CS168
How the Internet Works:
A bottom-up view

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Fall 2024

Goal for the next few lectures is to give you a broad overview of how the Internet works

- This lecture: bottom-up
  - Identify the fundamental pieces that make up the overall picture
- Next lecture: top-down
  - Identify the important architectural choices involved in the picture together

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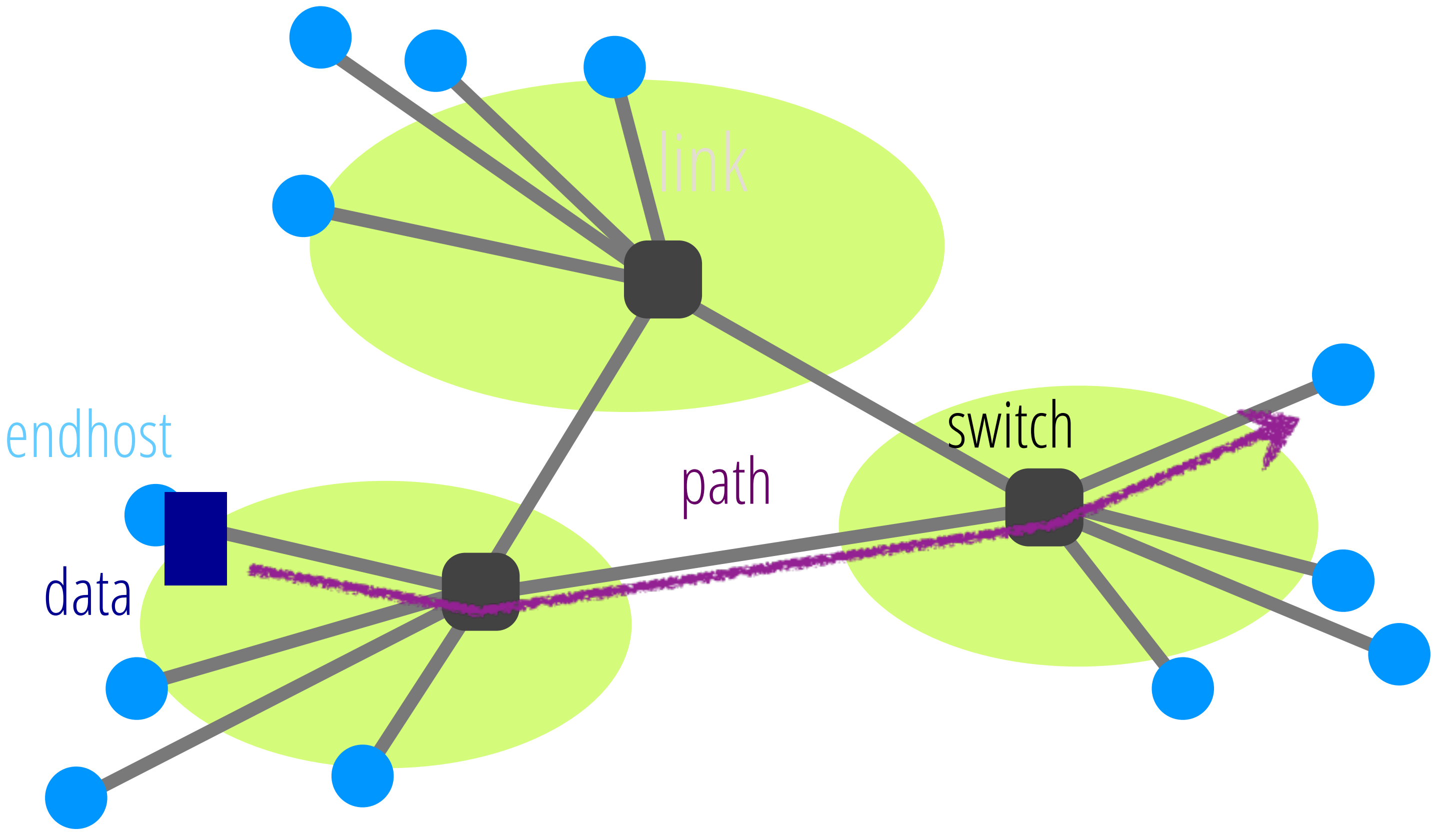
- How are network resources shared?
- Start understanding of the “life of a packet” through the network
- Along the way: identify the key topics we’ll be studying this semester

Recall, from last lecture



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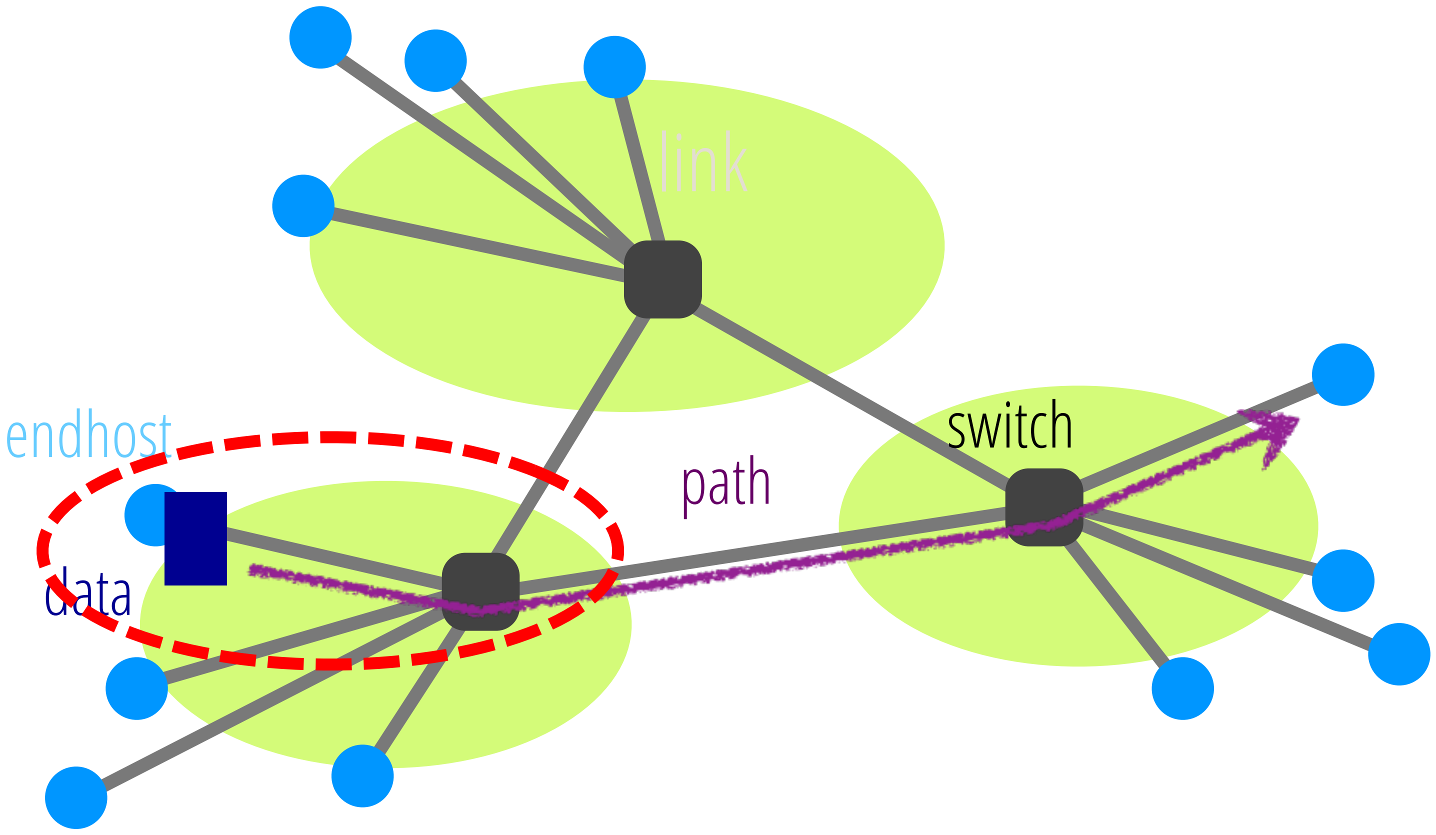

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Payload	Header

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- In practice, a packet has multiple headers (next lecture)

- And communication between a pair of endhosts involves multiple packets
  - "Flow": stream of packets exchanged between two endpoints (more on this later)

Packets on a link

Application data

Packets on a link

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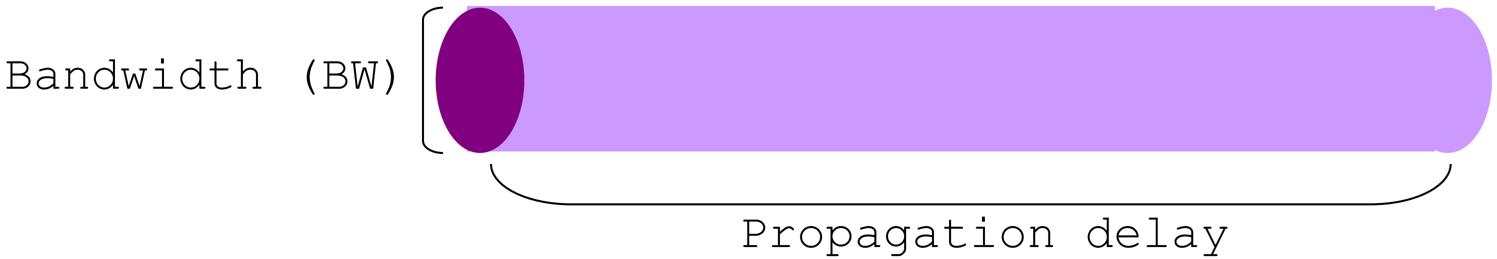

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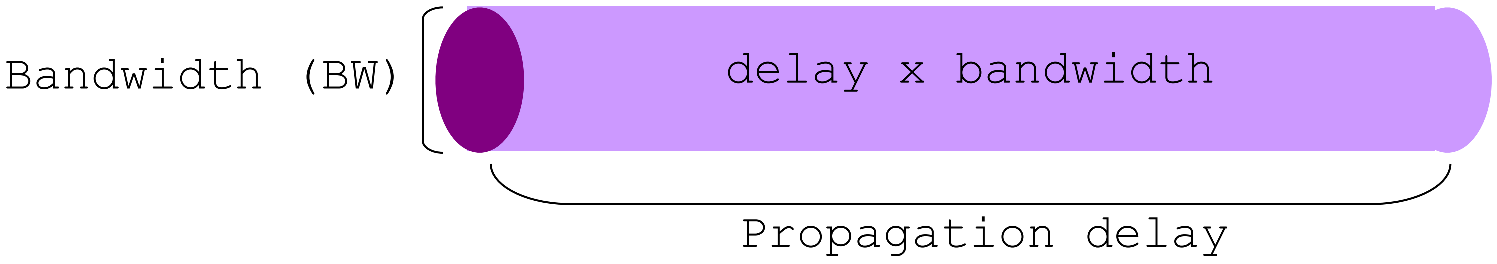

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- Bandwidth-Delay Product (BDP): bits/time x propagation delay (bits)
  - "capacity" of the link

Packets on a link: sending a 100B packet

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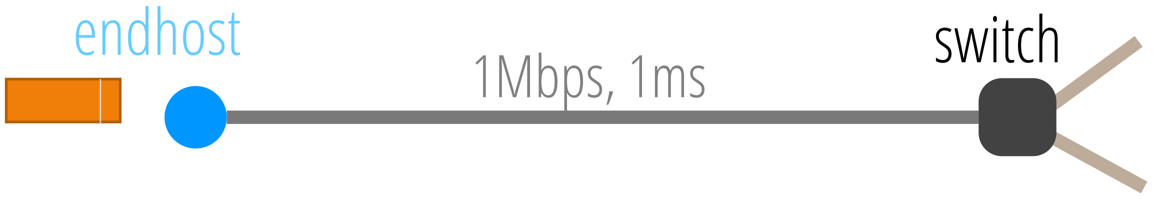

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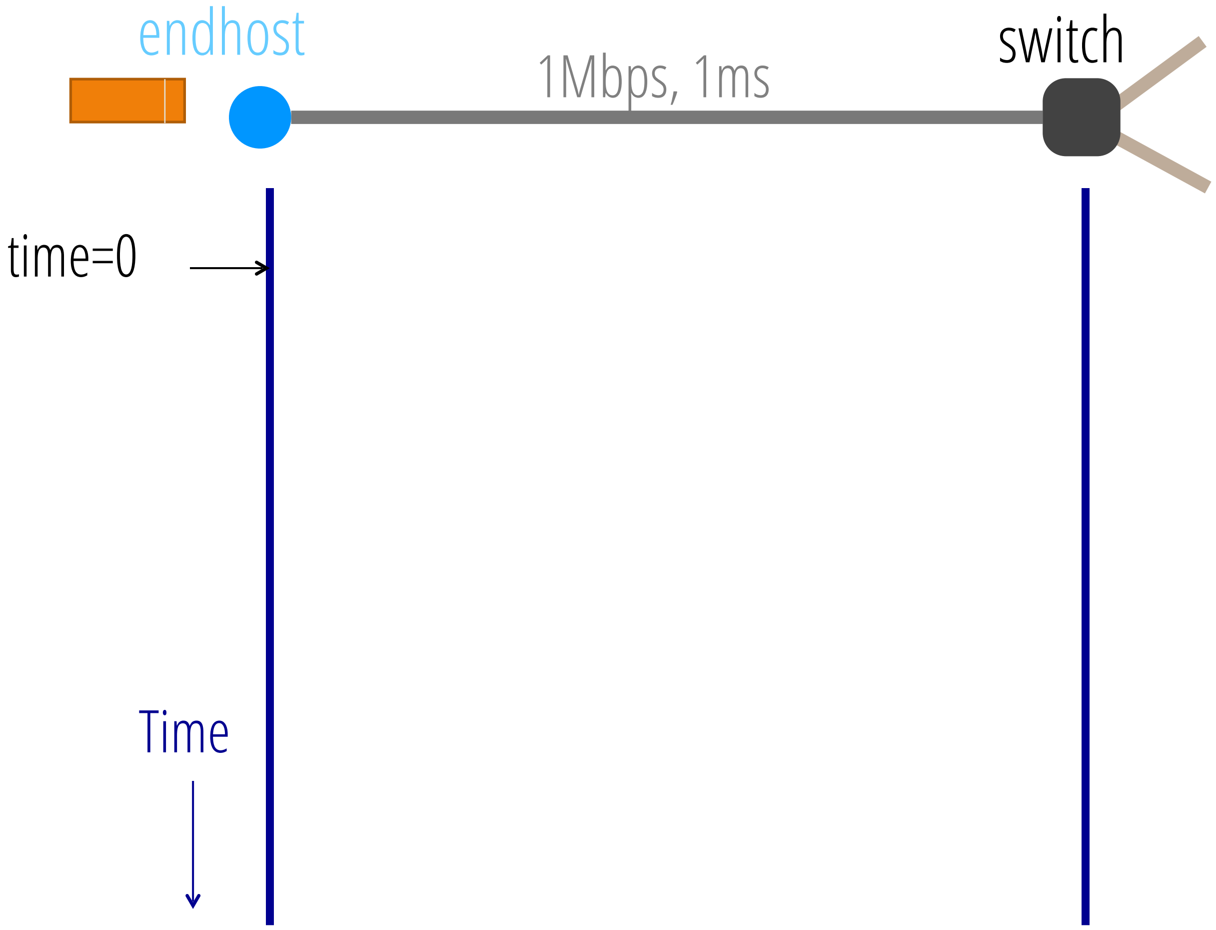

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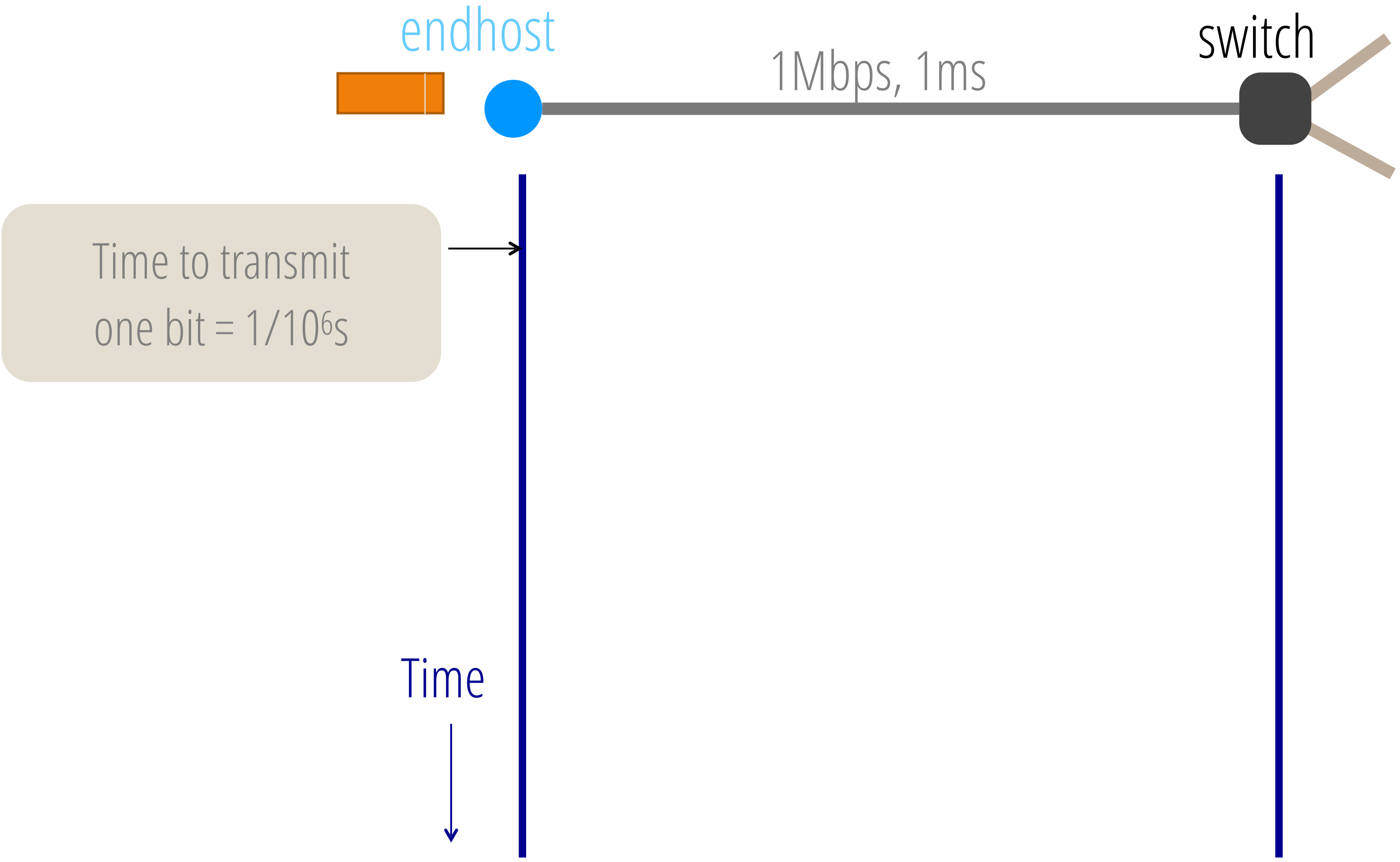

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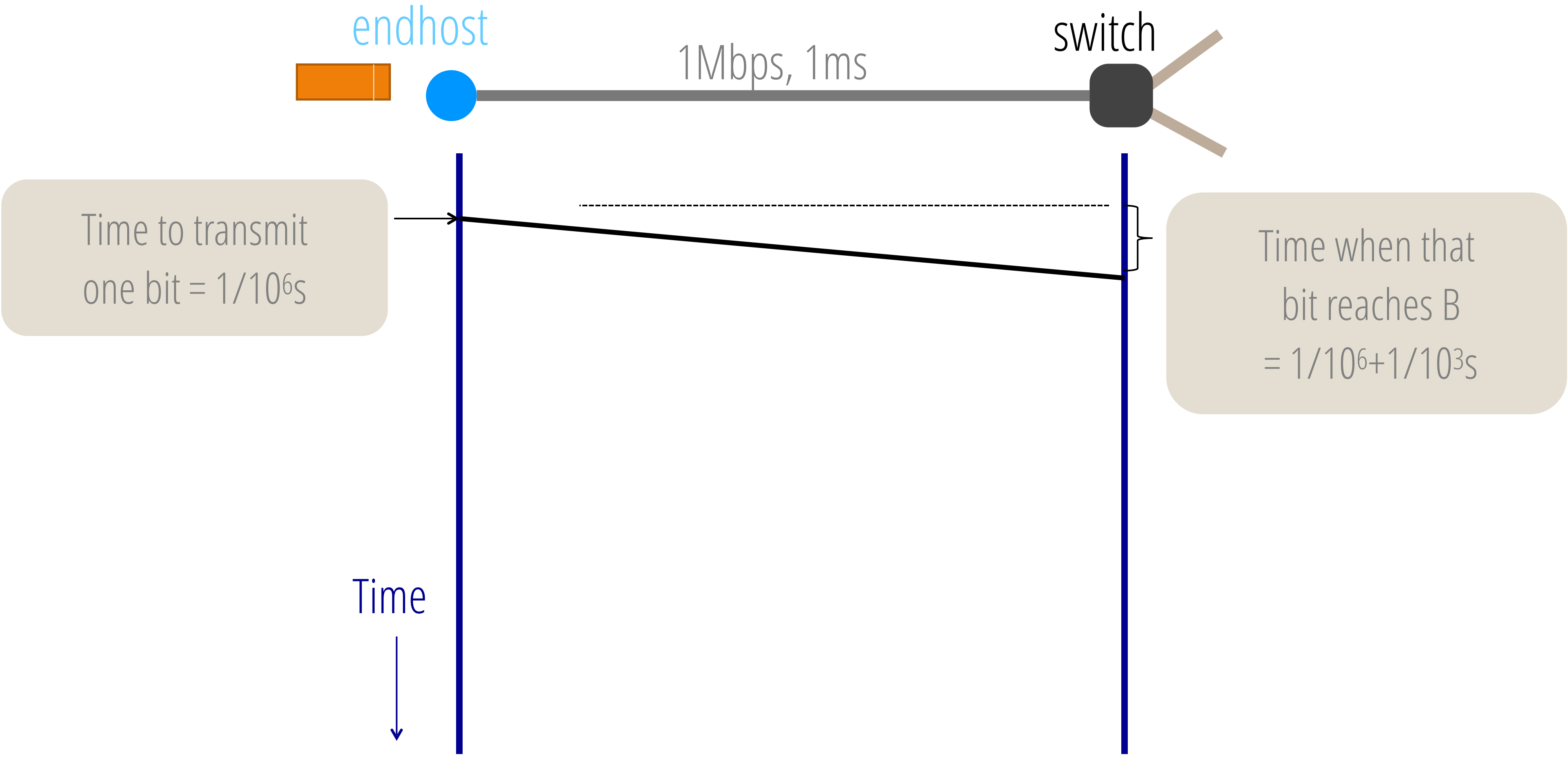

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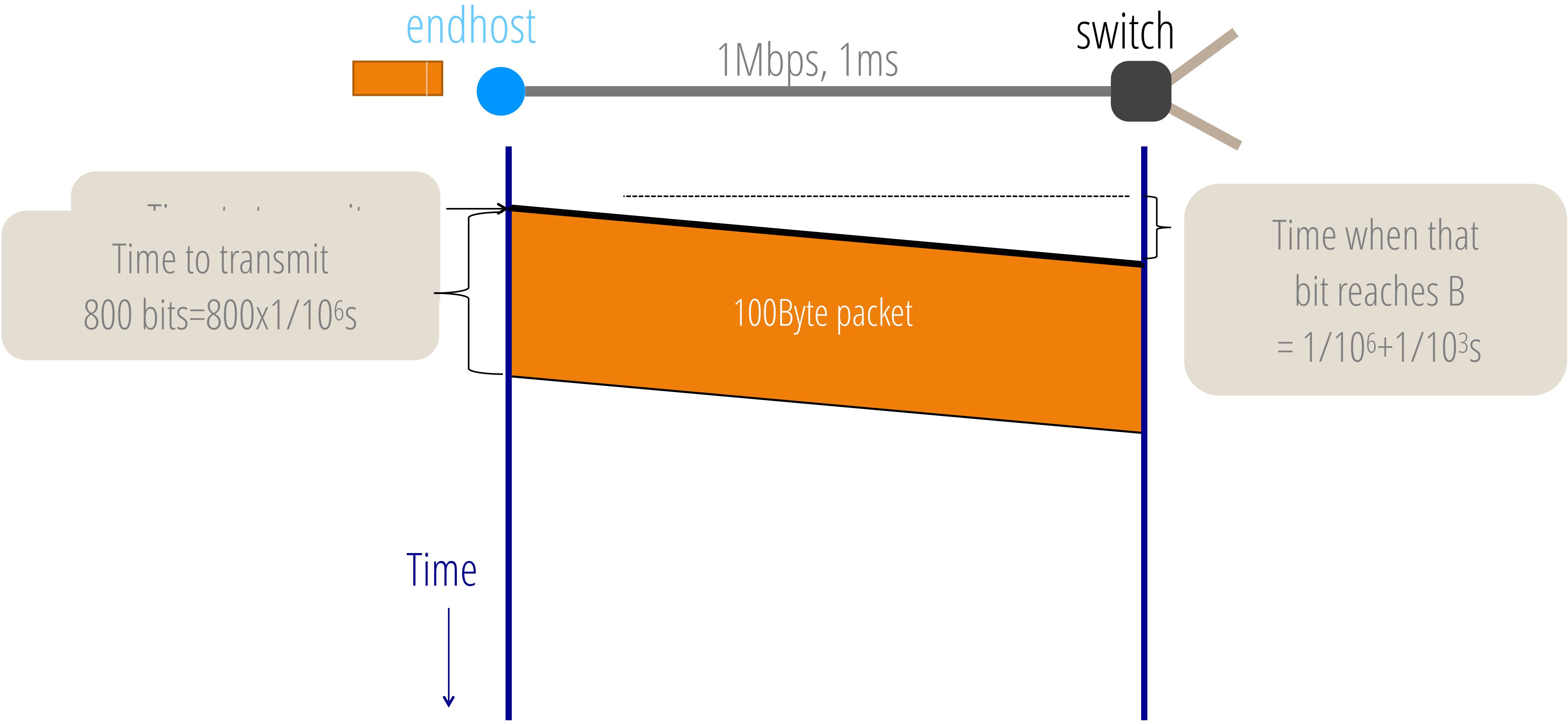

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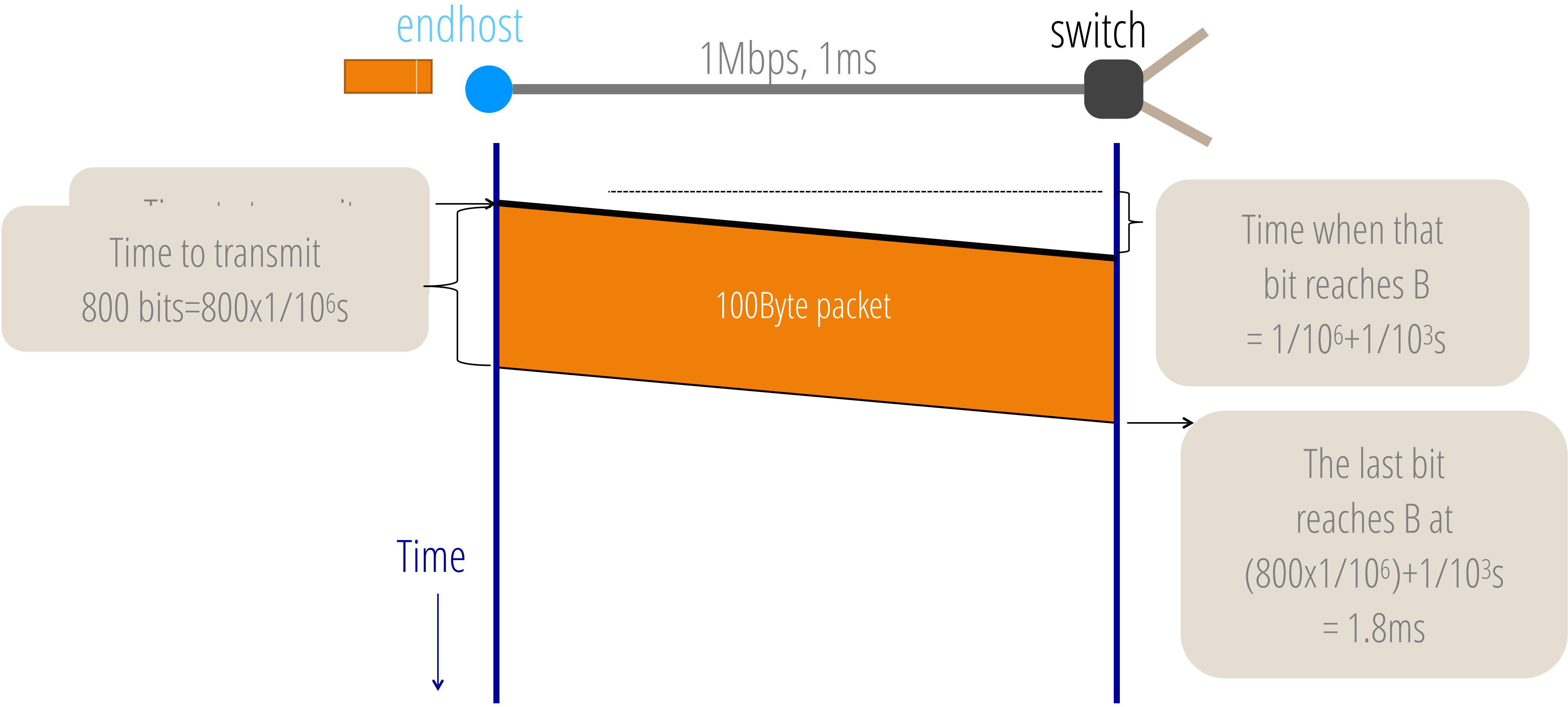

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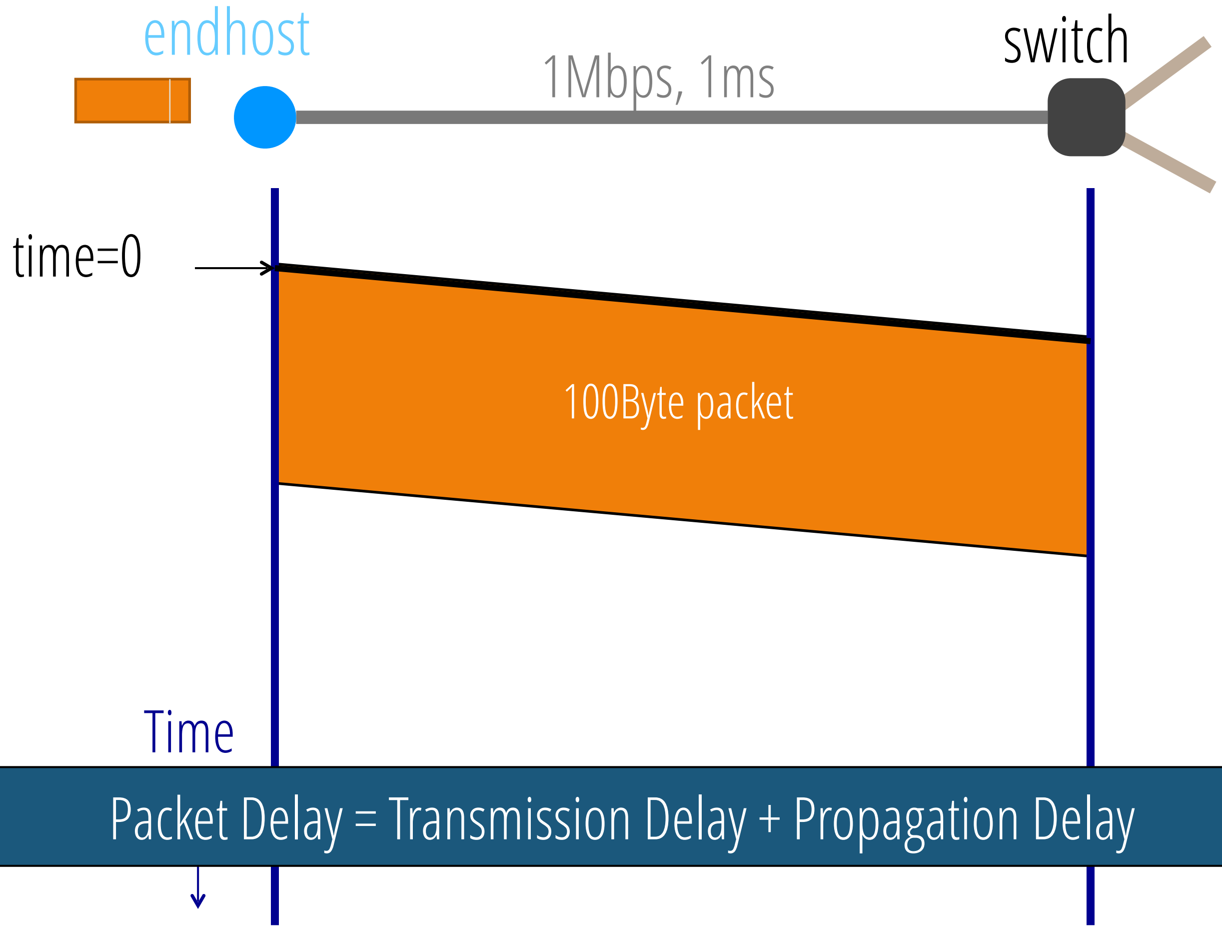

Packet Delay = Transmission Delay + Propagation Delay

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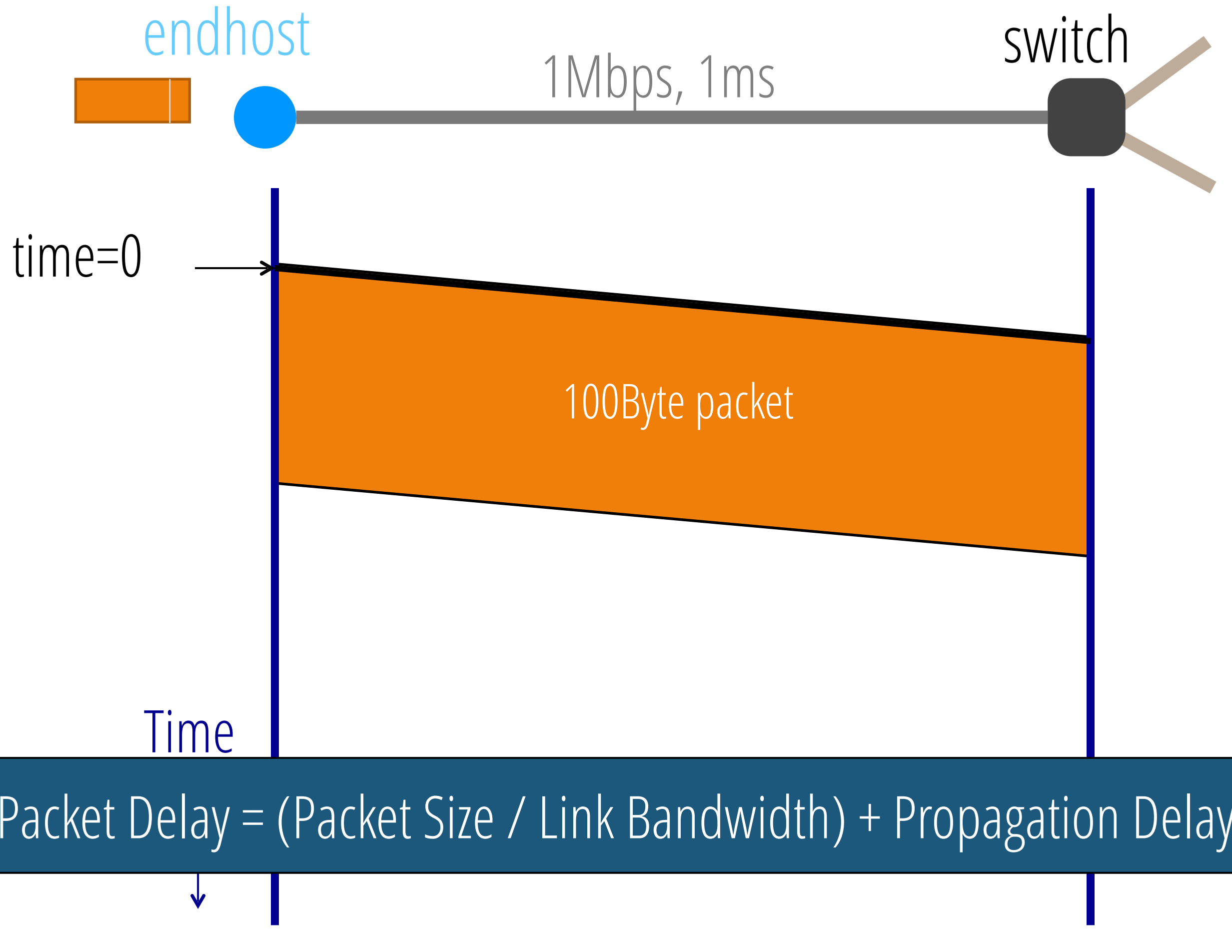

Packet Delay = (Packet Size / Link Bandwidth) + Propagation Delay

Question: which link is better?

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- For a 10,000B packet:
  - Link 1: ~18ms
  - Link 2: ~81ms

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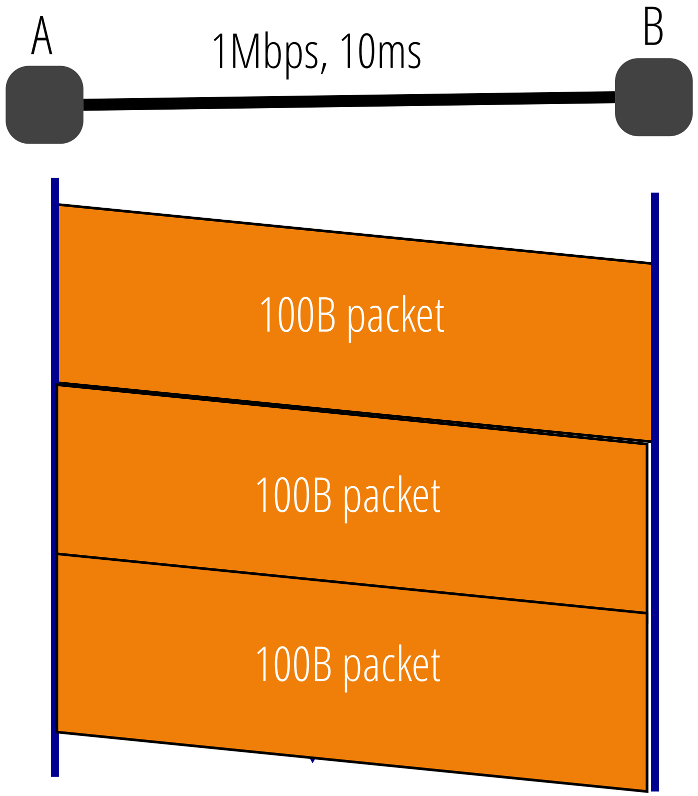
Packets on a link: an alternate "pipe" view



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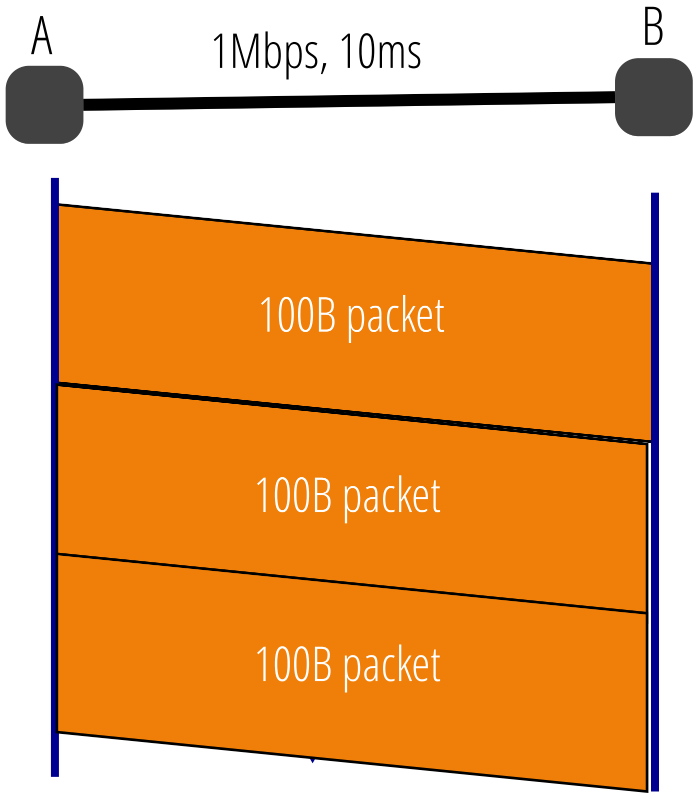

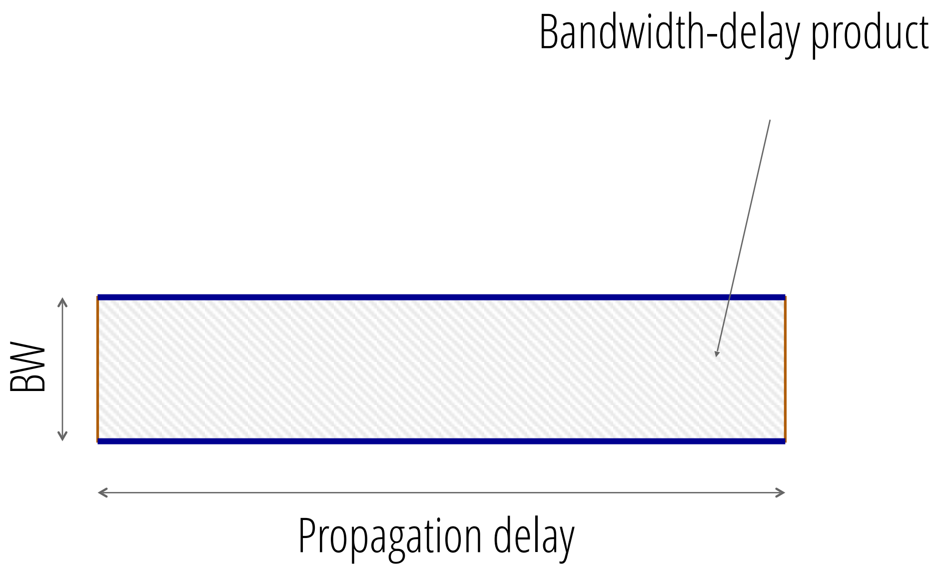

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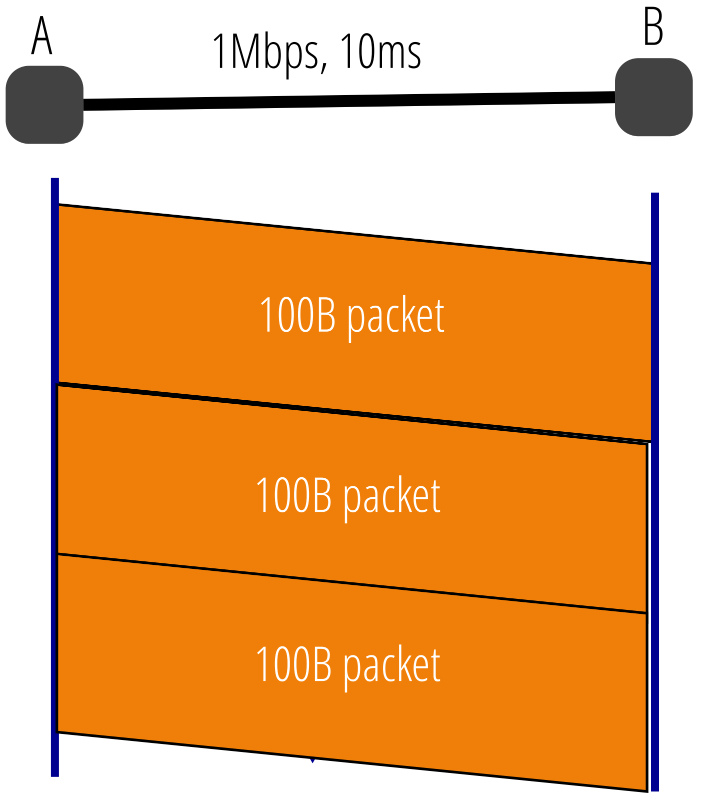

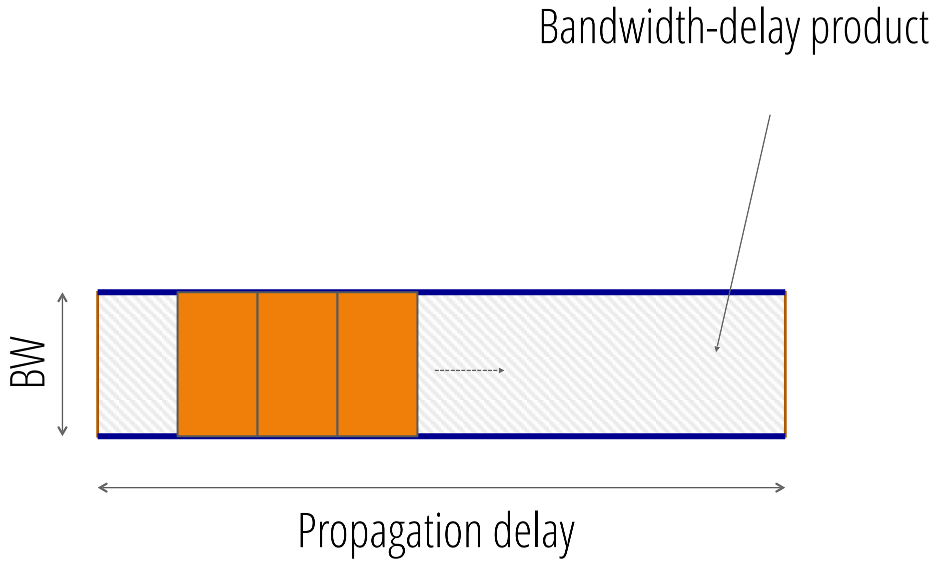

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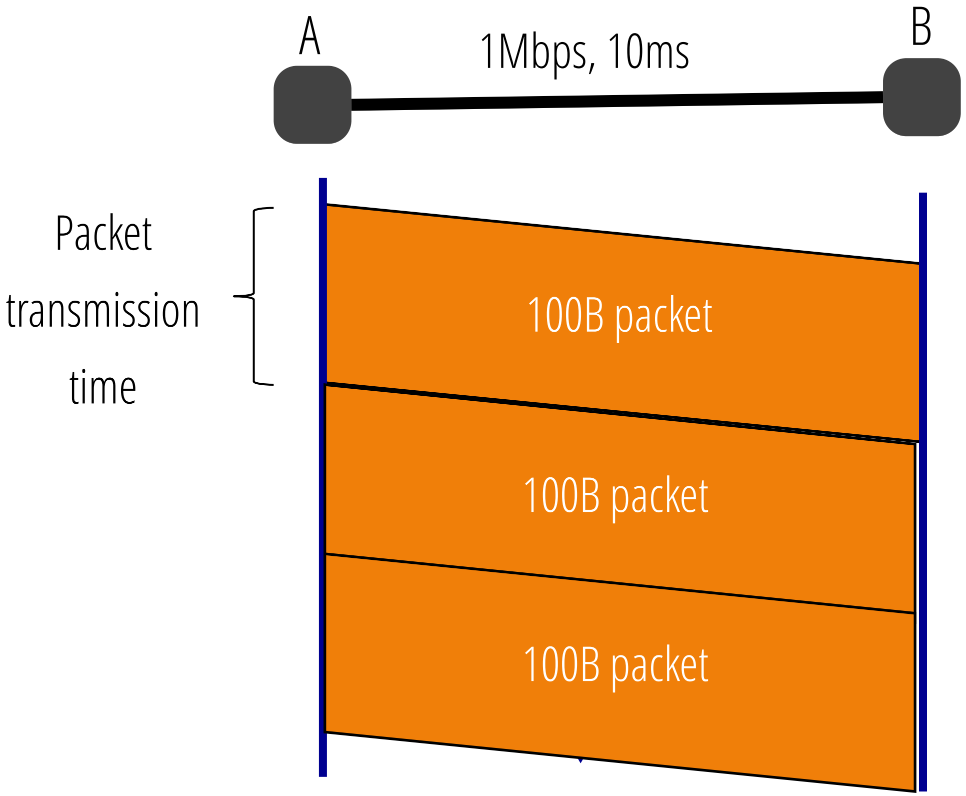

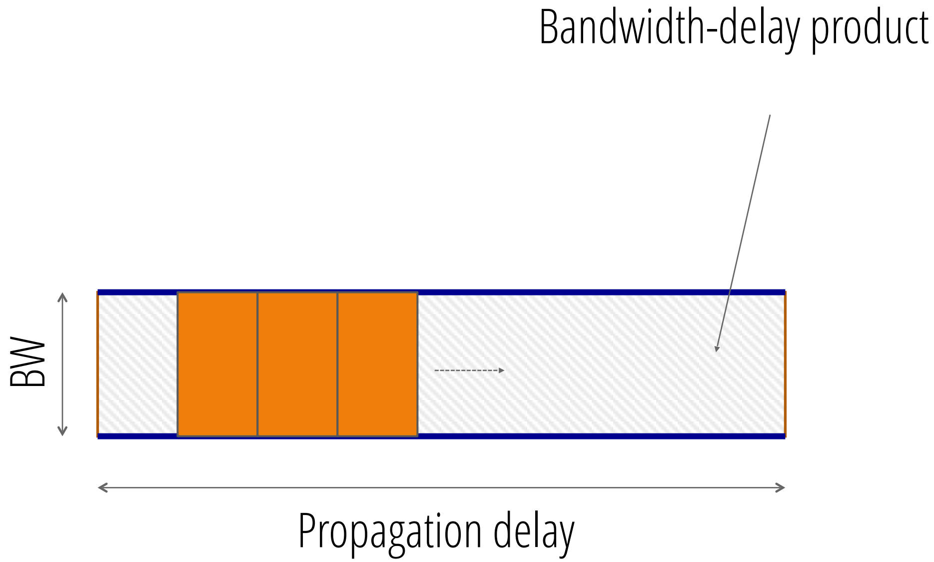

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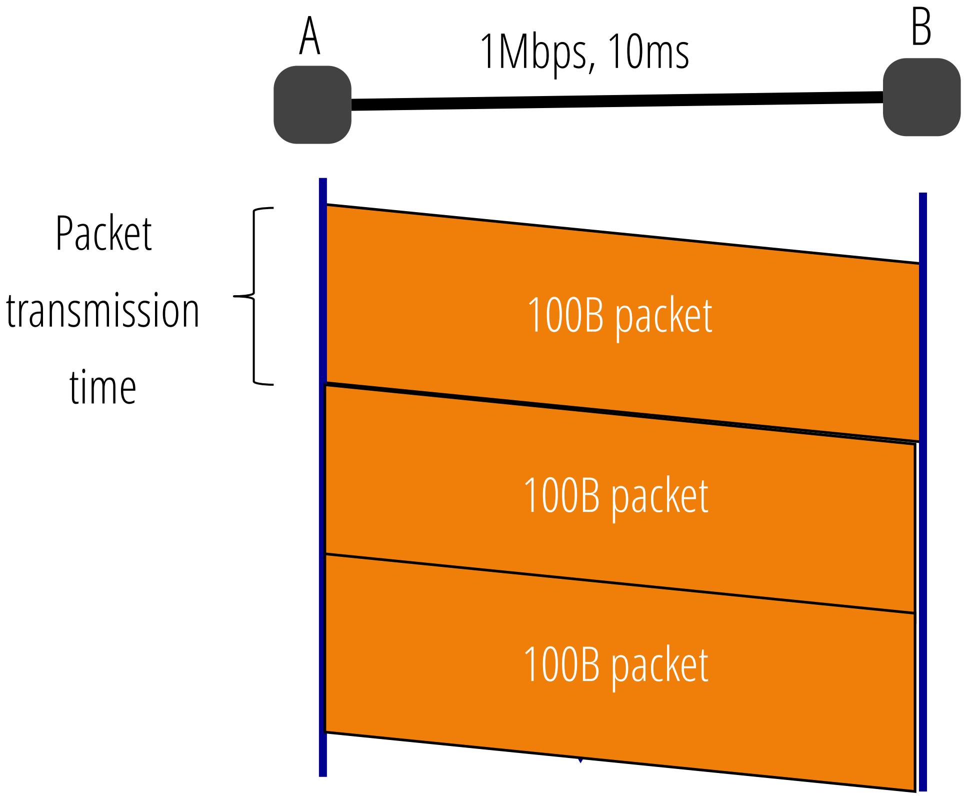

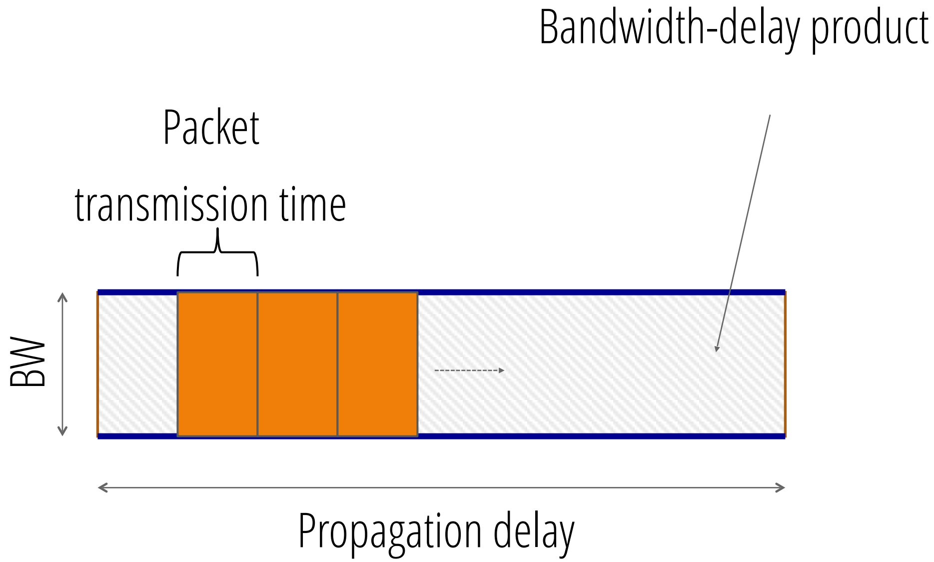

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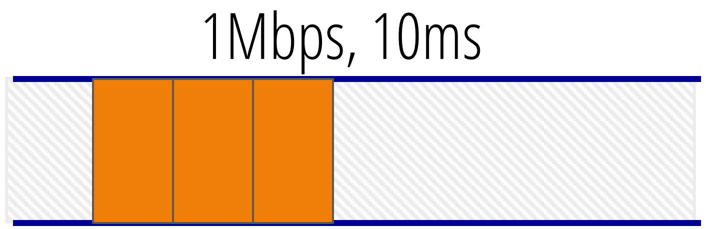

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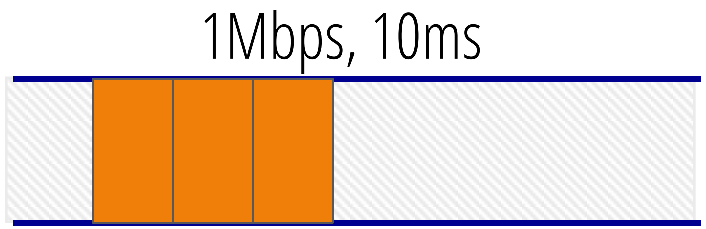

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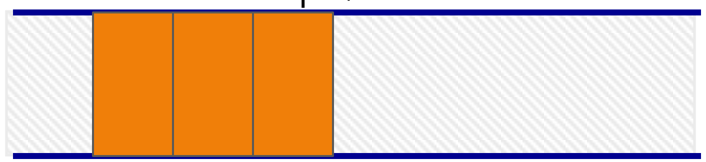

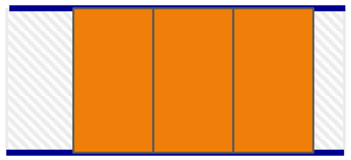

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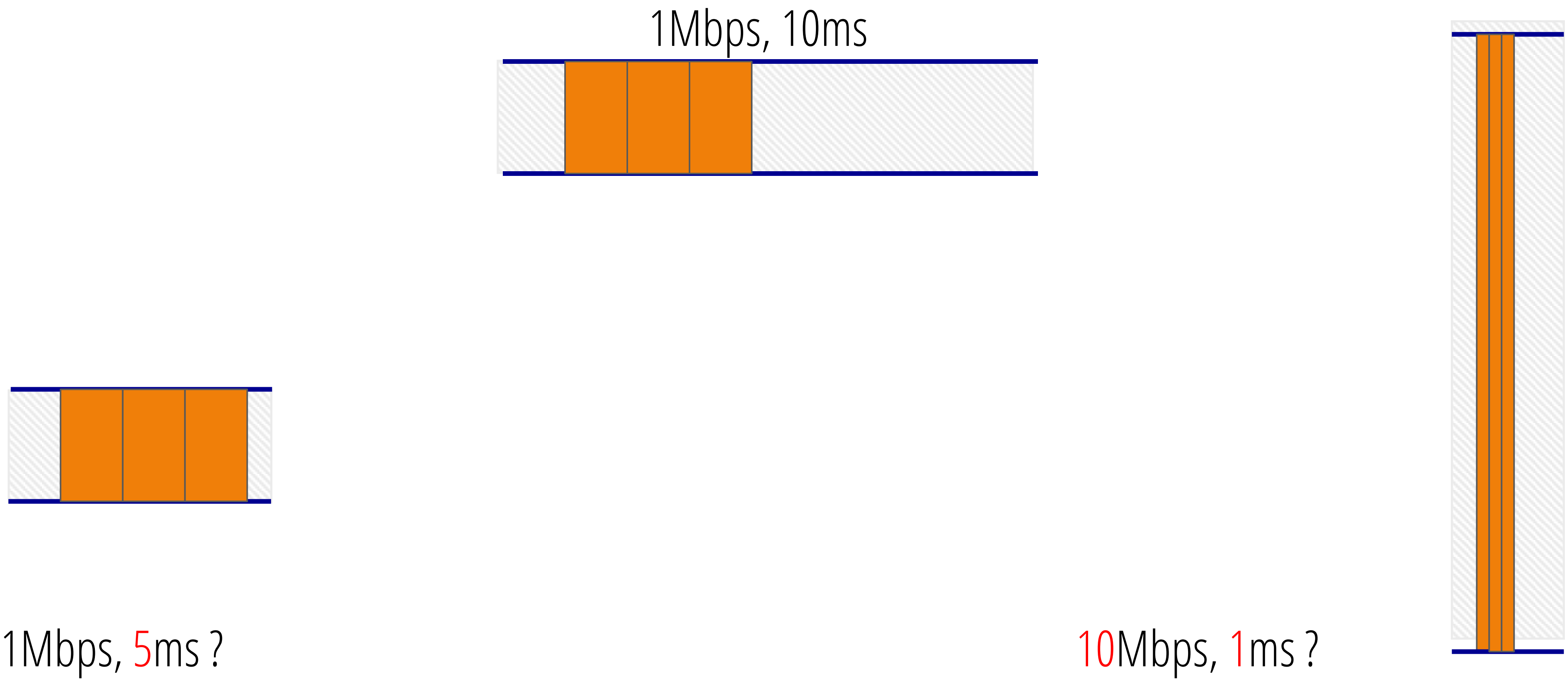

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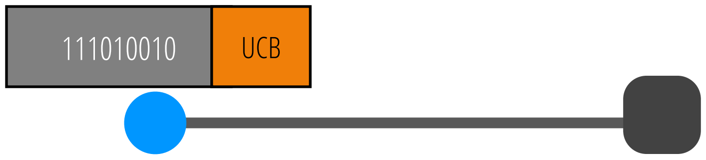

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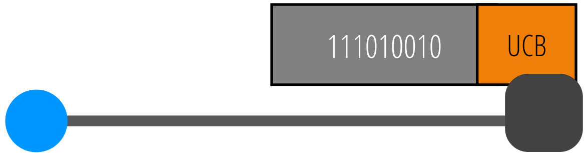

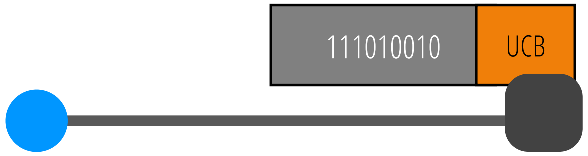
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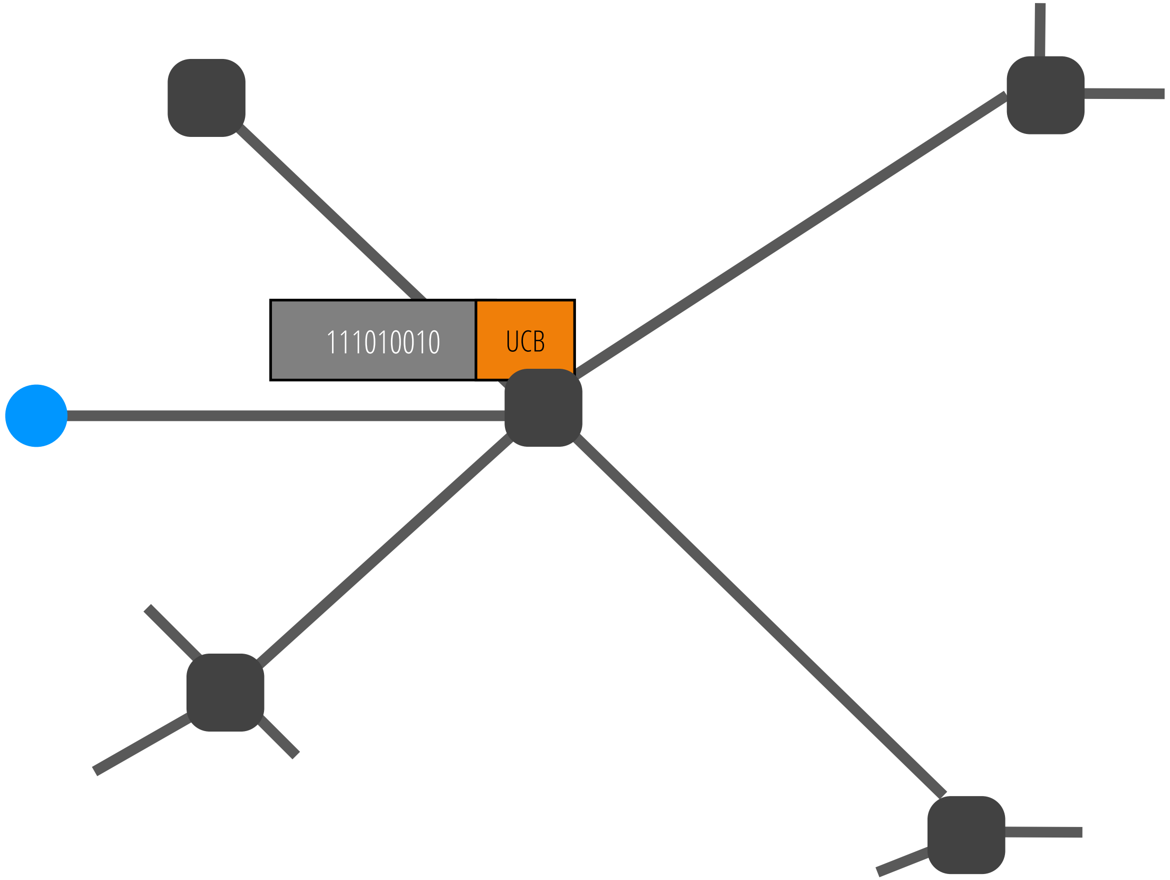
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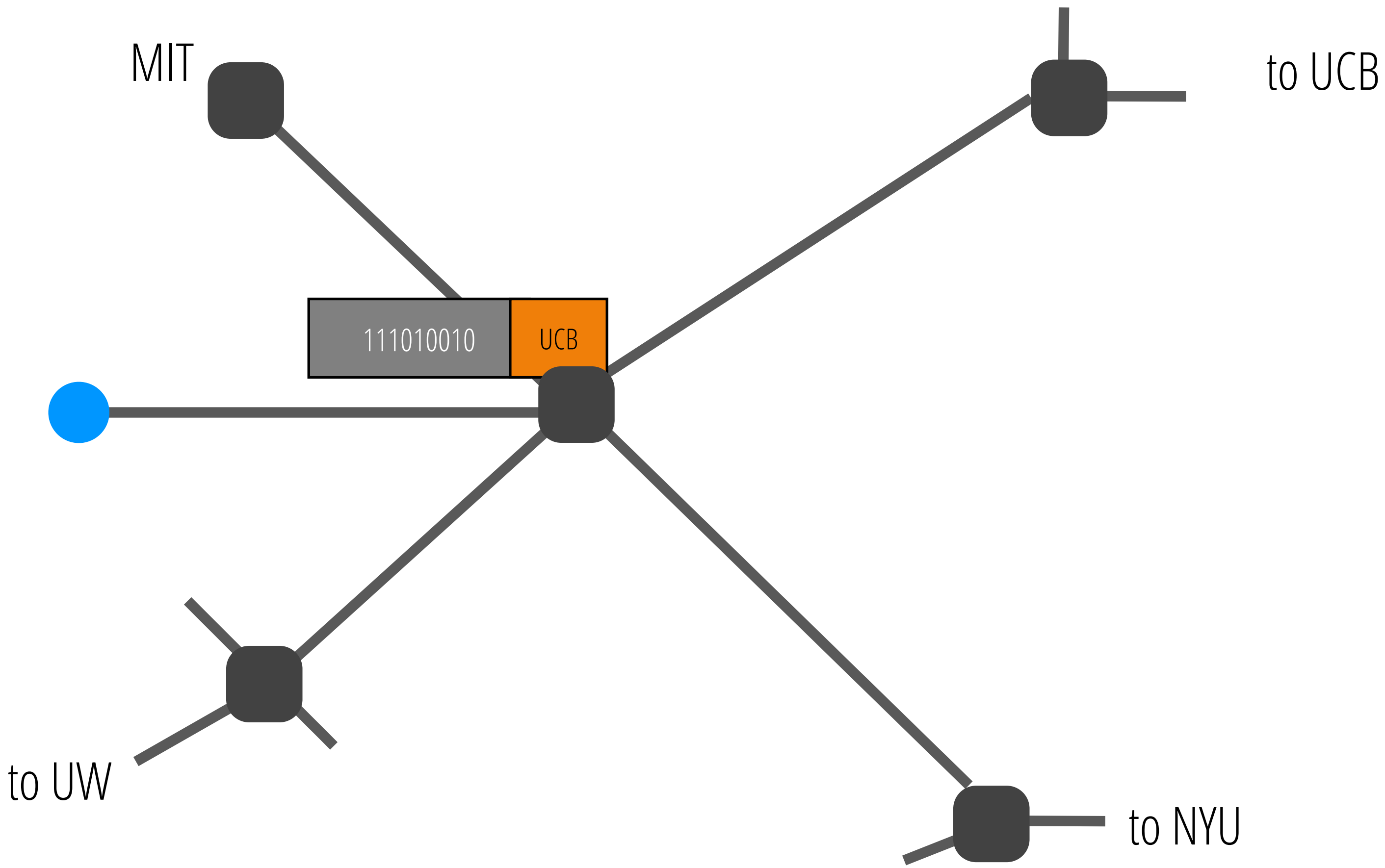

MIT
to UCB
111010010
UCB
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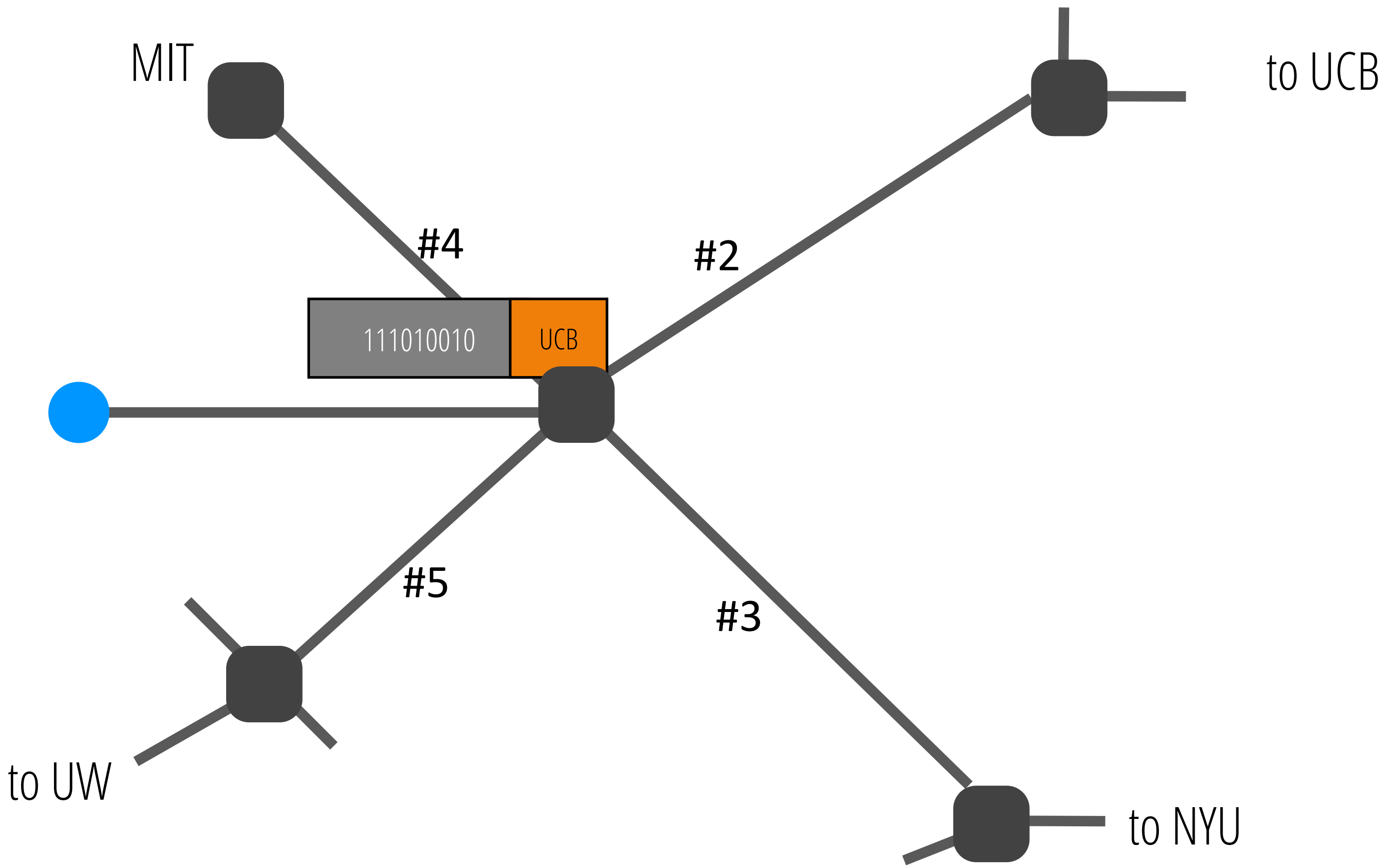
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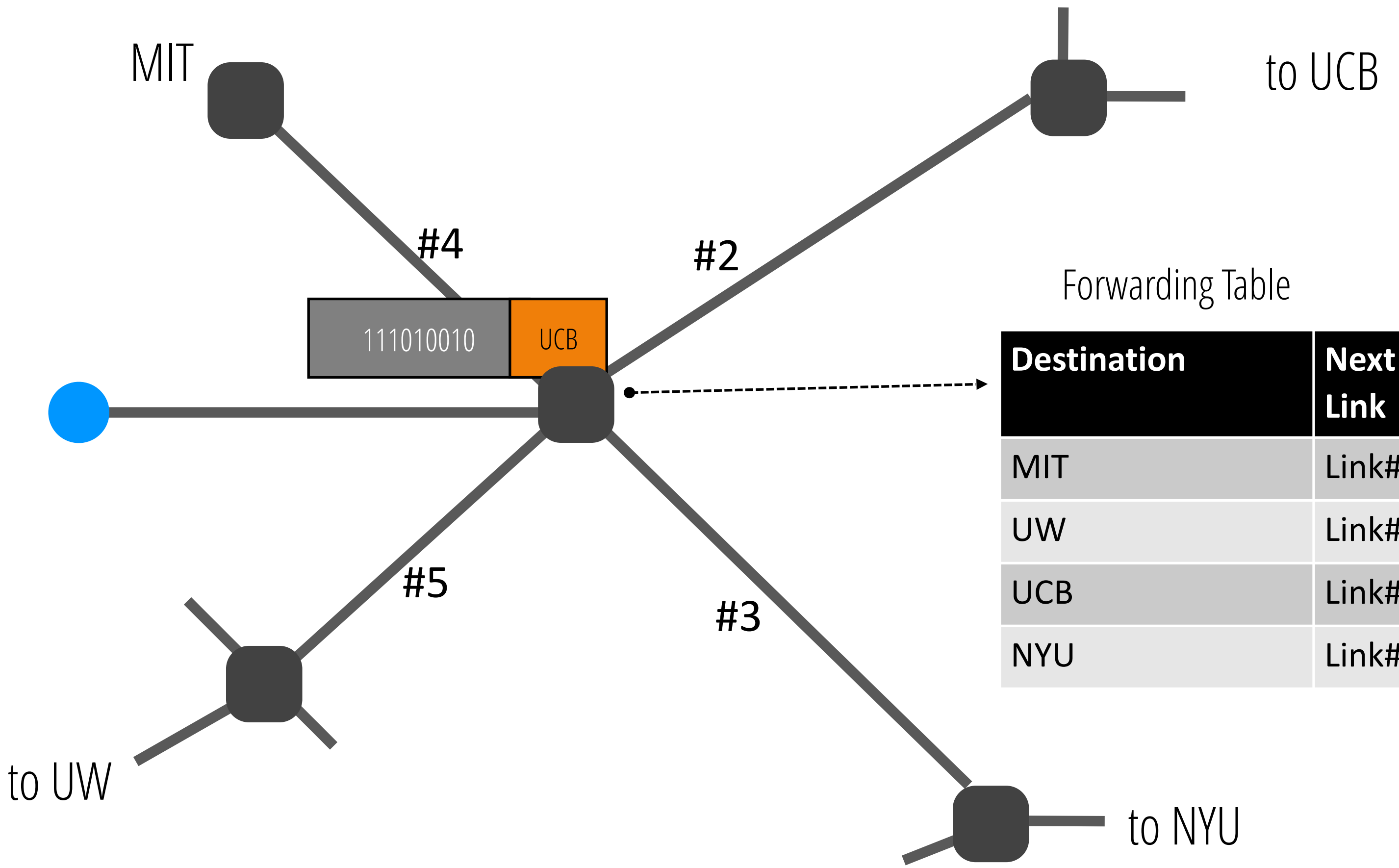

Forwarding Table

Destination	Next Hop Link
MIT	Link#4
UW	Link#5
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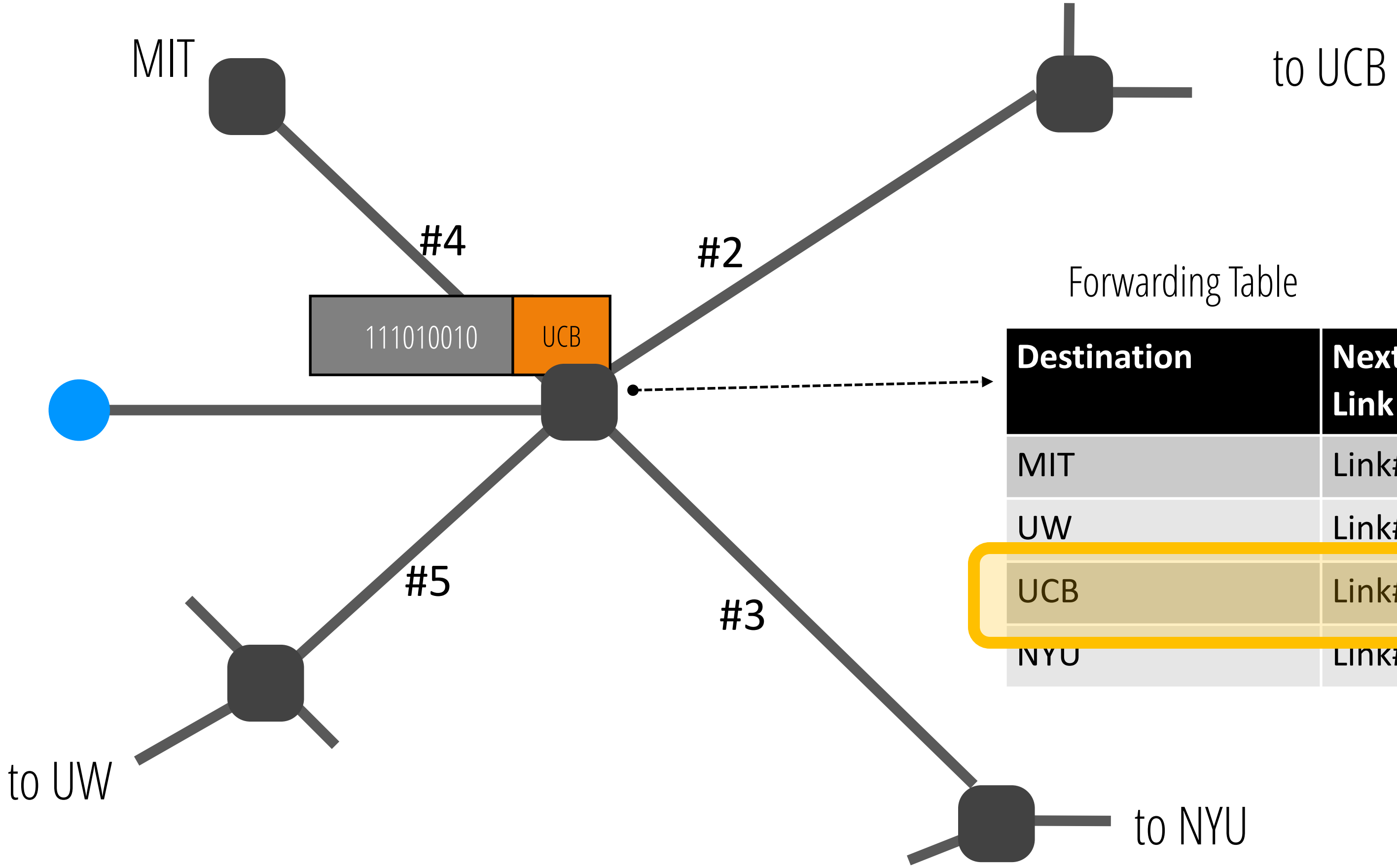

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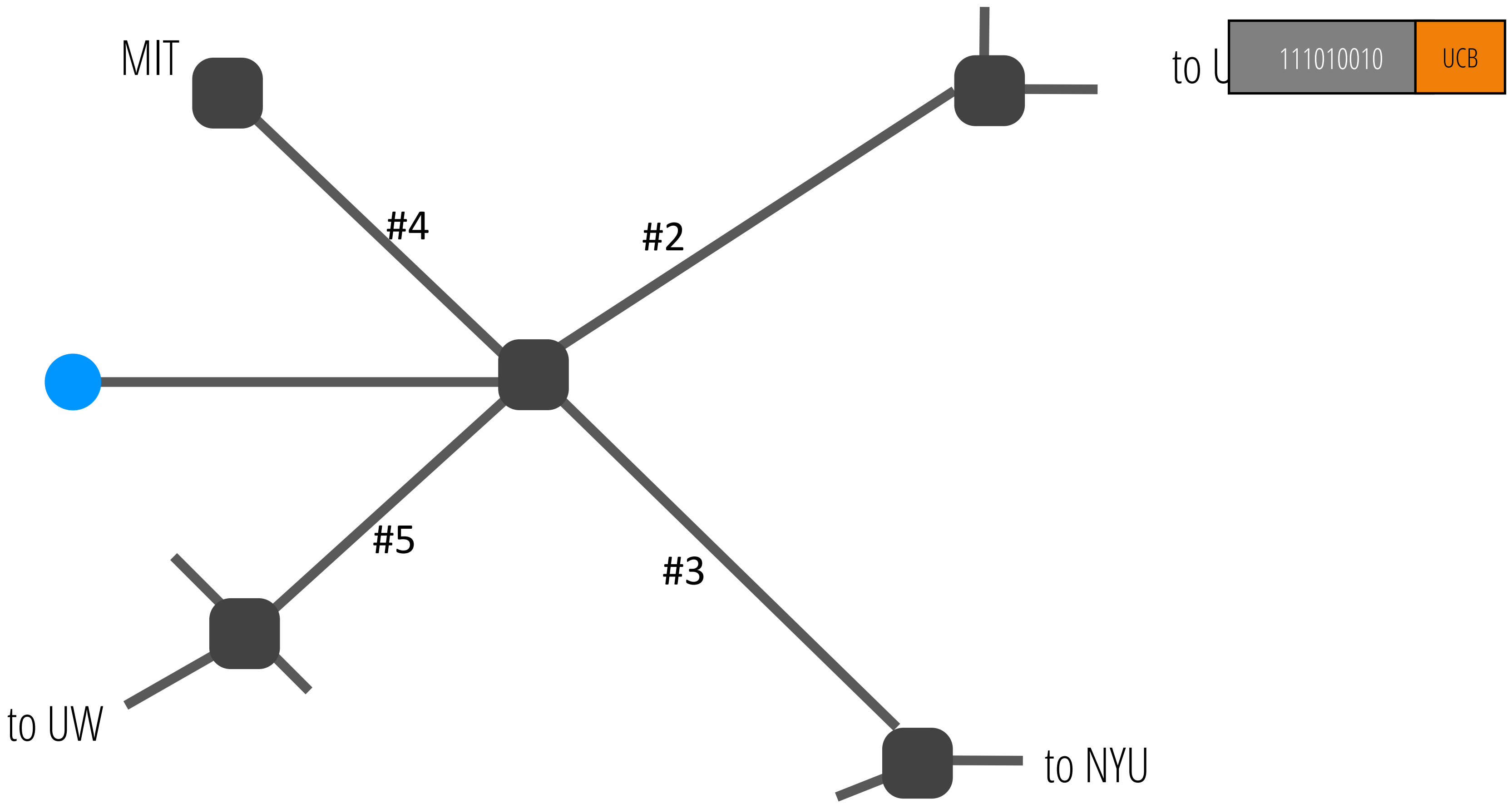

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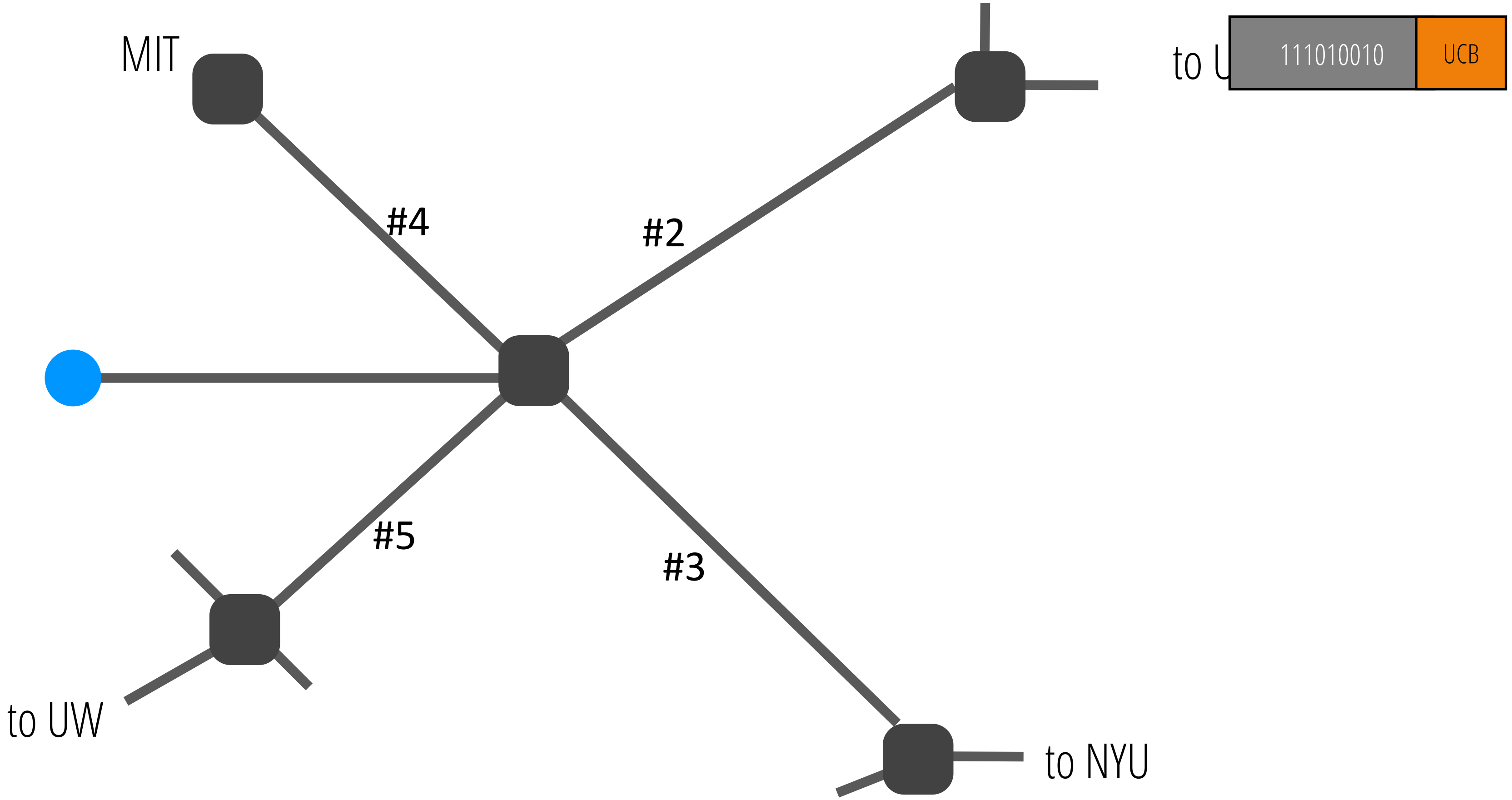
Switches "forward" packets



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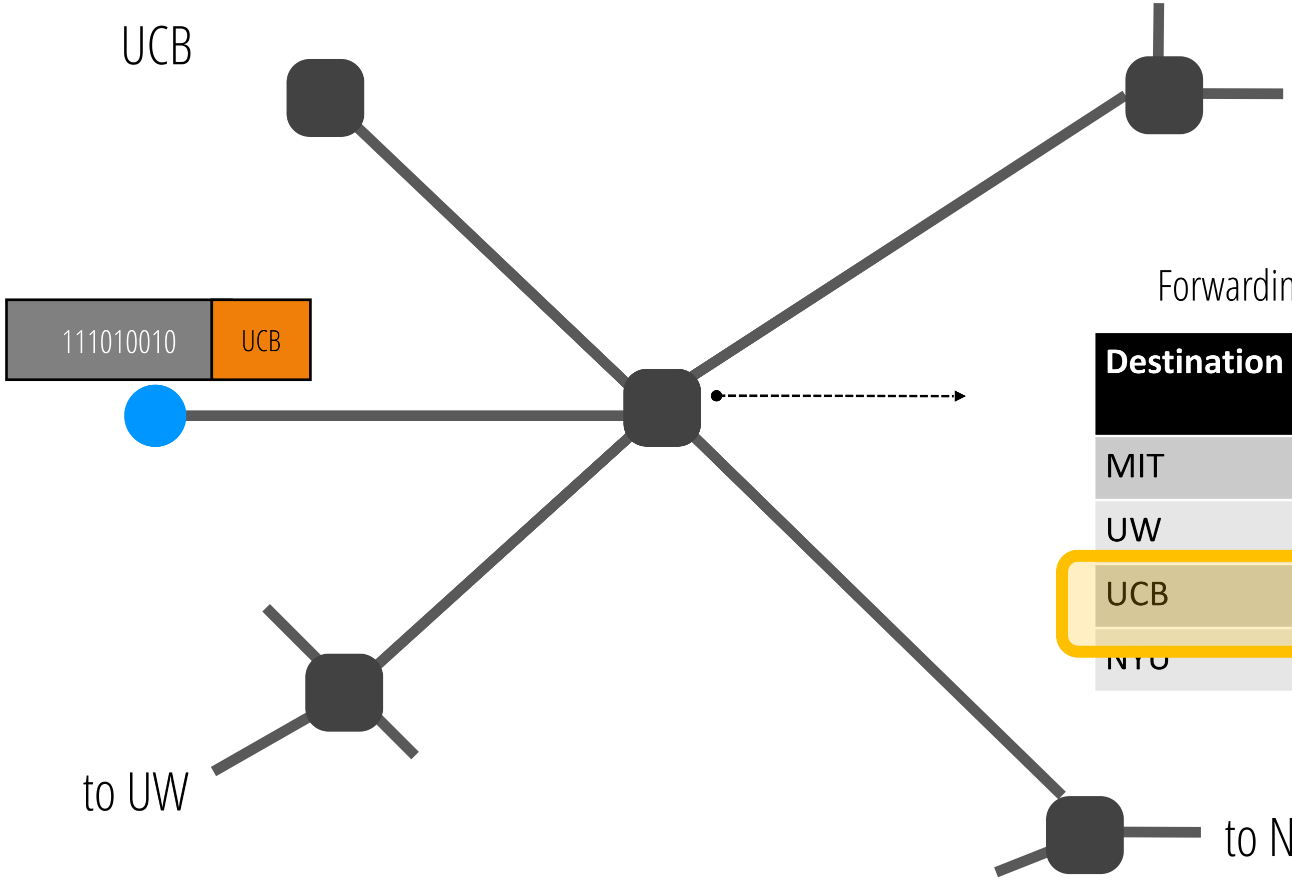

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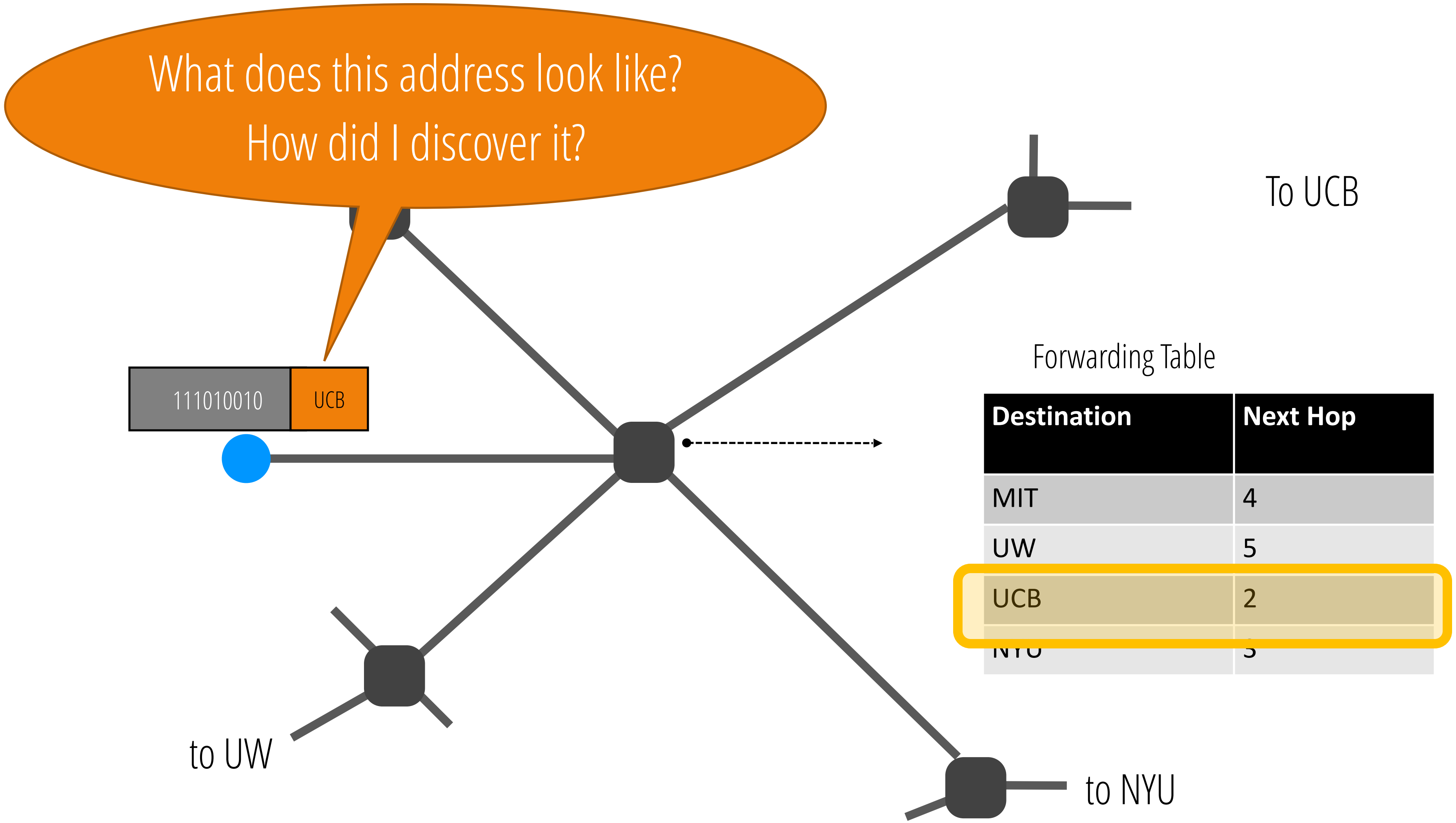

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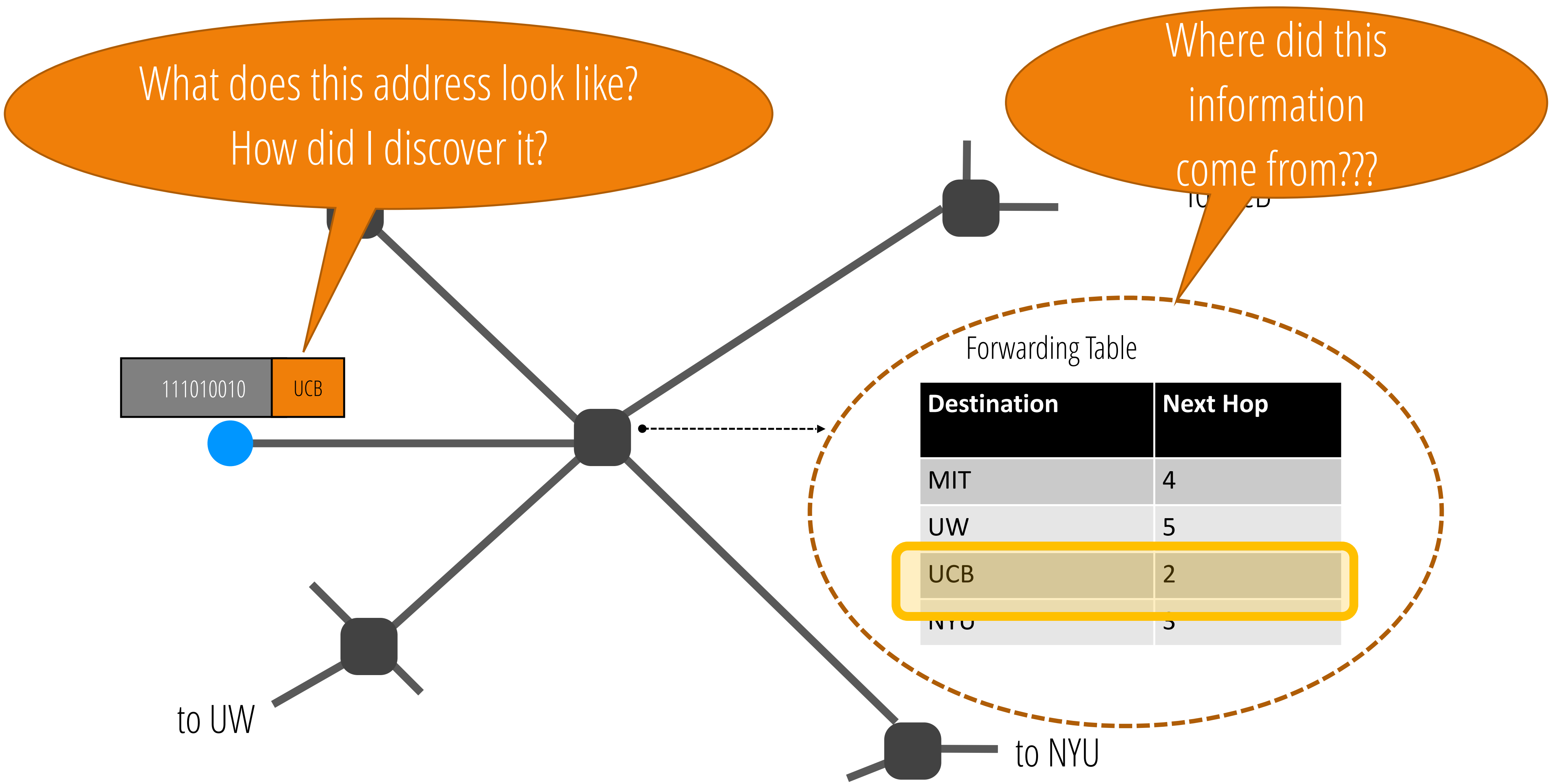

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Will discuss IP addressing a few lectures from now

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Will cover DNS in a later lecture (second half of semester)

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Will devote multiple lectures (and one project) to this question!

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- Data plane: using those tables to actually forward packets
  - Inherently local: depends only on arriving packet and local routing table
  - *Forwarding mechanism ("lookup" algorithm) is part of data plane*
  - Time scale: per packet arrival

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  (Will study BGP in depth later in the semester)

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- The following operations must be done after packet arrives (in ~10 nanoseconds or less)
  - Parse packet (extract address, etc.)
  - Look up address in forwarding table
  - Update other fields in packet header (if needed)
  - Update relevant internal counters, etc.
  - Send packet to appropriate output link

(Will study router designs and IP forwarding lookup algorithms.)

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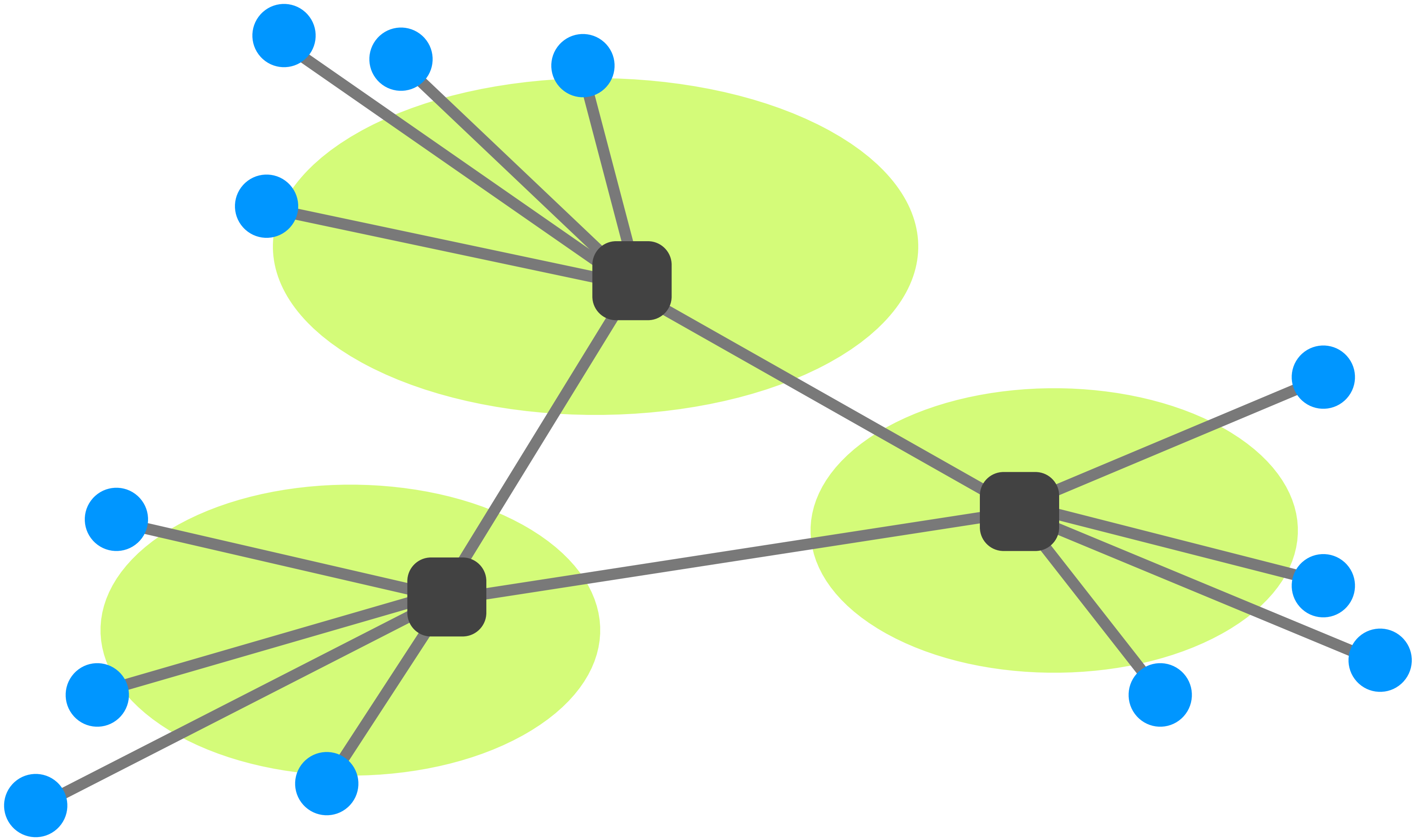
- How do we compute forwarding tables? (routing control plane → project 1)
- How do we forward packets? (routing data plane)

Questions??

Let’s back up a level...



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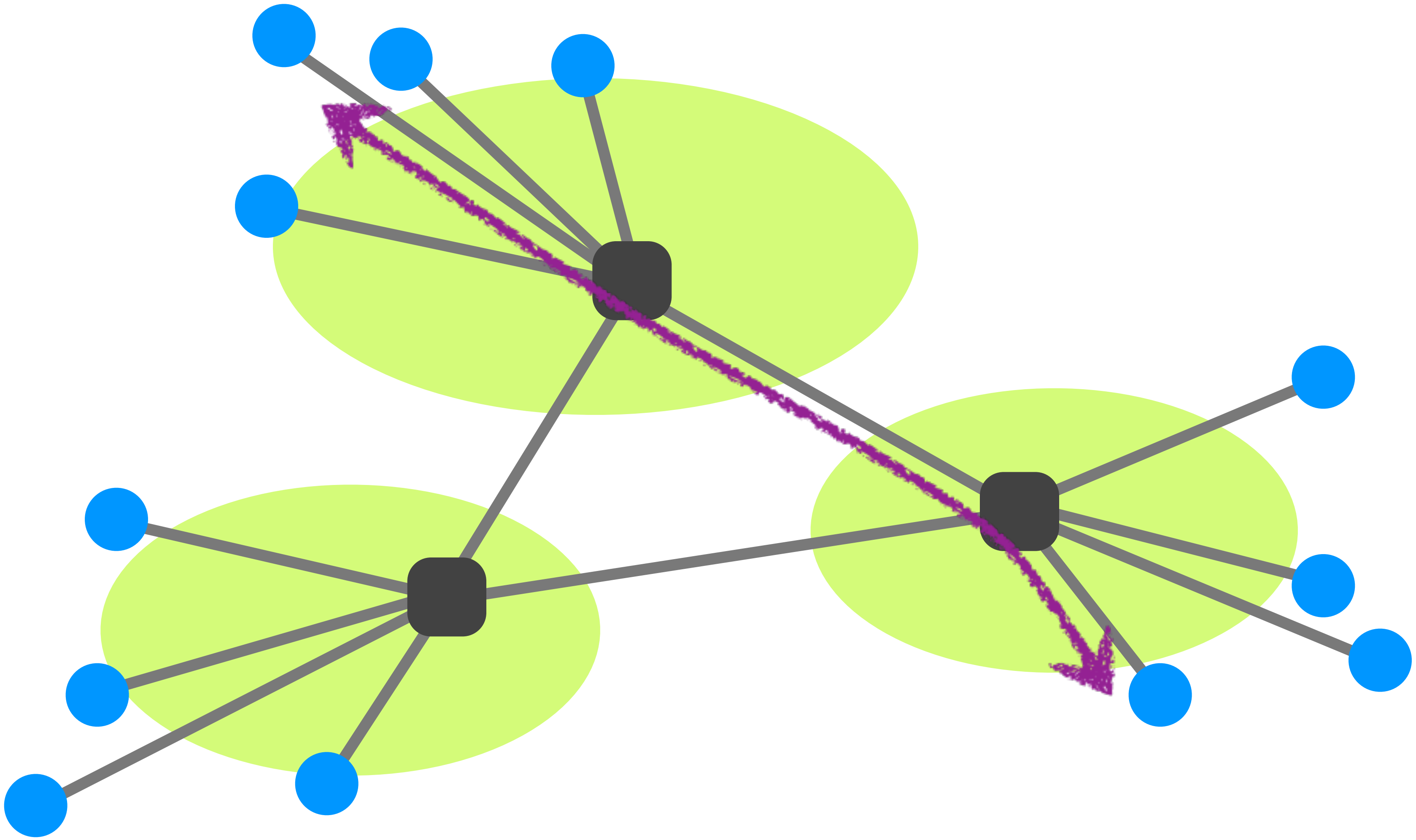

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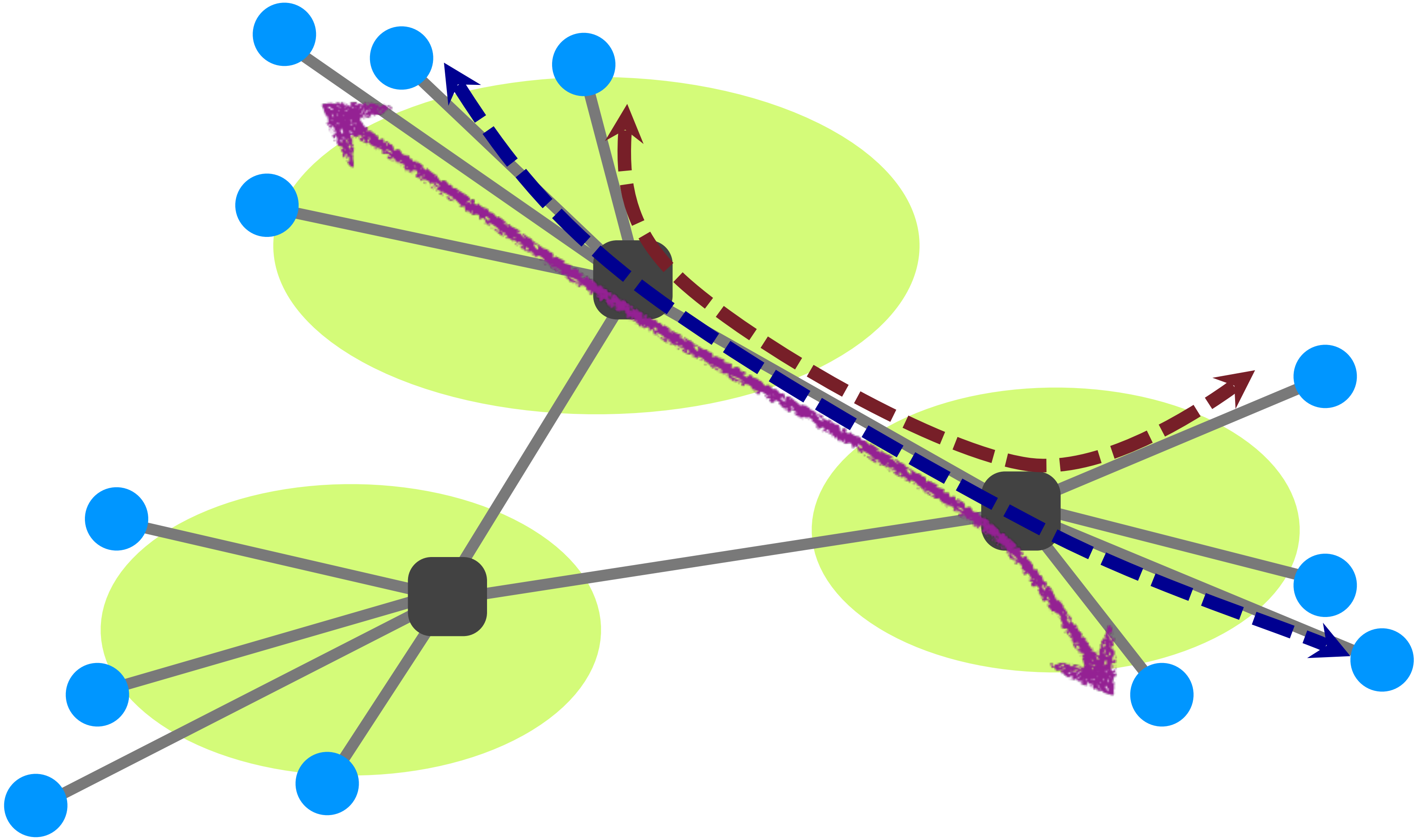

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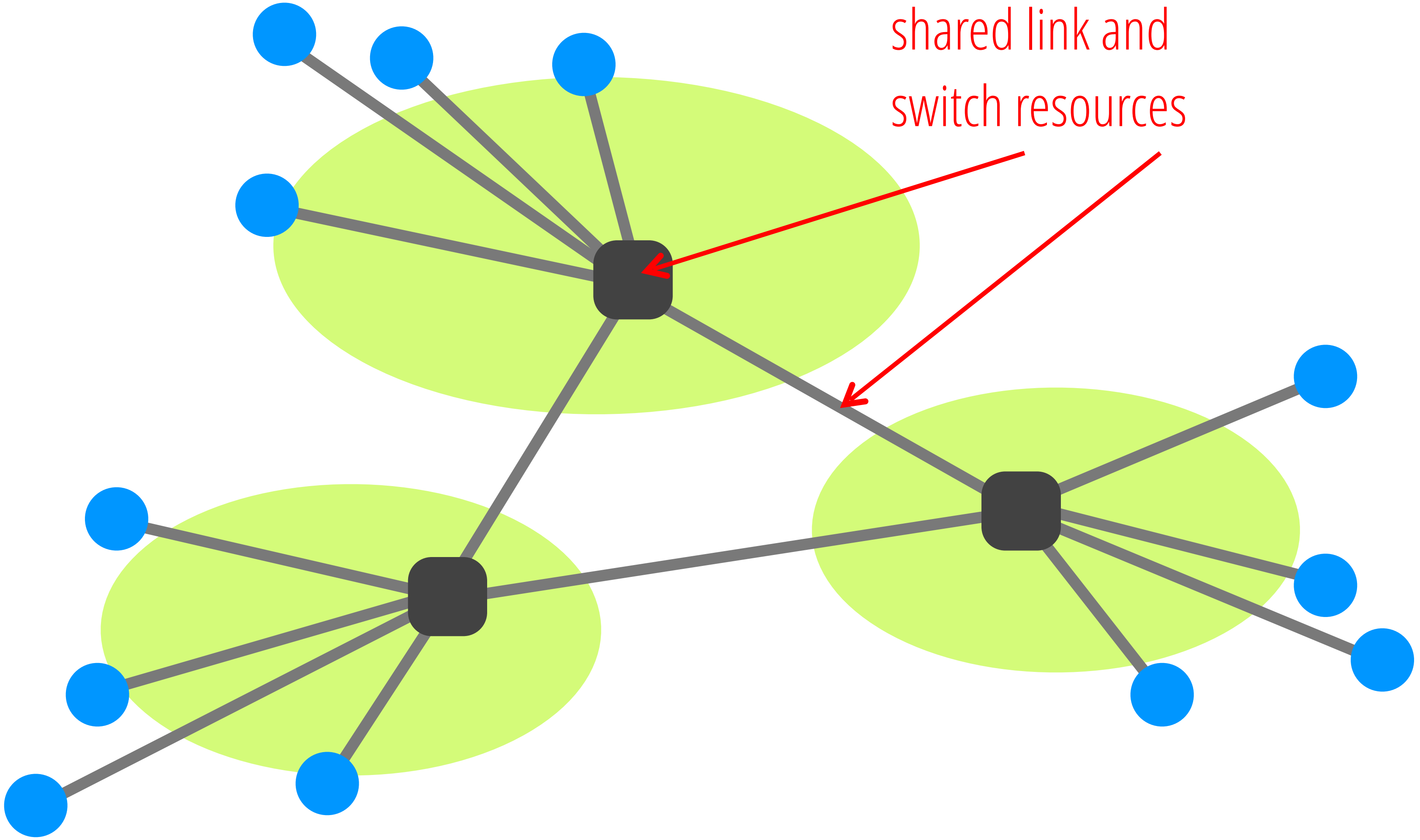

Fundamental Fact About Networks

- Network must support many simultaneous flows at the same time
  - Recall, flow = stream of packets sent between two end hosts

- Which means network resources (links and switches) are shared between end hosts

Network resources (i.e., bandwidth) are statistically multiplexed

Statistical Multiplexing

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- Based on premise: peak of aggregate demand is << aggregate of peak demands

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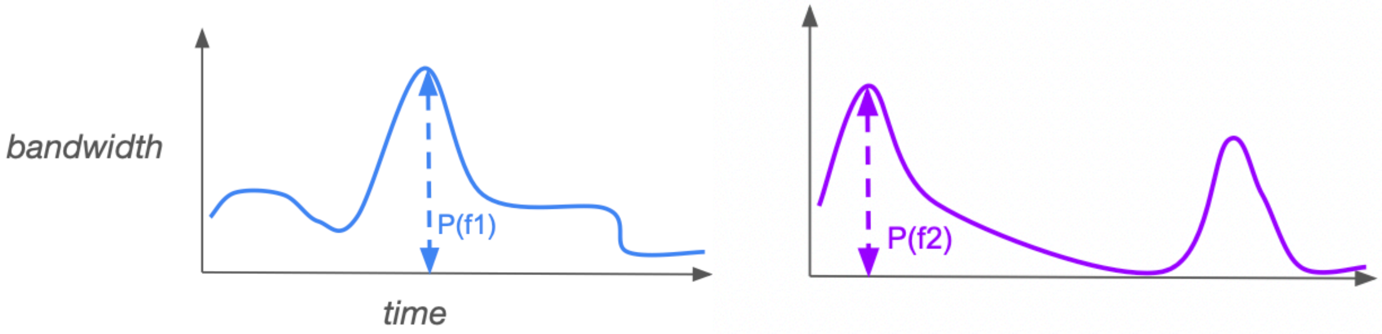

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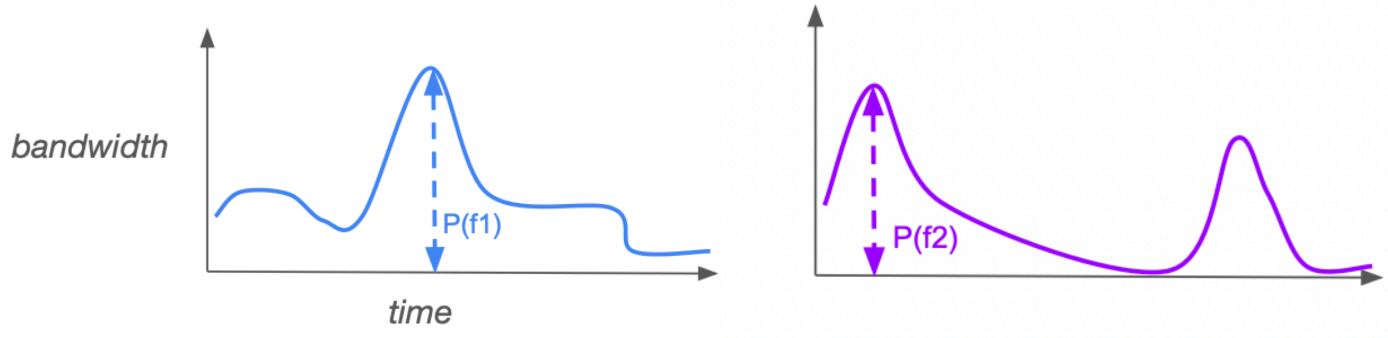

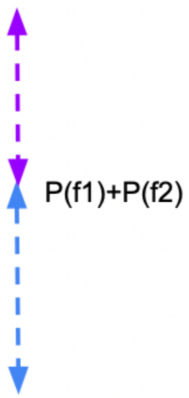

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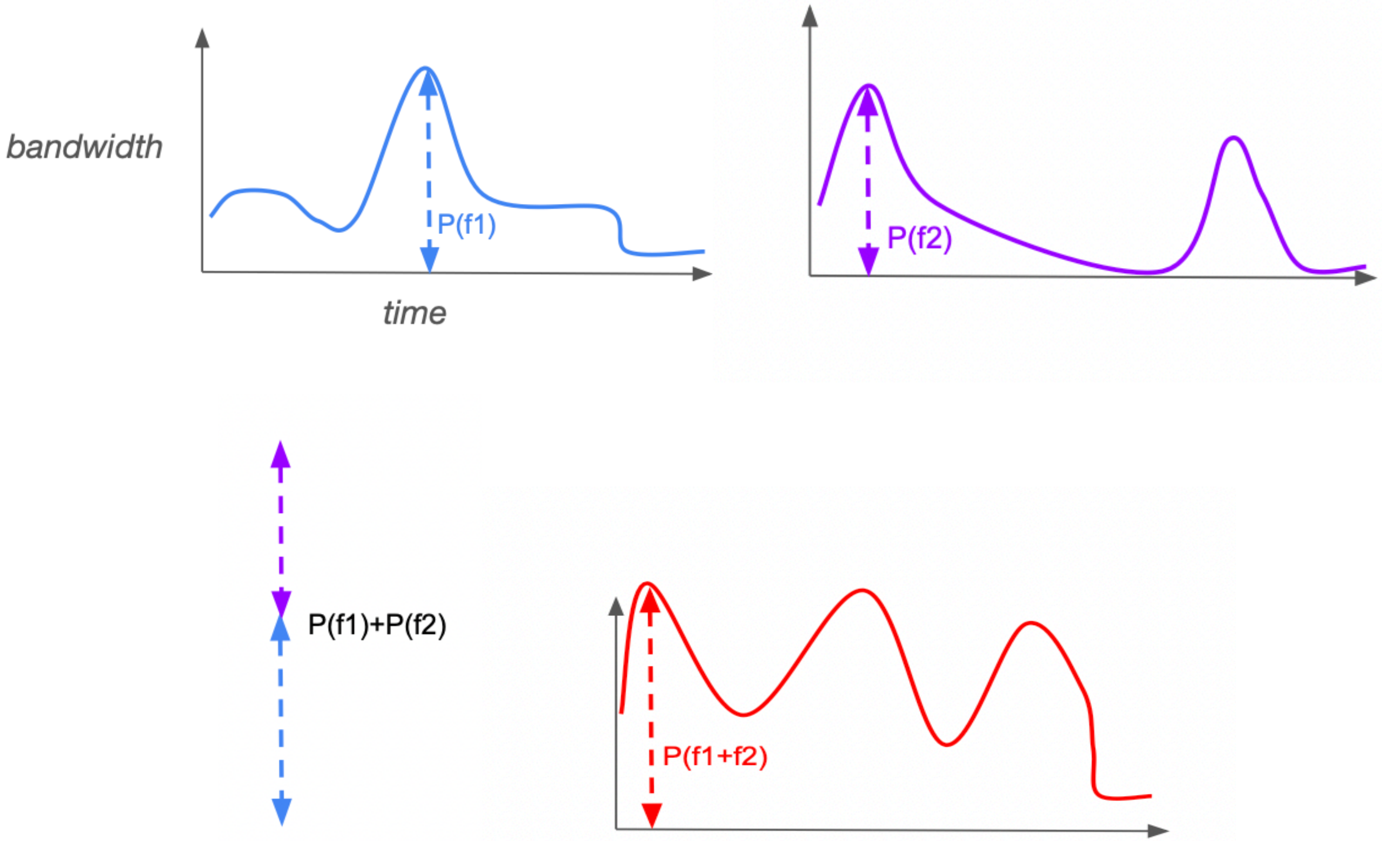

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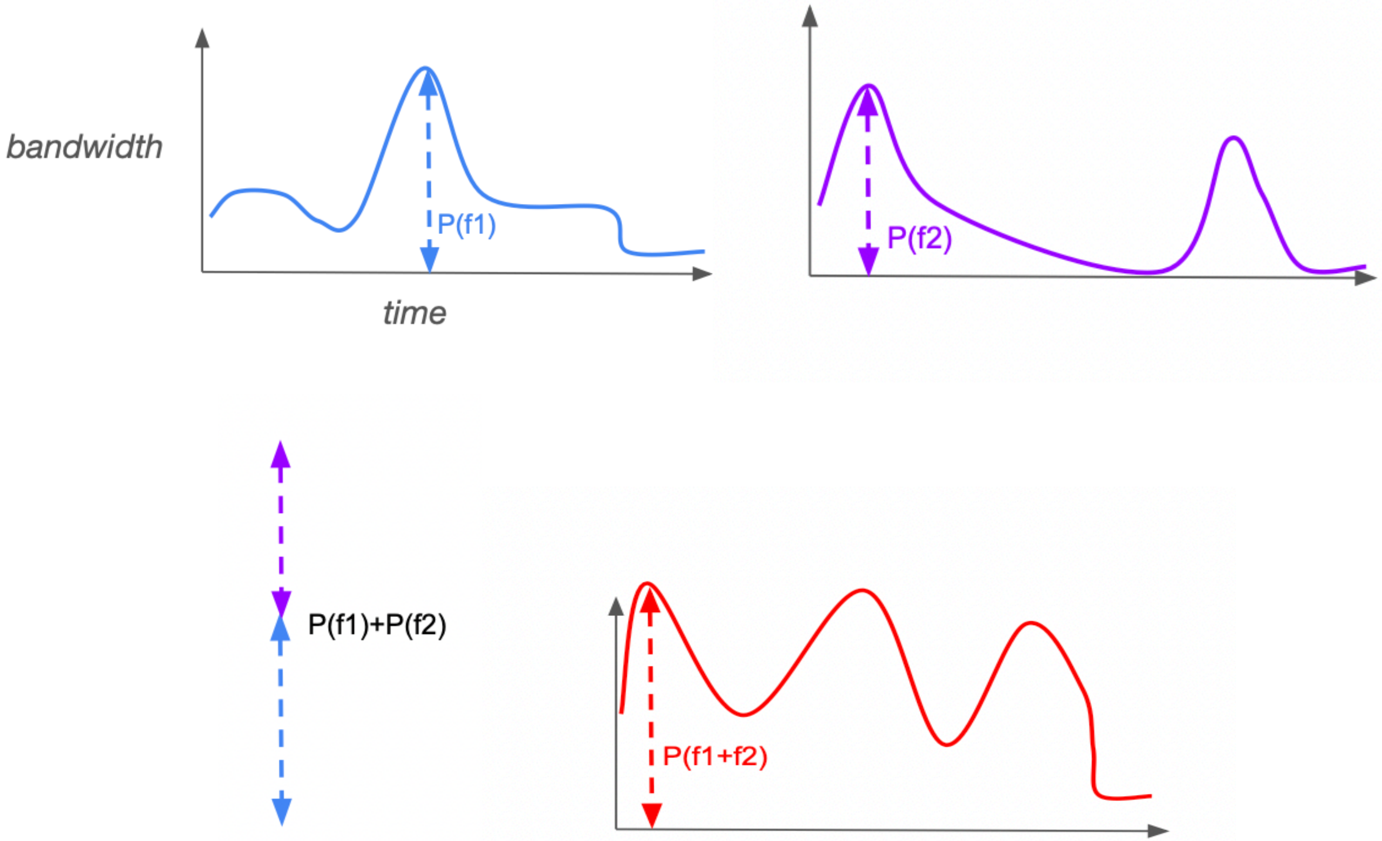
- Typically: P($\Sigma_{\{f\}}$f) ~ $\Sigma_{\{f\}}$A(f)
  - Where A(f) is the average rate of flow f



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- Statistical multiplexing merely means that you don’t provision for absolute worst case
  - When everything peaks at the same time
- Instead, you share resources and hope that peak rates don’t occur at same time

How would you share network resources?

Two approaches to sharing

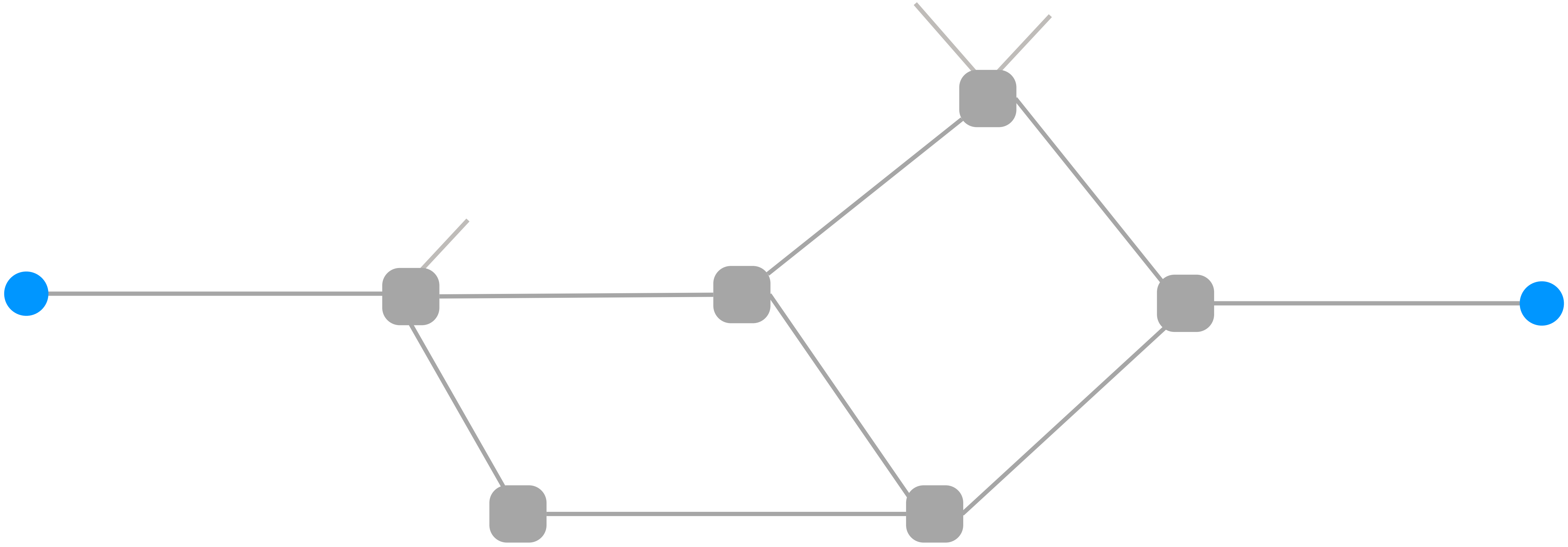
- Reservations: end-hosts explicitly reserve BW when needed (e.g., at the start of a flow)
  - Request/reserve resources
  - Send data
  - Release resources
- Best-effort: just send data packets when you have them and hope for the best ...

Implementing reservations / best-effort sharing

- Many possible approaches!

- Two canonical designs explored in research and industry
  - Reservations via circuit switching
  - Best-effort via packet switching

Reservations: e.g., circuit switching



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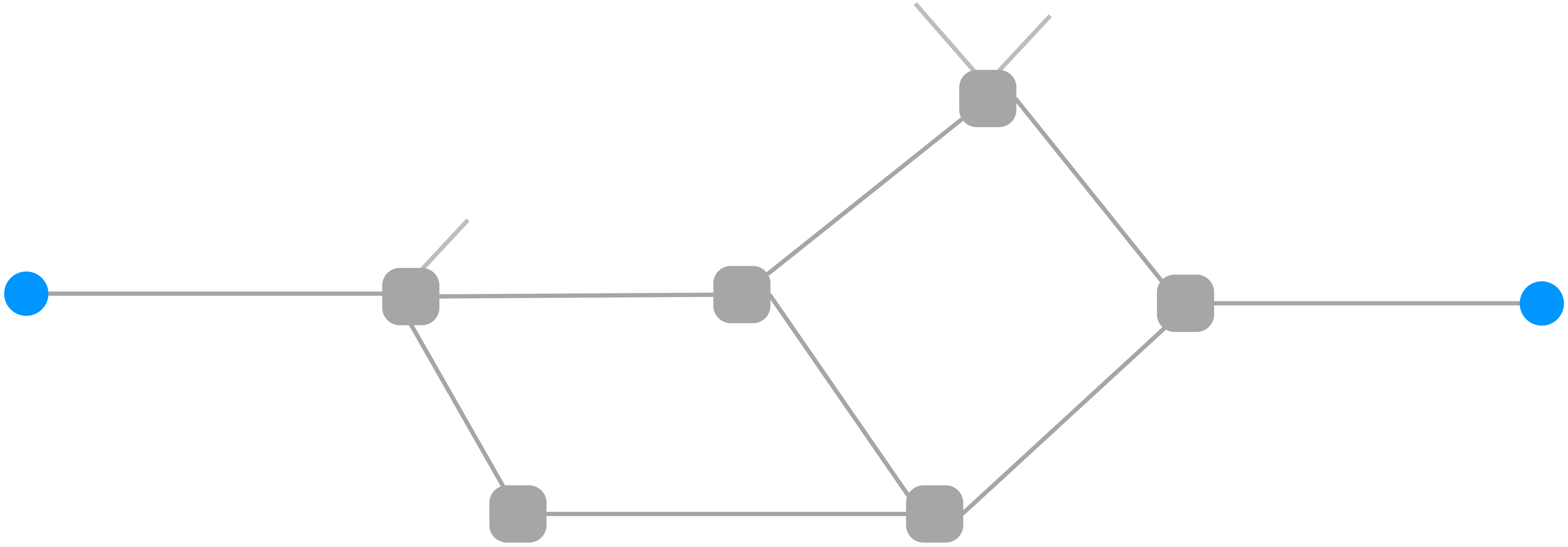

Idea: Reserve network capacity for all packets in a flow

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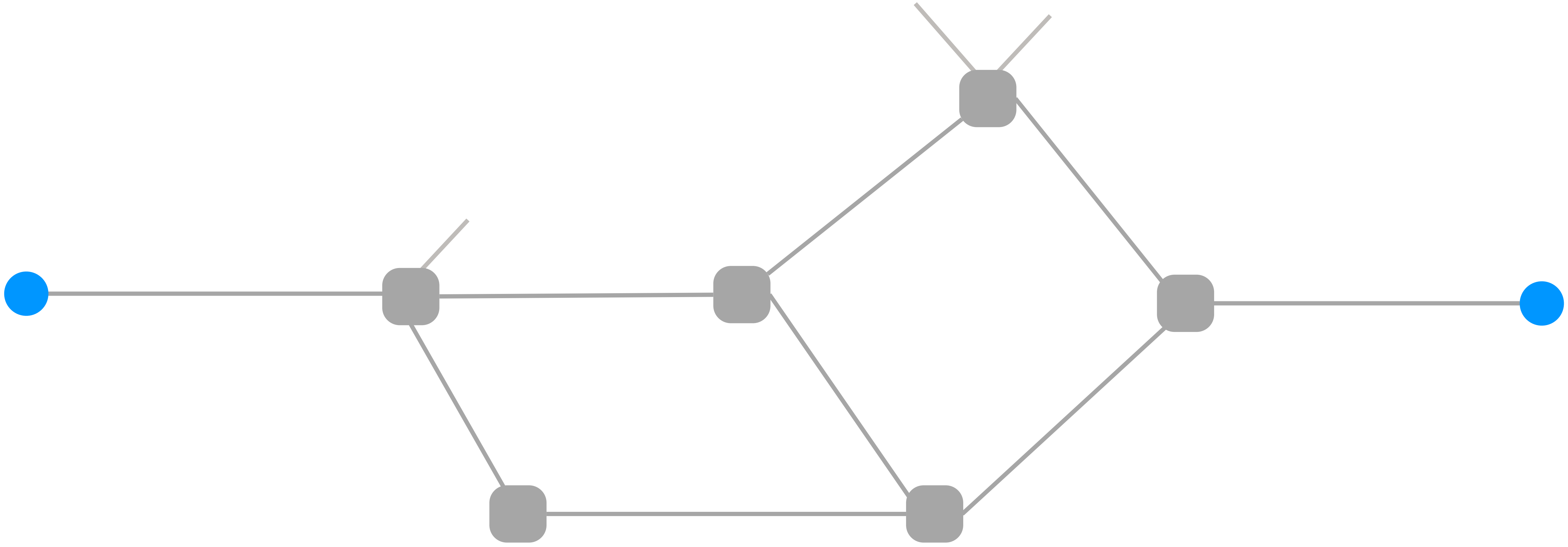

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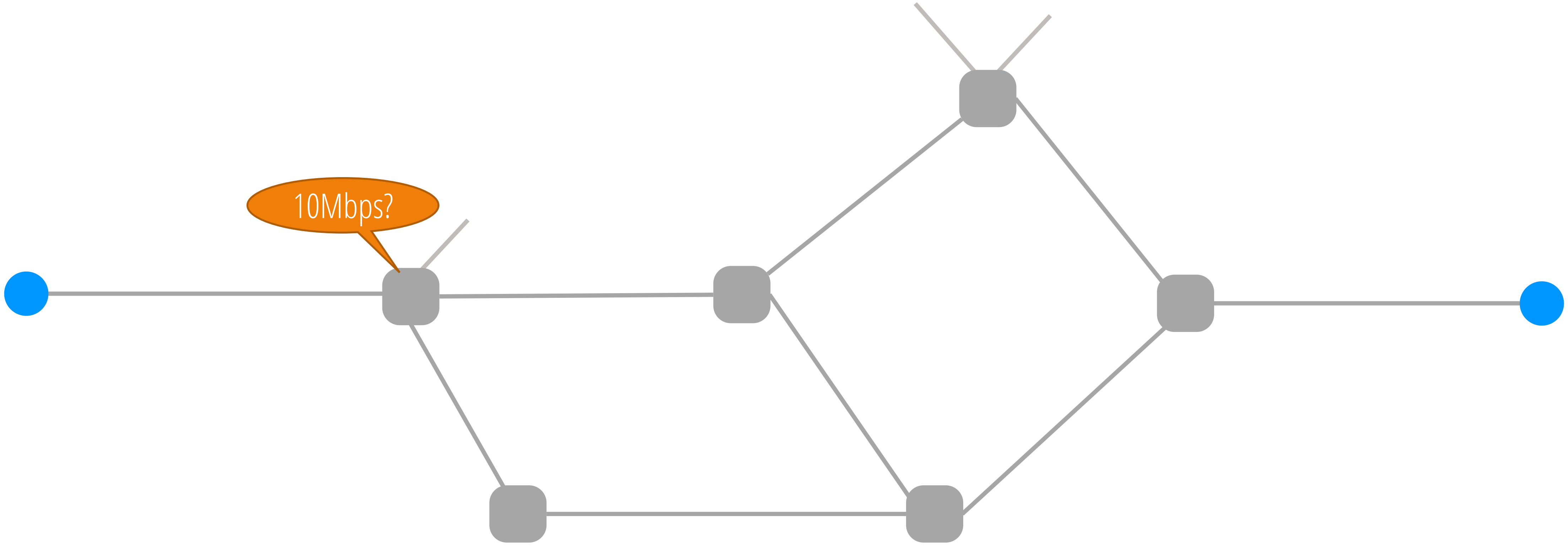

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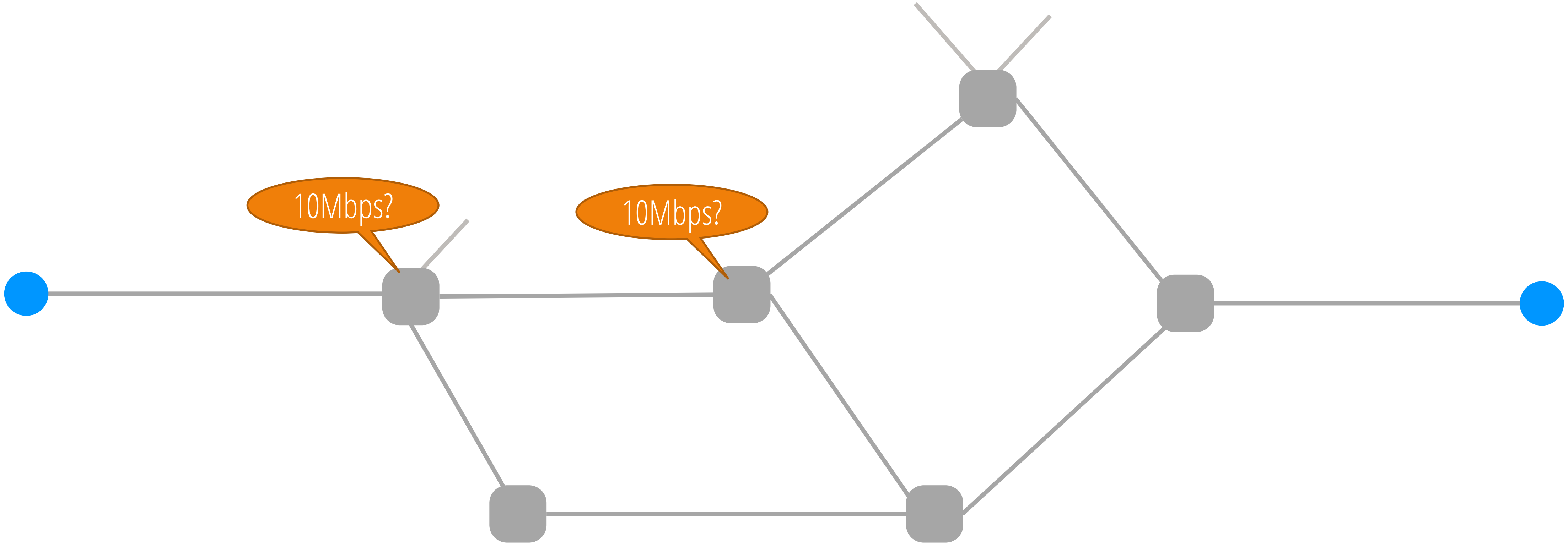

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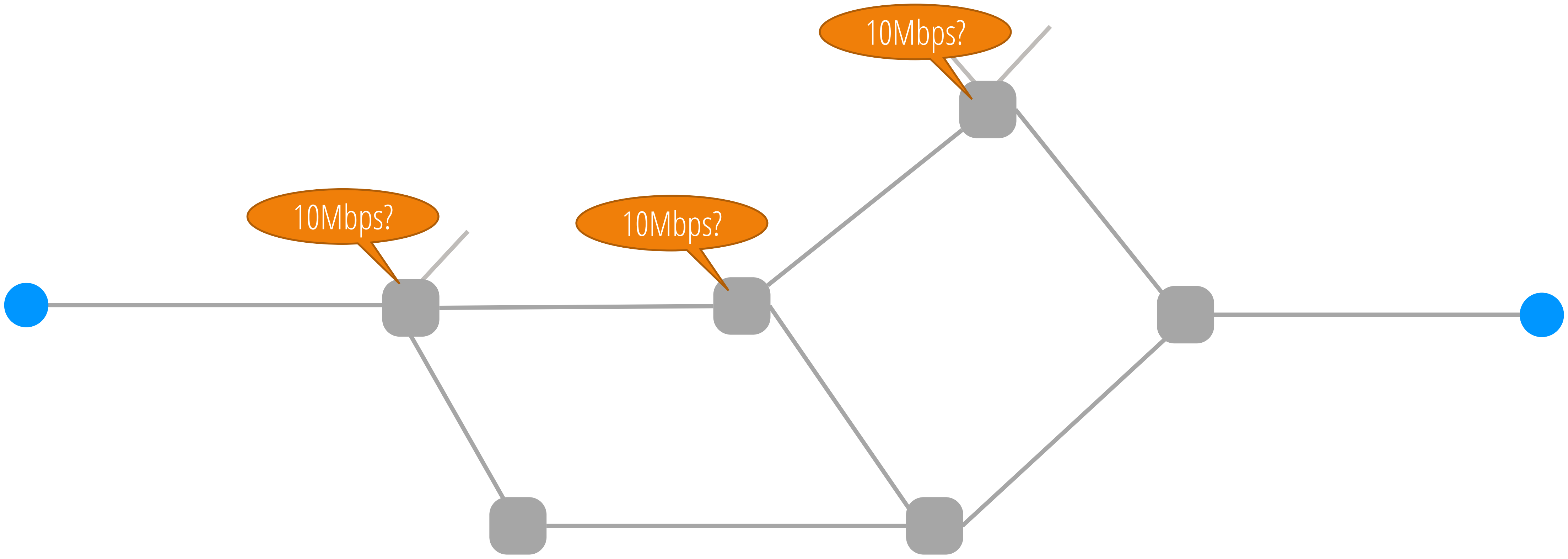

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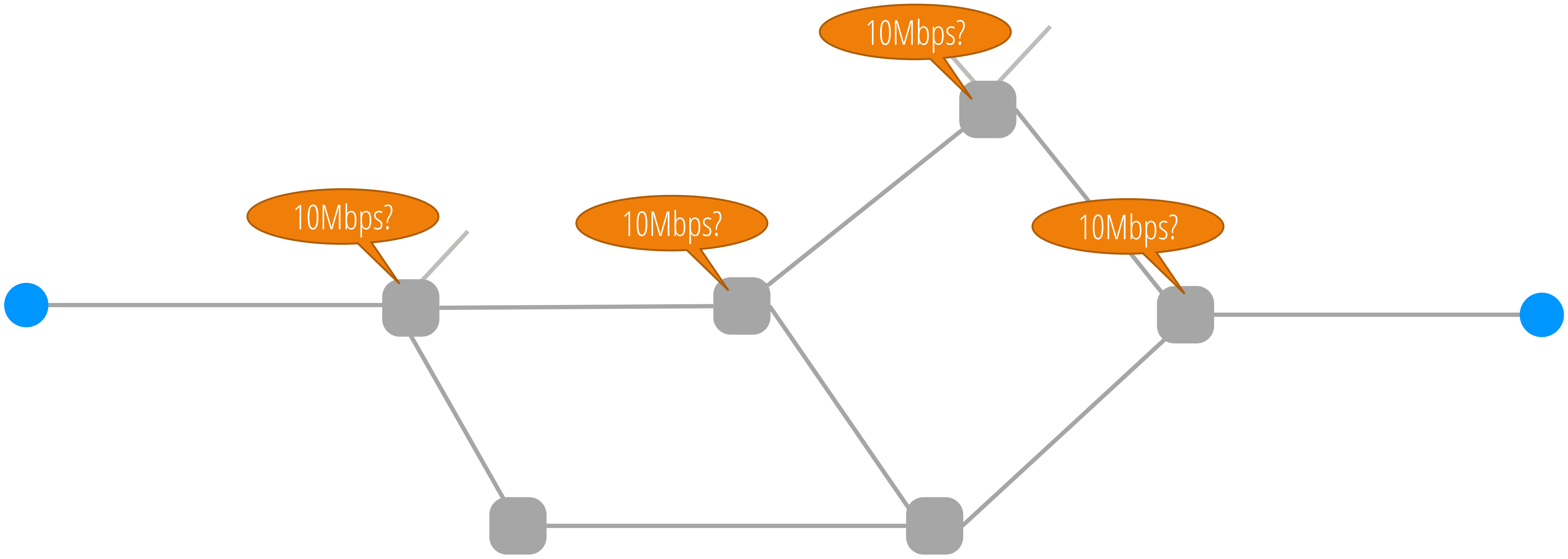

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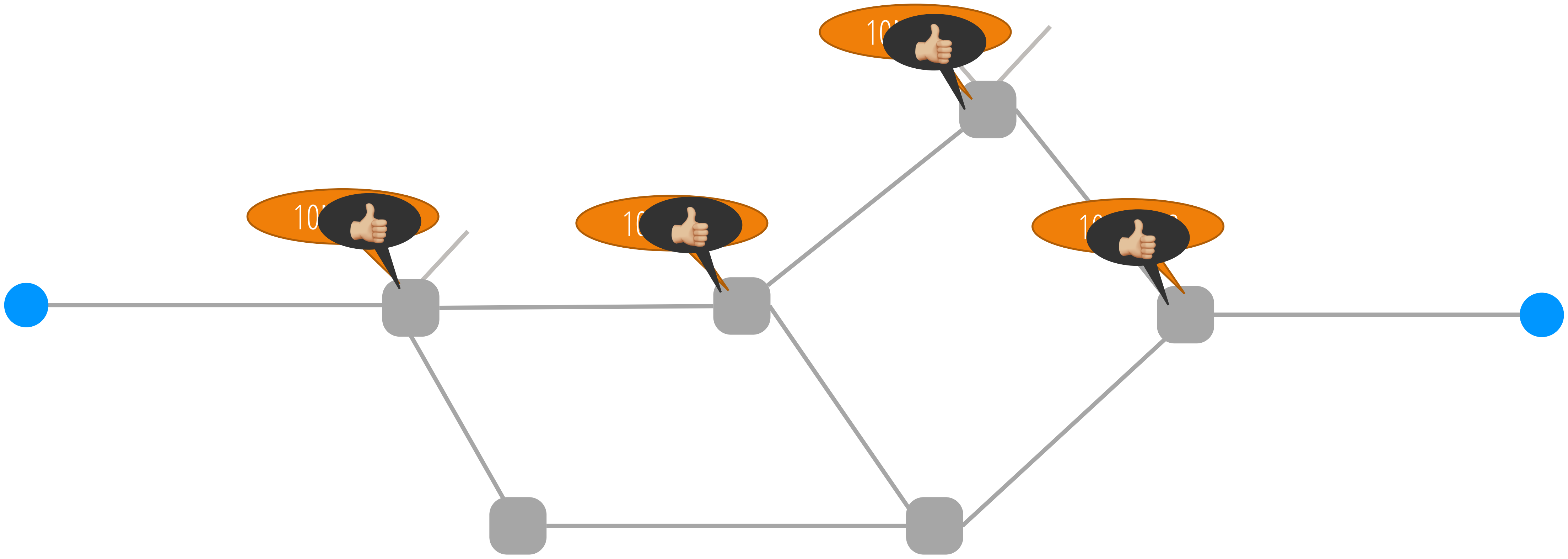

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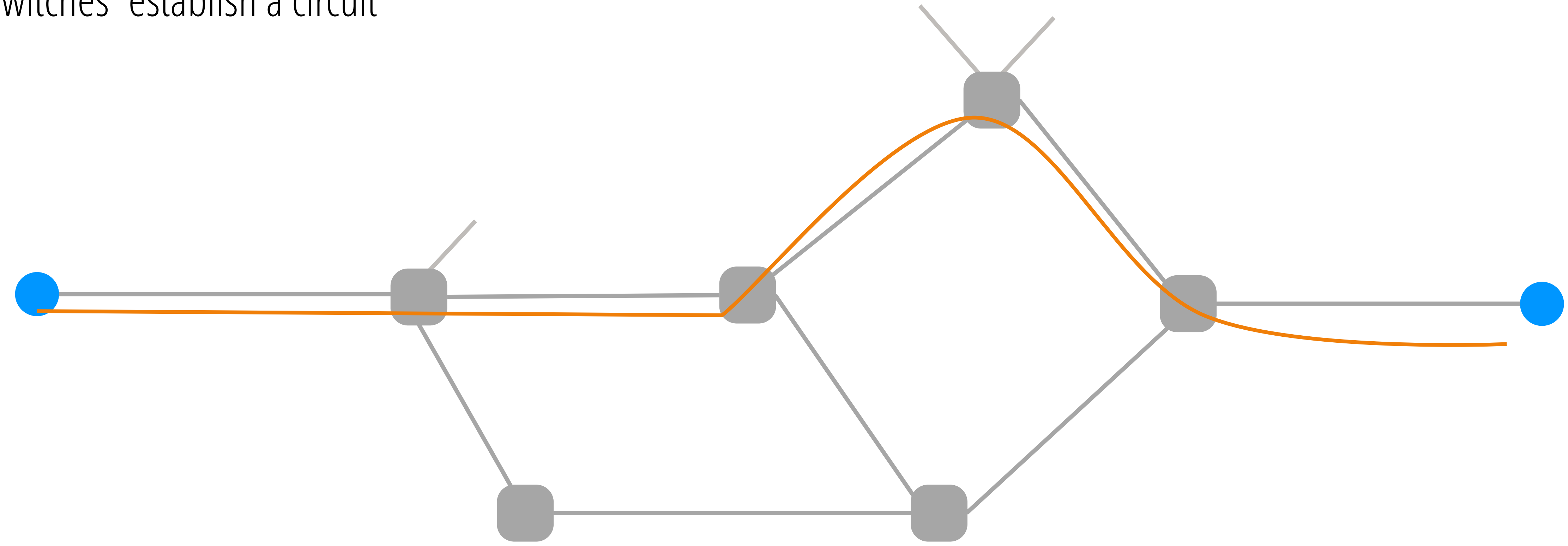

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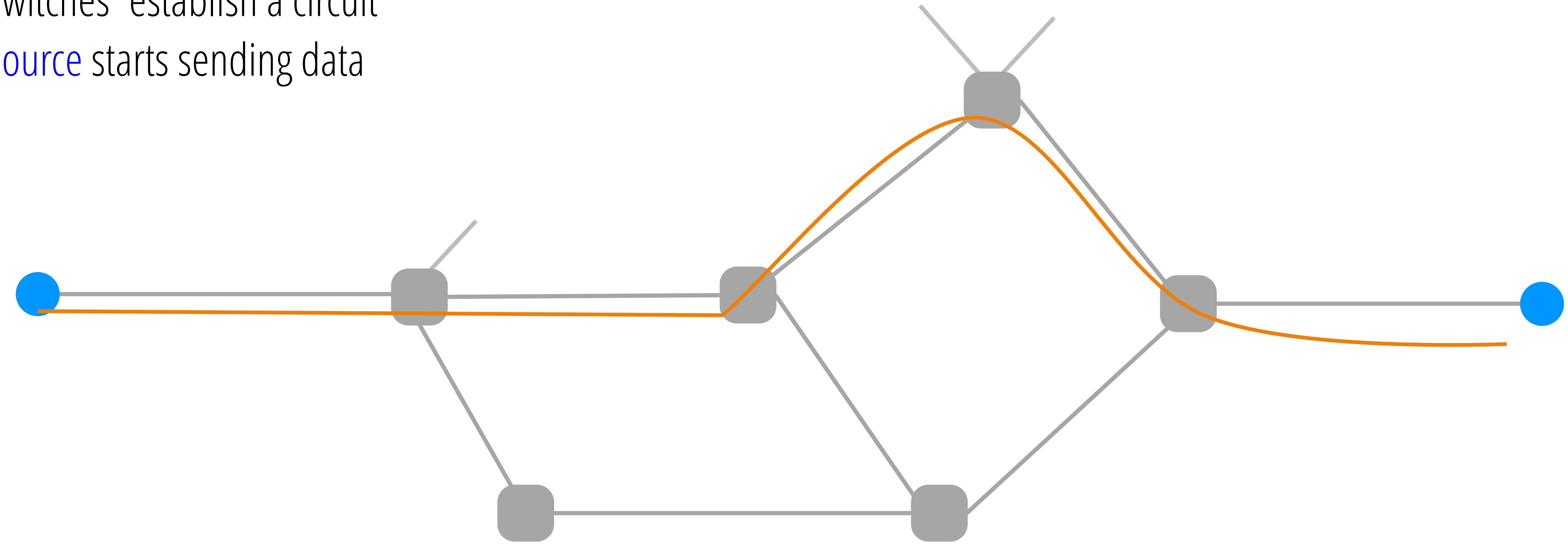

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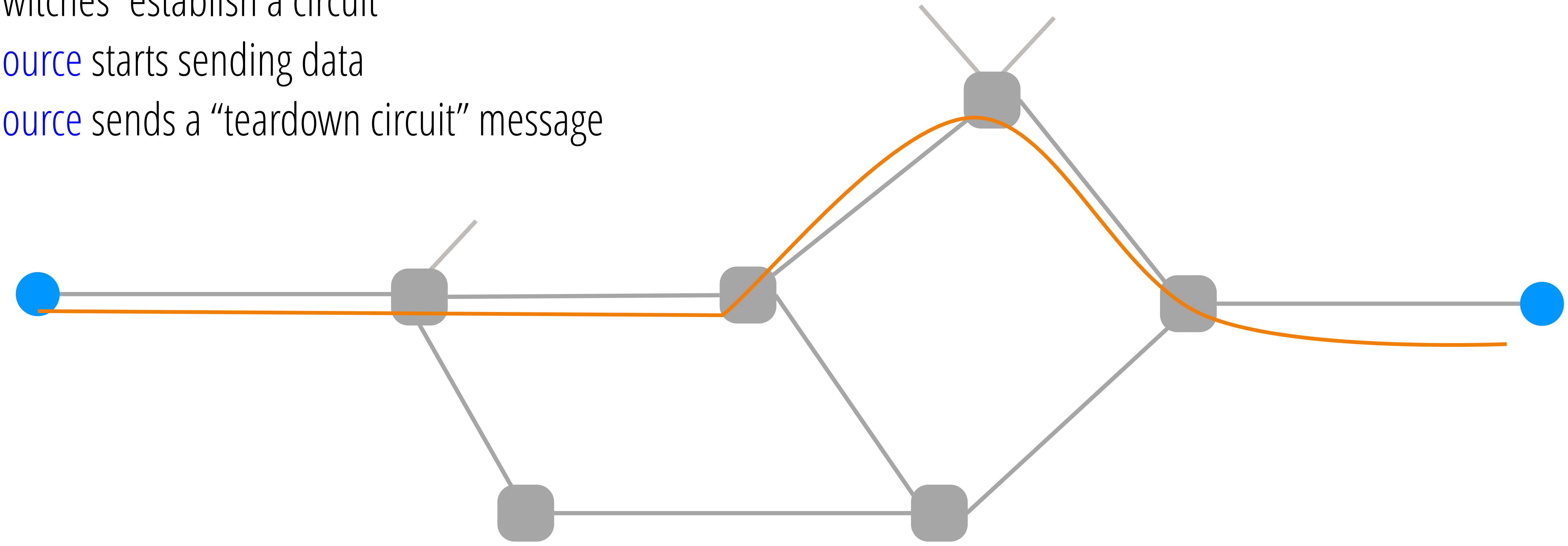

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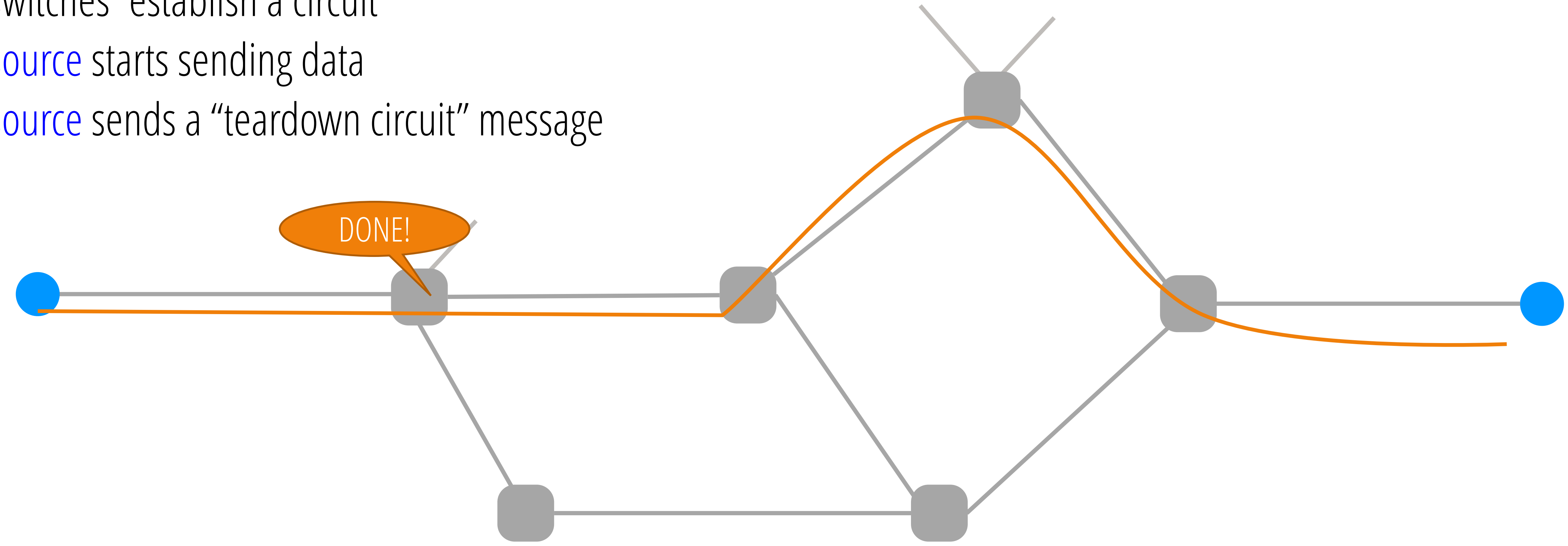

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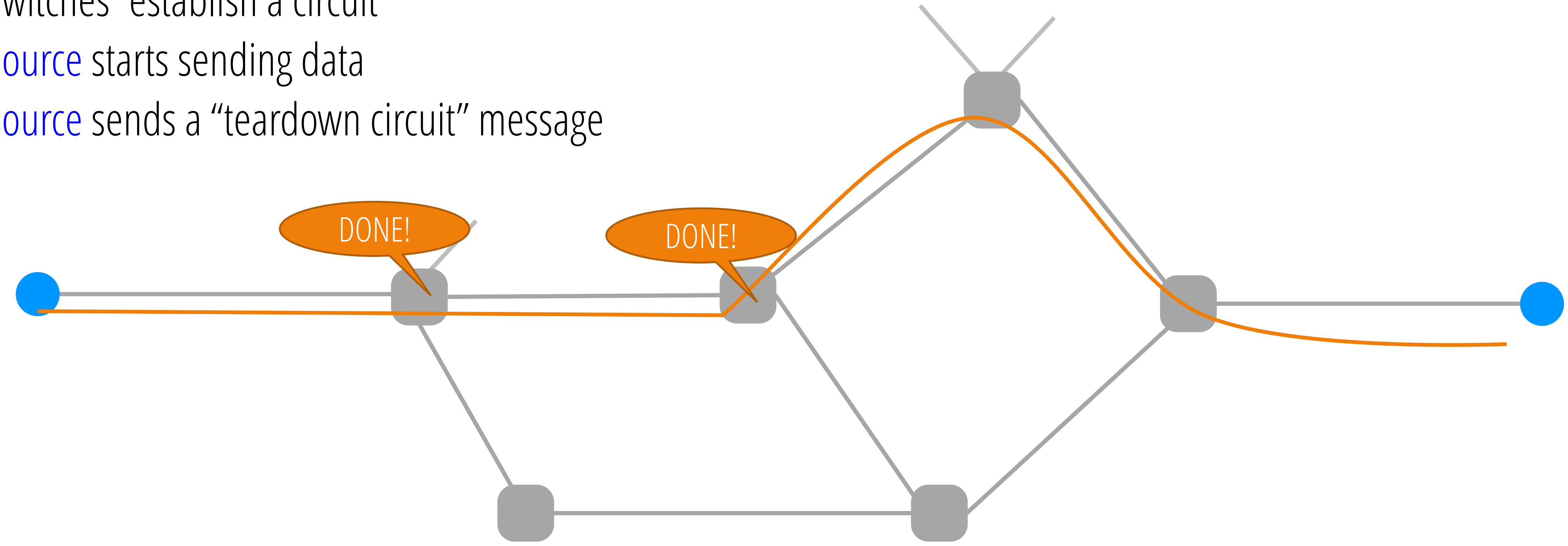

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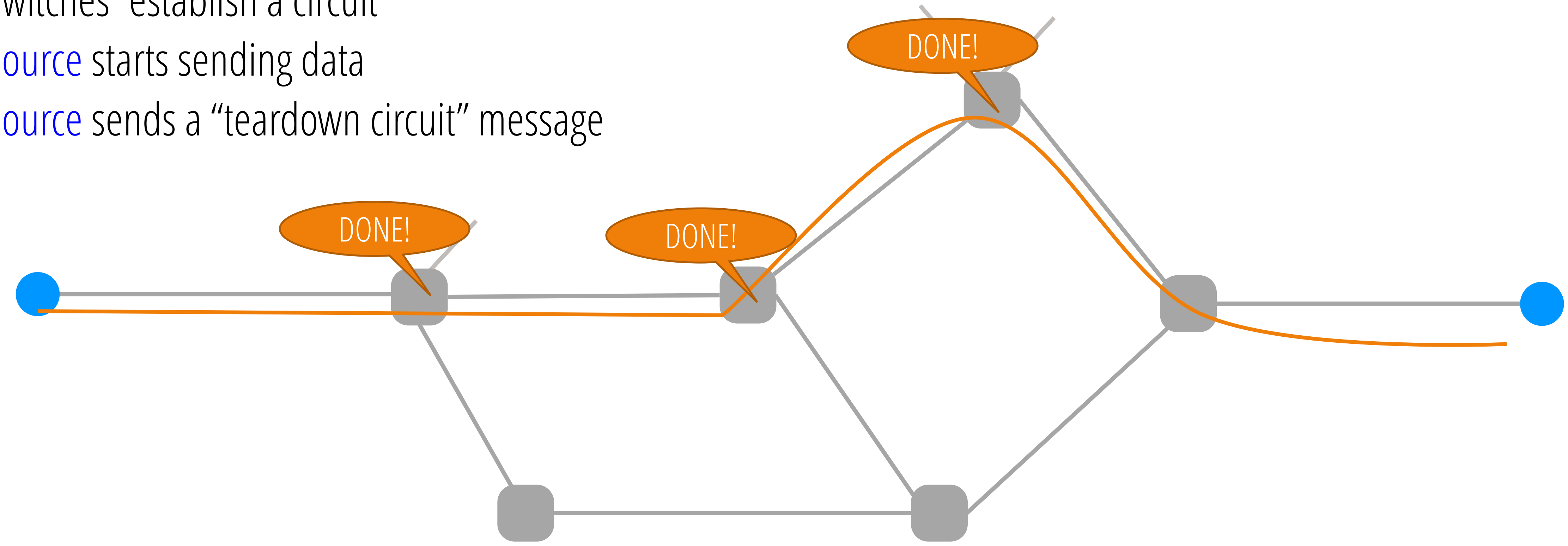

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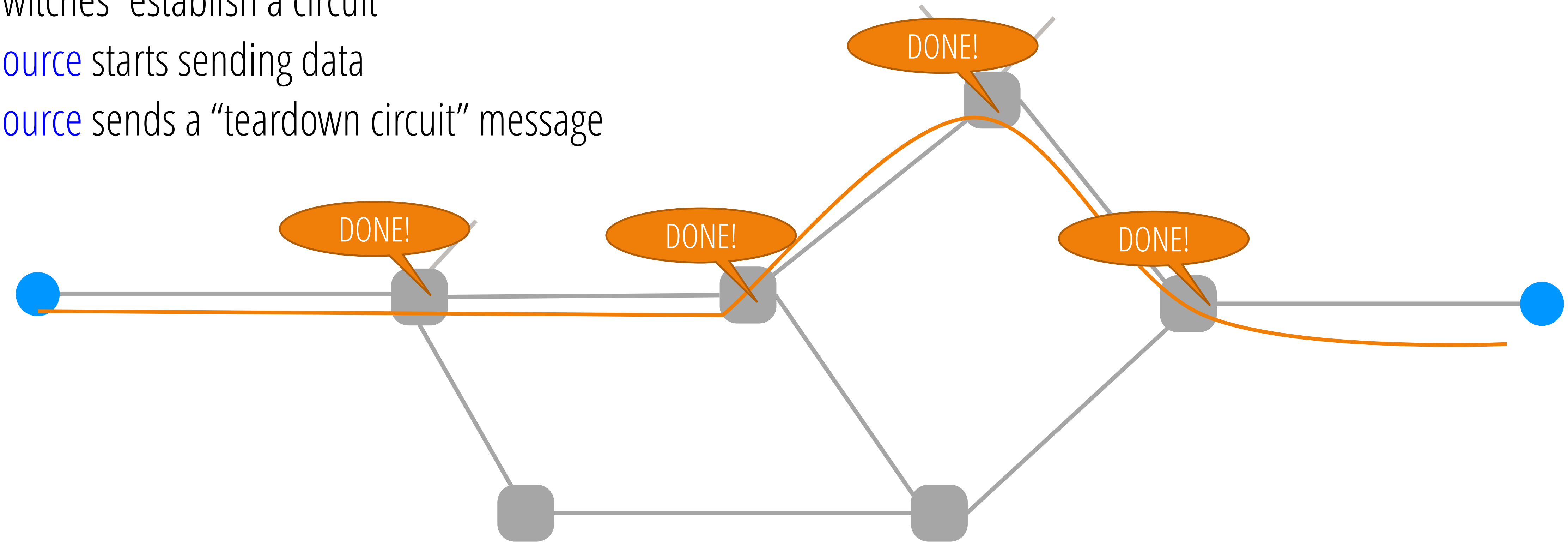

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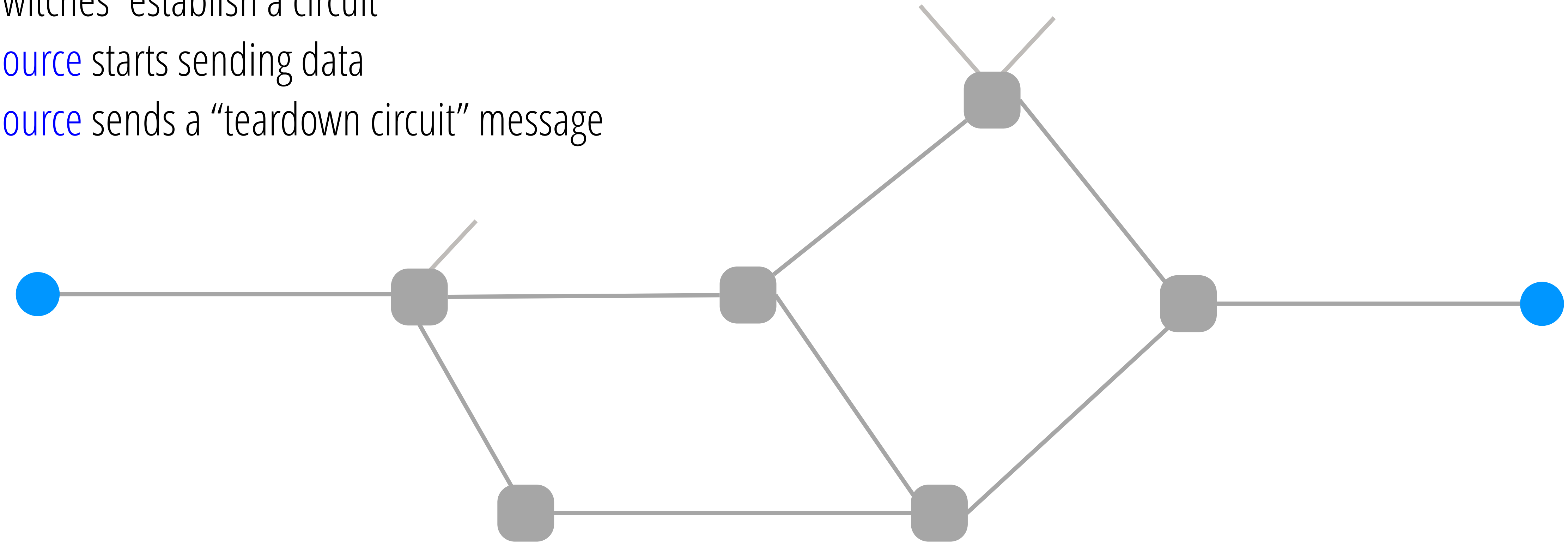

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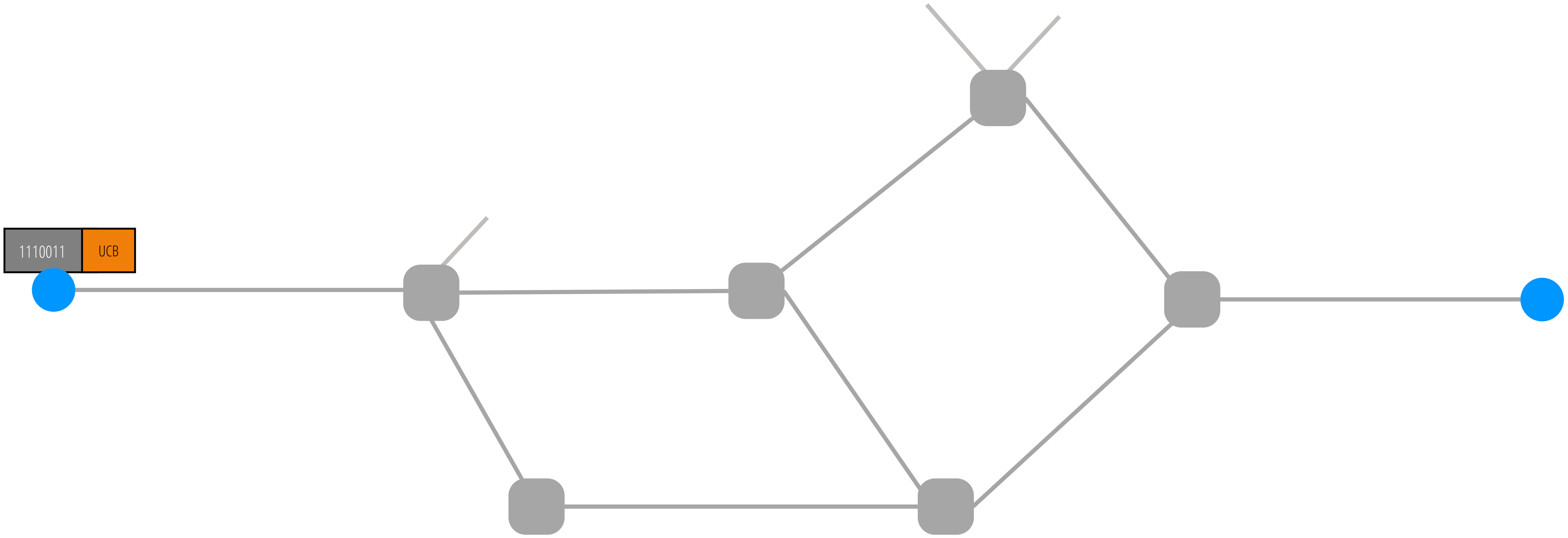

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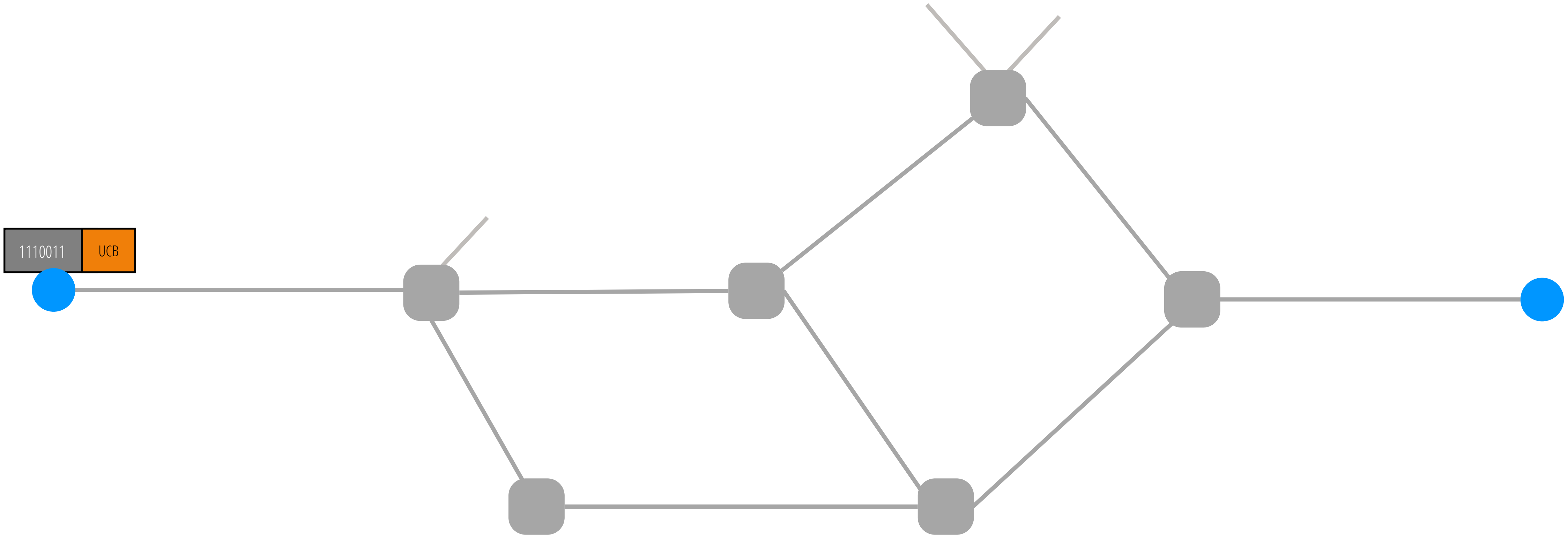

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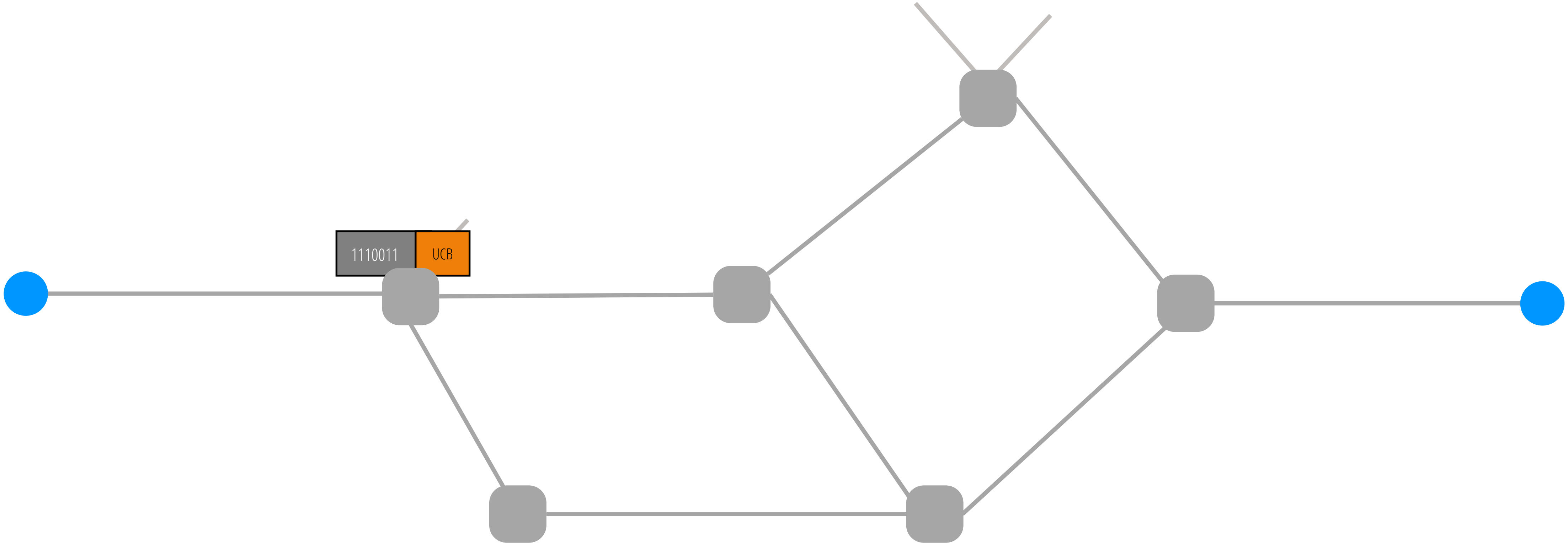

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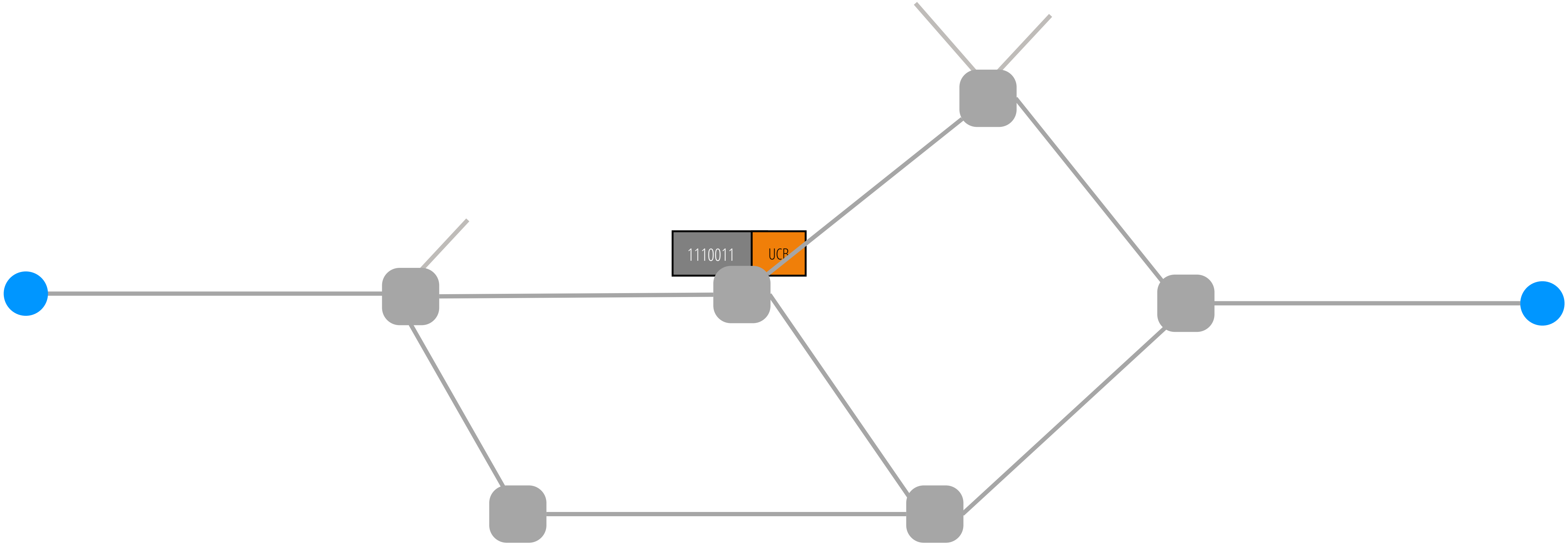

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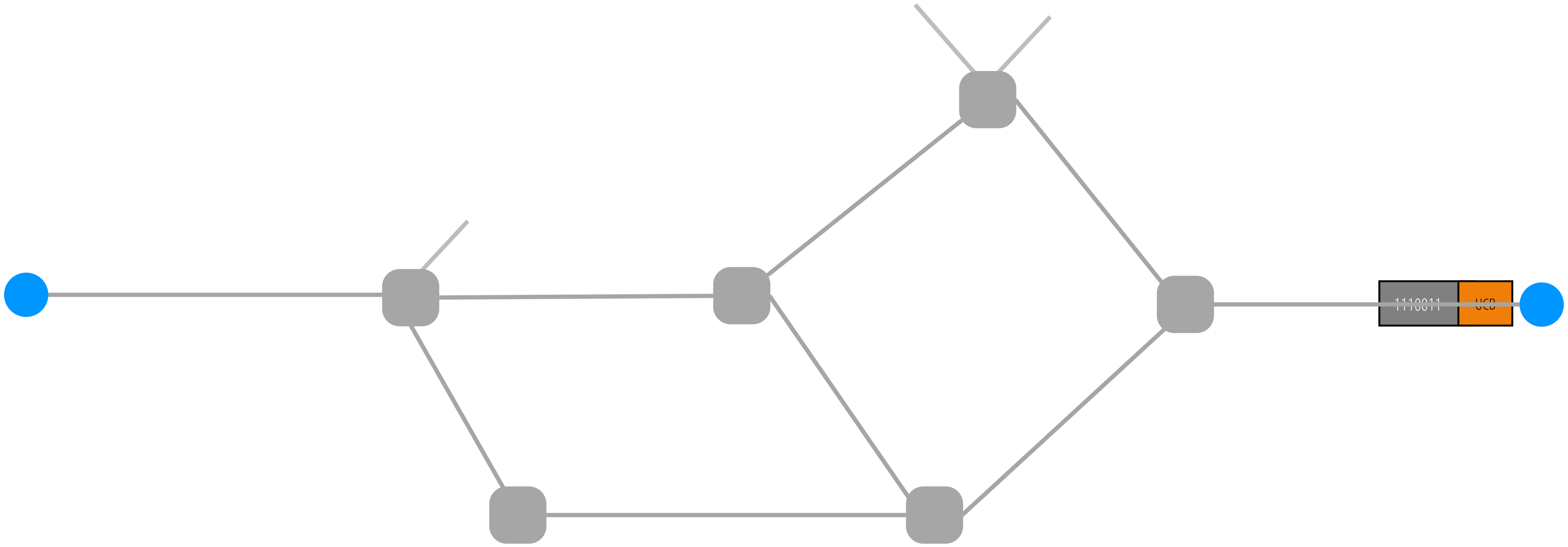

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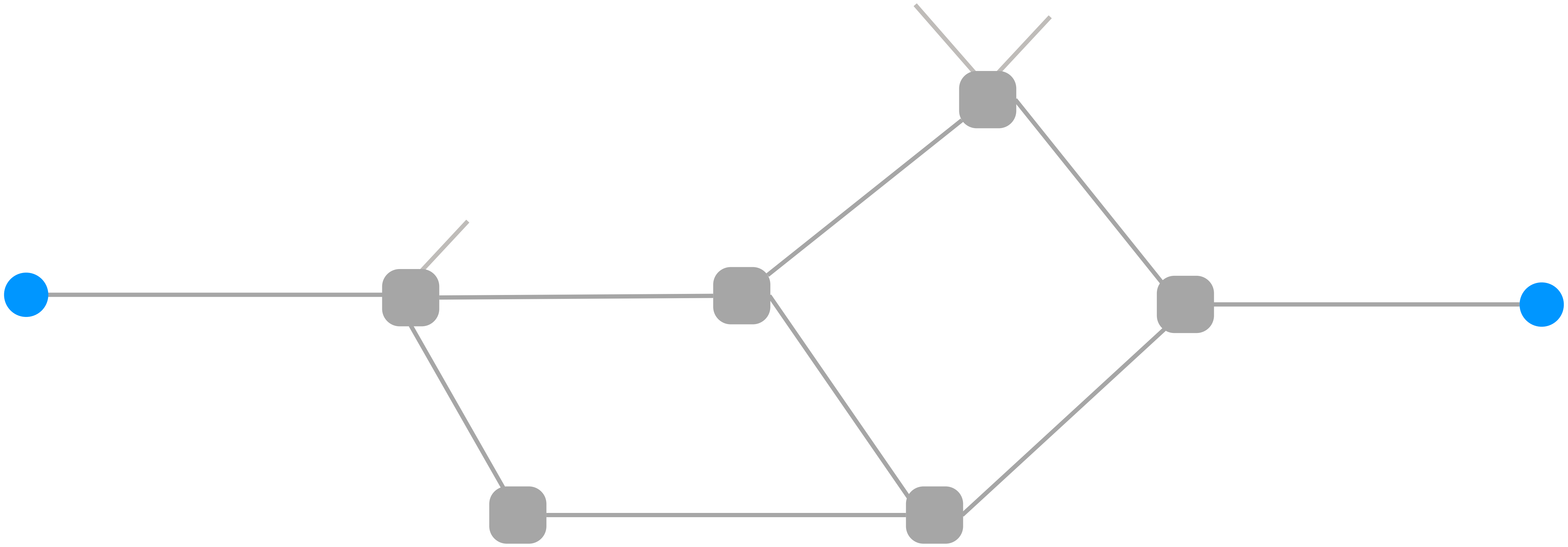

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  - Resources given out on packet-by-packet basis
  - Never reserve resources

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  - As an abstraction to applications
  - Efficiency (at scale)
  - Handling failures (at scale)
  - Complexity of implementation (at scale)