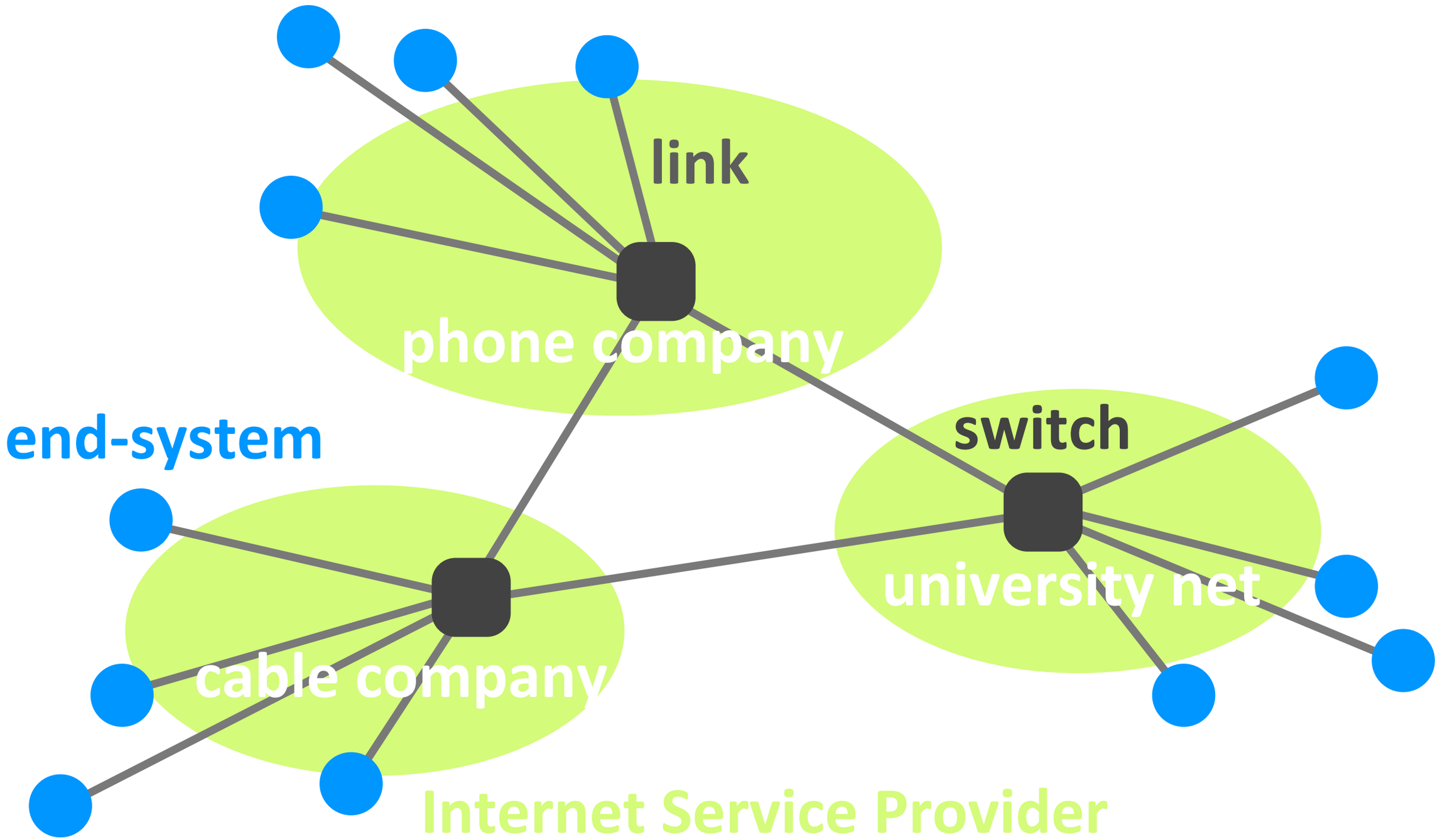
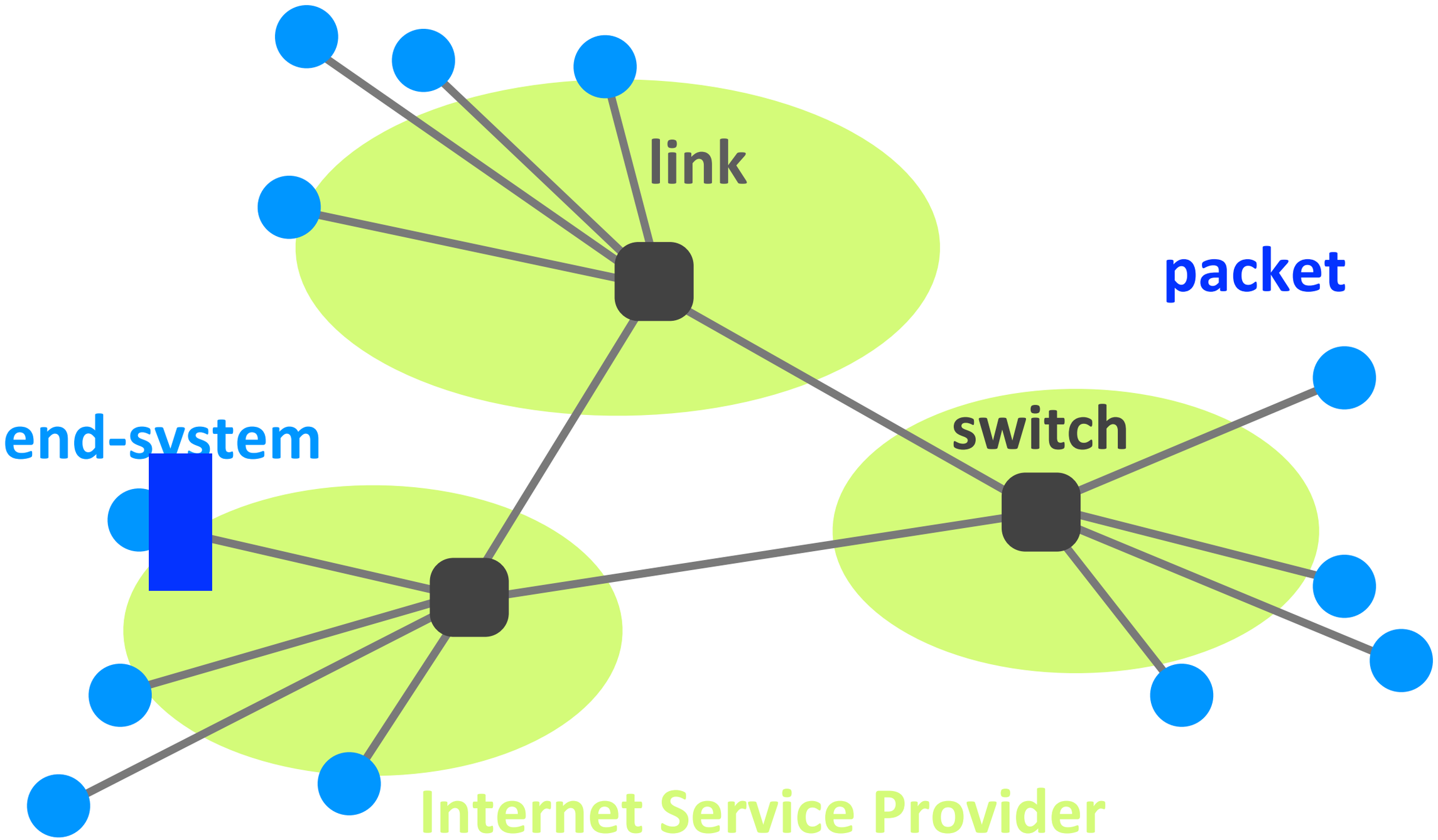
Chapter 1:
Computer Networks and the Internet

Katerina Argyraki, Mihai Dobrescu, Bryan Ford - EPFL

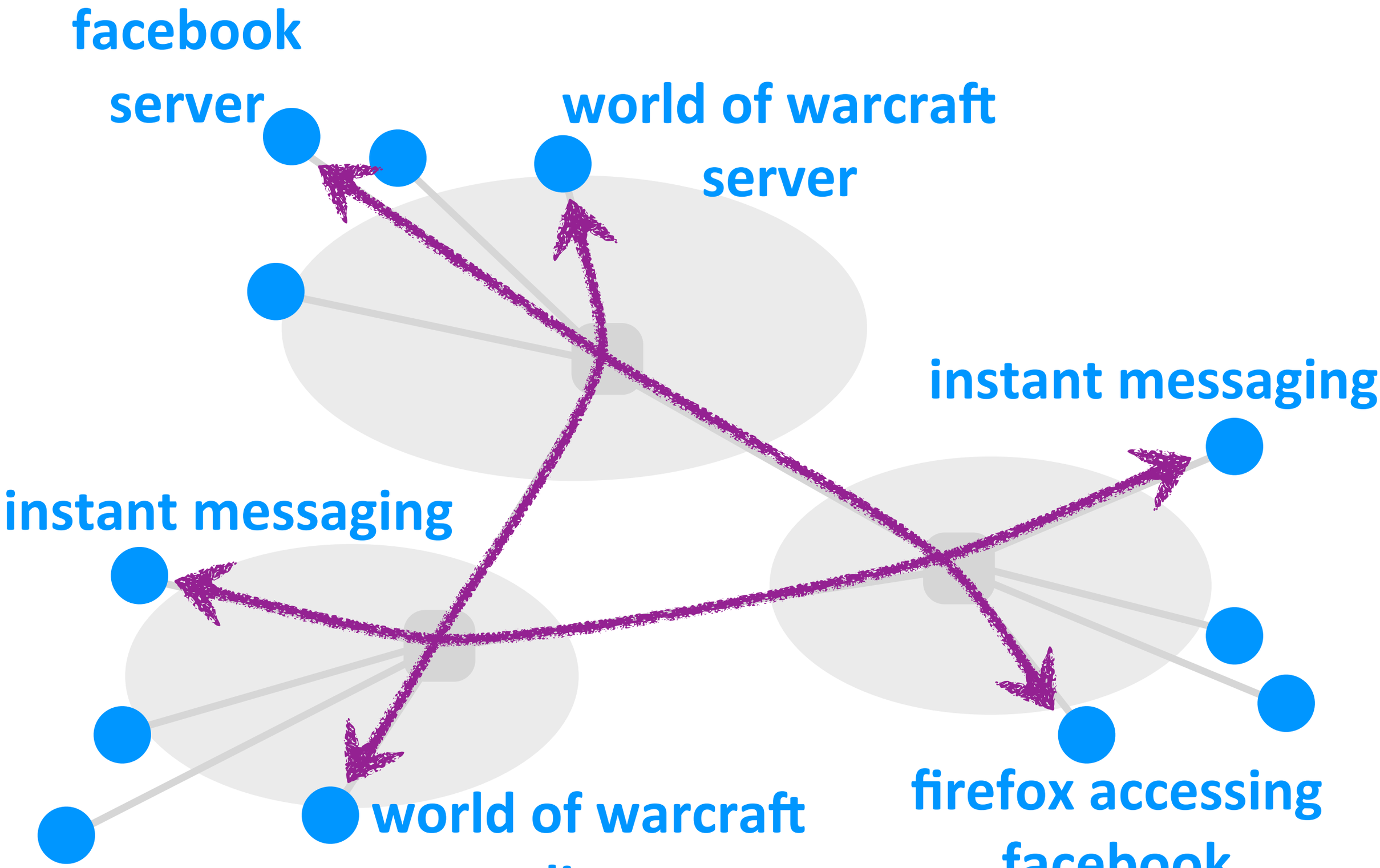
www.EngineeringBooksPdf.com



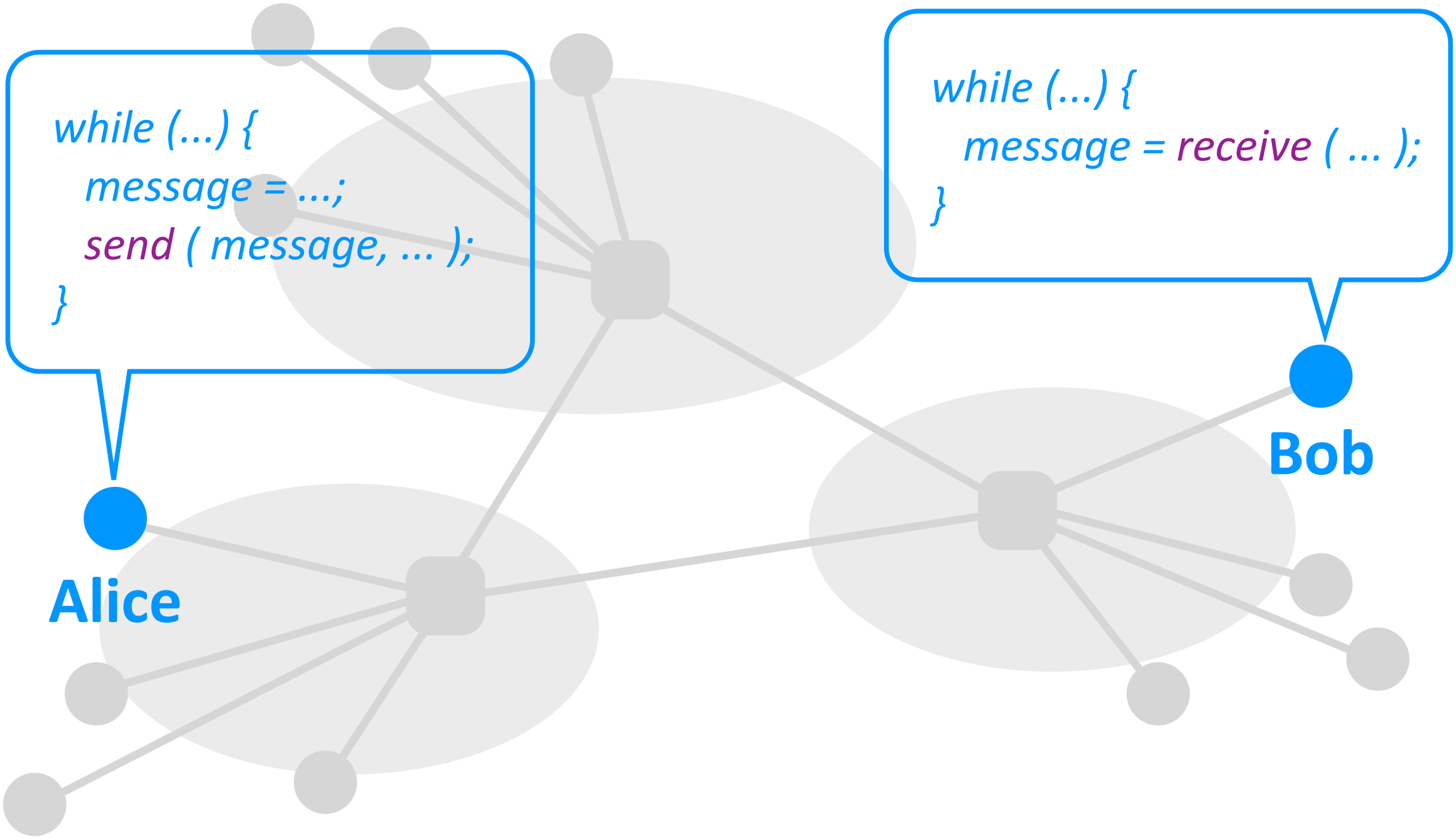
www.EngineeringBooksPdf.com



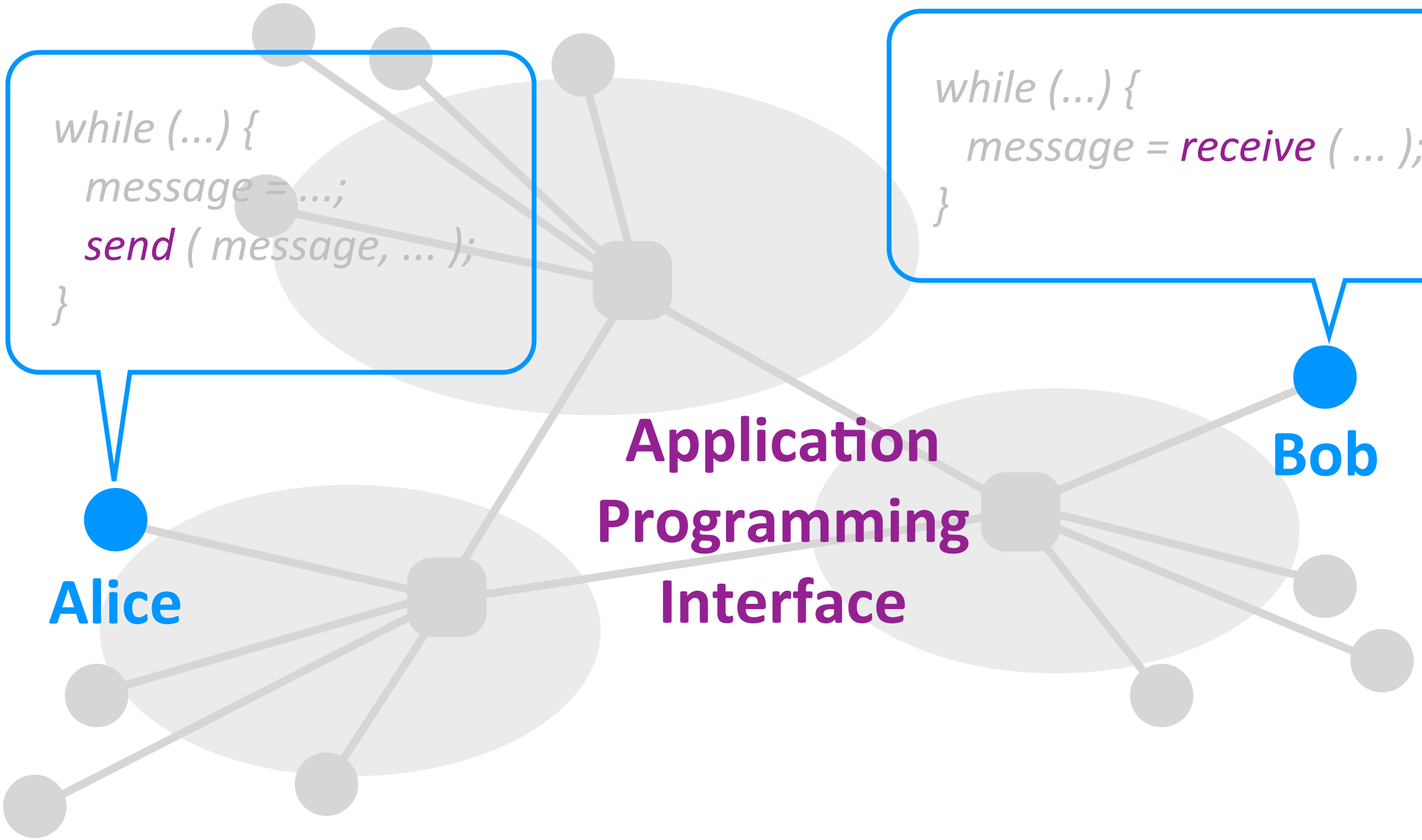
www.EngineeringBooksPdf.com



www.EngineeringBooksPdf.com



www.EngineeringBooksPdf.com



www.EngineeringBooksPdf.com

Questions

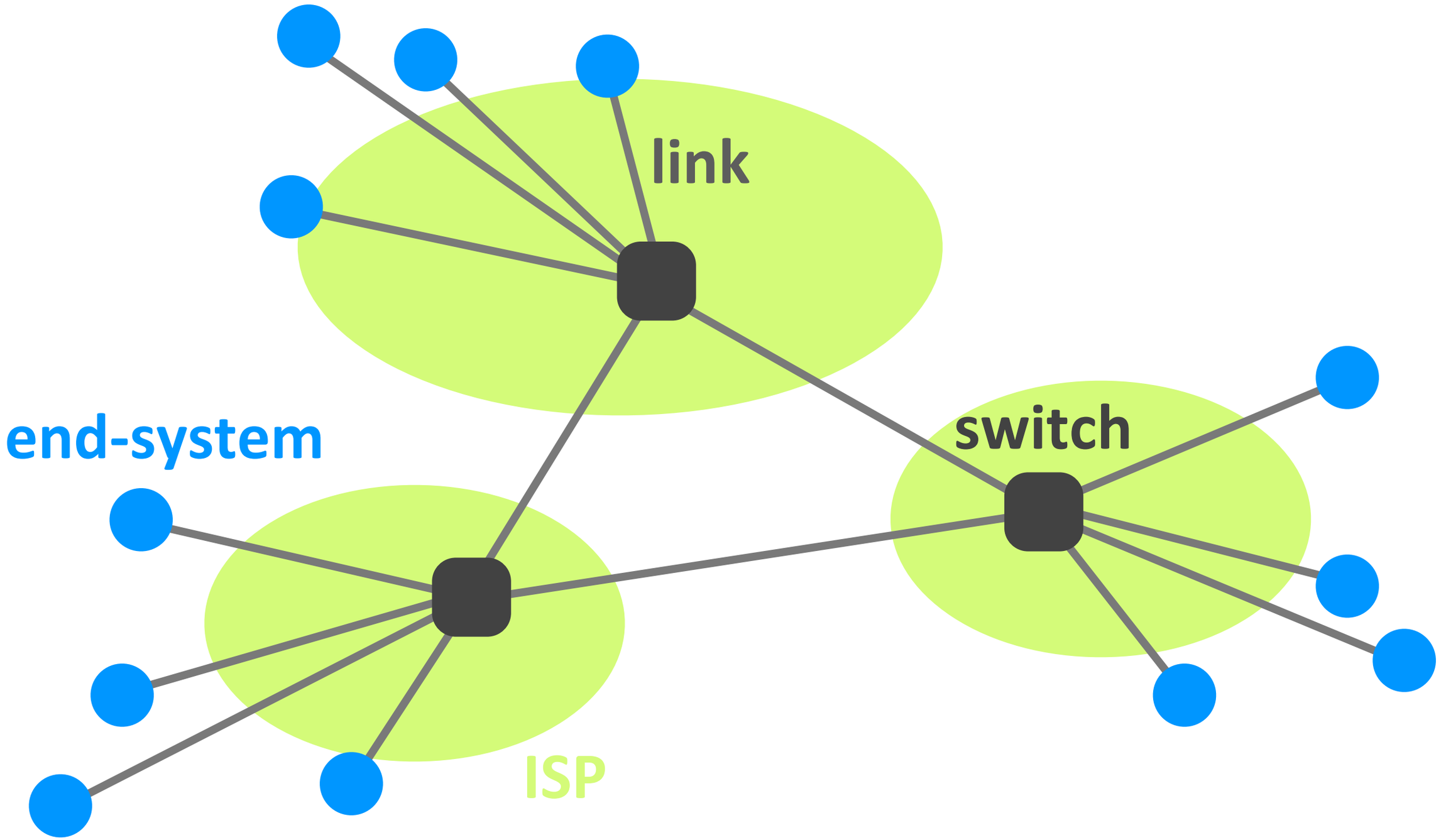
- What is a network made of?
- How is it shared?
- How is it organized?
- How does communication happen?
- How do we evaluate a network?

www.EngineeringBooksPdf.com

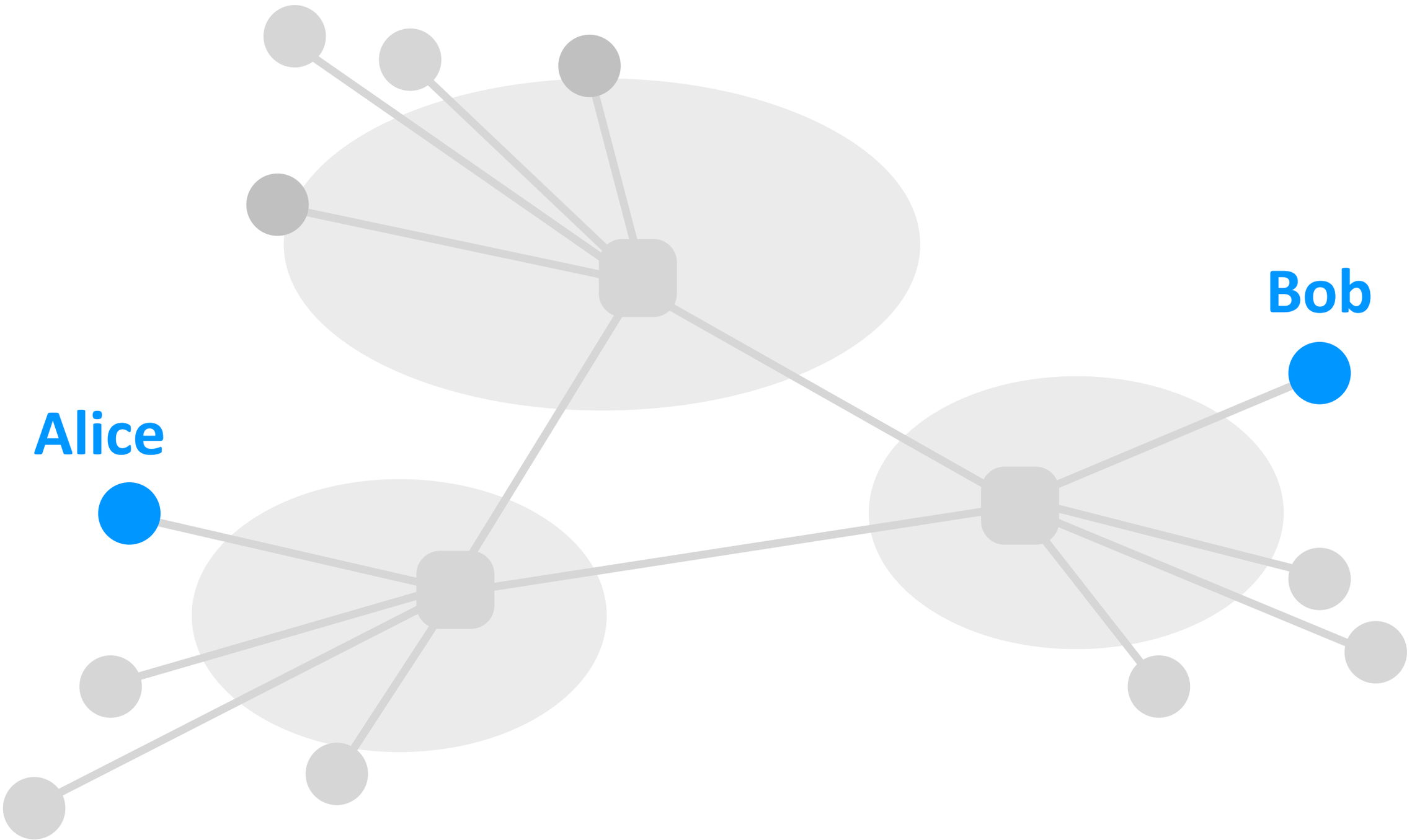
Questions

- What is a network made of?
- How is it shared?
- How is it organized?
- How does communication happen?
- How do we evaluate a network?

www.EngineeringBooksPdf.com



www.EngineeringBooksPdf.com



www.EngineeringBooksPdf.com

Alice

mail box

local post office

mail bag

central post office

Bob

mail box

local post office

mail bag

central post office

www.EngineeringBooksPdf.com

Layers

- Layer = a part of a system with well-defined interfaces to other parts

- Two layers interact only through the interface between them

- One layer interacts only with layer above and layer below

www.EngineeringBooksPdf.com

application	*applications that exchange data*
transport	*transports data between end-systems*
network	*moves data around the network*
link	*moves data across a link*
physical	*moves data across a physical medium*

www.EngineeringBooksPdf.com

application	*applications that exchange <u>messages</u>*
transport	*transports <u>segments</u> between end-systems*
network	*moves <u>datagrams</u> around the network*
link	*moves <u>frames</u> across a link*
physical	*moves data across a physical medium*

www.EngineeringBooksPdf.com

application	*HTTP (web)*	*SMTP (email)*	*FTP (file transfer)*			
transport	*TCP*	*UDP*				
network	*IP*					
link	*Ethernet*	*WiFi*	*DSL*	*Cable*	*Cellular*	
physical	*twisted pair*	*fiber*	*coaxial cable*		*wireless*	

www.EngineeringBooksPdf.com

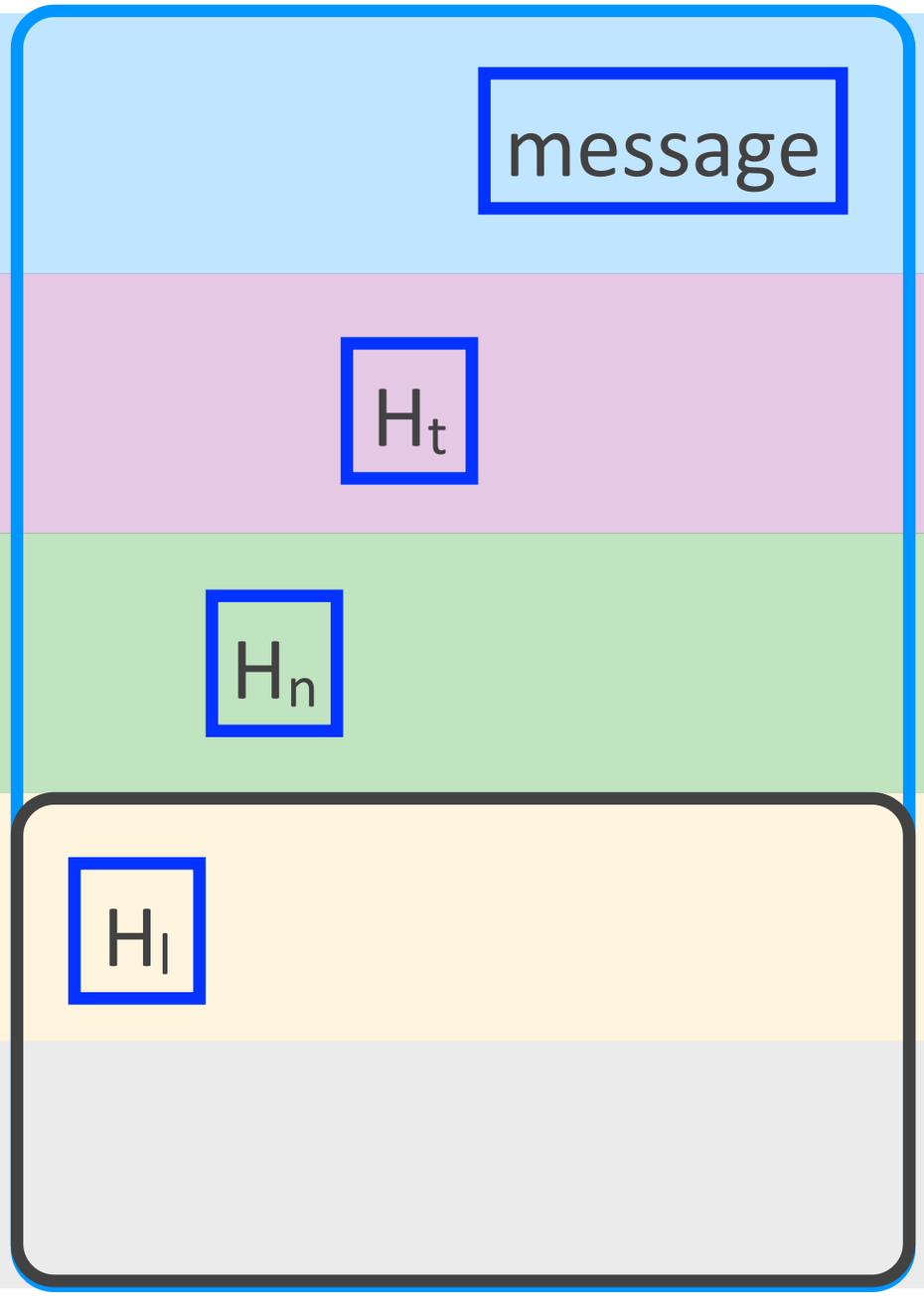
application

transport

network

link

physical



Alice's machine

switch

www.EngineeringBooksPdf.com

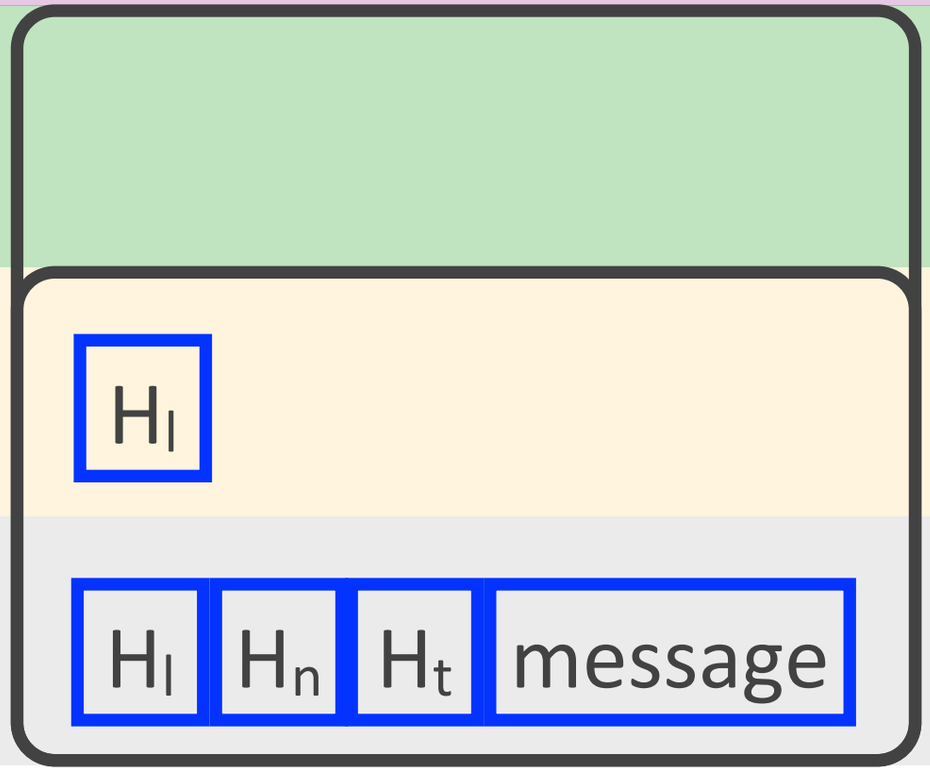
application

transport

network

link

physical



switch

www.EngineeringBooksPdf.com

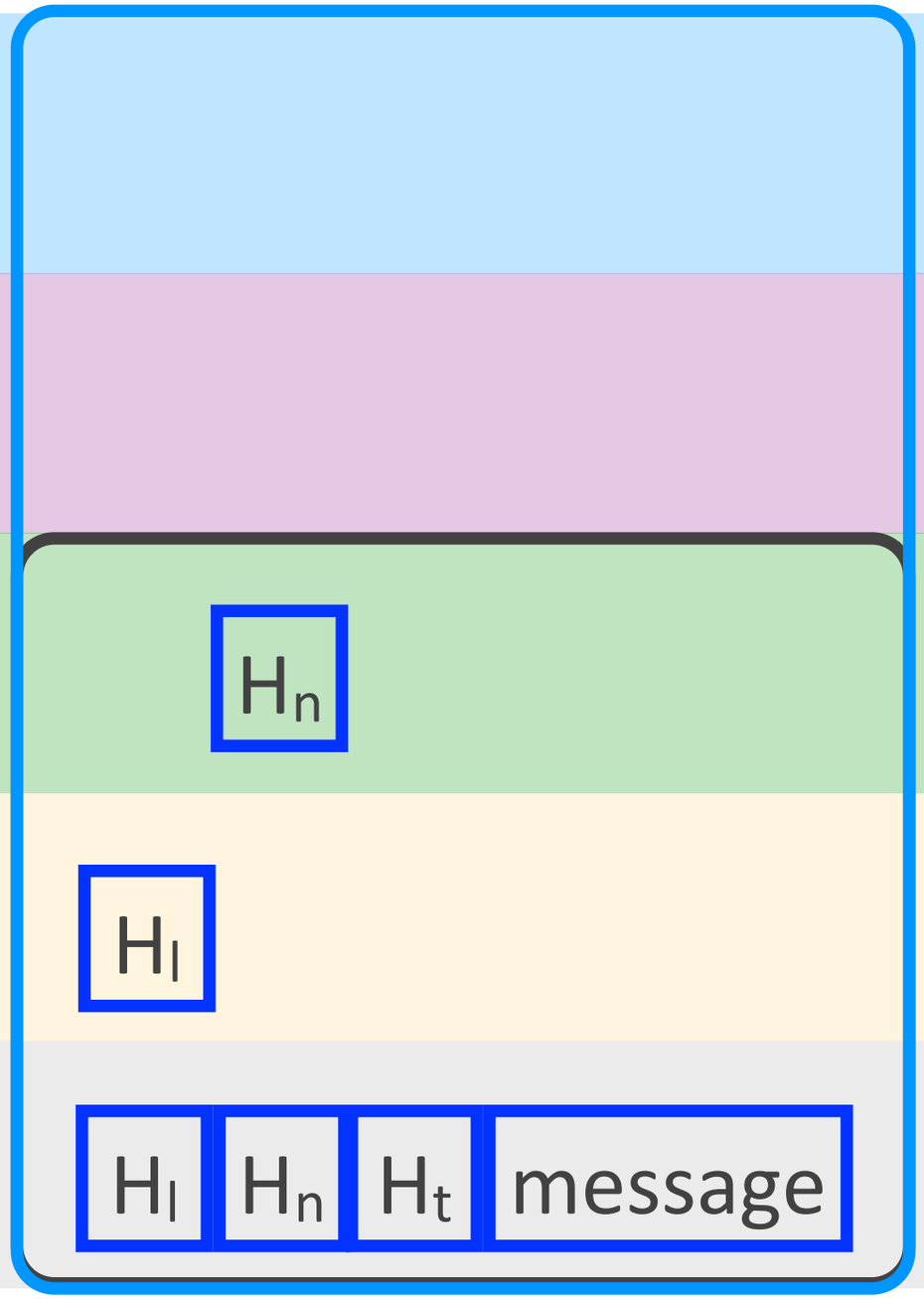
application

transport

network

link

physical



switch

Bob's machine

www.EngineeringBooksPdf.com

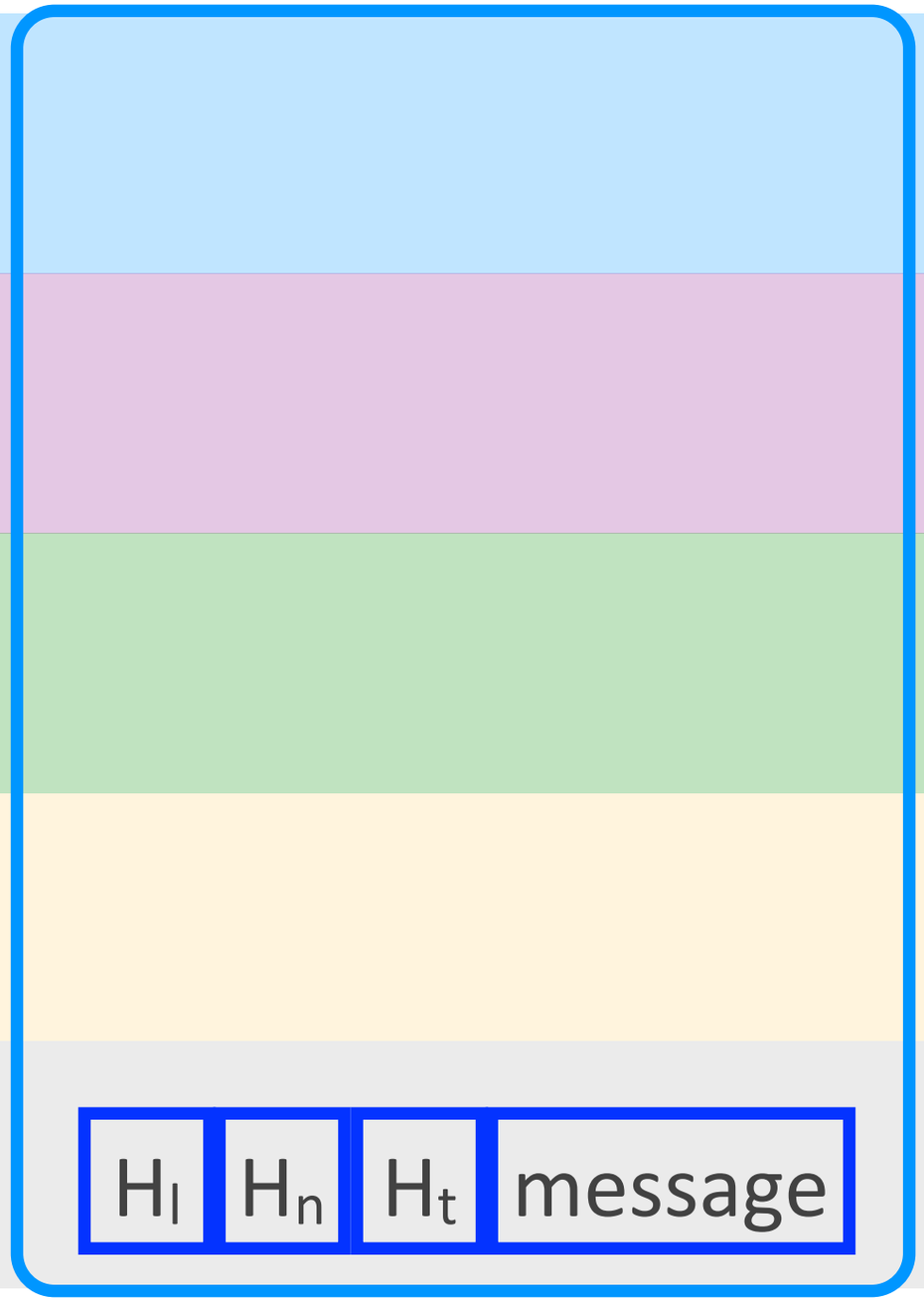
application

transport

network

link

physical



Bob's machine

www.EngineeringBooksPdf.com

Why layers?

- Reduce complexity
- Improve flexibility

www.EngineeringBooksPdf.com

Restaurant layers

customer tables

waiting service

cooking

www.EngineeringBooksPdf.com

Fast-food layers

customer queue

customer service

food packaging

food unfreezing & cooking

food preparation & freezing

www.EngineeringBooksPdf.com

application	*applications that exchange messages*
transport	*transports segments between two apps*
network	*moves datagrams around the network*
link	*moves frames across a link*
physical	*moves data across a physical medium*

www.EngineeringBooksPdf.com

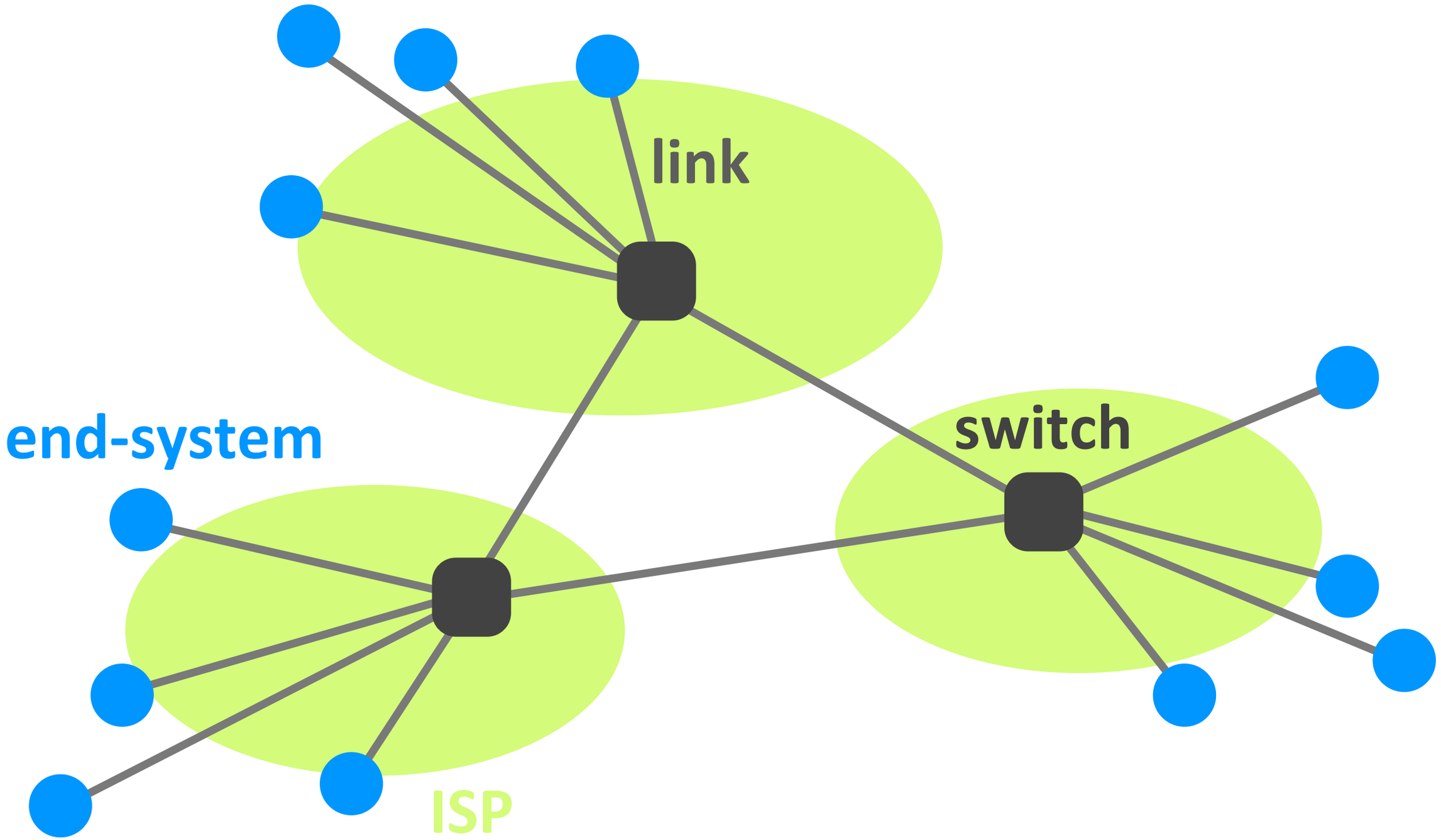
- What layers to define?

www.EngineeringBooksPdf.com

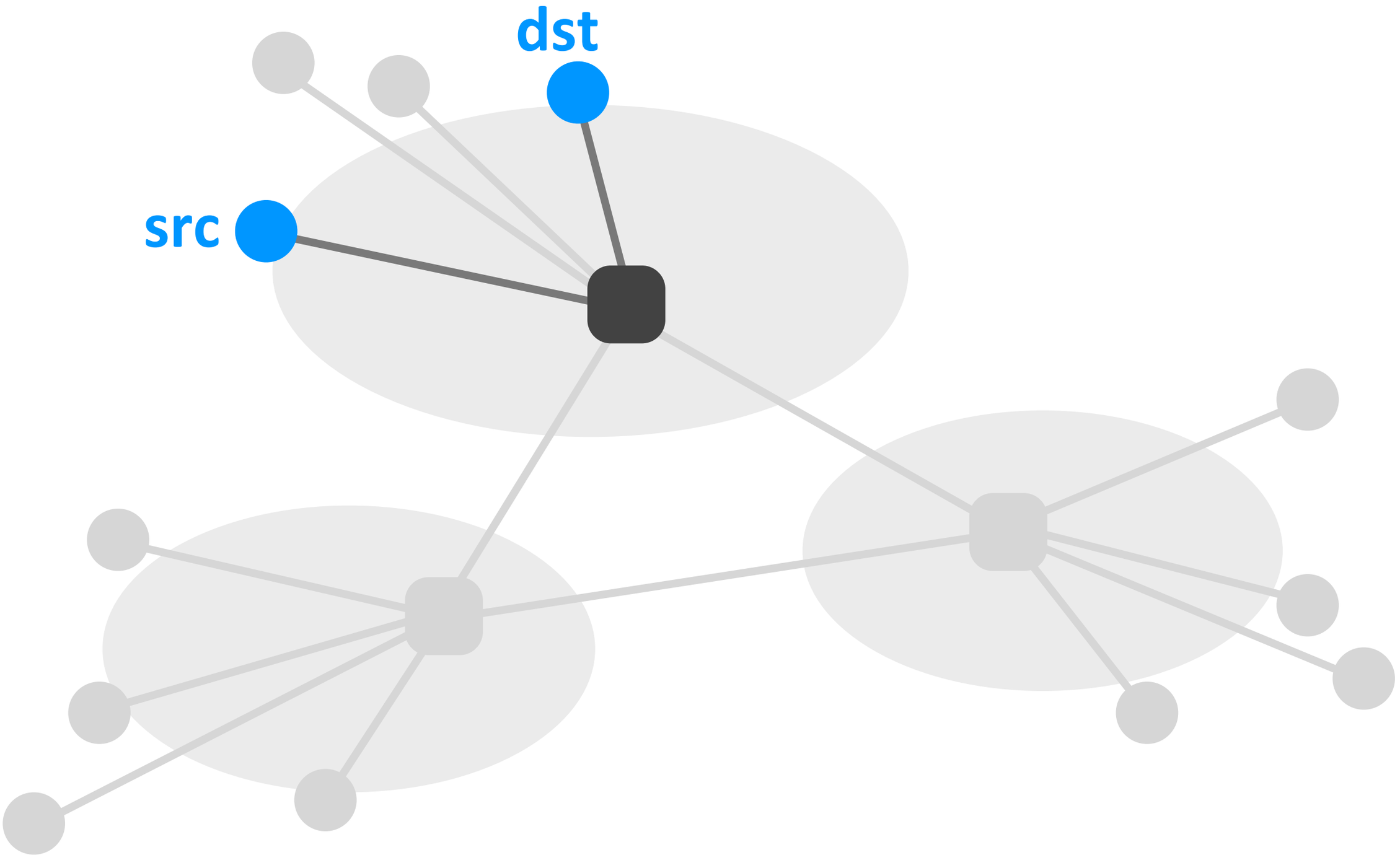
Questions

- What is a network made of?
- How is it shared?
- How is it organized?
- How does communication happen?
- How do we evaluate a network?

www.EngineeringBooksPdf.com



www.EngineeringBooksPdf.com



www.EngineeringBooksPdf.com

Delay

- How long does it take to send a packet from its source to its destination?

www.EngineeringBooksPdf.com

Delay

- Consists of many components
  - *transmission delay*
  - *propagation delay*
  - *queuing delay*
  - *processing delay*

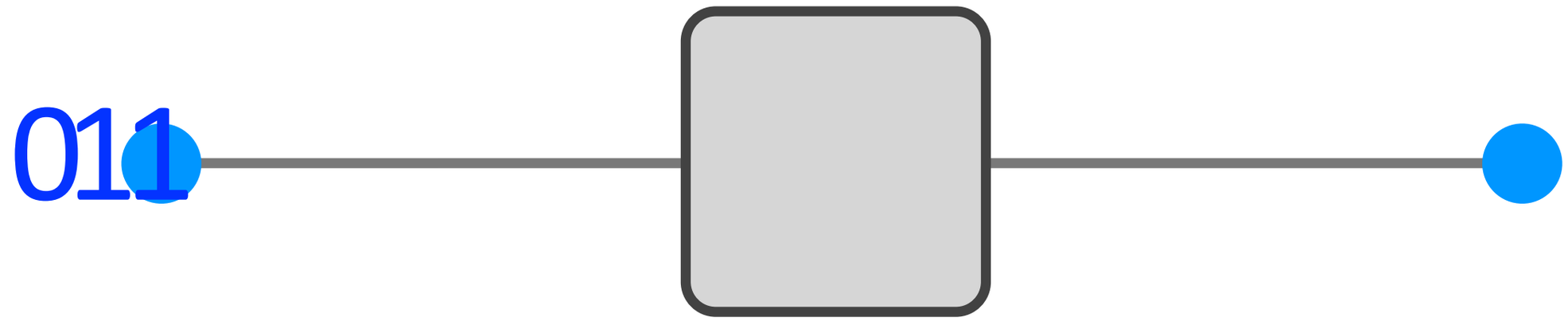
www.EngineeringBooksPdf.com

1. Transmission delay

- How long does it take to push all the bits of a packet into a link?

- Packet size / Transmission rate of the link
  - *for example:*
    1000 bits / 100 Mbits per sec = 10^{-5} sec

www.EngineeringBooksPdf.com



transmission delay

amount of time to push
all bits into a link

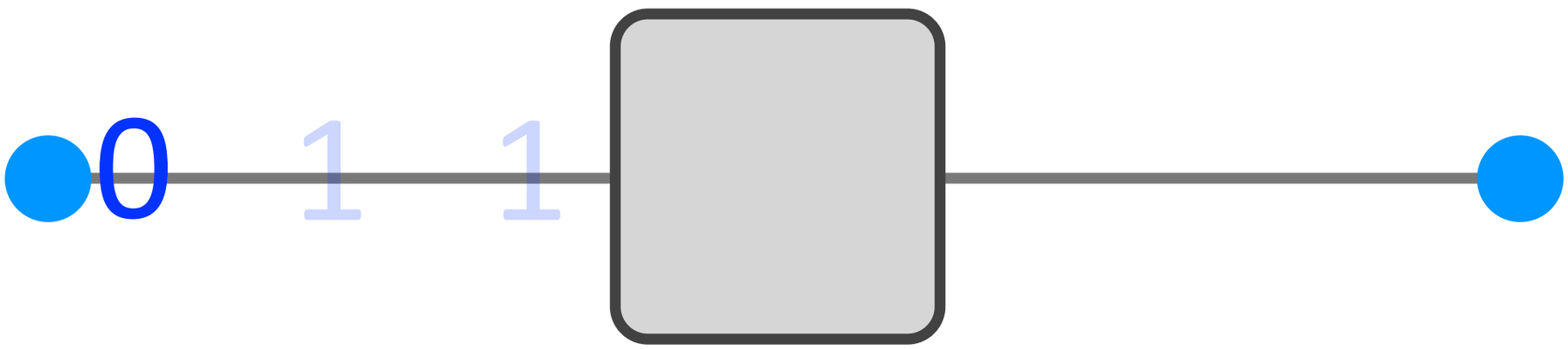
www.EngineeringBooksPdf.com

2. Propagation delay

- How long does it take to move one bit from one end of a link to the other?

- Link length / Propagation speed of link
  - *for example:*
    30 kilometers / 3 10^8 meters per sec = 10^{-4} sec

www.EngineeringBooksPdf.com



transmission delay

propagation delay

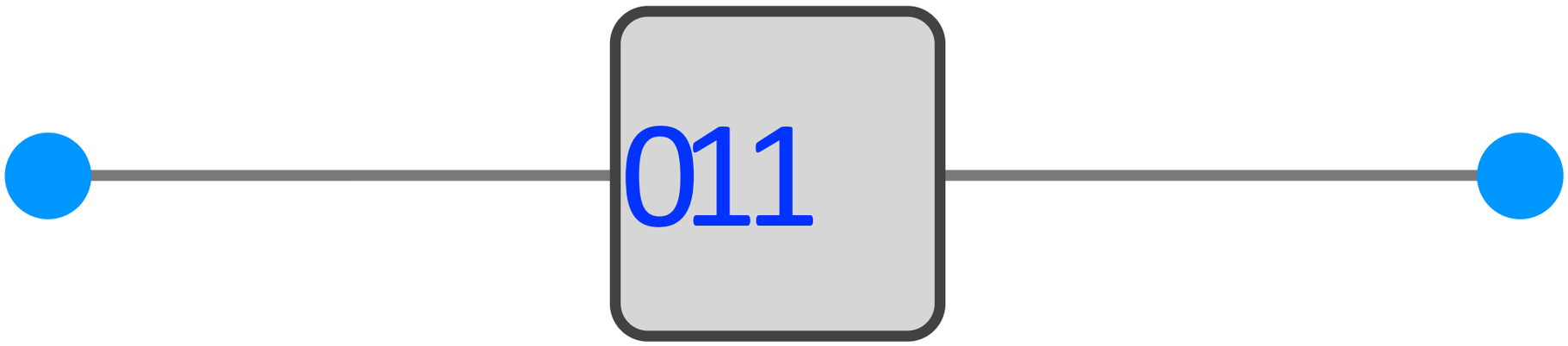
amount of time to move
one bit across a link

www.EngineeringBooksPdf.com

3. Queuing delay

- How long does a packet have to sit in a buffer before it is processed?

www.EngineeringBooksPdf.com



transmission delay

propagation delay

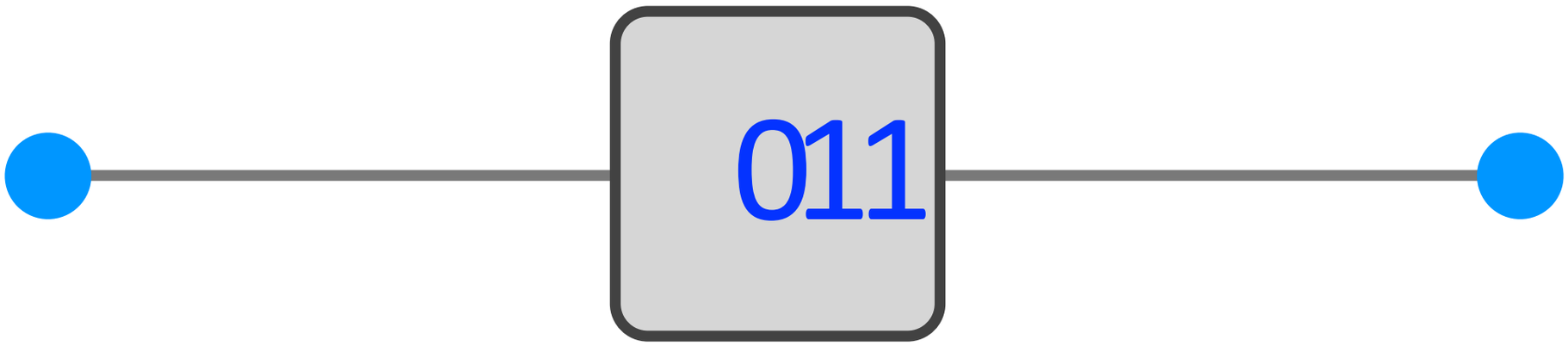
queuing delay

www.EngineeringBooksPdf.com

4. Processing delay

- How long does it take to process a packet?

www.EngineeringBooksPdf.com



transmission delay

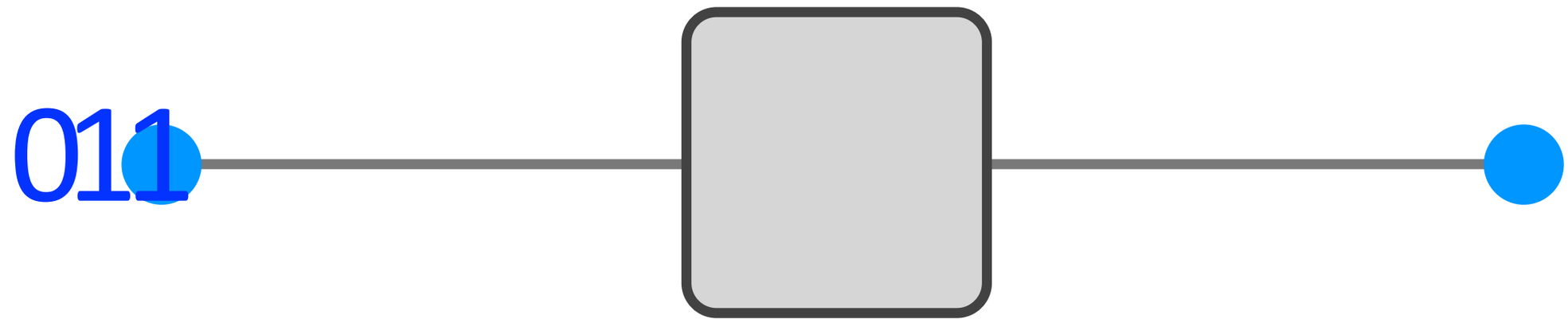
propagation delay

queuing delay

processing delay

www.EngineeringBooksPdf.com

Transmission vs. propagation delay

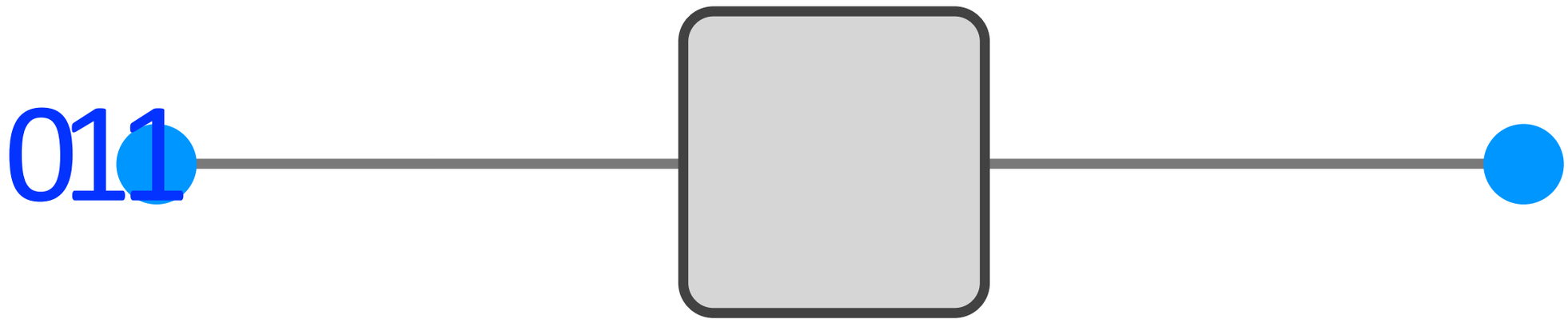


transmission delay

propagation delay

www.EngineeringBooksPdf.com

Transmission vs. propagation delay

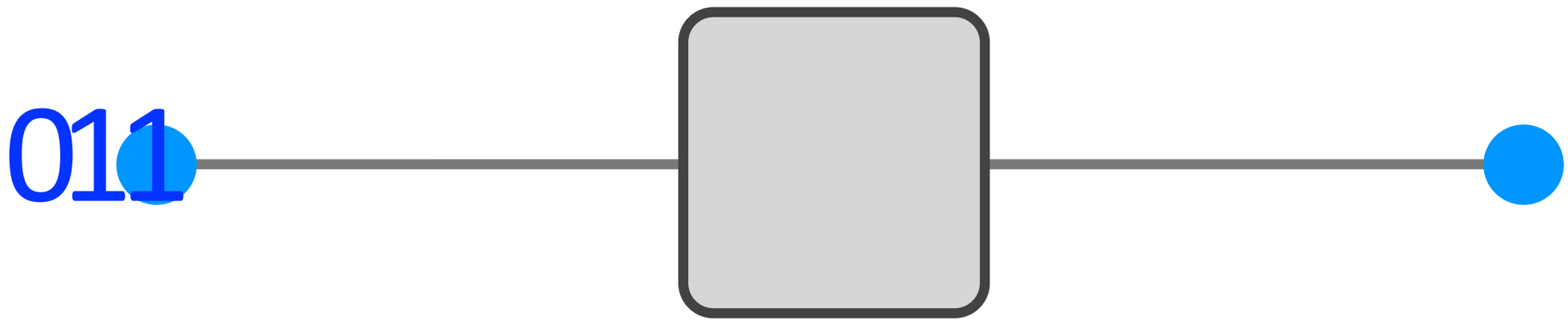


short transmission delay

long propagation delay

www.EngineeringBooksPdf.com

Transmission vs. propagation delay



long transmission delay

short propagation delay

www.EngineeringBooksPdf.com

Queuing delay

- Characterized with statistical measures
  - *average queuing delay*
  - *variance of queuing delay*
  - *probability that it exceeds a certain value*

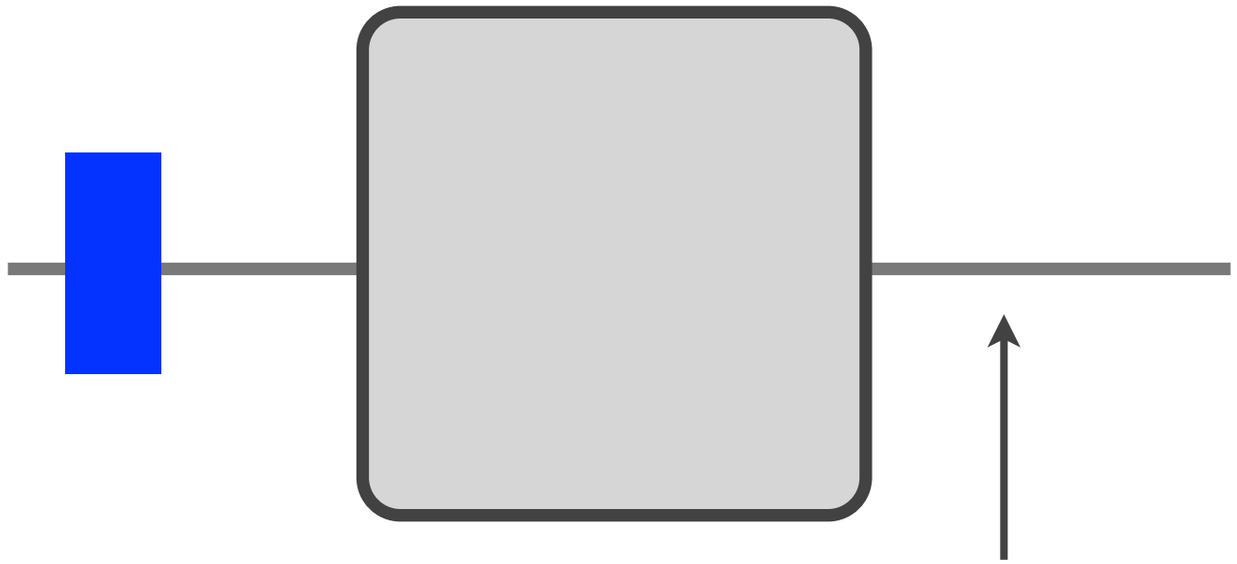
www.EngineeringBooksPdf.com

Queuing delay

- Depends on traffic pattern

  - *arrival rate at the queue*
  - *nature of arriving traffic (bursty or not?)*
  - *transmission rate of outgoing link*

www.EngineeringBooksPdf.com



packet size: L bits

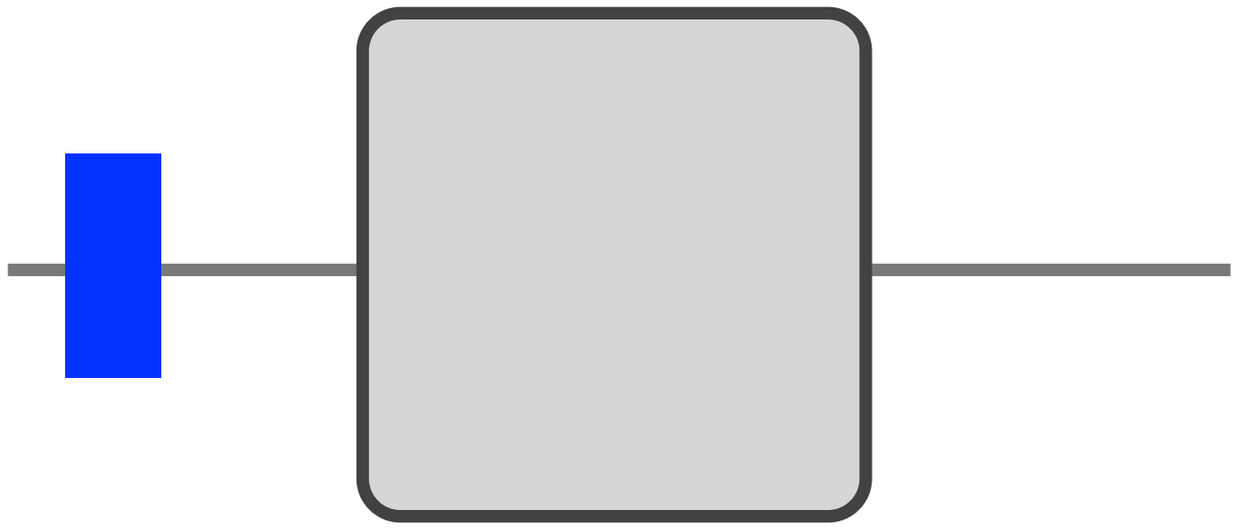
packet arrival rate: A packets/sec

transmission rate:
R bits/sec

bit arrival rate:
LA bits/sec

bit departure rate:
R bits/sec

www.EngineeringBooksPdf.com



bit arrival rate:
LA bits/sec

>

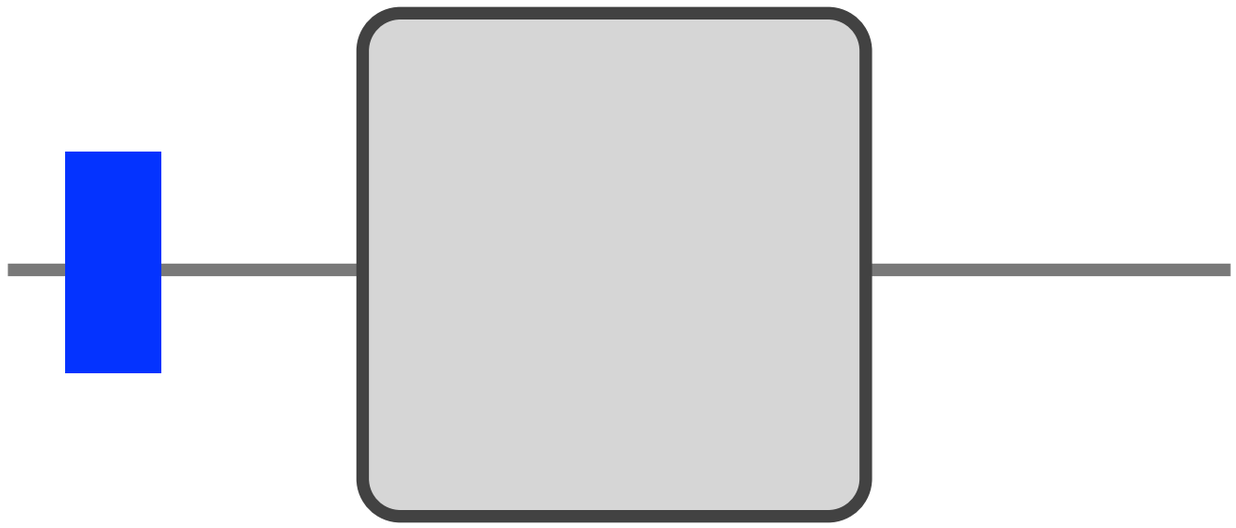
bit departure rate:
R bits/sec

www.EngineeringBooksPdf.com

Queuing delay

- Approaches infinity,
  if arrival rate > departure rate
  - *assuming an infinite buffer*

www.EngineeringBooksPdf.com

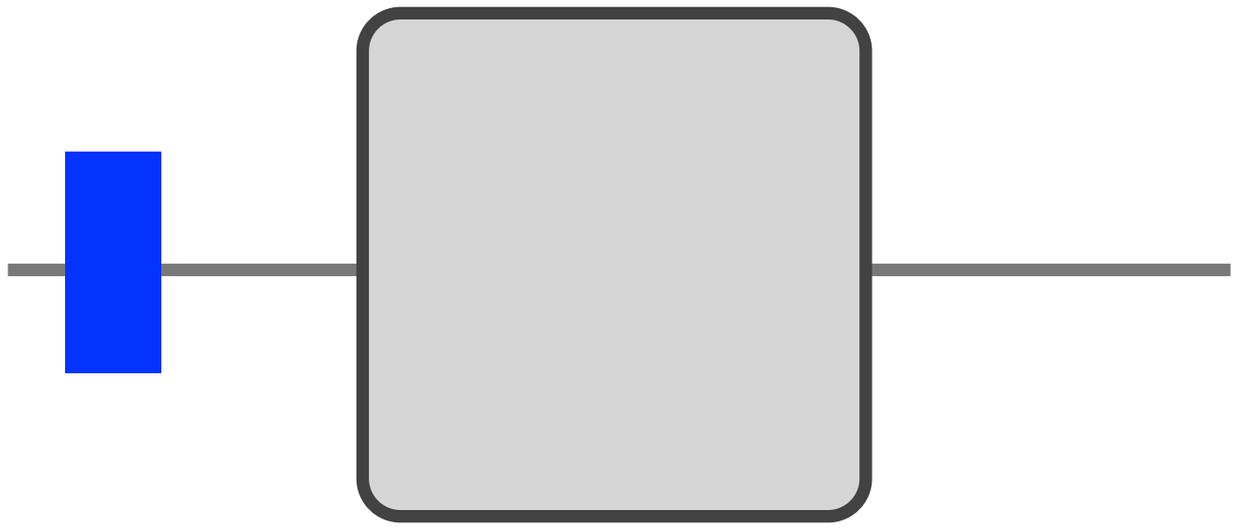


bit arrival rate:
LA bits/sec

<=

bit departure rate:
R bits/sec

www.EngineeringBooksPdf.com



0 msec

1 msec

2 msec

3 msec

bit arrival rate:

LA bits/sec

<=

bit departure rate:

R bits/sec

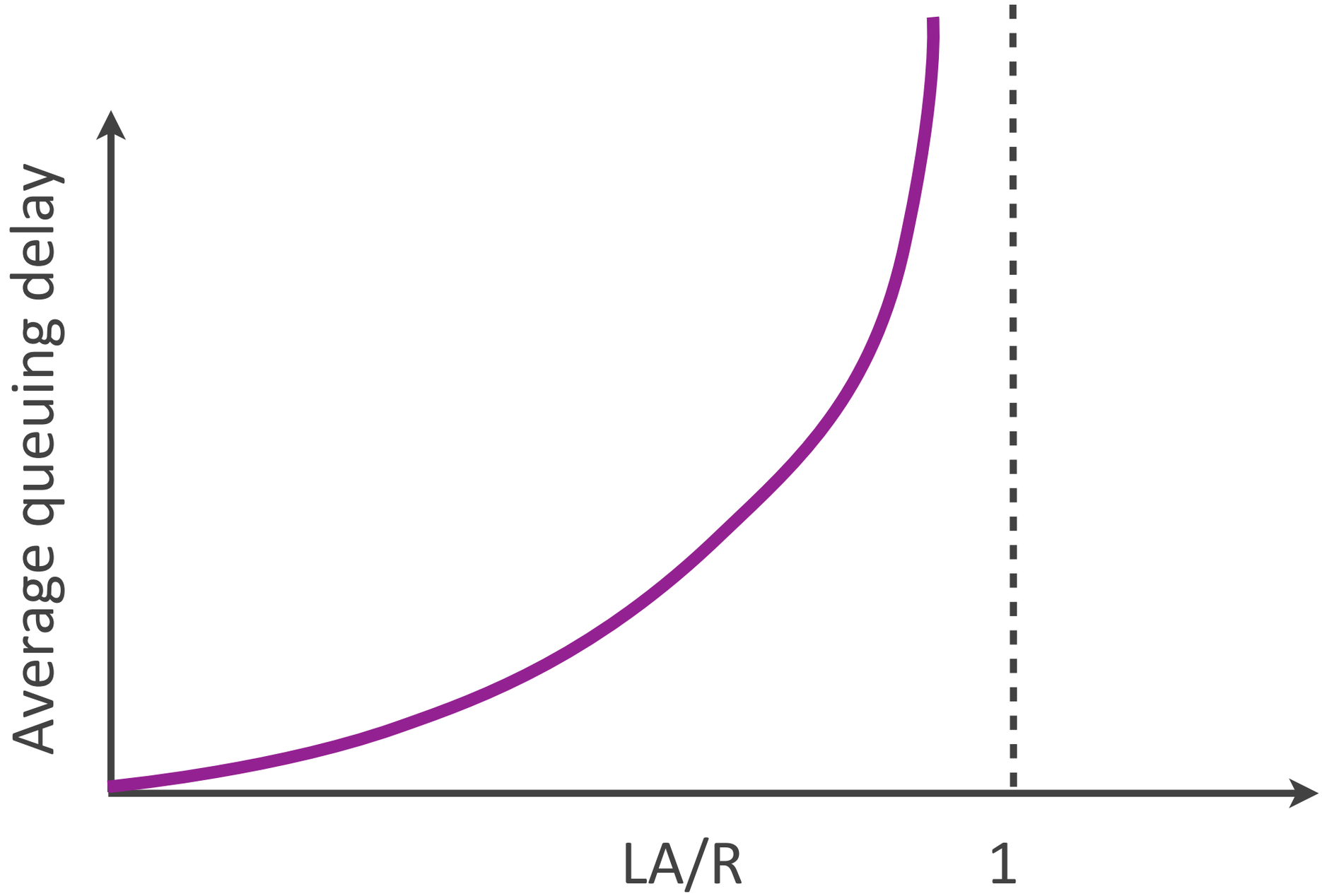
www.EngineeringBooksPdf.com

Queuing delay

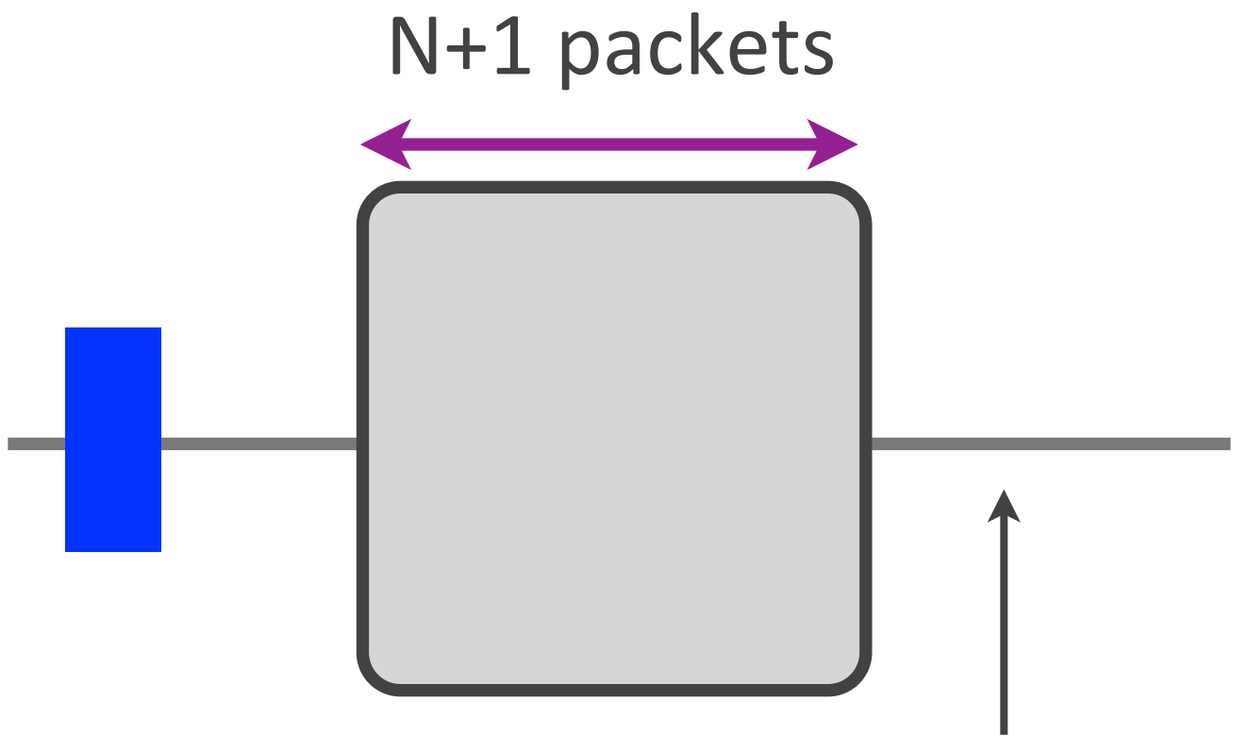
- Approaches infinity,
  if arrival rate > departure rate
  - *assuming an infinite buffer*

- Depends on burst size, otherwise

www.EngineeringBooksPdf.com



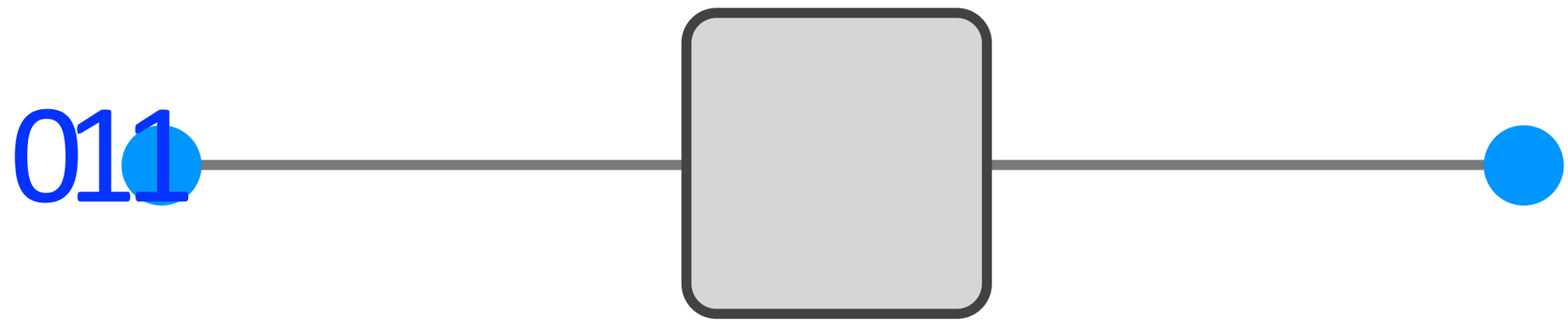
www.EngineeringBooksPdf.com



Queuing delay upper bound: **N** L/R

www.EngineeringBooksPdf.com

End-to-end delay



transmission delay

propagation delay

queuing delay

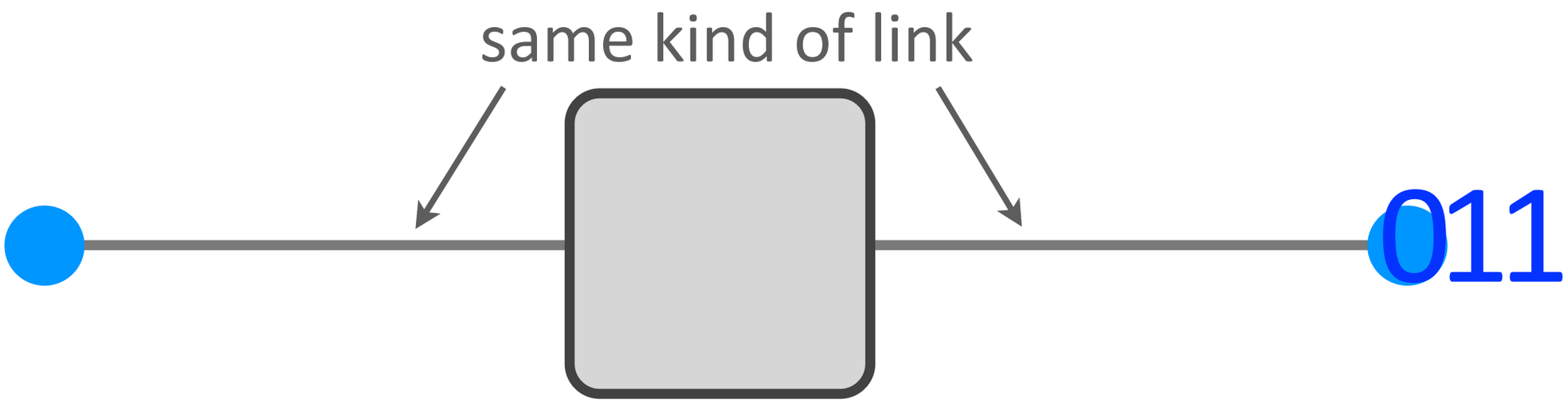
processing delay

transmission delay

propagation delay

www.EngineeringBooksPdf.com

End-to-end delay



transmission delay * number of hops **transmission delay**

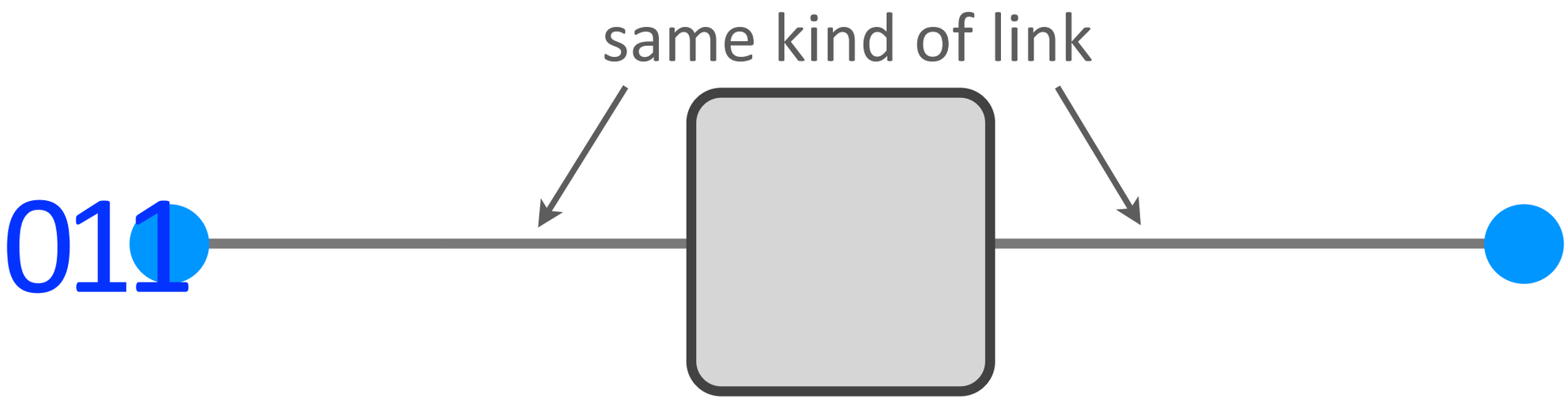
propagation delay propagation delay

queuing delay

processing delay

www.EngineeringBooksPdf.com

Without store & forward?



transmission delay ~~* number of links~~

propagation delay

propagation delay

queuing delay

processing delay

www.EngineeringBooksPdf.com

Delay

- How long does it take to send a packet from its source to its destination?

www.EngineeringBooksPdf.com

Loss

- What fraction of the packets sent from a source to a destination are dropped?

www.EngineeringBooksPdf.com

Throughput

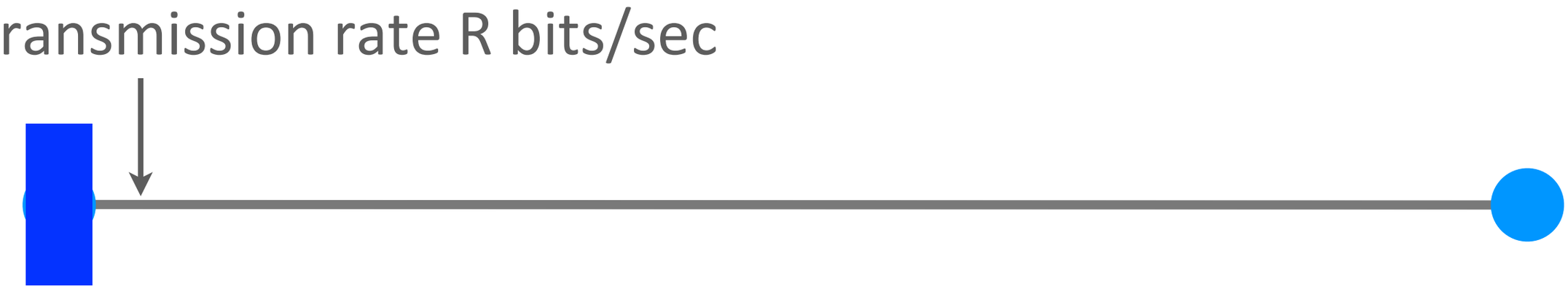
- At what rate is the destination receiving data from the source?

www.EngineeringBooksPdf.com

Average throughput

- Data size / Transfer time

www.EngineeringBooksPdf.com



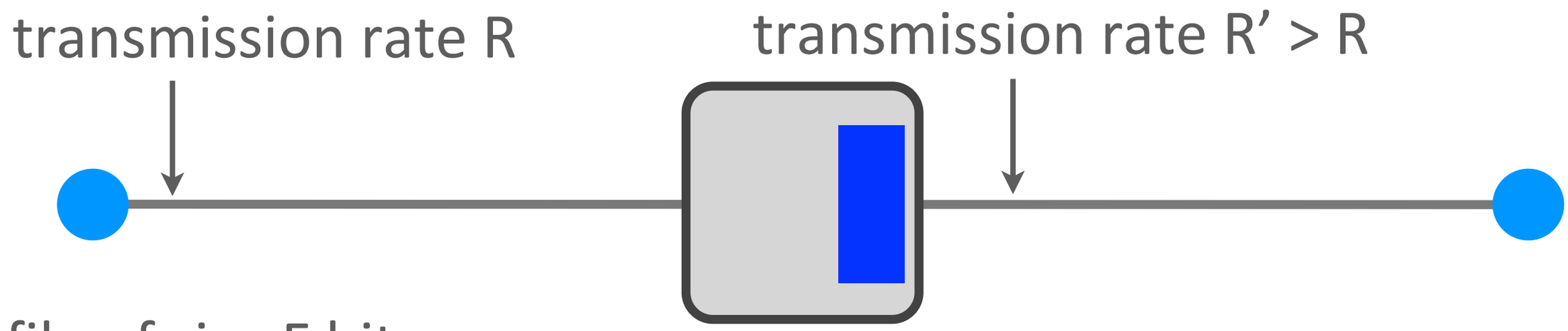
file of size F bits

packets of size L bits

Transfer time = F/R + propagation delay

Average throughput = R

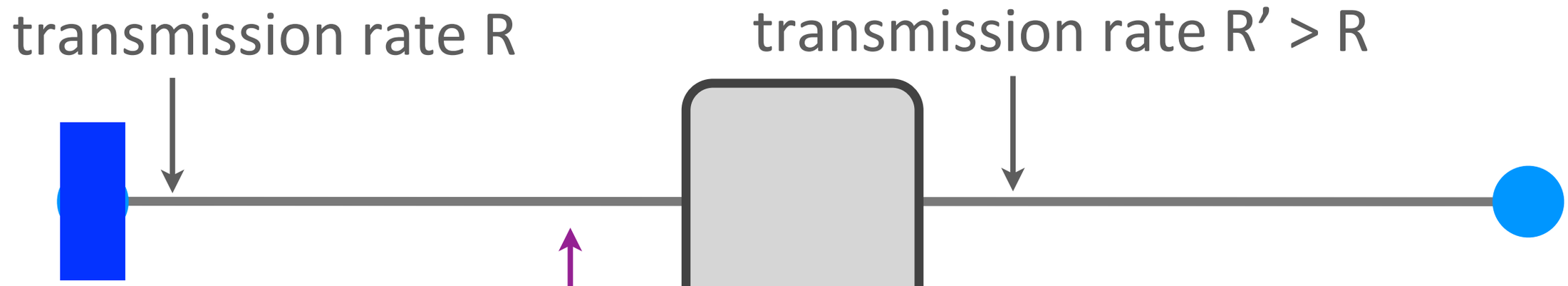
www.EngineeringBooksPdf.com



file of size F bits

packets of size L bits

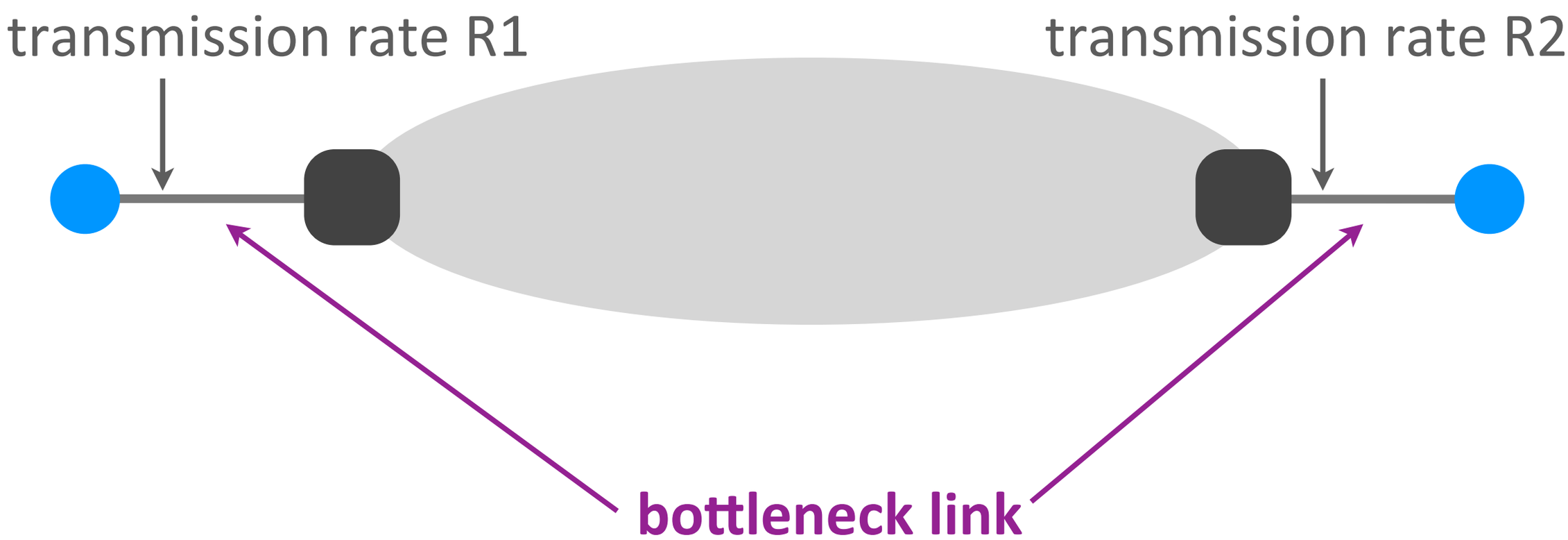
www.EngineeringBooksPdf.com



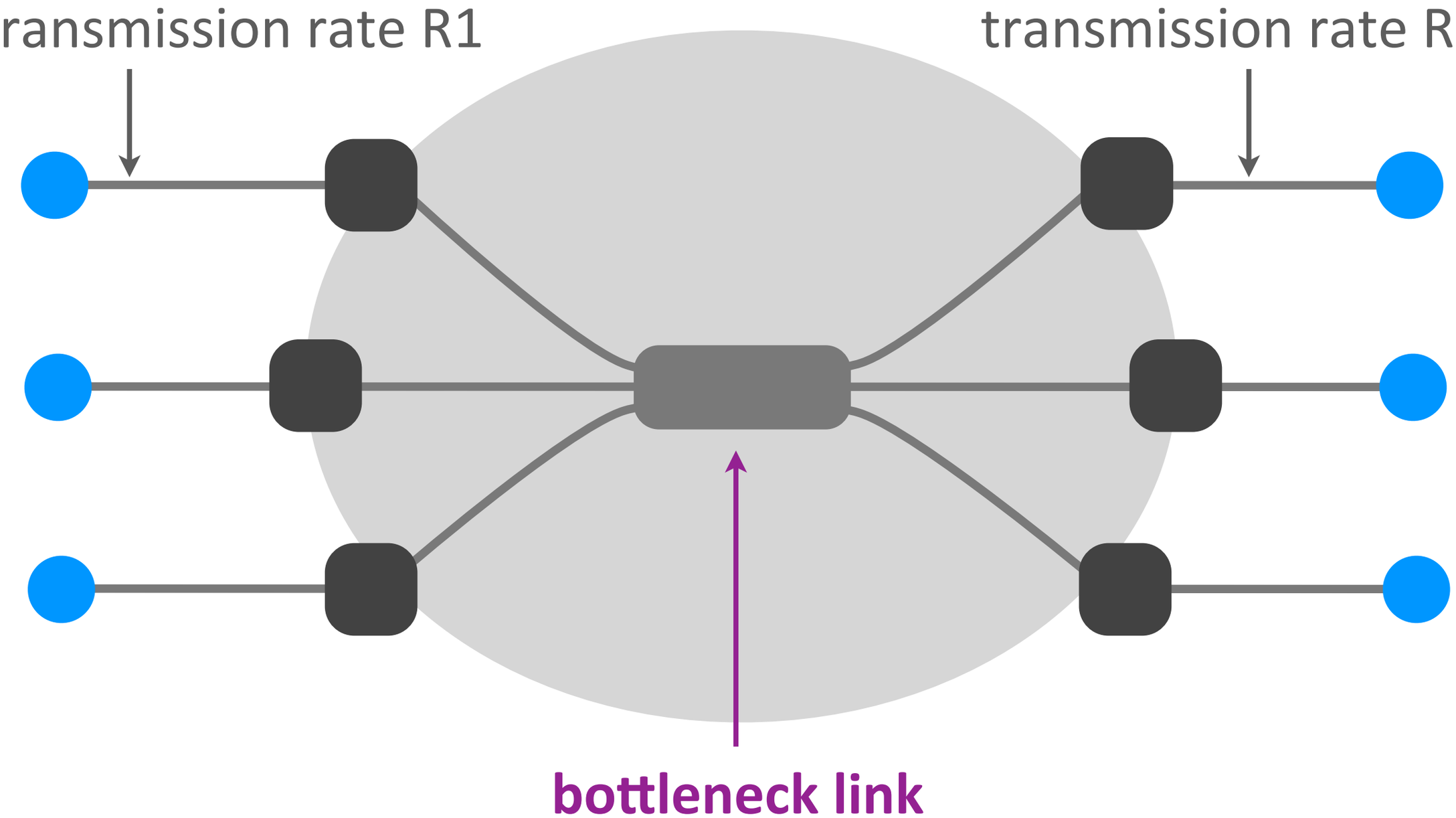
Transfer time = F/R + propagation delay + L/R’

Average throughput = min { R, R’ } = R

www.EngineeringBooksPdf.com



www.EngineeringBooksPdf.com



www.EngineeringBooksPdf.com

Throughput

- At what rate is the destination receiving data from the source?

www.EngineeringBooksPdf.com

Outline

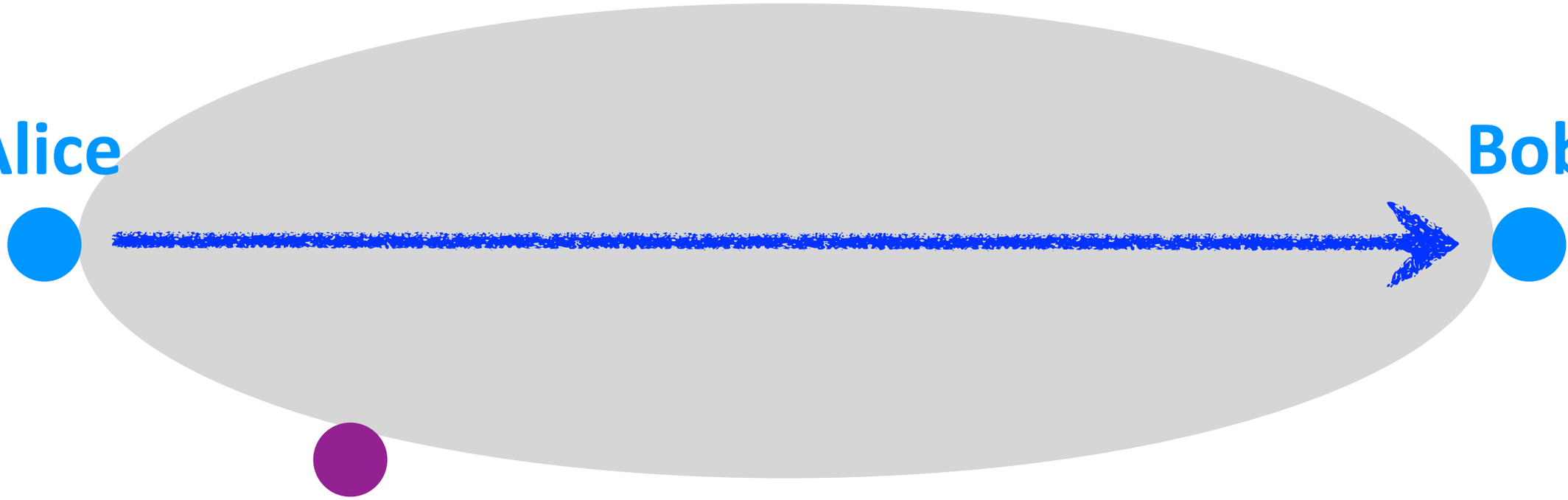
- What is a network made of?
- How is it shared?
- How is it organized?
- How does communication happen?
- How do we evaluate a network?

www.EngineeringBooksPdf.com

Security

- How does the network react to adversarial (= bad) behavior?
- What does the network assume about the behavior of end-systems and packet switches?

www.EngineeringBooksPdf.com



Eve (the eavesdropper)

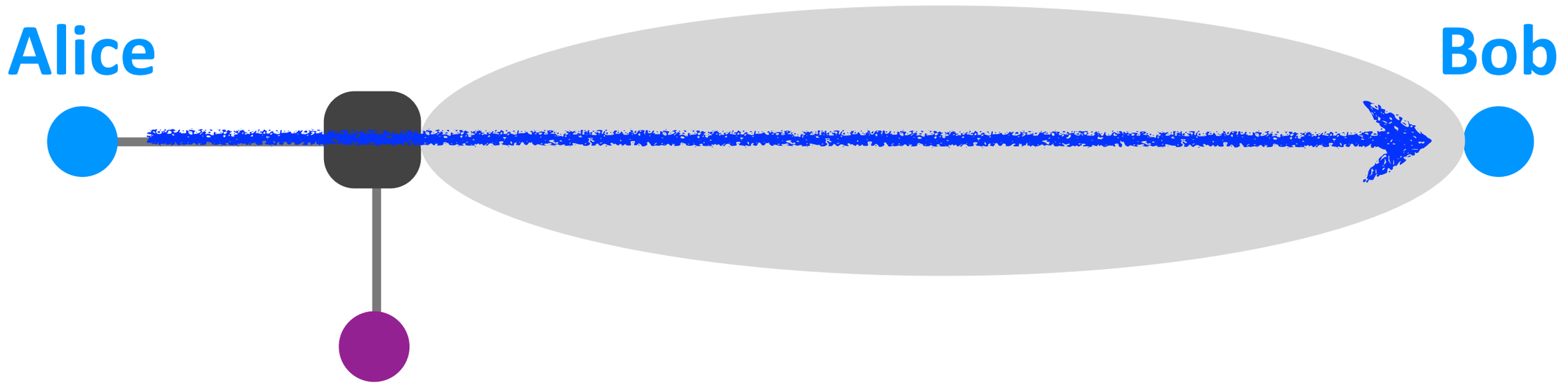
tries to listen in on the communication to obtain copies of the data

www.EngineeringBooksPdf.com

Eve (the eavesdropper)

tries to listen in on the communication
to obtain copies of the data

www.EngineeringBooksPdf.com

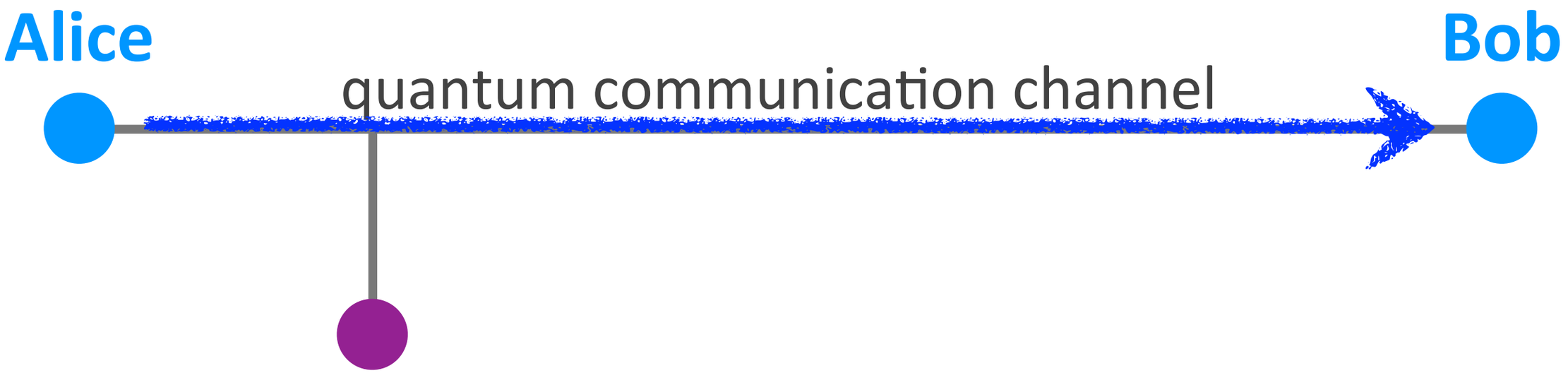


Eve (the eavesdropper)

tries to listen in on the communication to obtain copies of the data

www.EngineeringBooksPdf.com

Eve cannot eavesdrop on the quantum communication channel without changing the data



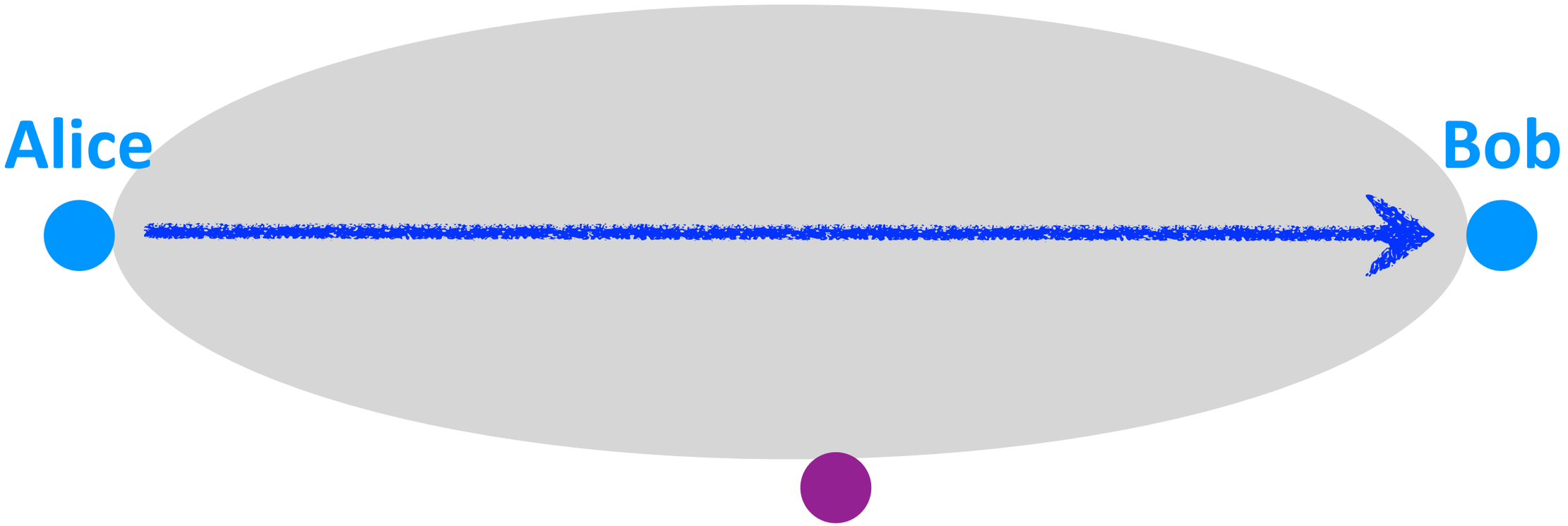
tries to listen in on the communication to obtain copies of the data

www.EngineeringBooksPdf.com

(Quantum cryptography)

- Alice transmits qubits, not bits
- Qubit = photon in a certain quantum state
- **Eve cannot measure a photon's state without affecting it**
- Alice and Bob can detect Eve's presence

www.EngineeringBooksPdf.com



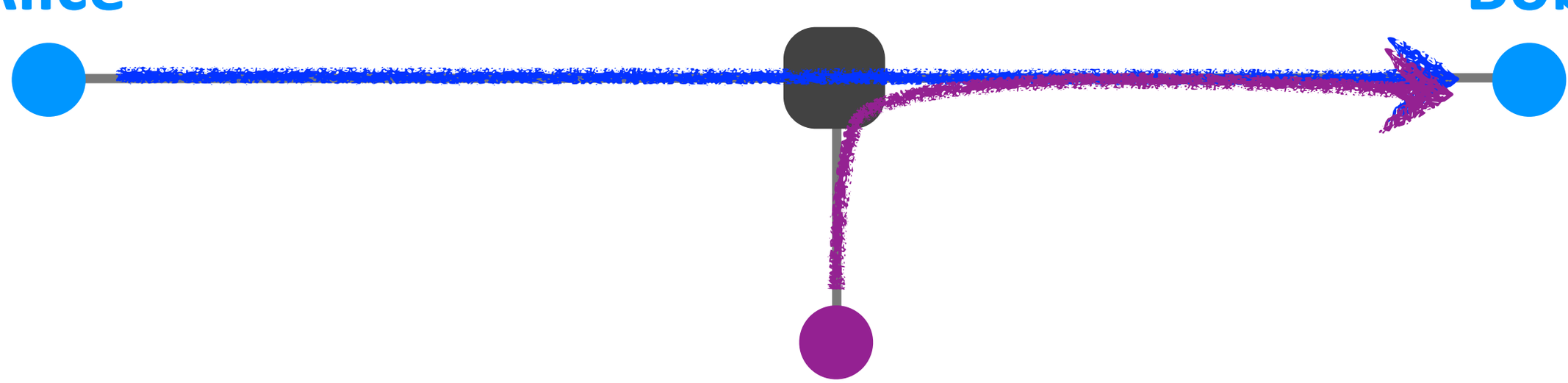
Persa (the impersonator)

pretends she is Alice to extract information from Bob

www.EngineeringBooksPdf.com

Alice

Bob



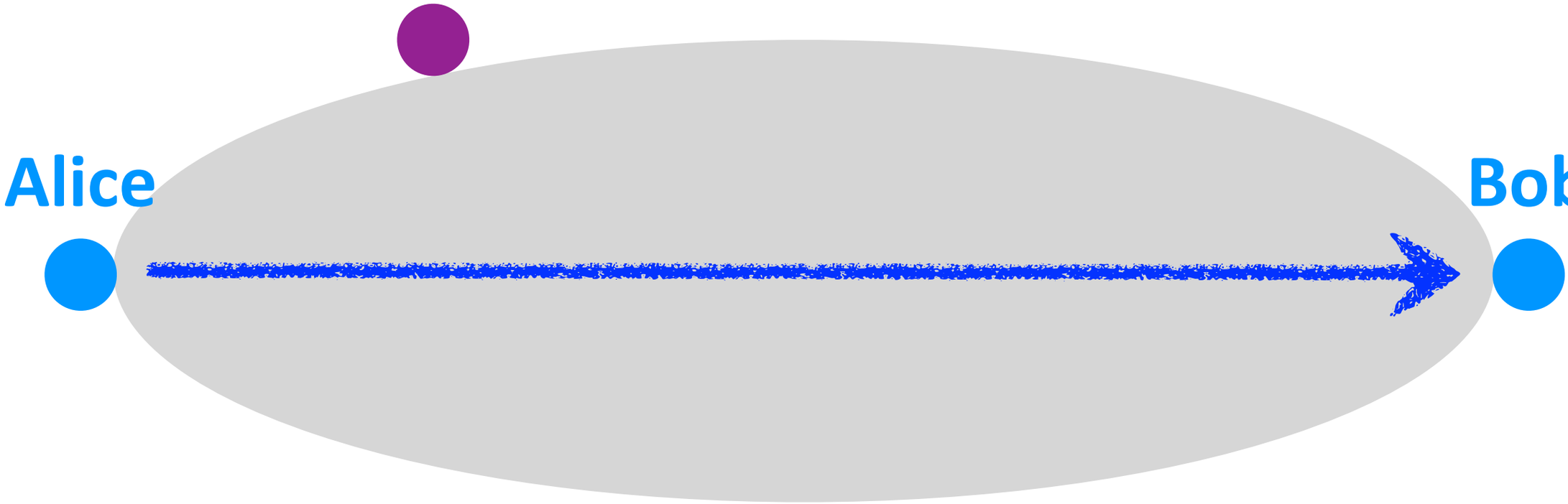
Persa (the impersonator)

pretends she is Alice to extract information from Bob

www.EngineeringBooksPdf.com

makes Alice or Bob crash or disconnect
and disrupts the communication

Denis (the denial-of-service attacker)



www.EngineeringBooksPdf.com

makes Alice or Bob crash or disconnect
and disrupts the communication

Denis (the denial-of-service attacker)

vulnerability attack

www.EngineeringBooksPdf.com

makes Alice or Bob crash or disconnect
and disrupts the communication

Denis (the denial-of-service attacker)

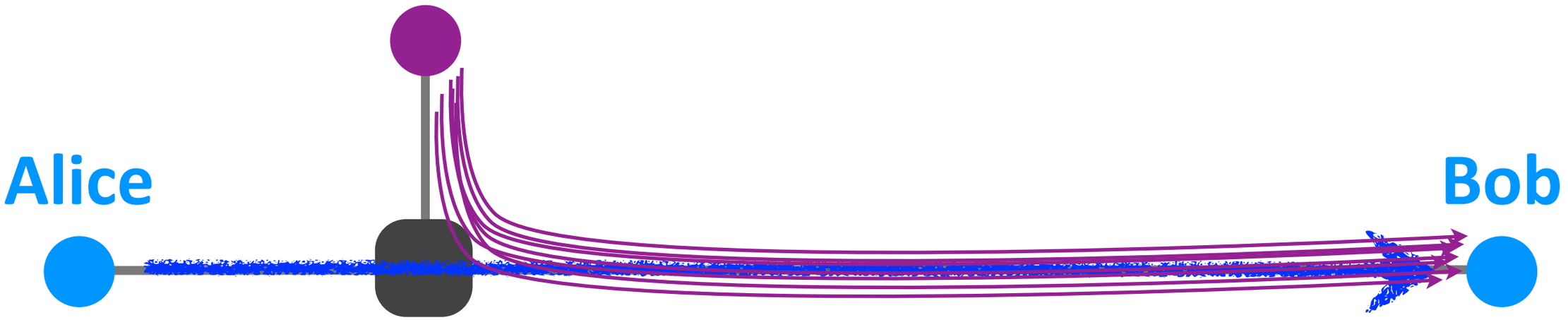
vulnerability attack

bandwidth flooding

www.EngineeringBooksPdf.com

makes Alice or Bob crash or disconnect
and disrupts the communication

Denis (the denial-of-service attacker)



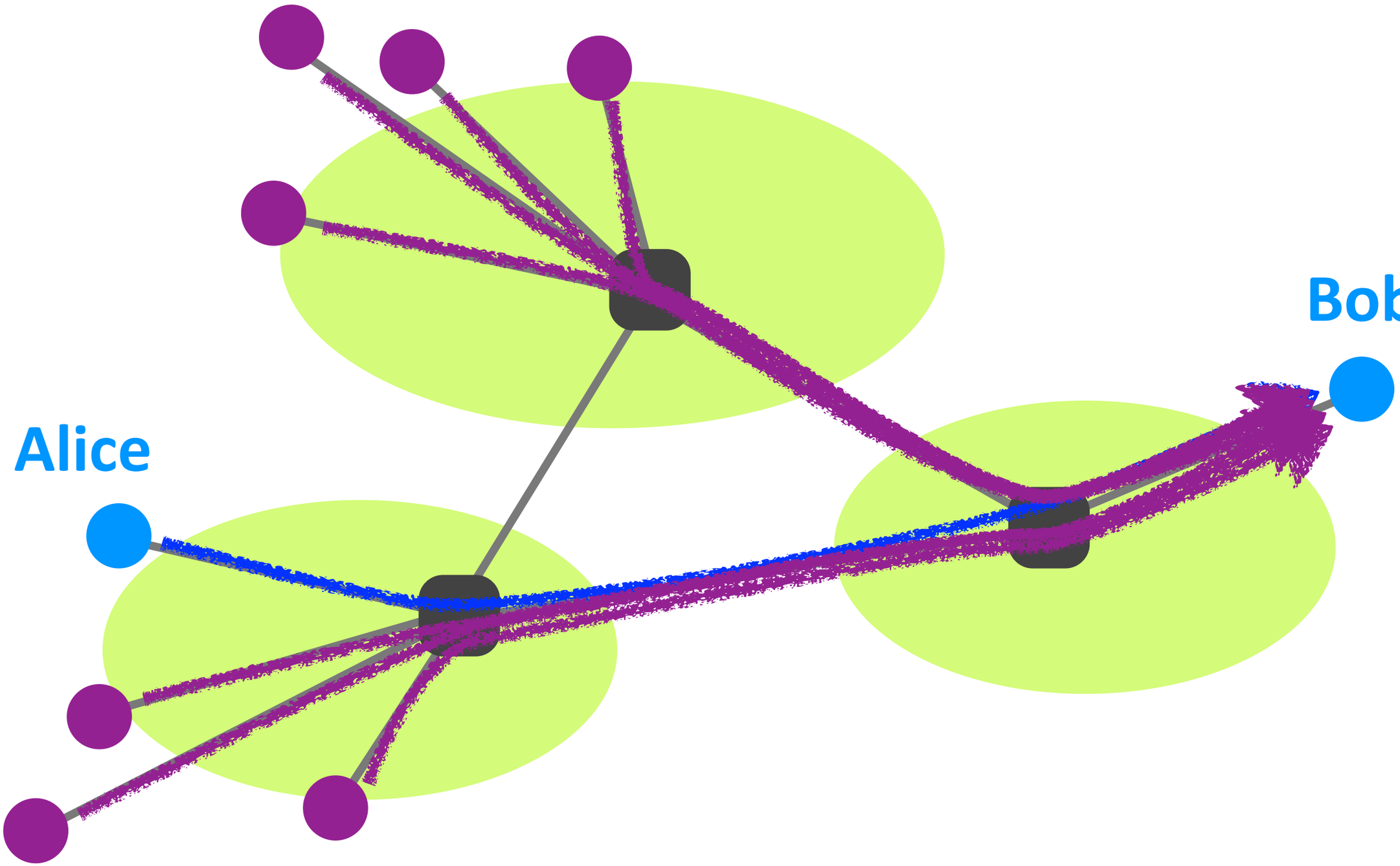
vulnerability attack

bandwidth flooding

connection flooding

www.EngineeringBooksPdf.com

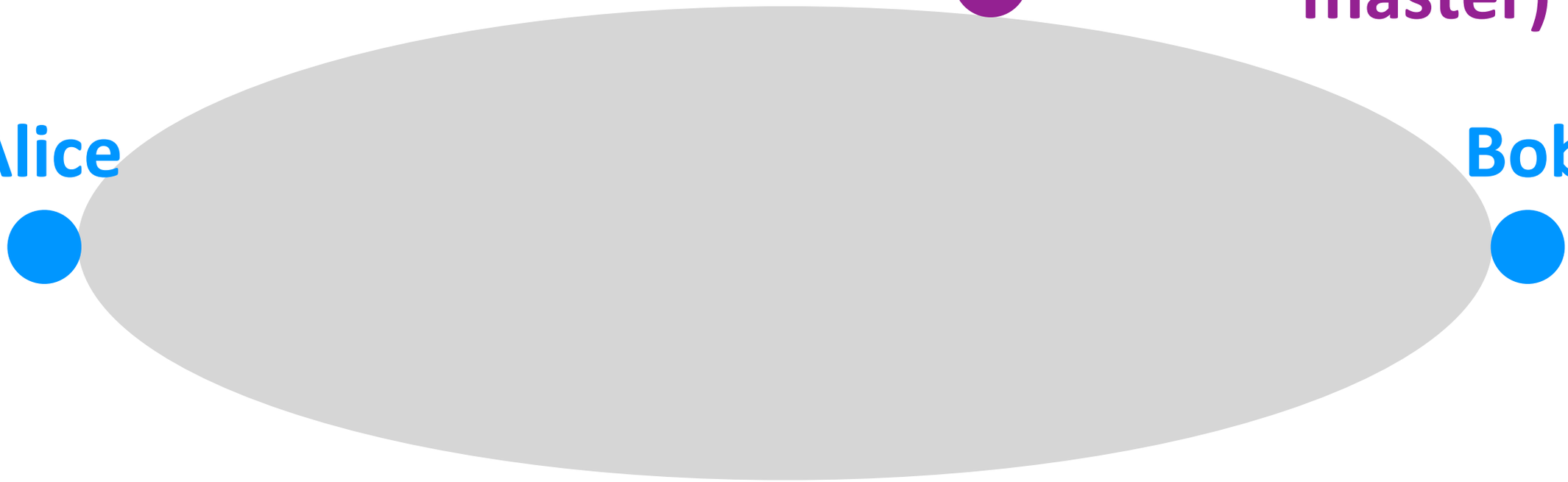
distributed denial-of-service attack



www.EngineeringBooksPdf.com

infects Alice or Bob with malware = bad software

Malik (the malware master)



www.EngineeringBooksPdf.com

infects Alice or Bob with malware = bad software

Malik (the malware master)

delete files

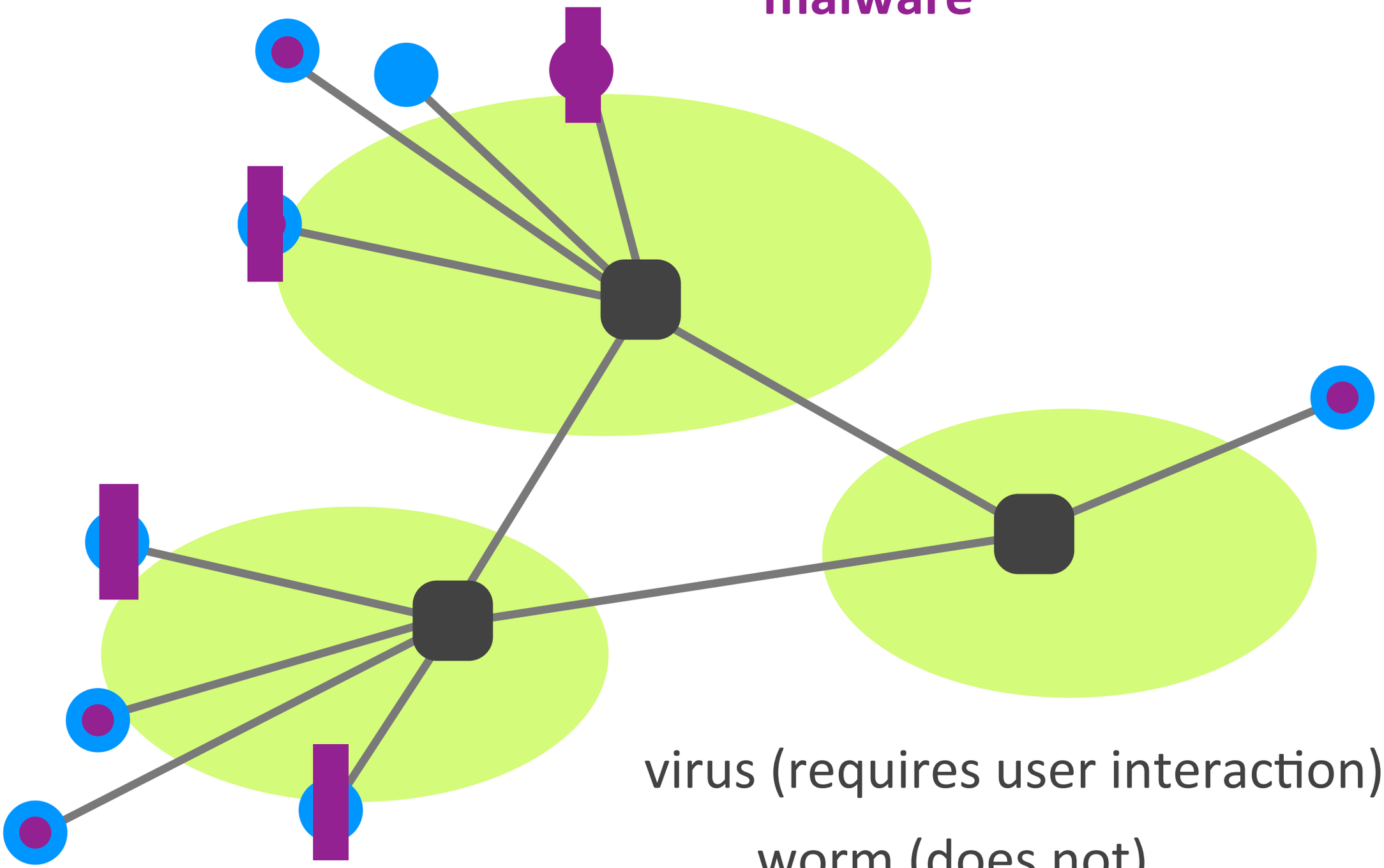
copy & export personal data

send spam email

launch denial of service

www.EngineeringBooksPdf.com

self-propagating malware

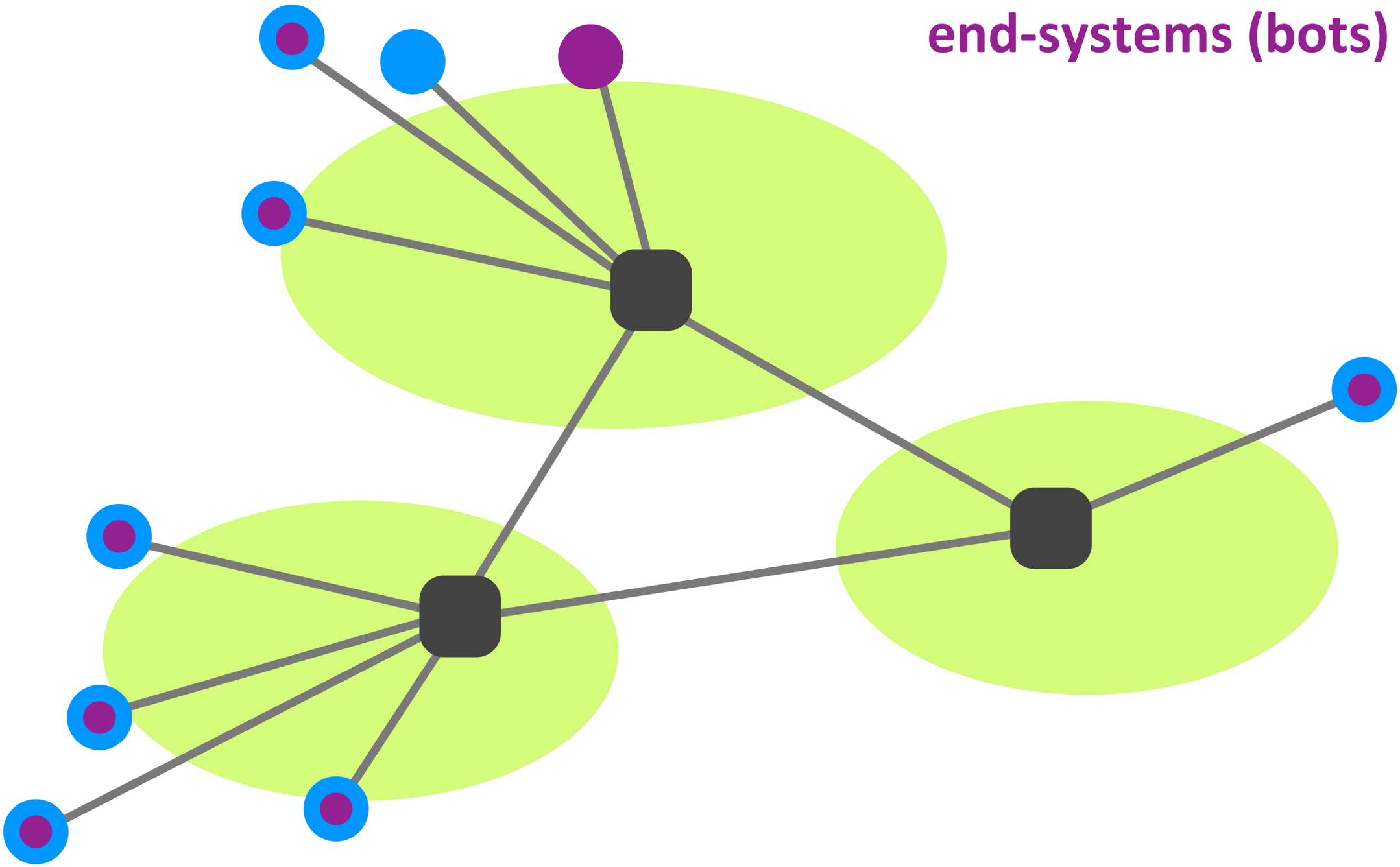


virus (requires user interaction)

worm (does not)

www.EngineeringBooksPdf.com

botnet =
army of compromised end-systems (bots)



www.EngineeringBooksPdf.com

Denis

Malik

Alice

Bob

Eve

Persa

www.EngineeringBooksPdf.com

Internet vulnerabilities

- Eavesdropping (sniffing)
- Impersonation (spoofing)
- Denial of service (dos-ing)
- Malware

www.EngineeringBooksPdf.com

- What trust model to design for?

www.EngineeringBooksPdf.com

The 60s

- Invention of packet switching
  - *Leonard Kleinrock wanted to be different*
  - *Paul Baran was afraid of the Soviets*

- Creation of the ARPAnet
  - *first message ("lo" from "login", Oct. 29, 1969)*
  - *first backbone (4 packet switches, Dec. 5, 1969)*

www.EngineeringBooksPdf.com

The 70s

- First shared broadcast technologies
  - *ALOHA wireless network (Abramson, 1970)*
  - *Ethernet (Metcalfe and Boggs, 1976)*

- First application
  - *email (Tomlinson, 1972)*

www.EngineeringBooksPdf.com

The 70s

- First network interconnection at DARPA
  - *Network Control Program (NCP)*
  - *creation of TCP (to replace NCP)*
  - *separation of IP from TCP, creation of UDP*
  - *led by Vint Cerf and Bob Kahn*

www.EngineeringBooksPdf.com

The 80s

- Official deployment of TCP/IP on ARPAnet
  - *all hosts switched over in 1 day (Jan. 1, 1983)*

- Mass deployment of Minitel in France
  - *terminals given for free by government*
  - *services free or pay-per-usage*

www.EngineeringBooksPdf.com

The 80s

- Congestion control added to TCP
  - *prevent accidental flooding of the network (Jacobson, 1988)*

- Invention of Domain Name Service (DNS)
  - *map IP addresses to human-readable names (Mockapetris, 1983)*

www.EngineeringBooksPdf.com

The 90s

- Internet backbone transferred to ISPs
  - *ARPAnet decommissioned in 1989*
  - *successor (NSFnet) decommissioned in 1995*
- Invention of the Web at CERN
  - *first web server & browser (Berners-Lee, 1991)*

www.EngineeringBooksPdf.com

The 90s

- Web-browsing
  - *creation of Mosaic in UIUC (Andreessen, 1992)*
  - *Netscape vs. Internet Explorer*

- Peer-to-peer file sharing
  - *creation of Napster (Fanning, Parker, Mendelson, 1999)*
  - *shut down due to copyright infringement issues*

www.EngineeringBooksPdf.com

The hot terms

- Global connectivity
  - *online medicine & education for remote areas*
  - *Internet connectivity = commodity*
- Content
  - *Google directly connected to access ISPs*
  - *traditional ISPs going out of business?*

www.EngineeringBooksPdf.com

The hot terms

- Online social networks (OSNs) & Privacy
  - *how does Facebook make money?*
  - *targeted advertising*

- The Cloud
  - [*infrastructure, platform, software*] *as a service*
  - *Amazon EC2, Google AppEngine, MS Azure*

www.EngineeringBooksPdf.com

Questions

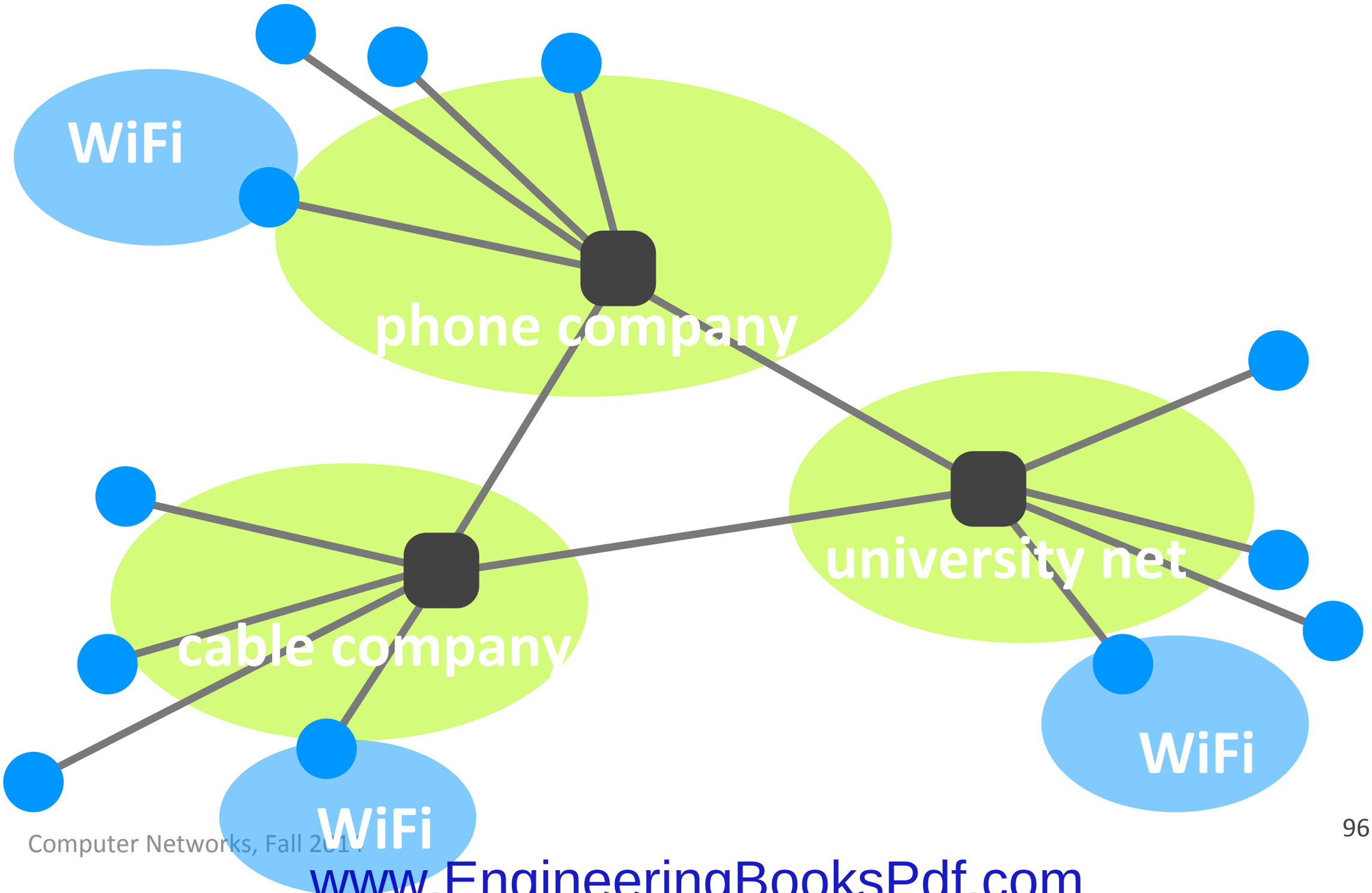
- What is a network made of?
- How is it shared?
- How is it organized?
- How does communication happen?
- How do we evaluate a network?

www.EngineeringBooksPdf.com

Questions

- What is a network made of?
- How is it shared?
- How is it organized?
- How does communication happen?
- How do we evaluate a network?

www.EngineeringBooksPdf.com



www.EngineeringBooksPdf.com

Questions

- What is a network made of?
- How is it shared?
- How is it organized?
- How does communication happen?
- How do we evaluate a network?

www.EngineeringBooksPdf.com

Resource management

- Packet switching
  - *efficient resource use*
  - *no performance guarantees*
  - *simpler to implement,*
    but requires congestion control

- "Connection switching"
  - *performance guarantees*
  - *inefficient resource use*

www.EngineeringBooksPdf.com

Many kinds of “circuits”

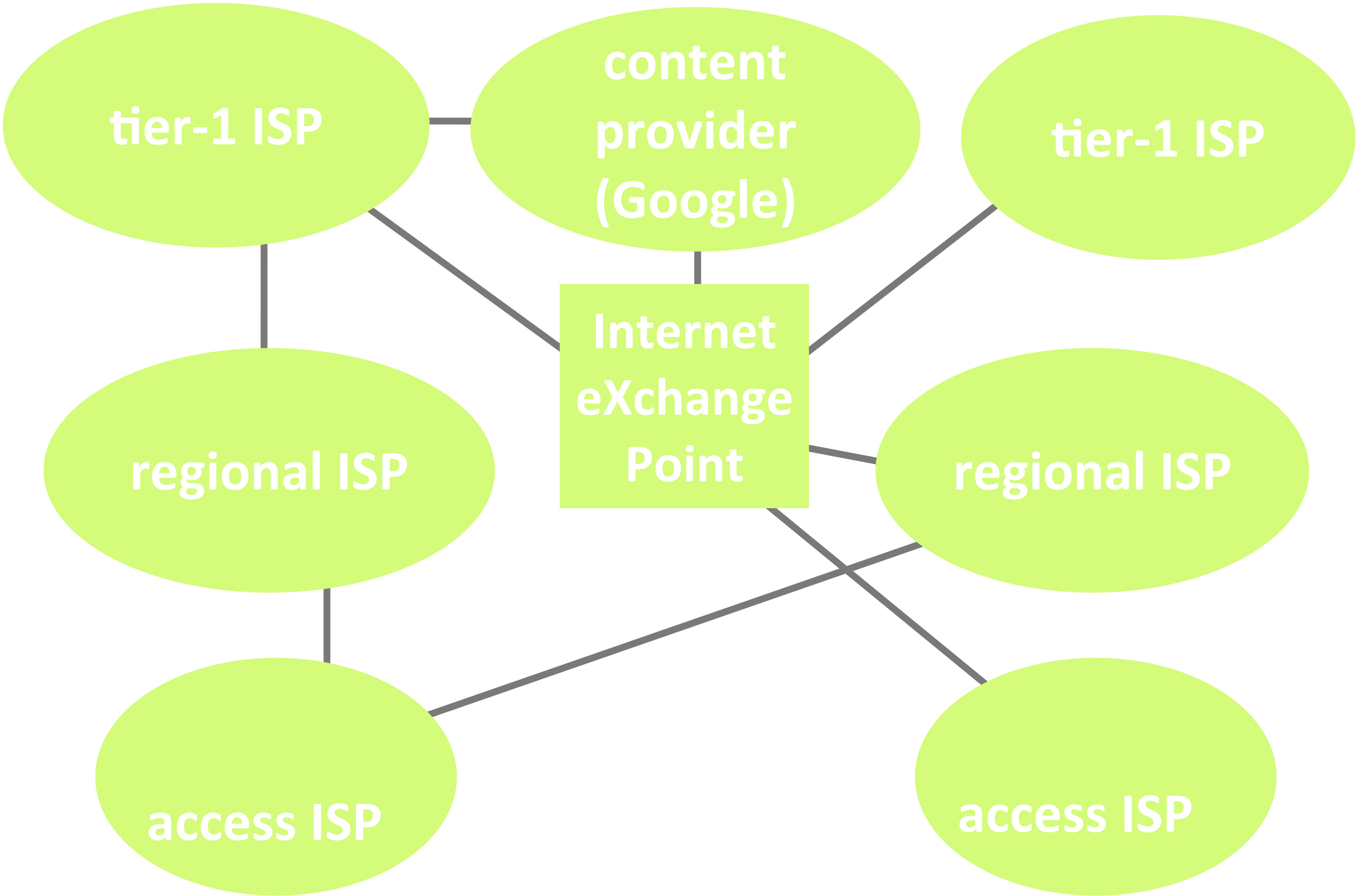
- Different ways to implement connection switching
- Create the illusion of a separate physical circuit per connection

www.EngineeringBooksPdf.com

Questions

- What is a network made of?
- How is it shared?
- How is it organized?
- How does communication happen?
- How do we evaluate a network?

www.EngineeringBooksPdf.com



www.EngineeringBooksPdf.com

Questions

- What is a network made of?
- How is it shared?
- How is it organized?
- How does communication happen?
- How do we evaluate a network?

www.EngineeringBooksPdf.com

application	*applications that exchange messages*
transport	*transports segments between two apps*
network	*moves datagrams around the network*
link	*moves frames across a link*
physical	*moves data across a physical medium*

www.EngineeringBooksPdf.com

Questions

- What is a network made of?
- How is it shared?
- How is it organized?
- How does communication happen?
- How do we evaluate a network?

www.EngineeringBooksPdf.com

Delay

- How long does it take to send a packet from its source to its destination?

www.EngineeringBooksPdf.com

Loss

- What fraction of the packets sent from a source to a destination are dropped?

www.EngineeringBooksPdf.com

Throughput

- At what rate is the destination receiving data from the source?

www.EngineeringBooksPdf.com

Security

- How does the network react to adversarial (= bad) behavior?
- What does the network assume about the behavior of end-systems and packet switches?

www.EngineeringBooksPdf.com

What physical infrastructure
is already available?

Treat on demand or reserve?

What modularity & hierarchy?

What layers to define?

What trust model to design for?

www.EngineeringBooksPdf.com