

Introduction to Mesh Networks for Amateur Radio

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24-Feb-2014

Rev. 02-Mar-2015



Mesh Networks Outline



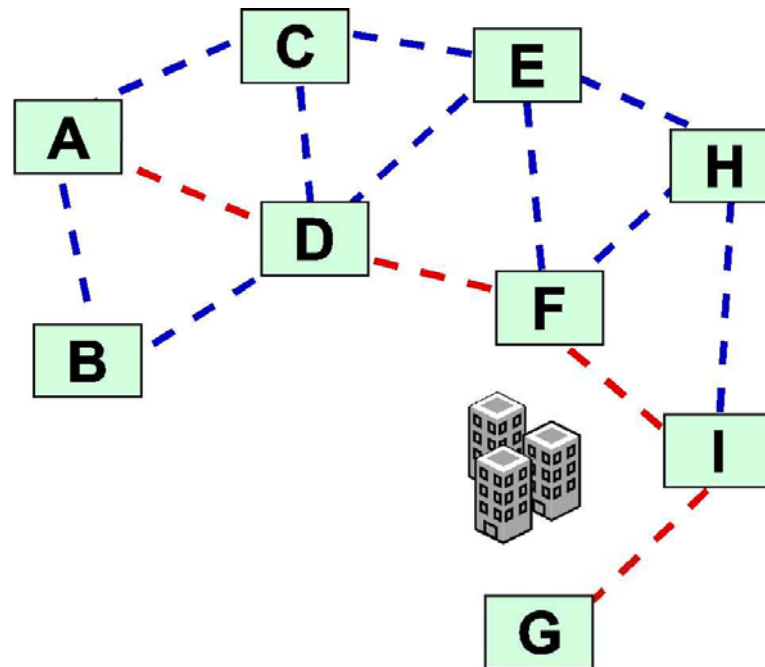
- What is a Mesh network
- Why should we consider Mesh Networks
- Broadband-HamNet
- Hardware
- Firmware
- Antennas
- Line of site and Fresnel Zones
- Additional Resources



What is a Mesh Network?



- Self discovering
- Automatically routes traffic

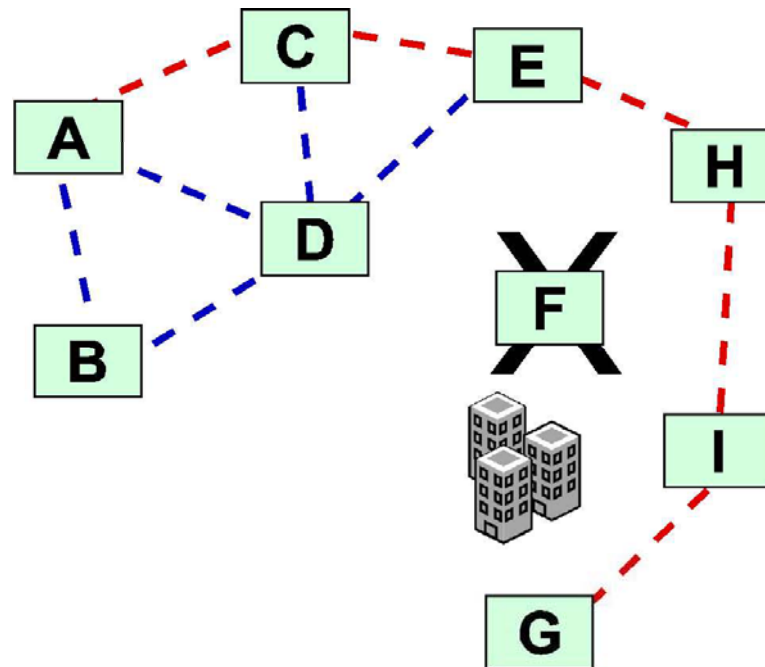




What is a Mesh Network?



- Self discovering
- Automatically routes traffic
- Fault tolerant
- Automatically reconfigures itself as nodes join or leave

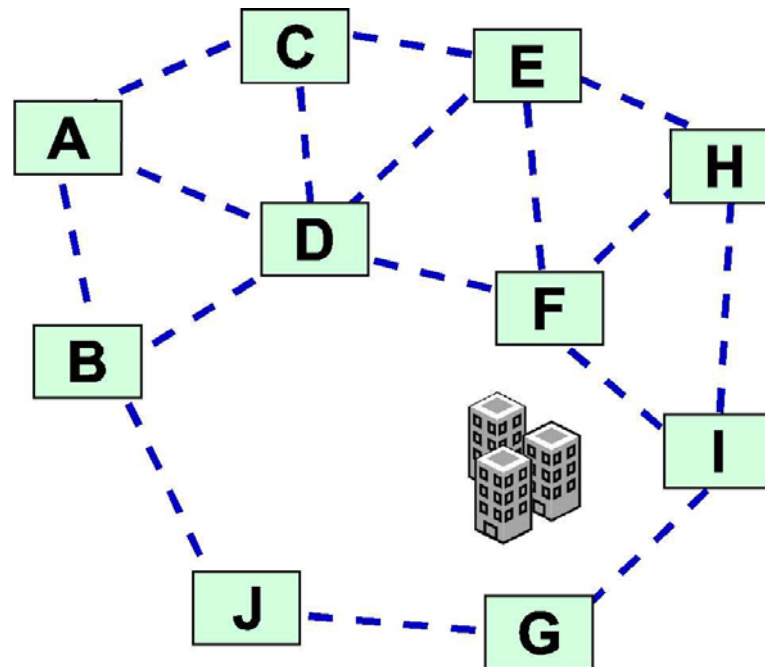




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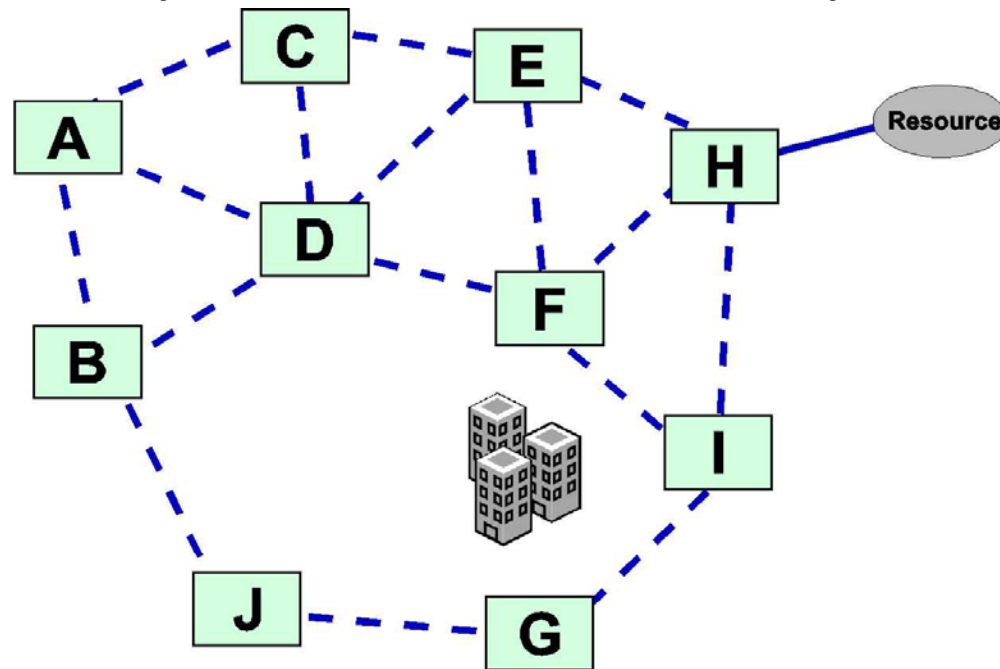




What is a Mesh Network?



- Self discovering
- Automatically routes traffic
- Fault tolerant
- Automatically reconfigures itself as nodes join or leave
- Resources on any node can be shared by all nodes





Mesh Network Nodes



- Each node is a router.
- Each node builds routing tables to track which nodes are currently connected to the mesh to enable routing messages through the mesh.
- If one endpoint cannot see its desired destination, but CAN see nodes in between, the data will hop from one to the next until the final connection is made.... completely automatically .
- If any node is connected to resources (internet, video camera, file server, mail server, etc.) it can provide access to the entire network.
- All nodes are remotely managed, you do not need physical access once installed.



Why Should EmComm Consider Mesh Networks?



- We live in a digital world.
 - Cell Phones Apps, Tablets, Web apps
 - PDFs, Excel files, Word docs
 - E-mail/Electronic/Text vs a telephone call
- High speed data is the norm not the exception.
- To be relevant EmComm needs to provide more than voice and slow speed data to our served agencies.
- High speed data networks allow exchange of text, formatted documents, database synchronization, voice, images and video.

Our roles as communicators is to get the message (data) through in the most efficient method available to us.

A mesh network is a highway over which data travels.



Broadband-HamNet™ (BBHN) AKA HSMM (High Speed Multi-Media)



What is Broadband-HamNet?

- Amateur radio utilization of mesh networking
- 802.11g on amateur radio frequencies
- Makes use of “commercial off the shelf” (COTS) equipment
 - Linksys WRT54GL
 - Ubiquiti
 - Raspberry Pi
- Initial experimentation began in 2004
- Has grown to a world wide interest in the Amateur community



Broadband-HamNet™ (BBHN)



- Part 15 - Wi-Fi Rules & Regulations – unlicensed, restrictions on power and antenna size.
- Part 97 - Amateur Radio Rules & Regulations – licensed, allows higher power and high gain antennas.

802.11b/g Wi-Fi falls within the 13 cm amateur band

Channel	Center Frequency	FCC Rules
1	2.412 GHz	Part 97 & Part 15
2	2.417 GHz	Part 97 & Part 15
3	2.422 GHz	Part 97 & Part 15
4	2.427 GHz	Part 97 & Part 15
5	2.432 GHz	Part 97 & Part 15
6	2.437 GHz	Part 97 & Part 15

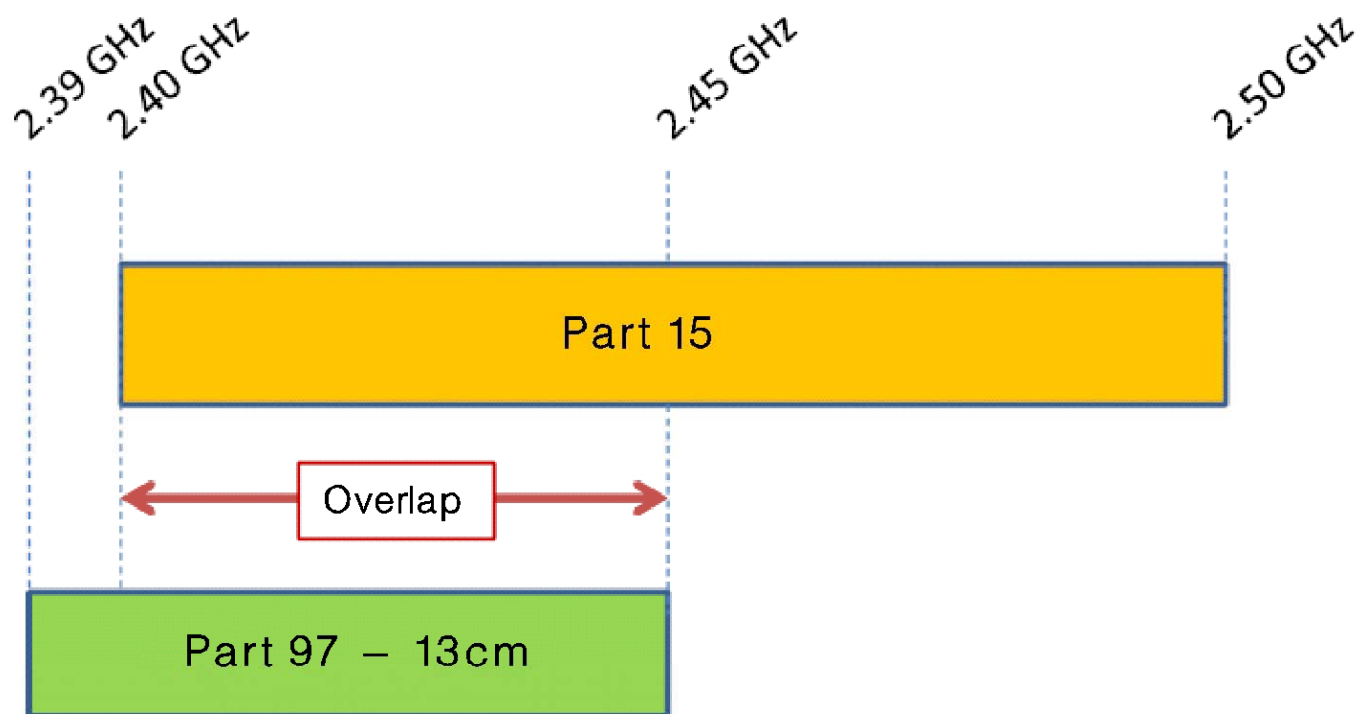
Channel 1 is the BBHN standard



Broadband-HamNet™ (BBHN)



802.11g Wireless Band





Amateur Radio Guidelines for 2.4GHz



- As always, we must operate under FCC Part 97 rules and regulations: no music, no profanity, no business activity, etc.
- Maximum Transmitter Power Output (TPO) is 100 watts (or 50dBm), although we will probably never encounter more than a couple watts.
- The Node Name (included with every transmission) must include your call sign. Common practice is to append a few additional identifying characters (e.g., KE6TIM-12), since your call sign may be associated with several nodes.
- Only licensed amateur radio operators should be able to access Part 97 hardware (in this case, modified Part 15 devices). So, take steps to prevent unauthorized users.
- **Safety First!** These are microwave frequencies—same as your kitchen microwave oven!



BBHN Uses



Anything that can be done over an existing network can be done over a mesh network, including:

- Email
- Keyboard chatting (IRC)
- File transfers (Word, Excel, PDF)
- Streaming video
- Voice over IP (VoIP)
- Web applications
- WebEOC
- Field Day/Contest Logging
- Repeater control, linking, and administration



July 2013 QST

***Within the bounds of FCC Part 97 regulations,
this is being done within the ham radio spectrum.***



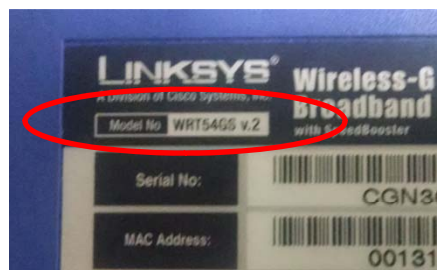
Linksys WRT54 Devices



- Repurposed home router - 2.4Ghz (13 cm band)
- Just a small Linux computer with router and Wi-Fi built in
- Inexpensive – around \$25 on Ebay and readily available
- 12 VDC Power
- Easy to flash memory with BBHN firmware
- Turns device in feature-rich mesh router
- Need to use gain antennas to cover more than 300-400'
- Need enclosure for outdoor use
- Not all models are usable--check before you buy

www.broadband-hamnet.org/images/hsmm_docs/WRT54Shop.pdf

MODEL	VERSION	USEABLE
WRT54G	1.0 - 4.0	OK
WRT54G	5.0 and up	NO
WRT54GS	1.0 - 4.0	OK
WRT54GS	5.0 and up	NO
WRT54GL	1.0 - 1.1	OK





Ubiquiti Devices



- **Ubiquiti 2.4GHz (13 cm band)**

Bullet M2 HP, \$76 + antenna

AirGrid M2 HP, \$69

NanoStation Loco M2, \$69

NanoStation M2, \$79

Rocket M2, \$79 + antenna



- Outdoor use without enclosure
- Higher power (Linksys 79 mW Ubiquiti 600 mW)
- Ubiquiti M5 (5.8 GHz) and M9 (900 MHz) devices are also supported.



Powering The Devices



Because these units are low powered, the way to get the greatest amount of transmit power is to put them near to the antenna to minimize cable losses.

But how to get power to them?

- Power over Ethernet (PoE) is one way to do this.
- A typical ethernet cable contains 4 pairs of 26ga wires.
- Only 2 pairs are used to connect a device. The cable provides 4 pairs so you can connect up 2 devices over one cable.
- Depending on the equipment, AC or DC voltage can be run up the unused pair and used to power the equipment.
- Ubiquiti equipment is designed to receive power in this manner.
- Linksys equipment doesn't have this built in, so you need an external feed and tap.





Flashing the Unit



Download appropriate firmware from broadband-hamnet.org site and use it to reprogram the router to be a mesh node.

The screenshot shows the Linksys administration interface for a WRT54G3G-ST router. The page title is 'Firmware Upgrade'. It features a 'Browse...' button for selecting a file, a warning message in red text: 'Warning: Upgrading firmware may take a few minutes, please don't turn off the power or press the reset button.', and an 'Upgrade' button at the bottom right. The interface includes a navigation menu with options like 'Setup', 'Wireless', 'Security', 'Access Restrictions', 'Applications & Gaming', 'Administration', and 'Status'. The Cisco Systems logo is visible in the bottom right corner.

LINKSYS
A Division of Cisco Systems, Inc. Firmware Version : v2.01.13

Wireless-G Router for Mobile Broadband WRT54G3G-ST

Administration

Setup | Wireless | Security | Access Restrictions | Applications & Gaming | Administration | Status

Management | Log | Diagnostics | Factory Defaults | Firmware Upgrade | Config Management

Upgrade Firmware

Firmware Upgrade

Please select a file to upgrade :

Warning: Upgrading firmware may take a few minutes, please don't turn off the power or press the reset button.

Upgrade must NOT be interrupted !

Click on the browse button to select the firmware file to be uploaded to the router.

Click the Upgrade button to begin the upgrade process. Upgrade must not be interrupted. [More...](#)

CISCO SYSTEMS



New Node Waiting to be Configured



NOCALL

[Help](#)

[Refresh](#)

[Setup](#)

Night Mode

This node is not yet configured.

Go to the setup page and set your node name and password.

Click Save Changes, even if you didn't make any changes, then the node will reboot.

WiFi/LAN address	172.27.0.1 /24 fe80::213:10ff:fea0:79d9 Link	firmware version	1.0.0
		configuration	not set
WAN address	192.168.0.3 /24 fe80::213:10ff:fea0:79d9 Link	system time	Thu Feb 6 2014 01:45:01 UTC
default gateway	192.168.0.1	uptime	2 min
your address	172.27.0.6	load average	0.82, 0.62, 0.25
			flash = 4348 KB
		free space	/tmp = 15208 KB memory = 17808 KB



Set-up Screen



[Node Status](#)

Basic Setup

[Port Forwarding,
DHCP, and Services](#)

[Administration](#)

[Help](#)

Save Changes

Reset Values

Default Values

Reboot

Node Name

Password

Node Type

Verify Password

WiFi	LAN	WAN
Protocol <input type="text" value="Static"/>	LAN Mode <input type="text" value="5 host Direct"/>	Protocol <input type="text" value="DHCP"/>
IP Address <input type="text" value="10.160.121.219"/>	IP Address <input type="text" value="10.3.206.217"/>	DNS 1 <input type="text" value="8.8.8.8"/>
Netmask <input type="text" value="255.0.0.0"/>	Netmask <input type="text" value="255.255.255.248"/>	DNS 2 <input type="text" value="8.8.4.4"/>
SSID <input type="text" value="BroadbandHamne"/>	DHCP Server <input checked="" type="checkbox"/>	
Mode <input type="text" value="Ad-Hoc"/>	DHCP Start <input type="text" value="218"/>	Mesh Gateway <input type="checkbox"/>
Channel <input type="text" value="1"/>	DHCP End <input type="text" value="222"/>	
Active Settings		
Rx Antenna <input type="text" value="Diversity"/>		
Tx Antenna <input type="text" value="Diversity"/>		
Tx Power <input type="text" value="19 dBm"/>		
Distance <input type="text" value="0"/>		
<input type="button" value="Apply"/>		



Node Status Screen

KE6TIM-105

[Help](#)[Refresh](#)[Mesh Status](#)[OLSR Status](#)[WiFi Scan](#)[Setup](#) Night Mode

WiFi address	10.130.130.43 / 8 fe80::213:10ff:fe82:822b Link	Signal/Noise/Ratio	-48 / -72 / 24 dB	Auto
LAN address	10.20.17.89 / 29 fe80::213:10ff:fe82:8229 Link	firmware version	1.0.0	
WAN address	192.168.1.7 / 24 fe80::213:10ff:fe82:8229 Link	configuration	mesh	
default gateway	192.168.1.1	system time	Fri Dec 31 1999 16:02:22 PST	
your address	10.20.17.91	uptime	2 min	
		load average	0.24, 0.19, 0.07	
		free space	flash = 4336 KB /tmp = 15168 KB memory = 16176 KB	



Mesh Status Screen

KE6TIM-105 mesh status

Refresh

Auto

Quit

Local Hosts

Services

Current Neighbors

LQ

Services

KE6TIM-105

• Info

[Web](#)

[KE6TIM-100](#)

94%

[KE6TIM-106](#)

100%

Remote Nodes

ETX

Services

Previous Neighbors

When

none

none



Set-up Screen



[Node Status](#)

Basic Setup

[Port Forwarding,
DHCP, and Services](#)

[Administration](#)

[Help](#)

Save Changes

Reset Values

Default Values

Reboot

Node Name Password

Node Type Verify Password

WiFi	LAN	WAN
Protocol <input type="text" value="Static"/>	LAN Mode <input type="text" value="5 host Direct"/>	Protocol <input type="text" value="DHCP"/>
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<input type="button" value="Apply"/>		



Antennas



Circular, Rectangular or Flat Panel = 8-24Dbi

12 El beam = 20Dbi
16 El beam = 24DBi

Verticals
8 Dbi
12 Dbi
15 Dbi

With 79mW (stock) power from Linksys node into a:

3.5dBi (stock rubber duck) - .176W EIRP

9dBi - .62W EIRP

14dBi - 1.9W EIRP

24dBi - 19.8W EIRP



RF Exposure & Safety



OET Bulletin 65, Supplement C, provides guidance on RF exposure with microwave frequencies.

Devices with integral monopole antenna <math><200\text{ mW}</math> at >2.5 cm (1")
(OET 65, Supplement C, Table 1, pg 18)

Devices with external antenna <math><4\text{ W EIRP}</math> at >20 cm (8")
(OET 65, Supplement C, Table 1, pg 19)

Direction gain antennas will have greater RF strength in the beam direction.

Don't stand directly in front of your 24 dBi antenna to check the line of sight path. Don't set your 15 dBi vertical next to your operating position.



Line of Sight



- Unlike the lower frequencies Microwaves are true line of sight.
- A clear unobstructed path between the transmitter and receiver is required.
- Trees are not microwave friendly– water absorbs microwaves
Someone said, “2.4 GHz will go 15 miles or through one tree”
- Even with a clear line of sight between antennas you may still have issues with nearby obstacles.



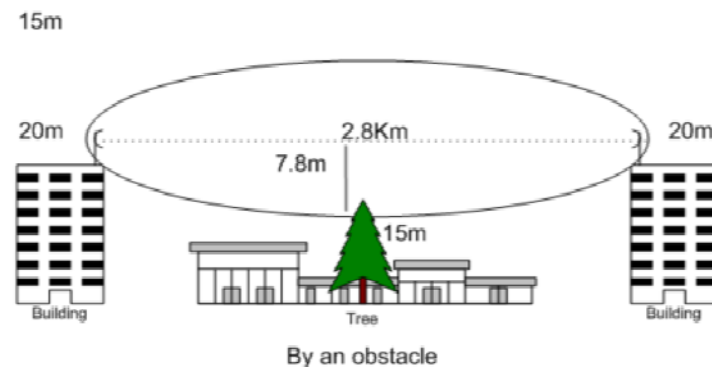
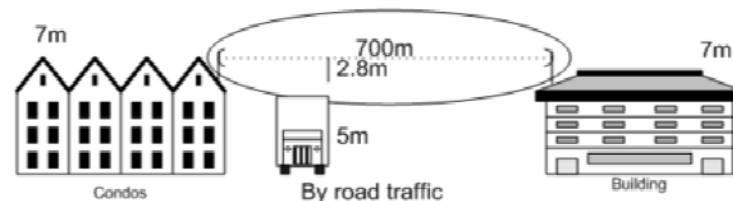
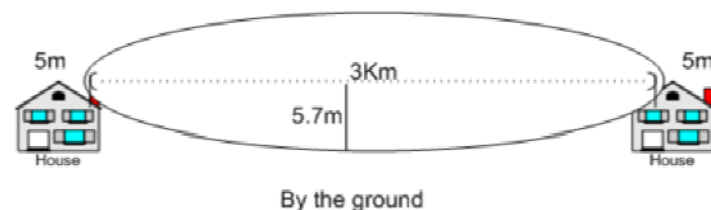
Why Line of Sight is Not Enough



Obstacles in the area around the visual line-of-sight that radio waves spread out into after they leave the antenna may cause the received signal strength to be affected.

These obstacles could be buildings, vegetation, water, or even the ground.

This area is called the Fresnel (*fray-NEL*) Zone.



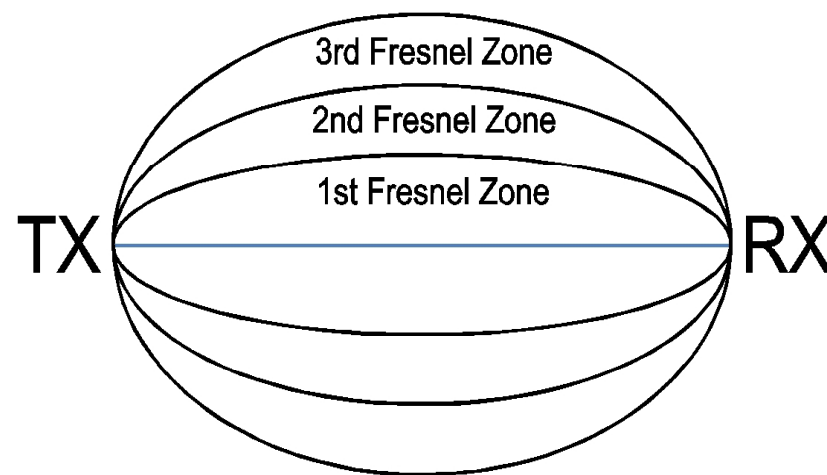


Fresnel Zone



Pronounced: fray-NEL (*silent s*)

- Each Fresnel zone is an ellipsoidal shape.
- Deflections from obstacles which occur anywhere in zone 1 will, if they arrive at the RX, create signals that will be 0 to 90° out of phase.
- In zone 2 they will be 90 to 270° out of phase.
- In zone 3 they will be 270 to 450° out of phase and so on.
- Even numbered zones are bad'ish (they have the maximum **phase cancelling** effect) and odd numbered zones are good'ish (they may actually add to the signal power).
- The signal strength (and hence the magnitude of the **phase cancelling** effect) is strongest in zone 1 and decreases in each successive zone simply because wave paths get longer (and signals get weaker) the further they are from the direct line from transmitter to receiver.





Fresnel Zone



- The radius of the first zone can be calculated

$$r = 36.03 \sqrt{\frac{D}{f}}$$

r = radius in feet

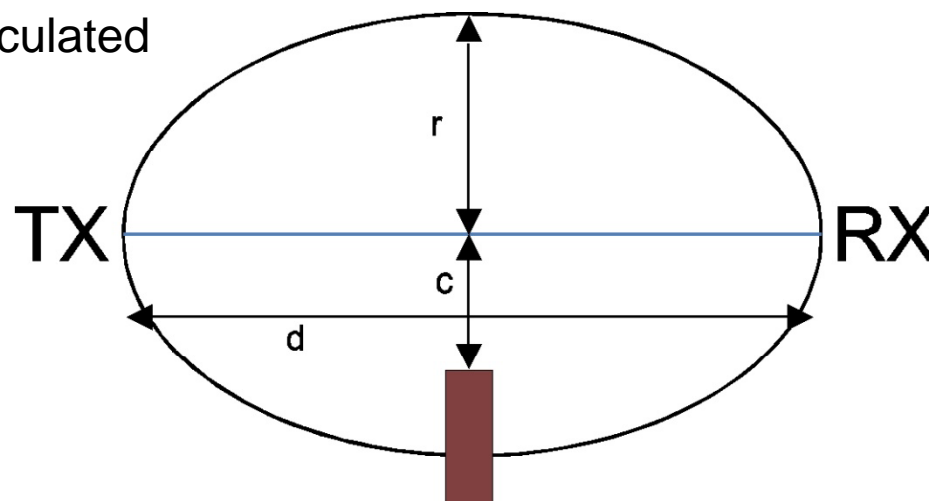
D = total distance in miles

f = frequency transmitted in GHz.

- The rule of thumb is that 60% of the 1st Fresnel zone must be clear of obstacles.

- Example: If r is 20', c must be at least 12'.

- On-line calculator: <http://www.wirelessconnections.net/calcs/FresnelZone.asp>



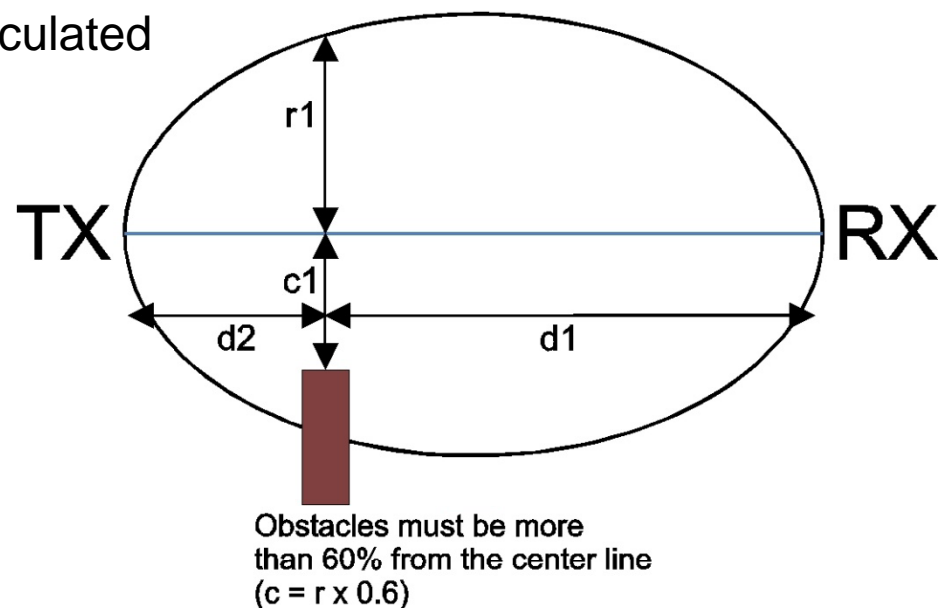
Obstacles must be more than 60% from the center line
($c = r \times 0.6$)



Fresnel Zone



- The radius of the first zone can be calculated



- If the obstacle is not in the center, the calculation becomes more difficult.
- On-line calculator: www.zytrax.com/tech/wireless/calc.htm#fresnel



Amateur Frequency Allocations

Most hams use less than 1% of the spectrum

Band	Frequencies	MHZ	Band Total
160M	1.800 – 2.000	0.200	
80M	3.500 – 4.000	0.500	
60M	5 channels	0.014	
40M	7.000 – 7.300	0.300	
30M	10.100 – 10.150	0.050	
20M	14.000 – 14.350	0.350	
17M	18.068 – 18.168	0.100	
15M	21.000 – 21.450	0.450	
12M	24.890 – 24.990	0.100	HF
10M	28.000 – 29.700	1.700	3.764
6M	50.00 – 54.00	4.000	
2M	144.00 – 148.00	4.000	VHF
1.25M	219 – 220, 222 – 225	4.000	12.000
70CM	420 – 450	30.000	
33CM	902 – 928	26.000	
23CM	1240 – 1300	60.000	
13CM	2300 – 2310, 2390 – 2450	70.000	
9CM	3300 – 3500	200.000	UHF < 10GHZ
5CM	5650 – 5925	275.000	661.000
3CM	10 – 10.5GHZ	500.000	
12MM	24 – 24.25GHZ	250.000	
6MM	47 – 47.2GHZ	200.000	
4MM	76 – 81GHZ	5000.000	
2.5MM	122.25 – 123GHZ	750.000	
2MM	134 – 141GHZ	7000.000	10GHZ and up
1.2MM	241 – 250GHZ	9000.000	22700.000
	> 275GHZ is unallocated		23376.764



Percent of Amateur Spectrum

0.016%

0.05 %

2.83%

97.10%

Source: 47 C.F.R. § 2.106, July 26, 2010



Mesh Networking Resources



Want to get involved or learn more?

- Review these resources:

The group in Austin, TX that wrote the firmware
www.broadband-hamnet.org/

Santa Clara County site
www.scc-ares-races.org/mesh/

SCCo Mesh Network Users Group
groups.yahoo.com/neo/groups/scc-mesh/info

- Get a unit or two and try it out.