Class 3:
Modern Wireless Systems

Use cases for Hobbyist and Ham Radio Applications

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Modern Wireless Systems

- AX-25 and APRS
- WSJT-X and its associated protocols
- Sailmail (for the high seas)→Winlink (Ham Radio)
- GPS
- WiFi
- Bluetooth
- ZigBee
- Z-Wave
- LoRa, Meshtastic, Meshcore

Frequency Bands for License Free Wireless

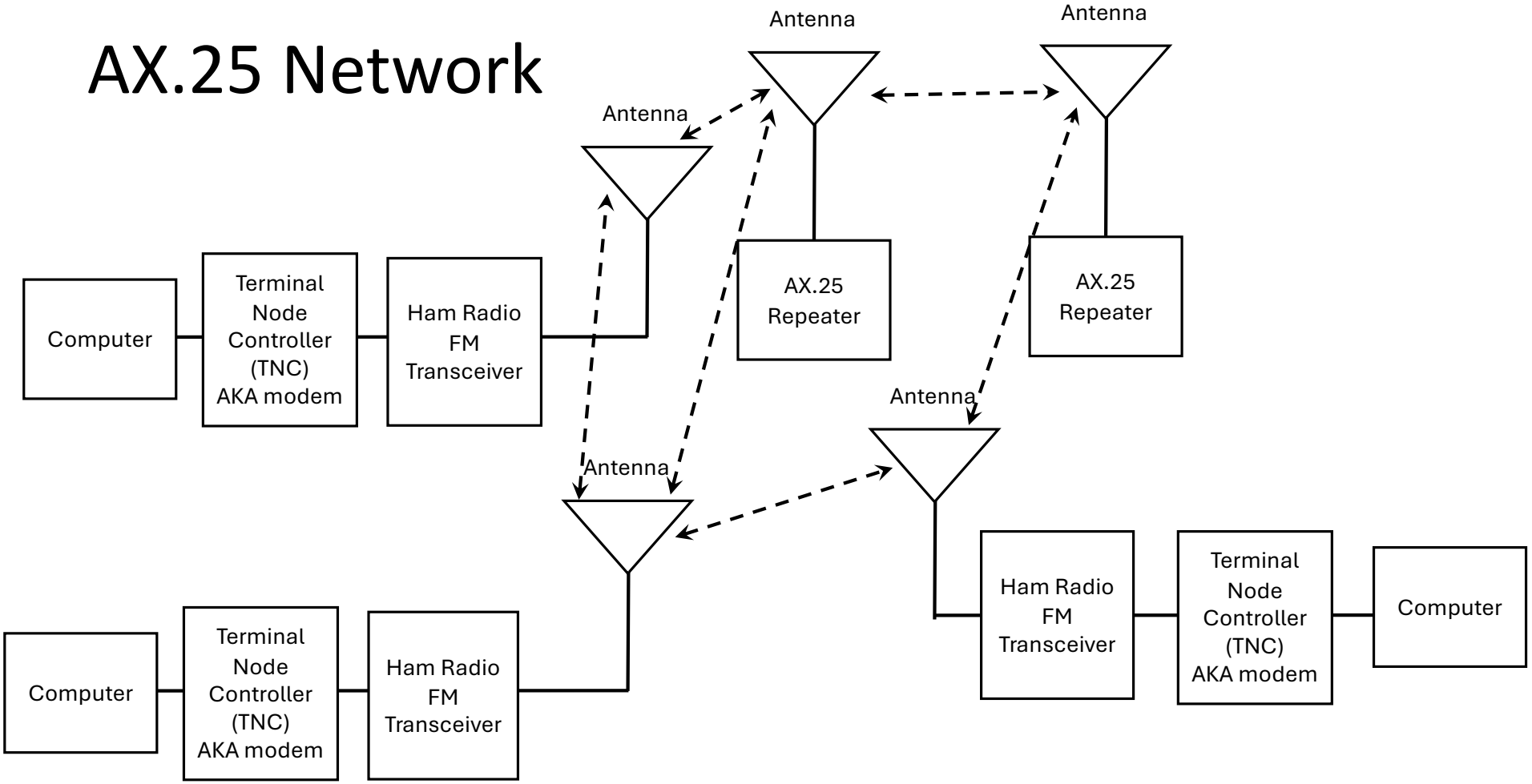
- In the United States, the Federal Communications Commission (FCC) controls all Wireless Communications
- For most wireless communications, a valid FCC license is required
- There are also some license free bands called: Industrial, Scientific, and Medical (ISM) bands
- The chart at the right shows some of the ISM bands
- Note: in the EU 433 MHz is a license free band so some equipment makes it to the US on that band as a low power license free transmitter
- But 420-450 MHz is a Ham band and requires a license

	Frequency range		USE
	13.553 MHz	13.567 MHz	Worldwide
	26.957 MHz	27.283 MHz	Worldwide
	40.66 MHz	40.7 MHz	Worldwide
	902 MHz	928 MHz	US
	2.4 GHz	2.5 GHz	Worldwide
	5.725 GHz	5.875 GHz	Worldwide
	24 GHz	24.25 GHz	Worldwide

AX-25 and APRS

- X.25 is a packet switching protocol used in Telecommunications
- A group of hams modified the protocol to include ham radio call letters and other changes to use over ham radio
- It was called AX-25 (A for Amateur)
- It became a popular for hams to exchange digital messages and there are digital repeaters still in operation
- APRS (Automatic Packet Reporting System) is based on AX.25 and transmits real-time data like GPS positions, weather, messages, and telemetry
- It is often used during public events like bike rides, walks, etc.. to identify where various checkpoints are located and when event participants pass a checkpoint
- There are various websites that show where users of APRS are currently located
- Since this is ham radio based:
  - It requires a Ham radio license to use, and
  - It can not be used for commercial functions
- For more information see:
  - https://en.wikipedia.org/wiki/X.25
  - https://en.wikipedia.org/wiki/AX.25

AX.25 Network



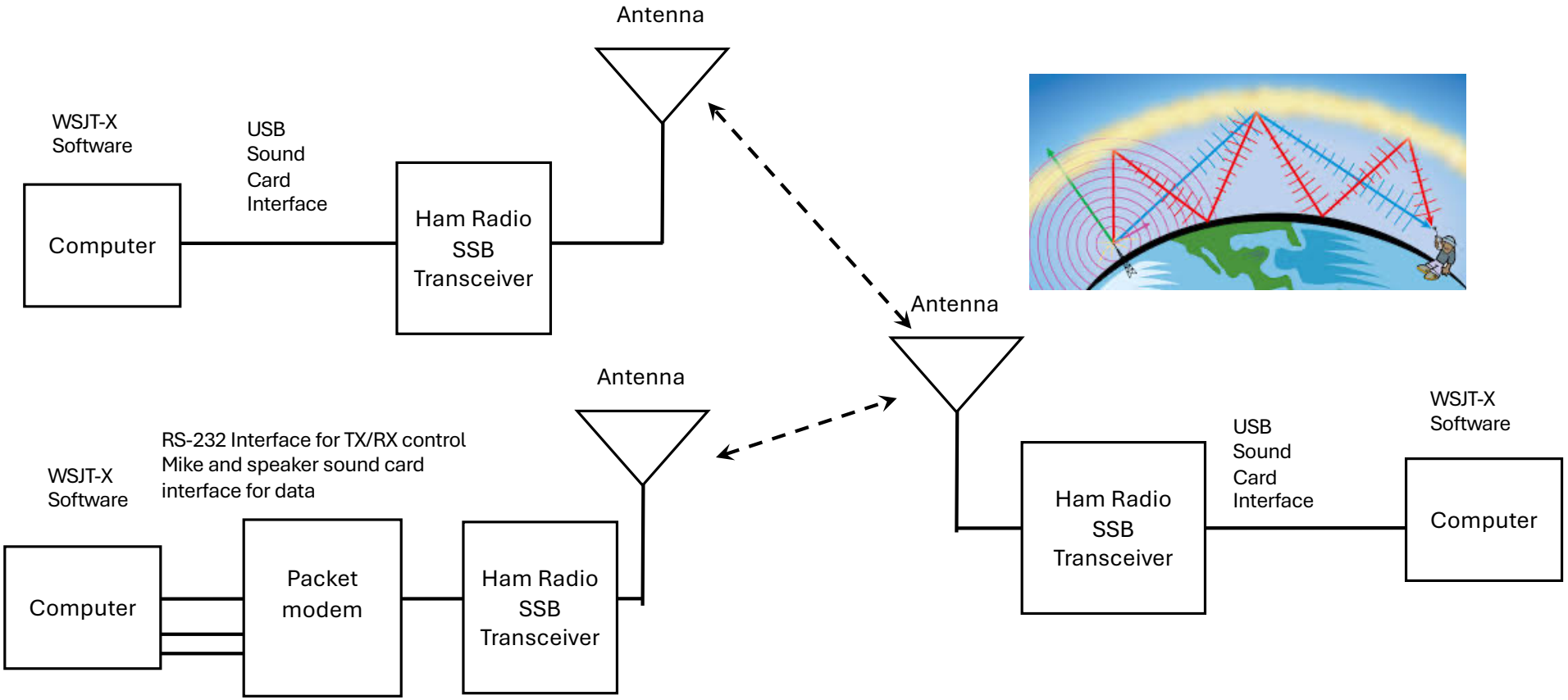
AX-25 Operation

- The data to/from the computer is sent over an RS-232 connection to a Terminal Node Controller (TNC), similar to a modem
- For VHF/UHF FM, the TNC converts the data into audio tones based on (old) 1200 baud wireline modems
  - A 1200 Hz tone for mark (typically a binary 1), and
  - A 2200 Hz tone for space (typically a binary 0).
- The audio is then sent to the FM transceiver either into the microphone input or a special data port on some radios
- For 9600 bps and for HF different coding is used

WSJT-X and its Associated Protocols

- WSJT-X (Weak Signal by Joe Taylor) was designed by Nobel Prize winner Dr. Joe Taylor, K1JT
- WSJT-X is a computer program used for weak-signal radio communication between amateur radio operators.
- The program was initially written by Joe Taylor, K1JT, but is now open source and is developed by a small team.
- The digital signal processing techniques in WSJT-X make it substantially easier for amateur radio operators to employ esoteric propagation modes, such as high-speed meteor scatter and Moon bounce
- Additionally, WSJT is able to send signal reports to spotting networks such as PSK Reporter

WSJT-X Network



WSJT-X Operation

- There are no WSJT-X repeaters
- Most modern transceivers have a USB sound card built-in, therefore, an external modem is not needed
- Communications is either direct line-of-sight, or
- By bouncing off the ionosphere, moon, etc.

WSJT-X

- The WSJT-X software runs on Windows, MAC-OSX, and Linux
- It is a free open source program
  - https://wsjt.sourceforge.io/wsjtx.html
- WSJT-X implements communication protocols or "modes" called FST4, FST4W, FT4, FT8, JT4, JT9, JT65, Q65, MSK144, and WSPR, as well as one called Echo for detecting and measuring your own radio signals reflected from the Moon
- These modes were designed for making reliable, confirmed QSOs under extreme weak-signal conditions
- Currently, ft-8 is the most common mode used

World wide FT-8 Frequencies

160m	1.840
80m	3.573
60m	5.357
40m	7.074
30m	10.136
20m	14.074
17m	18.100
15m	21.074
12m	24.915
10m	28.074
6m	50.313

4m	70.1	Region 1
4m	70.154	(Countries without access to 70.100)
2m	144.174	All

Note: Some countries do not have access to 6 M
They often have access to 4m instead

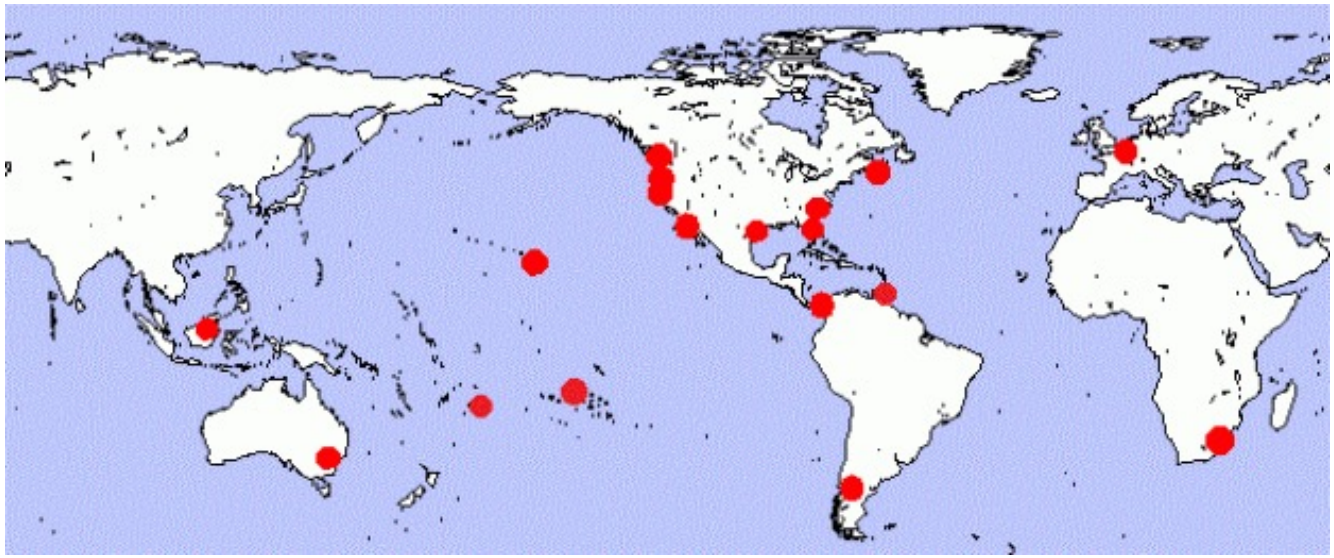
The US does not have access to 4m

The 144-146 MHz part of the 2 m band
is a world-wide allocation

SailMail

- The SailMail Association is a non-profit association of **yacht owners** that operates and maintains an email communications system for use by its members.
- SailMail supports email communications using every internet communications device in all oceans of the world.
- SailMail email can be transferred via any form of internet access e.g.
- Iridium, Inmarsat, VSAT, Globalstar, Thuraya, terrestrial WiFi, terrestrial cellular networks, or
- via SailMail's own world-wide network of SSB-Pactor radio stations.
- The SailMail Association maintains its own world-wide network of SSB-Pactor private coast stations in the Maritime Mobile Radio Service.
- The use of this network is available at no extra charge to SailMail members, but of course requires the member to have a SSB HF transceiver and a Pactor modem
- The current membership assessment is $275 per vessel, per year
- For more information and to subscribe to the service see: https://sailmail.com/

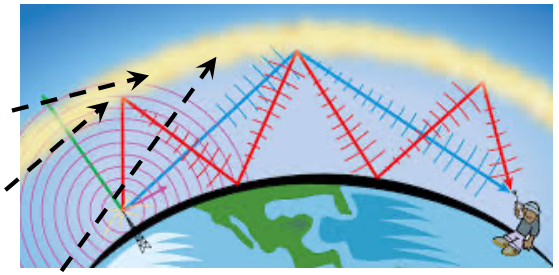
SailMail HF SSB stations worldwide



Winlink

- Winlink uses the same Pactor Modems as SailMail and has built its own network of stations to connect to the internet
- The email and other data from Winlink can be sent to any use on the Winlink network or the internet (assuming the the Internet is working)
- Winlink Global Radio Email is a network of amateur radio and authorized government stations that provide worldwide radio email using radio pathways where the internet is not present.
- The system is built, operated and administered entirely by licensed "Ham" volunteers.
- It supports email with attachments, position reporting, weather and information bulletins, and is well-known for its role in interoperable emergency and disaster relief communications.
- It is capable of operating completely without the internet--automatically--using smart-network radio relays.
- Licensed Winlink operators/stations use both amateur radio and government radio frequencies worldwide
- The main use case for Winlink is emergency communications
- To use Winlink you need
  - A winlink userid and password
  - A very expensive, proprietary, Pactor Modem ($1500 or more)
  - An HF SSB transceiver

Winlink Network



Antenna

Computer

Pactor modem

Ham Radio SSB Transceiver

Antenna

Antenna

Internet

Computer

Pactor modem

Ham Radio SSB Transceiver

Computer

Pactor modem

Ham Radio SSB Transceiver

Global Navigation Satellite Systems (GNSS)

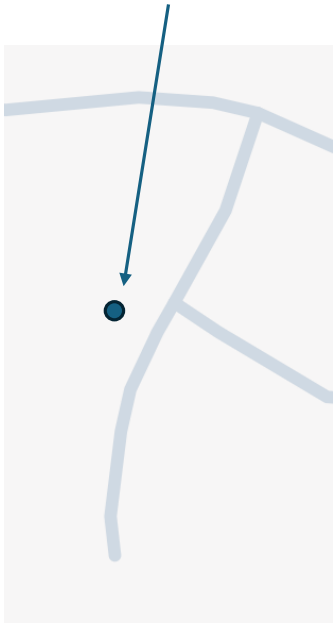
- Several countries and regions have deployed their own GPS-like Global Navigation Satellite Systems (GNSS), including
  - The United States (GPS),
  - Russia (GLONASS),
  - China (BeiDou),
  - The European Union (Galileo),
  - India (NavIC), and
  - Japan (QZSS),
- The US, Russia, China, and EU offer global coverage,
- India and Japan provide regional services.
- These systems offer Positioning, Navigation, and Timing (PNT) services, providing redundancy and strategic advantages, with Galileo being the only purely civilian system.

US Global Positioning System (GPS)

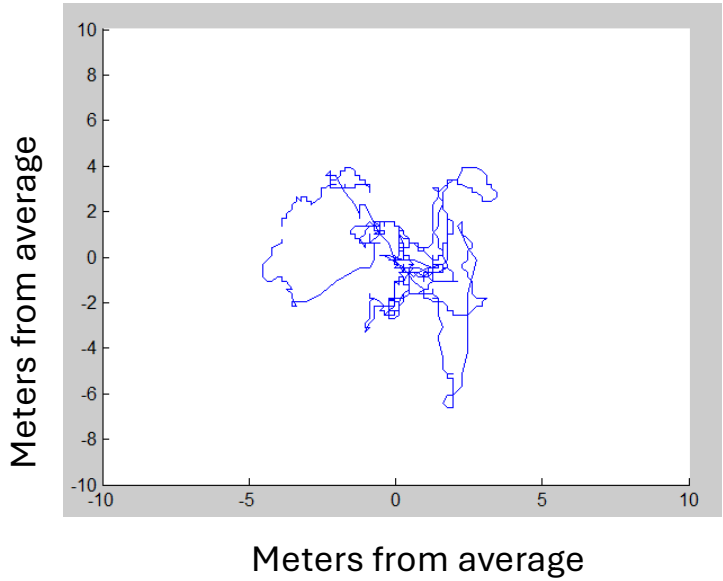
- The US military deployed GPS in the 1970s for miliary use
- There were two modes
  - Highly accurate military signals
  - Non-military with deliberate random errors (called Selective Availability-SA)
- SA created continuously changing, random errors, in the range of hundreds or thousands of meters
- The goal of SA was to avoid enemy missiles using them for targeting the US
- In 2000, President Clinton authorized the removal of selective availability, thus opening the market for civilian GPS units.
- Today Standard GPS has a time varying error of plus or minus 10 meters unless other means are used to improve accuracy
- Since the clocks on the satellite are moving, their time is slower than earth time and the calculations must include Einstein's Equations for Relativity

Plot of GPS location for a stationary object over a time period of about 1 Hour

- Actual location



- GPS Answer



How to improve GPS location

- Build a receiver that receives US, EU, and Russian signals and average the answer
- Build a map of the location of every WiFi access point in the country and use it to create better location data for sending location data on an emergency call (911 in US, other number in other countries)
- Very precise, Differential GPS
  - Survey a location and determine its Lat and Long very accurately
  - Calculate the Lat and Long from GPS and transmit the error on a local VHF frequency
  - Nearby GPS receivers receive the error data and correct their location
  - This can only be done for a short distance before the error data is not accurate

Precise Frequency and timing from GPS

- You get timing information from GPS by
  - using a receiver to decode precise time signals from atomic clocks on satellites,
  - which allows the receiver to synchronize its internal clock to UTC (Coordinated Universal Time) with high accuracy
  - It can also provide a 1 Pulse-Per-Second (PPS) signal
  - This involves locking onto signals from multiple satellites, calculating time differences, and using that data to set your system's time.
- How it works
  - Signal Acquisition: Your GPS receiver acquires signals from at least four satellites, each broadcasting its precise time from an atomic clock.
  - Time Calculation: By comparing the arrival times of these signals and accounting for signal travel time, the receiver calculates its own position and the precise time.
  - Synchronization: The receiver synchronizes its internal clock to the satellite time, providing highly accurate time data.

Wi-Fi

- WiFi was designed to replace wired cables in building and outdoors
- The range of WiFi can be as high as 1000 or more feet
- It works in the license free 2.4 GHz and 5.7 GHz Bands
- WiFi is defined by the 802.11 series of standards
- Each band has a defined set of channels
- Unfortunately, the channels partially overlap with each other so that in an area there less channels available
- Security of WiFi is always being improved but it is not perfect

Bluetooth

- Bluetooth is a low power short range communications system in the 2.4 GHz ISM band
- Typical ranges are 20 feet or less
- It uses frequency hopping and can some extent work even in the presence of WiFi
- The Bluetooth Standard supports a variety of ”profiles”
- Most devices do not support all profiles
- Example Profiles: Audio, Dial up Networking, Hands Free, Phone book, etc.

Zigbee

- Zigbee is a specification for a suite of high-level communication protocols used to create personal area networks for
  - Home automation,
  - Medical device data collection, and
  - Other, low-power low-bandwidth needs
- Many Home Automation devices use Zigbee
- Its low power consumption limits transmission distances to 10–100 meters (33–328 ft) line-of-sight, depending on power output and environmental characteristics, thus it is mostly a home network
- In the US is operates in the 902-928 ISM band
- For more information see: https://en.wikipedia.org/wiki/Zigbee

Z-Wave

- Z-Wave is another wireless communications protocol used primarily for residential and commercial building automation
- It operates in the 902-928 ISM band
- It is not interoperable with Zigbee

- Thus, when building a home automation system with parts from multiple vendors, attention to the wireless system used must be made

LoRa

- LoRa (from "long range") is a physical proprietary radio communication technique based on spread spectrum modulation
- It operates in the 902-928 ISM band in the US and other ISM bands outside the US
- LoRa enables long-range transmissions with low power consumption
- It can achieve data rates between 0.3 kbit/s and 27 kbit/s, depending upon the spreading factor
- The higher the speed the lower the transmission distance
- With proper outdoor, high, antennas, it can achieve ranges of 20 miles or more

Meshtastic

- Meshtastic is an open source,
  - off-grid, decentralized,
  - mesh network
  - built to run on affordable, low-power devices using LoRa
- Using an ISM band for each country (433, 848, 915 MHz)
- The radio uses low power about 1/10 watt and
- Has range of 0.5-20 miles depending on
  - terrain,
  - buildings,
  - vegetation and
  - antenna height
- The network is built by private citizens (at their own expense)

Meshtastic uses LoRa Equipment

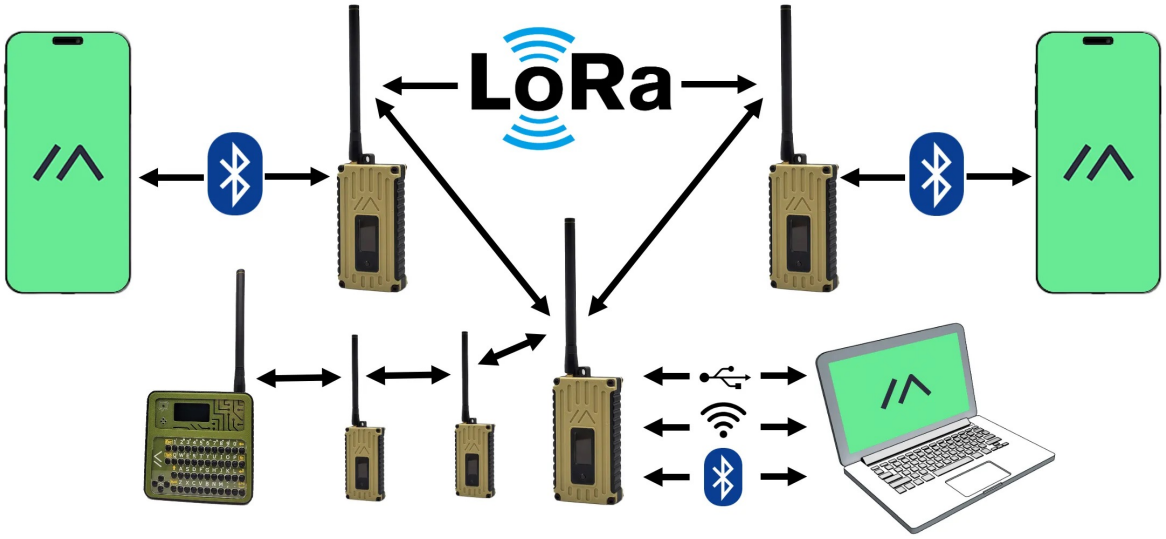
- The main use case is for off-the-grid communications
  - Preppers are main pushers of this technology
  - Techie nerds are the next group to push this technology
- Solar powered nodes are being deployed all over the world
- The Meshtastic application on a tablet or phone connects to a node via Bluetooth, text messages can be sent long distances
- Since paying for and deploying nodes is a “be a good citizen” vs “government” solution, hogging the network with personal data that can be transmitted via other means is frowned upon

Use Case for Meshtastic

- Primary: Alternate method to send ”text” messages (voice, video, data not supported) during an emergency when the cell phone network is overloaded or not working
- Secondary: A method to send ”text” messages (voice, video, data not supported) for groups camping, hiking, etc. in areas where cell phone coverage is spotty or non-existent (desert, mountains, wilderness) to keep in touch with each other and base camp
  - The users would be out of range of other Meshtastic systems and thus,
  - No external communications are possible
- Tertiary: for further discussion in class

Meshtastic Architecture

- For more information see https://meshtastic.org/docs/introduction/



Meshcore

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- Has range of 0.5-20 miles depending on
  - terrain,
  - buildings,
  - vegetation and
  - antenna height
- The network is built by private citizens (at their own expense)
- The architecture is similar to Meshtastic but use different software in the devices and is not inter-operable with Meshtastic
- For more information see: https://meshcore.co.uk/

Meshcore (cont.)

- Meshcore uses the Meshcore App on phones and tablets
- Meshcore defines 4 devices
  - Client connected via USB interface
  - Client connected via Bluetooth
  - Repeater (with connection via USB interface or the network)
  - Room Server (similar to old-fashioned pre World Wide Web Bulletin Board)

Meshtastic vs. Meshcore

Meshtastic

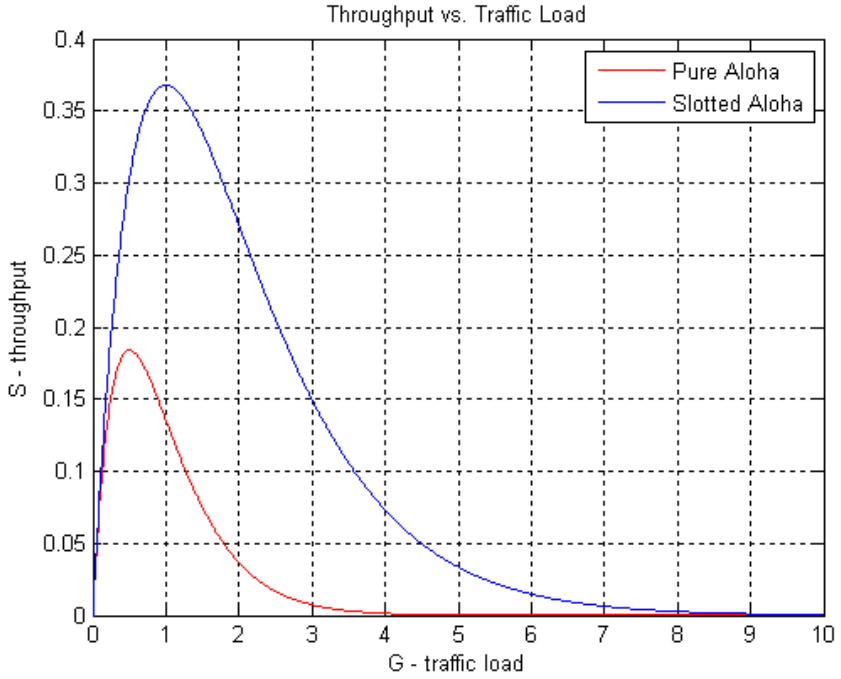
- All devices are repeaters by default
- Managed flood of messages Direct Messages use next-hop routing: flood to discover, then optimized relays for subsequent DMs
- Choose Meshtastic if you want a "bring-a-radio, it just works" experience for roaming groups, mapping, and rich telemetry modules, with minimal setup and no guaranteed infrastructure.
- For more information see: https://www.austinmesh.org/learn/meshcore-vs-meshtastic/

Meshcore

- Devices are personal or repeaters
- Flood-then-direct by design: first message floods to learn a path; later messages embed the learned path; if that route fails after a few retries, the node automatically fall back to flood
- Choose MeshCore if your aim is a resilient, city or region scale messaging network with fixed repeaters(DIY Solar Repeater Parts List), where end-users don’t rebroadcast by default
- CDL plans to deploy Meshcore to support Monmouth County Amateur Radio Emergency Service (ARES) that supports the American Red Cross

Main Problem with Mesh networks

- High traffic density causes collisions with other transmissions and causes the system to collapse
- There is no mechanism to tell a transmitter to delay or stop transmitting
- The early work on packet networks was done at the University of Hawaii in the 1970s and is called Aloha



Questions