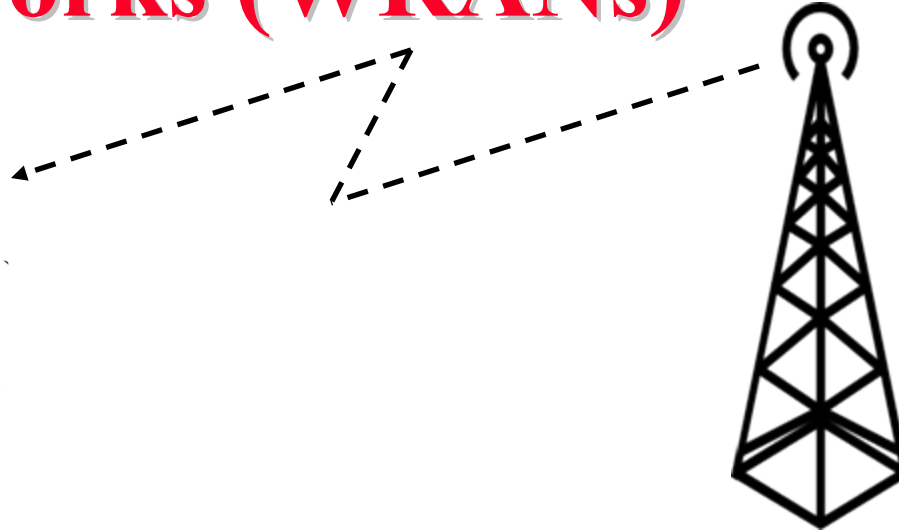# IEEE 802.22 Wireless Regional Area Networks (WRANs)

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Audio/Video recordings of this class lecture are available at:

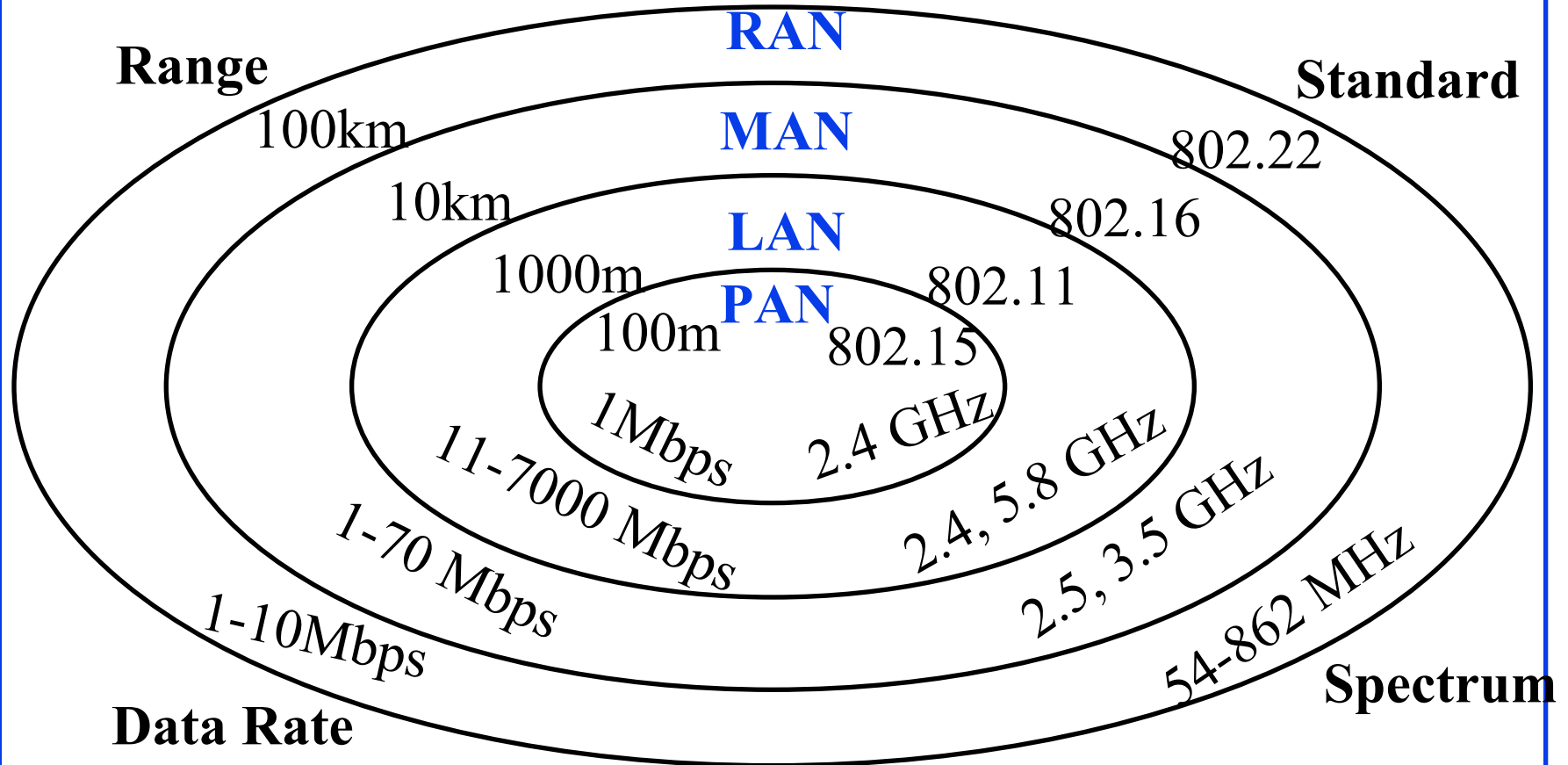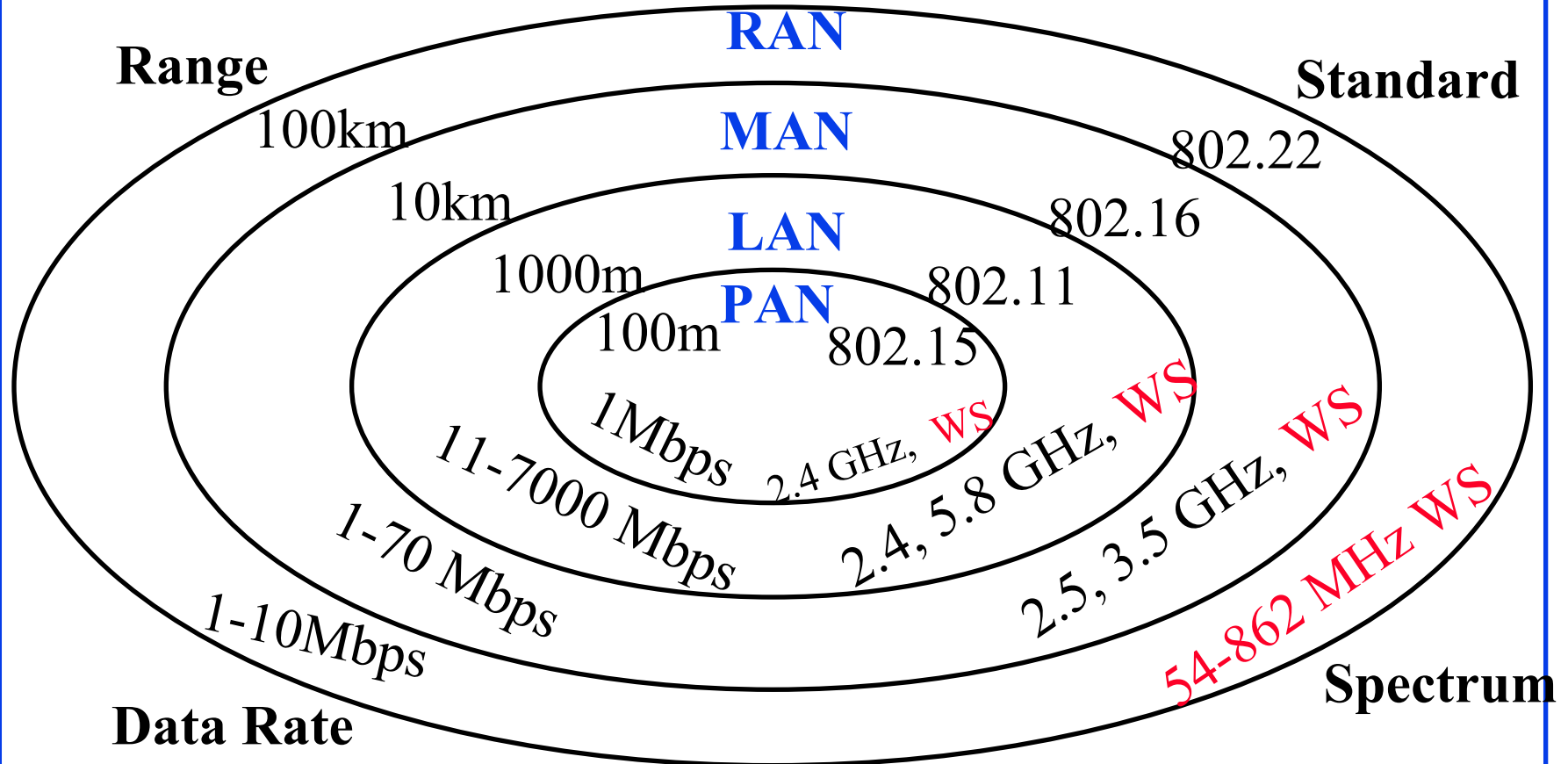http://www.cse.wustl.edu/~jain/cse574-14/

Overview

1. IEEE 802.22-2011: Key Features
2. Protocol Reference Model
3. Spectral Sensing Function
4. IEEE 802.22 MAC and PHY
5. Self-Coexistence

Note: This is the 2nd lecture in a series of two lectures on white space networking. IEEE 802.11af was covered in the 1st part.

Characteristics of Wireless Standards

Range

Standard

RAN

MAN

LAN

PAN

100km

10km

1000m

100m

802.22

802.16

802.11

802.15

1Mbps

2.4 GHz

11-7000 Mbps

2.4, 5.8 GHz

1-70 Mbps

2.5, 3.5 GHz

1-10Mbps

54-862 MHz

Spectrum

Data Rate

Wireless Standards (Cont)

Range
- 100km
- 10km
- 1000m
- 100m

RAN
MAN
LAN
PAN

Standard
- 802.22
- 802.16
- 802.11
- 802.15

Data Rate
- 1-10Mbps
- 1-70 Mbps
- 11-7000 Mbps
- 1Mbps

Spectrum
- 54-862 MHz WS
- 2.5, 3.5 GHz, WS
- 2.4, 5.8 GHz, WS
- 2.4 GHz, WS

IEEE 802.22 Working Group

❑ **IEEE 802.22-2011**: Cognitive Radio based Regional Area Networks (RAN) in TV White Spaces (TVWS)

❑ **IEEE 802.22.1-2010**: Enhanced Interference Protection Using Beaconing

❑ **IEEE 802.22.2-2012**: Recommended Practice for Installation and Deployment of 802.22 systems

❑ **IEEE 802.22.1a**: Advanced Beaconing

❑ **IEEE P802.22a**: Enhanced MIB and Management plane procedures

❑ **IEEE 802.22b**: Enhancement for Broadband Services and Monitoring Applications

❑ **Spectrum Occupancy Sensing (SOS)** Study Group

IEEE 802.22-2011: Key Features

❑ Wireless Regional Area Network (WRAN)

❑ Uses 54 MHz-862 MHz TV White Space (TVWS) Band

❑ 4.54 to 22.69 Mbps/ TV channel. More with channel bonding.

❑ 17 km to 30 km radius (100 km in good conditions).
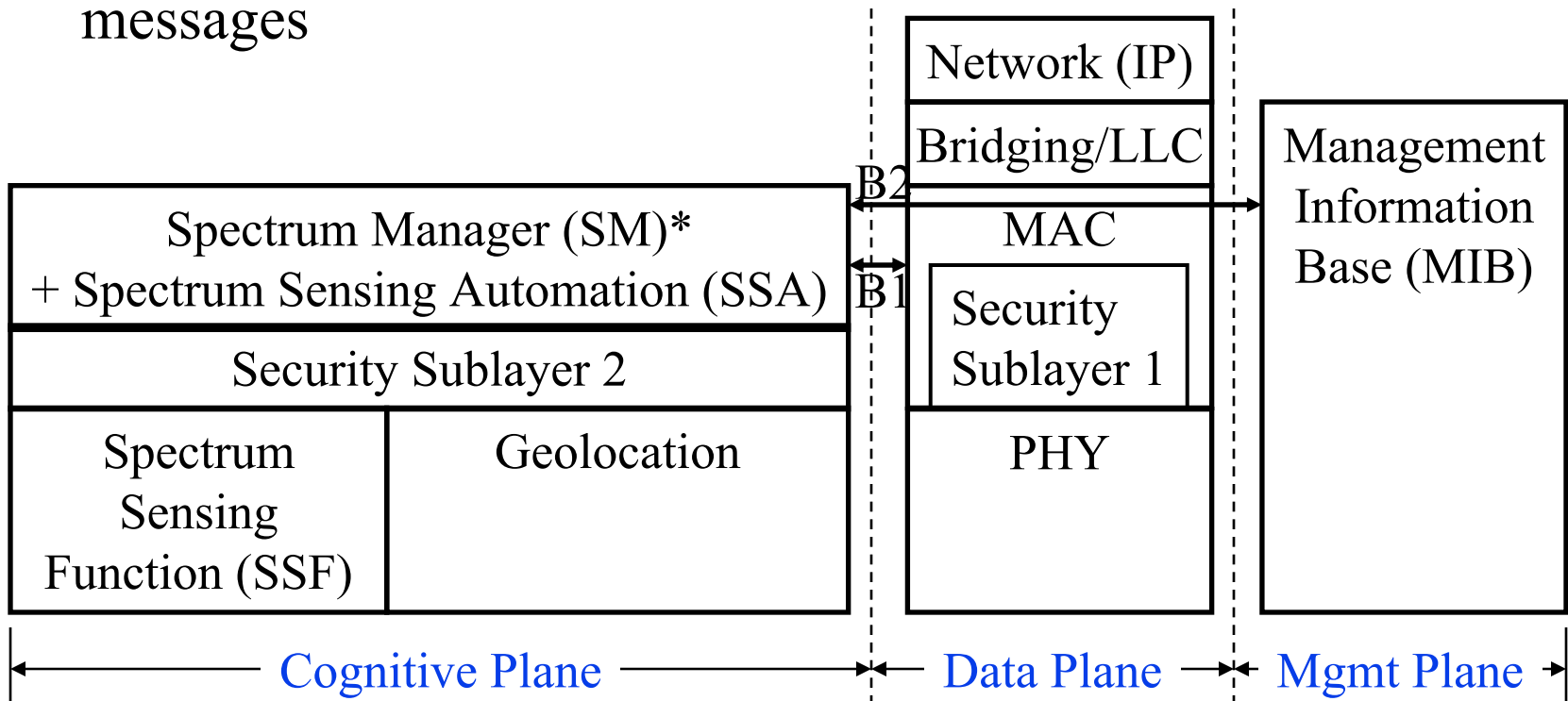 512 Customer Premise Equipment (CPEs).
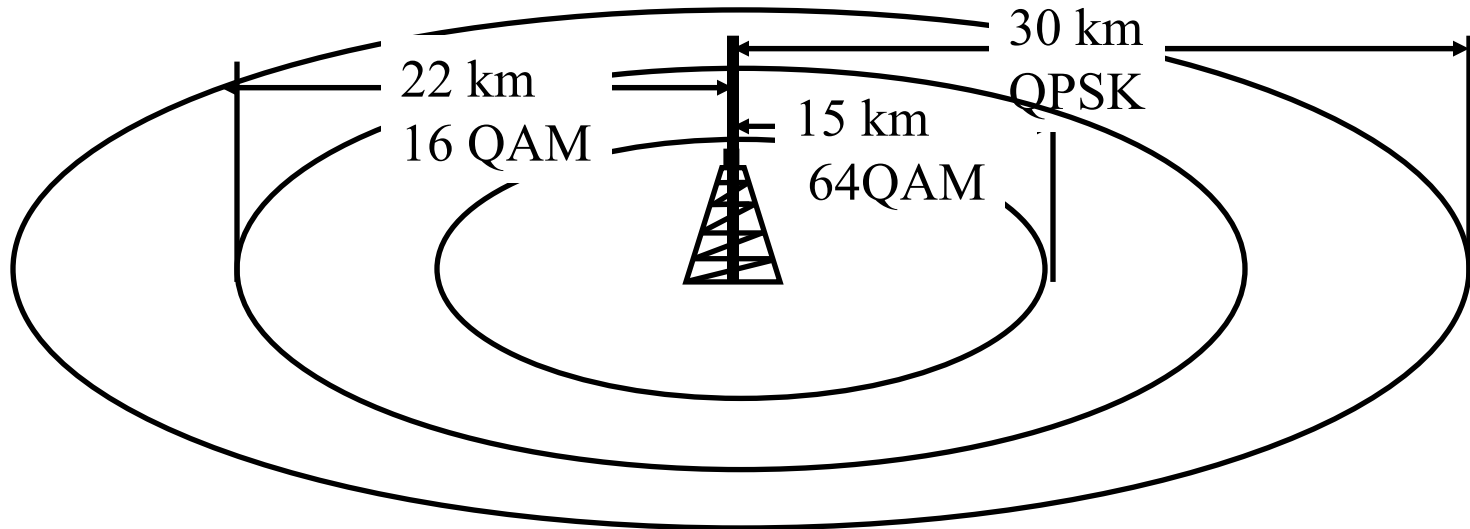
30 km
QPSK

22 km
16 QAM

15 km
64QAM

Ref: Telesystem Innovations Inc., "TV White Spaces: Unlicensed Access Spectrum in Sub-700 MHz Band,"
http://frankrayal.files.wordpress.com/2012/04/tv-white-space-whitepaper.pdf
http://www.cse.wustl.edu/~jain/cse574-14/

Protocol Reference Model

❑ **Cognitive Plane**: Spectrum sensing and Geolocation
❑ Data plane carries data, management, and cognitive plane messages

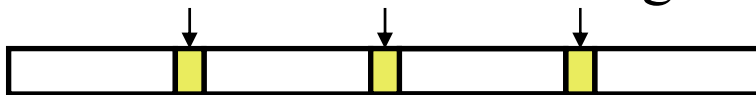| Cognitive Plane		Data Plane	Mgmt Plane
		Network (IP)	
		Bridging/LLC	Management Information Base (MIB)
Spectrum Manager (SM)* + Spectrum Sensing Automation (SSA)	B2 B1	MAC	
Security Sublayer 2		Security Sublayer 1	
Spectrum Sensing Function (SSF)	Geolocation	PHY	

* Base station only. Not in CPE.

Spectral Sensing Function

❑ Customer Premise Equipments (CPEs) and Base stations (BS) do spectrum sensing both in-band (used channels) and out-of-band (channels not used)

❑ Out-of-band sensing done when CPE is idle

❑ Spectrum Sensing: Quiet period and two phase sensing
  ➢ Fast sensing: Some quiet time allocated in a frame
  ➢ Fine sensing with several ms in occupied channels to look for transmitter info: Quiet period of multiple frames

❑ Dynamic Frequency Hopping (DFH): Sensing is done in parallel (Optional)

❑ Quiet Period for sensing ⇒ QoS Interruption

❑ Note: FCC no longer requires spectral sensing in TVWS. This feature may be required in other countries.

Intra-frame sensing   Inter-frame sensing
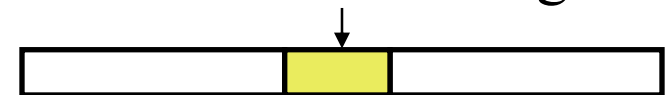
Spectrum Manager

❑ Spectrum availability info, channel lists, quiet period scheduling, coexistence mechanisms

❑ MAC notifies spectrum manager if excessive interference is sensed

❑ Spectrum manager schedules a quiet period during which CPEs sense in-band channels (N-1,N, N+1)

❑ Spectrum manager and MAC communicate using interface B1

❑ Management can configure spectrum manager and set policies using interface B2

❑ Security layer authenticates senders of beacons to each other

IEEE 802.22 MAC

❑ Designed for long round trip delays
❑ **Connection Oriented**: All PDUs are sent on bi-directional connections between BS and CPEs.
❑ Each connection has a particular QoS ⇒ May need multiple connections for a single CPE, e.g., Video, data, audio, etc.
❑ **Classification**: All SDUs are classified using SDU headers and assigned a 3-bit "flow ID".
❑ **Connection IDs**: 12-bits= 9-bit station ID+ 3-bit flow ID
⇒ 2^9 or 512 stations with 8 flows each
❑ **MPDU Aggregation**: Multiple MAC PDUs send in one burst Fragmentation also allowed
❑ **MSDU Aggregation**: Multiple MAC SDUs may be packed in one MAC PDU
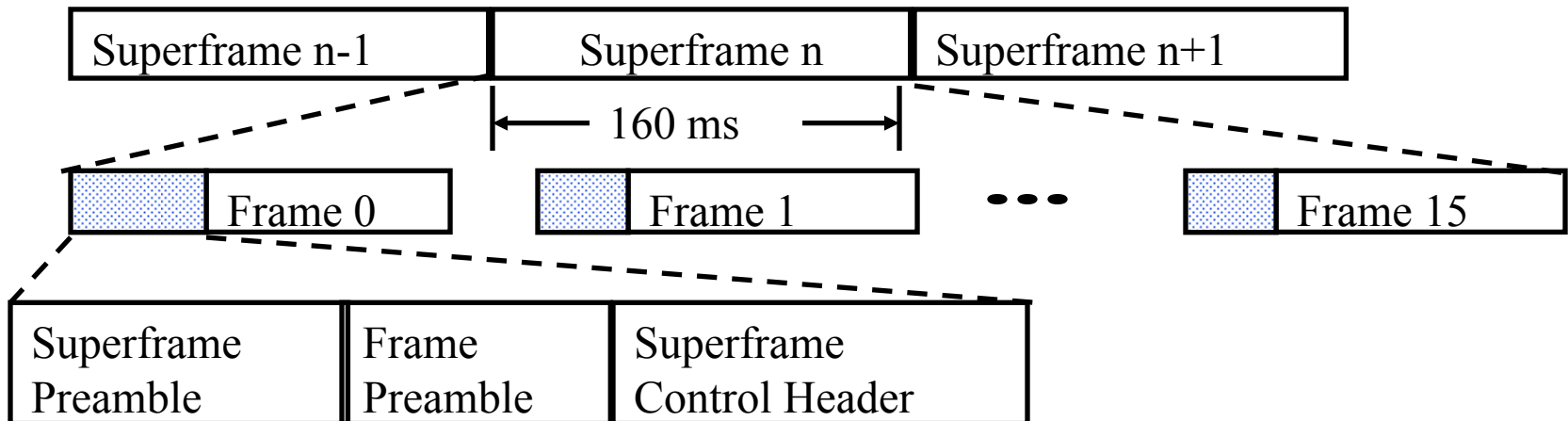❑ Retransmission for connections with **ARQ** (automatic repeat request) enabled

Bandwidth Allocation

❑ BS schedules all transmissions

❑ **Bandwidth Requests**:

   1. Piggybacked in MAC frame header

   2. CDMA: One of a set of reserved codes is transmitted during ranging

   3. Polling: AP allocates slots to CPE for bandwidth request

❑ CPE requests are for a particular connection.
  Once granted, CPE can use it for any connection.
  $\Rightarrow$ Do not waste allocated time

IEEE 802.22 – QoS Classes

❑ Centralized allocation at BS

❑ **Connection oriented**: All traffic is assigned a connection

❑ **Service Classes**:

1. **Unsolicited Grant Service (UGS)**: Constant Bit Rate (CBR) traffic, e.g., voice. Specified throughput, delay, and delay jitter

2. **Real-Time Polling Services (rtPS)**: Real-time variable bit rate (rtVBR), e.g., streaming video.
Specified peak and average throughput, delay and delay jitter.

3. **Non-Real-Time Polling Service (nrtPS)**: nrtVBR, e.g., FTP. Specified peak and average throughput

4. **Best Effort (BE)**; No throughput or delay guarantees

5. Contention for bandwidth request

❑ QoS parameters, Peak/sustained rates, max latency, jitter

IEEE 802.22 Superframe Structure

Superframe n-1	Superframe n	Superframe n+1

← 160 ms →

	Frame 0		Frame 1	...		Frame 15

| Superframe Preamble	Frame Preamble	Superframe Control Header

- ❑ **Superframe**: Group of 16 frames, with a superframe preamble and superframe control header (SCH).

- ❑ **Superframe Control Header (SCH)** indicates whether a frame or coexistence beacon follows it.

- ❑ It also indicates the position and duration of quiet period for inter-frame sensing.

- ❑ First frame payload is reduced by two symbols to compensate for Superframe preamble and superframe control header

IEEE 802.22 Frame Structure

- ❑ **Time Division Duplexing (TDD):** Each frame has downstream (DS) subframe and upstream (US) subframe.
- ❑ **Frame Preamble**: Time and frequency synchronization
- ❑ DS:US boundary is adaptive. In practice, neighboring WRANs should synchronize DS:US to avoid BS to CPE interference.
- ❑ Stations need time to turn around from receiving to transmitting
  - ➢ Transmit Time Guard (TTG)
  - ➢ Receive Time Guard (RTG)

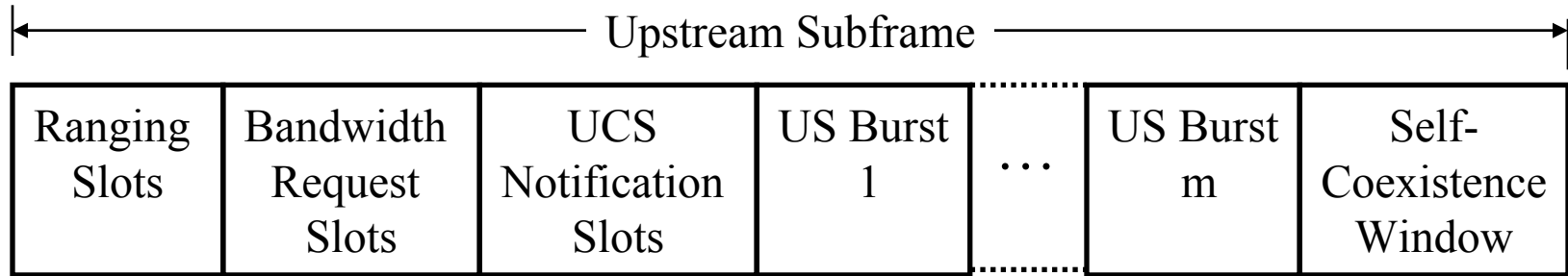| ← Frame →				← Frame →
Frame Preamble	DS Subframe	**TTG**	US Subframe	**RTG**	Frame Preamble

Downstream Subframe
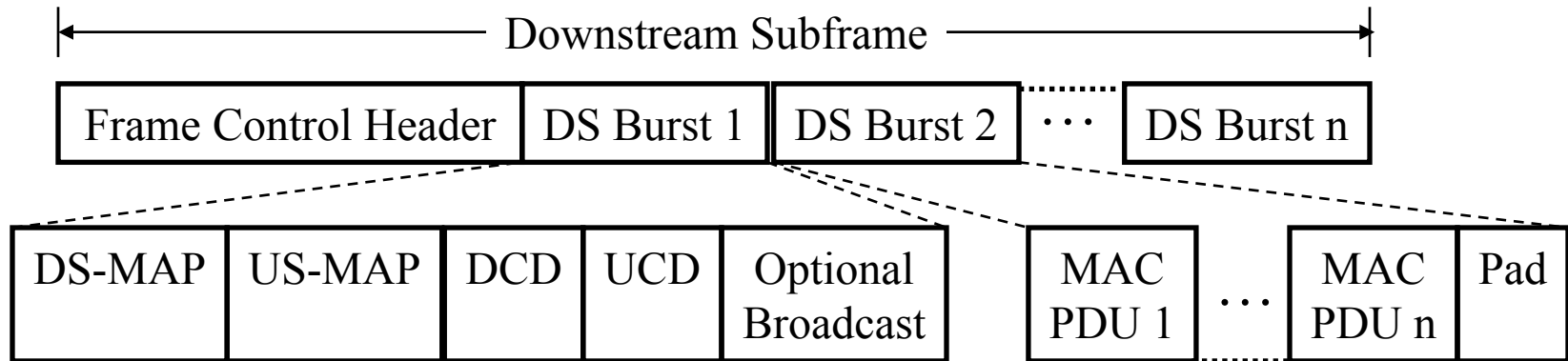
- **Frame Control Header (FCH):** Maps' lengths, modulation and coding, usable subcarriers
- First downstream burst contains information about the frame
- **Downlink Map**: Burst lengths for **this** frame.
- **Upstream Map**: Burst lengths for transmission from each CPE for **next** frame. Maps can be compressed
- **Downstream Channel Descriptor (DCD):** PHY characteristics of downstream bursts (modulation, coding)
- **Upstream Channel Descriptor (UCD)**

Upstream Subframe

Ranging Slots	Bandwidth Request Slots	UCS Notification Slots	US Burst 1	...	US Burst m	Self-Coexistence Window

(— Upstream Subframe —)

- **Upstream Contention-based region**: Ranging, bandwidth request, Urgent Co-existence situation (UCS) notification
- **Ranging**: CPE sends frames to find distance and determine frequency, time, and power adjustments. Initial and periodic.
- **Bandwidth Request**: bandwidth can be requested in any US burst. But need to contend if no previous burst.
- **Urgent Coexistence Situation (UCS):** Another signal sensed
- **Self-Coexistence Window**: CPEs send coexistence beacons to announce their presence to others

Cognitive Features of MAC

1. **Spectrum sensing**: Scheduling quiet periods
2. **Geolocation** using ranging
3. CPEs can **alert** BS for overlapping cells and interference
4. BS can ask particular CPEs to **move** to another channel
5. BS can coordinate with other BS to **share** or move to another channel

IEEE 802.22 PHY

❑ Optimized for long propagation delays, large delay spread, and highly frequency selective fading channels

❑ OFDM with 2048 subcarriers: 184 Left Guard, 1 DC, 183 Right Guard, 1440 Data + 240 Pilot
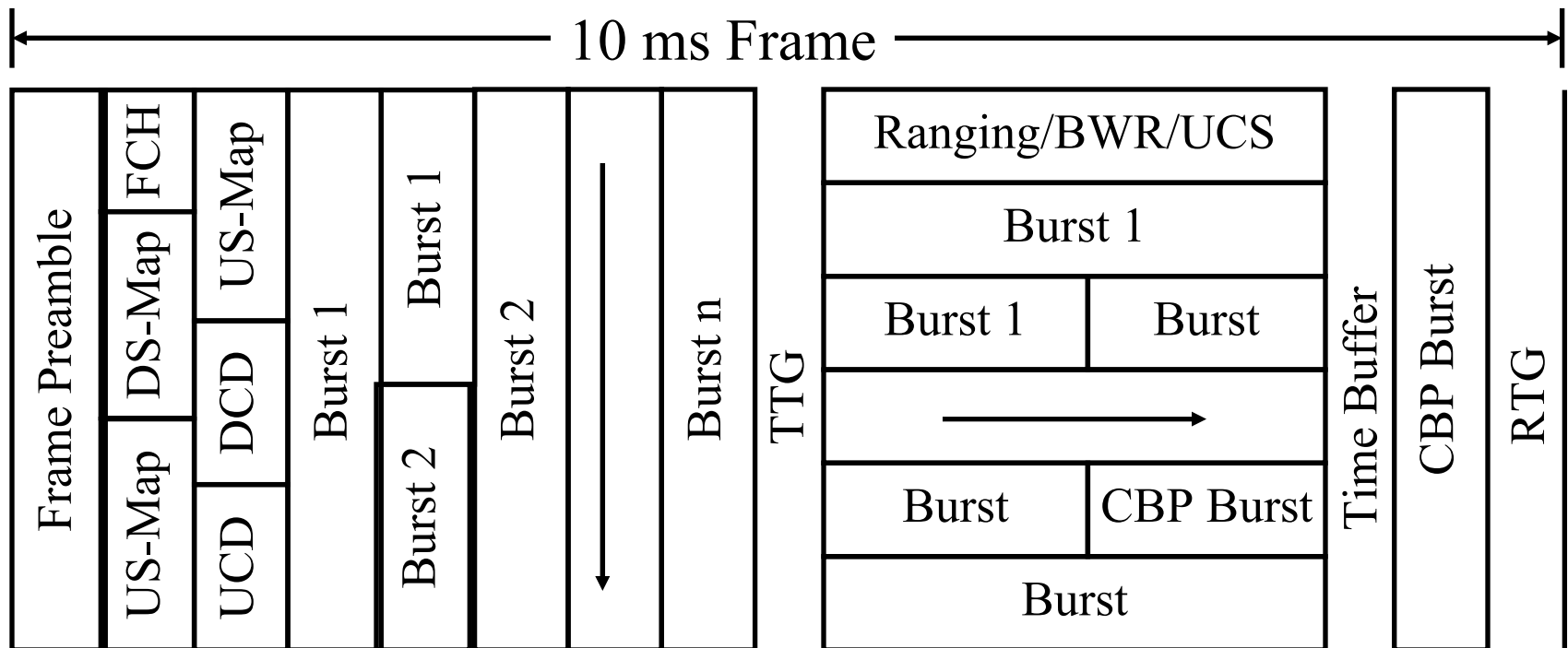
IEEE 802.22 PHY (Cont)

❑ OFDMA with allocations in units of **sub-channels**.

  ➢ 60 sub-channels of 24 data + 4 Pilot subcarriers each

❑ DS bursts are vertical, US bursts are horizontal

❑ Two-dimensional frame:

  ➢ Time in units of symbols in horizontal direction

  ➢ Frequency in units of subchannels in vertical direction

❑ 1 OFDM slot = 1 subchannel × 1 symbol

❑ Vertical DS⇒ Minimum time
⇒ Minimum interference from other WRANs

❑ Horizontal US ⇒ Minimum frequency
⇒ Maximum CPE power per subcarrier

Cyclic Prefix

❑ A copy of the last part of the symbol that is added to the front to overcome inter-symbol interference

❑ Protects against long delay spreads

❑ Cyclic Prefix Modes: 1/4, 1/8, 1/16, 1/32

Cyclic Prefix

Symbol
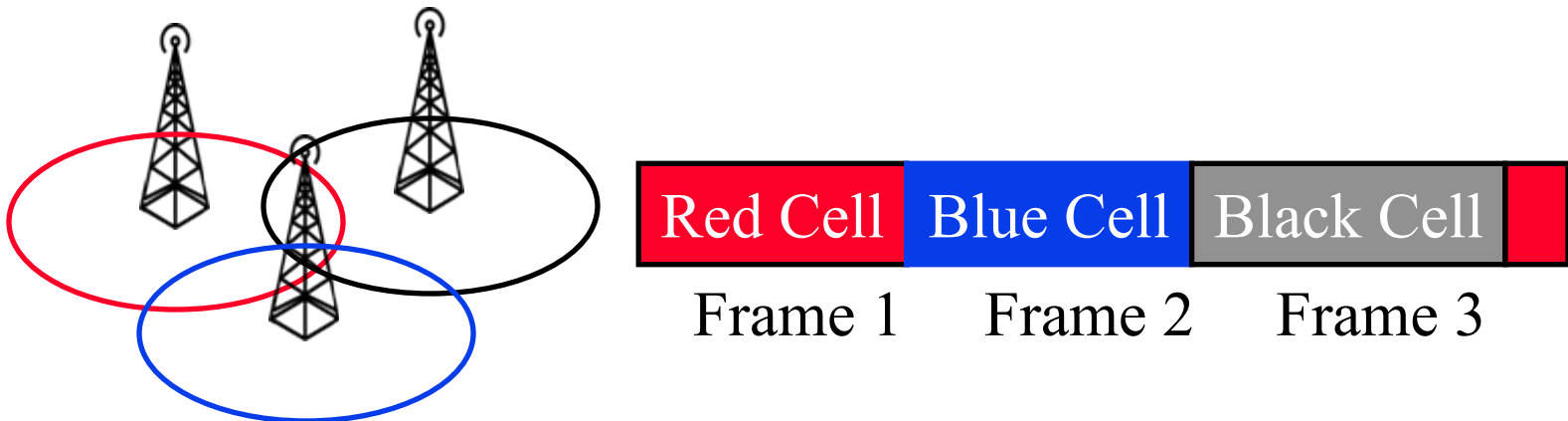
Transmitted:

Received:

Delay Spread
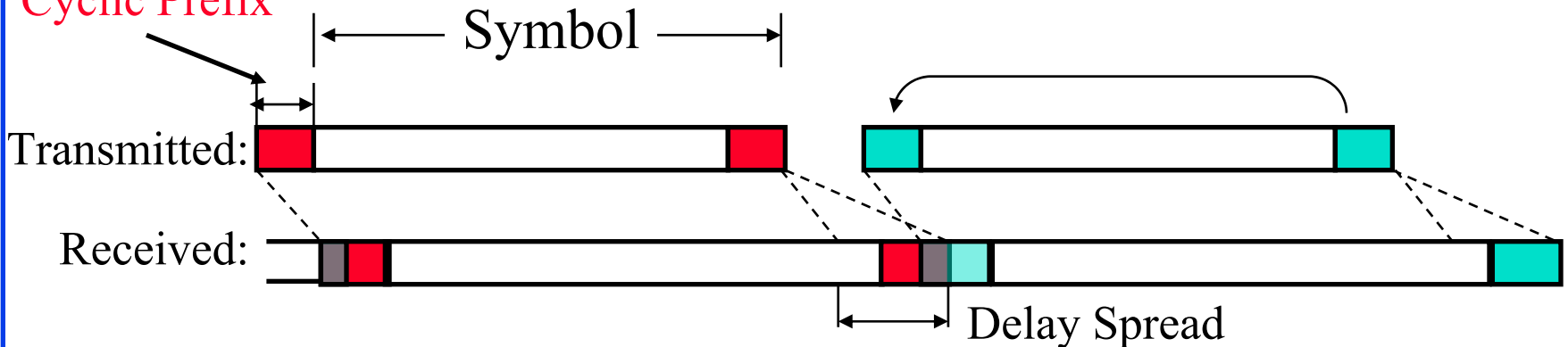
IEEE 802.22 PHY Parameters

Parameter	Value				Symbol
Channel Width	6 MHz				
Basic Sampling Frequency	6.856 MHz				F_s
FFT Size	2048				N_{FFT}
Inter-Carrier Spacing F_s/N_{FFT}	3.347656 KHz				Δf
FFT Period $1/\Delta f$	298.76 us				T_{FFT}
Cyclic Prefix	1/32	1/16	1/8	1/4	CP
CP Duration T_{FFT}/CP (us)	9.34	18.68	37.35	74.69	T_{CP}
Symbol Duration $T_{FFT}+T_{CP}$ (us)	308.1	317.4	336.1	373.4	T_{Sym}
EIRP	4W				
Guard subcarriers	184 L+1 DC+183 R=368				N_{LG}, N_{DC}, N_{RG}
Pilots	240				N_P
Data subcarriers	1440				N_D
Signal bandwidth $(N_D+N_P+N_{DC})\Delta f$	5.627 MHz				
Modulation	QPSK, 16-QAM, 64-QAM				
Coding Rate	1/2, 2/3, 3/4, 5/6				
Data rate	4.54 to 22.69 Mbps				

Self-Coexistence

❑ Two or more 802.22 networks in the same space/time/frequency

❑ Coexistent Beacon Protocol: To announce and find neighbors

❑ Resolution:

➢ Spectrum Etiquette: Find another available channel

➢ On-Demand Frame Contention Protocol:

❑ Multiple WRANs need to share one channel.

❑ Each WRAN gets a subset of frames in the superframe

Red Cell	Blue Cell	Black Cell	
Frame 1	Frame 2	Frame 3	

Co-Existence Beacon Protocol (CBP)

❑ For signaling to adjacent and overlapping WRAN cells and for geolocation

❑ CBP bursts are transmitted by selected CPEs at the end of US subframe.

❑ CPEs decode CBP packets from CPEs in cells operating on the same TV channel or adjacent channels.

❑ 14 types of CBP packets including CPE beacons.

❑ CPE beacons are transmitted by the CPEs and contain the TV channel #, backup channel #s, BS ID, CPE ID.

❑ CBP packets are used for coexistence and Geolocation

http://www.cse.wustl.edu/~jain/cse574-14/

IEEE 802.22 Coexistence Mode

Superframe n-1	Superframe n	Superframe n+1

|←——— 160 ms ———→|

	Frame 0		Frame 1	•••		Frame 15

Superframe Preamble	Frame Preamble	Superframe Control Header

WRAN1

WRAN2

Superframe Preamble	Frame Preamble	Superframe Control Header
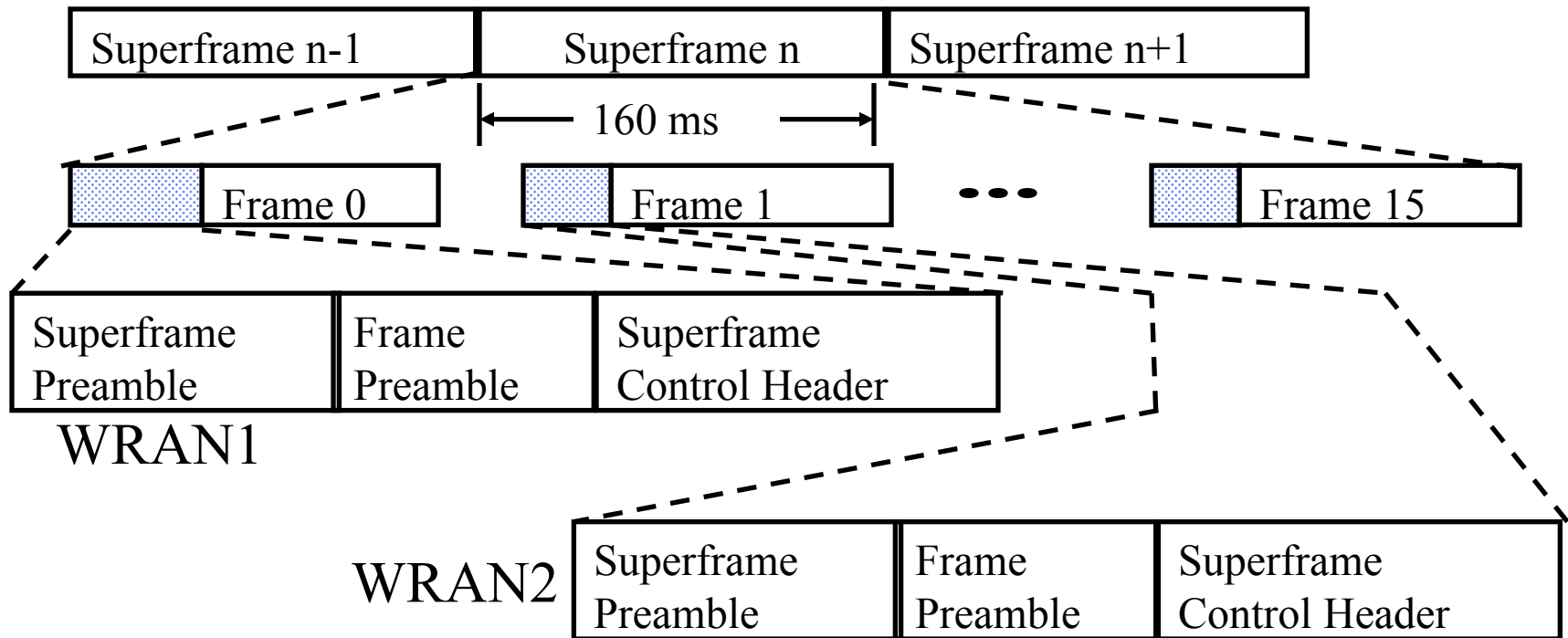
- ❑ **Coexistence Mode**: Multiple WRANs share a channel.
- ❑ Each WRAN is allocated a subset of Frames during 160ms
- ❑ First frame of each WRAN contains superframe preamble for that WRAN.

Geolocation

❑ **GPS based**: CPE's send their GPS coordinates

❑ **Measured**:

  ➢ Ranging is done between BS and CPEs

  ➢ BS can also ask other CPEs to listen to ranging and determine their distances from a CPE

Message Security

- **Confidentiality**: Encryption using AES-128 GCM (Advanced Encryption Standard with 128 bit keys and Galois/Counter Mode)

- **Integrity**: Integrity check value (ICV) using AES-GCM

- **Authentication**: RSA (Rivest-Shamir-Adleman) and ECC (Elliptic Curve Cryptography) based X.509 certificates Wireless Microphones are authenticated using ECC based digital signatures

- **Key Management**: Secure key exchange

- **Management Security**: Encrypted management messages

- **Device Security**: Trusted platform modules

Summary
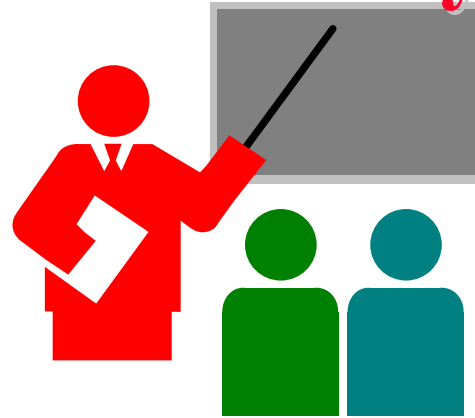
1. IEEE 802.22 wireless regional area network covers large rural areas using TV white spaces

2. MAC and PHY designed for long distances and long delay spreads

3. OFDMA with 2048 subcarriers.

4. Includes both database registration and spectrum sensing

5. Multiple IEEE 802.22 networks can co-exist in the same area on the same channel $\Rightarrow$ self-coexistence methods

Homework 10

❑ Download IEEE 802.22-2011 specification from GetIEEE802 website: http://standards.ieee.org/about/get/

Read page 13-24 of IEEE 802.22 specification and find the size of MAC addresses used by base stations.

Reading List

❑ IEEE Std 802.22-2011, Standard for Wireless Regional Area Networks—Part 22: Cognitive Wireless RAN Medium Access Control (MAC) and Physical Layer (PHY) specifications: Policies and procedures for operation in the TV Bands, July 2011,
http://standards.ieee.org/getieee802/download/802.22-2011.pdf

❑ A. Mody, G. Chouinard, "IEEE 802.22 Wireless Regional Area Networks (WRAN)," July 2012, Presentation
http://www.ieeeboston.org/publications/society_presentations/20120106_Overview_of_IEEE_802_22_Standard_v1.pdf

❑ Telesystem Innovations Inc., "TV White Spaces: Unlicensed Access Spectrum in Sub-700 MHz Band,"
http://frankrayal.files.wordpress.com/2012/04/tv-white-space-whitepaper.pdf

❑ M. Kalil, "Cognitive Radio: The IEEE 802.22 standard," Dec 2011, 34 slides, http://www.tu-ilmenau.de/fileadmin/public/iks/files/lehre/socs/SO-P2-L4-ieee802-Final.pdf

Wikipedia Links

- http://en.wikipedia.org/wiki/IEEE_802.22
- http://en.wikipedia.org/wiki/White_spaces_(radio)
- http://en.wikipedia.org/wiki/Super_Wi-Fi
- http://en.wikipedia.org/wiki/Cognitive_radio
- http://en.wikipedia.org/wiki/Dynamic_frequency_hopping
- http://en.wikipedia.org/wiki/Orthogonal_frequency-division_multiplexing
- http://en.wikipedia.org/wiki/Orthogonal_frequency-division_multiple_access
- http://en.wikipedia.org/wiki/Geolocation

References

- G. Ko, et al., "Channel Management in IEEE 802.22 WRAN Systems," IEEE Communications Magazine, Sept 2010, pp. 88-94, http://tinyurl.com/mez42zu

- Carl R. Stevenson, et al, "IEEE 802.22: The First Cognitive Radio Wireless Regional Area Network Standard," IEEE Communications Magazine, January 2009, pp 130-138.

- C. Cordeiro, et al., "IEEE 802.22: An Introduction to the First Wireless Standard based on Cognitive Radios," Journal of Communications, Vol. 1, No. 1, April 2006, http://www.cs.uc.edu/~cordeicm/papers/jcm06.pdf

IEEE 802.22 Specifications

❑ IEEE Std 802.22-2011, Standard for Wireless Regional Area Networks—Part 22: Cognitive Wireless RAN Medium Access Control (MAC) and Physical Layer (PHY) specifications: Policies and procedures for operation in the TV Bands, July 2011, http://standards.ieee.org/getieee802/download/802.22-2011.pdf

❑ IEEE Std 802.22.1-2010, "Part 22.1: Standard to Enhance Harmful Interference Protection for Low-Power Licensed Devices Operating in TV Broadcast Bands," Nov. 2010, http://standards.ieee.org/getieee802/download/802.22.1-2010.pdf

❑ IEEE Std 802.22.2-2012, "Part 22.2: Installation and Deployment of IEEE 802.22 Systems," Sep. 2012, http://standards.ieee.org/getieee802/download/802.22.2-2012.pdf

Acronyms

- AES   Advanced Encryption Standard
- AODCC   Adaptive On-Demand Channel Contention
- BE   Best Effort
- BS   Base Station
- BW   Bandwidth
- BWR   Bandwidth Request
- CBP   Co-Existence Beacon Protocol
- CBR   Constant Bit Rate
- CC   Channel Contention
- CHS   Channel Switching
- CINR   Carrier to Interference+Noise Ratio
- CPE   Customer Premises Equipment
- CQICH   Channel quality indicator channel
- DC   Direct Current
- DCD   Downstream Channel Descriptor
- DFH   Dynamic Frequency Hopping

Acronyms (Cont)

- DS   Downstream
- ECC   Elliptic Curve Cryptography
- FCC   Federal Communications Commission
- FCH   Frame Control Header
- FTP   File Transfer Protocol
- GCM   Galois/Counter Mode
- GHz   Giga Hertz
- GPS   Global Positioning System
- ID   Identification
- IDRP   Incumbent Detection Recovery Protocol
- IEEE   Institution of Electrical and Electronic Engineers
- LAN   Local Area Network
- MAC   Medium Access Control
- MAN   Metropolitan Area Network
- MHz   Mega Hertz
- MIB   Management Information Base

Acronyms (Cont)

- nrtPS   Non real time Polling Service
- nrtVBR   Non real time Variable Bit Rate
- OFDM   Orthogonal Frequency Division Multiplexing
- OFDMA   Orthogonal Frequency Division Multiple Access
- PAN   Personal Area Network
- PAR   Project Authorization Request
- PHY   Physical Layer
- PKM   Public Key Management
- QAM   Quadrature Amplitude Modulation
- QoS   Quality of Service
- QPSK   Quadrature Phase Shift Keying
- RAN   Regional Area Network
- REQ   Request
- RSA   Rivest-Shamir-Adelman
- RTG   Receive Time Guard
- SCH   Superframe Control Header

Acronyms (Cont)

- SOS   Spectrum Occupancy Sensing
- SSF   Spectrum Sensing Function
- SW   Software
- TDD   Time Division Duplexing
- TTG   Transmit Time Guard
- TV   Television
- TVWS   Television White Space
- UCD   Upstream Channel Descriptor
- UCS   Urgent Co-existence situation
- UGS   Unsolicited Grant Service
- US   United States
- WRAN   Wireless Regional Area Network
- WS   White Space