Computer Network [Day - 1]

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Question 1: Network Design and Optimization

Scenario:

You are a network architect for a multinational company that has five regional offices located in New York, London, Tokyo, Dubai, and Sydney. Each office needs to be connected to every other office to ensure real-time data sharing and high availability. However, due to budget constraints, you are allowed to establish a maximum of 7 physical links between the locations.

Each link has:

- A latency (ms)
- A bandwidth (Mbps)
- An associated cost (per km)

You are tasked to design an optimal network topology that fulfills the following:

Requirements:

1. Minimum network latency for critical communications between New York and Tokyo.
2. High fault tolerance — at least two alternative routes should exist between any two offices.
3. Least possible cost without exceeding the 7-link constraint.
4. Avoid bottlenecks — no single node should become a major point of failure.
5. Choose and justify the best topology (from mesh, ring, star, hybrid) that fits the above requirements.

Given Data Table (Sample):

Link	Distance (km)	Latency (ms)	Bandwidth (Mbps)	Cost per km ($)
NY ↔ London	5567	70	1000	3
NY ↔ Tokyo	10800	150	500	4
NY ↔ Dubai	11000	140	700	3.5
NY ↔ Sydney	15900	180	600	5
London ↔ Dubai	5500	60	1000	2.5
Tokyo ↔ Sydney	7800	90	800	4.2
Dubai ↔ Tokyo	8000	95	700	3.8

London ↔ Tokyo	9600	120	900	4
Dubai ↔ Sydney	12000	130	700	4.5

Tasks:

1. Select 7 links that fulfill all requirements.
2. Draw the resulting topology.
3. Justify your choice in terms of topology type and performance.
4. Calculate:
    - Total cost of selected links.
    - Average latency between any two offices.
    - Fault tolerance level (minimum alternate paths).
5. Identify one major drawback of your design and propose a mitigation strategy.

Answer:

Link Selection:

Link	Latency (ms)	Cost ($)
1. NY ↔ Tokyo	150	43,200
2. NY ↔ London	70	16,701
3. London ↔ Dubai	60	13,750
4. Dubai ↔ Tokyo	95	30,400
5. Tokyo ↔ Sydney	90	32,760
6. Dubai ↔ Sydney	130	54,000
7. NY ↔ Dubai	140	38,500

Topology Type:

- NY connects to: Tokyo, London, Dubai
- Tokyo connects to: NY, Sydney, Dubai
- Dubai connects to: NY, London, Tokyo, Sydney
- London connects to: NY, Dubai
- Sydney connects to: Dubai, Tokyo

Average Latency Estimation

- NY–Tokyo: 150 ms
- NY–Sydney: via Dubai = 270 ms
- London–Sydney: via Dubai = 190 ms
- Tokyo–London: via Dubai = 95 + 60 = 155 ms

Then estimates: average ~160–200 ms

Total Cost

Link	Cost ($)
NY ↔ Tokyo	43,200
NY ↔ London	16,701
London ↔ Dubai	13,750
Dubai ↔ Tokyo	30,400
Tokyo ↔ Sydney	32,760
Dubai ↔ Sydney	54,000
NY ↔ Dubai	38,500

Total Cost: 229,311

Fault Tolerance

For any two offices, there are at least two paths:

- NY–Tokyo: Direct + via Dubai or London
- NY–Sydney: via Dubai, via Tokyo
- London–Tokyo: via Dubai, via NY

So:

- Minimum 2 alternate paths per pair → YES

Drawback and Mitigation

Drawback:
High-cost link (e.g., Dubai ↔ Sydney at $54,000) impacts budget.
Mitigation:
Use MPLS or virtual private routing to simulate connectivity while reducing cost on physical infrastructure**.**

Question 2: Wireless and Wired Medium Access Protocol Design Challenge

Scenario:

You are working as a network protocol analyst for a tech company that is designing communication infrastructure for two separate systems:

1. A remote agricultural sensor network in a rural area using wireless communication for environmental data collection (e.g., temperature, soil moisture).
2. An automated factory system using wired Ethernet to connect robots, conveyor belts, and control units with real-time precision.

Each network faces unique challenges regarding collisions, medium access, bandwidth constraints, and efficiency.

Objectives:

Your task is to:

1. Select the most appropriate MAC (Medium Access Control) protocol from the following for each network:
   - Pure ALOHA
   - Slotted ALOHA
   - CSMA
   - CSMA/CD
   - CSMA/CA

Given Parameters:

- Agricultural sensors send small packets every 5–10 seconds and are powered by battery-operated IoT devices.
- The factory system requires real-time communication with 1 ms latency tolerance and minimal jitter.

Questions:

1. Which MAC protocol would you assign to each network and why?
2. What would be the expected efficiency of the chosen protocols under high and low load conditions?
3. How does each protocol manage collisions, and how does this affect energy consumption or latency?
4. Simulate or draw packet transmission timelines showing collision or backoff behavior for each protocol.
5. What trade-offs exist between complexity, reliability, and energy usage in your choices?
6. What changes would you make if the agricultural network became denser (i.e., more sensors within range)?
7. Suggest one improvement or hybrid approach that combines the strengths of multiple MAC protocols for any of the scenarios.

Answer:

MAC Protocol Assignment and Justification

System	Selected MAC Protocol	Justification
Agricultural Sensor Network	CSMA/CA (Carrier Sense Multiple Access with Collision Avoidance)	- Reduces collision risk in wireless medium - Conserves battery by avoiding unnecessary retransmissions - Fits low-data, energy-constrained use
Automated Factory System	CSMA/CD (Carrier Sense Multiple Access with Collision Detection) or ideally Switched Ethernet with Full Duplex (no MAC contention)	- Low latency in a controlled wired environment - Collision detection ensures real-time delivery - Switches avoid collision entirely

Efficiency Under Different Load Conditions

Protocol	Low Load Efficiency	High Load Efficiency
CSMA/CA	~70–80%	Drops to ~30–40% due to backoff delays and collisions
CSMA/CD	~90% (with low collisions)	Can degrade to ~40–50% under heavy traffic due to collisions and retransmissions

Collision Management and Impact

Protocol	Collision Management	Energy/Latency Impact
CSMA/CA	Listens before transmitting; uses **random backoff timers** if the medium is busy. Avoids collisions.	**Energy-efficient** but adds **delay due to backoff**, especially with dense nodes
CSMA/CD	Detects collision during transmission and immediately stops; retransmits after random backoff	Higher **energy waste** during collision but **low latency** if collisions are rare

Packet Transmission Timeline Diagrams

CSMA/CA (Wireless Sensor):

```
Time →
Device A: |Listen|     |Send|----------------|
Device B:     |Listen|     |Backoff|---|Send|
Device C:        |Listen|Backoff|--------|Send|
```

- Devices listen first.
- If busy, they back off randomly before retrying.

CSMA/CD (Factory Ethernet):
Time →
Device A: |Sense|Send|--X(Collision)--|Backoff|--Send|
Device B: |Sense|Send|--X(Collision)--|Backoff|---Send|

- Collision is detected during transmission.
- Retransmit after random time.

Trade-offs: Complexity vs Reliability vs Energy

Protocol	Complexity	Reliability	Energy Usage
CSMA/CA	Medium	High (for sparse networks)	Energy Efficient
CSMA/CD	Low–Medium	High (in wired setup)	Wastes energy during collisions
Switched Ethernet	Low complexity (no collisions)	Very high	Energy efficient

What If Agricultural Network Becomes Denser?

If more sensors are added:

- CSMA/CA becomes **less efficient** due to more frequent collisions and backoffs.
- Leads to **higher latency** and **increased energy consumption**.

Improvement Options:

- **Use TDMA** (Time Division Multiple Access): Assign time slots per sensor
- **Cluster-based MAC**: Elect cluster heads to coordinate communication
- **Duty Cycling**: Schedule node wake/sleep to avoid collisions

Suggested Hybrid MAC Improvement

For Wireless Sensor Network: CSMA/CA + TDMA Hybrid

- Use **CSMA/CA** in low-density, normal operation.
- Switch to **TDMA scheduling** when node density crosses threshold.

Advantages:

- **Low energy use** in sparse environments
- **Collision-free slots** during peak traffic
- **Adaptive behavior** improves both latency and battery life

Example Use Case:

- Sensors use CSMA/CA by default
- When traffic spikes (e.g., during weather anomaly), cluster head assigns TDMA slots