I. Mesh Networking


♦ Introduction

- A form of ad hoc networking.
- Clear distinctions are made between two types of nodes.
  - Mesh routers
    - More advanced than typical wireless ad hoc routers.
  - Mesh clients
    - Routing functions do not exist in these nodes.
    - Simpler hardware and software platform.

♦ Wireless Mesh Network (WMN) Architectures

- Infrastructure/Backbone WMNs

![Diagram of Infrastructure/Backbone WMNs](image-url)
Mesh routers form a backbone topology.
- Wired or wireless nodes can connect into the backbone.
- The backbone can connect to the Internet.

Mesh routers can be called ____________________________, since they form a stable infrastructure.
- May also have permanently connected power.
- Mesh routers can be advantageously placed for better coverage and interconnection – poles, rooftops, etc.

Mesh routers form a mesh of self-configuring, self-healing links among themselves.

This the most common form of WMN.

Client WMNs

![Mesh network diagram]

Fig. 4. Client WMNs.

- “Client nodes constitute the actual network to perform routing and configuration functionalities as well as providing end-user applications to customers.”
- How is this different from a general ad hoc network? Not sure.
Hybrid WMNs
- Combination of infrastructure and client meshing.

- There are a base set of routers which form a backbone.
- But mesh clients can also do routing in small clusters.
  - If the backbone is sparsely connected nearby.
  - Or just if on-demand it might be beneficial.

♦ Characteristics

- The goal is to use multi-hop routing as much as possible.
  - Communicate over short range (keep power levels low) so the same frequencies can be used elsewhere.
- Mesh routers are assumed to have limited mobility.
  - So routing protocols can be more proactive and assumed to not change as much.
- Mesh routers do not have power limitations.
  - But mesh clients do.
♦ Mesh network capabilities are greater than ad hoc networks.
  ➢ The author believes that ad hoc networks are actually a types of mesh networks.
    • So mesh networks are the more general concept.
    • Mesh networks allow for having or not having a backbone.
  ➢ Load on end-user devices is significantly decreased, since they do not to participate in routing.

♦ Application areas
  ➢ Home networking
  ➢ Community and neighborhood networking
  ➢ Enterprise networking
  ➢ Metropolitan area networks
  ➢ Transportation systems
  ➢ Building automation systems
  ➢ Medicine
  ➢ Security surveillance

♦ The WMN MAC layer
  ➢ Concerned with more than one hop communication.
    • Classical assumption: MAC layer for one hop, routing layer to go across multiple hops.
    • But here the communication two or more nodes away can have an effect.
      - Like the hidden node problem.
      - Or consider sending packets down a straight line of nodes.
        - Node 1 cannot transmit if Node 2 is sending the previous packet that Node 1 sent.
  ➢ The MAC is distributed
    • Cooperative between nodes.
      - No central controller is available.
    • Needs to work for multipoint-to-multipoint communication.
    • 802.16 mesh mode sends transmission requests to two-hop neighbors.
  ➢ Network self-organization is needed.
    • The MAC protocol must have knowledge of topology.
      - Knowing who will interfere with whom.
• The network can also organized to limit interference.
  - Not necessarily by moving the nodes, but just by controlling power levels.

➢ Mobility affects performance
• How mesh clients participate can significantly affect performance.

➢ Two approaches
• New MAC protocols to increase end-to-end throughput using a shared channel.
  - Protocols themselves cannot help too much if there is a lot of contention in the network.
  - Cross-layer protocols using directional antennas and power control could be especially helpful, however.
  - Maybe use TDMA or CDMA instead of CSMA.
• Use multiple channels.
  - Two nearby nodes can transmit at the same time if using different channels.
  - Then the MAC layer must coordinate who uses multiple channels and when.

♦ The paper lists many other areas of interest

➢ Critical factors affecting network performance
➢ Capacity of WMNs
➢ Physical Layer
➢ Network Layer
➢ Transport Layer
➢ Network Management
➢ Security
➢ Timing Synchronization
➢ Standards activities in 802.11, 802.15, and 802.16.
II. Satellite Configurations

♦ The heart of satellite communication is a satellite-based antenna in a stable orbit above the earth.

➢ There are different types of orbits, as discussed below.

♦ Terminology

➢ Earth stations – Antenna systems on or near the earth.
➢ Uplink – Transmission from the earth station to the satellite.
  • Downlink – The opposite.

➢ ___________________________ – Converts an uplink signal into a downlink signal.
  • Much of the purpose of a satellite is to reflect the signal back down.
  • To cover a wide area.

♦ What do you think are the main differences between satellite-based and terrestrial-based wireless communication?
Satellite Orbits

- Classifications
  - Circular or elliptical.
    - Circular with the earth at the center.
    - Elliptical with the earth at one of the foci of the ellipse.
  - May orbit around different planes.
    - Equatorial – directly above the equator.
    - Polar – Passes over both poles.
  - Altitude – Geostationary, medium earth orbit, low earth orbit.
- Minimum inclination angle \( \theta \) determines the range of coverage.
- \( \theta = 0 \) would provide the widest coverage.
  - But buildings, trees, or other terrestrial objects would block the line of sight.
  - Atmospheric attenuation is much worse at low angles.
  - Electrical noise can also have more of an effect.
- Design practice for downlinks is to use a minimum elevation angle of 5\(^\circ\) to 20\(^\circ\), depending on frequency.
Geostationary satellites

- The satellite rotates so as to be in perfect synchronization with the earth.
  - Stays at exactly the same place above the earth as it rotates.
- Advantages
  - No problems due to frequency changes (Doppler shifts) due to relative movements of antennas.
  - Simpler tracking of satellites by earth stations.
  - At that high of an altitude, the satellite can cover roughly ¼ of the earth.
    - Three satellites in orbit can cover most of the inhabited parts of the earth.
    - Ignoring polar areas.
• Problems
  - Signal can get quite weak because of received power is strongly dependent on distance.
  - But this is close to a free space transmission, so the pathloss exponent is near 2.
  - Polar regions are poorly covered.
  - Delay can be quite substantial.
    - Computation:

- Telephone conversations have around 0.50 sec. between one person speaking and then hearing a response.
- This is definitely noticeable.
- Can be used for broadcast TV programs, where delay is not so much a problem. Why is delay not so much a problem here?
  - It is a one-way transmission, so a half second delay at the start is not a problem.
- DIRECTV
  - See http://wwwDIRECTV.com/DTVAPP/learn/DTVTechnology.jsp
  - Started in 1994.
  - Uses 6 GEO satellites.
  - One satellite is a “spot beam” satellite that allows signals to target specific areas within the U.S., and is used by DIRECTV to deliver local programming.
  - Once installed, an earth station never needs to change its settings.
  - Uses MPEG-2 technology at 30 Mbps.
LEO – Low Earth Orbit

(a) Low earth orbit: often in polar orbit at 500 to 1500 km altitude

- See the characteristics in Table 9.1.

Table 9.1 Orbital Comparison for Satellite Communications Applications

<table>
<thead>
<tr>
<th>ORBITS</th>
<th>LEO</th>
<th>MEO</th>
<th>GEO</th>
</tr>
</thead>
<tbody>
<tr>
<td>Orbital period</td>
<td>1.5 to 2 h</td>
<td>5 to 10 h</td>
<td>24 h</td>
</tr>
<tr>
<td>Altitude range</td>
<td>500 to 1500 km</td>
<td>8000 to 18,000 km</td>
<td>35,863 km</td>
</tr>
<tr>
<td>Visibility duration</td>
<td>15 to 20 min/pass</td>
<td>2 to 8 hr/pass</td>
<td>Permanent</td>
</tr>
<tr>
<td>Elevation</td>
<td>Rapid variations; high and low angles</td>
<td>Slow variations; high angles</td>
<td>No variation; low angles at high latitudes</td>
</tr>
<tr>
<td>Round-trip propagation delay</td>
<td>Several milliseconds</td>
<td>Tens of milliseconds</td>
<td>≈ 250 ms</td>
</tr>
<tr>
<td>Instantaneous ground coverage (diameter at 10° elevation)</td>
<td>≈ 6000 km</td>
<td>≈ 12,000 to 15,000 km</td>
<td>16,000 km</td>
</tr>
<tr>
<td>Examples of systems</td>
<td>Iridium</td>
<td>Odyssey</td>
<td>Intelstat</td>
</tr>
<tr>
<td></td>
<td>Globalstar</td>
<td>Inmarsat</td>
<td>Interspoutnik</td>
</tr>
<tr>
<td></td>
<td>Teledesic</td>
<td></td>
<td>Inmarsat</td>
</tr>
<tr>
<td></td>
<td>Skybridge,</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Orbcomm</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
• Earth stations must be able to track the fast movement of the satellite across the sky.
• This fast movement causes frequency shifting (Doppler shifts).
• Continuous communication requires multiple satellites.
  - Several satellites in the same orbit.
  - Handing off the signal from one to another.
• Advantages over GEO
  - Reduced propagation delay.
  - Much stronger received signal.
  - More localized coverage, so more spectrum is available per unit area.
  - This technology is being pursued for mobile terminals.
    - Because of the strong signals.
    - But many satellites are needed.
  - Iridium is a prime example of this.
    - Global coverage.
    - 66 LEO satellites.
    - Designed for outdoor operation for voice calls.
  ➢ MEO – Medium Earth Orbit

(b) Medium earth orbit: inclined to the equator, at 5000 to 18,000 km altitude
• See Table 9.1 above.
  - Require much fewer handoffs than LEO.
  - More power and delay than LEO’s but substantially less than GEO’s.
• Global Positioning System (GPS)
  - See http://www.garmin.com/aboutGPS/.
  - GPS is a satellite-based navigation system made up of a network of 24 satellites placed into orbit by the U.S. Department of Defense.
  - Originally for military, but made available to the public in the 1980’s, at a lower quality.
  - Available anywhere in the world.
  - In any weather condition.
  - Satellites make two orbits every 24 hours.
  - Placed at an altitude of 12,000 miles (20,000 km).
  - The GPS receiver compares the time a signal that was transmitted by a satellite with the time it was received.
  - The time difference tells the GPS receiver how far away the satellite is.
  - What time resolution is required? Consider one satellite directly overhead and another 20100 km away.

- With distance measurements from a few more satellites, the receiver can determine the user's position.
- Must connect with 3 satellites for a 2D position.
- Four or more satellites can provide a 3D position.
- GPS receivers are accurate within 15 meters on average.
- Garmin mentions newer receivers with 3 meter accuracy.
- Other interesting facts mentioned by Garmin.
  - “The first GPS satellite was launched in 1978.
  - A full constellation of 24 satellites was achieved in 1994.
- Each satellite is built to last about 10 years. Replacements are constantly being built and launched into orbit.
- A GPS satellite weighs approximately 2,000 pounds and is about 17 feet across with the solar panels extended.
- “Transmitter power is only 50 watts or less.”
- GPS satellites transmit two low power radio signals.
  - Designated L1 and L2.
  - Civilian GPS uses the L1 frequency of 1575.42 MHz in the UHF band.
  - Line of sight signals.
  - “Will pass through clouds, glass and plastic but will not go through most solid objects such as buildings and mountains.”
- Sources of GPS signal errors
  - Ionosphere and troposphere delays.
  - Signal multipath
  - Receiver clock errors
  - Orbital errors – Inaccuracies in the satellite's reported location.
  - Number of satellites visible – The more satellites a GPS receiver can "see," the better the accuracy.
  - GPS units typically will not work indoors, underwater or underground.
  - Satellite geometry/shading – relative position of the satellites at any given time.
  - Intentional degradation of the satellite signal – “Selective Availability (SA) is an intentional degradation of the signal once imposed by the U.S. Department of Defense. SA was intended to prevent military adversaries from using the highly accurate GPS signals. The government turned off SA in May 2000, which significantly improved the accuracy of civilian GPS receivers.”
Frequencies

Table 9.2 lists frequency bands available for satellite communications.

Table 9.2 Frequency Bands for Satellite Communications

<table>
<thead>
<tr>
<th>Band</th>
<th>Frequency Range</th>
<th>Total Bandwidth</th>
<th>General Application</th>
</tr>
</thead>
<tbody>
<tr>
<td>L</td>
<td>1 to 2 GHz</td>
<td>1 GHz</td>
<td>Mobile satellite service (MSS)</td>
</tr>
<tr>
<td>S</td>
<td>2 to 4 GHz</td>
<td>2 GHz</td>
<td>MSS, NASA, deep space research</td>
</tr>
<tr>
<td>C</td>
<td>4 to 8 GHz</td>
<td>4 GHz</td>
<td>Fixed satellite service (FSS)</td>
</tr>
<tr>
<td>X</td>
<td>8 to 12.5 GHz</td>
<td>4.5 GHz</td>
<td>FSS military, terrestrial earth exploration, and meteorological satellites</td>
</tr>
<tr>
<td>Ku</td>
<td>12.5 to 18 GHz</td>
<td>5.5 GHz</td>
<td>FSS, broadcast satellite service (BSS)</td>
</tr>
<tr>
<td>K</td>
<td>18 to 26.5 GHz</td>
<td>8.5 GHz</td>
<td>BSS, FSS</td>
</tr>
<tr>
<td>Ka</td>
<td>26.5 to 40 GHz</td>
<td>13.5 GHz</td>
<td>FSS</td>
</tr>
</tbody>
</table>

- Why are the lower frequencies more suitable for a mobile satellite service?

For any service, there is an allocation of an uplink frequency band and a downlink band.
- The uplink band is at a higher frequency.
- The earth station is capable of higher transmission power, which can compensate for the limitations of the higher frequency.
- Recall that higher power is needed at a higher frequency.
  - Based on the dependence on $\lambda$ in the free space pathloss calculation.
III. Introduction

♦ Goals of a Cellular System
  ➢ High capacity
  ➢ Large coverage area
  ➢ Efficient use of limited spectrum

♦ Large coverage area – Bell system in New York City had early mobile radio
  ➢ Single Tx, high power, and tall tower
  ➢ Low cost
  ➢ Large coverage area - Bell system in New York City had 12 simultaneous channels for 1000 square miles
  ➢ Small # users
  ➢ Poor spectrum utilization

♦ What are possible ways we could increase the number of channels available in a cellular system?
Cellular concept

- Frequency reuse pattern

![Diagram of frequency reuse patterns for N=4, N=7, and N=19](image)

- Cells labeled with the same number use the same group of channels.
- Cell Cluster: group of N cells using complete set of available channels

- Many base stations, lower power, and shorter towers
- Small coverage areas called “cells”
- Each cell allocated a % of the total number of available channels
- Nearby (adjacent) cells assigned different channel groups
  - to prevent interference between neighboring base stations and mobile users
- Same frequency channels may be reused by cells a “reasonable” distance away
  - not in the adjacent cells. Maybe not even in the cells next to them.
  - reused many times as long as interference between same channel (co-channel) cells is < acceptable level
As frequency reuse increases ⇒ # possible simultaneous users increases ⇒ # subscribers increases ⇒ but system cost increases (more towers)

To increase number of users without increasing radio frequency allocation, reduce cell sizes (more base stations) ⇒ # of possible simultaneous users increases

The cellular concept allows all mobiles to be manufactured to use the same set of frequencies

*** A fixed # of channels serves a large # of users by reusing channels in a coverage area ***

IV. Frequency Reuse/Planning

♦ The design process involves selecting & allocating groups of channels to cellular base stations

♦ Two competing/conflicting objectives:
  1) maximize frequency reuse in specified area
  2) minimize interference between cells

♦ Cells
  ➢ base station antennas are designed to cover a specific cell area
  ➢ a hexagonal cell shape is assumed for planning
    • simple model for easy analysis → circles leave gaps
    • squares leave some neighboring cell centers farther away than others.
    • actual cell “footprint” is amorphous (no specific shape)
      - where Tx successfully serves mobile unit

V. System Capacity

Note: Most of this discussion relates to FDMA/TDMA based systems like GSM, AMPS, etc. Frequency reuse is different for CDMA systems.

♦ $S$: total # of duplex channels available for use in a given area; determined by:
  ➢ amount of allocated spectrum
  ➢ channel BW → modulation format and/or standard specs. (e.g. AMPS)
    • $k$: number of channels for each cell ($k < S$)
    • $N$: cluster size → # of cells forming cluster
    • $k = S / N$
    • $S = kN$
• \( M \): # of times a cluster is replicated over a geographic coverage area
• System Capacity = Total # Duplex Channels = \( C \)

\[
C = M \cdot S = M \cdot k \cdot N
\]

(assuming exactly \( MN \) cells will cover the area)

♦ If cluster size \( (N) \) is reduced and the geographic area for each cell is kept constant:
  - The geographic area covered by each \textit{cluster} is smaller, so \( M \) must \( \uparrow \) to cover the entire coverage area (more clusters needed).
  - \( S \) remains constant (same number of channels per cluster).
  - So \( C \uparrow \).
  - The smallest possible value of \( N \) is desirable to maximize system capacity.

♦ Cluster size \( N \) determines:
  - distance between co-channel cells \( (D) \)
  - A mobile or base station can only tolerate so much interference from other cells using the same frequency and maintain sufficient quality.
  - large \( N \) \( \rightarrow \) large \( D \) \( \rightarrow \) low interference \( \rightarrow \) but small \( M \) and low \( C \)!
  - Tradeoff in quality and cluster size.
  - The larger the capacity for a given geographic area, the poorer the quality.
  - Generally the design approach is to use the smallest cluster that will give acceptable voice quality.

♦ \( N \) cells/cluster
  - connect without gaps
  - specific values are required for hexagonal geometry
    • Move \( i \) cells along any chain of hexagons, then turn 60 degrees and move \( j \) cells.
    • \( N = i^2 + i \cdot j + j^2 \)
    • Typical \( N \) values \( \rightarrow \) 3, 4, 7, 12; \((i, j) = (1,1), (2,0), (2,1), (2,2)\)
  - See above figure for examples of 4, 7, and 19 cell clusters.
VI. Handoff Strategies

♦ Handoff: when a mobile unit moves from one cell to another while a call is in progress, the MSC must transfer (handoff) the call to a new channel belonging to a new base station.

- new voice and control channel frequencies
- very important task → often given higher priority than new call
  - It is worse to drop an in-progress call than to deny a new one

♦ Minimum useable signal level

- is the lowest acceptable voice quality
- call is dropped if below this level
- specified by system designers
- choose a (handoff threshold) > (minimum useable signal level)
  - so there is time to switch channels before level becomes too low
  - as mobile moves away from base station and toward another base station
A dropped handoff can be caused by two factors

- not enough time to perform handoff
- no channels available in new cell

Prioritizing Handoffs

- Issue: Perceived Grade of Service (GOS) – service quality as viewed by users
  - “quality” in terms of dropped or blocked calls (not voice quality)
  - assign higher priority to handoff vs. new call request
  - a dropped call is more aggravating than an occasional blocked call that cannot be started

- We have been studying ways of helping emergency calls.
- Possible approaches:
  - Holding back channels only for emergency users.
• Giving blocked emergency calls a chance to wait until a channel becomes available.
• Interrupt low priority calls – put them in a queue so they can return when a channel is available.

VII. Cellular Standards

♦ First Generation
  ➢ Analog
  ➢ One technology: AMPS (Advanced Mobile Phone System)
    • 30 kHz voice channels

♦ Second Generation
  ➢ Digital modulation
  ➢ TDMA/FDD or CDMA/FDD
    • FDD = Frequency Division Duplexing
      - The two channels for a voice conversation are given different frequencies.

♦ 4 popular standards for 2G
  ➢ Global System for Mobile (GSM)
    • Eight time-slotted users for each 200 kHz radio channel.
    • 270.833 kbps total data rate shared among those 8 users.
    • Deployed widely in Europe, Asia, Australia, South America, and some parts of the U.S. in the PCS band of spectrum.
    • GSM users, therefore, have global roaming capabilities.
    • GSM uses SIM (Subscriber Identity Module) cards that can be transferred from phone-to-phone. Phones for other types of technologies must be programmed.
    • T-Mobile, Cingular/AT&T in the U.S.
  ➢ Interim Standard 136 (IS-136)
    • Also called North American Digital Cellular (NADC)
  ➢ Pacific Digital Cellular (PDC)
    • Japanese standard
    • Similar to IS-136
  ➢ Interim Standard 95 (IS-95)
    • CDMA
    • Also known as cdmaOne
    • 64 users (i.e., 64 codes are used) in a 1.25 MHz channel.
    • Can be used in 800 MHz and 1900 MHz bands.
    • Sprint and Verizon in the U.S.
♦ General 2G Characteristics
  ➢ In summary, what is the difference between 1G and 2G?
    ➢ Enabled by sophisticated digital signal processing.

VIII. Evolution to 2.5G

♦ 2G Data Transmission Capabilities
  ➢ 2G transmits data over voice circuits
    • Just like a modem
    • Data is sent in place of voice over the same channel bandwidth, just like voice coding rates in the table above.
    • Capabilities around 10 kbps.

♦ New standards for data over 2G
  ➢ Called 2.5G technology
  ➢ Allows existing 2G equipment to be modified for higher data-rate transmissions.
  ➢ More advanced applications are possible.

♦ 2.5G Migration Paths
  ➢ Upgrade Path
    • A 2.5G technology must match an upgrade path from the 2G technology that is in place.
      - That is why it is not considered an upgrade to a next generation.
    • Same air interface
      - Do not want to require wholesale RF equipment changes at the base stations.
    • Only requires upgrades to software.
    • Plus addition of more equipment to work with base station equipment.
IX. Third Generation (3G) Wireless Networks

♦ Much broader new capabilities
  ➢ Multi-megabit Internet access
  ➢ Voice communication over Internet protocols
  ➢ Voice-activated calls
  ➢ "Always on" access
  ➢ Receiving live music
  ➢ Videoconferencing
  ➢ Virtual home entertainment
  ➢ Broadcasting
  ➢ Games
  ➢ Interactive video
  ➢ Simultaneous voice and data
  ➢ Key application: Business enterprises using mobile applications.

♦ Data services currently represent the only avenue for growth for cellular companies.
  ➢ Yet Wi-Fi and WiMax are also competitors.
Two major competing camps
- Based on what 2G technology is used already by each camp.
  - GSM/IS-136/PDC
    - 3G Partnership Project for Wideband CDMA – 3GPP
  - IS-95
    - 3G Partnership Project for cdma2000 – 3GPP2

Universal Mobile Telecommunications System (UMTS)
- Also called Wideband-CDMA (W-CDMA)
- From GSM/IS-136/PDC.
- Evolved since 1996.
- From European Telecommunications Standards Institute (ETSI)
- Backwards compatible with GSM, IS-136, PDC, HSCSD, GPRS, and EDGE
  - Equipment for the previous technologies will work in UMTS.
  - Network structure same as GSM.
  - Bit level packaging same as GSM.
  - But now uses CDMA.
- Up to 2.048 Mbps per user.
  - If user is stationary.
  - Up to 8 Mbps in the future.
- Needs a minimum spectrum allocation of 5 MHz
  - Instead of 200 kHz for GSM
  - Expensive: Requires a complete change of RF equipment at each base station.
  - 6 times more efficient use of spectrum than GSM
  - Uses CDMA
- AT&T offers UMTS service.
  - Speeds between 400K kbps and 700 kbps.

cdma2000 1x EV-DO
- From IS-95
- Works within original 2G CDMA channel bandwidth of 1.25 MHz.
- Allows wireless carriers to introduce 3G in a gradual manner.
  - Can introduce 3G capabilities at each cell
  - Do not have to change out entire base stations
  - Do not have to use different spectrum.
First air interface: cdma2000 1xRTT
- 1X = one times the original IS-95 (cdmaOne) channel bandwidth.
- RTT = Radio Transmission Technology
- Commonly just referred to as cdma2000 1X.
- Instantaneous data rate of 307 kbps.
  - Typical rates up to 144 kbps (as advertised by Verizon)
  - Depends on number of users.
  - Depends on velocity of the user.
  - Depends on the propagation conditions.
- Uses rapidly adjusting rates.
- No additional RF equipment is needed.
  - All changes made in software or with additional hardware.

cdma2000 1xEV
- EV = Evolutionary enhancement
- High data rate packet standard overlaid on existing IS-95, IS-95B, and cdma2000 networks.
- 1xEV-DO
  - Data only channel
  - Restricts a shared 1.25 MHz channel strictly to data users.
  - Supports greater than 2.4 Mbps throughput per user.
  - Actual data rates usually much lower.
  - Typical: Several hundred kbps.
  - Verizon advertises its EV-DO as having average speeds ranging from 300 kbps to 1 Mbps.
  - Verizon and Sprint both offering this service and have the highest rates in the industry (Verizon is offered in Kansas City).
  - Highly dependent on number of users, propagation conditions, and velocity of mobile.
- 1xEV-DO Rev. A
  - Supports quality of service, voice, and video.
  - Also better throughputs for uplinks and downlinks.
- 1xEV-DO Rev. B
  - Multicarrier.
  - Uses multiple 1.25 MHz channels.
  - Channels can be operated simultaneously in parallel.

Now you know everything there is to know about wireless networking!