Regulation and Policy in the Telecommunications Industry TM 612-WS

By Dr. Raziq Yaqub
dr.raziq@gmail.com

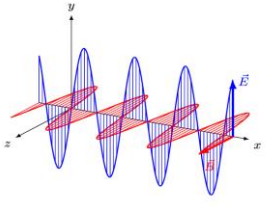
Lecture—08

Contents

Electromagnetic Waves and Spectrum

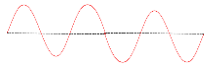
Electromagnetic Wave

- Consists of Electric Field and Magnetic Field
- The fields oscillate in two dimensions

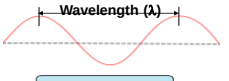


Electromagnetic Wave

- Radio waves are measured by:
  - Wavelength (λ)
  - or Frequency (f)



- The higher the frequency, the shorter the wavelength is
- Therefore GHz frequency wave is also called millimeter wave
- e.g. 30 GHz Frequency corresponds to 10 mm wavelength



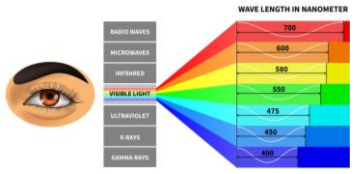
$$v = f\lambda$$

Velocity = Frequency x Wavelength

Or λ = c/f
c ≅ 3x10⁸m/s

Visible Light

- **Light that Human eye can detect**
  - Red light has a wavelength 700 **nanometers (or 428 THz frequency)**
  - Violet Light has a wavelength of 380 nanometer (or 989 THz frequency)
  - Red has the lowest frequency and longest wavelength, thus visible from far



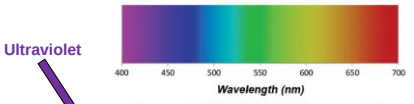
Wavelength 700 nanometer (428THz)

Wavelength 380 nanometer (989THz)

Dr. Raziq Yaqub

Electromagnetic Spectrum

- **Is a Continuum of all forms of light**



Ultraviolet

Infrared

Visible Spectrum

430 THz

Wavelength is **shorter** than that of **violet light** but longer than that of x-rays

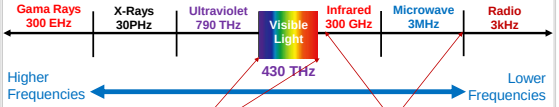
Wavelength is **greater than that of red light** but lesser than that of microwaves

Higher Frequencies ← → Lower Frequencies

Dr. Raziq Yaqub

Electromagnetic Spectrum

- **Spectrum consists of:**
  - X-Rays
  - Gama Rays
  - Infrared Waves
  - **Visible light waves**
  - Ultraviolet waves
  - Microwaves
  - Radio Waves

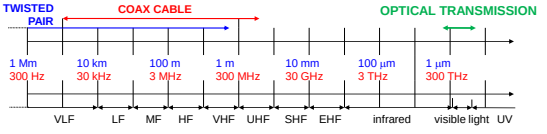


Higher Frequencies ← → Lower Frequencies

Where is Optical Fiber Communication?

Sweet spot for data communication is: Between 300 MHz and 6 GHz

Frequencies for communication



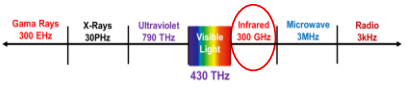
- VLF = Very Low Frequency
- LF = Low Frequency
- MF = Medium Frequency
- HF = High Frequency
- VHF = Very High Frequency

- UHF = Ultra High Frequency
- SHF = Super High Frequency
- EHF = Extra High Frequency
- UV = Ultraviolet Light

Sridhar Iyer

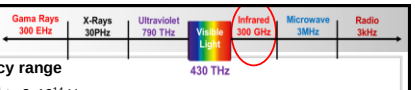
Electromagnetic Waves and Spectrum

Infrared Waves



Dr. Raziq Yaqub

Infrared Waves

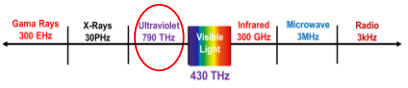


- **Infrared frequency range**
  - Roughly, $3x10^{11}$ to $2x10^{14}$ Hz
  - Useful in local point-to-point, multipoint applications within confined areas
- **These are invisible waves, and are detected as heat**
- **Used in**
  - Night Cameras, night vision security Cameras that detect heat, night goggles
  - Heat lamps
  - Toll/Parking

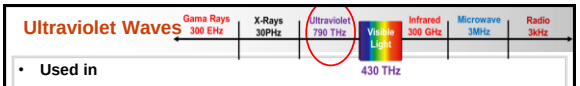
Dr. Raziq Yaqub

Electromagnetic Waves and Spectrum

Ultraviolet Waves



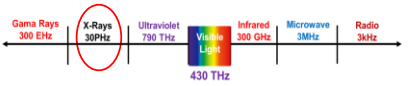
Ultraviolet Waves



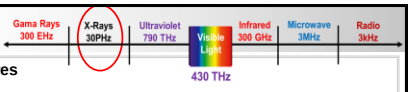
- **Used in**
  - Stimulates the production of vitamin D
  - Tanning
  - Eczema treatment
  - Sterilizing equipment
- **Also, can cause skin cancer**

Electromagnetic Waves and Spectrum

X-Rays



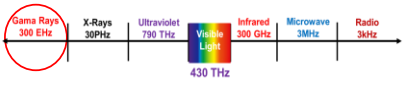
X-Rays



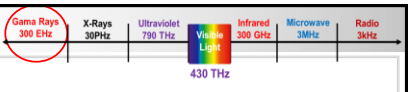
- **High Energy waves**
- **Used in**
  - Medicine to detect broken bones
  - Astronomy
- **Also, can cause cancer**

Electromagnetic Waves and Spectrum

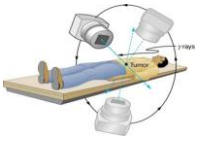
Gama Rays



Gama Rays

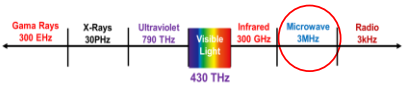


- **Arise from radio active decay of atomic nuclei**
  - Highest energy rays that are dangerous
- **Used in**
  - Medicines for treating tumors
- **Sun's Gama rays are blocked by atmosphere**



Electromagnetic Waves and Spectrum

Microwave

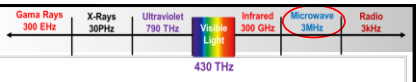


Frequencies for communication (Contd.)

Radio frequencies range from 9KHz to 400GHZ (ITU)

- **Microwave frequency range**
  - 1 GHz to 40 GHz
  - Directional beams possible
  - Suitable for point-to-point transmission
  - Used for satellite communications

Microwave



- **λ is shorter than radio, and longer than infrared/visible light**
- **Used for**
  - Radar, Satellite Communication
  - Medicine
  - Consumer use

Microwave Hyperthermia for Cancer treatment

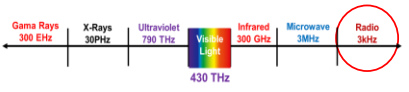
Microwave Link (Line of sight)

Internet Via Satellite

Microwave Oven Consumer Use

Electromagnetic Waves and Spectrum

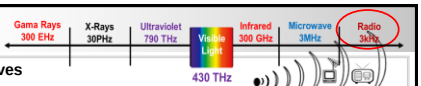
Radio Waves



Frequencies for communication (Contd.)

- **Radio frequency range**
  - 30 MHz to 1 GHz
  - Suitable for omnidirectional applications
- **VHF-/UHF-ranges for mobile radio**
  - Simple, small antenna for cars
  - Deterministic propagation characteristics, reliable connections
- **SHF and higher for directed radio links, satellite communication**
  - Small antenna, focusing
  - Large bandwidth available
- **Wireless LANs use frequencies in UHF to SHF spectrum**
  - Some systems planned up to EHF
  - Limitations due to absorption by water and oxygen molecules
    - Weather dependent fading, signal loss caused by heavy rainfall etc.

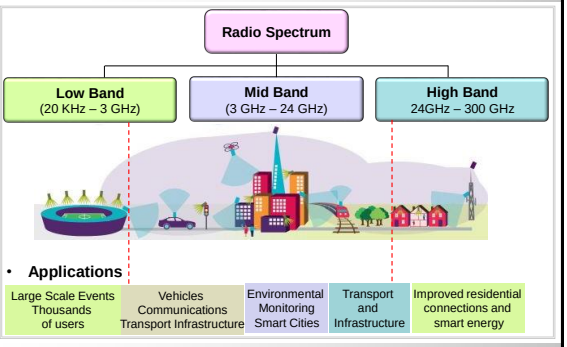
Radio Waves



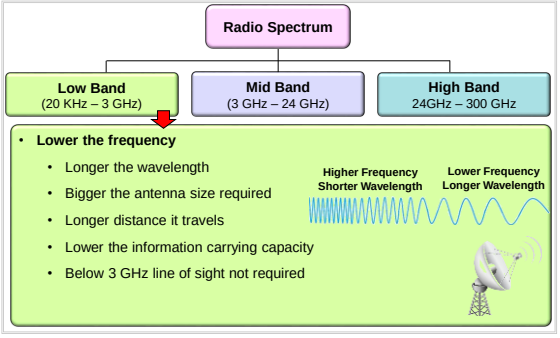
- **Low energy waves**
- **Ranging from 20 KHz to 300 GHz**
- **Used in wireless communication**
  - Radio (FM. AM), and TV
  - Remote Control items
  - Cell phones, Wireless phones

Classification of Radio Waves based on Frequency

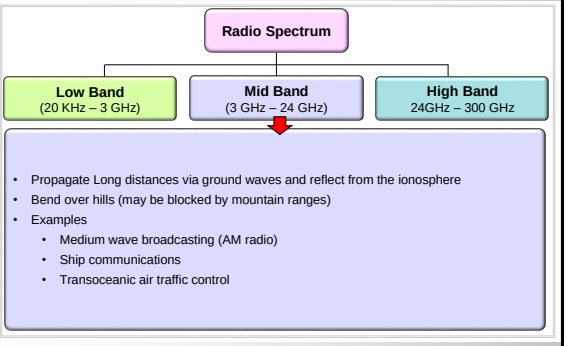
Classification of Radio Waves based on Frequency



Classification of Radio Waves based on Frequency (Contd.)

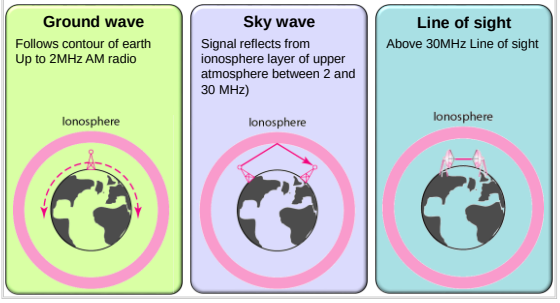


Classification of Radio Waves based on Frequency (Contd.)

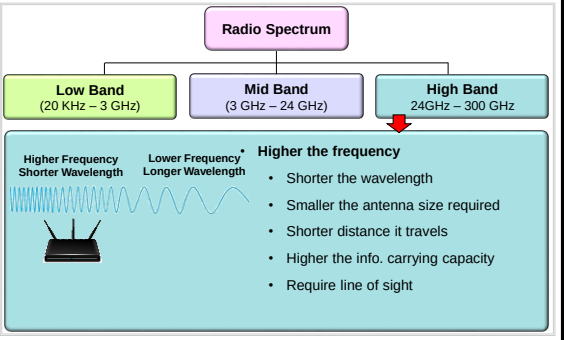


Classification of Radio Waves based on Frequency (Contd.)

- **Mid Band (3 GHz – 24 GHz) (Contd.)**



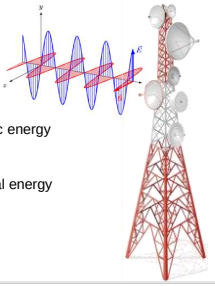
Classification of Radio Waves based on Frequency (Contd.)



Antenna Radiations

Antenna

- **Antenna**
  - A conductor used to radiate (Transmit) or collect (Receive) electromagnetic energy



- **Transmitter**
  - Converts electrical energy to electromagnetic energy
- **Receiver**
  - Converts Electromagnetic energy to electrical energy
- **Antenna Gain (in dB)**
  - Ratio of output Power to input power

Antenna Types

- **Isotropic antenna (Hypothetical point in space)**
  - Radiates in all directions (omnidirectional)

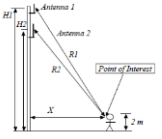
- **Directional Antenna**
  - Radiates or receives greater power in specific directions

- **Satellite**
  - Receives one frequency, amplifies/repeats signal and transmits on another frequency
  - Requires geo-stationary orbit (Height of 35,784km)
  - Antennas are hyperbolic

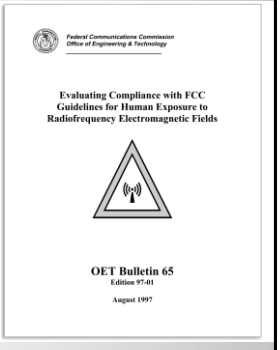
FCC Antenna Regulations

- **OET-65 FCC Regulations**

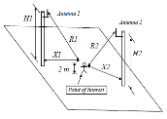
https://www.fcc.gov/wireless telecommunications/am-towers



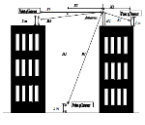
Single Tower Co-Located Antenna
Ground Level Exposure at 2m



FCC Antenna Regulations



Antennas on Multiple Towers Contributing to RF Field at Point of interest



Single Rooftop antenna, various exposure locations

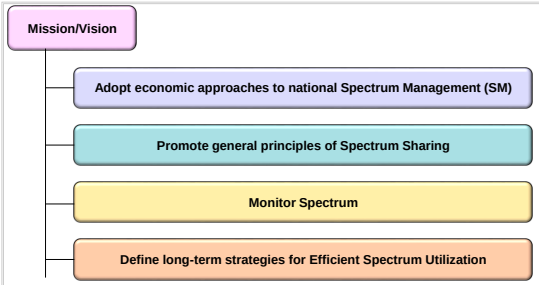
Power Threshold for Routine Evaluation of Amateur Radio Antennas

TABLE 1. Power threshold for routine evaluation of amateur radio stations.

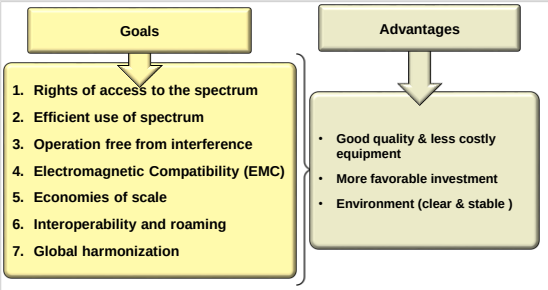
Wavelength Band	Transmitter Power (watts)
MF	
160 m	500
HF	
80 m	500
75 m	500
40 m	500
30 m	425
20 m	225
17 m	125
15 m	100
12 m	75
10 m	50
VHF (all bands)	50
UHF	
70 cm	70
33 cm	150
23 cm	200
13 cm	250
SHF (all bands)	250
EHF (all bands)	250

Spectrum and Role of Government

Government's Mission and Vision about Spectrum



Why Manage Spectrum?



Who Manages Spectrum?

- **Who Manages?**
  - Government (FCC, NTIA)
    - FCC = Federal Communications Commission
    - NTIA = National Telecommunications and Information Administration

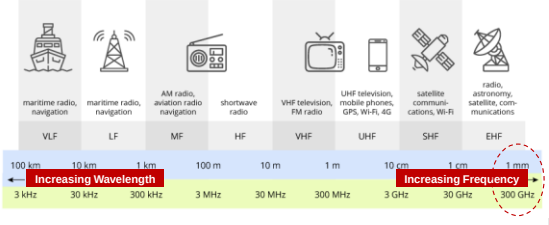
What does NTIA Manage?

- **NTIA oversees spectrum allocation for government usage**
  - Emergency services/ Public safety
  - Defense
  - Aviation
  - NASA



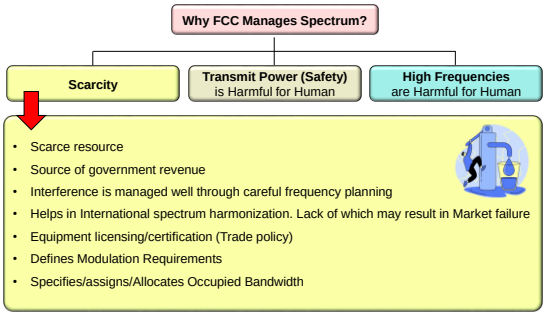
What does FCC Manage?

- **FCC oversees spectrum allocation for commercial usage**

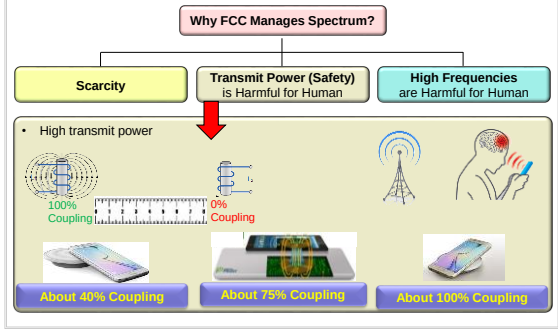


High Frequency waves are also called millimeter waves

Why FCC Manages Spectrum?

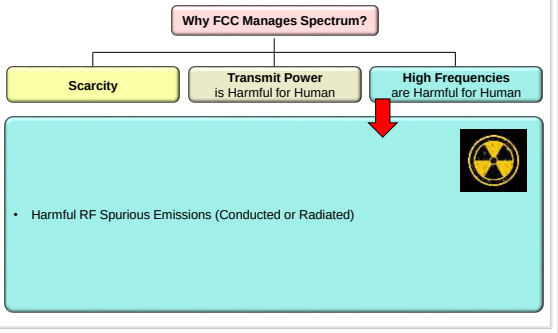


Why FCC Manages Spectrum?



e.g. For ISM the ERP= 30 dBm (1 watt)
For LTE ERP = up to 500 watts per channel (depending on the tower height)

Why FCC Manages Spectrum?

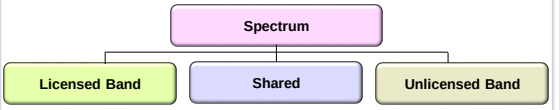


Classification of Radio Waves based on License

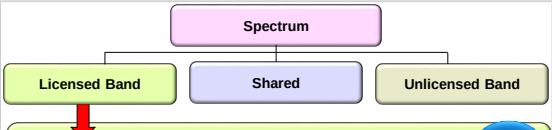
How FCC Manages Spectrum

- FCC Manages the Spectrum to Achieve its Goals through Licensing the Spectrum
- Commercial Spectrum is allocated/Assigned through Bidding
- Since 1993 the auctions have generated $200B+ in revenue for government

- Thus Radio Spectrum can be Classified based on Licensing



Classification of Spectrum—Licensed Band



License is required to be purchased for transmission or reception

Frequency planning avoids interference

Advantages:

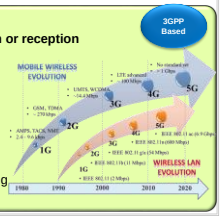
- Known and predictive interference

Disadvantages:

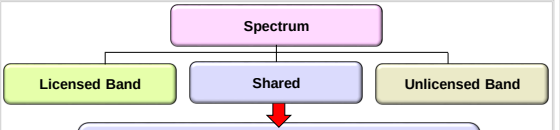
- Requires central management

Examples (Systems)

- GSM (2G), UMTS (3G), LTE (4G)/5G, TV broadcasting



Classification of Spectrum—Shared Band



Spectrum Sharing Decouples the spectrum from applications

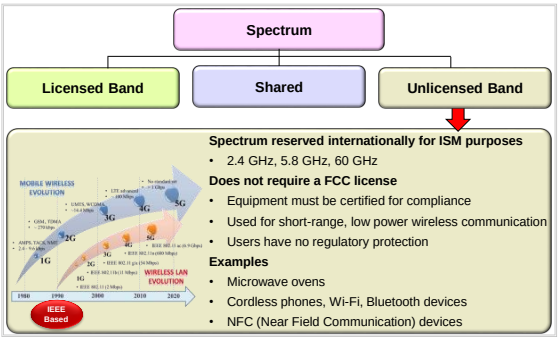
Cognitive Radio is one of the techniques for Spectrum Sharing

Future is of Shared Spectrum

Spectrum Sharing Allows

- Optimize use of the frequency bands
- Multiple categories of users to share the same frequency bands
- Mobile operators to use low-, mid-, and high-band frequencies and dynamically switch between LTE and 5G New Radio coverage based upon their network traffic demands.

Classification of Spectrum—Unlicensed Band



Spectrum reserved internationally for ISM purposes

- 2.4 GHz, 5.8 GHz, 60 GHz

Does not require a FCC license

- Equipment must be certified for compliance
- Used for short-range, low power wireless communication
- Users have no regulatory protection

Examples

- Microwave ovens
- Cordless phones, Wi-Fi, Bluetooth devices
- NFC (Near Field Communication) devices

ISM = Industrial Scientific and Medical

Frequencies for communication (Contd.)

Licensed Bands

9KHz to 300 MHZ in high demand (Especially VHF: 30-300MHZ)

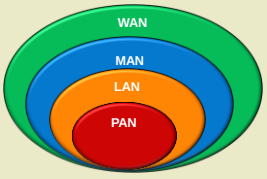
Unlicensed Bands

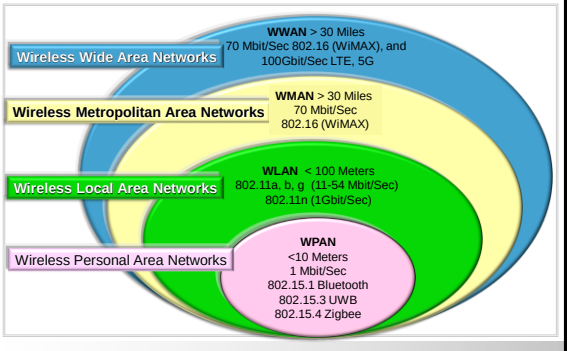
- 2.4 GHz, 5.8 GHz, 60 GHz

- **Different agencies in the world license and regulate spectrum**
  - www.fcc.gov - US
  - www.etsi.org - Europe
  - www.wpc.dot.gov.in - India
  - www.itu.org - International co-ordination

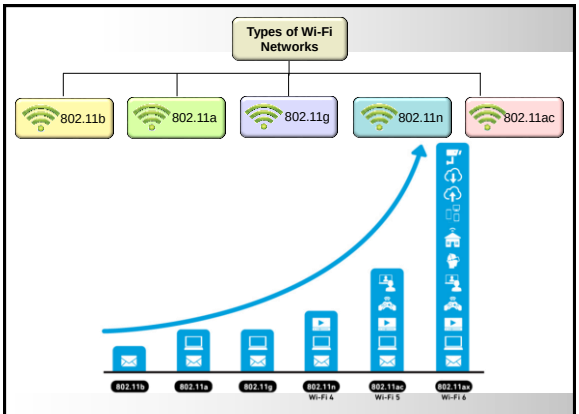
Unlicensed based Wireless Networks

- **IEEE Based Wireless Network**
  - Unlicensed Based
    - PAN
      - Personal Area Network
    - LAN
      - Local Area Network
  - Licensed Based
    - MAN
      - Metropolitan Area Network
    - WAN
      - Wide Area Network



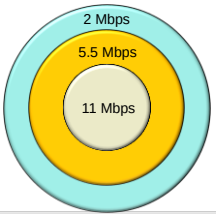


Main Types and Features of LAN (Wi-Fi)



802.11b

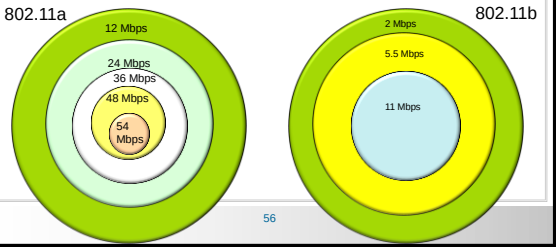
- **Supports Four Data Rates**
  - 1 Mbps, 2 Mbps, 5.5 Mbps, and 11 Mbps.
  - As terminal travels farther from its AP, the connection remains intact but connection speed decreases (falls back)



55

802.11a

- **Supports Four Data Rates of**
  - 6, 9, 12,18, 24, 36, 48, or 54 Mbps.
- **Supports rate fall back**
  - If distance between the transmitter and receiver increases, the data rate decreases



56

802.11g

- **802.11g**
  - Backward compatible
  - Operates in 2.4 GHz band
  - Delivers data rates from 6 Mbps to 54 Mbps.

57

Spectrum Stakeholders

- **Users**
  - **Content/Application providers**
    - Hollywood, music, games
  - **Manufacturers**
    - Chips, edge and network hardware and software
  - **Network service providers**
    - Mobile
    - BWFA (Broadband Wireless Fixed Access)
    - DBS (Direct broadcast satellite)
      - Satellite television (TV) systems in which the end users receive signals directly from geostationary satellites
      - Signals are broadcast in digital format at microwave frequencies.

Spectrum Policy Reforms

Need of Spectrum Policy Reform

- **Lots of new technologies are emerging—However:**
  - Spectrum is insufficient for emerging commercial uses
  - Available Spectrum is not used efficiently
  - License rules limit market flexibility
- **Problems:**
  - Sharing opportunities are missed
  - Innovation are blocked
  - High marginal cost for spectrum (e.g. auctions) bankrupt the service providers

These have created an Artificial spectrum scarcity!

Goals of Spectrum Policy Reform

- **Technology Revolution**
  - Accelerate the wireless broadband revolution
  - Promote the adoption of advanced technology
  - Encourage Convergence of Internet & wireless
  - Reform the underused spectrum
  - Enable new business models
    - e.g. MVNO and value added service providers

Chapter Review Questions (CRQ)

Chapter-08

Q1

- **Pick the most accurate statement.**
- **Electromagnetic Spectrum consists of**

A. X-Rays and Gama Rays

B. Microwaves and Radio Waves, the sweet spot for data communications

C. Infrared Waves and Ultraviolet Waves

D. All the statements are correct

Q2

- **Pick the most accurate statement**

Microwave frequency range is suitable for

A.Night Vision Security Cameras that detect heat

B.Point-to-point transmission/communication

C.Stimulating the production of vitamin D in human body

D.Optical fiber communication

Q3

- **Pick the most accurate statement**

A. Wireless LANs systems operate in ELF (Extremely Low Frequency, e.g. 300 Hz) considering human safety

B. One of the limitations of Wireless LANS systems is that they can operate in licensed band only

C. Wireless LANs use frequencies in UHF to SHF spectrum (between 2GHz to 30GHz)

D. One of the limitations of Wireless LANS systems is that they require ionosphere antennas to avoid weather dependent fading

Q4

- **Pick the most accurate statement**

One of the goals of Spectrum Policy Reform is:

A.Reform interference and penalize the interferers

B.Reform underused spectrum to enable new business models

C.Minimize the revenue made through bidding as it is tax payer's money

D.None of the statement is correct

Q5

- **Pick the most accurate statement**
- **FCC oversees spectrum allocation for:**
  - A. Commercial usage only (such as public radio, mobile communication, etc.)
  - B. For government usage (such as defense, aviation, etc.)
  - C. Making money to meet FCC's operations cost, and profit for government
  - D. Both A and B are correct

Answers to CRQ

Q1

- **Pick the most accurate statement.**
- **Electromagnetic Spectrum consists of**
  - A. X-Rays and Gama Rays
  - B. Microwaves and Radio Waves, the sweet spot for data communications
  - C. Infrared Waves and Ultraviolet Waves
  - D. All the statements are correct

D. All the statements are correct

Q2

- **Pick the most accurate statement**

Microwave frequency range is suitable for

A.Night Vision Security Cameras that detect heat

B.Point-to-point transmission/communication

C.Stimulating the production of vitamin D in human body

D.Optical fiber communication

B. Point-to-point transmission/communication

Q3

- **Pick the most accurate statement**
  - A. Wireless LANs systems operate in ELF (Extremely Low Frequency, e.g. 300 Hz) considering human safety
  - B. One of the limitations of Wireless LANS systems is that they can operate in licensed band only
  - C. Wireless LANs use frequencies in UHF to SHF spectrum (between 2GHz to 30GHz)
  - D. One of the limitations of Wireless LANS systems is that they require ionosphere antennas to avoid weather dependent fading

C. Wireless LANs use frequencies in UHF to SHF spectrum

Q4

- **Pick the most accurate statement**

One of the goals of Spectrum Policy Reform is:

A.Reform interference and penalize the interferers

B.Reform underused spectrum to enable new business models

C.Minimize the revenue made through bidding as it is tax payer's money

D.None of the statement is correct

B. Reform underused spectrum to enable new business models

Q5

- **Pick the most accurate statement**
- **FCC oversees spectrum allocation for:**
  - A. Commercial usage only (such as public radio, mobile communication, etc.)
  - B. For government usage (such as defense, aviation, etc.)
  - C. Making money to meet FCC's operations cost, and profit for government
  - D. Both A and B are correct

NTIA oversees spectrum allocation for government usage

A. Commercial usage only (such as public radio, mobile communication, etc.)

Home Assignment

Chapter-08

- **Review the entire chapter for reinforcement—nothing to submit today**
- **Important topics:**
  - Q1. Why and how FCC Manages Spectrum?
  - Q2. How government classifies the spectrum and what is its Mission and Vision about Spectrum
  - Spectrum Reform Policy-Need and Goals