Technische Universität Berlin

Rechnernetze

Einführung

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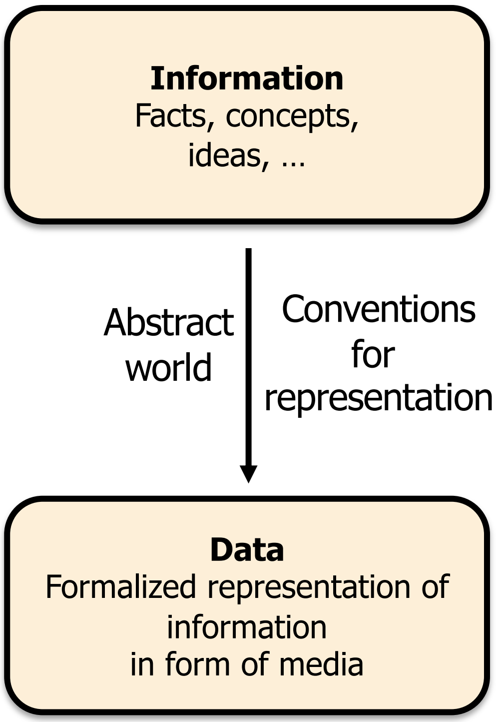
What to Communicate: Information, Data

- 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



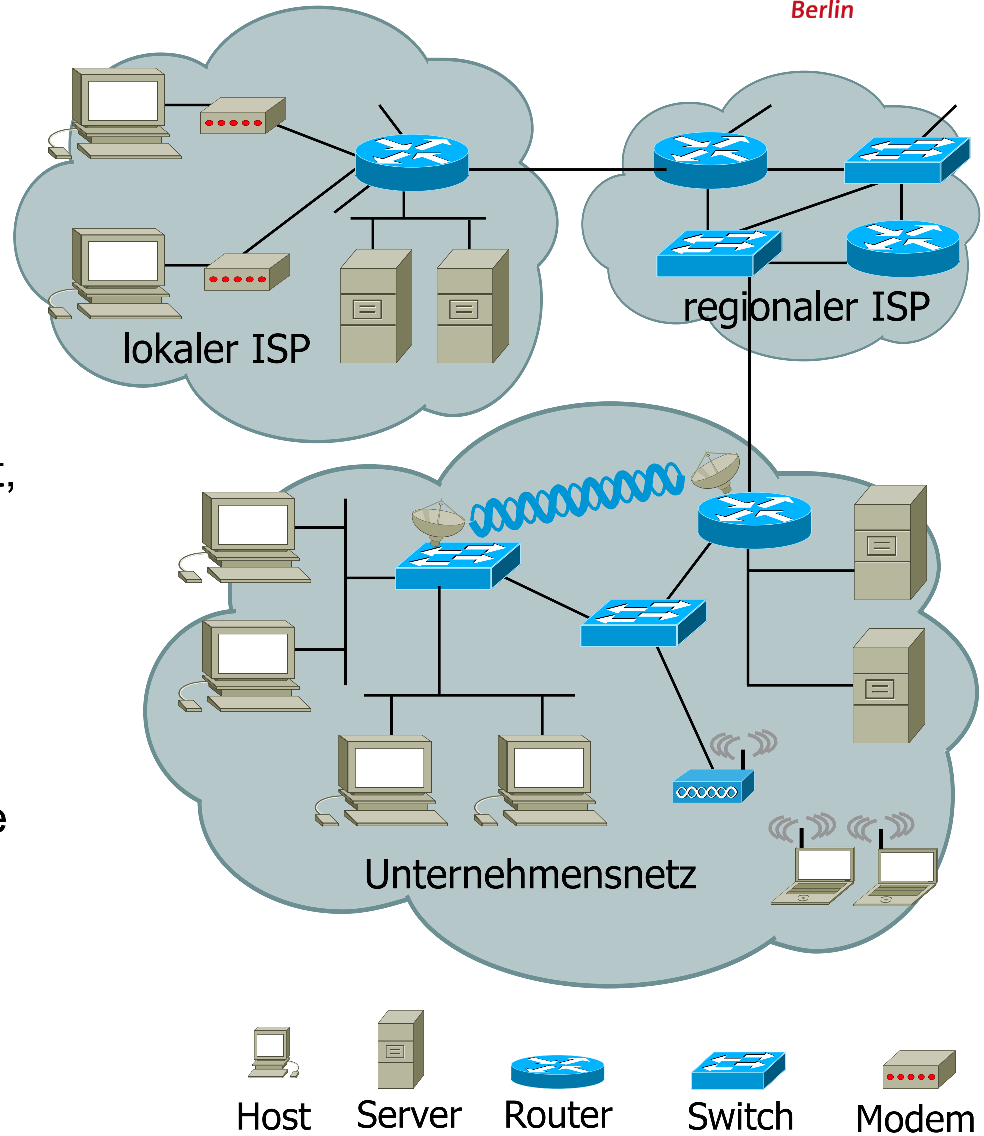
The Data Tsunami

- 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

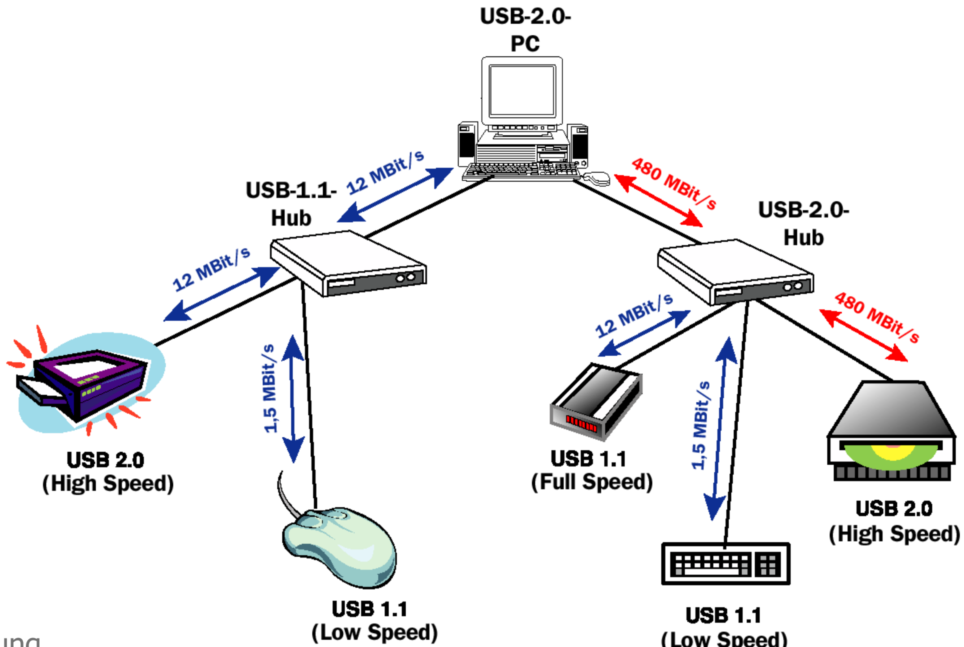
Beispiele für Rechnerkommunikation

- IP-Netz (Internet)
  - Kommunikation zwischen **Anwendungen** auf **Endsystemen** (**Host**, **Server**)
  - Verwendung von **Internet-Protokollen** (u.a. TCP, UDP, IP) und weiteren (z.B. Ethernet, WLAN)
  - Infrastruktur besteht u.a. aus Vermittlungseinheiten (**Switches**, **Router**), Funkbasis-stationen, Modems
  - kabelgebundene und drahtlose **Verbindungen**
  - Unterscheidung von **Zugangsnetz** und **Kernbereich**
  - Internet Service Provider (ISP)

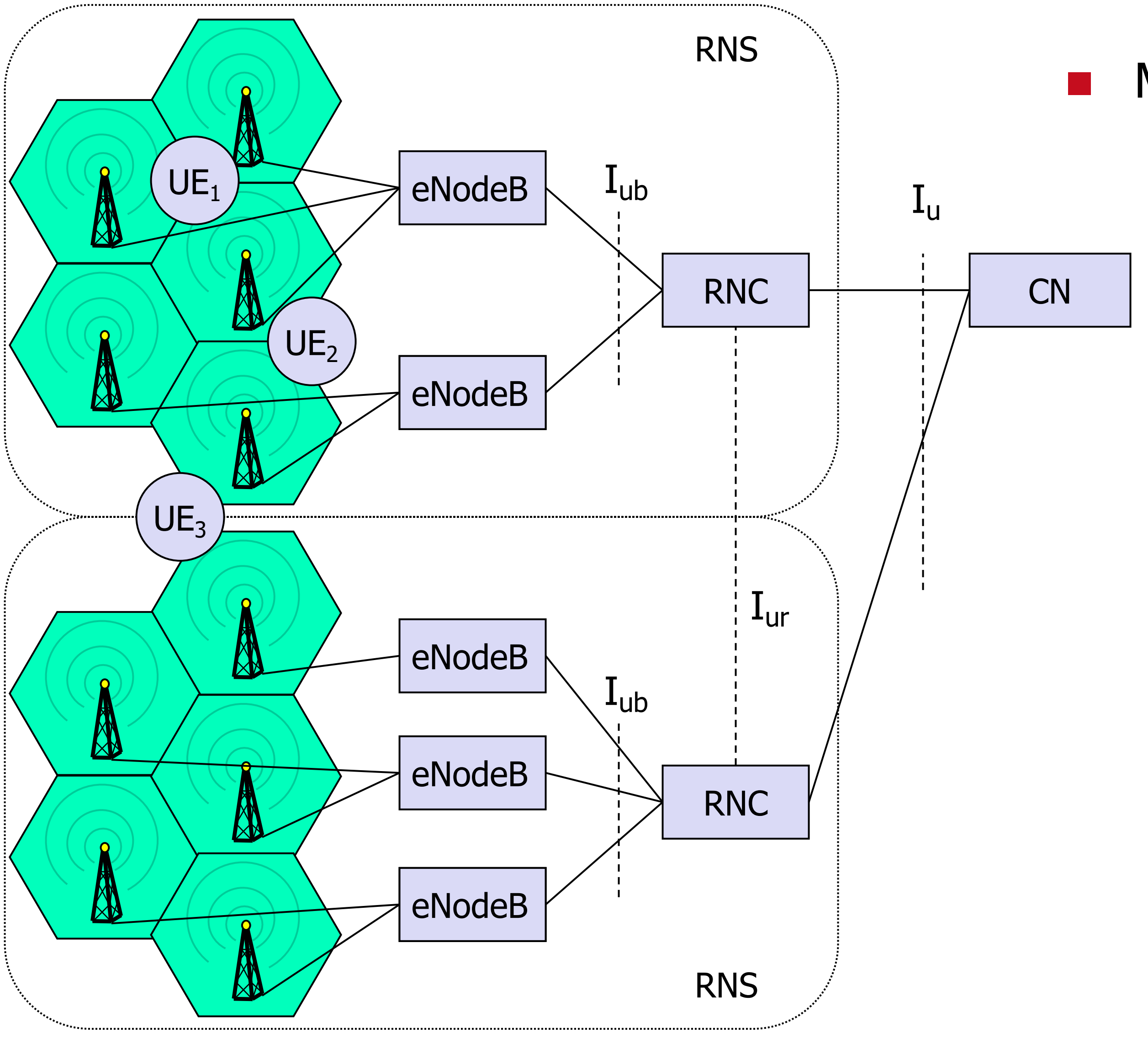


Beispiele für Rechnerkommunikation

- Universal Serial Bus (USB)
  - verbreitete serielle Anbindung von Peripheriegeräten an PC
  - Sterntopologie aus Blättern (Nodes) und Verteilern (Hubs)
  - Adressierung: 8 Bits für Node, 3 Bits für Endpunkt (Function) in Node
  - Aufbau von Kanälen (Pipes) zwischen PC und Functions
  - Protokoll für Übertragung basierend auf Sendeberechtigungen (Token)



Beispiele für Rechnerkommunikation



- Mobilfunknetze
  - mobile Telekommunikation: Sprache + Daten
  - Mobilstation (User Equipment)
  - Radio Network Subsystem für funkorientierte Funktionen mit Funkzellen und Basisstationen (eNodeB)
  - Zugangsnetz, Kernnetz für Signalisierung, Transport, Übergang zu anderen Netzen

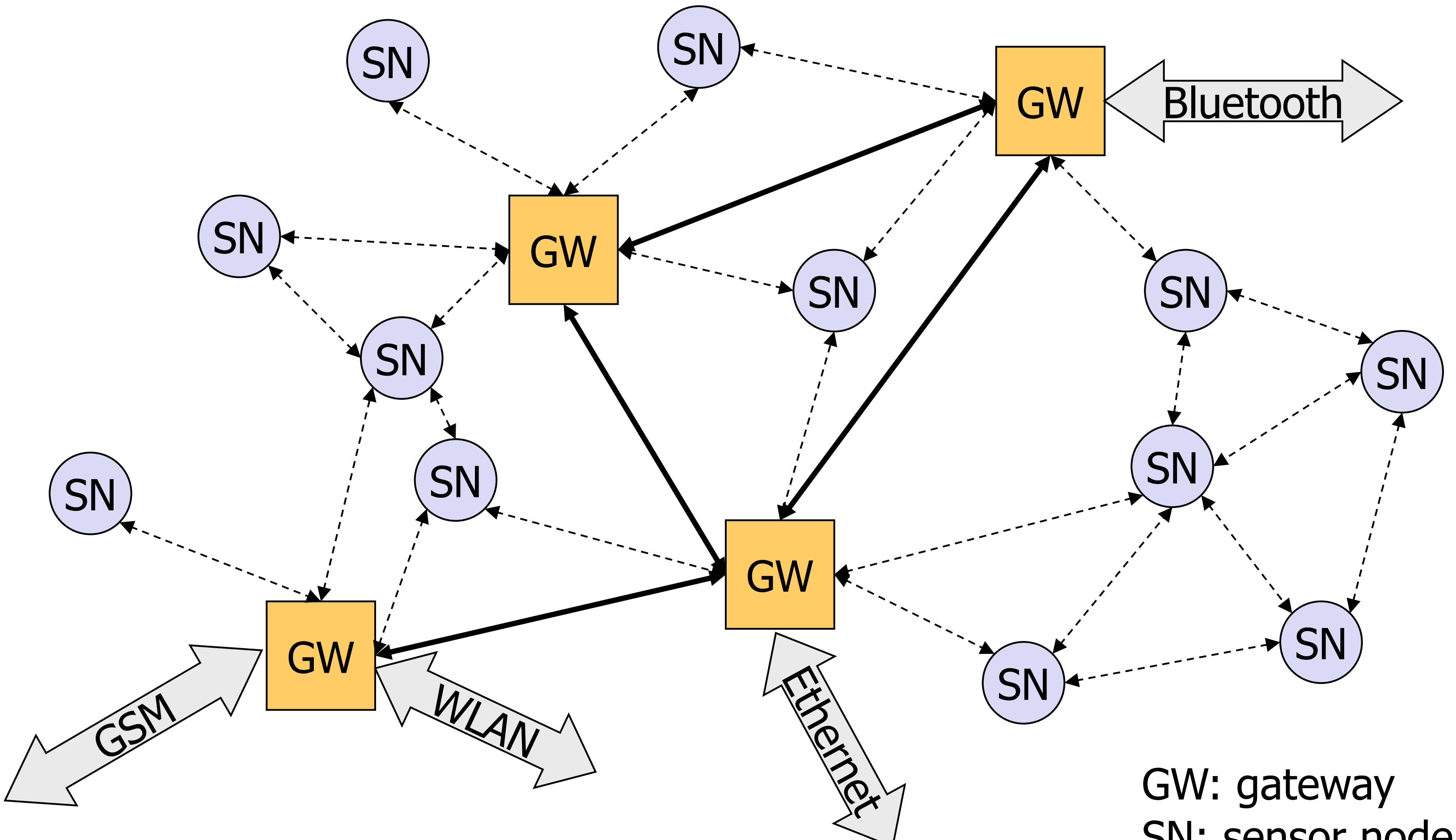
Beispiele für Rechnerkommunikation



- Ad-Hoc-Netze, Sensornetze
  - Ad-Hoc-Netze: ohne Infrastruktur, Nutzung von Endgeräten der Netzteilnehmer für die Vernetzung, selbstorganisierend
  - z.B. drahtlose Sensornetze (Wireless Sensor Networks, WSN)
    - einzelne Komponenten
      - klein (z. Zt. cm2, mm2 in Vorbereitung), billig
      - Energieversorgung (Batterie oder aus Umgebung)
      - Prozessor, Funkkommunikation
      - Sensoren: Licht, Feuchtigkeit, Druck, Erschütterung, Beschleunigung, Position, Magnetismus, Schall, …
    - Einsatzszenarien z.B.: Logistik, Sicherheit, Umwelt, Landwirtschaft, Gesundheitswesen, Heimautomatisierung, …

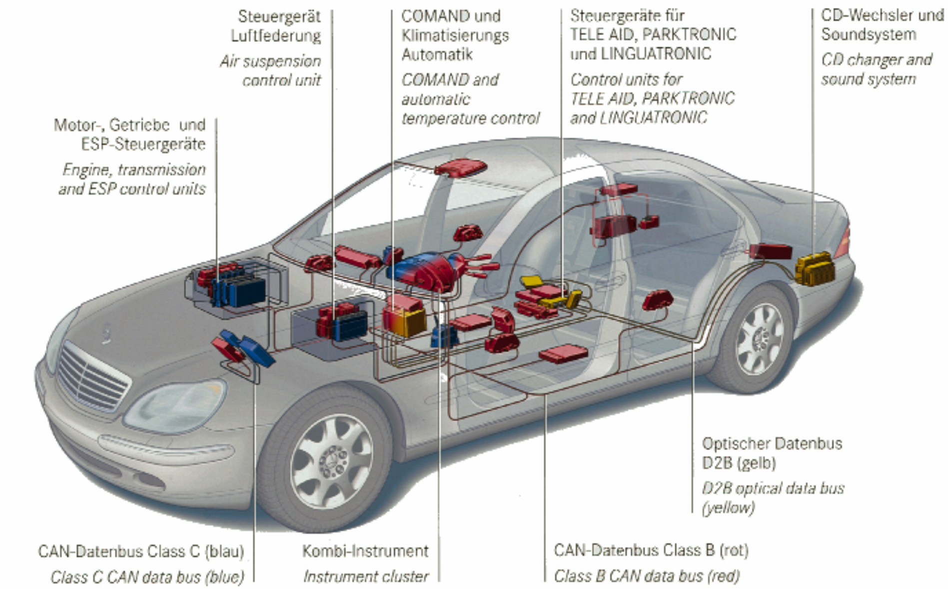
Beispiele für Rechnerkommunikation

- Ein typisches drahtloses Sensornetz



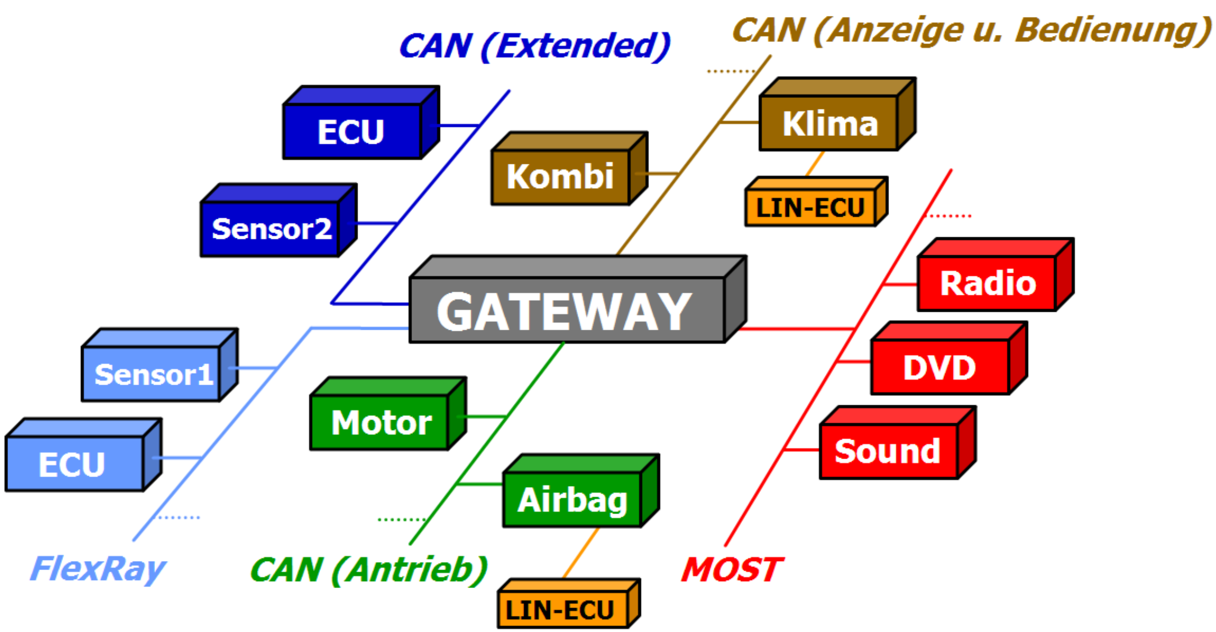
Beispiele für Rechnerkommunikation

- Vernetzung im Fahrzeug
  - heutige Mittelklasse- und Oberklasse-Fahrzeuge besitzen ca. 60 bis 100 elektronische Steuergeräte (Electronic Control Units, ECUs) für Antriebsstrang, Fahrerassistenz, Komfort, Infotainment
  - Controller Area Network (CAN) verbreitetes Bussystem zur Kommunikation
  - besondere Anforderungen an Zuverlässigkeit, Echtzeit



Beispiele für Rechnerkommunikation

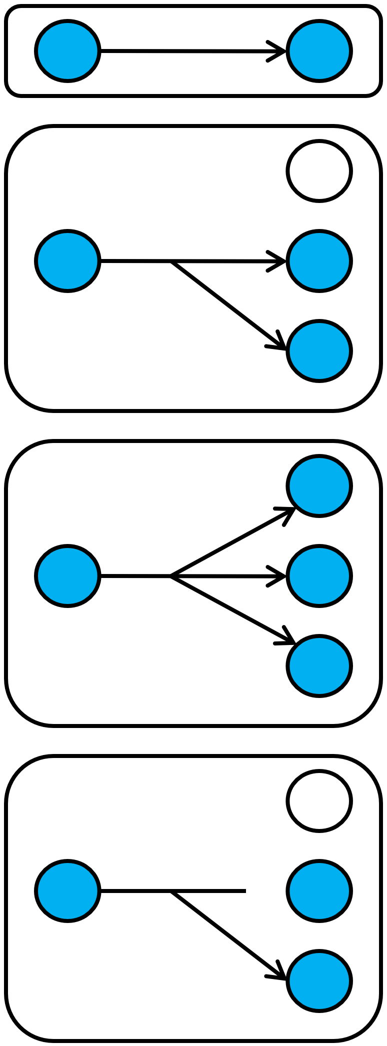
- Beispielhafte Vernetzungsarchitektur im Fahrzeug
  - zentrales Gateway
  - Anschluss der ECUs über mehrere CAN-Busse und weitere Bussysteme (z.B. FlexRay mit höheren Raten, MOST mit noch höheren Raten für Infotainment)
  - an ECUs weitere Busse, z.B. Local Interconnect Network (LIN)



Klassifikation von Kommunikationssystemen

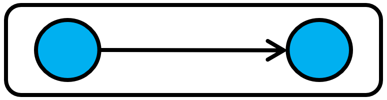
Klassifikation von Kommunikationssystemen

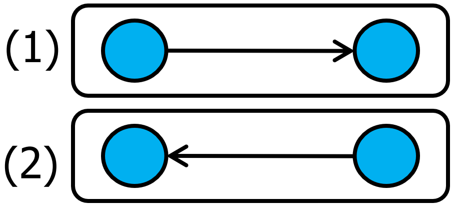
- Einige Unterscheidungsmerkmale …
- Kommunikationsart
  - **Unicast** (Punkt-zu-Punkt): ein Sender, ein Empfänger
  - **Multicast** (Punkt-zu-Mehrpunkt, Gruppenruf): ein Sender, ein Gruppe von Empfängern
  - **Broadcast** (Rundruf): an alle Teilnehmer des Netzes
  - **Anycast**: ein Empfänger aus einer Gruppe möglicher Ziele



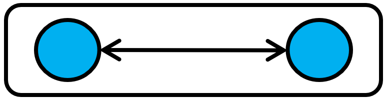
Klassifikation von Kommunikationssystemen

- Übertragungsart
  - Übertragungsrichtung
    - **simplex**: unidirektionale Verbindung





    - **halbduplex**: bidirektionale Verbindung mit Umschalten, also nicht gleichzeitig in beide Richtungen



    - **(voll-)duplex**: gleichzeitig in beide Richtungen

Klassifikation von Kommunikationssystemen

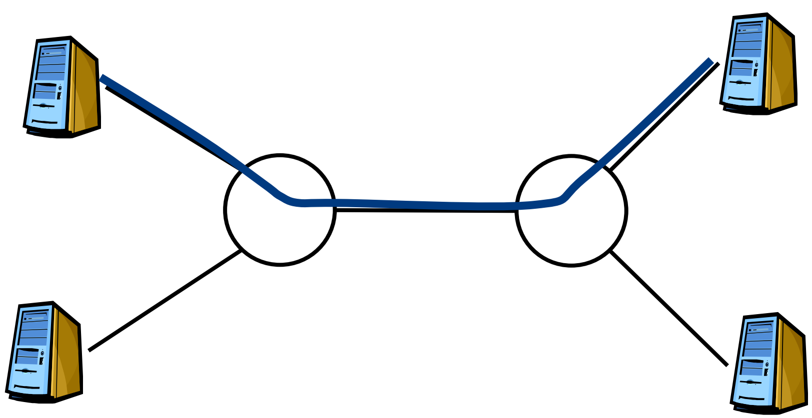
- Übertragungsmedium
  - **leitungsgebunden**
    - z.B. verdrillte Kupferdrähte, Glasfaser
    - Bitraten von Kbps bis viele Gbps
    - Signalausbreitungsgeschwindigkeit Teil der Lichtgeschwindigkeit, $c \approx 2 \cdot 10^8$ m/s = 200 m/µs
    - kleine Bitfehlerraten, bei Glasfaser z.B. 10^{-10}
  - **drahtlos**
    - z.B. Funk (terrestrisch, Satellit), Infrarot
    - Bitfehlerraten hoch wegen verschiedener Probleme bei der Ausbreitung von Funkwellen: 10^{-5} bis 10^{-2}
    - außerdem treten Bitfehler oft in Schüben (**Bursts**) auf

Klassifikation von Kommunikationssystemen

- Vermittlungsart
  - **Leitungsvermittlung (Circuit Switching)**
    - zwischen Sender und Empfänger wird mittels **Signalisierung** ein Kanal zur Übertragung aufgebaut (z.B. durch Zeit- oder Frequenzmultiplex)
    - die zur Verfügung stehende Bitrate muß fest auf die Kanäle aufgeteilt werden
    - Standardverfahren in der Telefonie, bei schwankenden Datenaufkommen mit vielen Pausen ineffizient
  - **Paketvermittlung (Packet Switching)**
    - Sender schickt Daten in Paketen, die einzeln zum Sender gelangen
    - die Bitrate wird effizienter aufgeteilt
    - kurzfristiges höheres Datenaufkommen kann über Puffer abgefangen werden
    - dies kann zu Verzögerungen und Pufferüberläufen führen

Option 1: Circuit Switching

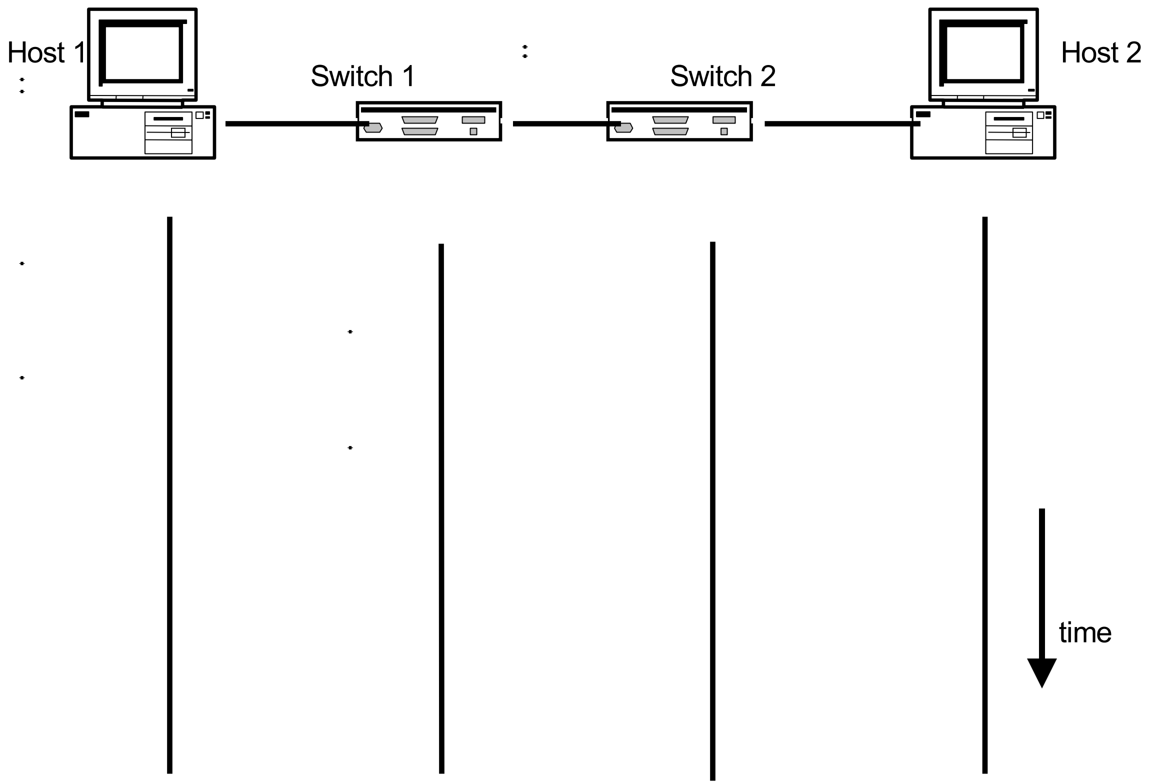
- Circuit switching: the switching elements configure, on demand, a “path” between terminals.
  - Determines really the route (cmp. “Fräulein vom Amt”) and resources!
  - The circuit lasts for duration of communication



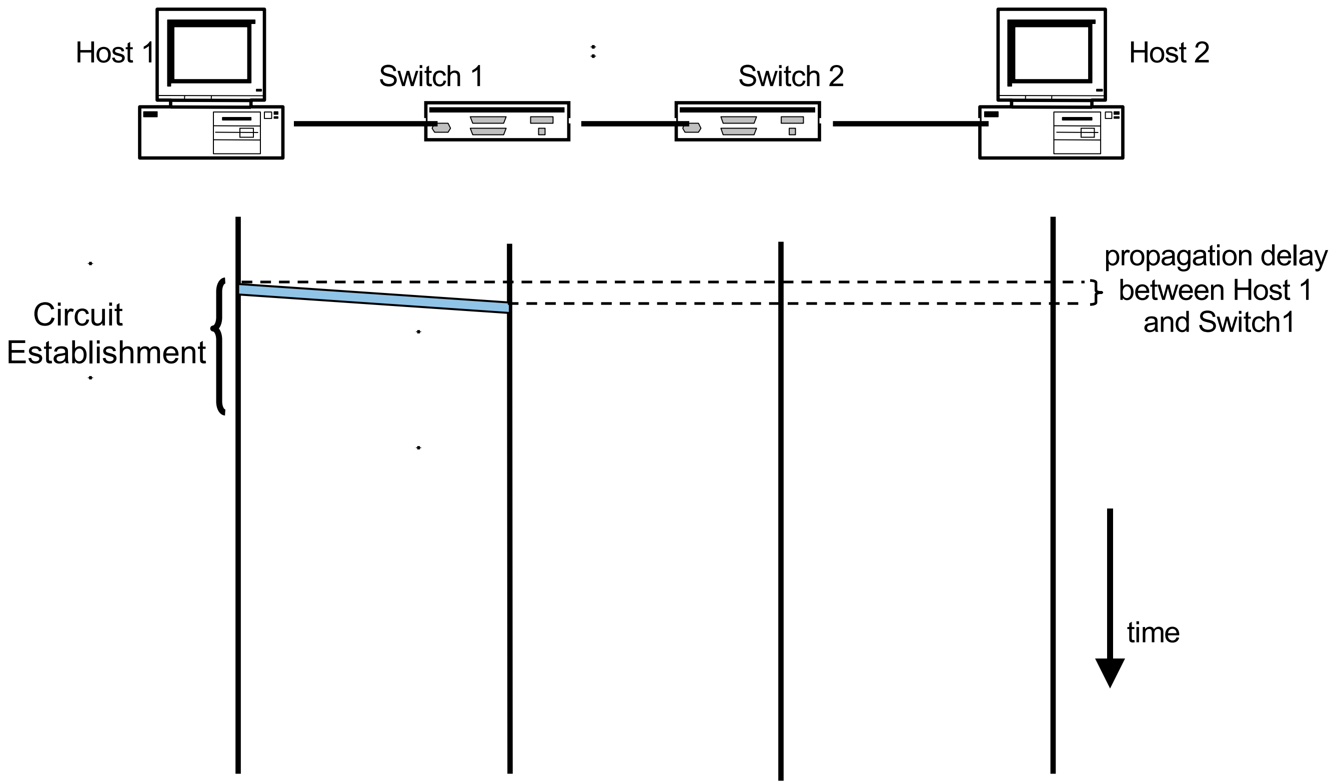
Source: wikipedia

TKN

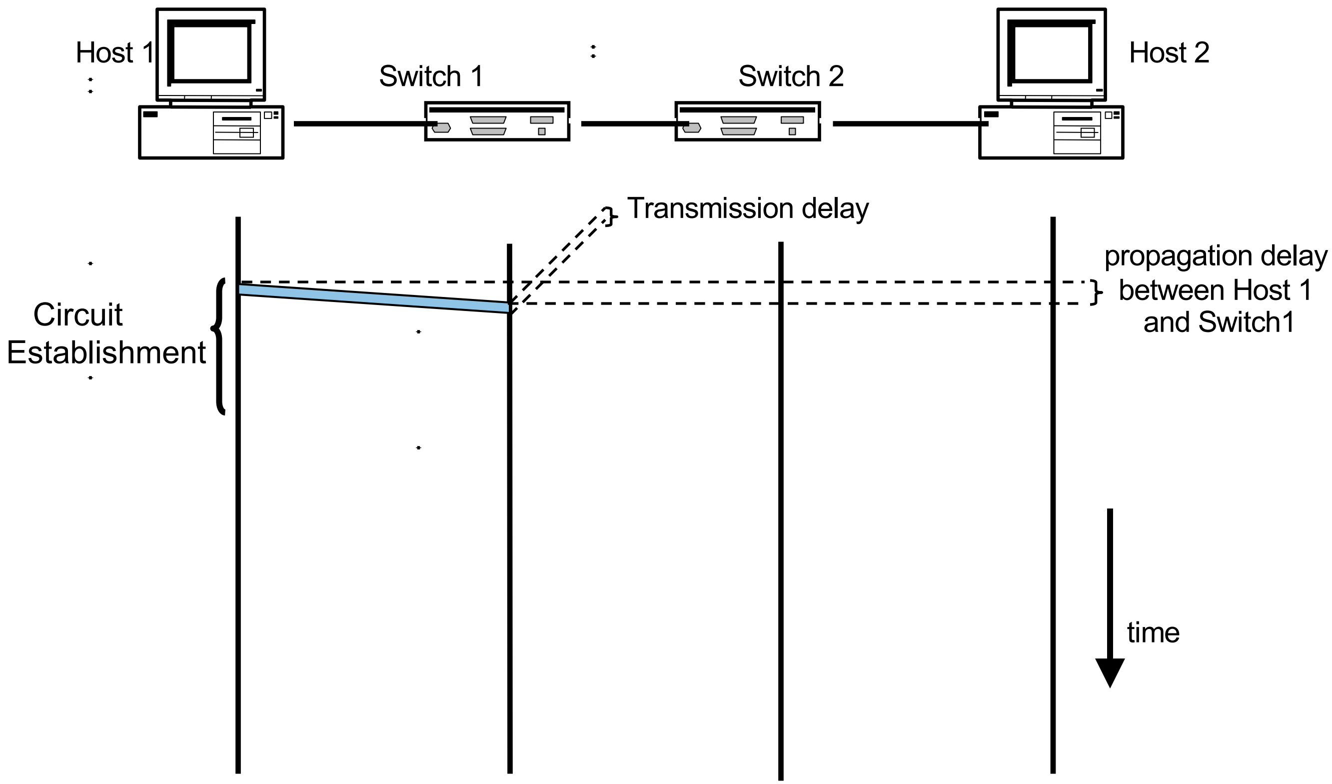
Timing in Circuit Switching (1)



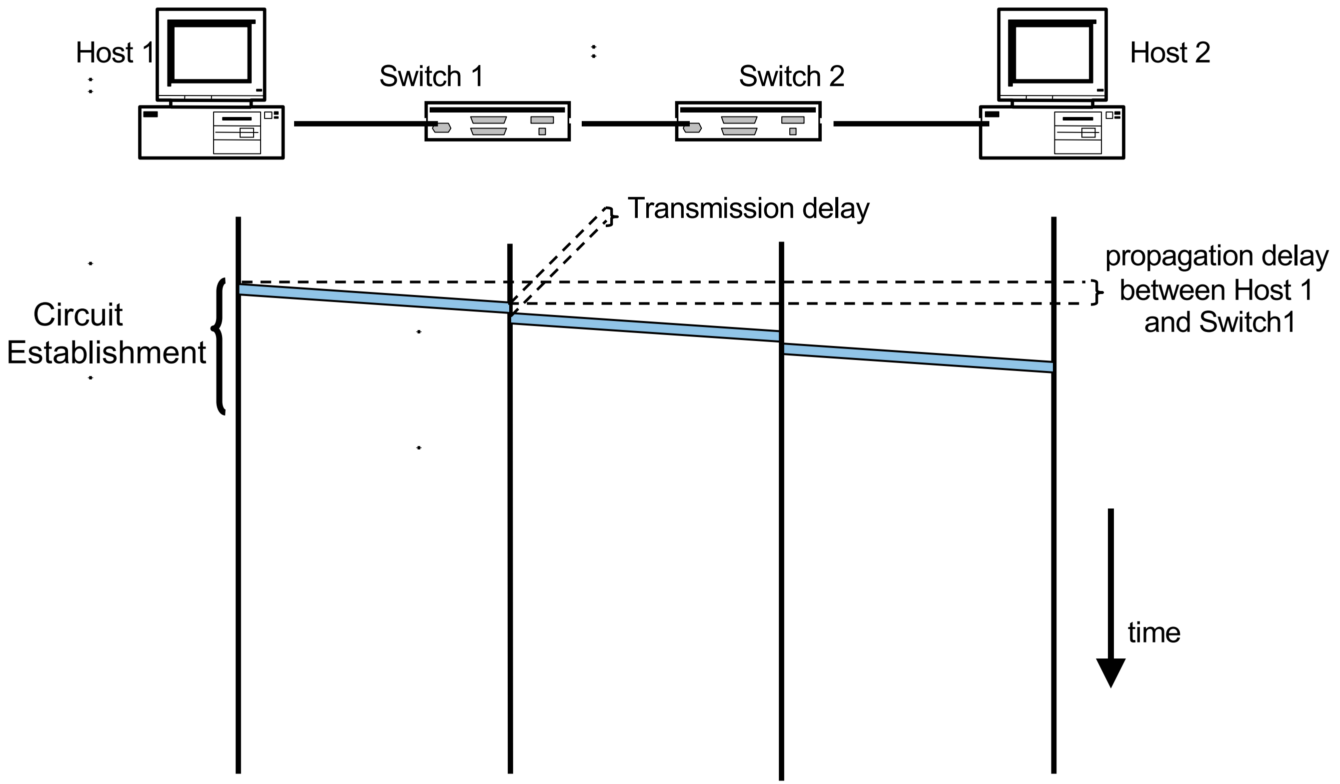
Timing in Circuit Switching (2)



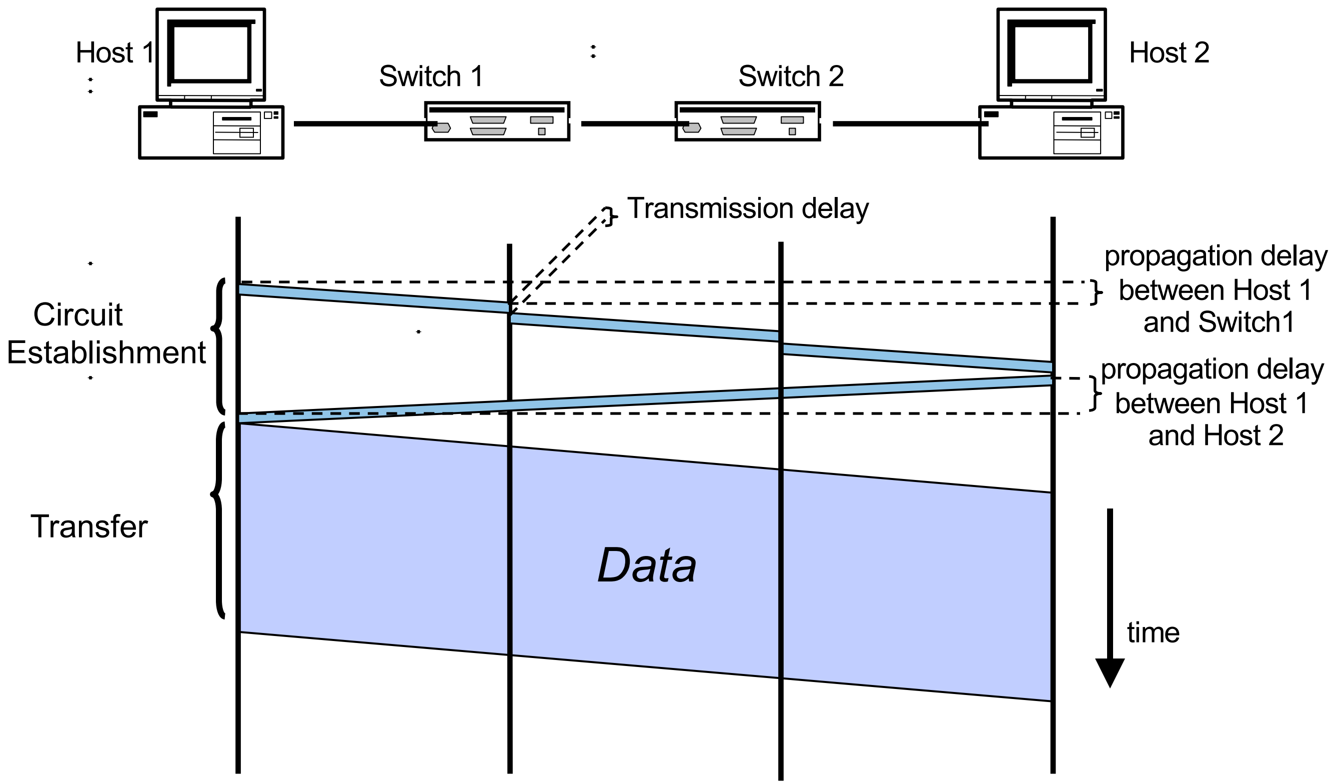
Timing in Circuit Switching (3)



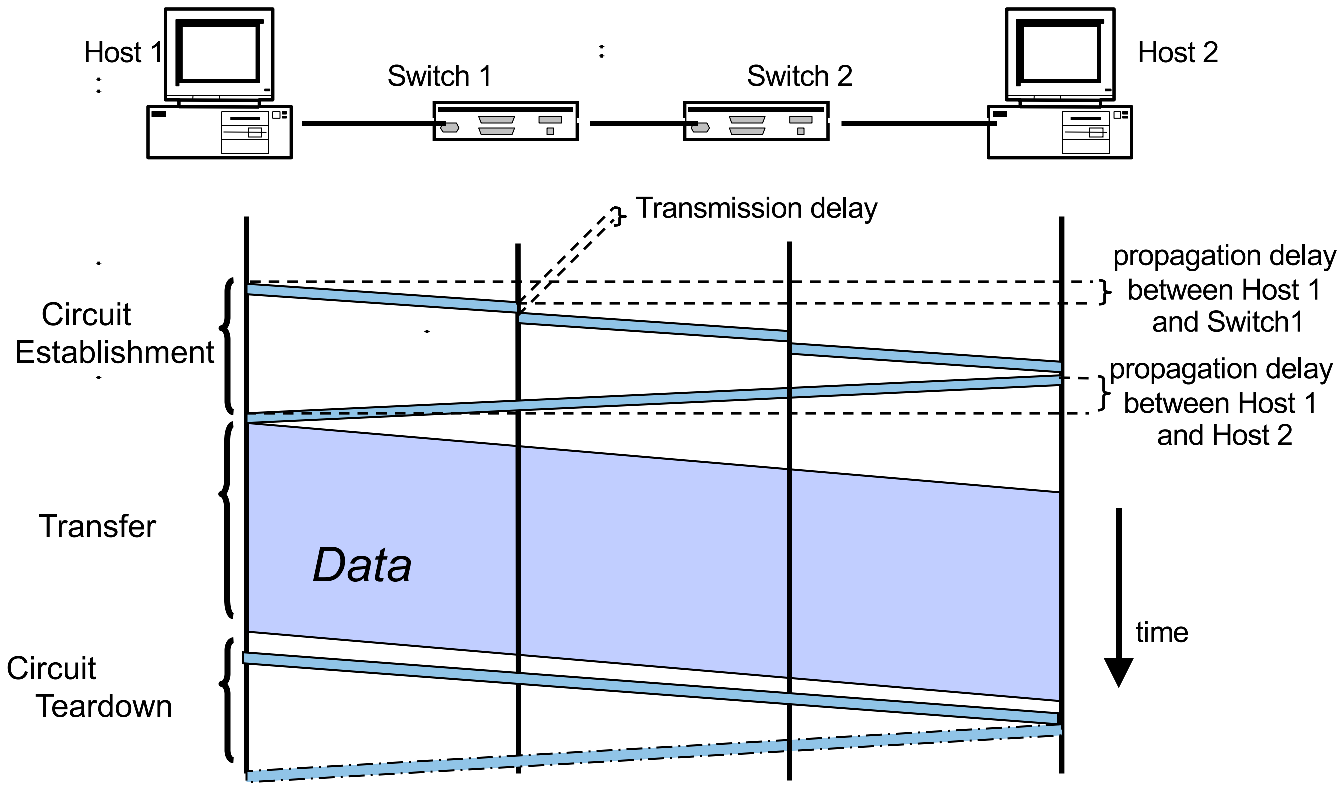
Timing in Circuit Switching (4)



Timing in Circuit Switching (5)



Timing in Circuit Switching (6)

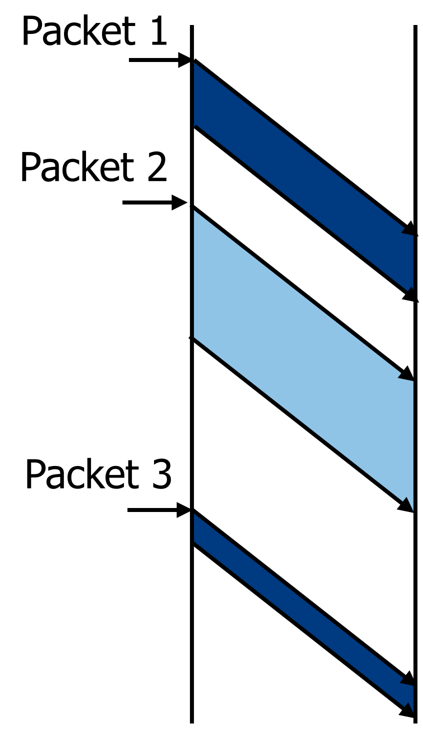


Circuit switching – Evaluation

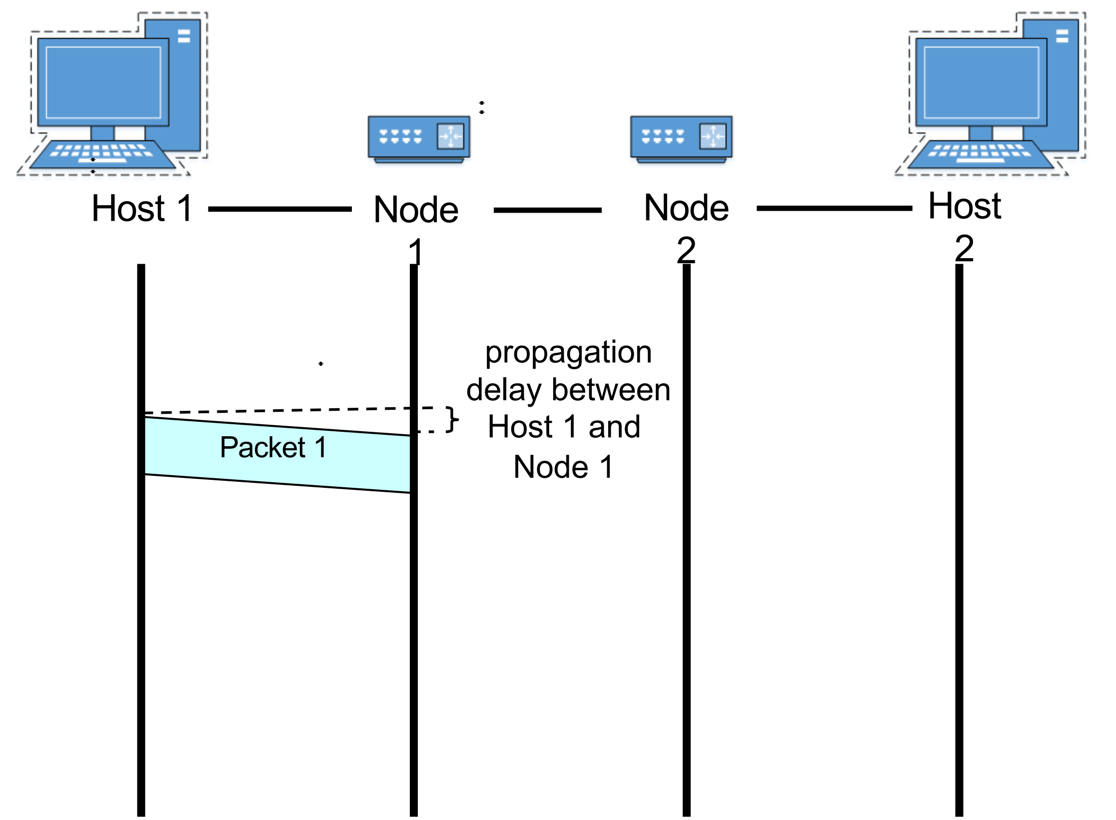
- Advantages
  - Once circuit is established, the resources are guaranteed to participating terminals,
  - Once circuit is established, data has only to follow the circuit (forwarding is very simple)
- Disadvantages
  - The need to establish the circuit upfront delays the begin of data transmission,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

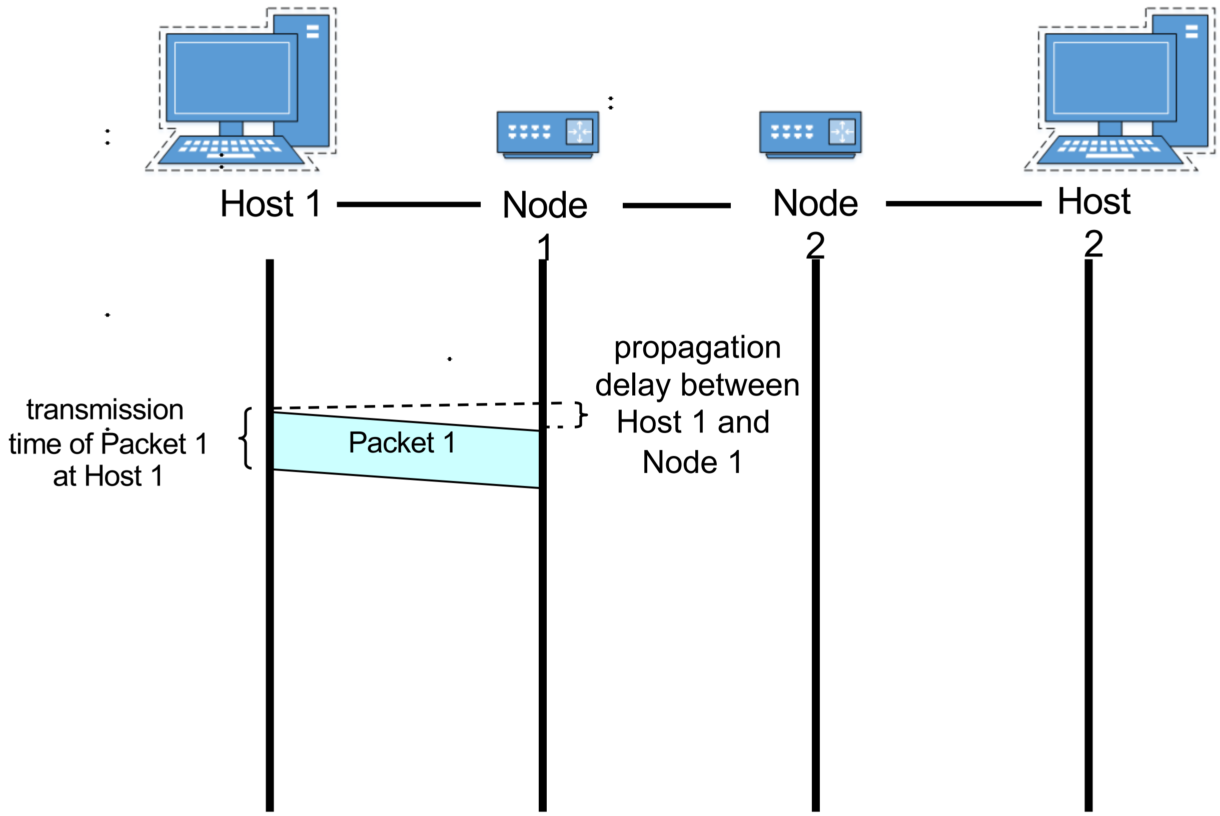
- Chunk data into packets
  - Packets contain some actual data that is to be delivered to the recipient (can have different, but bounded size),
  - Also need administrative information, e.g., who is the recipient,
  - Sender sends out a packet occasionally, instead of a continuous flow of data
- Problems: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



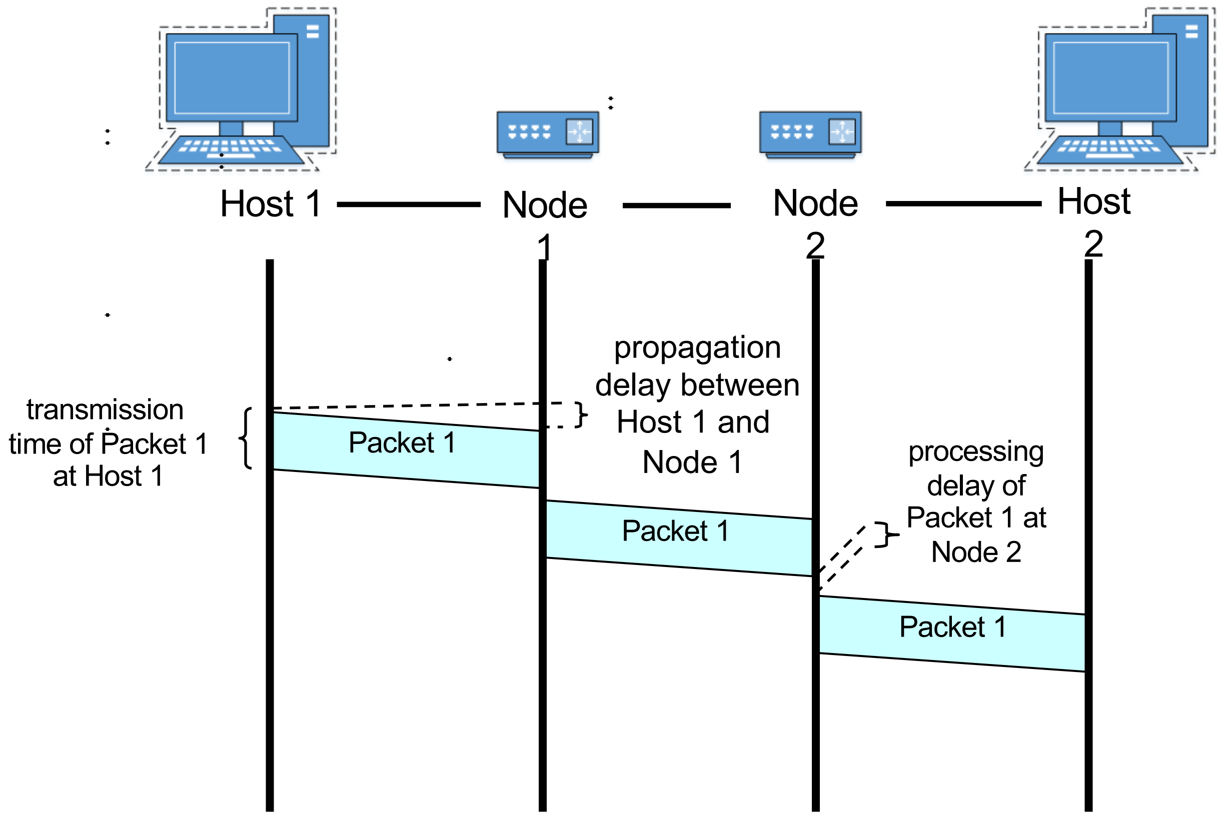
Timing of Datagram Packet Switching (1)



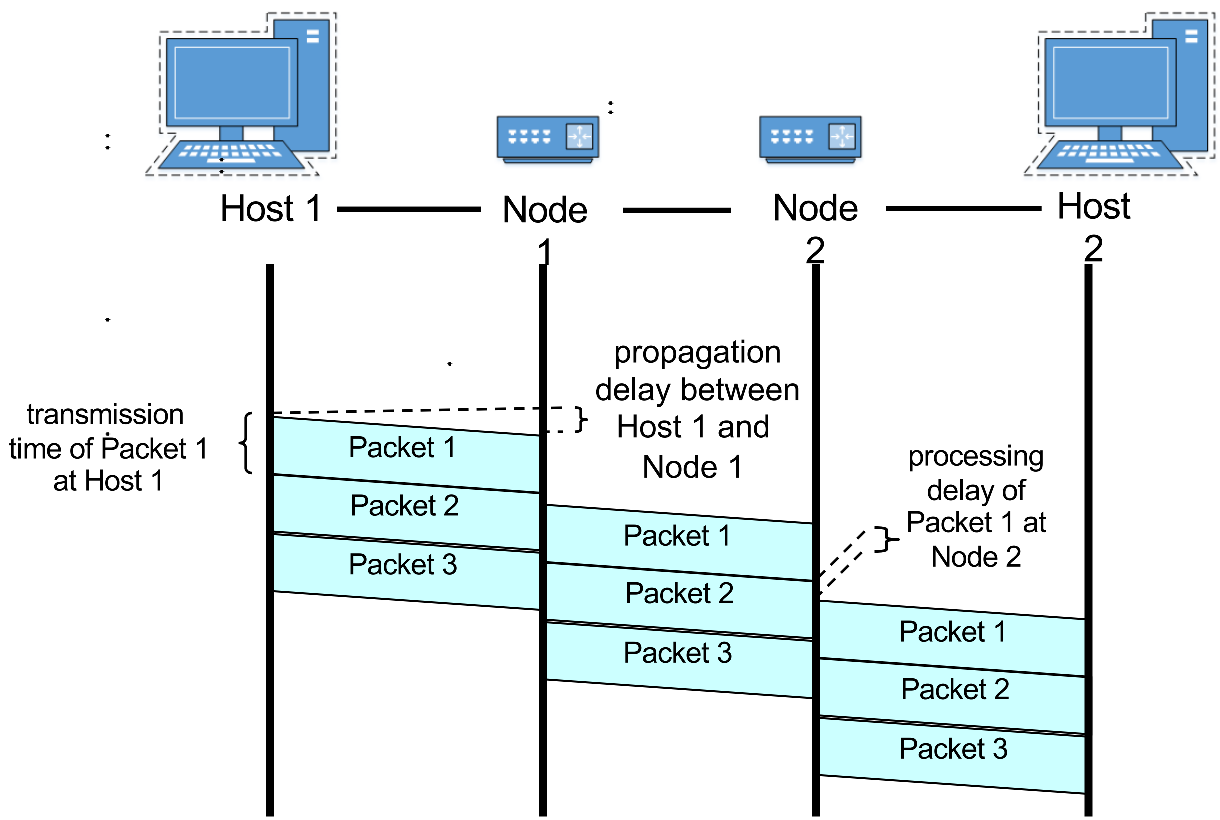
Timing of Datagram Packet Switching (2)



Timing of Datagram Packet Switching (3)



Timing of Datagram Packet Switching (4)

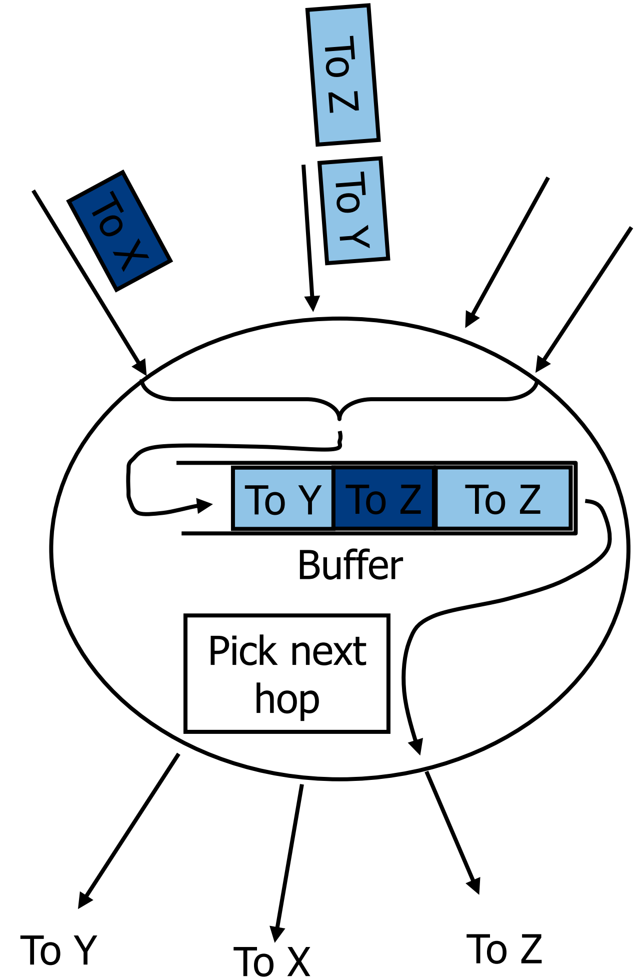


Comparison

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

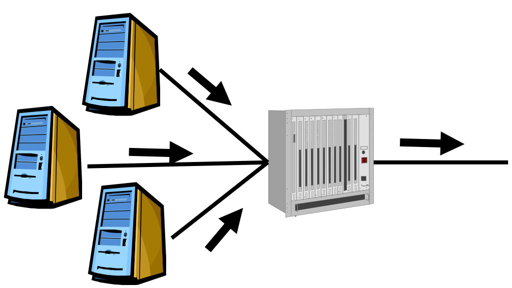
Packet Switches

- 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



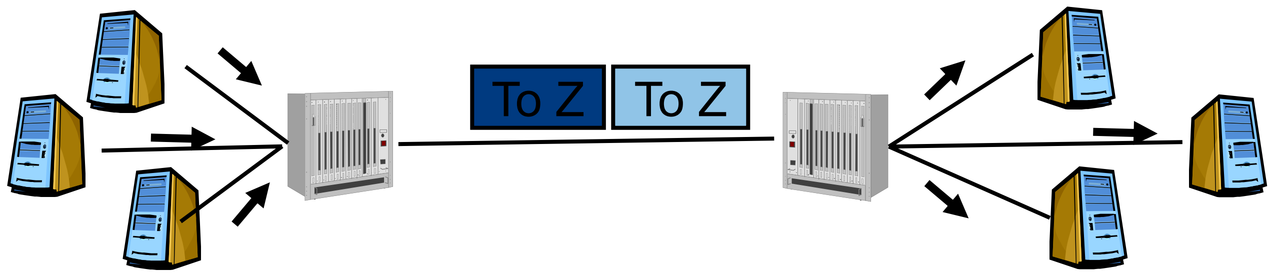
Multiplexing

- 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

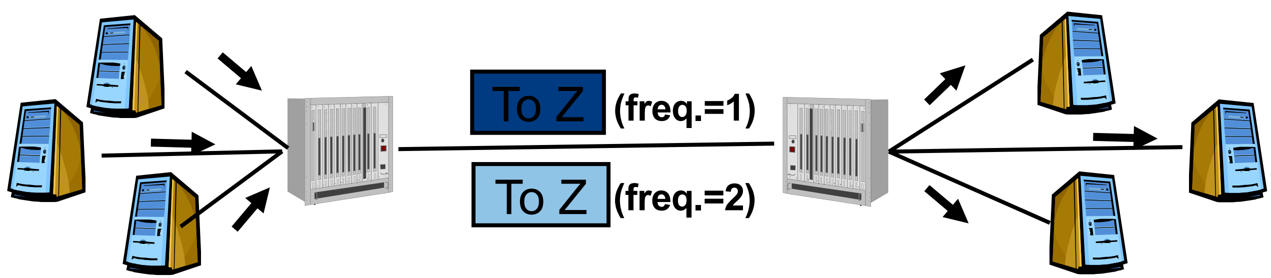


Multiplexing II

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

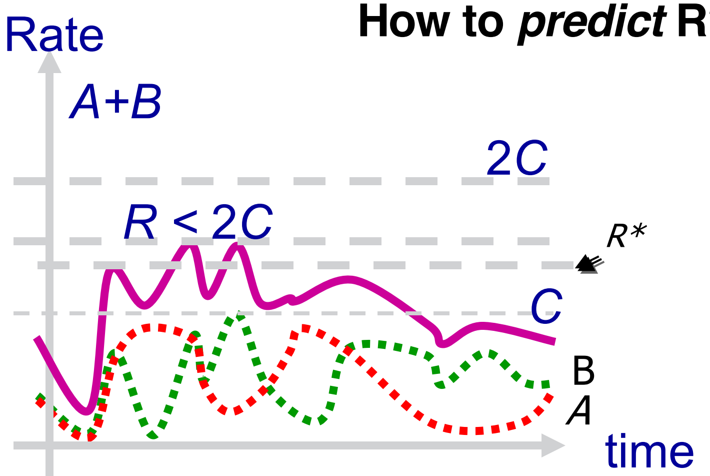


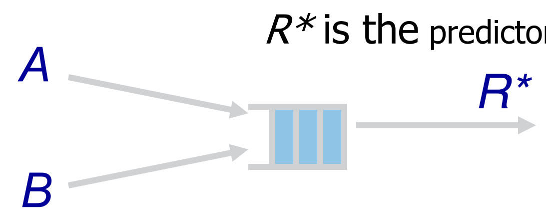
- Alternative: Frequency Division Multiplexing (FDM)
  - Use different frequencies to transmit several packets at the same time



Statistical Multiplexing Gain

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





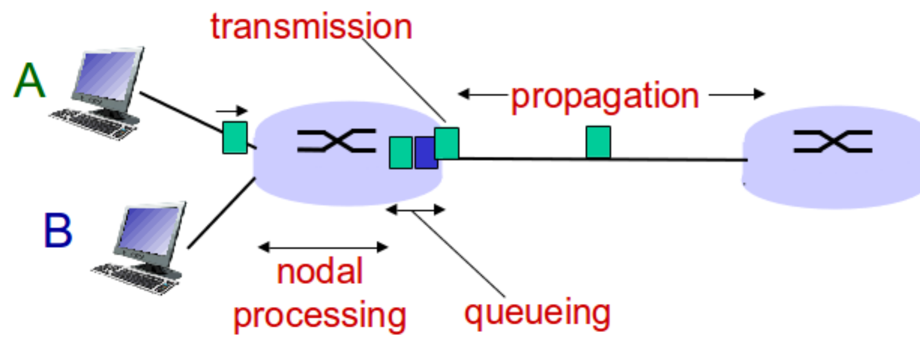
Statistical multiplexing gain (SMG) = $2C/R^*$

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

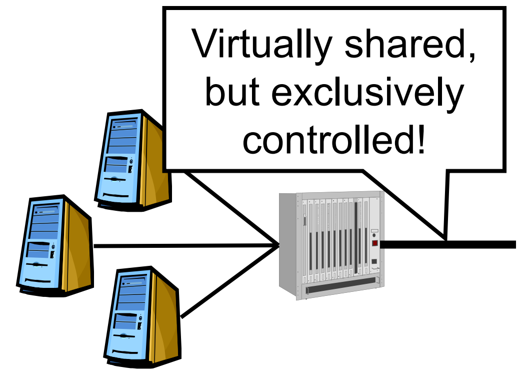
- 1. **Nodal processing**:
  - Check bit errors
  - Determine output
- 2. **Queueing**:
  - Time waiting at output for transmission
  - Depends on congestion at router
- 3. **Transmission delay**:
  - R = link bandwidth (bps)
  - L = packet length (bits)
  - Time to send bits into link: L/R
- 4. **Propagation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

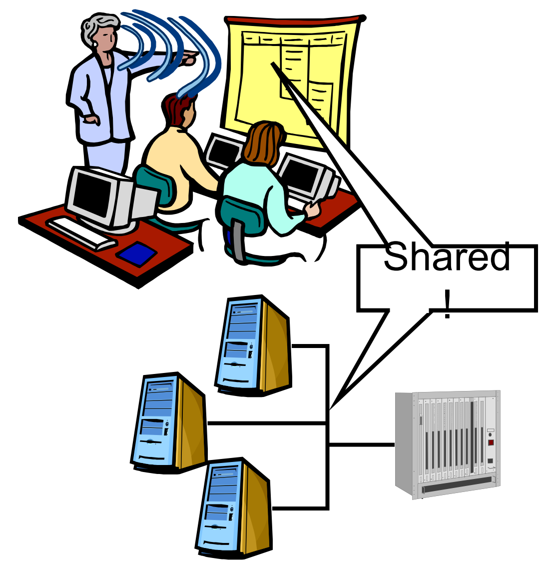


[Cheng, Lehigh Univ., op. cit.]

Multiplexing & shared resources

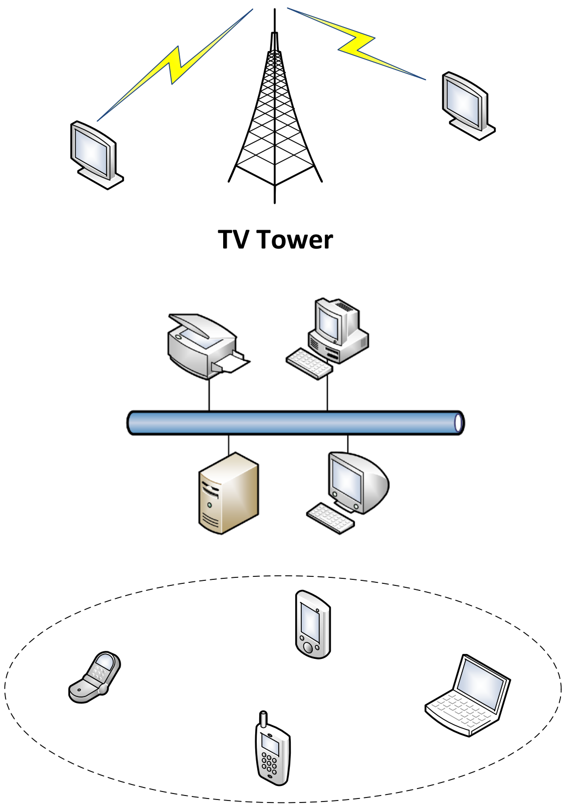
- Multiplexing can be viewed as a means to regulate the access to a resource that is shared by multiple users
  - The switching element/its outgoing line
  - With the switching element as the controller
- Other examples of “shared resources”?
  - Classroom, with “air” as physical medium
- Characteristic: 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



Klassifikation von Kommunikationssystemen

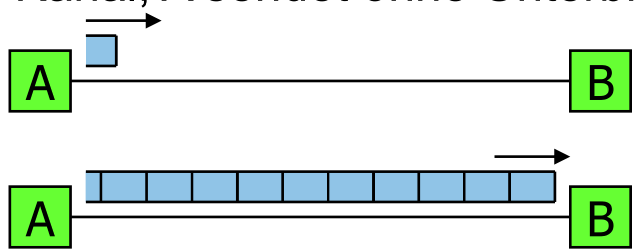
- Leistungsanalyse für Paketvermittlung

- Erste Fragestellungen:
  - Wie lange dauert die Übertragung eines Datenobjekts?
  - Welchen Einfluss haben Bitrate und Ausbreitungsverzögerung?
  - Wie groß ist die Speicherkapazität eines Datenkanals?

Klassifikation von Kommunikationssystemen

- Produkt aus Bitrate und Verzögerung
  - Bitrate R, Ausbreitungsverzögerung D vom Sender zum Empfänger
  - einfacher Kanal, A sendet ohne Unterbrechung an B

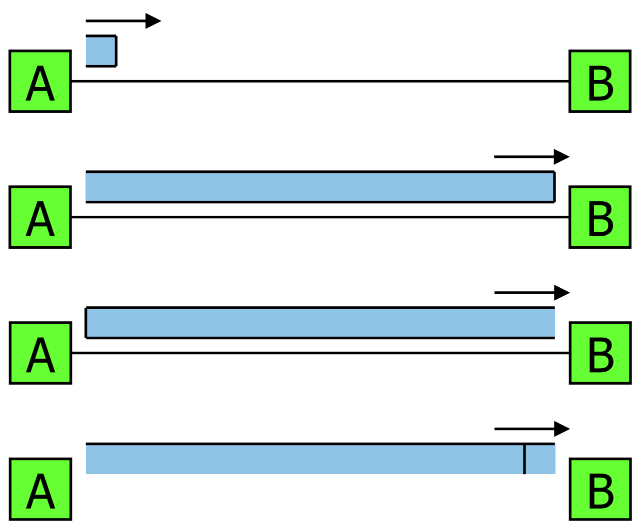
RD > 1:



t = 0: A beginnt zu senden

t = D: erstes Bit erreicht B,
RD Bits sind mittlerweile gesendet

RD < 1:



t = 0: A beginnt zu senden

t = D: der Anfang des Bits erreicht B,
RD·100% des Bits sind mittlerweile gesendet

t = 1/R: das Ende des Bits verläßt A

t = 1/R + D: das Ende des Bits erreicht B

Klassifikation von Kommunikationssystemen

- Kanalpuffergröße in Bits
  - $$R \cdot D = \frac{D}{1/R} = \frac{d/v}{1/R} = \frac{\text{Ausbreitungsverzögerung}}{\text{Bitsendezeit}}$$

    = Anzahl gesendeter Bits während sich das erste Bit vom Sender zum Empfänger ausbreitet = **Kanalpuffergröße in Bits**
  - Beispiel für RD > 1:
    - R = 100 Mbps, d = 4800 km, v = $3 \cdot 10^8$m/s
    - $$RD = 100 \cdot 10^6 \frac{bits}{s} \cdot \frac{4800 \cdot 10^3 m}{3 \cdot 10^8 m/s} = 1600 \cdot 10^3 bits = 195{,}3\, KB$$
  - Beispiel für RD < 1:
    - R = 10 Mbps, d = 10 m, v = $2 \cdot 10^8$m/s
    - $$RD = 10 \cdot 10^6 \frac{Bits}{s} \cdot \frac{10\, m}{2 \cdot 10^8 m/s} = 0{,}5\, Bits$$

Klassifikation von Kommunikationssystemen

- Kanalpuffergröße in Paketen

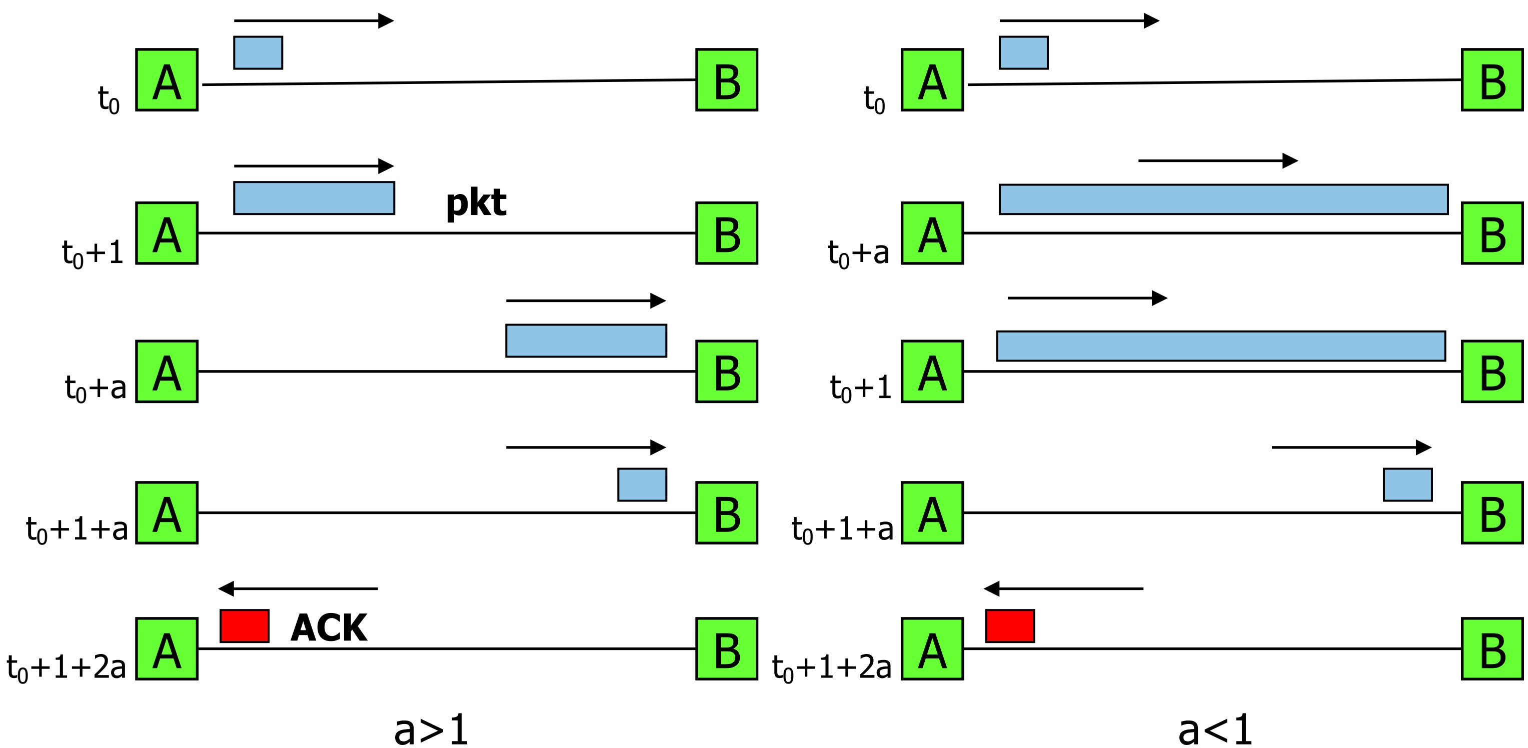
  - mit Paketgröße L:

$$a = \frac{R \cdot D}{L} = \frac{d / v}{L / R} = \frac{\text{Ausbreitungsverzögerung}}{\text{Paketsendezeit}}$$

= Anzahl gesendeter Pakete während sich das erste Bit vom Sender zum Empfänger ausbreitet = **Kanalpuffergröße in Paketen**

Klassifikation von Kommunikationssystemen

- Normierung der Zeit durch Paketsendezeit (L/R = eine Zeiteinheit), dann
  - ist 1 Zeiteinheit die Zeit zum Senden eines Pakets (1 L/R)
  - sind a Zeiteinheiten die Ausbreitungsverzögerung
    (a · L/R = RD/L · L/R = D)



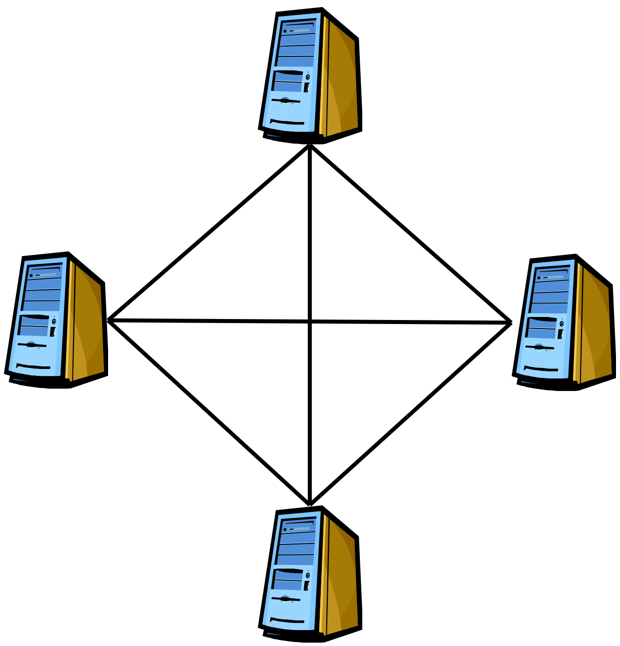
Einige Werte für die Kanalspeicherkapazität a

Bitrate (Mbps)	Paketgröße (Bits)	Entfernung (km)	a
1	1000	1	0,005
1	1000	3000	15
1	1000	35863	119,5
1	10.000	1	0,0005
1	10.000	3000	1,5
1	10.000	35863	11,95
10	1000	0,05	0,0025
10	1000	0,5	0,025
10	10.000	0,05	0,00025
10	10.000	0,5	0,0025
100	1000	0,1	0,05
100	10.000	0,1	0,005
1000	1000	0,1	0,5
1000	10.000	0,1	0,05

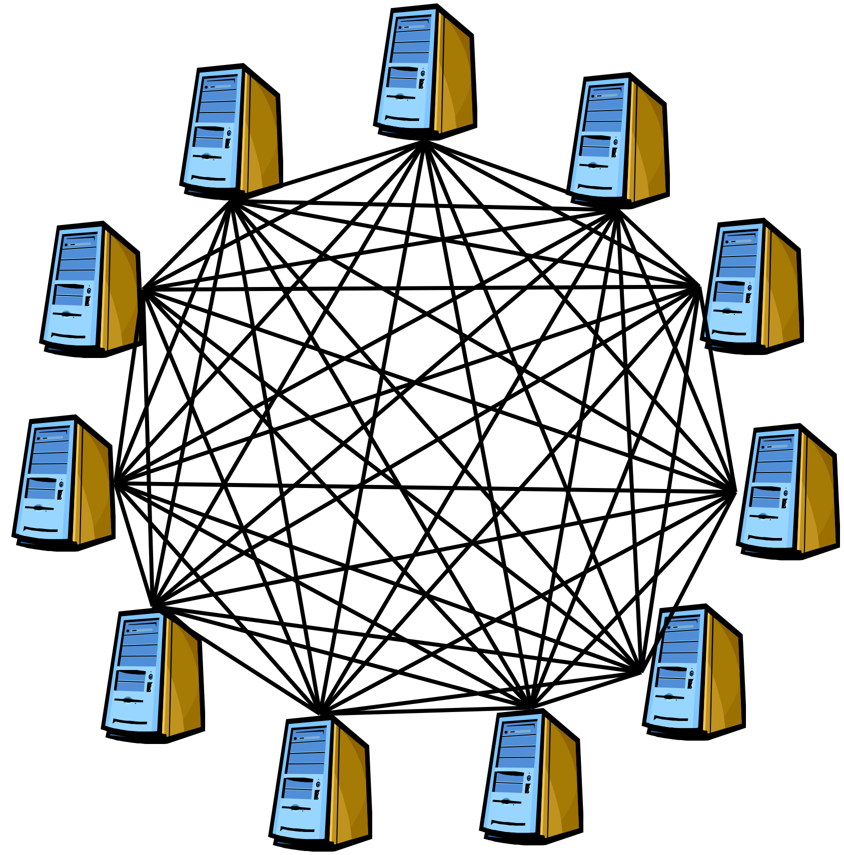
Klassifikation von Kommunikationssystemen

- Topologie

Vier Rechner:

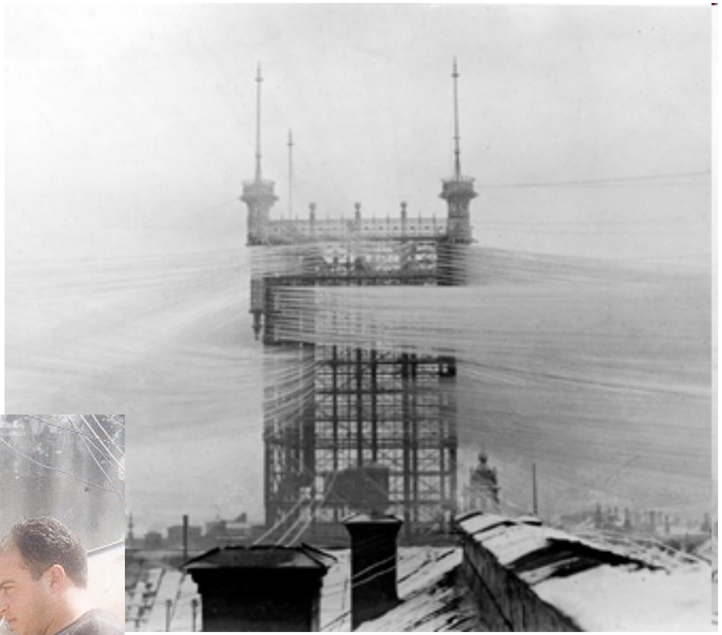


Elf Rechner:



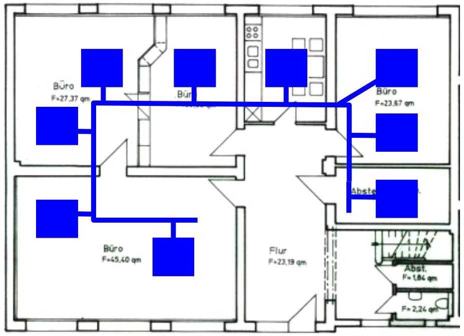
Klassifikation von Kommunikationssystemen

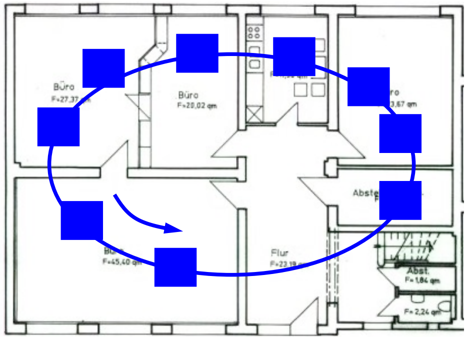
- Topologie

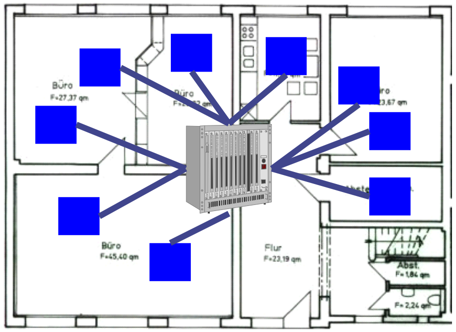


Klassifikation von Kommunikationssystemen

- Topologie
  - Mehr Struktur: Bus, Ring, Stern

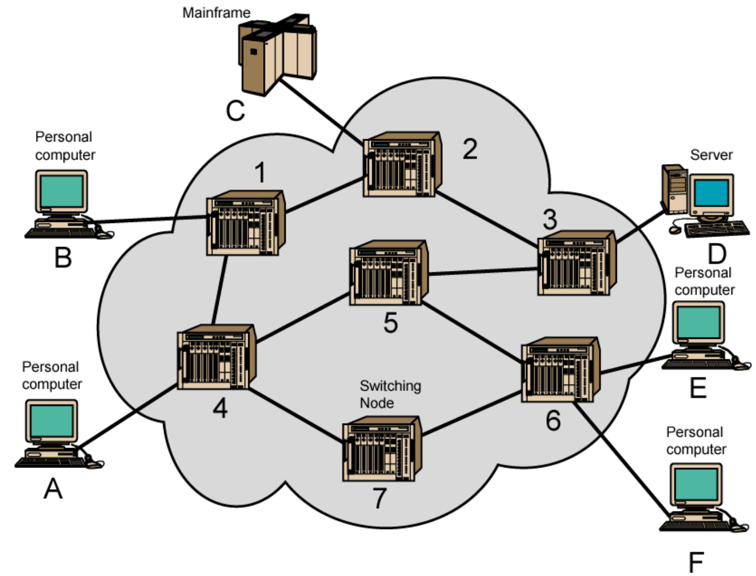






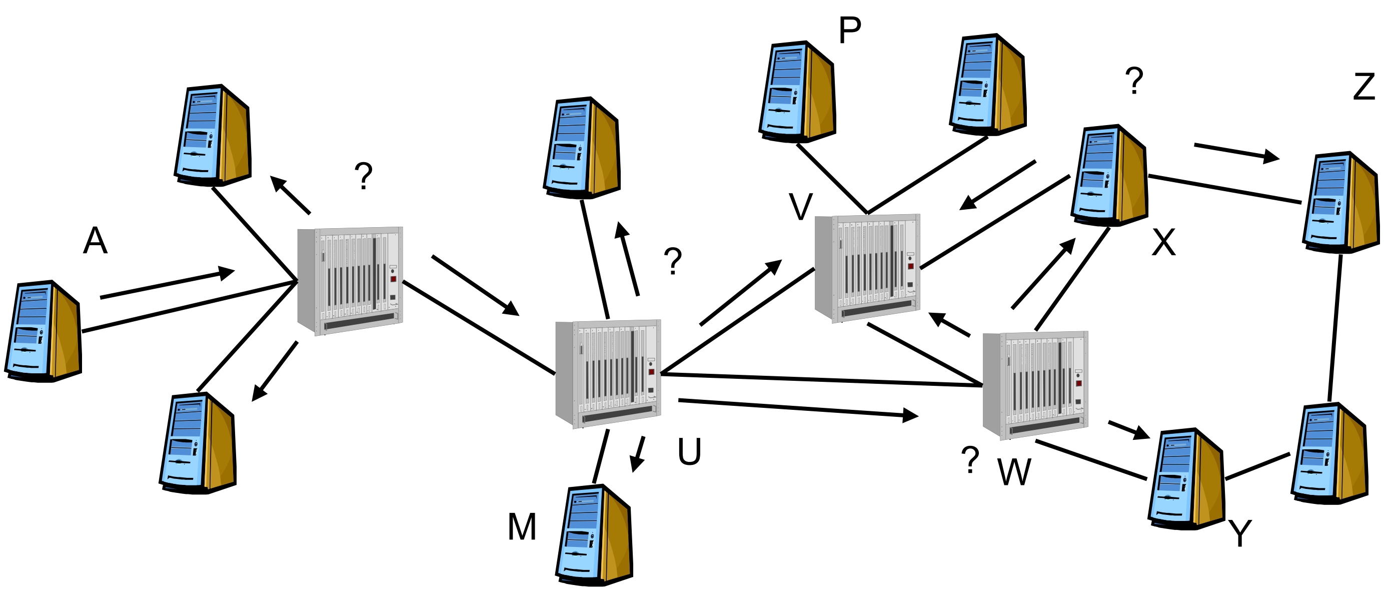
Reminder - Switched Network

- 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?

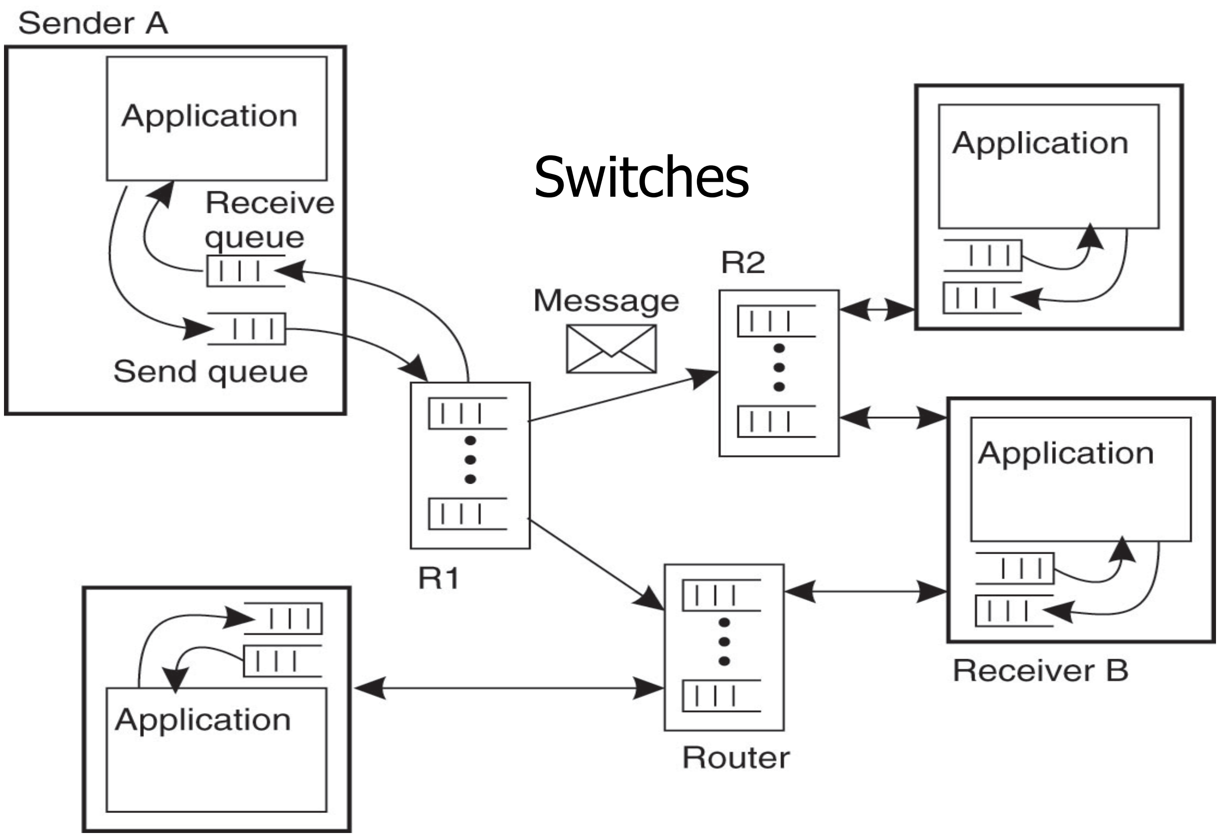


TKN

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



TKN

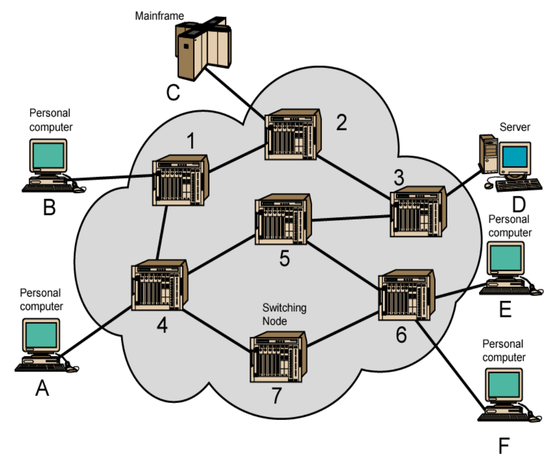
What is the value of a Network?

- 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]

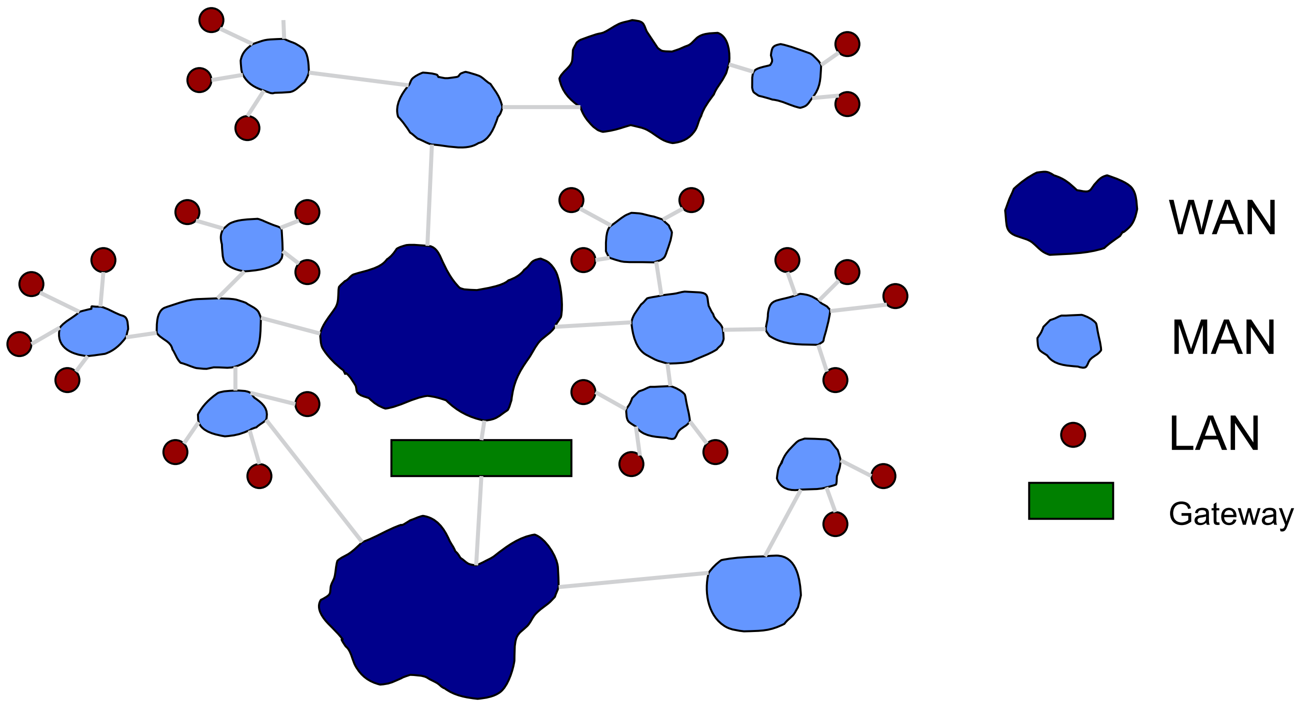
[1] Briscoe, B., Odlyzko, A., & Tilly, B. (2006). Metcalfe's law is wrong-communications networks increase in value as they add members-but by how much?. IEEE Spectrum, 43(7), 34-39.

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

TKN

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