Wireless link layer: Cellular Networks; Mobility

CS 352, Lecture 17
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(heavily adapted from slides by the textbook authors)
Review: The wireless link layer

• Wireless medium is very different from wired
  • Signal attenuation ("fading") much more important to handle
  • Hidden terminal problem

• Consequences of differences:
  • Link-layer ACKs
  • Transmission delays to control contention: SIFS, DIFS
  • Link reservation (RTS/CTS)

• Medium access control
  • Frequency division multiple access (AP channels in WiFi)
  • Random access (CSMA/CA for transmitting to/from WiFi AP)
  • Code division multiple access (simultaneous transmission in cellular networks)
Cellular networks: Overview
2G, 3G, 4G, 5G
Components of cellular network architecture

- **MSC**
  - connects cells to wired tel. net.
  - manages call setup (more later!)
  - handles mobility (more later!)

**Cell**
- covers geographical region
- *base station* (BS) analogous to 802.11 AP
- *mobile users* attach to network through BS
- *air-interface*: physical and link layer protocol between mobile and BS
Cellular networks: the first hop

Two techniques for sharing mobile-to-BS radio spectrum

• **combined FDMA/TDMA:** divide spectrum in frequency channels, divide each channel into time slots

• **CDMA:** code division multiple access
2G (voice) network architecture

Legend
- Base transceiver station (BTS)
- Base station controller (BSC)
- Mobile Switching Center (MSC)
- Mobile subscribers

Public telephone network

Base station system (BSS)
- BTS
- BSC

Gateway MSC
3G (voice+data) network architecture

Key insight: new cellular data network operates *in parallel* (except at edge) with existing cellular voice network
- voice network *unchanged* in core
- data network operates in parallel
3G (voice+data) network architecture

- Radio network controller
- MSC
- Gateway MSC
- SGSN
- GGSN

Radio access network (WCDMA, HSPA)

Core network
General Packet Radio Service (GPRS) Core Network

Public telephone network
Public Internet

Radio interface
Universal Terrestrial Radio Access Network (UTRAN)

Public Internet
3G versus 4G LTE network architecture

**3G**

- Radio network controller
- MSC
- SGSN
- Gateway

**4G-LTE**

- MME
- HSS
- S-GW
- P-GW
- GGSN
- Public telephone network
- Public Internet

Radio access network
Universal Terrestrial Radio Access Network (UTRAN)
Evolved Packet Core (EPC)
4G: differences from 3G

- all IP core: IP packets tunneled (through core IP network) from base station to gateway
- no separation between voice and data – all traffic carried over IP core to gateway
5G: the next generation

• Goal: higher data rates, lower delays

• Enabled by better transmission technology
  • (you don’t need to know what these terms mean:)
  • Multiple input multiple output antennas
  • New radio frequency bands
  • Beamforming

• To support novel applications
  • IoTs, edge networking, SDN, NFV, …
Mobility

How do hosts move and still retain network connectivity?
What is mobility?

• spectrum of mobility, from the network perspective:

  - no mobility
    - mobile wireless user, using same access point

  - high mobility
    - mobile user, passing through multiple access point while maintaining ongoing connections (like cell phone)
    - mobile user, connecting/disconnecting from network using DHCP.
Questions: IP addresses and routing

• An IP address refers to the point of attachment of a host to a network

• So, when a host moves, should its IP address change?

• What is the impact on the higher layers of the protocol stack?

• How will remote hosts reach (route to) the mobile host?
  • New connections?
  • Ongoing connections?
How do *you* contact a mobile friend:

Consider friend frequently changing addresses, how do you find her?

- search all phone books?
- call her parents?
- expect her to let you know where he/she is?
- Facebook!

I wonder where Alice moved to?
Mobility: vocabulary

**home network**: permanent “home” of mobile (e.g., 128.119.40/24)

**home agent**: entity that will perform mobility functions on behalf of mobile, when mobile is remote

**permanent address**: address in home network, can always be used to reach mobile (e.g., 128.119.40.186)
Mobility: more vocabulary

**permanent address**: remains constant (e.g., 128.119.40.186)

**visited network**: network in which mobile currently resides (e.g., 79.129.13/24)

**care-of-address**: address in visited network. (e.g., 79,129.13.2)

**foreign agent**: entity in visited network that performs mobility functions on behalf of mobile.

**correspondent**: wants to communicate with mobile

**wide area network**
Mobility: approaches

- **let routing handle it:** routers advertise permanent address of mobile-nodes-in-residence via usual routing table exchange.
  - routing tables indicate where each mobile located
  - no changes to end-systems

- **let end-systems handle it:**
  - **indirect routing:** communication from correspondent to mobile goes through home agent, then forwarded to remote
  - **direct routing:** correspondent gets foreign address of mobile, sends directly to mobile
Mobility: approaches

- let routing handle it: routers advertise permanent address of mobiles in residence via usual routing table exchange.
  - routing tables indicate where each mobile is located.
  - no changes to end-systems.
- let end-systems handle it:
  - indirect routing: communication from correspondent to mobile goes through home agent, then forwarded to remote.
  - direct routing: correspondent gets foreign address of mobile, sends directly to mobile.

Not scalable to millions of mobiles.
Mobility: registration

end result:
• foreign agent knows about mobile
• home agent knows location of mobile
Mobility via indirect routing

1. Correspondent addresses packets using the home address of the mobile.
2. Home agent intercepts packets and forwards them to the foreign agent.
3. Foreign agent receives the packets, forwards them to the mobile.
4. Mobile replies directly to the correspondent.

The network consists of a home network, a visited network, and a wide area network. The home agent and foreign agent play crucial roles in the routing process.
Mobile IP: indirect routing

permanent address: 128.119.40.186

Care-of address: 79.129.13.2

packet sent by home agent to foreign agent: a packet within a packet

dest: 79.129.13.2
dest: 128.119.40.186

foreign-agent-to-mobile packet

dest: 128.119.40.186

packet sent by correspondent

dest: 128.119.40.186

permanent address: 128.119.40.186

Care-of address: 79.129.13.2
Indirect Routing: comments

• mobile uses two addresses:
  • permanent address: used by correspondent (hence mobile location is *transparent* to correspondent)
  • care-of-address: used by home agent to forward datagrams to mobile

• foreign agent functions may be done by mobile itself

• triangle routing: correspondent-home-network-mobile
  • inefficient when correspondent, mobile are in same network
Indirect routing: moving between networks

- suppose mobile user moves to another network
  - registers with new foreign agent
  - new foreign agent registers with home agent
  - home agent update care-of-address for mobile
  - packets continue to be forwarded to mobile (but with new care-of-address)

- mobility, changing foreign networks transparent: 
  *on going connections can be maintained!*
Mobility via direct routing

1. Home network
   - Correspondent requests, receives foreign address of mobile

2. Correspondent forwards to foreign agent

3. Foreign agent receives packets, forwards to mobile

4. Mobile replies directly to correspondent
Mobility via direct routing: comments

• overcome triangle routing problem

• *non-transparent to correspondent*: correspondent must get care-of-address from home agent
  • what if mobile changes visited network?
Accommodating mobility with direct routing

- anchor foreign agent: FA in first visited network
- data always routed first to anchor FA
- when mobile moves: new FA arranges to have data forwarded from old FA (chaining)
Real implementations of mobility (1)

• Mobile IP: an extension to the IP protocol for mobility
  • RFC 3344

• Uses indirect routing + packet encapsulation
  • Registration protocol for home agent when mobile visits a different net
  • Agent discovery to let home agent know about foreign agent
Real implementations of mobility (2)

- Cellular network handoff
  - Can change base station associated with your phone due to better signal strength, load shedding, and yes, mobility :)

- Handoff between base stations uses indirect routing
  - Lots of resources set up to ensure calls don’t get dropped
  - Corresponding overheads

- Handoff between multiple Mobile Switching Stations (MSCs)
  - “Anchor MSC” from the first visited MSC
  - Chain of MSCs forwards packets
Impact of mobility on higher-layer protocols
Wireless, mobility: impact on higher layer protocols

• logically, impact *should* be minimal …
  • best effort service model remains unchanged
  • TCP and UDP can (and do) run over wireless, mobile

• … but performance-wise:
  • packet loss/delay due to bit-errors (discarded packets, delays for link-layer retransmissions), and handoff
  • TCP interprets loss as congestion, will decrease congestion window un-necessarily
  • delay impairments for real-time traffic
  • limited bandwidth of wireless links
Synthesis of protocols
**Synthesis**: a day in the life of a web request

- Our 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

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

Browser
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 802.3 Ethernet

  - Ethernet frame *broadcast* (dest: FFFFFFFFFFFFF) 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. 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

- web page finally (!!!) displayed

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