Data and Computer Communications

Tenth Edition

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CHAPTER 10

Cellular Wireless Network

"After the fire of 1805, Judge Woodward was the central figure involved in reestablishing the town. Influenced by Major Pierre L'Enfant's plans for Washington, DC, Judge Woodward envisioned a modern series of hexagons with major diagonal avenues centered on circular parks, or circuses, in the center of the hexagons."

—*Endangered Detroit*,
Friends of the Book-Cadillac Hotel

Principles of Cellular Networks

- Developed to increase the capacity available for mobile radio telephone service
- Prior to cellular radio:
  - Mobile service was only provided by a high powered transmitter/receiver
  - Typically supported about 25 channels
  - Had an effective radius of about 80km

Cellular Network Organization

- Key for mobile technologies
- Based on the use of multiple low power transmitters
- Area divided into cells
  - In a tiling pattern to provide full coverage
  - Each one with its own antenna
  - Each is allocated its own range of frequencies
  - Served by a base station
    - Consisting of transmitter, receiver, and control unit
  - Adjacent cells are assigned different frequencies to avoid interference or crosstalk
    - Cells sufficiently distant from each other can use the same frequency band

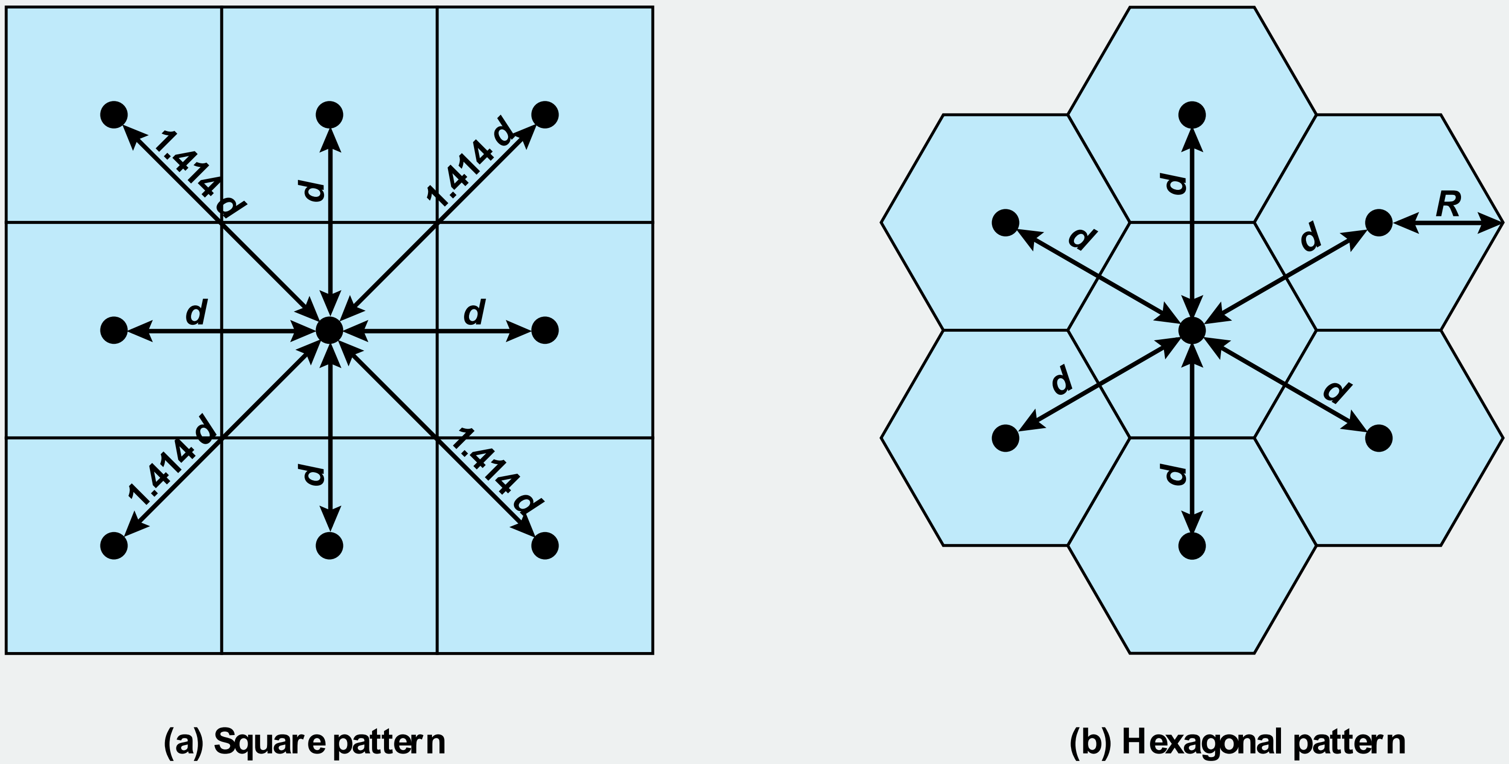


Figure 10.1 Cellular Geometries

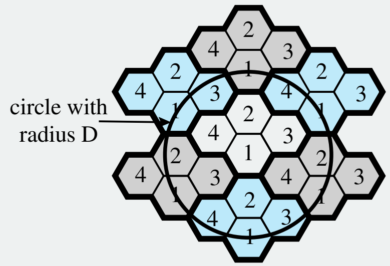
Frequency Reuse

Object is to share nearby cell frequencies without interfering with each other

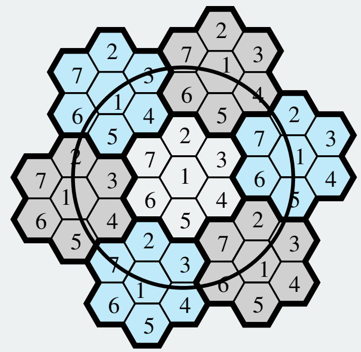
- Allows multiple simultaneous conversations
- 10 to 50 frequencies per cell

Power of base transceiver controlled

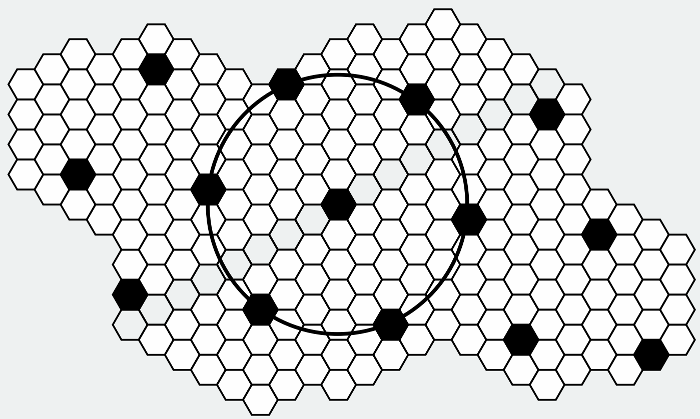
- Allow communications within cell on given frequency
- Limit escaping power to adjacent cells



(a) Frequency reuse pattern for $N = 4$



(b) Frequency reuse pattern for $N = 7$



(c) Black cells indicate a frequency reuse for $N = 19$

Figure 10.2 Frequency Reuse Patterns

Increasing Capacity

- Add new channels
  - Not all channels used to start with
- Frequency borrowing
  - Taken from adjacent cells by congested cells
  - Assign frequencies dynamically
- Cell splitting
  - Non-uniform topography and traffic distribution
  - Use smaller cells in high use areas

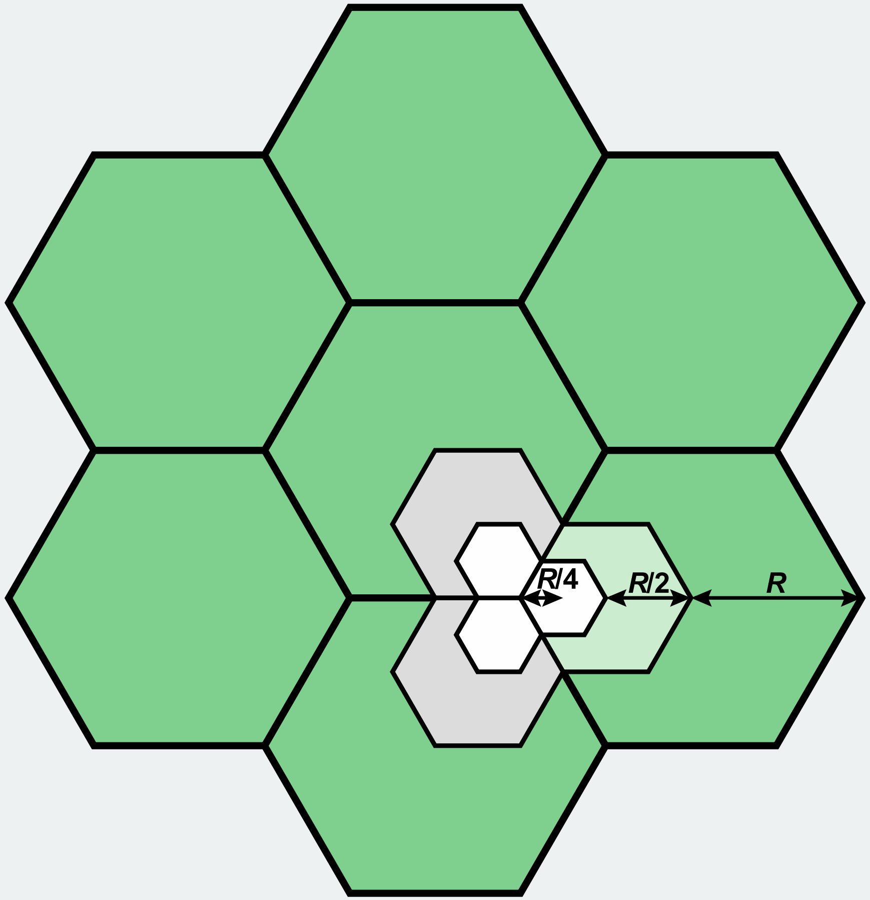


Figure 10.3 Cell Splitting with Cell Reduction Factor of $F = 2$

Increasing Capacity

Cell sectoring

- Cell is divided into wedge shaped sectors (3–6 per cell)
- Each sector is assigned a separate subset of the cell’s channels
- Directional antennas at base station are used to focus on each sector

Microcells

- As cells become smaller, antennas move from tops of hills and large buildings to tops of small buildings and sides of large buildings, to lamp posts, where they form microcells
- Use reduced power to cover a much smaller area
- Good for city streets in congested areas, along highways, inside large public buildings

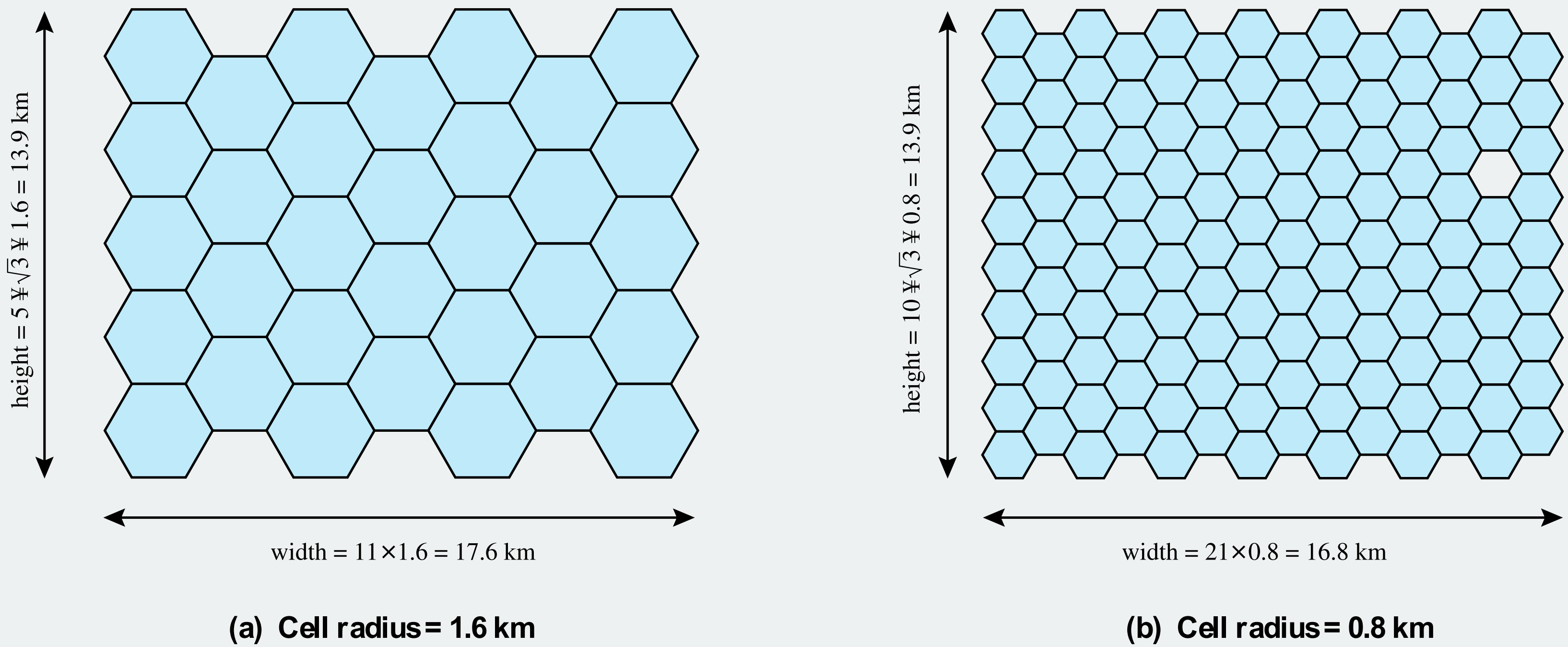


Figure 10.4 Frequency Reuse Example

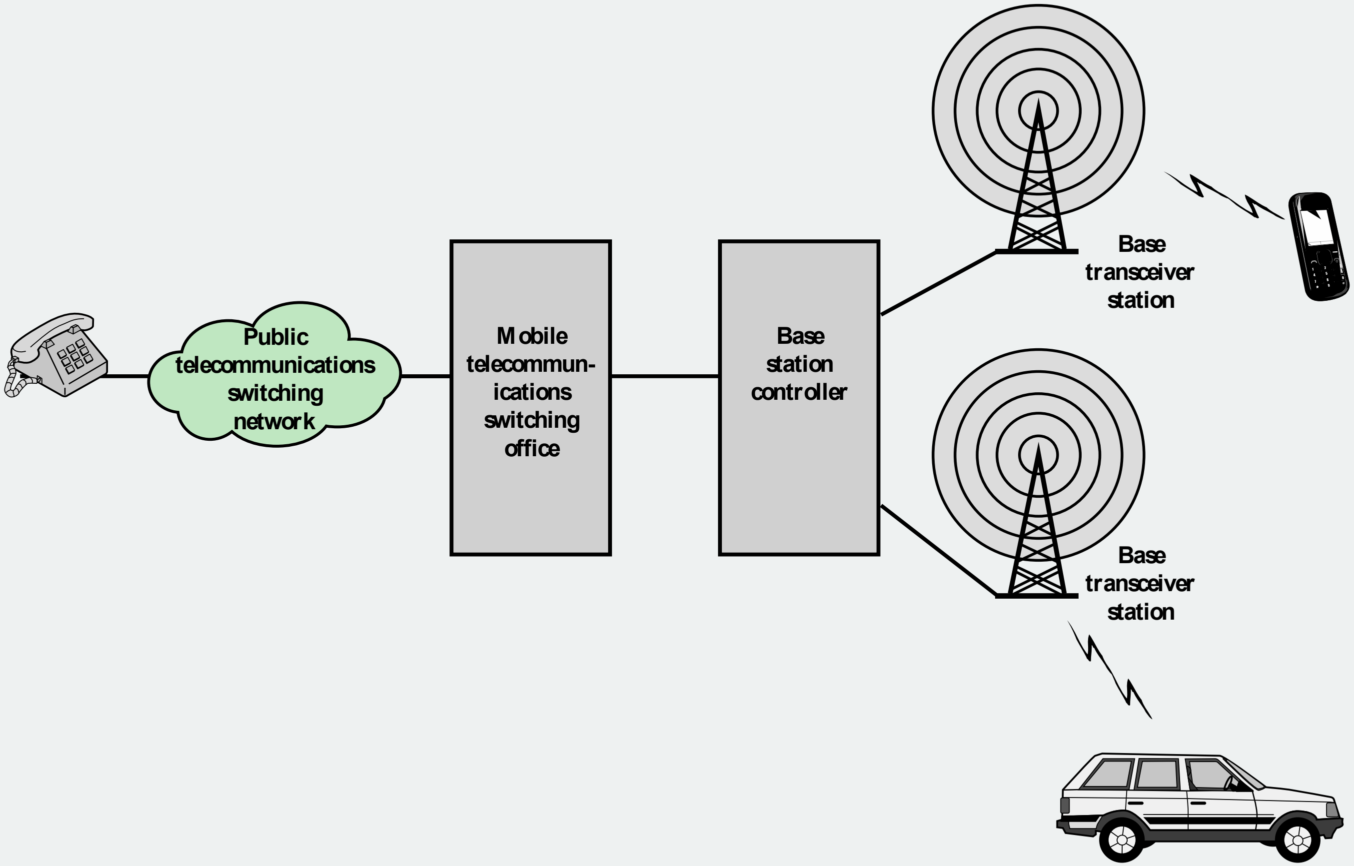


Figure 10.5 Overview of Cellular System

Cellular System Channels

Two types of channels are available between mobile unit and base station (BS)

- Control Channels
  - Set up and maintain calls
  - Establish relationship between mobile unit and nearest base station
- Traffic Channels
  - Carry voice and data

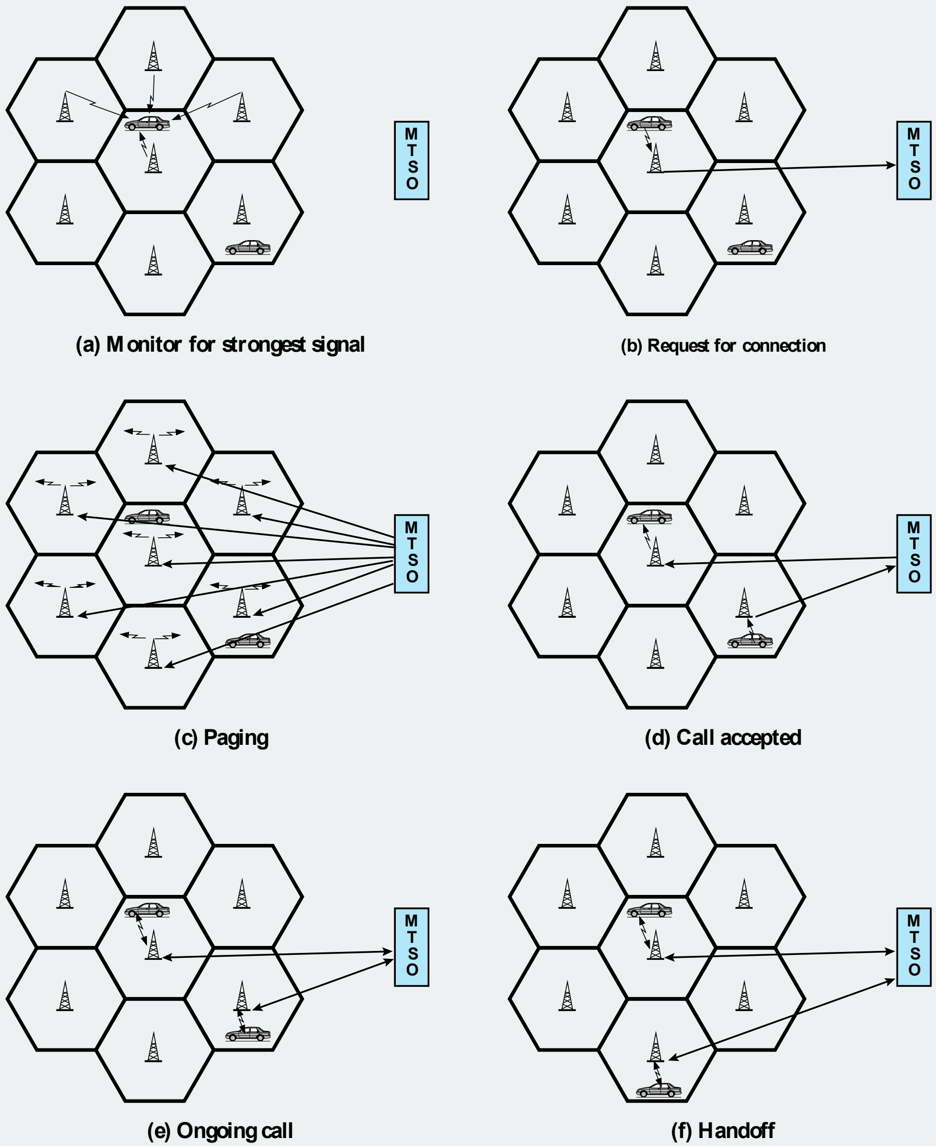


Figure 10.6 Example of Mobile Cellular Call

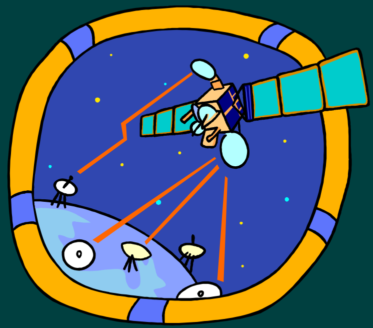
Other Functions

- Call blocking
  - After repeated attempts, if all traffic channels are busy, a busy tone is returned
- Call termination
  - When a user hangs up channels at the BS are released
- Call drop
  - When BS cannot maintain required signal strength
- Calls to/from fixed and remote mobile subscriber
  - MTSO connects to the PSTN

Mobile Radio Propagation Effects

- Signal strength
  - Strength of signal between BS and mobile unit needs to be strong enough to maintain signal quality
  - Not too strong so as to create co-channel interference
  - Must handle variations in noise

- Fading
  - Time variation of received signal
  - Caused by changes in transmission path(s)
  - Even if signal strength is in effective range, signal propagation effects may disrupt the signal



Design Factors

Propagation effects:

- Desired maximum transmit power level at BS and mobile units
- Typical height of mobile unit antenna
- Available height of the BS antenna

➢ Propagation effects are dynamic and difficult to predict

- Use model based on empirical data
  - Widely used model developed by Okumura and refined by Hata
    - Detailed analysis of Tokyo area
    - Produced path loss information for an urban environment
- Hata's model is an empirical formulation that takes into account a variety of conditions

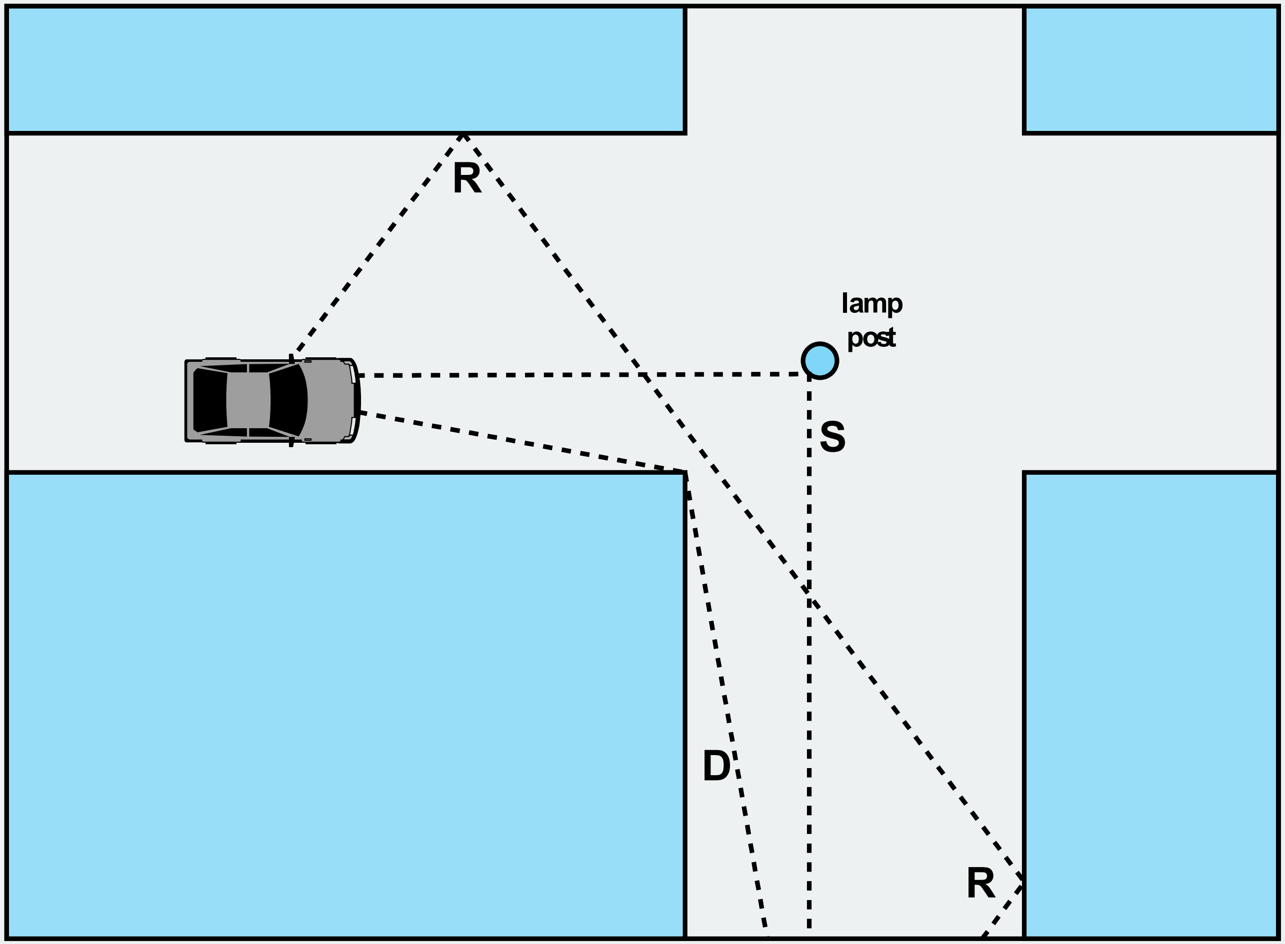


Figure 10.7 Sketch of Three Important Propagation Mechanisms: Reflection (R), Scattering (S), Diffraction (D)

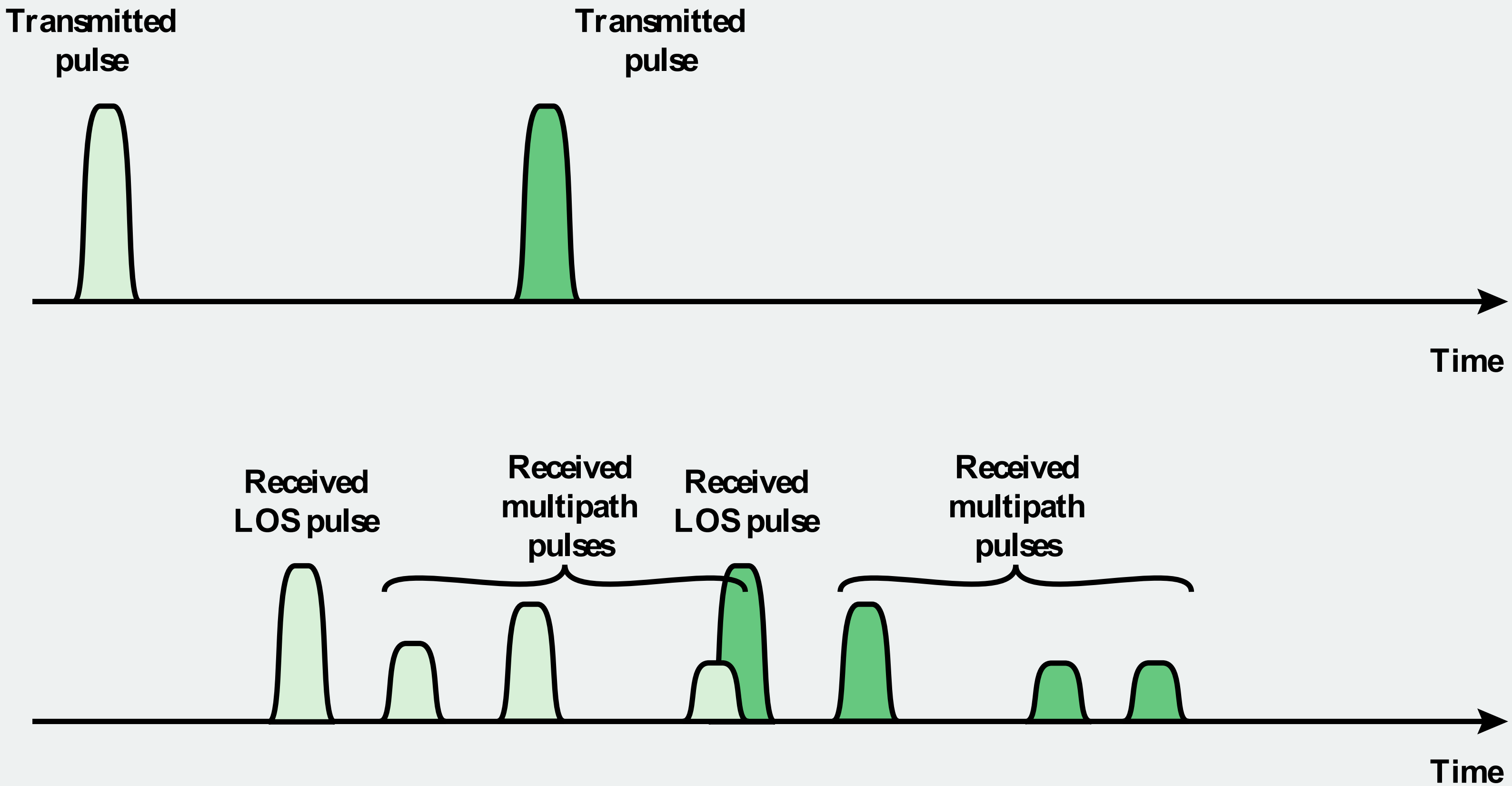


Figure 10.8 Two Pulses in Time-Variant Multipath

Types of Fading

Fast fading	Rapid variations in signal strength occur over distances of about one-half a wavelength
Slow fading	Change in the average received power level due to user passing different height buildings, vacant lots, intersections, etc.
Flat fading	All frequency components of the received signal fluctuate in the same proportions simultaneously
Selective fading	Attenuation occurring over a portion of the bandwidth of the signal

Error Compensation Mechanisms

- Forward error correction
  - Applicable in digital transmission applications
  - The ratio of total bits sent to data bits sent is between 2-3

- Adaptive equalization
  - Applied to transmissions that carry analog or digital information
  - Used to combat intersymbol interference
  - Involves gathering the dispersed symbol energy back together into its original time interval

Error Compensation Mechanisms

Diversity

- Based on the fact that individual channels experience independent fading events
- Use multiple logical channels between transmitter and receiver
- Send part of signal over each channel
- Doesn't eliminate errors, but reduces
- Space diversity involves physical transmission paths
- More commonly refers to frequency or time diversity
- Most important example of frequency diversity is spread spectrum

Table 10.1

Wireless Network Generations

Technol ogy	1G	2G	2. 5G	3G	4G
Design began	1970	1980	1985	1990	2000
Implementation	1984	1991	1999	2002	2012
Services	Analog voice	Digital voice	Higher capacity packetized data	Higher capacity, broadband	Completely IP based
Data rate	1.9. kbps	14.4 kbps	384 kbps	2 Mbps	200 Mbps
Multiplexing	FDMA	TDMA, CDMA	TDMA, CDMA	CDMA	OFDMA, SC-FDMA
Core network	PSTN	PSTN	PSTN, packet network	Packet network	IP backbone

First Generation (1G)

- Original cellular telephone networks
- Analog traffic channels
- Designed to be an extension of the public switched telephone networks
- The most widely deployed system was the Advanced Mobile Phone Service (AMPS)
- Also common in South America, Australia, and China

Second Generation (2G)

- Developed to provide higher quality signals, higher data rates for support of digital services, and greater capacity
- Key differences between 1G and 2G include:
  - Digital traffic channels
  - Encryption
  - Error detection and correction
  - Channel access
    - Time division multiple access (TDMA)
    - Code division multiple access (CDMA)

Third Generation (3G)

- Objective is to provide high-speed wireless communications to support multimedia, data, and video in addition to voice

3G capabilities:

- Voice quality comparable to PSTN
- 144 kbps available to users in high-speed motor vehicles over large areas
- 384 kbps available to pedestrians standing or moving slowly over small areas
- Support for 2.048 Mbps for office use
- Symmetrical and asymmetrical data rates
- Support for both packet-switched and circuit-switched data services
- Adaptive interface to Internet
- More efficient use of available spectrum
- Support for a wide variety of mobile equipment
- Flexibility to allow the introduction of new services and technologies

CDMA

- Dominant technology for 3G systems

CDMA schemes:

- Bandwidth (limit channel to 5 MHz)
- 5 MHz reasonable upper limit on what can be allocated for 3G
- 5 MHz is adequate for supporting data rates of 144 and 384 kHz

- Chip rate
  - Given bandwidth, chip rate depends on desired data rate, need for error control, and bandwidth limitations
  - Chip rate of 3 Mcpsor more is reasonable

CDMA – Multirate

- Provision of multiple fixed-data-rate channels to user
- Different data rates provided on different logical channels
- Logical channel traffic can be switched independently through wireless and fixed networks to different destinations
- Can flexibly support multiple simultaneous applications
- Can efficiently use available capacity by only providing the capacity required for each service

Fourth Generation (4G)

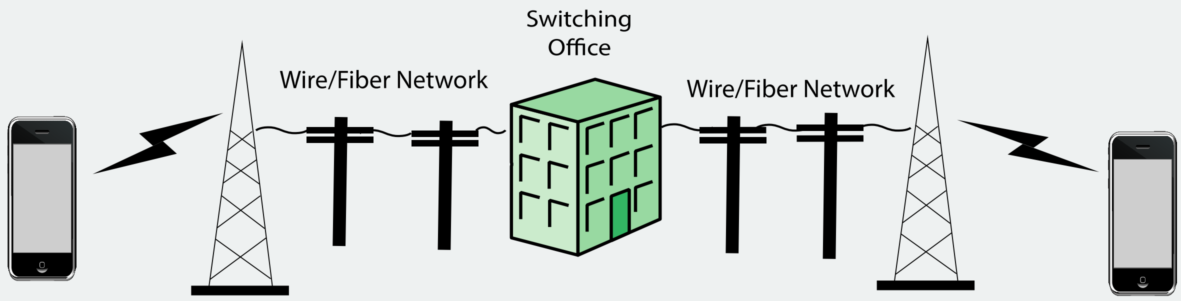
Provide ultra-broadband Internet access for a variety of mobile devices including laptops, smartphones, and tablet PCs

Minimum requirements:

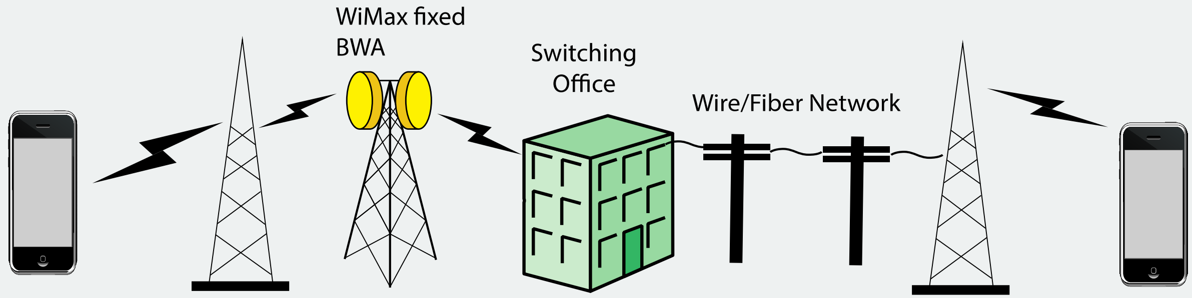
- Be based on an all-IP packet switched network
- Support peak data rates of up to approximately 100 Mbps for high-mobility mobile access and up to approximately 1 Gbps for low-mobility access such as local wireless access
- Dynamically share and use the network resources to support more simultaneous users per cell
- Support smooth handovers across heterogeneous networks
- Support high quality of service for next-generation multimedia applications

Support Mobile Web access and high-bandwidth applications such as high-definition mobile TV, mobile video conferencing, and gaming services

Designed to maximize bandwidth and throughput while also maximizing spectral efficiency



(a) Third Generation (3G) Cellular Network



(b) Fourth Generation (4G) Cellular Network

Figure 10.9 Third vs. Fourth Generation Cellular Networks

LTE - Advanced

- Based on use of orthogonal frequency division multiple access (OFDMA)

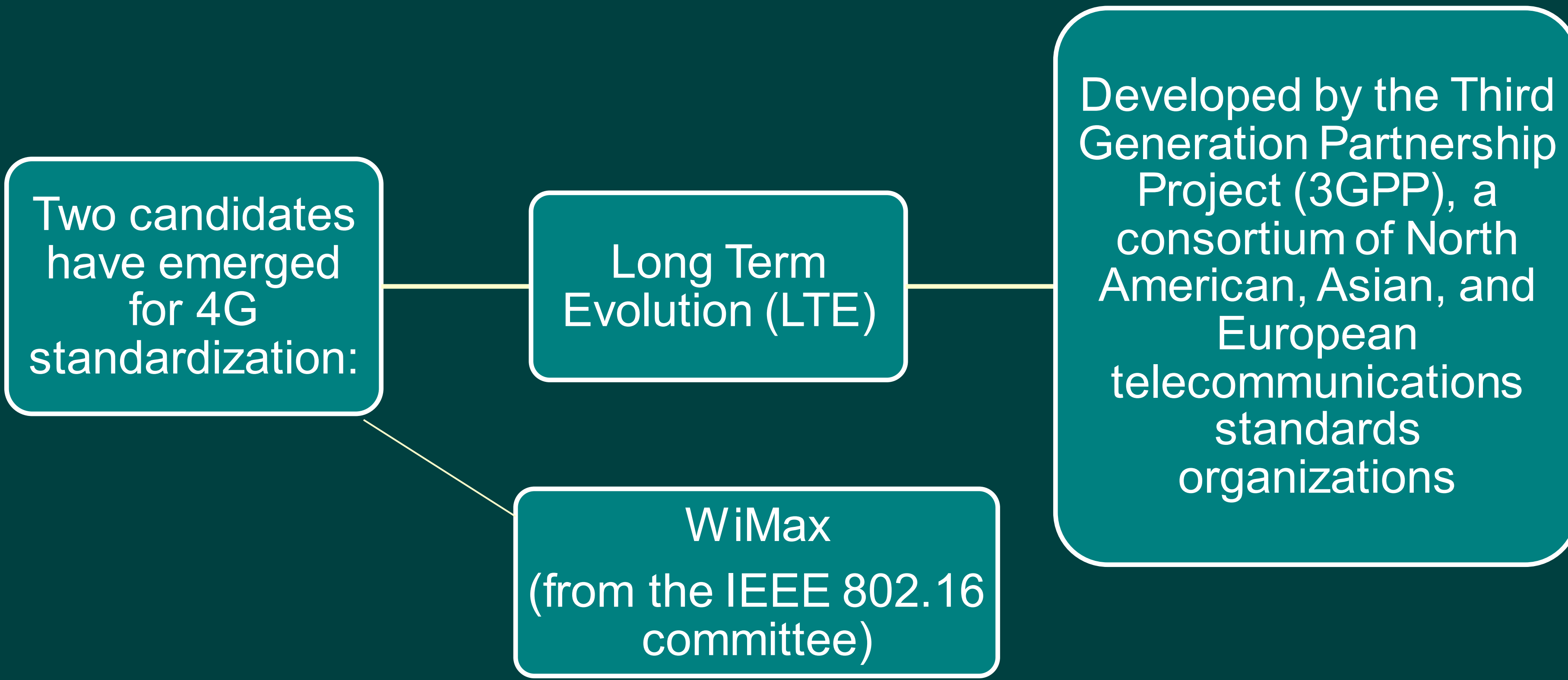


Table 10.2

Comparison of Performance Requirements for LTE and LTE-Advanced

System Performance		LTE	LTE-Advanced
Peak rate	Downlink	100 Mbps @20 MHz	1 Gbps @100 MHz
	Uplink	50 Mbps @20 MHz	500 Mbps @100 MHz
Control plane delay	Idle to connected	<100 ms	< 50 ms
	Dormant to active	<50 ms	< 10 ms
User plane delay		< 5ms	Lower than LTE
Spectral efficiency (peak)	Downlink	5 bps/Hz @2 2	30 bps/Hz @8 8
	Uplink	2.5 bps/Hz @1 2	15 bps/Hz @4 4
Mobility		Up to 350 km/h	Up to 350—500 km/h

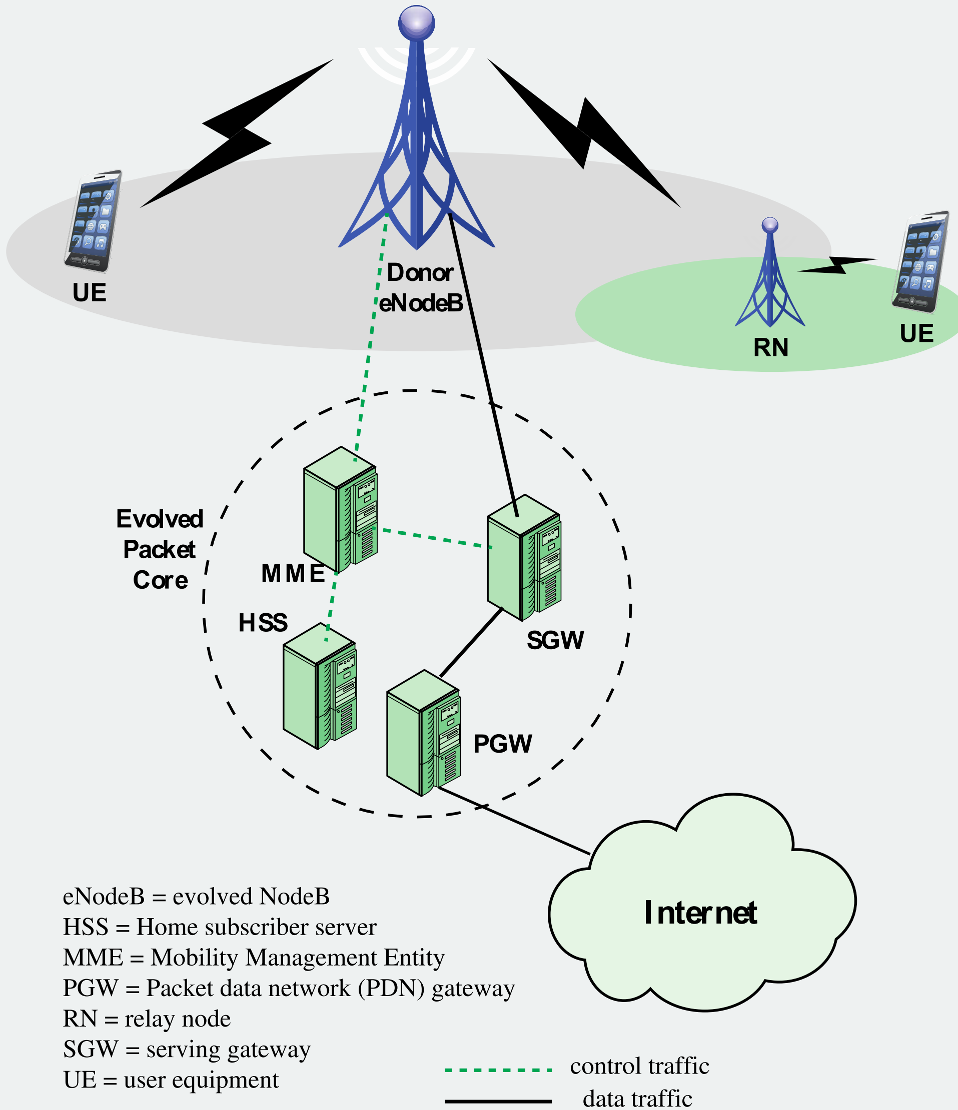


Figure 10.10 LTE-Advanced Configuration Elements

Femtocells

- A low-power, short range, self-contained base station
- Term has expanded to encompass higher capacity units for enterprise, rural and metropolitan areas
- By far the most numerous type of small cells
- Now outnumber macrocells

- Key attributes include:
  - IP backhaul
  - Self-optimization
  - Low power consumption
  - Ease of deployment

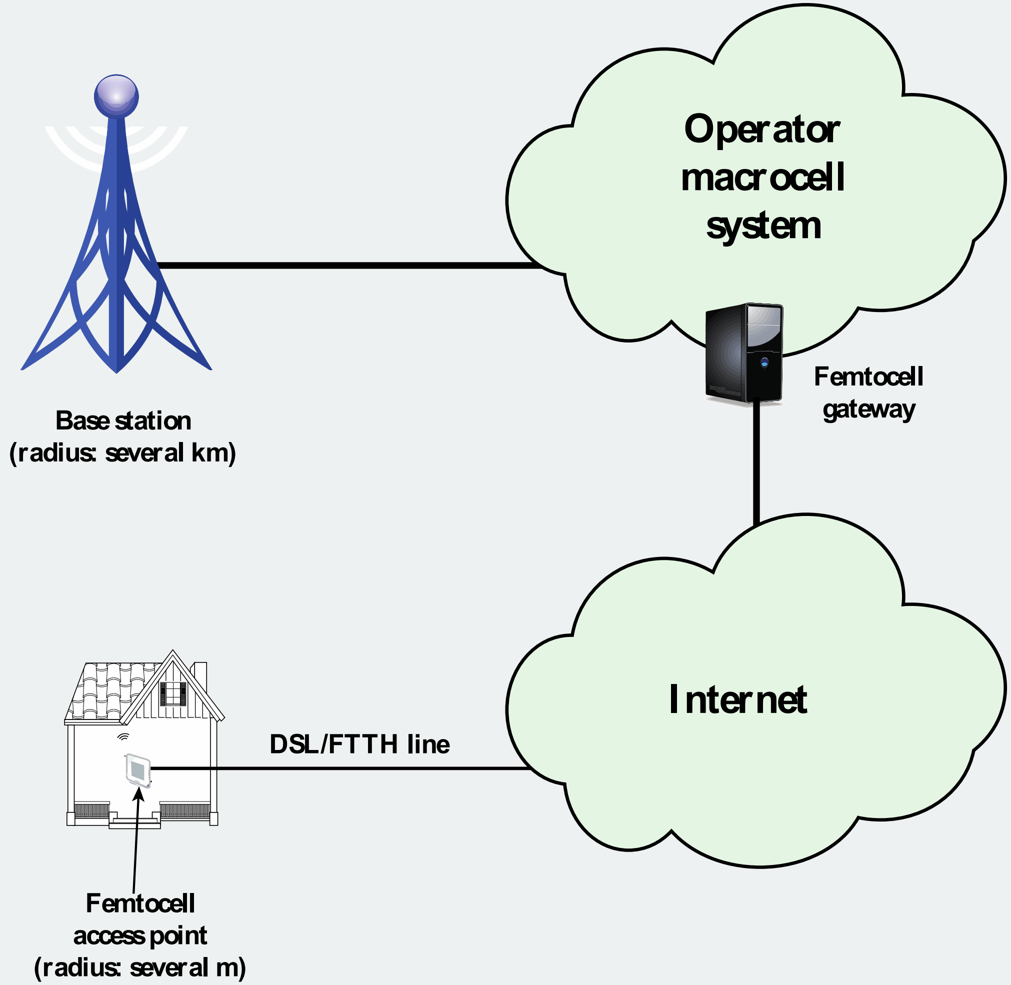


Figure 10.11 The Role of Femtocells

LTE-Advanced

- Relies on two key technologies to achieve high data rates and spectral efficiency:
  - Orthogonal frequency-division multiplexing (OFDM)
    - Signals have a high peak-to-average power ratio (PAPR), requiring a linear power amplifier with overall low efficiency
    - This is a poor quality for battery-operated handsets
  - Multiple-input multiple-output (MIMO) antennas

Table 10. 3

Characteristics of TDD and FDD for LTE-Advanced

PARAMETER	LTE-TDD	LTE-FDD
Paired spectrum	Does not require paired spectrum as both transmit and receive occur on the same channel.	Requires paired spectrum with sufficient frequency separation to allow simultaneous transmission and reception.
Hardware cost	Lower cost as no diplexer is needed to isolate the transmitter and receiver. As cost of the UEs is of major importance because of the vast numbers that are produced, this is a key aspect.	Diplexer is needed and cost is higher.
Channel reciprocity	Channel propagation is the same in both directions which enables transmit and receive to use one set of parameters.	Channel characteristics are different in the two directions as a result of the use of different frequencies.
UL / DL asymmetry	It is possible to dynamically change the UL and DL capacity ratio to match demand.	UL / DL capacity is determined by frequency allocation set out by the regulatory authorities. It is therefore not possible to make dynamic changes to match capacity. Regulatory changes would normally be required and capacity is normally allocated so that it is the same in either direction.
Guard period / guard band	Guard period required to ensure uplink and downlink transmissions do not clash. Large guard period will limit capacity. Larger guard period normally required if distances are increased to accommodate larger propagation times.	Guard band required to provide sufficient isolation between uplink and downlink. Large guard band does not impact capacity.
Discontinuous transmission	Discontinuous transmission is required to allow both uplink and downlink transmissions. This can degrade the performance of the RF power amplifier in the transmitter.	Continuous transmission is required.
Cross slot interference	Base stations need to be synchronized with respect to the uplink and downlink transmission times. If neighboring base stations use different uplink and downlink assignments and share the same channel, then interference may occur between cells.	Not applicable

(Table can be found on page 349 in textbook)

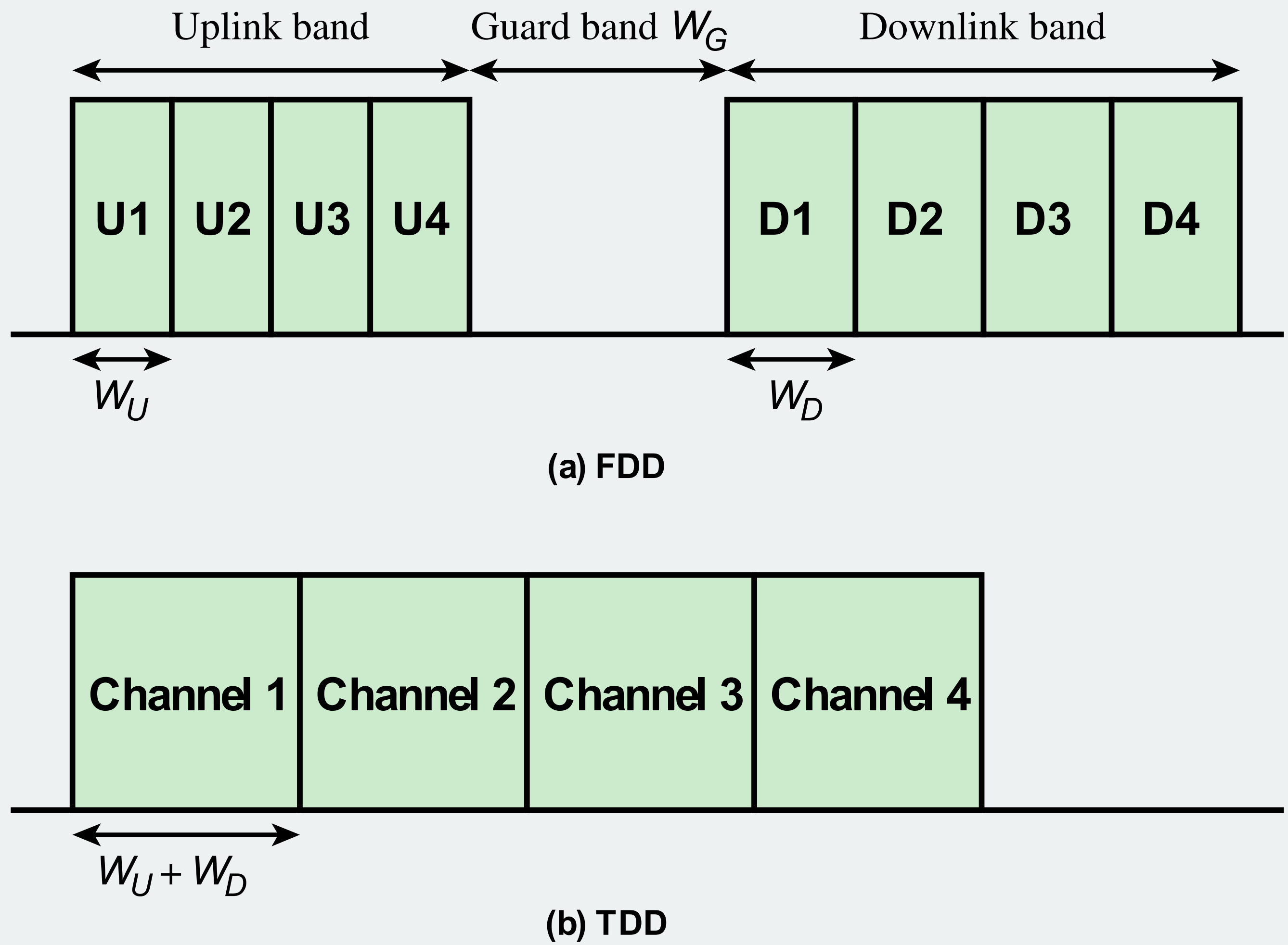


Figure 10.12 Spectrum Allocation for FDD and TDD

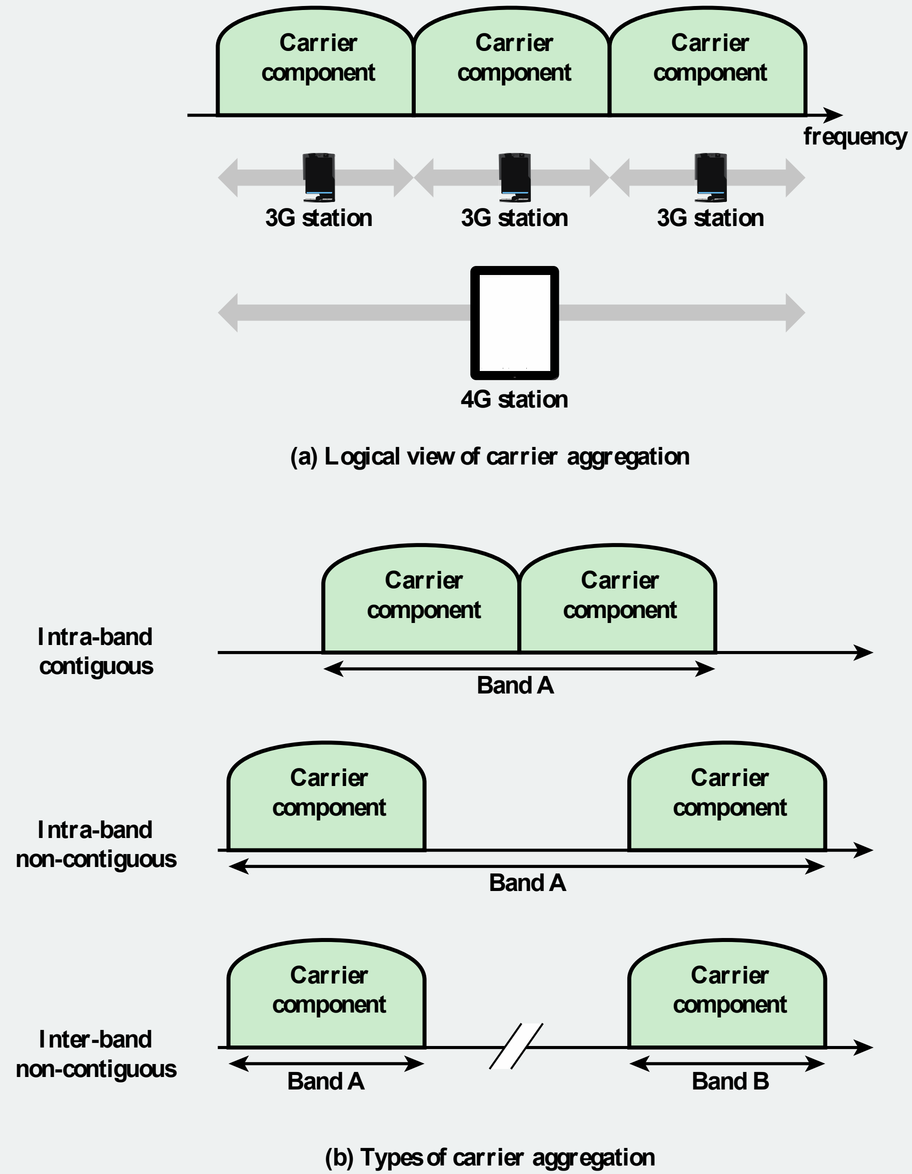


Figure 10.13 Carrier Aggregation

Summary

- Principles of cellular networks
  - Cellular network organization
  - Operation of cellular systems
  - Mobile radio propagation effects
  - Fading in the mobile environment
- Cellular network generations
  - First generation
  - Second generation
  - Third generation
  - Fourth generation
- LTE-Advanced
  - Architecture
  - Transmission characteristics