NETMET 2020-2021
connectivity, latency, loss, geolocation

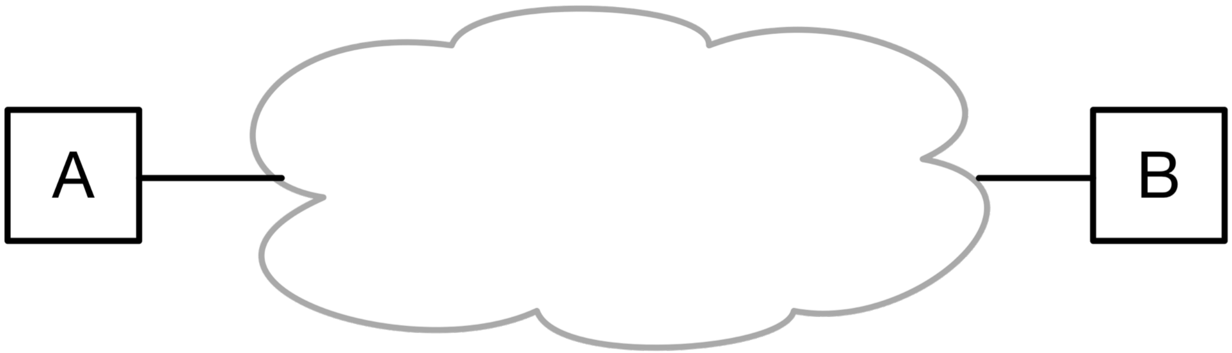
Timur Friedman

Outline

Connectivity, losses, and latency

- Ping
- Connectivity
- Losses
- Latency

Ping

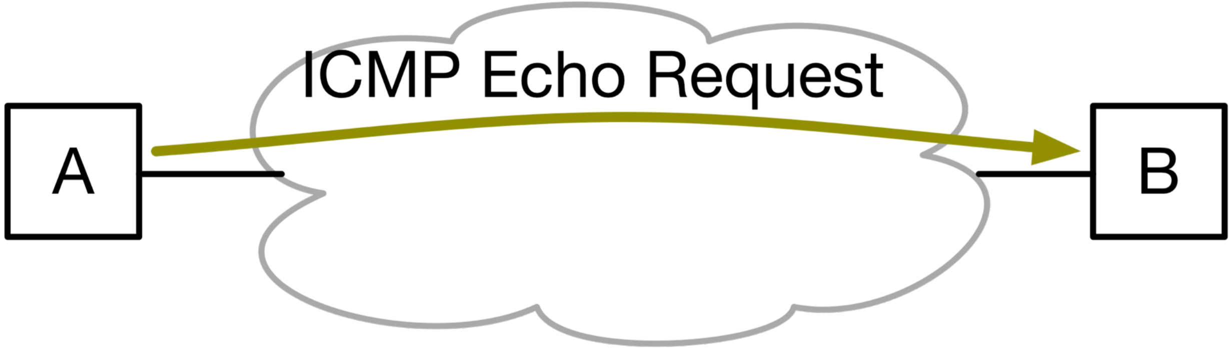


A series of packets and responses, to measure:

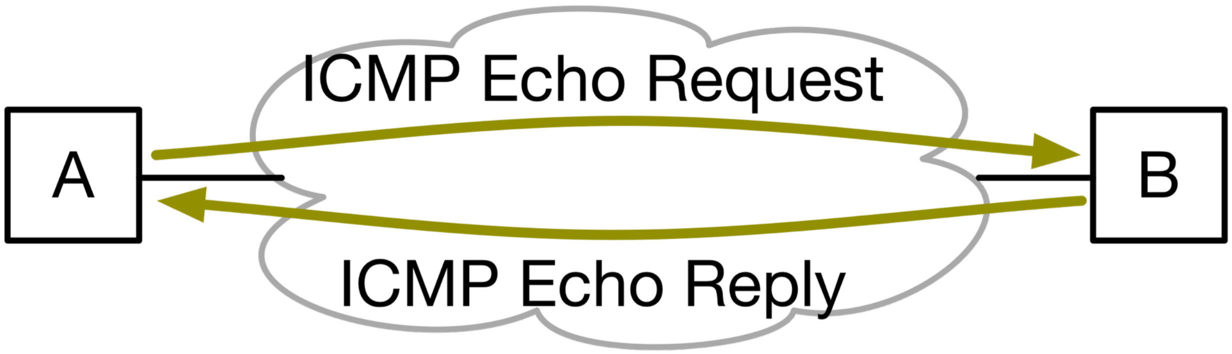
- connectivity
- loss rates
- latency

Ping

Created by Mike Muuss in 1983



Ping



RFC 1122: "Every host MUST implement an ICMP Echo server function that receives Echo Requests and sends corresponding Echo Replies."

```
$ ping www.example.com
PING www.example.com (93.184.216.34): 56 data bytes
64 bytes from 93.184.216.34: icmp_seq=0 ttl=54 time=89.080 ms
64 bytes from 93.184.216.34: icmp_seq=1 ttl=54 time=89.518 ms
64 bytes from 93.184.216.34: icmp_seq=2 ttl=54 time=91.680 ms
64 bytes from 93.184.216.34: icmp_seq=3 ttl=54 time=92.120 ms
^C
--- www.example.com ping statistics ---
4 packets transmitted, 4 packets received, 0.0% packet loss
round-trip min/avg/max/stddev = 89.080/90.600/92.120/1.319 ms
$
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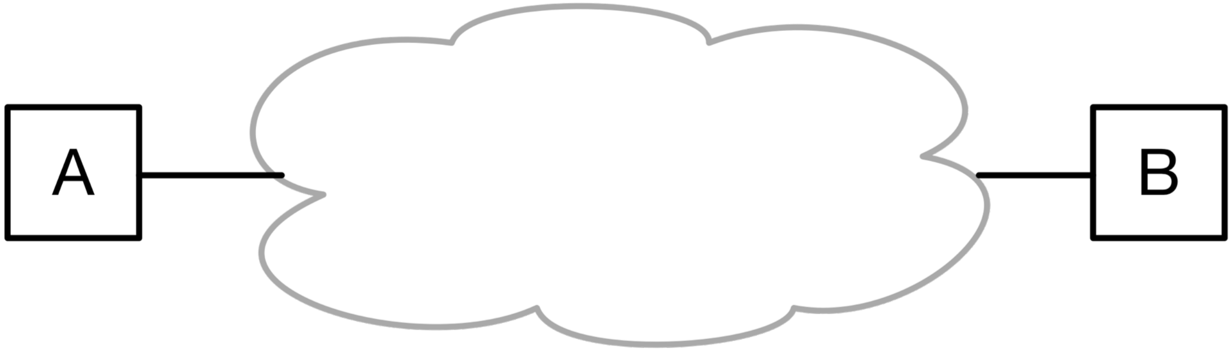
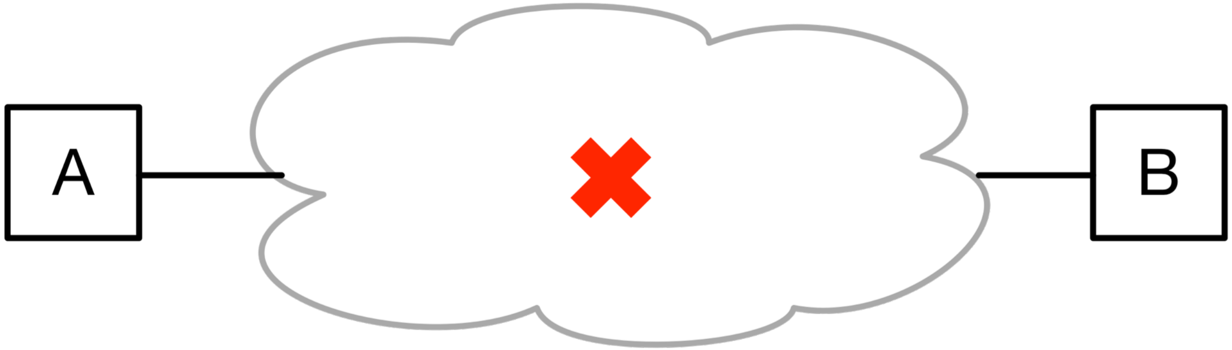
Connectivity



Connectivity or "reachability"

- can packets travel from A to B (and back)?

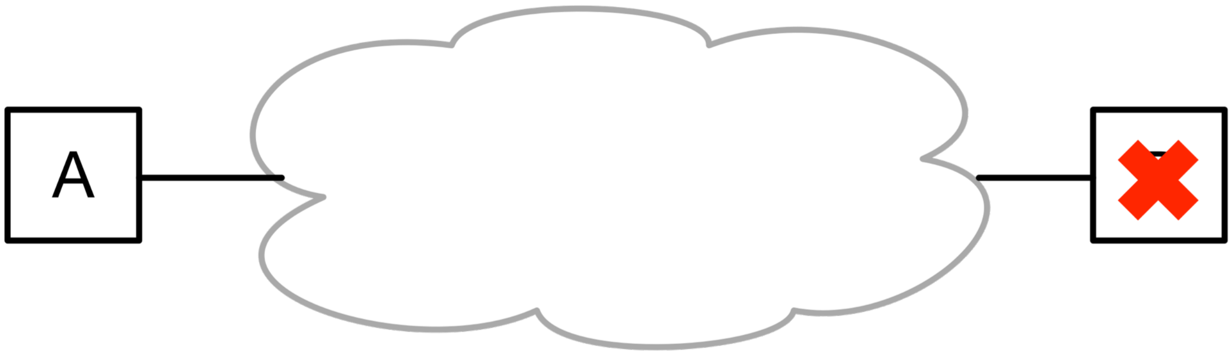
Connectivity



Some possible network problems

- link down
- congestion ➔ packet loss
- routing loop
- firewall or other middlebox

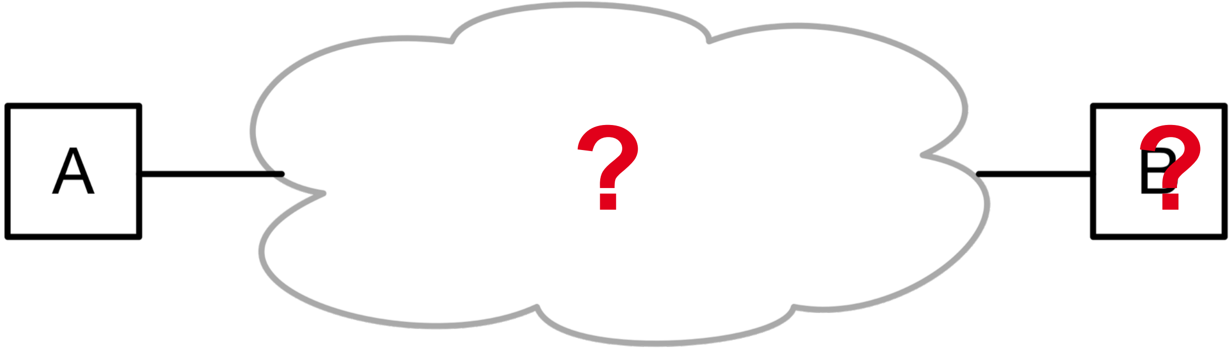
Connectivity



Some possible end-host problems

- host is down
- host running, network interface down
- host up, on network, but service not available

Connectivity



Troubleshooting connectivity

- Additional pings locally, elsewhere
- ICMP blocked?
  - check TCP connectivity
    with Telnet (e.g., port 22, port 80)
  - check UDP connectivity
    with UDP Traceroute (ICMP Port Unreachable)

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Losses

- A best effort network
- Causes of loss
  - Congestion
  - Medium errors
  - Routing loops
- Loss rates
- Conclusion

Losses

- **A best effort network**
- Causes of loss
  - Congestion
  - Medium errors
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Losses

- A best effort network
- Causes of loss
  - **Congestion**
    - ✓ Full buffers
    - ✓ Queue management (tail drop, RED or other)
  - Medium errors
  - Routing loops
- Loss rates
- Conclusion

Losses

- A best effort network
- Causes of loss
  - Congestion
  - **Medium errors**
    - ✓ Wireless: interference, multipath induced fading, etc.
    - ✓ Fiber optics, copper: lower rates
    - ✓ Individual bits ➔ corrupted packet
    - ✓ Burst of bits ➔ lost packet
    - ✓ Data link layer retransmission ➔ additional delays
  - Routing loops
- Loss rates
- Conclusion

Losses

- A best effort network
- Causes of loss
  - Congestion
  - Medium errors
  - **Routing loops**
    - ✓ TTL ➔ 0
- Loss rates
- Conclusion

Loss rates

loss rate	quality
below 0.1%	excellent
0.1% to 1%	good
1% to 2.5%	acceptable
2.5% to 5%	poor
5% to 12%	very poor
above 12%	bad

Source: PingER initiative at Stanford University, ICFA annual report 2015

- Loss rates to wealthier countries 0.01% to 0.1%
- Loss rates to poorer countries 0.1% to 1%
- Trend worldwide to lower loss rates
  - Very roughly an order of magnitude decrease over a decade

Losses

- A best effort network
- Causes of loss
  - Congestion
  - Medium errors
  - Routing loops
- Loss rates
- **Conclusion**
  - ✓ Bursty losses ➔ 2-state Markov model
    i.e., "Gilbert Elliott" model, alternating between:
  - – Burst state: high loss probability
  - – Gap state: low loss probability

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  - Introduction
  - Components
  - Clocks
  - Tools
  - Use for geolocation

Latency - Introduction

- **Latency matters**
  - Web
  - CDNs
  - Financial transactions
  - Voice over IP and interactive video
  - Online games, peer-to-peer
- Two definitions of latency
  - One-way delay
  - Round-trip times (RTTs)

Latency matters

Comparing a 0.4 second page load to a 0.9 second page load:

> *Half a second delay caused a 20% drop in traffic. Half a second delay killed user satisfaction... Being fast really matters... "Users really respond to speed."*

Marissa Meyer, VP Google in 2006

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  - **One-way delay**
  - Round-trip times (RTTs)

A

A

12:00:00.000

12:00:00.010

12:00:00.020

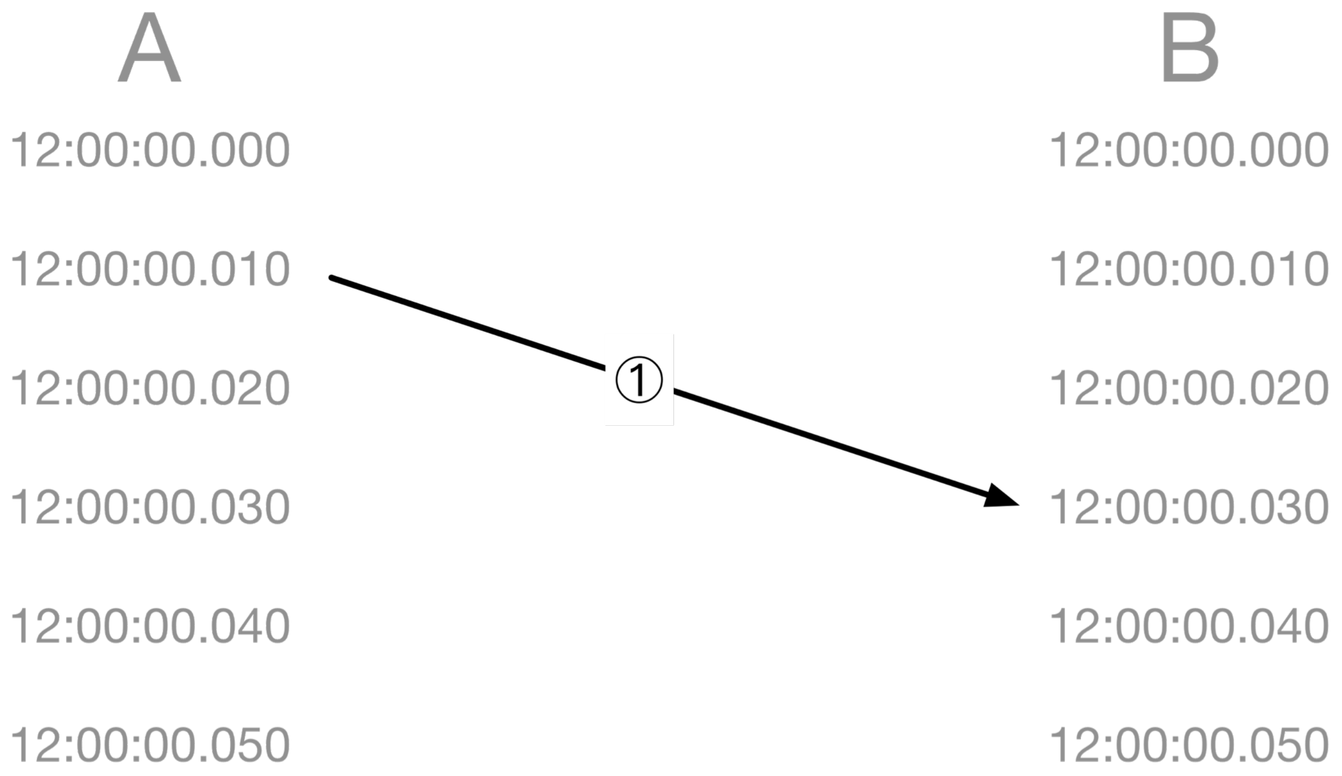
12:00:00.030

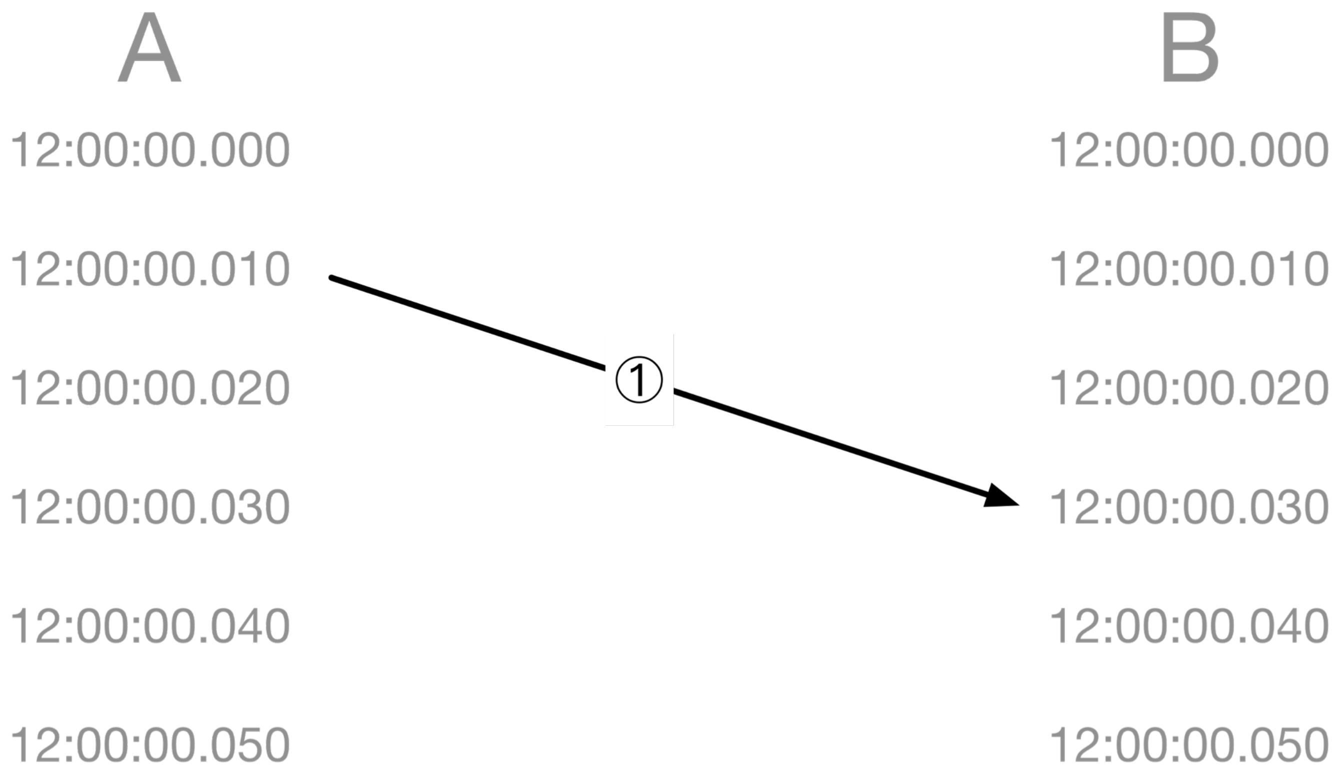
12:00:00.040

12:00:00.050

A	B
12:00:00.000	
12:00:00.010	
12:00:00.020	
12:00:00.030	
12:00:00.040	
12:00:00.050	

A	B
12:00:00.000	12:00:00.000
12:00:00.010	12:00:00.010
12:00:00.020	12:00:00.020
12:00:00.030	12:00:00.030
12:00:00.040	12:00:00.040
12:00:00.050	12:00:00.050


A
B
12:00:00.000
12:00:00.000
12:00:00.010
12:00:00.010
①
12:00:00.020
12:00:00.020
12:00:00.030
12:00:00.030
12:00:00.040
12:00:00.040
12:00:00.050
12:00:00.050



L_1 = 30 ms - 10 ms = 20 ms

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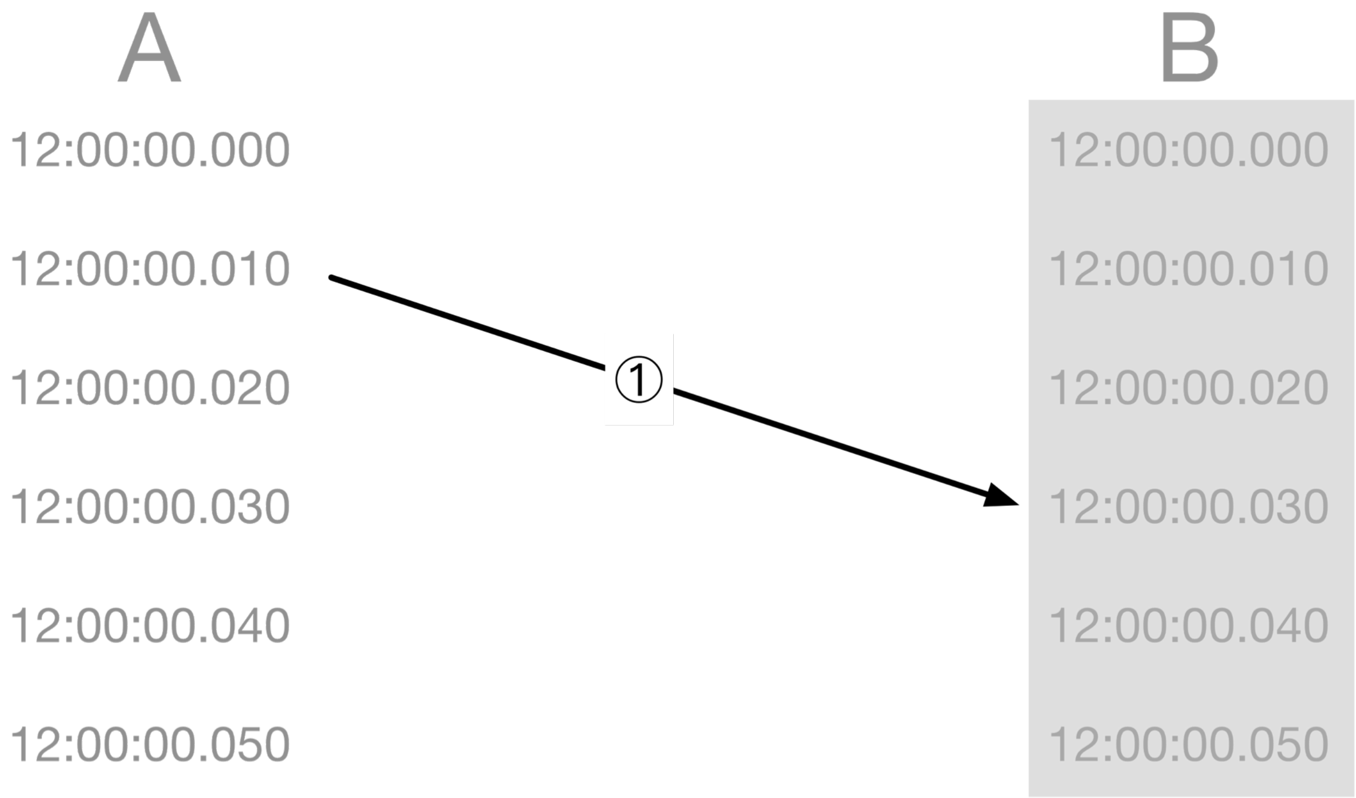
  - **Round-trip times (RTTs)**



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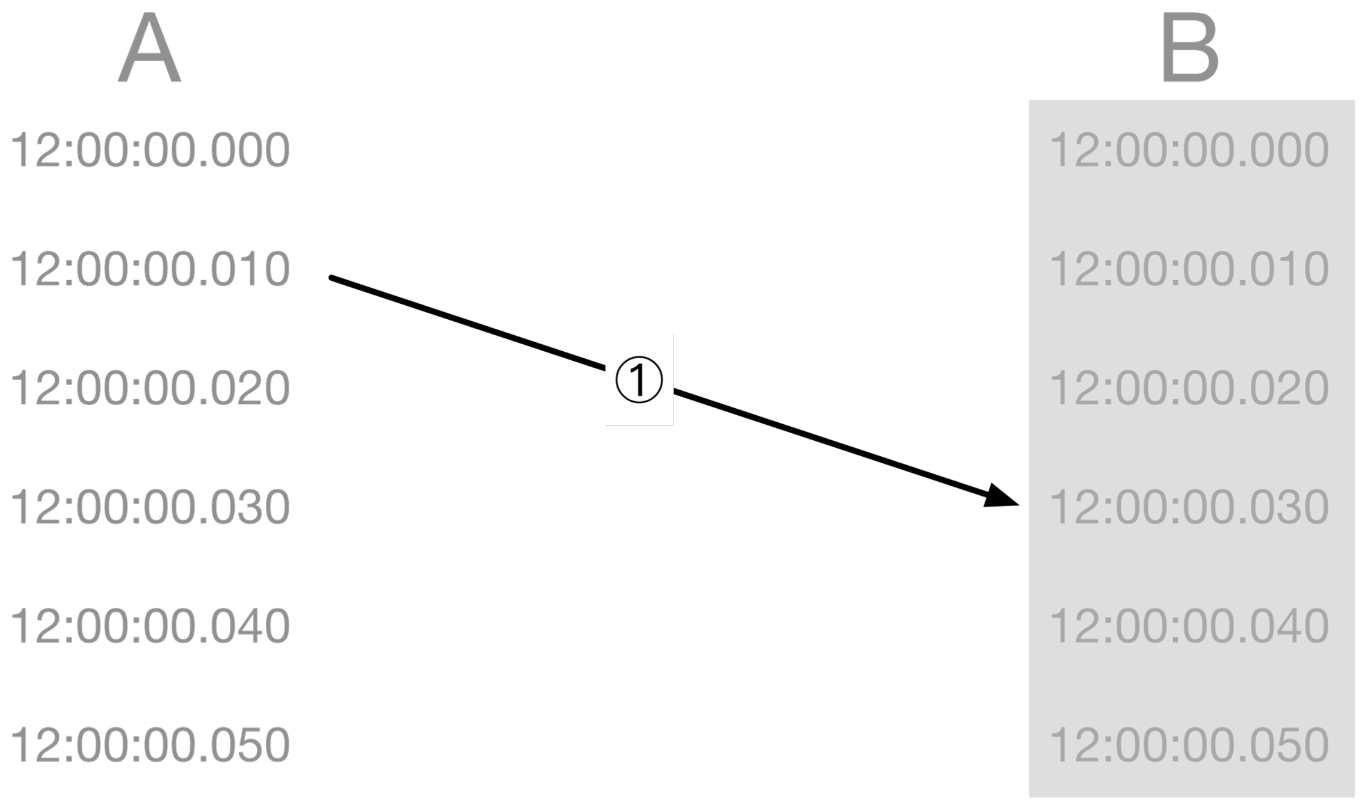
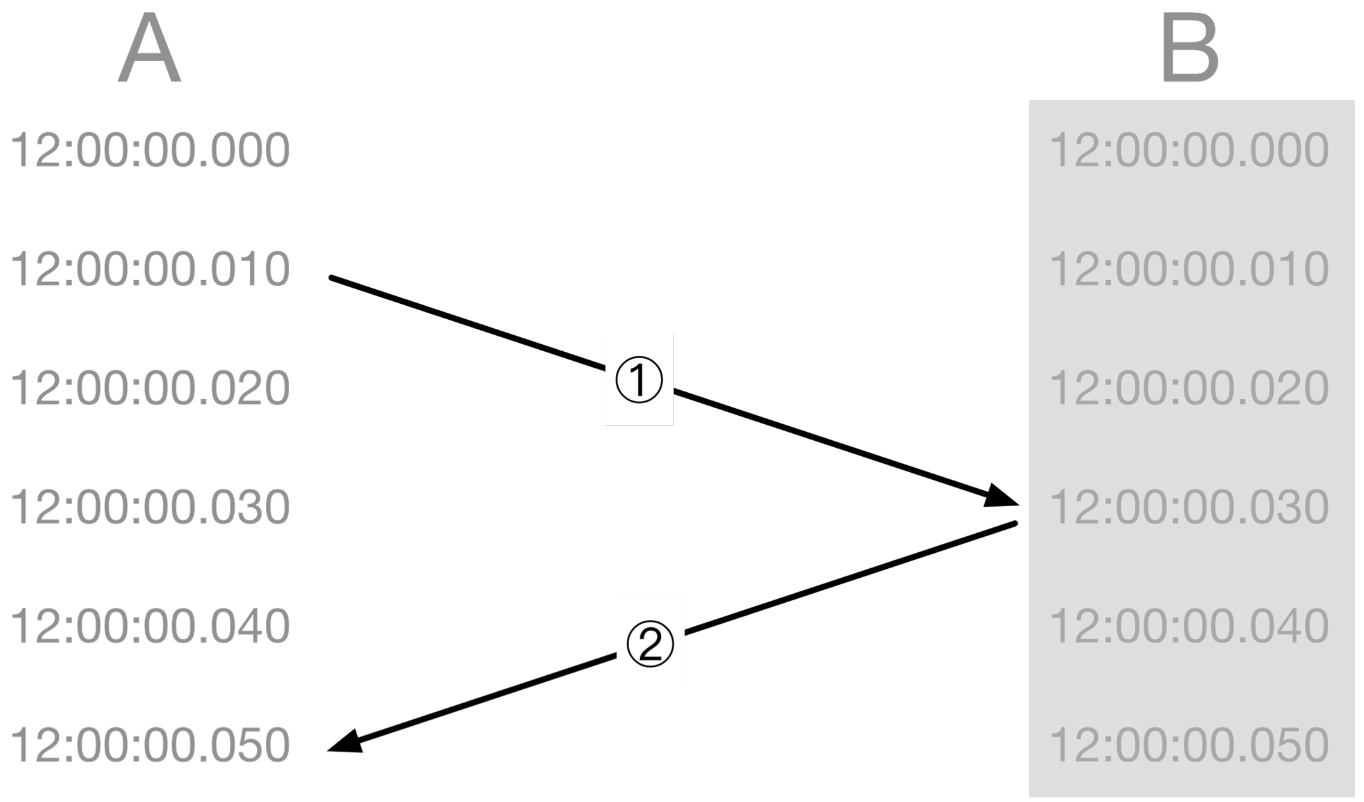


(L_1 = 30 ms - 10 ms = 20 ms)



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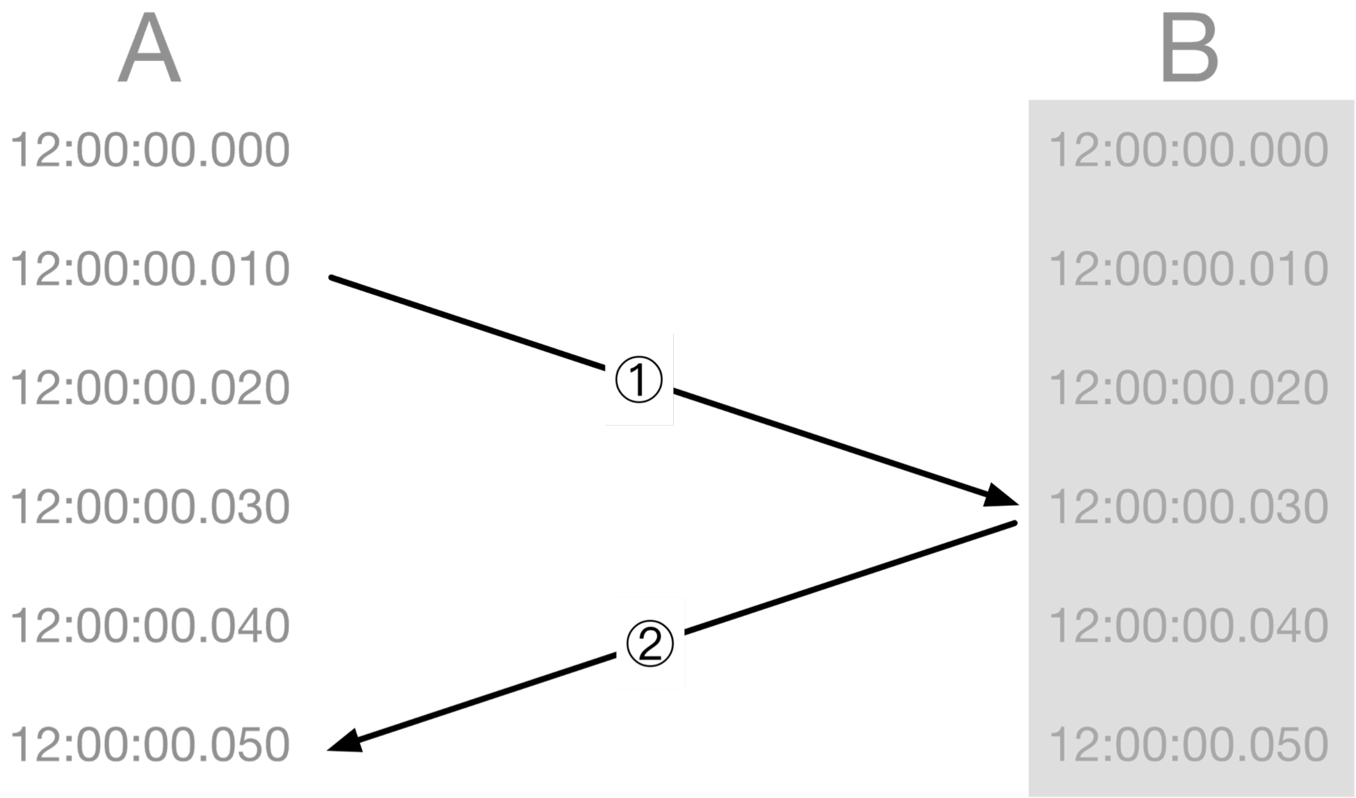
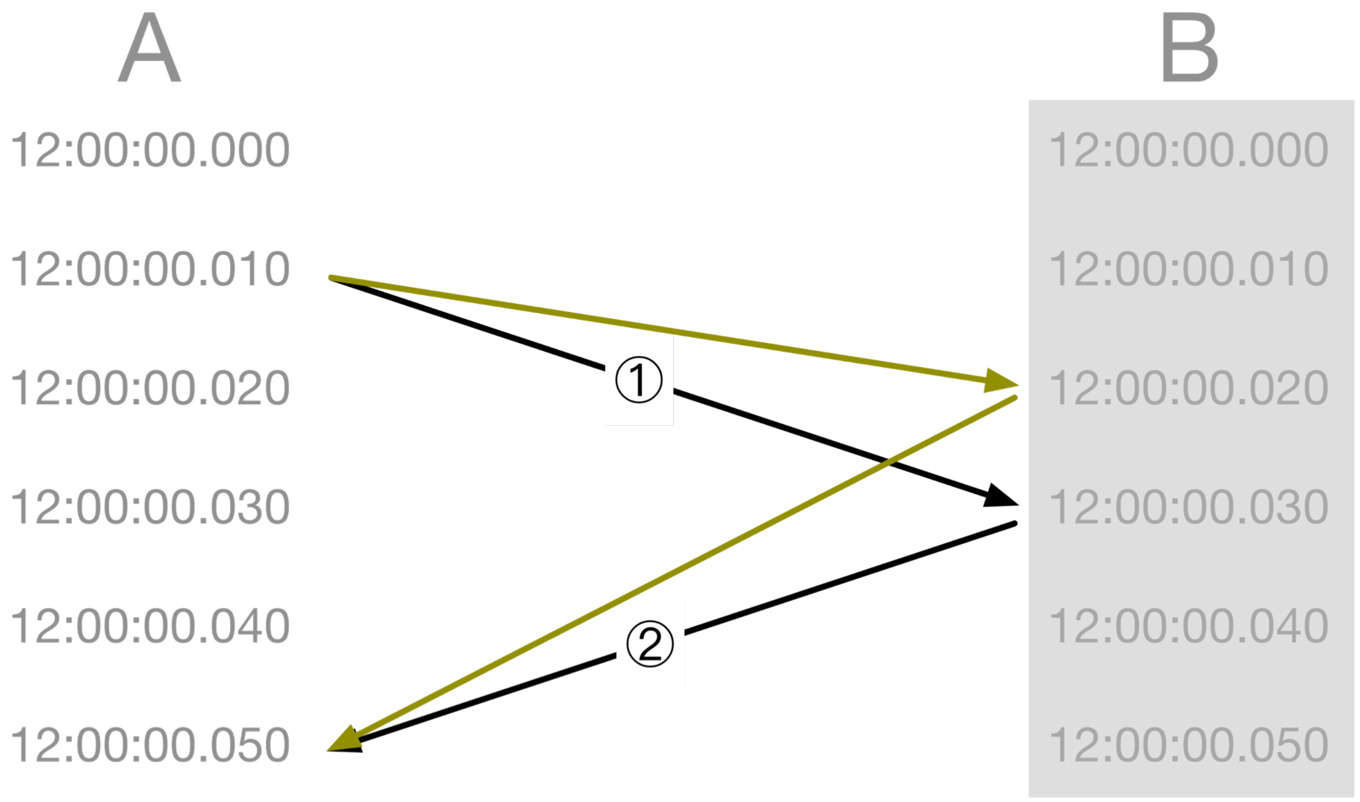


(L_1 = 30 ms - 10 ms = 20 ms)

L_1 = ½(50 ms - 10 ms) = 20 ms?



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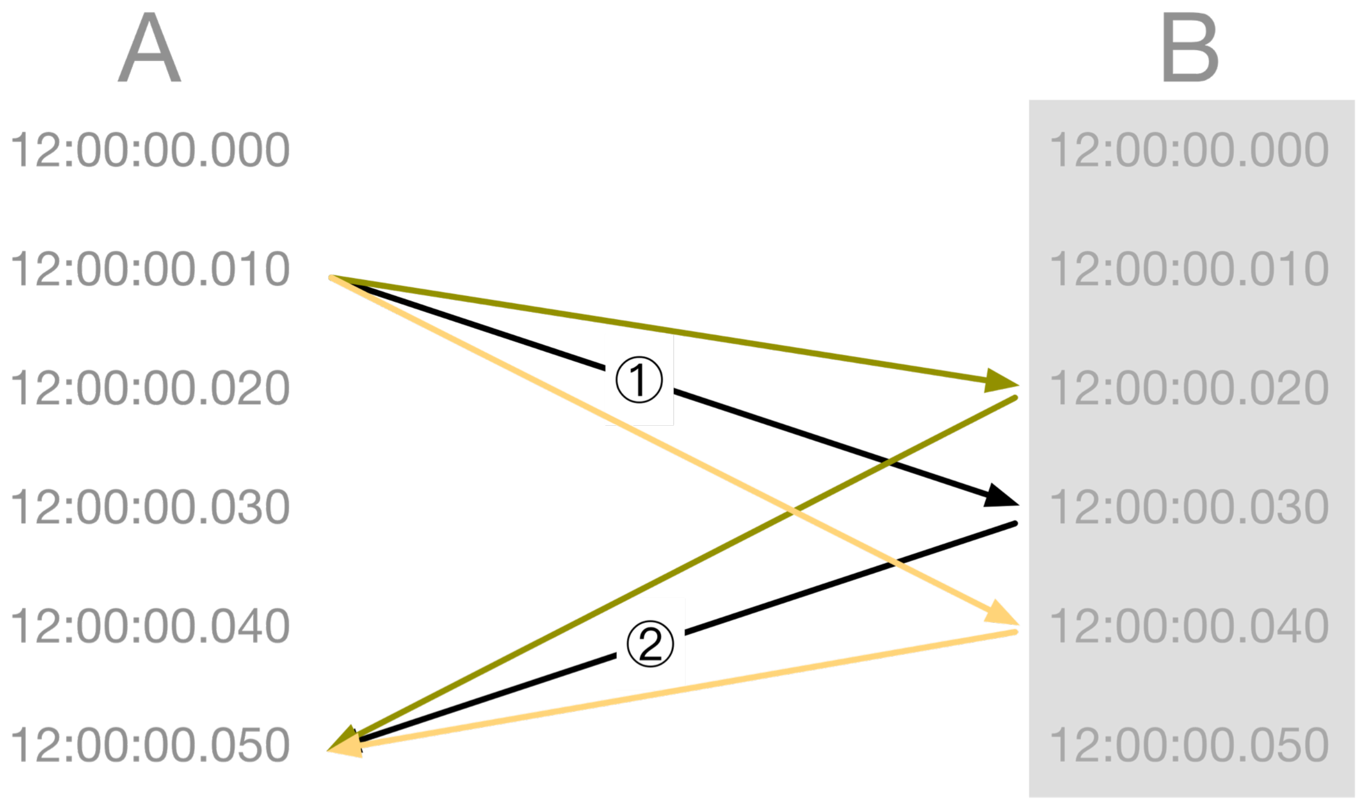

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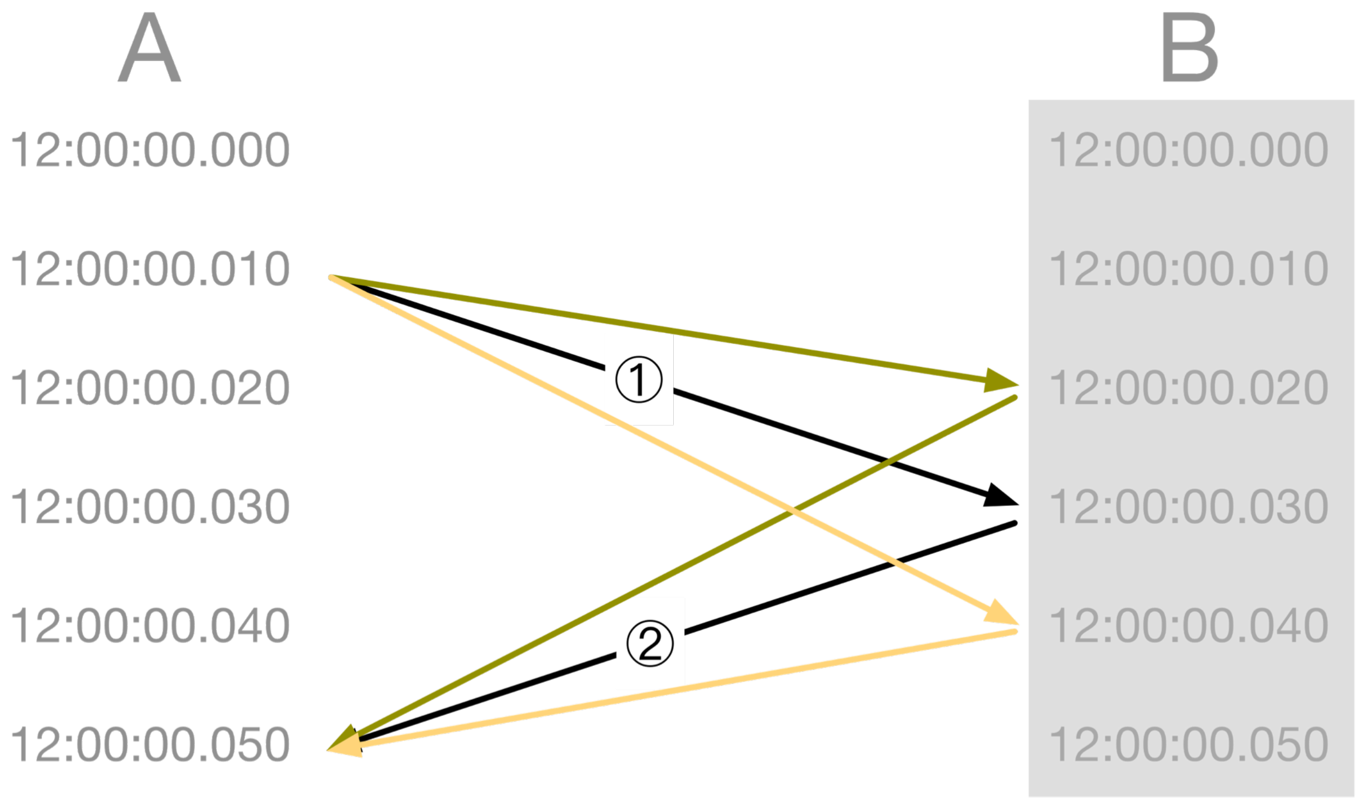
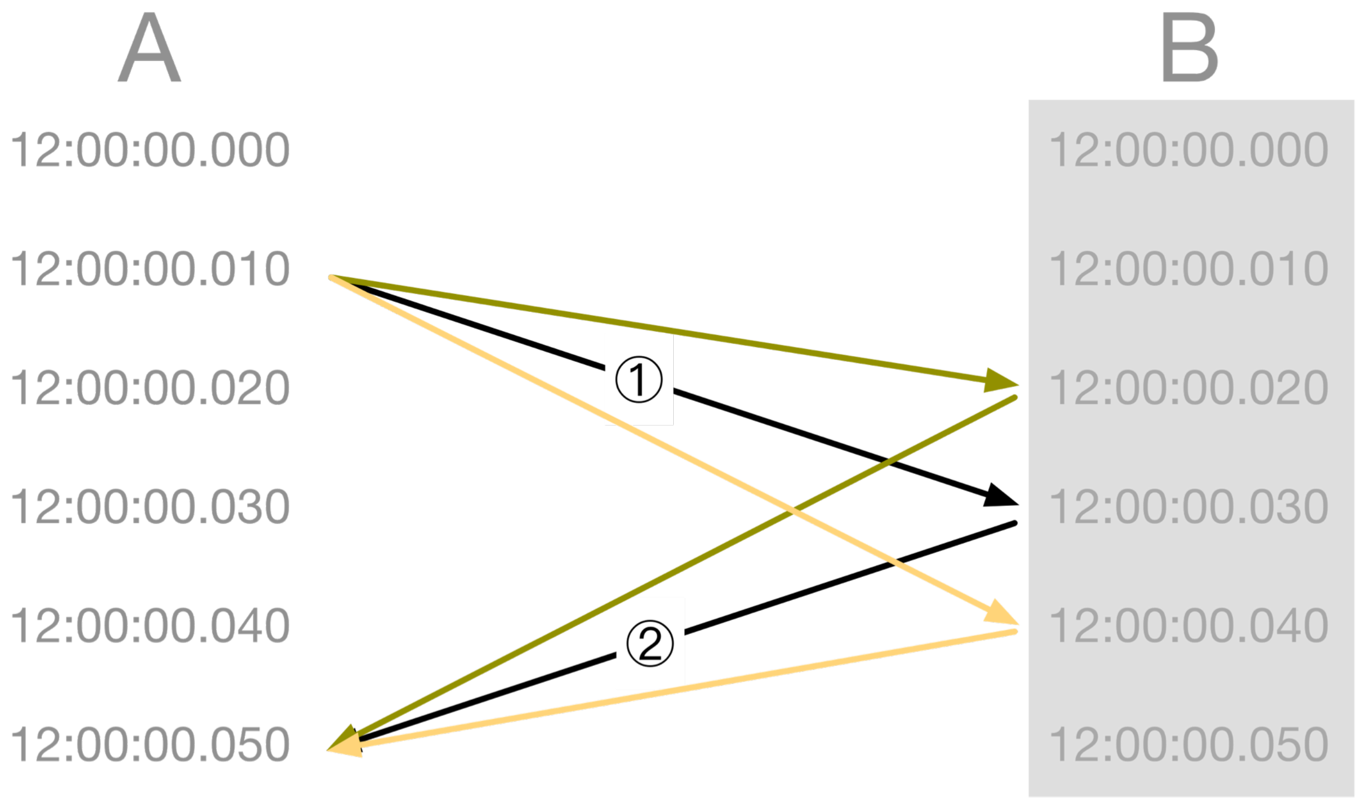


(L_1 = 30 ms - 10 ms = 20 ms)

$\cancel{L_1 = \frac{1}{2}(50\text{ ms} - 10\text{ ms}) = 20\text{ ms?}}$



(L_1 = 30 ms - 10 ms = 20 ms)

~~L_1 = ½(50 ms - 10 ms) = 20 ms?~~

RTT = 50 ms - 10 ms = 40 ms

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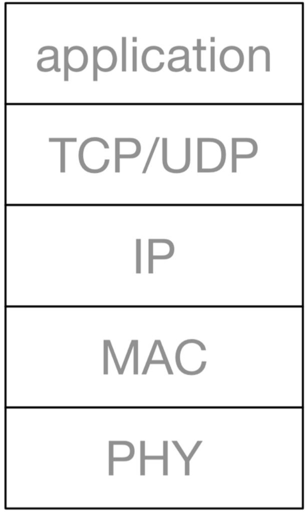
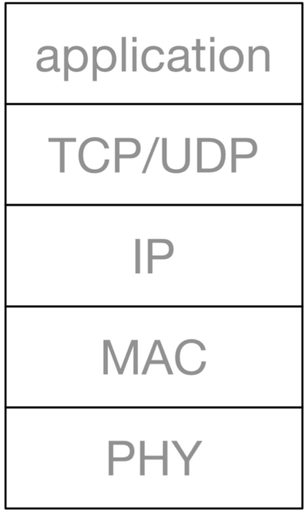
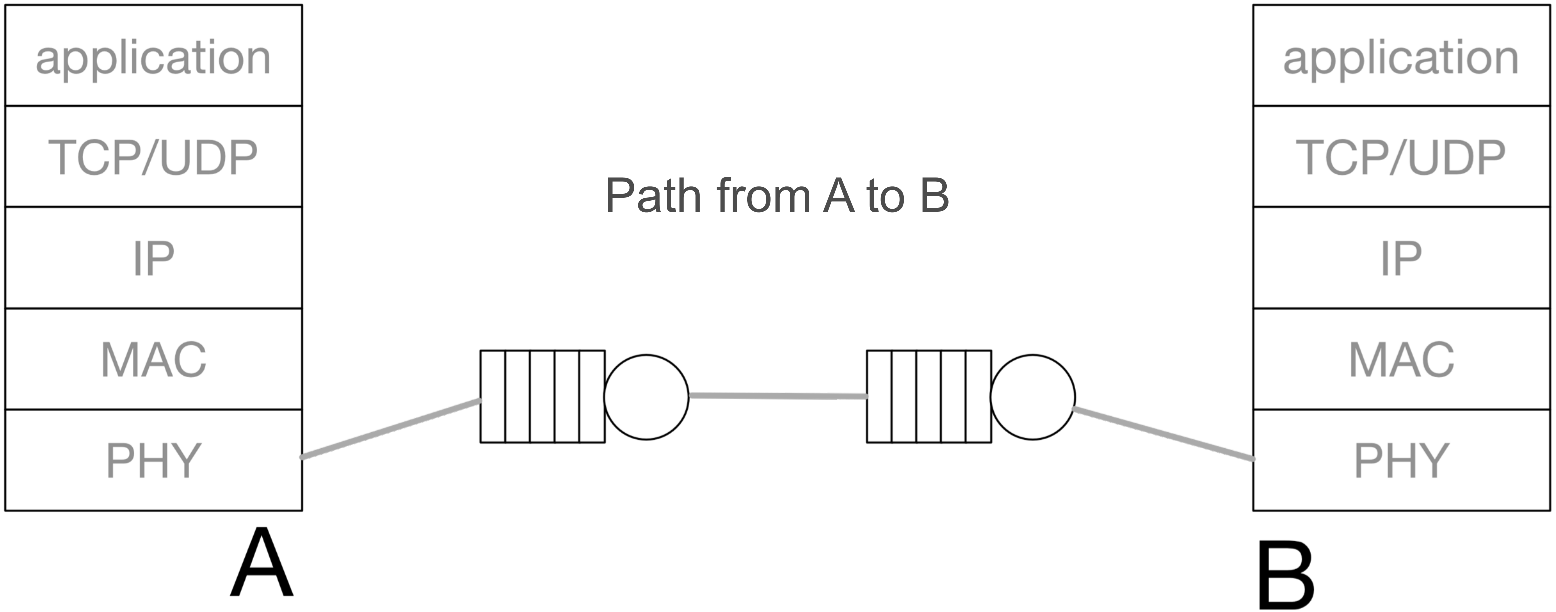
ICMP at this layer


application
TCP/UDP
IP
MAC
PHY

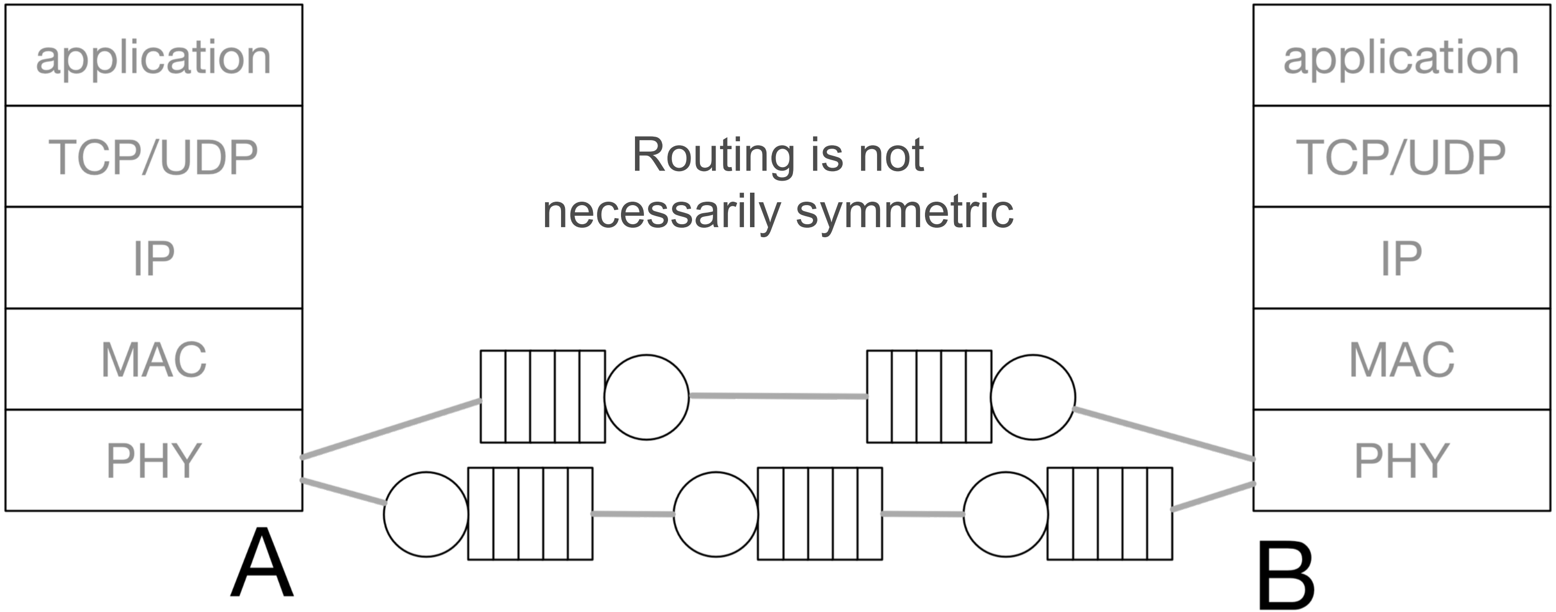
A


application
TCP/UDP
IP
MAC
PHY

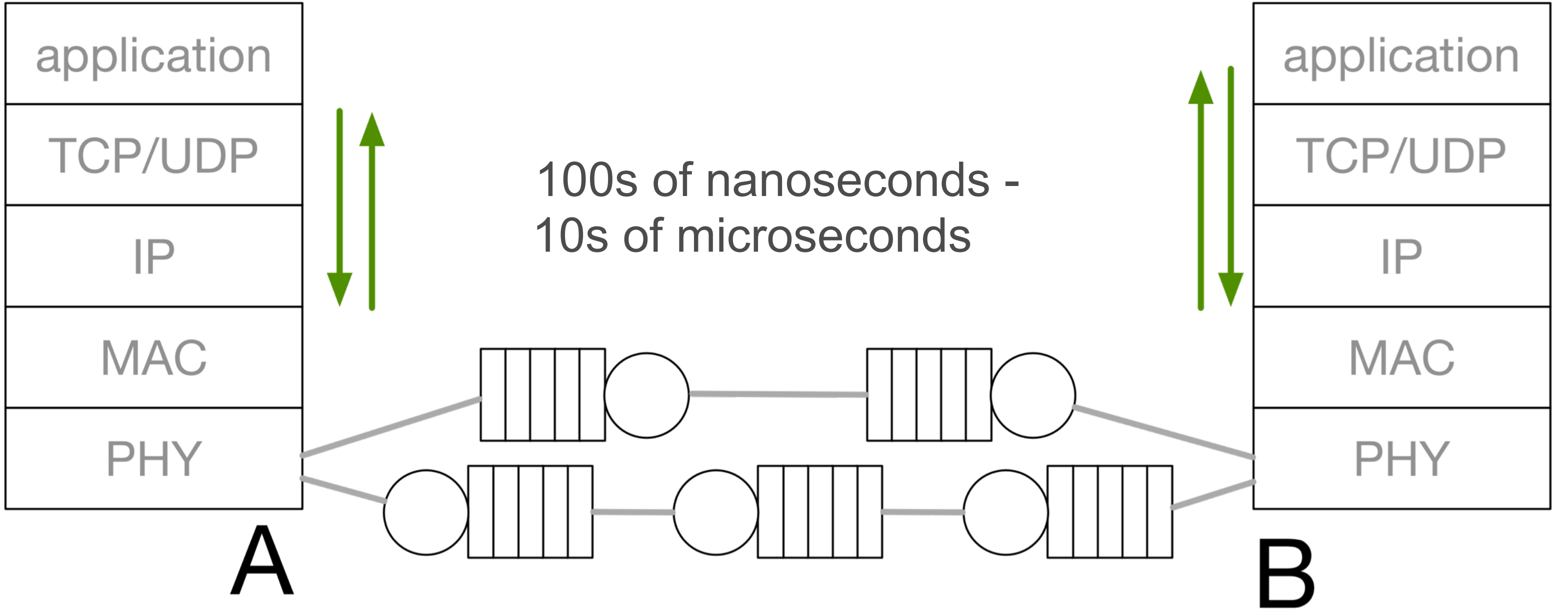
B


application
TCP/UDP
IP
MAC
PHY
A
Path from A to B
application
TCP/UDP
IP
MAC
PHY
B

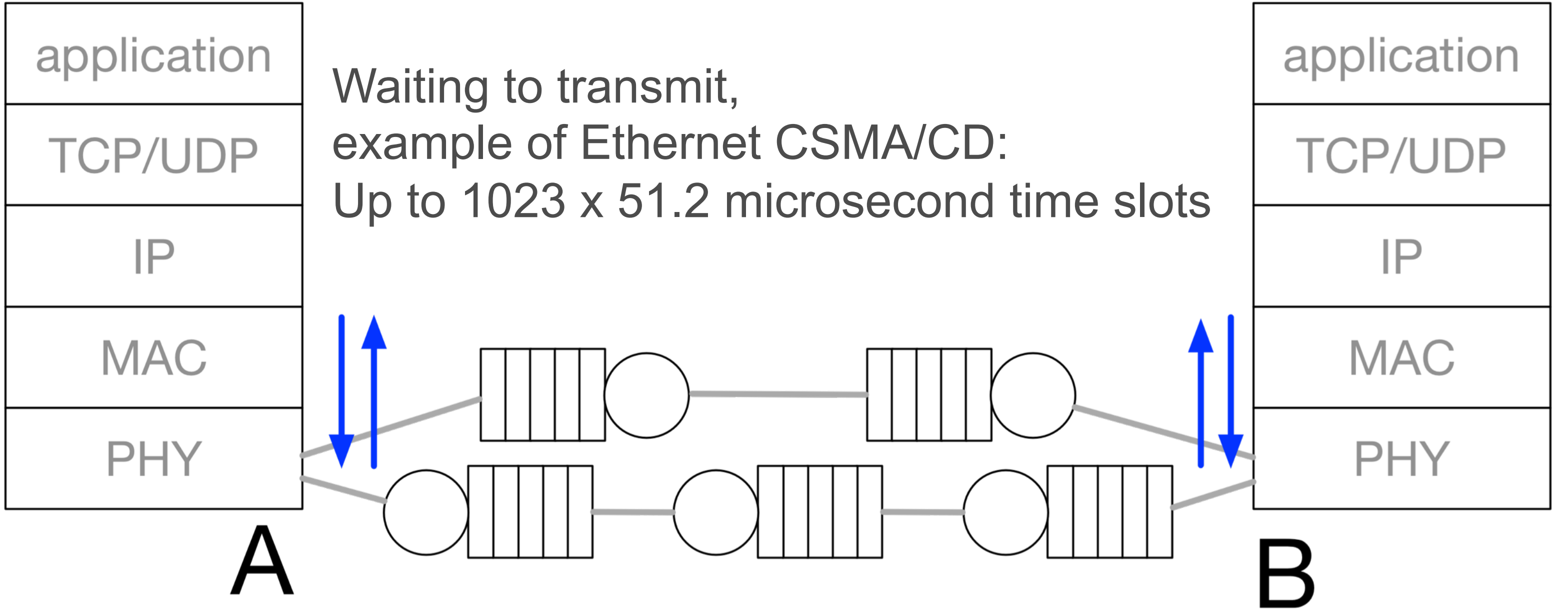
Routing is not necessarily symmetric



Processing delay



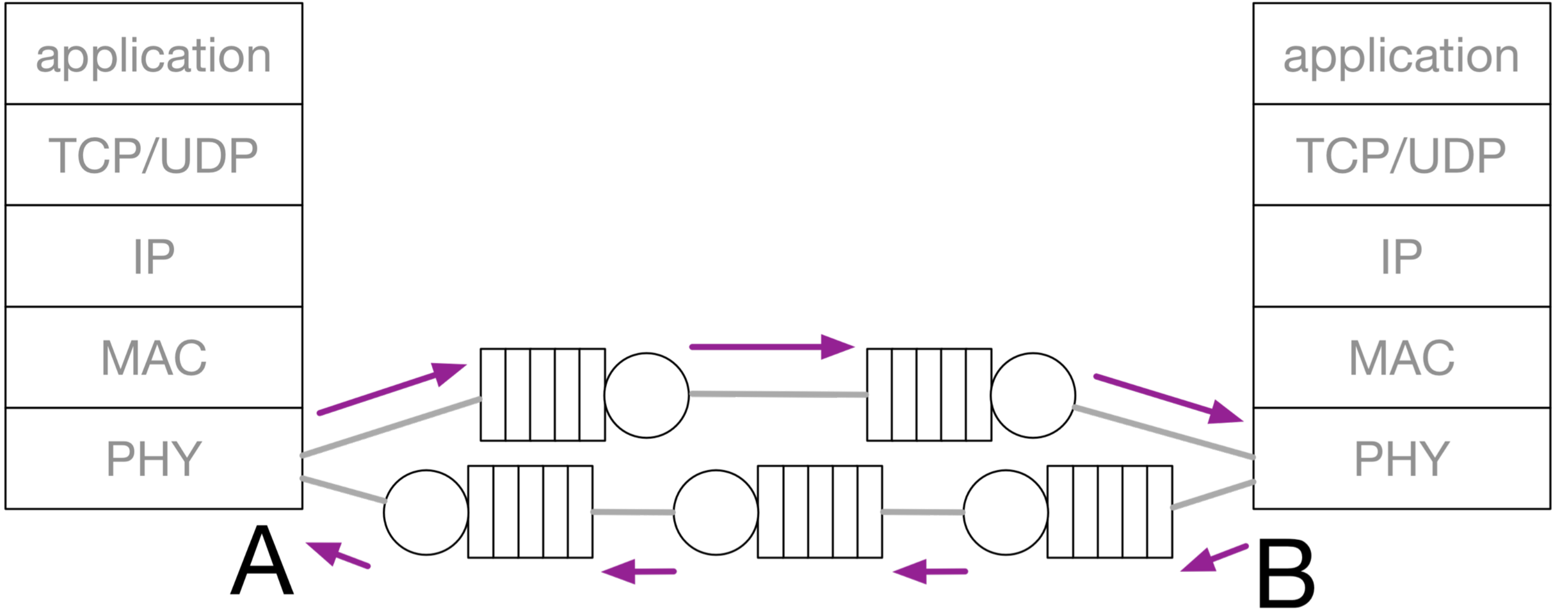
Transmission delay



Waiting to transmit,
example of Ethernet CSMA/CD:
Up to 1023 x 51.2 microsecond time slots

Transmitting:
9216 bytes jumbo Ethernet frame: 74 microseconds at 1 Gbps
1526 byte Ethernet frame: 1.2 milliseconds at 10 Mbps

Propagation delay



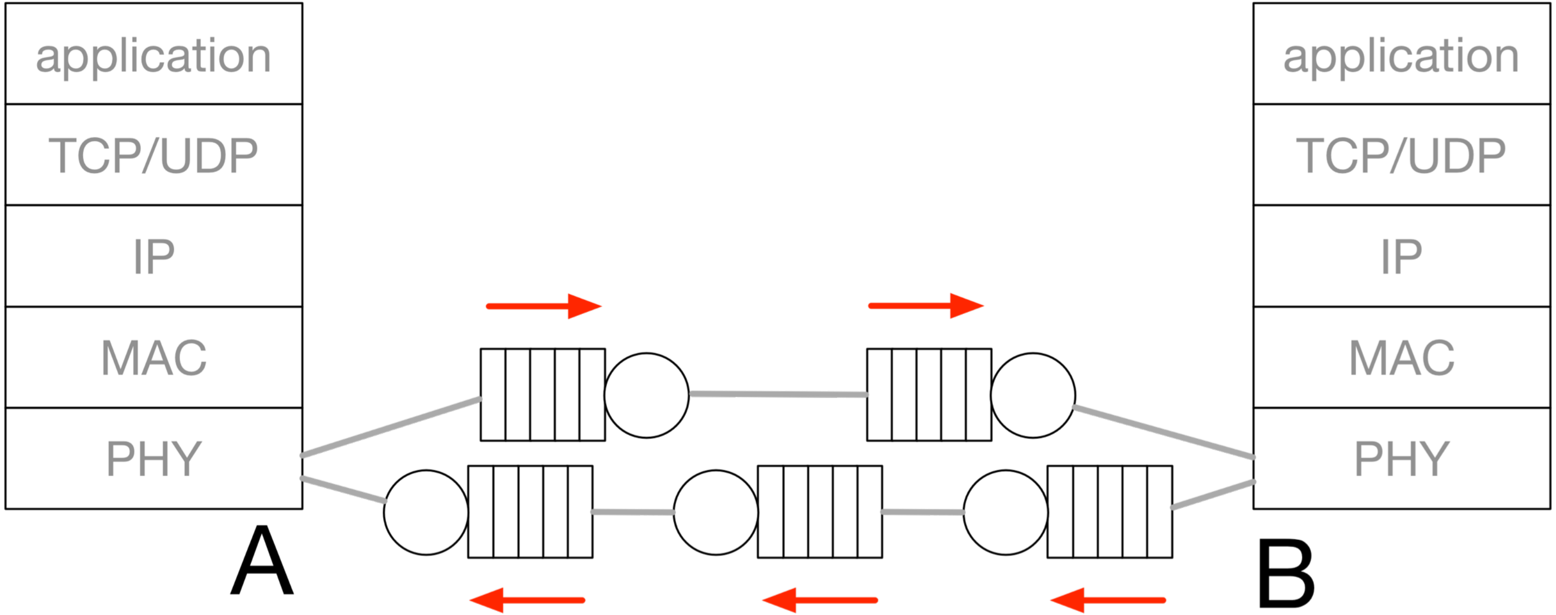
Speed of light: 300,000 km/sec

- To geostationary satellite and back: 240 milliseconds

Optical fiber at 2/3 speed of light

- Milliseconds within country
- 100 milliseconds halfway around the world

Queueing delay



- Unloaded network: queueing delay almost zero
- Large buffers: 250 milliseconds not unusual, up to six seconds observed ("bufferbloat")

Latency components

- Processing
  - Hundreds of nanoseconds to tens of microseconds
- Transmission
  - Tens or hundreds of microseconds, plus milliseconds for CSMA/CD backoff
- Propagation
  - A fraction of a millisecond to a couple of hundred milliseconds (one way)
- Queueing
  - Up to several seconds due to "bufferbloat"
  - Ideally, no more than a couple of milliseconds

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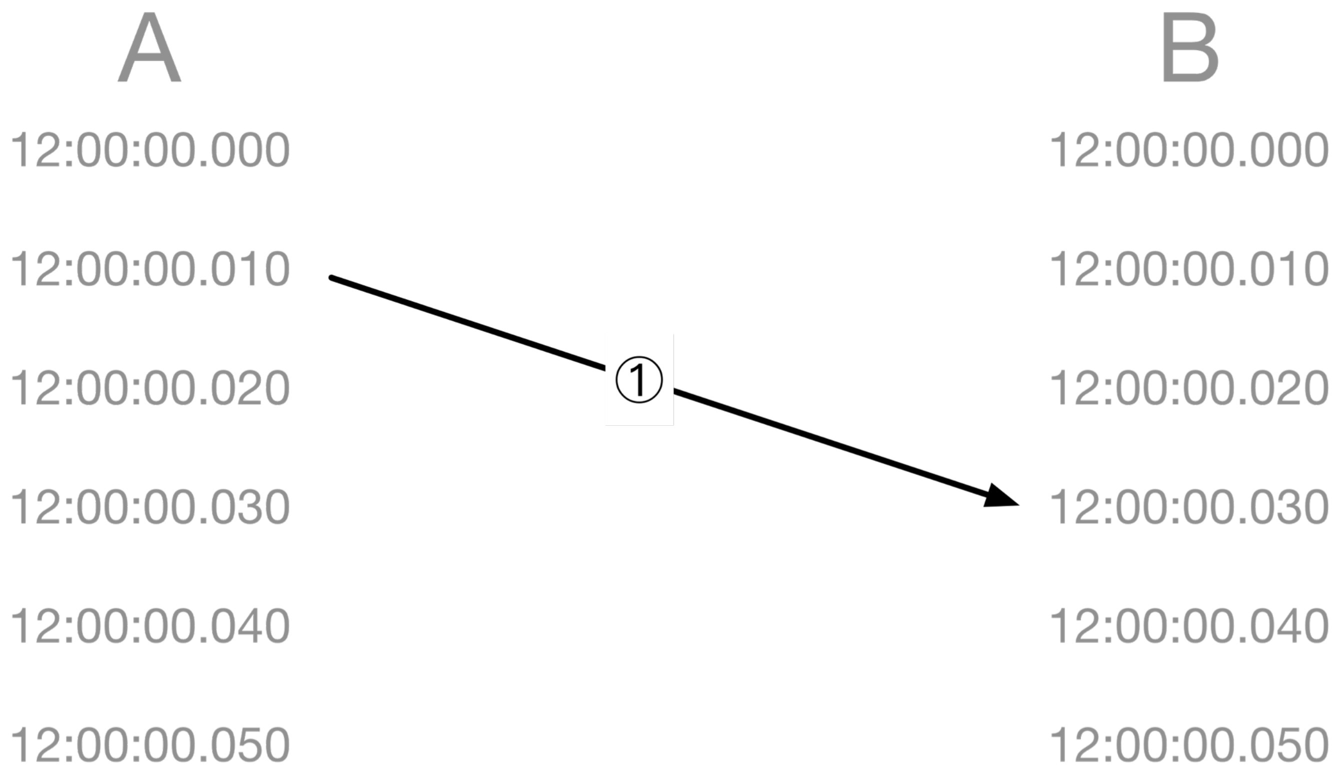
Latency - Clocks

- **Clock offset**
- Clock skew
- Clock drift
- Conclusion

Clock offset

RFC 2330 Framework for IP Performance Metrics

- Offset
  - Offset = difference between clock's time and true time
  - Relative offset = difference between two clocks' times



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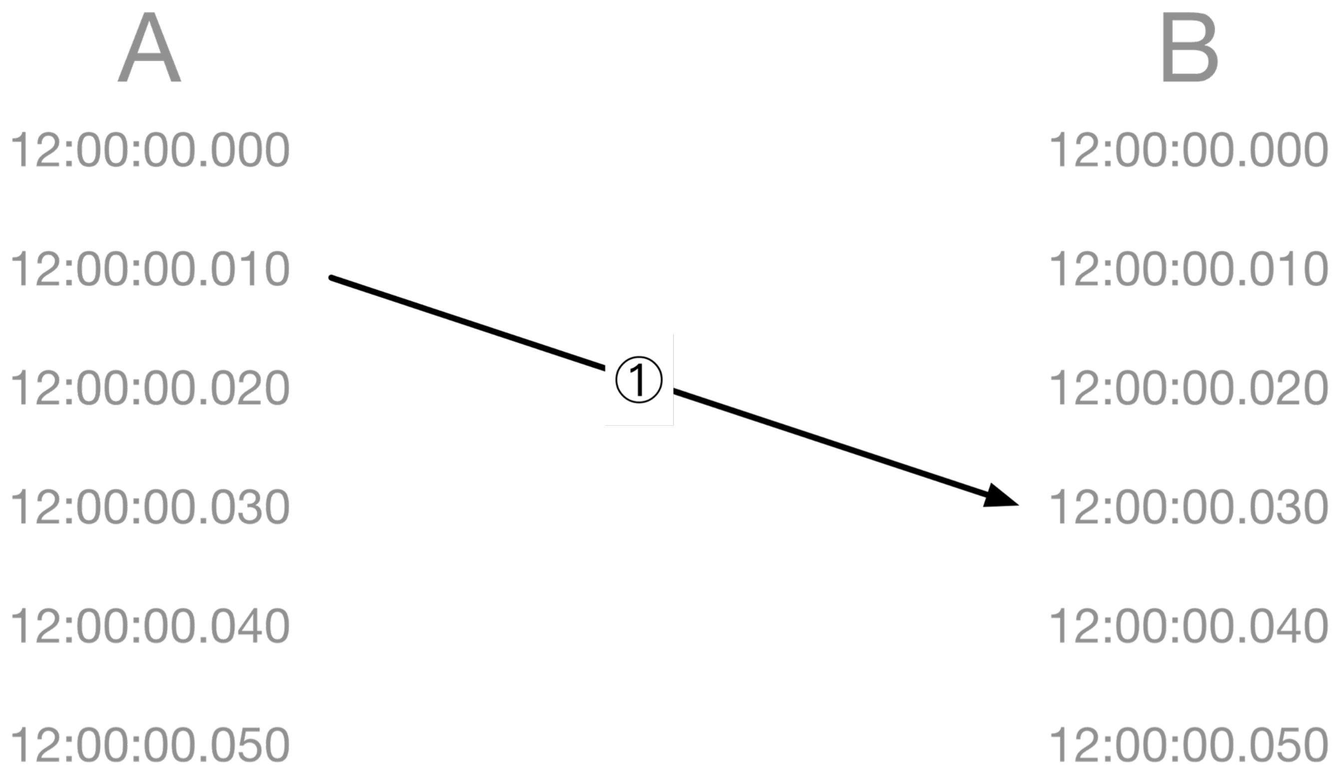

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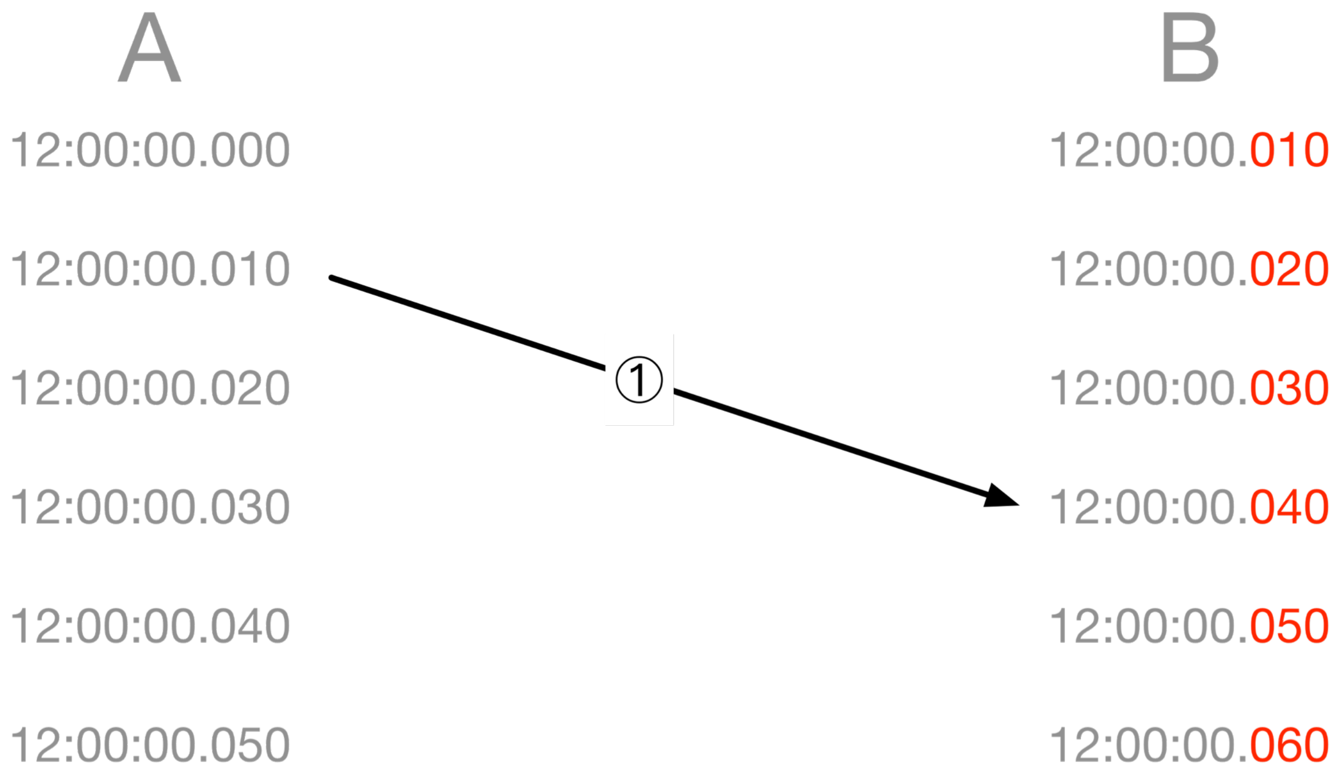


L_1 = 30 ms - 10 ms = 20 ms?

L_1 = 40 ms - 10 ms = 30 ms?

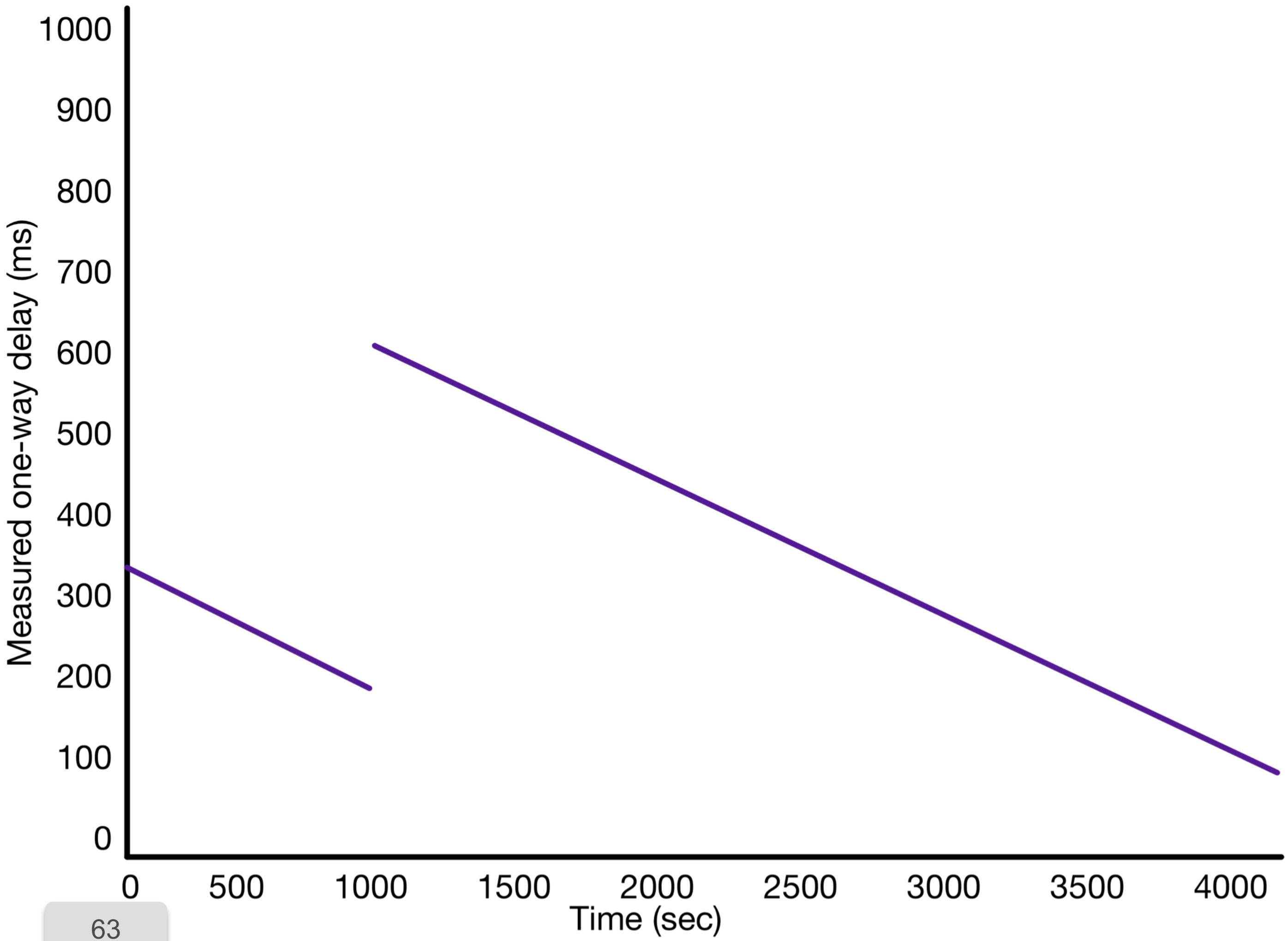
Latency - Clocks

- Clock offset
- **Clock skew**
- Clock drift
- Conclusion

Clock skew

RFC 2330 Framework for IP Performance Metrics

- Offset
  - Offset = difference between clock's time and true time
  - Relative offset = difference between two clocks' times
- Skew is the first derivative of offset
  - Skew = difference in frequency between clock and true time
  - Relative skew = difference in frequency between two clocks


Measured one-way delay (ms)
1000
900
800
700
600
500
400
300
200
100
0
0
500
1000
1500
2000
2500
3000
3500
4000
Time (sec)

Clock drift

RFC 2330 Framework for IP Performance Metrics

- Offset
  - Offset = difference between clock's time and true time
  - Relative offset = difference between two clocks' times
- Skew is the first derivative of offset
  - Skew = difference in frequency between clock and true time
  - Relative skew = difference in frequency between two clocks
- Drift is the second derivative of offset
  - Drift = the rate at which the clock's frequency is changing with respect to true time
  - Relative drift = rate at which the difference in frequency is changing

Latency - Clocks

- Clock offset
- Clock skew
- Clock drift
- **Conclusion**
  - ✓ GPS synchronization
    - accuracy 10 to 100 nanoseconds
    - needs GPS receiver, clear view of sky
  - ✓ NTP synchronization: accuracy 1 to 100 milliseconds

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Latency - Tools

- **Ping**
- tcptrace
- OWAMP

Latency - Tools

- Ping
- **tcptrace**
- OWAMP

http://www.tcptrace.org/

measure near the sender

Latency - Tools

- Ping
- tcptrace
- **OWAMP**

http://software.internet2.edu/owamp/

OWAMP RFC 4656
owampd + owping

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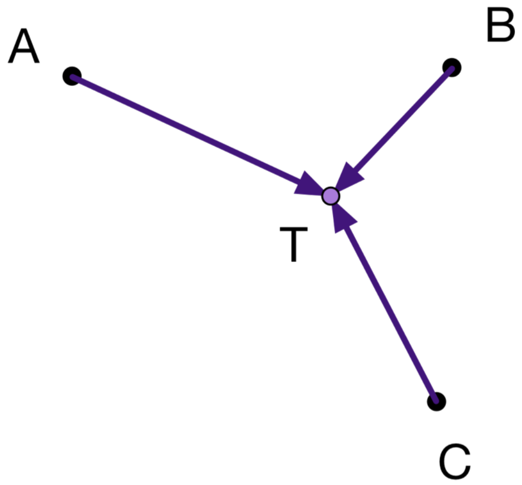
Geolocation

- **Reasons for geolocation**
  - ✓ Intellectual property owners to control delivery (e.g., BBC iPlayer)
  - ✓ Advertisers to target content
  - ✓ Security professionals to monitor communications
- Multilateration
- Anycast

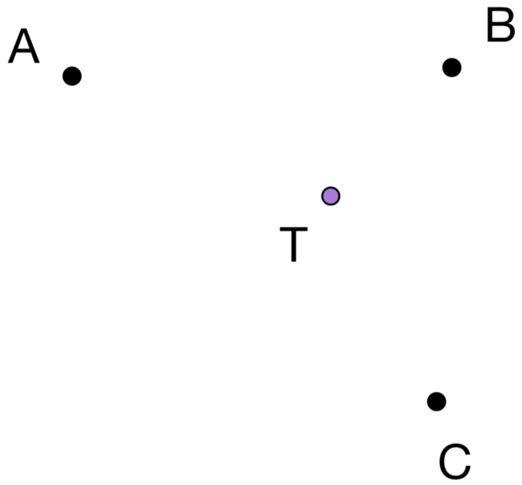
Multilateration

Triangulation



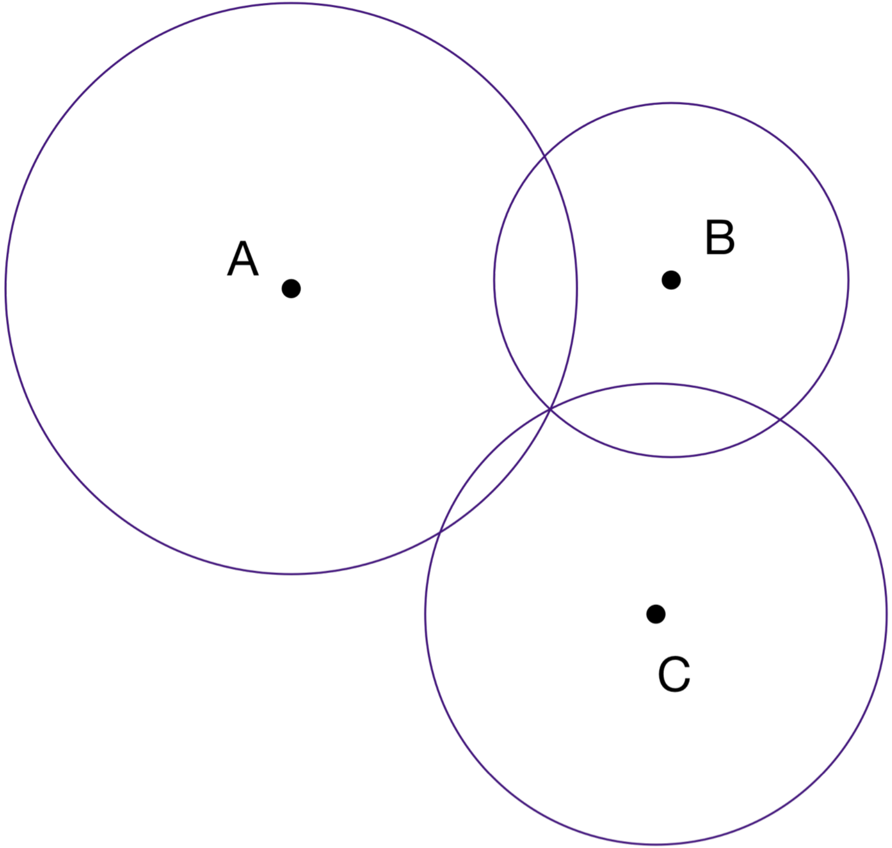
Multilateration

Triangulation ➔ Multilateration

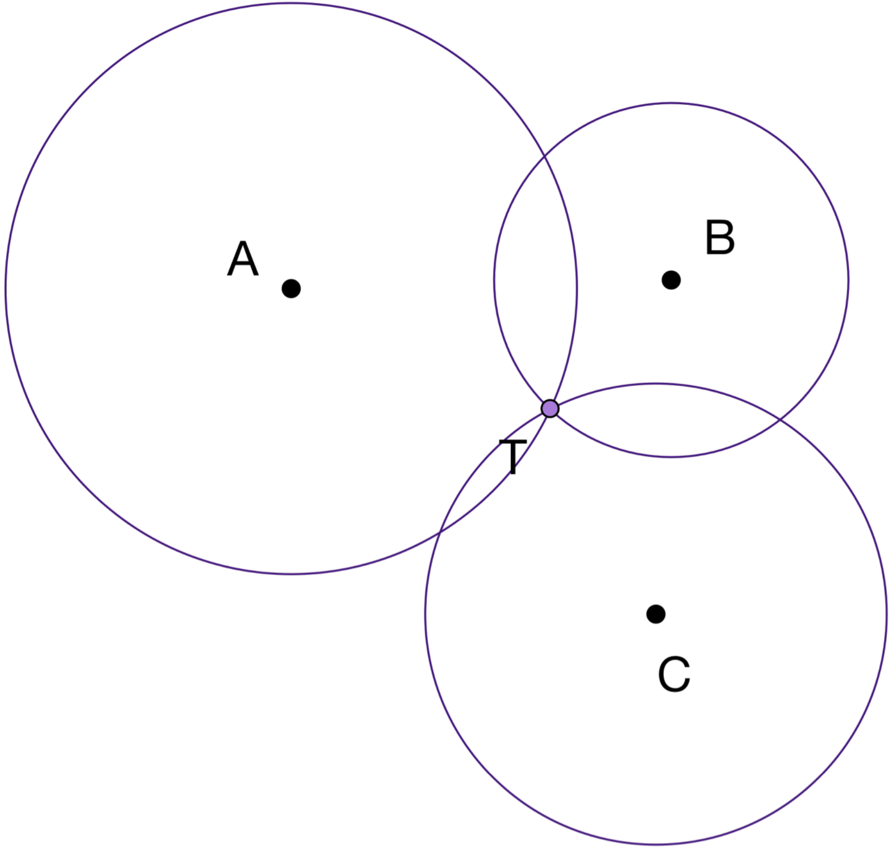


Multilateration

Speed of light circles

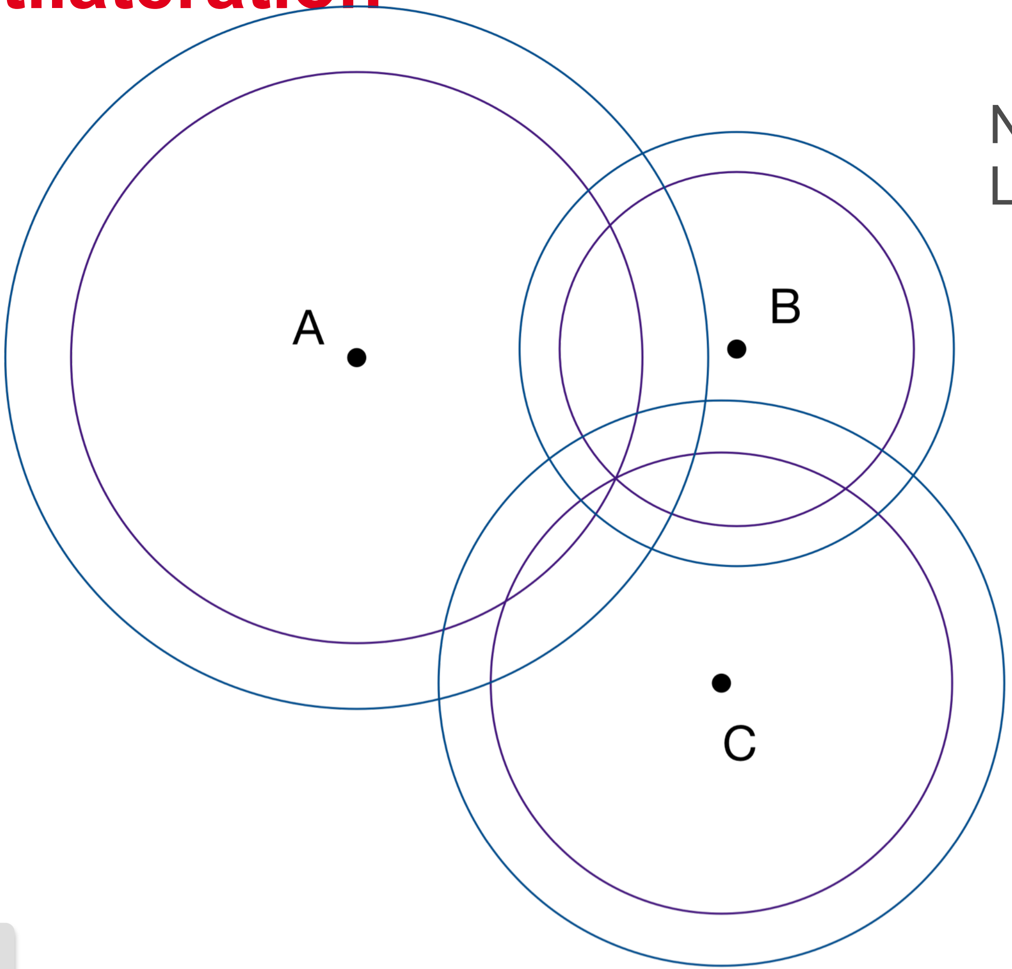


Multilateration



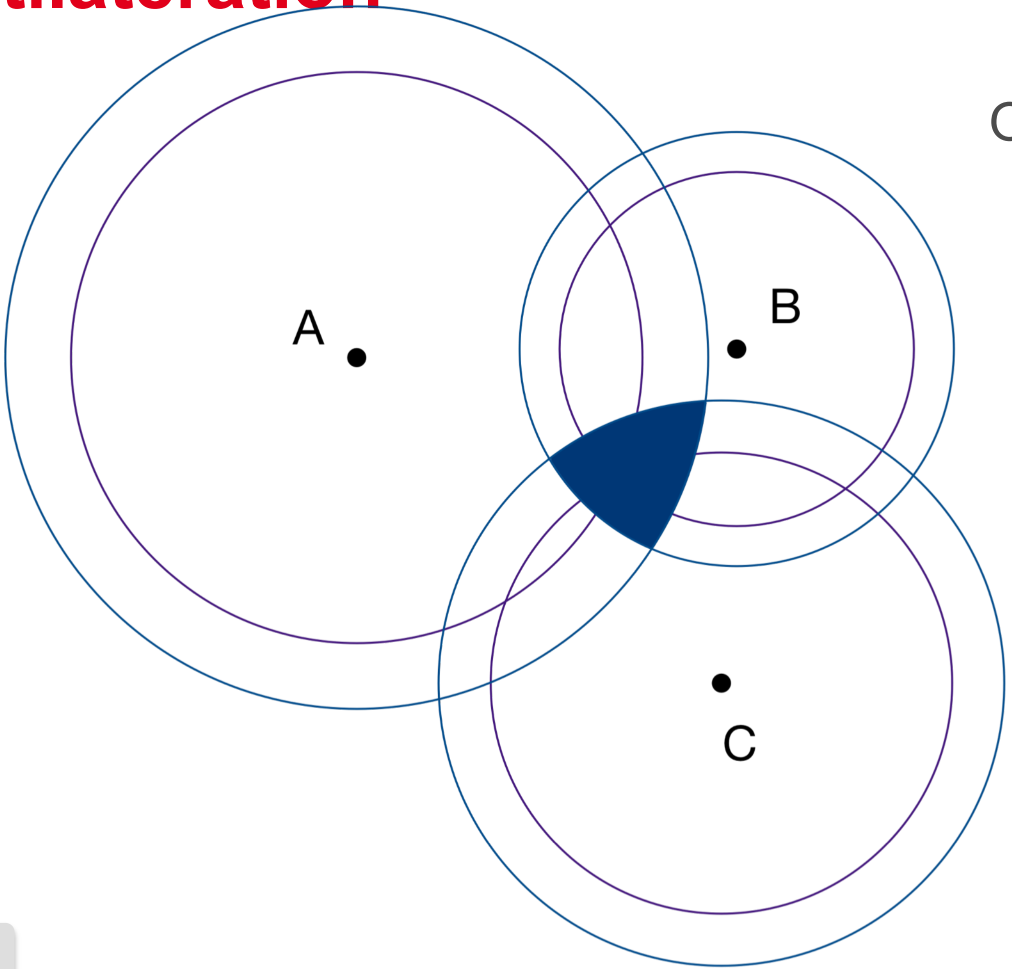
Precise intersection of the circles

Multilateration



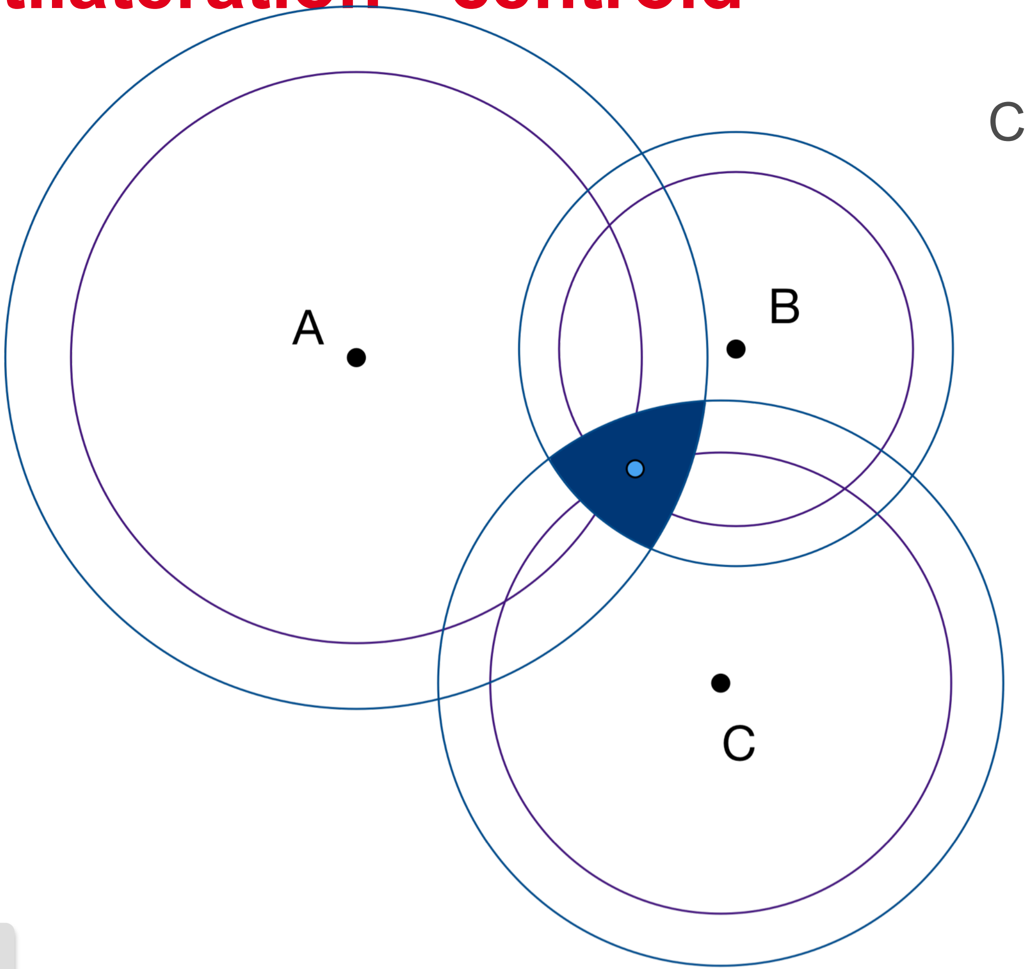
No straight lines ➔
Larger circles

Multilateration



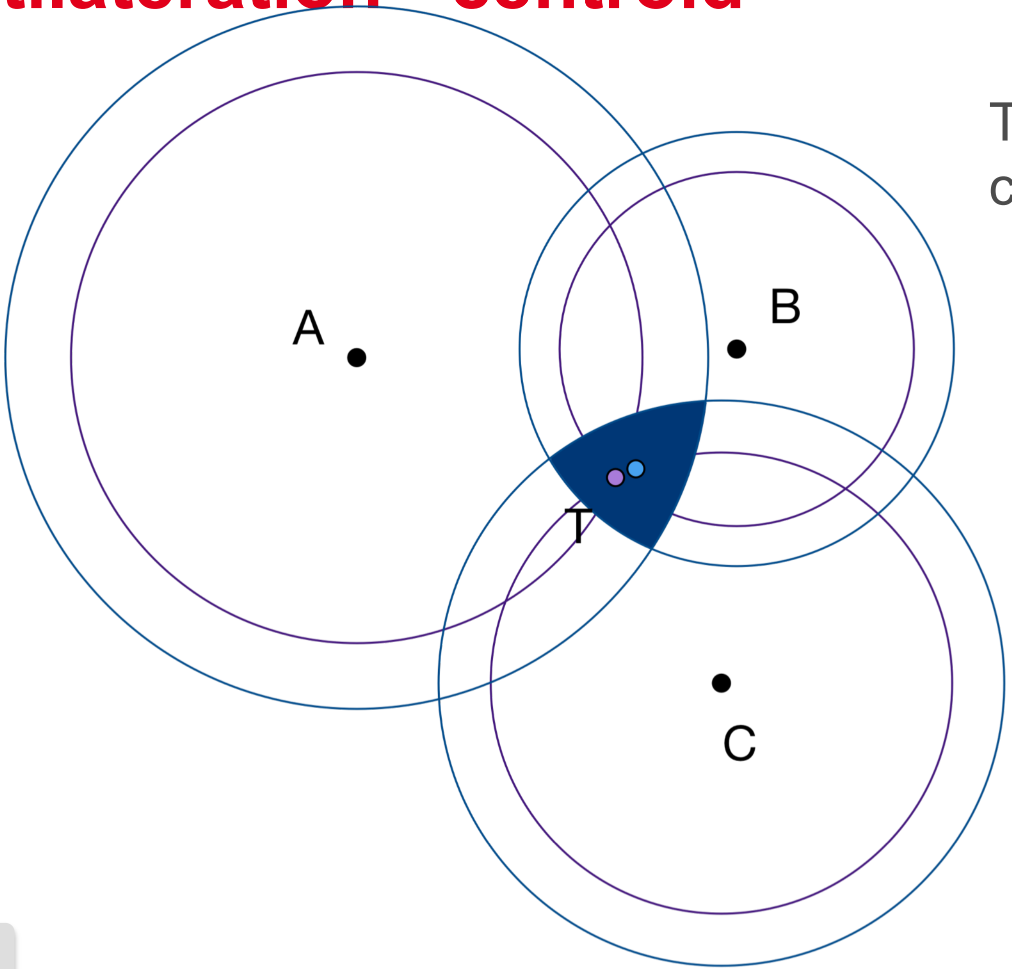
Overlap region

Multilateration - centroid



Centroid of the region

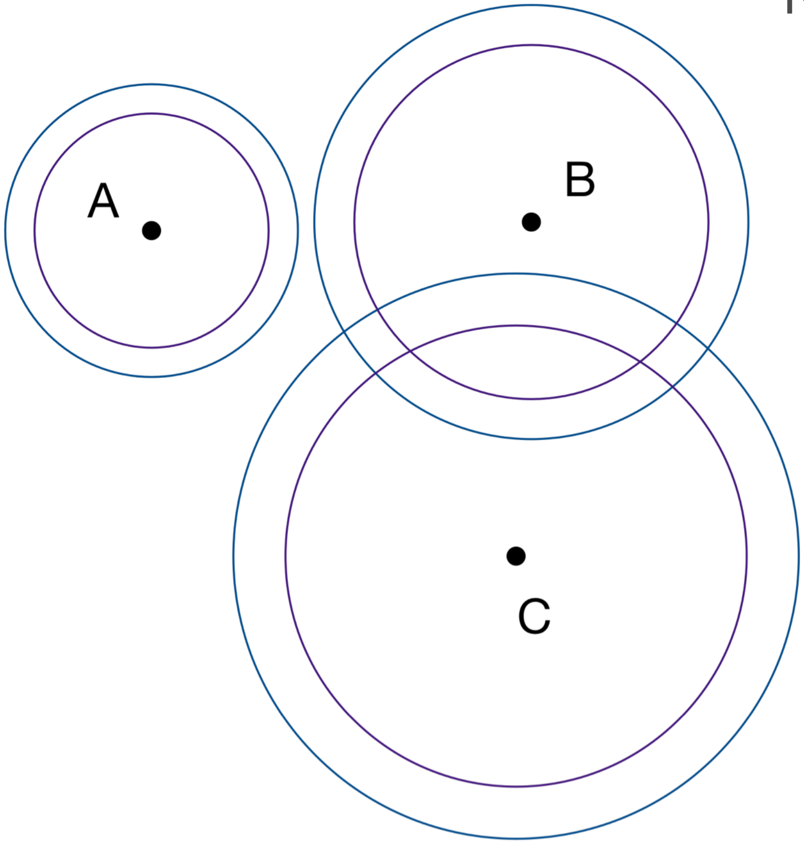
Multilateration - centroid



Target close to centroid

Anycast

Non-overlapping circles



Geolocation

- Reasons for geolocation
- Multilateration
- Anycast

Commercial geolocation services
e.g., MaxMind, NetAcuity

Outline

Connectivity, losses, and latency

- Ping
- Connectivity
- Losses
- Latency
  - Introduction
  - Components
  - Clocks
  - Tools
  - Use for geolocation

Summary: Connectivity, losses, and latency

1. **Introduction - Ping**
2. Connectivity
3. Losses
4. Latency
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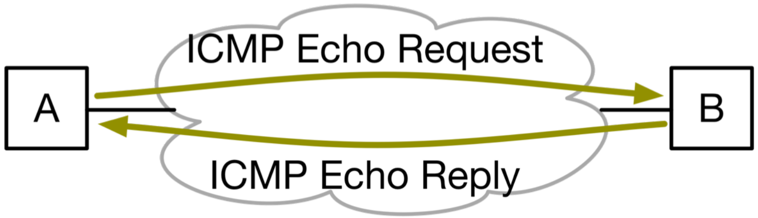
   B. Components
   C. Clocks
   D. Tools
   E. Geolocation
5. Conclusion



Summary: Connectivity, losses, and latency

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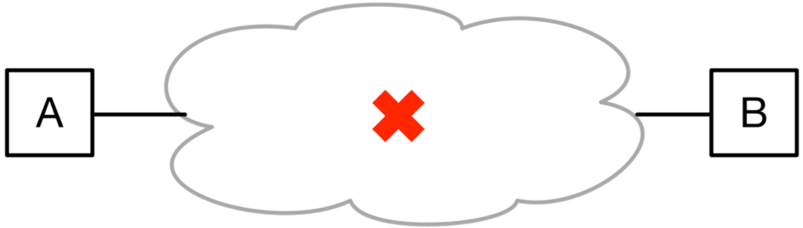

Summary: Connectivity, losses, and latency

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loss rate	quality (as per ICFA, 2015)
below 0.1%	excellent
0.1% to 1%	good
1% to 2.5%	acceptable
2.5% to 5%	poor
5% to 12%	very poor
above 12%	bad

Summary: Connectivity, losses, and latency

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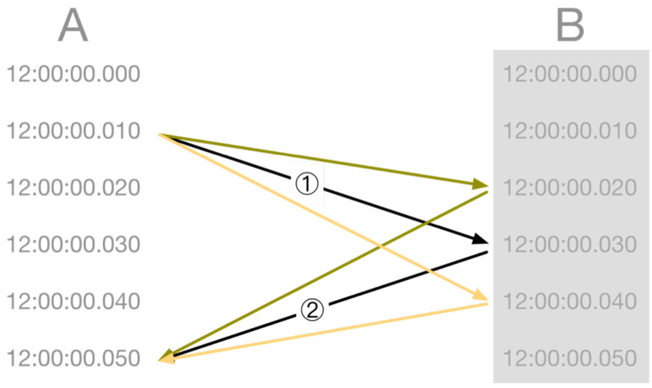

(L_1 = 30 ms - 10 ms = 20 ms)

~~L_1 = ½(50 ms - 10 ms) = 20 ms?~~

RTT = 50 ms - 10 ms = 40 ms

Summary: Connectivity, losses, and latency

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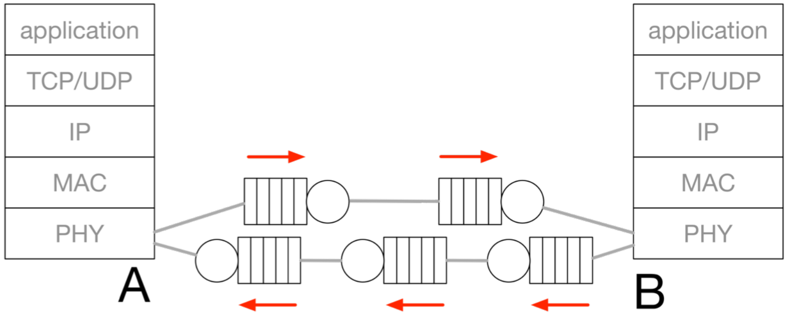

Summary: Connectivity, losses, and latency

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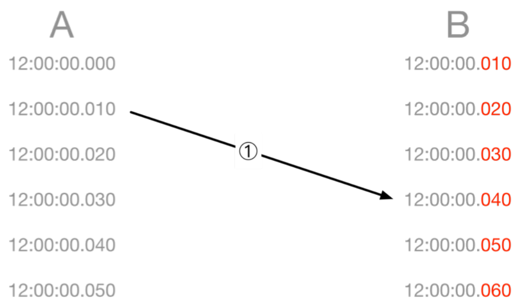
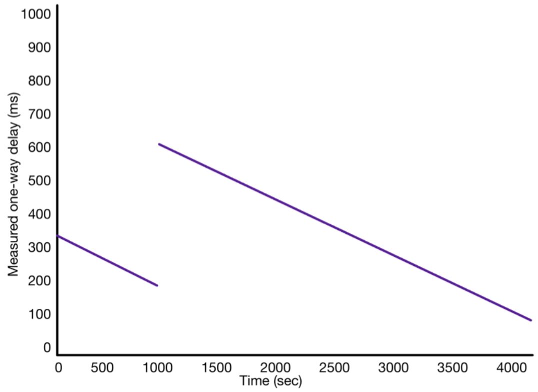


L_1 = 30 ms - 10 ms = 20 ms?
L_1 = 40 ms - 10 ms = 30 ms?



Summary: Connectivity, losses, and latency

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Latency - Tools

- Ping
- tcptrace
- OWAMP

Summary: Connectivity, losses, and latency

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