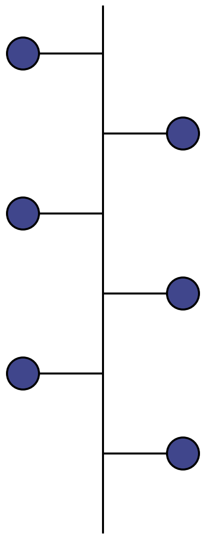
Introduction to Communication Networks and Distributed Systems



Unit I: Basics…

Prof. Dr.-Ing. Adam Wolisz

TKN Telecommunication Networks Group

Acknowledgements

- This set of slide has been created specifically for this class, in 2008 and used with continuous modifications by myself and Prof Kao (2011 und 2012)
- Numerous slides from Introductory courses by Prof. Holger Karl (Paderborn) have been used (with permission of the author).

What do we use communication for ?

- Exchanging Information !!! /Getting information…
  - Runners (marathon!), Flags, Mirrors…. etc..
  - E-mail, WWW…
- Maintaining inter-human relations
  - Letters (of affection!)
  - Phone …
  - SMS, CHAT, SOCIAL NETWORKS ….
- Entertainment
  - Passive

    Live Theater/Circus/Movies/Radio/TV/Videos (on demand?)
  - Active

    Games!!! – network games – virtual worlds

The Two Generals 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. Can they?
- 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 (and could be intercepted with a given probability p). A successful 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 !

Is a “better way” possible?

Just one possibility…

- Sender:
  Send the information. If no acknowledgment has been received within time “b“ ➔ send again.
- Receiver:
  Wait for an information. Acknowledge the received information

This is called a “send and wait” protocol !

Transmission protocols = Set of Rules for Communication

Is it better? Let us do some maths…

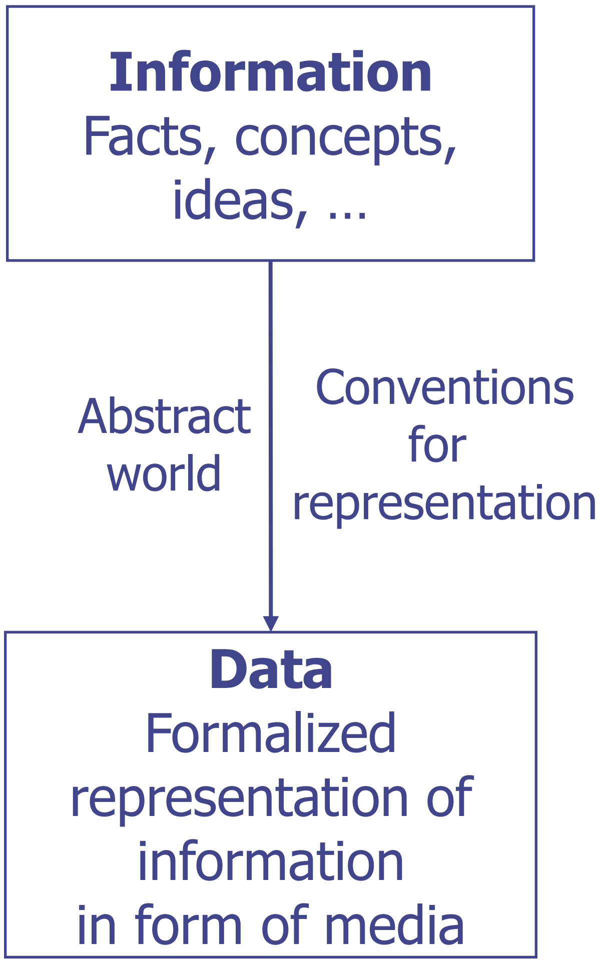
- Successful transmission is acknowledged after a constant time b.
- Assume that with probability Π there is NO acknowledgement.
- $\Pi = 1 - (1-p)^{\mathbf{2}}$ *while* $(1-p)$ **=** *probability of success both ways!*
- The time needed for a successful transmission is
  - b with probability $(1-\Pi)$
  - $2b$ with probability $(1-\Pi)\,\Pi$
  - $3b$ with probability $(1-\Pi)\,\Pi^2$
  - $(k+1)b$ with probability $(1-\Pi)\,\Pi^k$
- Assume that there is only time for N „rounds“
  The probability of successful attack is $1-\Pi^N$

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
  - A human interpretation of data, conferring meaning to data

Note

- Only ***data*** can be communicated,
- The recipient of data restores information
- This restoration is subject to personal interpretation! (Not covered here!!!)



The Data Tsunami

- In 2000 years of recorded history humans created 2 Exa-bytes of data.

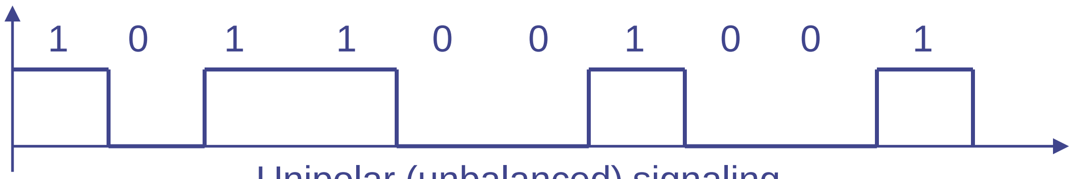
- We generate over 2.5 Exa-bytes of data/ day now !
  - Different sources

- The Problem: Extracting INFORMATION out of DATA!
  - Where to process them ?
  - Bringing Data to the Processing?
  - Processing Data where there emerge and transport (partial) results?

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

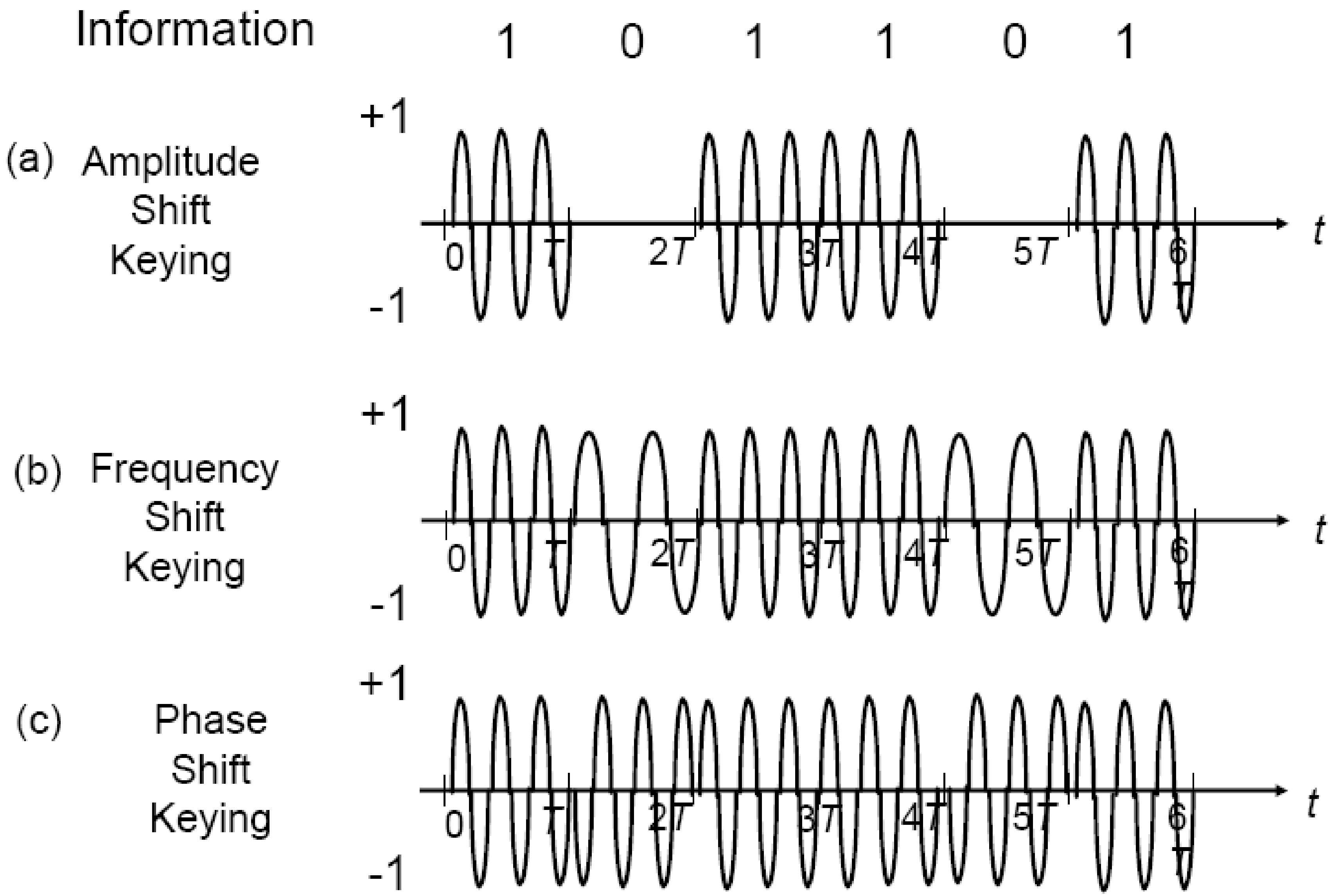
- A simplest convention for a copper wire:
  - A “1” is represented by current
  - A “0” is represented by no current



Unipolar (unbalanced) signaling

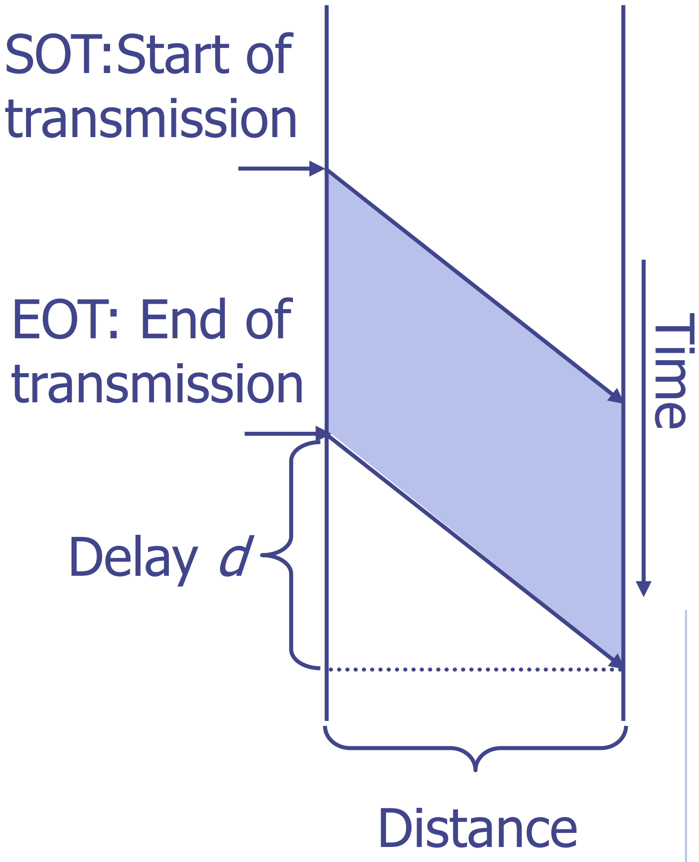
Questions: How to detect bits, decide on their length, handle errors?

Another transformation of bits to signals…



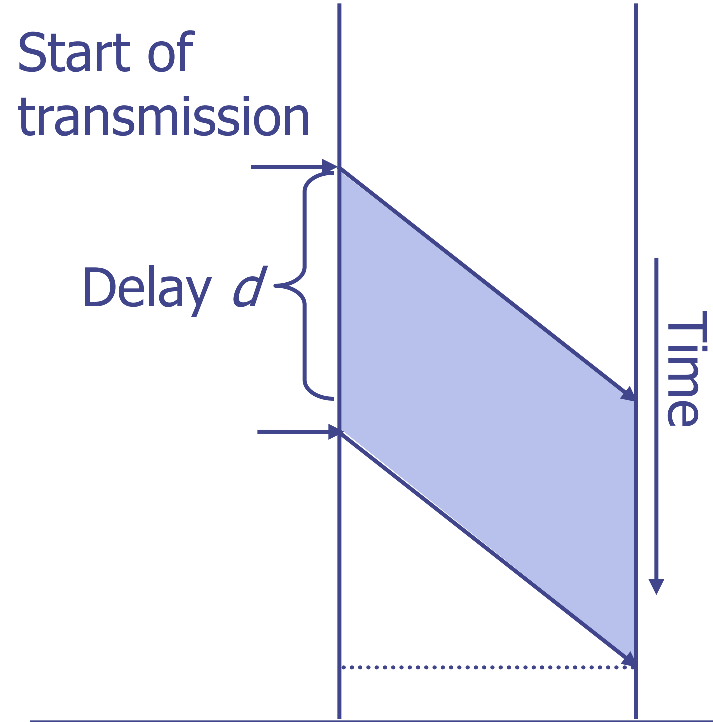
Realistic Transmission… [H.Karl, Paderborn]

- *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 / data rate**
- ***Error rate***: What is the rate of incorrect bits arriving at the receiver?
  - Messages containing incorrect bits might be DELETED…



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*r* bits
  - They are "stored in the wire" (or in the Air!)
- *d*r* is the product of delay and data rate
  - Commonly called ***bandwidth-delay product***
  - Crucial property



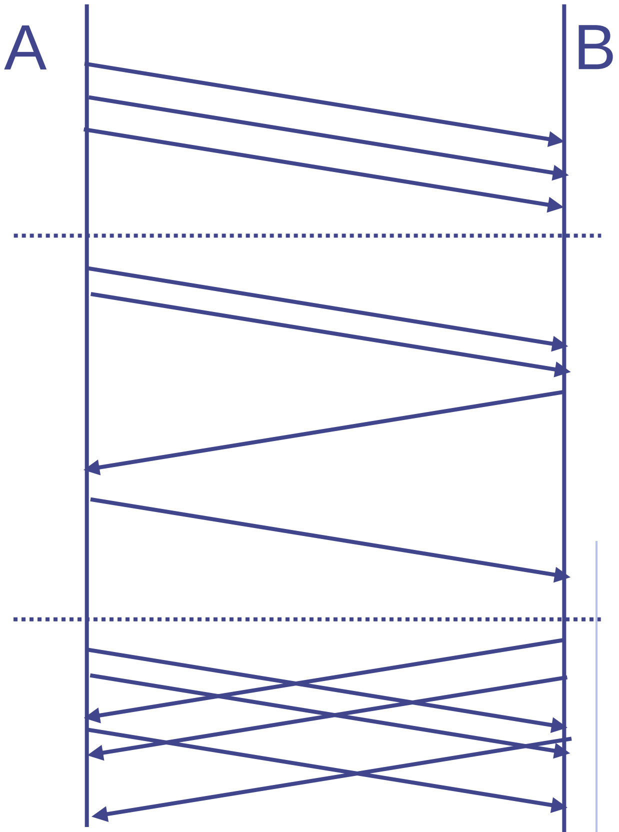
Example (transcontinental):

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

Communication patterns

- Two-way communication
  - Telephony: Both parties want to say something
  - WWW: Server needs to know which webpage shall be delivered

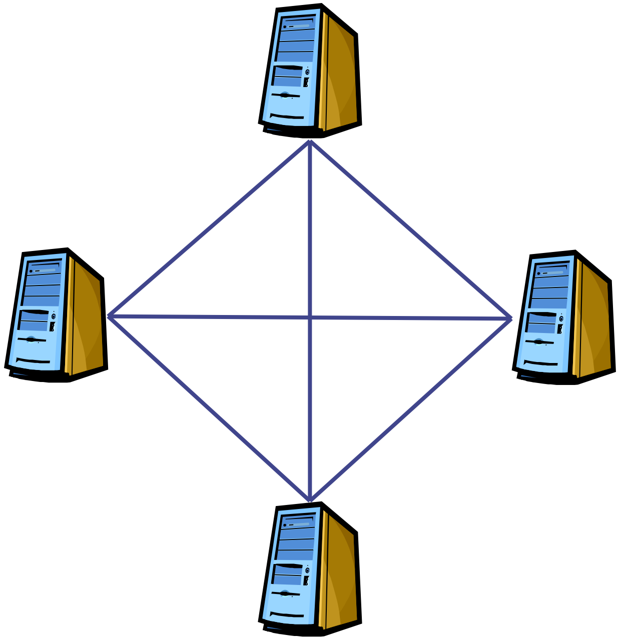
- Different cases possible
  - Simplex: Only one party transmits
    - Example: Radio broadcast
  - Half duplex: Parties alternatively send data
    - Example: Conversation
  - Full duplex: Both parties send all the time



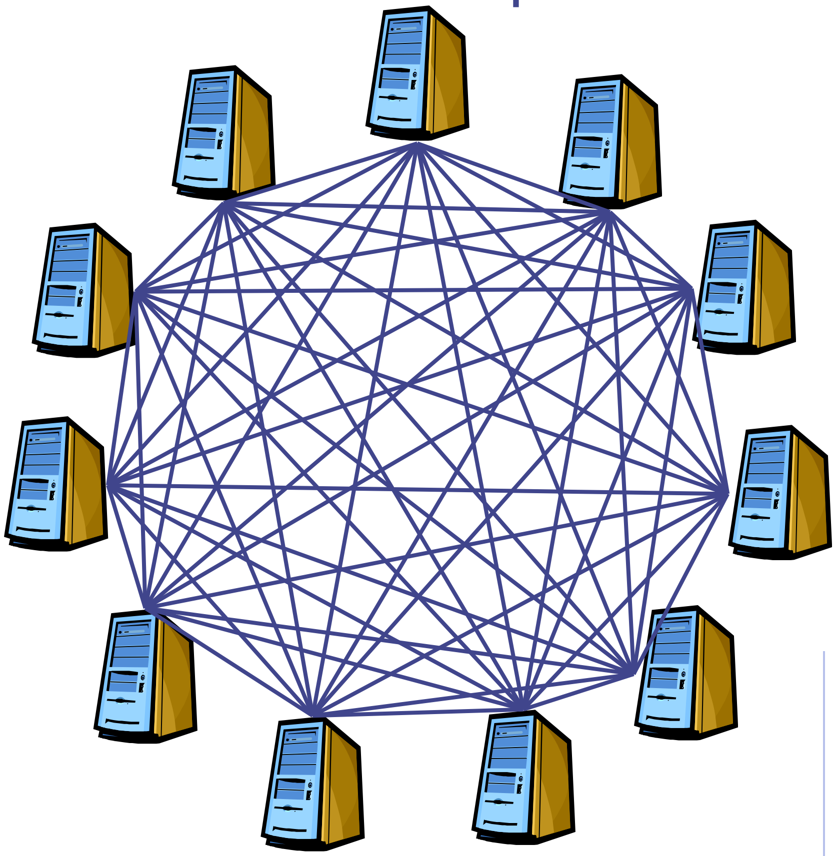
But – you have many friends/business partners

- Connect each telephone/computer with each other one?

With four computers:



With eleven computers:



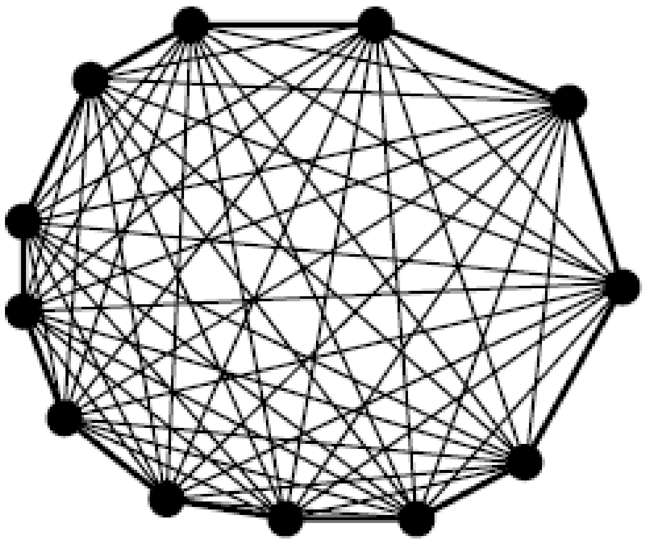
...

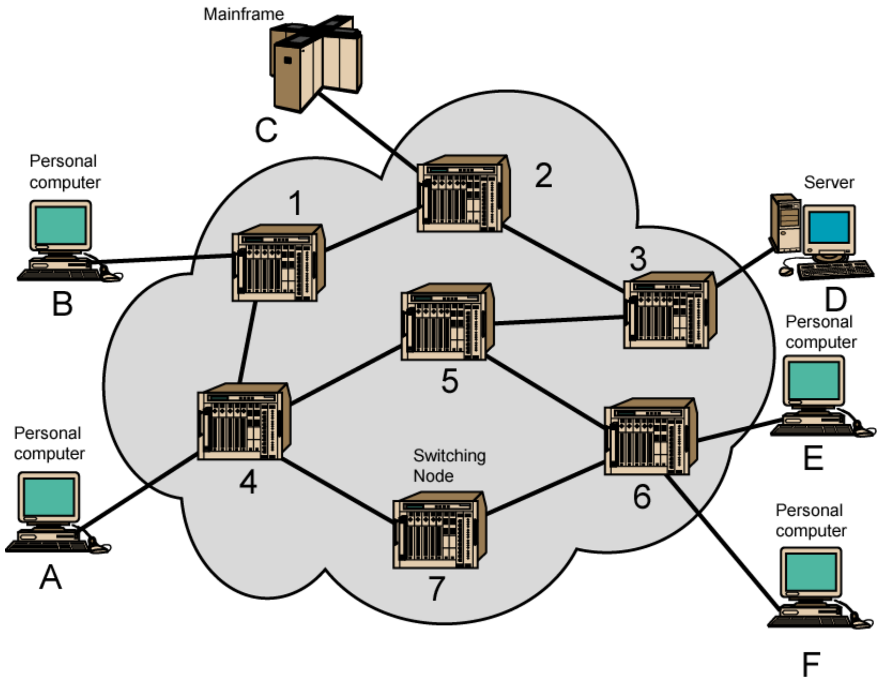
Not so nice..

- Connecting many phones in real life

Right?

Switching





- It is NOT efficient to build a physically separate path for each pair of communicating end systems (*left picture*).
- There is a set of path sections (e.g. electrical cables) and switches (*right picture*).

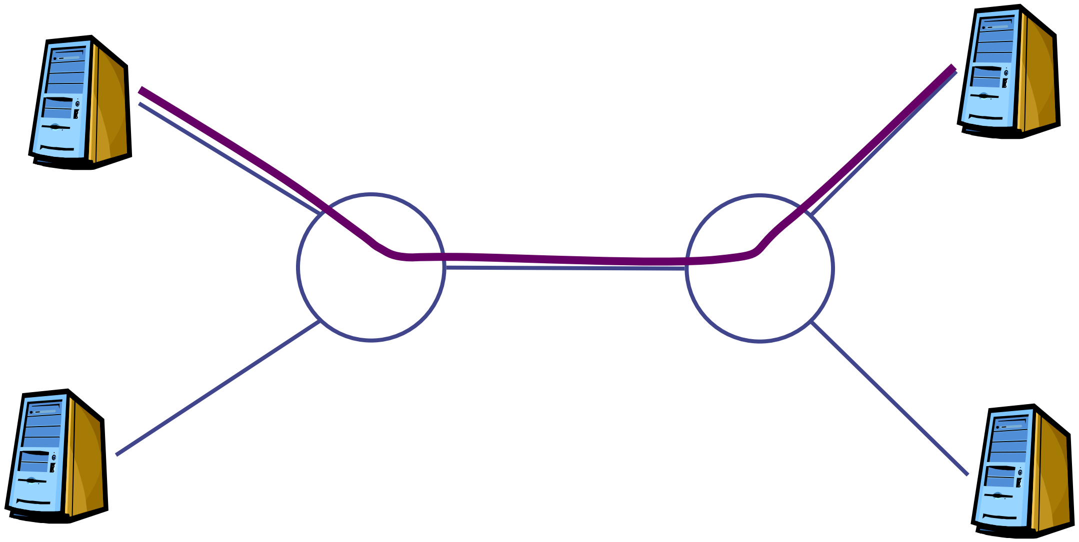
"End systems" a.k.a terminals/user devices
vs.
"switching elements" a.k.a routers/bridges

Different requirements…

- What happens when picking up a telephone and making a phone call?
  - How to find the peer’s phone? What happens when looking-up a web page?
  - How to find the “server” with a given data?
- The crucial differences in transmission:
  - Phone: Continuous flow of data with relatively fixed rate, each data portion must arrive in time, limited amount of errors acceptable
  - Web: Bunch 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.

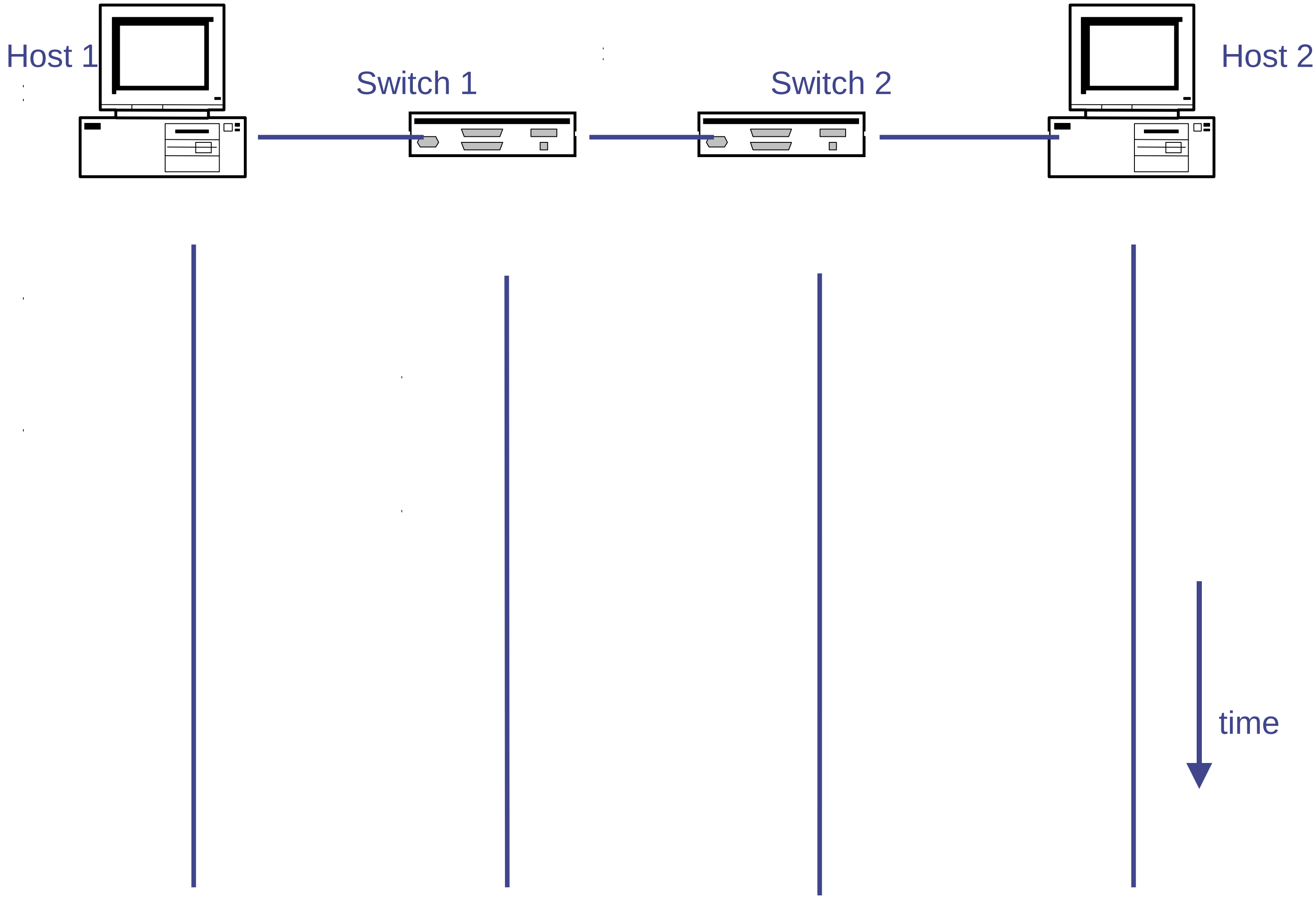
Option 1: Circuit switching

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

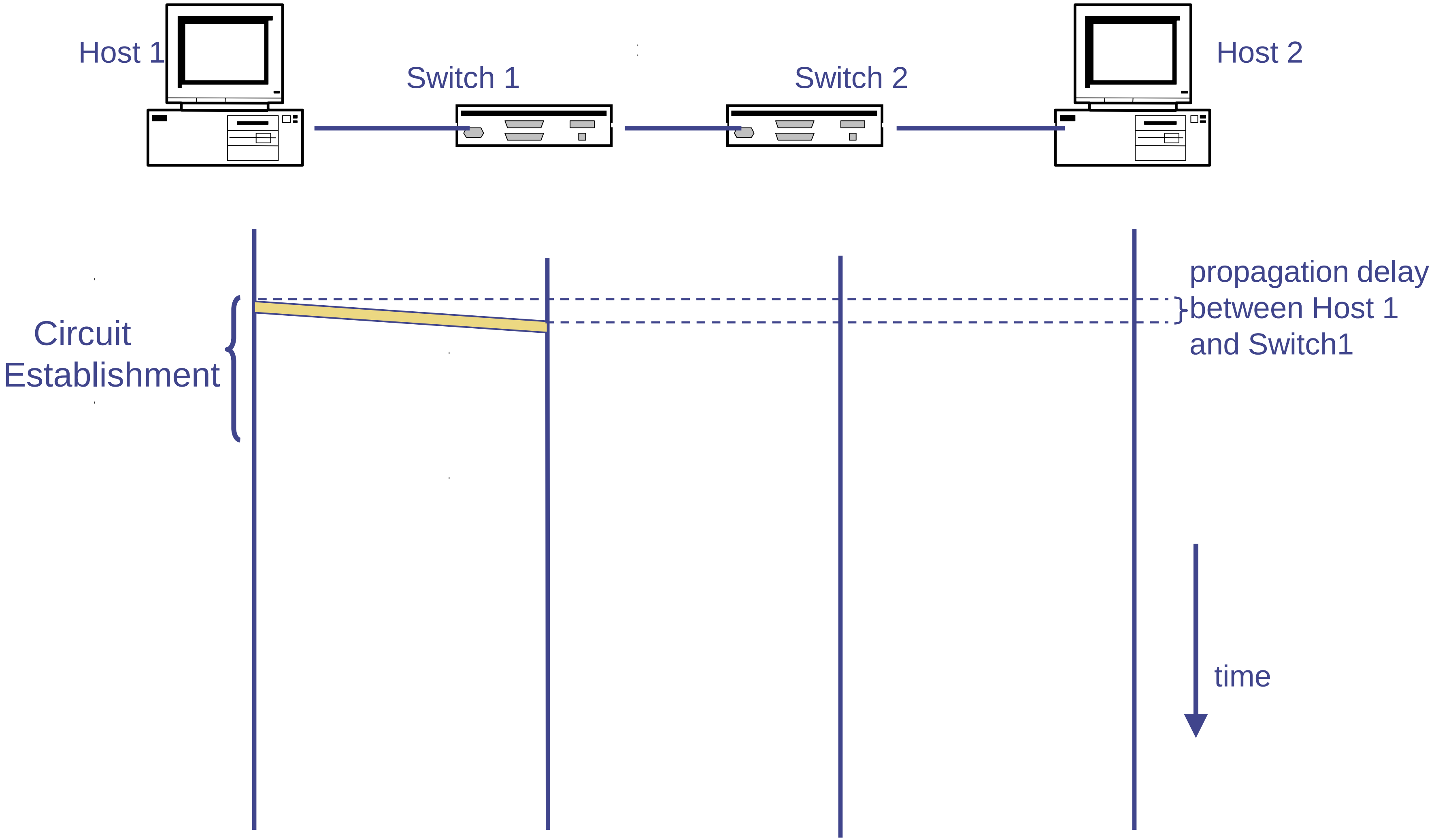


http://www.wdrcobg.com/switchboard.html

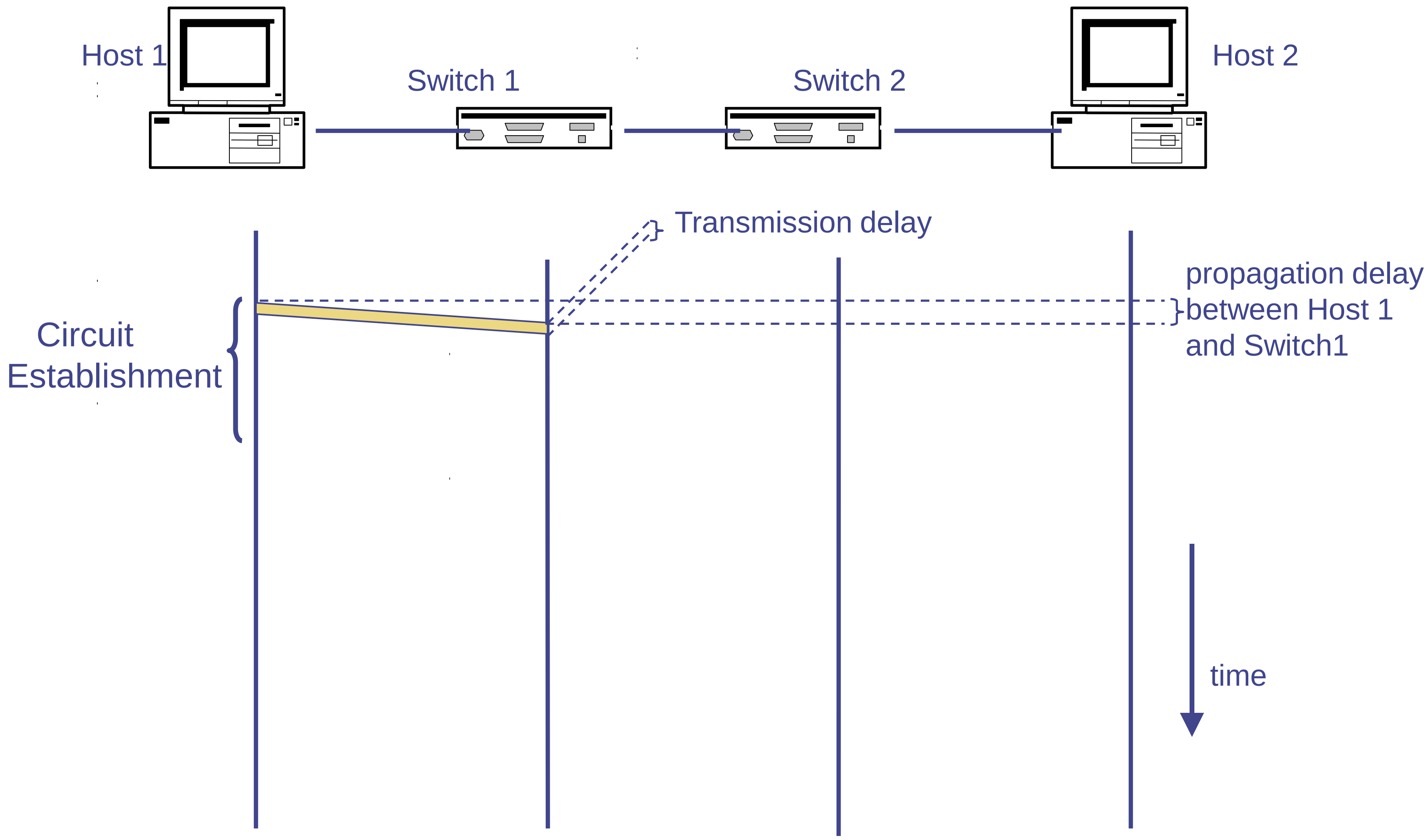
Timing in Circuit Switching (1)



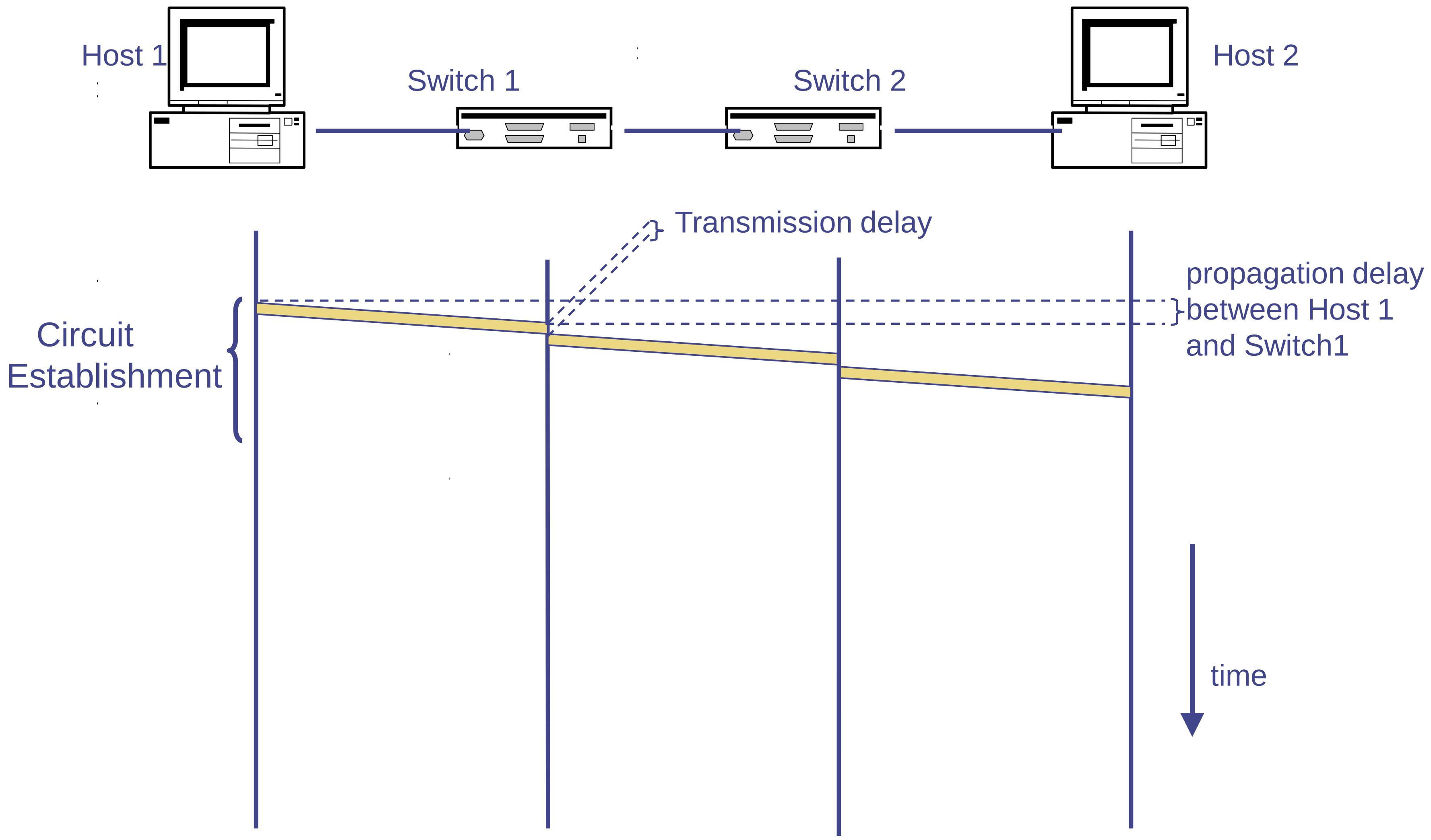
Timing in Circuit Switching (2)



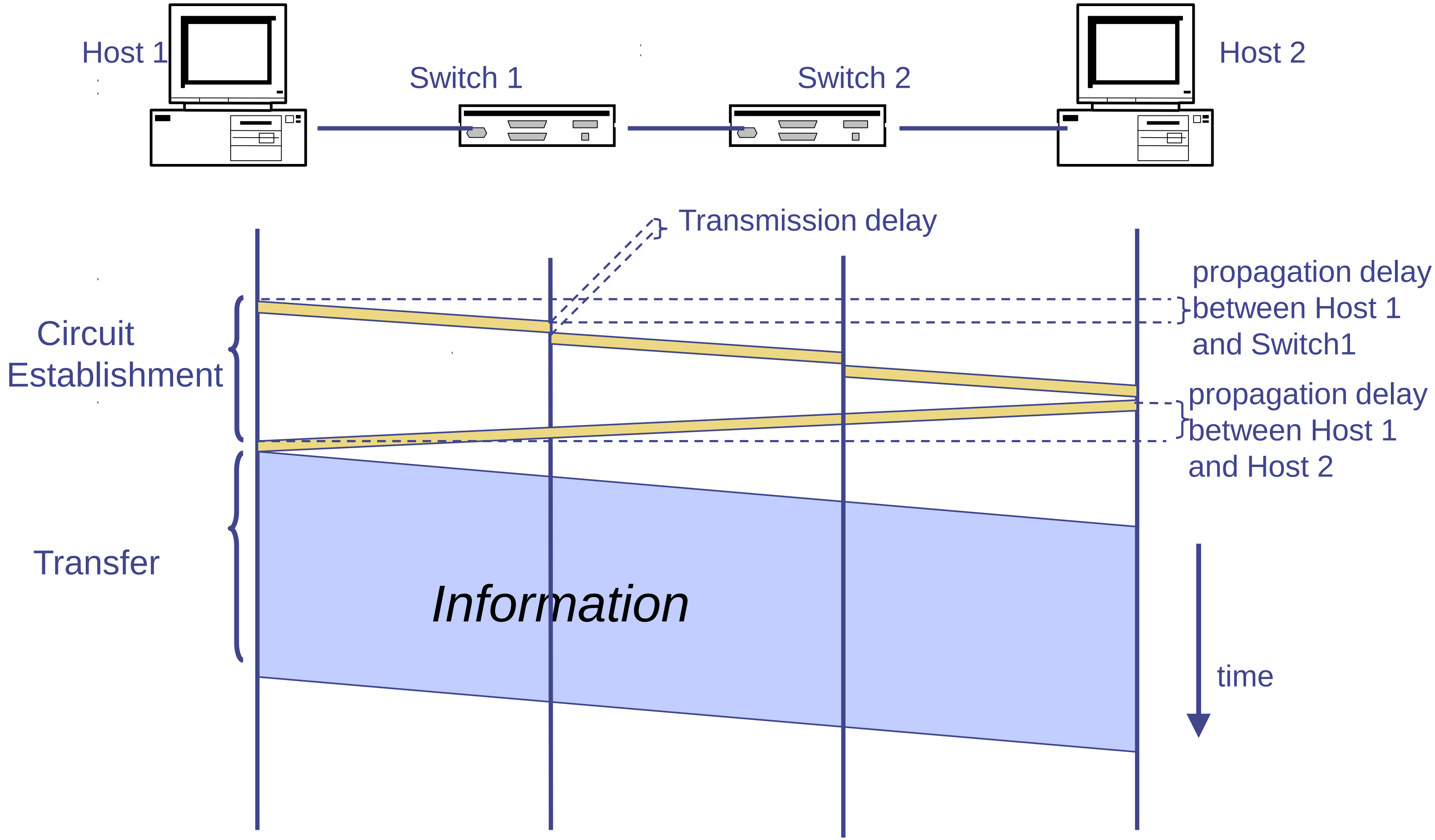
Timing in Circuit Switching (3)



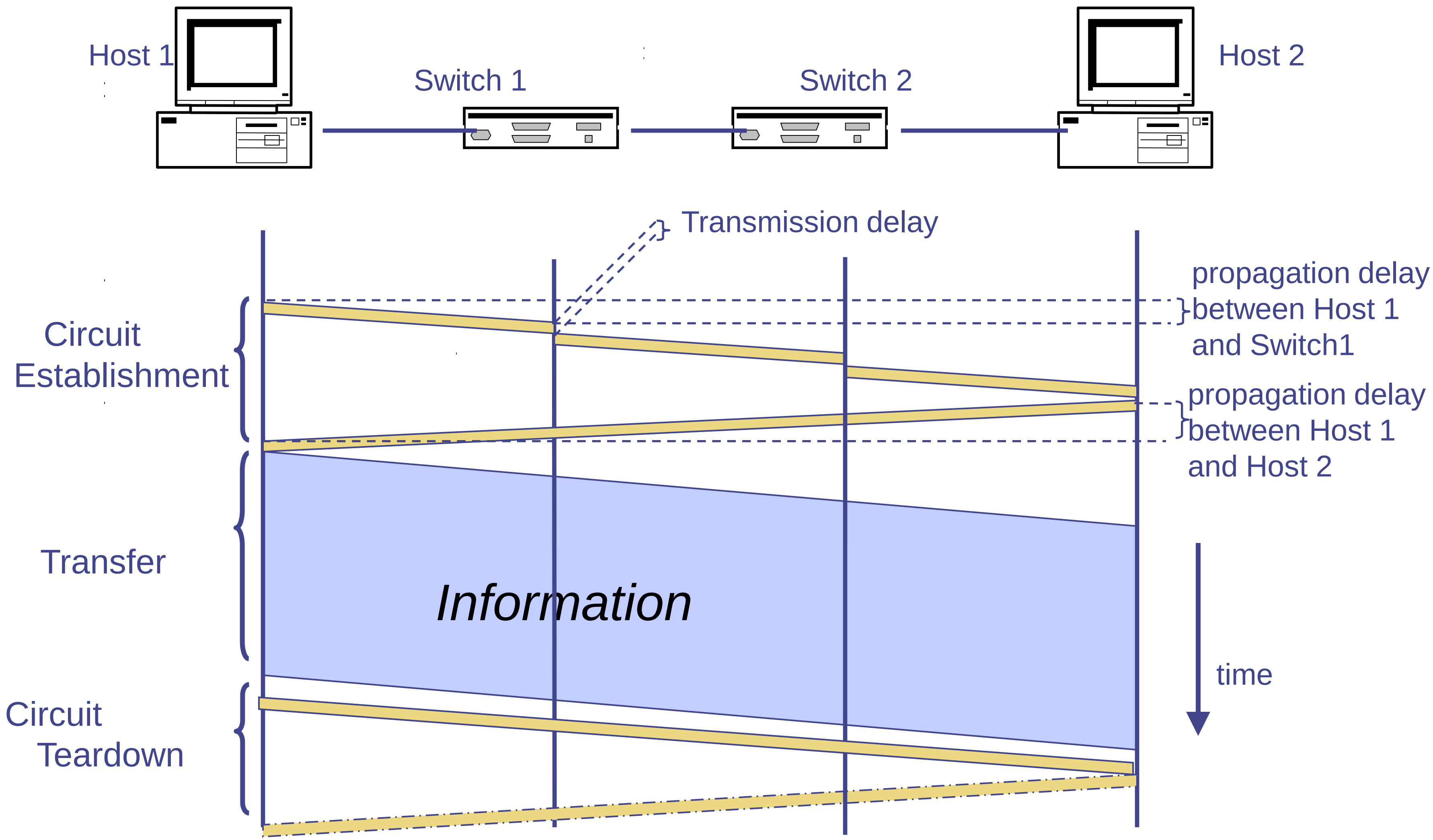
Timing in Circuit Switching (4)



Timing in Circuit Switching (5)



Timing in Circuit Switching (6)

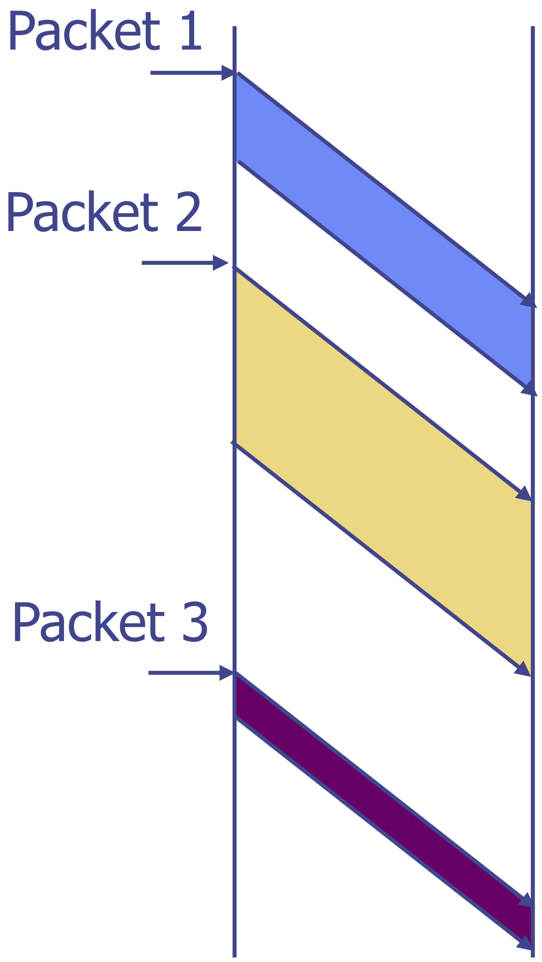


Circuit switching – evaluation

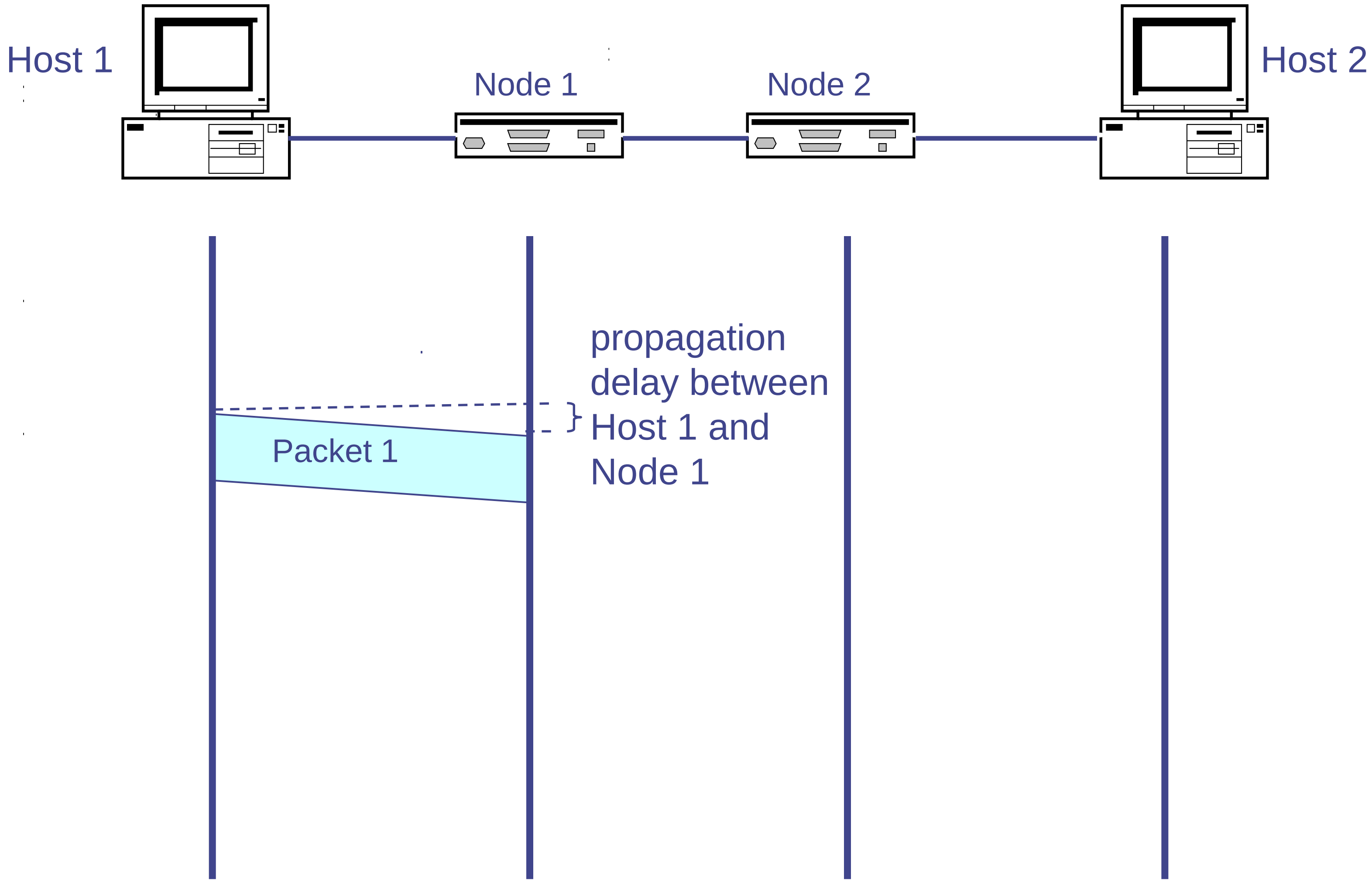
- Advantages of circuit switching
  - Once circuit is established, the resources are guaranteed to participating terminals
  - Once circuit is established, data only has to follow the circuit (forwarding is very simple !)
- Disadvantages
  - The need to establish the circuit upfront delays the begin 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

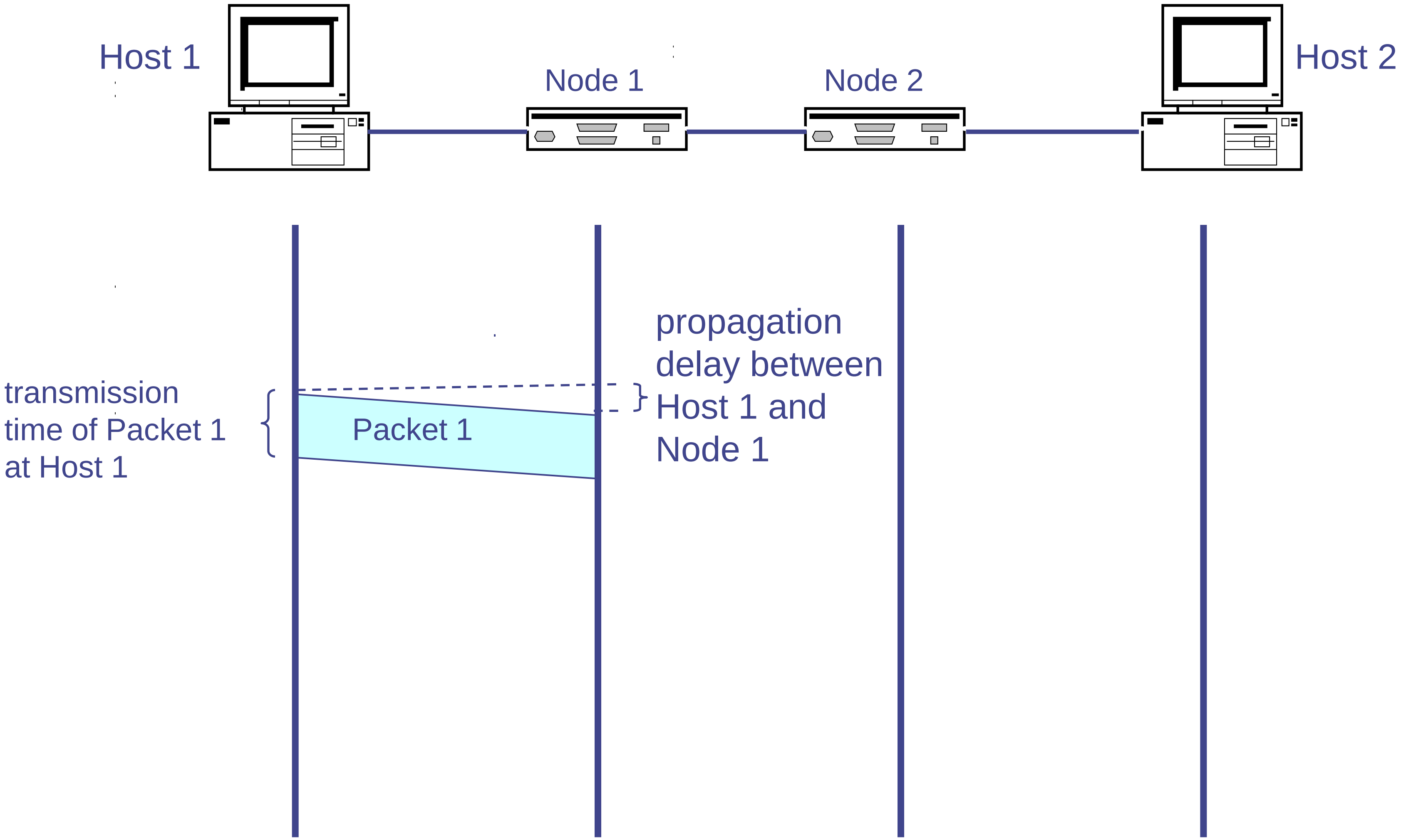
- Chop up data into packets
  - Packets contain some actual data that is to be delivered to the recipient (can have different - but bounded! - size)
  - Also need administrative information, e.g., who is the recipient
  - Sender then occasionally sends out a packet, instead of a continuous flow of data
- 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….



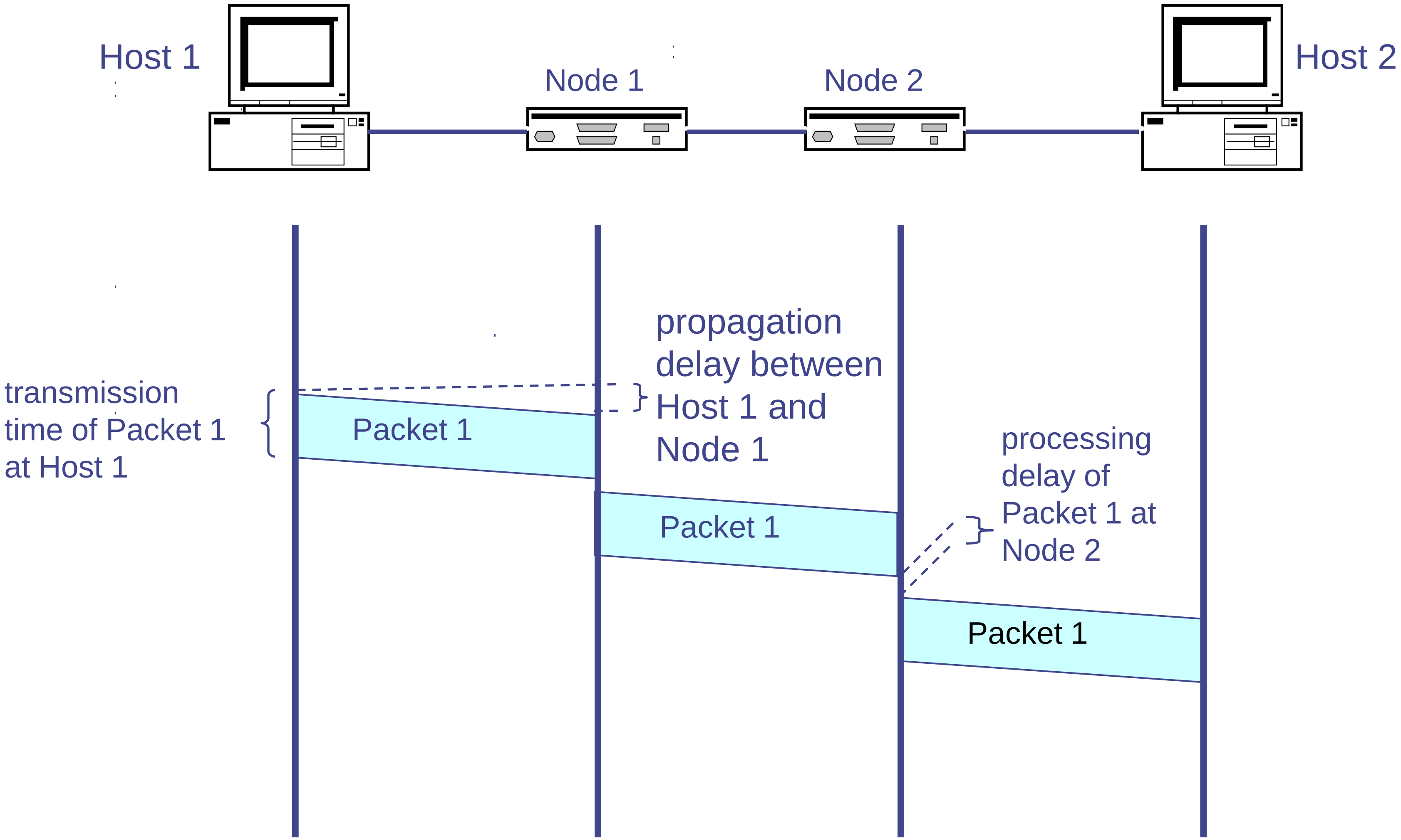
Timing of Datagram Packet Switching (1)



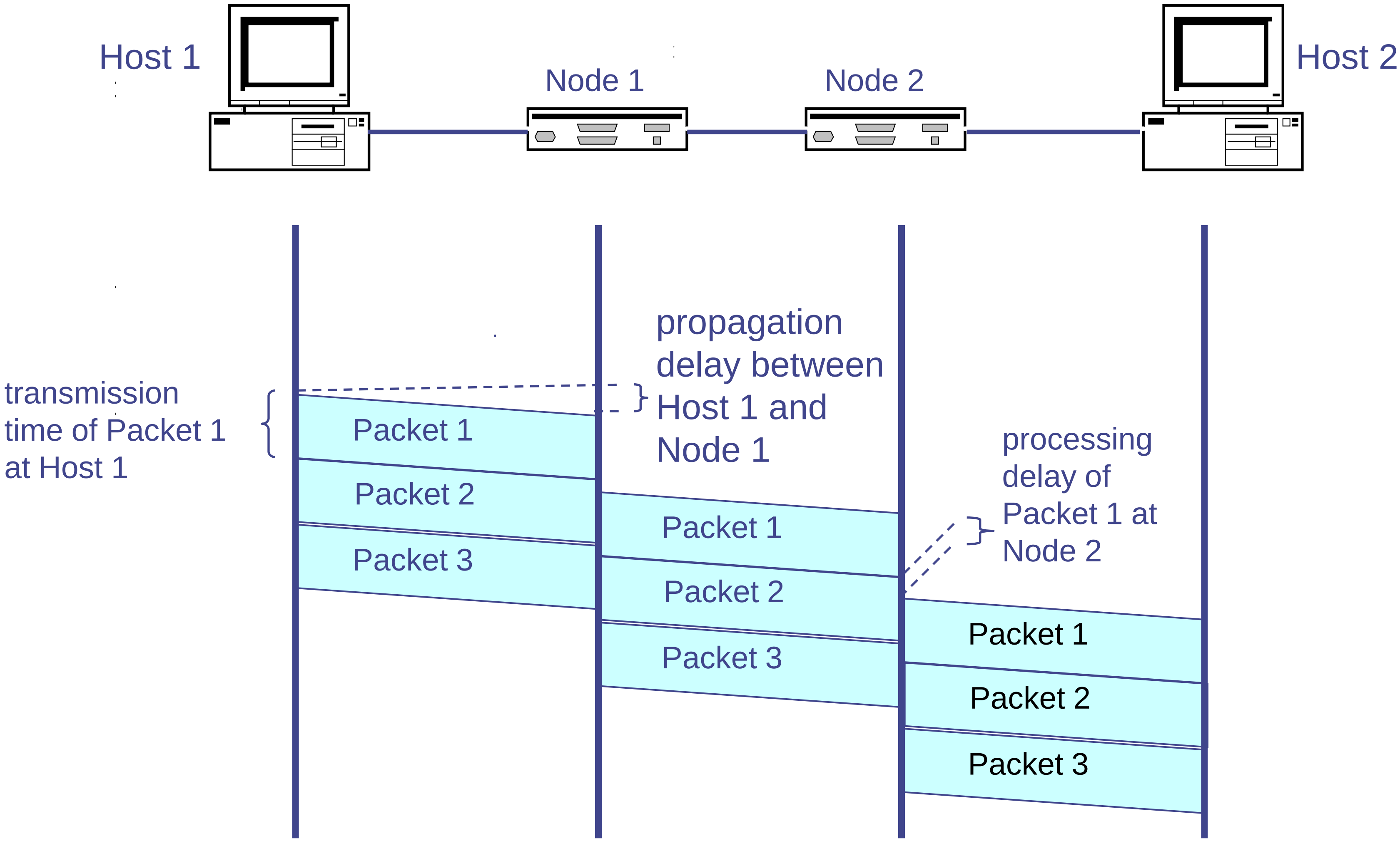
Timing of Datagram Packet Switching (2)



Timing of Datagram Packet Switching (3)

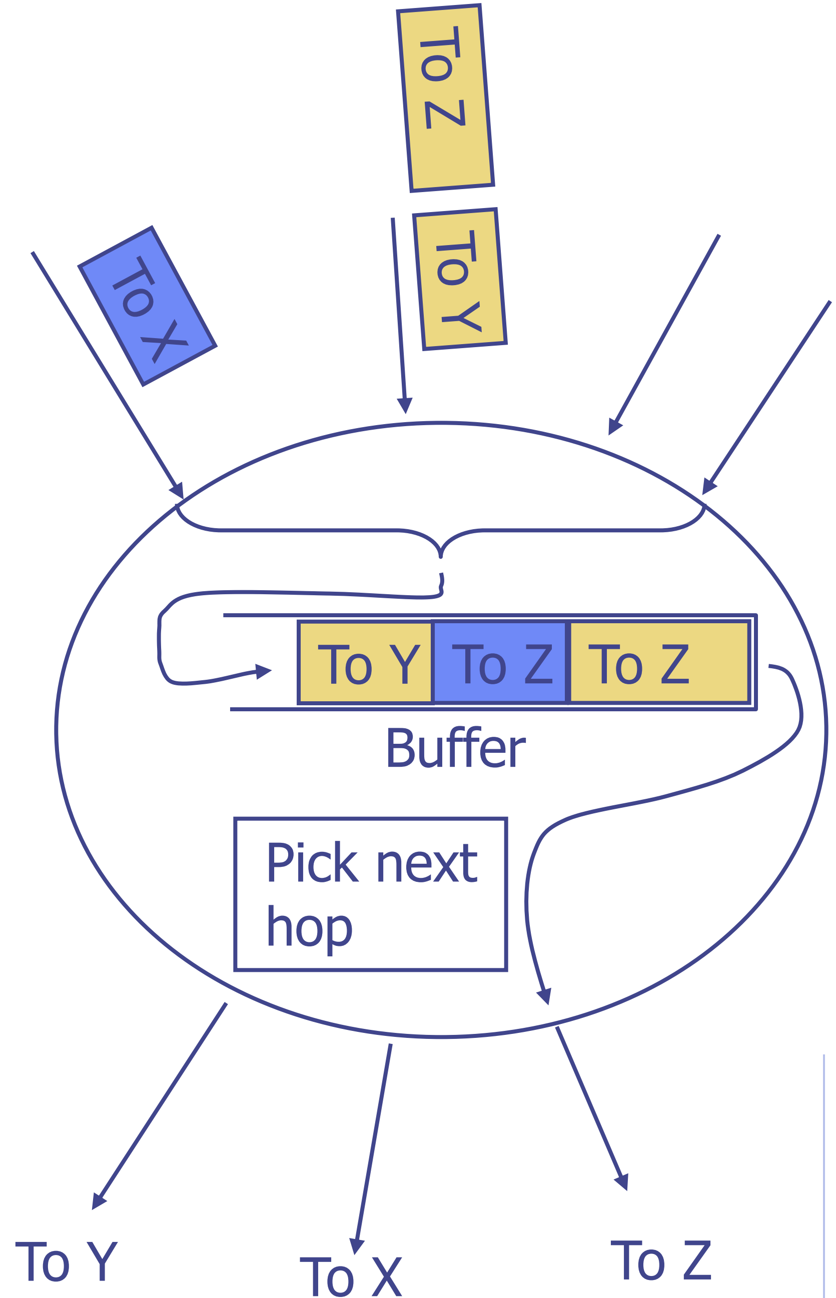


Timing of Datagram Packet Switching (4)



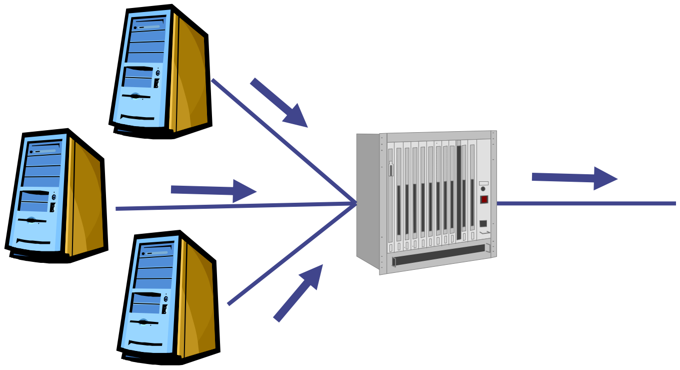
Packet switches

- 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



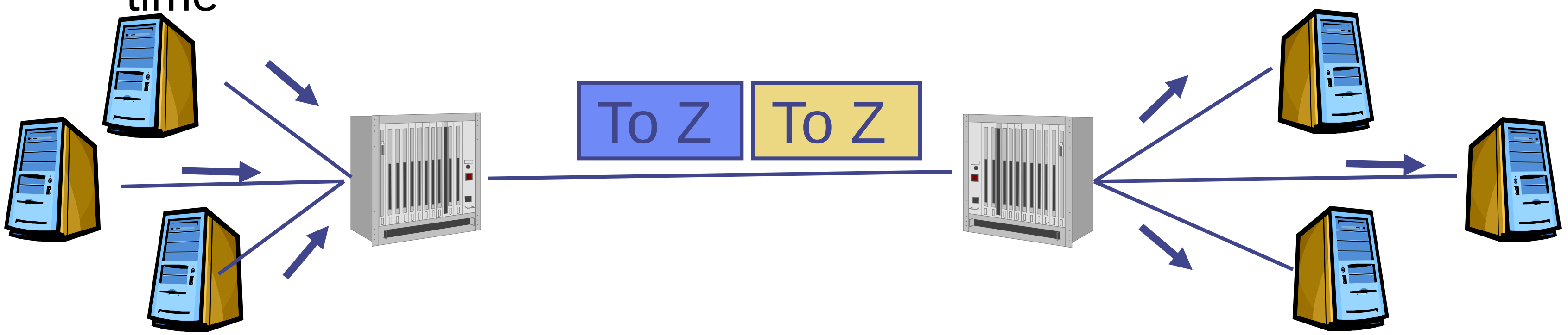
Multiplexing

- Previous example had two packets at the head of the queue destined for terminal Z
- Similar situation: a switching element has only a single outgoing connection
  - Such a special case is called a multiplexer
  - Organizing the forwarding of packets over such a single, shared connection is called multiplexing
  - Multiplexers in general need buffer space as well

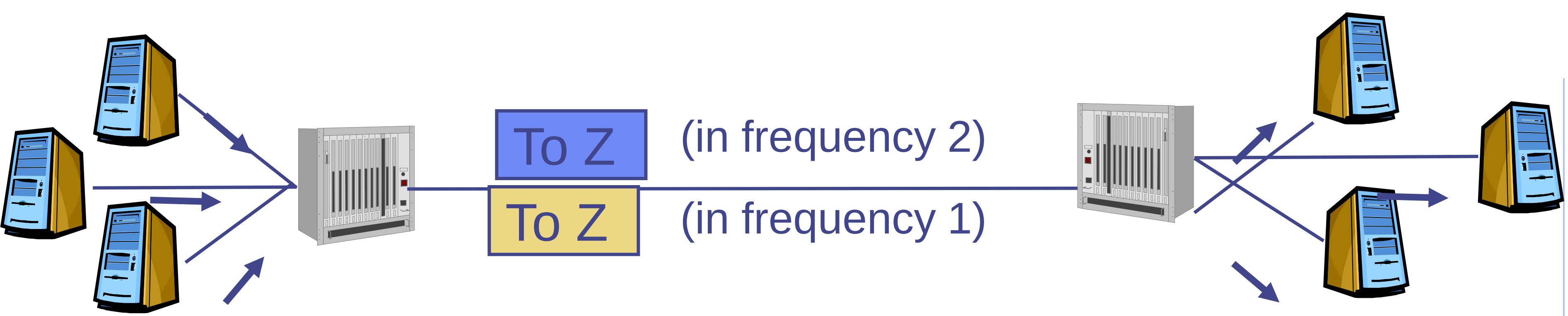


Multiplexing II

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

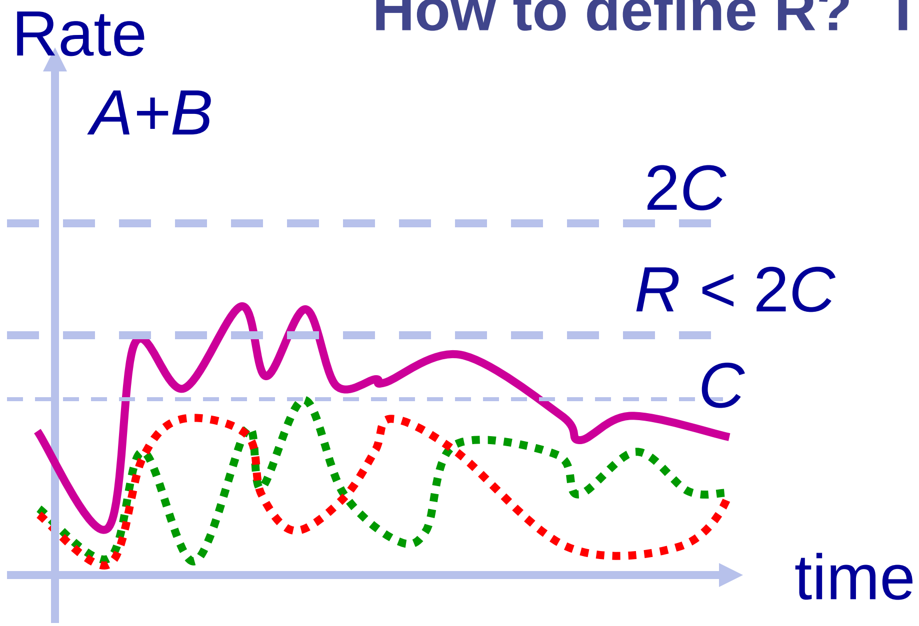


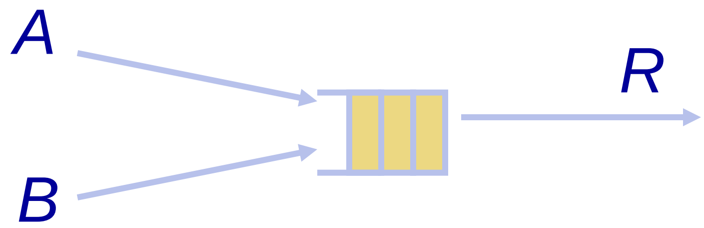
- Alternative: Frequency Division Multiplexing (FDM)
  - Use different frequencies to transmit several packets at the same time



Statistical Multiplexing Gain

Statistical multiplexing uses R<2C.
How to define 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.

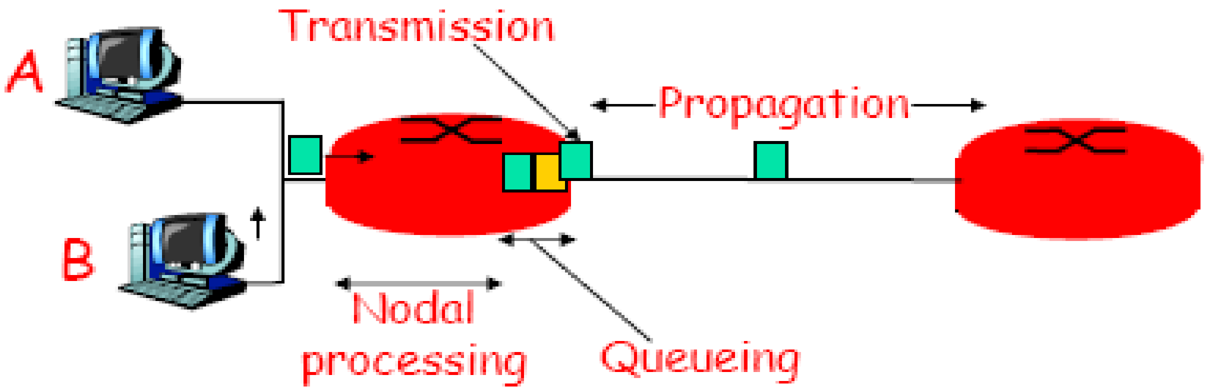
It is hardly possible to account for maximum demand of numerous sources!

Delay on the way – summary

[Cheng, Lehigh Univ.]

1. Nodal processing:
   - Check bit errors
   - Determine output
- 2. Queueing
   - Time waiting at output for trans.
   - Depends on congestion at router

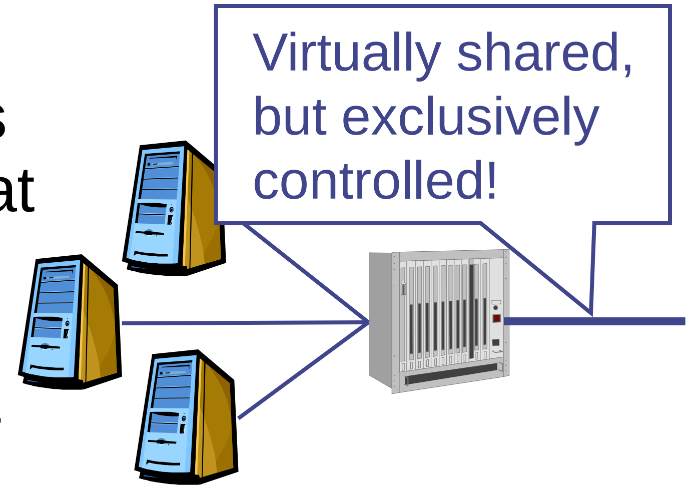
3. Transmission delay:
   - R=link bandwidth (bps)
   - L=packet length (bits)
   - Time to send bits into link: L/R
- 4. Propagation delay:
   - d = length of physical link
   - s = propagation speed in medium
   - Propagation delay = d/s



Just to remaind you the issue of queueing...

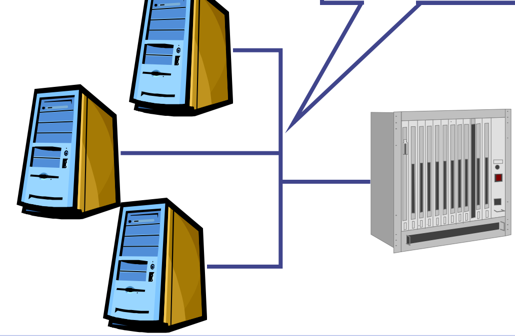
Multiplexing & shared resources

- 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



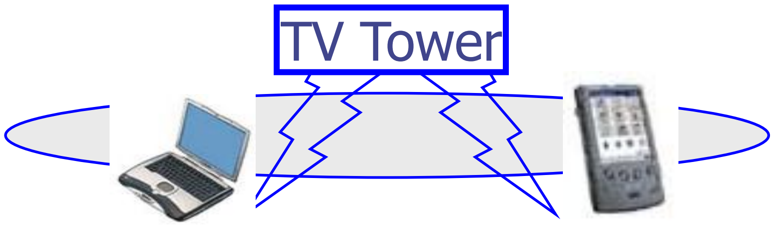
- Are there other examples of "shared resources"?
  - Classroom, with "air" as physical medium

- Characteristic: a broadcast medium!
  - Everybody can hear the sender
  - Addressing is necessary (if not sending to all)
    - Unicast (to one!)
    - Multicast (to a group)

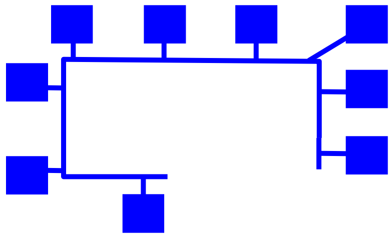


Broadcast medium and multiple access

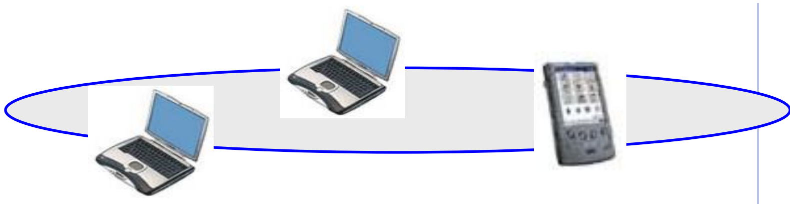
- Common characteristic of a broadcast medium: Only a single sender at a time!
  - ⇒Exclusive access is necessary
  - ⇒simple to achieve with a multiplexer



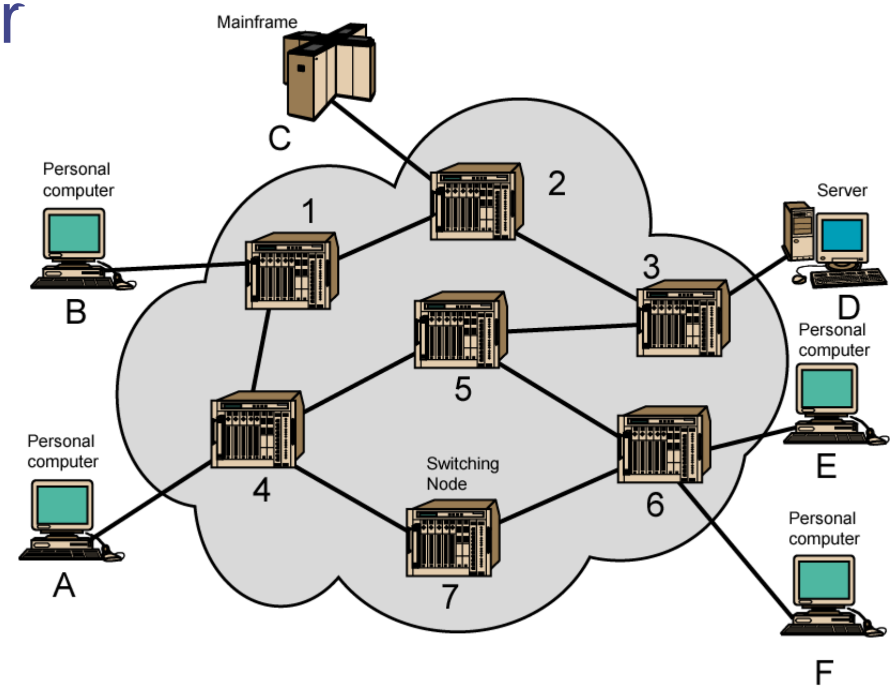
- What if **no** multiplexer is available?
  - – E.g. a bus: All nodes connected to a single wireline
  - – Exclusive access has to be ensured
  - ⇒Rules have to be agreed upon



- Or a group wireless devices?
  - – Compare: group of kids…



Switched network, reminder



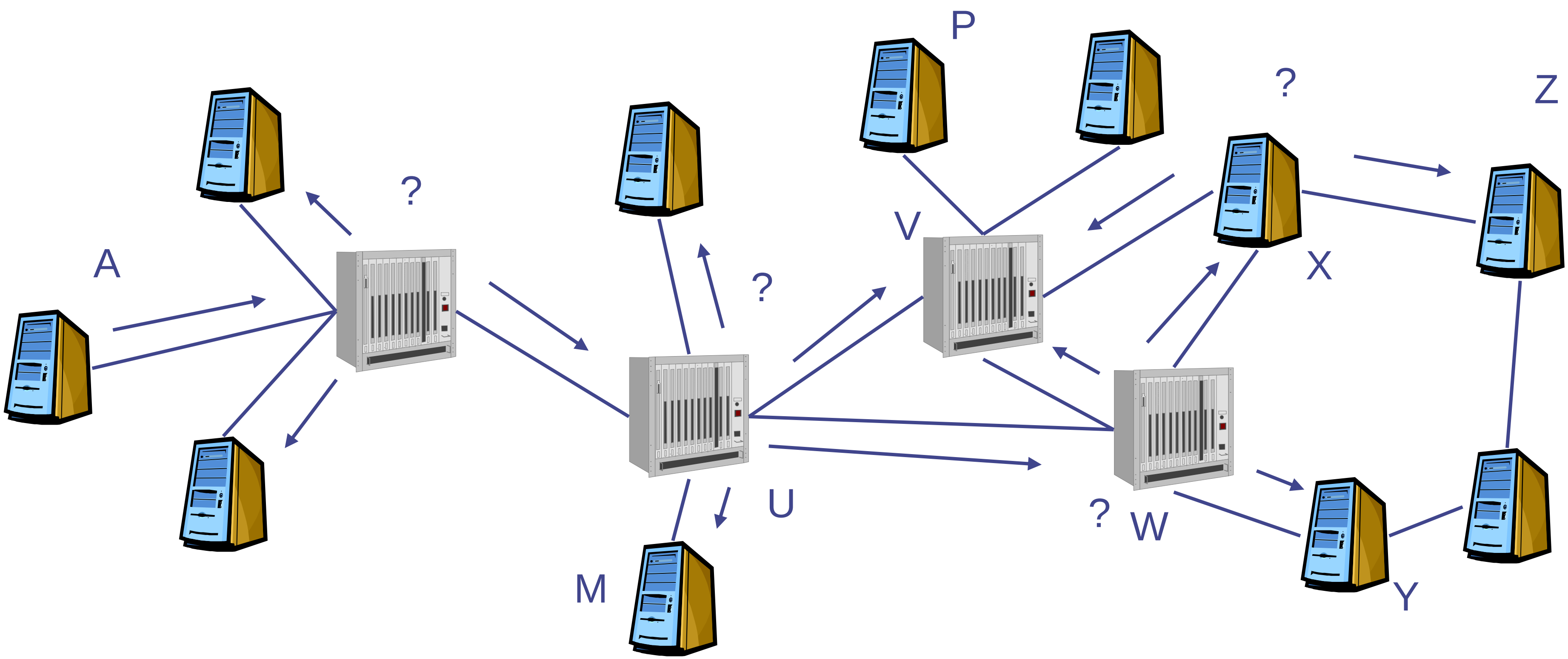
- There is a set of path sections (e.g. electrical cables) and switches "End systems" a.k.a terminals/user devices

vs.

"switching elements" a.k.a routers/bridges

Forwarding and next hop selection

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

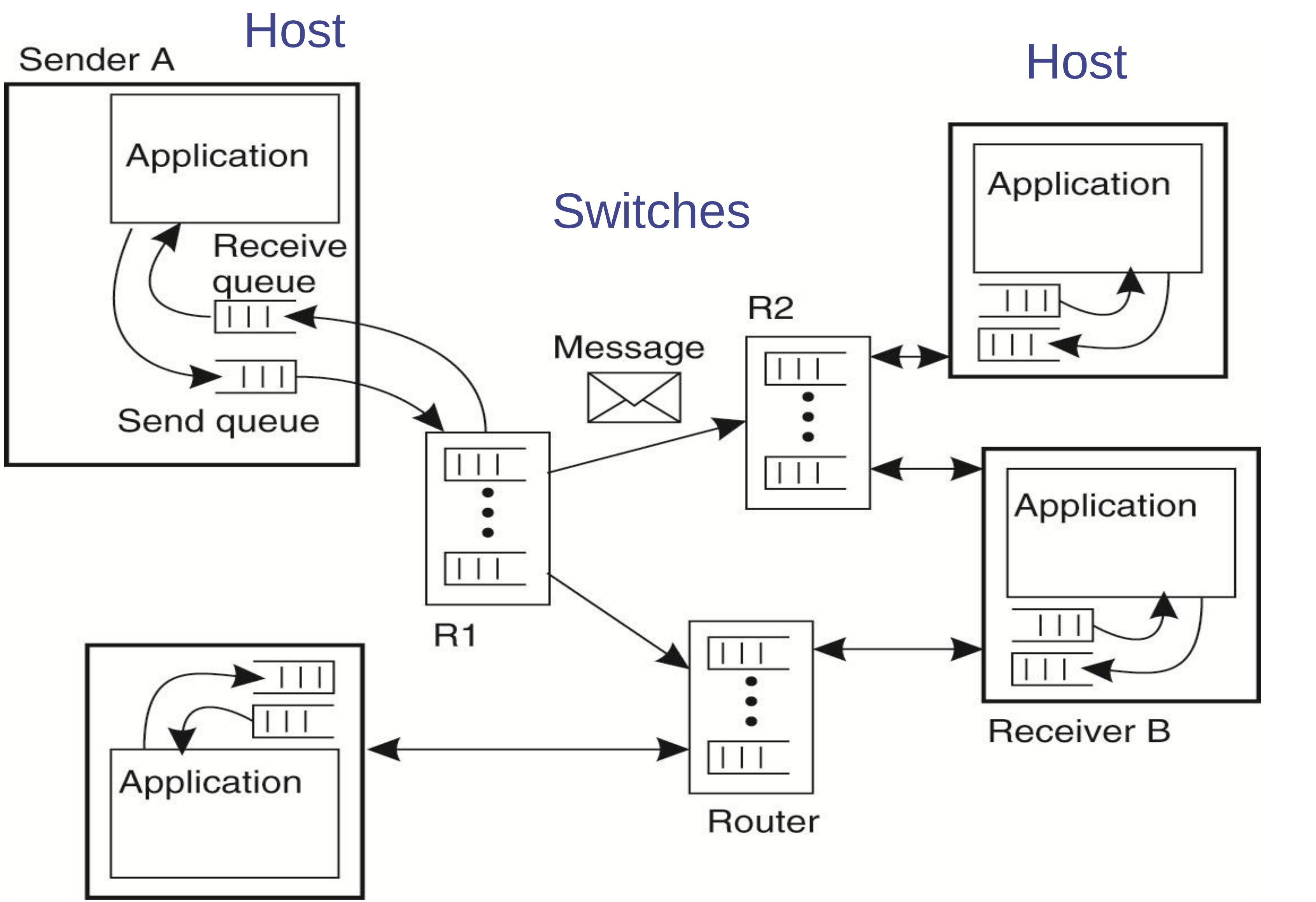


Adressing, Routing, Forwarding

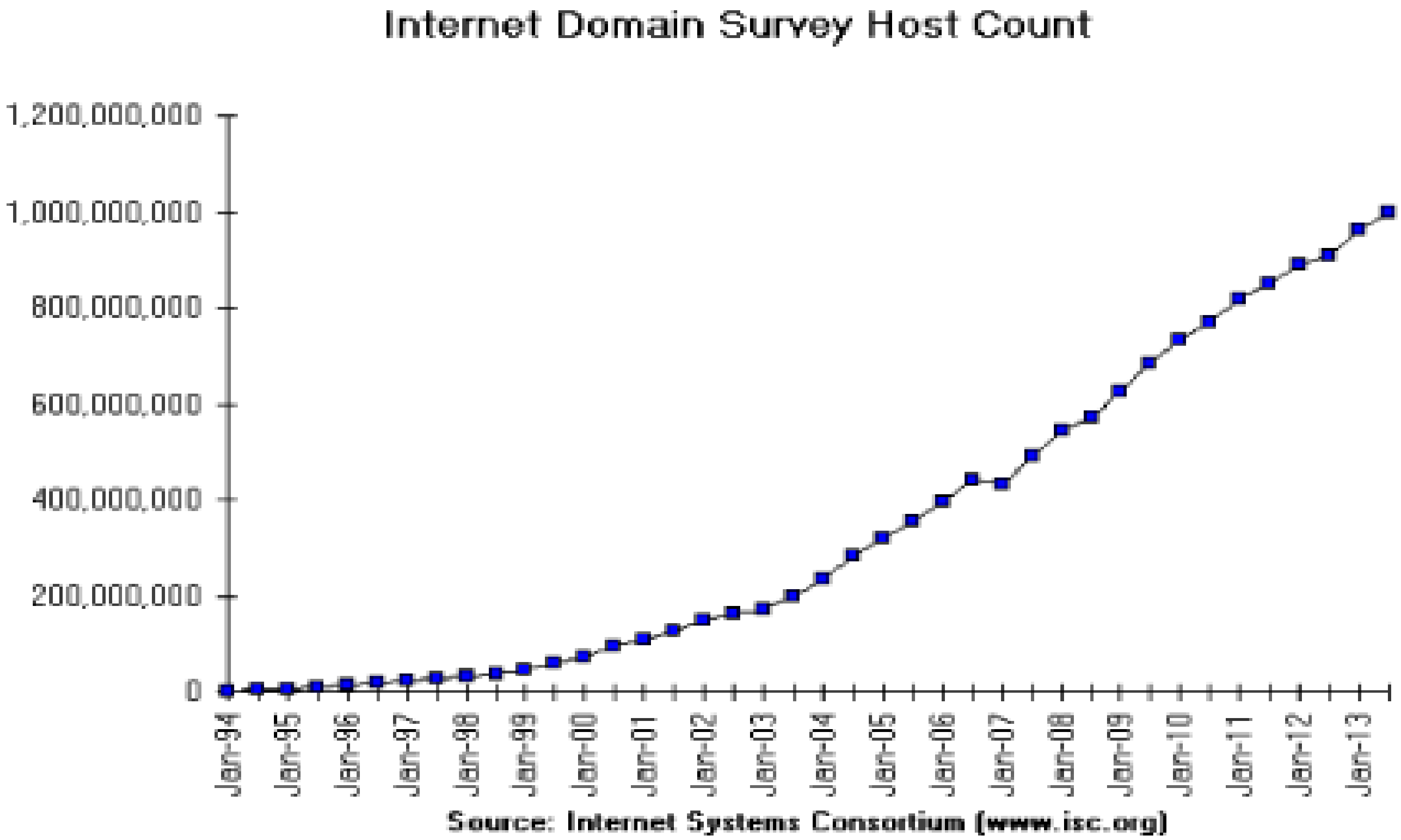
- **Naming:** whom would you like to reach? (**Object Identity**!)
- **Address:** Where is the object **- locator!**
- **Routing**: Each switch has to know which of his outputs should be used for a given destination address
  - Hopefully contributes to short "overall trip distance, time"
  - Some understanding 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]



Internet host count



https://www.isc.org/services/survey/

What is the value of a network ?

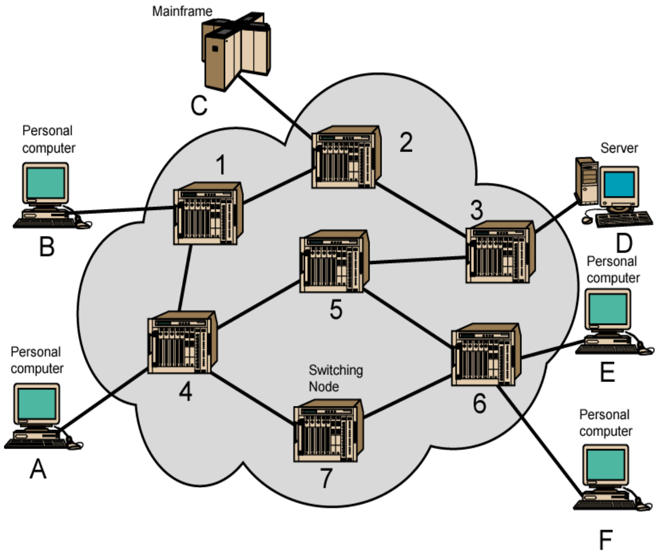
- Communications networks increase in value as they add members – but by how much?
  - How useful is a single phone using a unique new technology? Two phones? 20 Phones? 1 billion of phones….
  - Btw. as by October 2012 they are around 4.2 billion mobile communication users (and 6.3 billion subscriptions!) out of worlds population of over 7 billions of people!
- The Metcalfe's Law ➔The value of a communication network is proportional to the square of the user number!
- **Newer theory:**

The n log(n) Law

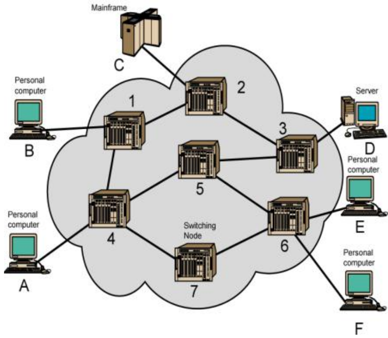
See: Bob Briscoe, Andrew Odlyzko, Benjamin Tilly
IEEE Spectrum July 2006, pp. 32- 39

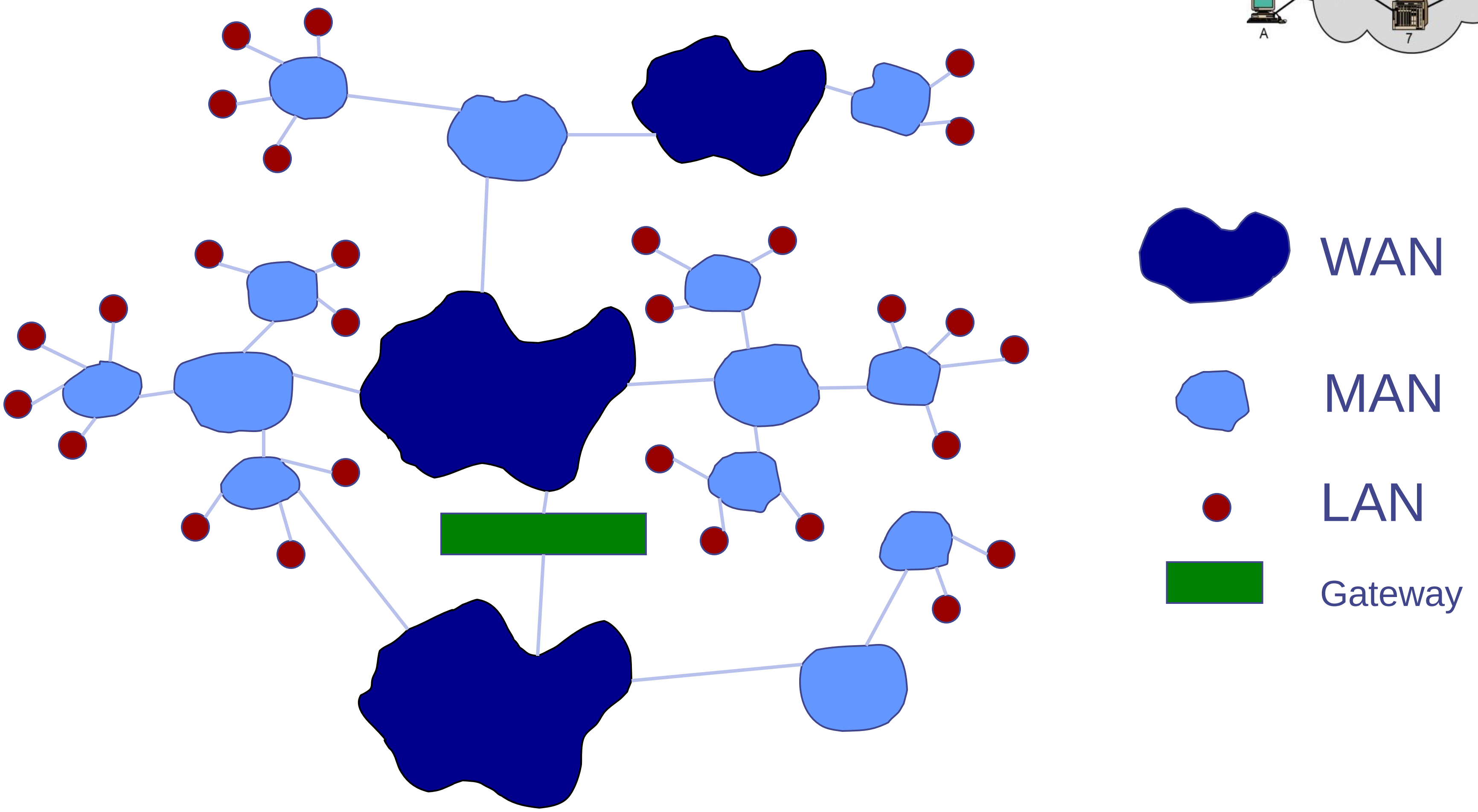
Large Networks need structure! Why?

- 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 requirements best served by NNN
  - Mulitple technologies for
- Administration
  - Who sets the rules for usage ???



Internet: Interoperability vs. Heterogeneity

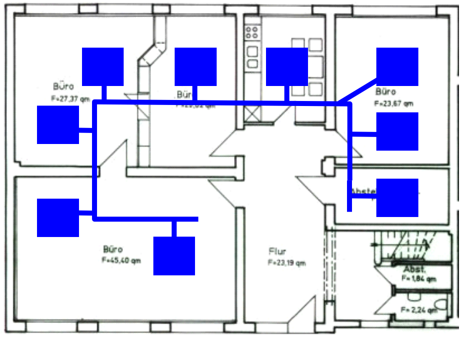


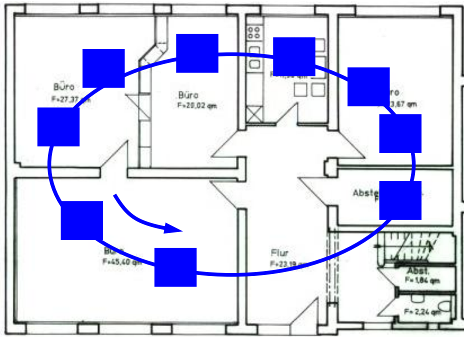


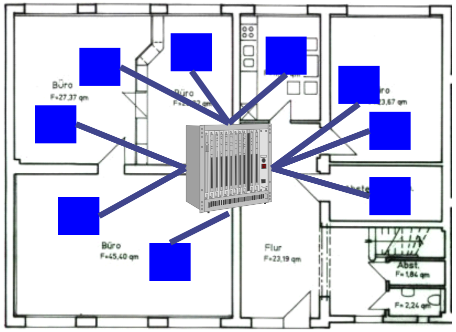
See: [The Brief History of the Internet]

Typical network structures for local installations

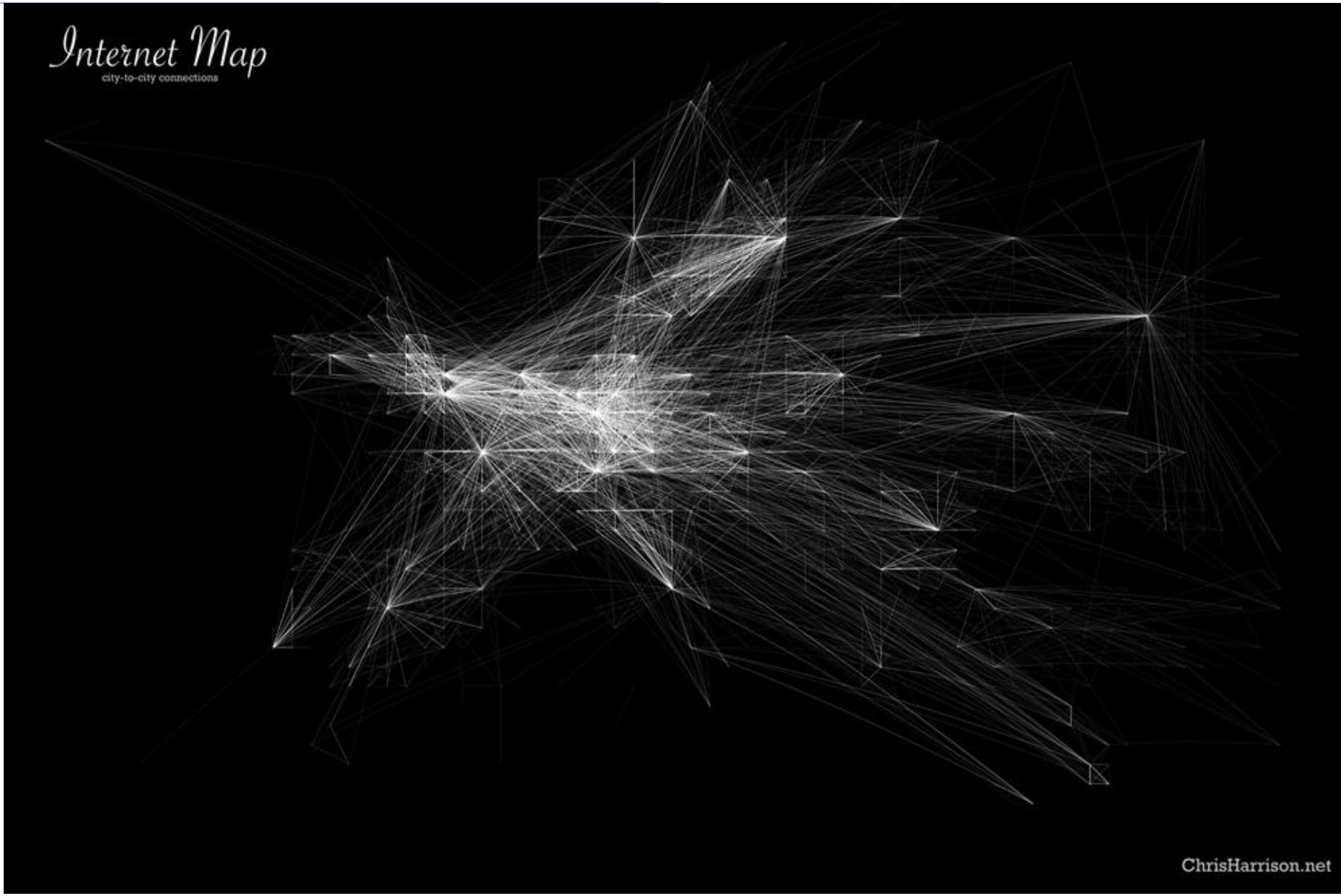
- “Busses”
  - All nodes connected to a single wireline
  - Cheap, but relatively inefficient, error-prone
- “Rings”
  - Nodes connected to a ring-shape network
  - Can compensate for a single break of pairwise connection
- “Star”
  - All nodes directly connected to a central cabling “hub”
  - Again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



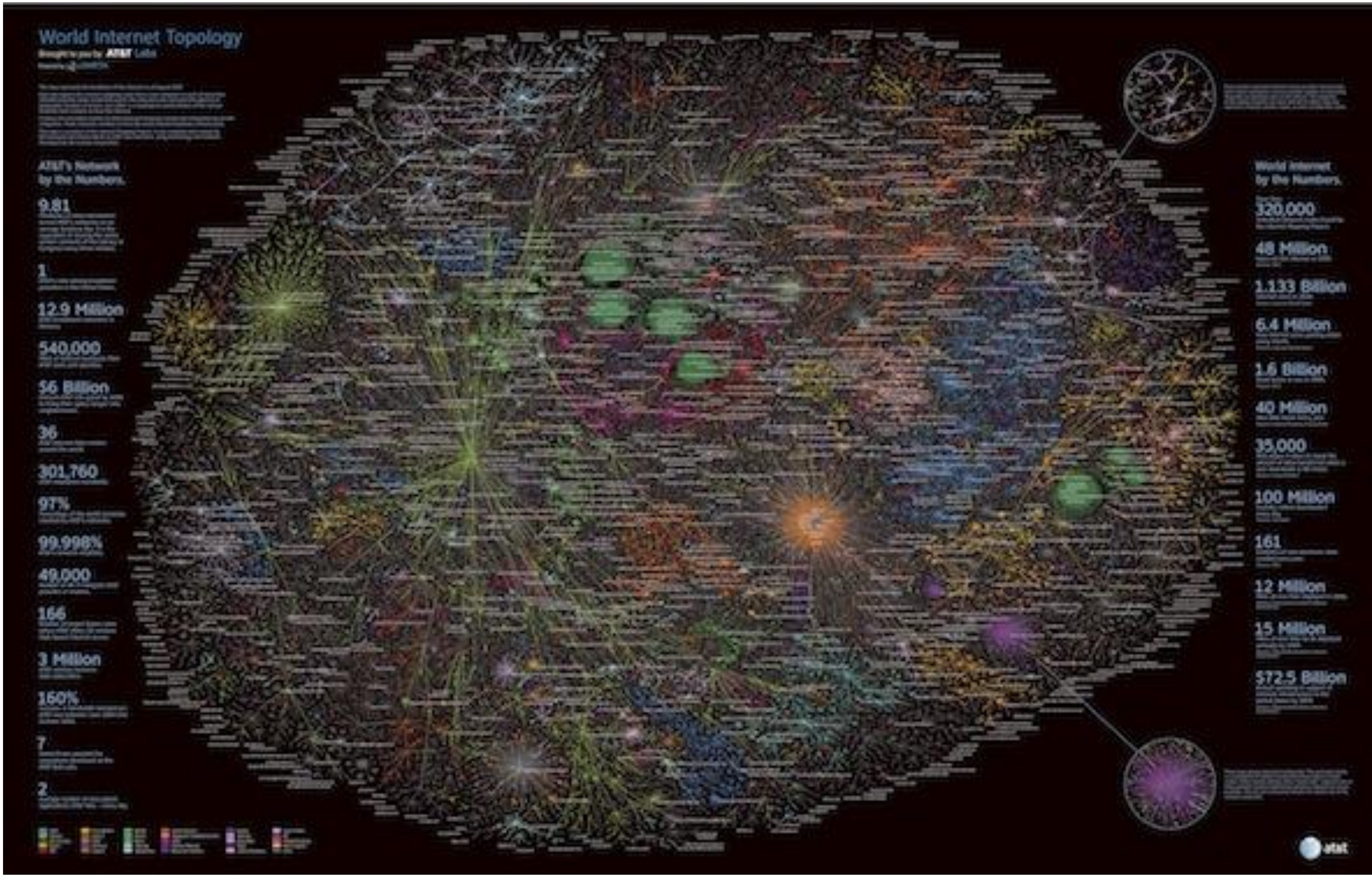




European City Connection Map



Internet maps



Internet maps