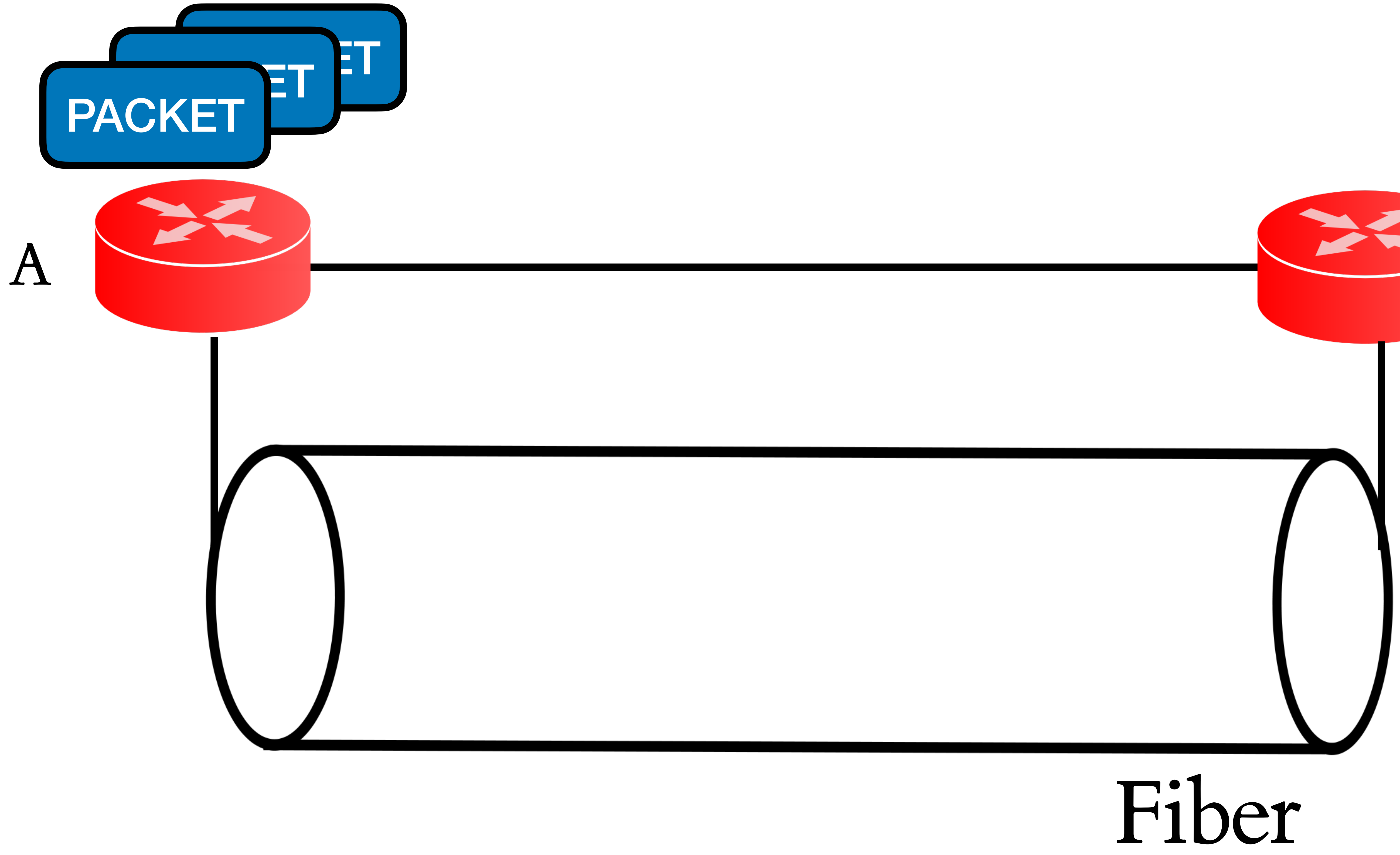
A physical layer perspective on WANs (Part 2)

Guest lecture: Rachee Singh

Microsoft → Cornell University Founded A.D. 1865 | Cornell Bowers CIS Computer Science

CS4450: Introduction to Computer Networks

Revise: optical fiber



Fiber (glass) is an efficient (low loss) medium for transmitting signals.

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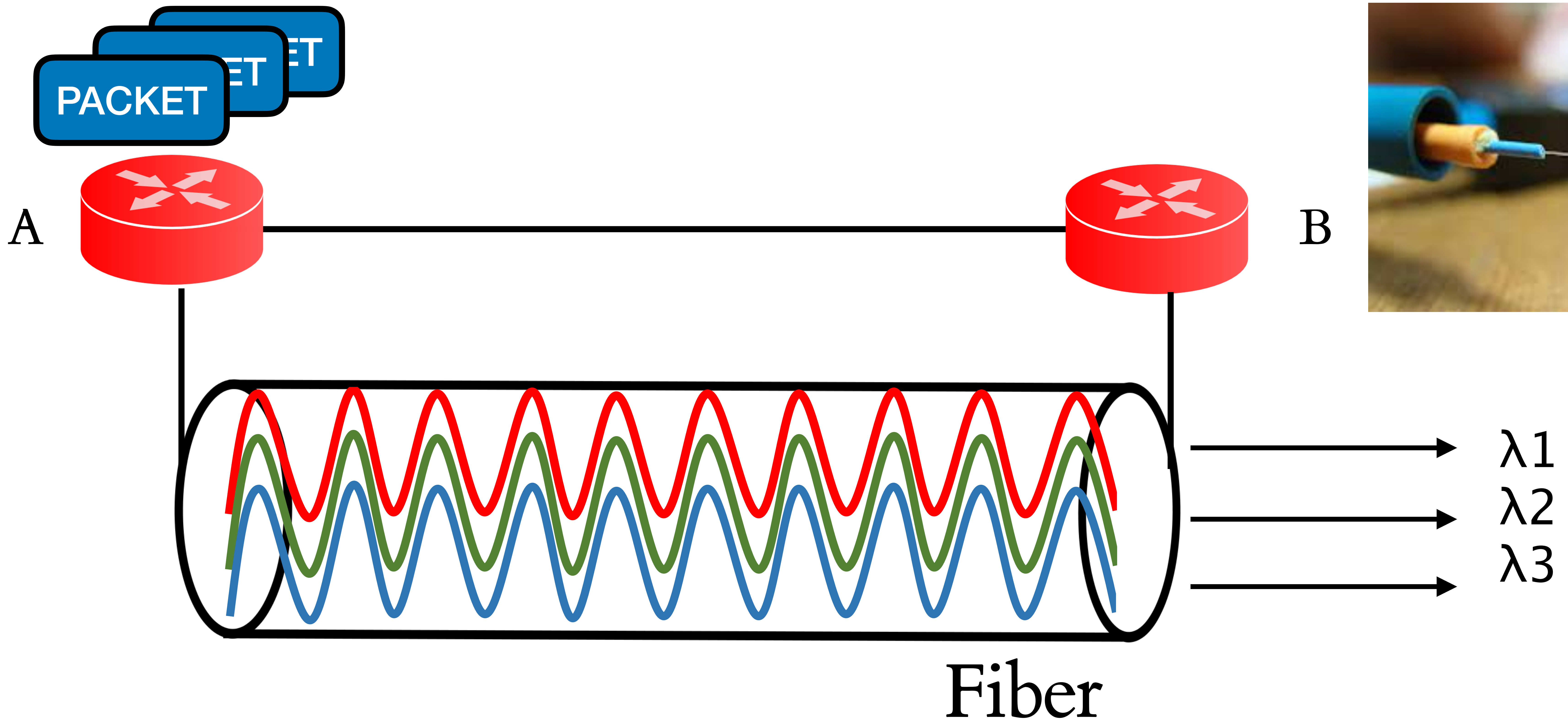

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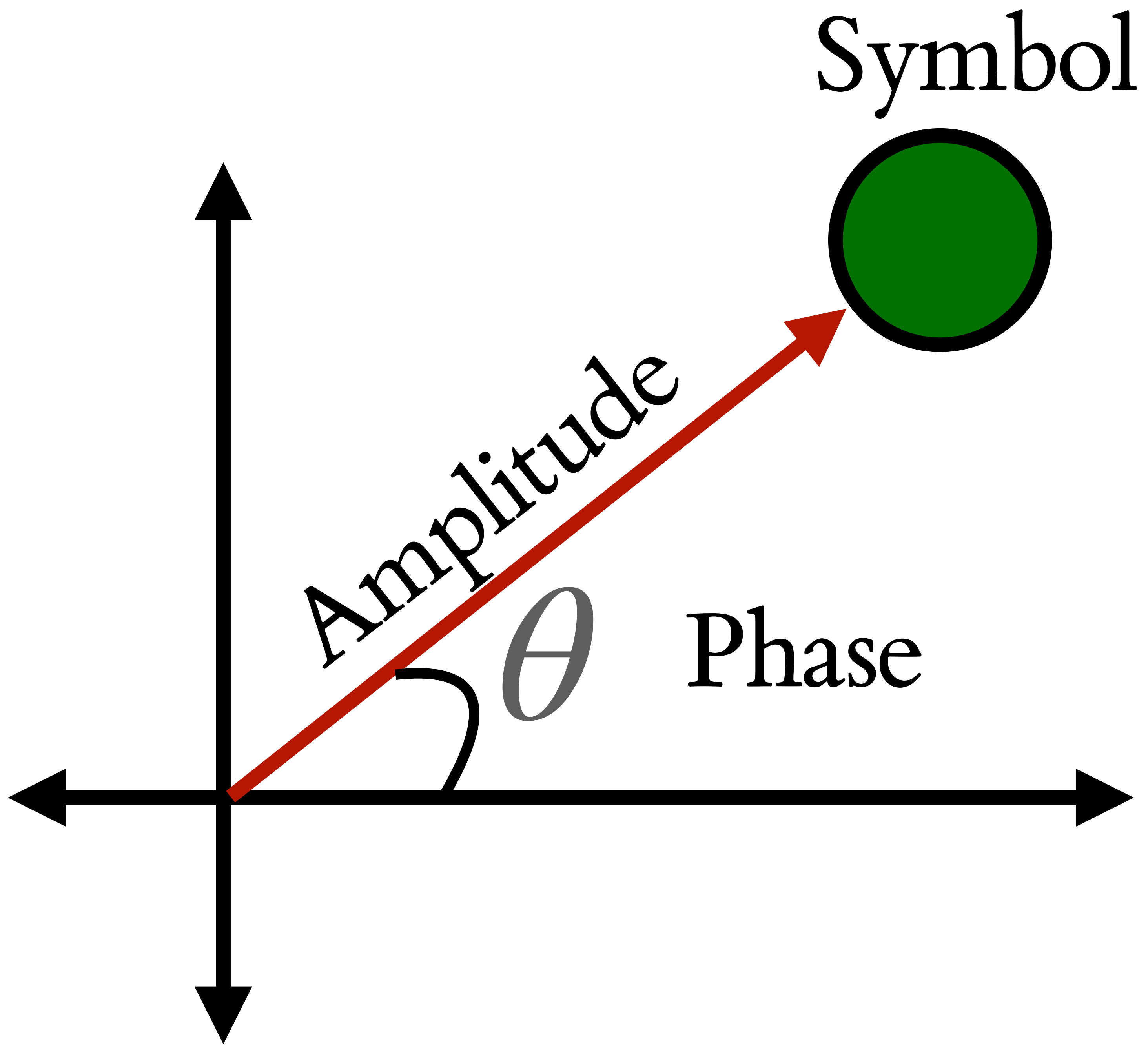

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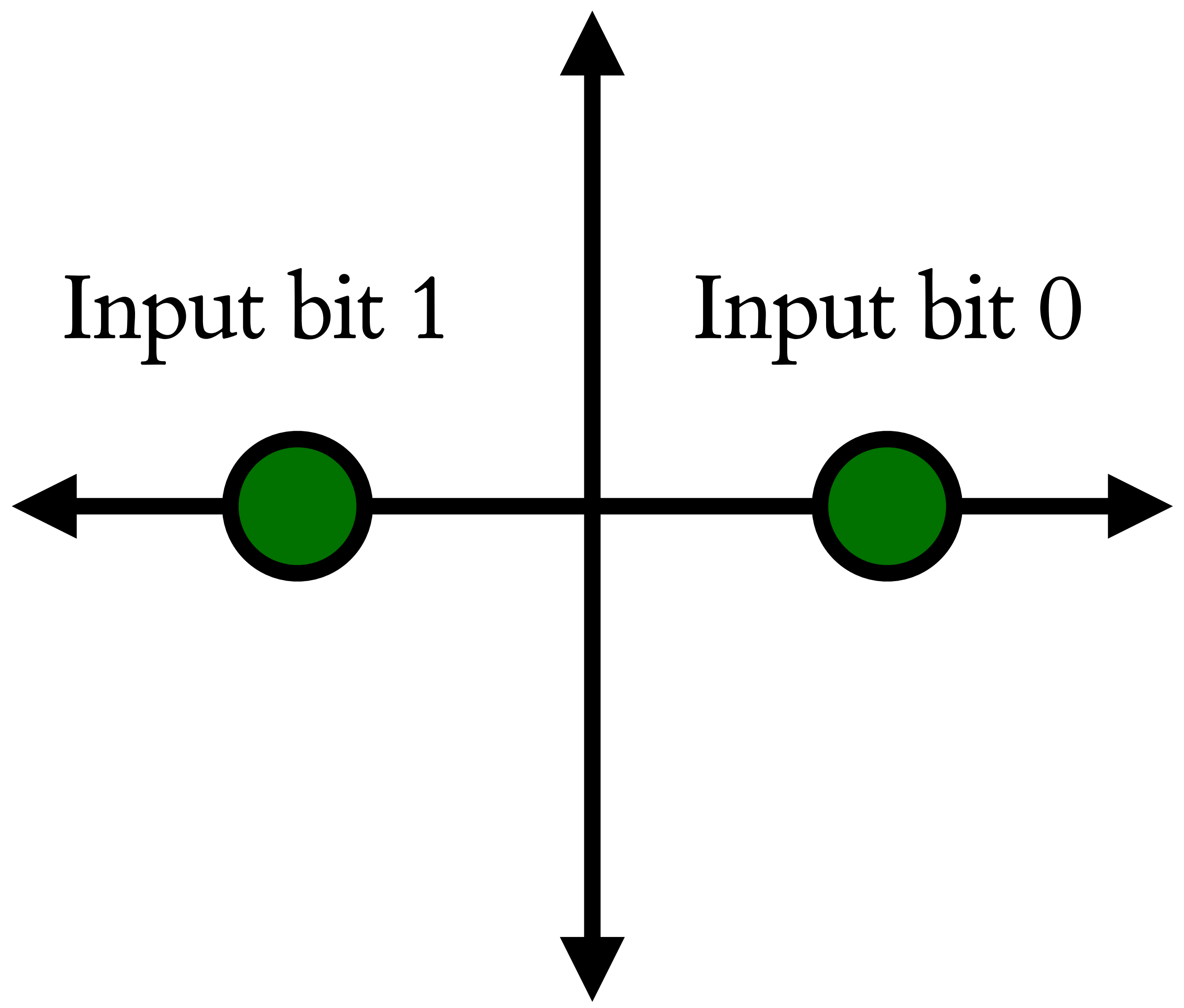

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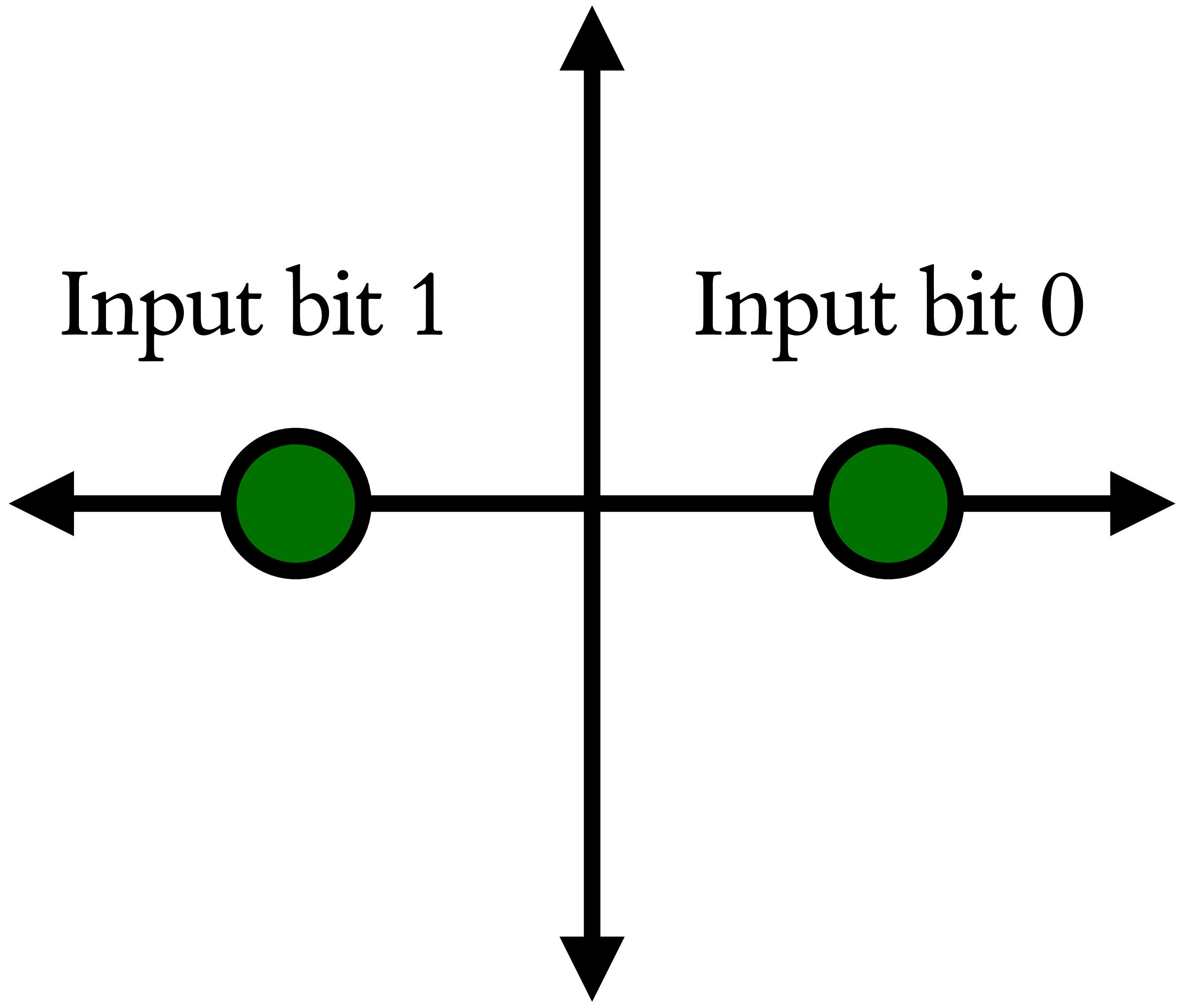

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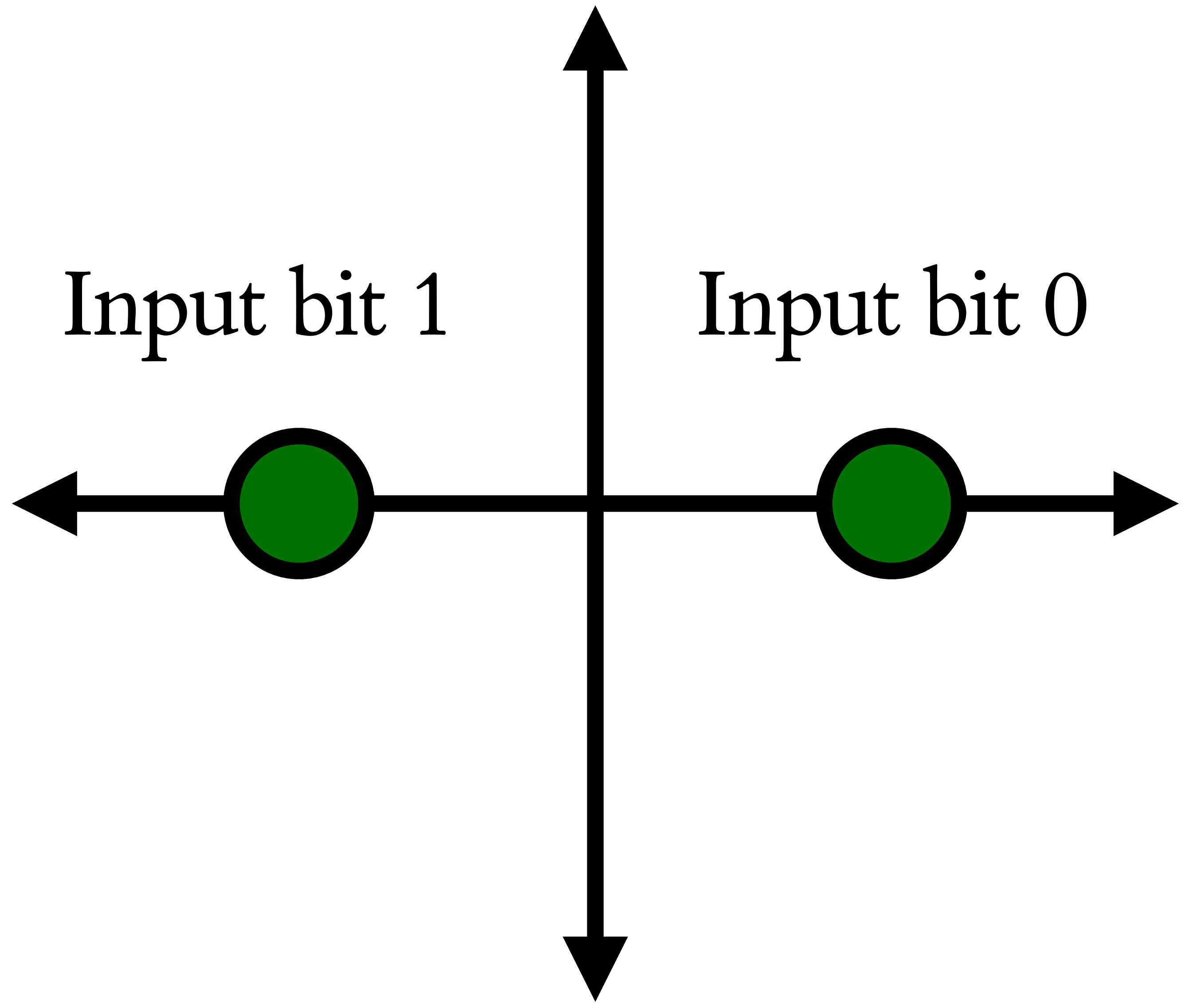

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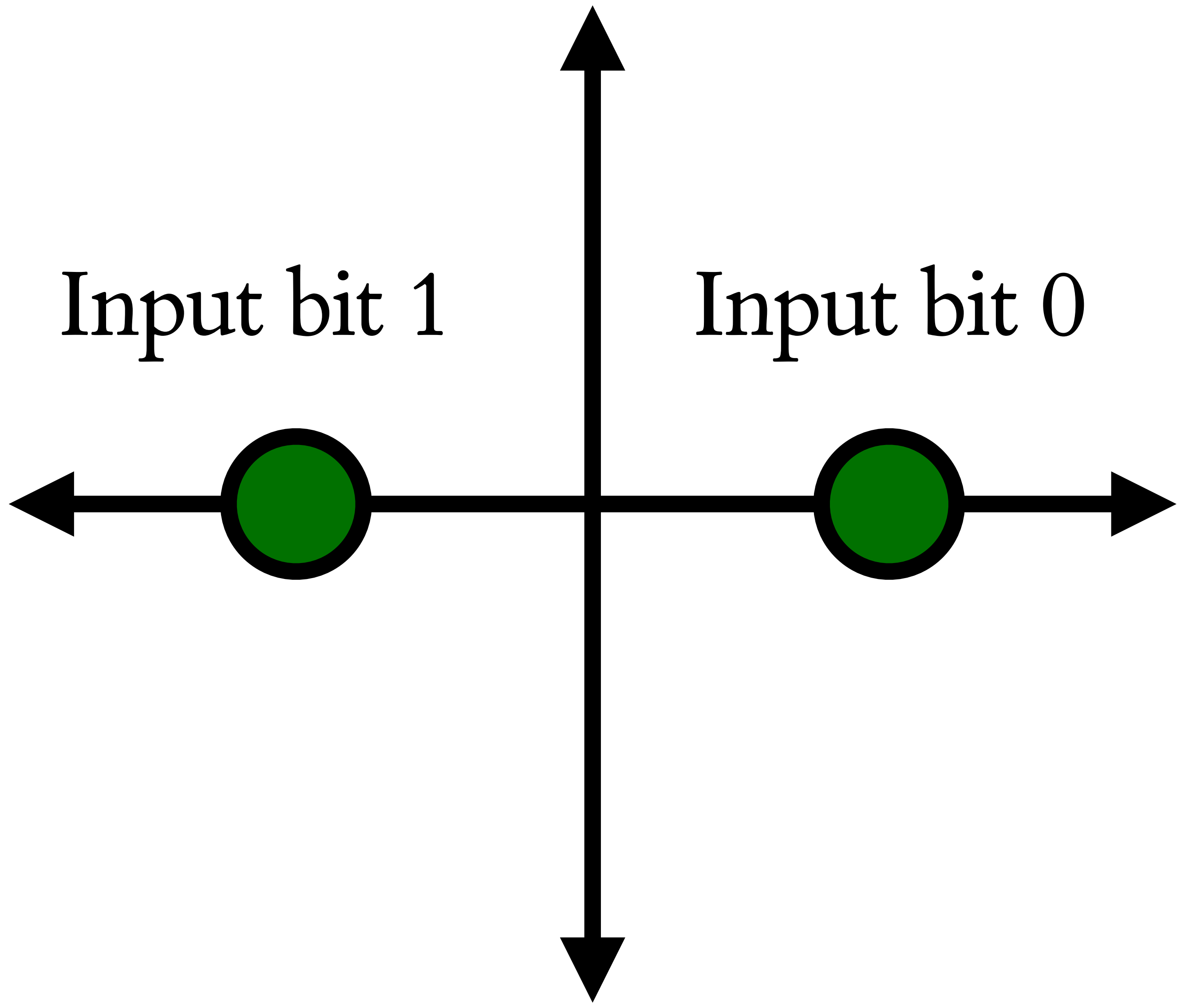

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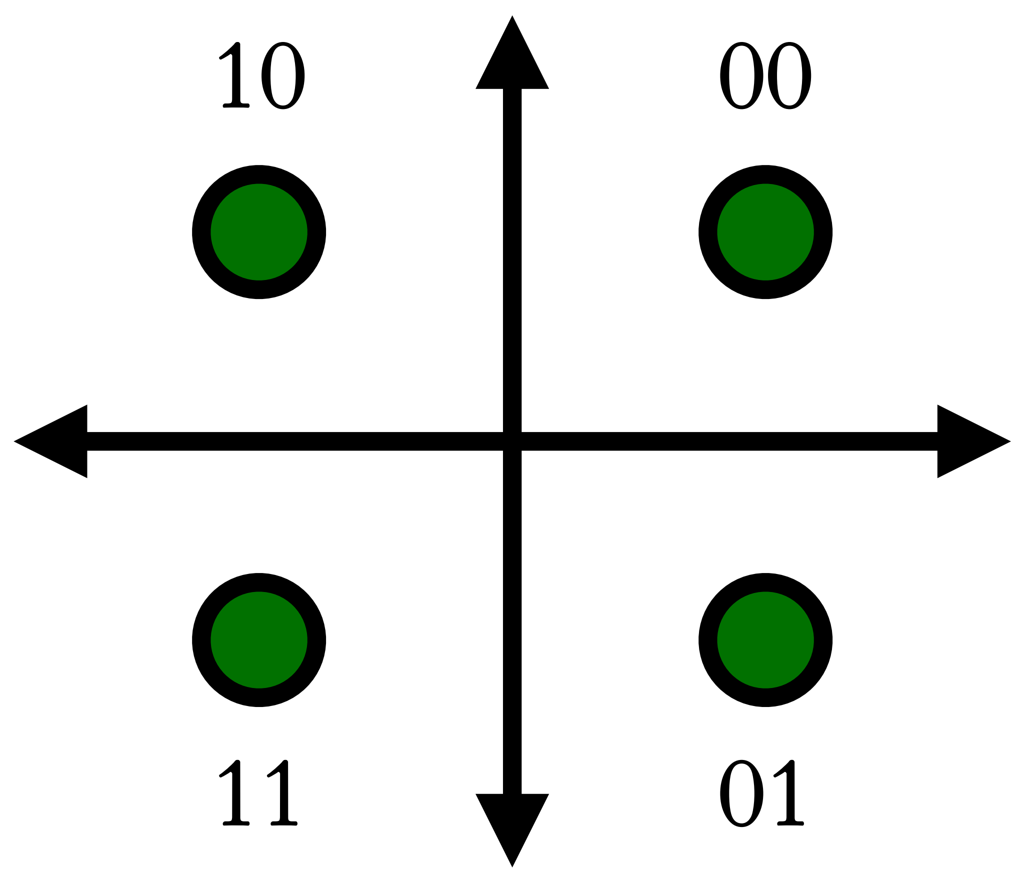
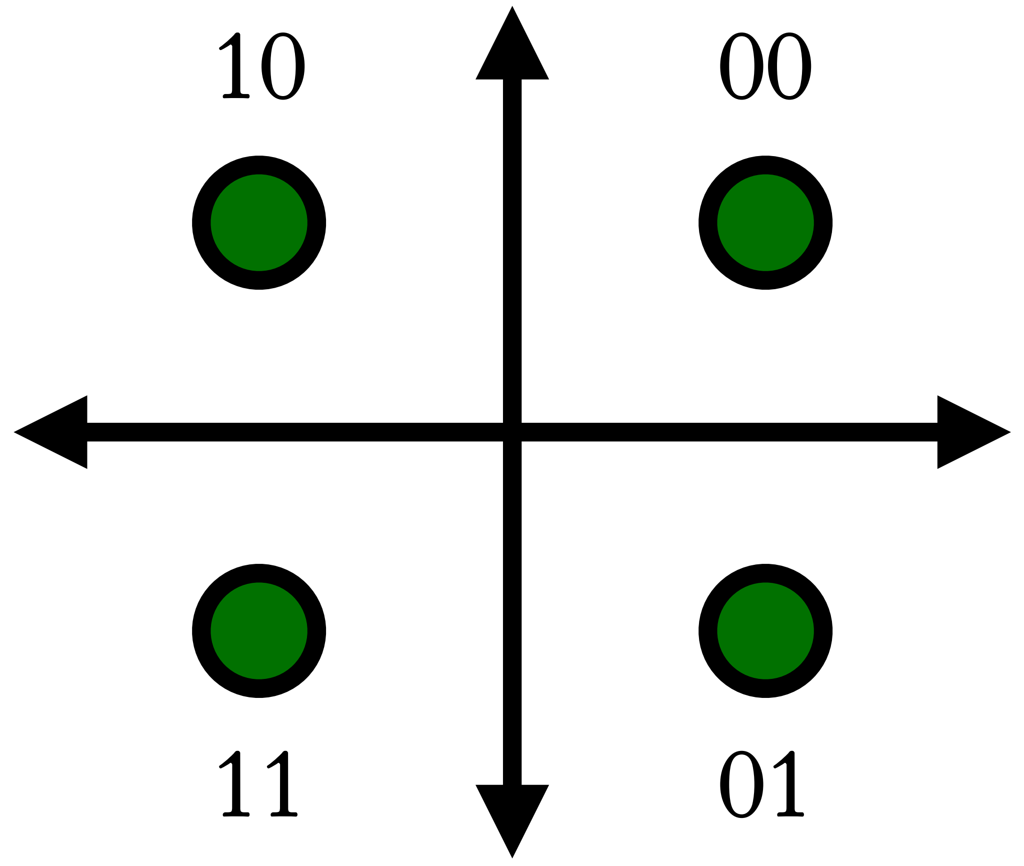


Transmitted Symbols

Revise: signal modulation

1. Quadrature phase shift keying (QPSK)



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Revise: signal modulation

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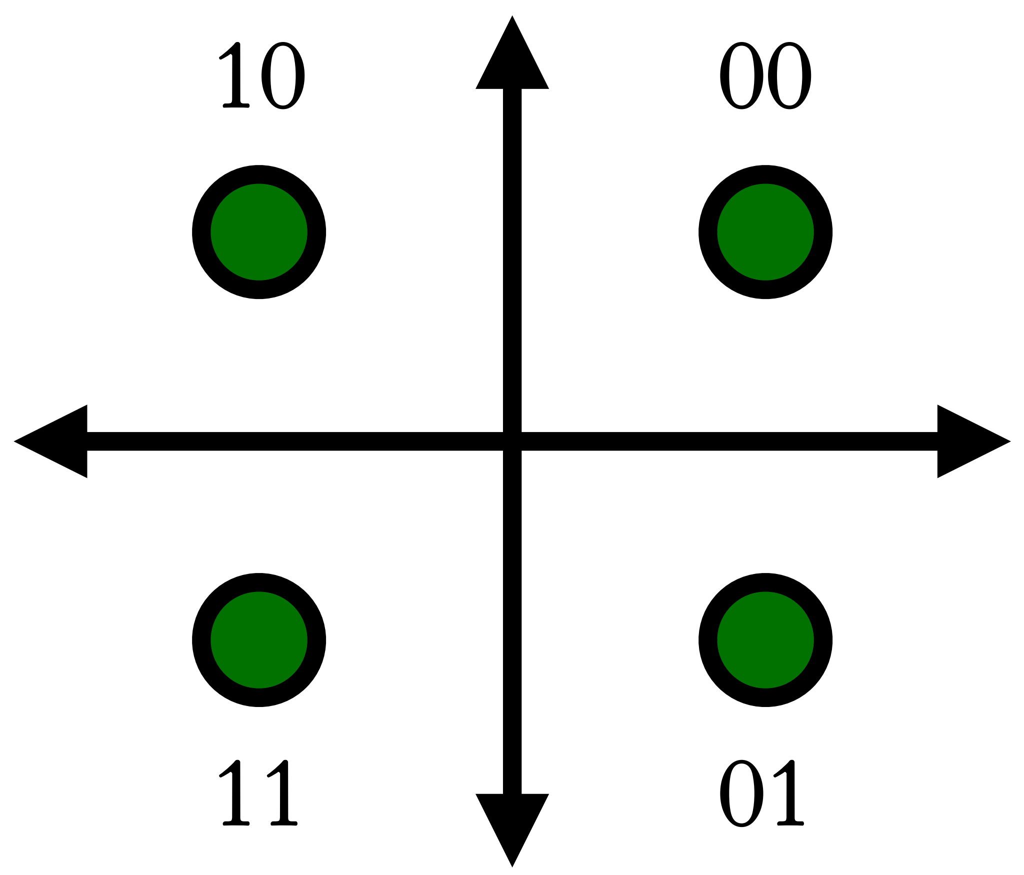
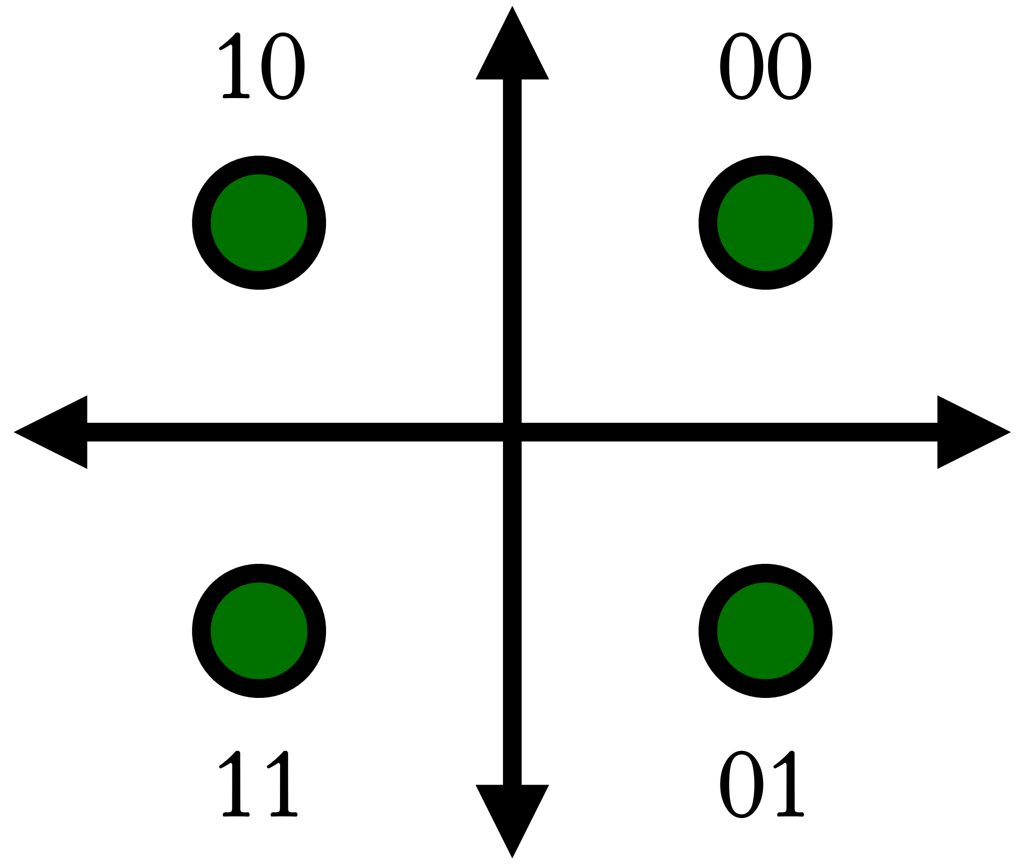


Transmitted Symbols

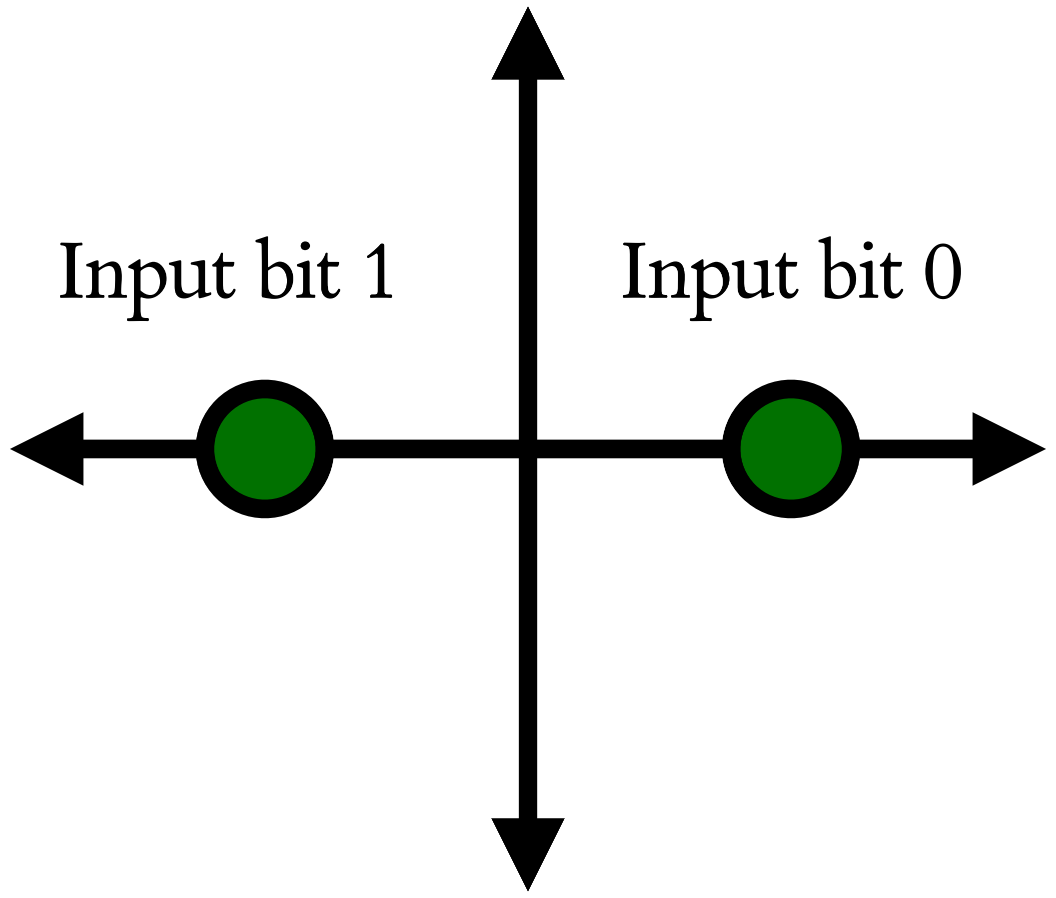
Revise: signal modulation

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



Transmitted Symbols

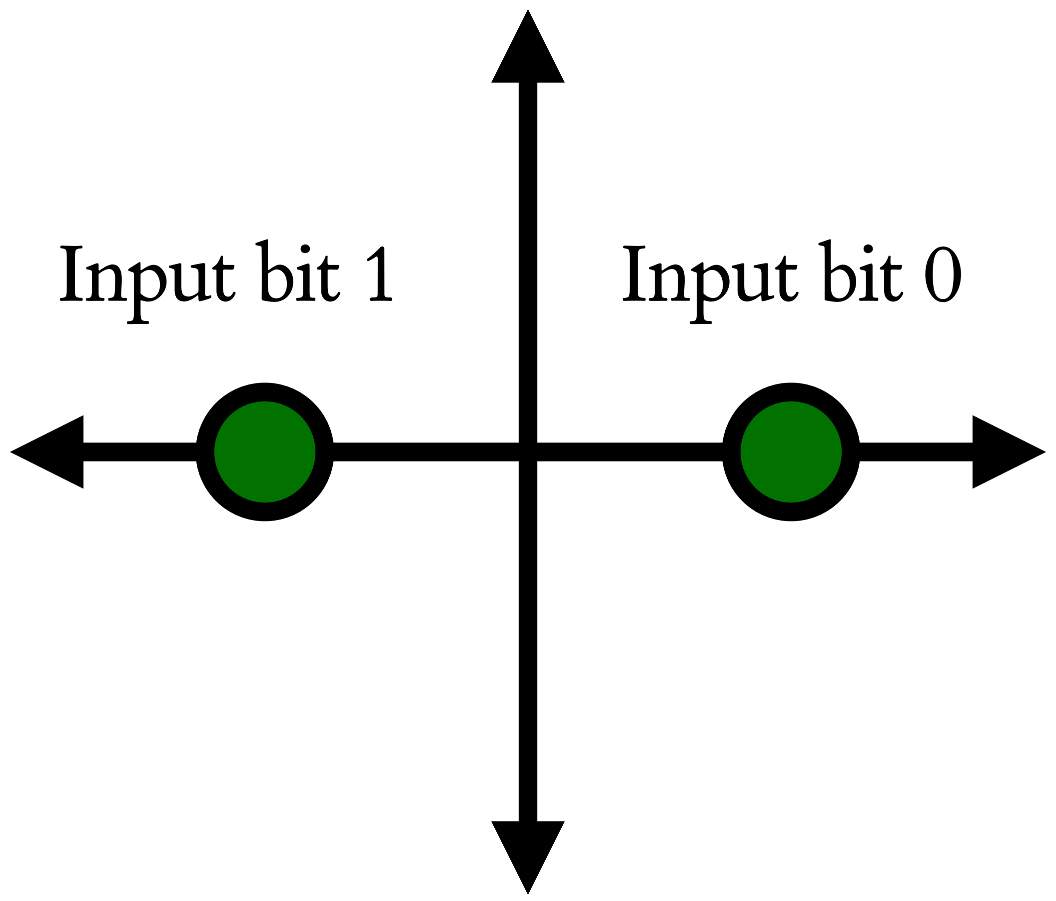
Signal modulation



BPSK

1 bit per symbol

Signal modulation



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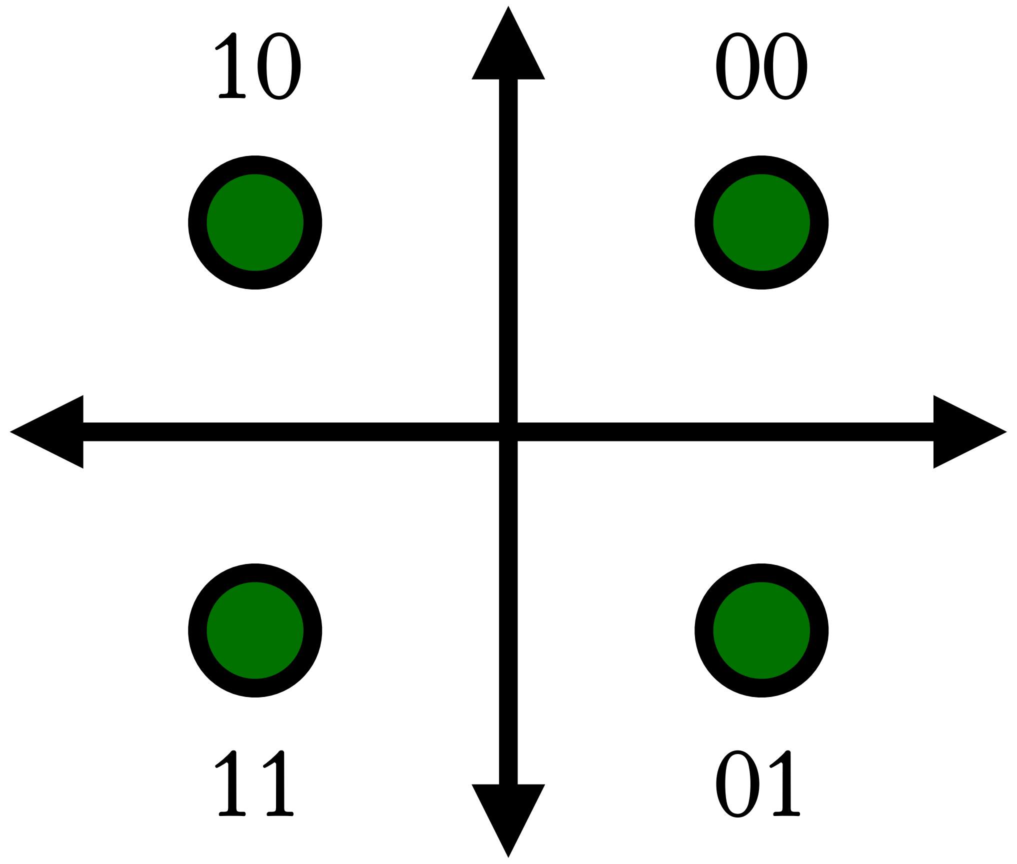

QPSK

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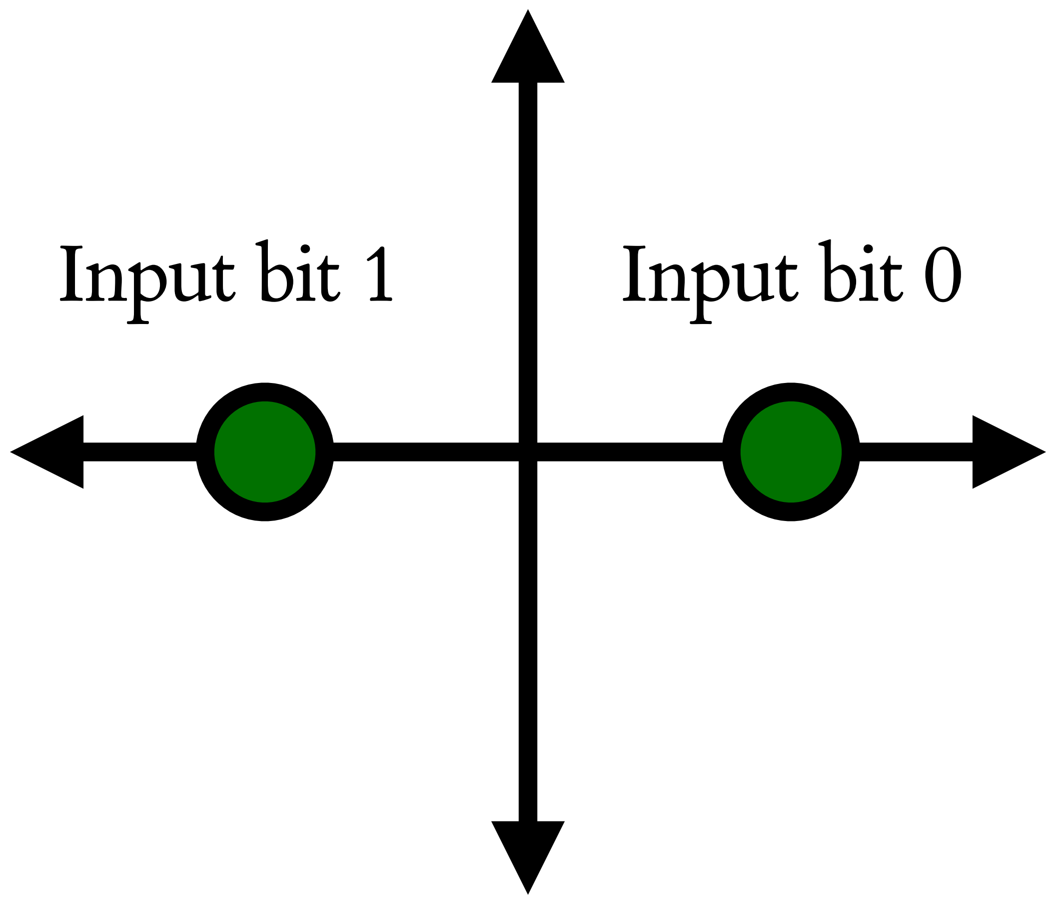
Signal modulation



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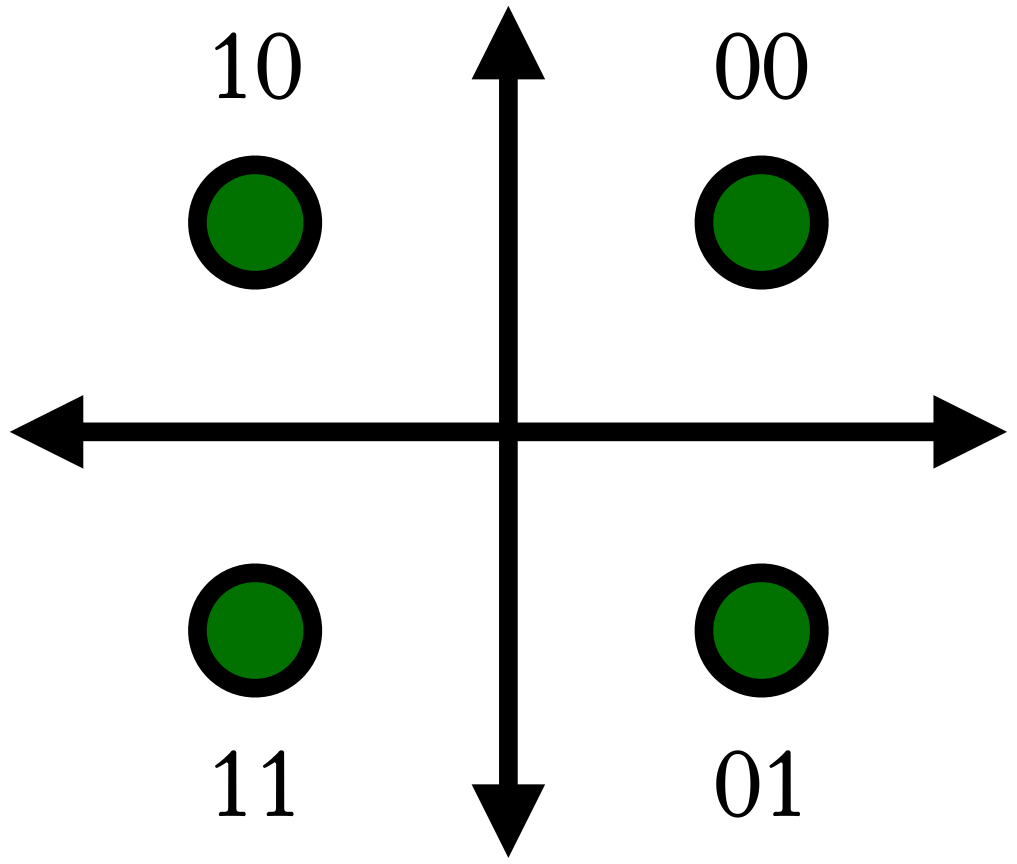

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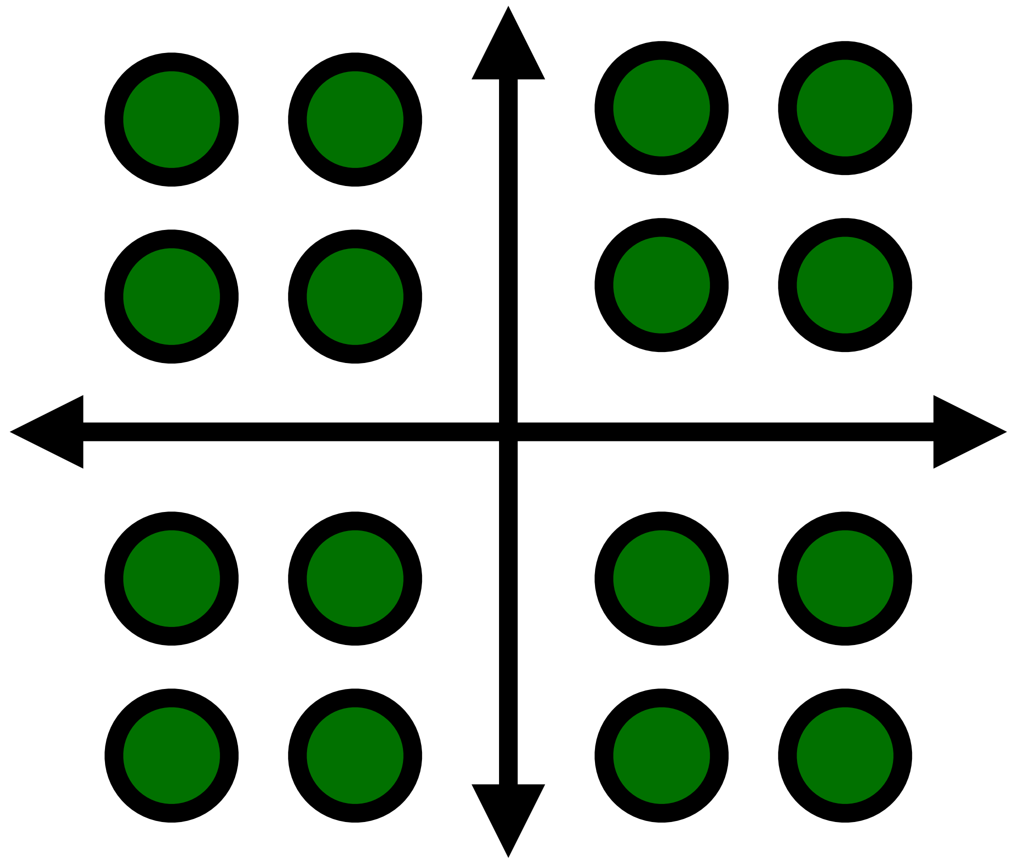
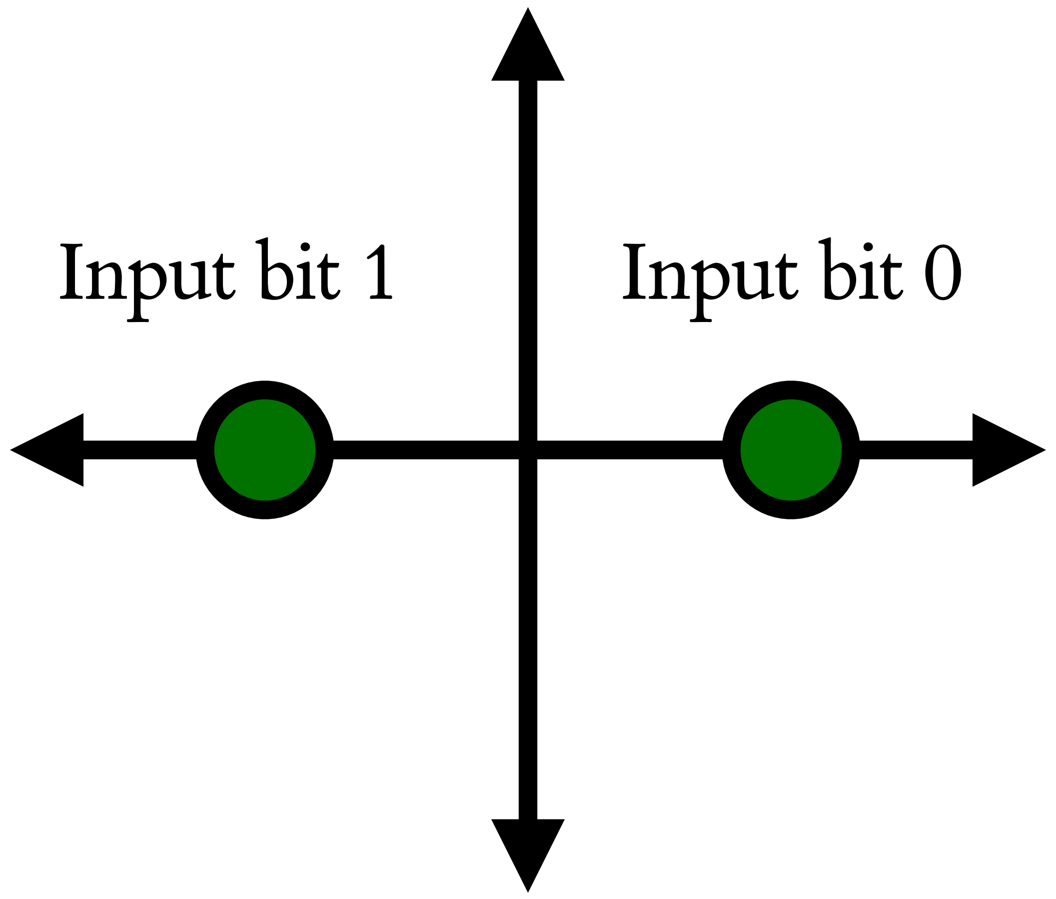


16-QAM

4 bits per symbol

Signal modulation



BPSK

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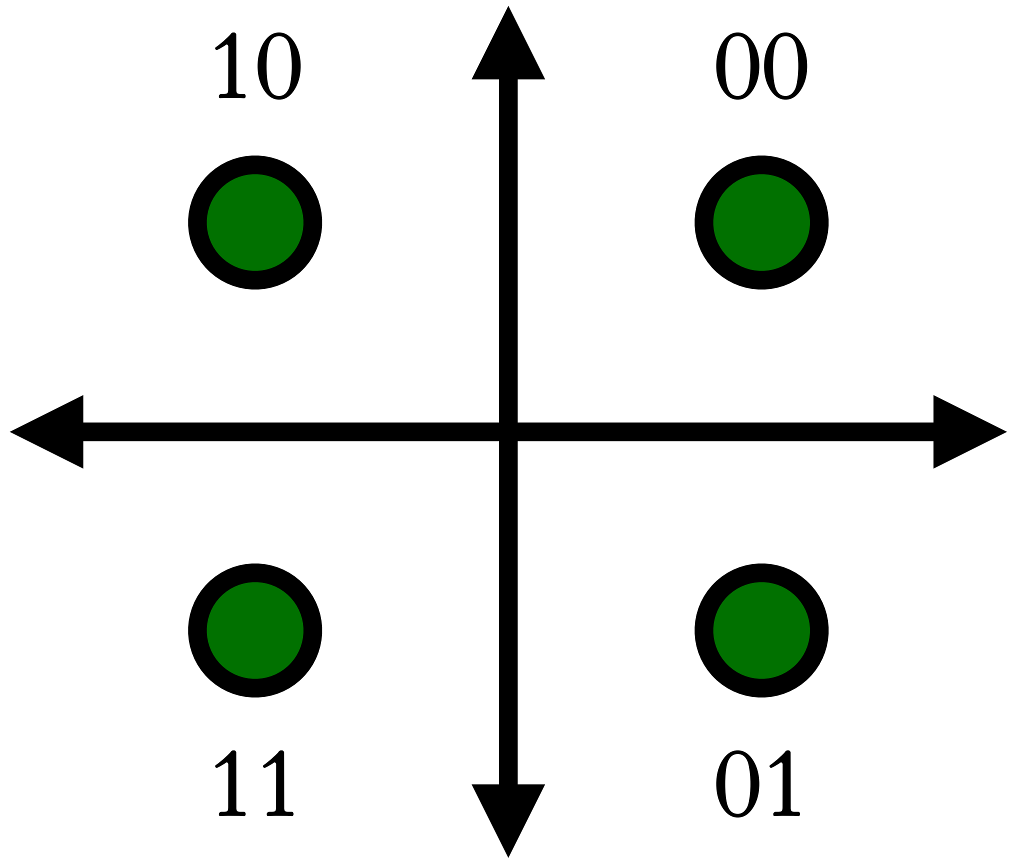
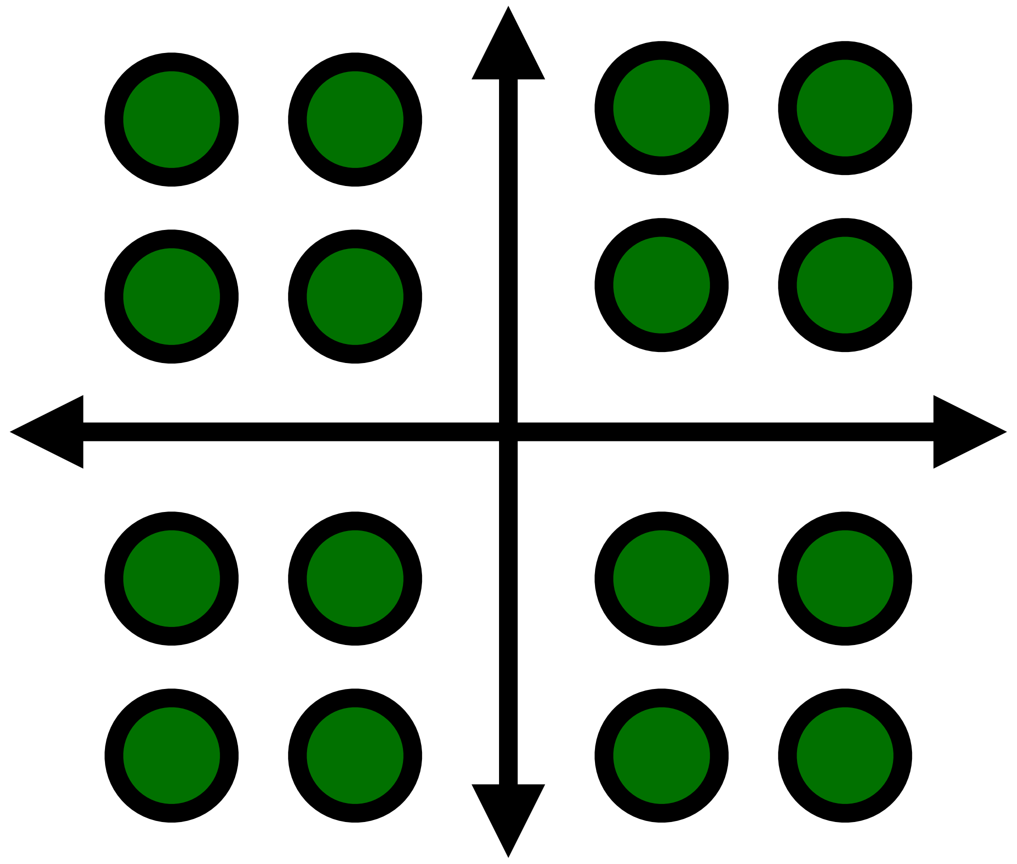


QPSK

2 bits per symbol



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Packing more bits per symbol with different modulation formats

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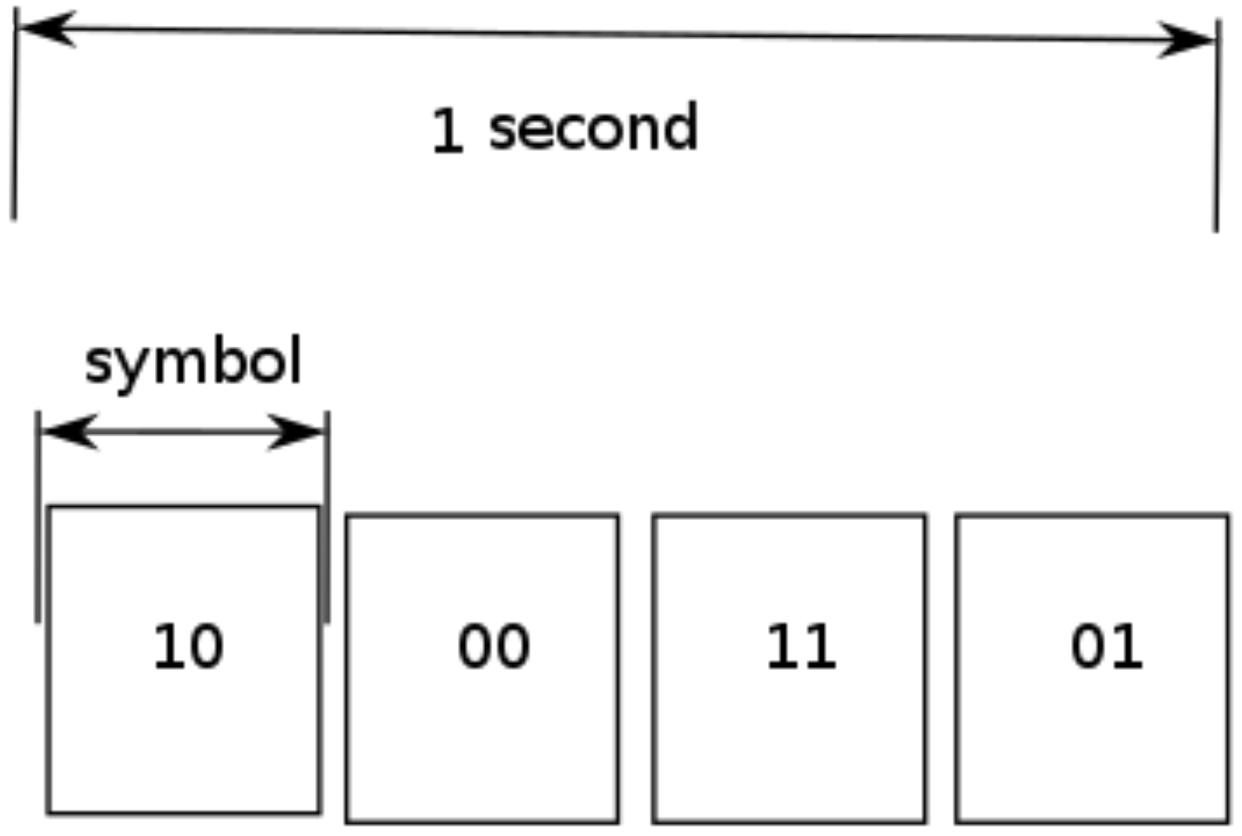


Baud rate = 4, N = 2

Revise: signal modulation

Hartley's Law

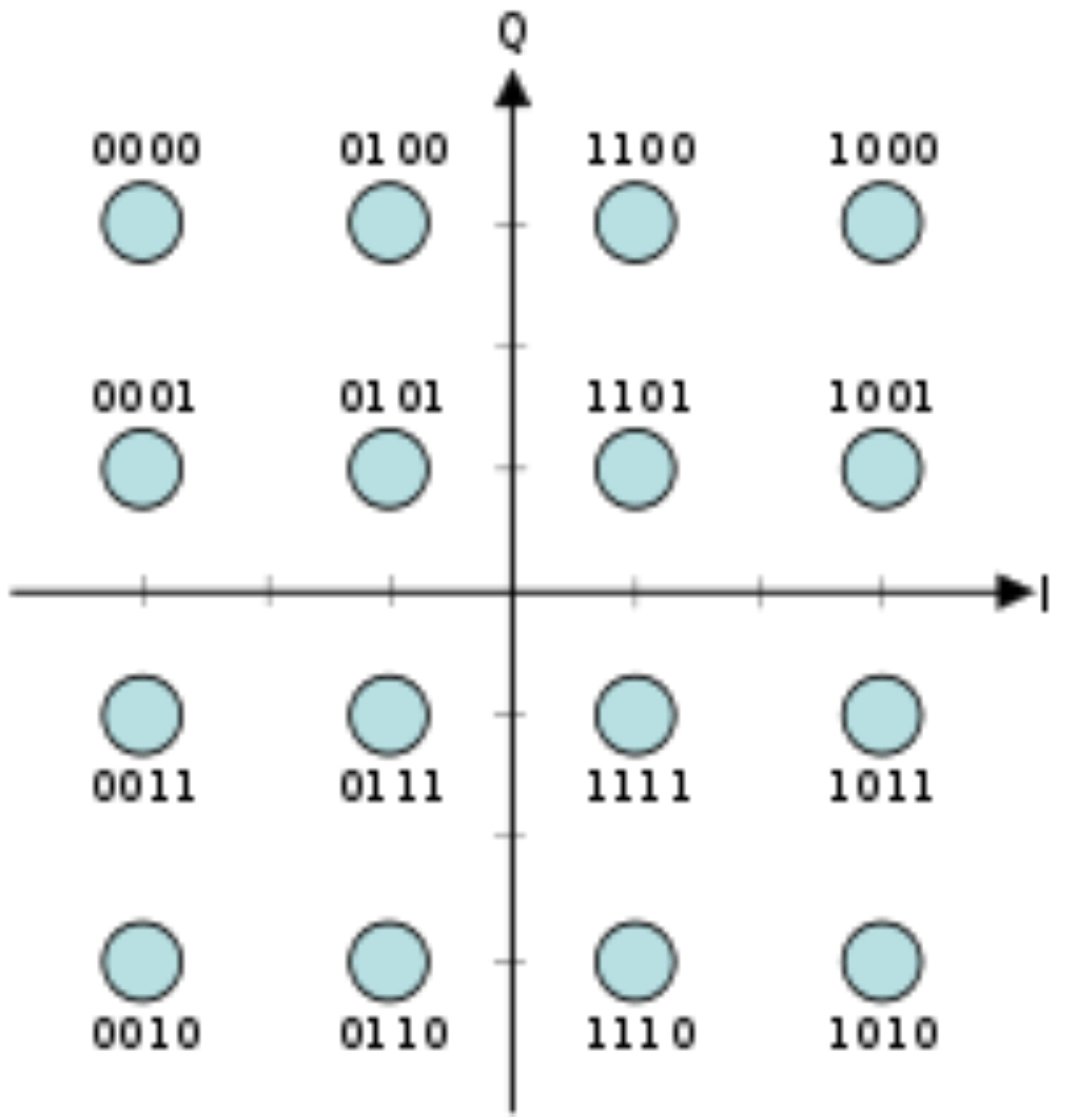
$R = f_p log_2 M$

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

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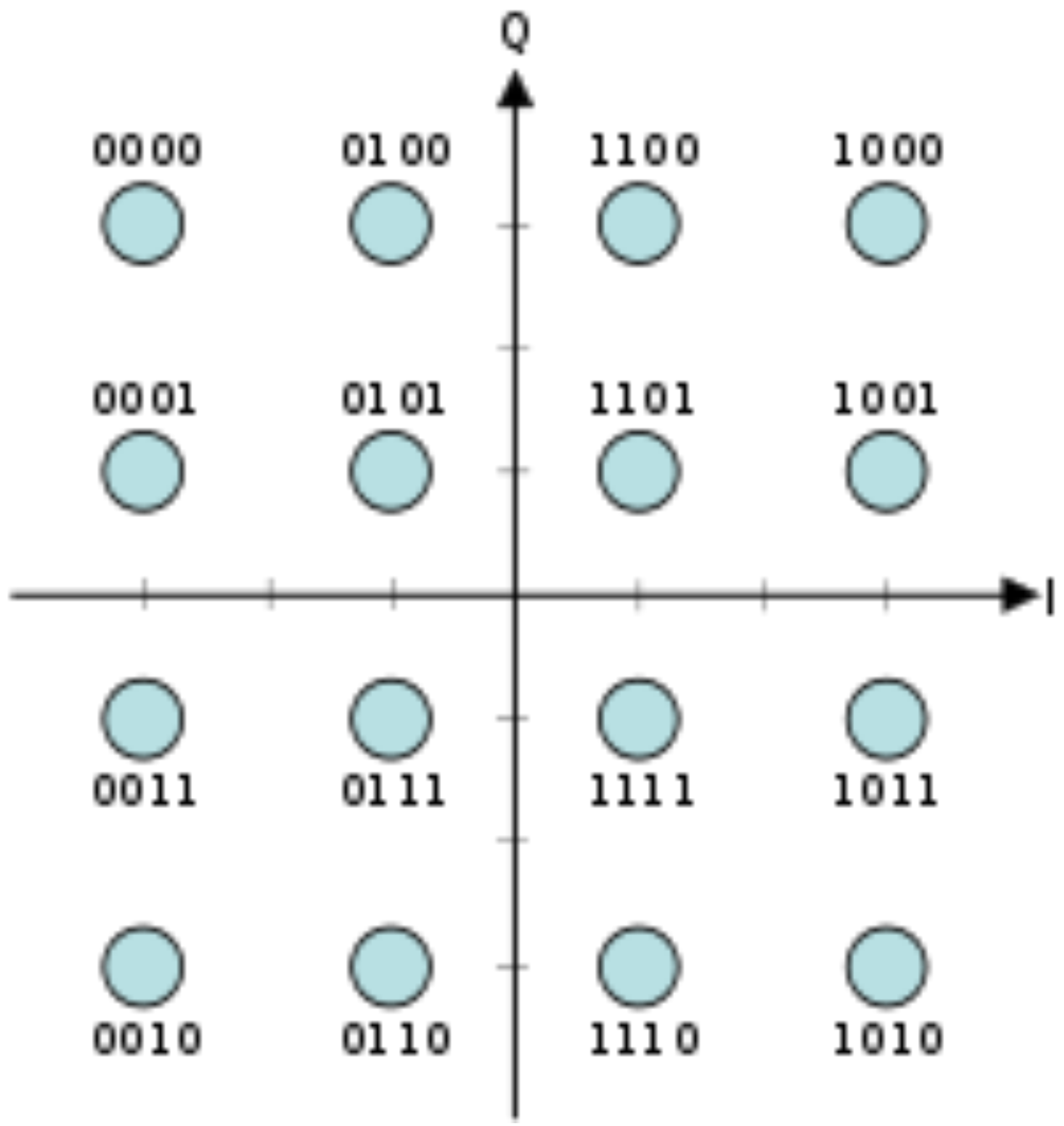

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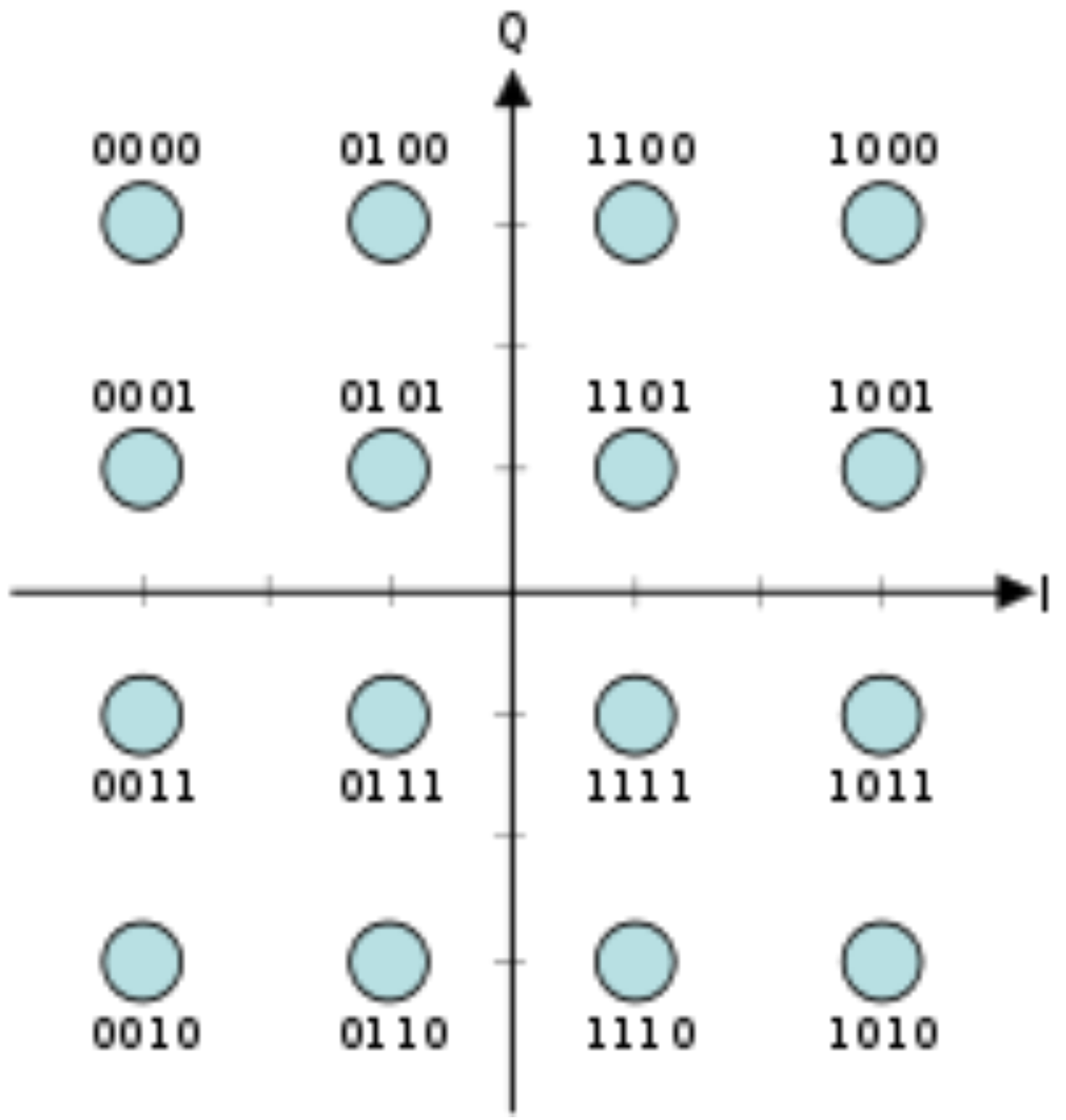

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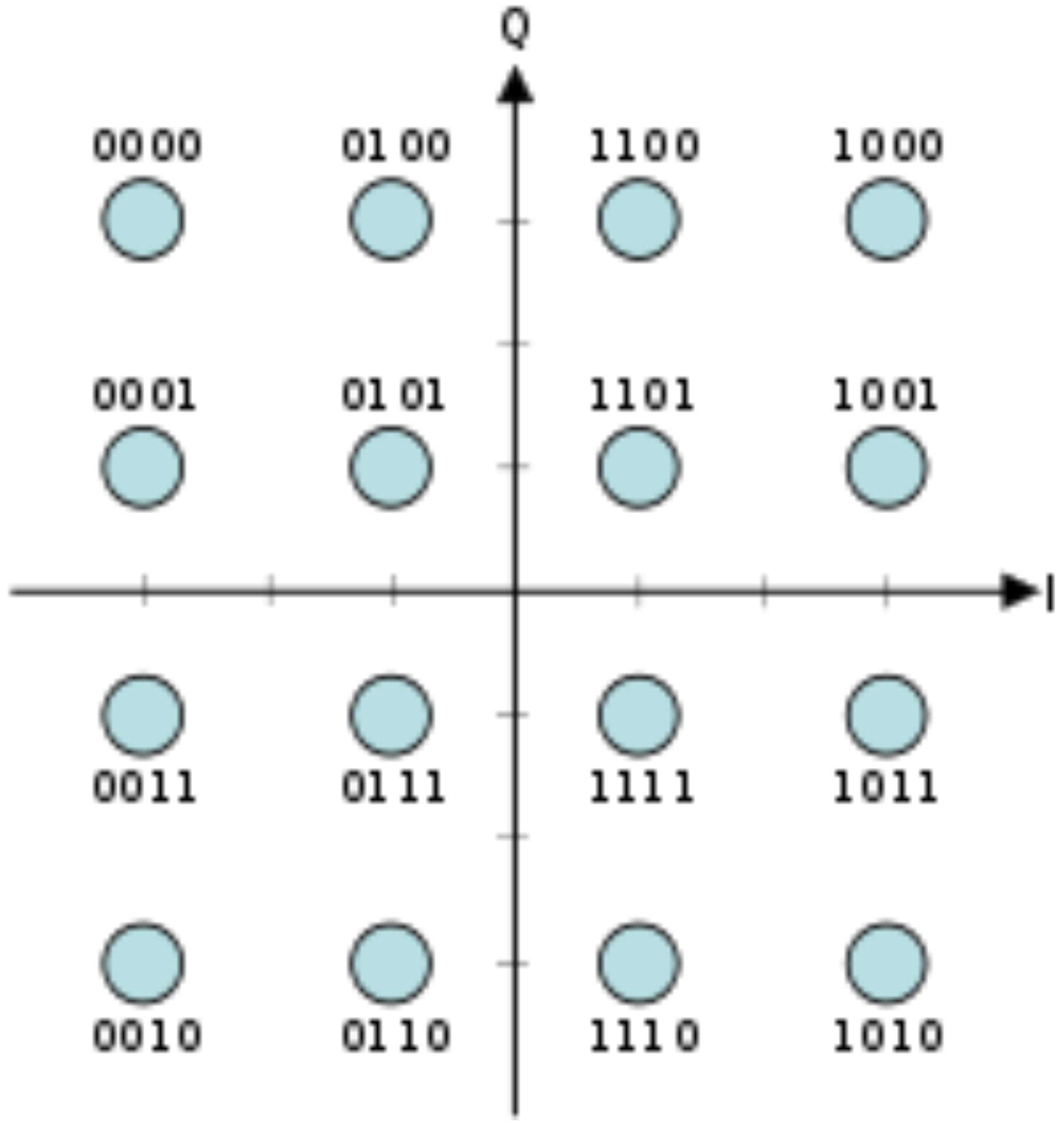

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$Answer = 50 * log_2 16 = 200 Gbps$

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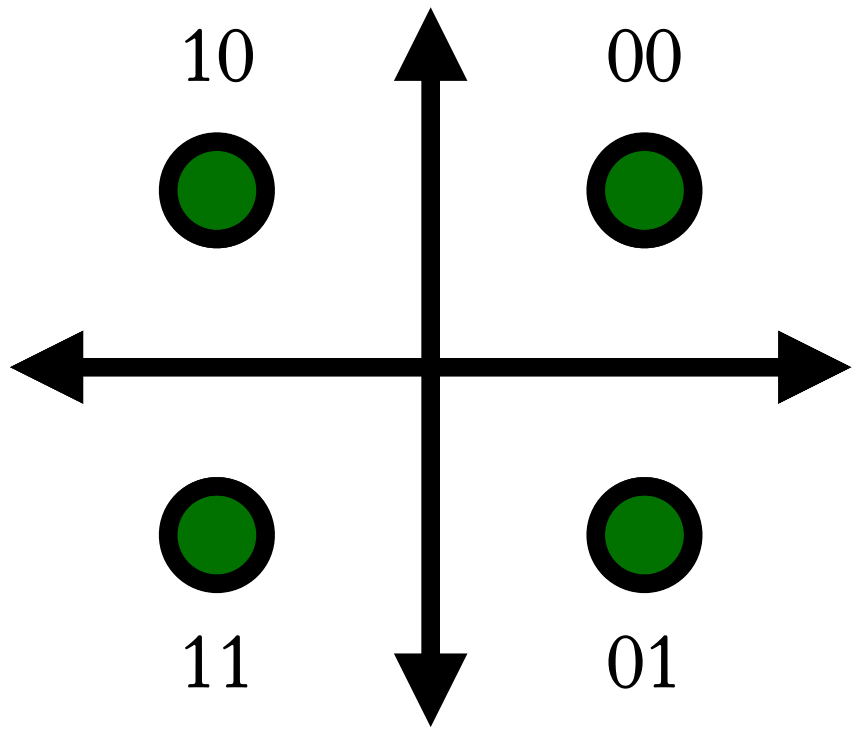
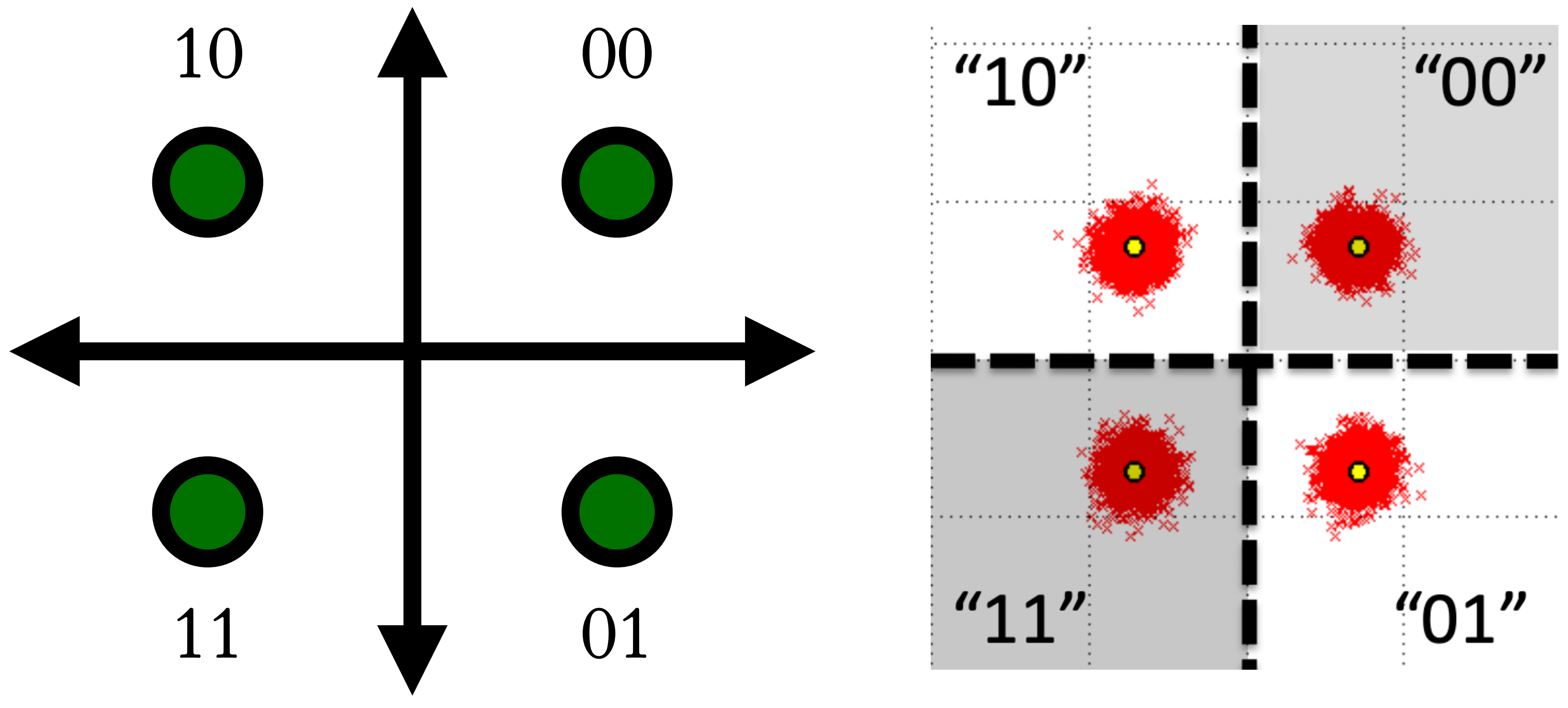


Transmitted

Noisy channels



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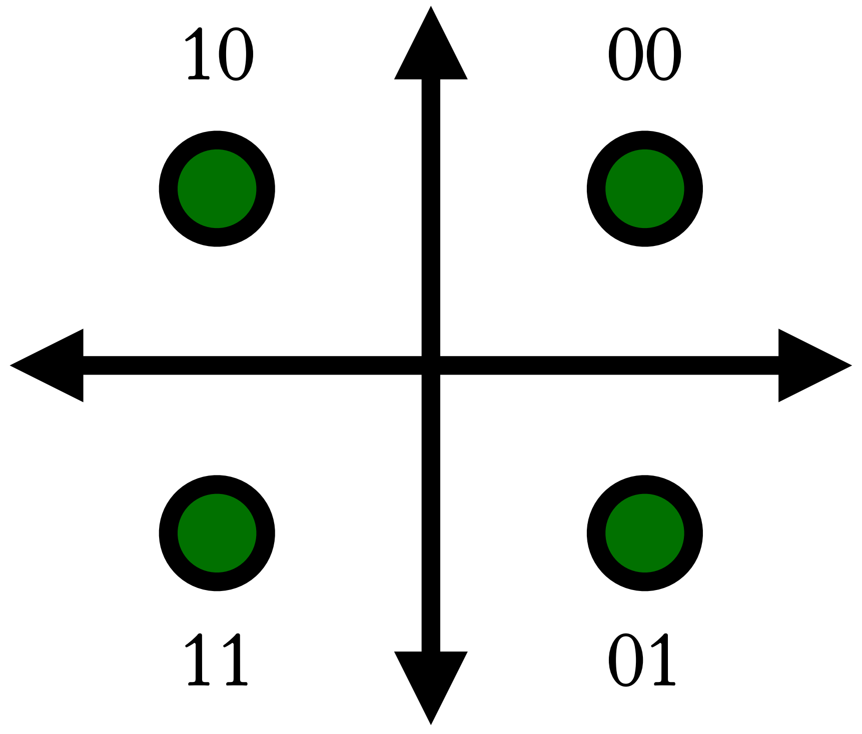

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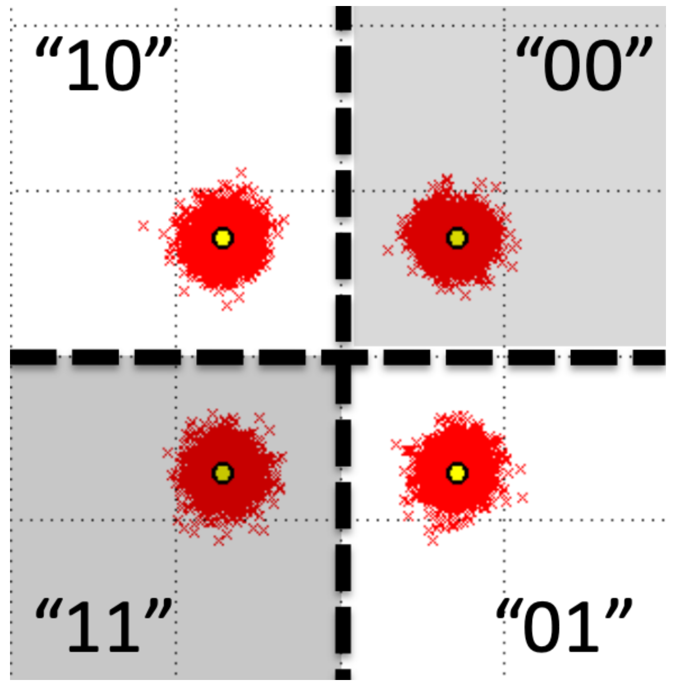

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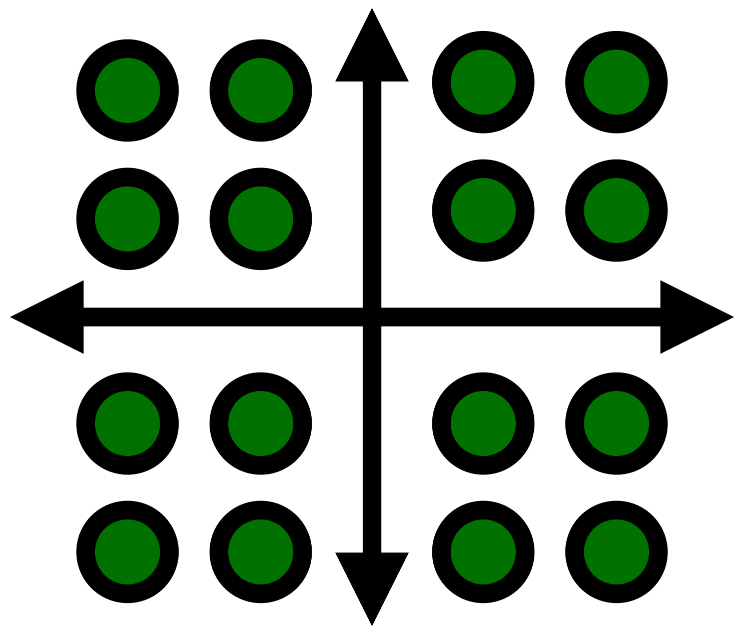

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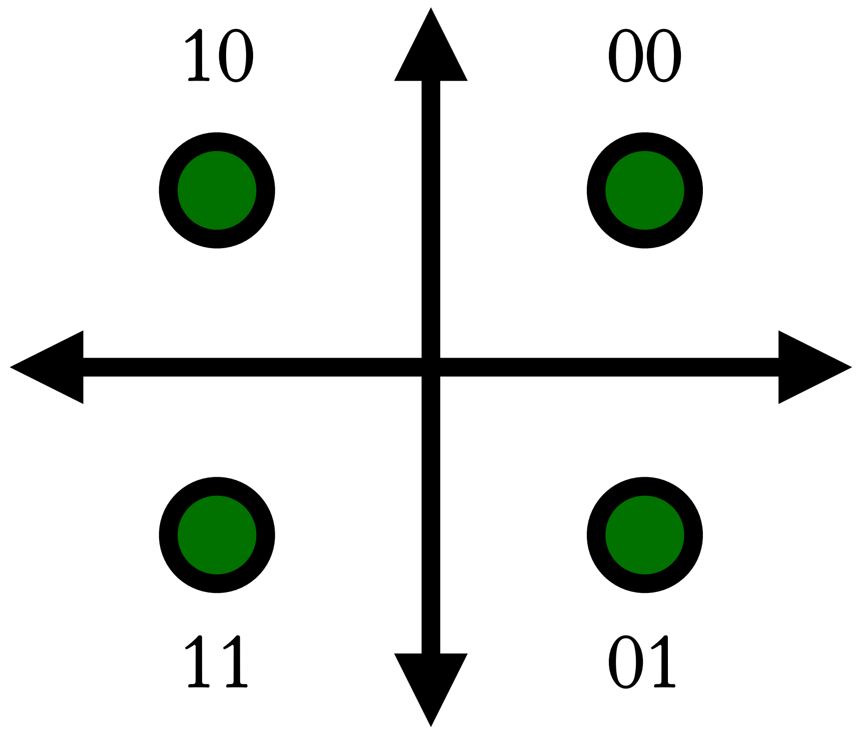

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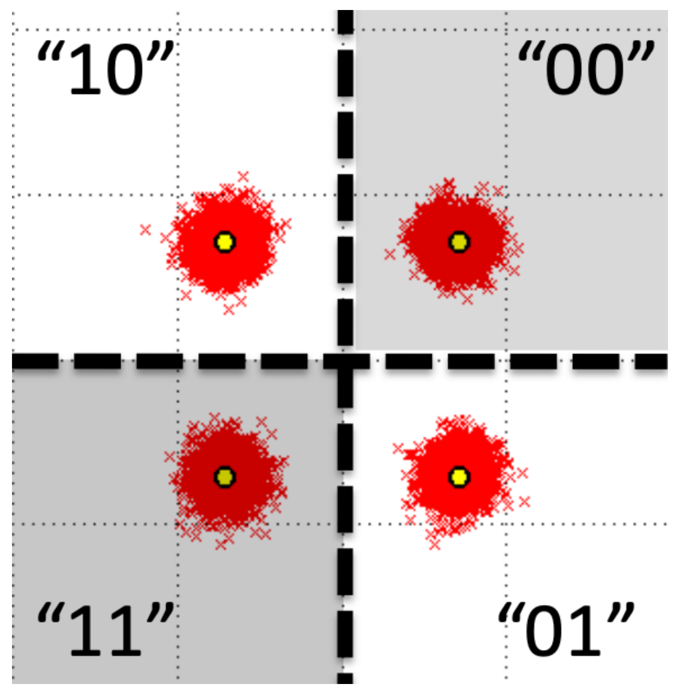

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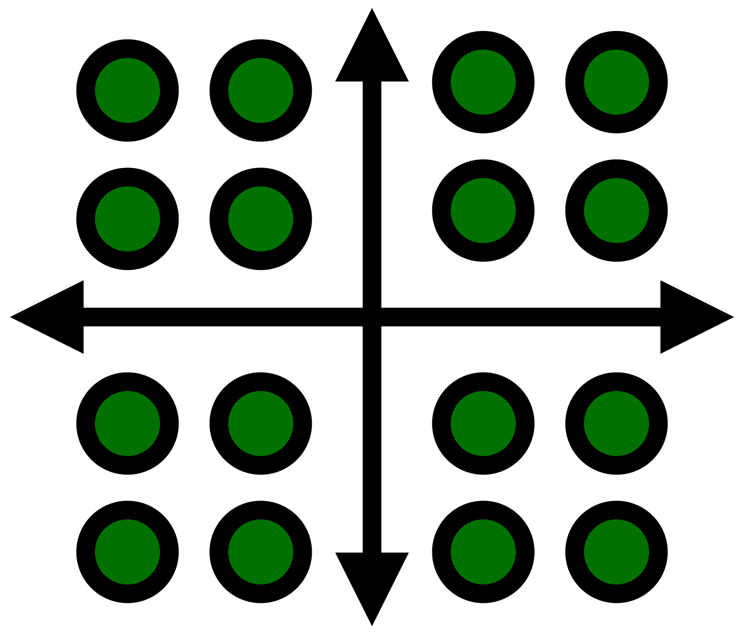
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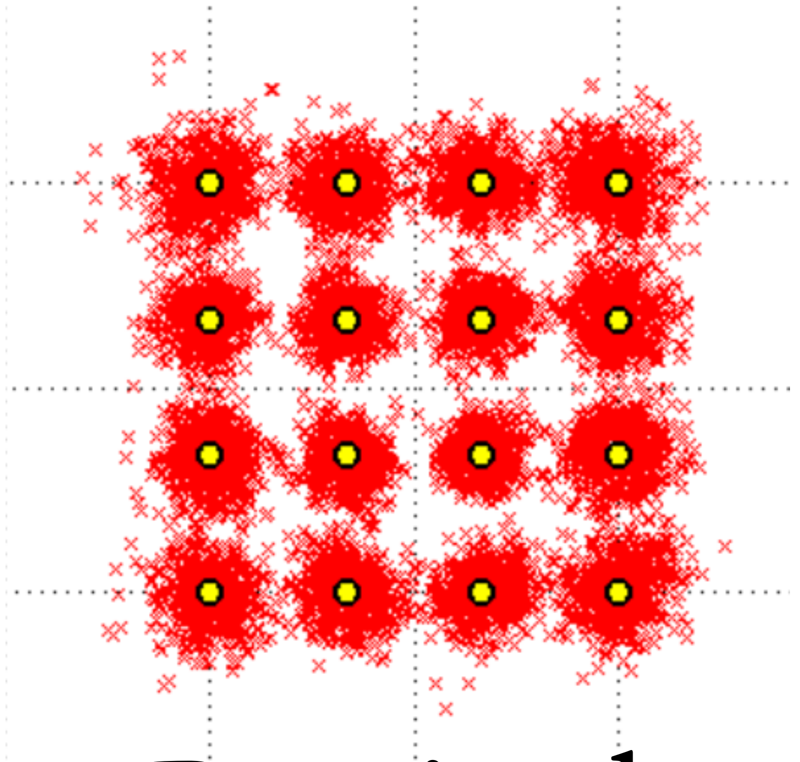
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   - $10log_{10}$ of a quantity makes the unit decibels

Long-haul network connectivity: Shannon capacity

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

$$R = B \cdot log_2(1 + SNR)$$

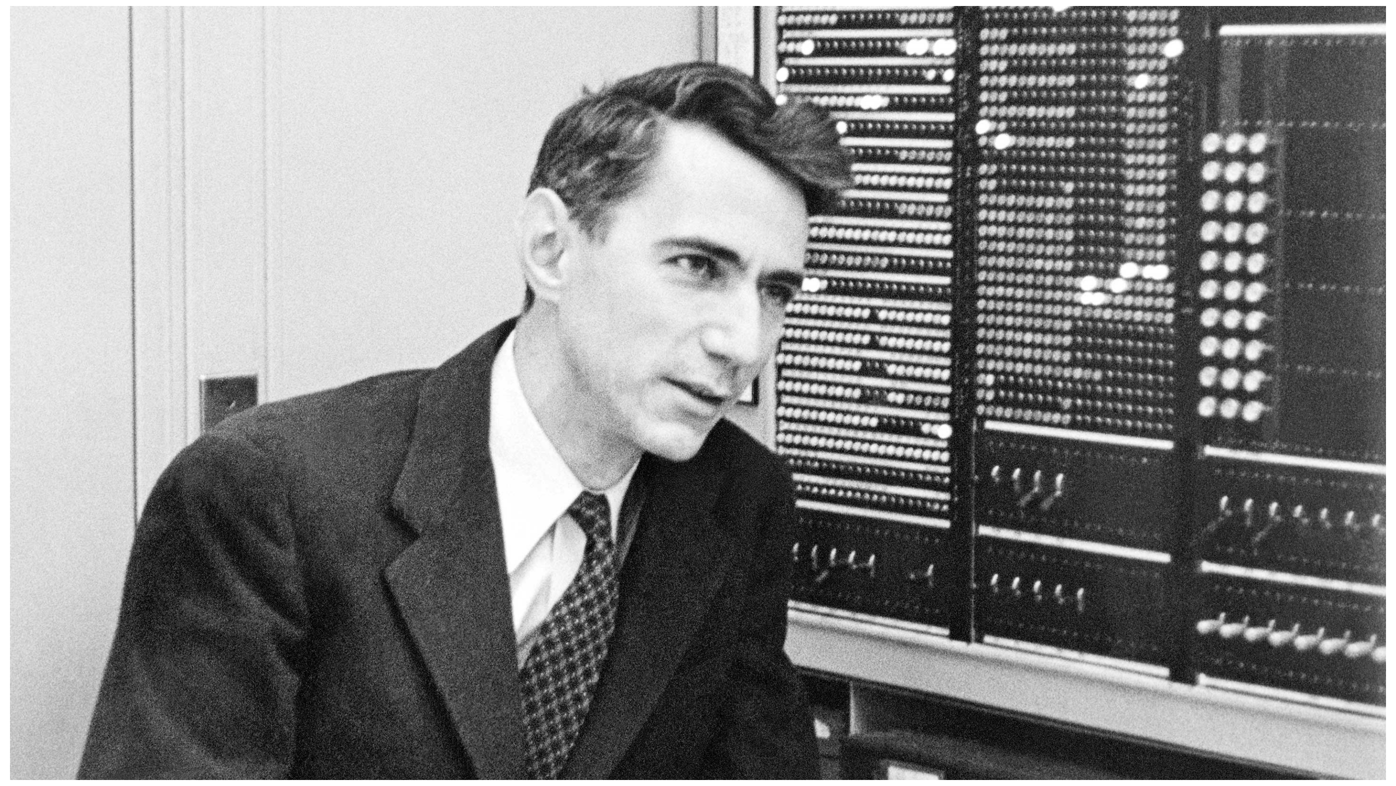
Where,

R = data rate, bit rate in bits/second

B = bandwidth in Hz of the channel

SNR = signal to noise ratio (measures signal quality)

$$R \approx 0.332 \cdot B \cdot SNR$$



Claude Shannon

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

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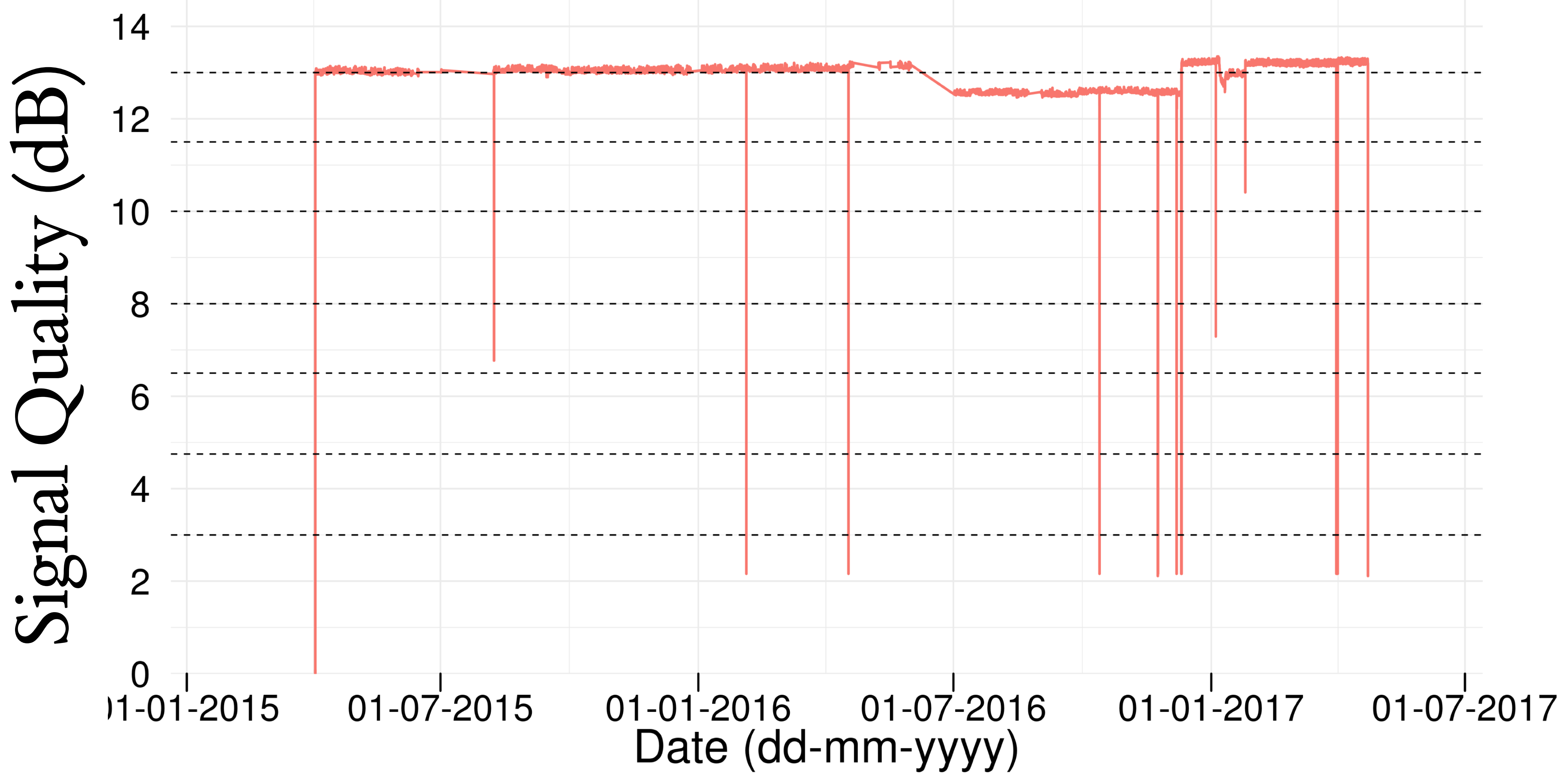
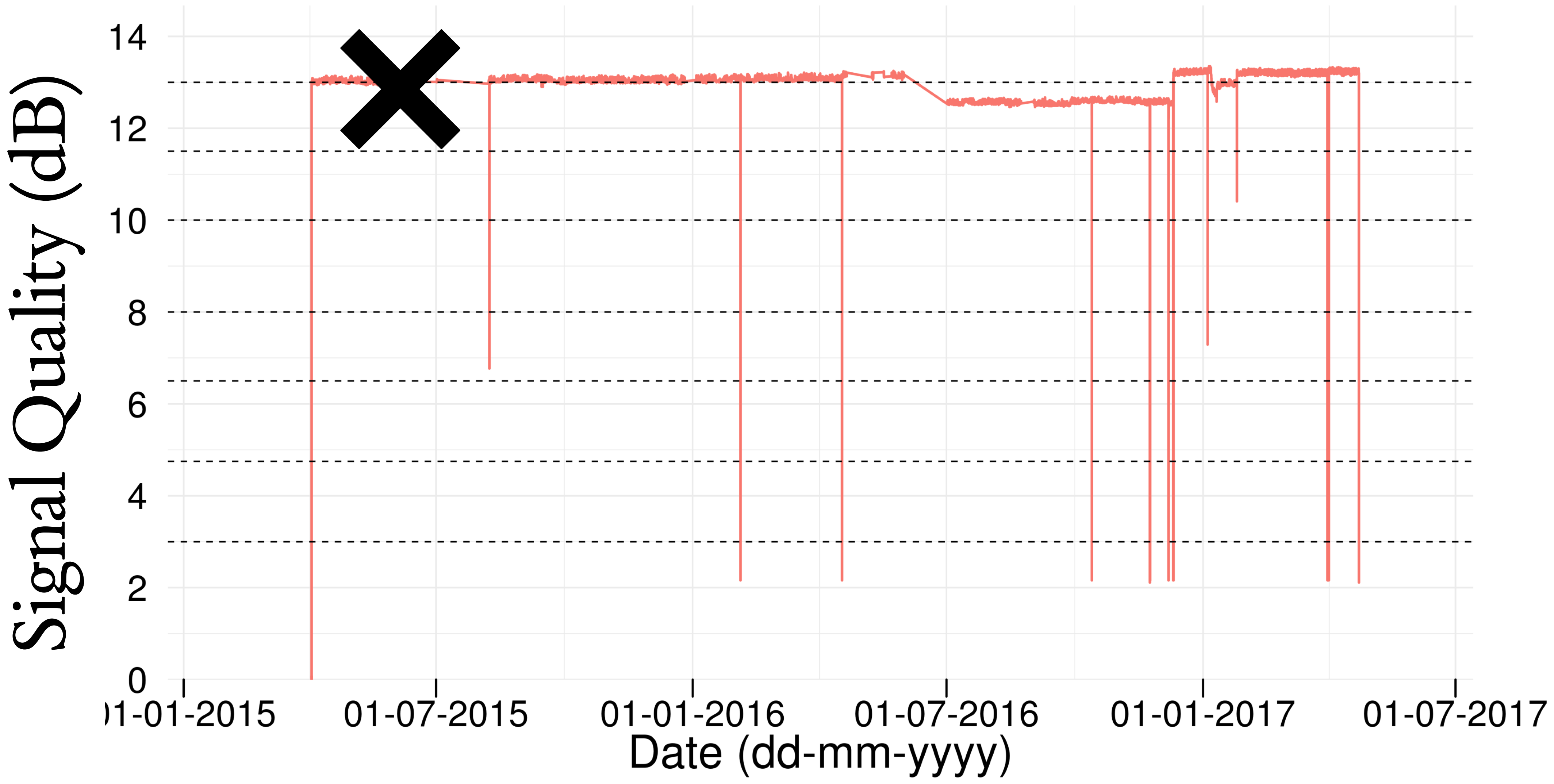


Signal quality of a wavelength on fiber in North America

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?



$$R = B \cdot log_2(1 + SNR)$$

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

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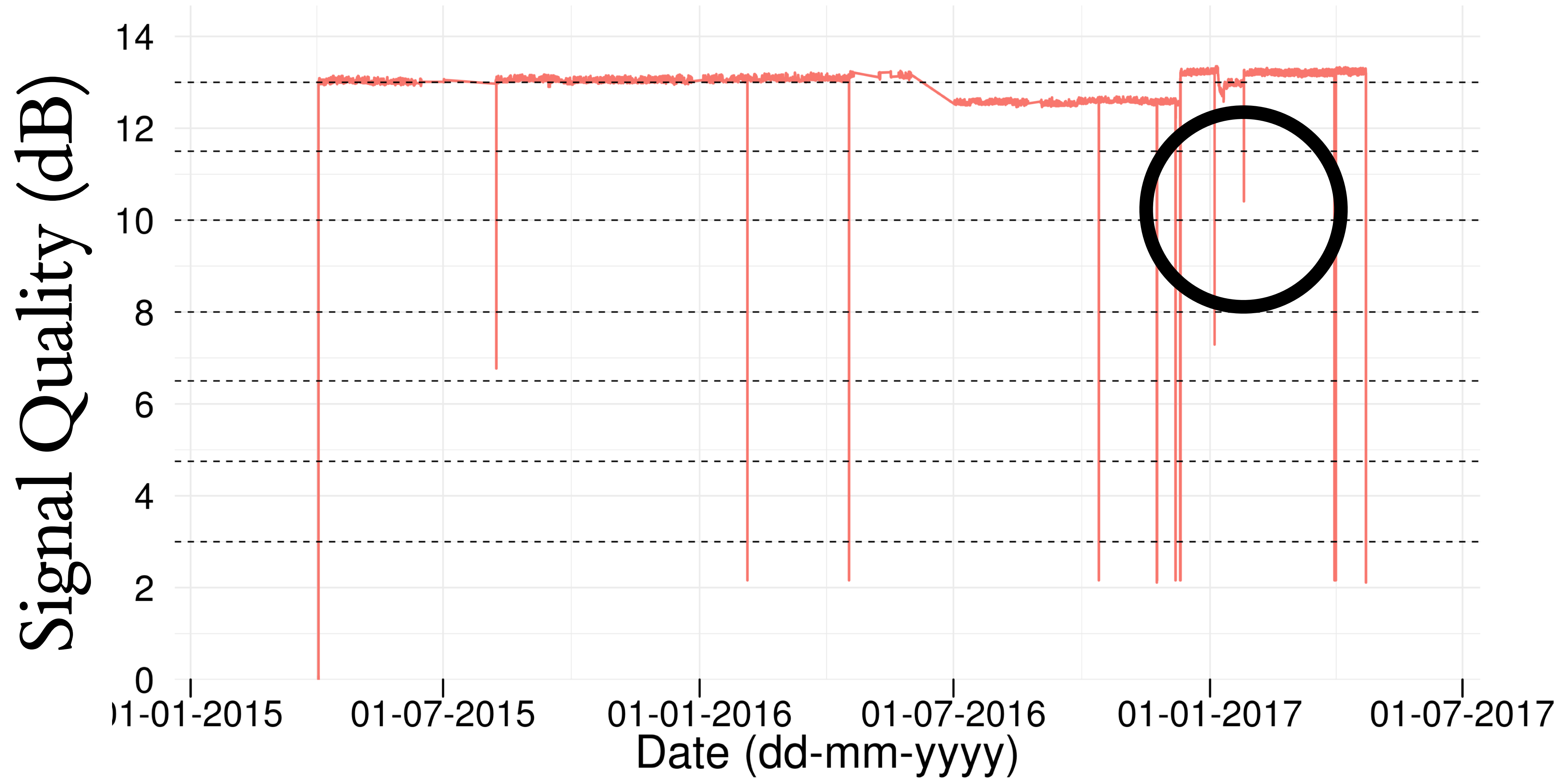

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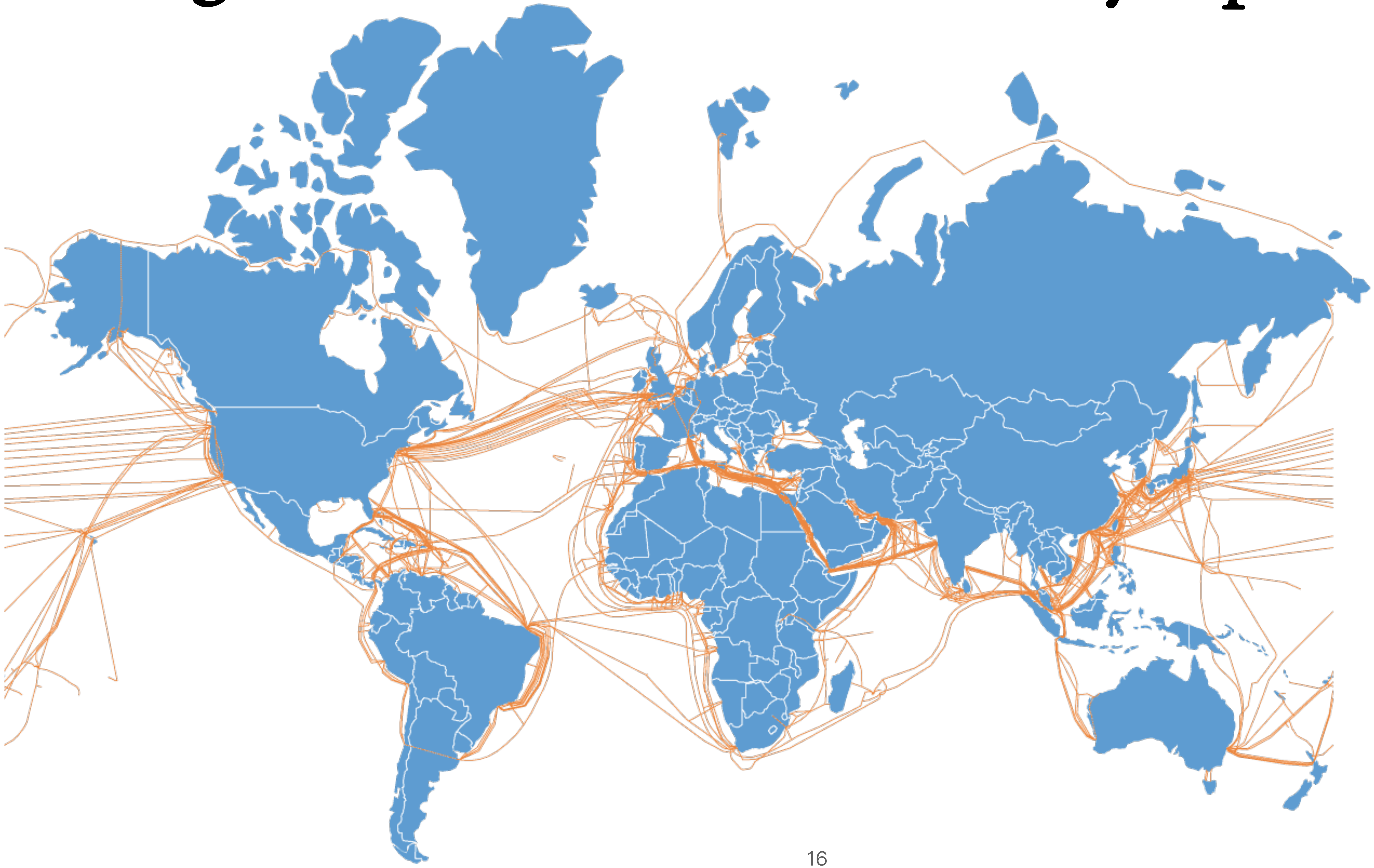
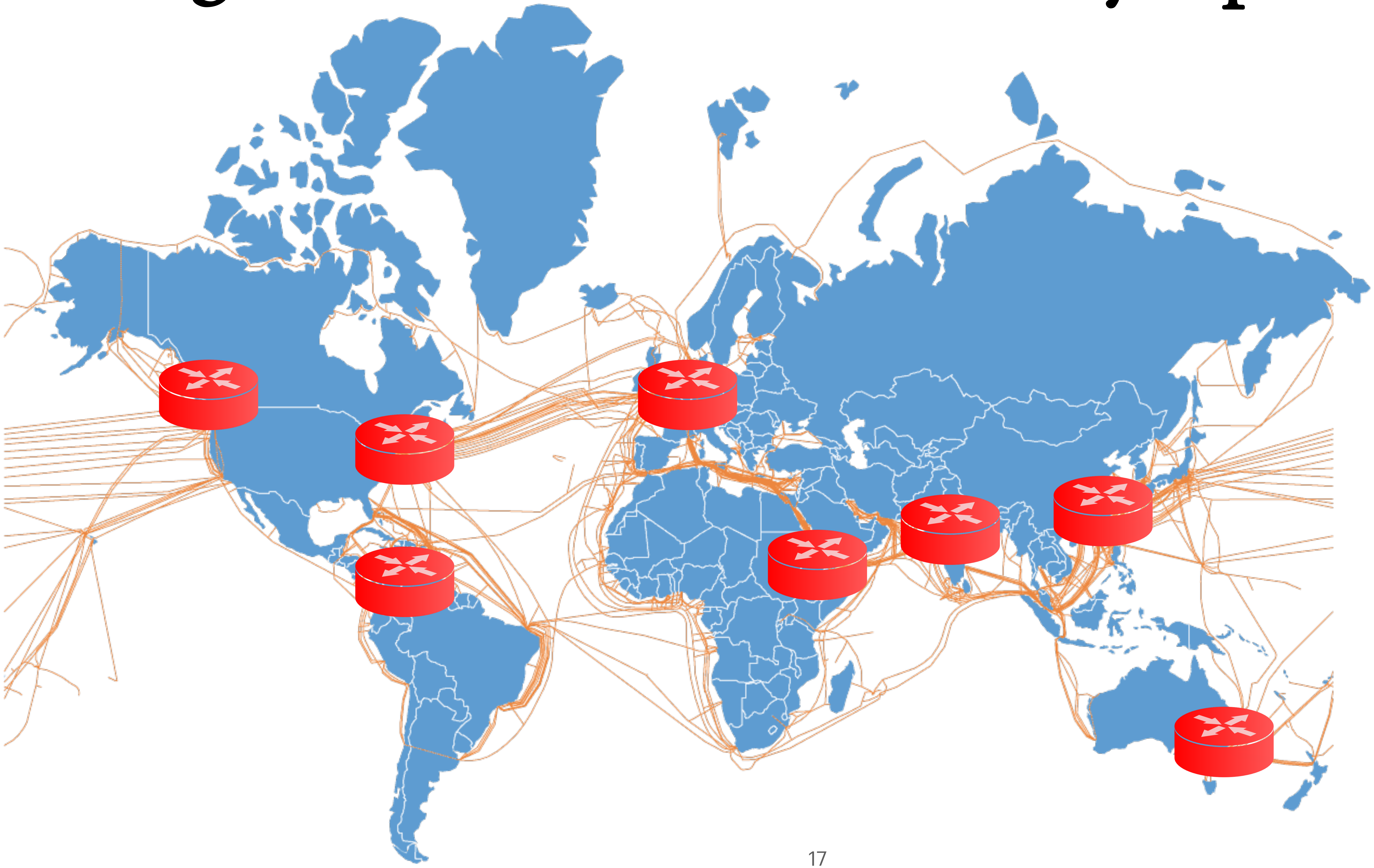
Long-haul network connectivity: optical fiber



Under-sea fiber

Terrestrial fiber

Long-haul network connectivity: optical fiber

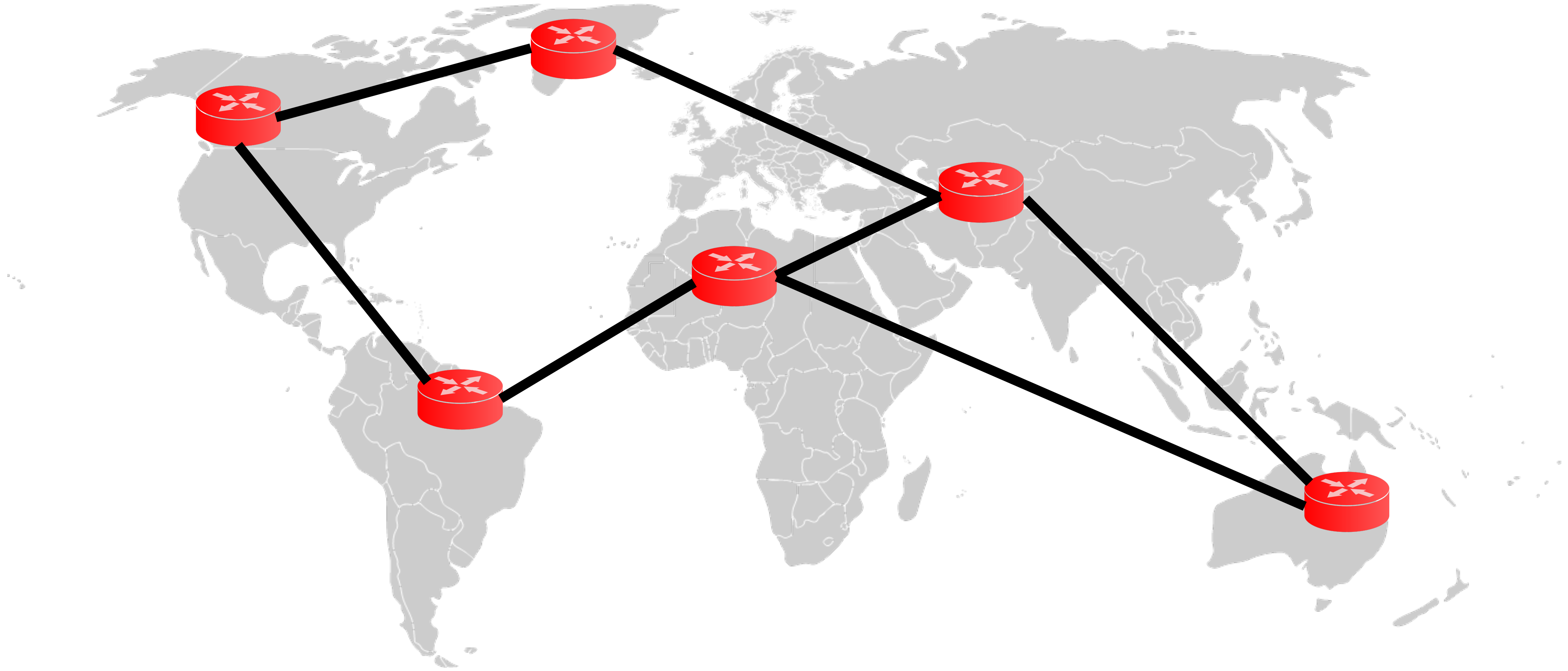


Under-sea fiber

Terrestrial fiber

WANs need high infrastructure investment

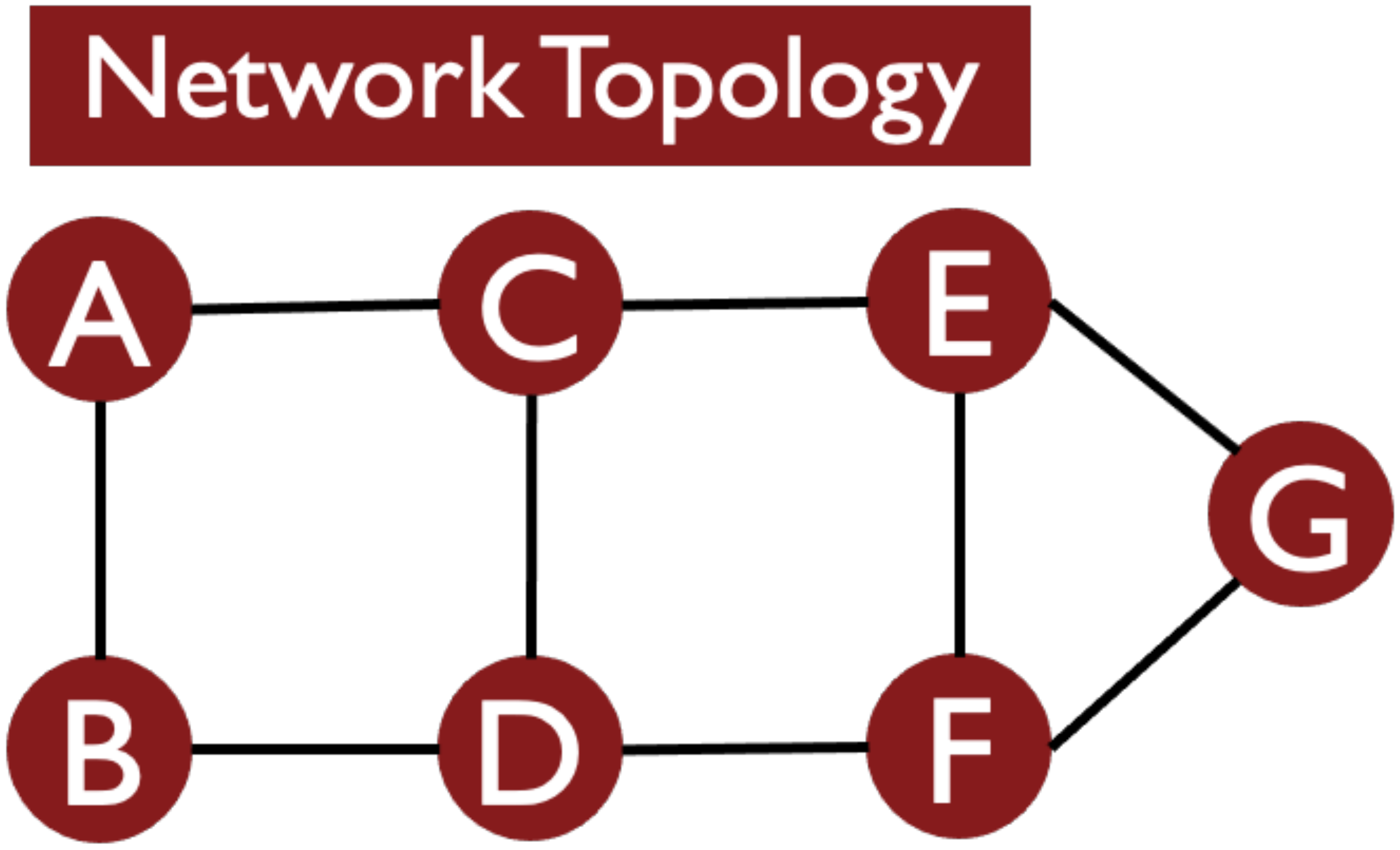
1. High capital expense (billions of $)
    1. Hardware costs for switches
    2. O(100,000) miles fiber
2. High operational expenses (millions of $ annually)
3. Crucial to operate efficient WANs

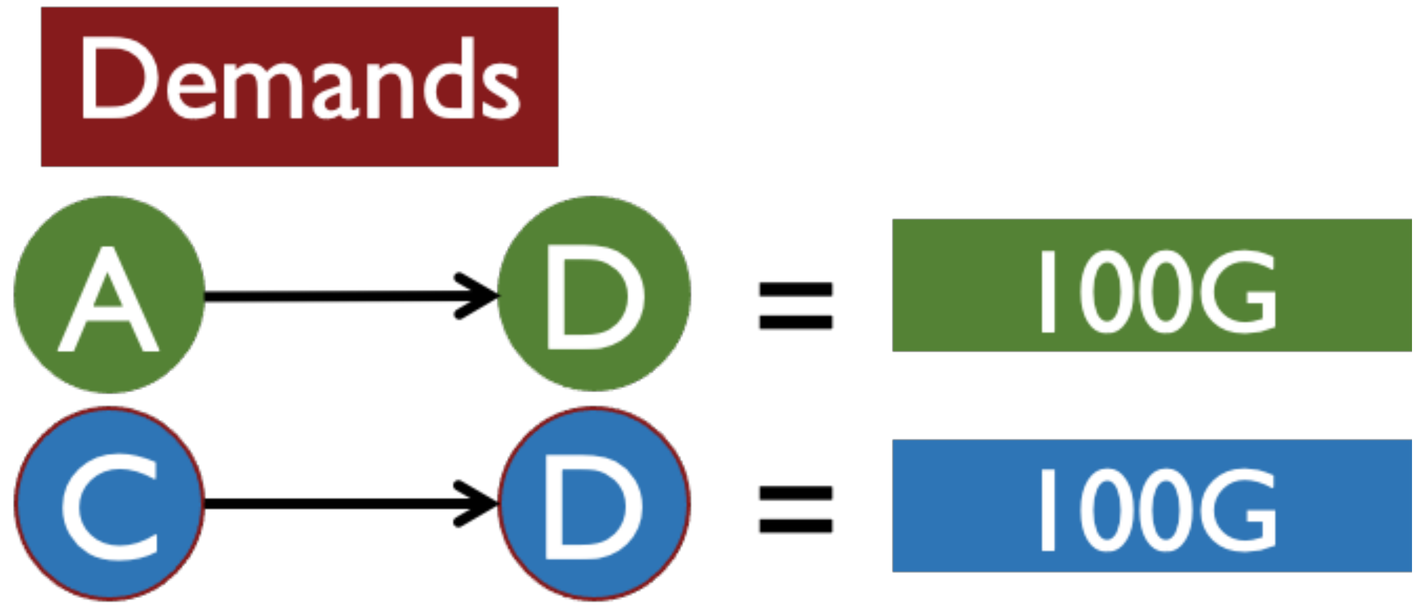


Using WANs efficiently

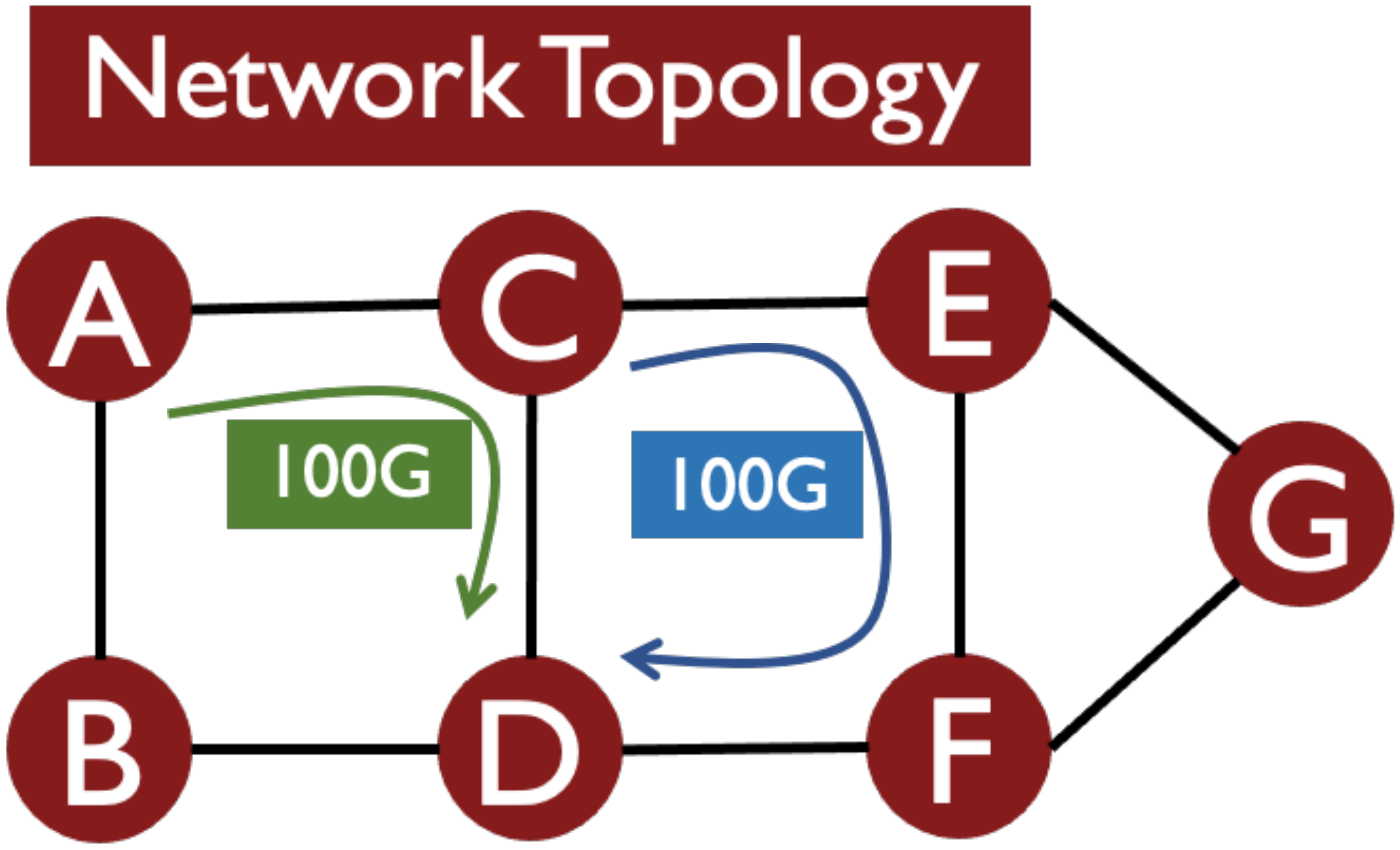
- Allocate traffic demands in the WAN to:
    - achieve optimal network *flow*
    - minimal traffic *latency*
    - *fairness* across traffic classes
    - …

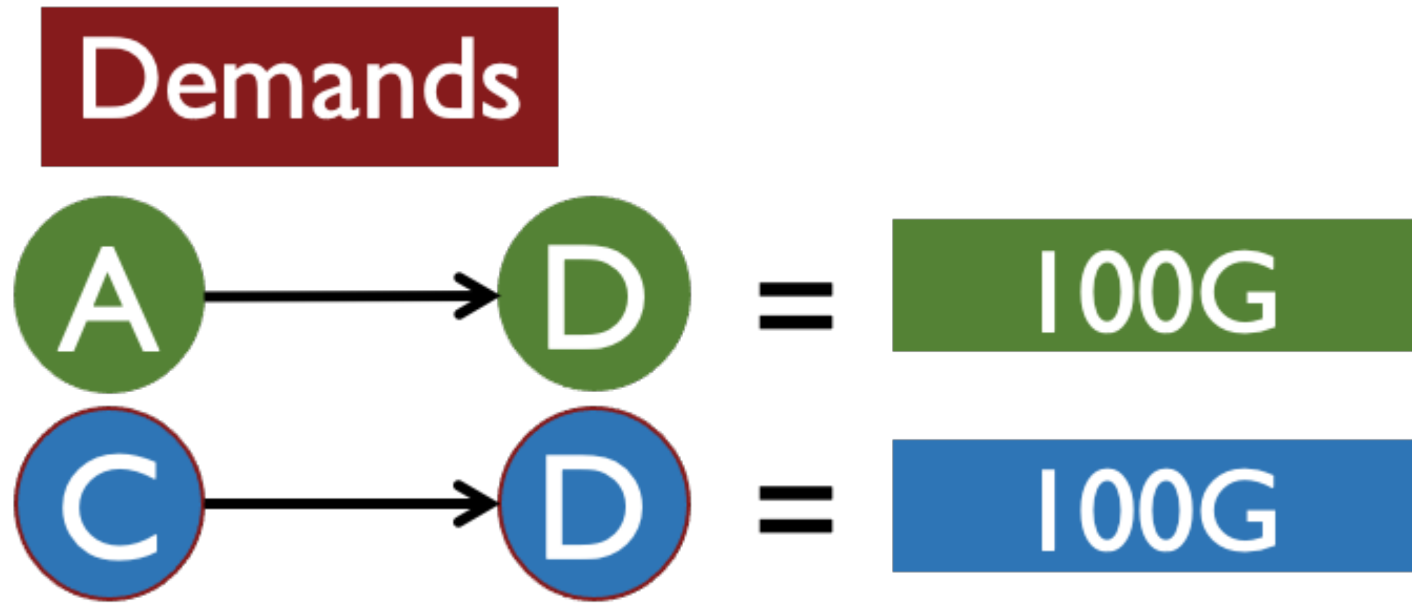
Using WANs efficiently



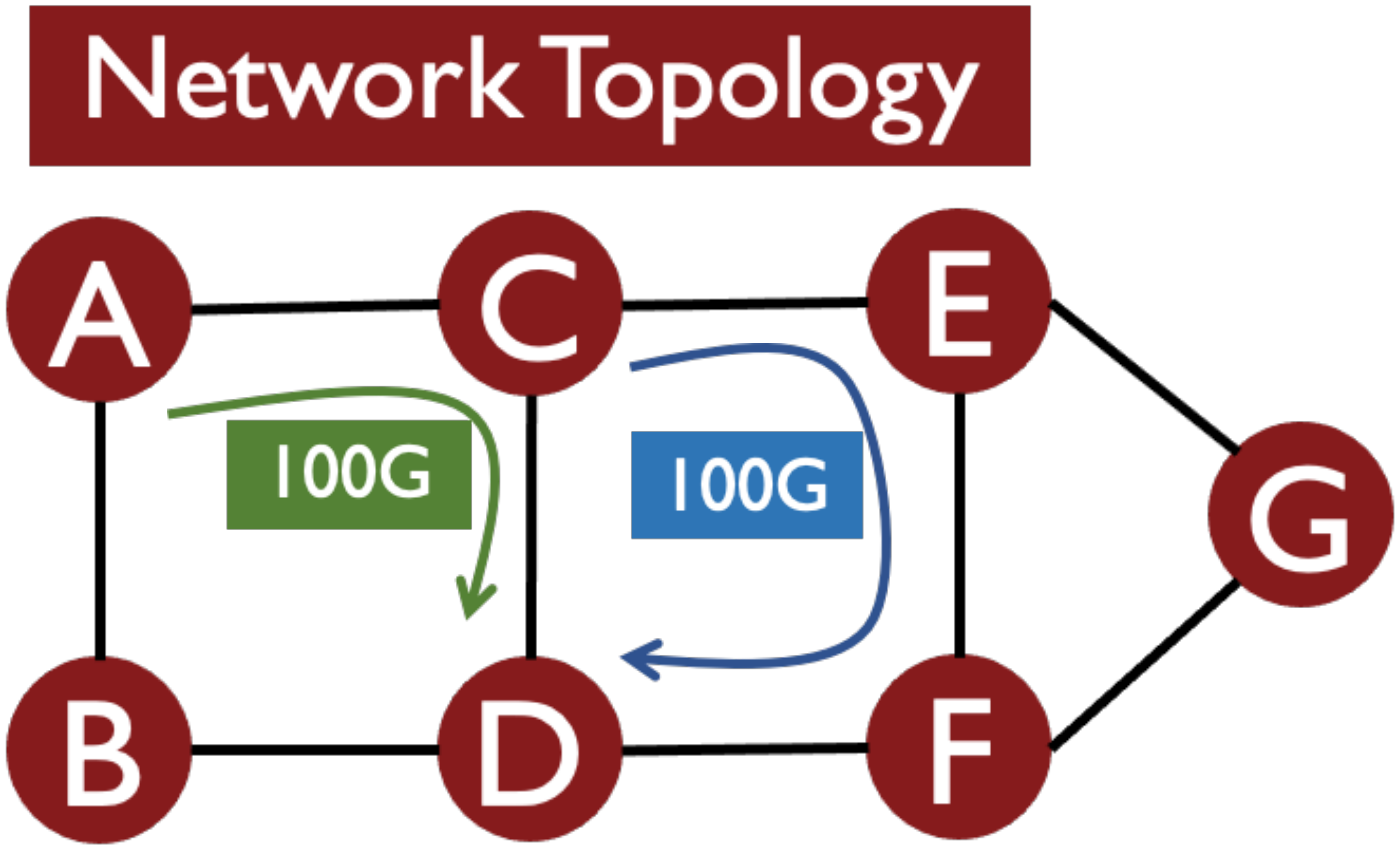


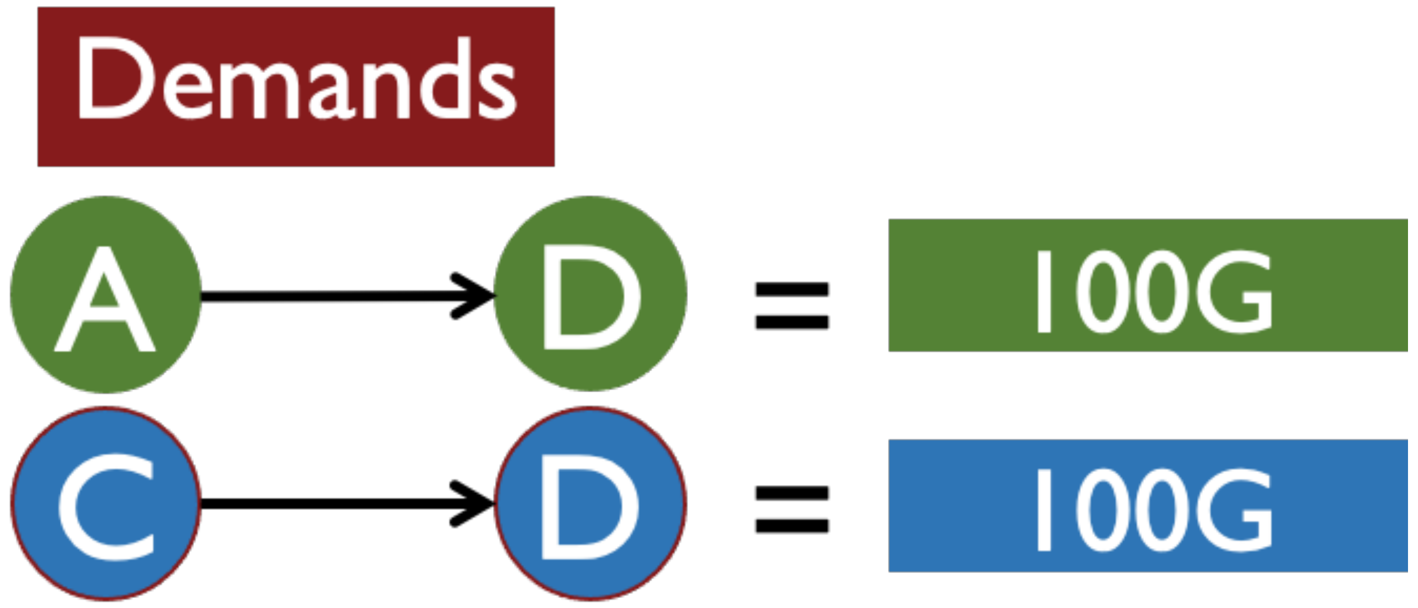
Using WANs efficiently





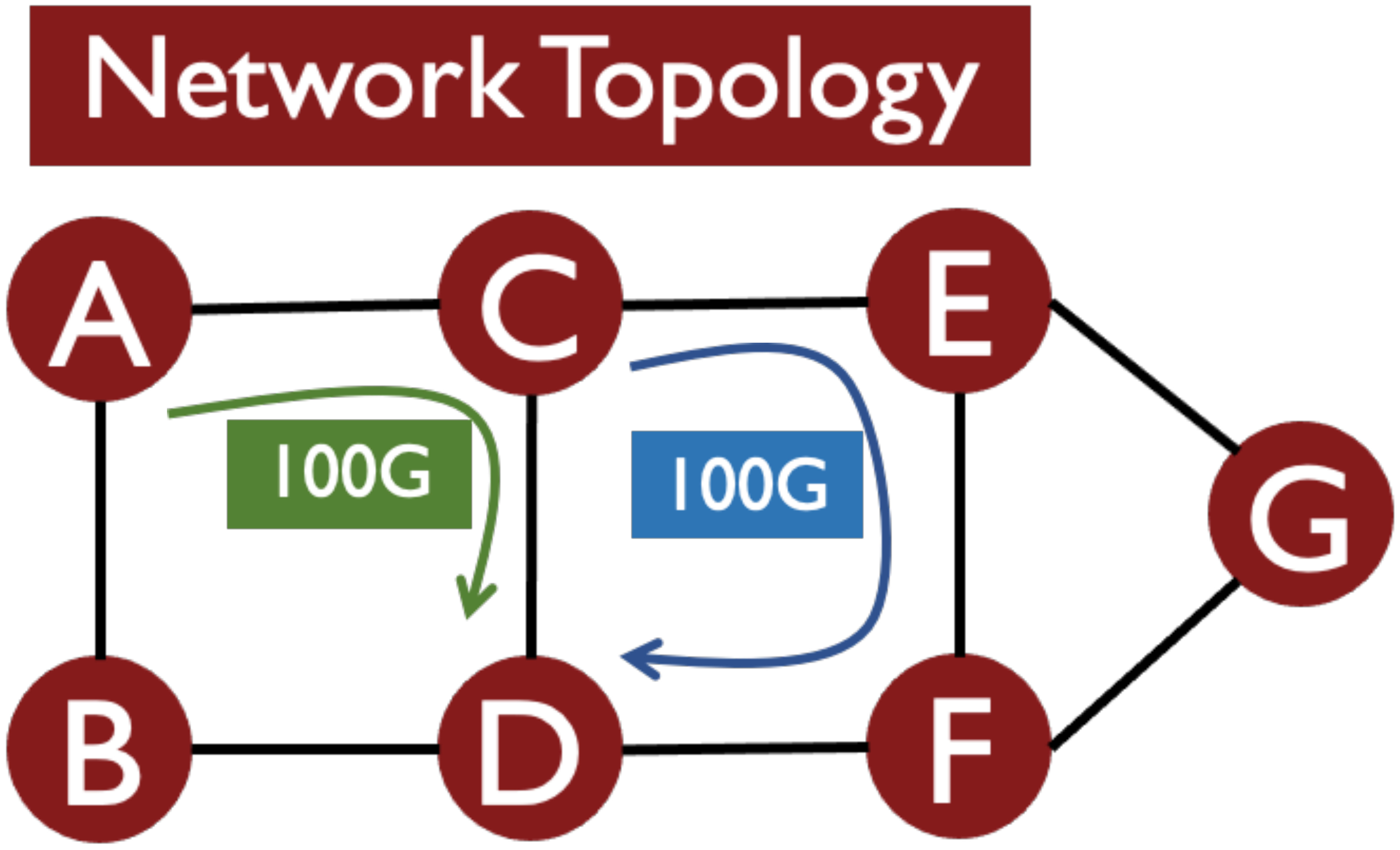
Using WANs efficiently

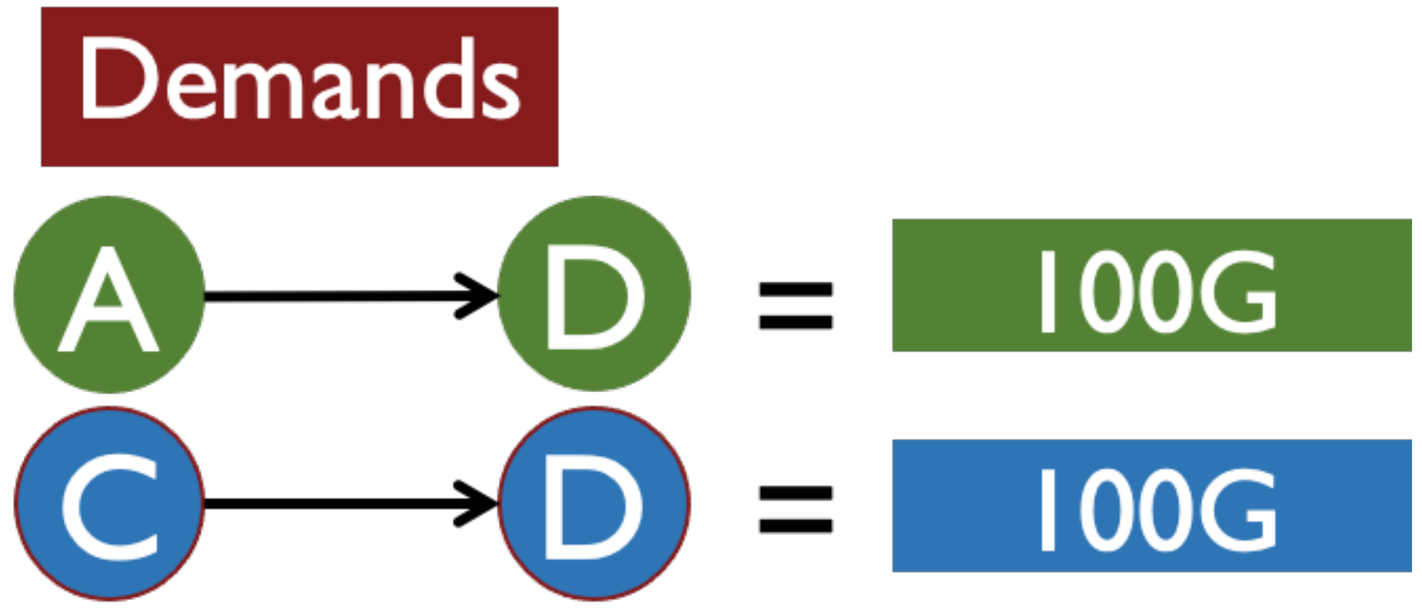




What does this remind me of from your algorithms class?

Using WANs efficiently





What does this remind me of from your algorithms class?

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

Optimization
Objective

Traffic engineering optimization

Inputs

Optimization
Objective

Traffic engineering optimization

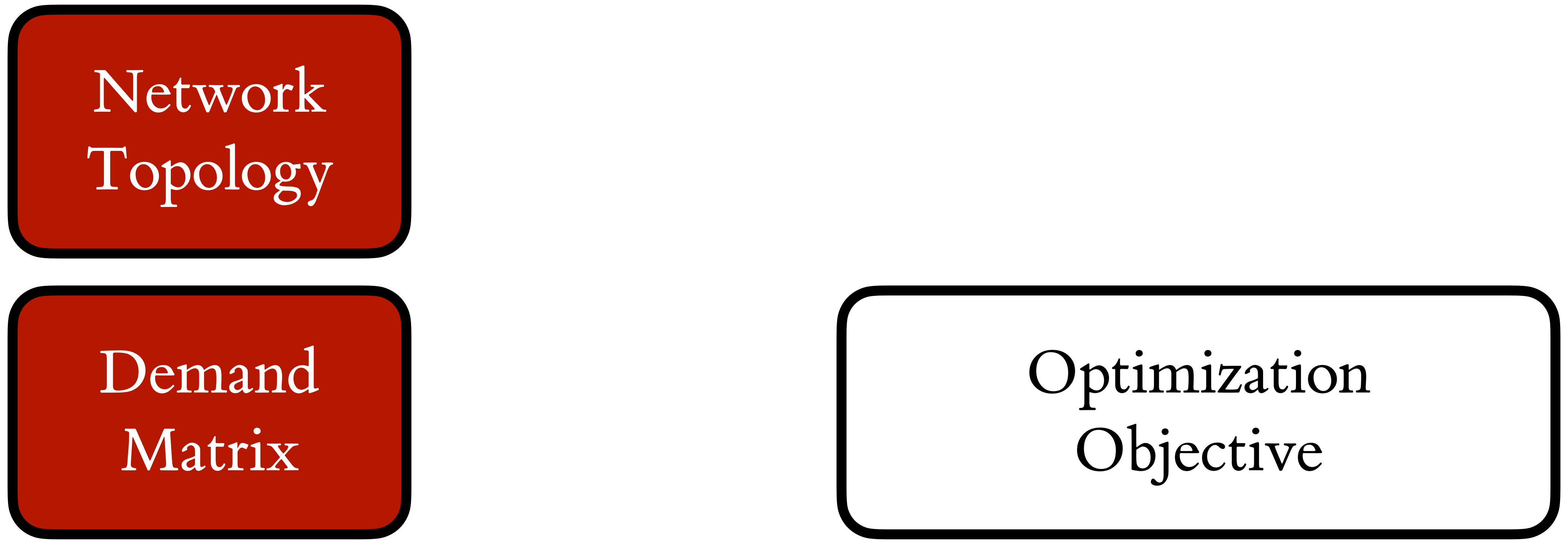
Inputs

Network Topology

Optimization Objective

Traffic engineering optimization

Inputs



Traffic engineering optimization

Inputs

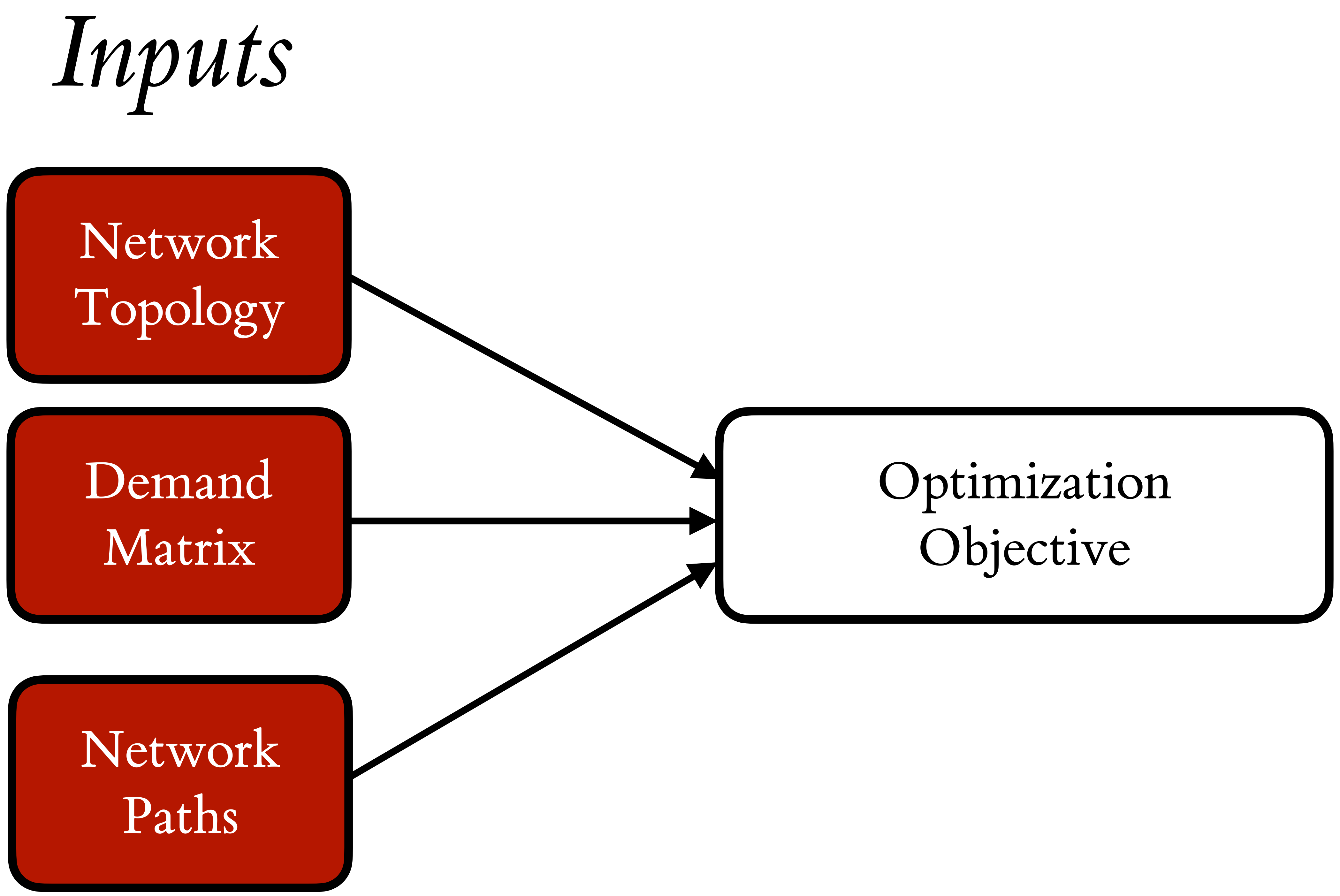
Network Topology

Demand Matrix

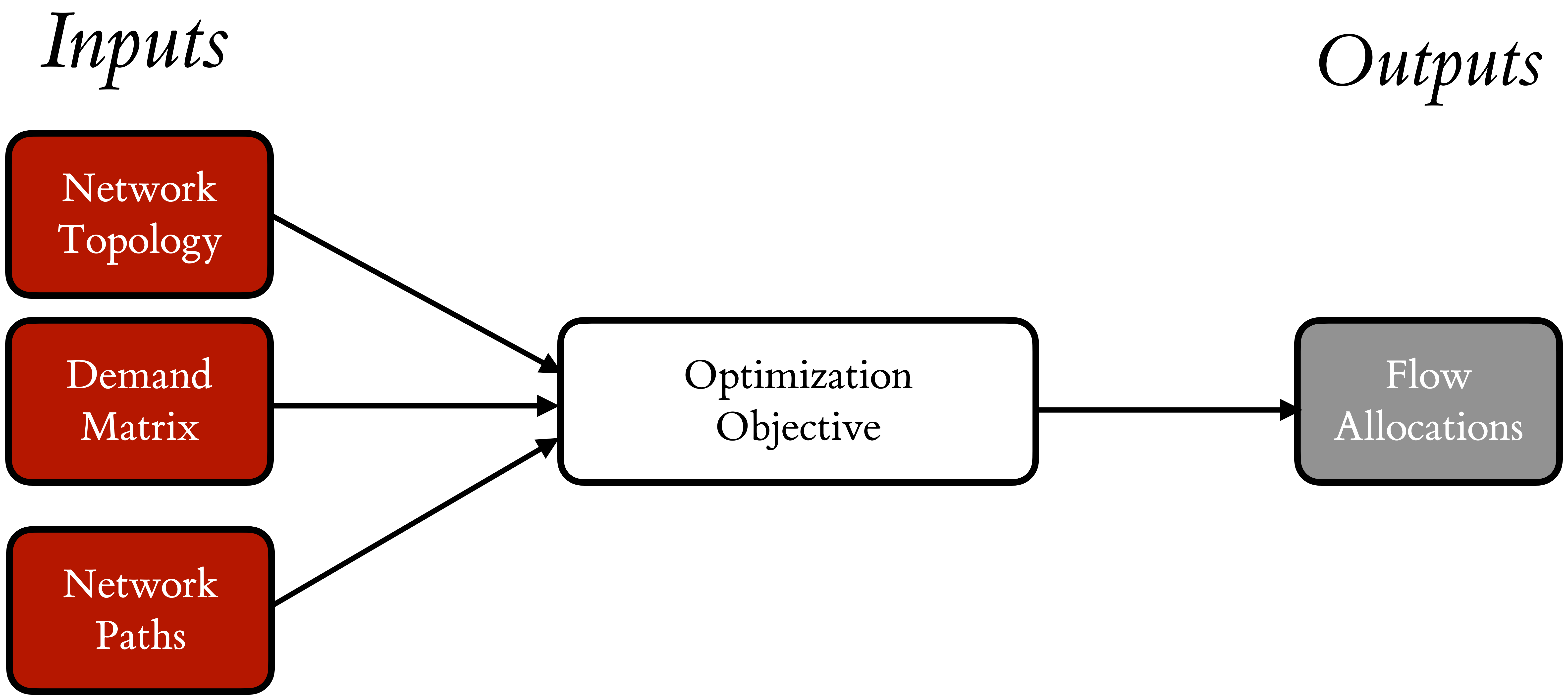
Network Paths

Optimization Objective

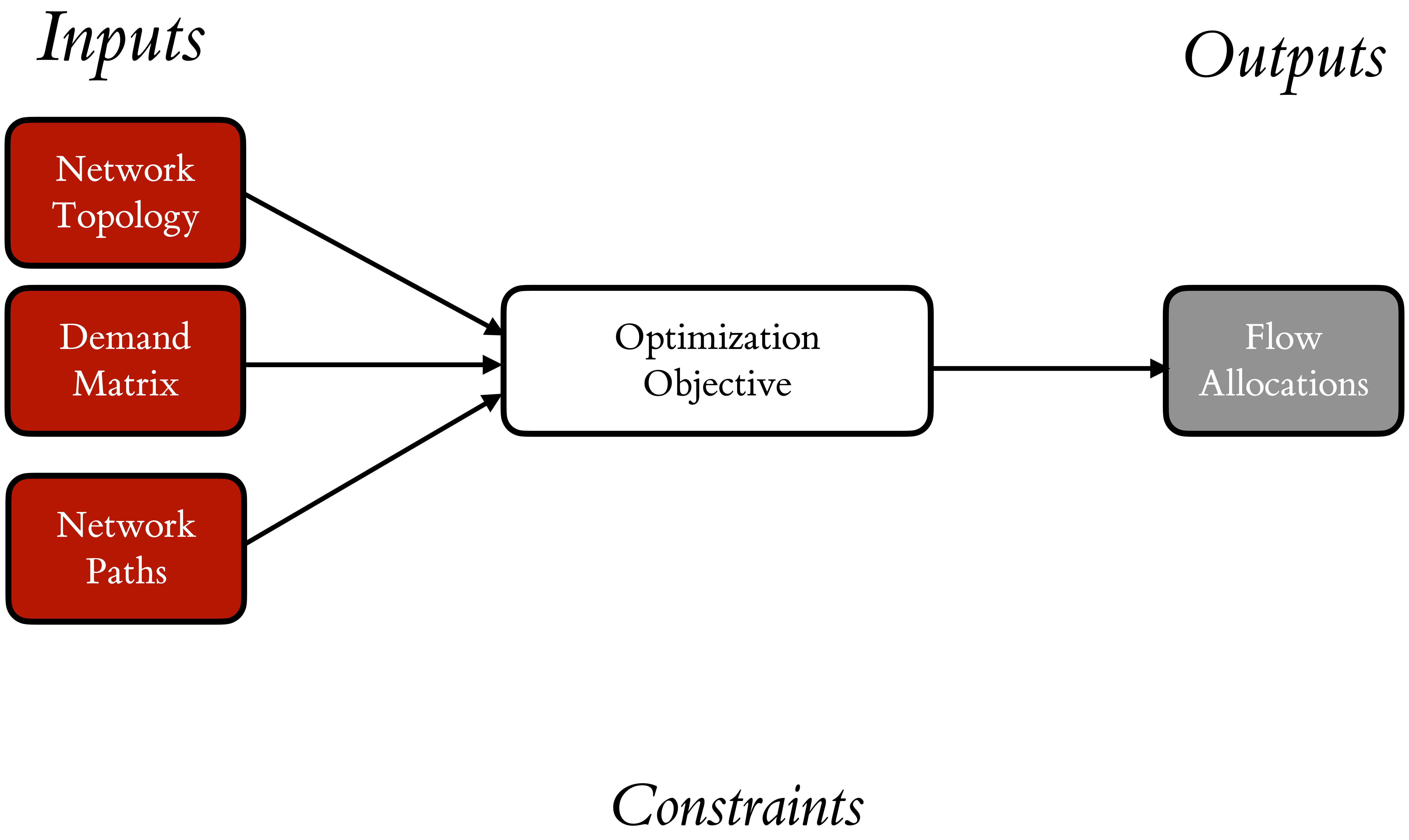
Traffic engineering optimization



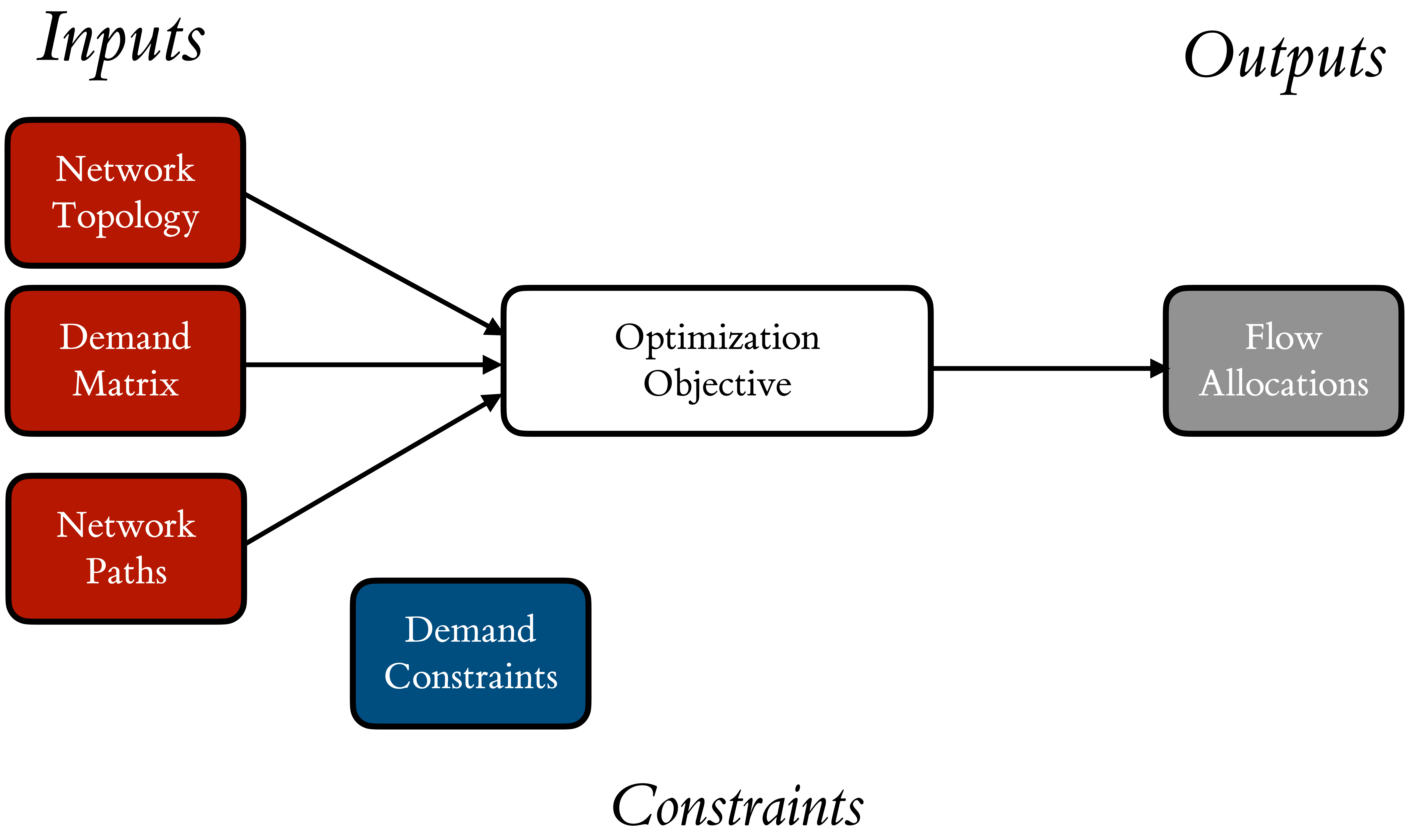
Traffic engineering optimization



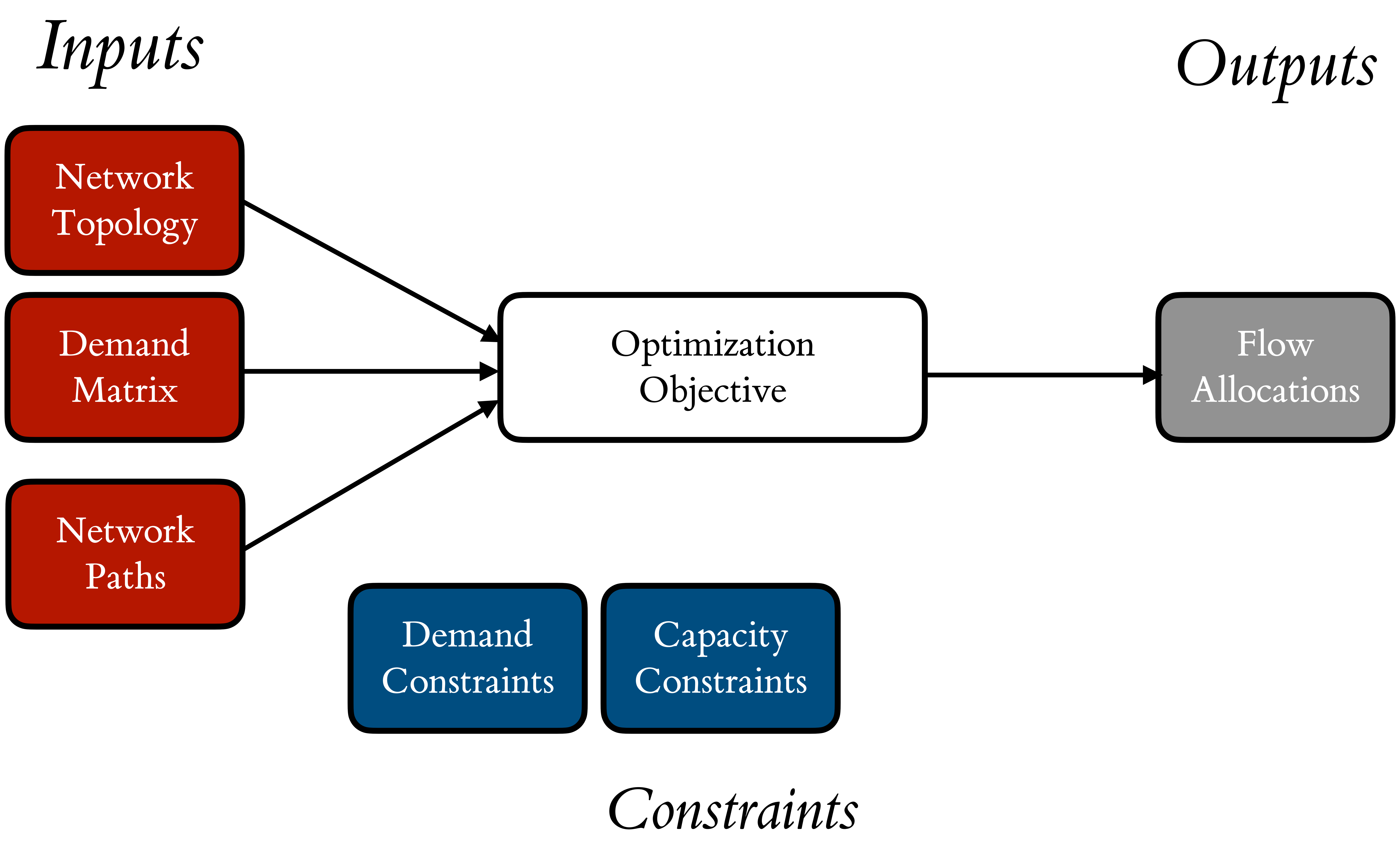
Traffic engineering optimization



Traffic engineering optimization



Traffic engineering optimization



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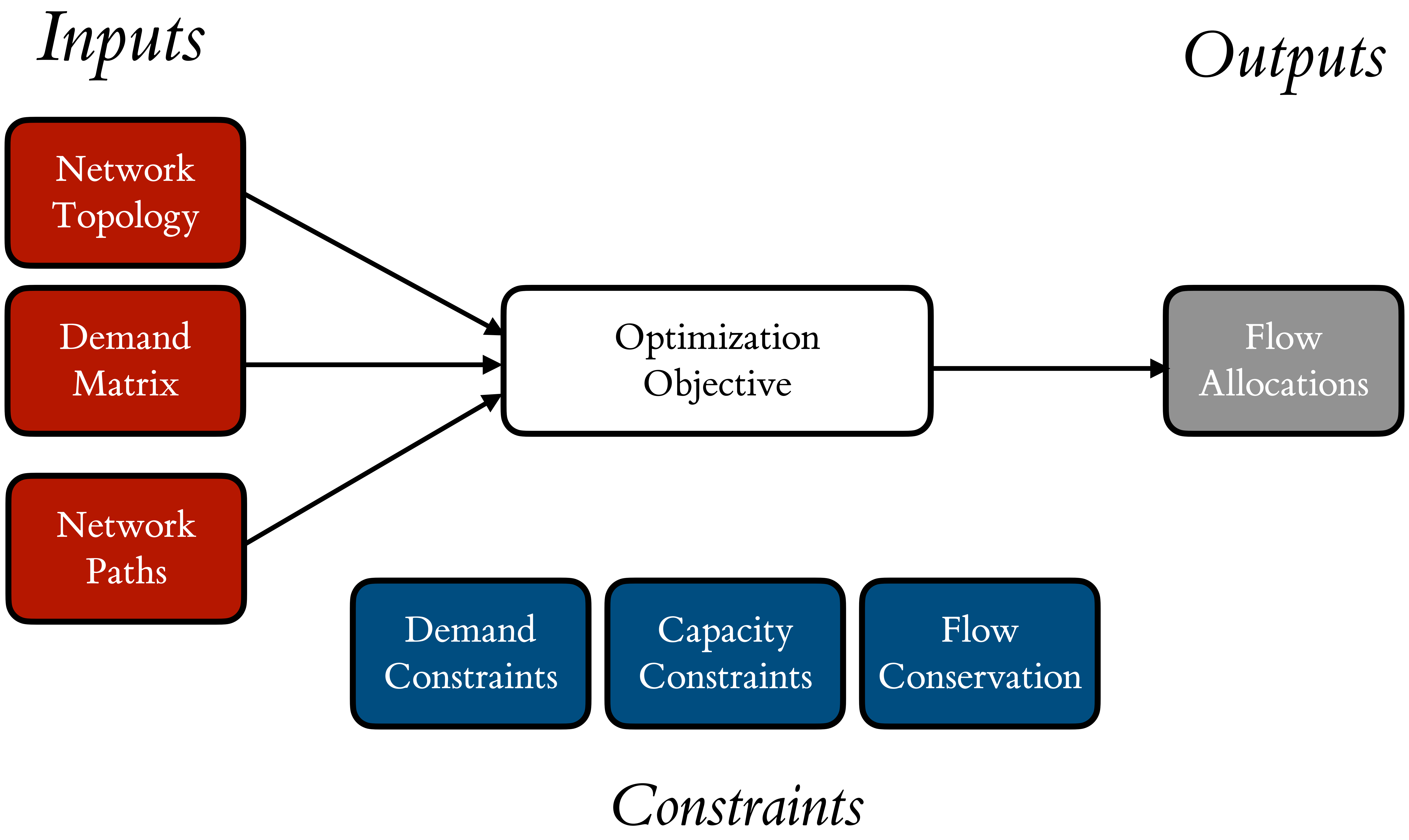

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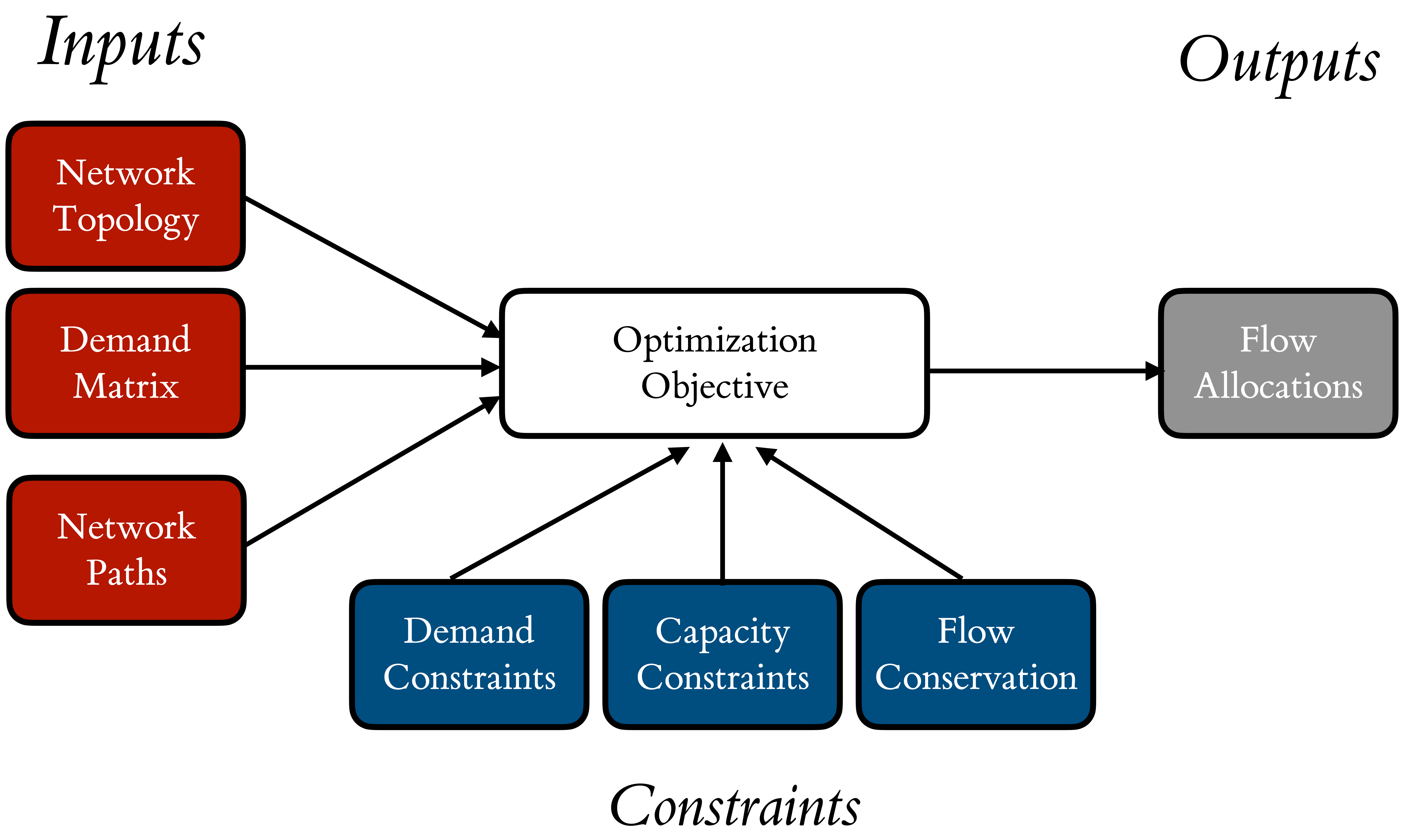
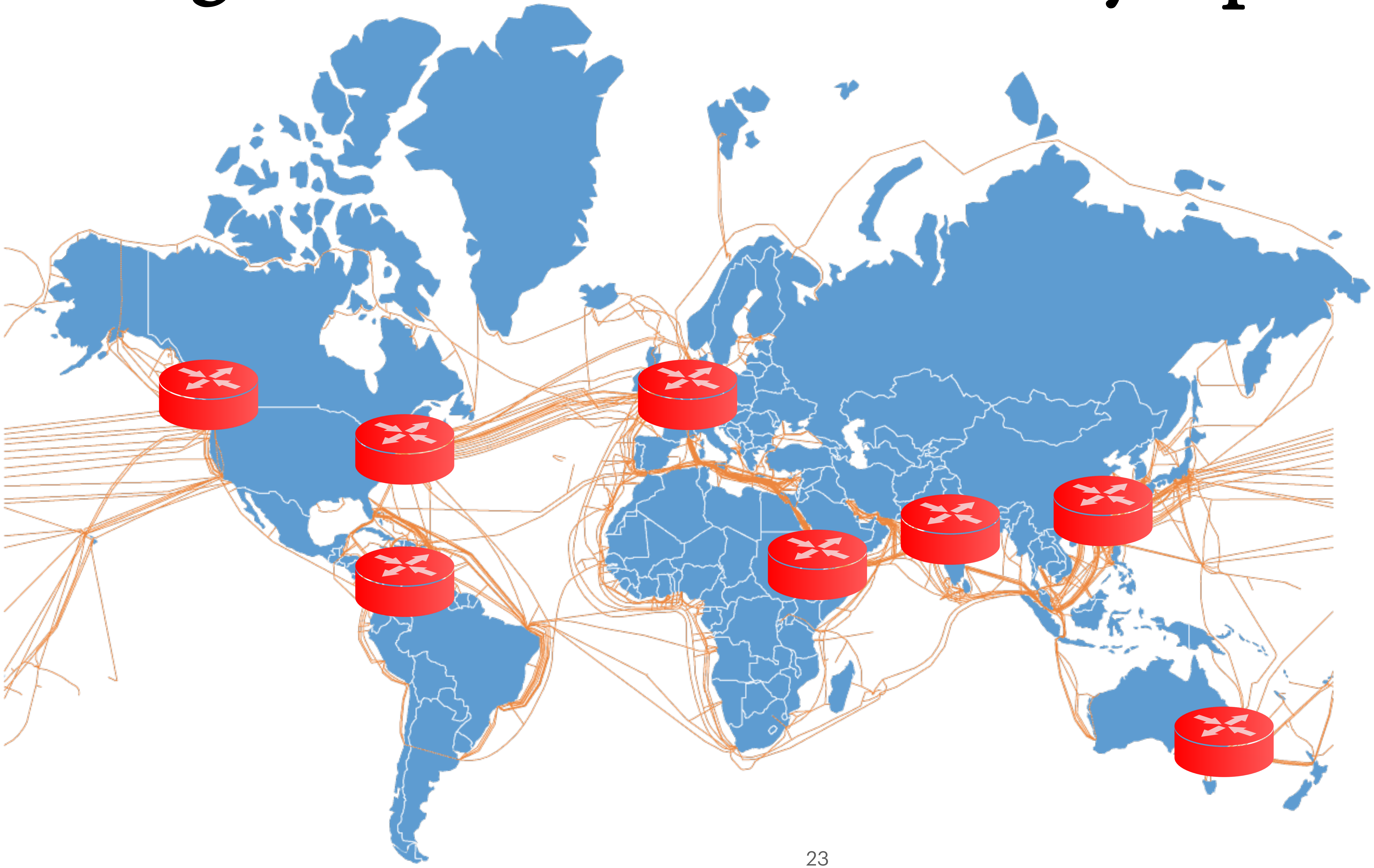


Long-haul network connectivity: optical fiber



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