Data and Computer Communications

Tenth Edition

by William Stallings

CHAPTER 18

Wireless Networks

"It was my old housekeeper who heard of it first by that strange wireless by which such people collect the news of the countryside.

—*The Adventure of the Lion's Mane,*
by Sir Arthur Conan Doyle

Fixed Broadband Wireless Access

- Increasing interest is being shown in competing wireless technologies for subscriber access
- Approaches are referred to as *wireless local loop* (WLL) or *fixed wireless access*
- WiMAX
  - Most prominent fixed broadband wireless access (fixed BWA) system
  - Based on the IEEE 802.16 standard

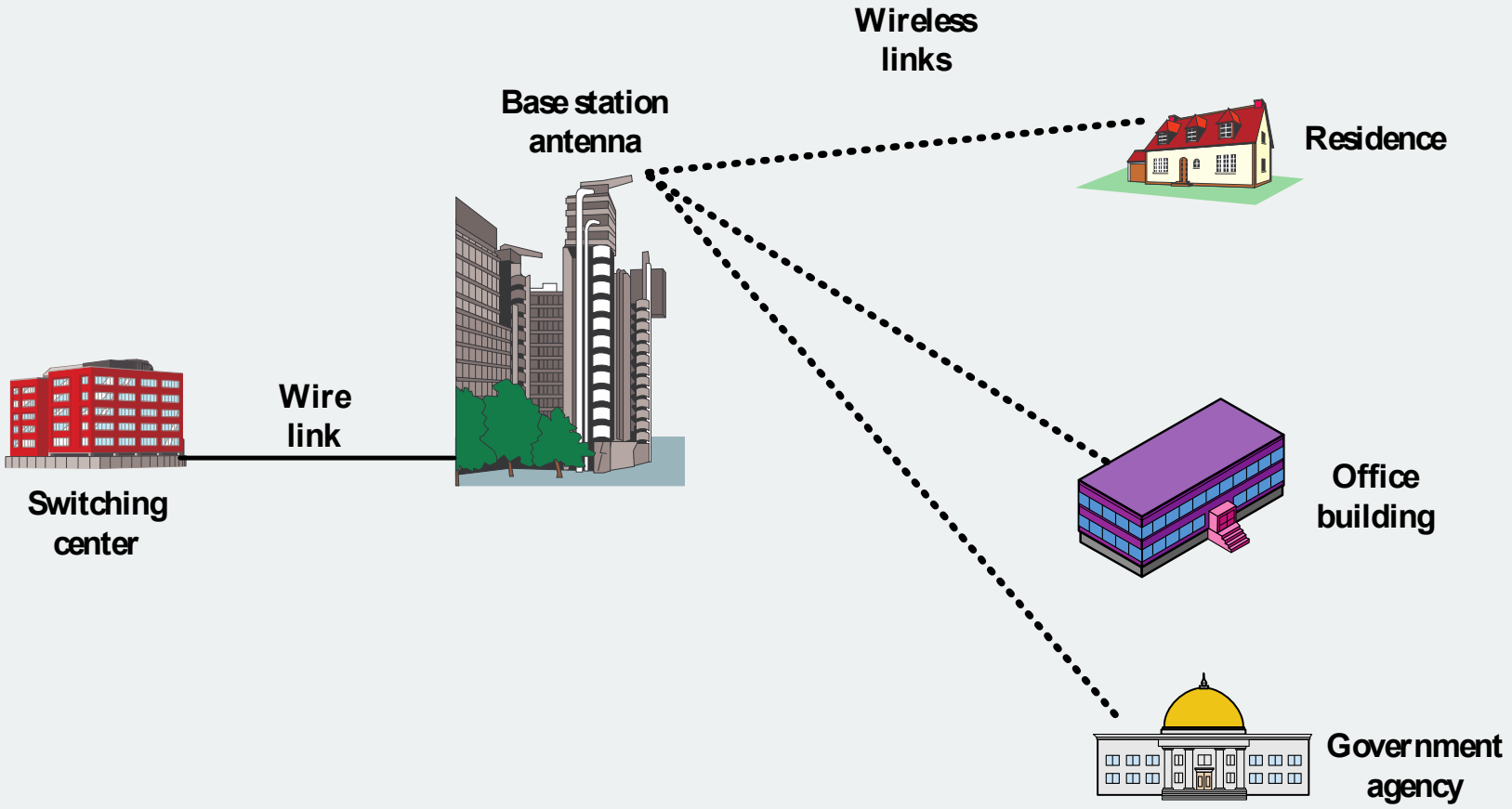


Figure 18.1 Fixed Broadband Wireless Configuration

Fixed WBA Advantages

- Cost
  - Wireless systems are less expensive than wired systems
- Installation time
  - Typically can be installed rapidly
  - Key stumbling blocks:
    - Obtaining permission to use a given frequency band
    - Finding a suitable elevated site for the BS antennas
- Selective installation
  - Radio units are installed only for those subscribers who want the service at a given time

Evaluating WBA

- WBA needs to be evaluated with respect to two alternatives:

Wired scheme using existing installed cable

- Lines not having a line of sufficient quality or are too far from the central office to effectively use xDSL
- Cable two-way data services not offered by cable provider
- WLL has become cost-competitive with wired schemes

Mobile cellular technology

- 4G cellular systems provide broadband support
- Fixed WBA BS can cover a larger area
- Higher data rates can be achieved

WiMAX/IEEE 802.16

- Need within the industry to develop standards for BWA services
- 802.16 working group was set up in 1999 to develop broadband wireless standards
- WiMAX (Worldwide Interoperability for Microwave Access) Forum
  - Formed to promote 802.16 standards and to develop interoperability specifications

- Charter for the group was to develop standards that:
  - Use wireless links with microwave or millimeter wave radios
  - Use licensed spectrum (typically)
  - Are metropolitan in scale
  - Provide public network service to fee-paying customers (typically)
  - Use point-to-multipoint architecture with stationary rooftop or tower-mounted antennas
  - Provide efficient transport of heterogeneous traffic supporting quality of service (QoS)
  - Are capable of broadband transmissions (>2 Mbps)

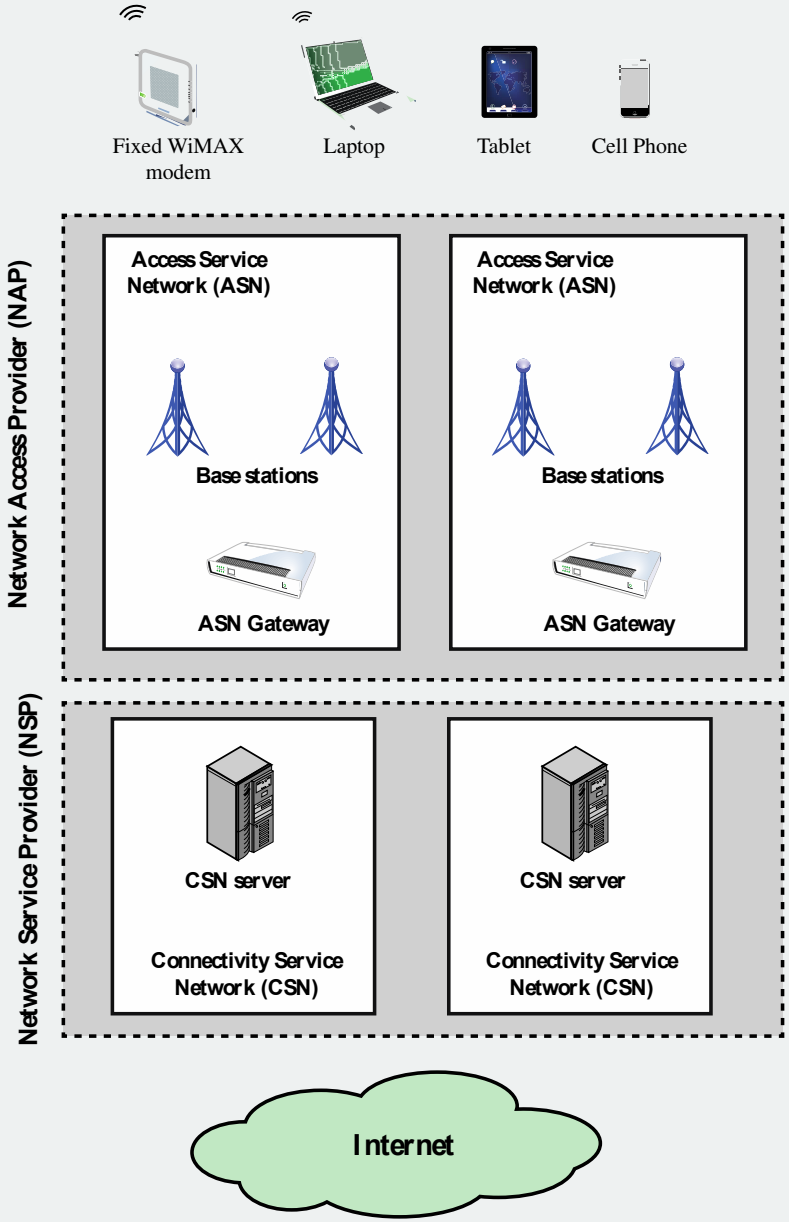


Figure 18.2 Elements of the WiMAX Network Reference Model

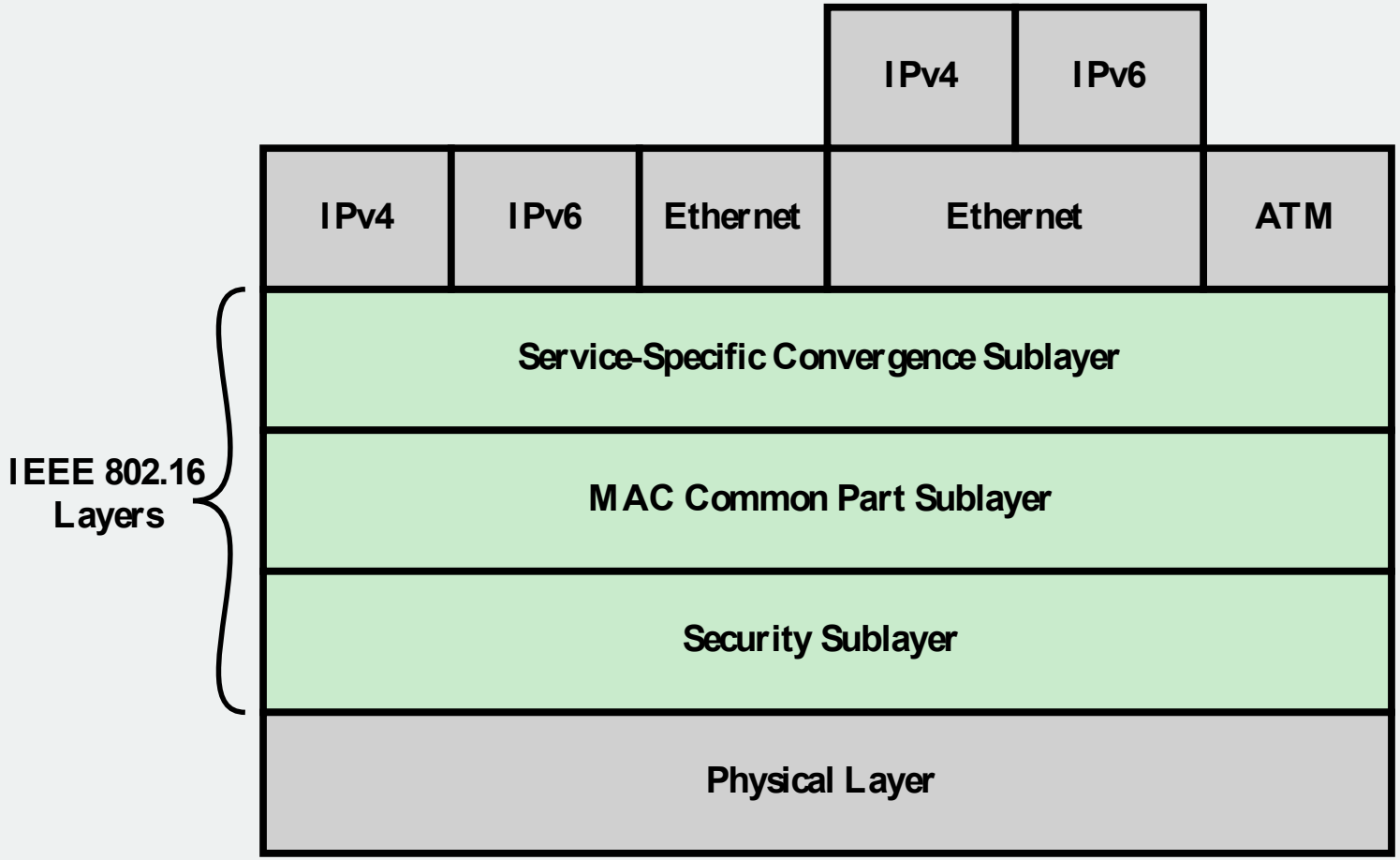
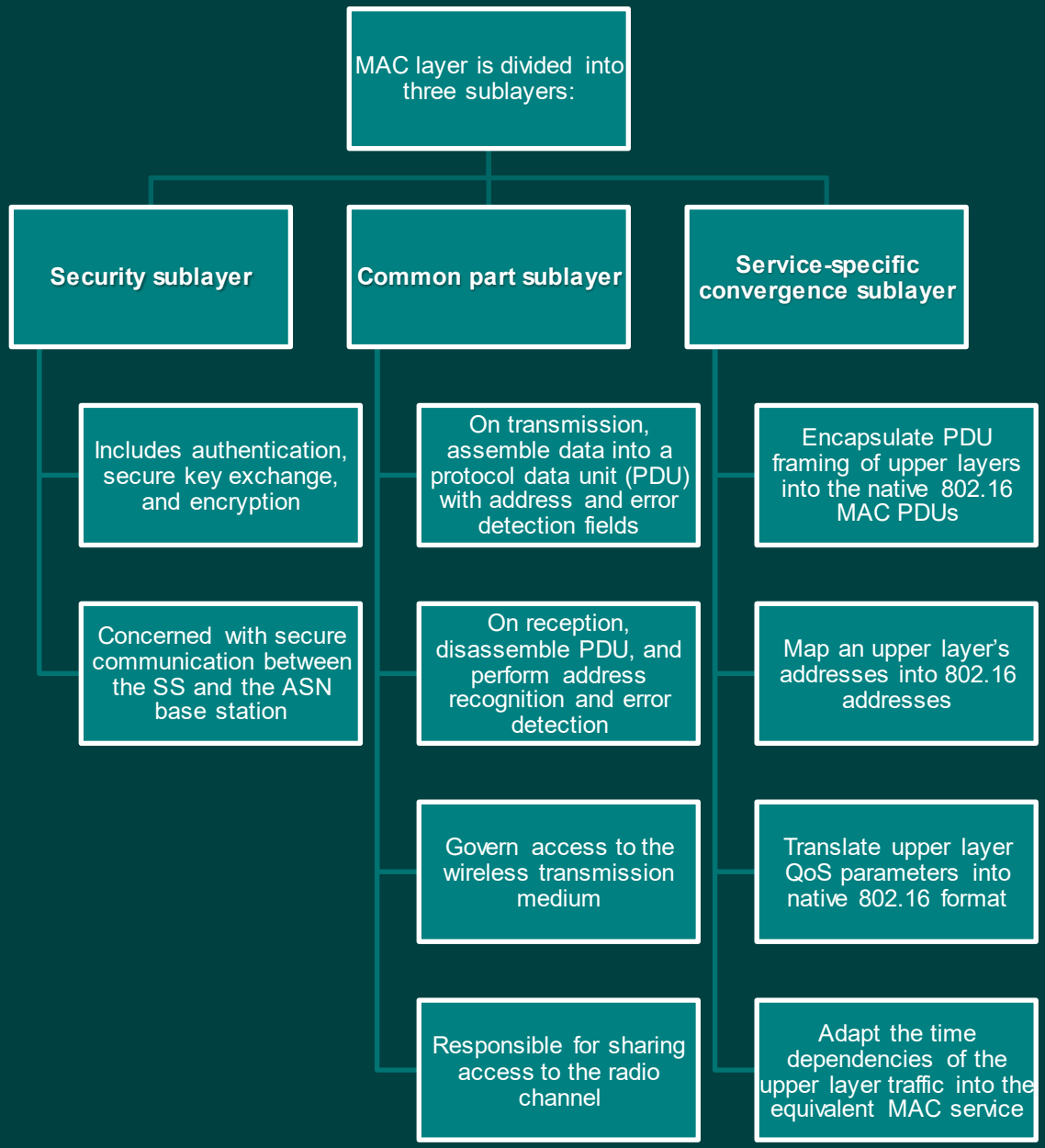


Figure 18.3 IEEE 802.16 Protocol Architecture

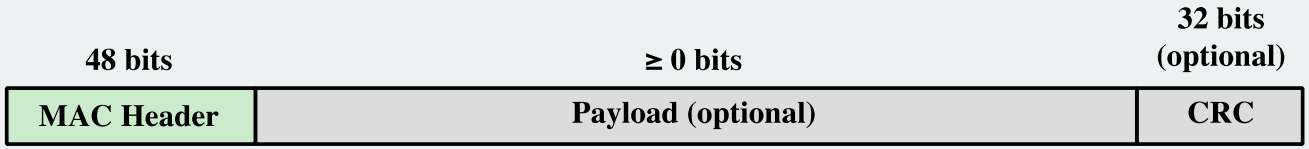
Protocol Architecture

- Physical layer
  - Encoding/decoding of signals
  - Preamble generation/removal (for synchronization)
  - Bit transmission/reception
  - Frequency band and bandwidth allocation

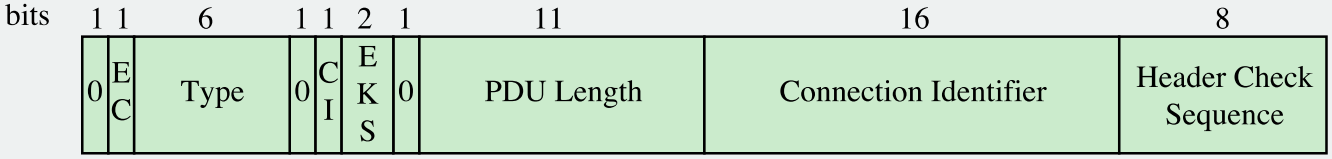


IEEE 802.16 MAC Layer

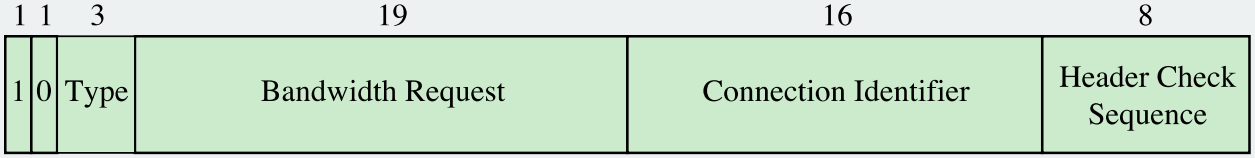
- Connection oriented
- Each MAC PDU includes a connection ID which is used by the MAC protocol to deliver incoming data to the correct MAC user
- There is a one-to-one correspondence between a connection ID and service flow
- Service flow defines the QoS parameters for the PDUs that are exchanged on the connection
- Examples of service flow parameters are latency, jitter, and throughput



(a) Overall MAC PDU format



(b) Generic MAC Header Format



(c) Bandwidth Request Header Format

ATM = Asynchronous Transfer Mode
CI = CRC indicator
EC = encryption control
EKS = encryption key sequence

Figure 18.4 IEEE 802.16 MAC PDU Formats

Scheduling Service and QoS

Maximum sustained traffic rate	• The peak information rate, in bits per second of the service • Rate pertains to the service data units at the input to the system • Parameter is 6 bits in length and includes values in the range from 1200 bps to 1.921 Mbps
Minimum reserved traffic rate	• The minimum rate, in bits per second, reserved for this service flow • The BS shall be able to satisfy bandwidth requests for a connection up to its minimum reserved traffic rate • Values range from 1200 bps to 1.921 Mbps
Maximum latency	• The maximum interval between the reception of a packet at the convergence sublayer of the BS or the SS and the forwarding of the SDU to its air interface • Values range from 1 ms to 10 s
Tolerated jitter	• The maximum delay variation (jitter) for the connection • Values range from 1 ms to 10 s
Traffic priority	• The priority of the associated service flow • The higher-priority service flow should be given lower delay and higher buffering preference • For otherwise nonidentical service flows, the priority parameter should not take precedence over any conflicting service flow QoS parameter • Eight priority levels are used

Table 18.1
IEEE 802.16 Service Classes and QoS Parameters

Scheduling Service (uplink)	Data Delivery Service (downlink)	Applications	QoS Parameters
Unsolicited grant service (UGS)	Unsolicited grant service (UGS)	VoIP	•Minimum reserved traffic rate •Maximum latency •Tolerated jitter
Real-time polling service (rtPS)	Real-time variable-rate service (RT-VR)	Streaming audio or video	•Minimum reserved traffic rate •Maximum sustained traffic rate •Maximum latency •Traffic priority
Non-real-time polling service (nrtPS)	Non-real-time variable-rate service (NRT-VR)	FTP	•Minimum reserved traffic rate •Maximum sustained traffic rate •Traffic priority
Best effort service (BE)	Best effort service (BE)	Data transfer, Web browsing, etc.	•Maximum sustained traffic rate •Traffic priority
Extended rtPS	Extended real-time variable-rate service (ERT-VR)	VoIP (voice with activity detection)	•Minimum reserved traffic rate •Maximum sustained traffic rate •Maximum latency •Tolerted jitter •Traffic priority

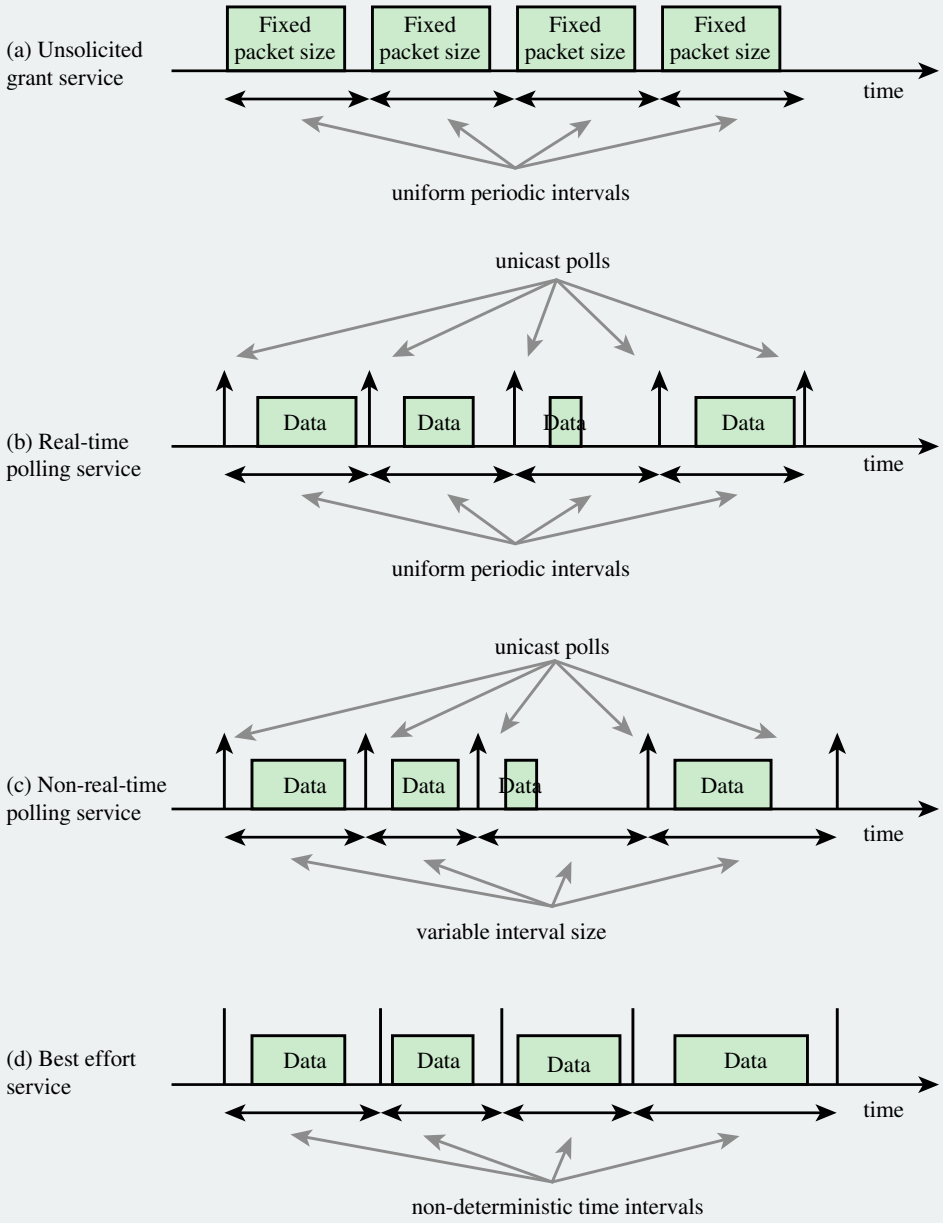


Figure 18.5 IEEE 802.16 Services

Table 18.2
IEEE 801.16 Physical Layer Modes

	WirelessMAN-SC	WirelessMAN-OFDM	WirelessMAN-OFDMA
Frequency band	10 to 66 GHz	≤ 11 GHz	≤ 11 GHz
LOS limitation	LOS	NLOS	NLOS
Duplexing technique	TDD, FDD	TDD, FDD	TDD, FDD
Uplink access	TDMA, DAMA	OFDM	OFDMA
Downlink access	TDM, TDMA	OFDM	OFDMA
Downlink modulation	QPSK, 16-QAM, 64-QAM	QPSK, 16-QAM, 64-QAM, BPSK	QPSK, 16-QAM, 64-QAM, BPSK
Uplink modulation	QPSK, 16-QAM, 64-QAM	QPSK, 16-QAM, 64-QAM, BPSK	QPSK, 16-QAM, 64-QAM, BPSK
Channel size	20 to 28 MHz	1.75 TO 20 MHZ	1.25 TO 20 MHZ
Subcarrier spacing	N/A	11.16 kHz	11.16 kHz
Data rate	32 to 134 Mbps	≤ 70 Mbps	≤ 70 Mbps
Downlink FEC	Reed-Solomon	Reed-Solomon	Convolutional
Uplink FEC	Reed-Solomon	Reed-Solomon	Convolutional

Table 18.3

Data Rates Achieved at Various WirelessMAN-OFDM Bandwidths

Modulation	QPSK	QPSK	16-QAM	16-QAM	64-QAM	64-QAM
Code Rate	1/2	3/4	1/2	3/4	2/3	3/4
1.75 MHz	1.04	2.18	2.91	4.36	5.94	6.55
3.5 MHz	2.08	4.37	5.82	8.73	11.88	13.09
7.0 MHz	4.15	8.73	11.64	17.45	23.75	26.18
10.0 MHz	8.31	12.47	16.63	24.94	33.25	37.40
20.0 MHz	16.62	24.94	33.25	49.87	66.49	74.81

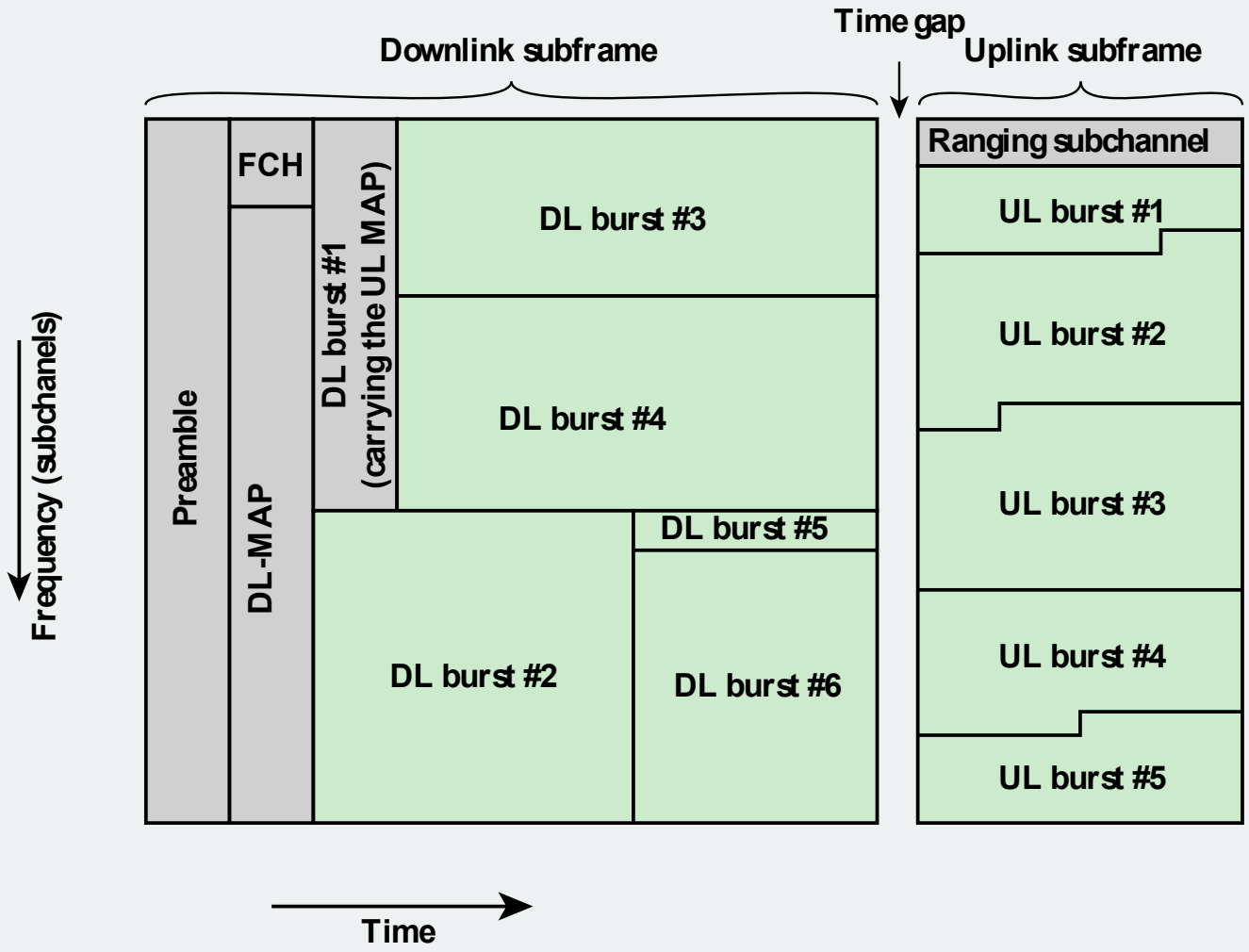
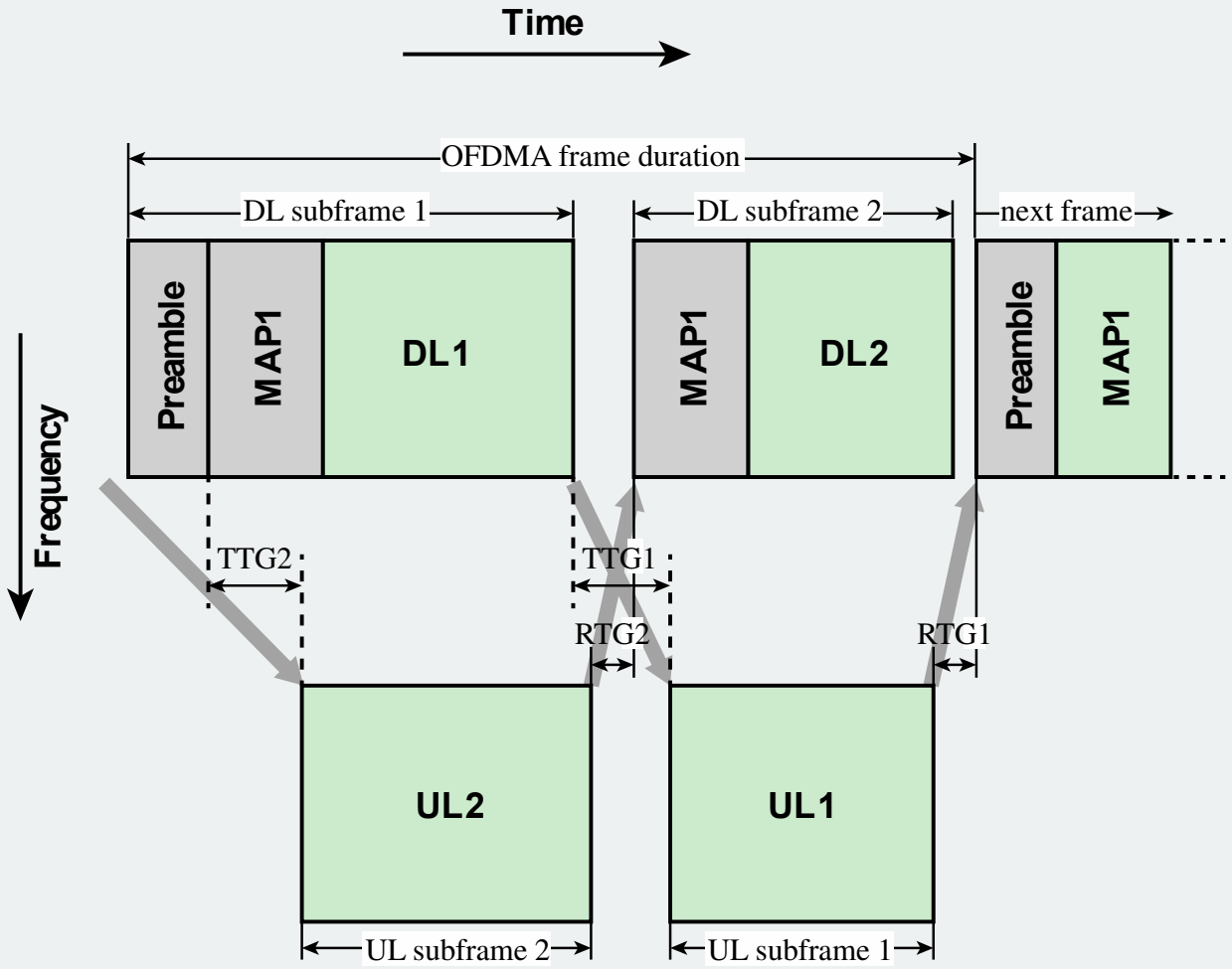


Figure 18.6 IEEE 802.16 OFDMA Frame Structure in TDD Mode

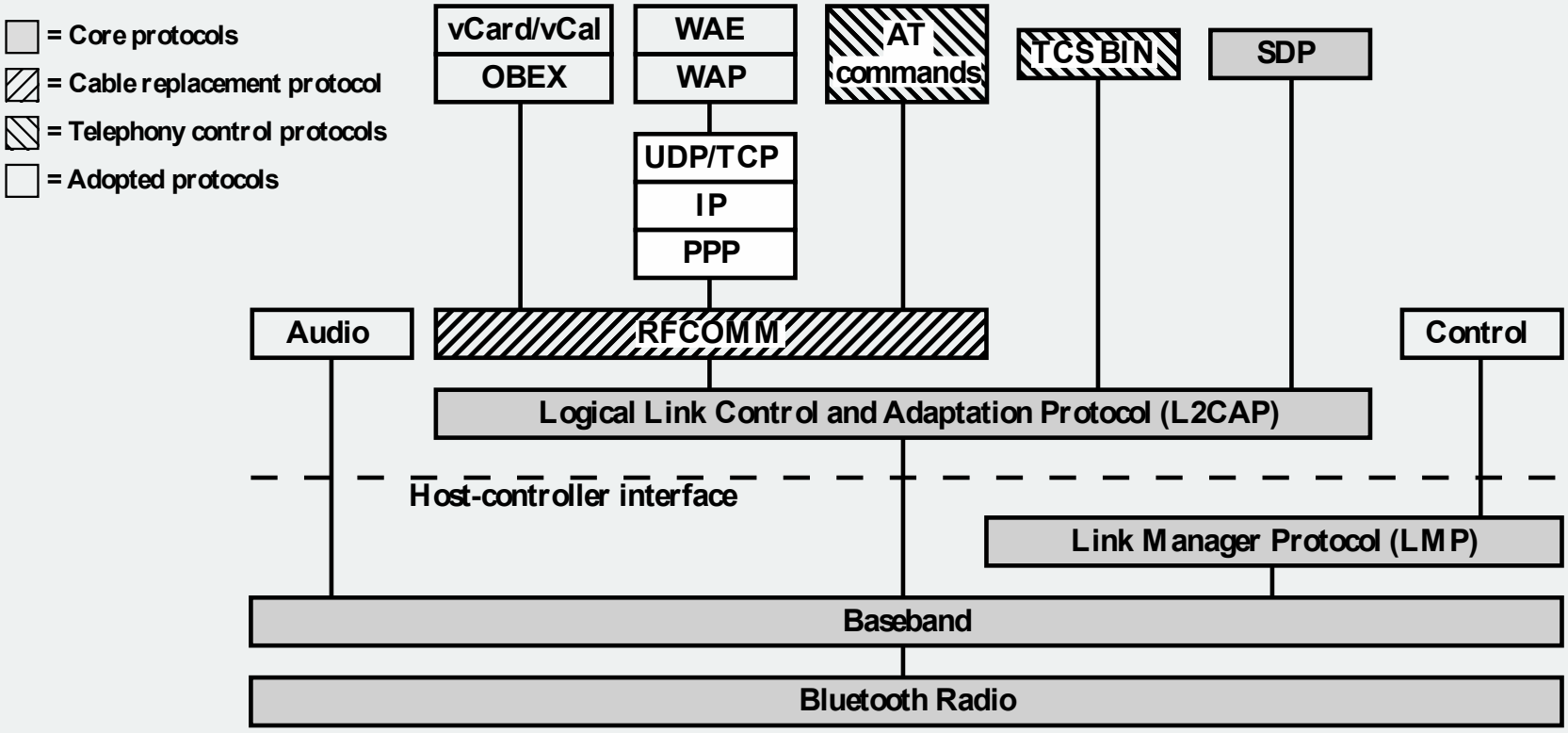


TTG = transmitter-to-receiver gap
RTG = receiver-to-transmitter gap

Figure 18.7 IEEE 802.16 OFDMA Frame Structure in FDD Mode

Bluetooth Overview

- An always-on, short-range radio hookup that resides on a microchip
- Concept behind Bluetooth is to provide a universal short-range wireless capability
- Intended to support an open-ended list of applications
- Bluetooth capabilities:
  - Make calls from a wireless headset connected remotely to a cell phone
  - Eliminate cables linking computers to printers, keyboards, and the mouse
  - Hook up MP3 players wirelessly to other machines to download music
  - Set up home networks so that a couch potato can remotely monitor air-conditioning, the oven, and children's Internet surfing
  - Call home from a remote location to turn appliances on and off, set the alarm, and monitor activity



AT	= attention sequence (modem prefix)	TCS BIN	= telephony control specification - binary
IP	= Internet Protocol	UDP	= User Datagram Protocol
OBEX	= Object exchange protocol	vCal	= virtual calendar
PPP	= Point-to-Point Protocol	vCard	= virtual card
RFCOMM	= radio frequency communications	WAE	= wireless application environment
SDP	= service discovery protocol	WAP	= wireless application protocol
TCP	= transmission control protocol		

Figure 18.8 Bluetooth Protocol Stack

Adopted Protocols

PPP	The point-to-point protocol is an Internet standard protocol for transporting IP datagrams over a point-to-point link
TCP/UDP/IP	These are the foundation protocols of the TCP/IP
OBEX	The object exchange protocol is a session-level protocol developed by the Infrared Data Association
WAE/WAP	Bluetooth incorporates the wireless application environment and the wireless application

Piconets

- A small network in which up to eight devices can communicate
- Consists of a master and from one to seven active slave devices
  - The radio designated as the master makes the determination of the channel and phase that shall be used by all devices on the piconet
  - A slave may only communicate with the master and may only communicate when granted permission by the master
- Ten of these piconets can coexist in the same coverage of the Bluetooth radio
- To provide security each link is encoded and protected against eavesdropping and interference

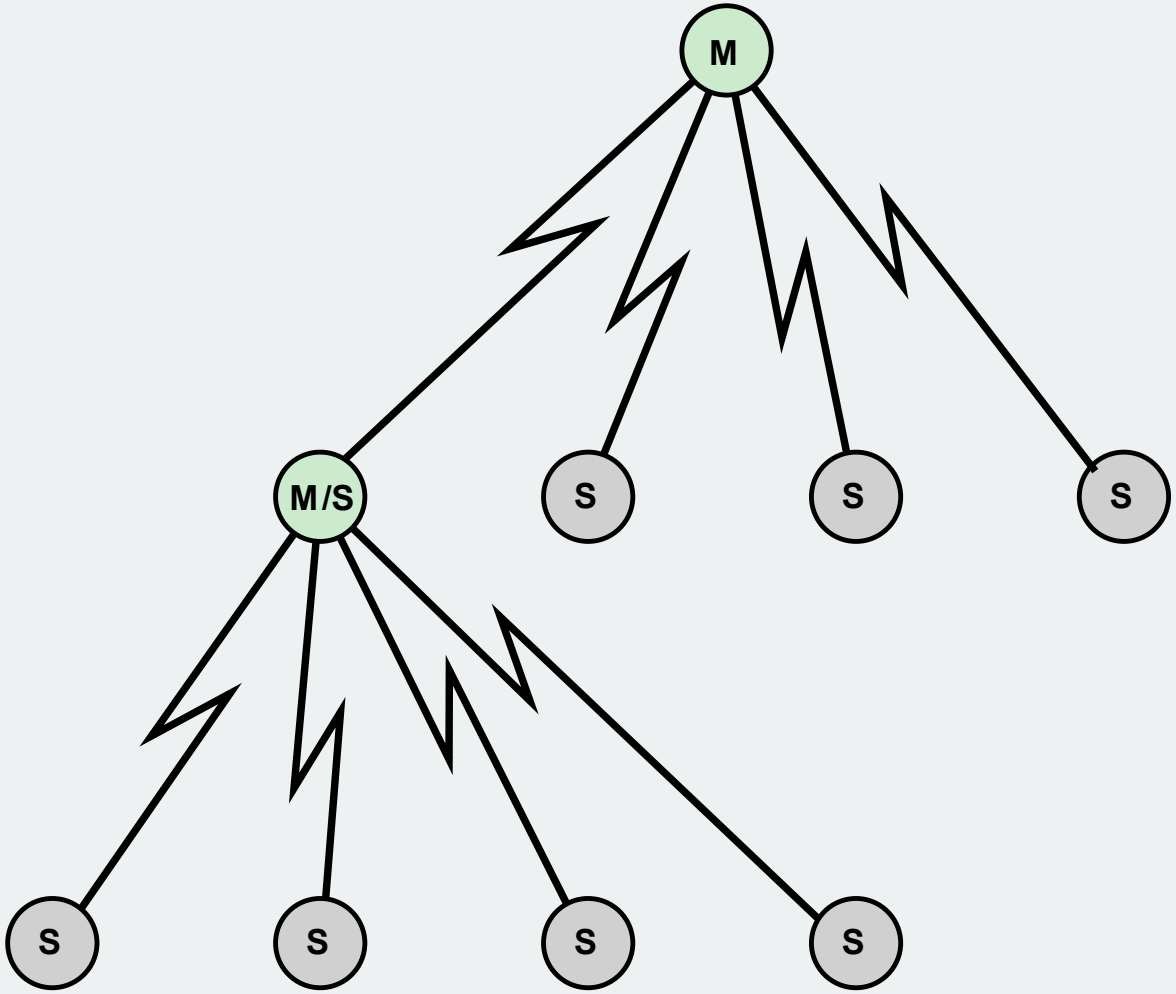
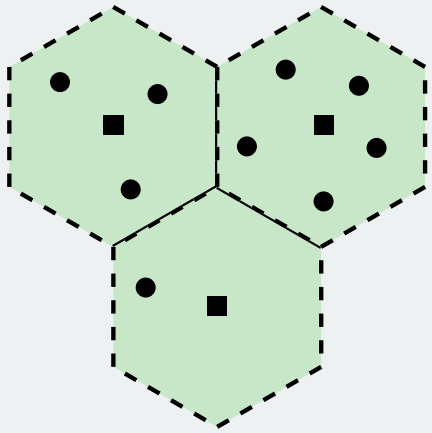
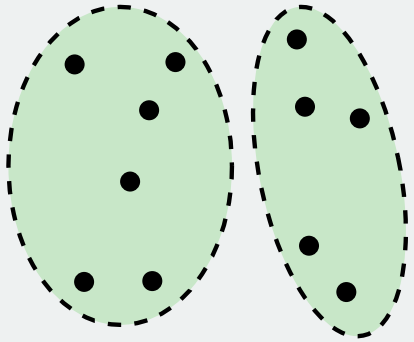


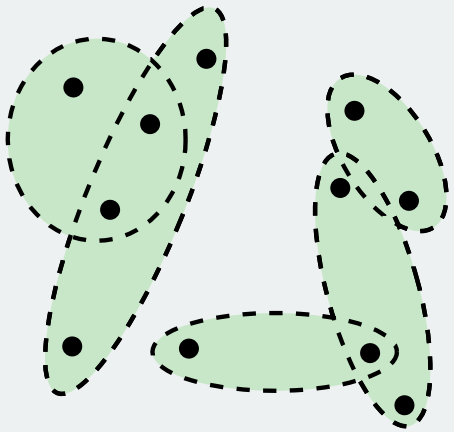
Figure 18.9 Master/Slave Relationships



(a) Cellular system (squares represent stationary base stations)



(b) Conventional ad hoc systems



(c) Scatternets

Figure 18.10 Wireless Network Configurations

Table 18.4
Bluetooth Radio and Baseband Parameters

Topology	Up to 7 simultaneous links in a logical star
Modulation	GFSK
Peak data rate	1 Mbps
RF bandwidth	220 kHz (−3 dB), 1 MHz (−20 dB)
RF band	2.4 GHz, ISM band
RF carriers	23/79
Carrier spacing	1 MHz
Transmit power	0.1 W
Piconet access	FH-TDD-TDMA
Frequency hop rate	1600 hops/s
Scatternet access	FH-CDMA

Frequency Hopping (FH)

In Bluetooth serves two purposes:

- It provides resistance to interference and multipath effects
- It provides a form of multiple access among co-located devices in different piconets

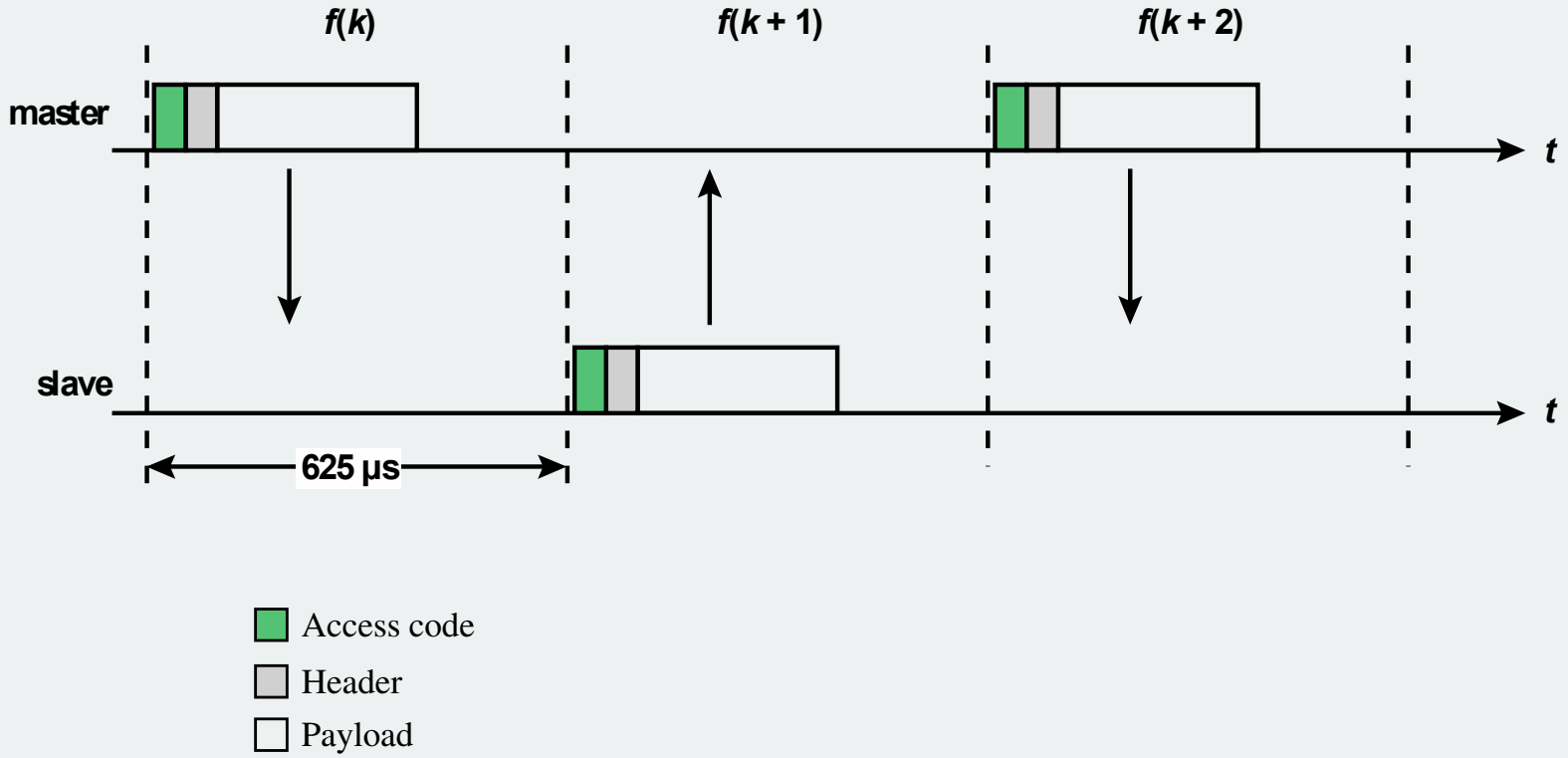


Figure 18.11 Frequency-Hop Time-Division Duplex

Physical Links

- Two types of links can be established between a master and a slave:

Synchronous connection oriented (SCO)	Asynchronous connectionless (ACL)
• Allocates a fixed bandwidth between a point-to-point connection involving the master and a single slave • The master maintains the SCO link by using reserved slots at regular intervals • The master can support up to three simultaneous SCO links, while a slave can support two or three SCO links • Are never retransmitted	• A point-to-multipoint link between the master and all the slaves in the piconet • In slots not reserved for SCO links, the master can exchange packets with any slave on a per-slot basis

- SCO links are used primarily to exchange time-bounded data requiring guaranteed data rate but without guaranteed delivery
- ACL links provide a packet-switched style of connection

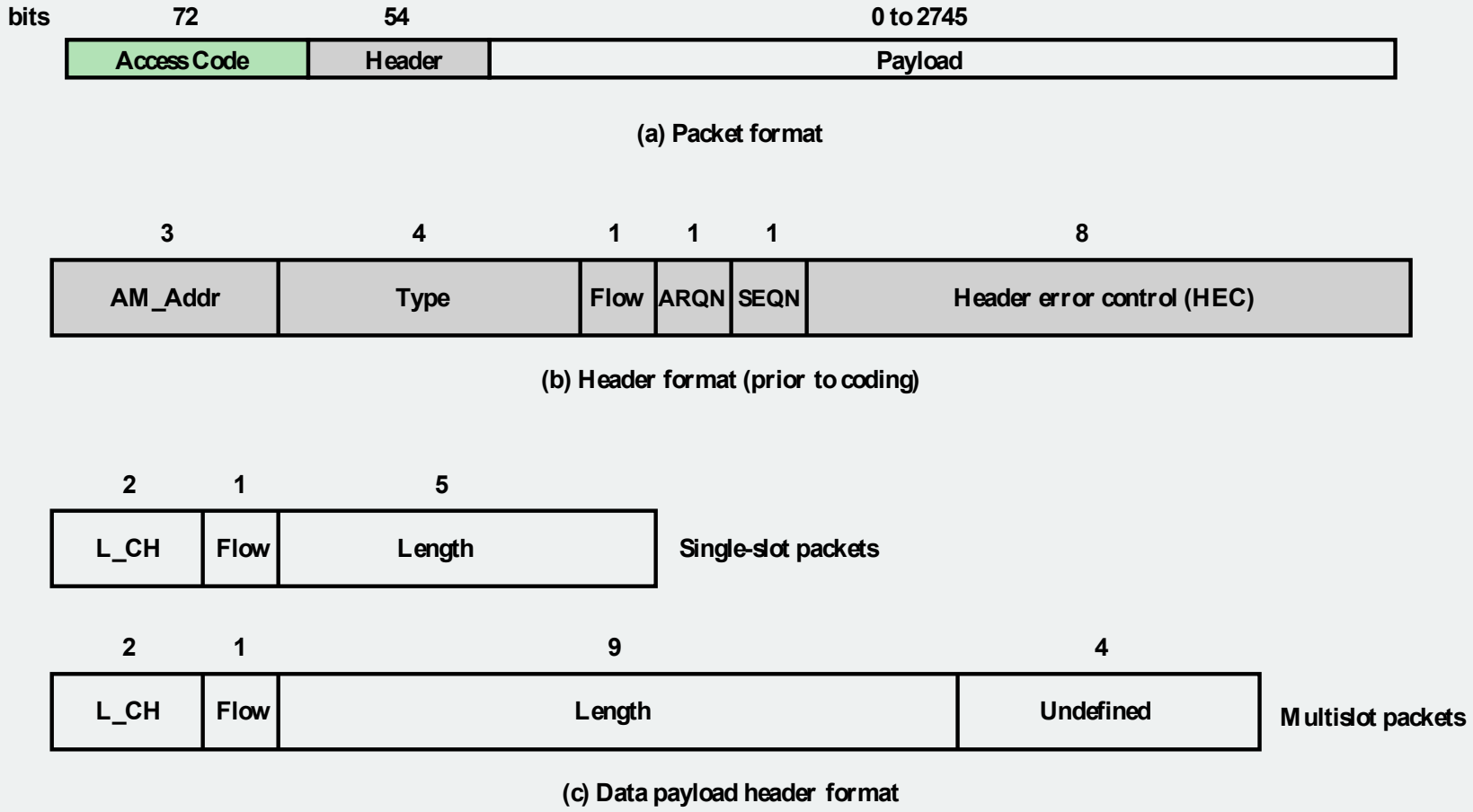


Figure 18.12 Bluetooth Baseband Formats

Error Correction

- At the baseband level Bluetooth makes use of three error correction schemes:
- 1/3 rate FEC (forward error correction)
  - Used on the 18-bit packet header and also for the voice field in an HV1 packet
  - Scheme involves sending three copies of each bit
- 2/3 rate FEC
  - Used in all DM packets
    - In the data field of the DV packet, in the FHS packet, and in the HV2 packet
    - Code can correct all single errors and detects double errors in each codeword
  - ARQ (automatic repeat request)
    - Used with DM and DH packets, and the data field of DV packets
    - Scheme similar to ARQ schemes used in data link control protocols

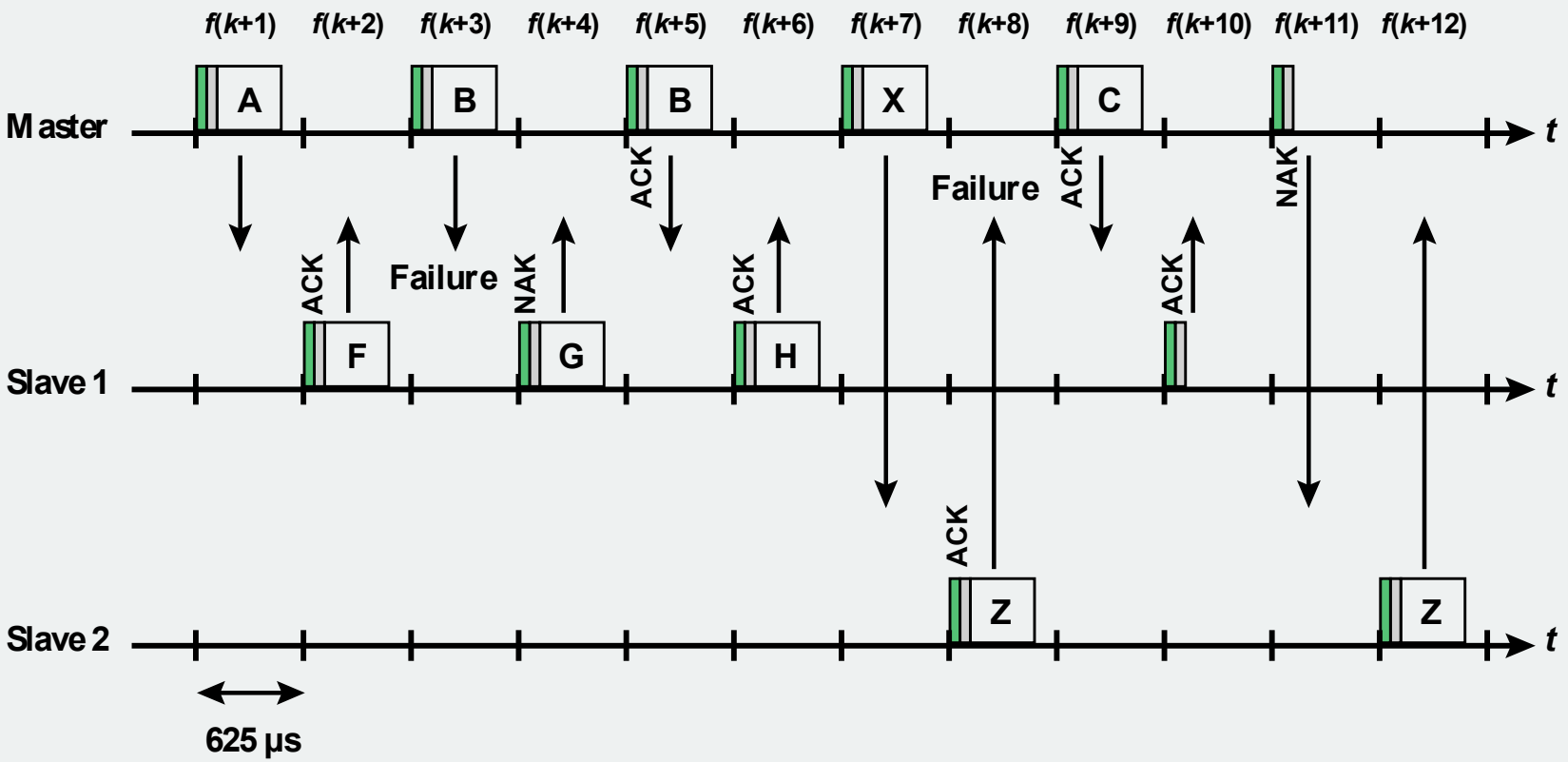


Figure 18.13 An Example of Retransmission Operation

Logical Channels

- Bluetooth defines five types of logical data channels designated to carry different types of payload traffic:

Link control (LC)	•Used to manage the flow of packets over the link interface •Carries low level link control information like ARQ, flow control, and payload characterization •Carried in every packet except in the ID packet which has no packet header
Link manager (LM)	•Transports link management information between participating stations •Supports LMP traffic and can be carried over either an SCO or an ACL link
User asynchronous (UA)	•Carries asynchronous user data •Carried over the ACL link but may be carried in a DV packet on the SCO link
User isochronous (UI)	•Carries isochronous user data •Carried over the ACL link but may be carried in a DV packet on the SCO link
User synchronous (US)	•Carries synchronous user data •Carried over the SCO link

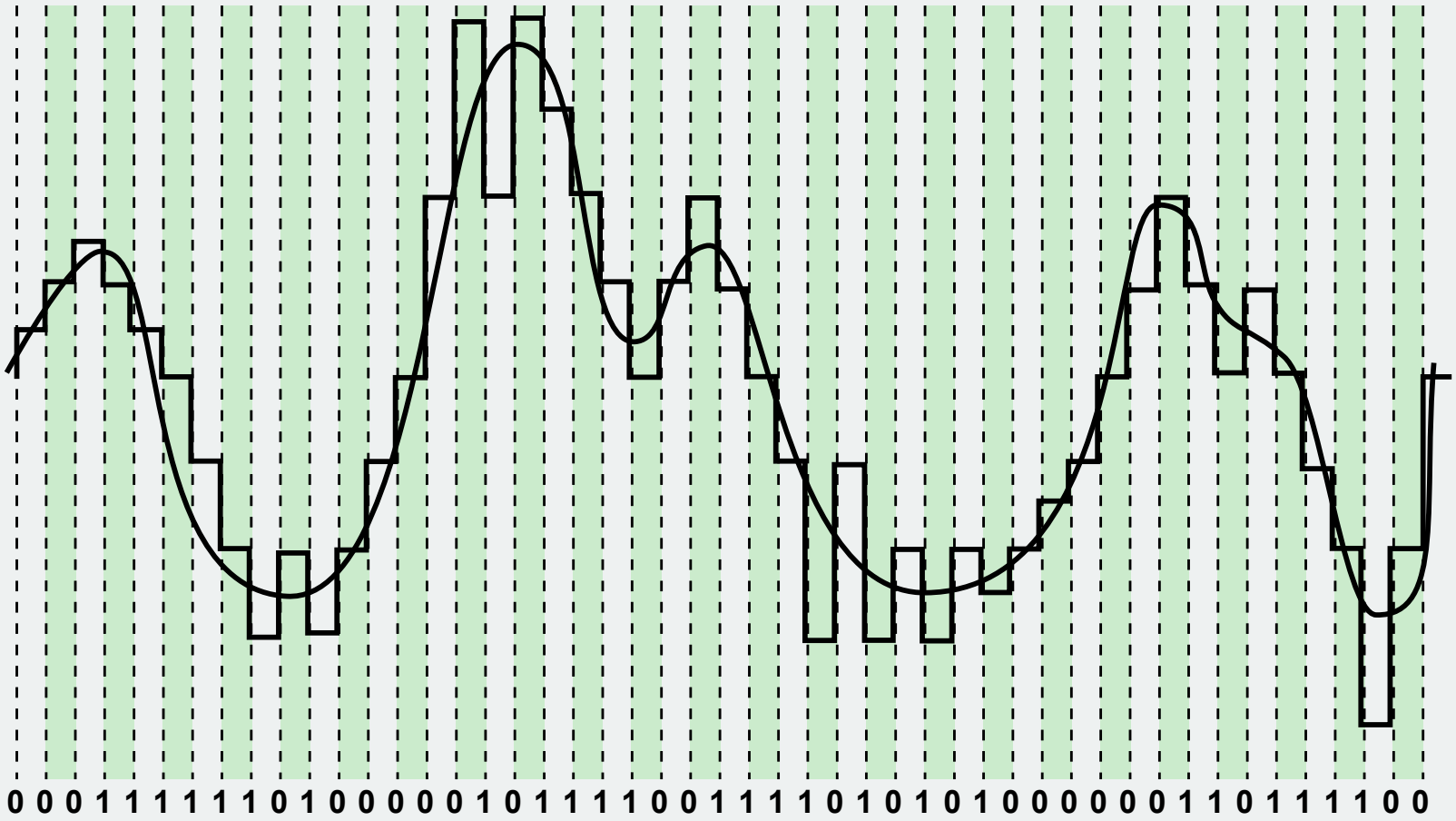
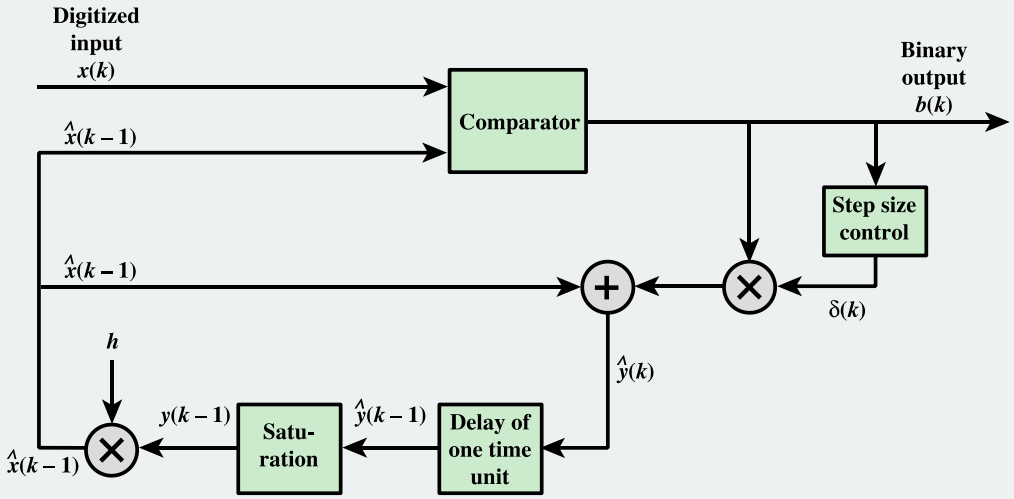
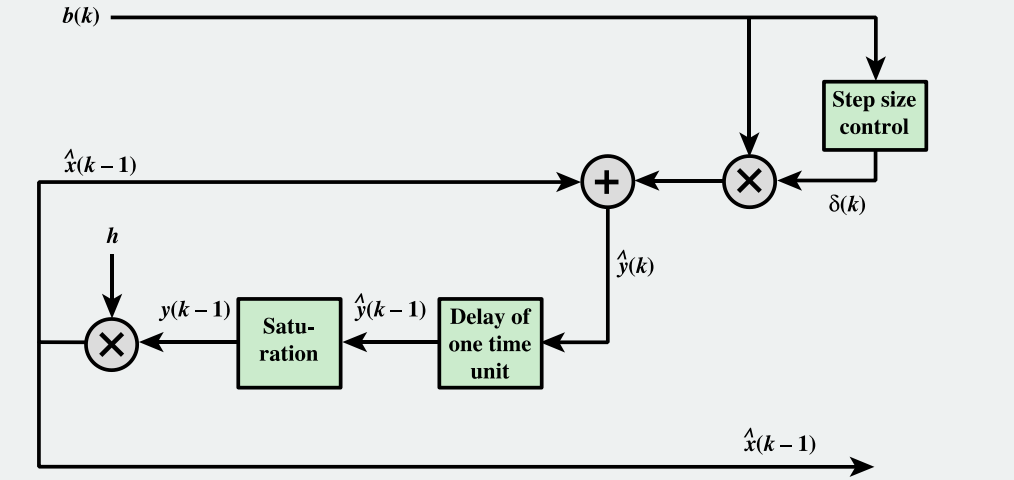


Figure 18.14 Example of Continuously Variable Slope Delta Modulation



(a) Encoder



(b) Decoder

Figure 18.15 Continuously Variable Slope Delta Modulation

Table 18.5
CVSD Parameter Values

Parameter	Value
h	$1 \quad \frac{1}{32} = 0.96875$
	$1 \quad \frac{1}{1024} \quad 0.999$
J	4
K	4
$_{min}$	10
$_{max}$	1280
y_{min}	-2^{15} or $-2^{15}+1$
y_{max}	$2^{15}-1$

Bluetooth Logical Link Control and Adaptation Protocol

- L2CAP provides:
  - A link-layer protocol between entities across a shared-medium network
  - A number of services and relies on a lower layer for flow and error control
  - Two alternative services to upper-layer protocols:
    - Connectionless service
      - This is a reliable datagram style of service
    - Connection-mode service
      - A logical connection is set up between two users exchanging data, and flow control and error control are provided

L2CAP Logical Channels

- Connectionless
  - Supports the connectionless service
  - Each channel is unidirectional
  - Typically used for broadcast from the master to multiple slaves
- Connection oriented
  - Supports the connection-oriented service
  - Each channel is bidirectional (full duplex)
  - A QOS flow specification is assigned in each direction
- Signaling
  - Provides for the exchange of signaling messages between L2CAP entities
- Associated with each logical channel is a channel identifier (CID)

Flow Specification

- Set of parameters that indicate a performance level that the transmitter will attempt to achieve
- Consists of the following parameters:
  - Service type
  - Token rate (bytes/second)
  - Token bucket size (bytes)
  - Peak bandwidth (bytes/second)
  - Latency (microseconds)
  - Delay variation (microseconds)

Summary

- Fixed broadband wireless access
- WiMAX/IEEE 802.16
  - 802.16 architecture
  - 802.16 MAC layer
  - 802.16 physical layer
- Bluetooth overview
  - Protocol architecture
  - Piconets and scatternets
- Bluetooth radio specification
- Bluetooth baseband specification
  - Frequency hopping
  - Physical links
  - Packets
  - Error correction
  - Logical channels
  - Bluetooth audio
- Bluetooth logical link control and adaption protocol