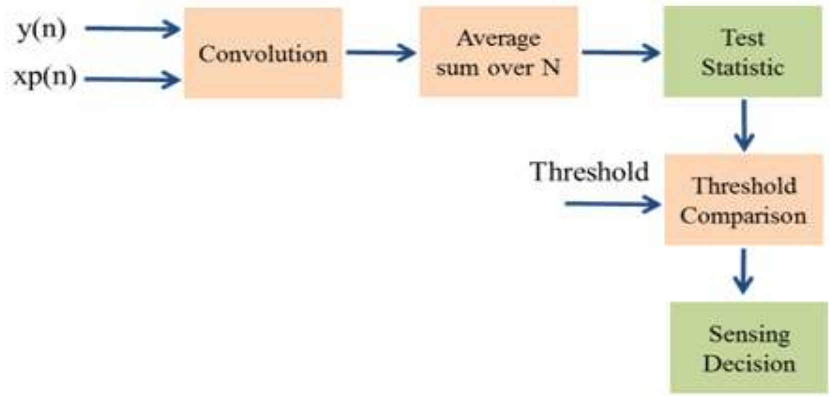
- In order to measure the signal energy in frequency domain, the received signal is first selects the interesting bandwidth by a band pass filter and sampled, then converted to frequency domain taking FFT followed by squaring the coefficients and then taking the average over the observation band.
- Finally, according to a comparison between the average and threshold, the presence or absence of the PU can be detected as shown in figure 12.



- The energy detection can be implemented in the frequency domain using periodograms and the Welch's periodogram.
- The periodogram method is a Discrete Fourier Transform (DFT) based method to estimate Power Spectral Density(PSD).

Matched Filter Detection

- The matched filter detector that can use as detection technique.The matched filter (also referred to as coherent detector), it can consider as a best sensing technique if CR has knowledge of PU waveform.
- It is very accurate since it maximizes the received signal-to-noise ratio (SNR).
- Hence, if this information is not accurate, then the matched filter operates weakly



- If a priori knowledge of primary user signal is available , Match filter detection is optimal because it maximizes SNR in AWGN channel
- In this case :

$$S = \mathrm{Re}\left[\sum_{n=1}^{N_B} y(n)x^*(n)\right]$$

When there is no signal present :

$$S = S_0 = \mathrm{Re}\left[\sum_{n=1}^{N_B} z(n)x^*(n)\right]$$

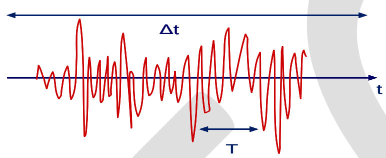
When there is signal present:

$$S = S_1 = \sum_{n=1}^{N_B} |x(n)|^2 + \mathrm{Re}\left[\sum_{n=1}^{N_B} z(n)x^*(n)\right]$$

- Matched filter correlates the signal with time shifted version and compares between the final output of matched filter and predetermined threshold will determine the PU presence.

Cyclostationary or Feature Detection

- Spectrum sensing which can differentiate the modulated signal from the additive noise. A signal is said to be cyclostationary if its mean and autocorrelation are a periodic function.
- Feature detection denotes to extracting features from the received signal and performing the detection based on the extracted features.
- Cyclostationary feature detection can distinguish PU signal from noise, and used at very low Signal to Noise Ratio (SNR) detection by using the information embedded in the PU signal that are not present in the noise.

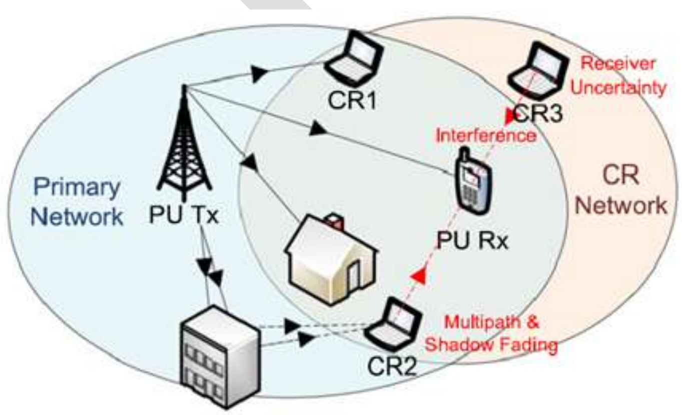


$$S_x^{\alpha}(f) = \lim_{\Delta t \to \infty} \lim_{T \to \infty} \frac{1}{\Delta t} \frac{1}{T} \int_{-\Delta t/2}^{\Delta t/2} X_T(t, f + \frac{\alpha}{2}) X_T^*(t, f - \frac{\alpha}{2}) dt$$

$$X_T(t, f) = \int_{t-T/2}^{t+T/2} x(u) e^{-j2\pi f u} du$$

Receiver Detection (Cooperative Detection)

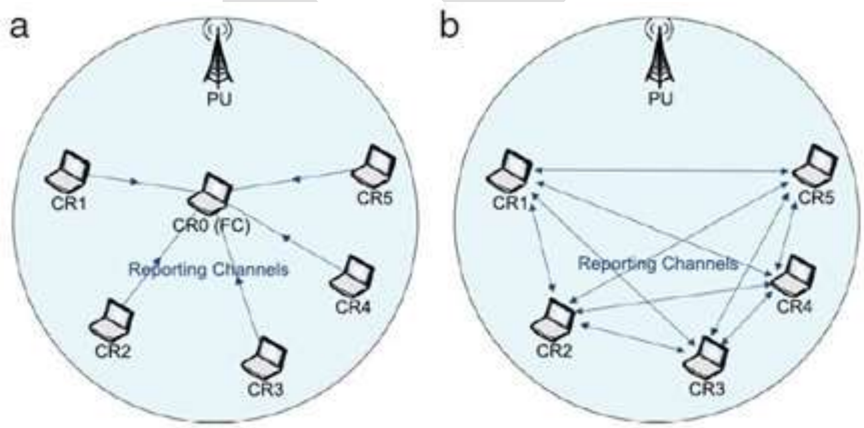
- CR cooperative spectrum sensing occurs when a group or network of CRs share the sense information they gain for PU detection.
- This provides a more accurate spectrum sensing over the area where the CRs are located.
- Cooperative spectrum sensing plays a very important role in the research of CR due to its ability in improving sensing performance especially in the fading, shadowing and noise uncertainty.



- Figure illustrates multipath fading, shadowing and receiver's uncertainty. As shown in the figure, CR1 and CR2 are placed inside the transmission range of the PU transmitter (PU TX) while CR3 is outside the range.
- Due to multiple attenuated copies of the PU signal and the blocking of a house, CR2 experiences multipath and shadow fading such that the PU's signal may not be correctly detected. Moreover, CR3 suffers from the receiver uncertainty problem because it is unaware of the PU's transmission and the existence of the primary receiver

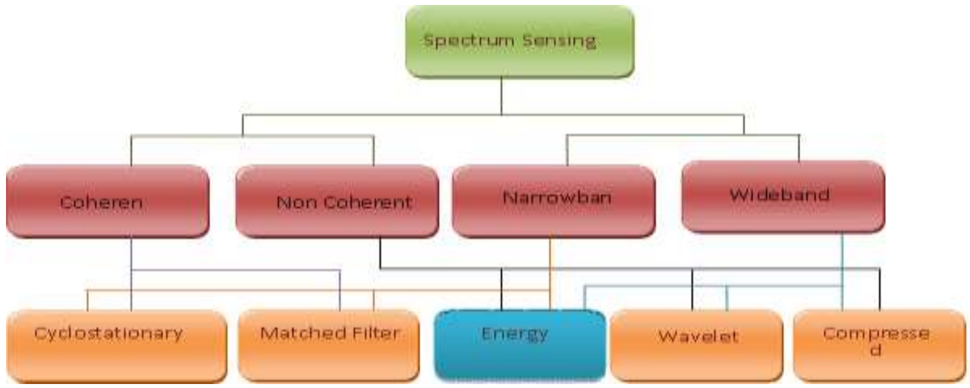
There are broadly two approaches to cooperative spectrum sensing :

1. **Centralized approach:** In this approach to CR cooperative spectrum sensing, there is a central CR called fusion centre (FC) within the network that collects the sensing information from all the sense CRs within the network. For data cooperative, all CRs are tuned to a control channel where a physical point-to-point link between each cooperating CR and the FC for sending the sensing results is called a reporting channel as shown in Figure (a). FC then analyses the information and determines the bands that can and cannot be used.
2. **Distributed approach:** Unlike centralized approach, distributed cooperative sensing does not depend on a FC for making the cooperative decision. Using the distributed approach for CR cooperative spectrum sensing, no one CR takes control. Each CR sends its specific data of sensing to other CRs, merges its data with the received data of sensing, and decides whether or not the PU is present by using a local condition as shown in Figure (b).



Interference Based Detection

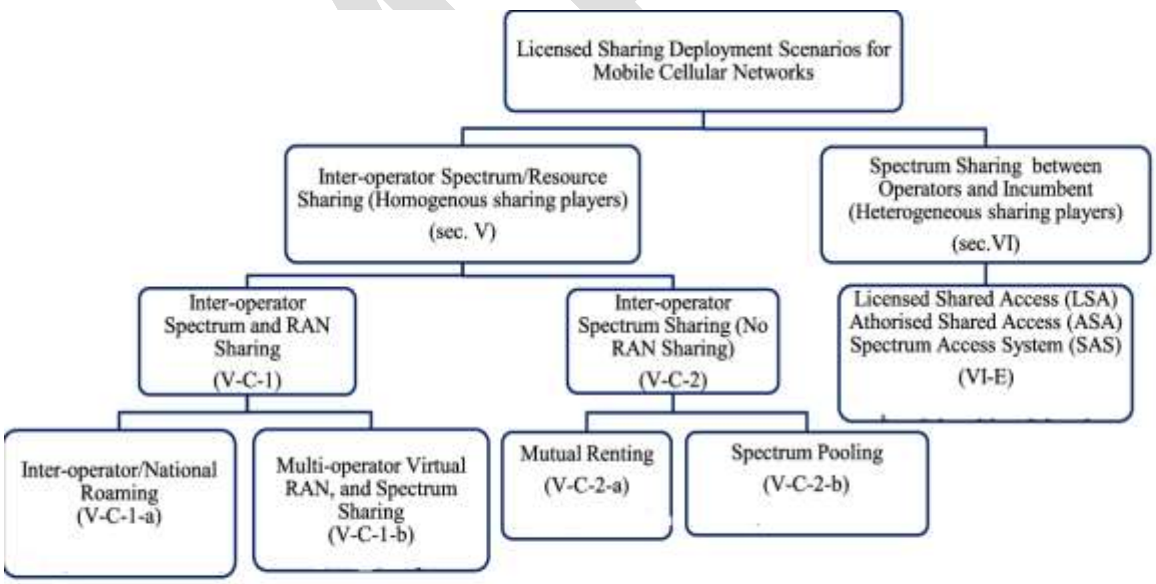
- Under the assumptions that if a signal *A* can interfere with signal *B*, then signal *B* is within the communication range of signal *A* .A signal can be detected by checking the interference with the detector's signal.
- Another way to classify sensing techniques is based on the bandwidth of the spectrum of interest for sensing: narrowband and wideband as shown in Figure



2. **What is licensed band? How the licensed band spectrums are sharing by different schemes.**

Classification of the licensed sharing schemes based on types of sharing players:

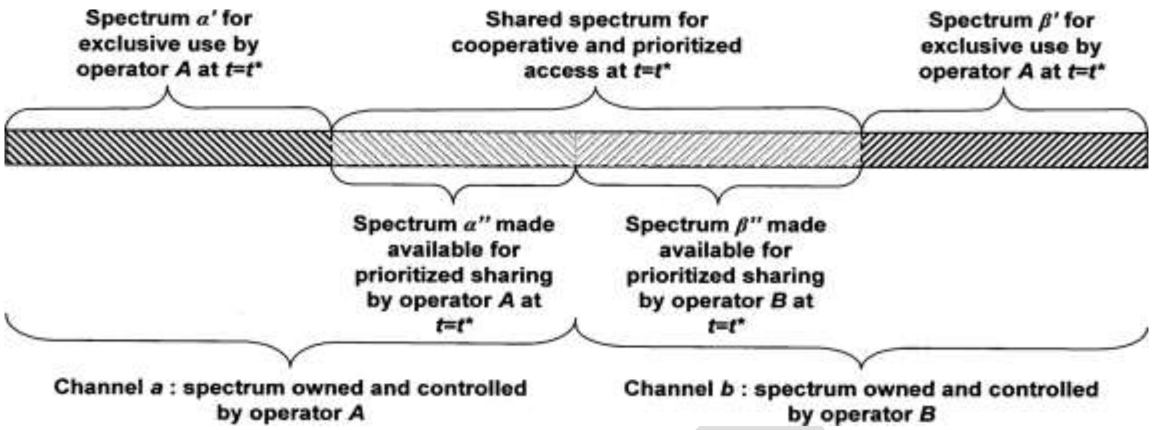
- **Homogenous sharing players:** sharing players are of the same nature (e.g., multiple mobile operators), and encompasses various types
- **Heterogeneous sharing players:** sharing players are of different nature (e.g., military service providers and mobile operators)



Homogenous Sharing Players

Inter-operator Spectrum Sharing (No RAN sharing)

Mutual renting: mobile operators rent part of their _exclusive spectrum_ to be exploited by other mobile operators (can be on bi-lateral or unilateral basis)



Spectrum pooling: mobile operators can exploit licensed bands in a shared manner with the same right of access (e.g., the bands are made available from LSA framework)

Inter-operator RAN and/or Spectrum Sharing (RAN sharing)

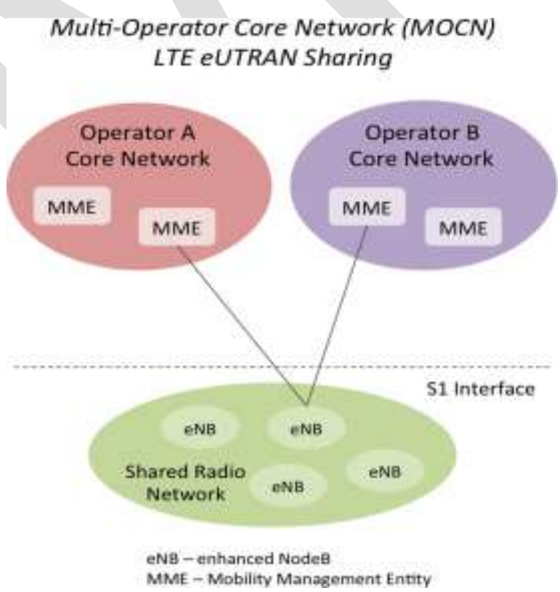
Multi operators:

1.Multi-operator Radio Access Networks (MORAN)

- With MORAN everything in the RAN except the spectrum is shared between multiple operators

2.Multi-Operator Core Network (MOCN)

- With MOCN everything in the RAN as well as spectrum can be shared between multiple operators



Comparison of MORAN & MOCAN:

Attributes / Types	MORAN	MOCN
Spectrum	Exclusive	Shared
Feature implementation and configurations upgrade	Independent	Shared
Operational data monitoring	Independent	Can be shared
Transmission pipes	Independent or shared	Independent or shared
Physical links	Shared	Shared
Core network	Independent	Independent
Use cases	For keeping some degree of independence for operators on RAN level	Where there is no limitation for spectrum sharing

Inter-operator National Roaming:

- Support of user device operation in a network other than its own home network (within the same country) is referred to as national roaming
- When mobile operators provide coverage in different geographical areas
- For mitigating network outage and congestion
- Suitable for Mobile Virtual Network Operator (MVNO) which does not own RAN
- For the new entrants at initial deployment steps
- For the smaller operators who may not be able to sustain the costs of covering a large territory with a low population density

Heterogeneous Sharing Players

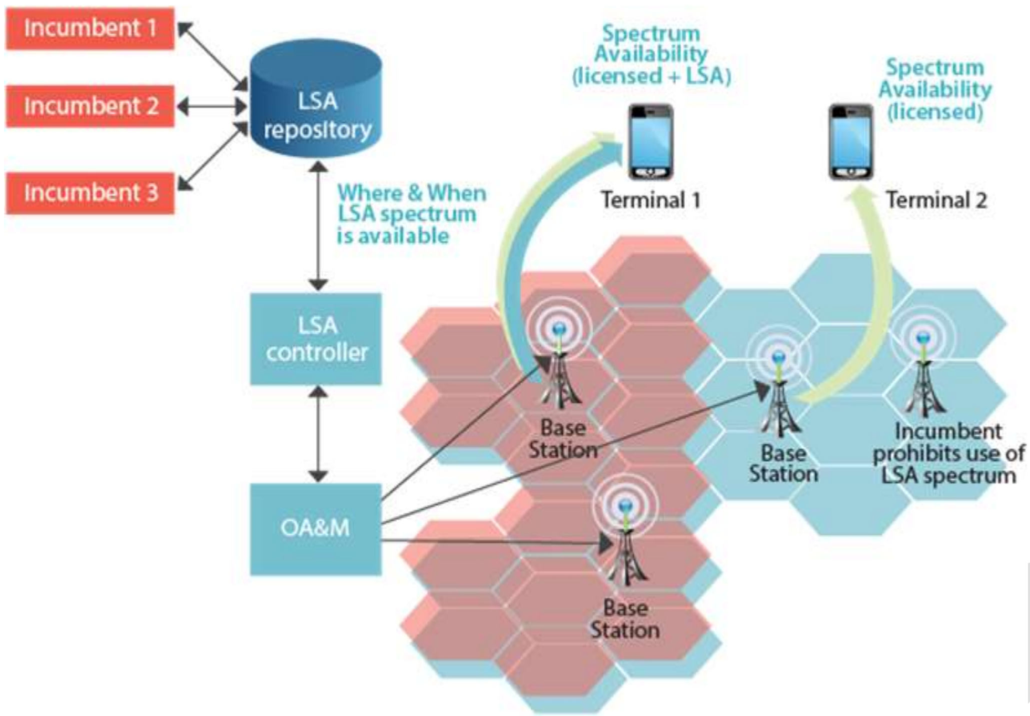
It is classified as

- Authorized Shared Access (ASA)
- Licensed Shared Access (LSA)
- Spectrum Access System (SAS)

1.ASA a sharing framework which facilitates use of 2.3-2.4GHz (in the EU) and 3.5GHz (in the U.S.) bands, in a shared and non-interference basis for mobile cellular systems only

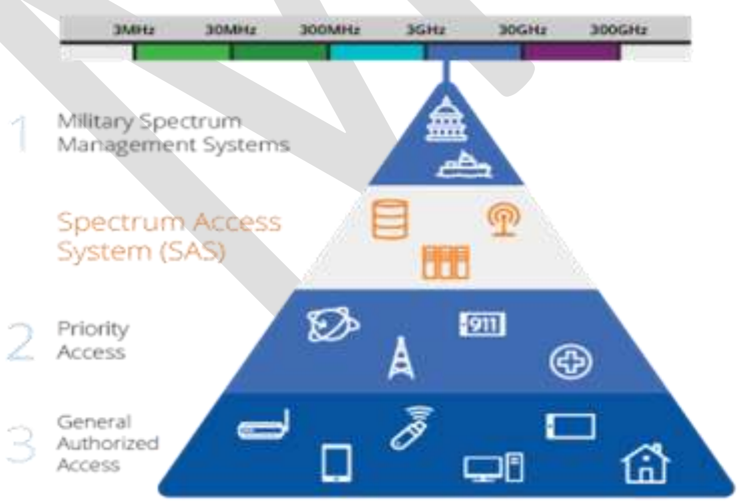
2.LSA is an extension of ASA concept, and is proposed by CEPT ECC to support sharing between various types of spectrum users and various bands

LSA Reference System Architecture

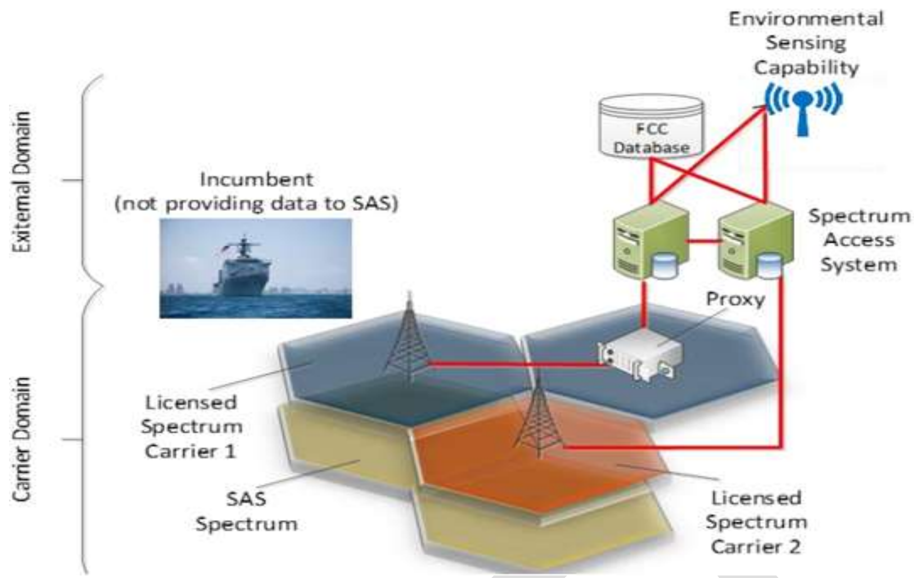


3. **SAS** framework operates in 3.55-3.7GHz (LTE Bands 42/3), and follows *three- tier* strategy

- Incumbent
- Primary Access (PA)
- General Authorised Access (GAA)



SAS Framework Architecture



ASA, LSA, and SAS Frameworks Comparison:

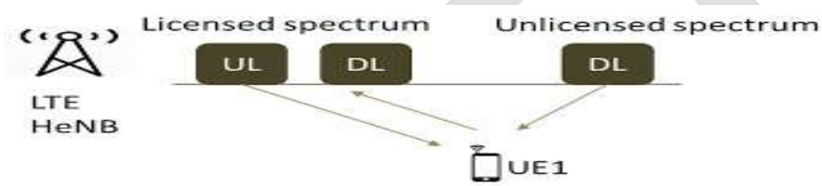
Scheme / Attribute	ASA	LSA	SAS *
Incumbent types	Military applications/ Wireless cameras/ Satellite	Initially the same as ASA, To be extended into various types of service providers	Federal and Fixed Satellite Service (FSS)
Prospective Licensees	Mobile broadband Service	Initially for mobile broadband service (to be extended for any spectrum user)	PA: hospitals, public safety entities, Mobile Broadband GAA: LAA, Wi-Fi
Spectrum range	2300 to 2400 MHz, and 3800GHz	Not only limited to IMT bands	3550 to 3650MHz
Spectrum opportunity detection method	Geolocation Database (& sensing if necessary)	Geolocation Database (& sensing if necessary)	Sensing & Database
Incumbent protection	Protection from harmful interference	Protection from harmful interference	Protection from harmful interference
Licensee QoS provisioning	Predictable QoS for all authorised users (Must ensure certain access guarantees and interference protection)	Predictable QoS for all authorised users (Must ensure certain access guarantees and interference protection)	"Some" interference protection for PA And "no" protection guarantees for GAA users

3.What is licensed band? How the Unlicensed band spectrums are sharing by different schemes.

- **LTE-Unlicensed (LTE-U)**: LTE in the Unlicensed Spectrum (5 GHz band; 5150-5925 MHz)By Qualcomm in 2013; Pre-standard proprietary version backed by LTE-U Forum
- **Licensed Assisted Access (LAA)**: 3GPP standardization version (5 GHz band)Part of ongoing Release 13 (Down Link); Completion: 2016
- **Enhanced LAA (eLAA)**: 3GPP standardization version Part of future Release 14 (Down Link and Up Link); Expected Completion: 2017
- **LTE-WLAN Aggregation (LWA)**: 3GPP standardization version Part of ongoing Release 13; Completion: 2016
- **MultiPath (TCP) Aggregation (MPTCP):** Standardized by IETF (Commercialization underway)

1.LTE-Unlicensed and Licensed Assisted Access

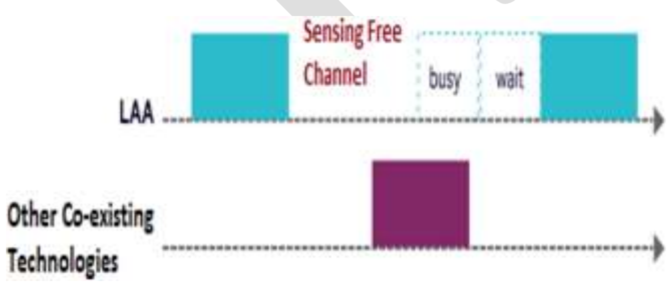
- LTE transmission in licensed band would expand into the unlicensed bands to increase size of available



Advantages:

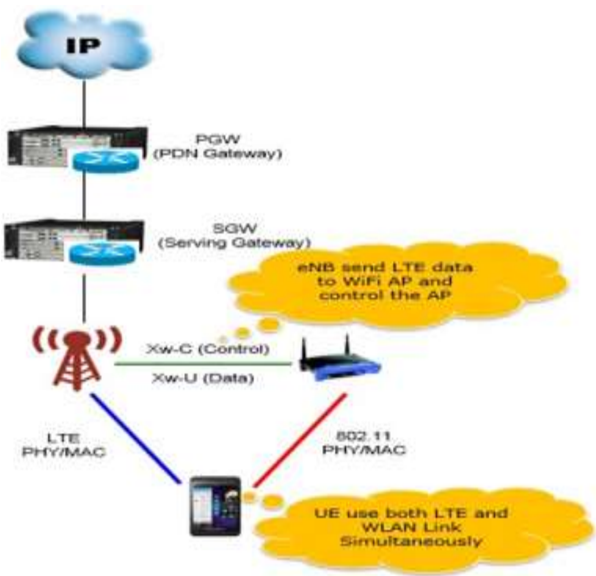
- Greater data capacity
- Faster download speeds → as simultaneous data transmission over both licensed and unlicensed spectrum
- Easy bundling of LTE-U with existing LTE carriers in

2.LAA → Listen-Before-Talk or LBT (regulatory requirement in unlicensed bands to check whether channel is free before talking; part of 3GPP Rel 13 standard)



3.LTE-U → Carrier Sensing Adaptive Transmission or CSAT (non-regulatory and on-off duty-cycling based; part of 3GPP Rel 10-12 standards)

LTE-WLAN Aggregation and MulteFire

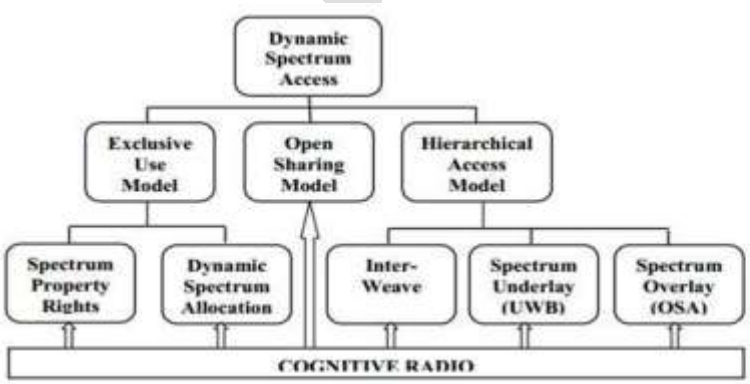


LTE and Wi-Fi: Coexistence in the Unlicensed Bands

- WiFi operators not happy with the sharing and fear that WiFi performance will suffer
- LTU-U Forum (Ericsson, Qualcomm, Samsung, Verizon etc.):

4. What is Dynamic spectrum access ? Explain its models in spectrum sharing.

DSA Models



- Dynamic exclusive use
- Open sharing model
- Hierarchical access model

Dynamic Exclusive Use model:

- Basic structure of the current spectrum regulation policy are maintained in this model
- Spectrum bands licensed to services for exclusive use
- Improves spectrum efficiency by introducing flexibility

Spectrum property rights:

- Allows licensees to sell and trade spectrum and to choose technology freely Economy, profit- play important role with the most profitable use of this limited resource

Dynamic spectrum allocation

- Improve efficiency through spectrum assignment by using spatial / temporal traffic statistics of different services

Open sharing model:

- Spectrum commons model
- Every user has equal rights to use the spectrum
- Applied for wireless services which operates in unlicensed ISM radio bands(WLAN)

3 Types:

- Uncontrolled commons
- Managed commons
- Private commons

Uncontrolled commons

- –No entity has exclusive license to the spectrum band

Managed – commons

- Imposes a limited form of structure of spectrum access
- Resource which is owned or controlled by a group of individuals or entities
- Characterized by restrictions on when and how the resource is used

Private commons

- Introduced by FCC. And allows advanced technologies which enable multiple users to access the spectrum

Hierarchial access models :

- Interweave
- Underlay
- Overlay

Interweave model

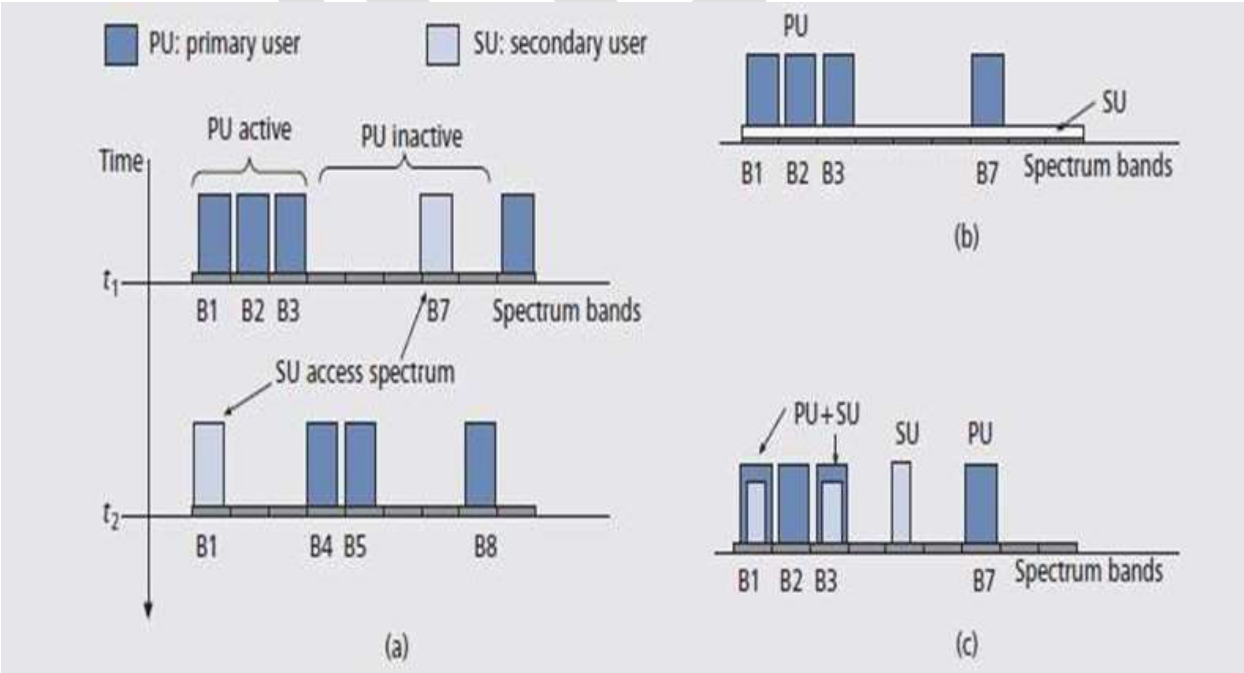
- Different from overlay and underlay DSA models
- SU cannot access a licensed spectrum band as long as PU is active on the band
- PU-absolute priority on the spectrum band in fig a
- SU accessing the spectrum band must yield to PU whenever PU starts to access the band
- Also called opportunistic spectrum access.

Underlay Model

- Allows SU to transmit on a licensed spectrum band regardless of the PU accessing the band or not, subject to a constraint that the accumulated interference from all SU's is tolerable by the PU ie. below some threshold in fig b

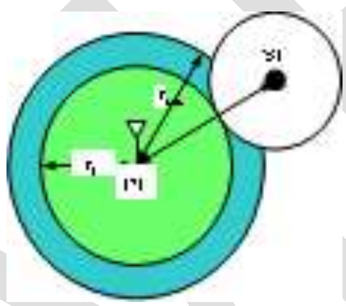
Overlay Model

- SU transmit on the licensed spectrum band even when the PU is accessing the band.
- Targets maintaining the PU performance
- SU are allowed to transmit simultaneously with PU s as long as there is no performance degradation in fig c

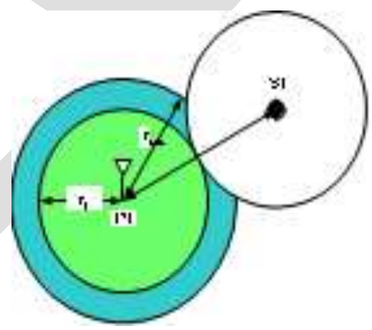


5. Explain about Fundamental trade off in cognitive radio while spectrum sharing.

- A number of concerns must be alleviated before regulators will allow Cognitive Radios to transmit opportunistically in already allocated bands.
- The most important constraint is that of non-interference to the primary receivers.
- While a traditional link budget analysis reflects the impact of these factors on a system's minimum transmit power, under the opportunistic regime the constraint is placed upon a system's maximum transmit power.
- Alternatively, if a system's transmit power is fixed, it dictates how far away the system must be before it is allowed to transmit.
- Figure illustrates the fundamental tradeoffs between a primary receiver's margin of protection and a single opportunistic user's transmission power .
- The large antenna at the center represents a primary system's transmitter. These primary users may be providing socially important services, or they might simply be legacy systems that are unable to change.
- The outer circle (1a) represents the boundary of decodability for a single- user system.
- That is, in the absence of all interference, a user within the outer circle would be able to decode a signal from the transmitter, while a user outside the circle would not.



(a)



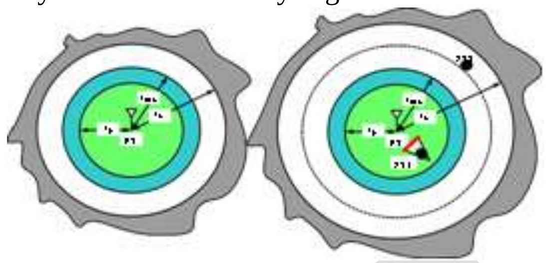
(b)

- The inner shaded circle represents the "protected radius" where we guarantee decodability to primary receivers.
- The more we shrink the bound of the protected region inside the decodability region, the smaller the necessary no-talk zones become.
- Similarly, the power of the secondary user's transmissions is important. If they are "mice," (Figure 1a) who squeak softly, then the no-talk radius can be much smaller.
- If they are "lions," (Figure 1b) roaring with high power transmissions, the radius of the no-talk zones will become much larger.
- Finally, the service areas of the primary systems might be unknown or time-varying.
- Hence it is expected that secondary radios, after detecting the primary signal, will estimate the signal's strength and use it as a proxy for distance from the primary transmitter.

Shadowing/Fading

- Even if there are only a few primary receivers, secondary users must stay out of the space that is the union of all possible no-talk zones (Figure 2a) (secondary transmitters can exist in the external grey zone).

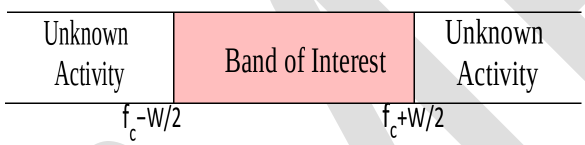
- We note that in the hypothetical example, the prohibited region for secondary users has already extended beyond the decodability region.



(a) (b)

- If we take fading into account (Figure 2b), the prohibited region continues to grow. Shadowing and multipath fading can cause the secondary user in the no talk zone to see a very low power primary transmission.
- As a result, a secondary has no way to tell if it is safely outside the protected region (ST2) or in the global quiet zone but behind a building (ST1).
- To avoid secondary users in a local shadow interfering with unshadowed primary receiver, the no-talk zone must be pushed out even further.

SINGLE RADIO DETECTOR: LIMITS ON ROBUST SENSING

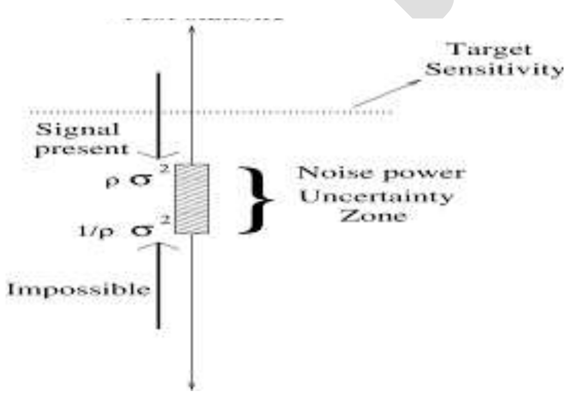


Sampling the 'band of interest' at Nyquist, the detection problem can be formulated as a binary hypothesis testing prob- lem, where the aim is to distinguish the following hypotheses:

$$H_0 : Y[n] = W[n] \qquad n = 1, \ldots, N$$

$$H_1 : Y[n] = X[n] + W[n] \qquad n = 1, \ldots, N$$

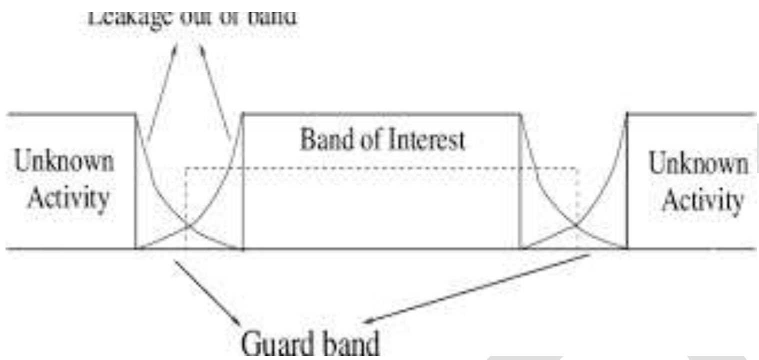
Radiometeric detection:



- The radiometer is a simple detector which senses for the presence/absence of the primary signal based on the energy of the received signal samples.

Interference estimation

- In order to reduce the mandatory coordination radius, it is clear that we need to estimate the interference from the secondary transmissions.



- The frequency spectrum is broken up into different chunks of bandwidth and is allocated to primary users by the FCC.
- However, for practical reasons small guard bands (see fig. 5) between these spectrum chunks are left unallocated.
- We can use these guard bands to estimate the interference. For in- stance consider the scenario in figure.

Power-Coordination tradeoffs

- We propose the existence of a mandated "sensing MAC" among systems which ensures that whenever a particular cog- nitive node is sensing for the primary signal, all nodes within a certain coordination radius, r_s, refrain from transmitting.
- This sensing MAC must ensure that the uncertainty due to the interference from secondary transmissions is tolerable.

6.**Give the limitations of Cognitive radio in wireless networks.**

1. **Spectrum: Allocation vs Usage**
    - Apparent spectrum scarcity
    - Actual measurements show that > 70% of spectrum is unused.
    - Enough free spectrum for DVD-res cameras every few feet!

2. Primitive analog hardware

3. Devices fixed to bands

4. Interference a severe challenge

5. Long range applications

6. Bands allocated by law

7. Enforce by licensing devices

8. The optimal detector behaves like an energy detector.

- If one exists, just detecting a pilot signal is nearly optimal.

  signals without pilots are difficult to detect.

9.Noise uncertainty

- In practice there is always uncertainty about the noise.

- Sources of uncertainty:

  Thermal noise in components (Non-uniform, time-varying)

  Noise due to transmissions by other users

  Unintentional (Close-by)

  Intentional (Far-away)

- Cognitive radio can enable significant spectrum reuse.
- Tofunction, we must be able to detect the presence of undecodable signals.
- Just knowing the modulation scheme and codebooks is nearly useless: stuck with energy detector performance.
- Even small noise uncertainty causes serious limits in detectability.
- Quantization makes matters evenworse.
- Primary users should transmit pilot signals.
- If not, some infrastructure and/or collaboration will be needed to support cognitive radio deployment.
- Similar limits apply to secondary markets.

Mailam Engineering College

Mailam, Villupuram (Dt), Pin – 604 304

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DEPARTMENT OF ELECTRONICS & COMMUNICATION ENGG

Sub Code/Name : EC8071/ COGNITIVE RADIO

Unit No: 4

Year/Sem: IV YEAR/7th SEM

Total No.Pages & Copies:

UNIT IV

MAC AND NETWORK LAYER DESIGN FOR COGNITIVERADIO

MAC for cognitive radios – Polling, ALOHA, slotted ALOHA, CSMA, CSMA / CA, Network layer design – routing in cognitive radios, flow control and error control techniques.

Reference Book:

Huseyin Arslan (Ed.), -Cognitive Radio, Software Defined Radio, and Adaptive Wireless Systems, Springer, 2007. (Unit V)

Prepared by

1. Ms.C.JENITHA, Ast.Prof /ECE

Staff i/c	BC	HoD	Principal

Part A

1. What is Cognitive MAC (C-MAC) protocols?

The design of C-MAC protocols that enable large spectrum efficiency gains while providing high level of protection and transparency for the primary system.

2. What is ALOHA?

ALOHA, the earliest random access method, It was designed for a radio (wireless) LAN, but it can be used on any shared medium. When a station sends data, another station may attempt to do so at the same time. The data from the two stations collide and become garbled.

3. *What is Pure ALOHA?*

The original ALOHA protocol is called pure ALOHA. This is a simple, but elegant protocol. When each station sends a frame whenever it has a frame to send, there is the possibility of collision between frames from different stations.

4. *What is Slotted ALOHA:*

Slotted ALOHA was invented to improve the efficiency of pure ALOHA. In slotted ALOHA we divide the time into slots and force the station to send only at the beginning of the time slot.

5. What is Flow Control?

Flow control is a mechanism which is used to avoid the overflow of data at the receiver side, and it tells the sender to slow down the sending of data to avoid the overflow. In most protocols, flow control is a set of procedures that tells the sender how much data it can transmit before it must wait for an acknowledgment from the receiver.

6. What is Error Control

Error control is both error detection and error correction. It allows the receiver to inform the sender of any frames lost or damaged in transmission and retransmission of those frames by the sender. Any time an error is detected in an exchange, specified frames are retransmitted. This process is called automatic repeat request (ARQ).Error control in the data link layer is based on automatic repeat request, which is the retransmission of data.

7. What is STOP N WAIT PROTOCOL:

If data frames arrive at the receiver site faster than the receiver processing, the data will be overflow. So that the frames will be discarded or the service will be denial.
To avoid that stop n wait protocol is used. The sender sends one frame and stop until it receives the acknowledgement for the corresponding frame.
After that it will send the next frame.

8. What is CSMA/CD

In CSMA-CD, the frame size should be restricted. Before setting the last bit of the frame, the sending station must detect a collision if collision occurs and that collision will be detected and aborted.

9. What is CSMA/CA

It senses the channel before transmitting the data, if the channel is idle (not busy) we can transmit the data if it is not idle (busy). It will wait to find the line idle.

The collision are avoided through the use of CSMA-CA's 3 strategies

i) Inter frame space (IFS)
ii) Contention window
iii) Acknowledgement

The CSMA-CA is not effective useful collision reduction in wireless network.

10. What is Persistent method?

i) **I- persistence method:** - It is simple and straight forward method in this after the station finds the line idle (not busy). It sends the frame immediately. In this there is more chance for highest collision.

ii) **Non- persistence method:** - The line is idle, it sends the frame immediately. If the line is not idle, it waits a random amount of time and then its sense the line again & transmit the data.

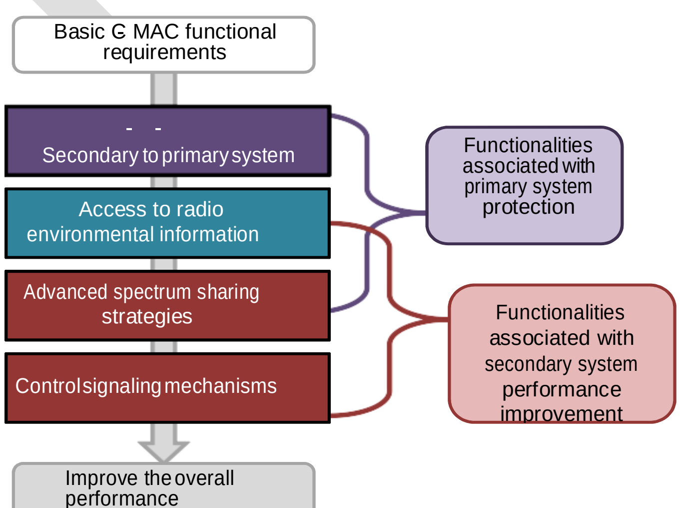
PART B

1.Explain about MAC Protocols in Cognitive networks and how it is specially designed for Cognitive networks?

- The Cognitive Radio (CR) and its related concepts and applications are expected to improve the spectrum utilization efficiency and provide solution to the spectrum scarcity problem.
- Since the introduction of the CR in, it continuously attracts a lot of interest in both research community and industry, making the CR and the Cognitive Radio Networks (CRNs) one of the most intensively studied paradigms in contemporary wireless communications.
- In parallel, there have been many efforts from various national regulatory agencies to introduce flexible spectrum usage regulations and novel licensing schemes that enable spectrum sharing, coexistence and provide support for efficient operation of the CRN in licensed and unlicensed spectrum.

Cognitive MAC (C-MAC) protocols

- The overall importance for efficient operation of CRN, basic features with respect to the operational settings and main challenges concerning the design of C-MAC protocols that enable large spectrum efficiency gains while providing high level of protection and transparency for the primary system.
- Table I compares several general aspects between C-MAC protocols and legacy MAC protocols.
- The highlighted general aspects (Table I) and latest research advances in CR technology, extract the following multidimensional and conflicting functional requirements that each C-MAC protocol should address in the below figure.



Secondary to primary system transparency:

- The operation of the secondary system in the licensed bands should not disrupt the operation of the primary system, i.e. the operation of the secondary system should be as harmless as possible to the primary system.
- This could be accomplished by Secondary User (SU)-to-Primary User (PU) interference avoidance and mitigation strategies.

Access to radio environmental information:

- The secondary system deployment should provide the C-MAC layer with radio environmental information by enabling high fidelity spectrum sensing mechanisms and/or access to up-to-date radio environmental information stored in databases.
- This radio context information should serve as the main enabler of radio environmental awareness for the CRN.

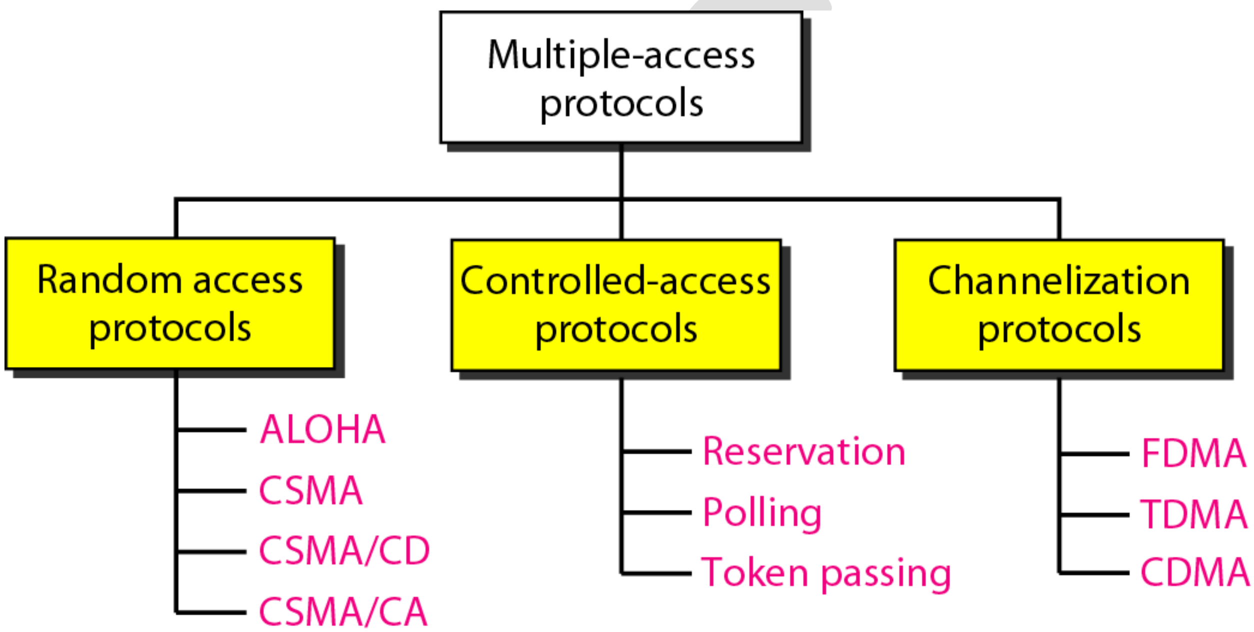
Control signaling mechanisms:

- Fully operational C-MAC protocol requires efficient management and reliable dissemination of control data through identification, definition, establishment and management of reliable and secure control channel.
- More specifically, the C-MAC protocol design addresses plethora of research topics related to the involved functional requirements such as: cooperative spectrum sensing, multi- band operation, coordination among network nodes, spectrum.

2.Explain about the ALOHA, Unslotted ALOHA,CSMA/CD and CSMA/CA advanced communication systems works and give its overview and Classification.

MULTIPLE ACCESS: RANDOM ACCESS – CONTROLLED ACCESS

RANDOM ACCESS METHOD:



i) CSMA-CD - Carrier Sense Multiple Access – Collision Detection

ii) CSMA-CA - Carrier Sense Multiple Access – Collision Avoidance

iii) CSMA - Carrier Sense Multiple Access

- **i)** **CSMA** is protocol used to minimize the chance of collision and increase the performance of the transmission
- **ii)** CSMA is based on two principle
  - a) Sense before transmit (CSMA-CA)
  - b) Sense after transmit (CSMA-CD)

In CSMA there is propagation time, which is the time needed for a signal to propagate one end of the medium to the other.

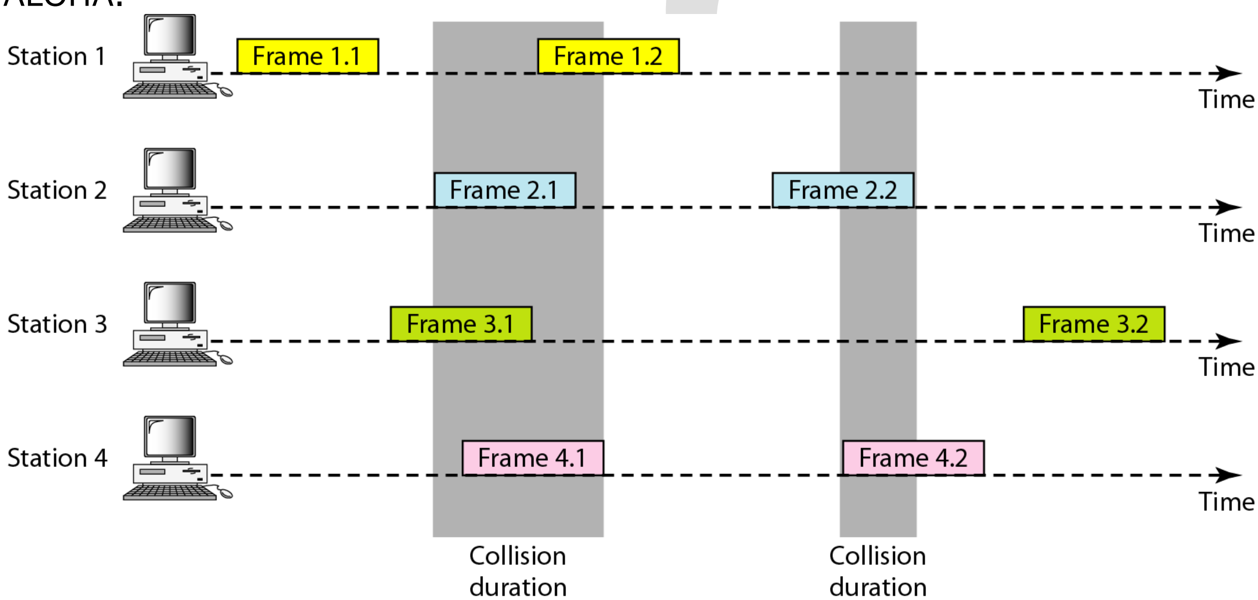
ALOHA:

ALOHA, the earliest random access method, It was designed for a radio (wireless) LAN, but it can be used on any shared medium.

When a station sends data, another station may attempt to do so at the same time. The data from the two stations collide and become garbled.

Pure ALOHA:

The original ALOHA protocol is called pure ALOHA. This is a simple, but elegant protocol. When each station sends a frame whenever it has a frame to send, there is the possibility of collision between frames from different stations. The below figure shows an example of frame collisions in pure ALOHA.



There are four stations accessing in the shared channel. The above figure shows that each station sends two frames; there are a total of eight frames on the shared medium. Some of these frames collide because multiple frames are in contention for the shared channel. In above figure shows that only two frames survive: frame 1.1 from station 1 and frame 3.2 from station 3. We need to mention that even if one bit of a frame coexists on the channel with one bit from another frame, there is a collision and both will be destroyed.

It is obvious that we need to resend the frames that have been destroyed during transmission. The pure ALOHA protocol relies on acknowledgments from the receiver. When a station sends a frame, it expects the receiver to send an acknowledgment. If the acknowledgment does not arrive after a time-out period, the station assumes that the frame (or the acknowledgment) has been destroyed and resends the frame.

A collision involves two or more stations. If all these stations try to resend their frames after the time-out, the frames will collide again. Pure ALOHA dictates that when the time-out period passes, each station waits a random amount of time before resending its frame. The randomness will help avoid more collisions. We call this time the back-off time

For G:

$P(k \text{ transmissions in } 2X \text{ seconds})$

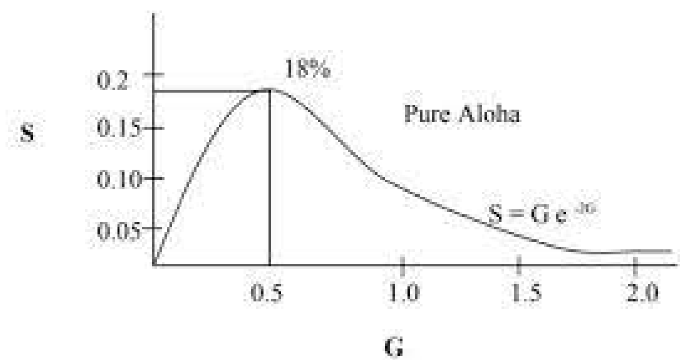
$= \frac{(2G)^k}{k!} e^{-2G}, \quad k = 0, 1, 2, \ldots$

(on average, $2G$ arrivals$/2X$ seconds)

The throughput $S = GP(\text{no collision})$

$= GP[0 \text{ transmission in 2X seconds}]$

$= G\frac{(2G)^0}{0!} e^{-2G} = Ge^{-2G}$



Throughput S versus load G for pure ALOHA

- S reaches a peak value of 1/2e at G=0.5, and then declines back toward
- For a given value of S, say, S=0.05, there are two associated values of G.
- For small G, S ¼ G.
- For large G, there are many backlogged users.
- ALOHA system cannot achieve throughput higher than 18.4 percent (1/2e).

<u>The average (delay)</u> number of transmission attempts/packet is

- Thus the average packet transmission time is approximately given by

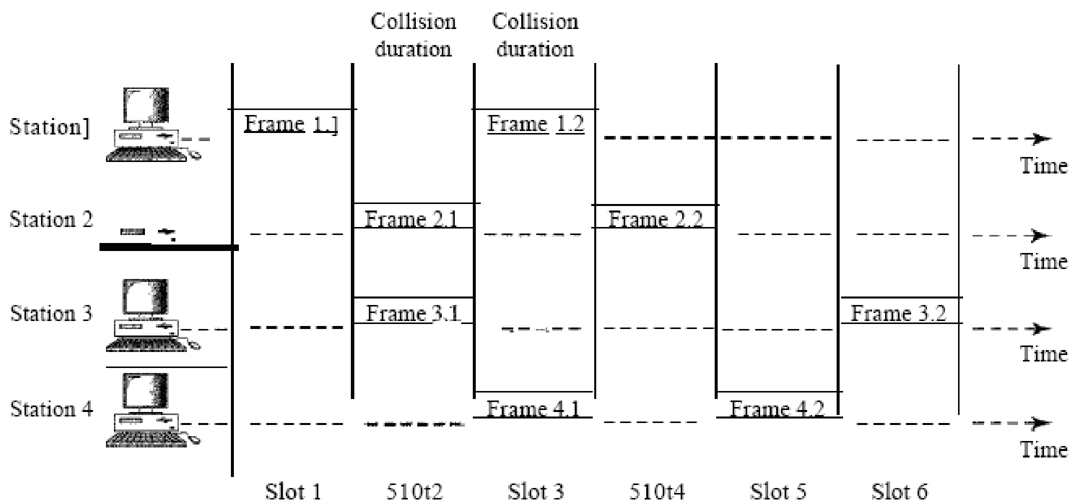
  $E[T_{aloha}] = X + t_{prop} + (e^{2G} - 1)(X + 2t_{prop} + B)$ Express delay in multiples of X

$$E[T_{aloha}]/X = 1+a+(e^{2G}-1)(1+2a+B/X)$$

Slotted ALOHA:

Slotted ALOHA was invented to improve the efficiency of pure ALOHA.

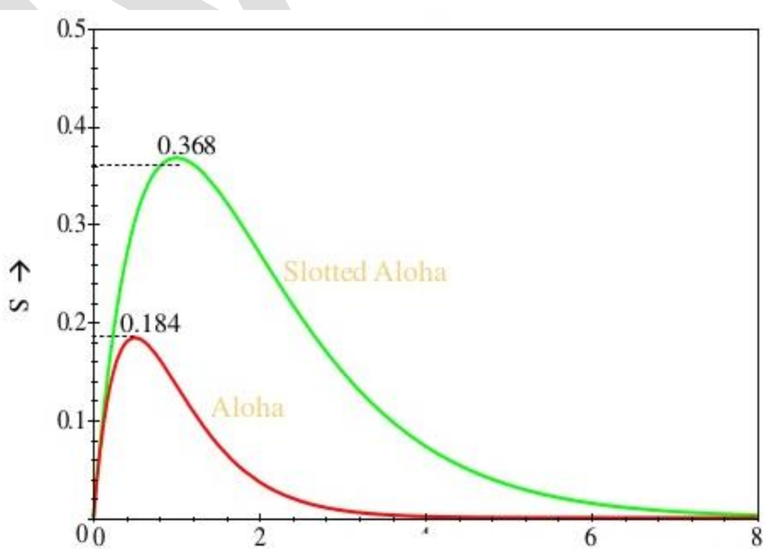
In slotted ALOHA we divide the time into slots and force the station to send only at the beginning of the time slot. The below figure shows an example of frame collisions in slotted ALOHA.



Throughput of Slotted ALOHA

$$S = GP[\text{no collision}] = GP[\text{no arrivals in X seconds}$$

$$G.(G)^0/0!\ \ e^{-G} = G.\ e^{-G}$$



G

$S_{max}=1/e=36.8\%$

Efficiency=throughput · 36% (upper bound=36%)

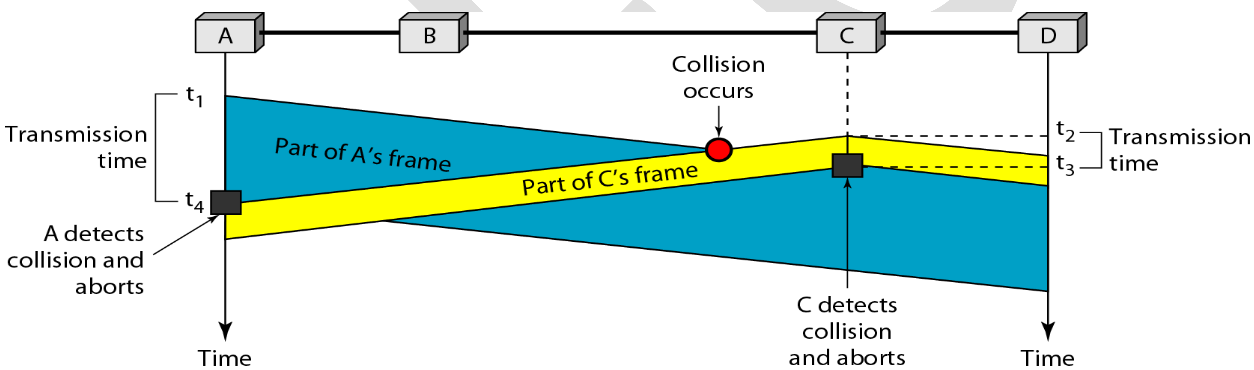
The average packet delay in slotted ALOHA

$E[T_{slotted\text{-}aloha}]/X=1+a+(e^G-1)(1+2a+B/X)$

CSMA-CD (CARRIER SENSE MULTIPLE ACCESS – COLLISION DETECTION):

It is to handle the collision. In this method a station monitors the medium after it sends a frame to see if the transmission is successful.

Collision aborts in CSMA-CD:



i) In CSMA-CD, the frame size should be restricted. Before setting the last bit of the frame, the sending station must detect a collision if collision occurs and that collision will be detected and aborted.

ii)The station A transmits the 1st bit, the collision occurs in between B & C station. At this case the station C detects the collision and aborted and reaches to the D station, now if C station sends the 1st bit to A station, at the time B station avoid the sensing channel, the A station captures the collision and aborted.

CSMA-CA (CARRIER SENSE MULTIPLE ACCESS – COLLISION AVOIDANCE):

It senses the channel before transmitting the data, if the channel is idle (not busy) we can transmit the data if it is not idle (busy). It will wait to find the line idle.

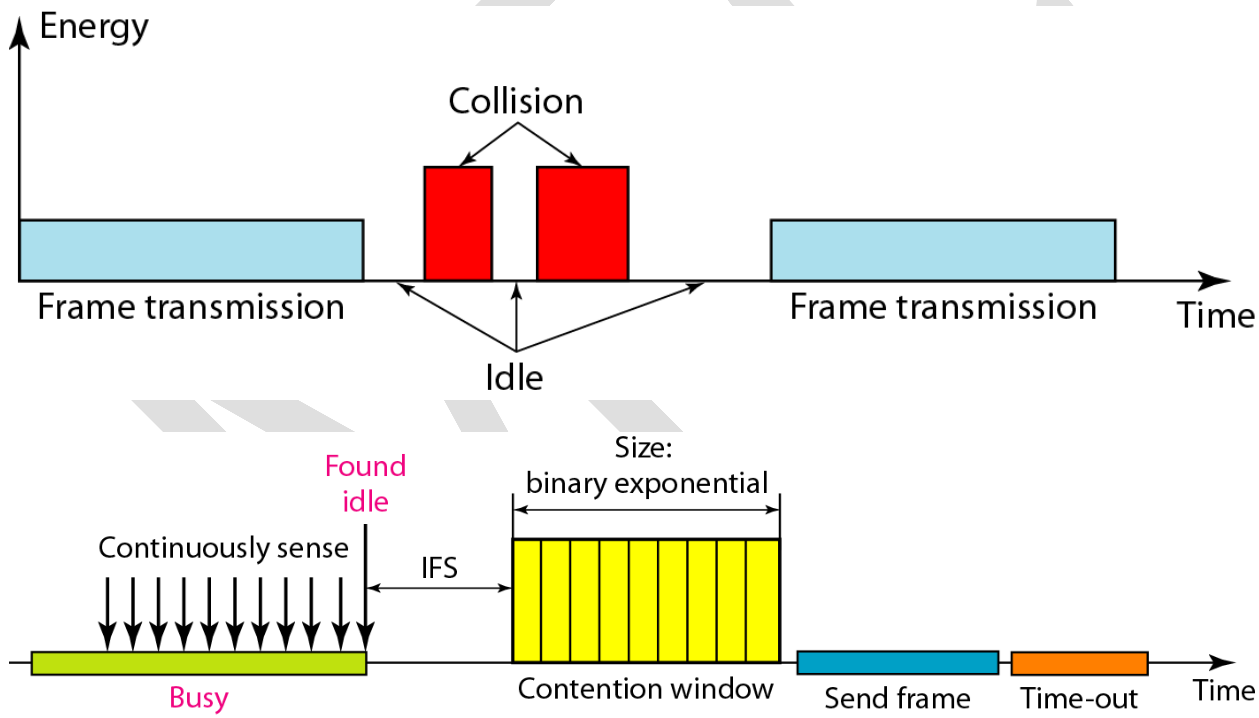
The collision are avoided through the use of CSMA-CA's 3 strategies

i) Inter frame space (IFS)

ii) Contention window

iii) Acknowledgement

The CSMA-CA is not effective useful collision reduction in wireless network.



IFS:

In CSMA-CA, the IFS is used to define a priority of a station or a frame. When an idle channel is found, the station doesn't send immediately. It wait for a period of time called as IFS.

Contention Window:

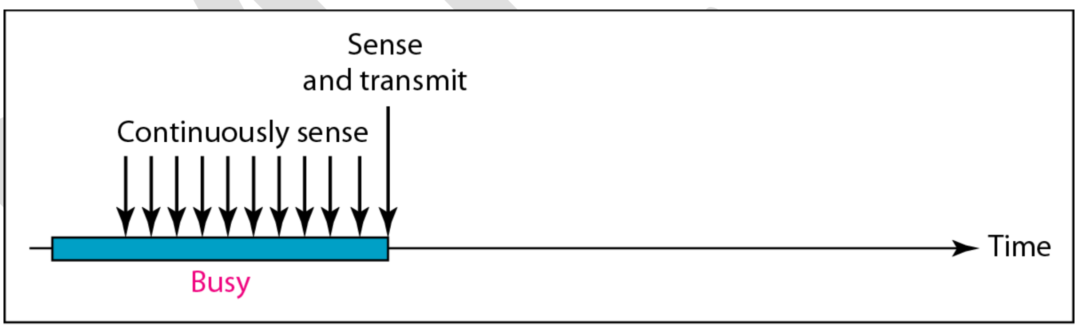
- The contention window is an amount of time divided into slots.
- A station that is ready to send chooses a random no. of slots.
- The no. of slots is based on a binary exponential back off strategy.
- In CSMA-CA, if the station finds the channel busy, it doesn't restart the timer of the contention window, it stops the timer and restart it when the channel become idle.

Acknowledgements:

In this the data may be corrupted during the transmission. The NAK acknowledgement and the time out timer can help guarantee that the receiver has received the frame or not.

PERISTENCE METHOD:

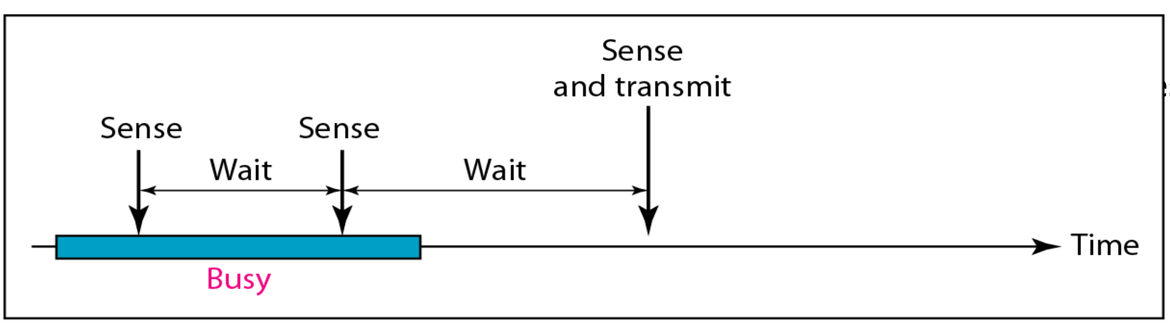
iii) **I- persistence method:** - It is simple and straight forward method in this after the station finds the line idle (not busy). It sends the frame immediately. In this there is more chance for highest collision.



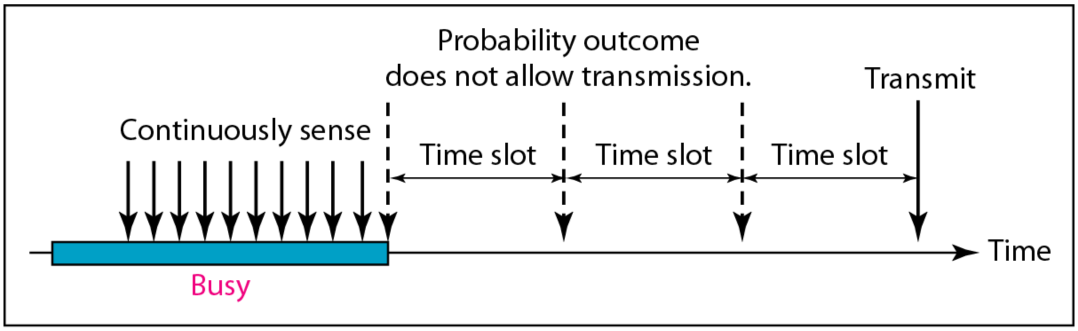
a. 1-persistent

iv) **Non- persistence method:** - The line is idle, it sends the frame immediately. If the line is not idle, it waits a random amount of time and then its sense the line again & transmit the data.

It sense and reduce highest collision



b. Nonpersistent

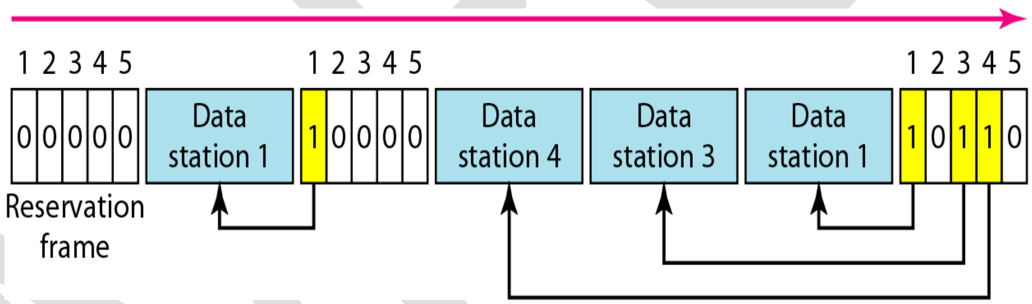


c. p-persistent

CONTROLLED ACCESS METHOD:

1. Reservation Method:

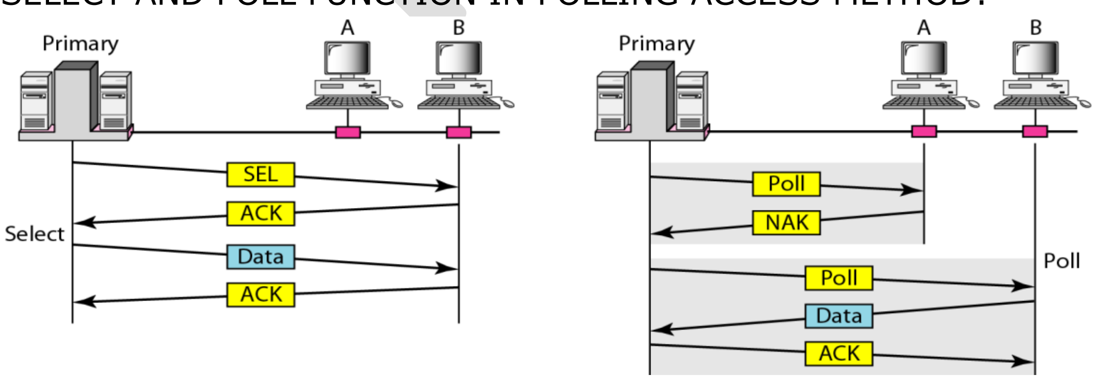
A station needs to make reservation before sending the data, with five stations and a five-minislot reservation frame. In the first interval, only stations 1, 3, and 4 have made reservations. In the sec-ond interval, only station 1 has made a reservation.



2.Polling Method:

In this the primary device controls the link, the secondary devices follow its instruction. The primary devices determine which device is allowed to use the channel at a given time.

SELECT AND POLL FUNCTION IN POLLING ACCESS METHOD:



POLL FUNCTION:

The *poll* function is used by the primary device to solicit transmissions from the secondary devices. When the primary is ready to receive data, it must ask (poll) each device in turn if it has anything to send. When the first secondary is approached, it responds either with a NAK frame if it has nothing to send or with data (in the form of a data frame) if it does. If the response is negative (a NAK frame), then the primary polls the next secondary in the same manner until it finds one with data to send. When the response is positive (a data frame), the primary reads the frame and returns an acknowledgment (ACK frame), verifying its receipt.

SELECT FUNCTION:

If the primary wants to send data, it tells the secondary to get ready to receive, this is called select function. Before sending data, the primary creates and transmits select frames (SEL frames).

If secondary is in ready state the transmission begins from primary and conformed to acknowledgement for successful transmission.

3.Explain about Network layer design and flow control and error control techniques in networks.

FLOW CONTROL AND ERROR CONTROL:

Flow Control

Flow control is a mechanism which is used to avoid the overflow of data at the receiver side, and it tells the sender to slow down the sending of data to avoid the overflow. In most protocols, flow control is a set of procedures that tells the sender how much data it can transmit before it must wait for an acknowledgment from the receiver.

Error Control

Error control is both error detection and error correction. It allows the receiver to inform the sender of any frames lost or damaged in transmission and retransmission of those frames by the sender. Any time an error is detected in an exchange, specified frames are retransmitted. This process is called automatic repeat request (ARQ).Error control in the data link layer is based on automatic repeat request, which is the retransmission of data.

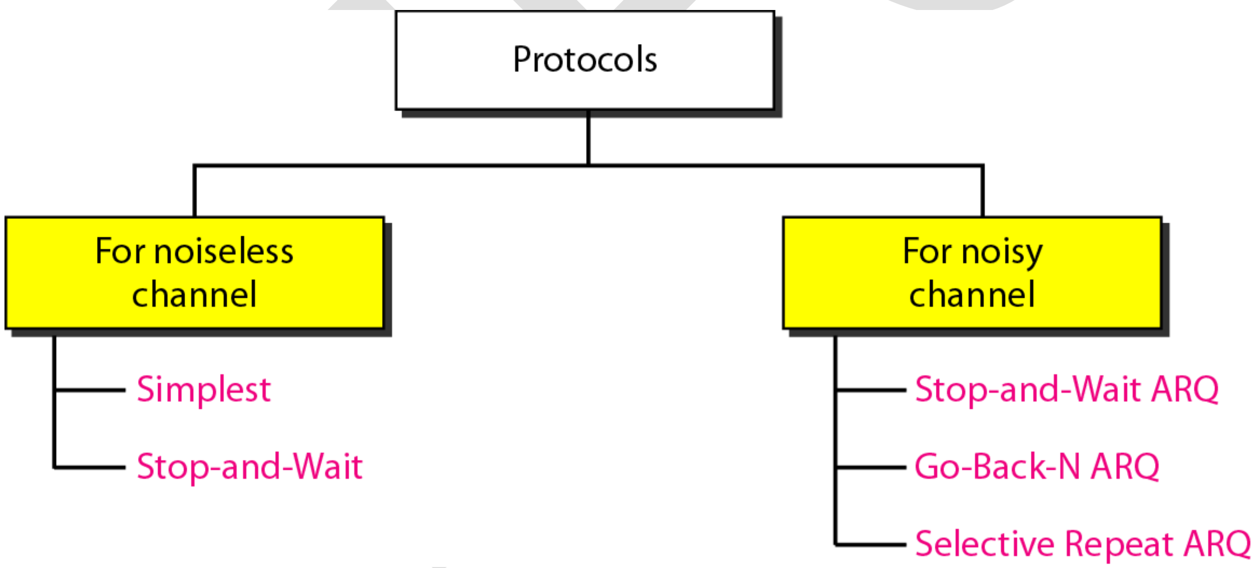
NOISY CHANNEL AND NOISELESS CHANNEL PROTOCOLS:

NOISY CHANNEL PROTOCOLS:

1. Stop & wait ARQ protocol
2. Go back- N ARQ protocol
3. Selective repeat ARQ protocol

NOISELESS CHANNEL PROTOCOLS:

1. Simplest protocol
2. Stop n wait protocol



NOISELESS CHANNEL PROTOCOLS:

SIMPLEST PROTOCOL:

It has no flow and error control. It is unidirectional protocol in which data frames are traveling in only one direction. The processing time in this is very small.

Design

There is no need for flow control. The data link layer at the sender site gets data from its network layer, makes a frame out of the data, and sends it. The data link layer at the receiver site receives a frame from its physical layer, extracts data from the frame, and delivers the data to its network layer. The below **Figure A** shows a design.

THE DESIGN OF THE SIMPLEST PROTOCOL WITH NO FLOW OR ERROR CONTROL:

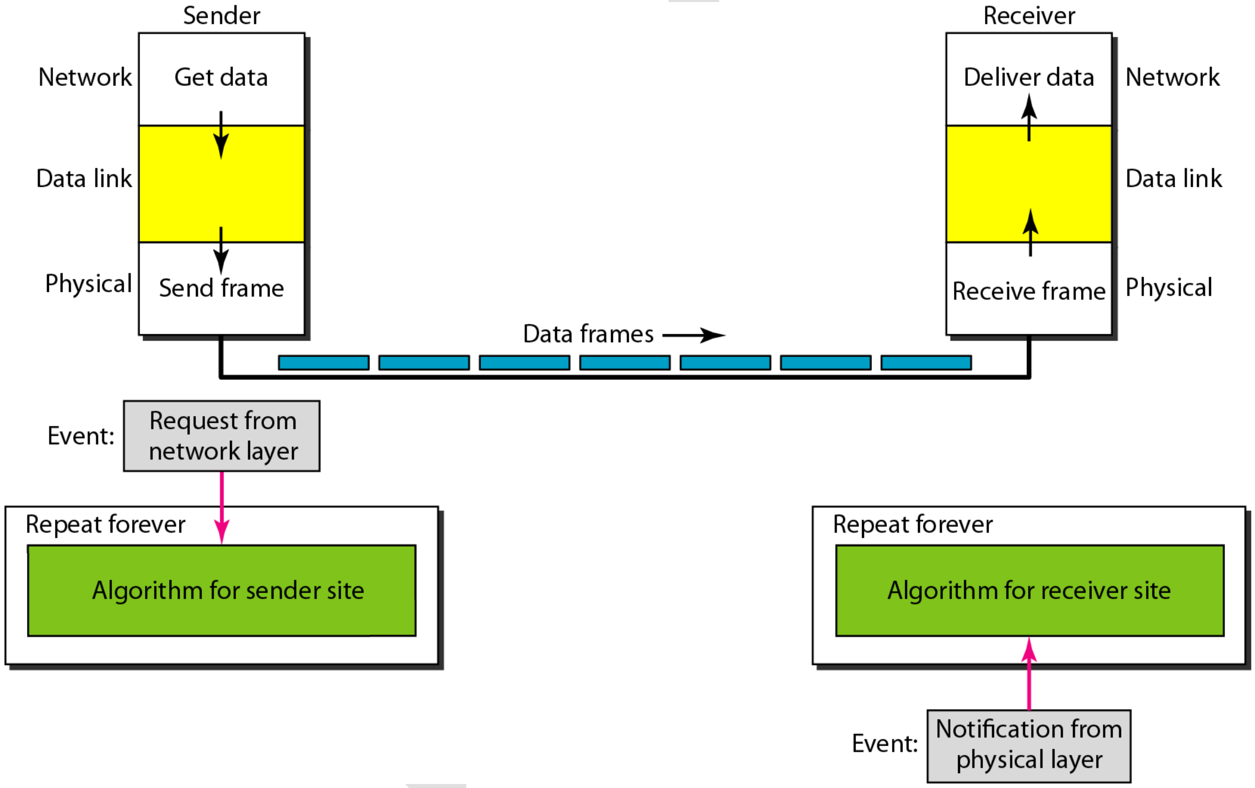
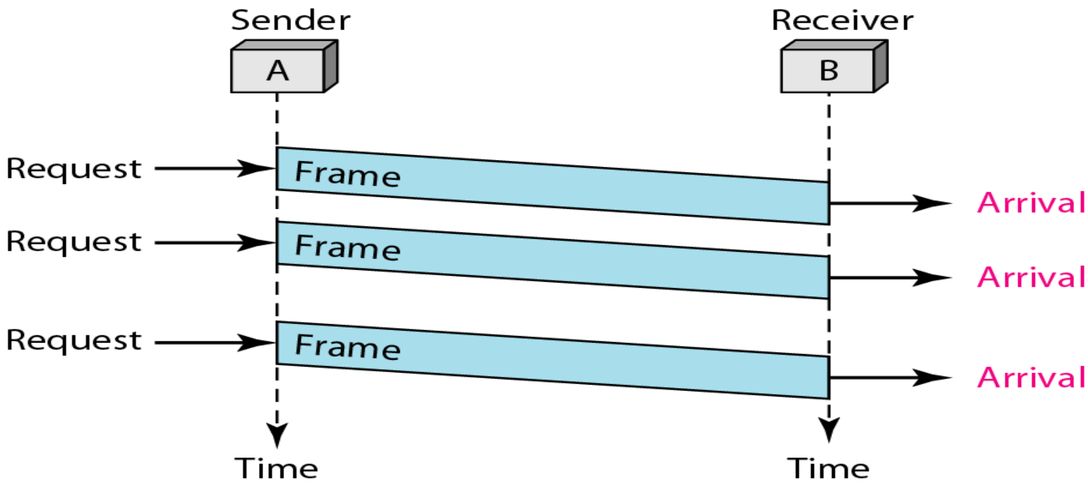


Figure A

The sender site cannot send a frame until its network layer has a data packet to send. The receiver site cannot deliver a data packet to its network layer until a frame arrives. The procedure at the sender site is constantly running; there is no action until there is a request from the network layer. The procedure at the receiver site is also constantly running, but there is no action until notification from the physical layer arrives.



STOP N WAIT PROTOCOL:

If data frames arrive at the receiver site faster than the receiver processing, the data will be overflow. So that the frames will be discarded or the service will be denial.

To avoid that stop n wait protocol is used. The sender sends one frame and stop until it receives the acknowledgement for the corresponding frame.

After that it will send the next frame.

It is also unidirectional communication for data frames, but acknowledgement will travels from other direction.

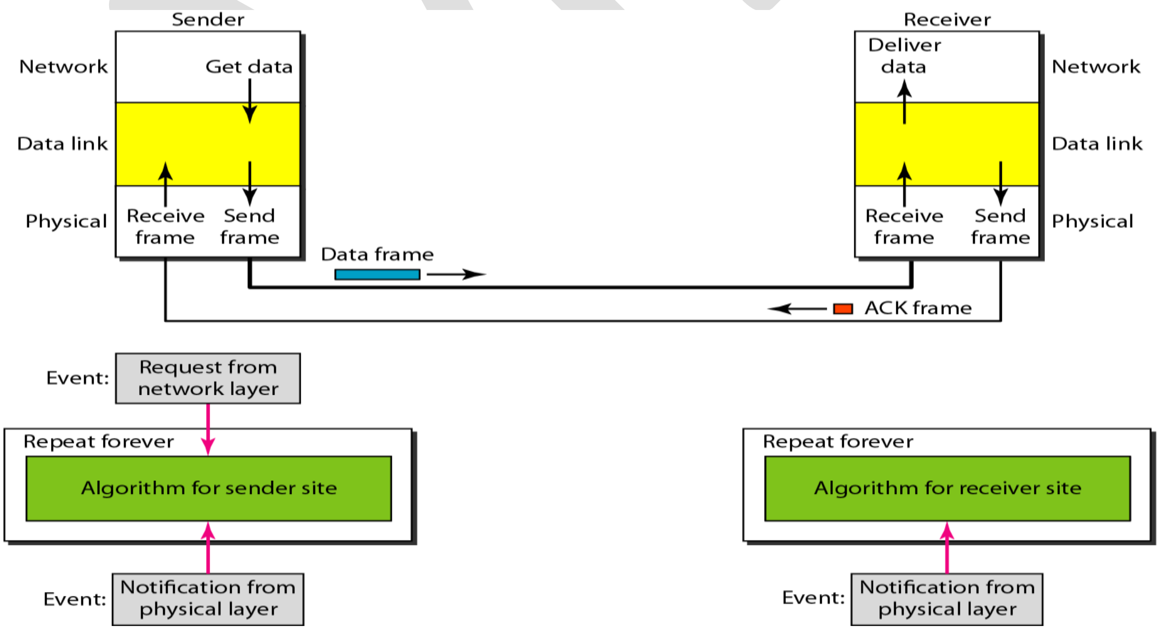
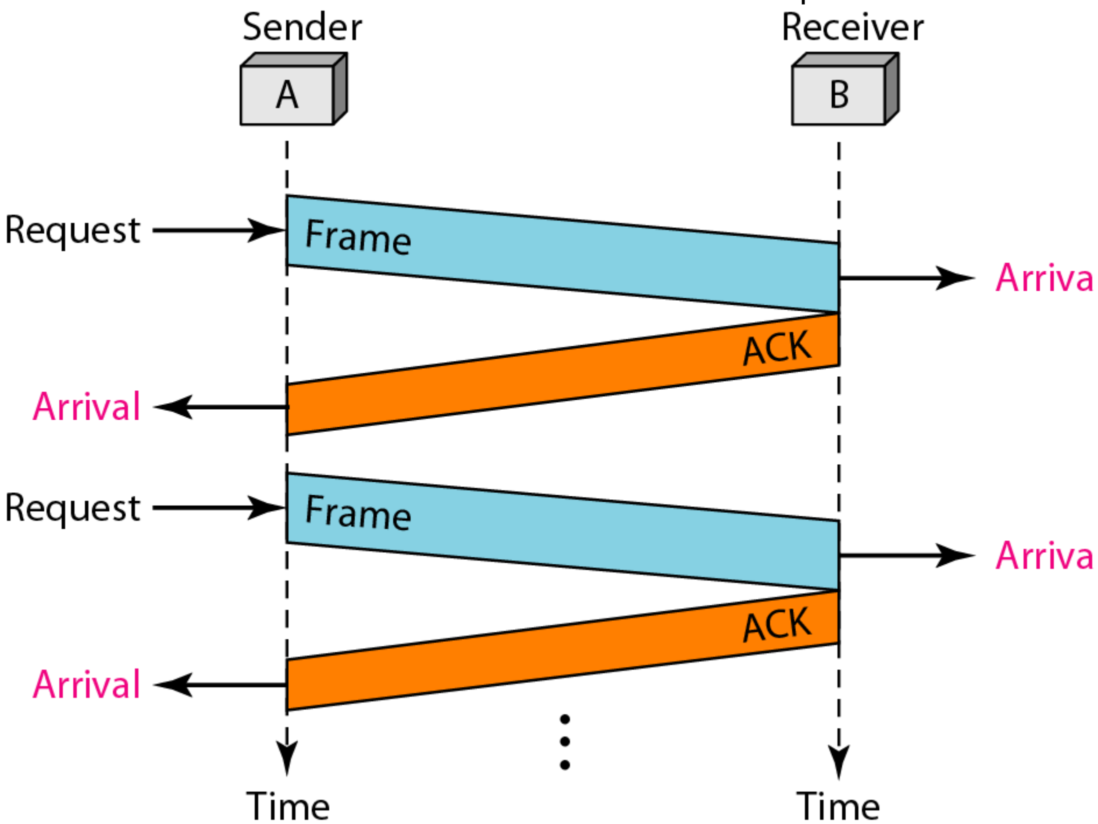


Figure B

Design:

Comparing the figure A with figure B, we can see the traffic on the forward channel (from sender to receiver) and the reverse channel. At any time, there is either one data frame on the forward channel or one ACK frame on the reverse channel. We therefore need a half-duplex link.



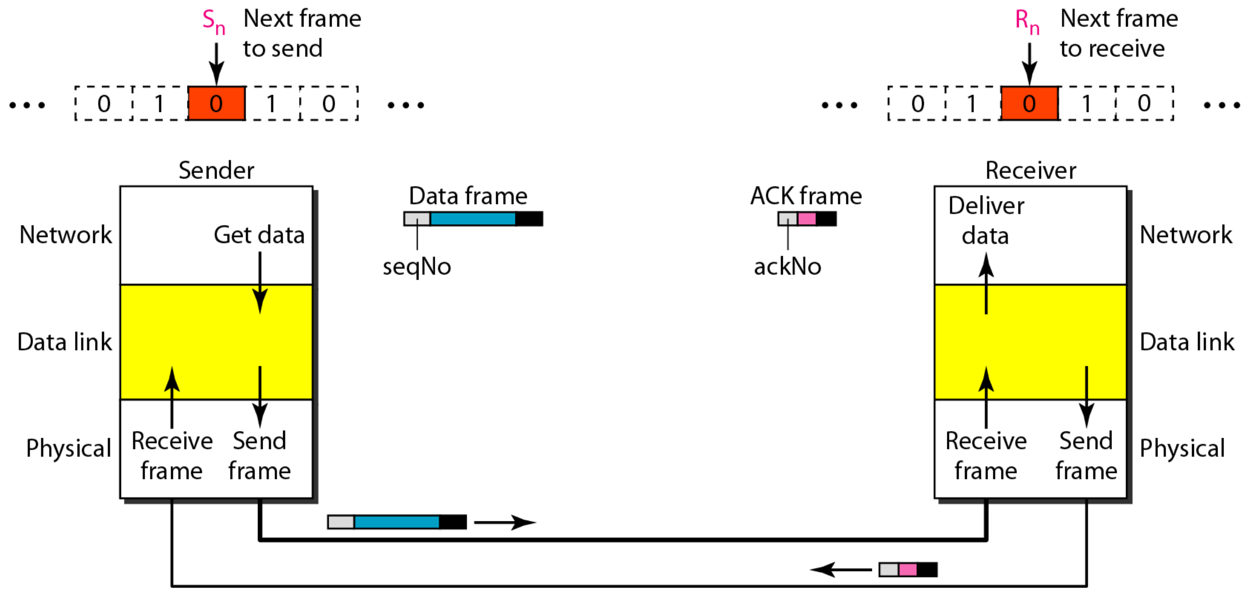
NOISY CHANNEL PROTOCOLS:

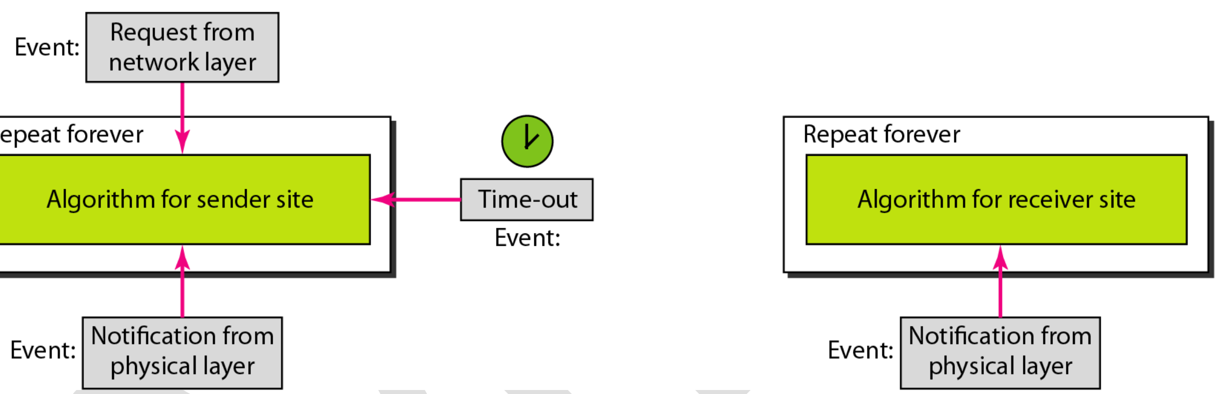
STOP N WAIT ARQ PROTOCOL:

It acts simple error control mechanism, this protocol detects and corrects the error by adding the redundancy bits in data frames.

The corrupted and lost data and ACK frame need to be reset in this protocol through sequence number in the frame.

Error correction in stop n wait ARQ is done by keeping a copy of the sent frame. And retransmitting of the frames when the time expires.





Sequence number:

The protocol specifies that frames need to be numbered. This is done by using sequence numbers.

The sequence numbers starts from 0. If we specified bits by length a m, the 0 goes to 2m-1. It is based on modulo -2-aritmetic.

Acknowledgement number:

If frame 0 has arrived safe, the receiver sends an acknowledgement frame with acknowledge number and vice versa.

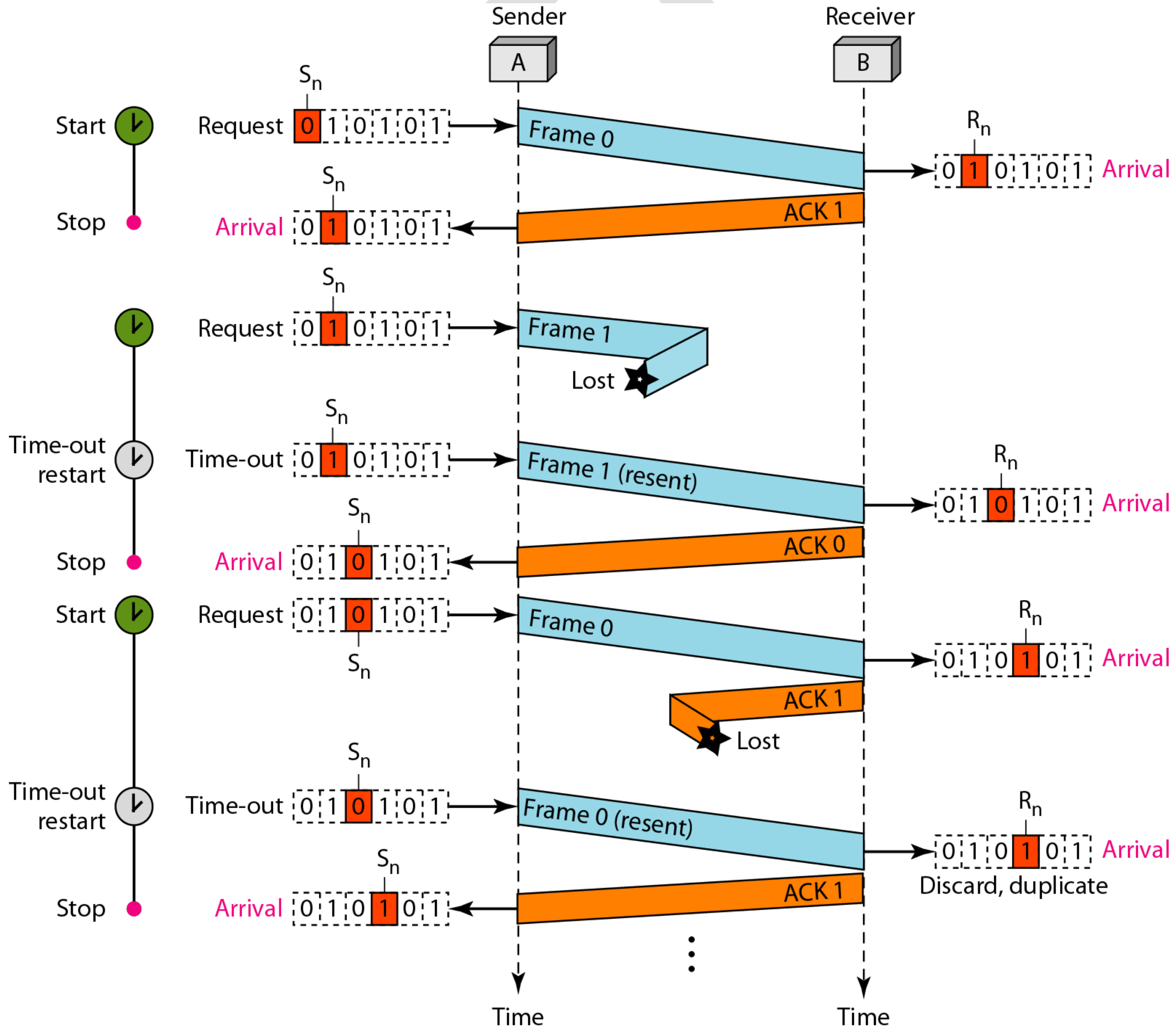
Efficiency:

The stop n wait ARQ is very inefficient if one channel is thick (last bandwidth) and long (round trip delay)

If we don't use pipelining the stop n wait ARQ protocol is inefficient. Here a pipelining is a channel.

Pipelining:

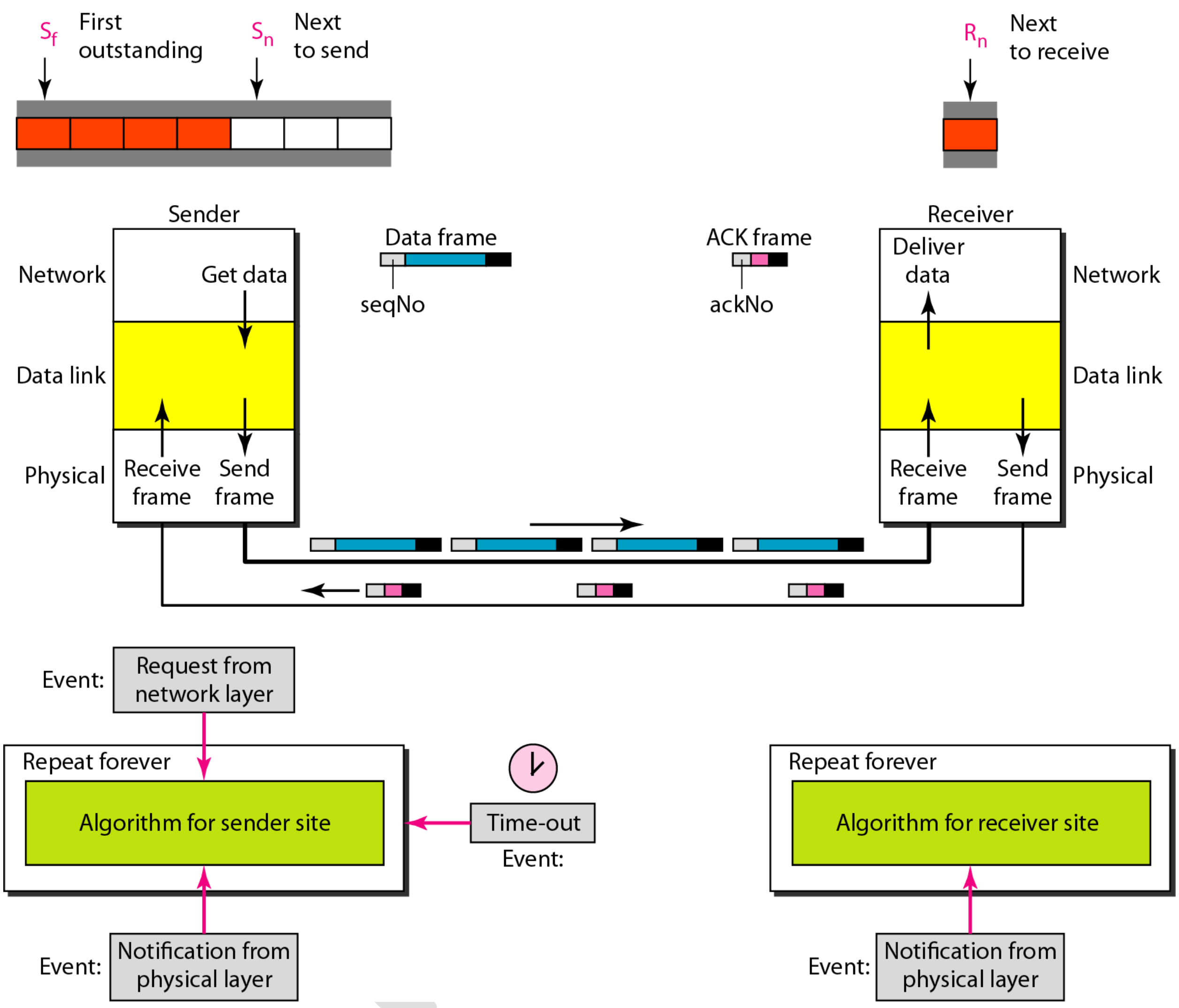
In networking and in other area a task is often begun before the previous task has ended. Here there is no pipelining used by stop n wait ARQ protocol.



GO BACK N ARQ PROTOCOL:

To improve the efficiency of the transmission this protocol can send several frames before receiving acknowledgements.

We keep the copy of these frames until the acknowledgement receives.

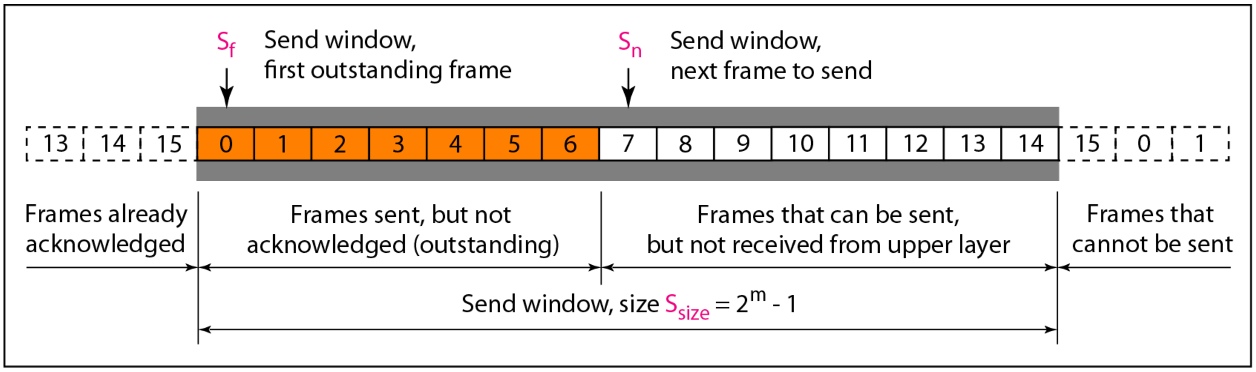


SLIDING WINDOW:

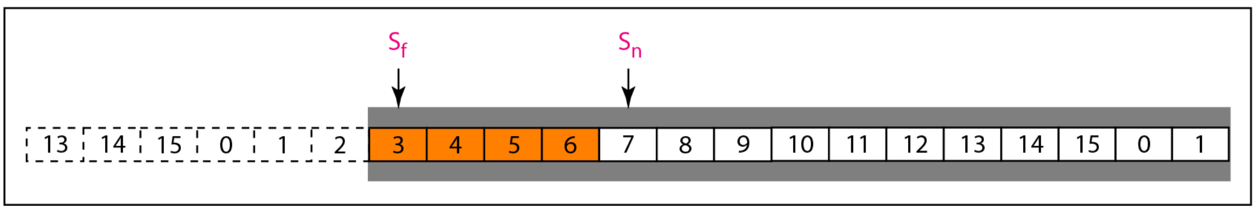
It defines the range of sequence numbers. For example if we specify bits length m=4, the sequence number starts with o to 2m-1.

Sending window for Go back N ARQ:

Send window before & after sliding:



a. Send window before sliding

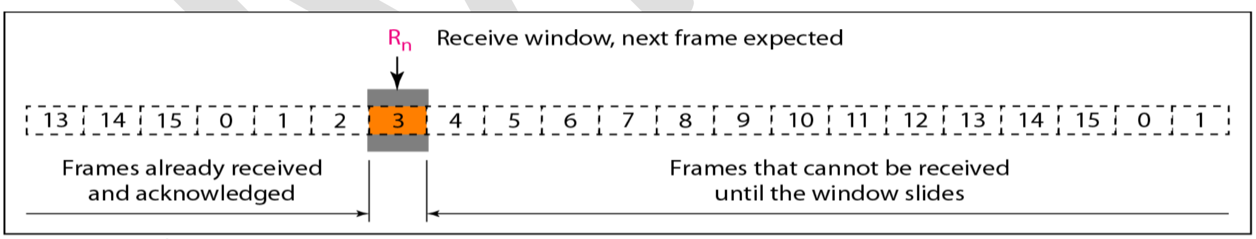


b. Send window after sliding

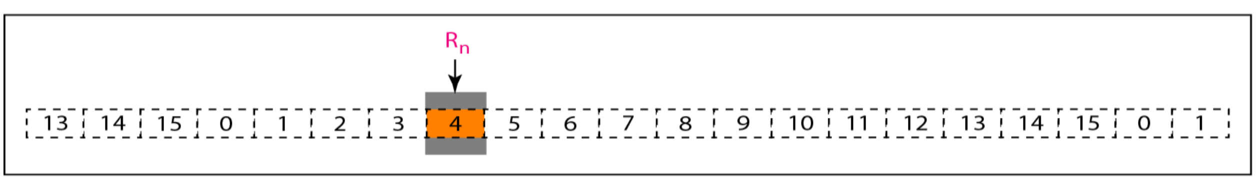
Send window define imaginary of size 2m-1 with 3 variables. i.e:Sf,Sn and Ssize

Receive window for Go back N ARQ:

Receive window Rn , next frame excepted:



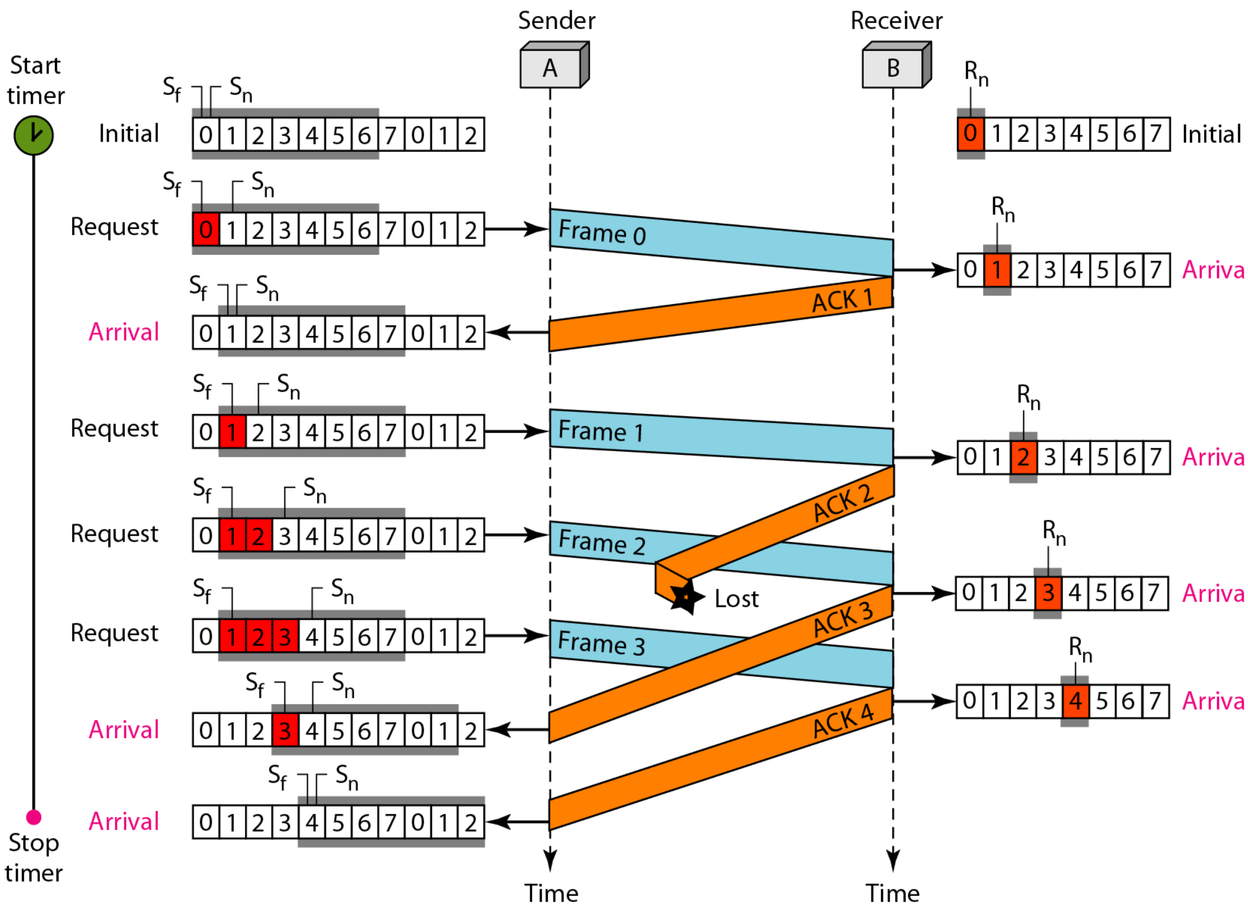
a. Receive window



b. Window after sliding

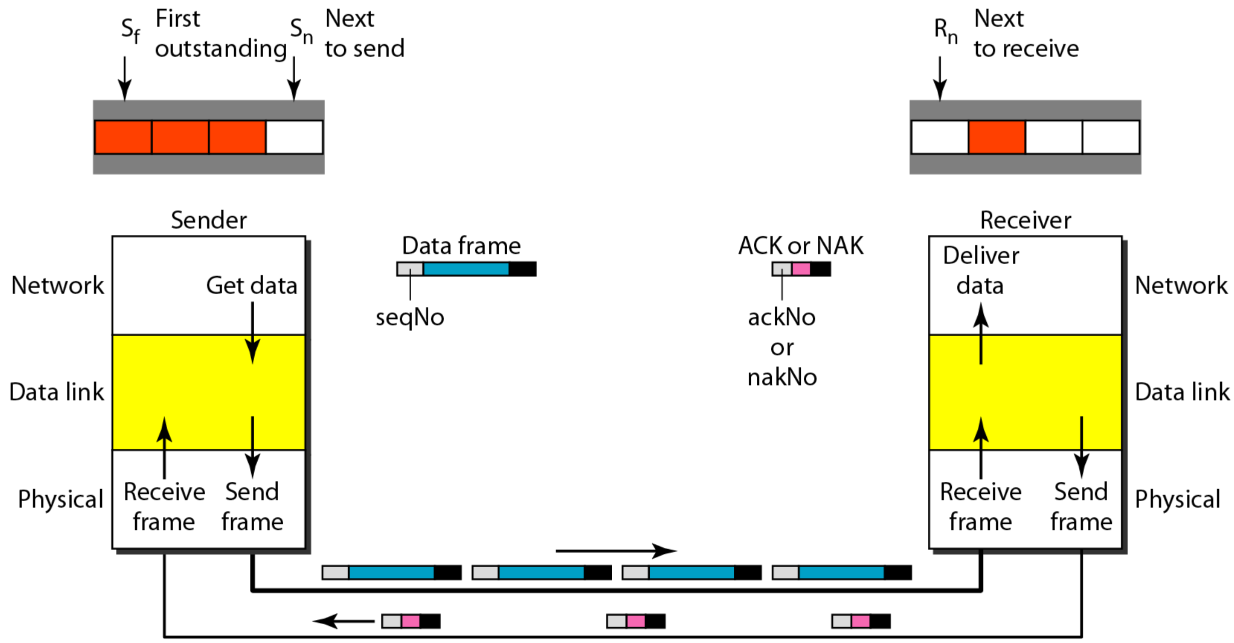
Window after sliding:

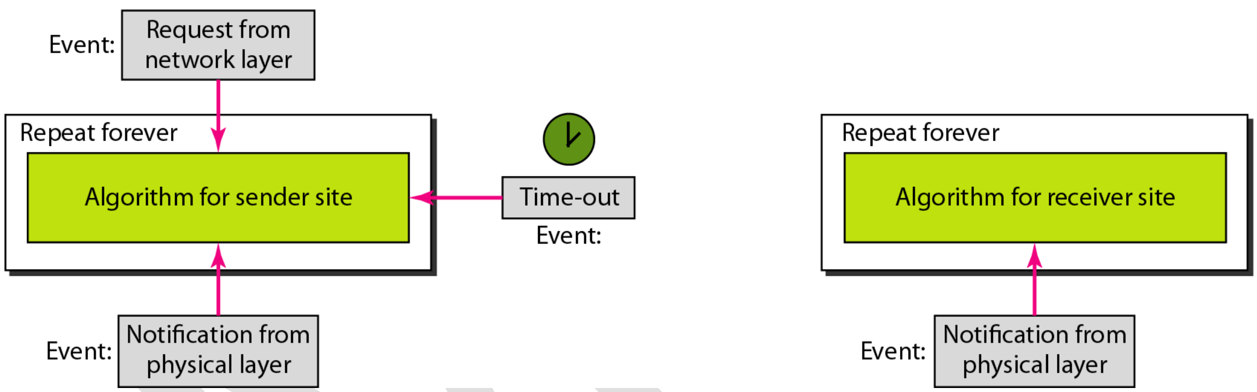
Receive window define an imaginary box of size 1 with one single variable Rn. The window slides when a correct frame has arrived, sliding occurs one slot at a time.



SELECTIVE REPEAT ARQ PROTOCOL:

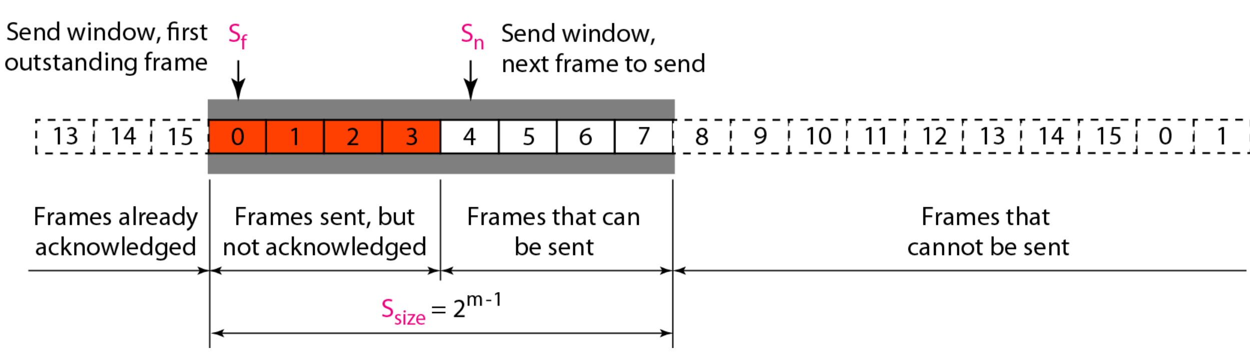
It does not resend n frames when just one frame is damaged, only the damaged frame is resend. It is more efficient for noisy channel compare to Go back N and stop and wait protocol, but the processing at the reciver is more complex.





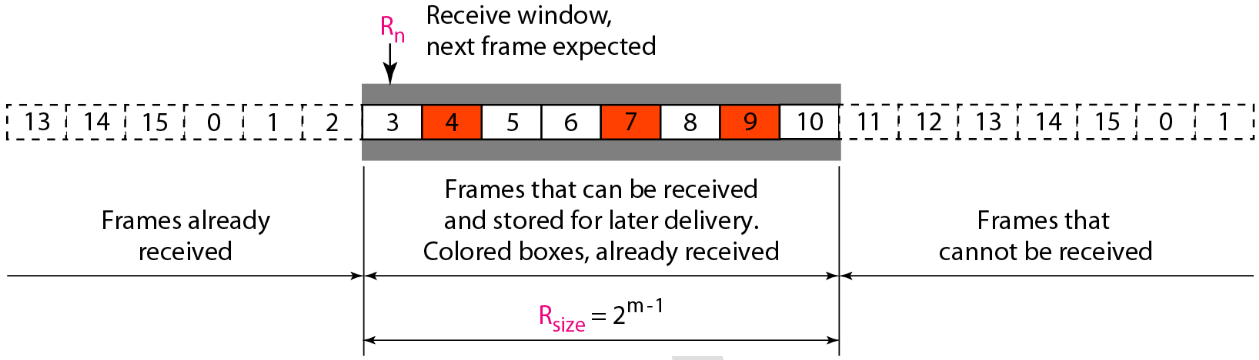
Send window:

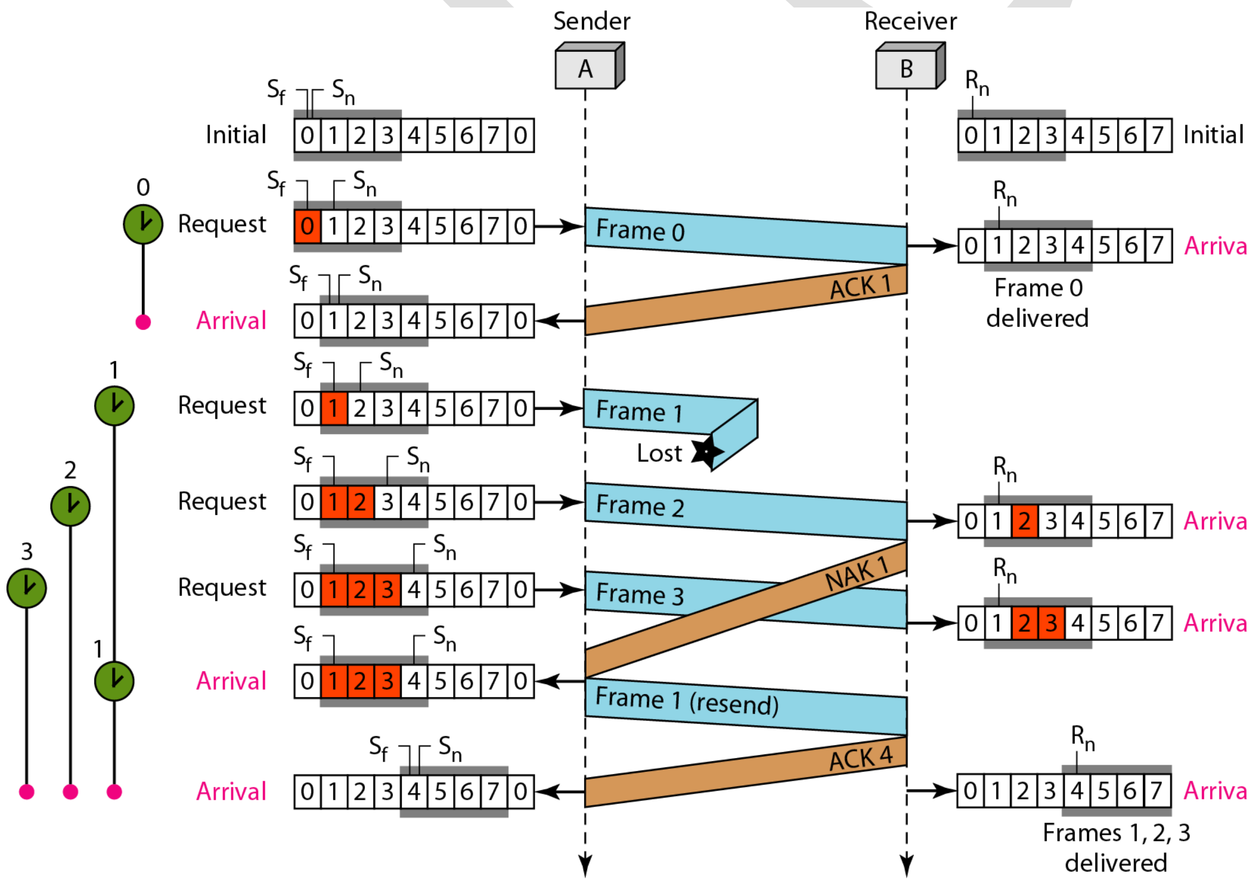
Here the size of the window is smaller as compared to Go back N ARQ, in this receive window is same size of the send window. Assume the size of the window is 8 in selective repeat ARQ.



Receive window:

In this many frames are received and all the frmes in the send window can arrive out of order, so that the frames are stored until they can be deliver.

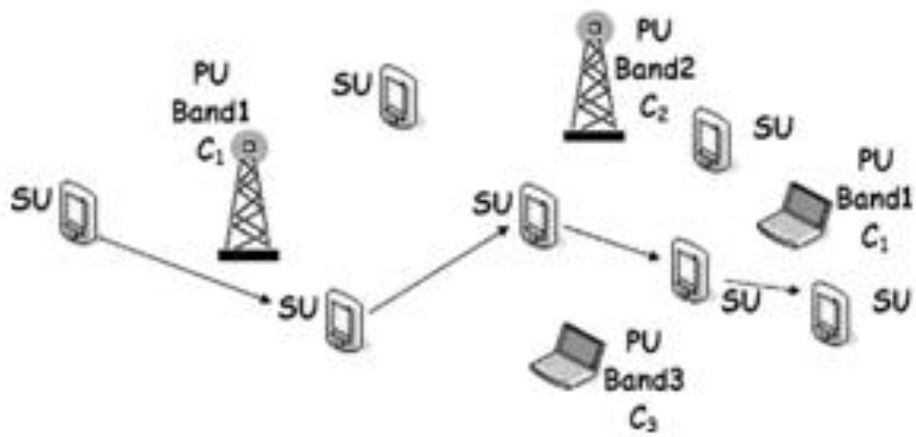




4.Explain in brief about Routing schemes in cognitive networks.

Routing challenges in multi-hop CRNs

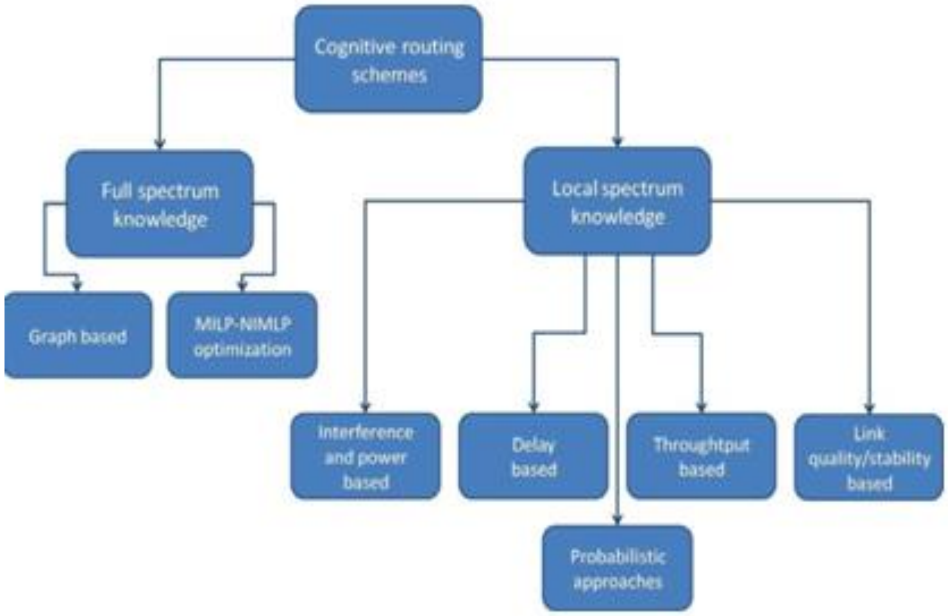
- The reference network model reported in Fig. 1 features secondary devices which share different spectrum bands (or SOPs) with primary users.
- Several spectrum bands (1, ... , M) may exist with different capacities C_1, C_2, C_M, and the SUs may have different views of the available spectrum bands due to inherent locality of the spectrum sensing process.



We broadly categorize the proposed solutions into two main classes depending on the assumptions taken on the issue of spectrum-awareness.

- full spectrum knowledge
- local spectrum knowledge

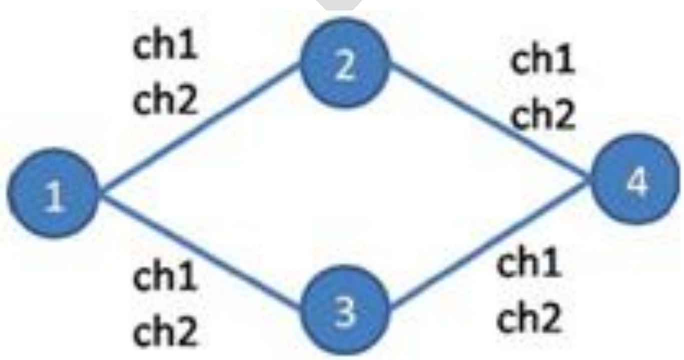
Classification of cognitive routing schemes:

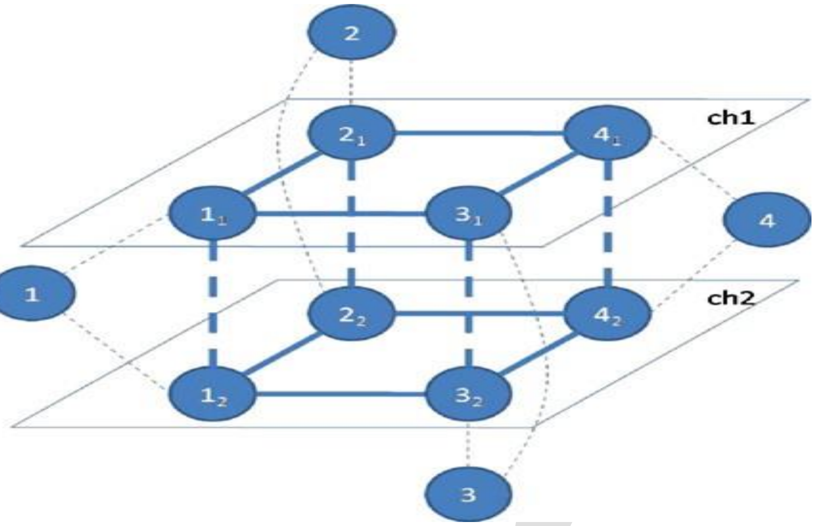


A.Routing schemes based on full spectrum knowledge

1.Graph-based routing approaches

- Route design in classical wired/wireless networks has been tackled widely resorting to graph-theoretic tools.
- Graph theory provides extremely effective methodologies to model the multi-hop behavior of telecommunication networks, as well as powerful and flexible algorithms to compute multi-hop routes.





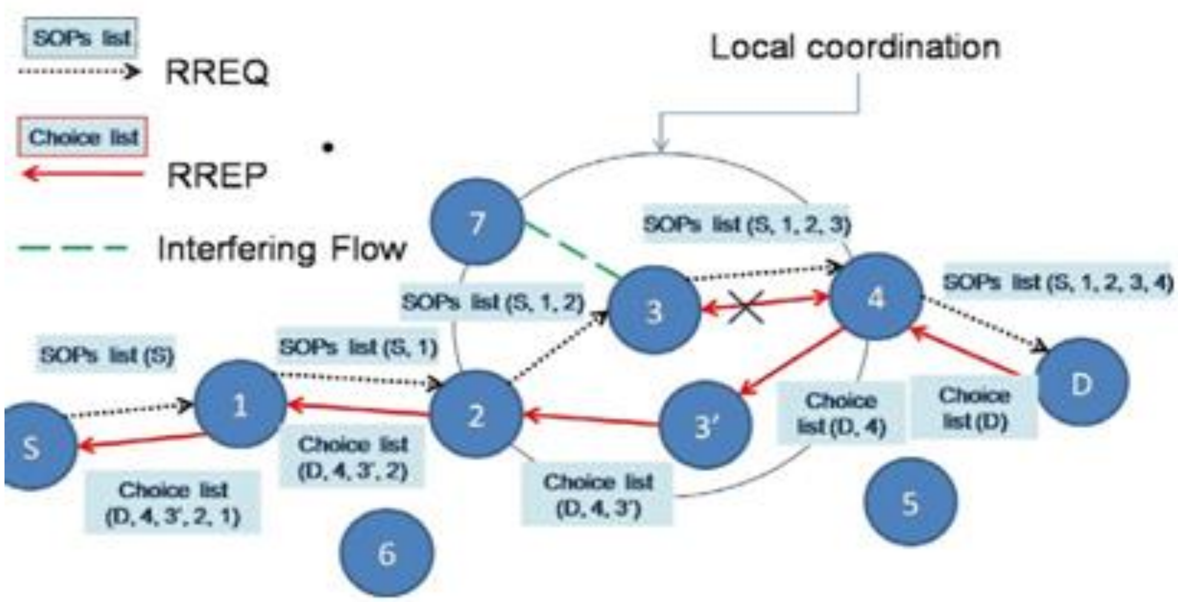
2.Optimization approaches to routing design

- A Mixed Integer Non-Linear Programming (MINLP) formulation whose objective is to maximize the spectrum reuse factor throughout the net- work, or equivalently, to minimize the overall bandwidth usage throughout the network.
- The proposed formulation captures all major aspects of multi-hop wireless networking, i.e., link capacity, interference, and routing.
- *Routing:* flow balance constraints at each node are used to capture traffic routing in the MINLP formulation; for each source–destination traffic flow, for every node in the network other than source and destination, the flow balance constraint forces the incoming flow to a node to be equal to the outgoing flow; source and destination are respectively flow creation and flow sink points.

B.Routing schemes based on local spectrum knowledge

1.Interference and power based solutions
2. Minimum power routing
3. Bandwidth footprint minimization
4. Throughput-based solutions
5. Link quality/stability based solutions

Effective Route establishment



- Under the proposed routing scheme, SUs interact with each other to adjust their transmission parameters to minimize the end-to-end delay such that *K* different delay sensitivity classes can be supported.