Fundamentals of Communications Networks

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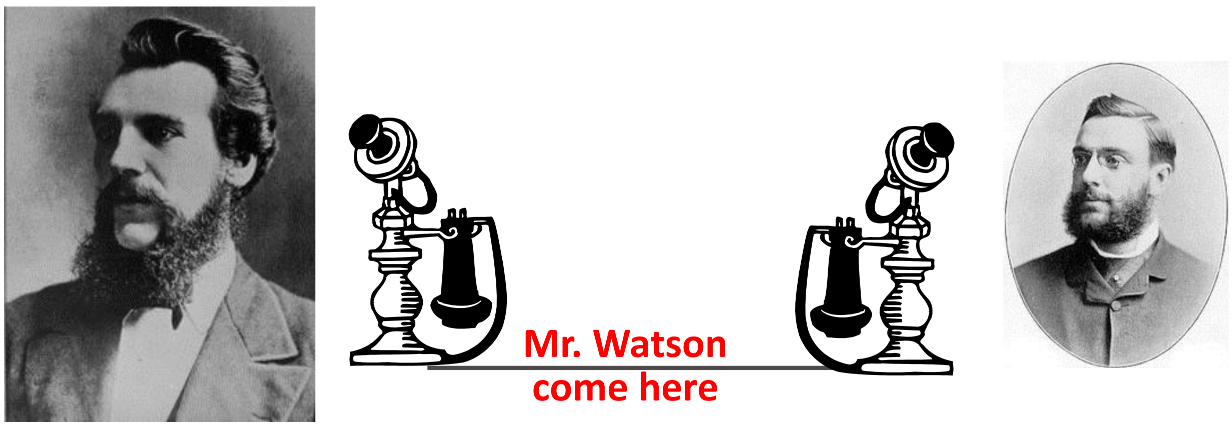
Digital Communications *Services* and *Networks*

Father of the *telephone*

Everyone knows that the father of the **telephone** was
Alexander Graham Bell
(along with his assistant Thomas Watson)



But they are not relevant for our present course for **3 reasons**

Digital vs. Analog

1. Bell's telephone was **analog** (see patent 174,465)
   while we will deal only with **digital** communications

digital

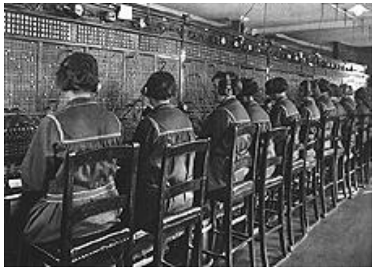
analog

digital

Product vs. Service

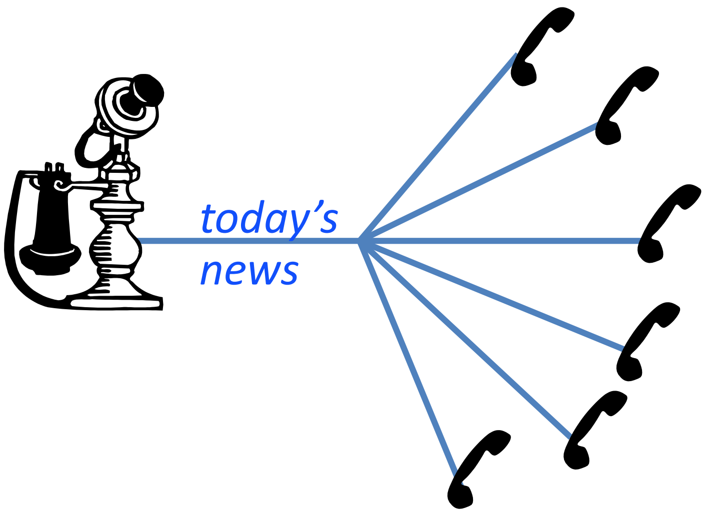
2. Bell's business model was to sell phones to customers

while we deal only with communications **services**



Telephone Network

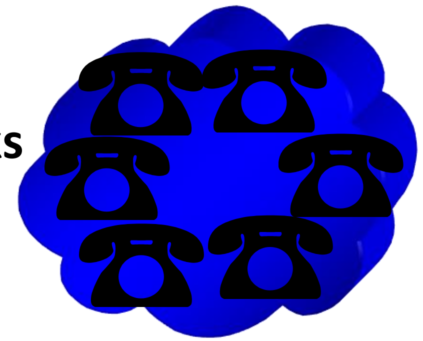
3. Bell's original idea was point-to-multipoint (broadcast)



his backer (and father in law)

convinced him to adopt **point to point** connectivity

while we will deal only with communications **networks**



Father of the telephone *network*

The father of the telephone **network** was **Theodore Vail**
- Cousin of Alfred Vail (Morse's co-worker)
- Ex-General Superintendent of US Railway Mail Service
- First general manager of Bell Telephone
- **Father of the PSTN**

Organized telephony as a **service** (like the *postal service*!) *

Why *else* is he important?
- Established principle of reinvestment in R&D
- Established Bell Telephones IPR division
- Executed merger with Western Union to form AT&T
- Solved major technological problems
  - use of copper wire
  - use of twisted pairs

* **Vailism** is the philosophy that public services should be run as closed centralized monopolies for the public good

Why is *digital* important ?

Communications is about moving information from place to place

Information comes in many forms :

- telephone quality Speech
- high quality audio
- pictures
- video
- text files
- executable files
- synchronization/Timing (frequency and Time of Day) information
- …

some of which are analog and some digital

It would be plausible that

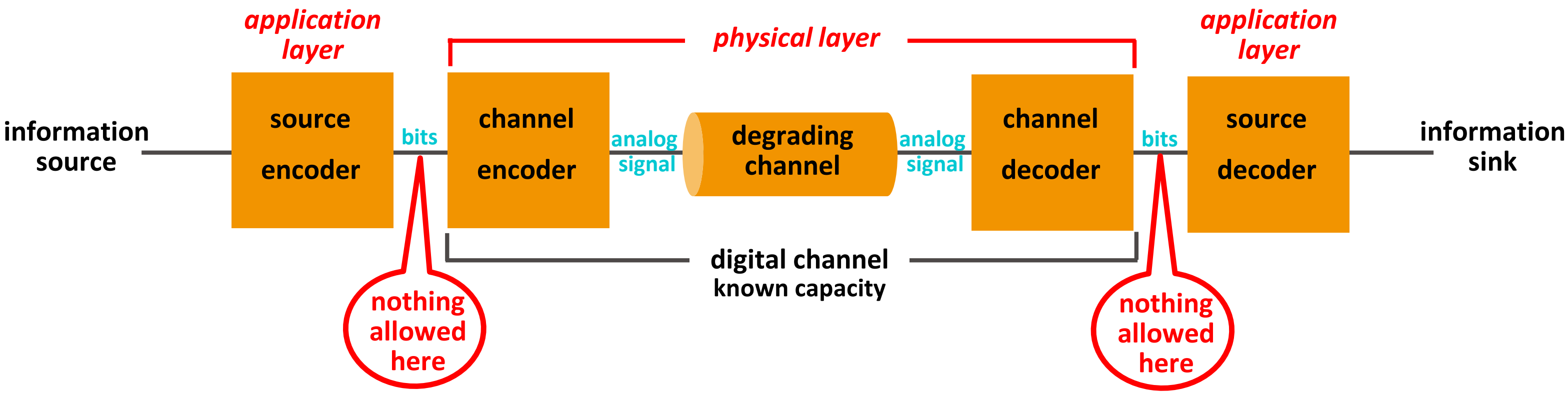
- the best way to send analog information is via analog communications
- the best way to send digital information is via digital communications

Shannon showed us that this is wrong

It is always best to use digital communications

Shannon's 3 theorems

1. **Separation Theorem**



2. **Source Encoding Theorem**

   Information can be quantified and is commonly measured in bits (and bytes, where each byte is 8 bits)

   Do not confuse Tukey's bit with Shannon's bit

   - Tukey's bit (**bi**nary digi**t**) is a symbol for representing number
   - Shannon's bit is the basic unit of information

3. **Channel Capacity Theorem**

   Physical links have finite capacity (bits per second)

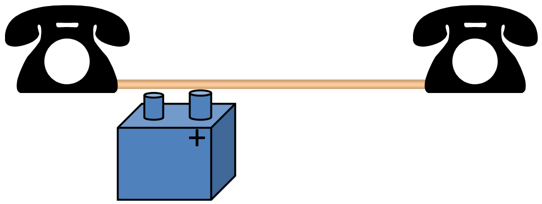
   $C = BW \log_2 (SNR + 1)$

Why is *service* important?

In the Bell-Watson model

the customer pays once, but is responsible for

- installation
  - wires
  - wiring
- operations
  - power
  - fault repair
  - performance (distortion and noise)
- infrastructure maintenance



while the Bell company is responsible only

for providing functioning telephones

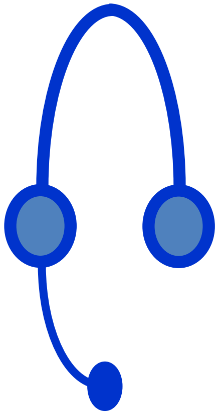
In the Vail model the customer pays a monthly fee

and the **S**ervice **P**rovider assumes responsibility for everything

including fault repair and performance maintenance

The telephone company owns the telephones and even the wires in the walls !

Why do we pay for services ?



Generally good (and frequently much better than toll quality) voice service is available free of charge (e.g., Skype)

So why does anyone pay for ***voice*** services ?

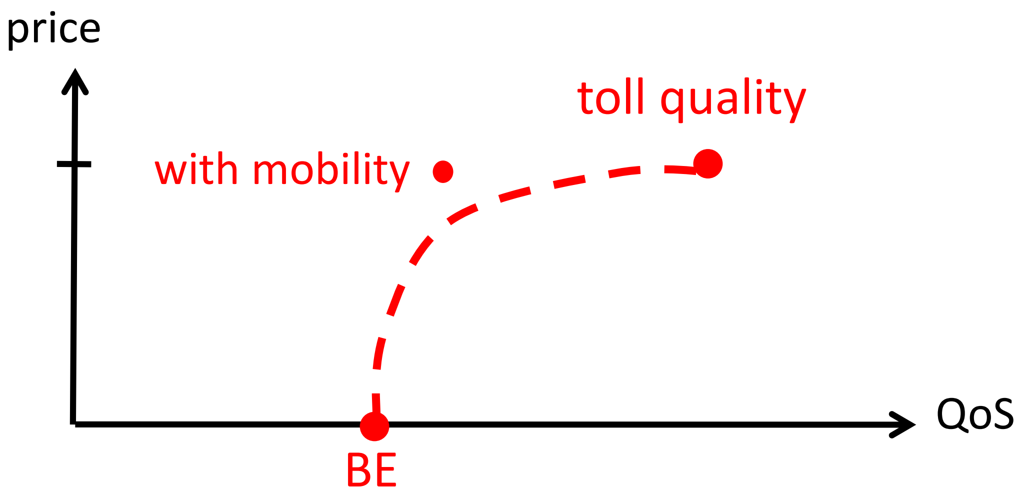
Similarly, one can get free
- (WiFi) Internet access
- email boxes
- search services
- file storage and sharing
- web hosting
- software services

So why pay for ***any*** service ?

Paying for QoS

The simple answer is that one no longer pays for a (best effort) service
one pays for **Q**uality **o**f **S**ervice guarantees

For example, for voice communications services



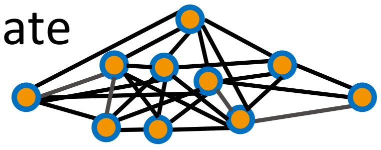
Of course, one really would like to pay for **Q**uality **o**f **E**xperience

Mechanisms to measure and monitor QoS are called
Operations, **A**dministration, and **M**aintenance (not Management!!!)

Why is network important?

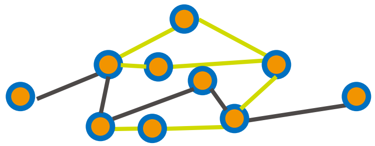
Early telegraph and telephone *connections* were individual *links*

However, it is impossible (or at least very inefficient)
to directly connect every 2 entities that need to communicate



Instead, one builds a **network**

Networks are arbitrary connected *graphs*



- nodes are called **N**etwork **E**lements
- edges are **links**

End-points (customers) are nodes, and are called *peers* or *hosts*

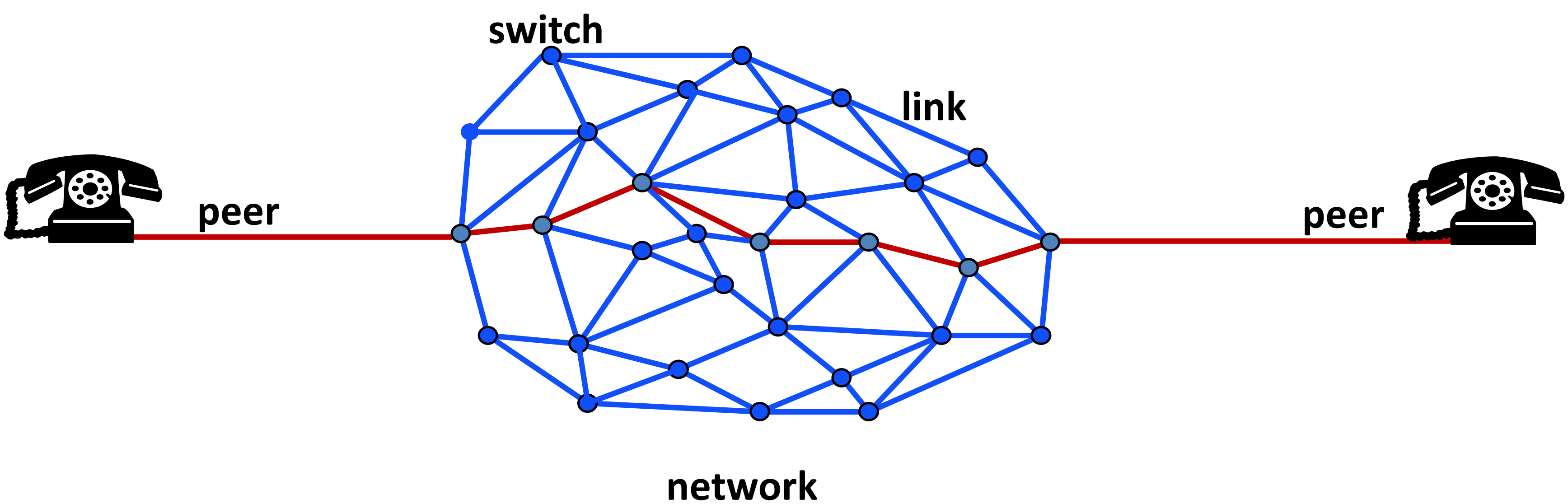
Nodes that are not end-points include :

- *switches*
- *routers*
- *gateways*
- *middleboxes*

Path Computation and routing

Finding a *path* through the graph is called *path computation* or *routing*

- *path computation when performed centrally*
- *routing* when performed by distributed protocols



Why is network important?

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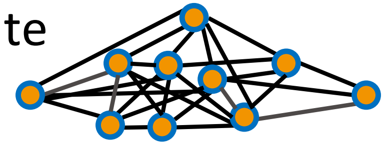
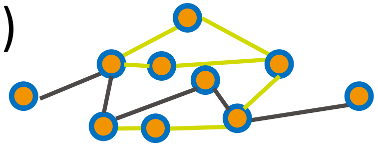
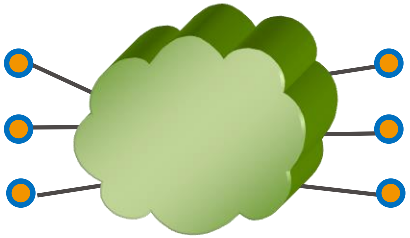


Instead, one builds a **network**

- create a connected *graph* of arbitrary topology
- find a path connecting any two points (a *virtual* connection)



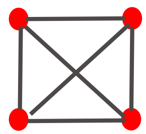
In order to implement this idea, one must
associate an *address* to each point
implement a scheme to forward information
through the network



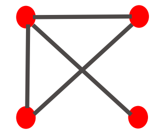
Network topologies

There are many possible network *topologies*

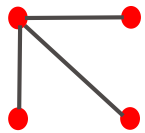
full mesh



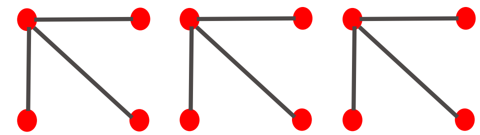
partial mesh



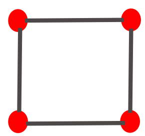
tree



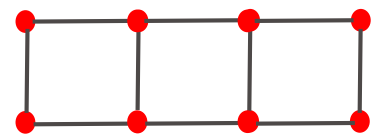
forest



ring



ladder

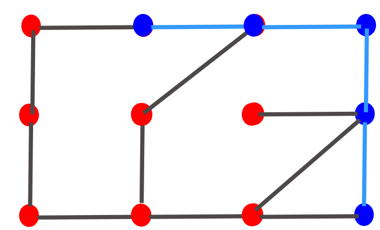


Autonomous networks can be joined to form **internetworks**

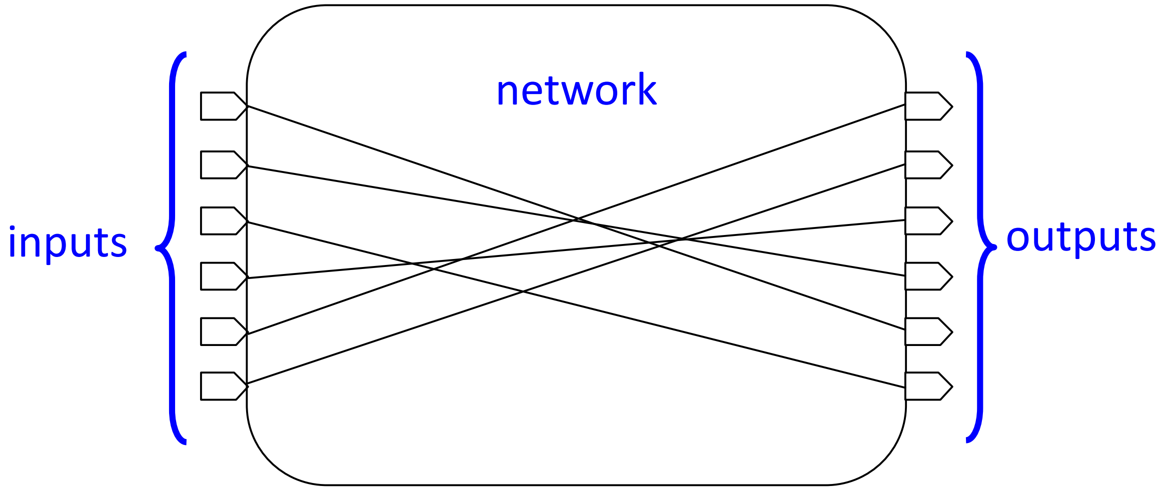
Networks can be partitioned to form **subnetworks**

Virtual **private networks (VPNs)**

are subnetworks accessible by a customer
and simulate a private network



Information Theory PoV



From an information-theory point of view
a network has *inputs* and *outputs*

Information is input to the network at an input
and is required to reach an output with no (or minimal) degradation

The association of an input with an output is called
a **connection** (when the association is long lived)
a **flow** (when the association is transient)

Network value

While communicating with only one peer has value
the capability of communicating with **N** peers has *more* value

What do we mean quantitatively by the value **V** of a network ?
Each peer is willing to pay for the capability of contacting N peers
The value is the payment of all peers

Values superlinear in N cause networks to merge

- **Metcalfe's Law** (follows from the number of *peer-peer calls*)
  $\mathbf{V \sim N^2}$
- **Reed's Law** (follows from the number of *conference calls*)
  $\mathbf{V \sim 2^N}$
- **Odlyzko's Law** (follows from Zipfian distribution of *peers of interest*)
  $\mathbf{V \sim N \log N}$
- **Stein's LinkedIn Law** (follows from **F**riend **O**f **A** **F**riend connectivity)
  $\mathbf{V \sim N^{4/3}}$

Characteristics (non-exhaustive list)

Links are characterized by :

- physical layer technology (DSL, fiber, LTE, WiFi, ...)
- synchronous / asynchronous
- QoS parameters, e.g.,
  - bandwidth / data-rate (constant, variable, shared)
  - latency (propagation delay)
- OAM mechanisms

Network elements are characterized by :

- functionality (Ethernet switch, IP router, NAT, firewall, ...)
- managed/unmanaged, participation in control protocols
- fan-in / fan-out (number of ports and type)
- processing data-rate

Networks are characterized by

- planning
- number of NEs and links
- addressing, segmentation, partitioning, interworking
- control and management mechanisms

Research topics

- How can Shannon theory be extended to networks ?
  - how much information is needed for addressing ? OAM ? redundancy ?
- Communications contribute 2% of global power / CO_2 emissions
  Energy consumption can be theoretically reduced by a factor of 10,000
  - how can we design networks to minimize power consumption?
- Virtual private networks function within the single global network
  - how can *intrusion* and *resource-theft* be avoided ?
  - how can *privacy* be maintained ?
- **Moore's law -** Best computation rate doubles every 2 years
  Butters' Law - Optical transmission speeds double every 9 months
  - how can we keep up ?
- How can huge or rapidly expanding networks be optimally *planned* ?
  - what should be centralized?
  - what should be distributed ?