Chapter 5
Link Layer and LANs

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Computer Networking:
A Top Down Approach
5th edition.
Jim Kurose, Keith Ross
Addison-Wesley, April 2009.
Synthesis: a day in the life of a web request

- journey down protocol stack complete!
  - application, transport, network, link
- putting-it-all-together: synthesis!
  - goal: identify, review, understand protocols (at all layers) involved in seemingly simple scenario: requesting www page
  - scenario: student attaches laptop to campus network, requests/receives www.google.com
A day in the life: scenario

- **Browser**
- **Comcast network** (68.80.0.0/13)
- **Google’s network** (64.233.160.0/19)
- **DNS server**
- **School network** (68.80.2.0/24)
- **Web server** (64.233.169.105)
- **Web page**
A day in the life... connecting to the Internet

- connecting laptop needs to get its own IP address, addr of first-hop router, addr of DNS server: use **DHCP**
- DHCP request *encapsulated* in **UDP**, encapsulated in **IP**, encapsulated in **802.1** Ethernet
- Ethernet frame *broadcast* (dest: FFFFFFFF) on LAN, received at router running **DHCP** server
- Ethernet *demuxed* to IP demuxed, UDP demuxed to **DHCP**
A day in the life… connecting to the Internet

- DHCP server formulates **DHCP ACK** containing client’s IP address, IP address of first-hop router for client, name & IP address of DNS server
- encapsulation at DHCP server, frame forwarded (*switch learning*) through LAN, demultiplexing at client
- DHCP client receives DHCP ACK reply

*Client now has IP address, knows name & addr of DNS server, IP address of its first-hop router*
A day in the life... ARP (before DNS, before HTTP)

- before sending **HTTP** request, need IP address of www.google.com: **DNS**
- DNS query created, encapsulated in UDP, encapsulated in IP, encapsulated in Eth. In order to send frame to router, need MAC address of router interface: **ARP**
- **ARP query** broadcast, received by router, which replies with **ARP reply** giving MAC address of router interface
- client now knows MAC address of first hop router, so can now send frame containing DNS query
A day in the life... using DNS

- IP datagram containing DNS query forwarded via LAN switch from client to 1st hop router
- IP datagram forwarded from campus network into Comcast network, routed (tables created by RIP, OSPF, IS-IS and/or BGP routing protocols) to DNS server
- Demuxed to DNS server
- DNS server replies to client with IP address of www.google.com
A day in the life... TCP connection carrying HTTP

- to send HTTP request, client first opens **TCP socket** to web server
- TCP ** SYN segment** (step 1 in 3-way handshake) *inter-domain routed* to web server
- web server responds with **TCP SYNACK** (step 2 in 3-way handshake)
- TCP **connection established!**
A day in the life... HTTP request/reply

- **HTTP request** sent into TCP socket
- IP datagram containing HTTP request routed to www.google.com
- web server responds with **HTTP reply** (containing web page)
- IP datagram containing HTTP reply routed back to client

- web page *finally (!!!)* displayed
Chapter 5: Summary

❖ principles behind data link layer services:
  ▪ error detection, correction
  ▪ sharing a broadcast channel: multiple access
  ▪ link layer addressing

❖ instantiation and implementation of various link layer technologies
  ▪ Ethernet
  ▪ switched LANS, VLANs
  ▪ PPP
  ▪ virtualized networks as a link layer: MPLS

❖ synthesis: a day in the life of a web request
Chapter 5: let’s take a breath

- journey down protocol stack complete (except PHY)
- solid understanding of networking principles, practice
- ..... could stop here .... but lots of interesting topics!
  - wireless
  - multimedia
  - security
  - network management
Queueing Theory Primer

1. What is the Poisson process

2. What is a single server queue?

3. Little’s formula & its applications

4. Poisson Queues
   - And a comparison of packet/circuit switching
Poisson process

- Allows to answer question like
  - “If I receive ten messages per minute, what is the probability that I receive 3 or more in the next second?”
  - Assumes that events happen independently at any particular time, with a constant “rate”.
    - Does not capture dependence or synchronization

- How to construct a Poisson process?
  - Iteratively: next event after an exp. Interval
  - Then start a new exp. interval
Poisson Process (Reminder)

Thm: These conditions are equivalent:

(i) The process is stationary and “spatial independent”
\[ \forall a, b, t \in \mathbb{R}, N([a + t; b + t]) = N([a; b]) \]
\[ \forall I, I' \text{ disjoint}, N(I) \text{ and } N(I') \text{ are independent.} \]

(ii) Condition (i) + \[ \mathbb{P}[N([a, b]) = k] = \frac{(\lambda(b-a))^k}{k!} e^{-\lambda(b-a)} \]

(iii) The inter-event times \{E_1, E_2, E_3, \ldots\} are i.i.d.
And follows exponential distribution
\[ \mathbb{P}[E_i > x] = e^{-\lambda x} \quad \mathbb{E}[f(E_i)] = \int_0^\infty \lambda e^{-\lambda x} f(x)dx \]

- The process is then called the Poisson Process(\(\lambda\))
Queueing Theory Primer

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2. What is a single server queue?
3. Little's formula & its applications
4. Poisson Queues
   - And a comparison of packet/circuit switching
**Single server queue**

- Allows one to model
  - Post-office, assembly lines, packets in a router
  - Answer question like “what is the average delay seen by a customer?”

- Parameters:
  - Input rate (Process of arrivals)
  - Service rate (customer served / unit of time)
  - The queue (Buffer size, Discipline used)
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Little’s formula

- Let us introduce notation
  - $\lambda$: is the arrival rate in the queue
- Let us consider two performance metric
  - $N$: average # of customers in \{queue, server\}
  - $D$: average time spent in the system
- Then we have $N = \lambda \times D$
  - Seems intuitive, and is true VERY generally
  - General arrival process, service rate
  - For any queue (buffer, discipline) and part of it
Applications of Little’s formula

- In an network interface card and links:
  - Transmission line between two nodes
    - Delay $D = D_{\text{prop}}$, $N = \lambda * D = \lambda * D_{\text{prop}}$
  - Transmitter (~ server):
    - Delay $D = D_{\text{trans}}$, $N = \lambda * D_{\text{trans}}$ = utilization
  - In the queueing buffer:
    - Delay $D = D_{\text{queueing}}$, $N = \lambda * D_{\text{queueing}}$ = queue length
Queueing Theory Primer

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What are the types of Queue

- The most important parameters are the arrival of process and the service time.

- Kendall’s notation: $X/Y/k$
  - $k$ denotes the number of server (typically $k=1$)
  - $X$ denotes the process of arrivals
    - $M$ is for “memoryless”, which means it’s Poisson
  - $Y$ denotes the service time distribution
    - $M$ is for “memoryless”, = exponential service time
    - There are also $G$ for general, $D$ for deterministic
The M/M/1 queue

- It is the simplest to analyze
  - Because the system evolves with no memory
  - Even simpler than constant service time!
  - It has only two parameters
    - Arrival rate (how many customers arrived per sec.)
    - Service rate (how many customers can be served per sec.)
The M/M/1 Queue

Its evolution follows a Markov Chain

1. Each state 0, 1, 2, ..., i denotes “there are i customers in {queue, server}”
2. During a small time slot δ, there is a probability
   - λδ to receive a new customer: i -> i+1
   - μδ to complete servicing an existing customer: i -> i-1
The M/M/1 queue steady state

- Since this is a Markov chain,
  - its long term evolution follows a stationary measure $P(n)$ that is invariant by the transitions
  - Assume that: $\lambda P(n) = \mu P(n+1)$
    - Then $P(n)$ is a stationary measure
    - This also implies: $P(n) = \rho^n P(0)$ where $\rho = \lambda / \mu$
  - Hence, if $\rho < 1$ we can show that $P(n) = \rho^n (1-\rho)$ is a stationary measure
The \( \text{M/M/1 queue steady state} \)

\[ P(\# \text{ customer} = n) = \rho^n (1-\rho) \] implies

- **Expected \# of customers:**
  \[ N = \sum_{n=0}^{\infty} nP(n) = \sum_{n=0}^{\infty} n\rho^n (1 - \rho) = \frac{\rho}{1 - \rho} \]
  - Which is also: \( N = \frac{\rho}{1 - \rho} = \frac{\lambda/\mu}{1 - \lambda/\mu} = \frac{\lambda}{\mu - \lambda} \)

- **Expected delay \( D \) in the system?**
  - Obtained by Little’s law: \( D = \frac{1}{\mu - \lambda} \)
The \( M/M/1 \) queue steady state

\[ P(\text{# customer} = n) = \rho^n (1-\rho) \] implies

- **Expected delay** \( W \) spent waiting in queue:
  - \( W = D - \text{Expected time of service} \)
  - So
    \[
    W = D - \frac{1}{\mu} = \frac{1}{\mu - \lambda} - \frac{1}{\mu}
    \]

- **Expected # customers in queue** \( Q \):
  - By Little's law:
    \[
    Q = \lambda W = \frac{\lambda}{\mu - \lambda} - \frac{\lambda}{\mu}
    \]
  - Note that we do not have \( Q = N - 1 \), because when the queue is empty \( \#\text{cust}=\#\text{cust in queue} \)
A real example

- Let’s say
  - 100 hungry students in an hour \( (=\lambda? =\mu?) \)
  - 30 seconds to give them a falafel
    - What is the service rate?

- Characterizing this
  - \( \mu=120 \) customers in an hour
  - \( D=1/(\mu-\lambda)=1/20 \) hour=3 minutes
  - \( N=\)number of people arriving in 3min = 5
  - What is chance of being served immediately?
Circuit vs. Packet Switching

1  λ/M

2  λ/M

N  λ/M

Packets generated at random times

TDM, Time Division Multiplexing
Each user can send \( \mu/N \) packets/sec and has packet arriving at rate \( \lambda/N \) packets/sec

\[
D = \frac{M(\lambda/\mu)}{\mu - \lambda}
\]

Statistical Mutliplexer

\[
D = \frac{1}{\mu} + \frac{(\lambda/\mu)}{\mu - \lambda}
\]

Buffer

\( \lambda \) packets/sec

\( \mu \) packets/sec

Data Link Layer 5-28