A physical layer perspective on WANs (Part 2)

Guest lecture: Rachee Singh

CS4450: Introduction to Computer Networks
Fiber (glass) is an efficient (low loss) medium for transmitting signals.
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Revise: signal modulation
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Revise: signal modulation

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1. Four symbols
Revise: signal modulation

1. Quadrature phase shift keying (QPSK)
   1. Four symbols
   2. 2 bits per symbol

Transmitted Symbols:
- 10
- 00
- 11
- 01
Signal modulation

BPSK
1 bit per symbol
Signal modulation

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1 bit per symbol

QPSK
2 bits per symbol
Signal modulation

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16-QAM
4 bits per symbol
Signal modulation

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1 bit per symbol

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16-QAM
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Packing more bits per symbol with different modulation formats
Revise: signal modulation
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Symbol rate or baud rate:
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1. Decides number of symbols per second
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Baud rate = 4, N = 2
Hartley’s Law

\[ R = f_p \log_2 M \]

Where,
\[ R \] = data rate, bit rate in bits/second
\[ f_p \] = symbol rate or baud rate in symbols/second
\[ M \] = number of levels in a given symbol

Constellation Diagram of 16-QAM
Hartley’s Law

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Exercise: If the baud rate of the transmission is 50 Gbaud, what is the data rate of a wavelength modulated with 16-QAM modulation?
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*Answer* = \( 50 \times \log_2 16 = 200 \text{ Gbps} \)
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Long-haul network connectivity: channel noise
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Long-haul network connectivity: channel noise

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   • \( 10\log_{10} \) of a quantity makes the unit decibels
Long-haul network connectivity: Shannon capacity

Shannon–Hartley Law states the max. rate at which information can be transmitted over a noisy channel

\[ R = B \cdot \log_2(1 + SNR) \]

Where,

- \( R \) = data rate, bit rate in bits/second
- \( B \) = bandwidth in Hz of the channel
- \( SNR \) = signal to noise ratio (measures signal quality)

\[ R \approx 0.332 \cdot B \cdot SNR \]
Long-haul network connectivity: Shannon capacity

1. Shannon–Hartley Law
   1. \[ R \approx 0.332 \cdot B \cdot SNR \]

2. Fundamental limit on the capacity of a channel

3. Cannot pack more bits by
   1. Increasing modulation format
   2. Increasing symbol rate
Long-haul network connectivity: signal quality
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1. Measure signal quality on a fiber over time
Long-haul network connectivity: signal quality

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Signal quality of a wavelength on fiber in North America
Long-haul network connectivity: Shannon capacity

Exercise: What is the maximum data rate that could be supported by this wavelength at the time shown by the cross if the bandwidth of the wavelength is 50GHz?

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Long-haul network connectivity: optical fiber

Under-sea fiber

Terrestrial fiber
Long-haul network connectivity: optical fiber

Under-sea fiber

Terrestrial fiber
WANs need high infrastructure investment

1. High capital expense (billions of $)
   1. Hardware costs for switches
   2. O(100,000) miles fiber
2. High operational expenses (millions of $ annually)
3. Crucial to operate efficient WANs
Using WANs efficiently

• Allocate traffic demands in the WAN to:
  • achieve optimal network flow
  • minimal traffic latency
  • fairness across traffic classes
  • …
Using WANs efficiently

Network Topology

Demands

A → D = 100G
C → D = 100G
Using WANs efficiently

Network Topology

Demands

\[ AD = 100G \]
\[ CD = 100G \]
Using WANs efficiently

What does this remind me of from your algorithms class?
Using WANs efficiently

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Max flow algorithms:
Ford Fulkerson, Edmond’s Karp etc.
Using WANs efficiently: traffic engineering

• Complex Objectives
  • achieve optimal network *flow*
  • minimal traffic *latency*
  • *fairness* across traffic classes
  • ...

• Traffic optimization over WANs to achieve different goals is called *traffic engineering*
Traffic engineering optimization
Traffic engineering optimization

Inputs

Optimization
Objective
Traffic engineering optimization

Inputs

Network Topology

Optimization Objective
Traffic engineering optimization

*Inputs*

- Network Topology
- Demand Matrix

Optimization Objective
Traffic engineering optimization

**Inputs**

- Network Topology
- Demand Matrix
- Network Paths

Optimization Objective
Traffic engineering optimization

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Optimization Objective
Traffic engineering optimization

**Inputs**
- Network Topology
- Demand Matrix
- Network Paths

**Outputs**
- Flow Allocations

- Optimization Objective
Traffic engineering optimization

**Inputs**
- Network Topology
- Demand Matrix
- Network Paths

**Optimization Objective**

**Outputs**
- Flow Allocations

**Constraints**
Traffic engineering optimization

**Inputs**
- Network Topology
- Demand Matrix
- Network Paths

**Constraints**
- Demand Constraints

**Outputs**
- Flow Allocations

**Optimization Objective**

*For the full understanding of the text, please see the PDF or document.*
Traffic engineering optimization

Inputs
- Network Topology
- Demand Matrix
- Network Paths

Constraints
- Demand Constraints
- Capacity Constraints

Optimization Objective

Outputs
- Flow Allocations
Traffic engineering optimization

Inputs

- Network Topology
- Demand Matrix
- Network Paths

Outputs

- Flow Allocations

Constraints

- Demand Constraints
- Capacity Constraints
- Flow Conservation
Traffic engineering optimization

**Inputs**
- Network Topology
- Demand Matrix
- Network Paths

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- Capacity Constraints
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**Optimization Objective**

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Long-haul network connectivity: optical fiber

Under-sea fiber

Terrestrial fiber