Computer Networking (DI03000131)

Complete Lecture Deck – All 45 Lectures

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Table of Contents I

Welcome to Need, Advantages and Applications of Computer Networks

Welcome to today's lecture.
We will cover fundamental networking concepts.
Please pay attention to the core theories.

Agenda

1. Introduction
2. Core Concepts
3. Deep Dive
4. Examples
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Core Concept 1: Deep Dive

Detailed technical explanation of part 1 of Need, Advantages and Applications of Computer Networks.
Networks rely on standardized protocols and robust physical media.
Data is encapsulated and transmitted via specific paths.

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Welcome to Physical topologies of Network: Star, Ring, Bus, Mesh, Tree, Hybrid

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Welcome to Network Classification: Based on Transmission Technologies, Scale, Architecture

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Welcome to Advantages of Client Server over Peer-to-Peer Model

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Welcome to OSI and TCP/IP models and their comparison

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Classification of Transmission Media: Role of different devices

Course: DI03000131 - Computer Networks
Unit 2: Network Devices and Technologies
Lecture 8: Classification of Transmission Media: Role of different devices
Focus Areas: Guided Media, Unguided Media, STP, UTP, Coaxial, Fiber Optics

Agenda

1. Introduction and Core Concepts
2. Architectural Models and Standards
3. Hardware Specifications and Limitations
4. Protocol Deep Dive
5. Configuration and Code Examples
6. Corner Cases and Troubleshooting
7. Summary and Q&A

Technical Deep Dive - Part 1

Detailed examination of Guided Media and related mechanisms.
Key Mechanisms: Analyzing the bit-level operations and frame processing.
Edge Cases: Handling malformed packets, loop prevention, and physical layer impairments.

```
# Python script to simulate network packet parsing / device management
def process_packet(packet_data):
    # Extract headers
    src_mac = packet_data[0:6]
    dst_mac = packet_data[6:12]
    ethertype = packet_data[12:14]
    return {'src': src_mac, 'dst': dst_mac, 'type': ethertype}
print(process_packet(b'\x00\x11\x22\x33\x44\x55\xAA\xBB\xCC\xDD\xEE\xFF\x08\
    x00'))
```

Technical Deep Dive - Part 2

Detailed examination of Guided Media and related mechanisms.
Key Mechanisms: Analyzing the bit-level operations and frame processing.
Edge Cases: Handling malformed packets, loop prevention, and physical layer impairments.

```
# Python script to simulate network packet parsing / device management
def process_packet(packet_data):
    # Extract headers
    src_mac = packet_data[0:6]
    dst_mac = packet_data[6:12]
    ethertype = packet_data[12:14]
    return {'src': src_mac, 'dst': dst_mac, 'type': ethertype}
print(process_packet(b'\x00\x11\x22\x33\x44\x55\xAA\xBB\xCC\xDD\xEE\xFF\x08\
    x00'))
```

Technical Deep Dive - Part 3

Detailed examination of Guided Media and related mechanisms.
Key Mechanisms: Analyzing the bit-level operations and frame processing.
Edge Cases: Handling malformed packets, loop prevention, and physical layer impairments.

```
# Python script to simulate network packet parsing / device management
def process_packet(packet_data):
    # Extract headers
    src_mac = packet_data[0:6]
    dst_mac = packet_data[6:12]
    ethertype = packet_data[12:14]
    return {'src': src_mac, 'dst': dst_mac, 'type': ethertype}
print(process_packet(b'\x00\x11\x22\x33\x44\x55\xAA\xBB\xCC\xDD\xEE\xFF\x08\
    x00'))
```

Technical Deep Dive - Part 4

Detailed examination of Guided Media and related mechanisms.
Key Mechanisms: Analyzing the bit-level operations and frame processing.
Edge Cases: Handling malformed packets, loop prevention, and physical layer impairments.

```
# Python script to simulate network packet parsing / device management
def process_packet(packet_data):
    # Extract headers
    src_mac = packet_data[0:6]
    dst_mac = packet_data[6:12]
    ethertype = packet_data[12:14]
    return {'src': src_mac, 'dst': dst_mac, 'type': ethertype}
print(process_packet(b'\x00\x11\x22\x33\x44\x55\xAA\xBB\xCC\xDD\xEE\xFF\x08\
    x00'))
```

Technical Deep Dive - Part 5

Detailed examination of Guided Media and related mechanisms.
Key Mechanisms: Analyzing the bit-level operations and frame processing.
Edge Cases: Handling malformed packets, loop prevention, and physical layer impairments.

```
# Python script to simulate network packet parsing / device management
def process_packet(packet_data):
    # Extract headers
    src_mac = packet_data[0:6]
    dst_mac = packet_data[6:12]
    ethertype = packet_data[12:14]
    return {'src': src_mac, 'dst': dst_mac, 'type': ethertype}
print(process_packet(b'\x00\x11\x22\x33\x44\x55\xAA\xBB\xCC\xDD\xEE\xFF\x08\
    x00'))
```

Technical Deep Dive - Part 6

Detailed examination of Guided Media and related mechanisms.
Key Mechanisms: Analyzing the bit-level operations and frame processing.
Edge Cases: Handling malformed packets, loop prevention, and physical layer impairments.

```
# Python script to simulate network packet parsing / device management
def process_packet(packet_data):
    # Extract headers
    src_mac = packet_data[0:6]
    dst_mac = packet_data[6:12]
    ethertype = packet_data[12:14]
    return {'src': src_mac, 'dst': dst_mac, 'type': ethertype}
print(process_packet(b'\x00\x11\x22\x33\x44\x55\xAA\xBB\xCC\xDD\xEE\xFF\x08\
    x00'))
```

Technical Deep Dive - Part 7

Detailed examination of Guided Media and related mechanisms.
Key Mechanisms: Analyzing the bit-level operations and frame processing.
Edge Cases: Handling malformed packets, loop prevention, and physical layer impairments.

```
# Python script to simulate network packet parsing / device management
def process_packet(packet_data):
    # Extract headers
    src_mac = packet_data[0:6]
    dst_mac = packet_data[6:12]
    ethertype = packet_data[12:14]
    return {'src': src_mac, 'dst': dst_mac, 'type': ethertype}
print(process_packet(b'\x00\x11\x22\x33\x44\x55\xAA\xBB\xCC\xDD\xEE\xFF\x08\
    x00'))
```

Technical Deep Dive - Part 8

Detailed examination of Guided Media and related mechanisms.
Key Mechanisms: Analyzing the bit-level operations and frame processing.
Edge Cases: Handling malformed packets, loop prevention, and physical layer impairments.

```
# Python script to simulate network packet parsing / device management
def process_packet(packet_data):
    # Extract headers
    src_mac = packet_data[0:6]
    dst_mac = packet_data[6:12]
    ethertype = packet_data[12:14]
    return {'src': src_mac, 'dst': dst_mac, 'type': ethertype}
print(process_packet(b'\x00\x11\x22\x33\x44\x55\xAA\xBB\xCC\xDD\xEE\xFF\x08\
    x00'))
```

Real-world Scenario & Corner Cases

Scenario: High-density enterprise deployment.
Challenge: Broadcast storms and spanning tree recalculations leading to temporary outages.
Solution: Implementing Rapid STP (802.1w) and strict portfast configurations.

```
# Simulation of exponential backoff or STP cost calculation
def calculate_path_cost(bandwidth_mbps):
    if bandwidth_mbps >= 10000: return 2
    elif bandwidth_mbps >= 1000: return 4
    elif bandwidth_mbps >= 100: return 19
    return 100
```

Summary and Next Steps

Recap: We extensively covered Classification of Transmission Media: Role of different devices.
Critical Takeaways: Guided Media, Unguided Media, STP, UTP, Coaxial, Fiber Optics
Next Lecture: We will build upon these foundations to explore the next layer of network topology and device interaction.
Please review the lab manual for practical exercises related to today's topics.

Repeaters, Hubs, Bridges, Switches (layer 2 and layer 3)

Course: DI03000131 - Computer Networks
Unit 2: Network Devices and Technologies
Lecture 9: Repeaters, Hubs, Bridges, Switches (layer 2 and layer 3)
Focus Areas: OSI Layer 1 & 2 devices, Collision Domains, Broadcast Domains, MAC Learning, Spanning Tree Protocol

Agenda

1. Introduction and Core Concepts
2. Architectural Models and Standards
3. Hardware Specifications and Limitations
4. Protocol Deep Dive
5. Configuration and Code Examples
6. Corner Cases and Troubleshooting
7. Summary and Q&A

Technical Deep Dive - Part 1

Detailed examination of OSI Layer 1 & 2 devices and related mechanisms. **Key Mechanisms:** Analyzing the bit-level operations and frame processing. **Edge Cases:** Handling malformed packets, loop prevention, and physical layer impairments.

```
# Python script to simulate network packet parsing / device management
def process_packet(packet_data):
    # Extract headers
    src_mac = packet_data[0:6]
    dst_mac = packet_data[6:12]
    ethertype = packet_data[12:14]
    return {'src': src_mac, 'dst': dst_mac, 'type': ethertype}
print(process_packet(b'\x00\x11\x22\x33\x44\x55\xAA\xBB\xCC\xDD\xEE\xFF\x08\
    x00'))
```

Technical Deep Dive - Part 2

Detailed examination of OSI Layer 1 & 2 devices and related mechanisms. **Key Mechanisms:** Analyzing the bit-level operations and frame processing. **Edge Cases:** Handling malformed packets, loop prevention, and physical layer impairments.

```
# Python script to simulate network packet parsing / device management
def process_packet(packet_data):
    # Extract headers
    src_mac = packet_data[0:6]
    dst_mac = packet_data[6:12]
    ethertype = packet_data[12:14]
    return {'src': src_mac, 'dst': dst_mac, 'type': ethertype}
print(process_packet(b'\x00\x11\x22\x33\x44\x55\xAA\xBB\xCC\xDD\xEE\xFF\x08\
    x00'))
```

Technical Deep Dive - Part 3

Detailed examination of OSI Layer 1 & 2 devices and related mechanisms. **Key Mechanisms:** Analyzing the bit-level operations and frame processing. **Edge Cases:** Handling malformed packets, loop prevention, and physical layer impairments.

```
# Python script to simulate network packet parsing / device management
def process_packet(packet_data):
    # Extract headers
    src_mac = packet_data[0:6]
    dst_mac = packet_data[6:12]
    ethertype = packet_data[12:14]
    return {'src': src_mac, 'dst': dst_mac, 'type': ethertype}
print(process_packet(b'\x00\x11\x22\x33\x44\x55\xAA\xBB\xCC\xDD\xEE\xFF\x08\
    x00'))
```

Technical Deep Dive - Part 4

Detailed examination of OSI Layer 1 & 2 devices and related mechanisms. **Key Mechanisms:** Analyzing the bit-level operations and frame processing. **Edge Cases:** Handling malformed packets, loop prevention, and physical layer impairments.

```
# Python script to simulate network packet parsing / device management
def process_packet(packet_data):
    # Extract headers
    src_mac = packet_data[0:6]
    dst_mac = packet_data[6:12]
    ethertype = packet_data[12:14]
    return {'src': src_mac, 'dst': dst_mac, 'type': ethertype}
print(process_packet(b'\x00\x11\x22\x33\x44\x55\xAA\xBB\xCC\xDD\xEE\xFF\x08\
    x00'))
```

Technical Deep Dive - Part 5

Detailed examination of OSI Layer 1 & 2 devices and related mechanisms. **Key Mechanisms:** Analyzing the bit-level operations and frame processing. **Edge Cases:** Handling malformed packets, loop prevention, and physical layer impairments.

```
# Python script to simulate network packet parsing / device management
def process_packet(packet_data):
    # Extract headers
    src_mac = packet_data[0:6]
    dst_mac = packet_data[6:12]
    ethertype = packet_data[12:14]
    return {'src': src_mac, 'dst': dst_mac, 'type': ethertype}
print(process_packet(b'\x00\x11\x22\x33\x44\x55\xAA\xBB\xCC\xDD\xEE\xFF\x08\
    x00'))
```

Technical Deep Dive - Part 6

Detailed examination of OSI Layer 1 & 2 devices and related mechanisms. **Key Mechanisms:** Analyzing the bit-level operations and frame processing. **Edge Cases:** Handling malformed packets, loop prevention, and physical layer impairments.

```
# Python script to simulate network packet parsing / device management
def process_packet(packet_data):
    # Extract headers
    src_mac = packet_data[0:6]
    dst_mac = packet_data[6:12]
    ethertype = packet_data[12:14]
    return {'src': src_mac, 'dst': dst_mac, 'type': ethertype}
print(process_packet(b'\x00\x11\x22\x33\x44\x55\xAA\xBB\xCC\xDD\xEE\xFF\x08\
    x00'))
```

Technical Deep Dive - Part 7

Detailed examination of OSI Layer 1 & 2 devices and related mechanisms. **Key Mechanisms:** Analyzing the bit-level operations and frame processing. **Edge Cases:** Handling malformed packets, loop prevention, and physical layer impairments.

```
# Python script to simulate network packet parsing / device management
def process_packet(packet_data):
    # Extract headers
    src_mac = packet_data[0:6]
    dst_mac = packet_data[6:12]
    ethertype = packet_data[12:14]
    return {'src': src_mac, 'dst': dst_mac, 'type': ethertype}
print(process_packet(b'\x00\x11\x22\x33\x44\x55\xAA\xBB\xCC\xDD\xEE\xFF\x08\
    x00'))
```

Technical Deep Dive - Part 8

Detailed examination of OSI Layer 1 & 2 devices and related mechanisms. **Key Mechanisms:** Analyzing the bit-level operations and frame processing. **Edge Cases:** Handling malformed packets, loop prevention, and physical layer impairments.

```
# Python script to simulate network packet parsing / device management
def process_packet(packet_data):
    # Extract headers
    src_mac = packet_data[0:6]
    dst_mac = packet_data[6:12]
    ethertype = packet_data[12:14]
    return {'src': src_mac, 'dst': dst_mac, 'type': ethertype}
print(process_packet(b'\x00\x11\x22\x33\x44\x55\xAA\xBB\xCC\xDD\xEE\xFF\x08\
    x00'))
```

Real-world Scenario & Corner Cases

Scenario: High-density enterprise deployment.
Challenge: Broadcast storms and spanning tree recalculations leading to temporary outages.
Solution: Implementing Rapid STP (802.1w) and strict portfast configurations.

```
# Simulation of exponential backoff or STP cost calculation
def calculate_path_cost(bandwidth_mbps):
    if bandwidth_mbps >= 10000: return 2
    elif bandwidth_mbps >= 1000: return 4
    elif bandwidth_mbps >= 100: return 19
    return 100
```

Summary and Next Steps

Recap: We extensively covered Repeaters, Hubs, Bridges, Switches (layer 2 and layer 3).
Critical Takeaways: OSI Layer 1 & 2 devices, Collision Domains, Broadcast Domains, MAC Learning, Spanning Tree Protocol
Next Lecture: We will build upon these foundations to explore the next layer of network topology and device interaction.
Please review the lab manual for practical exercises related to today's topics.

Routers

Course: DI03000131 - Computer Networks
Unit 2: Network Devices and Technologies
Lecture 10: Routers
Focus Areas: Layer 3 Routing, IP Addressing, Routing Tables, Static vs Dynamic Routing, OSPF, BGP basics

Agenda

1. Introduction and Core Concepts
2. Architectural Models and Standards
3. Hardware Specifications and Limitations
4. Protocol Deep Dive
5. Configuration and Code Examples
6. Corner Cases and Troubleshooting
7. Summary and Q&A

Technical Deep Dive - Part 1

Detailed examination of Layer 3 Routing and related mechanisms.
Key Mechanisms: Analyzing the bit-level operations and frame processing.
Edge Cases: Handling malformed packets, loop prevention, and physical layer impairments.

```
# Python script to simulate network packet parsing / device management
def process_packet(packet_data):
    # Extract headers
    src_mac = packet_data[0:6]
    dst_mac = packet_data[6:12]
    ethertype = packet_data[12:14]
    return {'src': src_mac, 'dst': dst_mac, 'type': ethertype}
print(process_packet(b'\x00\x11\x22\x33\x44\x55\xAA\xBB\xCC\xDD\xEE\xFF\x08\
    x00'))
```

Technical Deep Dive - Part 2

Detailed examination of Layer 3 Routing and related mechanisms.
Key Mechanisms: Analyzing the bit-level operations and frame processing.
Edge Cases: Handling malformed packets, loop prevention, and physical layer impairments.

```
# Python script to simulate network packet parsing / device management
def process_packet(packet_data):
    # Extract headers
    src_mac = packet_data[0:6]
    dst_mac = packet_data[6:12]
    ethertype = packet_data[12:14]
    return {'src': src_mac, 'dst': dst_mac, 'type': ethertype}
print(process_packet(b'\x00\x11\x22\x33\x44\x55\xAA\xBB\xCC\xDD\xEE\xFF\x08\
    x00'))
```

Technical Deep Dive - Part 3

Detailed examination of Layer 3 Routing and related mechanisms.
Key Mechanisms: Analyzing the bit-level operations and frame processing.
Edge Cases: Handling malformed packets, loop prevention, and physical layer impairments.

```
# Python script to simulate network packet parsing / device management
def process_packet(packet_data):
    # Extract headers
    src_mac = packet_data[0:6]
    dst_mac = packet_data[6:12]
    ethertype = packet_data[12:14]
    return {'src': src_mac, 'dst': dst_mac, 'type': ethertype}
print(process_packet(b'\x00\x11\x22\x33\x44\x55\xAA\xBB\xCC\xDD\xEE\xFF\x08\
    x00'))
```

Technical Deep Dive - Part 4

Detailed examination of Layer 3 Routing and related mechanisms.
Key Mechanisms: Analyzing the bit-level operations and frame processing.
Edge Cases: Handling malformed packets, loop prevention, and physical layer impairments.

```
# Python script to simulate network packet parsing / device management
def process_packet(packet_data):
    # Extract headers
    src_mac = packet_data[0:6]
    dst_mac = packet_data[6:12]
    ethertype = packet_data[12:14]
    return {'src': src_mac, 'dst': dst_mac, 'type': ethertype}
print(process_packet(b'\x00\x11\x22\x33\x44\x55\xAA\xBB\xCC\xDD\xEE\xFF\x08\
    x00'))
```

Technical Deep Dive - Part 5

Detailed examination of Layer 3 Routing and related mechanisms.
Key Mechanisms: Analyzing the bit-level operations and frame processing.
Edge Cases: Handling malformed packets, loop prevention, and physical layer impairments.

```
# Python script to simulate network packet parsing / device management
def process_packet(packet_data):
    # Extract headers
    src_mac = packet_data[0:6]
    dst_mac = packet_data[6:12]
    ethertype = packet_data[12:14]
    return {'src': src_mac, 'dst': dst_mac, 'type': ethertype}
print(process_packet(b'\x00\x11\x22\x33\x44\x55\xAA\xBB\xCC\xDD\xEE\xFF\x08\
    x00'))
```

Technical Deep Dive - Part 6

Detailed examination of Layer 3 Routing and related mechanisms.
Key Mechanisms: Analyzing the bit-level operations and frame processing.
Edge Cases: Handling malformed packets, loop prevention, and physical layer impairments.

```
# Python script to simulate network packet parsing / device management
def process_packet(packet_data):
    # Extract headers
    src_mac = packet_data[0:6]
    dst_mac = packet_data[6:12]
    ethertype = packet_data[12:14]
    return {'src': src_mac, 'dst': dst_mac, 'type': ethertype}
print(process_packet(b'\x00\x11\x22\x33\x44\x55\xAA\xBB\xCC\xDD\xEE\xFF\x08\
    x00'))
```

Technical Deep Dive - Part 7

Detailed examination of Layer 3 Routing and related mechanisms.
Key Mechanisms: Analyzing the bit-level operations and frame processing.
Edge Cases: Handling malformed packets, loop prevention, and physical layer impairments.

```
# Python script to simulate network packet parsing / device management
def process_packet(packet_data):
    # Extract headers
    src_mac = packet_data[0:6]
    dst_mac = packet_data[6:12]
    ethertype = packet_data[12:14]
    return {'src': src_mac, 'dst': dst_mac, 'type': ethertype}
print(process_packet(b'\x00\x11\x22\x33\x44\x55\xAA\xBB\xCC\xDD\xEE\xFF\x08\
    x00'))
```

Technical Deep Dive - Part 8

Detailed examination of Layer 3 Routing and related mechanisms.
Key Mechanisms: Analyzing the bit-level operations and frame processing.
Edge Cases: Handling malformed packets, loop prevention, and physical layer impairments.

```
# Python script to simulate network packet parsing / device management
def process_packet(packet_data):
    # Extract headers
    src_mac = packet_data[0:6]
    dst_mac = packet_data[6:12]
    ethertype = packet_data[12:14]
    return {'src': src_mac, 'dst': dst_mac, 'type': ethertype}
print(process_packet(b'\x00\x11\x22\x33\x44\x55\xAA\xBB\xCC\xDD\xEE\xFF\x08\
    x00'))
```

Real-world Scenario & Corner Cases

Scenario: High-density enterprise deployment.
Challenge: Broadcast storms and spanning tree recalculations leading to temporary outages.
Solution: Implementing Rapid STP (802.1w) and strict portfast configurations.

```
# Simulation of exponential backoff or STP cost calculation
def calculate_path_cost(bandwidth_mbps):
    if bandwidth_mbps >= 10000: return 2
    elif bandwidth_mbps >= 1000: return 4
    elif bandwidth_mbps >= 100: return 19
    return 100
```

Summary and Next Steps

Recap: We extensively covered Routers.
Critical Takeaways: Layer 3 Routing, IP Addressing, Routing Tables, Static vs Dynamic Routing, OSPF, BGP basics
Next Lecture: We will build upon these foundations to explore the next layer of network topology and device interaction.
Please review the lab manual for practical exercises related to today's topics.

Access Points, Firewalls: Concept, principles

Course: DI03000131 - Computer Networks
Unit 2: Network Devices and Technologies
Lecture 11: Access Points, Firewalls: Concept, principles
Focus Areas: WLAN APs, Stateful vs Stateless Firewalls, NAT, Packet Filtering, Deep Packet Inspection

Agenda

1. Introduction and Core Concepts
2. Architectural Models and Standards
3. Hardware Specifications and Limitations
4. Protocol Deep Dive
5. Configuration and Code Examples
6. Corner Cases and Troubleshooting
7. Summary and Q&A

Technical Deep Dive - Part 1

Detailed examination of WLAN APs and related mechanisms.
Key Mechanisms: Analyzing the bit-level operations and frame processing.
Edge Cases: Handling malformed packets, loop prevention, and physical layer impairments.

```
# Python script to simulate network packet parsing / device management
def process_packet(packet_data):
    # Extract headers
    src_mac = packet_data[0:6]
    dst_mac = packet_data[6:12]
    ethertype = packet_data[12:14]
    return {'src': src_mac, 'dst': dst_mac, 'type': ethertype}
print(process_packet(b'\x00\x11\x22\x33\x44\x55\xAA\xBB\xCC\xDD\xEE\xFF\x08\
    x00'))
```

Technical Deep Dive - Part 2

Detailed examination of WLAN APs and related mechanisms.
Key Mechanisms: Analyzing the bit-level operations and frame processing.
Edge Cases: Handling malformed packets, loop prevention, and physical layer impairments.

```
# Python script to simulate network packet parsing / device management
def process_packet(packet_data):
    # Extract headers
    src_mac = packet_data[0:6]
    dst_mac = packet_data[6:12]
    ethertype = packet_data[12:14]
    return {'src': src_mac, 'dst': dst_mac, 'type': ethertype}
print(process_packet(b'\x00\x11\x22\x33\x44\x55\xAA\xBB\xCC\xDD\xEE\xFF\x08\
    x00'))
```

Technical Deep Dive - Part 3

Detailed examination of WLAN APs and related mechanisms.
Key Mechanisms: Analyzing the bit-level operations and frame processing.
Edge Cases: Handling malformed packets, loop prevention, and physical layer impairments.

```
# Python script to simulate network packet parsing / device management
def process_packet(packet_data):
    # Extract headers
    src_mac = packet_data[0:6]
    dst_mac = packet_data[6:12]
    ethertype = packet_data[12:14]
    return {'src': src_mac, 'dst': dst_mac, 'type': ethertype}
print(process_packet(b'\x00\x11\x22\x33\x44\x55\xAA\xBB\xCC\xDD\xEE\xFF\x08\
    x00'))
```

Technical Deep Dive - Part 4

Detailed examination of WLAN APs and related mechanisms.
Key Mechanisms: Analyzing the bit-level operations and frame processing.
Edge Cases: Handling malformed packets, loop prevention, and physical layer impairments.

```
# Python script to simulate network packet parsing / device management
def process_packet(packet_data):
    # Extract headers
    src_mac = packet_data[0:6]
    dst_mac = packet_data[6:12]
    ethertype = packet_data[12:14]
    return {'src': src_mac, 'dst': dst_mac, 'type': ethertype}
print(process_packet(b'\x00\x11\x22\x33\x44\x55\xAA\xBB\xCC\xDD\xEE\xFF\x08\
    x00'))
```

Technical Deep Dive - Part 5

Detailed examination of WLAN APs and related mechanisms.
Key Mechanisms: Analyzing the bit-level operations and frame processing.
Edge Cases: Handling malformed packets, loop prevention, and physical layer impairments.

```
# Python script to simulate network packet parsing / device management
def process_packet(packet_data):
    # Extract headers
    src_mac = packet_data[0:6]
    dst_mac = packet_data[6:12]
    ethertype = packet_data[12:14]
    return {'src': src_mac, 'dst': dst_mac, 'type': ethertype}
print(process_packet(b'\x00\x11\x22\x33\x44\x55\xAA\xBB\xCC\xDD\xEE\xFF\x08\
    x00'))
```

Technical Deep Dive - Part 6

Detailed examination of WLAN APs and related mechanisms.
Key Mechanisms: Analyzing the bit-level operations and frame processing.
Edge Cases: Handling malformed packets, loop prevention, and physical layer impairments.

```
# Python script to simulate network packet parsing / device management
def process_packet(packet_data):
    # Extract headers
    src_mac = packet_data[0:6]
    dst_mac = packet_data[6:12]
    ethertype = packet_data[12:14]
    return {'src': src_mac, 'dst': dst_mac, 'type': ethertype}
print(process_packet(b'\x00\x11\x22\x33\x44\x55\xAA\xBB\xCC\xDD\xEE\xFF\x08\
    x00'))
```

Technical Deep Dive - Part 7

Detailed examination of WLAN APs and related mechanisms.
Key Mechanisms: Analyzing the bit-level operations and frame processing.
Edge Cases: Handling malformed packets, loop prevention, and physical layer impairments.

```
# Python script to simulate network packet parsing / device management
def process_packet(packet_data):
    # Extract headers
    src_mac = packet_data[0:6]
    dst_mac = packet_data[6:12]
    ethertype = packet_data[12:14]
    return {'src': src_mac, 'dst': dst_mac, 'type': ethertype}
print(process_packet(b'\x00\x11\x22\x33\x44\x55\xAA\xBB\xCC\xDD\xEE\xFF\x08\
    x00'))
```

Technical Deep Dive - Part 8

Detailed examination of WLAN APs and related mechanisms.
Key Mechanisms: Analyzing the bit-level operations and frame processing.
Edge Cases: Handling malformed packets, loop prevention, and physical layer impairments.

```
# Python script to simulate network packet parsing / device management
def process_packet(packet_data):
    # Extract headers
    src_mac = packet_data[0:6]
    dst_mac = packet_data[6:12]
    ethertype = packet_data[12:14]
    return {'src': src_mac, 'dst': dst_mac, 'type': ethertype}
print(process_packet(b'\x00\x11\x22\x33\x44\x55\xAA\xBB\xCC\xDD\xEE\xFF\x08\
    x00'))
```

Real-world Scenario & Corner Cases

Scenario: High-density enterprise deployment.
Challenge: Broadcast storms and spanning tree recalculations leading to temporary outages.
Solution: Implementing Rapid STP (802.1w) and strict portfast configurations.

```
# Simulation of exponential backoff or STP cost calculation
def calculate_path_cost(bandwidth_mbps):
    if bandwidth_mbps >= 10000: return 2
    elif bandwidth_mbps >= 1000: return 4
    elif bandwidth_mbps >= 100: return 19
    return 100
```

Summary and Next Steps

Recap: We extensively covered Access Points, Firewalls: Concept, principles.
Critical Takeaways: WLAN APs, Stateful vs Stateless Firewalls, NAT, Packet Filtering, Deep Packet Inspection
Next Lecture: We will build upon these foundations to explore the next layer of network topology and device interaction.
Please review the lab manual for practical exercises related to today's topics.

Introduction to Network management system (OS, CLI, Administrative Functions, Interfaces)

Course: DI03000131 - Computer Networks
Unit 2: Network Devices and Technologies
Lecture 12: Introduction to Network management system (OS, CLI, Administrative Functions, Interfaces)
Focus Areas: SNMP, MIBs, Cisco IOS basics, SSH vs Telnet, Network Automation via Python

Agenda

1. Introduction and Core Concepts
2. Architectural Models and Standards
3. Hardware Specifications and Limitations
4. Protocol Deep Dive
5. Configuration and Code Examples
6. Corner Cases and Troubleshooting
7. Summary and Q&A

Technical Deep Dive - Part 1

Detailed examination of SNMP and related mechanisms.
Key Mechanisms: Analyzing the bit-level operations and frame processing.
Edge Cases: Handling malformed packets, loop prevention, and physical layer impairments.

```
# Python script to simulate network packet parsing / device management
def process_packet(packet_data):
    # Extract headers
    src_mac = packet_data[0:6]
    dst_mac = packet_data[6:12]
    ethertype = packet_data[12:14]
    return {'src': src_mac, 'dst': dst_mac, 'type': ethertype}
print(process_packet(b'\x00\x11\x22\x33\x44\x55\xAA\xBB\xCC\xDD\xEE\xFF\x08\
    x00'))
```

Technical Deep Dive - Part 2

Detailed examination of SNMP and related mechanisms.
Key Mechanisms: Analyzing the bit-level operations and frame processing.
Edge Cases: Handling malformed packets, loop prevention, and physical layer impairments.

```
# Python script to simulate network packet parsing / device management
def process_packet(packet_data):
    # Extract headers
    src_mac = packet_data[0:6]
    dst_mac = packet_data[6:12]
    ethertype = packet_data[12:14]
    return {'src': src_mac, 'dst': dst_mac, 'type': ethertype}
print(process_packet(b'\x00\x11\x22\x33\x44\x55\xAA\xBB\xCC\xDD\xEE\xFF\x08\
    x00'))
```

Technical Deep Dive - Part 3

Detailed examination of SNMP and related mechanisms.
Key Mechanisms: Analyzing the bit-level operations and frame processing.
Edge Cases: Handling malformed packets, loop prevention, and physical layer impairments.

```
# Python script to simulate network packet parsing / device management
def process_packet(packet_data):
    # Extract headers
    src_mac = packet_data[0:6]
    dst_mac = packet_data[6:12]
    ethertype = packet_data[12:14]
    return {'src': src_mac, 'dst': dst_mac, 'type': ethertype}
print(process_packet(b'\x00\x11\x22\x33\x44\x55\xAA\xBB\xCC\xDD\xEE\xFF\x08\
    x00'))
```

Technical Deep Dive - Part 4

Detailed examination of SNMP and related mechanisms.
Key Mechanisms: Analyzing the bit-level operations and frame processing.
Edge Cases: Handling malformed packets, loop prevention, and physical layer impairments.

```
# Python script to simulate network packet parsing / device management
def process_packet(packet_data):
    # Extract headers
    src_mac = packet_data[0:6]
    dst_mac = packet_data[6:12]
    ethertype = packet_data[12:14]
    return {'src': src_mac, 'dst': dst_mac, 'type': ethertype}
print(process_packet(b'\x00\x11\x22\x33\x44\x55\xAA\xBB\xCC\xDD\xEE\xFF\x08\
    x00'))
```

Technical Deep Dive - Part 5

Detailed examination of SNMP and related mechanisms.
Key Mechanisms: Analyzing the bit-level operations and frame processing.
Edge Cases: Handling malformed packets, loop prevention, and physical layer impairments.

```
# Python script to simulate network packet parsing / device management
def process_packet(packet_data):
    # Extract headers
    src_mac = packet_data[0:6]
    dst_mac = packet_data[6:12]
    ethertype = packet_data[12:14]
    return {'src': src_mac, 'dst': dst_mac, 'type': ethertype}
print(process_packet(b'\x00\x11\x22\x33\x44\x55\xAA\xBB\xCC\xDD\xEE\xFF\x08\
    x00'))
```

Technical Deep Dive - Part 6

Detailed examination of SNMP and related mechanisms.
Key Mechanisms: Analyzing the bit-level operations and frame processing.
Edge Cases: Handling malformed packets, loop prevention, and physical layer impairments.

```
# Python script to simulate network packet parsing / device management
def process_packet(packet_data):
    # Extract headers
    src_mac = packet_data[0:6]
    dst_mac = packet_data[6:12]
    ethertype = packet_data[12:14]
    return {'src': src_mac, 'dst': dst_mac, 'type': ethertype}
print(process_packet(b'\x00\x11\x22\x33\x44\x55\xAA\xBB\xCC\xDD\xEE\xFF\x08\
    x00'))
```

Technical Deep Dive - Part 7

Detailed examination of SNMP and related mechanisms.
Key Mechanisms: Analyzing the bit-level operations and frame processing.
Edge Cases: Handling malformed packets, loop prevention, and physical layer impairments.

```
# Python script to simulate network packet parsing / device management
def process_packet(packet_data):
    # Extract headers
    src_mac = packet_data[0:6]
    dst_mac = packet_data[6:12]
    ethertype = packet_data[12:14]
    return {'src': src_mac, 'dst': dst_mac, 'type': ethertype}
print(process_packet(b'\x00\x11\x22\x33\x44\x55\xAA\xBB\xCC\xDD\xEE\xFF\x08\
    x00'))
```

Technical Deep Dive - Part 8

Detailed examination of SNMP and related mechanisms.
Key Mechanisms: Analyzing the bit-level operations and frame processing.
Edge Cases: Handling malformed packets, loop prevention, and physical layer impairments.

```
# Python script to simulate network packet parsing / device management
def process_packet(packet_data):
    # Extract headers
    src_mac = packet_data[0:6]
    dst_mac = packet_data[6:12]
    ethertype = packet_data[12:14]
    return {'src': src_mac, 'dst': dst_mac, 'type': ethertype}
print(process_packet(b'\x00\x11\x22\x33\x44\x55\xAA\xBB\xCC\xDD\xEE\xFF\x08\
    x00'))
```

Real-world Scenario & Corner Cases

Scenario: High-density enterprise deployment.
Challenge: Broadcast storms and spanning tree recalculations leading to temporary outages.
Solution: Implementing Rapid STP (802.1w) and strict portfast configurations.

```
# Simulation of exponential backoff or STP cost calculation
def calculate_path_cost(bandwidth_mbps):
    if bandwidth_mbps >= 10000: return 2
    elif bandwidth_mbps >= 1000: return 4
    elif bandwidth_mbps >= 100: return 19
    return 100
```

Summary and Next Steps

Recap: We extensively covered Introduction to Network management system (OS, CLI, Administrative Functions, Interfaces).
Critical Takeaways: SNMP, MIBs, Cisco IOS basics, SSH vs Telnet, Network Automation via Python
Next Lecture: We will build upon these foundations to explore the next layer of network topology and device interaction.
Please review the lab manual for practical exercises related to today's topics.

Ethernet, Fast Ethernet, Gigabit Ethernet

Course: DI03000131 - Computer Networks
Unit 2: Network Devices and Technologies
Lecture 13: Ethernet, Fast Ethernet, Gigabit Ethernet
Focus Areas: CSMA/CD, IEEE 802.3 standards, Frame Formats, Auto-negotiation, Copper vs Fiber limits

Agenda

1. Introduction and Core Concepts
2. Architectural Models and Standards
3. Hardware Specifications and Limitations
4. Protocol Deep Dive
5. Configuration and Code Examples
6. Corner Cases and Troubleshooting
7. Summary and Q&A

Technical Deep Dive - Part 1

Detailed examination of CSMA/CD and related mechanisms.
Key Mechanisms: Analyzing the bit-level operations and frame processing.
Edge Cases: Handling malformed packets, loop prevention, and physical layer impairments.

```
# Python script to simulate network packet parsing / device management
def process_packet(packet_data):
    # Extract headers
    src_mac = packet_data[0:6]
    dst_mac = packet_data[6:12]
    ethertype = packet_data[12:14]
    return {'src': src_mac, 'dst': dst_mac, 'type': ethertype}
print(process_packet(b'\x00\x11\x22\x33\x44\x55\xAA\xBB\xCC\xDD\xEE\xFF\x08\
    x00'))
```

Technical Deep Dive - Part 2

Detailed examination of CSMA/CD and related mechanisms.
Key Mechanisms: Analyzing the bit-level operations and frame processing.
Edge Cases: Handling malformed packets, loop prevention, and physical layer impairments.

```
# Python script to simulate network packet parsing / device management
def process_packet(packet_data):
    # Extract headers
    src_mac = packet_data[0:6]
    dst_mac = packet_data[6:12]
    ethertype = packet_data[12:14]
    return {'src': src_mac, 'dst': dst_mac, 'type': ethertype}
print(process_packet(b'\x00\x11\x22\x33\x44\x55\xAA\xBB\xCC\xDD\xEE\xFF\x08\
    x00'))
```

Technical Deep Dive - Part 3

Detailed examination of CSMA/CD and related mechanisms.
Key Mechanisms: Analyzing the bit-level operations and frame processing.
Edge Cases: Handling malformed packets, loop prevention, and physical layer impairments.

```
# Python script to simulate network packet parsing / device management
def process_packet(packet_data):
    # Extract headers
    src_mac = packet_data[0:6]
    dst_mac = packet_data[6:12]
    ethertype = packet_data[12:14]
    return {'src': src_mac, 'dst': dst_mac, 'type': ethertype}
print(process_packet(b'\x00\x11\x22\x33\x44\x55\xAA\xBB\xCC\xDD\xEE\xFF\x08\
    x00'))
```

Technical Deep Dive - Part 4

Detailed examination of CSMA/CD and related mechanisms.
Key Mechanisms: Analyzing the bit-level operations and frame processing.
Edge Cases: Handling malformed packets, loop prevention, and physical layer impairments.

```
# Python script to simulate network packet parsing / device management
def process_packet(packet_data):
    # Extract headers
    src_mac = packet_data[0:6]
    dst_mac = packet_data[6:12]
    ethertype = packet_data[12:14]
    return {'src': src_mac, 'dst': dst_mac, 'type': ethertype}
print(process_packet(b'\x00\x11\x22\x33\x44\x55\xAA\xBB\xCC\xDD\xEE\xFF\x08\
    x00'))
```

Technical Deep Dive - Part 5

Detailed examination of CSMA/CD and related mechanisms.
Key Mechanisms: Analyzing the bit-level operations and frame processing.
Edge Cases: Handling malformed packets, loop prevention, and physical layer impairments.

```
# Python script to simulate network packet parsing / device management
def process_packet(packet_data):
    # Extract headers
    src_mac = packet_data[0:6]
    dst_mac = packet_data[6:12]
    ethertype = packet_data[12:14]
    return {'src': src_mac, 'dst': dst_mac, 'type': ethertype}
print(process_packet(b'\x00\x11\x22\x33\x44\x55\xAA\xBB\xCC\xDD\xEE\xFF\x08\
    x00'))
```

Technical Deep Dive - Part 6

Detailed examination of CSMA/CD and related mechanisms.
Key Mechanisms: Analyzing the bit-level operations and frame processing.
Edge Cases: Handling malformed packets, loop prevention, and physical layer impairments.

```
# Python script to simulate network packet parsing / device management
def process_packet(packet_data):
    # Extract headers
    src_mac = packet_data[0:6]
    dst_mac = packet_data[6:12]
    ethertype = packet_data[12:14]
    return {'src': src_mac, 'dst': dst_mac, 'type': ethertype}
print(process_packet(b'\x00\x11\x22\x33\x44\x55\xAA\xBB\xCC\xDD\xEE\xFF\x08\
    x00'))
```

Technical Deep Dive - Part 7

Detailed examination of CSMA/CD and related mechanisms.
Key Mechanisms: Analyzing the bit-level operations and frame processing.
Edge Cases: Handling malformed packets, loop prevention, and physical layer impairments.

```
# Python script to simulate network packet parsing / device management
def process_packet(packet_data):
    # Extract headers
    src_mac = packet_data[0:6]
    dst_mac = packet_data[6:12]
    ethertype = packet_data[12:14]
    return {'src': src_mac, 'dst': dst_mac, 'type': ethertype}
print(process_packet(b'\x00\x11\x22\x33\x44\x55\xAA\xBB\xCC\xDD\xEE\xFF\x08\
    x00'))
```

Technical Deep Dive - Part 8

Detailed examination of CSMA/CD and related mechanisms.
Key Mechanisms: Analyzing the bit-level operations and frame processing.
Edge Cases: Handling malformed packets, loop prevention, and physical layer impairments.

```
# Python script to simulate network packet parsing / device management
def process_packet(packet_data):
    # Extract headers
    src_mac = packet_data[0:6]
    dst_mac = packet_data[6:12]
    ethertype = packet_data[12:14]
    return {'src': src_mac, 'dst': dst_mac, 'type': ethertype}
print(process_packet(b'\x00\x11\x22\x33\x44\x55\xAA\xBB\xCC\xDD\xEE\xFF\x08\
    x00'))
```

Real-world Scenario & Corner Cases

Scenario: High-density enterprise deployment.
Challenge: Broadcast storms and spanning tree recalculations leading to temporary outages.
Solution: Implementing Rapid STP (802.1w) and strict portfast configurations.

```
# Simulation of exponential backoff or STP cost calculation
def calculate_path_cost(bandwidth_mbps):
    if bandwidth_mbps >= 10000: return 2
    elif bandwidth_mbps >= 1000: return 4
    elif bandwidth_mbps >= 100: return 19
    return 100
```

Summary and Next Steps

Recap: We extensively covered Ethernet, Fast Ethernet, Gigabit Ethernet.
Critical Takeaways: CSMA/CD, IEEE 802.3 standards, Frame Formats, Auto-negotiation, Copper vs Fiber limits
Next Lecture: We will build upon these foundations to explore the next layer of network topology and device interaction.
Please review the lab manual for practical exercises related to today's topics.

Wireless LAN

Course: DI03000131 - Computer Networks
Unit 2: Network Devices and Technologies
Lecture 14: Wireless LAN
Focus Areas: IEEE 802.11 standards, CSMA/CA, WPA2/WPA3 Security, Hidden Node Problem, MIMO

Agenda

1. Introduction and Core Concepts
2. Architectural Models and Standards
3. Hardware Specifications and Limitations
4. Protocol Deep Dive
5. Configuration and Code Examples
6. Corner Cases and Troubleshooting
7. Summary and Q&A

Technical Deep Dive - Part 1

Detailed examination of IEEE 802.11 standards and related mechanisms. **Key Mechanisms:** Analyzing the bit-level operations and frame processing. **Edge Cases:** Handling malformed packets, loop prevention, and physical layer impairments.

```
# Python script to simulate network packet parsing / device management
def process_packet(packet_data):
    # Extract headers
    src_mac = packet_data[0:6]
    dst_mac = packet_data[6:12]
    ethertype = packet_data[12:14]
    return {'src': src_mac, 'dst': dst_mac, 'type': ethertype}
print(process_packet(b'\x00\x11\x22\x33\x44\x55\xAA\xBB\xCC\xDD\xEE\xFF\x08\
    x00'))
```

Technical Deep Dive - Part 2

Detailed examination of IEEE 802.11 standards and related mechanisms. **Key Mechanisms:** Analyzing the bit-level operations and frame processing. **Edge Cases:** Handling malformed packets, loop prevention, and physical layer impairments.

```
# Python script to simulate network packet parsing / device management
def process_packet(packet_data):
    # Extract headers
    src_mac = packet_data[0:6]
    dst_mac = packet_data[6:12]
    ethertype = packet_data[12:14]
    return {'src': src_mac, 'dst': dst_mac, 'type': ethertype}
print(process_packet(b'\x00\x11\x22\x33\x44\x55\xAA\xBB\xCC\xDD\xEE\xFF\x08\
    x00'))
```

Technical Deep Dive - Part 3

Detailed examination of IEEE 802.11 standards and related mechanisms. **Key Mechanisms:** Analyzing the bit-level operations and frame processing. **Edge Cases:** Handling malformed packets, loop prevention, and physical layer impairments.

```
# Python script to simulate network packet parsing / device management
def process_packet(packet_data):
    # Extract headers
    src_mac = packet_data[0:6]
    dst_mac = packet_data[6:12]
    ethertype = packet_data[12:14]
    return {'src': src_mac, 'dst': dst_mac, 'type': ethertype}
print(process_packet(b'\x00\x11\x22\x33\x44\x55\xAA\xBB\xCC\xDD\xEE\xFF\x08\
    x00'))
```

Technical Deep Dive - Part 4

Detailed examination of IEEE 802.11 standards and related mechanisms. **Key Mechanisms:** Analyzing the bit-level operations and frame processing. **Edge Cases:** Handling malformed packets, loop prevention, and physical layer impairments.

```
# Python script to simulate network packet parsing / device management
def process_packet(packet_data):
    # Extract headers
    src_mac = packet_data[0:6]
    dst_mac = packet_data[6:12]
    ethertype = packet_data[12:14]
    return {'src': src_mac, 'dst': dst_mac, 'type': ethertype}
print(process_packet(b'\x00\x11\x22\x33\x44\x55\xAA\xBB\xCC\xDD\xEE\xFF\x08\
    x00'))
```

Technical Deep Dive - Part 5

Detailed examination of IEEE 802.11 standards and related mechanisms. **Key Mechanisms:** Analyzing the bit-level operations and frame processing. **Edge Cases:** Handling malformed packets, loop prevention, and physical layer impairments.

```
# Python script to simulate network packet parsing / device management
def process_packet(packet_data):
    # Extract headers
    src_mac = packet_data[0:6]
    dst_mac = packet_data[6:12]
    ethertype = packet_data[12:14]
    return {'src': src_mac, 'dst': dst_mac, 'type': ethertype}
print(process_packet(b'\x00\x11\x22\x33\x44\x55\xAA\xBB\xCC\xDD\xEE\xFF\x08\
    x00'))
```

Technical Deep Dive - Part 6

Detailed examination of IEEE 802.11 standards and related mechanisms. **Key Mechanisms:** Analyzing the bit-level operations and frame processing. **Edge Cases:** Handling malformed packets, loop prevention, and physical layer impairments.

```
# Python script to simulate network packet parsing / device management
def process_packet(packet_data):
    # Extract headers
    src_mac = packet_data[0:6]
    dst_mac = packet_data[6:12]
    ethertype = packet_data[12:14]
    return {'src': src_mac, 'dst': dst_mac, 'type': ethertype}
print(process_packet(b'\x00\x11\x22\x33\x44\x55\xAA\xBB\xCC\xDD\xEE\xFF\x08\
    x00'))
```

Technical Deep Dive - Part 7

Detailed examination of IEEE 802.11 standards and related mechanisms. **Key Mechanisms:** Analyzing the bit-level operations and frame processing. **Edge Cases:** Handling malformed packets, loop prevention, and physical layer impairments.

```
# Python script to simulate network packet parsing / device management
def process_packet(packet_data):
    # Extract headers
    src_mac = packet_data[0:6]
    dst_mac = packet_data[6:12]
    ethertype = packet_data[12:14]
    return {'src': src_mac, 'dst': dst_mac, 'type': ethertype}
print(process_packet(b'\x00\x11\x22\x33\x44\x55\xAA\xBB\xCC\xDD\xEE\xFF\x08\
    x00'))
```

Technical Deep Dive - Part 8

Detailed examination of IEEE 802.11 standards and related mechanisms. **Key Mechanisms:** Analyzing the bit-level operations and frame processing. **Edge Cases:** Handling malformed packets, loop prevention, and physical layer impairments.

```
# Python script to simulate network packet parsing / device management
def process_packet(packet_data):
    # Extract headers
    src_mac = packet_data[0:6]
    dst_mac = packet_data[6:12]
    ethertype = packet_data[12:14]
    return {'src': src_mac, 'dst': dst_mac, 'type': ethertype}
print(process_packet(b'\x00\x11\x22\x33\x44\x55\xAA\xBB\xCC\xDD\xEE\xFF\x08\
    x00'))
```

Real-world Scenario & Corner Cases

Scenario: High-density enterprise deployment.
Challenge: Broadcast storms and spanning tree recalculations leading to temporary outages.
Solution: Implementing Rapid STP (802.1w) and strict portfast configurations.

```
# Simulation of exponential backoff or STP cost calculation
def calculate_path_cost(bandwidth_mbps):
    if bandwidth_mbps >= 10000: return 2
    elif bandwidth_mbps >= 1000: return 4
    elif bandwidth_mbps >= 100: return 19
    return 100
```

Summary and Next Steps

Recap: We extensively covered Wireless LAN.
Critical Takeaways: IEEE 802.11 standards, CSMA/CA, WPA2/WPA3 Security, Hidden Node Problem, MIMO
Next Lecture: We will build upon these foundations to explore the next layer of network topology and device interaction.
Please review the lab manual for practical exercises related to today's topics.

FDDI & CDDI, Software defined network

Course: DI03000131 - Computer Networks
Unit 2: Network Devices and Technologies
Lecture 15: FDDI & CDDI, Software defined network
Focus Areas: Token Ring concepts, Dual Ring Topology, OpenFlow, SDN Controllers, Control vs Data Plane separation

Agenda

1. Introduction and Core Concepts
2. Architectural Models and Standards
3. Hardware Specifications and Limitations
4. Protocol Deep Dive
5. Configuration and Code Examples
6. Corner Cases and Troubleshooting
7. Summary and Q&A

Technical Deep Dive - Part 1

Detailed examination of Token Ring concepts and related mechanisms.
Key Mechanisms: Analyzing the bit-level operations and frame processing.
Edge Cases: Handling malformed packets, loop prevention, and physical layer impairments.

```
# Python script to simulate network packet parsing / device management
def process_packet(packet_data):
    # Extract headers
    src_mac = packet_data[0:6]
    dst_mac = packet_data[6:12]
    ethertype = packet_data[12:14]
    return {'src': src_mac, 'dst': dst_mac, 'type': ethertype}
print(process_packet(b'\x00\x11\x22\x33\x44\x55\xAA\xBB\xCC\xDD\xEE\xFF\x08\
    x00'))
```

Technical Deep Dive - Part 2

Detailed examination of Token Ring concepts and related mechanisms. **Key Mechanisms:** Analyzing the bit-level operations and frame processing. **Edge Cases:** Handling malformed packets, loop prevention, and physical layer impairments.

```
# Python script to simulate network packet parsing / device management
def process_packet(packet_data):
    # Extract headers
    src_mac = packet_data[0:6]
    dst_mac = packet_data[6:12]
    ethertype = packet_data[12:14]
    return {'src': src_mac, 'dst': dst_mac, 'type': ethertype}
print(process_packet(b'\x00\x11\x22\x33\x44\x55\xAA\xBB\xCC\xDD\xEE\xFF\x08\
    x00'))
```

Technical Deep Dive - Part 3

Detailed examination of Token Ring concepts and related mechanisms. **Key Mechanisms:** Analyzing the bit-level operations and frame processing. **Edge Cases:** Handling malformed packets, loop prevention, and physical layer impairments.

```
# Python script to simulate network packet parsing / device management
def process_packet(packet_data):
    # Extract headers
    src_mac = packet_data[0:6]
    dst_mac = packet_data[6:12]
    ethertype = packet_data[12:14]
    return {'src': src_mac, 'dst': dst_mac, 'type': ethertype}
print(process_packet(b'\x00\x11\x22\x33\x44\x55\xAA\xBB\xCC\xDD\xEE\xFF\x08\
    x00'))
```

Technical Deep Dive - Part 4

Detailed examination of Token Ring concepts and related mechanisms. **Key Mechanisms:** Analyzing the bit-level operations and frame processing. **Edge Cases:** Handling malformed packets, loop prevention, and physical layer impairments.

```
# Python script to simulate network packet parsing / device management
def process_packet(packet_data):
    # Extract headers
    src_mac = packet_data[0:6]
    dst_mac = packet_data[6:12]
    ethertype = packet_data[12:14]
    return {'src': src_mac, 'dst': dst_mac, 'type': ethertype}
print(process_packet(b'\x00\x11\x22\x33\x44\x55\xAA\xBB\xCC\xDD\xEE\xFF\x08\
    x00'))
```

Technical Deep Dive - Part 5

Detailed examination of Token Ring concepts and related mechanisms. **Key Mechanisms:** Analyzing the bit-level operations and frame processing. **Edge Cases:** Handling malformed packets, loop prevention, and physical layer impairments.

```
# Python script to simulate network packet parsing / device management
def process_packet(packet_data):
    # Extract headers
    src_mac = packet_data[0:6]
    dst_mac = packet_data[6:12]
    ethertype = packet_data[12:14]
    return {'src': src_mac, 'dst': dst_mac, 'type': ethertype}
print(process_packet(b'\x00\x11\x22\x33\x44\x55\xAA\xBB\xCC\xDD\xEE\xFF\x08\
    x00'))
```

Technical Deep Dive - Part 6

Detailed examination of Token Ring concepts and related mechanisms. **Key Mechanisms:** Analyzing the bit-level operations and frame processing. **Edge Cases:** Handling malformed packets, loop prevention, and physical layer impairments.

```
# Python script to simulate network packet parsing / device management
def process_packet(packet_data):
    # Extract headers
    src_mac = packet_data[0:6]
    dst_mac = packet_data[6:12]
    ethertype = packet_data[12:14]
    return {'src': src_mac, 'dst': dst_mac, 'type': ethertype}
print(process_packet(b'\x00\x11\x22\x33\x44\x55\xAA\xBB\xCC\xDD\xEE\xFF\x08\
    x00'))
```

Technical Deep Dive - Part 7

Detailed examination of Token Ring concepts and related mechanisms. **Key Mechanisms:** Analyzing the bit-level operations and frame processing. **Edge Cases:** Handling malformed packets, loop prevention, and physical layer impairments.

```
# Python script to simulate network packet parsing / device management
def process_packet(packet_data):
    # Extract headers
    src_mac = packet_data[0:6]
    dst_mac = packet_data[6:12]
    ethertype = packet_data[12:14]
    return {'src': src_mac, 'dst': dst_mac, 'type': ethertype}
print(process_packet(b'\x00\x11\x22\x33\x44\x55\xAA\xBB\xCC\xDD\xEE\xFF\x08\
    x00'))
```

Technical Deep Dive - Part 8

Detailed examination of Token Ring concepts and related mechanisms. **Key Mechanisms:** Analyzing the bit-level operations and frame processing. **Edge Cases:** Handling malformed packets, loop prevention, and physical layer impairments.

```
# Python script to simulate network packet parsing / device management
def process_packet(packet_data):
    # Extract headers
    src_mac = packet_data[0:6]
    dst_mac = packet_data[6:12]
    ethertype = packet_data[12:14]
    return {'src': src_mac, 'dst': dst_mac, 'type': ethertype}
print(process_packet(b'\x00\x11\x22\x33\x44\x55\xAA\xBB\xCC\xDD\xEE\xFF\x08\
    x00'))
```

Real-world Scenario & Corner Cases

Scenario: High-density enterprise deployment.
Challenge: Broadcast storms and spanning tree recalculations leading to temporary outages.
Solution: Implementing Rapid STP (802.1w) and strict portfast configurations.

```
# Simulation of exponential backoff or STP cost calculation
def calculate_path_cost(bandwidth_mbps):
    if bandwidth_mbps >= 10000: return 2
    elif bandwidth_mbps >= 1000: return 4
    elif bandwidth_mbps >= 100: return 19
    return 100
```

Summary and Next Steps

Recap: We extensively covered FDDI & CDDI, Software defined network.
Critical Takeaways: Token Ring concepts, Dual Ring Topology, OpenFlow, SDN Controllers, Control vs Data Plane separation
Next Lecture: We will build upon these foundations to explore the next layer of network topology and device interaction.
Please review the lab manual for practical exercises related to today's topics.

Physical Layer: Transmission media (Twisted pair, Coaxial cable, Fiber optic cable)

Welcome to Lecture 16
Course: Computer Networks

Agenda

Introduction to Transmission Media
Twisted Pair Cables (UTP/STP)
UTP Technical Specifications
Coaxial Cable Basics
Coaxial Cable Applications
Fiber Optic Cable Fundamentals
Fiber Optic Specifications
Comparison of Guided Media

Introduction to Transmission Media

- Guided vs Unguided media
- Characteristics of transmission media
- Bandwidth, attenuation, and interference
- Selection criteria for enterprise networks

Twisted Pair Cables (UTP/STP)

- Structure: Copper conductors, insulation, twisting
- Why twisting? Electromagnetic interference (EMI) cancellation
- Categories: Cat5e, Cat6, Cat6a, Cat7, Cat8 specifications
- Maximum distances and data rates

UTP Technical Specifications

- Characteristic impedance: 100 ohms
- Attenuation limits per EIA/TIA-568 standards
- Near-End Crosstalk (NEXT) and Far-End Crosstalk (FEXT)
- Return Loss and Insertion Loss

Coaxial Cable Basics

- Structure: Inner conductor, dielectric insulator, metallic shield, plastic jacket
- Baseband vs Broadband transmission
- BNC connectors and termination (50 ohm vs 75 ohm)

Coaxial Cable Applications

- RG-59 vs RG-6 specifications
- Historical use in 10Base2 (Thinnet) and 10Base5 (Thicknet)
- Modern use in Hybrid Fiber-Coaxial (HFC) networks
- Skin effect at high frequencies

Fiber Optic Cable Fundamentals

- Principle of Total Internal Reflection (TIR)
- Core, cladding, and buffer coating layers
- Light sources: LEDs vs Laser Diodes
- Single-mode fiber (SMF) vs Multi-mode fiber (MMF)

Fiber Optic Specifications

- Core diameters (9µm SMF, 50/62.5µm MMF)
- Wavelengths (850nm, 1300nm, 1550nm)
- Modal dispersion in MMF and chromatic dispersion in SMF
- Attenuation (dB/km) characteristics

Comparison of Guided Media

- Bandwidth-distance product (MHz·km)
- Cost of installation and maintenance
- Security and eavesdropping resistance
- Environmental factors (temperature, EMI, physical stress)

Summary

Recap of main points covered today.
Review of technical details.
Final thoughts.

Next Lecture

Preview of upcoming topics.
Reading assignment.

Wireless Medium as Physical layer

Welcome to Lecture 17
Course: Computer Networks

Agenda

Electromagnetic Spectrum
Propagation Characteristics
Antennas and Radiation Patterns
Radio Frequency Impairments
Modulation Techniques in Wireless
Spread Spectrum Technology
Orthogonal Frequency-Division Multiplexing (OFDM)
MIMO Technology

Electromagnetic Spectrum

- Frequency ranges for wireless communication
- Radio waves, Microwaves, Infrared, and Visible light
- Wavelength vs Frequency ($c = \lambda f$)
- Regulatory bodies (ITU-R, FCC, TRAI)

Propagation Characteristics

- Ground wave, Sky wave, and Line-of-Sight (LoS) propagation
- Free Space Path Loss (FSPL) equation
- Absorption, reflection, refraction, and diffraction
- Multipath fading and delay spread

Antennas and Radiation Patterns

- Isotropic, Omnidirectional, and Directional antennas
- Antenna Gain (dBi, dBd)
- Beamwidth (Azimuth and Elevation)
- Polarization (Vertical, Horizontal, Circular)

Radio Frequency Impairments

- Signal-to-Noise Ratio (SNR) and Shannon-Hartley theorem
- Co-channel and Adjacent channel interference
- Doppler shift in mobile communications
- Thermal noise and noise figure

Modulation Techniques in Wireless

- Analog vs Digital modulation
- Amplitude Shift Keying (ASK), Frequency Shift Keying (FSK)
- Phase Shift Keying (PSK, BPSK, QPSK)
- Quadrature Amplitude Modulation (16-QAM, 64-QAM, 256-QAM)

Spread Spectrum Technology

- Direct Sequence Spread Spectrum (DSSS)
- Frequency Hopping Spread Spectrum (FHSS)
- Processing gain and jamming margin
- CDMA fundamentals

Orthogonal Frequency-Division Multiplexing (OFDM)

- Overlapping orthogonal subcarriers
- Cyclic Prefix (CP) to mitigate Inter-Symbol Interference (ISI)
- Peak-to-Average Power Ratio (PAPR) challenges
- Application in Wi-Fi (802.11a/g/n/ac/ax) and 4G/5G

MIMO Technology

- Multiple Input Multiple Output (MIMO) principles
- Spatial Multiplexing and Transmit Diversity
- Beamforming and MU-MIMO
- Capacity scaling with antenna arrays

Summary

Recap of main points covered today.
Review of technical details.
Final thoughts.

Next Lecture

Preview of upcoming topics.
Reading assignment.

ISM Band

Welcome to Lecture 18
Course: Computer Networks

Agenda

Introduction to ISM Bands
The 2.4 GHz ISM Band
The 5 GHz ISM and U-NII Bands
Sub-1 GHz ISM Bands
Interference Mitigation in ISM Bands
Regulatory Requirements
Protocols Operating in ISM
Future of Unlicensed Spectrum

Introduction to ISM Bands

- Industrial, Scientific, and Medical (ISM) radio bands
- Unlicensed spectrum concept
- ITU Radio Regulations and regional allocations
- Common ISM frequencies: 2.4 GHz, 5 GHz, 915 MHz

The 2.4 GHz ISM Band

- Frequency range: 2.400–2.4835 GHz
- Channelization in 802.11b/g/n (14 channels, 22/20 MHz wide)
- Overlapping and non-overlapping channels (1, 6, 11)
- Coexistence challenges (Bluetooth, Zigbee, Microwaves)

The 5 GHz ISM and U-NII Bands

- U-NII-1, U-NII-2A, U-NII-2C, U-NII-3 bands
- Dynamic Frequency Selection (DFS) requirements for radar avoidance
- Transmit Power Control (TPC)
- Wider channels (40, 80, 160 MHz) in 802.11ac/ax

Sub-1 GHz ISM Bands

- 902–928 MHz (Region 2), 868 MHz (Region 1), 433 MHz
- Excellent propagation characteristics for IoT
- LPWAN technologies: LoRa, Sigfox, IEEE 802.11ah (HaLow)
- Duty cycle regulations and transmit power limits

Interference Mitigation in ISM Bands

- Clear Channel Assessment (CCA) and Carrier Sense Multiple Access (CSMA/CA)
- Adaptive Frequency Hopping (AFH) in Bluetooth
- Channel bonding constraints
- Spectrum analyzers and site surveys

Regulatory Requirements

- Maximum Equivalent Isotropically Radiated Power (EIRP)
- Out-of-band emissions and spectral masks
- Equipment certification (FCC Part 15 rules)
- Listen Before Talk (LBT) mechanisms

Protocols Operating in ISM

- IEEE 802.11 (Wi-Fi)
- IEEE 802.15.1 (Bluetooth classic/BLE)
- IEEE 802.15.4 (Zigbee, Thread)
- Proprietary protocols (e.g., ANT+, Z-Wave)

Future of Unlicensed Spectrum

- The 6 GHz band allocation (Wi-Fi 6E / Wi-Fi 7)
- 1200 MHz of new continuous spectrum
- Automated Frequency Coordination (AFC) for standard power operation
- 60 GHz band (WiGig / 802.11ad/ay)

Summary

Recap of main points covered today.
Review of technical details.
Final thoughts.

Next Lecture

Preview of upcoming topics.
Reading assignment.

Cable modem

Welcome to Lecture 19
Course: Computer Networks

Agenda

Hybrid Fiber-Coaxial (HFC) Architecture
DOCSIS Standards Overview
Frequency Allocation
Modulation in Cable Modems
Channel Bonding
MAC Layer in DOCSIS
Cable Modem Initialization Sequence
Security and Quality of Service (QoS)

Hybrid Fiber-Coaxial (HFC) Architecture

- Headend to fiber nodes
- Coaxial distribution network from node to premises
- Amplifiers (Trunk, Bridger, Line Extender)
- Taps and drops

DOCSIS Standards Overview

- Data Over Cable Service Interface Specification
- Evolution: DOCSIS 1.0/1.1 to 2.0 to 3.0 to 3.1 to 4.0
- Backward compatibility
- Asymmetric nature of typical HFC deployments

Frequency Allocation

- Downstream frequency band (e.g., 54 MHz to 1002 MHz or higher)
- Upstream frequency band (e.g., 5-42 MHz, 5-85 MHz, or 5-204 MHz mid-split/high-split)
- Separation of analog TV, digital TV, and data services
- Guard bands

Modulation in Cable Modems

- Downstream: 64-QAM and 256-QAM (DOCSIS 3.0)
- Upstream: QPSK, 16-QAM, 64-QAM
- DOCSIS 3.1: OFDM and OFDMA (up to 4096-QAM or 16384-QAM)
- Symbol rates and channel bandwidths (6 MHz in NA, 8 MHz in Europe)

Channel Bonding

- Introduced in DOCSIS 3.0
- Combining multiple RF channels for higher throughput
- e.g., 8x4, 16x4, 32x8 configurations (Downstream x Upstream channels)
- Load balancing across bonded channels

MAC Layer in DOCSIS

- Time Division Multiple Access (TDMA) for upstream
- Cable Modem Termination System (CMTS) controls timing
- MAP messages for bandwidth allocation
- Request/Grant mechanism

Cable Modem Initialization Sequence

1. Scan for downstream channel
2. Obtain upstream parameters (UCD)
3. Ranging (timing and power adjustment)
4. DHCP for IP address
5. Time of Day (ToD) server
6. Download configuration file via TFTP
7. Registration with CMTS

Security and Quality of Service (QoS)

- Baseline Privacy Interface Plus (BPI+)
- X.509 certificates and AES encryption
- Service Flows and QoS parameters (Maximum Sustained Rate, Minimum Reserved Rate)
- Traffic policing and shaping

Summary

Recap of main points covered today.
Review of technical details.
Final thoughts.

Next Lecture

Preview of upcoming topics.
Reading assignment.

Sub Layers of Data Link Layer and functions: Error control, Flow control examples

Welcome to Lecture 20
Course: Computer Networks

Agenda

Data Link Layer Overview
Logical Link Control (LLC) Sublayer
Media Access Control (MAC) Sublayer
Error Detection Techniques
Error Correction Techniques
Flow Control Fundamentals
Stop-and-Wait ARQ
Sliding Window Protocols

Data Link Layer Overview

- Layer 2 of the OSI Model
- Node-to-node delivery
- Framing, Physical Addressing (MAC)
- Divided into two sublayers: LLC and MAC

Logical Link Control (LLC) Sublayer

- IEEE 802.2 standard
- Hides differences between different MAC layer protocols (Ethernet, Wi-Fi, Token Ring) from the Network Layer
- Multiplexing/Demultiplexing of network layer protocols via SAPs (Service Access Points)
- Optional flow and error control (e.g., LLC Type 2)

Media Access Control (MAC) Sublayer

- Specific to the physical medium (e.g., 802.3 Ethernet, 802.11 Wi-Fi)
- Channel access control mechanisms (CSMA/CD, CSMA/CA)
- MAC addressing structure (OUI + NIC Specific, 48-bit)
- Frame assembly and disassembly

Error Detection Techniques

- Parity check (even/odd, 1D/2D)
- Checksum (used more in IP/TCP/UDP)
- Cyclic Redundancy Check (CRC)
- CRC generator polynomials (e.g., CRC-32 used in Ethernet: 0x04C11DB7)

Error Correction Techniques

- Forward Error Correction (FEC)
- Hamming Distance concept
- Hamming Code example (calculating redundant bits)
- Trade-off between redundancy overhead and retransmission delay

Flow Control Fundamentals

- Preventing a fast sender from overwhelming a slow receiver
- Buffer management at the receiver
- Feedback mechanisms (ACKs)
- Implementation at Data Link vs Transport Layer

Stop-and-Wait ARQ

- Simplest flow and error control protocol
- Sender transmits one frame and waits for ACK
- Timeout mechanism for lost frames
- Sequence numbers (0 and 1) to handle duplicate frames
- Very low channel utilization on long-delay links

Sliding Window Protocols

- Go-Back-N ARQ: Sender window size ¿ 1, Receiver window size = 1. Retransmits entire window upon error.
- Selective Repeat ARQ: Sender and Receiver window sizes ¿ 1. Retransmits only the corrupted frame.
- Window size considerations (Max window size for n-bit sequence number: $2^n - 1$ for GBN, 2^{n-1} for SR)
- Piggybacking ACKs

Summary

Recap of main points covered today.
Review of technical details.
Final thoughts.

Next Lecture

Preview of upcoming topics.
Reading assignment.

Network Layer: Packet Switching

Welcome to Lecture 21
Course: Computer Networks

Agenda

Network Layer Functions
Switching Techniques Overview
Packet Switching Principles
Datagram Approach (Connectionless)
Virtual Circuit Approach (Connection-oriented)
Routing vs Forwarding
Router Architecture
Performance Metrics in Packet Switching

Network Layer Functions

- Layer 3 of OSI Model
- Host-to-host delivery across multiple networks
- Logical addressing (IP addresses)
- Routing and Forwarding

Switching Techniques Overview

- Circuit Switching (e.g., PSTN)
- Message Switching
- Packet Switching (e.g., Internet)
- Fundamental differences in resource allocation

Packet Switching Principles

- Data broken into discrete 'packets'
- Statistical multiplexing of shared links
- Store-and-forward mechanism at routers
- Queuing delays and potential for packet loss

Datagram Approach (Connectionless)

- Used by IP (Internet Protocol)
- Each packet treated independently
- Packets may take different routes to destination
- Packets may arrive out of order
- No setup phase, robust against router failures

Virtual Circuit Approach (Connection-oriented)

- Used by ATM, Frame Relay, X.25, MPLS
- Setup phase, Data transfer phase, Teardown phase
- Packets follow the same path
- In-order delivery guaranteed
- Virtual Circuit Identifier (VCI) translation at each switch

Routing vs Forwarding

- Routing: Control plane operation, running algorithms (OSPF, BGP) to populate the Routing Table
- Forwarding: Data plane operation, moving a packet from input port to output port based on the Forwarding Information Base (FIB)
- Hardware switching via ASICs vs Software switching

Router Architecture

- Input ports (Physical layer, Data link processing, Lookup/Forwarding, Queuing)
- Switching Fabric (Memory, Bus, Crossbar)
- Output ports (Queuing, Scheduling, Data link, Physical layer)
- Routing Processor (Control Plane)

Performance Metrics in Packet Switching

- End-to-end delay = N * (d_proc + d_queue + d_trans + d_prop)
- Processing delay (d_proc)
- Queuing delay (d_queue) based on traffic intensity
- Transmission delay (L/R) vs Propagation delay (d/s)

Summary

Recap of main points covered today.
Review of technical details.
Final thoughts.

Next Lecture

Preview of upcoming topics.
Reading assignment.

IP Addressing

Welcome to Lecture 22
Course: Computer Networks

Agenda

IPv4 Address Structure
Classful Addressing
Subnetting Concepts
Subnetting Calculations
Variable Length Subnet Masking (VLSM)
Special IPv4 Addresses
Private vs Public IP Addresses
Address Resolution Protocol (ARP)

IPv4 Address Structure

- 32-bit logical address
- Dotted-decimal notation (e.g., 192.168.1.1)
- Network portion (NetID) and Host portion (HostID)
- Hierarchical addressing scheme

Classful Addressing

- Historical addressing architecture
- Class A: /8 (First bit 0, 1.0.0.0 to 126.0.0.0)
- Class B: /16 (First bits 10, 128.0.0.0 to 191.255.0.0)
- Class C: /24 (First bits 110, 192.0.0.0 to 223.255.255.0)
- Class D (Multicast: 224-239) and Class E (Reserved: 240-255)

Subnetting Concepts

- Borrowing host bits to create multiple smaller networks
- Reasons for subnetting: Broadcast domain reduction, security, management
- Subnet mask: 32-bit number indicating network bits (1s) and host bits (0s)
- Default vs Custom subnet masks

Subnetting Calculations

- Given IP and Mask, find Network Address (Bitwise AND)
- Number of subnets created $= 2^s$ (s = borrowed bits)
- Number of usable hosts per subnet $= 2^h - 2$ (h = host bits)
- -2 accounts for Network Address and Directed Broadcast Address

Variable Length Subnet Masking (VLSM)

- Subnetting a subnet
- Allows different subnet masks within the same major network
- Highly efficient utilization of IP address space
- Requires routing protocols that support VLSM (RIPv2, OSPF, EIGRP)

Special IPv4 Addresses

- Loopback addresses (127.0.0.0/8, typically 127.0.0.1)
- Link-local / APIPA (169.254.0.0/16)
- Default route (0.0.0.0/0)
- Broadcast addresses (Limited: 255.255.255.255, Directed)

Private vs Public IP Addresses

- RFC 1918 Private Address Space
- 10.0.0.0/8 (1 network, 16.7M hosts)
- 172.16.0.0/12 (16 networks, 65K hosts each)
- 192.168.0.0/16 (256 networks, 254 hosts each)
- Not routable on the public Internet

Address Resolution Protocol (ARP)

- Mapping IP addresses (Layer 3) to MAC addresses (Layer 2)
- ARP Request (Broadcast MAC) and ARP Reply (Unicast MAC)
- ARP Cache/Table
- Gratuitous ARP and ARP spoofing security risks

Summary

Recap of main points covered today.
Review of technical details.
Final thoughts.

Next Lecture

Preview of upcoming topics.
Reading assignment.

CIDR & NAT

Welcome to Lecture 23
Course: Computer Networks

Agenda

Classless Inter-Domain Routing (CIDR)
Route Aggregation (Supernetting)
Longest Prefix Match
Network Address Translation (NAT) Purpose
Types of NAT
PAT (NAT Overload) Mechanics
NAT Limitations and Workarounds
Carrier-Grade NAT (CGNAT)

Classless Inter-Domain Routing (CIDR)

- Introduced in RFC 1519 to address IPv4 exhaustion and routing table explosion
- Abandons classful A/B/C boundaries
- CIDR notation (Slash notation): e.g., 192.168.1.0/24
- Arbitrary length for network prefix

Route Aggregation (Supernetting)

- Combining multiple contiguous smaller networks into one larger route advertisement
- e.g., Aggregating four /24 networks (192.168.0.0/24 to 192.168.3.0/24) into one /22 network (192.168.0.0/22)
- Reduces size of BGP routing tables
- Requires contiguous IP blocks and matching binary prefix

Longest Prefix Match

- Forwarding decision process in CIDR-aware routers
- Router compares destination IP against all matching routes in FIB
- Selects the route with the longest subnet mask (most specific match)
- Example: Default route (0.0.0.0/0) vs Specific route (10.1.1.0/24)

Network Address Translation (NAT) Purpose

- Defined in RFC 1631/3022
- Solves IPv4 address depletion by allowing entire private networks to share a few public IPs
- Provides implicit security by hiding internal topology
- Translates IP headers on the fly

Types of NAT

- Static NAT (1-to-1 mapping, useful for internal servers)
- Dynamic NAT (Many-to-Many, pool of public IPs)
- Port Address Translation (PAT) / NAT Overload (Many-to-One)
- PAT uses source port numbers to multiplex connections

PAT (NAT Overload) Mechanics

- Inside Local, Inside Global, Outside Local, Outside Global addresses
- Translation Table entries (Protocol, Inside Local IP:Port, Inside Global IP:Port)
- Ephemeral port generation
- TCP/UDP state tracking

NAT Limitations and Workarounds

- Breaks end-to-end IP principle
- Issues with protocols embedding IPs in payload (FTP, SIP, IPsec)
- Application Level Gateways (ALGs) required to inspect and modify payloads
- NAT Traversal techniques (STUN, TURN, ICE) for P2P/VoIP

Carrier-Grade NAT (CGNAT)

- Large Scale NAT (LSN) implemented by ISPs
- Customers receive private IPs (RFC 6598: 100.64.0.0/10) instead of public IPs
- 'NAT444' architecture (Customer NAT + Provider NAT)
- Causes issues for user self-hosting and port forwarding

Summary

Recap of main points covered today.
Review of technical details.
Final thoughts.

Next Lecture

Preview of upcoming topics.
Reading assignment.

IP layer protocols (ICMP, ARP, RARP, DHCP, BOOTP)

Welcome to Lecture 24
Course: Computer Networks

Agenda

Internet Control Message Protocol (ICMP)
ICMP Message Types
Address Resolution Protocol (ARP) Deep Dive
Reverse ARP (RARP)
BOOTP (Bootstrap Protocol)
Dynamic Host Configuration Protocol (DHCP)
DHCP DORA Process
DHCP Relay and Security

Internet Control Message Protocol (ICMP)

- RFC 792
- Network layer protocol used for diagnostics and error reporting
- Encapsulated in IP datagrams (Protocol Number 1)
- Does not correct errors, only reports them to original source

ICMP Message Types

- Echo Request (Type 8) and Echo Reply (Type 0) - Used by Ping
- Destination Unreachable (Type 3) - Codes for Network, Host, Port, Protocol unreachable
- Time Exceeded (Type 11) - Used by Traceroute (TTL $= 0$)
- Redirect (Type 5) - Informs host of a better router

Address Resolution Protocol (ARP) Deep Dive

- RFC 826
- Resolves IPv4 addresses to MAC addresses on the same broadcast domain
- Packet structure: Hardware type, Protocol type, HLEN, PLEN, Opcode
- Sender MAC, Sender IP, Target MAC (0s in request), Target IP
- Security: ARP Spoofing/Poisoning and Dynamic ARP Inspection (DAI)

Reverse ARP (RARP)

- RFC 903
- Obsolete protocol
- Resolves MAC address to an IP address
- Used by diskless workstations to discover their own IP during boot
- Required a RARP server on every local network segment

BOOTP (Bootstrap Protocol)

- RFC 951
- Replaced RARP, operates over UDP (Ports 67, 68)
- Provides IP address, Subnet Mask, Default Gateway, and TFTP server IP for boot image
- Static mapping based on MAC addresses
- Can cross routers using BOOTP Relay Agents

Dynamic Host Configuration Protocol (DHCP)

- RFC 2131, extension of BOOTP
- Dynamic IP allocation from a pool (scope)
- Leases with expiration times (T1 renewal, T2 rebinding)
- DHCP Options (Option 3: Router, Option 6: DNS, Option 150: TFTP)

DHCP DORA Process

- Discover (Client -¿ Broadcast, looking for server)
- Offer (Server -¿ Client/Broadcast, offers IP lease)
- Request (Client -¿ Broadcast, accepts specific offer)
- Acknowledge (Server -¿ Client/Broadcast, confirms lease)
- Uses UDP Port 67 (Server) and Port 68 (Client)

DHCP Relay and Security

- DHCP messages are broadcasts, routers don't forward them
- IP Helper Address / DHCP Relay Agent converts broadcast to unicast directed at DHCP server
- Rogue DHCP Servers and mitigation via DHCP Snooping

Summary

Recap of main points covered today.
Review of technical details.
Final thoughts.

Next Lecture

Preview of upcoming topics.
Reading assignment.

IPv4 and IPv6 comparison

Welcome to Lecture 25
Course: Computer Networks

Agenda

The Need for IPv6
Address Space and Representation
Header Format Comparison
Extension Headers in IPv6
Fragmentation and MTU
Broadcast vs Multicast
Address Configuration
Security (IPsec)

The Need for IPv6

- IPv4 address space exhaustion (4.3 billion addresses)
- Workarounds like NAT introduced complexity and broke end-to-end connectivity
- Need for better multicasting, mobility, and security integration
- Simpler header processing for faster routing

Address Space and Representation

- IPv4: 32-bit addresses (˜4.3x10ˆ9)
- IPv6: 128-bit addresses (˜3.4x10ˆ38)
- IPv4 format: Dotted-decimal (192.168.1.1)
- IPv6 format: 8 groups of 4 hexadecimal digits separated by colons (2001:0db8:85a3:0000:0000:8a2e:0370:7334)
- Zero compression rules in IPv6

Header Format Comparison

- IPv4 Header: 20-60 bytes (variable length), 14 fields
- IPv6 Header: 40 bytes (fixed length), 8 fields
- IPv6 removes Checksum, Fragmentation fields, Header Length field
- IPv6 uses Next Header field for Extension Headers

Extension Headers in IPv6

- IPv4 options were embedded in the main header, slowing down processing
- IPv6 places options in separate headers (Hop-by-Hop, Routing, Fragment, ESP, AH)
- Routers only process Extension Headers if necessary
- Improves routing efficiency in the data plane

Fragmentation and MTU

- IPv4: Routers can fragment packets if they exceed outbound MTU
- IPv6: Routers drop oversized packets and send ICMPv6 Packet Too Big
- IPv6 fragmentation is done ONLY by the source host
- Path MTU Discovery (PMTUD) is mandatory in IPv6

Broadcast vs Multicast

- IPv4 uses Broadcast (255.255.255.255), Unicast, and Multicast
- IPv6 eliminates Broadcast entirely
- IPv6 relies heavily on Multicast (Solicited-node multicast) and Anycast
- Reduces unnecessary network interruptions for end hosts

Address Configuration

- IPv4: Manual, DHCP, or APIPA
- IPv6: Manual, Stateful DHCPv6, Stateless Address Autoconfiguration (SLAAC)
- SLAAC uses ICMPv6 Router Solicitations and Router Advertisements (RS/RA)
- EUI-64 format for host portion generation from MAC address

Security (IPsec)

- IPv4: IPsec is optional, added as an afterthought
- IPv6: IPsec was originally mandatory, now technically optional but deeply integrated
- Support for Authentication Header (AH) and Encapsulating Security Payload (ESP)
- End-to-end encryption without NAT breaking protocols

Summary

Recap of main points covered today.
Review of technical details.
Final thoughts.

Next Lecture

Preview of upcoming topics.
Reading assignment.

IPv4 and IPv6 comparison (Continued)

Welcome to Lecture 26
Course: Computer Networks

Agenda

ICMPv4 vs ICMPv6
Neighbor Discovery Protocol (NDP)
IPv6 Address Types
Quality of Service (QoS)
Mobility Support
Transition Mechanisms Overview
Dual Stack Operations
NAT64 and DNS64

ICMPv4 vs ICMPv6

- ICMPv6 is much more robust and critical than ICMPv4
- Incorporates IGMP (Internet Group Management Protocol) via Multicast Listener Discovery (MLD)
- Incorporates ARP via Neighbor Discovery Protocol (NDP)
- Essential for SLAAC and PMTUD

Neighbor Discovery Protocol (NDP)

- Replaces ARP and IPv4 Router Discovery
- Uses ICMPv6 messages (Types 133-137)
- Router Solicitation (RS) and Router Advertisement (RA)
- Neighbor Solicitation (NS) and Neighbor Advertisement (NA)
- Duplicate Address Detection (DAD)

IPv6 Address Types

- Global Unicast (starts with 2000::/3) - Public Internet routing
- Unique Local (starts with fc00::/7) - Similar to IPv4 Private ranges
- Link-Local (starts with fe80::/10) - Required on every IPv6 interface, non-routable
- Multicast (starts with ff00::/8)

Quality of Service (QoS)

- IPv4: Type of Service (ToS) / Differentiated Services Code Point (DSCP)
- IPv6: Traffic Class (8 bits) and Flow Label (20 bits)
- Flow Label identifies packets of the same flow, allowing routers to apply QoS without inspecting deeper layers
- Useful for encrypted payloads

Mobility Support

- Mobile IPv4 has issues with triangular routing and requires Foreign Agents
- Mobile IPv6 is built-in, uses Extension Headers (Destination Options and Routing Header type 2)
- No Foreign Agent required
- Route optimization allows direct communication between Mobile Node and Correspondent Node

Transition Mechanisms Overview

- Dual Stack: Running both IPv4 and IPv6 on nodes
- Tunneling: Encapsulating IPv6 inside IPv4 (6to4, ISATAP, Teredo)
- Translation: NAT64/DNS64 allowing IPv6-only clients to talk to IPv4-only servers
- Phased approach to complete migration

Dual Stack Operations

- OS prefers IPv6 if both AAAA and A DNS records are returned (RFC 6724)
- Happy Eyeballs algorithm (RFC 8305) to prevent delays if IPv6 is broken
- Requires maintaining routing tables and security policies for both protocols
- Most common deployment method today

NAT64 and DNS64

- DNS64 synthesizes AAAA records from A records (e.g., embedding IPv4 inside 64:ff9b::/96 prefix)
- NAT64 router translates IPv6 packets to IPv4 and vice versa
- Critical for modern mobile networks (e.g., 4G/5G running IPv6-only internally)
- Removes the need for IPv4 addresses on client devices

Summary

Recap of main points covered today.
Review of technical details.
Final thoughts.

Next Lecture

Preview of upcoming topics.
Reading assignment.

Transport Layer Fundamentals

- Welcome to Unit 4
- Transport Layer Overview
- TCP vs UDP

Agenda

1. Transport Layer Duties
2. Addressing (Ports)
3. UDP: Connectionless Protocol
4. TCP: Connection-Oriented Protocol
5. TCP Connection Establishment
6. TCP Flow & Error Control
7. Comparison

Role of the Transport Layer

- **Process-to-Process Delivery**: Network layer delivers to host, Transport layer delivers to specific process.
- **Multiplexing / Demultiplexing**: Using port numbers.
- **Error Control**: Checksums for end-to-end reliability.
- **Flow Control**: Managing data rate between endpoints.

Port Addresses

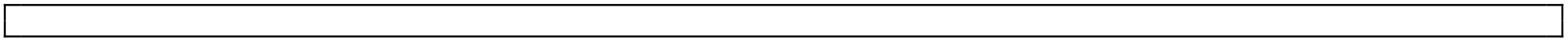
- 16-bit integer (0 to 65535)
- **Well-known ports**: 0 - 1023 (e.g., HTTP=80, HTTPS=443, SSH=22)
- **Registered ports**: 1024 - 49151
- **Dynamic / Private ports**: 49152 - 65535
- Socket Address = IP Address + Port Number

UDP: User Datagram Protocol

- **Connectionless**: No setup/teardown.
- **Unreliable**: No acknowledgments, no retransmissions.
- **Stateless**: Endpoints do not maintain connection state.
- **Low Overhead**: 8-byte header.
- Use cases: DNS, DHCP, VoIP, streaming video.

UDP Header Format

- Source Port (16 bits)
- Destination Port (16 bits)
- Length (16 bits)
- Checksum (16 bits)



TCP: Transmission Control Protocol

- **Connection-Oriented**: 3-way handshake.
- **Reliable**: Acknowledgments, retransmissions, timeouts.
- **Ordered**: Sequence numbers ensure ordered delivery.
- **Flow Control**: Sliding window protocol.
- **Congestion Control**: AIMD, Slow Start.

TCP Connection Establishment (3-Way Handshake)

1. **SYN**: Client sends SYN segment (seq=x)
2. **SYN-ACK**: Server replies with SYN (seq=y) and ACK (ack=x+1)
3. **ACK**: Client replies with ACK (ack=y+1)

- Establishes initial sequence numbers (ISN).
- Allocates buffers and state variables.

TCP Header Format

- Source & Dest Ports (16 bits each)
- Sequence Number (32 bits)
- Acknowledgment Number (32 bits)
- Data Offset (4 bits), Flags (9 bits), Window Size (16 bits)
- Checksum (16 bits), Urgent Pointer (16 bits)

Connectionless vs Connection-Oriented

— Feature — Connectionless (UDP) — Connection-Oriented (TCP) —
———————
— Setup — None — 3-way Handshake —
— Reliability — Unreliable — Reliable (ACKs) —
— Ordering — No guarantee — Ordered —
— Overhead — Low (8 bytes) — High (20+ bytes) —
— Flow Control — None — Sliding Window —

Python Socket Example: UDP vs TCP

UDP Client:

```
**TCP Client**:
```

Summary

- Transport layer manages process-to-process delivery.
- Ports identify processes.
- UDP is fast, stateless, connectionless.
- TCP is reliable, connection-oriented.
- Application requirements dictate protocol choice.

Application Layer: DNS

- Domain Name System
- Architecture
- Resolution

Agenda

1. Why DNS?
2. DNS Hierarchy
3. Name Servers
4. Query Resolution
5. DNS Records
6. Caching
7. DNS Protocol

Why DNS?

- Humans prefer names (www.google.com).
- Routers prefer IP addresses (142.250.190.4).
- DNS is a distributed database.
- Maps hostnames to IP addresses.
- Host aliasing, Mail server aliasing, Load distribution.

DNS Hierarchy

- **Root DNS Servers**: 13 logical root servers globally.
- **Top-Level Domain (TLD) Servers**: .com, .org, .net, .edu.
- **Authoritative DNS Servers**: Maintained by organizations (e.g., specific university or company).
- Decentralized and scalable architecture.

Local DNS Name Server

- Does not strictly belong to hierarchy.
- Each ISP has one (default name server).
- Host sends query to local DNS server.
- Acts as a proxy, forwards query into hierarchy if not in cache.
- Also known as a Recursive Resolver.

Recursive vs Iterative Queries

- **Iterative**: Contacted server replies with name of server to contact next. 'I don't know this name, but ask this server.'
- **Recursive**: Puts burden of name resolution on contacted name server. 'Please find this out for me.'
- Typical pattern: Host to Local DNS is recursive; Local DNS to Root/TLD/Auth is iterative.

DNS Caching

- Once any name server learns mapping, it caches mapping.
- Cache entries timeout (Time to Live - TTL).
- TLD servers typically cached in local name servers.
- Caching drastically reduces DNS traffic at root/TLD level.
- Speeds up resolution for end users.

DNS Resource Records (RR)

- Format: (Name, Value, Type, TTL)
- **Type=A**: Name = hostname, Value = IPv4 address
- **Type=AAAA**: Name = hostname, Value = IPv6 address
- **Type=NS**: Name = domain, Value = hostname of authoritative name server
- **Type=CNAME**: Name = alias, Value = canonical name
- **Type=MX**: Value = mail server associated with name

DNS Protocol & Messages

- Uses **UDP** port 53 for standard queries.
- TCP port 53 used for zone transfers or large responses.
- Message format:
- 12-byte header (Identification, Flags, No. of questions, etc.)
- Questions section
- Answers section
- Authority section
- Additional information section

DNS Resolution Example in Python

DNS Vulnerabilities

- **DNS Cache Poisoning / Spoofing**: Attacker sends fake replies to local DNS server, polluting the cache.
- **DDoS Attacks**: Overwhelming root or TLD servers with queries.
- **DNS Amplification Attack**: Using open resolvers with spoofed IP to overwhelm a target.
- **DNSSEC**: Security extensions adding cryptographic signatures to DNS records to ensure authenticity.

Summary

- DNS is a distributed database mapping names to IPs.
- Hierarchical: Root, TLD, Authoritative.
- Relies heavily on caching (TTL).
- Uses UDP port 53.
- Various record types (A, CNAME, MX).

World Wide Web

- Web Architecture
- HTTP Protocol
- HTML Basics

Agenda

1. WWW Architecture
2. Uniform Resource Locators (URL)
3. Web Browsers & Servers
4. HTTP Overview
5. HTTP Request & Response
6. Cookies & State
7. HTML Basics

WWW Architecture

- Web page consists of objects (HTML file, JPEG image, Java applet, audio file).
- Base HTML file includes referenced objects.
- **Client**: Browser that requests, receives, and displays Web objects.
- **Server**: Web server sends objects in response to requests.
- Follows Client-Server model.

URLs: Uniform Resource Locators

- Identifies a resource on the internet.
- Format: ‘protocol://hostname:port/path?query#fragment‘
- Example:
‘https://www.example.com:443/folder/page.html?id=123#section1‘
- **Protocol**: http, https, ftp
- **Hostname**: Domain name or IP
- **Path**: Location on the server

HTTP: HyperText Transfer Protocol

- Web's application layer protocol.
- Client/server model.
- **Uses TCP**: Port 80 (HTTP) or 443 (HTTPS).
- **Stateless**: Server maintains no information about past client requests.
- Non-persistent HTTP vs Persistent HTTP (HTTP/1.1 default).

HTTP Request Message

- Format: Request line, Header lines, Blank line, Body (optional)
- **Methods**: GET, POST, HEAD, PUT, DELETE

```
- GET: Request data. POST: Submit data.
```

HTTP Response Message

- Format: Status line, Header lines, Blank line, Body (data)
- **Status Codes**:
- 200 OK
- 301 Moved Permanently
- 400 Bad Request
- 404 Not Found
- 500 Internal Server Error

Maintaining State: Cookies

- Since HTTP is stateless, how do websites remember you?
- **Cookies**: Small piece of data sent from server, stored in user's browser.
- Server sends 'Set-Cookie' header in response.
- Browser sends 'Cookie' header in subsequent requests.
- Used for session management, personalization, tracking.

Web Caches (Proxy Servers)

- Satisfy client request without involving origin server.
- Browser sends all HTTP requests to cache.
- If object in cache, cache returns it. Else, cache requests from origin server, caches it, returns to client.
- Reduces response time and access link bandwidth.
- Conditional GET (‘If-Modified-Since‘) prevents stale data.

HTML: HyperText Markup Language

- Standard markup language for creating Web pages.
- Describes the structure of a Web page semantically.
- Consists of a series of elements (tags).
- Tags label pieces of content such as 'heading', 'paragraph', 'table', etc.
- Browsers do not display HTML tags, but use them to render content.

HTML Basic Structure

- `<!DOCTYPE html>` defines document type (HTML5).
- `<body>` contains visible page content.

Summary

- WWW is a collection of linked documents.
- URLs identify resources.
- HTTP is the stateless protocol over TCP.
- Cookies add state to HTTP.
- HTML structures the web pages.

Electronic Mail & Other Protocols

- Email Architecture
- SMTP, POP3, IMAP
- FTP and Remote Login

Agenda

1. Email System Components
2. Message Format
3. SMTP Protocol
4. Mail Access Protocols (POP3, IMAP)
5. FTP (File Transfer Protocol)
6. Remote Login (Telnet, SSH)
7. Summary

Email System Components

- **User Agents (UA)**: Mail reader (e.g., Outlook, Apple Mail). Composing, editing, reading mail.
- **Mail Servers**: Mailbox contains incoming messages; message queue contains outgoing messages.
- **Simple Mail Transfer Protocol (SMTP)**: Protocol between mail servers to send email.
- Follows push protocol model for delivery.

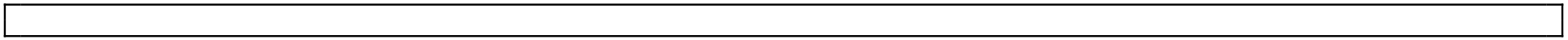
Message Format (RFC 5322)

- Email message consists of a header and a body.
- Header lines: ‘To:‘, ‘From:‘, ‘Subject:‘, ‘Date:‘
- Body: The message itself (ASCII characters only).
- **MIME (Multipurpose Internet Mail Extensions)**: Extension allowing non-ASCII data (images, audio, attachments).
- MIME defines new headers: ‘Content-Type:‘, ‘Content-Transfer-Encoding:‘

SMTP: Simple Mail Transfer Protocol

- Uses **TCP** on port **25**.
- Direct transfer: sending server to receiving server.
- Three phases: Handshake, Transfer of messages, Closure.
- Command/Response interaction (like HTTP). Commands in ASCII, responses are status codes/phrases.
- Message must be in 7-bit ASCII.
- Push protocol.

SMTP Interaction Example



Mail Access Protocols

- SMTP is used to *send* mail to the receiver's mail server.
- How does the receiver get mail from their server? Cannot use SMTP (push). Need a pull protocol.
- **POP3 (Post Office Protocol v3)**: Simple, download-and-delete or download-and-keep.
- **IMAP (Internet Mail Access Protocol)**: More complex, keeps state on server, allows folder management on server.
- **HTTP**: Webmail interfaces (Gmail, Yahoo) use HTTP to access mail from the server.

POP3 Details

- Uses **TCP** port **110**.
- Phases: Authorization (login), Transaction (list, retrieve, delete), Update (server deletes messages and closes).
- 'Download and Delete' mode means if you read mail on phone, it's gone from laptop.
- 'Download and Keep' leaves copies.
- POP3 is stateless across sessions.

FTP: File Transfer Protocol

- Transfer file to/from remote host.
- Uses **two parallel TCP connections**:
1. **Control connection**: Port 21 (for commands and replies).
2. **Data connection**: Port 20 (for actual file transfer).
- FTP server maintains state (current directory, earlier authentication).
- Out-of-band control (commands are on a separate connection from data).

Remote Login: Telnet and SSH

- Allow a user to log into a remote machine.
- **Telnet**: Port 23. Transmits data in plain text (insecure). Not used much today.
- **SSH (Secure Shell)**: Port 22. Provides strong encryption and authentication.
- Provides a virtual terminal over the network.
- Often used for remote administration and secure file transfer (SFTP/SCP).

Python: Sending Email with smtplib

Summary

- Email uses SMTP for transfer (push) and POP3/IMAP for access (pull).
- Messages are 7-bit ASCII, extended by MIME.
- FTP uses out-of-band control connections (ports 20/21).
- SSH (port 22) replaces Telnet (port 23) for secure remote login.

Voice and Video over IP (Part 1)

- Real-Time Interactive Applications
- Streaming Stored Audio/Video
- Protocols: RTP, SIP

Agenda

1. Multimedia Networking Applications
2. Audio/Video Compression
3. Streaming Stored Video
4. VoIP Characteristics
5. RTP & RTCP
6. SIP Protocol
7. QoS Requirements

Multimedia Networking Applications

- **Streaming stored audio/video**: YouTube, Netflix. (Can pause, rewind).
- **Conversational voice/video over IP**: Skype, Zoom. (Real-time, interactive).
- **Streaming live audio/video**: Live sports broadcast.
- Key challenges: Delay, Jitter, Packet loss.

Audio and Video Compression

- Analog signal digitized (sampled, quantized).
- **Audio**: PCM (Pulse Code Modulation), 8000 samples/sec, 8 bits/sample = 64 kbps (G.711).
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Challenges of Real-Time Traffic

- **Packet Loss**: Network congestion causes router drops.
- **End-to-End Delay**: Processing, queueing, transmission, propagation delays. (¿ 400ms is unacceptable for voice).
- **Jitter**: Variability of packet delays within the same packet stream.
- TCP is often inappropriate due to retransmission delays. UDP is preferred.

Mitigating Jitter: Playout Buffer

- Packets experience variable delays.
- Receiver attempts to play out audio/video at constant rate.
- Use a **playout buffer**: Delay playout to allow for network delay variations.
- If packet arrives after its scheduled playout time, it's considered lost.
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RTP: Real-Time Transport Protocol

- Runs on top of **UDP**.
- Provides payload type identification, sequence numbering, timestamping.
- Does NOT provide QoS guarantees or ensure timely delivery.
- Sequence numbers allow receiver to detect packet loss and restore packet order.
- Timestamps used for synchronization and jitter calculation.

RTP Header Format

- 12-byte minimum header.
- **Payload Type (7 bits)**: Indicates encoding (e.g., 0 for PCM u-law).
- **Sequence Number (16 bits)**: Increments by one for each packet sent.
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- **Synchronization Source ID (SSRC)**: Identifies the stream source.

RTCP: RTP Control Protocol

- Works in conjunction with RTP.
- Senders and receivers periodically send RTCP packets.
- Contain statistics: number of packets sent/received, number of lost packets, interarrival jitter.
- Feedback used to adapt transmission rate or change encoding.
- Synchronizes multiple streams (e.g., audio and video) using NTP timestamps.

SIP: Session Initiation Protocol

- Application layer control protocol for establishing, modifying, and terminating multimedia sessions.
- Similar in structure to HTTP (text-based).
- Uses URIs (e.g., sip:alice@example.com).
- Functions: Caller translation, feature negotiation, call management.
- Often works alongside RTP (which carries the actual media).

SIP Message Exchange

Summary

- Real-time applications require low delay and tolerate some loss.
- Playout buffers mitigate network jitter.
- RTP provides timestamps and sequence numbers over UDP.
- RTCP provides QoS feedback.
- SIP handles session setup and teardown.

Voice and Video over IP (Part 2)

- Real-Time Interactive Applications
- Streaming Stored Audio/Video
- Protocols: RTP, SIP

Agenda

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6. SIP Protocol
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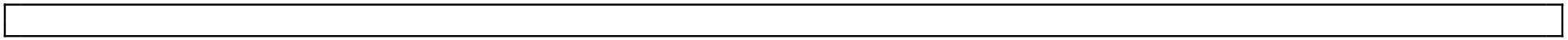

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Voice and Video over IP (Part 3)

- Real-Time Interactive Applications
- Streaming Stored Audio/Video
- Protocols: RTP, SIP

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Voice and Video over IP (Part 4)

- Real-Time Interactive Applications
- Streaming Stored Audio/Video
- Protocols: RTP, SIP

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Voice and Video over IP (Part 5)

- Real-Time Interactive Applications
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- Protocols: RTP, SIP

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- Packets experience variable delays.
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- Fixed vs Adaptive playout delay.

RTP: Real-Time Transport Protocol

- Runs on top of **UDP**.
- Provides payload type identification, sequence numbering, timestamping.
- Does NOT provide QoS guarantees or ensure timely delivery.
- Sequence numbers allow receiver to detect packet loss and restore packet order.
- Timestamps used for synchronization and jitter calculation.

RTP Header Format

- 12-byte minimum header.
- **Payload Type (7 bits)**: Indicates encoding (e.g., 0 for PCM u-law).
- **Sequence Number (16 bits)**: Increments by one for each packet sent.
- **Timestamp (32 bits)**: Reflects sampling instant of first byte in packet.
- **Synchronization Source ID (SSRC)**: Identifies the stream source.

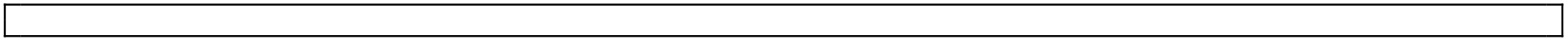
RTCP: RTP Control Protocol

- Works in conjunction with RTP.
- Senders and receivers periodically send RTCP packets.
- Contain statistics: number of packets sent/received, number of lost packets, interarrival jitter.
- Feedback used to adapt transmission rate or change encoding.
- Synchronizes multiple streams (e.g., audio and video) using NTP timestamps.

SIP: Session Initiation Protocol

- Application layer control protocol for establishing, modifying, and terminating multimedia sessions.
- Similar in structure to HTTP (text-based).
- Uses URIs (e.g., sip:alice@example.com).
- Functions: Caller translation, feature negotiation, call management.
- Often works alongside RTP (which carries the actual media).

SIP Message Exchange



Summary

- Real-time applications require low delay and tolerate some loss.
- Playout buffers mitigate network jitter.
- RTP provides timestamps and sequence numbers over UDP.
- RTCP provides QoS feedback.
- SIP handles session setup and teardown.

Voice and Video over IP (Part 6)

- Real-Time Interactive Applications
- Streaming Stored Audio/Video
- Protocols: RTP, SIP

Agenda

1. Multimedia Networking Applications
2. Audio/Video Compression
3. Streaming Stored Video
4. VoIP Characteristics
5. RTP & RTCP
6. SIP Protocol
7. QoS Requirements

Multimedia Networking Applications

- **Streaming stored audio/video**: YouTube, Netflix. (Can pause, rewind).
- **Conversational voice/video over IP**: Skype, Zoom. (Real-time, interactive).
- **Streaming live audio/video**: Live sports broadcast.
- Key challenges: Delay, Jitter, Packet loss.

Audio and Video Compression

- Analog signal digitized (sampled, quantized).
- **Audio**: PCM (Pulse Code Modulation), 8000 samples/sec, 8 bits/sample = 64 kbps (G.711).
- Compression reduces bitrate (e.g., MP3, AAC).
- **Video**: Sequence of images at constant rate (e.g., 24 fps).
- Spatial and Temporal redundancy exploited for compression (e.g., MPEG-4, H.264, H.265).

Challenges of Real-Time Traffic

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- Real-Time Interactive Applications
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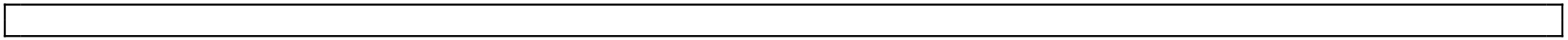

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Introduction to Network Security & Cryptography

Course: DI03000131 Information Security
Unit 5: Network Security
Lecture 38: Intro to Network Security, Cryptography
Focus: Core principles of protecting network communications and cryptographic foundations.

Lecture Overview

1. The Need for Network Security
2. The CIA Triad in Networking
3. Common Network Threats and Attacks
4. Introduction to Cryptography
5. Symmetric vs. Asymmetric Cryptography
6. Cryptographic Hash Functions
7. Digital Signatures and Certificates

The Need for Network Security

Network Security Overview:
- Protects the usability, reliability, integrity, and safety of network and data.
- Targets a variety of threats: passive eavesdropping to active data manipulation.

Why is it complex?
- Networks (like the Internet) are inherently public and shared.
- Data transits through multiple untrusted intermediary nodes (routers, switches).
- Endpoint diversity increases the attack surface (IoT, mobile, servers).

The CIA Triad in Networking

Confidentiality:
- Ensures unauthorized entities cannot read the data in transit.
- Primarily achieved via encryption (e.g., AES, ChaCha20).
Integrity:
- Ensures data has not been altered in transit.
- Achieved via Message Authentication Codes (MACs) and Hash functions (e.g., SHA-256).
Availability:
- Ensures network services remain accessible to legitimate users.
- Thwarted by Denial of Service (DoS) attacks; mitigated by redundancy, rate limiting, and firewalls.

Network Threats and Attacks

Passive Attacks:
- **Eavesdropping/Sniffing:** Capturing network traffic (e.g., using Wireshark).
- **Traffic Analysis:** Observing patterns of communication even if payload is encrypted.
Active Attacks:
- **Spoofing:** Impersonating another device (e.g., IP spoofing, ARP spoofing).
- **Man-in-the-Middle (MitM):** Intercepting and possibly altering communications between two parties.
- **Replay Attacks:** Capturing valid data transmissions and maliciously repeating them.

Introduction to Cryptography

Cryptography Definition:
- The practice and study of techniques for secure communication in the presence of adversarial behavior.
Core Concepts:
- **Plaintext:** The original, readable message.
- **Ciphertext:** The scrambled, unreadable output.
- **Cipher:** The mathematical algorithm used for encryption/decryption.
- **Key:** A piece of information determining the functional output of a cryptographic algorithm.

Symmetric Key Cryptography

Concept:
- Uses a **single shared key** for both encryption and decryption.
Characteristics:
- **Fast and efficient:** Suitable for bulk data encryption.
- **Key Distribution Problem:** How do two parties securely share the key over an insecure network?
Common Algorithms:
- **AES (Advanced Encryption Standard):** Current standard (128, 192, 256-bit keys).
- **DES/3DES:** Legacy algorithms, largely deprecated due to small key sizes.

Asymmetric Key Cryptography

Concept:
- Uses a **key pair**: a Public Key (shared openly) and a Private Key (kept secret).
- Encrypt with Public Key $\rightarrow$ Decrypt with Private Key.
Characteristics:
- Solves the key distribution problem.
- Computationally intensive (much slower than symmetric).
Common Algorithms:
- **RSA (Rivest-Shamir-Adleman):** Based on the difficulty of factoring large integers.
- **ECC (Elliptic Curve Cryptography):** Offers similar security to RSA but with much smaller key sizes.

Hybrid Cryptography (Real-world usage)

The Best of Both Worlds:
- In practice, symmetric and asymmetric cryptography are combined.
The Hybrid Process (e.g., TLS):
1. **Key Exchange:** Asymmetric cryptography (e.g., RSA or Diffie-Hellman) is used to securely exchange a temporary 'Session Key'.
2. **Bulk Encryption:** The established Session Key is then used with a symmetric algorithm (e.g., AES) to encrypt the actual data traffic.
- This provides the security of asymmetric key exchange with the speed of symmetric encryption.

Cryptographic Hash Functions

Concept:
- A one-way mathematical function that maps data of arbitrary size to a fixed-size bit string (hash value/digest).
Properties:
- **Deterministic:** Same input always yields the same output.
- **Fast computation.**
- **Pre-image resistance:** Computationally infeasible to reverse the hash to find the input.
- **Collision resistance:** Hard to find two different inputs that produce the same hash.
Common Algorithms: SHA-2 (SHA-256), SHA-3.

Digital Signatures

Purpose: Provides Authentication, Non-repudiation, and Integrity.
How it works:
1. **Sender:** Hashes the message.
2. **Sender:** Encrypts the hash with their **Private Key** (this is the signature).
3. **Sender:** Sends the message and the signature.
4. **Receiver:** Decrypts the signature using the sender's **Public Key** to reveal the hash.
5. **Receiver:** Hashes the received message and compares it to the decrypted hash.
If they match, the message is authentic and unaltered.

Summary & Next Steps

Summary:
- Network security protects data in transit across untrusted environments.
- The CIA triad (Confidentiality, Integrity, Availability) guides security implementations.
- Cryptography provides the mathematical mechanisms (Symmetric, Asymmetric, Hashing) to achieve these goals.
- Hybrid systems combine asymmetric key exchange with symmetric bulk encryption.
Next Lecture:
- We will explore how these concepts apply to network architecture.
- Topics include Security Topologies, DMZs, VLANs, and Tunnelling.

Security Topologies & Architecture

Course: DI03000131 Information Security
Unit 5: Network Security
Lecture 39: Security topologies, DMZ, VLAN, Tunnelling
Focus: Designing networks with built-in defensive layers.

Agenda

1. Concept of Security Zones
2. The Internet vs Intranet
3. Demilitarized Zone (DMZ) Architecture
4. Virtual Local Area Networks (VLANs)
5. VLAN Security Implications
6. Network Tunnelling Principles
7. Architectural Security Implications

Security Zones Overview

What are Security Zones?
- Network segments defined by their level of trust and security requirements.
- Traffic between zones is restricted and inspected (usually by firewalls).
Core Principle: Defense in Depth
- Avoid a 'flat' network where compromising one machine compromises all.
- Segment based on function (HR vs. Engineering) and exposure (Public Web Server vs. Internal Database).

Internet vs. Intranet

The Internet (Untrusted Zone):
- The public, global network.
- Inherently hostile; traffic originating from here is assumed malicious until proven otherwise.
The Intranet (Trusted Zone):
- The internal, private network of an organization.
- Houses sensitive data, employee workstations, and internal servers.
- Requires strict access controls to prevent external (and internal) unauthorized access.

The Demilitarized Zone (DMZ)

What is a DMZ?
- A physical or logical subnetwork that contains and exposes an organization's external-facing services to an untrusted network (the Internet).
Purpose:
- Acts as a buffer zone between the Internet and the strict Intranet.
- External users can access services in the DMZ (Web, DNS, Email servers), but cannot reach the Intranet.

DMZ Architectures

Single Firewall (Three-leg perimeter):
- One firewall with 3 interfaces: Internet, Intranet, DMZ.
- Single point of failure.
Dual Firewall (Back-to-back):
- **Firewall 1 (External):** Between Internet and DMZ (Allows HTTP/HTTPS).
- **Firewall 2 (Internal):** Between DMZ and Intranet (Allows highly restricted DB queries from Web Server).
- More secure, especially if firewalls are from different vendors (prevents a single exploit from bypassing both).

Virtual Local Area Networks (VLANs)

What is a VLAN?
- A logical grouping of network devices that behave as if they are on the same physical switch, even if they are not.
- Operates at Layer 2 (Data Link Layer).
Benefits:
- **Segmentation:** Separates broadcast domains without buying separate hardware.
- **Security:** HR computers can't natively see Engineering broadcast traffic.
- **Flexibility:** Network configuration is done in software, not by re-plugging cables.

Security Implications of VLANs

VLAN Routing:
- Devices on different VLANs require a Layer 3 device (Router/L3 Switch) to communicate. This choke point allows firewall rule application.
VLAN Hopping Attacks:
- **Switch Spoofing:** Attacker tricks a switch into creating a trunk link to access all VLANs.
- **Double Tagging:** Attacker embeds a second 802.1Q VLAN tag inside the frame to bypass isolation.
Mitigation: Disable Dynamic Trunking Protocol (DTP), put unused ports in a dead VLAN.

Network Tunnelling

Concept:
- Encapsulating one network protocol within another payload protocol.
- Used to carry traffic over an incompatible or insecure network (like the Internet).
How it works:
- Original Packet (IP Header + Data) is treated entirely as 'Data' by the encapsulating protocol.
- A new Header (e.g., IPSec or GRE) is added to route it over the transit network.

Tunnelling Security Implications

Pros:
- Enables VPNs (Virtual Private Networks).
- Can bypass network restrictions (e.g., SSH tunnelling).
Cons / Risks:
- **Blind Spots:** Firewalls and IDS cannot inspect encrypted tunnel traffic.
- **Data Exfiltration:** Attackers often use tunnels (e.g., DNS or ICMP tunnelling) to sneak stolen data out of a network.
Mitigation: DPI (Deep Packet Inspection), SSL Decryption, blocking unauthorized tunnel protocols.

Summary of Architectural Security

Designing for Security:
1. **Assume Breach:** Design the internal network assuming attackers will get in.
2. **Micro-segmentation:** Use VLANs and internal firewalls aggressively.
3. **Isolate Public Services:** Always use a DMZ for web/email servers.
4. **Control Transit:** Use secure tunnelling for remote access, but monitor for unauthorized tunnels.

Summary & Next Steps

Summary:
- Security zones dictate trust levels (Internet, Intranet, DMZ).
- DMZs safely isolate public-facing services.
- VLANs provide logical Layer 2 segmentation but must be secured against hopping.
- Tunnelling enables VPNs but introduces monitoring challenges.

Next Lecture:
- We will dive deep into IP Security (IPsec).
- Covering IPsec architecture, AH, ESP, and configuration modes.

IP Security (IPsec): Overview, Architecture, Configuration

Course: DI03000131 Information Security
Unit 5: Network Security
Lecture 40: IPsec
Focus: Securing IP communications at the Network Layer.

Agenda

1. Why IPsec? The Network Layer Context
2. IPsec Services and Features
3. Core Protocols: AH (Authentication Header)
4. Core Protocols: ESP (Encapsulating Security Payload)
5. IKE (Internet Key Exchange)
6. Operating Modes: Transport Mode
7. Operating Modes: Tunnel Mode
8. IPsec Architecture Overview

Why Network Layer Security?

The Problem:
- Standard IP (IPv4) offers **no** data confidentiality, integrity, or source authentication.
- Packets can be easily spoofed, intercepted, or modified in transit.
The IPsec Solution:
- Operates at **Layer 3 (Network Layer)** of the OSI model.
- Protects *all* higher-layer protocols (TCP, UDP, ICMP) automatically without modifying the applications.
- Applications are completely unaware that IPsec is running.

IPsec Services

What IPsec Provides:
1. **Data Confidentiality:** Encrypts the packet payload (ESP).
2. **Data Integrity:** Ensures packets haven't been altered (AH & ESP).
3. **Data Origin Authentication:** Verifies the sender is who they claim to be.
4. **Anti-Replay Protection:** Prevents attackers from capturing and re-sending legitimate packets (using Sequence Numbers).
5. **Key Management:** Securely negotiates keys between endpoints (IKE).

Authentication Header (AH)

Purpose: Provides Integrity and Authentication, but **NO Confidentiality** (no encryption).
Mechanism:
- Calculates a hash (MAC) over the packet payload and *immutable* parts of the IP header (like Source/Dest IP).
- Inserts the AH header between the IP header and the payload.
Limitations:
- Because it signs the original IP header, it breaks when passing through NAT (Network Address Translation) routers, which change IP addresses.

Encapsulating Security Payload (ESP)

Purpose: Provides Confidentiality (Encryption), Integrity, and Authentication.
Mechanism:
- Encrypts the payload (using AES, etc.).
- Appends an ESP header and an ESP trailer around the payload.
- Computes an integrity check (hash) over the ESP header and encrypted payload.
Advantage over AH:
- Supports NAT-Traversal (NAT-T) because it does not include the outer IP header in its integrity check.

Internet Key Exchange (IKE)

Purpose: The control plane of IPsec. Used to negotiate Security Associations (SAs).
What is a Security Association (SA)?
- A unidirectional agreement between two endpoints dictating how to protect traffic (which algorithms to use, which keys).
IKE Phases (IKEv1):
- **Phase 1:** Establishes a secure, authenticated channel (ISAKMP SA).
- **Phase 2:** Negotiates the actual IPsec SAs used to encrypt data traffic over the Phase 1 tunnel.
- *Note: IKEv2 simplifies this process and improves reliability.*

IPsec Modes: Transport Mode

Use Case: End-to-end communication (Host-to-Host).
How it works:
- Only the **payload** of the IP packet is protected (encrypted/authenticated).
- The **original IP header is kept intact** and used for routing.
- IP Header — IPsec Header — Encrypted Payload
Characteristics:
- Less overhead.
- Exposes internal IP addresses to the network.

IPsec Modes: Tunnel Mode

Use Case: Network-to-Network (Site-to-Site VPN) or Host-to-Network.
How it works:
- The **entire original IP packet** (header + payload) is encrypted and encapsulated.
- A **new outer IP header** is added (usually with the IP addresses of the VPN gateways).
- New IP Header — IPsec Header — [Encrypted: Orig IP Header — Payload]
Characteristics:
- Hides internal network topology.
- Standard mode for VPNs.

IPsec Configuration Flow

Basic Steps to configure Site-to-Site IPsec (e.g., on Cisco/Palo Alto):
1. **Define Interesting Traffic:** (ACL) What traffic should trigger the VPN? (e.g., Subnet A to Subnet B).
2. **IKE Phase 1 (ISAKMP):** Define policy (Encryption: AES, Hash: SHA, Auth: Pre-Shared Key, DH Group).
3. **IKE Phase 2 (IPsec):** Define Transform Set (e.g., ESP-AES-256-SHA).
4. **Crypto Map/VPN Profile:** Bind the ACL, Transform Set, and Remote Peer IP together.
5. **Apply:** Apply the Crypto Map to the external interface.

Troubleshooting IPsec

Common Failure Points:
- **Mismatched Pre-Shared Keys (PSK):** Phase 1 fails to authenticate.
- **Mismatched Policies:** AES-128 on one side, AES-256 on the other. Phase 1 or 2 will drop.
- **NAT Issues:** ESP traffic (Protocol 50) blocked, or NAT-T (UDP 4500) not allowed through firewalls.
- **Routing:** Traffic reaches the router but no route exists to send it through the tunnel.

Tools: Logs, ‘show crypto isakmp sa‘, packet captures.

Summary & Next Steps

Summary:
- IPsec secures IP traffic transparently at Layer 3.
- **AH** provides integrity; **ESP** provides confidentiality and integrity.
- **IKE** handles key negotiation (Phase 1 & 2).
- **Transport mode** (Host-to-Host) vs **Tunnel mode** (Site-to-Site VPN).

Next Lecture:
- Virtual Private Networks (VPNs).
- Exploring how IPsec and other protocols are used to build comprehensive VPN solutions.

Virtual Private Networks (VPNs)

Course: DI03000131 Information Security
Unit 5: Network Security
Lecture 41: Virtual Private Network
Focus: Extending private networks securely across public infrastructure.

Agenda

1. What is a VPN?
2. Core VPN Characteristics
3. Site-to-Site VPN Architecture
4. Remote Access VPN Architecture
5. IPsec VPNs
6. SSL/TLS VPNs
7. VPN Split Tunnelling vs Full Tunnelling
8. VPN Security Concerns and Best Practices

What is a VPN?

Concept:
- A technology that establishes a secure, encrypted connection (a tunnel) over a less secure network, such as the Internet.
- It makes an external device or network appear as if it is directly connected to the local private network.
Why use a VPN?
- **Cost Efficiency:** Replaces expensive leased lines (WAN) with cheap Internet connections.
- **Security:** Protects sensitive data from eavesdropping on public Wi-Fi or transit routers.
- **Accessibility:** Allows remote workers to access internal corporate resources securely.

Site-to-Site VPN

Architecture:
- Connects entire networks to each other (e.g., Branch Office to Headquarters).
- Terminated by routers or firewalls (VPN Gateways) at each location.
Characteristics:
- **Transparent to Users:** End users don't know they are using a VPN; routing is handled by the gateways.
- Typically uses **IPsec** in **Tunnel Mode**.
- Requires static IP addresses on at least one side (usually) for reliable connection setup.

Remote Access VPN

Architecture:
- Connects individual remote users (laptops, mobile devices) to a corporate network.
- Terminated at a corporate VPN concentrator/firewall, requiring client software on the endpoint.
Characteristics:
- Uses dynamic IPs; users can connect from anywhere (hotels, coffee shops).
- Uses either **IPsec** or **SSL/TLS** (e.g., OpenVPN, Cisco AnyConnect).
- Highly reliant on user authentication (MFA is critical).

IPsec VPNs (Revisited)

Pros:
- Operates at Network Layer: Secures all traffic regardless of application.
- Industry standard for Site-to-Site connections.
Cons:
- Client configuration can be complex for Remote Access.
- Firewalls and NAT devices often block IPsec traffic (ESP/Protocol 50, UDP 500) if not explicitly allowed or if NAT-T isn't configured.

SSL/TLS VPNs

Architecture:
- Relies on the TLS protocol (same as HTTPS).
- Operates primarily at the Transport/Application layer.
Two Types:
- **Clientless (Web-based):** Access via a standard web browser (often used for specific web apps).
- **Full Tunnel Client:** Uses software (like OpenVPN) to create a virtual network adapter for full network access.
Advantages over IPsec for Remote Access:
- Uses TCP Port 443. Almost never blocked by public firewalls, works seamlessly through NAT.

Split Tunnelling vs. Full Tunnelling

Full Tunnelling:
- ALL user traffic (corporate AND personal web browsing) goes through the VPN to the corporate firewall.
- **Pro:** Maximum security, all traffic is filtered by corporate policies.
- **Con:** High bandwidth strain on the corporate internet connection.

Split Tunnelling:
- Only traffic destined for corporate subnets goes through the VPN. Internet traffic goes out the user's local connection.
- **Pro:** Saves corporate bandwidth, better user experience for generic web browsing.
- **Con:** Security risk (endpoint can be infected via local internet and bridge malware to corporate network).

VPN Authentication and Security

Strong Authentication is Mandatory:
- Usernames/Passwords are easily compromised (phishing).
- **MFA (Multi-Factor Authentication):** Requires token/app approval.
Endpoint Posture Checking:
- Modern VPNs check the health of the connecting device before allowing access.
- Checks for: Updated Antivirus, OS patches, specific registry keys, corporate domain membership.
- If posture fails, device is placed in a quarantine VLAN.

Example: OpenVPN Architecture

Overview: Open-source, heavily used SSL/TLS-based VPN.
Under the Hood:
- Uses standard TLS for key exchange and authentication.
- Uses the TUN/TAP driver in the OS to create virtual network interfaces.
- **TUN:** Routing (Layer 3) - standard IP routing.
- **TAP:** Bridging (Layer 2) - can transmit Ethernet frames, useful for legacy protocols.
- Can run over UDP (faster, preferred) or TCP (reliable, better firewall traversal).

Modern VPN Alternatives: Zero Trust (ZTNA)

The Problem with VPNs:
- Once connected, users often have broad network access (implicit trust).
Zero Trust Network Access (ZTNA):
- Replaces traditional VPNs.
- Never connect a user directly to the network; connect them only to specific applications.
- Continuous authentication and authorization per request, not just once at login.
- Often provided as a cloud service (e.g., Zscaler, Cloudflare Access).

Summary & Next Steps

Summary:
- VPNs provide secure tunnelling over public networks.
- Site-to-Site connects networks (IPsec); Remote Access connects users (often SSL/TLS).
- Split vs. Full tunnelling dictates how non-corporate traffic is routed.
- Robust authentication and endpoint posture checks are critical.

Next Lecture:
- Email Security.
- We will examine protocols like PGP, S/MIME, and how spam and phishing are handled.

Email Security & Standards

Course: DI03000131 Information Security
Unit 5: Network Security
Lecture 42: Email Security Standards
Focus: Protecting the confidentiality, integrity, and authenticity of email.

Agenda

1. The Inherent Insecurity of SMTP
2. Email Security Goals
3. Privacy Enhanced Mail (PEM)
4. Pretty Good Privacy (PGP)
5. PGP Web of Trust
6. S/MIME (Secure/Multipurpose Internet Mail Extensions)
7. PGP vs. S/MIME
8. Spam and Modern Defenses (SPF, DKIM, DMARC)

SMTP and its Vulnerabilities

SMTP (Simple Mail Transfer Protocol):
- The standard protocol for sending emails.
- Operates over TCP port 25.
Security Flaws:
- **Plaintext Transmission:** By default, emails are sent in clear text. Anyone on the path can read them.
- **No Authentication:** Standard SMTP does not verify the sender. It is trivial to spoof the 'From' address.
- **No Integrity:** Emails can be intercepted and altered in transit without detection.

Goals of Email Security

To secure email, we must apply the principles of cryptography:
1. **Confidentiality:** Only the intended recipient can read the email (Encryption).
2. **Authentication:** Proving the sender is actually who they claim to be (Digital Signatures).
3. **Integrity:** Ensuring the message was not modified in transit (Hashes).
4. **Non-repudiation:** The sender cannot deny sending the email.
Transport vs. End-to-End Security:
- TLS (STARTTLS) secures the hop between mail servers.
- PGP/S/MIME secure the message end-to-end (Client to Client).

Privacy Enhanced Mail (PEM)

History:
- One of the earliest standards proposed by the IETF for secure email.
Architecture:
- Relied heavily on a strict, rigid, hierarchical Public Key Infrastructure (PKI).
- Required users to obtain certificates from central Certificate Authorities (CAs).
Outcome:
- Largely failed in adoption because the required global PKI infrastructure didn't exist at the time, and it was too complex for average users.
- Replaced by more flexible systems like PGP and S/MIME.

Pretty Good Privacy (PGP)

Overview:
- Created by Phil Zimmermann in 1991. Now an open standard (OpenPGP).
- Provides cryptographic privacy and authentication for data communication.
How it works (Encryption):
1. Creates a random session key (symmetric).
2. Encrypts the email payload with the session key.
3. Encrypts the session key with the recipient's **Public Key**.
4. Sends both to the recipient.
How it works (Signatures):
- Sender hashes the email and encrypts the hash with their **Private Key**.

PGP: The Web of Trust

The Key Distribution Problem:
- How do you know a public key actually belongs to Bob, and not an attacker pretending to be Bob?
The Web of Trust Approach:
- Decentralized trust model (unlike PEM/S/MIME).
- Users physically meet (Key Signing Parties) and sign each other's public keys.
- If Alice trusts Bob, and Bob has signed Charlie's key, Alice can choose to inherently trust Charlie's key.
- Relies on a decentralized network of keyservers.

S/MIME (Secure/Multipurpose Internet Mail Extensions)

Overview:
- A standard for public key encryption and signing of MIME data.
- Built directly into most modern enterprise email clients (Outlook, Apple Mail).
Trust Model:
- Uses standard X.509 certificates and a strict, centralized **PKI (Public Key Infrastructure)**.
- You must buy or be issued a certificate from a trusted Certificate Authority (CA), just like a web server for HTTPS.
Usage:
- Heavily used in corporate and government environments where IT controls the CAs.

PGP vs. S/MIME

— Feature — PGP (OpenPGP) — S/MIME —
— :— — :— — :— —
— **Trust Model** — Web of Trust (Decentralized) — PKI / X.509 (Centralized CA) —
— **Format** — Radix-64, specific PGP format — Native MIME format —
— **Adoption** — Individuals, open-source communities — Enterprises, Governments —
— **Client Support**— Requires plugins (GnuPG, Enigmail) — Native in most enterprise clients —
— **Cost** — Usually Free — Requires paid/issued CA certs —

Spam and Email Spoofing

The Problem:
- Spam wastes bandwidth and storage.
- Phishing (malicious spam) is the primary entry point for malware and ransomware.
- Because SMTP lacks authentication, anyone can claim to be ‘ceo@yourcompany.com‘.
Legacy Defenses:
- Keyword filtering (Bayesian filters).
- IP Blacklists (RBLs).
- These are reactive and often produce false positives.

Modern Anti-Spam/Spoofing Frameworks

SPF (Sender Policy Framework):
- A DNS record listing which IP addresses are allowed to send mail on behalf of a domain.
DKIM (DomainKeys Identified Mail):
- The sending server cryptographically signs the email header.
- The receiving server verifies the signature using a public key published in the sender's DNS.
DMARC (Domain-based Message Authentication, Reporting, and Conformance):
- Ties SPF and DKIM together.
- Tells the receiving server what to do if SPF/DKIM fail (e.g., 'Reject the email' or 'Send to Spam').

Summary & Next Steps

Summary:
- SMTP is fundamentally insecure, requiring external security mechanisms.
- **PGP** uses a decentralized Web of Trust for end-to-end security.
- **S/MIME** uses centralized PKI and is the enterprise standard.
- **SPF, DKIM, and DMARC** are critical DNS-based protocols to prevent spoofing and spam.

Next Lecture:
- Information Security Standards and Cyber Law.
- We will explore ISO standards, the IT Act, and the legal frameworks governing cyber security.

Information Security Standards & Cyber Laws

Course: DI03000131 Information Security
Unit 5: Network Security
Lecture 43: InfoSec Standards, ISO, Cyber Laws, Copyright
Focus: The compliance, management, and legal frameworks of cybersecurity.

Agenda

1. The Need for Information Security Standards
2. ISO/IEC 27000 Series Overview
3. Deep Dive: ISO/IEC 27001 (ISMS)
4. Introduction to Cyber Law
5. Cyber Jurisprudence in India
6. Overview of the IT Act, 2000
7. Intellectual Property in Cyberspace
8. The Copyright Act & Digital Piracy

Why Security Standards?

The Challenge:
- Security is not just buying a firewall; it's a continuous process.
- How does a client know a vendor is secure? How do stakeholders measure risk?

The Role of Standards:
- Provides a proven, structured framework for implementing security.
- Ensures consistency and comprehensive coverage (preventing 'blind spots').
- Enables **Certification** (third-party audits build trust).
- Aligns technical controls with business objectives and risk appetite.

ISO/IEC 27000 Series

What is it?
- A family of standards published jointly by the International Organization for Standardization (ISO) and the International Electrotechnical Commission (IEC).
Key Standards in the Family:
- **ISO/IEC 27000:** Vocabulary and Overview.
- **ISO/IEC 27001:** **Requirements** for an Information Security Management System (ISMS). (This is the certifiable standard).
- **ISO/IEC 27002:** Code of practice and **guidance** on implementing security controls.
- **ISO/IEC 27005:** Information security risk management.

ISO/IEC 27001: The ISMS

Information Security Management System (ISMS):
- A systematic approach to managing sensitive company information so that it remains secure.
- Includes people, processes, and IT systems.
Core Concept: PDCA Cycle (Deming Cycle)
- **Plan:** Establish ISMS policy, objectives, processes, and procedures.
- **Do:** Implement and operate the ISMS policy.
- **Check:** Assess and, where applicable, measure process performance.
- **Act:** Take corrective and preventive actions for continual improvement.

Introduction to Cyber Law

What is Cyber Law?
- The legal framework addressing issues related to the Internet, computing, digital information, and communication technologies.
Why is it complex?
- **Jurisdiction:** The Internet is borderless. If a hacker in Russia attacks a server in the US hosting data belonging to an Indian citizen, whose laws apply?
- **Anonymity:** Difficult to legally attribute actions to physical individuals.
- **Pace of Technology:** Laws take years to pass; technology evolves in months.

Cyber Laws in India

The Information Technology (IT) Act, 2000:
- The primary law in India dealing with cybercrime and electronic commerce.
- Based on the UNCITRAL Model Law on Electronic Commerce.
Primary Objectives:
1. Give legal recognition to electronic documents and digital signatures.
2. Facilitate e-governance and electronic filing of documents.
3. Provide a legal framework for prosecuting cybercrimes (hacking, data theft, publishing obscene material).

Intellectual Property (IP) in Cyberspace

What is IP?
- Creations of the mind: inventions, literary and artistic works, designs, symbols, names, and images used in commerce.
Types of IP relevant to IT:
- **Patents:** Protects inventions (e.g., a novel software algorithm, though software patentability varies by country).
- **Trademarks:** Protects brand names and logos (e.g., domain name disputes / Cybersquatting).
- **Copyrights:** Protects the expression of ideas, specifically source code and digital media.

The Copyright Act & Digital Piracy

The Indian Copyright Act, 1957 (Amended for Digital):
- Computer programs (source code and object code) are protected as 'literary works'.
- Grants the creator exclusive rights to reproduce, distribute, and adapt the software.
Digital Piracy:
- Unauthorized copying, distribution, or use of copyrighted digital material.
- Includes software cracking, illegal downloading of movies/music.
- **DRM (Digital Rights Management):** Technological measures used to prevent piracy, protected legally under anti-circumvention laws.

Case Study: Domain Name Disputes

Cybersquatting:
- The practice of registering a domain name that matches a well-known trademark with the intent of selling it back to the trademark owner at a premium.
Resolution Mechanisms:
- Traditional Trademark infringement lawsuits.
- **UDRP (Uniform Domain-Name Dispute-Resolution Policy):** Provided by ICANN. A faster, international arbitration process to resolve domain disputes without going to court.
- **INDRP:** The equivalent process for '.in' domains in India.

Compliance vs. Security

Are they the same?
- **No.**
- **Compliance:** Meeting the minimum legally or contractually mandated standards (e.g., ISO 27001, IT Act). Checking the boxes.
- **Security:** The actual technical and operational state of being protected against threats.
The Reality:
- You can be 100% compliant and still be breached.
- However, compliance drives security budgets and establishes a baseline of best practices.

Summary & Next Steps

Summary:
- Information security requires structured management frameworks like ISO 27001 (PDCA cycle).
- Cyber laws (like India's IT Act) provide the legal foundation for prosecuting digital crimes and recognizing digital signatures.
- Intellectual Property, particularly Copyright, protects software and digital media from piracy.
Next Lecture:
- Deep dive into the IT Act 2000.
- We will explore specific provisions, penalties, and recent amendments to the law.

IT Act 2000: Provisions & Amendments

Course: DI03000131 Information Security
Unit 5: Network Security
Lecture 44: IT Act 2000 & Amendments
Focus: Detailed legal provisions governing cyberspace in India.

Agenda

1. Structure of the IT Act, 2000
2. E-Governance and Digital Signatures
3. Section 43: Damage to Computer Systems
4. Section 65: Tampering with Source Code
5. Section 66: Computer Related Offences (Hacking)
6. The 2008 Amendments (ITAA 2008)
7. Section 66A (and its unconstitutionality)
8. Data Protection and Intermediary Liability (Sec 43A & 79)

Structure and Scope of the IT Act

Applicability:
- Applies to the whole of India.
- Extends to offenses committed *outside* India by any person if the act involves a computer system located *in India* (Section 75).
Core Chapters:
- **Chapter II:** Digital/Electronic Signatures.
- **Chapter III:** E-Governance (Legal recognition of e-records).
- **Chapter IX:** Penalties, Compensation, and Adjudication.
- **Chapter XI:** Offences (Cybercrimes carrying imprisonment).

Legalizing the Digital World

Section 3 & 4: Electronic Signatures & Records
- Grants electronic records the same legal status as physical paper documents.
- Grants digital signatures (based on asymmetric cryptography) the same legal validity as handwritten signatures.
Impact:
- Enabled online banking, e-filing of taxes, and electronic contracts.
- Required the establishment of a Controller of Certifying Authorities (CCA) to regulate digital certificates in India.

Section 43: Civil Liability for Damage

Provisions of Sec 43:
Imposes heavy civil penalties (compensation) on anyone who, without permission:
- Accesses or secures access to a computer/network.
- Downloads, copies, or extracts data.
- Introduces any computer virus or contaminant.
- Disrupts or causes disruption of any system (DoS attacks).
Nature:
- This section deals with **compensation** to the victim, not imprisonment (which falls under Chapter XI).

Chapter XI: Criminal Offences

Section 65: Tampering with Source Code
- Concealing, destroying, or altering computer source code required to be kept by law.
- Penalty: Up to 3 years imprisonment or fine up to 2 lakh rupees.
Section 66: Computer Related Offences
- Any act referred to in Section 43 (unauthorized access, virus, etc.) done **dishonestly or fraudulently**.
- This is the primary 'Hacking' section of the IT Act.
- Penalty: Up to 3 years imprisonment or fine up to 5 lakh rupees.

The 2008 Amendments (ITAA 2008)

Why was it needed?
- The original 2000 act didn't cover new technologies like smartphones, or crimes like identity theft and cyber terrorism.
Key Additions:
- **Sec 66C:** Identity Theft (using someone's electronic signature/password).
- **Sec 66D:** Cheating by personation (phishing).
- **Sec 66E:** Violation of privacy (capturing/publishing images of private areas).
- **Sec 66F:** Cyber Terrorism (attacks threatening the unity, integrity, security of India).

The Controversy of Section 66A

The Law (Added in 2008):
- Criminalized sending 'grossly offensive' or 'menacing' information via electronic communication.
- Penalty: Up to 3 years imprisonment.
The Issue:
- Terms like 'grossly offensive' were highly subjective and broadly interpreted by police to arrest individuals for Facebook posts or tweets critical of politicians.
The Resolution (Shreya Singhal v. Union of India, 2015):
- The Supreme Court of India struck down Section 66A entirely, declaring it unconstitutional and a violation of the fundamental right to free speech (Article 19(1)(a)).

Corporate Data Protection: Section 43A

Compensation for failure to protect data:
- Added in the 2008 amendment.
- If a 'Body Corporate' possesses 'sensitive personal data' and fails to implement 'reasonable security practices', leading to wrongful loss/gain.
- They are liable to pay compensation to the affected person.
Significance:
- Forced Indian IT/BPO companies to adopt standards like ISO 27001 to prove they had 'reasonable security practices' to avoid massive civil liability.

Intermediary Liability: Section 79

What is an Intermediary?
- ISPs, Telecom operators, Web hosts, Social Media platforms (Facebook, Twitter).
Safe Harbor Protection:
- Section 79 states that an intermediary shall not be legally liable for any third-party information or data made available by them.
Conditions for Safe Harbor:
- They must act merely as a conduit (not modify the data).
- They must observe 'due diligence' and take down illegal content when ordered by a court or government agency (Notice and Takedown).

Summary & Next Steps

Summary:
- The IT Act 2000 legalizes digital signatures and penalizes unauthorized computer access.
- Section 43 (Civil) and Section 66 (Criminal) form the core anti-hacking laws.
- The 2008 amendments addressed modern threats (Identity theft, Cyber terrorism) and corporate data liability (43A).
- Safe Harbor (Sec 79) protects intermediaries.

Next Lecture:
- Social Issues, Hacking, and Precautions.
- We will look at the ethical dimensions of hacking and personal security precautions.

Cybersecurity: Social Issues, Hacking & Precautions

Course: DI03000131 Information Security
Unit 5: Network Security
Lecture 45: Social issues, Hacking, precautions
Focus: The human element of cybersecurity and practical defenses.

Agenda

1. Social Issues in Cyberspace
2. The Privacy vs. Security Debate
3. Cyberbullying and Digital Harassment
4. The Concept of Hacking
5. Black Hat, White Hat, Grey Hat
6. Ethical Hacking (Penetration Testing)
7. Social Engineering Attacks
8. Fundamental Precautions (Organizational and Personal)

Social Issues in Cyberspace

Digital Divide:
- Inequality in access to technology and secure infrastructure.
- Vulnerable populations are disproportionately targeted by scams.
Misinformation & Deepfakes:
- The weaponization of digital media to manipulate public opinion and democratic processes.
Erosion of Trust:
- Constant data breaches lead to public fatigue and distrust in digital institutions (banks, government portals).

The Privacy vs. Security Debate

The Conflict:
- **Privacy:** Individuals have a fundamental right to keep their data and communications secret.
- **Security (Law Enforcement):** Governments argue they need to intercept communications to prevent terrorism and crime.
The Encryption Backdoor Argument:
- Governments frequently demand 'backdoors' in encryption (like WhatsApp E2EE).
- **The Security Rebuttal:** Mathematically, you cannot build a backdoor that only the 'good guys' can use. A backdoor for law enforcement is a backdoor for hackers.

The Evolution of 'Hacking'

Original Definition:
- 1960s MIT Tech Model Railroad Club: A 'hack' was a clever, creative technical solution or modification.
Modern Public Perception:
- Illegally breaking into computer systems to steal data or cause damage.
The Reality:
- Hacking is simply exploring the limits of a system's capabilities, often finding ways to use it that the designer never intended. It can be used for good or evil.

Types of Hackers

Black Hat (Malicious):
- Hack for personal gain, financial profit, or malicious intent.
- Break laws and exploit systems (e.g., deploying ransomware).
White Hat (Ethical):
- Hack systems to find vulnerabilities *before* the bad guys do.
- Have explicit, written permission from the system owner.
- Goal is to improve security.
Grey Hat:
- Operate without malicious intent but also without permission.
- May illegally scan a company's network and then notify them of the flaw (sometimes asking for a bounty).

Ethical Hacking / Penetration Testing

What is Pen Testing?
- A simulated cyber attack against a computer system to check for exploitable vulnerabilities.
The Process:
1. **Reconnaissance:** Gathering information about the target.
2. **Scanning:** Identifying open ports and services.
3. **Exploitation:** Attempting to gain unauthorized access.
4. **Reporting:** Providing a detailed remediation report to the organization.
Bug Bounties:
- Programs where companies legally pay independent researchers for finding and responsibly disclosing bugs.

The Human Element: Social Engineering

The Concept:
- Hacking the human mind rather than the computer system.
- Manipulating people into giving up confidential information (passwords, physical access).
Common Techniques:
- **Phishing:** Deceptive emails mimicking legitimate institutions.
- **Spear Phishing:** Highly targeted phishing aimed at specific individuals.
- **Pretexting:** Creating a fabricated scenario (e.g., pretending to be IT support over the phone).
- **Tailgating:** Following an authorized person through a secure physical door.

Personal Precautions (Cyber Hygiene)

Authentication:
- Use long, unique passphrases for every account (use a Password Manager).
- **Enable MFA (Multi-Factor Authentication)** everywhere.
Device Security:
- Keep OS and applications aggressively updated (Patching).
- Avoid public, unencrypted Wi-Fi (Use a VPN).
Behavioral:
- Be skeptical of urgent requests (Social Engineering red flags).
- Verify links before clicking (hover to check the actual URL).

Organizational Precautions

Defense in Depth:
- Layered security (Firewalls + IDS/IPS + Endpoint Antivirus).
Principle of Least Privilege:
- Users and programs should only have the bare minimum permissions necessary to do their job.
Security Awareness Training:
- Regularly training employees to recognize phishing and social engineering.
Incident Response Plan:
- Having a documented plan for what to do *when* (not if) a breach occurs.

Unit 5 Summary & Conclusion

In this Unit we covered:
- **Cryptography:** The mathematical foundation (Symmetric, Asymmetric, Hashes).
- **Architecture:** Security Zones, DMZs, VLANs.
- **Network Protocols:** IPsec, VPNs, SSL/TLS.
- **Application Security:** Email vulnerabilities and defenses (PGP, S/MIME, DMARC).
- **Governance:** ISO Standards, IT Act 2000, and Legal frameworks.
- **Human Element:** Social issues, Ethical Hacking, and Defense strategies.