Introduction to Communication Networks and Distributed Systems

Unit 1 - Basics -

Fachgebiet Telekommunikationsnetze

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Acknowledgements

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- Numerous slides from Introductory courses by Prof. Holger Karl (Paderborn) have been used (with permission of the author).

How do People achieve Common Knowledge?

- Joint observations
  - Where is my pointer?

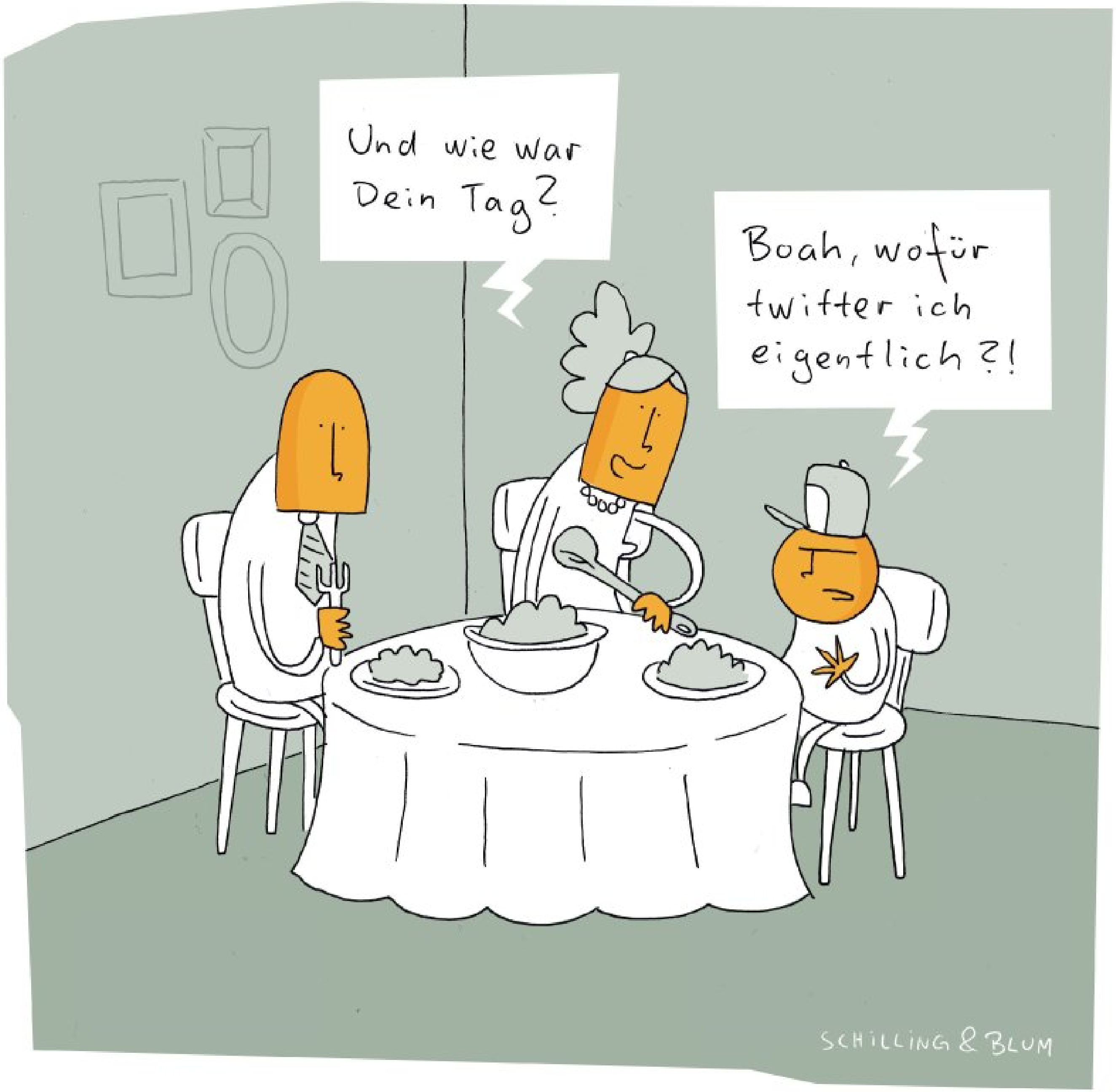
- **Communication**
  - He has told me that I should register for the lab …

- Usage of joint „archives“ (storage of data)
  - You can look it up in …

What do we use Communication for? How?

- Exchanging information & getting information
  - Runners (marathon), flags, mirrors, etc.
  - E-mail, WWW

- Maintaining inter-human relations
  - Letters, letters of affection,
  - Phone,
  - SMS, chat, social networks


Und wie war Dein Tag?
Boah, wofür twitter ich eigentlich?!
SCHILLING & BLUM

What do we use Communication for?

- ….
- Entertainment:
  - Passive
    - Live theater, circus, movies, radio, TV, videos (on demand?)
  - Active
    - Video games – network games – virtual worlds

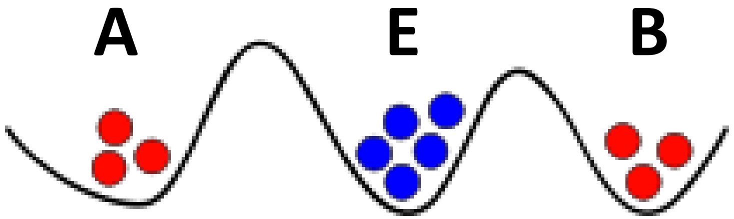
The Two Army Problem

- Principles:
  - A and B have 2N soldiers each.
  - The black army has 3N soldiers.
  - In case of conflict the bigger force wins.
  - The two orange forces have to communicate to synchronize their attack.
  - Q.: Can they?

The Two Army Problem (II)

- For this communication they need:
  - A common language (possibly not understood by the black army),
  - A communication path - a messenger - who has to pass through the land occupied by the enemy
    - Could be intercepted with a given probability *p*,
    - A successful one-way trip takes time *D*

Some Difficulties …

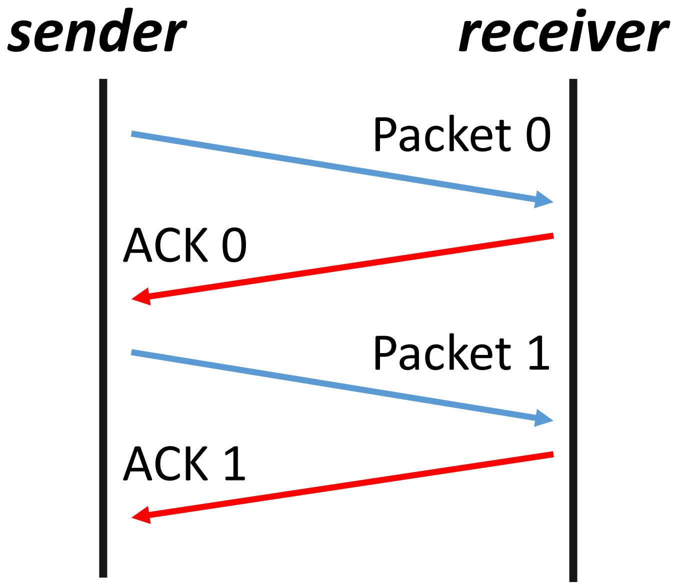


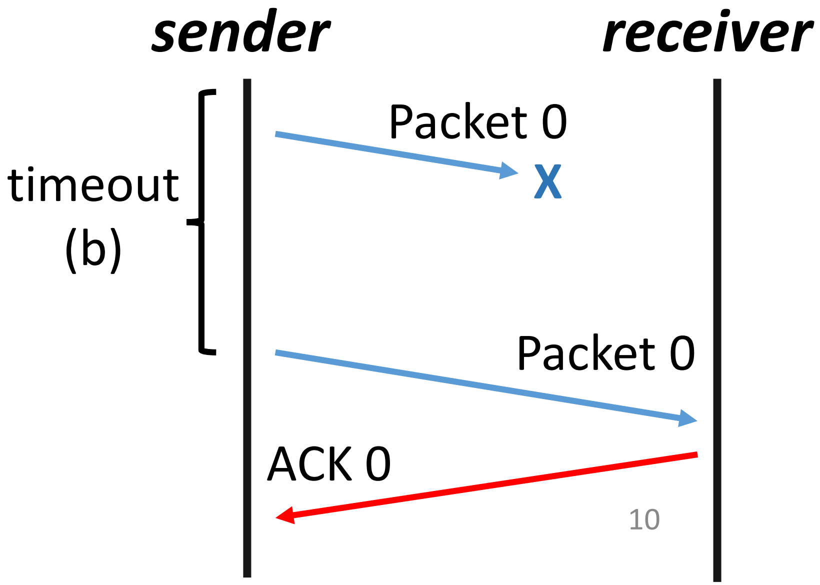
- Assume that commander A and commander B send a messenger to the counterpart with different suggested time for an attack. Afterwards both agree for the suggestion of the partner.
  The play goes on ...
- Let the commander A (senior) send a messenger with an order
  - Did the commander B receive the message? When? How does commander A know?
  - Let request the commander B to acknowledge his readiness to follow the orders. Is the victory sure? How does B know that A got the acknowledgment?
- If one of the units (A or B) decides to attack after posting the „last confirmation“ it always fails with probability *p*!

Can we find a “better” Strategy?

- One possible mechanism to avoid losses
- Sender:
  - Sends the information.
  - If no acknowledgment has been received within time $b = 2D+\delta$ → send again.
- Receiver:
  - Waits for an information.
  - Acknowledge the received information.

- This is called a “send/stop and wait” protocol
- Transmission protocols
  = set of rules for communication



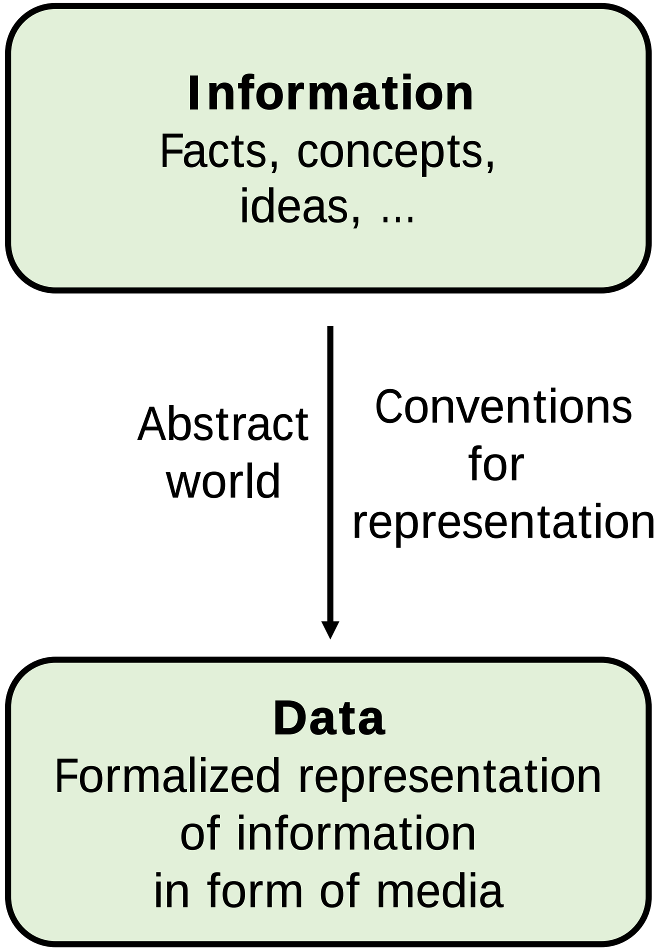


Is it better? Let us do some Math

- Successful transmission is acknowledged after a constant time *b* while *p* is the loss probability.
- Let $\prod$ be the probability of no acknowledgement:
  - $\prod = 1 - (1-p)^2$ note: (1-p) = prob. of one way success
- The time needed for a successful transmission is
  - b with probability $(1-\prod)$
  - 2b with probability $(1-\prod)\prod$
  - 3b with probability $(1-\prod)\prod^2$
  - (k+1)b with probability $(1-\prod)\prod^k$
- Assume that there is only time for *N* „rounds“:
  - The probability of successful attack is $(1-\prod^N)$
- The success is never guaranteed! Bigger *N* helps …

What to Communicate: Information, Data

- Information
  - Facts, concepts, ideas
  - A human-oriented term
- **Data** (encapsulated in media)
  - A formalized representation of facts, concepts, ideas
  - Example: text, speech, picture, video
  - A human interpretation of data, conferring meaning to data
- Note:
  - Only **data** can be communicated,
  - The recipient of data restores information,
  - The recipient interprets data – subject to her interpretation



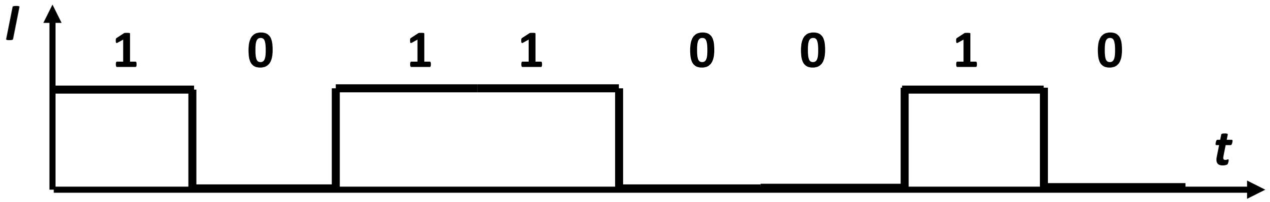
The Data Tsunami

- In 2000 years of recorded history humans created 2 Exabytes of data.
- We generate over 2.5 Exabytes of data/day now!
  - Different sources
- Problem: extracting information out of **data**
  - Where to process them?
  - Bringing data to the processing?
  - Processing data where it emerges and transport (partial) results?

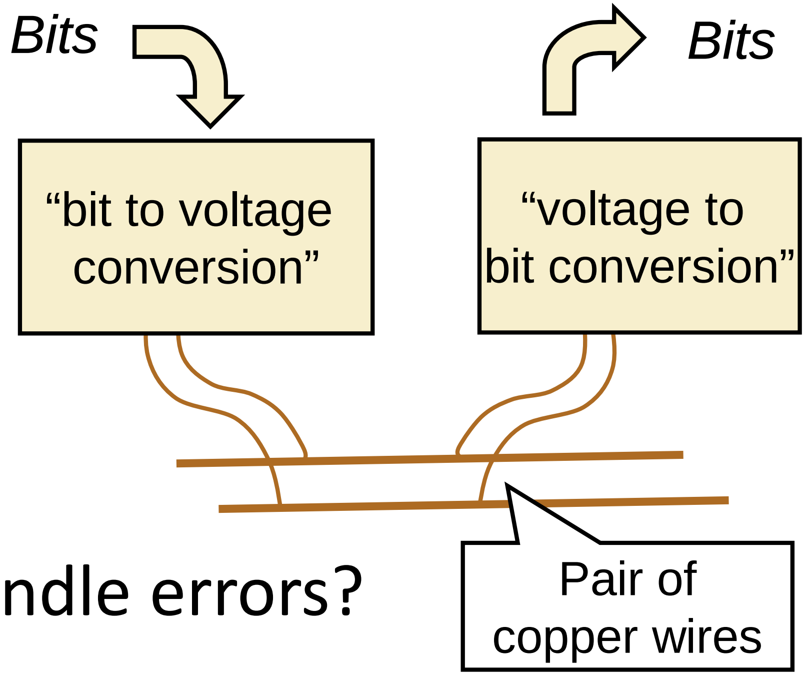
Value	Metric	
1000	kB	kilobyte
1000^2	MB	megabyte
1000^3	GB	gigabyte
1000^4	TB	terabyte
1000^5	PB	petabyte
1000^6	EB	exabyte
1000^7	ZB	zettabyte
1000^8	YB	yottabyte

Bits and Signals

- What should be communicated: **data**, represented as bits
- What can be communicated between remote entities: **signals**
- Needed: a means to transform bits into signals
  - … and from signals back into bits at the receiver
- A simplest convention for a copper wire:
  - A “1” is represented by current
  - A “0” is represented by no current



Or voltage:

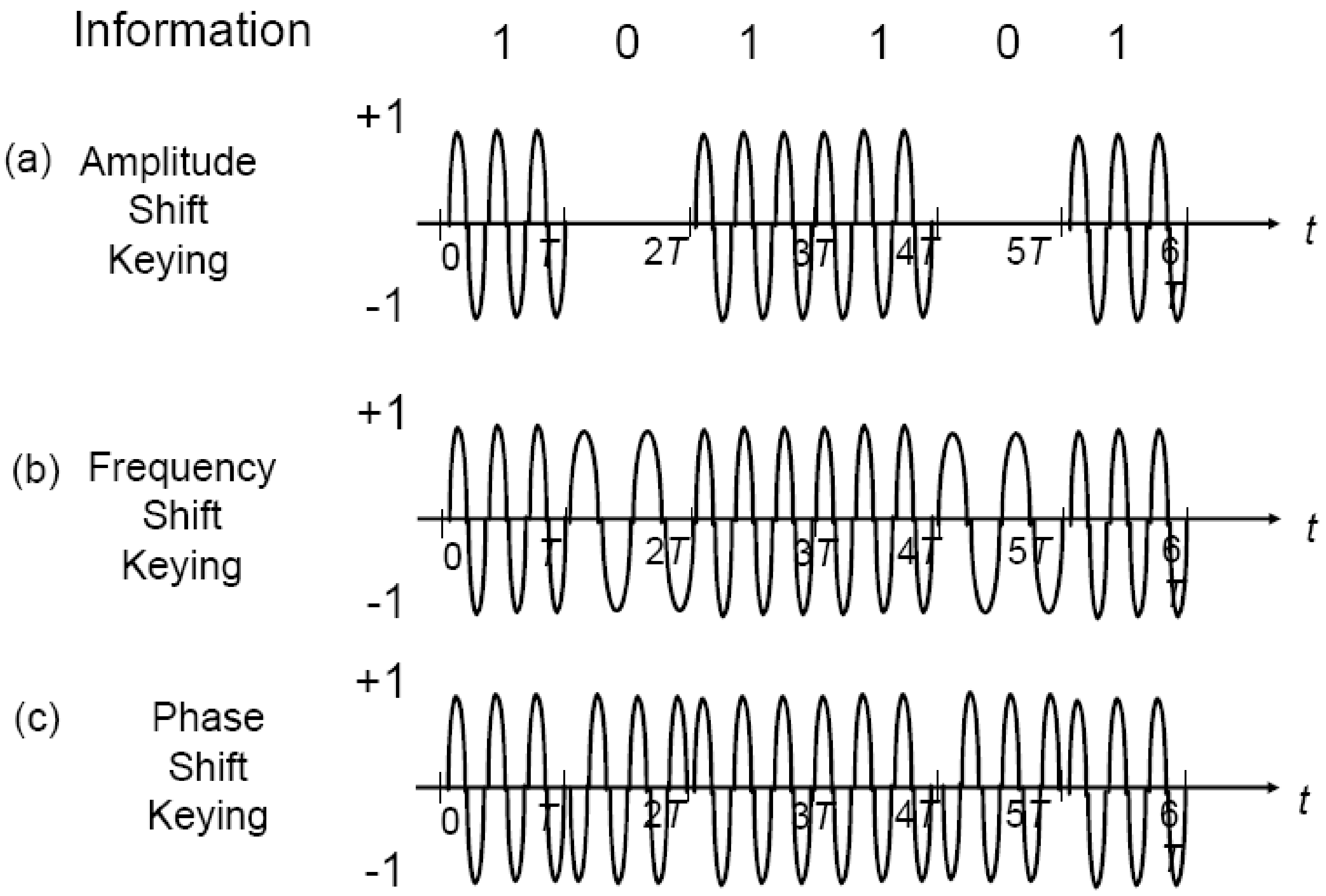


- Q.: How to detect bits, decide on their length, handle errors?

Another transformation of bits to signals…

- **Modem**: hardware that converts data into a format suitable for a transmission medium (e.g. telephone wires) so that it can be transmitted from computer to computer

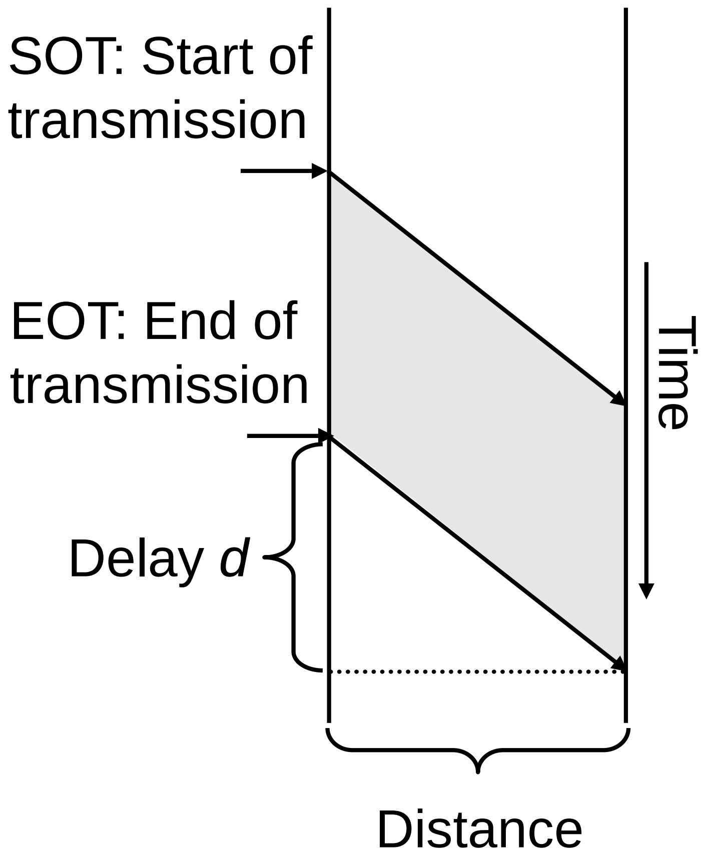
src: wikipedia



Realistic Transmission

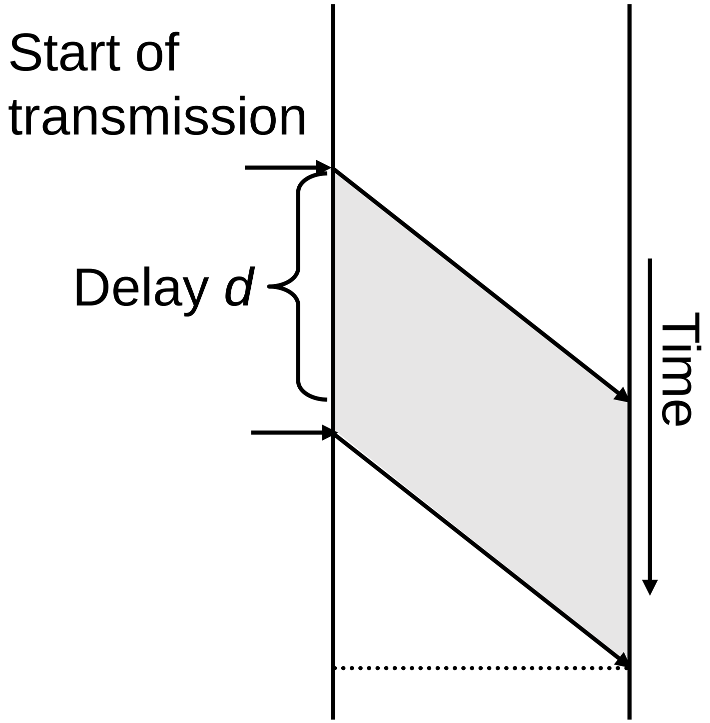
[H. Karl, Paderborn, op. cit.]

- **Propagation delay *d***:
  - Propagation speed *v*:
    - Speed of light: $v=c$,
    - In copper/fiber: $v \sim 2/3\ c$
  - d = distance / v
- **Data rate r**: How much bits/second can a sender transmit?
  - (EOT – SOT) = data size [bits] / data rate [bits/s]
- **Error rate**: What is the rate of incorrect bits arriving at the receiver?
  - Messages containing incorrect bits might be discarded



Transmission Medium can store Data

- What happens during a transmission?
  - Bits propagate to the receiver,
  - Sender keeps sending bits,
  - First bit arrives after *d* seconds,
  - In this time, sender has transmitted $d{\times}r$ bits
  - They are "stored in the wire" (or in the air!)



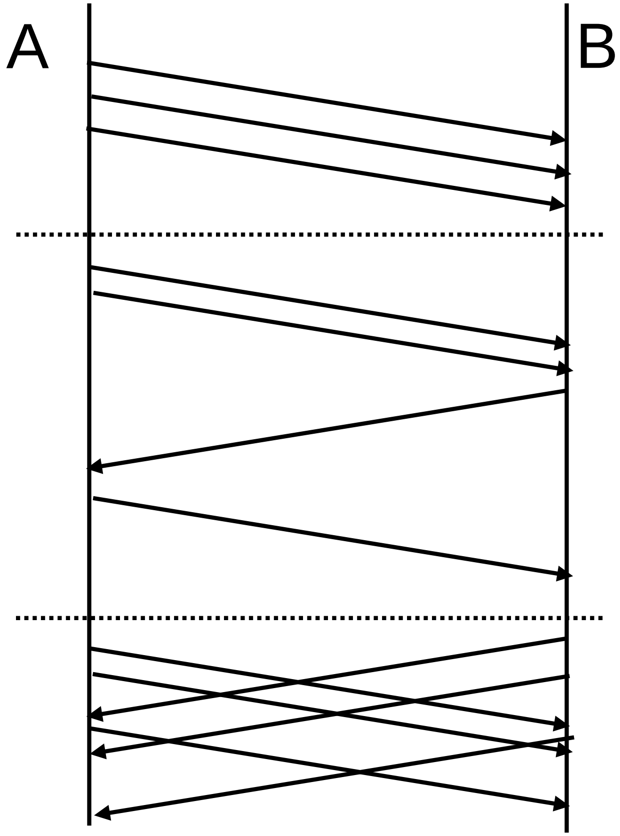
- $d{\times}r$ is the product of delay and data rate
  - Commonly called **bandwidth-delay product**
  - Crucial network property

Example (transcontinental cable):

- Data rate 100 Mbit/s
- Delay 4000 km / (2/3c) = 0.02 s
- $d \times r = 2$ Mbit (in the wire)

Communication Patterns

- One way communication, two-way communication
  - Announcement, request – response, meeting….
- Different patterns possible
  - **Simplex**: Only one party transmits
    - Example: radio broadcast,
  - **Half duplex**: Parties alternatively send data
    - Example: conversation,
  - **Full duplex**: both parties send all the time
    - Example: quarrel, parliament ☺



Just Connections?

[H. Karl, op. cit.]

- Connecting many users (e.g. phones) - the simple issue?

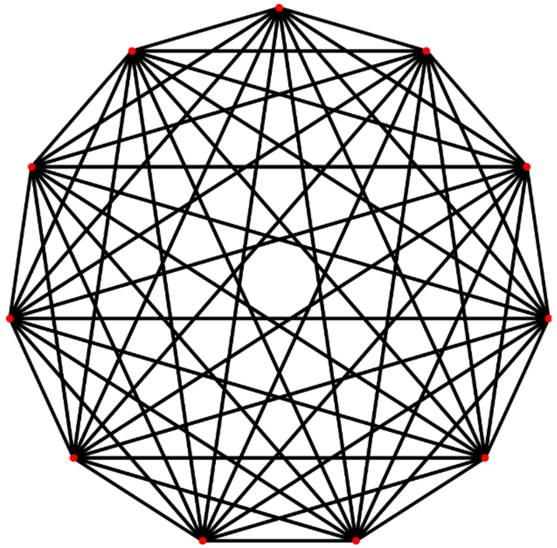
Switching

- It is not efficient to build a physically separate path for each pair of communicating end systems (*upper*)
- **Concept - the network**:
  - A set of path sections (e.g. electrical cables) and switches (*lower*)

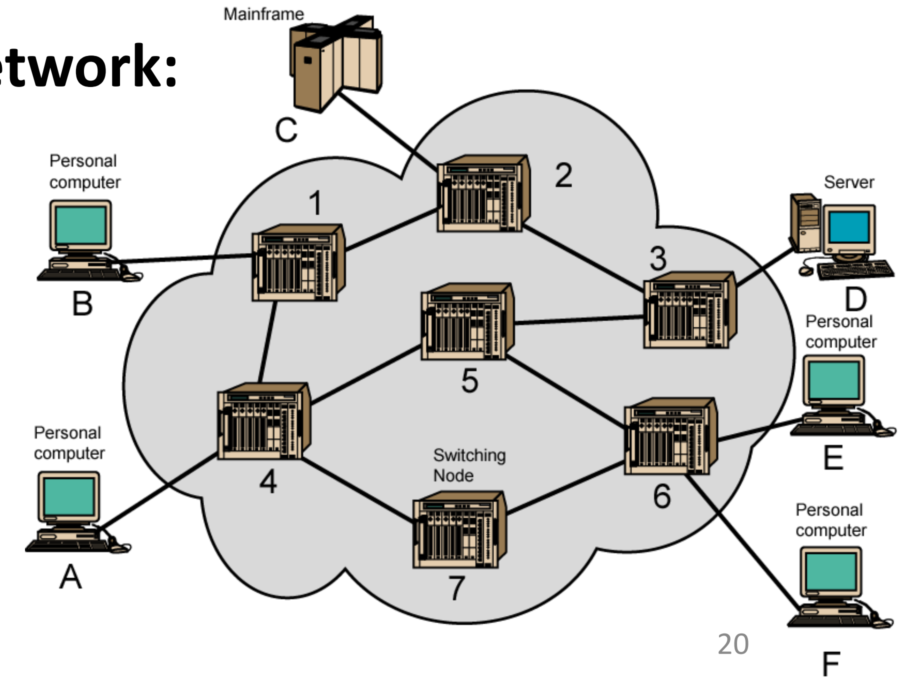
  “end systems” aka terminals/user devices
  vs.
  “switching elements” aka routers/bridges

- Note the similarity to other networks (electrical, transportation, water)

Directly connected:



Network:



Communication Networks – lot‘s of Questions

- Individual links
  - Propagation?
  - Speed of transmission: possibly variable, …
  - How to structure data? “portions”? flows?
- Mixing streams in the switches … overload? Losses or variable delay?
- Path selection?
- Binding of the communication in the end systems?
- Many, many other issues …

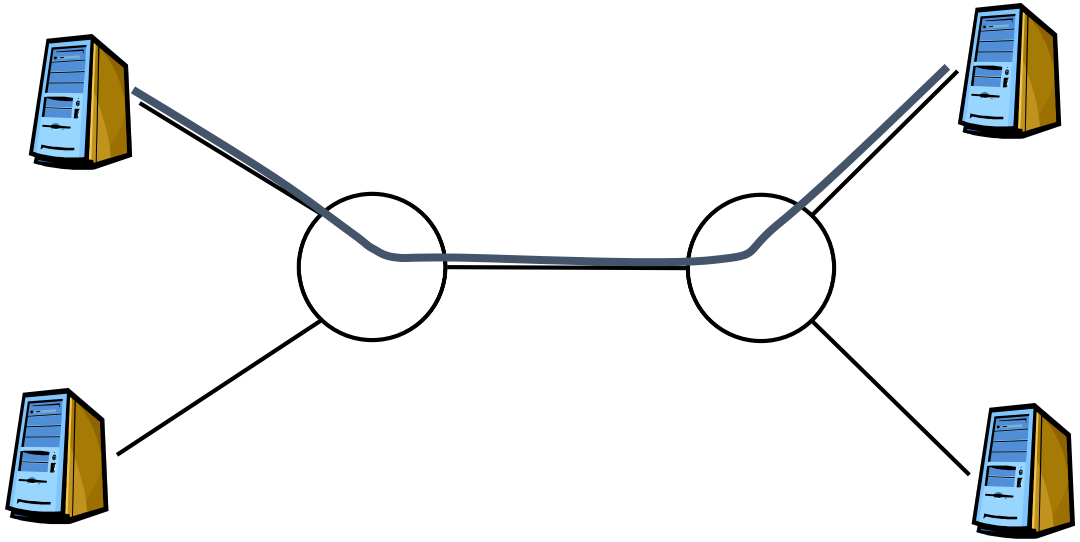
Similar Questions – Different Requirements

- What do you expect while
  - Picking up a telephone and making a phone call?
  - Looking-up a web page?
- The crucial differences in transmission:
  - Phone call: **continuous flow** of data with relatively fixed rate, each data portion must arrive in time, limited amount of errors acceptable,
  - Web browsing: **bunch** (burst) **of data** are requested irregularly (both the time of the request and the amount of data vary significantly); all the data have to be transmitted correctly

➔ This has led to different designs of switches.

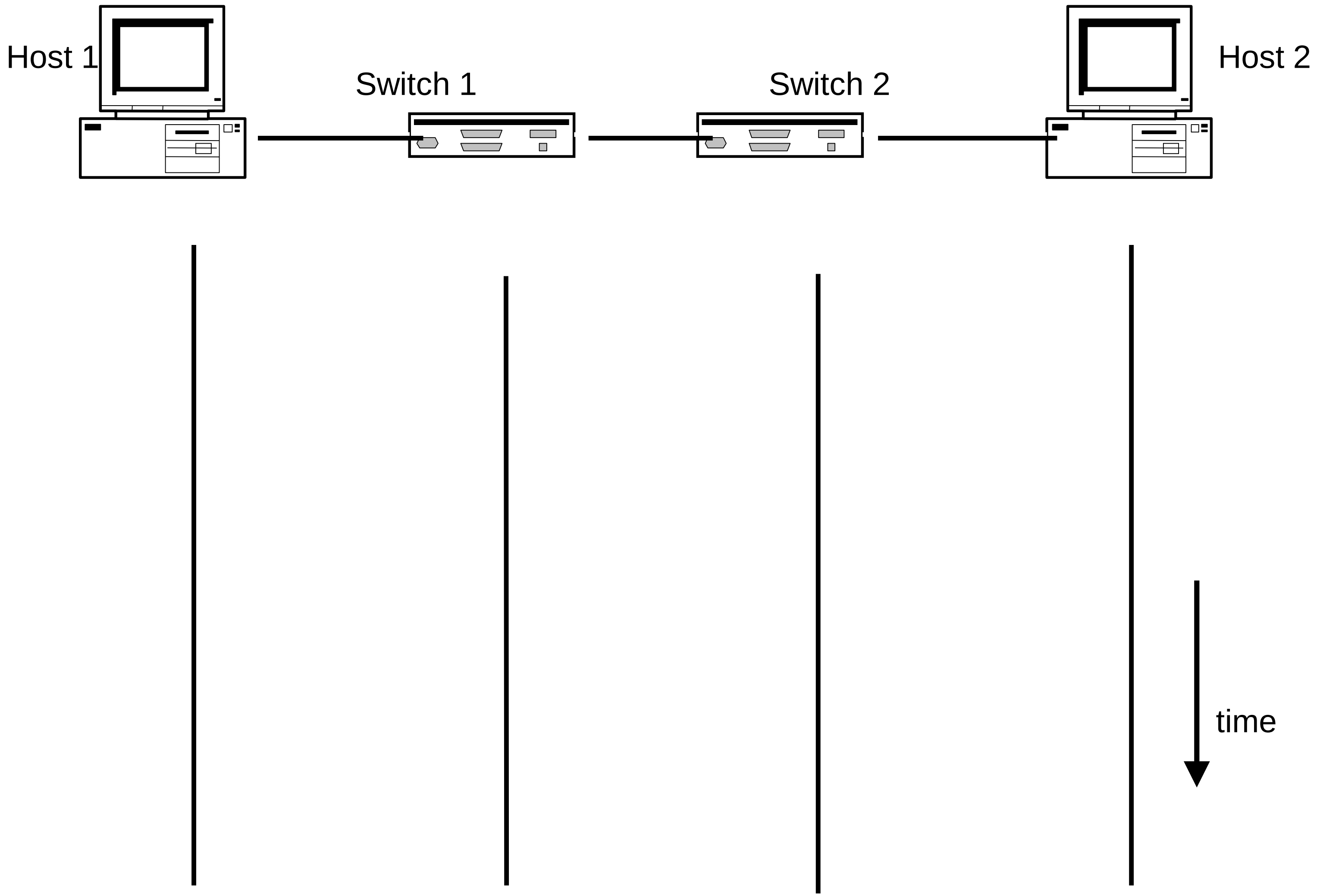
Option 1: Circuit Switching

- Circuit switching: the switching elements configure, on demand, a "path" between terminals.
  - Determines really the route (cmp. "Fräulein vom Amt") and resources!
  - The circuit lasts for duration of communication

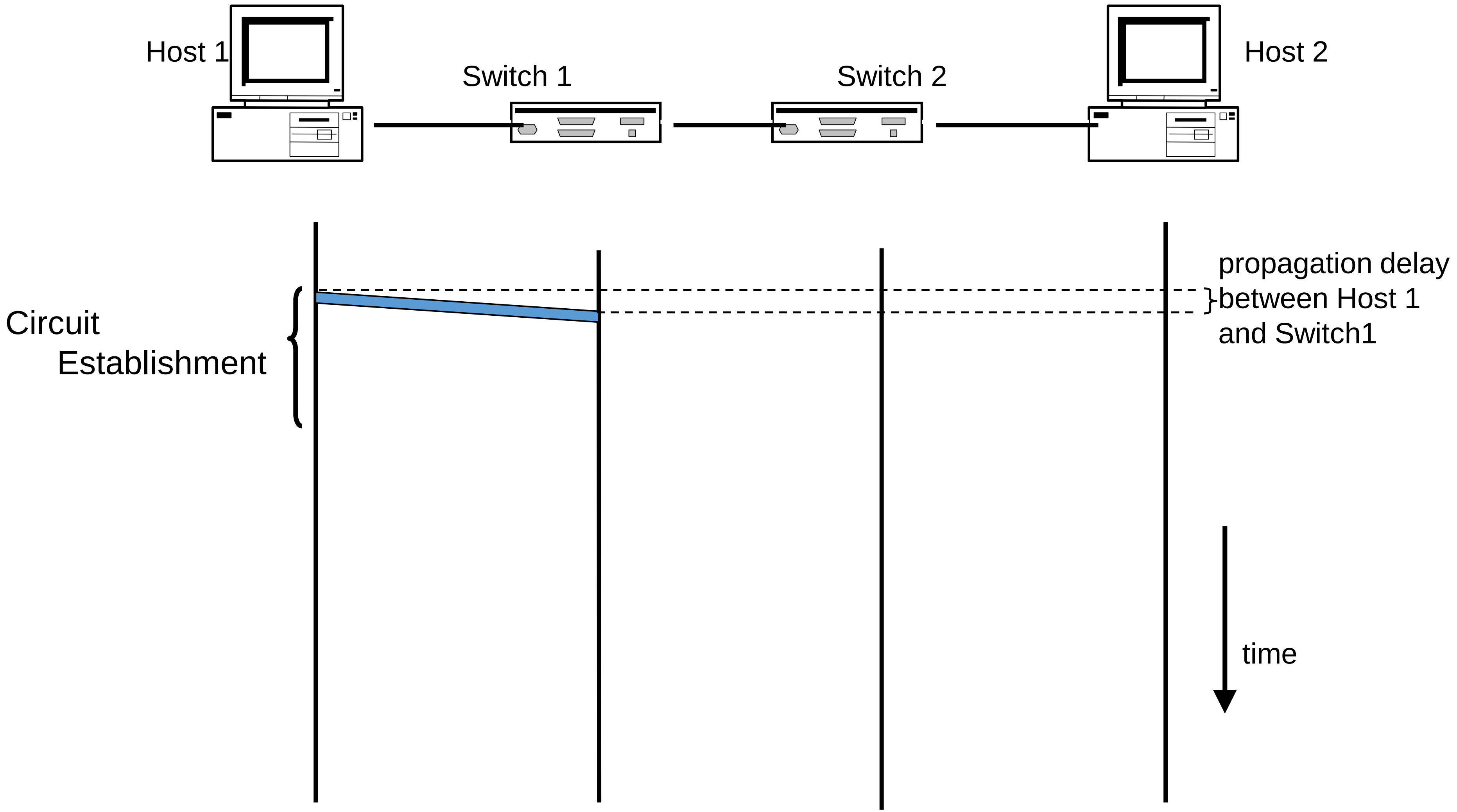


Source: wikipedia

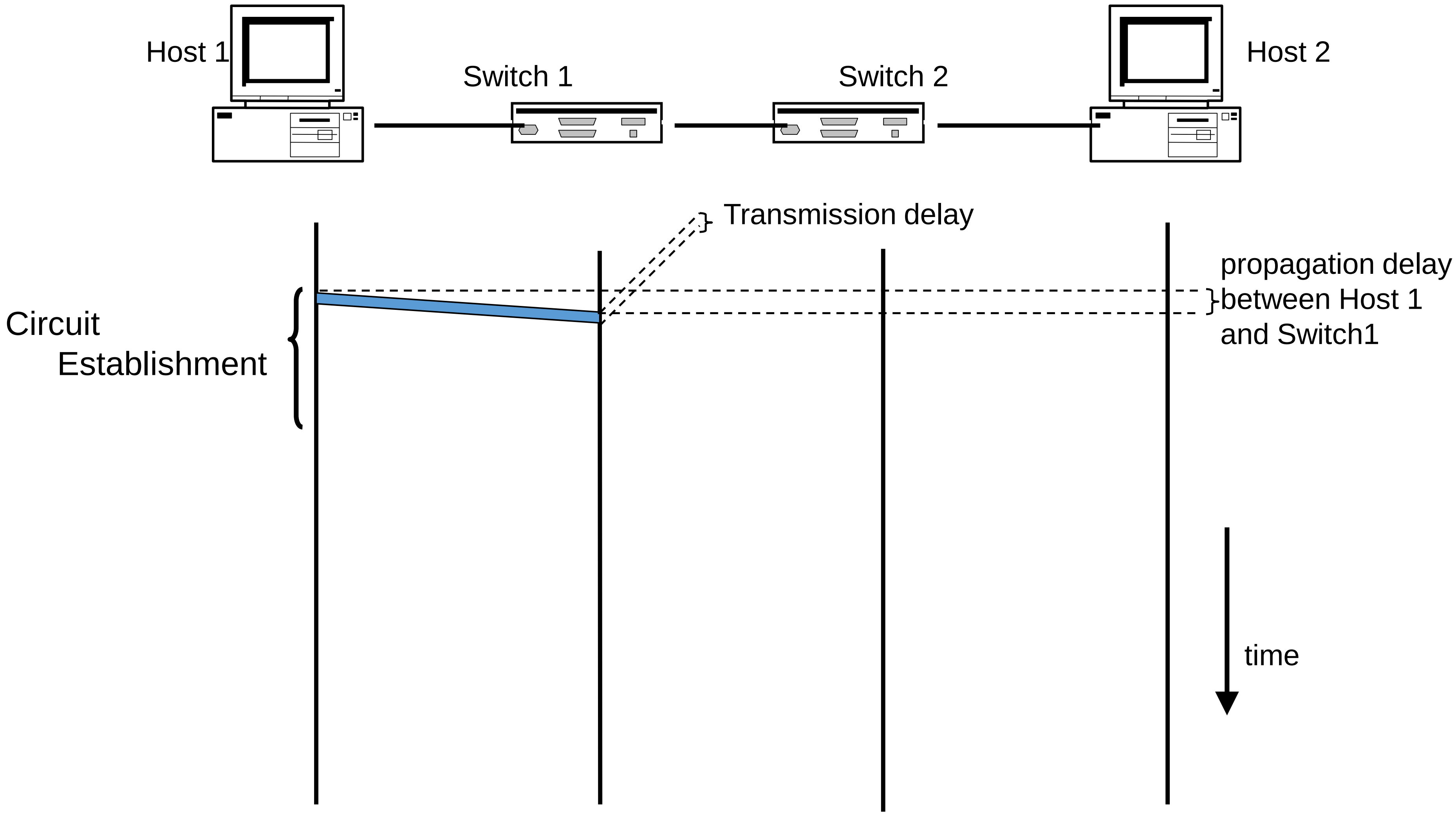
Timing in Circuit Switching (1)



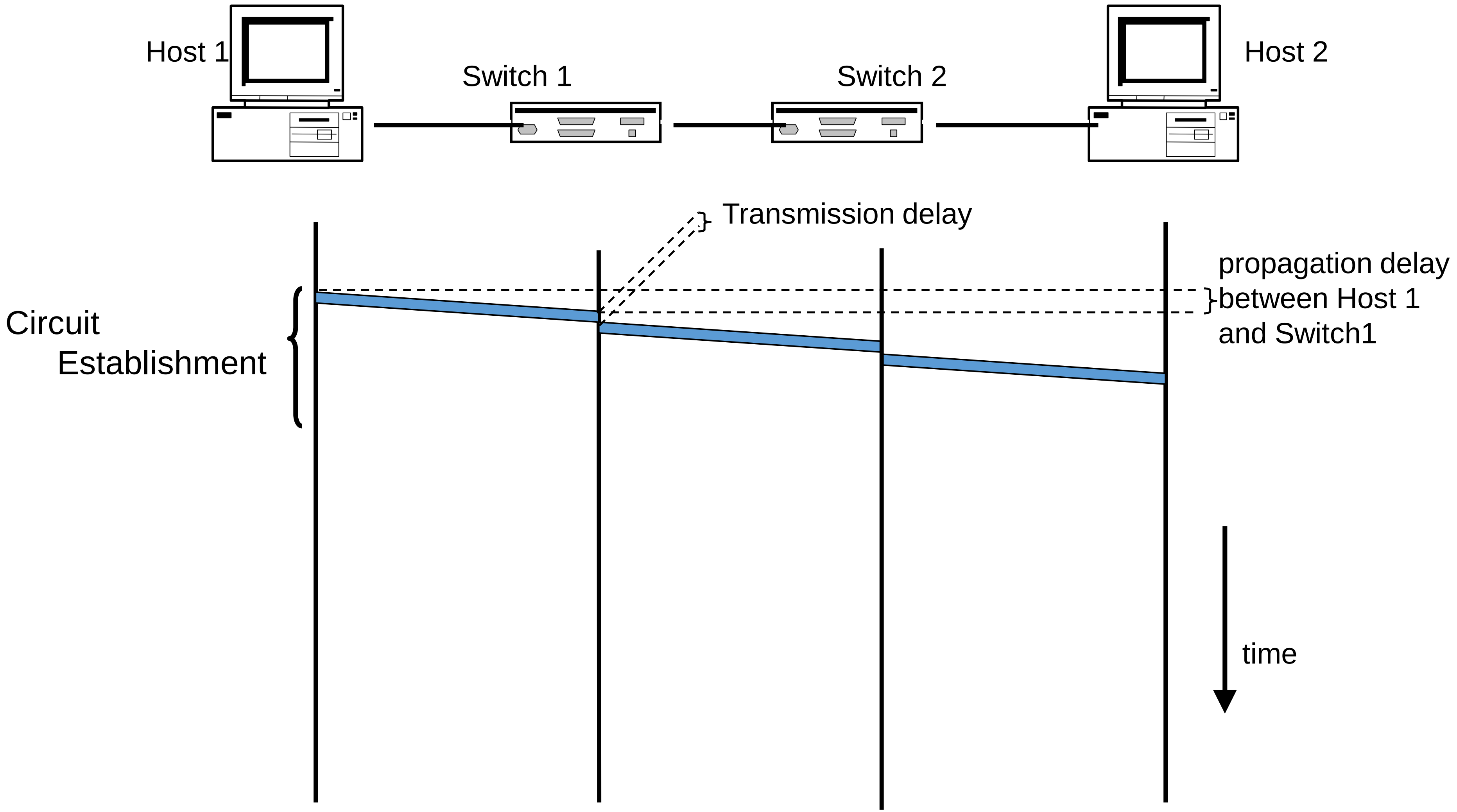
Timing in Circuit Switching (2)



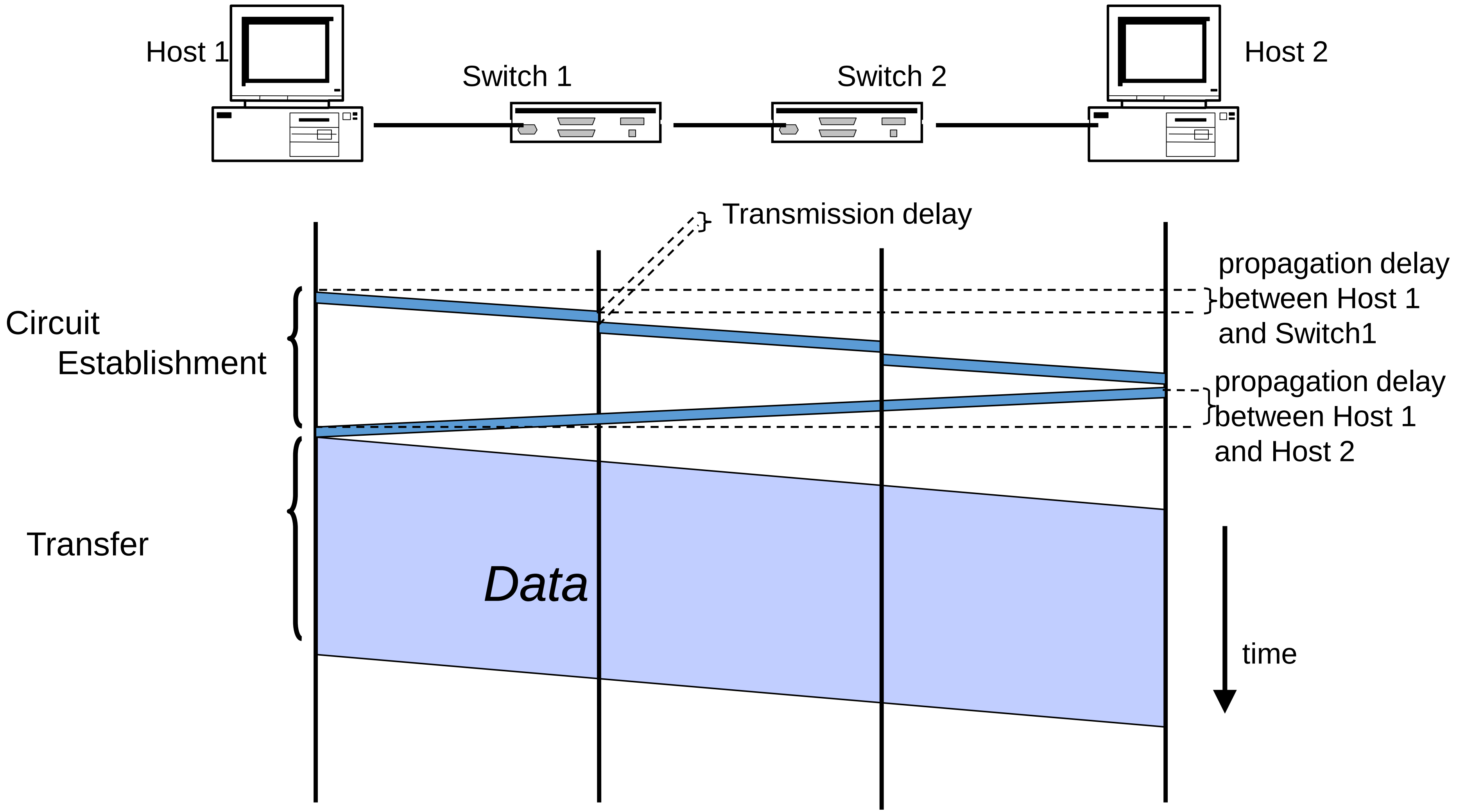
Timing in Circuit Switching (3)



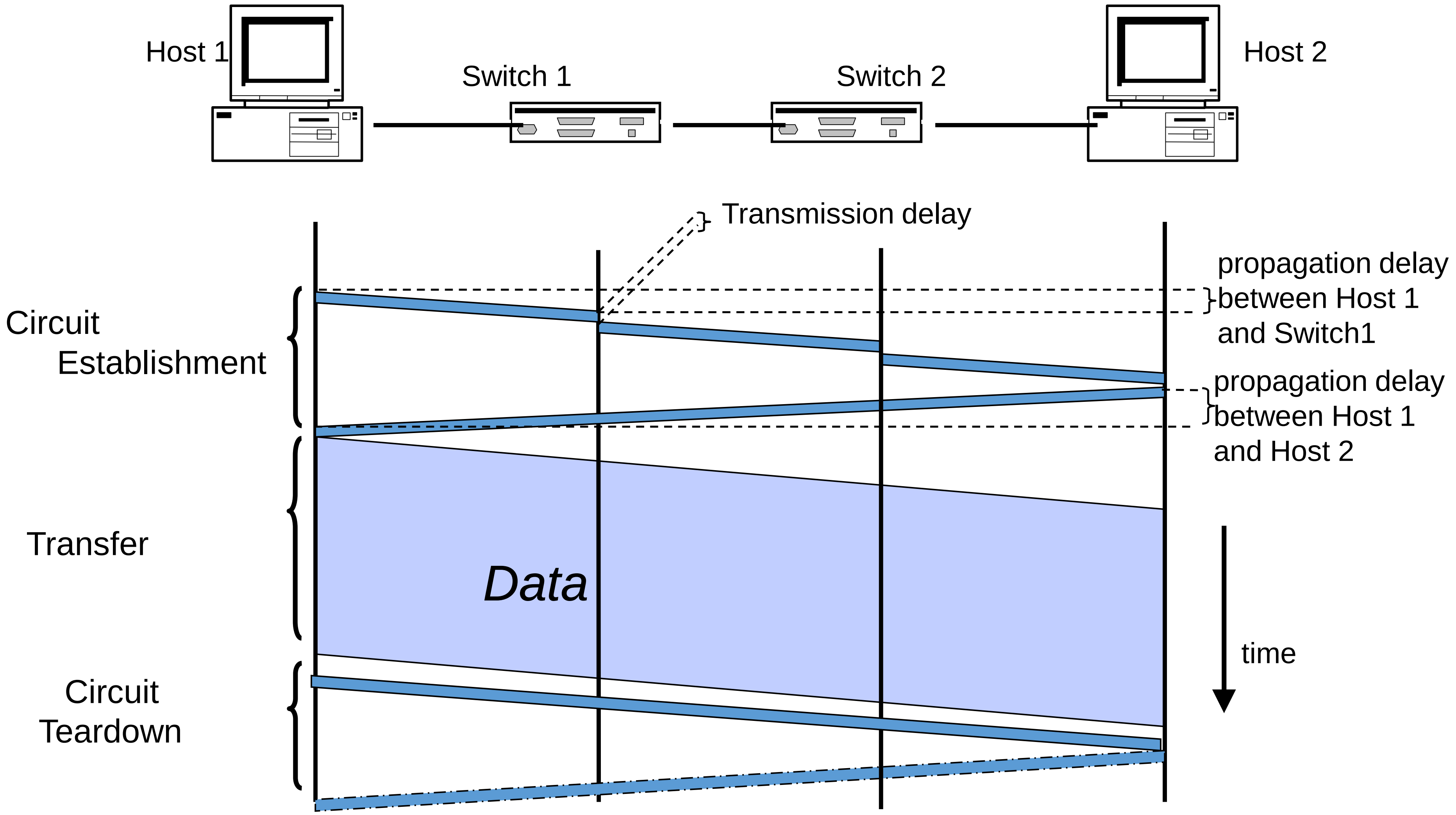
Timing in Circuit Switching (4)



Timing in Circuit Switching (5)



Timing in Circuit Switching (6)

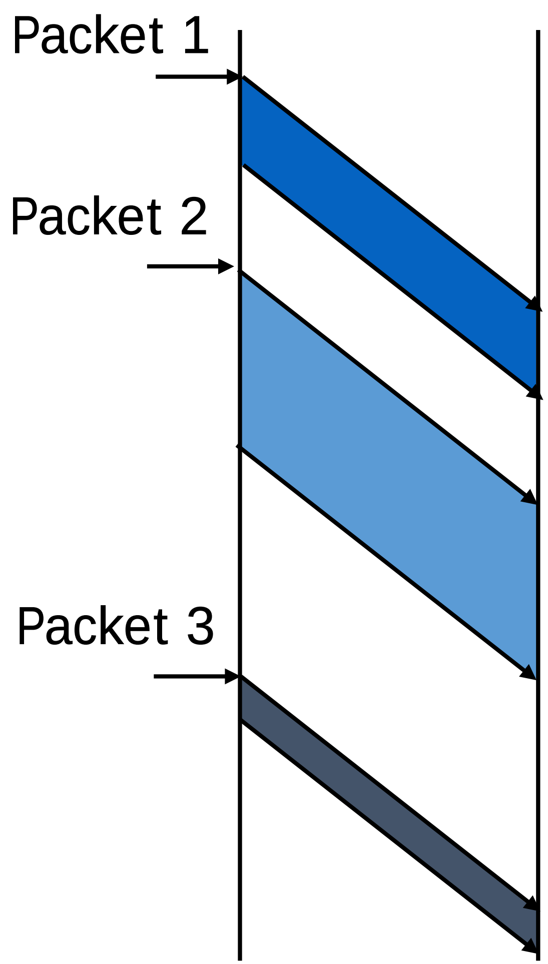


Circuit switching – Evaluation

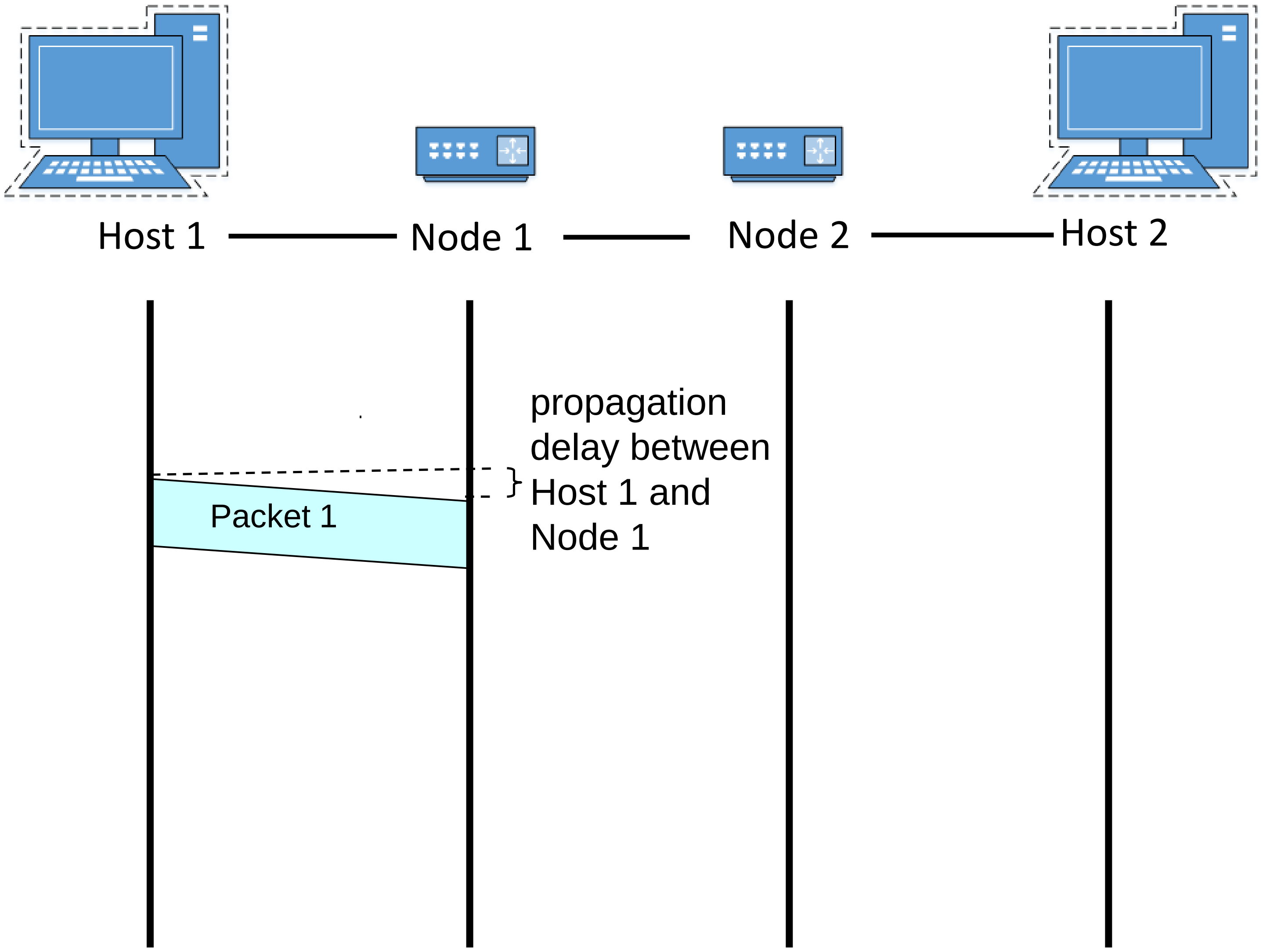
- Advantages
  - Once circuit is established, the resources are guaranteed to participating terminals,
  - Once circuit is established, data has only to follow the circuit (forwarding is very simple)
- Disadvantages
  - The need to establish the circuit upfront delays the begin of data transmission,
  - Resources are dedicated – what if there is a pause in the communication?
  - The route is fixed – what if one of the switches breaks down?

Option 2: (Datagram) Packet Switching

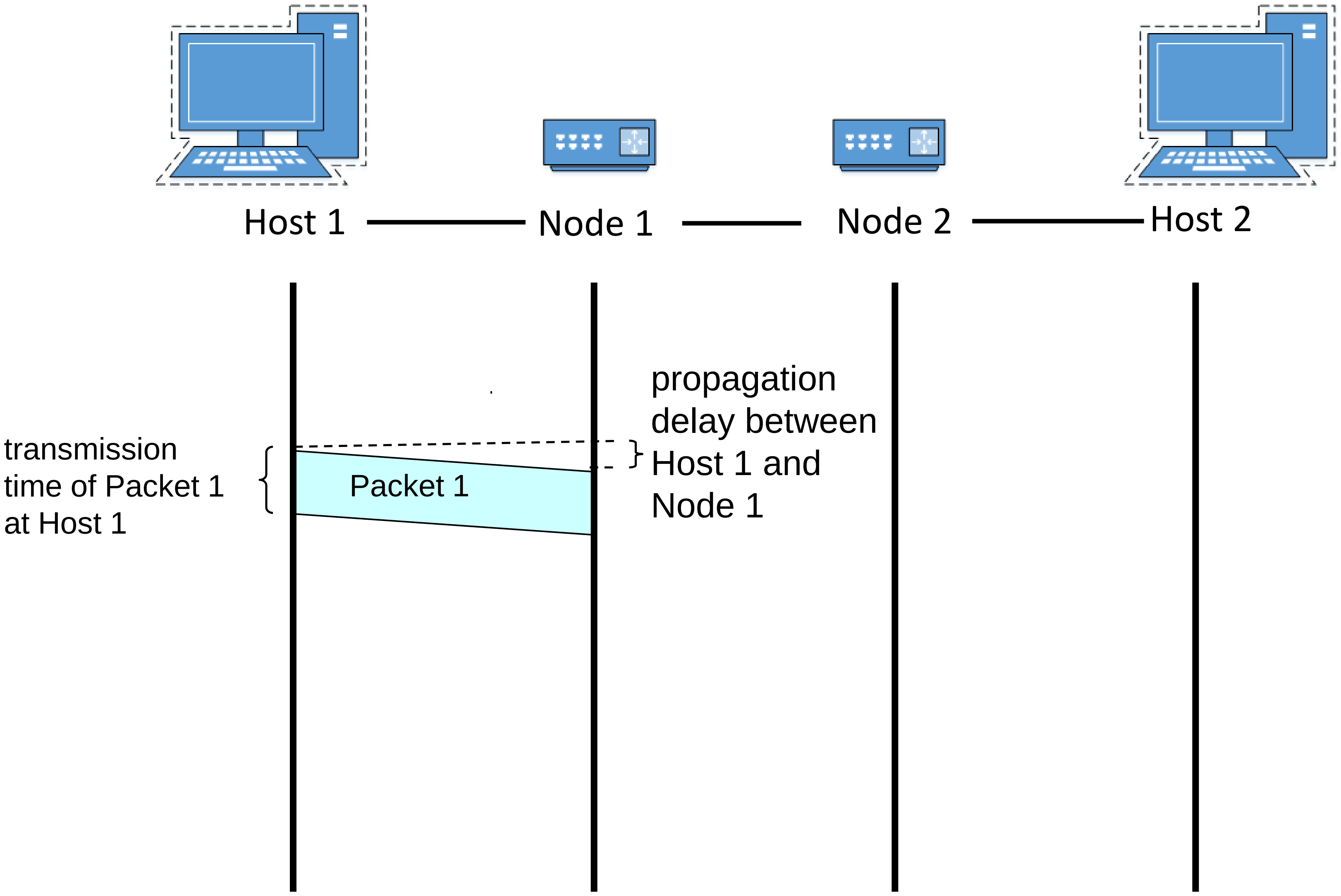
- Chunk data into packets
  - Packets contain some actual data that is to be delivered to the recipient (can have different, but bounded size),
  - Also need administrative information, e.g., who is the recipient,
  - Sender sends out a packet occasionally, instead of a continuous flow of data
- Problems: How to detect start and end of a packet, which information to put into a packet, …
- Higher per packet processing cost in each switch …



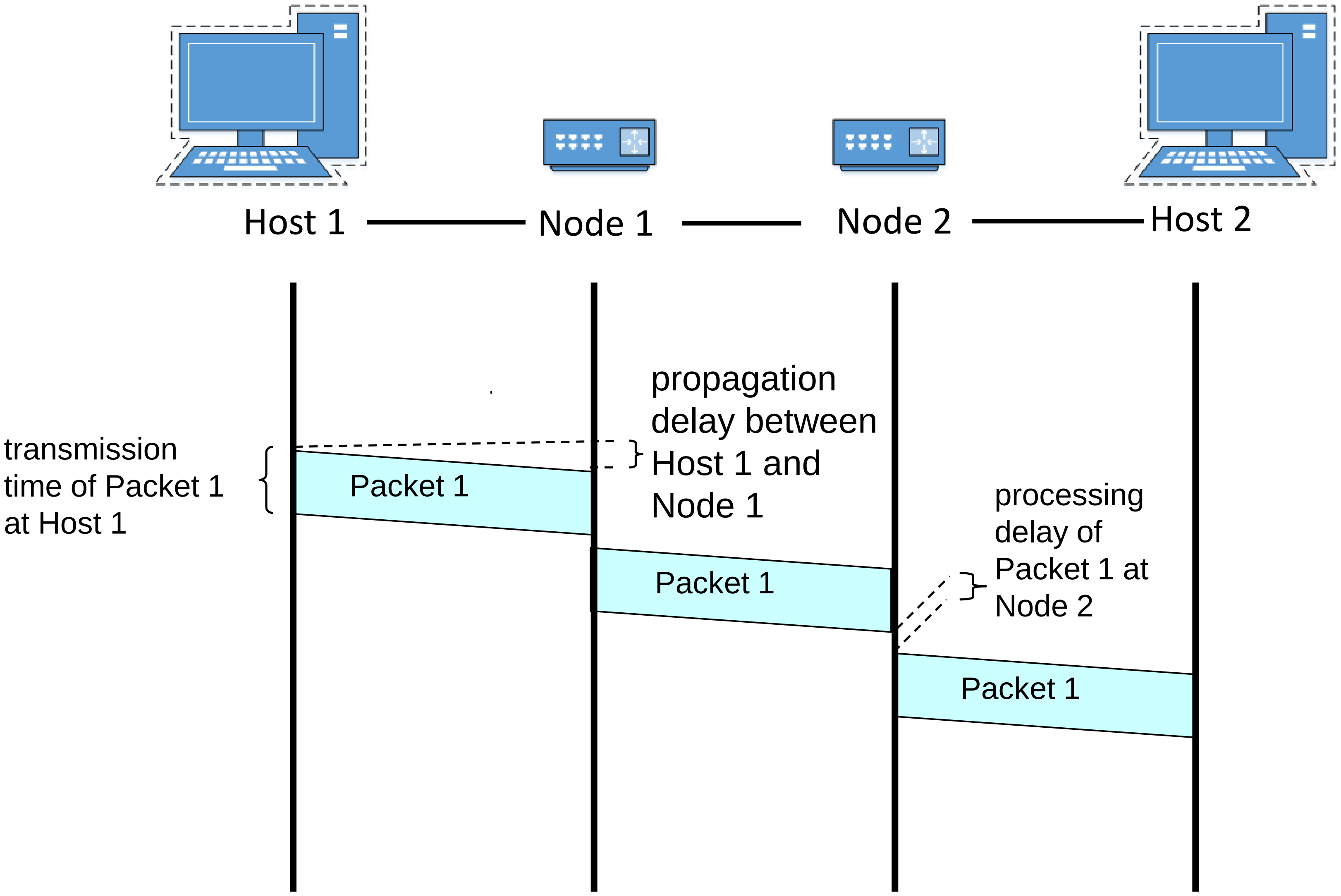
Timing of Datagram Packet Switching (1)



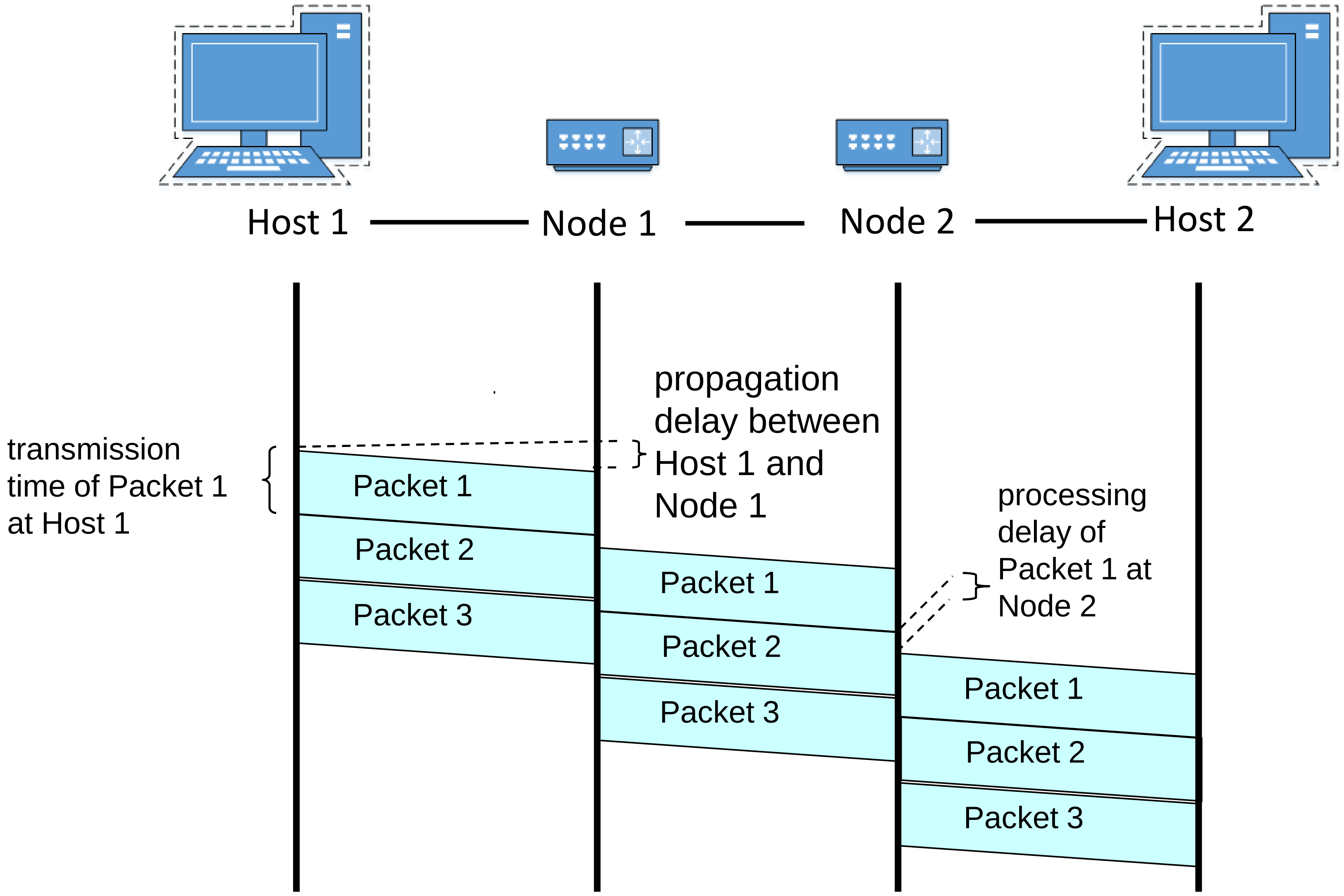
Timing of Datagram Packet Switching (2)



Timing of Datagram Packet Switching (3)



Timing of Datagram Packet Switching (4)



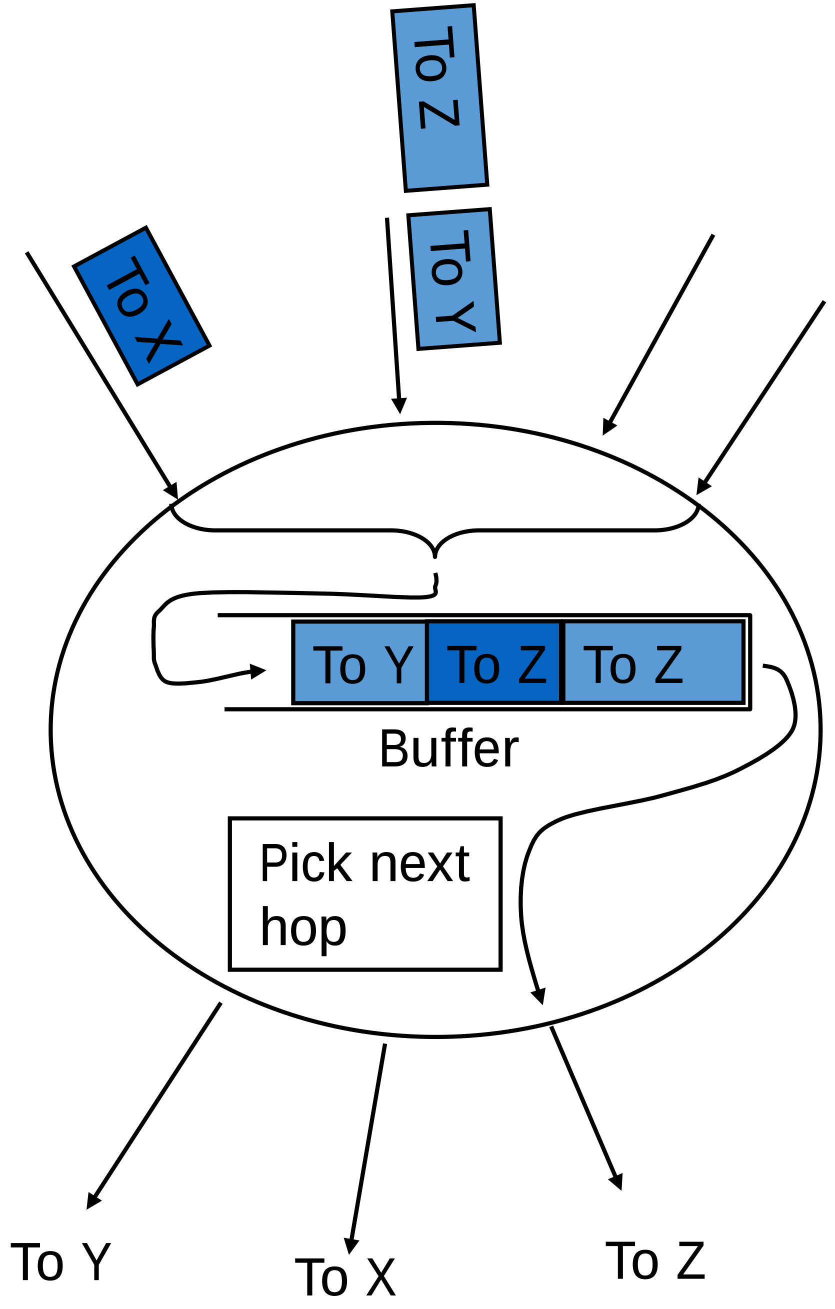
Comparison

[Tanenbaum, op. cit.]

Item	Circuit switched	Packet switched
Call setup	Required	Not needed
Dedicated physical path	Yes	No
Each packet follows the same route	Yes	No
Packets arrive in order	Yes	No
Is a switch crash fatal	Yes	No
Bandwidth available	Fixed	Dynamic
Time of possible congestion	At setup time	On every packet
Potentially wasted bandwidth	Yes	No
Store-and-forward transmission	No	Yes
Transparency	Yes	No
Charging	Per minute	Per packet

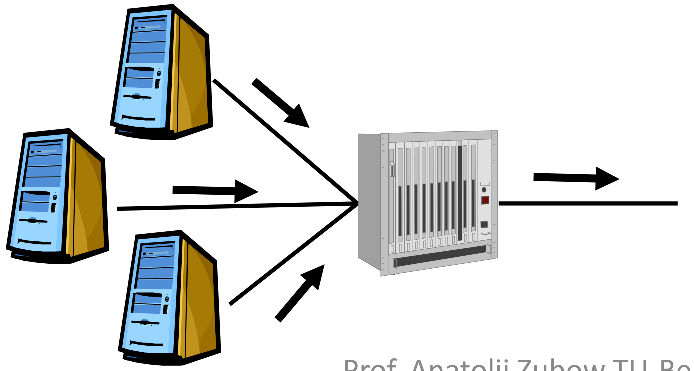
Packet Switches

- Switches take on additional tasks
  - Receive a complete packet
  - Store the packet in a buffer
  - Find out the packet's destination
  - Decide where the packet should be sent next to reach its destination
    - Information about the network graph necessary
  - Forward the packet to this next hop of its journey
- Also called "store-and-forward" network



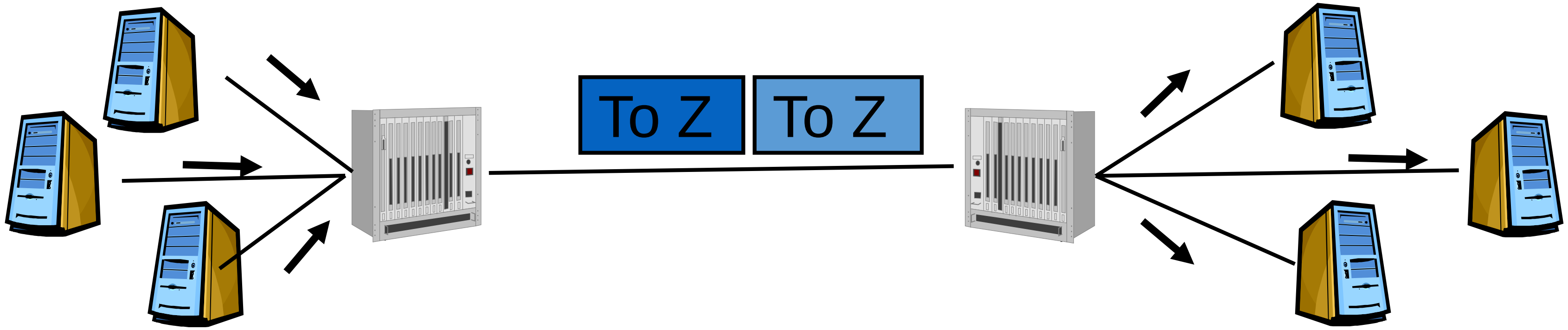
Multiplexing

- Previous example had two packets at the head of the queue destined for terminal Z
- Let us consider a switch with only a single outgoing line
  - Such a special case is called a multiplexer
  - Organizing the forwarding of packets over such a single, shared line is called multiplexing
  - Multiplexers in general need buffer space as well

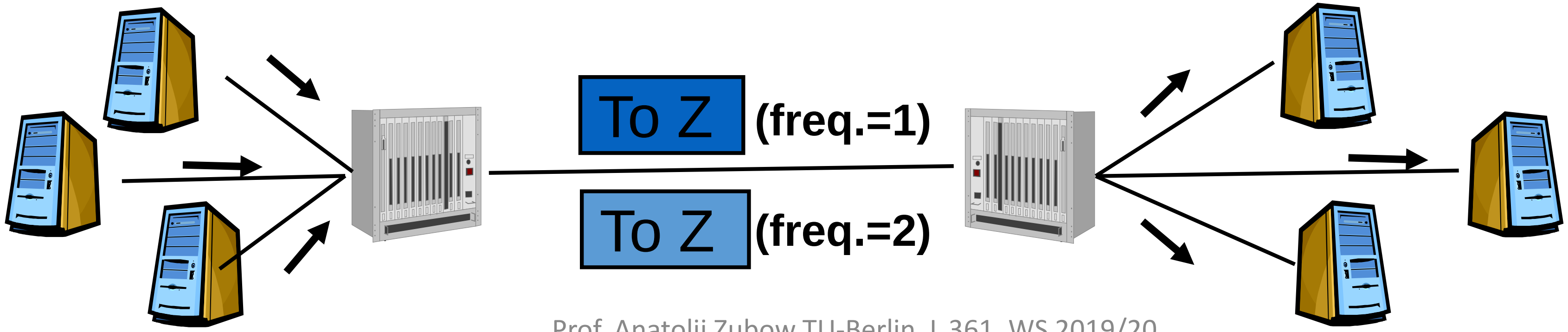


Multiplexing II

- Obvious option: Time Division Multiplexing (TDM)
  - Serve one packet after the other; divide the use of the connection in time

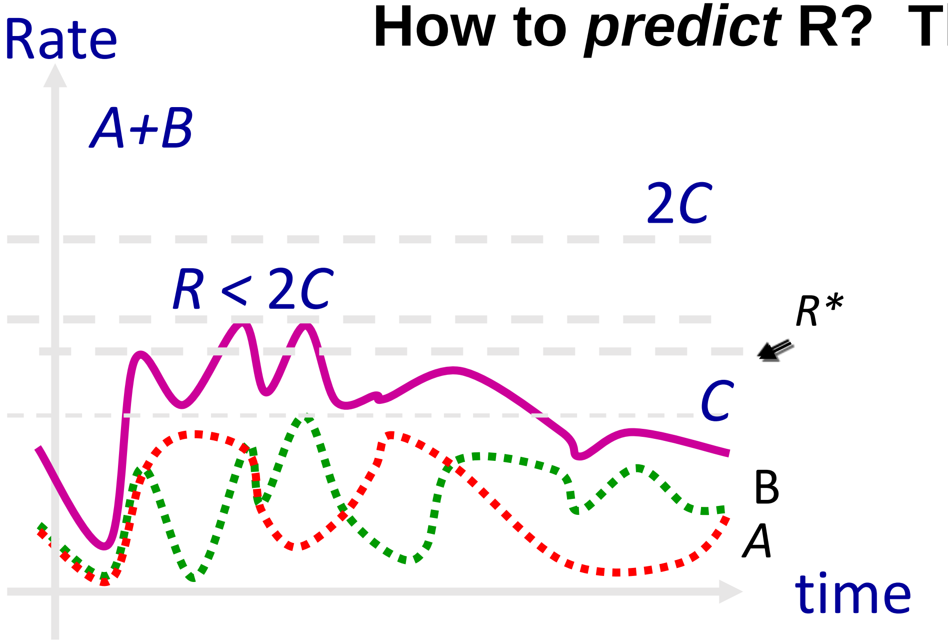


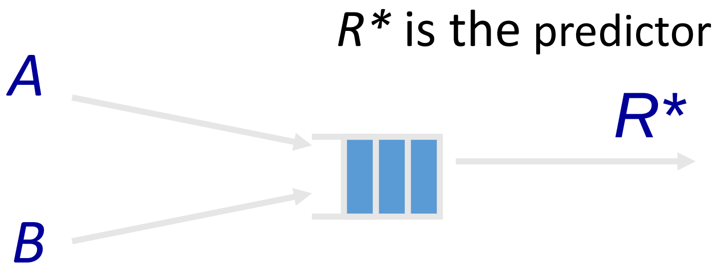
- Alternative: Frequency Division Multiplexing (FDM)
  - Use different frequencies to transmit several packets at the same time



Statistical Multiplexing Gain

Statistical multiplexing uses at most R<2C.
How to *predict* R? There might be losses!





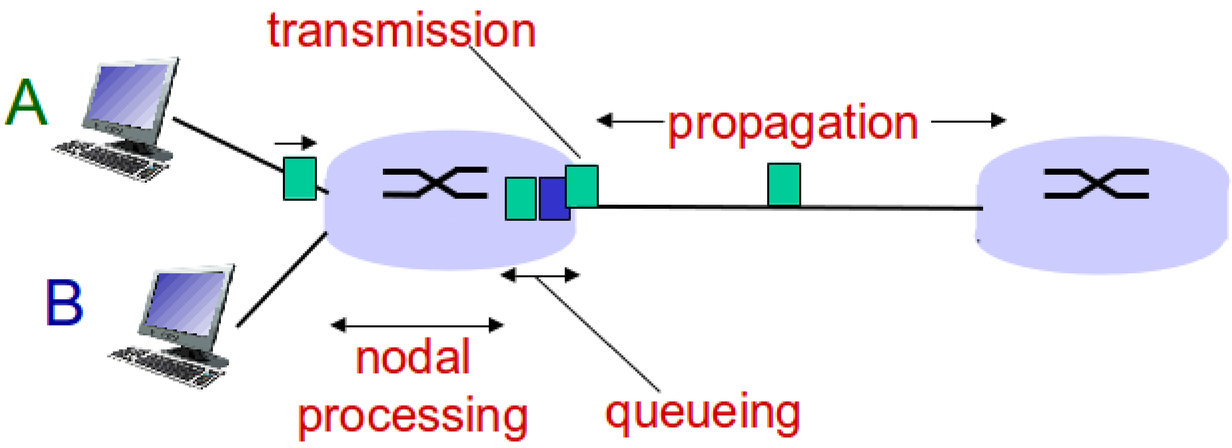
Statistical multiplexing gain (SMG) = $2C/R^*$

SMG: The ratio of rates that give rise to a particular queue occupancy, or particular loss probability.

It is hardly possible to account for maximum demand of numerous sources!

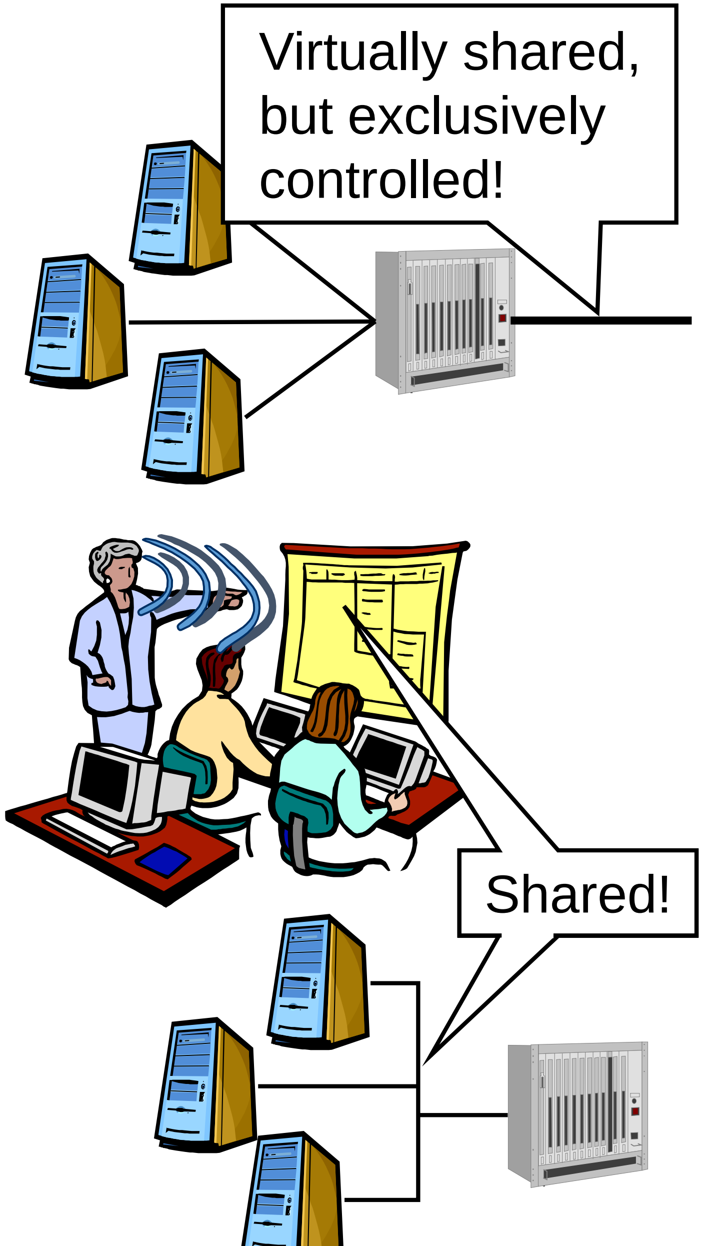
Delay on the way – Summary [Cheng, Lehigh Univ., op. cit.]

- **1. Nodal processing**:
  - Check bit errors
  - Determine output
- **2. Queueing**:
  - Time waiting at output for transmission
  - Depends on congestion at router
- **3. Transmission delay**:
  - R = link bandwidth (bps)
  - L = packet length (bits)
  - Time to send bits into link: L/R
- **4. Propagation delay**:
  - d = length of physical link
  - s = propagation speed in medium
  - Propagation delay = d/s
- Just to remind you the issue of queueing ...



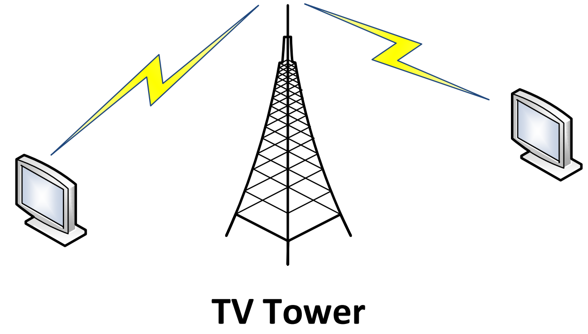
Multiplexing & shared resources

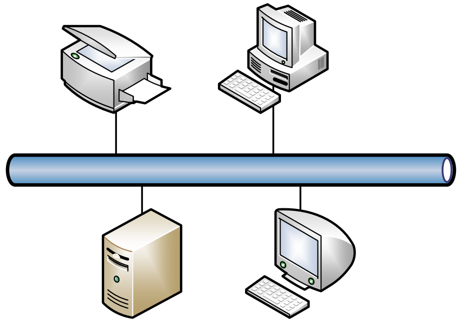
- Multiplexing can be viewed as a means to regulate the access to a resource that is shared by multiple users
  - The switching element/its outgoing line
  - With the switching element as the controller
- Other examples of "shared resources"?
  - Classroom, with "air" as physical medium
- Characteristic: a broadcast medium!
  - Everybody can hear the sender
  - Addressing is necessary (if not sending to all)
    - Unicast (to one)
    - Multicast (to a group)

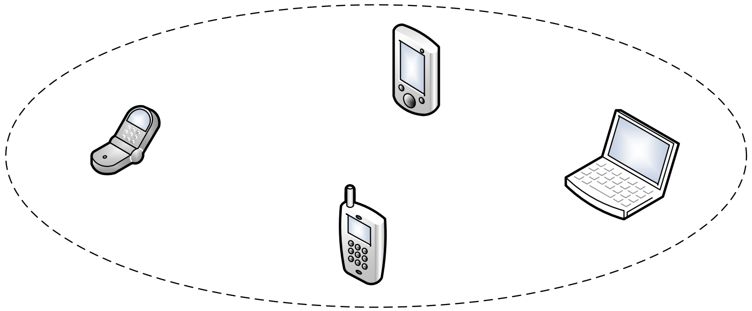


Broadcast Medium & Multiple Access

- Common characteristic of a broadcast medium:
  - Only a single sender at a time,
  - Exclusive access is necessary,
  - Simple to achieve with a multiplexer
- What if no multiplexer is available?
  - E.g. a bus: all nodes connected to a single wireline
  - Or a group wireless devices? Compare: group of kids …
- Exclusive access has to be ensured
  - Rules have to be agreed upon

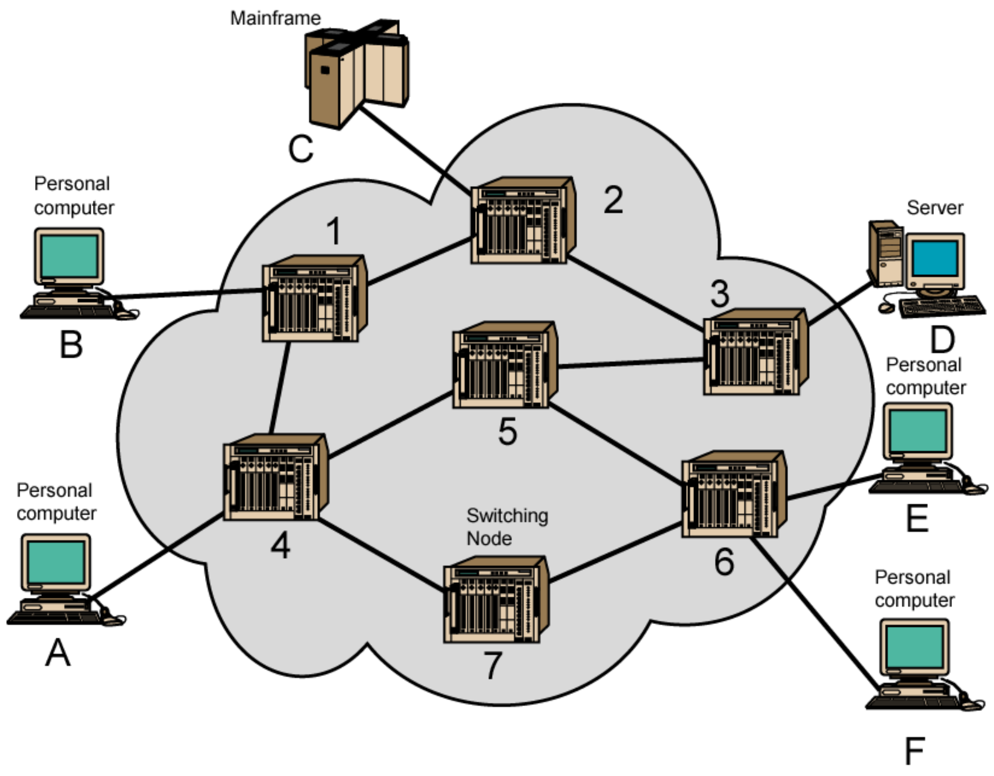






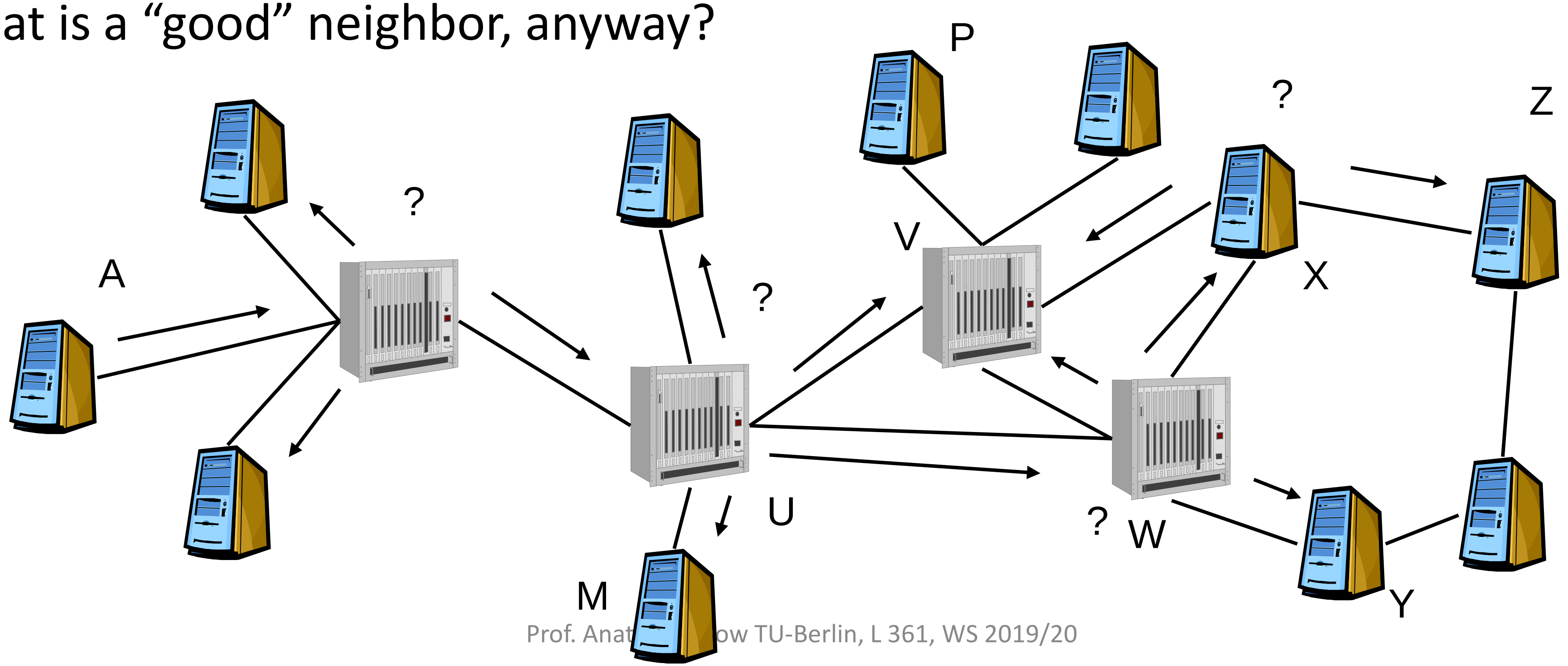
Reminder - Switched Network

- A set of path sections (e.g. electrical cables) and switches,
- “end systems” (terminals/user devices) vs. “switching elements” (routers/bridges)



Forwarding and Next Hop Selection

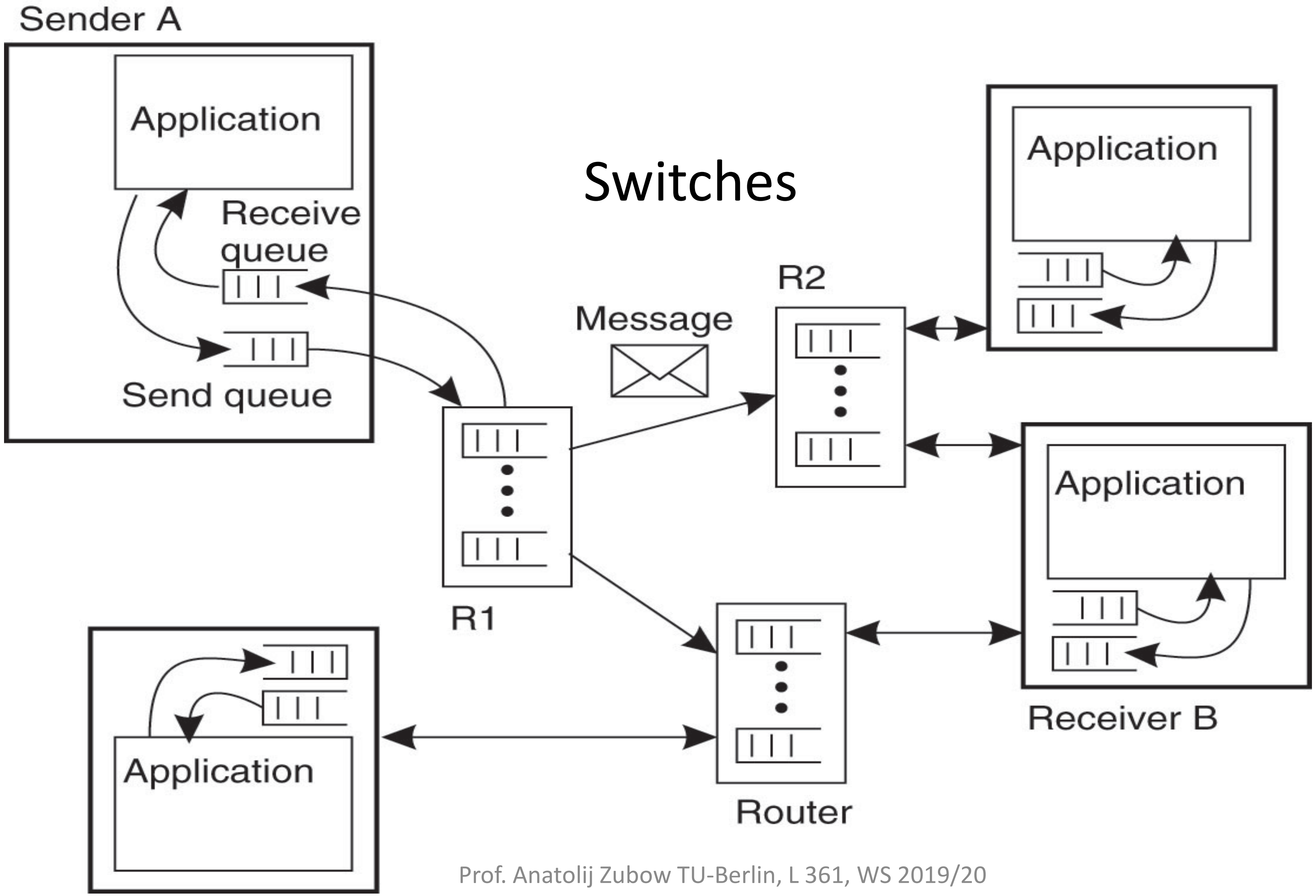
- Switch forwards a packet onto the next "piece"
- Recall: A switching element → a hop towards its destination
- How does a switch know which of its neighbors is the best one towards a destination?
- What is a "good" neighbor, anyway?



Addressing, Routing, Forwarding

- **Name**: whom would you like to reach? (**object identity**)
- **Address**: where is the object? (locator)
- **Routing**: each switch has to know which of his outputs should be used for a given destination address
  - Hopefully contributes to short “overall trip distance, time”
  - Some understanding of the possible routes is necessary to decide
- **Forwarding**: a packet has arrived. How to “get rid of it” in the way consistent with the routing?
  - With possibly short delay and - hopefully - little delay variation,
  - Structuring of the information describing packet destination and the way routing information is stored matters for execution time

General Architecture of a Message System [Tanenbaum, op. cit.]



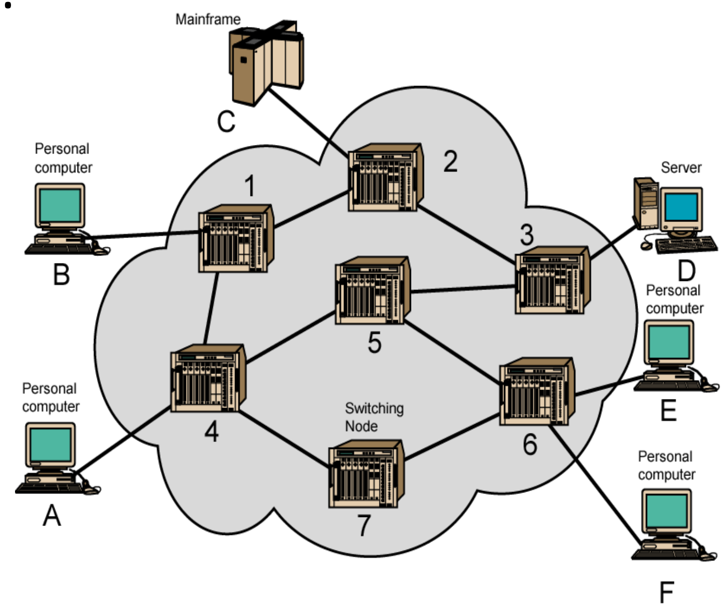
What is the value of a Network?

- Communications networks increase in value as they add members
  - but by how much?
  - How useful is a single phone using a unique new technology?
    Two phones? 20 phones? 1 billion of phones …
  - Btw. as by 2017 they are around 5 billion mobile communication users out of worlds population of over 7.8 billions of people
- The Metcalfe´s Law „The value of a communication network is proportional to the square of the user number”
- Other: **n log(n)** law [1]

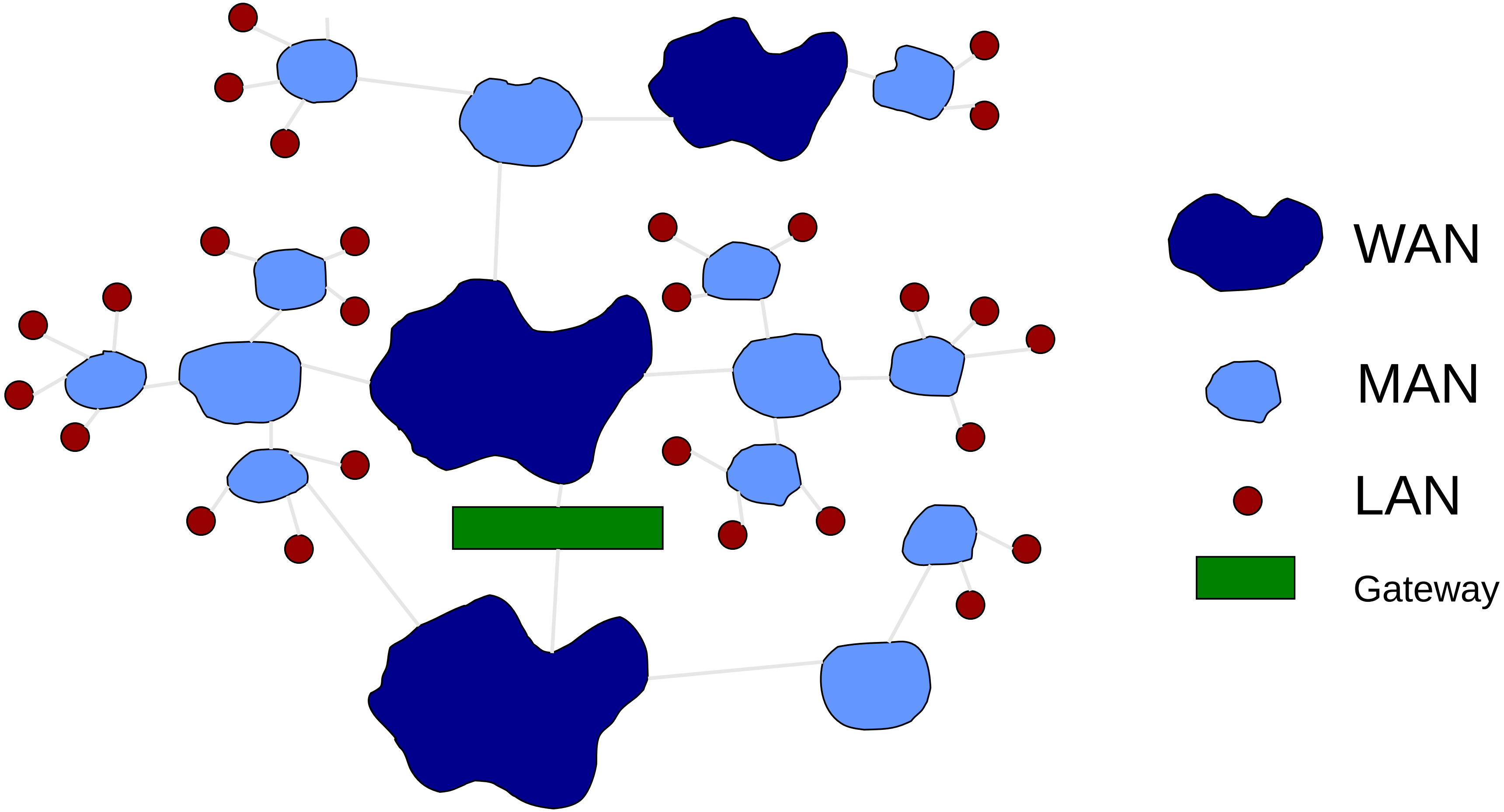
[1] Briscoe, B., Odlyzko, A., & Tilly, B. (2006). Metcalfe's law is wrong-communications networks increase in value as they add members-but by how much?. IEEE Spectrum, 43(7), 34-39.

Large Networks need Structure! Why?

- Scaling
  - Remember: each switch knows route to each destination …
  - Hierarchy usually simplifies a lot …
- Locality
  - Close hosts are clustered,
  - Local networks
- Heterogeneity
  - Different applications (e.g. control, sensing) have different requirements,
  - Multiple technologies for access (e.g. wired, wireless)
- Administration
  - Who sets the rules for usage?



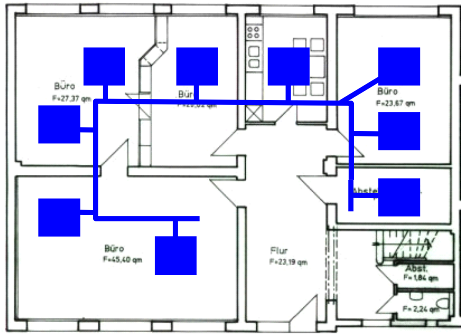
Internet: Interoperability vs. Heterogeneity

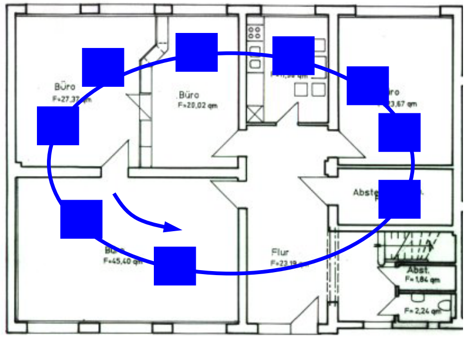


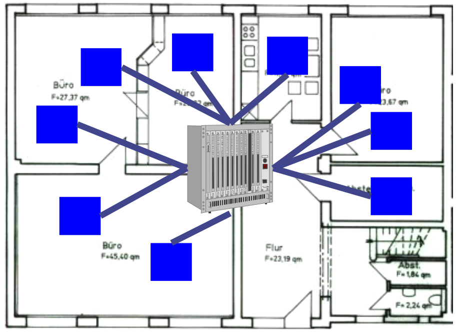
WAN = Wide Area Network, MAN = Metropolitan Area Network, LAN = Local Area Network

Typical Network Structures for Local Installations

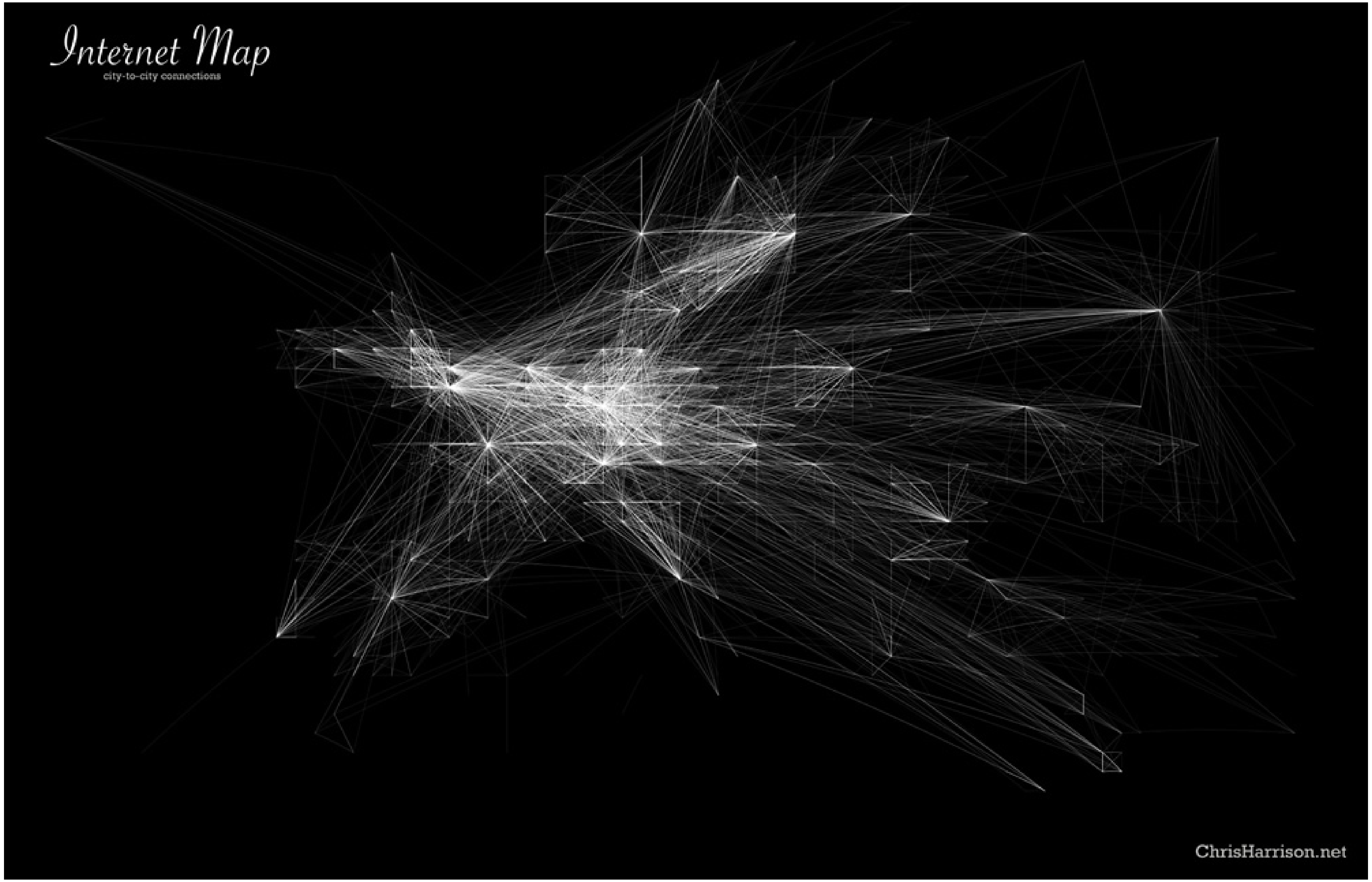
- "Busses"
  - All nodes connected to a single wireline,
  - Cheap, but relatively inefficient, error-prone.
- "Rings"
  - Nodes connected to a ring-shape network,
  - Can compensate for a single break of pairwise connection.
- "Star"
  - All nodes directly connected to a central cabling "hub",
  - Again error-prone, but easy to administer, manage.





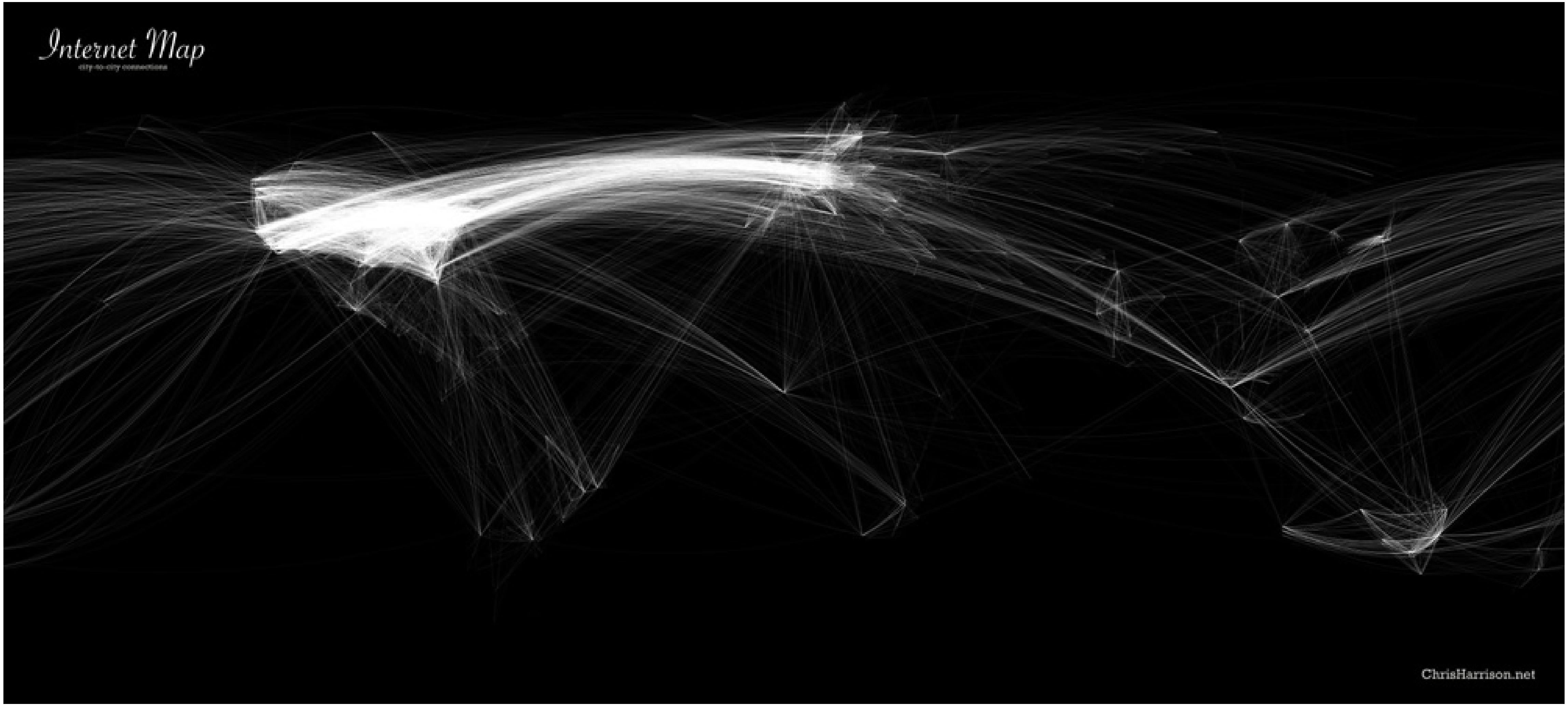


European City-to-City Connections in 2007



Source: https://bit.ly/1CGsNMn

World City-to-City Connections in 2007



Source: https://bit.ly/1CGsNMn