Course Overview and Outline

• **Main Goal**
  – Investigate and understand the concepts and technologies needed in “The Last Mile”

• **Topics Covered**
  – Introduction
  – Basics of Broadband Wireless Communications
  – Wireless Local Loops (WLLs)
  – Wireless Local Area Networks (WLANs)
  – Wireless Personal Area Networks (WPANs)
  – Conclusions and Future Directions
Wireless Technologies

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<td>2 to 54+ Mbps</td>
<td>22+ Mbps</td>
<td>10 to 384Kbps</td>
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<td>Medium</td>
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<td>Long</td>
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<td>Enterprise networks</td>
<td>Fixed, last mile access</td>
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Wireless Market Segments

Wireless Internetworking Overview

Residential/Premise/Campus
- IEEE 802.11
- BLUE TOOTH
- MMDS
- LMDS

Fixed Broadband Multiservice

Mobile
- 2G+ Cellular
- Data Services
- GPRS Mobile IP
- 3G Cellular
- Packet Data/Voice
- UMTS
Introduction

**Last Mile**
- Connectivity between local signal distributor (provider) and home (or the end user)
- The interconnection and interoperation of
  - Home appliances
  - Entertainment devices
  - PC hardware
  - Networking devices
  - Security, lighting and environmental control systems

**Objective**
High-speed distribution of information (Audio, Video, and Data) requiring higher bandwidth

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Why Wireless Broadband?

- Provide the ability to access information and communicate anytime, anywhere
  - Bring the network to the hands of the consumer (Pervasive Computing)
  - Interconnect people in data, voice and video
  - Enables users to communicate and share data
  - Bring interconnectivity to intelligent devices
  - Portability and "no new-wires"
Envisioned Communication puzzle of 4G

4G provides a seamless integration of different types of wireless networks

Broadband Home Access (BHA) Architecture

Four Components

- Broadband Local Loop
- Residential Gateway (RG)
- Home Area Network (HAN)
- Electrodomestic Network Devices (END)
• Broadband local loop
  – Connection between the local provider and consumer
    • Telephone Wires, Coaxial Cable, Fiber Optics, Wireless RF, Satellite Communications

• Residential Gateway (RG)
  – Interface device connecting Broadband local loop and in-home network
  – Centralized access point

• Home Area Network (HAN)
  – High speed network connecting ENDS, e.g., 10Base-T/Cat5

• Electro-domestic Network Devices (END)
  – Set of “intelligent” processing tools, e.g., computers, appliances and electronics

Review of Basic Concepts
The diagram illustrates the concept of dB (decibels), a unit of measurement used to express the ratio between two power levels.

**dB (relative measure)**

- **10,000 times** at 40 dB
- **1,000 times** at 30 dB
- **10,000,000 times** at **70 dB**

Path loss in dB

- **10 W**
- **1 mW**
- **1 µW**

Path loss from source to d2 = 70 dB

**Power**

- **10 W**
- **1 mW**
- **1 µW**

**dB = 10 log (times)**

Net worth

- **$10B**
- **$10M**
- **$10K**
Radio Propagation: Path Loss (Free-space)

Path Loss in Free-space

Path Loss Lf (dB) vs. Distance d (km)

- fc=150MHz
- fc=200MHz
- fc=400MHz
- fc=600MHz
- fc=800MHz
- fc=1000MHz
- fc=1500MHz
**Fading and Multipath**

**Fading**: rapid fluctuation of the amplitude of a radio signal over a short period of time or travel distance

Effects of multipath
- Fading
- Varying doppler shifts on different multipath signals
- Time dispersion (causing inter symbol interference)

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**Bandwidth of Digital Data**

- Baseband signal cannot directly be transmitted on the wireless medium
- Need to translate the baseband signal to a new frequency so that it can be transmitted easily and accurately over a communication channel
Channel Coding and Modulation

- Modulation
- Channel coding
- Baseband signal

- Demodulation
- Channel decoding
- Baseband signal

Last Mile Broadband Wireless Access
Last Mile Broadband Wireless Access

*Several wireless systems in several bands competing for “last mile”*

Infrared (IR)
- Line of Sight (LOS)
- Diffused-IR can work without LOS

Radio Frequency (RF)
- Narrow Band → microwave
- Spread Spectrum → FHSS, DSSS

*Interconnect class of devices which constitute a sub-network with wireless technology*

Services and Carrier Requirement of BWA

- Internet Access, Multiline voice, Audio, Streaming video
- Quality of Service (QoS) guarantees
- Scalability
- Radio Interoperability
Deployment Scenarios for BWA

- **Supercells**
  - Cell radius ~ 30mi
  - Single-cell Configuration
- **Macrocells**
  - Cell radius ~ 5mi
  - Frequency reuse between cells
- **Microcells**
  - Cell radius ~ 1mi
  - Provides indoor coverage

Challenges in Fixed Wireless Networks

- Technology Standardization
- Higher Data Rate
- Sophisticated physical and radio link layers
  - To maintain reuse factor of 3
- Reliability
BWA Channels

Wireless channel are limited by radio spectrum availability, path loss, interference and multipath propagation

- Multipath
- Delay Spread
- Path Loss
- Fading (Fast and Slow)

BWA system: Physical Layer

**Modulation**

1. **Single-Carrier (SC) Modulation with Equalization** (several equalization options)
   - Maximum-likelihood (ML) Equalization
     - Computationally Complex
   - Decision-feedback Equalization (DFE)
   - Linear Equalization

*High Delay and/or high data rate requirements pose limits on the performance of SC systems*
Physical Layer (cont.)

2. Direct Sequence Code-Division Multiple Access (DS-CDMA)
   • Spreading code sequence at higher data rate is used to spread the transmitted symbol in frequency.
     – The larger the spreading factor (SF), the larger the operating bandwidth has to be
       » 160 MHz for a SF of 32
       » 3G = 4 MHz for a SF of 4
   • RAKE receiver can be used for frequency diversity.

3. Orthogonal Frequency-Division Multiplexing (OFDM)
   • Uses guard interval (cyclic prefix) which changes with delay spread and/or data rate.
   • Transmitter: Inverse Fast Fourier Transform (IFFT)
   • Receiver: Fast Fourier Transform (FFT)

4. Ultra-Wideband Modulation (UWBM)
   • Sub-nanosecond pulses are used to convey information
   • Pulses are transmitted across an ultra-wideband spectrum, and appears as a noise to other systems.

Some Issues

– Hardware Considerations
  • OFDM is less complex than SC and DS-CDMA, but it makes the system sensitive to power amplifier nonlinearities.

– Channel Coding (e.g., amplitude, phase)
Physical Layer (cont.)

– Synchronization
  • OFDM is more sensitive to synchronization errors than SC and DS-CDMA

– Link Adaptation
  • Dynamic variation in modulation and FEC can be used for better channel throughput.

– Multiple Access
  • Time Division Multiple Access (TDMA)
  • Code Division Multiple Access (CDMA)

– Time Division Duplex (TDD) vs Frequency Division Duplex (FDD)

MAC Layer and Radio Link Protocol (RLP)

MAC Functions

– Scheduling
  • Uplink and downlink transmission
  • Support multiple service flows

– Admission Control
  • Enforce Policy and Authorization
  • Accommodate QoS requirement of new flow
MAC Layer and RLP (cont.)

- Link Initialization and maintenance
  - Channel Choice, Synchronization, Registration, and Security Issues

- Support for Integrated Voice and Data
  - Bandwidth guarantees, bounded loss, delay and jitter

- Fragmentation, Automatic Repeat Request (ARQ), Adaptive Modulation and Coding

MAC Layer and RLP (cont.)

MAC Features

- Fragmentation
- Retransmission
- Scheduling Support
- Link Maintenance and Support
Multiple Antennas in BWA

*Multiple antennas to provide high-data-rate and high-quality wireless broadband access*

**Features**

- **Array gain**
  - Combine signals to increase C/N (Carrier-to-noise) ratio
- **Diversity gain**
  - Spatial diversity
- **Interference suppression**
  - Suppress CCI (Co-Channel Interference)
- **Multiplexing gain**
  - Open up parallel spatial data pipes within the same bandwidth

Last Mile Broadband Wireless Access Technologies
Last Mile Broadband Wireless Access Technologies

- Multichannel Multipoint Distribution System (MMDS)
- Local Multipoint Distribution Service (LMDS)
- Satellite Communications
- IEEE Standard 802.16
- IEEE 802.11 as a Last Mile Alternative
- Various Standards

Multichannel Multipoint Distribution System (MMDS)

- Analog-Based
- Initially
  - Two channels
- Later
  - Thirty-one 6 MHz channels in 2.5 to 2.7 GHz frequency band
- In 1983, FCC allocated 200 MHz bandwidth for licensed network
MMDS Components

- MMDS tower
- Central head-end
- 2.1 and 2.7 GHz
- MMDS tower
- Antenna and downconverter
- Antenna and downconverter
- MMDS Broadband Connectivity

Local Multipoint Distribution Service (LMDS)

- Architecture similar to MMDS
- Base Station to end user → Point-to-Multipoint
  - Transmitter covers a sector of 60-90° wide
  - Typically requires 4-6 transmitters for full coverage
  - Streams transmitted at 34-38 Mb/s
- End user to Base Station → Point-to-Point
  - Capacity determined by requirements of end user
LMDS (cont.)

• Operation
  – Cluster of cells with separate base stations
  – One base station site serves as coordination center
  – Intercell networking is done through fiber optic or short hop radio relay connections (e.g., microwave)
  – Infrastructure sharing with co-located mobile base station

LMDS (cont.)

• Limitations
  – Severe attenuation due to precipitation
    • For example, depending on climactic zone and frequency of operation, the range of operation could be of 3-5 km
  – Full coverage not possible
    • 40-70% is normally possible
    • Use of overlapped cell configuration may increase coverage
  – Attenuation caused by transmission through vegetation

• Positive side
  – Propagation issues are now well understood
LMDS (cont.)

- Operating Frequencies
  - Several systems compete for frequency allocations
    - Difficult to obtain worldwide allocation for LMDS
  - US
    - 1.3 GHz in the 28-29 GHz band has been allocated
  - Europe
    - Different frequencies in different bands from 24 GHz up to 43.5 GHz

LMDS (cont.)

- Technology Employed
  - A high-capacity broadcast-based downlink is shared among several users
    - 25 dBm output power per 36 Mb/s transport beam
  - Transmission format based on Quadrature Phase Shift Keying (QPSK)
    - Adopted by both for Digital Video Broadcasting (DVB) & Digital Audio/Visual Council (DAVIC) project
  - In DVB, IP or ATM data are included in MPEG transport stream in combination with TV programs
    - Out of band transmissions are also possible
LMDS (cont.)

• Technology Employed
  – Different technologies may be used for uplink (low capacity return links)
    • General Packet Radio Service (GPRS) and PSTN/ISDN are adequate
  – In-band radio link for more demanding users
  – Radio-based return link for small and medium-size enterprises
    • Which may be symmetric or asymmetric in either directions
  – Capacity depends on available frequency resource
    • For a cellular system using QPSK modulation, capacity of a 2 GHz system is around 1.5 Gb/s per cell for downlink and uplink channels

LMDS (cont.)

• Application
  – Flexible
    • Allows for increased capacity on demand
  – Increase in total capacity by
    • Changing the cell size through reduction of cell diameter
    • Reduction of illumination angle
  – In Europe, LMDS is considered as a supplement/alternative to cable TV → wireless cable
  – Interactive Television
  – Teleteaching
Satellite Communications

- Orbiting microwave relay stations
- Links two or more earth-based microwave stations
- Used for long distance telephone traffic, private data networks and distribution of television signals
- Direct Broadcast Satellite (DBS) system used for consumers
  - Delivers content to home network at 45 Mbps
  - Uses a slow telephone line for uplink connection

A Typical Satellite System
Example: GPS

GPS Nominal Constellation
24 Satellites in 6 Orbital Planes
4 Satellites in each Plane

Satellite Communications

- Operational Frequencies

<table>
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<th>Uplink</th>
<th>Downlink</th>
<th>Bandwidth</th>
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<tbody>
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<td>1.6 GHz</td>
<td>1.5 GHz</td>
<td>Narrowband</td>
</tr>
<tr>
<td>C-band 6/4 GHz</td>
<td>5.850-6.425 GHz</td>
<td>3.625-4.200 GHz</td>
<td>500/500 MHz</td>
</tr>
<tr>
<td>X-band 8/7 GHz</td>
<td>7.925-8.425 GHz</td>
<td>7.250-7.750 GHz</td>
<td>500/500 MHz</td>
</tr>
<tr>
<td>Ku-band 14/12 GHz</td>
<td>14-14.5 GHz</td>
<td>11.5-12.75 GHz</td>
<td>500/500 MHz</td>
</tr>
<tr>
<td>Ka-band 30/20 GHz</td>
<td>27.5-31 GHz</td>
<td>17.7-21.2 GHz</td>
<td>3.5/3.5 GHz</td>
</tr>
</tbody>
</table>

Satellite Frequency Bands
Satellite Communications

• Multiple Access Schemes
  – Allows users to share the same bandwidth, antenna and satellite systems
  – Multiplexing Schemes
    • Preassigned Multiple Access (PAMA)
      – Permanently assigns a channel or a time to a user
      – All other users use different time slots and hence are multiplexed
    • Demand Assigned Multiple Access (DAMA)
      – Similar to TDMA in cellular system
      – It is on demand and each user takes time slot when needed
    • Frequency Division Multiplex (FDM/FDMA)
      – Different frequency slots for different users

Satellite Communications

• Propagation Delay
  – Problem in real-time communication because of large distance between earth and satellite
    • Distance ~ 35,000 meters above earth
  – Echo Cancellation
    • Needed for quality of voice communication

\[\text{Distance (km)}\]
\[\text{Delay (ms)}\]

\[\text{Elevation angle (degrees)}\]

\[\text{Distance (km)}\]
\[\text{Delay (ms)}\]

\[\text{Elevation angle (degrees)}\]
IEEE Standard 802.16

- Working group set up in 1999
- Standardizes the WirelessMAN™ air interface and related functions for wireless MANs
- Common MAC Protocol supporting multiple physical layers which, in turn, depend on spectrum in use and regulations
- Features
  - Network Access to Building through exterior antennas
  - Alternative to cabled access networks such as DSL, fiber optics, coaxial systems, etc.
  - Less Expensive
  - Broad geographic area coverage
IEEE Standard 802.16

• Air Interface (PHYs with common MAC)
  – P802.16: 10-66 GHz (approved in 2001)
  – P802.16a: 2-11 GHz
    • Licensed bands (some license-exempt too)
  – P802.16b: 5-6 GHz
    • License exempt
    • WirelessHUMAN™ – Wireless High-Speed Unlicensed Metropolitan Area Network

• Coexistence
  – IEEE 802.16.2 (10-66 GHz)
  – P802.16.2a: amendment with 2-11 GHz licensed

IEEE Standard 802.16

• Point-to-Multipoint Wireless MAN: not a LAN
  – Base station (BS) connected to public networks
  – BS serves Subscriber Stations (SS)
    • BS and SS are stationary
    • SS typically serves a building
  – Multiple services, with different QoS priority, simultaneously
802.16 MAC Layer

• High bit rates for both uplink and downlink
• Support multiple services for end users
  – Voice & data, IP, VoIP
• Accommodate both continuous and bursty traffic
• Support QoS for multiple traffic types
  – Provides a wide range of service types analogous to the classic ATM service categories as well as new categories such as Guaranteed Frame Rate (GFR)
• Support both ATM and packet-based (IP) protocols

802.16 MAC Layer

• MAC Layer Details
  – Service Specific Convergence Sublayer (Maps the transport layer specific traffic to MAC)
  – Common Part Sublayer

The IEEE 802.16 Protocol Stack
**802.16 MAC Layer**

- **Service Specific Convergence Sublayer**
  - Interface to higher layers
  - Defines two general service-specific convergence sublayers
    - ATM convergence sublayer
    - Packet convergence sublayer
  - Sublayer classifies service data units to proper MAC connection:
    - Preserve or enable QoS, bandwidth allocation
  - Supports header suppression and reconstruction

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**802.16 MAC Layer**

- **Common Part Sublayer**
  - General Architecture
    - Point-to-multipoint architecture
    - Connection-oriented
      - All services are mapped to connections
      - Enabled association of QoS, bandwidth, traffic parameters, etc.
    - Connections are referenced by 16-bit connection identifiers (CID)
    - Downlink to the SSs is multiplexed in TDM fashion
    - Uplink shared between SSs in TDMA fashion
802.16 MAC Layer

• Common Part Sublayer
  – General Architecture
    • SS has 48-bit MAC address
    • SSs are assigned three management connections
      – Different management levels
    • Connection 1 (Basic Connection):
      – Used for short time critical MAC and RLC messages
    • Connection 2 (Primary Connection):
      – Used for longer and more delay tolerant message
    • Connection 3 (Secondary Connection):
      – Transfer of standard-based management messages such as DHCP, TFTP, SNMP, etc.

802.16 MAC Layer

• Transmission of MAC PDUs
  – Fragmentation
  – Packing

• PHY Support and Frame Structure
  – Supports both TDD and FDD
802.16 Radio Link Control

• Requirements
  – Capability of PHY to change from one burst profile to another
    • Periodic broadcast of burst profile chosen for uplink and downlink
    • Modulation and FEC
  – Power Control
  – Ranging
• IP Connectivity
  – SS attains IP address via DHCP

802.16 Physical Layer

• 10-66 GHz
  – Line of sight (LOS) propagation
  – Single Carrier modulation on designated wireless interface “WirelessMAN-SC” (both FDD and TDD are supported)
• 2-11 GHz
  – Driven by the need for Non-LOS propagation
    • Residential/Small business applications are expected (low rooftops)
  – Three air interface specifications:
    • WirelessMAN-SC2
    • WirelessMAN-OFDM (Mandatory for license-exempt bands)
    • WirelessMAN-OFDMA
802.16 Physical Layer Details

- For 10-66 GHz PHY specification
  - Single-carrier modulation with adaptive burst profiling
  - Dynamic adjustment of transmission parameter
    - Modulation and coding schemes (FEC)
  - Various frame sizes are used
    - Frame divided into physical slots
    - In TDD, uplink subframe follows the downlink on the same carrier frequency
    - In FDD, uplink and downlink are coincident in time (higher radio complexity) but are carried on separate frequency

802.16 Adaptive Physical Layer
Summary

- The IEEE 802.16 WirelessMAN Air Interface addresses worldwide BWA market needs
- The 802.16 MAC is flexible and powerful enough to support any fixed BWA technology variant
- The 802.16 Air Interface provides great opportunities for vendor differentiation without compromising interoperability

IEEE 802.11 as a Last Mile Alternative

- Extremely low cost as compared to existing BWA technologies
- Works in 2.4 GHz ISM unlicensed band
  - Double edged-sword (cost X interference)
- IEEE 802.11b can provide reliable broadband access
- IEEE 802.11b can achieve 7.66 Mb/s data rate for a distance of 1Km
Various Standards

Different countries/regions use different terms when referring to these standards

- Europe → ETSI Broadband Radio Access Networks (BRAN)
- United States → LMDS, 802.16, and BWA systems
- Canada → Local Multipoint Communications Systems (LMCS)

The applications are varied such as High-speed internet access, telephony, video conferencing, broadcast video, etc…

Various Standards

- ETSI BRAN
  - High Performance Radio Access (HIPERACCESS)
    - Connects mainly residential, SOHO
    - Transmission rate varies between 2-25 Mb/s
    - Above 11 GHz
    - IEEE ahead in schedule
  - HIPERMAN
    - Below 11 GHz
    - Recently selected 802.16 MAC as baseline (IEEE went first)
  - HIPERLAN
    - Controlled QoS
  - HIPERLINK
    - Network-Network radio interconnection
    - 155Mbps
Wireless Local Area Networking

• Increased Mobility, Flexibility, and Transmission range
• Various applications
  – Medical environment
  – Campus
  – Business
  – Internet access
• Wireless Home Networking Application Requirements
  – Home networks incorporate multimedia
  – Adding more nodes to home networks
  – High speed broadband Internet Access
• The IEEE standard 802.11 is the major representative
IEEE Standard 802.11 for WLANs

- Architectural Requirements
  - Single MAC to support multiple PHYs.
    - IR
    - FHSS
    - DSSS (widely available in the 2.4 GHz ISM band)
  - Should allow overlap of multiple networks in the same area and channel space.
  - Robust for Interference
    - Microwave, other non-802.11 interferers (e.g., Bluetooth)
    - Co-channel interference

802.11 Protocol Architecture

Configuration:
- Basic Service Set (BSS): Independent
- Extended Service Set (ESS): Infrastructured

Possible network topologies
802.11 Protocol: Issues

- Hidden and Exposed Terminal Problems
- Reliability
- Collision avoidance
- Congestion control

Hidden Terminal Problem

- Hidden terminals
  - A sends to B, C cannot detect A’s transmission
  - C wants to send to B, C senses a “free” medium (CS fails)
  - collision at B, A cannot detect the collision (CD fails)
  - A is “hidden” for C
Exposed Terminal Problem

- Exposed terminals
  - B sends to A, C wants to send to D
  - C senses carrier, finds medium in use and has to wait
  - A is outside the radio range of C, therefore waiting is not necessary
  - C is “exposed” to B

Multiple Access with Collision Avoidance (MACA)

- MACA uses signaling packets for collision avoidance
  - RTS (request to send)
    - sender request the right to send from a receiver with a short RTS packet before it sends a data packet
  - CTS (clear to send)
    - receiver grants the right to send as soon as it is ready to receive

- Signaling packets contain
  - sender address
  - receiver address
  - Duration

- Variants of this method are used in IEEE 802.11
MACA Solutions

- MACA avoids the problem of hidden terminals
  - A and C want to send to B
  - A sends RTS first
  - C waits after receiving CTS from B

- MACA avoids the problem of exposed terminals
  - B wants to send to A, C to another terminal
  - now C does not have to wait, as it cannot receive CTS from A

MAC: Reliability

- Wireless links are prone to errors
  - High packet loss rate is detrimental to transport-layer performance (TCP)
- Solution: Use of acknowledgements
  - When node B receives a data packet from node A, node B sends an Acknowledgement (Ack).
  - If node A fails to receive an Ack, it will retransmit the packet

- IEEE 802.11 Wireless MAC
  - Distributed and centralized MAC components
    - Distributed Coordination Function (DCF)
    - Point Coordination Function (PCF)
  - PCF suitable for access point-based networking
  - DCF suitable for ad hoc networking
IEEE 802.11 DCF

- Uses RTS-CTS exchange to avoid hidden terminal problem
  - Any node overhearing a RTS or CTS cannot transmit for the duration of the transfer
  - Note that RTS/CTS can collide

- Uses ACK to achieve reliability

- Any node receiving the RTS cannot transmit for the duration of the transfer
  - To prevent collision with ACK when it arrives at the sender
  - When B is sending data to C, node A will keep quiet

DCF Operation

Station 1
- NAV
- random backoff (7 slots)

Station 2
- NAV
- DIFS
- RTS
- SIFS
- CTS
- DATA
- ACK
- new random backoff (16 slots)

Station 3
- NAV
- random backoff (9 slots)

Station 4
- NAV
- DIFS
- SIFS
- Station defers
- remaining backoff (2 slots)
- ACK
- DATA

Station 5
- SIFS
- ACK

Station 6
- SIFS
- DATA

Station sets NAV upon receiving RTS
Station sets NAV upon receiving CTS, this station is hidden to station 1

Time
MAC: Collision Avoidance

- With half-duplex radios, collision detection is not possible
- **Collision avoidance:** Once channel becomes idle, the node waits for a randomly chosen duration before attempting to transmit

**IEEE 802.11 DCF**
- When transmitting a packet, choose a backoff interval in the range \([0, cw]\); \(cw\) is contention window
- Count down the backoff interval when medium is idle
- Count-down is suspended if medium becomes busy
- When backoff interval reaches 0, transmit RTS

- Time spent counting down backoff intervals is a part of MAC overhead
  - large \(cw\) leads to larger backoff intervals
  - small \(cw\) leads to larger number of collisions

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DCF Example

B1 = 25

\[\text{wait} \quad | \quad \text{data}\]

B2 = 20

B1 = 5

\[\text{data} \quad | \quad \text{wait}\]

B2 = 15

B2 = 10

\(cw = 31\)

B1 and B2 are backoff intervals at nodes 1 and 2
MAC Protocols: Issues

- Hidden and Exposed Terminal Problems
- Reliability
- Collision avoidance
- Congestion control

MAC: Congestion Control

- IEEE 802.11 DCF: Congestion control achieved by dynamically choosing the contention window $cw$

- Binary Exponential Backoff in DCF:
  - When a node fails to receive CTS in response to its RTS, it increases the contention window
    - $cw$ is doubled (up to an upper bound)
    - Fairness problems
  - When a node successfully completes a data transfer, it restores $cw$ to $CW_{min}$
802.11 Physical Layer

- Both FHSS and DSSS modes are specified in 2.4 GHz spectrum
- Infrared is also supported at 850 to 950nm range

- IEEE 802.11b details
  - Supports data rate of up to 11 Mbps
  - 22 MHz occupied bandwidth by spread spectrum
  - Uses complementary code keying (CCK) as modulation scheme for higher data rate
  - Header and preamble are sent at 1 Mbps (basic rate)

802.11a Details

- Employs 300 MHz bandwidth in the 5 GHz band

<table>
<thead>
<tr>
<th>Data Rate (Mbit/s)</th>
<th>Modulation Type</th>
<th>Coding Rate (Convolutional Encoding &amp; Puncturing)</th>
<th>Coded bits per subcarrier symbol</th>
<th>Coded bits per OFDM symbol</th>
<th>Data bits per OFDM symbol</th>
</tr>
</thead>
<tbody>
<tr>
<td>6</td>
<td>BPSK</td>
<td>1/2</td>
<td>1</td>
<td>48</td>
<td>24</td>
</tr>
<tr>
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<td>BPSK</td>
<td>3/4</td>
<td>1</td>
<td>48</td>
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<td>24</td>
<td>16-QAM</td>
<td>1/2</td>
<td>4</td>
<td>192</td>
<td>96</td>
</tr>
<tr>
<td>36</td>
<td>16-QAM</td>
<td>3/4</td>
<td>4</td>
<td>192</td>
<td>144</td>
</tr>
<tr>
<td>48</td>
<td>64-QAM</td>
<td>2/3</td>
<td>6</td>
<td>288</td>
<td>192</td>
</tr>
<tr>
<td>54</td>
<td>64-QAM</td>
<td>3/4</td>
<td>6</td>
<td>288</td>
<td>216</td>
</tr>
</tbody>
</table>

* Support for these data rates is required by the 802.11a standard

802.11a data rate description
IEEE 802.11 Protocols

- IEEE 802.11a
  - PHY Standard: 8 channels: 54 Mbps: Products are available.
- IEEE 802.11b
  - PHY Standard: 3 channels: 11 Mbps: Products are available.
- IEEE 802.11d
  - MAC Standard: operate in variable power levels: ongoing
- IEEE 802.11e
- IEEE 802.11f
  - Inter-Access Point Protocol: 2nd half of 2002
- IEEE 802.11g
  - PHY Standard: 3 channels: OFDM and PBCC: 2nd half of 2002
- IEEE 802.11h
  - Supplementary MAC Standard: TPC and DFS: 2nd half of 2002
- IEEE 802.11i
  - Supplementary MAC Standard: Alternative WEP: 2nd half of 2002

Frequency Bands

- Industrial, Scientific, and Medical (ISM) bands
- Unlicensed, 22 MHz channel bandwidth

![Frequency Bands Diagram](image)
MAC Protocols: Summary

- Wireless medium is prone to hidden and exposed terminal problems
- Protocols are typically based on CSMA/CA
- RTS/CTS based signaling
- ACKs for reliability
- Contention window is used for congestion control
- IEEE 802.11 wireless LAN standard
- Fairness issues are still unclear

Wireless Personal Area Networking (WPAN)
Outline

– Introduction to WPANs
– Bluetooth
– Infrared Data Association - IrDA
  • Serial Infrared - SIR
  • Advanced Infrared - AIR
– Home RF
– IEEE 802.15
  • 802.15.3
  • 802.15.4
– Comparative Analysis of WPAN Technologies
– WLAN vs WPAN

Wireless Personal Area Networks (WPAN)

• Connects devices in the Personal Operation Space (POS)

• Extremely short-range (a few meters)

• Primarily designed as cable replacement technologies

• Consists of devices that are portable and generally resource constrained

• Prominent examples include: Bluetooth, IrDA, HomeRF, IEEE 802.15, etc.
Bluetooth - Introduction

- Open Industry standard led by the Bluetooth SIG
- Initially developed as a cable replacement technology, but has evolved to include diverse scenarios like ad hoc networking
- Defines components for both the core and application layers
- Applications
  - Headsets for mobile phones from all leading vendors
  - Cameras from Sony
  - PDAs from Palm, HP, Sony
  - Laptops from HP

The Bluetooth SIG
Bluetooth

- A cable replacement technology
- 1 Mb/s symbol rate
- Range 10+ meters
- Operates in the 2.4 GHz ISM band
- Single chip radio + baseband
  - at low power & low price point

Why not use Wireless LANs?

- power
- cost

Bluetooth Physical Link

- Point to point link
  - Master/Slave relationship
  - Radios can function as masters or slaves

- Piconet
  - Master can connect to 7 slaves
  - Each piconet has max capacity (1 Mbps)
  - Hopping pattern is determined by the master
Scatternet

Piconet 1

Piconet 2

Piconet 3

Cell phone

Bridge (Slave)

Bridge (Master)

Bridge (Master)

Cell phone

Cordless headset

Mouse

Bluetooth Protocol Stack

(LMP)

Link Management Protocol

• Links: Creation, Configuration, and Termination.
• Authentication.
• Quality of Service (QoS).
• Helps to Attach/Detach Slave.
• Manages Low Power Modes: hold, sniff, and park.

(HCI)

Host Controller Interface

• Provides Uniform Command Interface to Baseband and LMP.
• Provides access to Control and Status Registers.
• Used by Host to Send Commands to LMP.

(L2CAP)

Logical Link Control and Adaptation Protocol

• Segmentation and Reassembly.
• Protocol Multiplexing.
• Manages Creation and Termination of Virtual Channels.
• Negotiates QoS, Power Modes: hold, etc.
Infrared Data Association (IrDA) - SIR and AIR

- Developed by the Infrared Data Association (IrDA)

- GOAL
  - Low cost, Low Power, Half-Duplex, Serial Data Interconnection for a walk-up, point-to-point user model.

- Consists of Serial Infrared (SIR) and Advanced Infrared (AIR)

- SIR – deployed in over 100 million devices
  - IrDA PC99 – low speed devices like keyboards, mice, etc.,
  - IrDA Control – For In-room, cordless devices like phones, scanners, printers, PDAs.
  - IrDA Data – For high-speed, Line of Sight data transfer.

IrDA Data

- High Speed, Short-Range (1 – 2 meters), Line of Sight type of data transfer
  - LoS problem
  - Extremely short-range

- Supports both voice and data packets
- Optical Signaling in the 850nm range
- Uses a polling access scheme
- Data rates vary from 2400 bps to 4 Mbps

IrDA - AIR

- AIR actively monitors the symbol error rate in order to maintain a good channel (high SNR)

- The data rate is inversely proportional to the range
  - AIR has been shown to work at 4 Mbps for 5 meters and 256 kbps at 10 meters.
Home RF
Shared Wireless Access Protocol – Cordless Access (SWAP-CA)

- Developed by the HomeRF Working Group, with a focus on connecting devices in a home environment.

- SWAP-CA is one of the several methods within HomeRF
  - Uses RF in the 2.4 GHz ISM band
  - Supports both managed and ad hoc networks of devices at home

- Based on 802.11 (data) and cordless DECT (voice).

- Supports isochronous (TDMA type) slave devices to PCs and asynchronous (CSMA/CA) peer-to-peer devices like an Ethernet LAN.

SWAP-CA

- Supports up to 127 devices per network within a 50 meter range

- Device Types in each network
  - Connection Points (CP) (Access point functionality)
  - Isochronous nodes, I-nodes (End Point)
  - Asynchronous nodes, A-nodes (End Point)
  - Combined AI-nodes

- Managed network (using the CP) can support both voice and data traffic
  - Ad Hoc mode can support data only

- Variations to SWAP-CA include
  - SWAP-MM: focuses on audio/video requirements of home theatre systems, etc.
  - SWAP-lite: looks at keyboards, remote controls, joysticks, etc.
IEEE 802.15 Working Group (WG)

- 802.15
  - 802.15.1 - Medium rate WPAN (a Bluetooth derivative)
  - 802.15.2 - Co-Existence Mechanisms
  - 802.15.3 - High-Rate of up to 55 Mbps WPAN standard
  - 802.15.4 - Low Rate, Low Power WPAN
IEEE 802.15.3

• Range limited to about 10m, supporting rates of 11-55 Mbps depending on the modulation scheme

• Supports Ad hoc networking by using a master/slave concept and has an extremely short connection time

• Robust support for multimedia QoS by using Guaranteed Time Slots (GTS).
  - A MAC super-frame would consist of both Contention Access Periods (CAP) and GTS, dynamically changing depending on requirements.

• Very low current drain (less than 80mA)
  - Contributes to effective power management.

• Widely seen as a competitor to 802.11 and as a complementary technology to Bluetooth

IEEE 802.15.4

• Referred to as the Low Rate PAN (LR-PAN)

• Key Motivation
  - Low Rate, Low Power, Low Cost.

• Target Applications
  - Home automation like heating, ventilation, security, lighting, climate control, control of windows, doors, etc.

  - Industrial control, agricultural applications, medical sensors and actuators with low data rate requirements.

  - Electronics like TVs, home theatres, DVD players, remote controls and PC applications like keyboards, mice, joystick
IEEE 802.15.4

• Current development is by the 802.15 WG and the ZigBee Alliance.

• The MAC is divided into the service layer (MCPS-SAP) and the management layer (MLME-SAP).

• The MAC defines 4 different types of frames based on the type of application
  – Beacon, Data, Acknowledgement, Command

• Can provide dedicated bandwidth under the superframe mode of operation.
  – Superframe: One node acts as the PAN coordinator, and sends beacons at intervals ranging from 12ms to 245ms.
  – Superframe can have both contention-based and Guaranteed Time Slots (GTS)

• Provides three levels of security
  – No Security
  – Access Control Lists
  – Symmetric Key Encryption using AES-128

IEEE 802.15.4 (contd.)

• 868/915 MHz frequency band for Europe and USA and 2.4 GHz for the rest of the world

• Data rates vary between 20 and 250 kbps

• Range dependent on sensitivity of receiver

• Uses DSSS with each bit represented by a 15 chip sequence

• Both PHY types maintain a common interface to the MAC
## WPAN Technologies – A Comparison

<table>
<thead>
<tr>
<th>Technology</th>
<th>IrDa</th>
<th>HomeRF</th>
<th>Bluetooth (IEEE 802.15.1)</th>
<th>IEEE 802.15.3</th>
<th>IEEE 802.15.4</th>
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</thead>
<tbody>
<tr>
<td>Operational</td>
<td>Infrared</td>
<td>2.4 GHz</td>
<td>2.4 GHz ISM band</td>
<td>2.4 GHz and 868/915 MHz</td>
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<tr>
<td>Spectrum</td>
<td>850 nm</td>
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<td>Physical Details</td>
<td>Optical</td>
<td>FHSS</td>
<td>FHSS</td>
<td>Uncoded QPSK,</td>
<td>DSSS with BPSK or MSK (O-QPSK)</td>
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<tr>
<td></td>
<td>Rays</td>
<td>with</td>
<td></td>
<td>Trellis Coded QPSK or 16/32/64-QAM scheme</td>
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<tr>
<td></td>
<td></td>
<td>FSK</td>
<td></td>
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<td>Channel Access</td>
<td>Polling</td>
<td>CSMA-CA</td>
<td>Master-Slave Polling,</td>
<td>CSMA-CA, and Guaranteed</td>
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<td></td>
<td></td>
<td>and TDMA</td>
<td>Time Division Duplex (TDD)</td>
<td>Time Slots (GTS) in a Superframe structure</td>
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<tr>
<td>Maximum</td>
<td>4 Mbps</td>
<td>10 Mbps</td>
<td>Up to 1 Mbps</td>
<td>11-55 Mbps</td>
<td></td>
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<tr>
<td>Data Rate</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>868 MHz - 20, 915 MHz - 40,</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>2.4 GHz - 250 kbps</td>
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<tr>
<td>Coverage</td>
<td>&lt; 10 m</td>
<td>&gt; 50 m</td>
<td>&lt; 10 m</td>
<td>&lt; 10m</td>
<td></td>
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<tr>
<td>Power Level</td>
<td>Distance</td>
<td>&lt; 500 mA</td>
<td>1 mA – 60 mA</td>
<td>80 mA</td>
<td>Very Low current drain</td>
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<tr>
<td>Issues</td>
<td>Based</td>
<td>peak current</td>
<td>20-50 µA</td>
<td>Very Low current drain</td>
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<tr>
<td>Interference</td>
<td>Present</td>
<td>Present</td>
<td>Present</td>
<td>Present</td>
<td>Security features in development.</td>
</tr>
<tr>
<td>Price</td>
<td>Low (&lt; $ 10)</td>
<td>Medium</td>
<td>Low (&lt; $ 10)</td>
<td>Medium</td>
<td></td>
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<tr>
<td>Security</td>
<td>Secure</td>
<td>Secured by encryption</td>
<td>Less Secure. Uses the SAFER+ encryption at the baseband layer. Relies on higher layer security.</td>
<td>Very High level of Security including authentication, privacy, encryption and digital certificate services.</td>
<td></td>
</tr>
</tbody>
</table>

### WLAN vs WPAN

- Typically WLANs have a much larger range than WPANs.
- WPANs are lean more towards cable replacement rather than network access.
- Complementary Technologies not Competitive.
- Exceptionally Effective Low Power Strategies in WPAN.
The Scope of the Various WLAN and WPAN Standards

Conclusions and Future Directions
Conclusions and Future Directions

- We have thoroughly investigated current high-speed BWA, WLANs, and WPANs systems
  - Major players in the world of last mile broadband wireless access
- Some future directions
  - Bandwidth on demand and high spectrum utilization
  - Reconfigurable systems and adaptivity to support multiband
  - Convergence of BWA and 4Gmobile will be a major focus of activity

Thank you !!!

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