Technical Brief
AN252 **Rev A1**

Long Range RF Communications

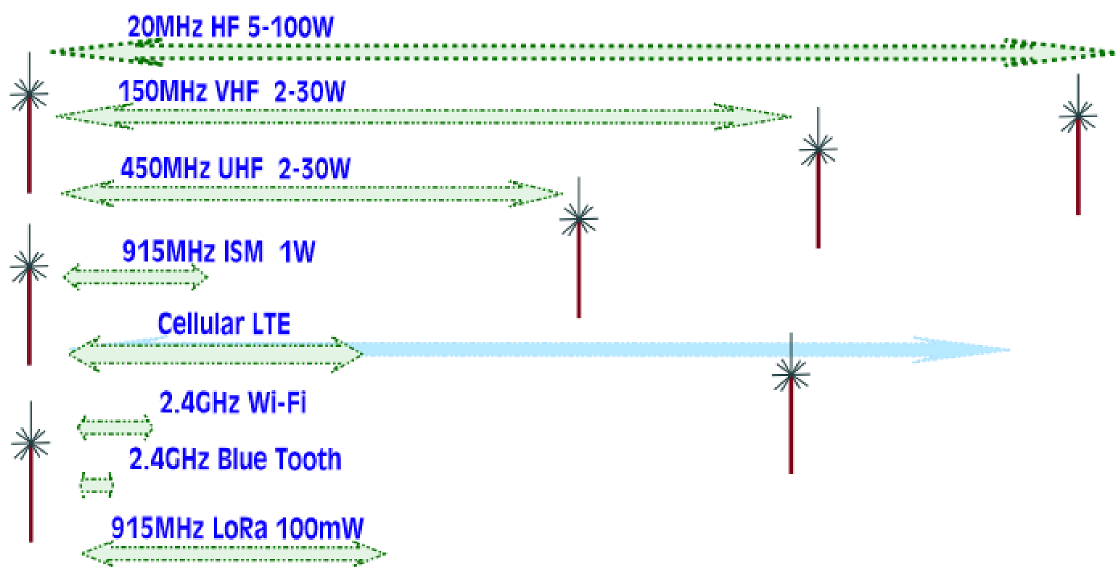
By John Sonnenberg

Raveon Technologies Corp

Overview

Long Range RF Data Communications can be accomplished in different ways. This document explains the Pros and Cons of variations in wireless data communications.

Communication Range depends on Frequency, baud rate, and TX (transmit) power



The Science of RF Communications

- **To send data bits long range**
  - **T**ransmit each bit of **data with energy.**
    Receiver looks for energy and recovers the data
- **RF energy drops over distance:**
  - 20 * log(distance)
- **RF energy received comes in via an antenna**
  - Taller antennas necessary for Lower Frequencies are better
- **Sensitive receivers pick up weak signals.**
  - 3dB more sensitive is as good as 2X TX power
  - 10dB more sensitive is like 10X more power

- **The longer the bit, the more energy it has**
- **Link Margin = 36.6 + 20 * log(D) + 20 * log(F)**

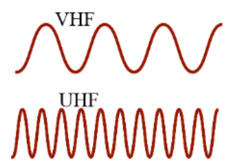
What Affects Communication Range?

Here are the principle things that affect communication range:

- **Transmit power**
- **Receiver sensitivity**
- **Antenna gains and antenna heights.**
- **Frequency of the system**
- **The energy per bit (baud rate/data rate)**
- **Modulation Methods**
- **Local interference**
- **Topography/Terrain**
- **In-Band Noise filtering**

High-tech radio modems like Raveon’s Data Radio Modems are optimized and can be setup to work over the range a system needs to work. Set your power, baud rate, and frequency, the way your system needs to work. Work reliably 1 mile or even 100 miles based on how your system is set up per these considerations that affect the range.

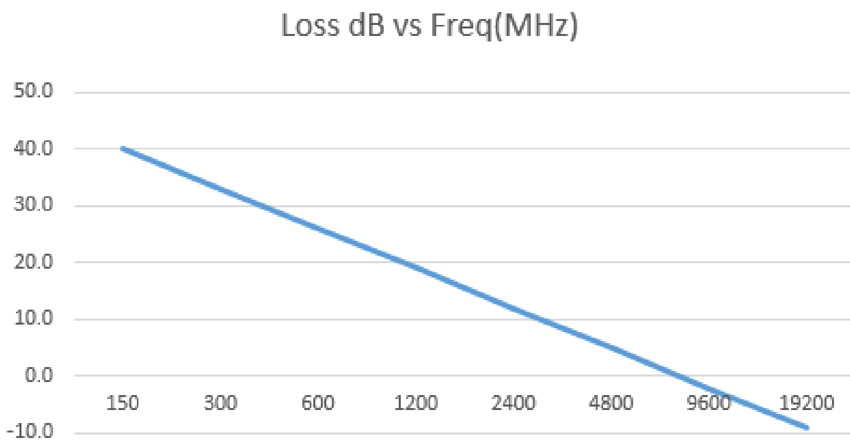
Frequency of the System



The faster the frequency, the shorter the range. VHF is longer range than UHF because VHF waves have more power per cycle. Every RF engineer knows the equation for RF communication that shows the higher the **frequency of the system**, the more the loss. The Path Loss (L) is:

- L = 36.6 + 20 * log(D) + 20 * log(F)
- D(Distance in Miles) F(Frequency)

Path Loss is the signal loss over the path on that Frequency with that Distance, established as a ‘free space’ transmission. As you can see in this chart, when the frequency goes up, the dB signal level goes down. The lower the signal level, the weaker it is, and receivers with weak signals need to be closer to the transmitter. In general, 6dB provides for roughly 2 times the range.



As you can see, 9.6GHz is 40dB lower than 150MHz. 40/6 = 6.6 so 150Mhz signals are 6.6 times longer range than 9.6GHz.

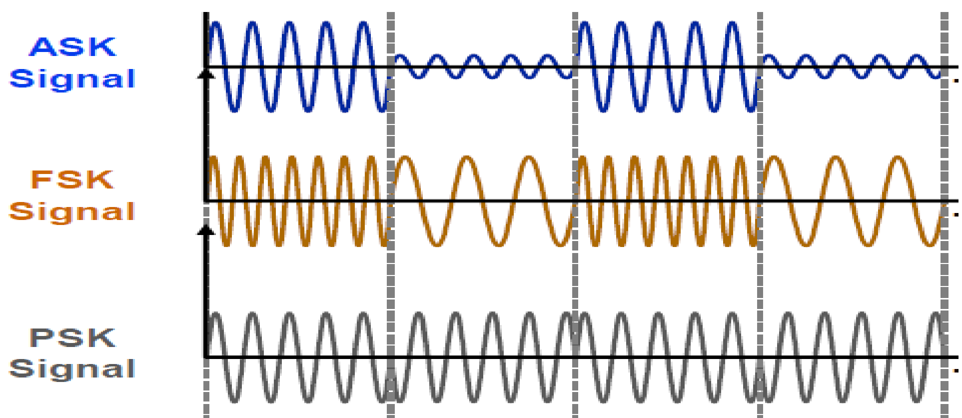
900 MHz radios will transmit more than twice as far in free space as a 2.4 GHz radio when both radios use the same modulation and output power.

Receiver Performance and Modulation Methods

When a receiver's sensitivity is increased by 10 times, it provides the same communication range improvement as increasing the transmitter power 10 times.

Sensitivity is limited by the signal/noise ratio. Receiver demodulation varies by Technology:

- **ASK** Amplitude modulation: Susceptible to noise
- **FSK** Frequency modulation: Better noise resistance
- **PSK** Phase modulation: Excellent noise resistance



Historically, the world found out back in the 1950s that FM was much better than AM modulation, so high performance radios used FM. If you are old enough, you will remember when your first local FM radio station came on the air, and how much better the sound quality was over the AM stations. The Phase Shift Keying modulation and quadrature amplitude modulation (QAM) also provide very good RF receiver sensitivity.

Antenna Gains and Antenna Heights

Very tall/long antennas (Low Frequency) are bigger and better. The bigger the antenna, the better the reception. Lower frequencies typically use longer antennas, and are an important factor in why low frequencies receive better signals. Larger antennas gather larger RF energy. An antenna that is 2X longer, will pick up 2X more RF energy, so especially in remote areas it will receive better than a small antenna will.

In Band Noise Filtering

High performance radio receivers have many filters in them that are high performance. All Raveon radios have these filters.

- Harmonic filter to eliminate any RF energy/noise that is outside the radio's band.
- Front End Filter. A good filter to pass signals in the band and reject out of band noise into the receiver. Some Raveon radios have narrow adjustable front-end filter that are set on-frequency being received. Most also have 2-5 front-end filters on the receiver to make sure large signals outside the band do not come into the receiver.
- Precision channel filters to filter out any other interference, and even adjacent channels.

Baud Rate (Energy Per Bit)

To reliably detect or receive a data bit, the receiver looks for each bit. There is RF noise on every channel, so when the RF energy per bit is sufficiently above the noise, the bit can be properly detected. The RF energy per bit is based on the duration of the bit. Slow bits have larger energy that fast bits.

Data rates that are 1Mbits/sec compared to 4800 bits/sec, have bits with 208 times less RF energy. 1Mb baud rates are very low-range compared to 4800 baud. Back when paging was popular, one city could be covered by a 500 baud POCSAG transmitter, where now high-speed cellular systems need dozens and hundreds of base stations to cover a city as their data rate is much higher.

Long Range radio (LoRa) technology

With LoRa spread spectrum, you get the great range improvements without any increase in power consumption or transmitter power. As most license-free bands restrict transmit power, LoRa provides a great way to increase the communication range of a wireless data link. Raveon is one of the early implementers of LoRa technology in the USA, and one of the first to get a full-power LoRa device FCC certified. LoRa is a radio modulation technique and protocol that enables a device to have unprecedented long-range.

Interference Immunity

There are a number of different types of interference all wireless systems must deal with:

A. ***Co-channel interference***. This is where there is some other transmitter on the exact same frequency that the system is currently utilizing. Many RF systems stop working if the interference is even 10dB weaker than the signal being received. With LoRa, the interference can be as much as 19dB larger than the signal being received, and the receiver will still detect the signal. This means LoRa systems will keep working reliably as the frequency get crowded.

B. ***Blocking Rejection***. Sometimes a system needs to operate in a location where there is a powerful interfering signal nearby. For example, in the USA the 906-924MHz ISM band that LoRa uses is only 50mHz away from the 800MHz radio bands where powerful narrow-band transmitters emit 100watts, or 2-watt cellular 869-894MHz transmitters. Even though LoRa is 10 time more sensitive, it is still 20 X less susceptible to overload from these powerful out of band signals.

Forward Error Correction

FEC is commonly used to increase a receiver's sensitivity by reducing the bit-error rate of the system. LoRa radios have integrated FEC(forward error correction) into the protocol. FEC effectively increases the energy per bit and enables the device to correct for bit errors. By adding extra overhead bits to groups of bits being transmitted, the payload data throughput is correspondingly reduced, but the bit-error-rate is lower even with weak signals, increasing the reliability of the receiver.

LoRa Link Margin Comparison

The LoRa (short for **Lo**ng **Ra**nge) modulation scheme is a modulation technique combined with a data encoding technique that gives a broad-band spread-spectrum radio the receive sensitivity of a very narrow-band long range radio.

When one compares a LoRa radio system to a traditional UHF or VHF radio modem, we see that the communication range for LoRa is very similar to VHF and UHF, but it achieves this with much less RF power. The spreadsheet calculations below show the theoretical link margin for LoRa 900MHz compared to VHF and UHF radio systems.

	LoRa 200mW	**LoRa 10mW**	**UHF 2W**	**VHF 2W**
Operating Frequency (MHz)	915	915	460	160
Transmitter Output Power	23 dBm	10 dBm	33 dBm	33 dBm
Link Distance, km	180 km	40 km	150 km	450 km
Link Distance, miles	111 mi	24 mi	93 mi	279 mi
Transmit Antenna Gain (dBi)	5	5	3	3
Antenna feed loss (both ends)	1 dB	1 dB	1 dB	1 dB
Receive Antenna Gain (dBi)	5	5	3	3
Receiver Sensitivity	-128dBm	-128dBm	-115dBm	-115dBm

System Gain (dB)	151	138	148	148
Link Fade Margin (dB)	**22.2**	**22.3**	**22.8**	**22.4**
Link Path Loss (dB)	-136.8	-123.7	-129.2	-129.6
Effective Radiated Power	27	14	35	35

The theoretical calculations show that a 200mW LoRa radio will work about as long-range as a 2-watt UHF radio. A 2-watt VHF will work a bit longer range, but it is using more power. Raveon's field tests support these theoretical calculations. We have seen VHF and UHF reliably go 50-100 miles line of site, and LoRa can easily go 20-50 miles (at 1/10th the power consumption).

As building, forest, and foliage penetration is much better with VHF and UHF radio technology, 900MHz systems will typically require taller antennas at the base stations and more base stations to get good coverage. This is offset by the lower cost and power of LoRa radios versus traditional VHF and UHF systems so building out large area networks with LoRa can be an excellent approach.

To Get Long Range without High TX Power

- ***Lower Speed*** data.
  - P = Energy/bit So make big bits for big energy
- Encode data with ***Forward Error Correction (FEC)***
  - One Byte uses 12+ bits, to reject noise and correct bit errors.
- **Synchronized** Demodulation
  - When RX knows the TX freq. and phase, demodulation works great.
- ***Phase Shifted*** Modulation (PSK)
  - Easier to synchronize, reject noise, and multi-level data throughput
- A technology invented in France does ALL of the ABOVE
  - ***LoRa*** Long Range Radio technology

Increasing Communication Range

LoRa is usually used in long-range communication systems. There are many ways to increase the range of a communication system, and the LoRa protocol has implemented many of them. The others are something everyone building a wireless data system should consider.

The range of a communication system is determined by:

1. **Antenna gains and antenna heights.**
2. **Transmitted power**
3. **Receiver sensitivity**

4. **Frequency of the system**
5. **The energy per bit (data rate)**

Antenna gains and antenna heights can make huge improvements to the range of a communication system. Antenna performance is one of the most economical ways to improve a system. However, antenna gains are sometimes limited by regulatory rules or practical considerations.

The more **transmit power** a device radiates the further away it can be received. In the real world, you must increase power by 4-10 times to double the communication range. Sometimes even a 20 times increase is needed to double the range.

A receiver with good **receive sensitivity** can pick up a signal from much further away than a poor receiver. A receiver that is 4 times (6dB) more sensitive than another receiver will greatly increase the communication range. 6dB receive sensitivity improvement is the same as transmitting 4X more power. But a 6dB better receiver will consume very little additional power. It is always better, less expensive, and more efficient to use a more sensitive receiver than a more powerful transmitter.

As mentioned earlier every RF engineer knows the equation for RF communication that shows the higher the **frequency of the system**, the more the loss.

$$L = C + 20 * \log(D) + 20 * \log(F)$$

C is 36.6 if D is measured in miles. L is the free space path loss. You can see that the loss goes up as the distance (D) goes up and as the frequency (F) goes up. If you use a frequency like 900MHz instead of 150MHz, the path-loss is 15dB more. This common formula is often cited as proof that the atmosphere (or sheer distance) attenuates higher frequencies more than lower frequencies.

Exacerbating this issue, 900MHz systems also suffer more loss as the 900MHz antennas are shorter, so they collect less energy than a 150MHz antenna that is almost 2 meters tall.

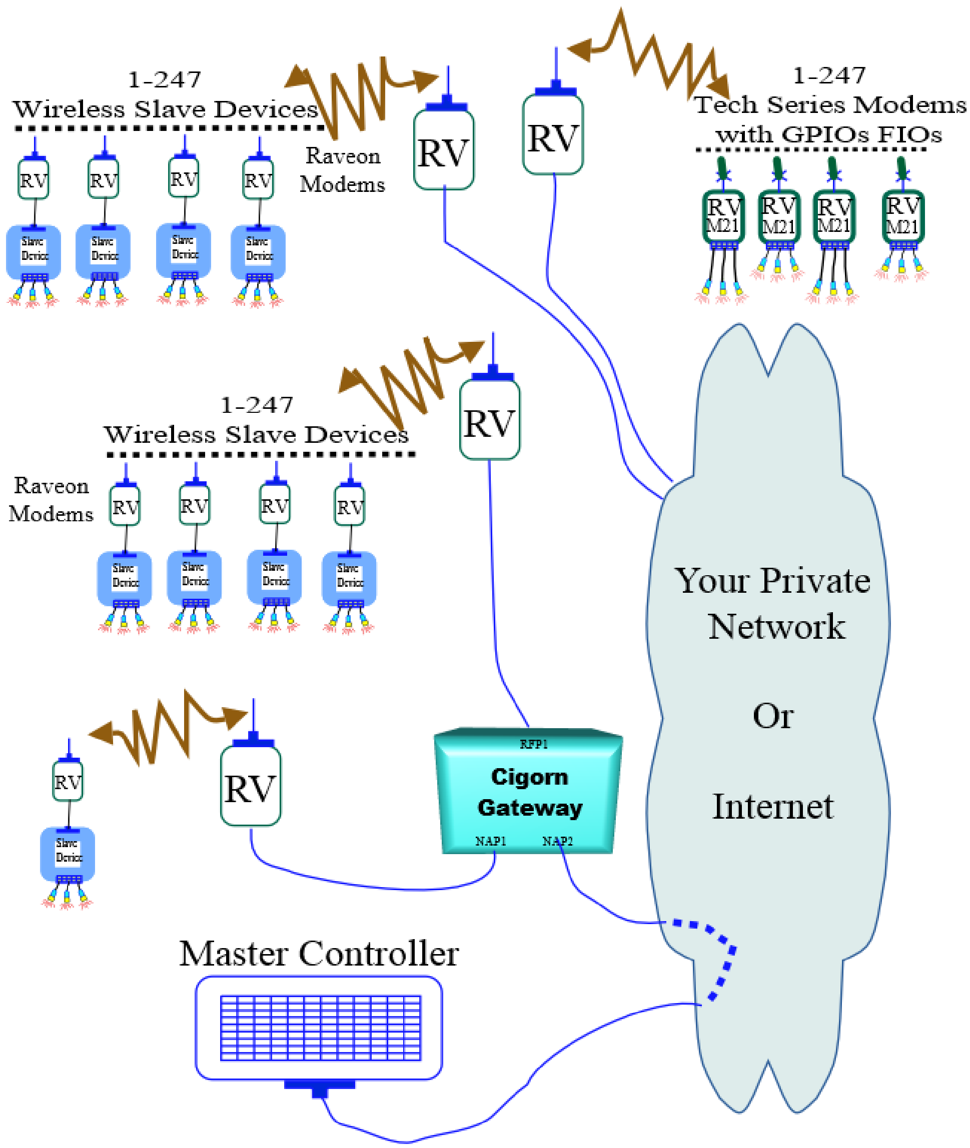
The **energy per bit (Eb/N0)** is the transmit power divided by the over-the-air data rate. In the 1940s, Claude Shannon determined the communication performance limits for channel coding. He determined that the noise floor, channel bandwidth, and the energy per bit fundamentally limited the ability to communicate. To this day, his theorem still stands true. Thus, reducing the data rate in half will provide you the same range improvement as doubling your power or doubling your receive sensitivity. Slow data rate radios go much farther than fast data rate radios. It's in the physics of RF. LoRa over-the-air baud rates are very slow, typically in the 900 to 22000 bits per second. This is a 100 times slower than Wi-Fi, Bluetooth, or Zigbee but a LoRa radio will have 100 times the Eb/No and 10-100 times their range.

Use Multiple Raveon Base Stations

Long Range RF Communication has been explained, but if you need large areas with faster data and lots of radios, deploying multiple base stations is a common technique.

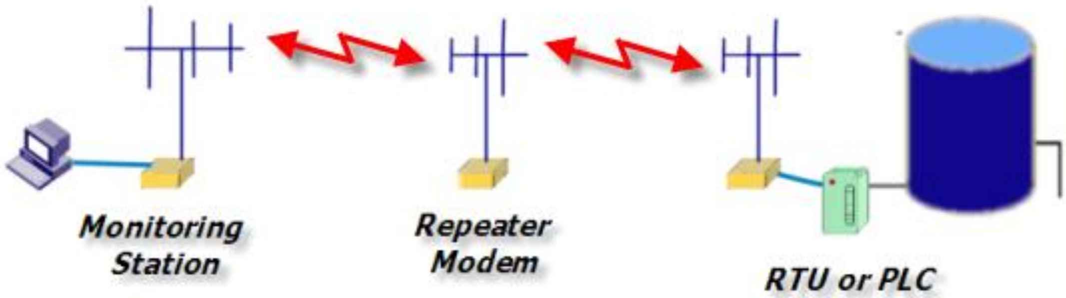
By using multiple base station modems, a system can communicate with hundreds of other radios over large areas. The Raveon data radio modems shown here (RV) can be used as the base stations and as the modems for tSCADA devices. Different groups with different radio base station RVs can have unique GROUP IDs, so groups don't cross-communicate.

Raveon's Ethernet gateway router called CIGORN can route your messages to and from the devices and the base stations you want to use. It can communicate with dozens of base stations, and each of the base stations can talk to 247 different SLAVE devices or Tech Series SCADA products.



Repeating For Wide Area Extended Range

For ultra-long communications range, high RF noise environments, or obstructed line of sight applications, it may be necessary to use a repeater to establish a reliable communications link.



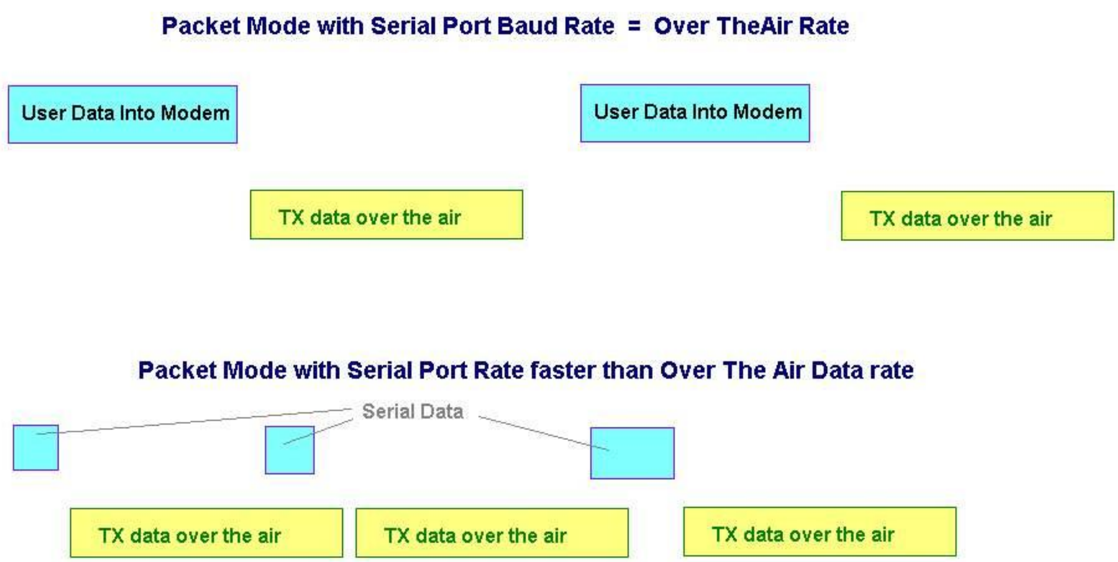
Incorporated in all Raveon Data Radio Modems is a ***store-and-forward repeater*** function.

The repeater function works in Raveon's Packet Mode. A repeater can extend the range of a system by 2-20X, depending upon how high-up above the average terrain the repeater is mounted. Repeater systems often cover 100 to 500 square miles per repeater.

Store Forward Repeating   Long Range

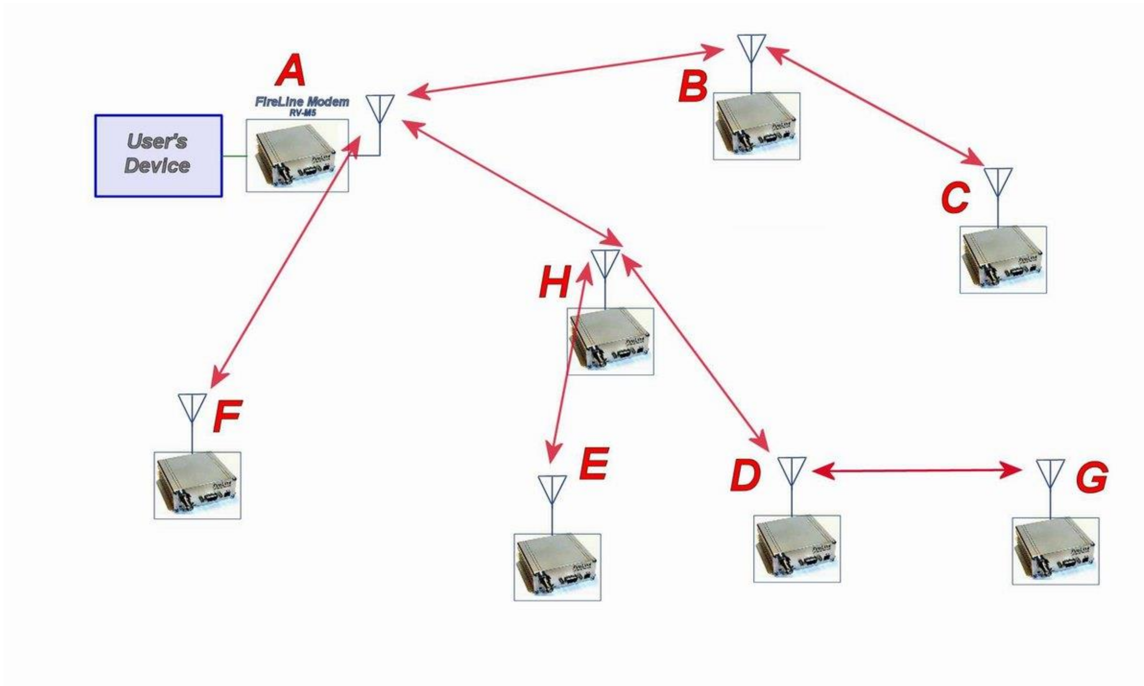
Most al Raveon Data Radios packets are structured so that they may be repeated using a store-and-forward repeater, and/or routed using specialized hardware.

(Packet Mode of Operation)



The packet or paging mode of operation is configured using the **ATMT** command.

Overview of Repeater Operation



In the example shown in Figure 3 above, *RADIO* **A** is will communicate with all other modems in the system. It can directly communicate with **B, H**, and **F**. Because of propagation limits, it cannot communicate reliable to **E, D, C,** and **G**.

To solve this problem, some of the *RADIO M*odems are configured as repeaters. The still are able to send and receive data, but they also will repeat data out to the modems that are out of range of *RADIO* **A**.

H is configured to repeat all messages to/from **E, D**, and **G**. **B** is configured to repeat all messages to/from **C**, and **D** is configured to repeat all messages to/from **G**.

The data radios can be configured to repeat certain type of messages based on the ID codes being sent.

The AT commands, change any of the default operating parameters that must be modified. From the factory, the modems are configured and shipped ready-to-use. Out of the box, they will communicate on the default radio channel using the factory defaults.
In general, there are many parameters you may want to modify for your system:

ATFX	Frequency for this channel. Set to your frequency.
ATBD	Serial port baud rate
ATMY	The ID of this unit. Default is 1234.
ATMK	The network address mask. Default is FFFF.
ATDT	The address of the unit this modem will talk to. Default is 1234.

Store-and-forward repeating is manually enabled with the ATXR command. **ATXR 1** enables repeating. **ATXR 0** disables it.

Raveon Technologies Corporation

2320 Cousteau Court

Vista, CA 92081

sales@raveon.com

760-444-5995