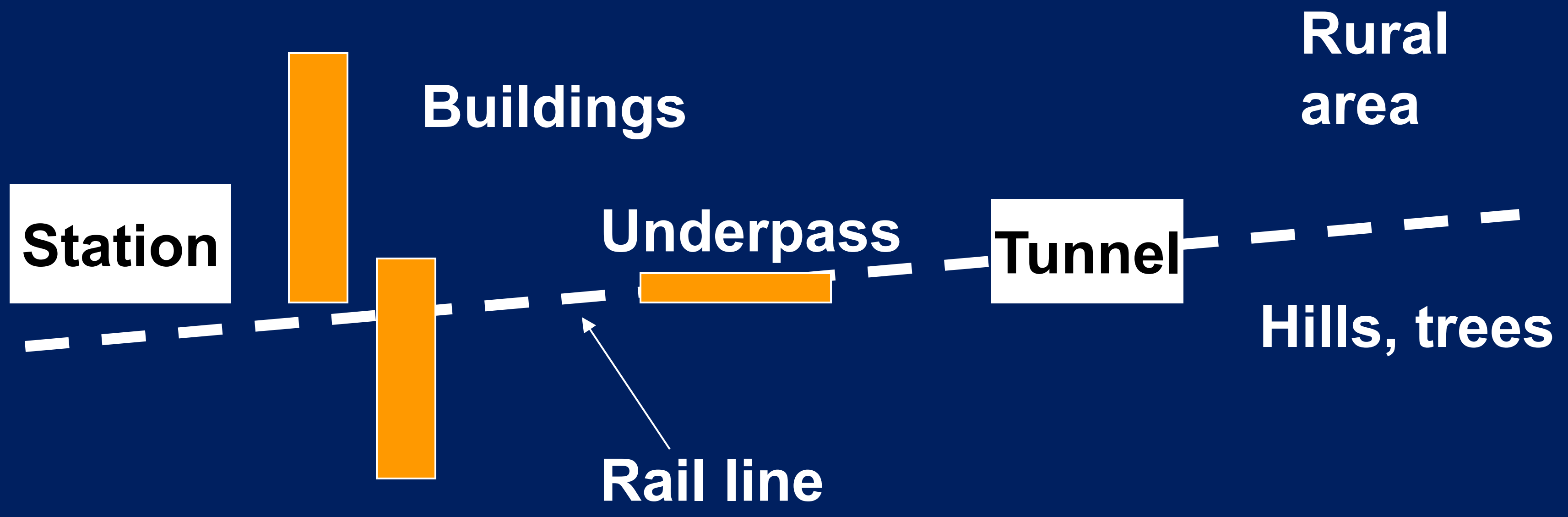
1.264 Lecture 36

Telecom: Wireless networks

Exercise

- Design a system for an intercity rail passenger train to provide Internet access to its passengers and operating crew. Address each challenge:
  - Metro areas: frequent physical obstructions, such as underpasses, tall buildings
  - Tunnels
  - Rural areas: gaps in cellular coverage, trees, hills obstruct line of sight
  - Multiple applications: what to do when a user wants to download a 200MB file
  - Network changes: train goes through many networks of varying quality at varying speeds
  - Reception in passenger cars: metal car bodies affect signal

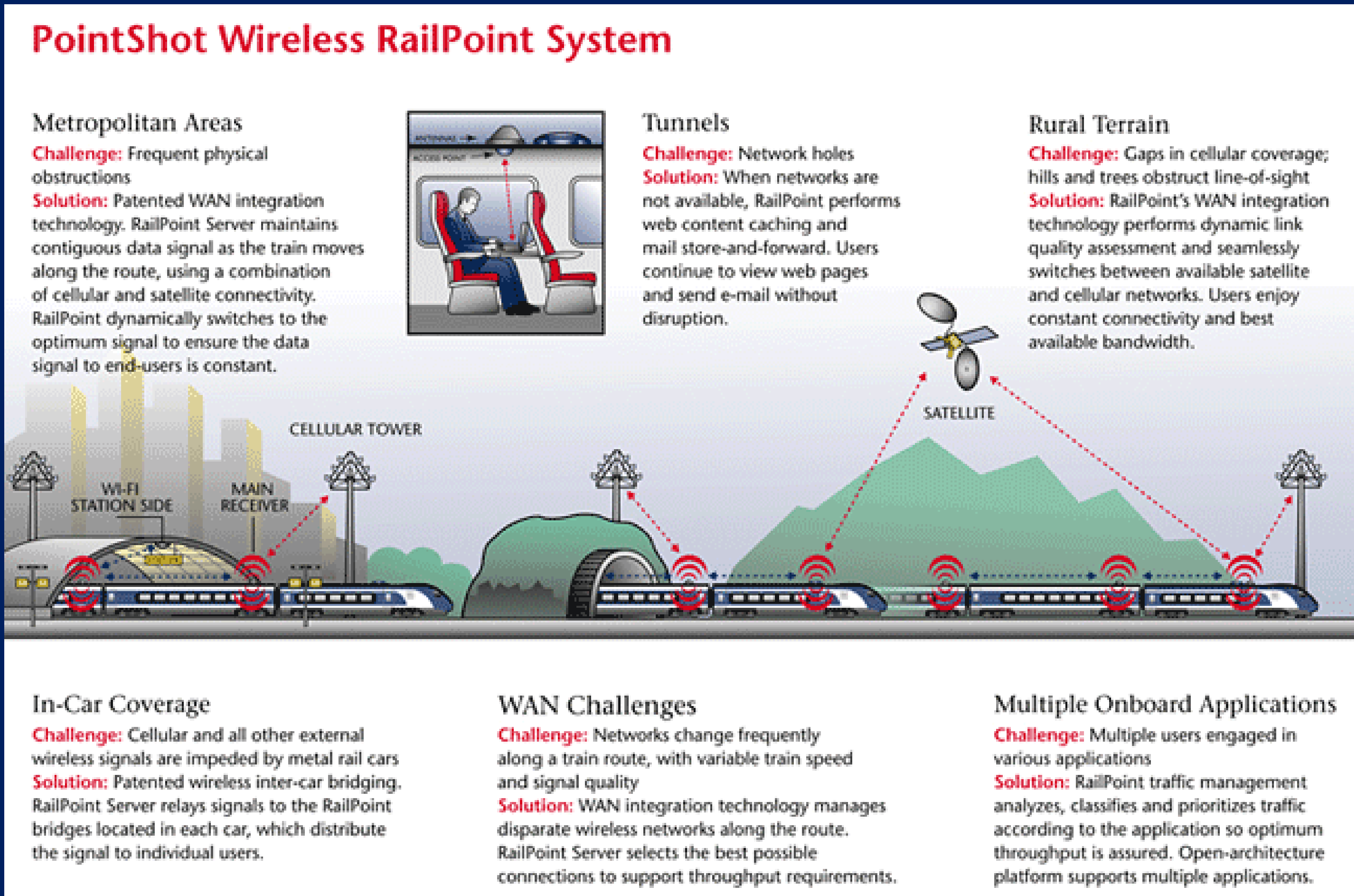
Exercise


Rural
area
Buildings
Station
Underpass
Tunnel
Hills, trees
Rail line

Solution

- Metro area:
  - Multiple cellular data carriers
  - Server on train chooses best signal, maintains continuity
  - Use WiFi (wireless LAN) at stations
- Tunnels (short ones):
  - Server on train caches Web content, handles email via store and forward
  - Long tunnels require leaky fiber and/or base stations
- Rural areas:
  - Multiple cellular data carriers, and satellite services
- Within train:
  - Antennas mounted on multiple cars, wireless LAN between cars so any antenna can serve all cars
- Server, applications:
  - On train server manages traffic, ensures ‘fairness’
  - Server handles authentication and billing
- (How do long distance trucking, buses do this?)

Solution example



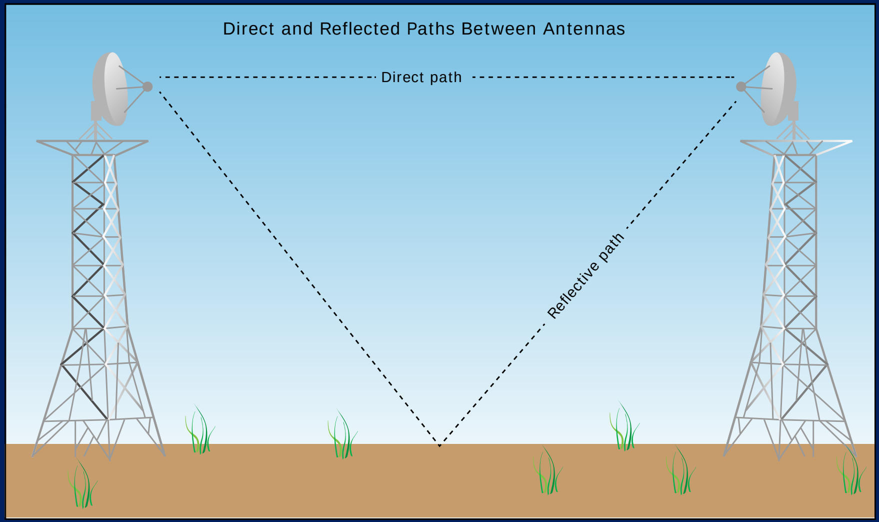
Solution example: Railroad wireless coverage in Northeastern US

Image by MIT OpenCourseWare.

Radio propagation

- Losses:
  - Free space loss
  - Atmospheric attenuation: rain, water, dust
  - Multipath loss: water body or fog causes reflections, and signals arrive out of phase at destination
  - Diffraction: hills, buildings, obstructions
- Antenna problems:
  - Snow, icing (use heaters, radomes)
  - Zoning restrictions (hide antennas in buildings)
- Microwave frequencies are line of sight
  - Behave like light, can be focused and reflected
- These issues hold for mobile phones, wireless data, satellites also

Radio loss



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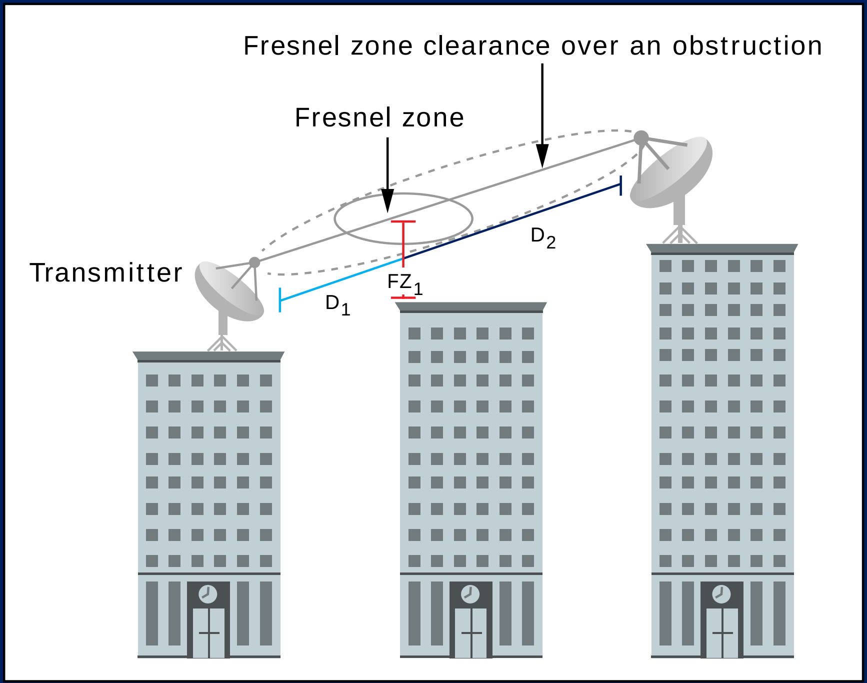

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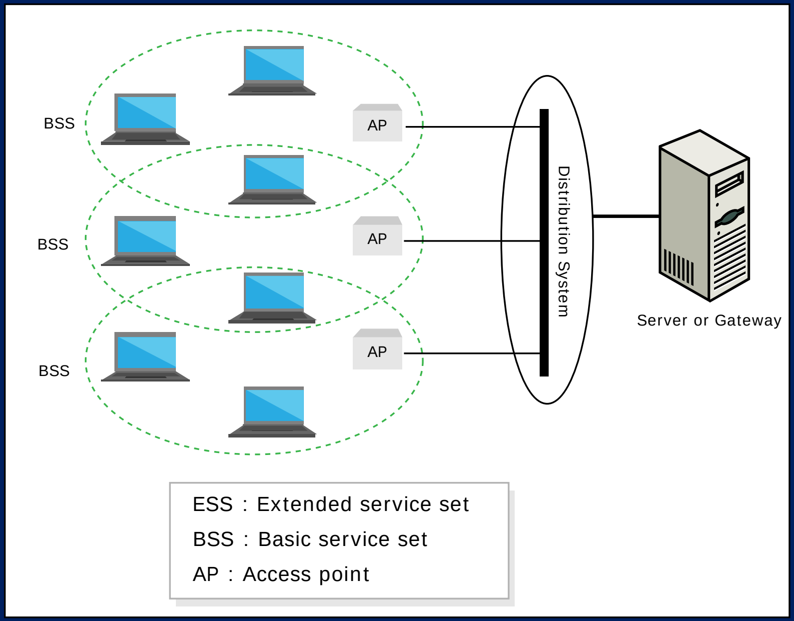
Wireless LAN

- Wireless LAN (WiFi) standard is IEEE 802.11
- Two types of wireless LAN:
  - Ad hoc, where stations (computers) directly connect
  - Infrastructure, with an access point (AP) that connects to a wired LAN and usually a MAN/WAN
- Distributed coordination required between stations due to collisions
  - Carrier sense multiple access/collision avoidance (CSMA/CA) protocol is used, as discussed earlier
- Wireless environment is very noisy
  - Frames are fragmented into small frames so retransmission, which is frequent, is more efficient

Wireless LAN service sets



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- A room or area is a typical BSS (basic service set)
- An ESS is a set of rooms and areas in the LAN
- Stations capabilities may be:
  - Stationary only
  - Can move within a single BSS (ad hoc or infrastructure)
  - Can move between BSS, but communication may not be continuous during the move

Wireless LAN issues

- WiFi (802.11b, 802.11g, 802.11n)
  - Inexpensive, pervasive, reliable, easy to manage
  - Hot spots common, but unscalable for metro area use
  - Range ~100 meters: ok within buildings, campuses
  - Bandwidth: 11 Mbps (b), 54 Mbps (g), 100 Mbps (n)
  - Actual bandwidth often half of nominal due to interference, fading, etc.
  - Half of traffic at many companies is non-work (music or video streaming, Web access, personal email, …)
  - Security is difficult, because signals propagate beyond the building or site
    - WEP easy to break; use WPA and WPA2 instead
    - Don’t use WPS (WiFi protected setup); it has a security flaw
  - Municipal network plans problematic (30+ points/sq mi)

Exercise

- In a warehouse, what type of LAN would you set up (ad hoc, BSS, ESS), and why?
  - Assume there are forklifts and other vehicles operating
  - Assume there are pick/pack stations, conveyors, etc.
- Would you try to lay out the network to minimize handoffs, or is that not important? Why or why not?
- With 802.11b, how would you stream video from 25 forklifts/vehicles in the warehouse?
  - Assume your video is 1.5 Mbps

Solution

- Set up an ESS, to allow handoffs and to connect all devices/stations to the WAN if needed
- Lay out the network to cover aisles/areas that minimize handoffs
  - Communications is not continuous in wireless LAN handoffs
- Video: 802.11b is 11 Mbps, or 5.5 Mbps practically
  - You need 25 * 1.5 Mbps, or 37.5 Mbps, or at least 8 BSS, which is one AP for every 3 vehicles in an area
  - Because of interference, fading, etc. you may need more
  - If you use 802.11n, at 100 Mbps nominal or 50 Mbps actual, you may find 2 APs sufficient (1 for redundancy)

Mobile telephony

- Mobile telephony is dominant. Alternatives are:
  - Specialized mobile radio (SMR), used primarily for local dispatch
    - About 3,000 licensed SMR providers in US (taxi, trucking..)
    - Nextel bought many SMR providers and created national network: radio, cell phone, data, messaging
    - Nextel uses variation on GSM cellular technology
  - Private mobile radio service (police, fire, railroads…)
    - Shared frequencies among all users
    - Base stations, repeaters; squelch or tone control
    - Trunking radio (multiple channels) used by larger organizations
      - One control channel to which all units listen
      - Talk channel then designated
  - These options use spectrum less well than cell phones
    - Being pushed to narrowband; other measures

Mobile (cellular) telephony

- A cell phone is a radio
- Before cell phones, there was mobile radio, with one tower per metro area and about 25 channels
  - Car phones had to be high powered but for little usage
- Cellular telephony divides a metro area into cells for much, much more capacity
- 832 channels in standard US cellular radio spectrum band; European GSM varies but similar
  - Up to 5 more bands have been allocated via auction in US
  - Phone can operate on any of these 1,000+ channels
- Cellular switches are called Mobile Telephone Switching Offices, or MTSOs
  - Functions same as standard telco voice switch, plus handoff across cells, for voice calls
  - Handles TCP/IP data for data and video

GSM (2G)

- GSM is European standard, adopted worldwide and increasingly in US
  - It's a 2G (second generation) standard, being superseded by 3G
  - It switches voice calls, like landlines, and is being replaced by voice over IP
- Each voice band is 13 kbps (versus 64 kbps fiber)
- Standard GSM has 124 channels
- Each channel is 270.8 kbps carried in 200 kHz
  - 8 users per channel
  - GSM can (re)use 1/3 of channels in each cell, due to good error correction
  - Capacity =~ 124 channels * 8 users/channel * 1/3 reuse= 329 calls (users) per cell
- GSM data is carried over GPRS (General Packet Radio Services), often considered 2.5G

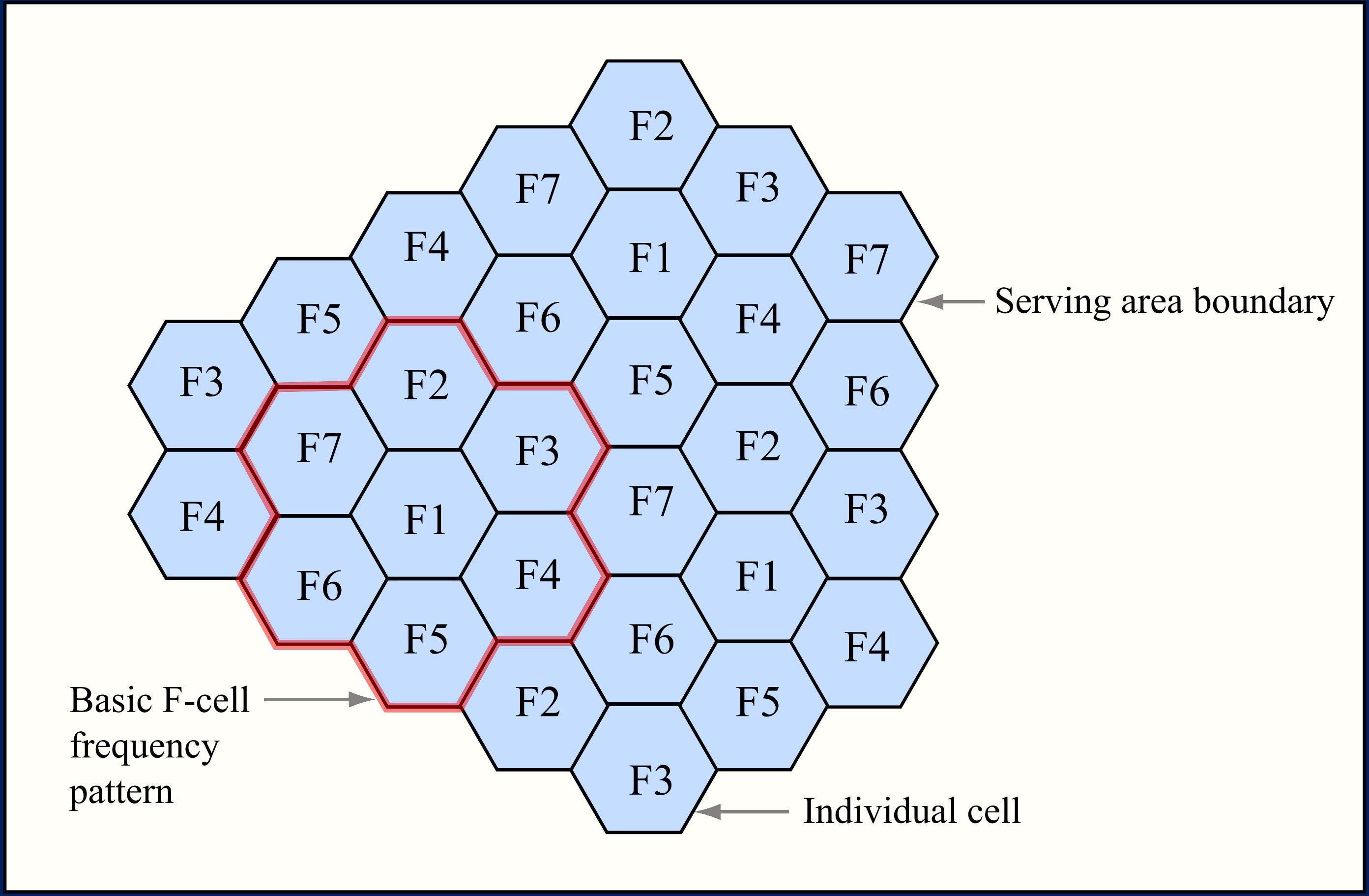
3G wireless

- Worldwide standard, though frequency bands vary by region
  - Roaming phones must use different frequency bands
  - There are a few common frequency bands worldwide
- Designed for many services:
  - Real-time gaming
  - Voice
  - File download and upload
  - Video
  - Web and email
- 3G data protocols are WCDMA, HSPA
  - In broad use, continue to evolve new features
  - Will be supported for many years until full 4G usage
  - Data rates of 500 kbps to 1 Mbps typical

4G wireless

- 4G is also called LTE (long term evolution) and release 8.
  - Standard is 3GPP (in GSM lineage)
  - Not backward compatible with 3G
  - Entirely IP based; no voice switched traffic
  - Supports spectrum flexibility for worldwide operation
  - Handoffs at 350 km/hr to support high speed rail
  - (Any individual phone supports limited spectrum, since RF and filter design are expensive/inflexible)
  - Data rates of up to 20 Mbps typical
  - Scarcity of bandwidth resulting in throttling of use
- CDMA (50% of US) 1x-EV-DO Rev C is very similar to LTE, and is converging.
  - Standard is 3GPP2 (in CDMA lineage)

Frequency reuse in cellular telephony



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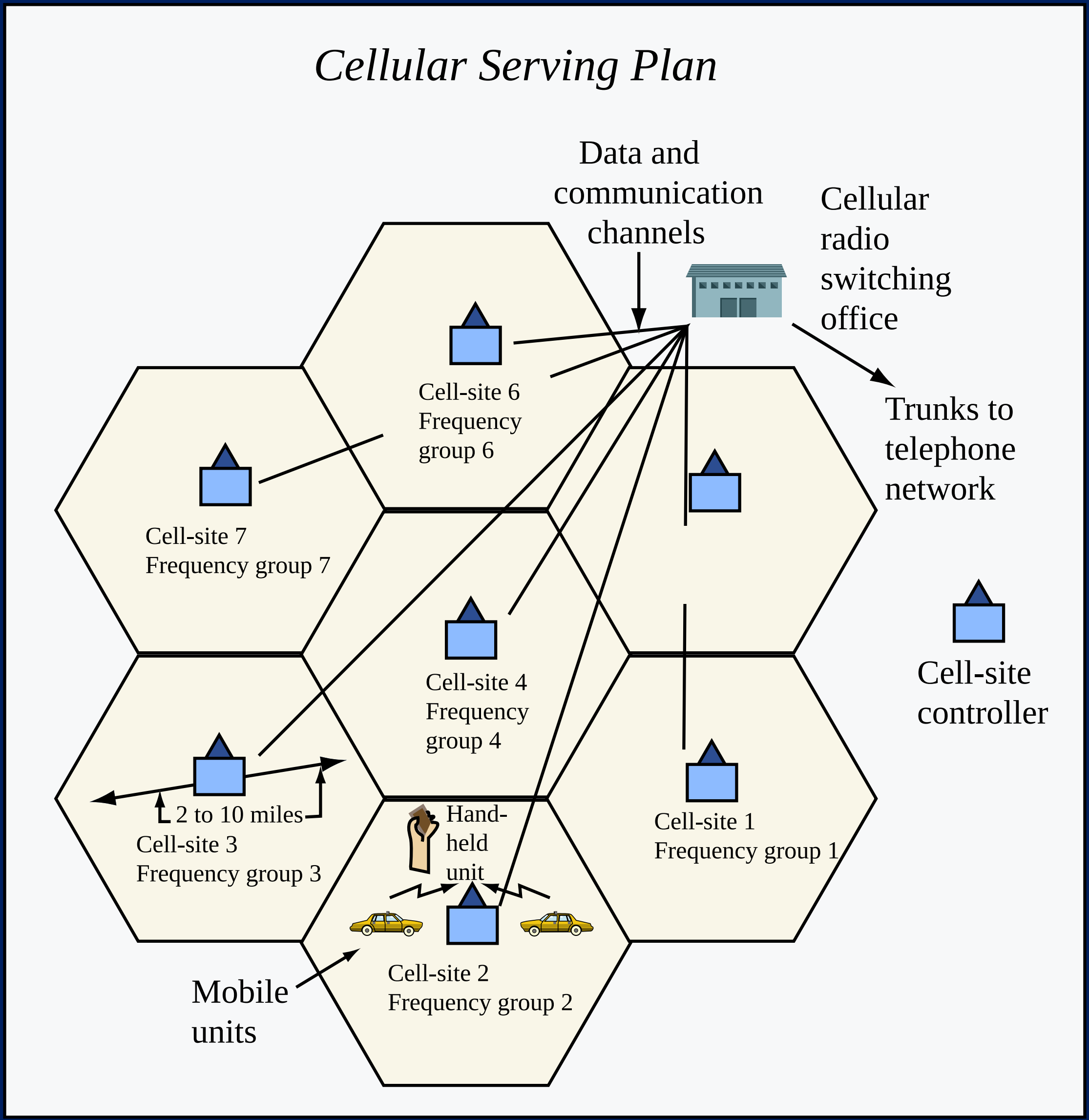
This is a 7-cell pattern; 9-cell is also common.

Cellular serving plan



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Simple honeycomb pattern rarely holds. Actual cell coverage highly variable.

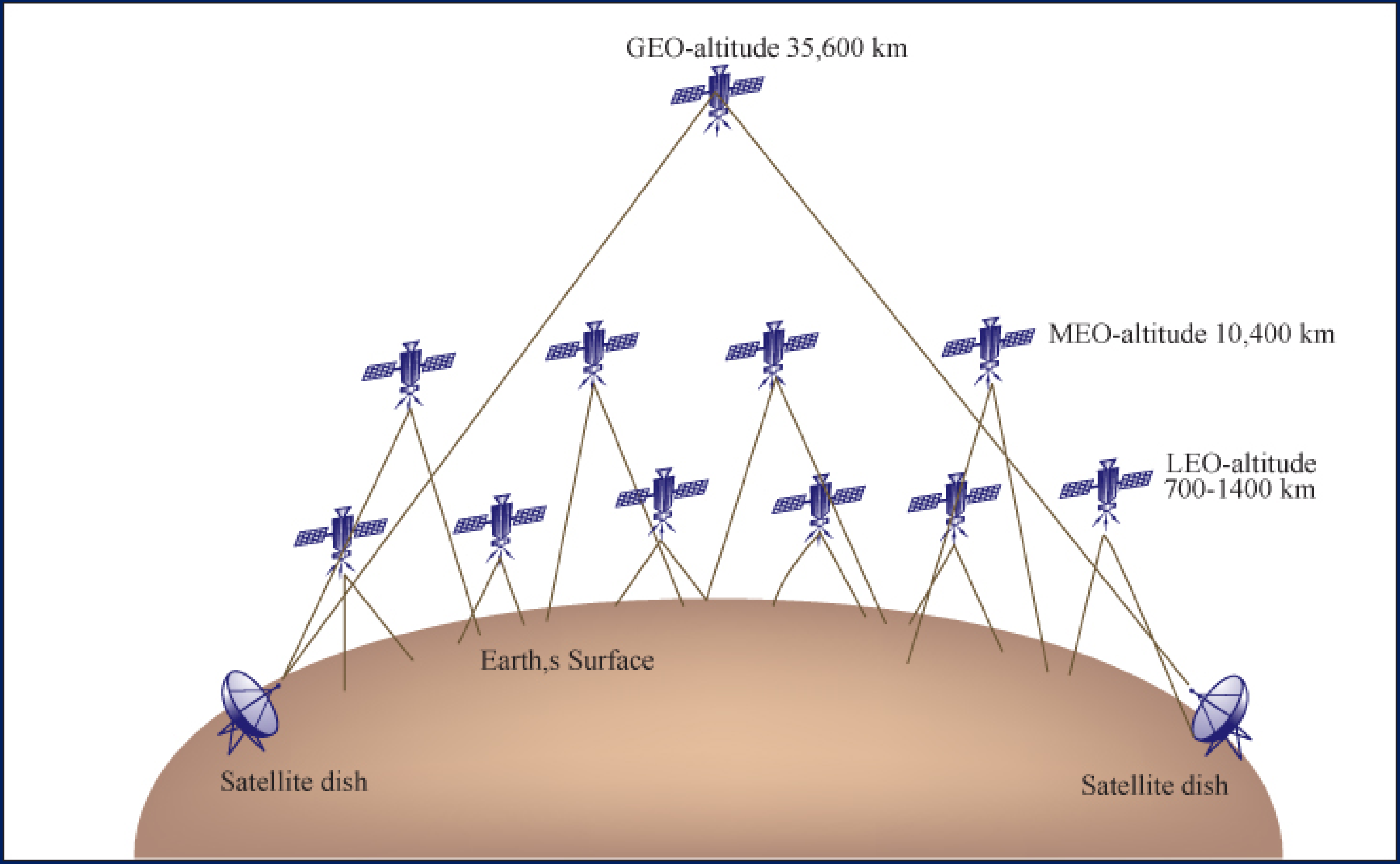
Exercise

- Assume LTE can provide 20 Mbps to areas with industry/warehousing to <u>each</u> location served
  - Assume 100 locations in the cell
  - Assume each has 10 Web users (1 Mbps), 1 Web/data server (5 Mbps), limited videoconference/video (4 Mbps)
    - Total bandwidth for each location is 10 Mbps (1+5+4)
- Compare LTE to:
  - DSL (1.5-13 Mbps, asymmetric)
  - CATV (30-300 Mbps, asymmetric but <u>shared</u> over all 100 users
  - T1 over copper (1.5 Mbps, symmetric)
  - Gigabit Ethernet MAN (1 Gbps, symmetric)
- Can LTE solve the ‘last mile’ problem sometimes?

Solution

- An average user needs 10 Mbps
  - DSL (1.5-13 Mbps) may meet it in some cases, but usually not. DSL usually 3-6 Mbps
  - CATV has 30-300 Mbps, but 100 users *10 Mbps= 1 Gbps. CATV would need many segments; not effective.
  - T1 over copper (1.5 Mbps) is not enough
  - Gigabit Ethernet MAN is plenty, of course
  - LTE (20 Mbps) is sufficient if bandwidth is available. In lower and medium density areas, it should be ok.
    - A cell can handle 100+ channels at 20 Mbps
  - LTE appears to solve the 'last mile' problem for residences (low/medium density) and low/medium density small business, but not major bandwidth users

Long-range wireless: satellite communications



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Satellites (wireless WAN)

- GEO satellites are on the equator and orbit every 24 hours, appearing stationary
  - 3 satellites 120 degrees apart can cover the Earth
- MEO orbits are between the two Van Allen belts of charged particles that would destroy a satellite
  - MEO satellites orbit every 6 to 8 hours
  - GPS is a set of 24 MEO satellites in 6 orbits, designed so 4 satellites are always visible from any point on Earth
  - GPS triangulates among the 4 satellites to determine position in 3D; it computes intersection of spheres
- LEO satellites are in polar orbits
  - They orbit every 90 to 120 minutes
  - They are managed like a set of cells on Earth
  - “Little” LEOs: text messaging (e.g. trucking)
  - “Big” LEOs: Iridium, Globalstar (e.g. sat phones)
  - Broadband LEOs: network video, other broadband

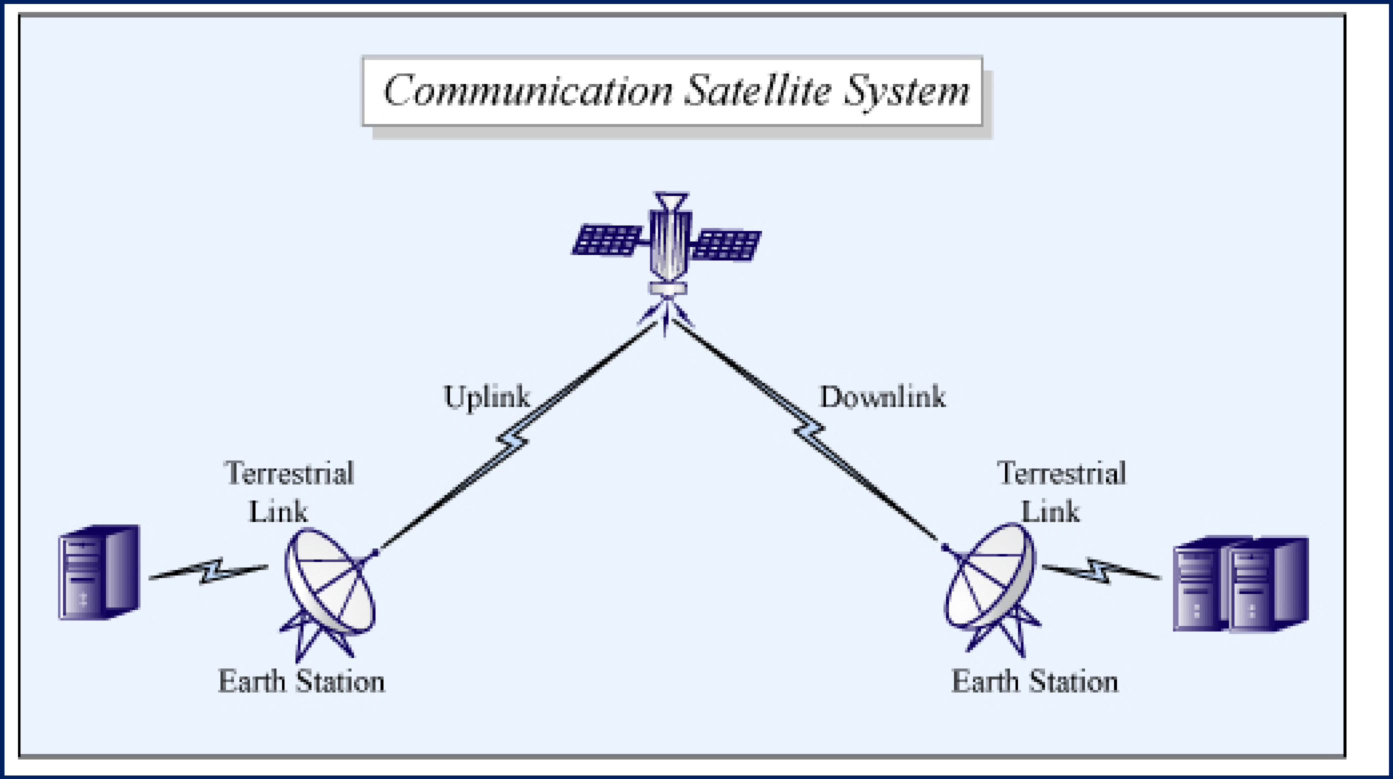
GEO satellite applications

- Inmarsat for marine and remote applications
  - 300,000 ships, vehicles, aircraft
  - 432 kbps Internet access data rate, 11 satellites
  - Morse service ended in 2005 for commercial vessels
- Very small aperture terminal (VSAT): 56 kbps- 4 Mbps for remote areas.
  - Some areas can get 18 Mbps down, 4 Mbps up
  - Most data rates 512 kbps or less down, 128 kbps up
  - 'Satellite Internet providers' for rural consumers
  - VSAT operators for Africa, other areas without fiber
- TV programming distribution
- Direct broadcast TV

MEO, LEO satellite applications

- Broadband LEO:
  - Teldesic, similar to fiber, failed
- Big LEO:
  - Iridium not successful but still operating
    - Too expensive to compete with terrestrial cell service
    - 66 satellites, each with 48 spot beams: ~2000 cells
    - Voice, fax, paging at 2.4 to 4.8 kbps
  - Globalstar has 48 satellites, similar service as Iridium
- Little LEO:
  - Trucking and rail information systems, paging
- MEO:
  - Global positioning system (GPS)

Satellite links



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Satellite data

- Delay:
  - 250 milliseconds (1/4 second) delay between two Earth stations communicating via geosynchronous (GEO) satellite
  - Delay noticeable for voice communications
  - Delay requires special treatment of data
    - TCP/IP will assume network congestion or dropped packets with these delays; must use special parameters or equipment to spoof acknowledgements
- Rain absorption
- Sun transit outage at equinoxes
- Power is limited on satellite
  - Limited signal to noise ratio, limits bandwidth
  - Direct Broadcast Satellite (DBS) satellites are overpowered to allow small consumer antennas; overall system costs are high
- Little room left for satellites in equatorial (GEO) orbit

Exercise

- You operate a diamond mine in northern Canada and need 20 Mbps to remotely monitor and diagnose mining equipment, provide Internet and some video for employees, handle email and files, etc.
  - Compare GEO, big LEO, little LEO, broadband LEO, MEO to meet your needs
  - Where would the other end of the satellite link connect? Does it matter? Options are your corporate HQ, a large peering point, etc.

Solution

- If you need 20 Mbps up and down in northern Canada:
  - GEO offers max 18 Mbps down and 4 Mbps up, and not in all areas.
  - Polar areas are strange: beams are turned off from lack of demand but could possibly be turned on
  - You might need 5 connections, which would be expensive…but a diamond mine can probably pay it
  - Big LEO and Little LEO are low bandwidth
  - MEO does not offer data services
  - Broadband LEO (Teledesic) failed
- Probably connect near corporate HQ to use MAN from ground station to HQ for cost, bandwidth, security reasons

Glossary

- BSS: Basic service set (WiFi)
- ESS: Extended service set (WiFi)
- WEP: Wired Equivalent Privacy (WiFi security)
- WPA: WiFi Protected Access (WiFi security)
- SMR: Specialized Mobile Radio
- CDMA: Code Division Multiple Access (US wireless)
- GSM: Global System for Mobile Communications (wireless voice standard, worldwide)
- GPRS: General Packet Radio Service, over GSM
- WCDMA: Wideband Code Division Multiple Access (3G data standard)
- HSPA: High Speed Packet Access (3G data std)
- 3GPP: 3G Partnership Project (sets 3G/4G stds)
- 1x EV-DO: Evolution-Data Optimized (3G CDMA std)