ECE257A Review Problems Lecture 1-4

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I. Lecture 2. Network architecture and work flow.

1. The modern Internet is a "network of networks". What does this mean? Draw a figure to illustrate the Internet topology as a network of different levels of operators.
2. Understand the function separation between the two major modules in a cellular architecture: RAN and core network.
3. Qualitative understanding of how cellular networks' PHY layer technologies evolved from 2G to 5G.
4. What is mobile SDN and mobile edge computing? How do these technologies address the limitations of current cellular network architecture?
5. Qualitative understanding of how WiFi networks' PHY layer technologies evolved (802.11a/g→802.11n→802.11ac and 802.11ad).

Answer :

1. Modern Internet is a hierarchical architecture which can achieves scalability. The top are content provider networks and tier 1 ISPs(Internet Service Providers), the middle layer are regional ISPs and bottom layer are access ISPs. IXPs (Inter Exchange Points) connect ISPs of different layer.

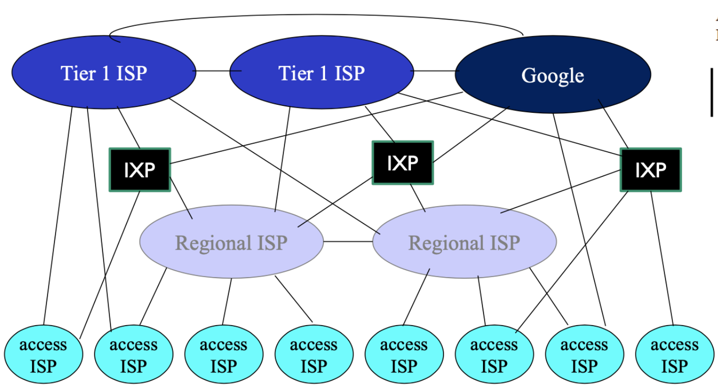

Fig. 1. Network of networks

2.

Core Network vs. Radio Access Network	
Network	Function
Core Network	1. Manages subscriber information, location etc. 2. Intermediate Relay between base statioins and the Internet
Radio Access Network	1. Connection network between base stations and mobile devices

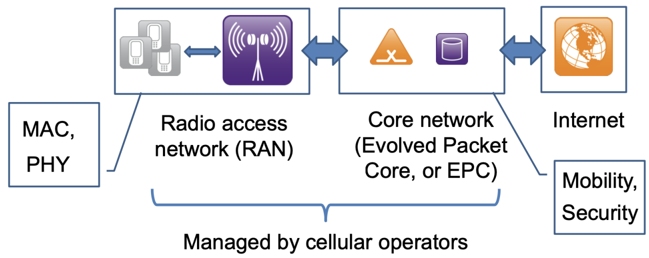

Fig. 2. 4G cellular mobile broadband

3.

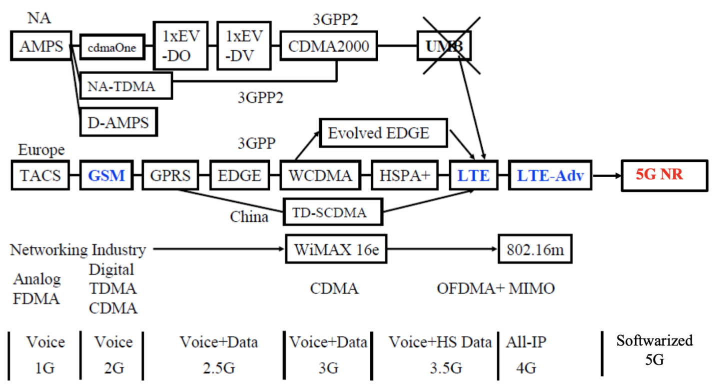

Fig. 3. Evolution of cellular access network standards

Cellular Network Generations			
Gen	Data	Modulation	MAC feature
1G	analog comm voice only	AMPS	FDMA
2G	digital comm voice only	GMSK	TDMA, FDMA, CDMA
3G	voice+data	Spread Spectrum	CDMA
4G	high-speed data	OFDM	OFDMA+MIMO
5G	ultra-high speed data	OFDM	SDM

4. **Mobile software defined networking (mobile SDN)**
(1) Split the control and data plane
(2) Centralize the control functions to ease coordination
(3) Control plane should have low latency; data have high throughput

(4) Virtualize gateways and other core network entities, for higher flexibility, better scalability, and lower cost

Mobile edge computing (MEC)

(1) Deploy application servers closer to users for lower latency

(2) Virtualize server resources for flexibility and scalability

(3) Features

(a) Computation offloading: run computationally intensive applications (e.g., machine learning, AR/VR) directly on edge servers to reduce latency

(b) Traffic offloading: reduce congestion within the core network by avoiding routing through the gateways

(c) Capability exposure: expose RAN info to control plane or upper layers to make informed decisions (more details in later lectures)

5.

	Bit-rate	Spectrum	Bandwidth	Modulation	Spatial streams
802.11a/g	54 Mbps	2.4 GHz and 5 GHz	20 MHz	OFDM	1
802.11n	Up to 600 Mbps	2.4 GHz and 5 GHz	Up to 40 MHz	OFDM + MIMO	Up to 4
802.11ac	Up to 6 Gbps	5 GHz	Up to 160 MHz	OFDM + MIMO	Up to 8
802.11ad	Up to 7 Gbps	60 GHz	Up to 2 GHz	OFDM + phased-array beamforming	1

Fig. 4.

(1) Towards higher network capacity : Wider spectrum (e.g., from 20 MHz to 160 MHz for WiFi, and 2 GHz for millimeter-wave networks), Better spectrum utilization (e.g., higher modulation levels, multiplexing gain from MIMO), Better spatial reuse (e.g., using directional beams so as to pack more links into the same area), Higher network density (more small-cells and pico-cells)

(2) Towards lower power consumption : High-efficiency electronics (e.g., better power amplifier and CPUs) reduce run-time power consumption, Better MAC and sleep scheduling protocols reduce power wastage

II. Lecture 3. Wireless Internet workflow; Mobile Internet workflow

1. Qualitative understanding of the differences between WiFi, Bluetooth, cellular networks and 60 GHz WiFi (bit-rate, range, power consumption).

2. Describe the major protocols involved in a mobile Web browsing session, and their work flow.

Answer :

1. Rate : 5G≈60GHz WiFi>WiFi>4G>3G>Bluetooth

Range : 4G>3G>5G>WiFi>60GHz WiFi≈Bluetooth

Power : 5G>60GHz WiFi>4G>3G>WiFi>Bluetooth

2.

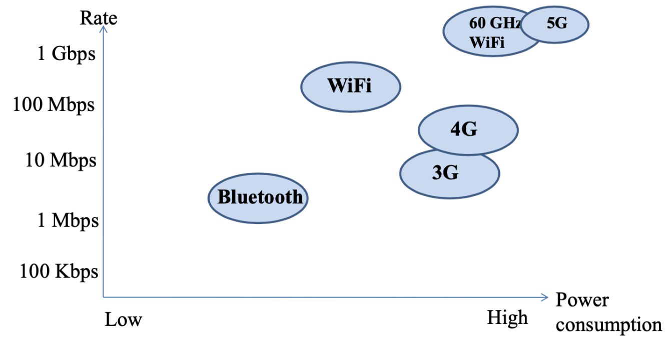

Fig. 5. Data rate vs. power consumption

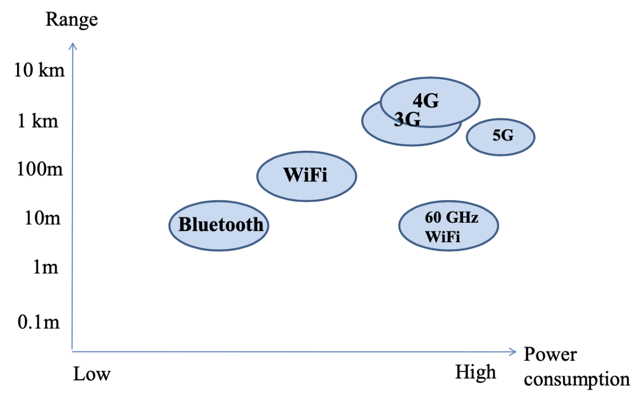

Fig. 6. Range vs. power consumption

Network discovery and association WiFi AP keeps broadcasting beacons, with its MAC address embedded in beacons. Client listens, and sends association request. Authentication and association → client connects to WiFi AP.

IP address allocation The smartphone client needs to get its own IP address, addr of first-hop router, addr of DNS server. All done using DHCP (Dynamic Host Configuration Protocol). DHCP procedure: client broadcasts request, DHCP server (running on first-hop router) responds and allocates an

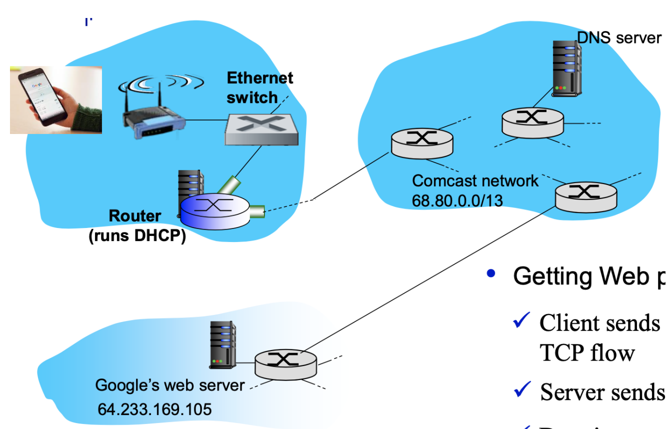

Fig. 7. Elements of the Internet architecture involved in the process

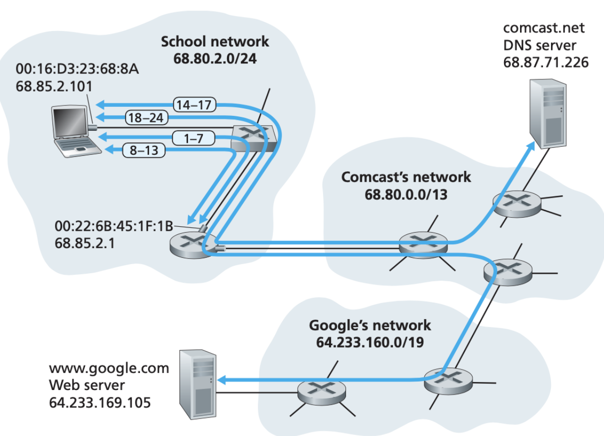

Fig. 8. Web Request Workflow

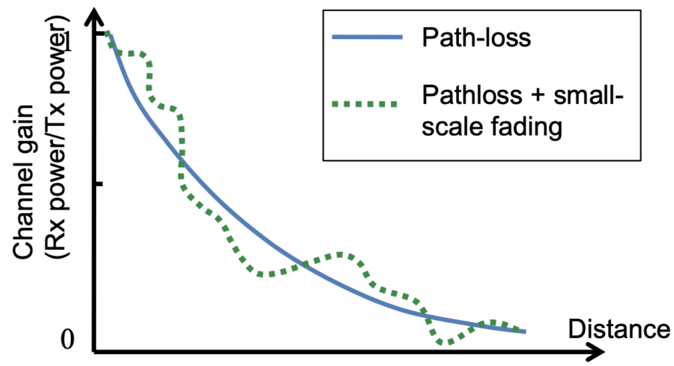

Fig. 9. Composite effects of all distortions

IP address to it.

DNS request (domain name server) Need to know the IP address corresponding to URL, e.g., www.google.com, Need to request DNS server to map URL to IP addr. Need to route the request to DNS server.

Routing DNS request Need to ask first-hop router to route the request. To communicate with first-hop router, client needs to know its MAC address. Done by ARP (address resolution protocol).

Sending DNS request Client creates an IP packet containing DNS request, which goes to first-hop router. Router forwards packet from campus network to Comcast network to DNS server, following Internet routing protocol. DNS server replies to the client with the IP address of www.google.com.

Establish TCP flow Client creates a TCP flow to Web server (end-to-end path needs to be established first through Internet routing protocol)

Getting Web page www.google.com Client sends HTTP request through the TCP flow. Server sends the Web page back to client. Done!

III. Lecture 4. Wireless channel model; digital modulation

1. Understand the freespace pathloss model.

2. Understand the causes and effects of small-scale fading (Doppler fading, multipath fading).

3. Understand the quantitative measures of small-scale fading and their relationship

4. Understand the generic model for digital modulation (major stages and their objectives)

Answer :

1.

$$P_r = G_r G_t (\frac{\lambda}{4\pi d})^2 P_t$$

Pr : received power, Pt : transmitted power, Gr, Gt : receiver and transmitter antenna gain, $\lambda (= c/f)$: wavelength

Channel distortions consists of large-scale pathloss $P_r = G_r G_t (\frac{\lambda}{4\pi d})^2 P_t$, and small-scale fading, i.e. random variation upon minor distance change. In practice, channel gain = pathloss + small scale fading, and it varies over time!

2. **Multipath effect**

(a) Shadowing (e.g., through a wall or a door), refraction depending on the density of a medium, reflection at large obstacles, scattering at small obstacles, diffraction at edges, all these distorted versions add up at the receiver.

(b) Multipath fading causes inter-symbol interference : Multiple copies of the same signal are received, each following a different path, and arriving at different times. Distortion in time-domain causes inter-symbol interference.

(c) Multipath effect causes frequency-selective fading : Copies can either strengthen or weaken each other, depending on whether they are in or out of phase. For a given receiver location, whether two waves are in or out of phase depends on frequency.

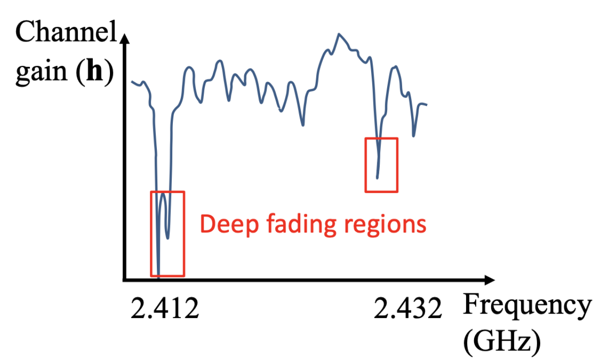

Fig. 10. Frequency-selective fading

Doppler effect

(a) Movement by the transmitter, receiver, or objects in the environment can create a Doppler shift. Maximum doppler shift f_d occurs when the wave is traveling along the moving direction $f_d = \frac{v}{c} \times f$. v is moving speed, f is center frequency of signals. Doppler shift distorts the frequency of the signals, if a single sine wave with frequency f is transmitted, then, its frequency will become $f + f_d$ or $f - f_d$.

(b) But in practice, the sine wave suffers from the combined effects of multipath and doppler fading. Many different copies of the sine wave coming from different directions with different f_d , so the signal power is spread out, forming a "U" shaped power spectrum.

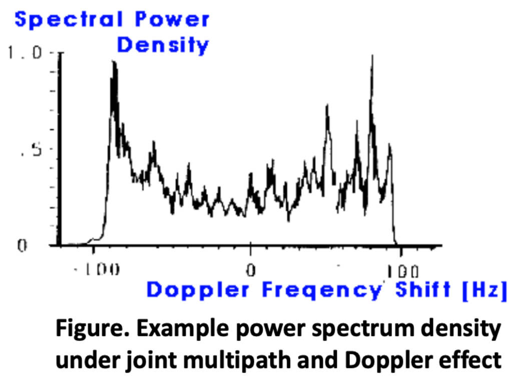

Fig. 11. Power spectrum density under joint multipath and Doppler effect

Variation over time

Channel distortion varies over time due to environment change: movement, blockage, hands waving across, etc. Grand challenge for wireless communication (PHY layer) : How to shape the signals to ensure they can be recovered by the receiver, even after distortion? Need proper modulation, demodulation, channel coding, etc.

3.

Doppler spread - Doppler effect Doppler fading can characterized by Doppler spread $f_d = \frac{v}{c} \times f$ which depe on moving speed and signal frequency.

Coherence time - Doppler effect Time duration over wh the received signal experiences consistent amplitude/ph distortion. Depends on movement speed, Empirical model is Doppler shift) :

$$T_c = \frac{9}{16\pi f_d} = \frac{9c}{16\pi v f}$$

Delay spread - Multipath effect Multipath fading can be characterized by delay spread, the arrival time difference between first path and the "last" path that's sufficiently weak.

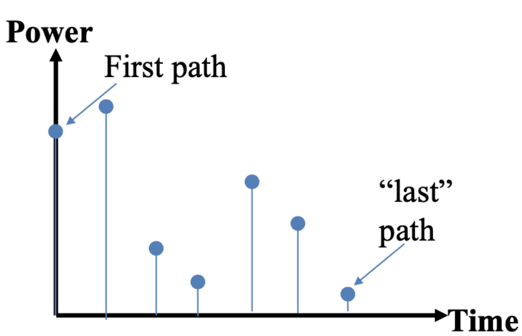

Fig. 12. Delay spread

Coherence bandwidth - Multipath effect Stability of channel over frequency. Frequency range within which two signals experience similar amplitude/phase distortion. Depends on multipath fading effect. Empirical model (D is delay spread):

$$f_c = \frac{1}{D}$$

4.

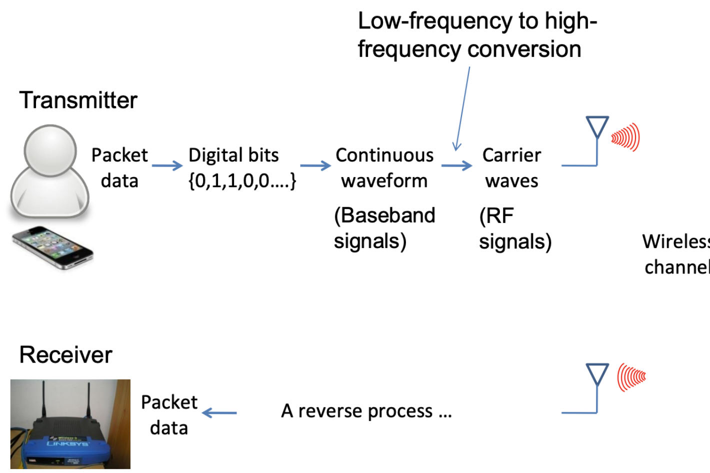

Fig. 13. Generic model for wave shaping and recovery (modulation and demodulation)

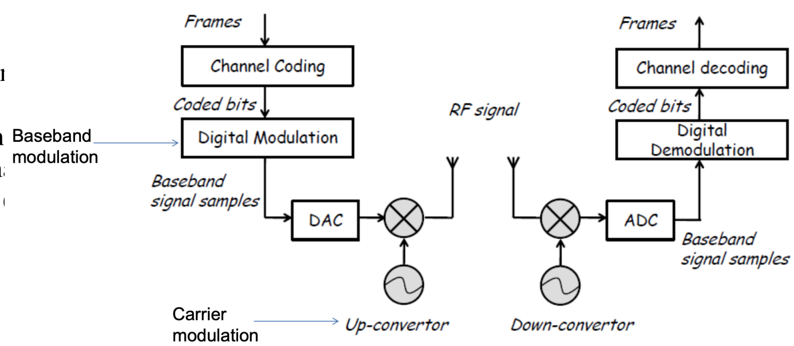

Fig. 14. Generic model for wave shaping and recovery (implementation in a radio hardware)

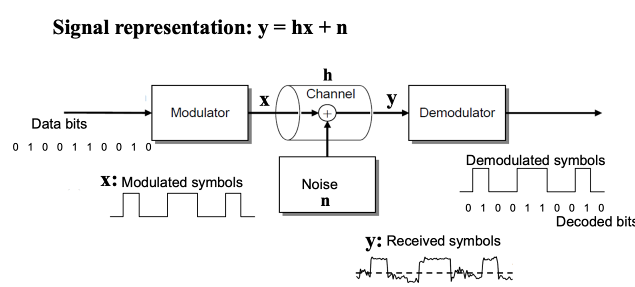

Fig. 15. Generic model for wave shaping and recovery (abstract model)

h models all the channel distortion effects. Communication system design is all about how to estimate h, and then decode the transmitted signal $x \approx \frac{y}{h} = x + \frac{n}{h}$.