Lecture 3

```
- How do we evaluate a network?
- How is communication organized?
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Circuits vs Packets

Circuits	**Packets**
predictable performance	unpredictable performance
inefficient use of network resources	efficient use of network resources
complex (state int he network)	simple (no state in the network)

How do we evaluate a network?

- Delay
- Loss
- Throughput

Delay

- How long does it take tos end a packet from its source to destination?
- Consists of four components
    - Transmission delay
        - Due to link properties
    - Propagation delay

        - Due to link properties
    - Queuing delay
        - Due to traffic mix and switch internals
    - Processing delay
        - Due to traffic mix and switch internals

A network link

- Link bandwidth
    - Number of bits sent / received per unit time (bits / sec or bps)
- Propagation delay
    - Time for one bit to move through the link (seconds)
- Bandwidth-Delay Product (BDP)
    - Number of bits “in flight” at any time
    - BDP = bandwidth x propagation delay

Example

- Same city over a slow link
    - bandwidth: ~100 Mbps
    - propagation delay: ~0.1 msec
    - BDP: 10,000 bits (1.25KBytes)
- Corss-country over fast link
    - bandwidth: ~10Gbps
    - propagation delay: ~10 msec

    - BDP: 10^8 bits (12.5 MBytes)

Transmission delay

- Time taken to push all the bits of a packet into the link
- Packet size / link bandwidth

Propagation delay

- Time taken to move one bit from one end of a link to the other
- Link length / link propagation delay

Queuing delay

- Time a packet sits in a buffer before it is processed
- If arrival rate > departure rate (**persistent overload**)
    - approaches infinity (assuming an infinite buffer)
    - in practice, finite buffer -> loss
- If arrival rate < departure rate
    - depends on burst size

Basic Queuing Theory Terminology

- Arrival process: how packets arrive
    - Average rate A
- W: average time packets wait in the queue
    - W for "waiting time"
- L: average number of packets waiting int he queue

    - L for “length of queue”

Little’s Law 1961

```
L = A x W
```

- Compute L: count packets in queue every second
    - How often does a single packet gets counted? W times
- Why do you care?
    - Easy to compute L, harder to compute W

Processing Delay

- Time taken for the switch to process a packet
    - Typically assume this is negligible

Loss

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

Throughput

- At what rate is the destination receiving data from the source?
    - Data size / transfer time
- Transfer time = F / R + propagation delay
    - F = file of size (bits)
    - R = average throughput

```
Where's my delay coming from?
```

How is communication organized?

- **Decompose** the problem into tasks
- **Organize** these tasks
- **Assign** tasks to entities (who does that)

The path of the letter

```
Semantic content -> Identity -> Location
```

In the Internet: decomposition

1. **Applications** [L7]
2. **Transport**: Reliable (or unreliable) transport) [L4]
3. **Network**: Best-effort global packet delivery [L3]
4. **Data link**: Best-effort local packet delivery [L2]
5. **Physical**: Physical transfer of bits [L1]

Layers

```
A part of a system with well-defined interfaces to other parts
```

- One layer interacts only with layer above and layer below
- Two layers interact only through the interface between them

Protocols and Layers

- Communication between peer layers on different systems is defined by **protocols**

Protocols

```
An agreement between parties on how to communicate
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- Defines the syntax for communication
    - **Header**: instructions for how to process the payload
    - Each protocol defined the format of its packet headers
        - e.g. the first 32 bits carry the destination address
    - And semantics
        - First a hello, then a request…
    - Protocols exits at many levels, hardware and software
        - Defined by variety of standard bodies (IETF, IEEE, ITU)

Protocols at different layers