Link Budget Calculation

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Goals

- To be able to calculate how far we can go with the equipment we have
- To understand why we need high masts for long links
- To learn about software that helps to automate the process of planning radio links

Free space loss

- Signal power is diminished by the geometric spreading of the wavefront, commonly known as ***Free Space Loss***.
  - The power of the signal is spread over a wave front, the area of which increases as the distance from the transmitter increases. Therefore, the power density diminishes.

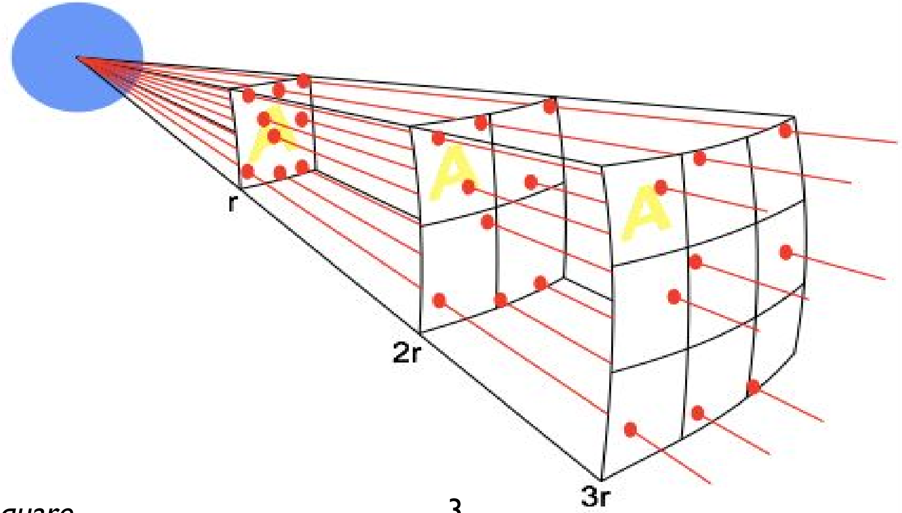


Figure from
http://en.wikipedia.org/wiki/Inverse_square

Free Space Loss at 2.4 GHz

- Using decibels to express the loss and using 2.4 GHz as the signal frequency, the equation for the Free Space Loss is:

$$\boldsymbol{L_{fs}} = 100 + 20*\log_{10}(d)$$

- ...where $\boldsymbol{L_{fs}}$ is expressed in dB and $\boldsymbol{d}$ is in kilometers.

Free Space Loss (any frequency)

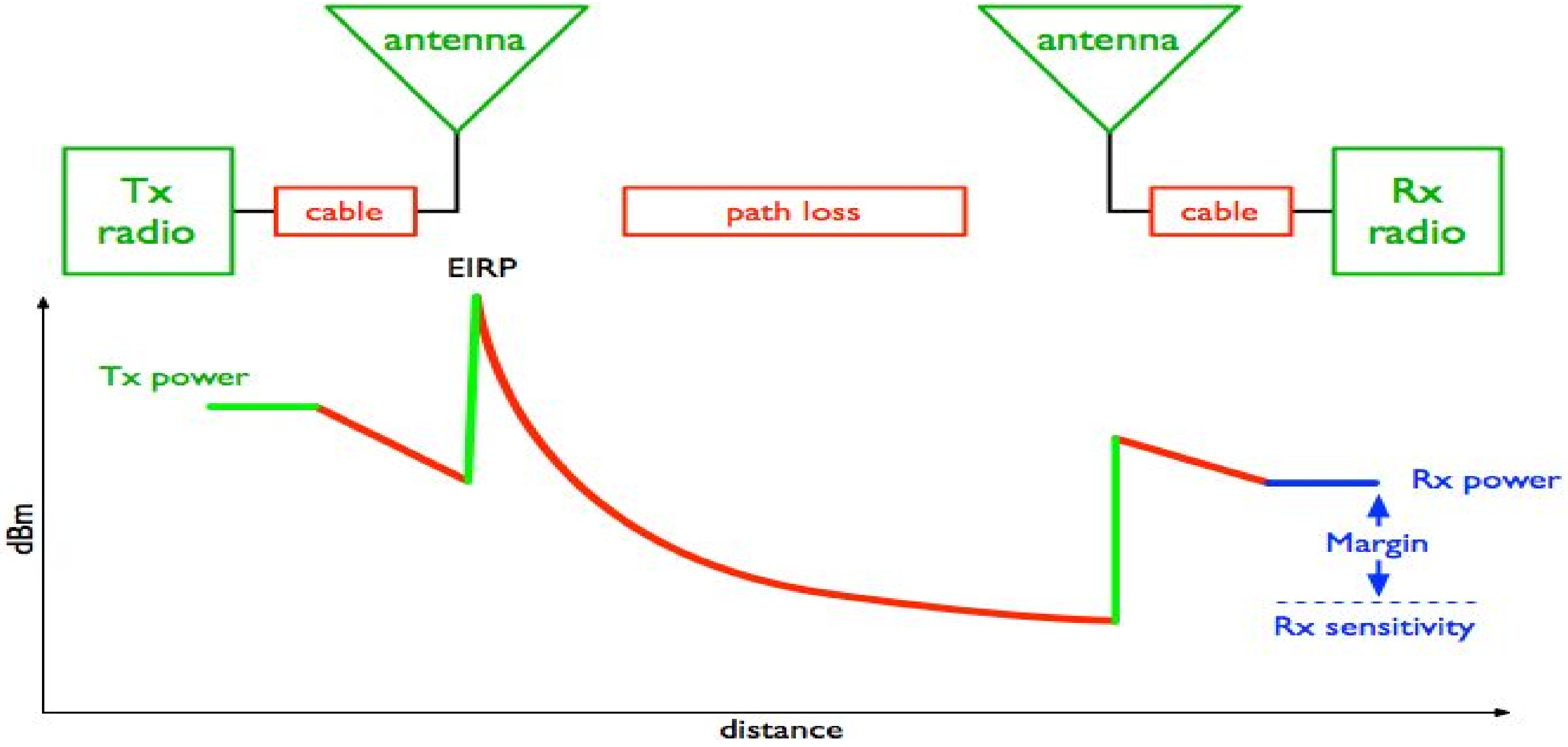
- Using decibels to express the loss and at a generic frequency f, the equation for the Free Space Loss is:

$$L_{fs} = 92,45 + 20*\log(d) + 20*\log(f)$$

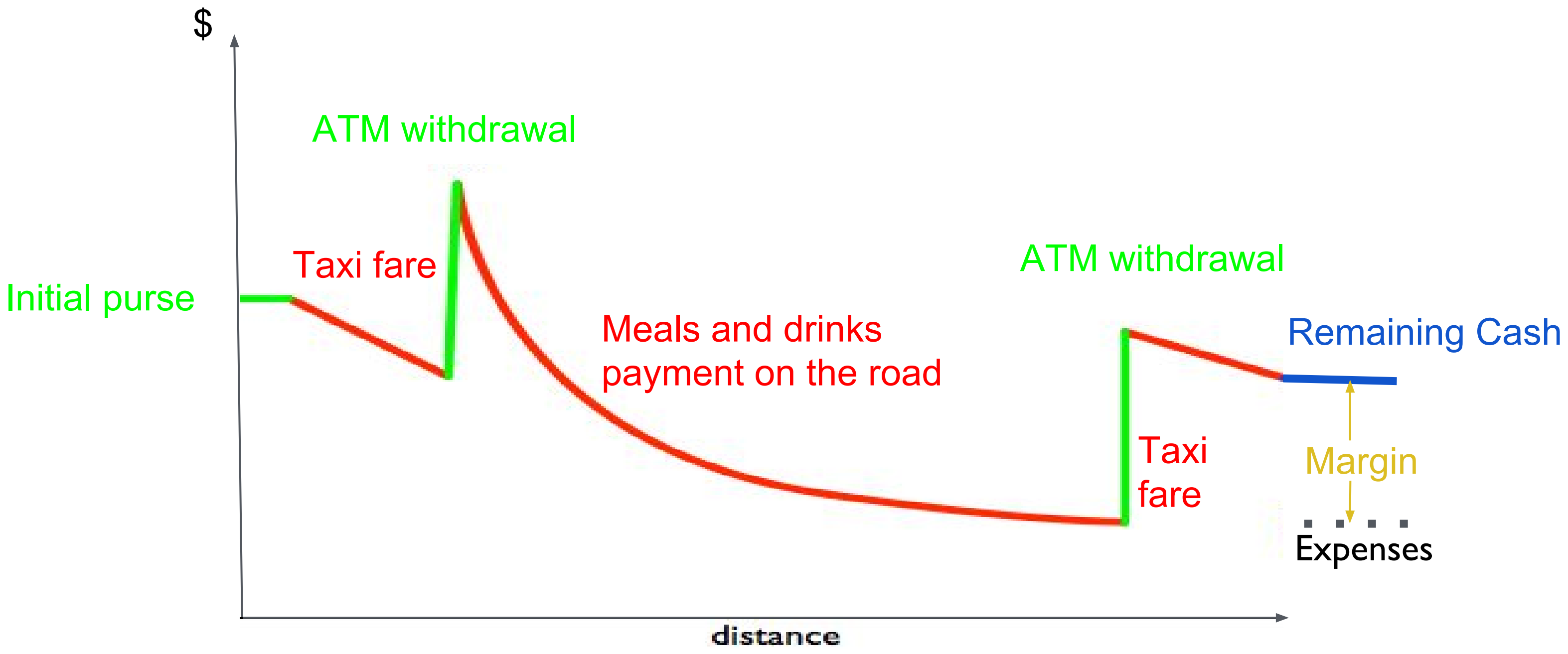
- ...where $\boldsymbol{L_{fs}}$ is expressed in dB, ***d*** is in kilometers and **f** is in GHz.

Free Space Loss Versus distance for different bands

Power in a wireless system



Analogy money in a journey



Link budget

- ***Link budget*** is a way of quantifying the link performance.
- The received power in an wireless link is determined by three factors: ***transmit power***, ***transmitting antenna gain***, and ***receiving antenna gain***.
- If that power, minus the ***free space loss*** of the link path, is greater than the ***minimum received signal level*** of the receiving radio, then a link is possible.
- The difference between the minimum received signal level and the actual received power is called the ***link margin***.
- The link margin must be positive, and should be maximized

Example of wireless device specs: LBE-5AC-23

Output Power: 24 dBm							
TX Power Specifications				RX Power Specifications			
Modulation	Data Rate	Avg. TX	Tolerance	Modulation	Data Rate	Sensitivity	Tolerance
airMAX ac	1x BPSK (½)	24 dBm	± 2 dB	airMAX ac	1x BPSK (½)	-96 dBm	± 2 dB
	2x QPSK (½)	24 dBm	± 2 dB		2x QPSK (½)	-95 dBm	± 2 dB
	2x QPSK (¾)	24 dBm	± 2 dB		2x QPSK (¾)	-92 dBm	± 2 dB
	4x 16QAM (½)	24 dBm	± 2 dB		4x 16QAM (½)	-90 dBm	± 2 dB
	4x 16QAM (¾)	24 dBm	± 2 dB		4x 16QAM (¾)	-86 dBm	± 2 dB
	6x 64QAM (⅔)	23 dBm	± 2 dB		6x 64QAM (⅔)	-83 dBm	± 2 dB
	6x 64QAM (¾)	22 dBm	± 2 dB		6x 64QAM (¾)	-77 dBm	± 2 dB
	6x 64QAM (⅚)	21 dBm	± 2 dB		6x 64QAM (⅚)	-74 dBm	± 2 dB
	8x 256QAM (¾)	20 dBm	± 2 dB		8x 256QAM (¾)	-69 dBm	± 2 dB
	8x 256QAM (⅚)	19 dBm	± 2 dB		8x 256QAM (⅚)	-65 dBm	± 2 dB

Antenna Information	
Operating Frequency	Worldwide: 5150 - 5875 MHz USA: 5725 - 5850 MHz
Output Power	25 dBm
Gain	23 dBi
Max. VSWR	1.5:1

Example link budget calculation

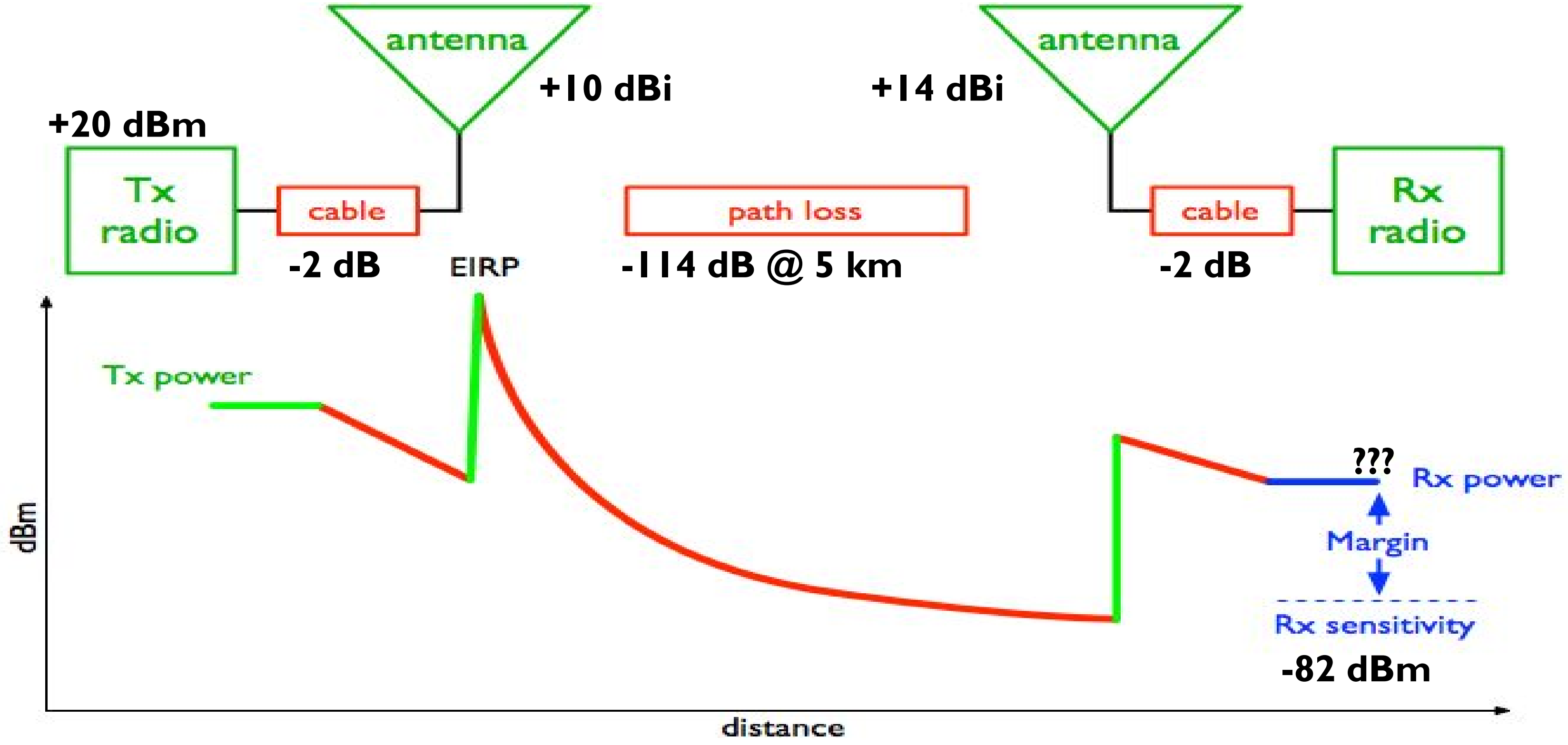
Let's estimate the feasibility of a **5 km** link, with one access point and one client radio.

The access point is connected to an antenna with **10 dBi** gain, with a transmitting power of **20 dBm** and a receive sensitivity of **-89 dBm**.

The client is connected to an antenna with **14 dBi** gain, with a transmitting power of **15 dBm** and a receive sensitivity of **-82 dBm**.

The cables in both systems are short, with a loss of **2dB** at each side at the 2.4 GHz frequency of operation.

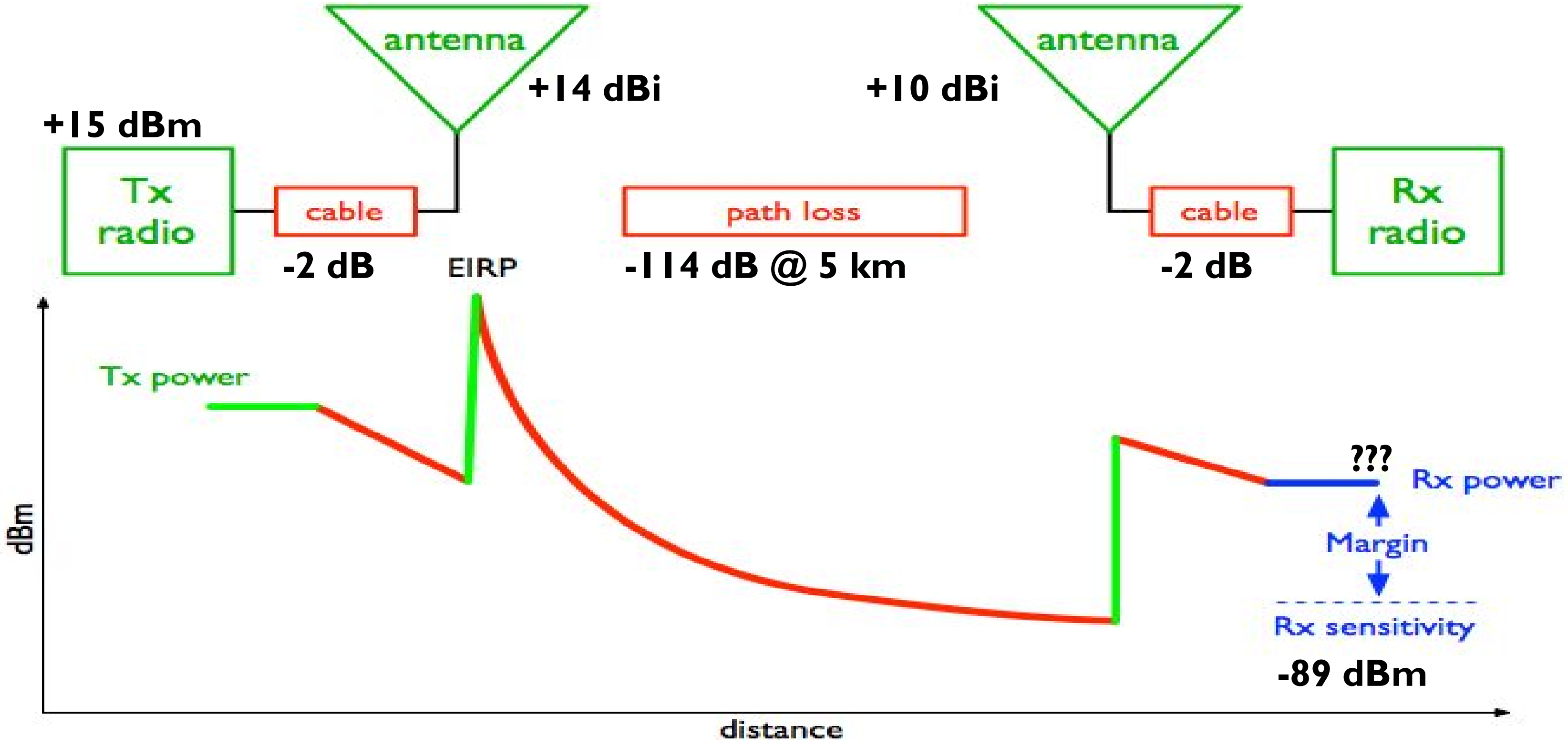
AP to Client link



Link budget: AP to Client link

20 dBm	(TX Power AP)
+ 10 dBi	(AP Antenna Gain)
- 2 dB	(AP Cable Losses)
-114 dB	(free space loss @5 km)
+ 14 dBi	(Client Antenna Gain)
- 2 dB	(Client Cable Losses)
-74 dBm	(expected received signal level)
-(-82 dBm)	(sensitivity of Client)
8 dB	(link margin)

Opposite direction: Client to AP



Link budget: Client to AP link

15 dBm	(Client TX Power)
- 2 dB	(Client Cable Losses)
+ 14 dBi	(Client Antenna Gain)
-114 dB	(free space loss @5 km)
+ 10 dBi	(AP Antenna Gain)
- 2 dB	(AP Cable Losses)
- 79 dBm	(expected received signal level)
-(-89 dBm)	(sensitivity of AP)
10 dB	(link margin)

Fresnel Zone

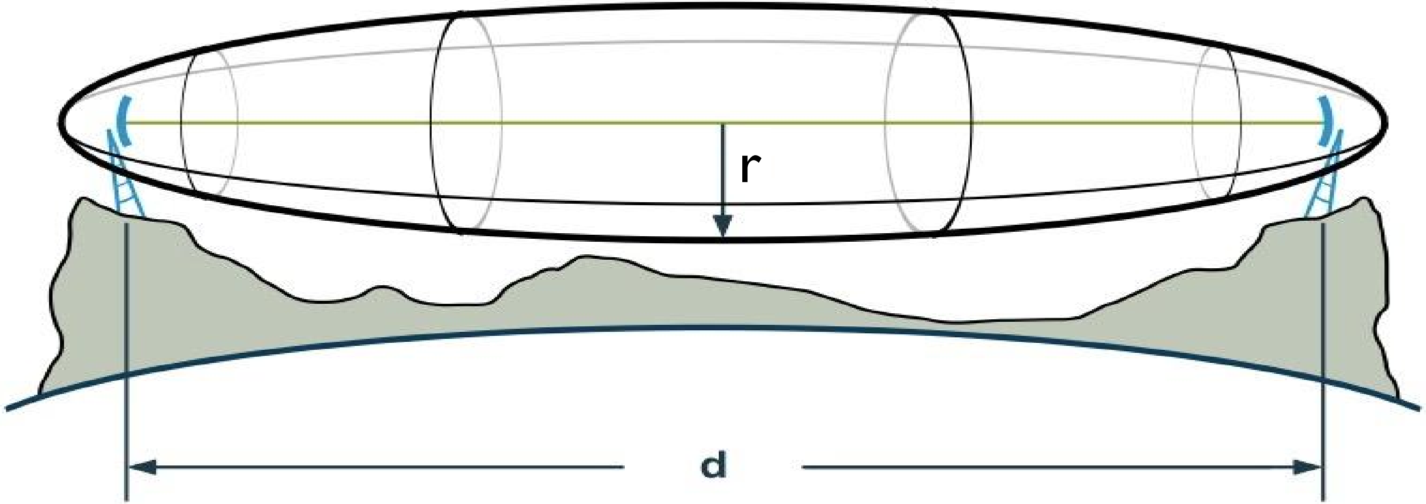
- The First Fresnel Zone is an ellipsoid-shaped volume around the Line-of-Sight (LOS) path between transmitter and receiver.
- The Fresnel Zone clearance is important to the integrity of the RF link because it defines a volume around the LOS that must be clear of any obstacle for the the maximum power to reach the receiving antenna.
- Objects in the Fresnel Zone as trees, hilltops and buildings can considerably attenuate the received signal, even when there is an unobstructed line between the TX and RX.

Optical and Radio LOS

Optical signals also have a Fresnel zone, but since the wavelength is so small, we don't notice it.

Therefore, clearance of optical LOS does not guarantee the clearance of RADIO LOS.

Line of Sight and Fresnel Zones



a free line-of-sight **IS NOT EQUAL TO** a free Fresnel Zone

Fresnel Zone

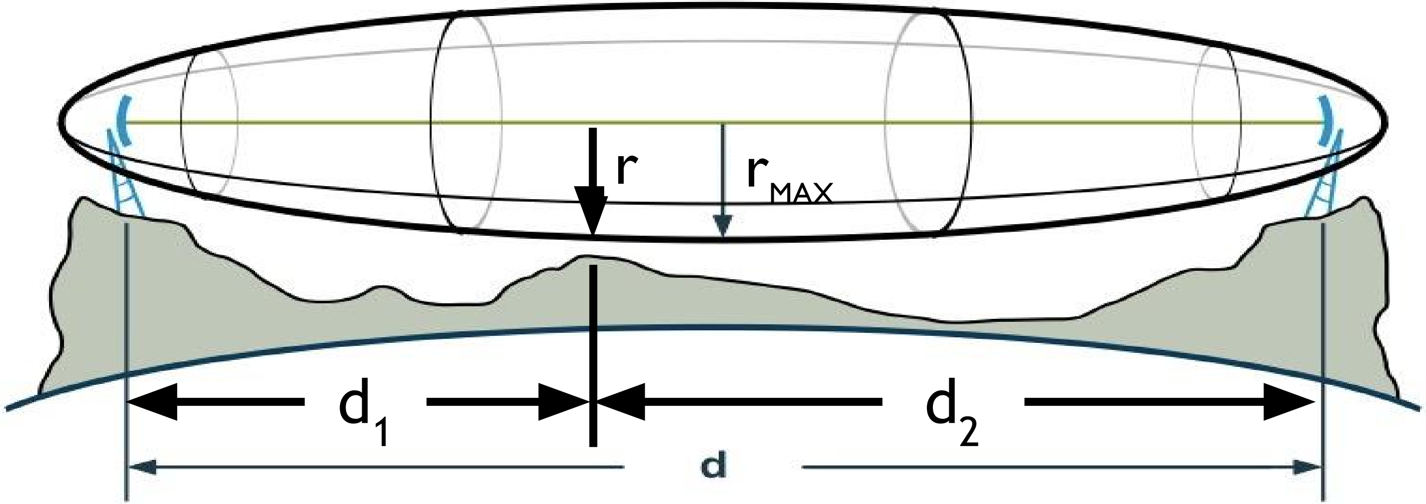
- The radius of the first Fresnel Zone at a given point between the transmitter and the receiver can be calculated as:

$$r = \mathrm{sqrt}(\boldsymbol{\lambda}*(d_1*d_2)/(d))$$

- ...where **r** is the radius of the zone in meters, $\mathbf{d_1}$ and $\mathbf{d_2}$ are distances from the obstacle to the link end points in meters, **d** is the total link distance in meters, and $\boldsymbol{\lambda}$ is the wavelength in m.

- Note that this gives you the radius of the zone, not the height above ground. To calculate the height above ground, you need to subtract the result from a line drawn directly between the tops of the two towers.

Line of Sight and Fresnel Zones



$$r = \text{sqrt}(\lambda * d_1 * d_2 / d)$$

$$r_{MAX} = 1/2 * \text{sqrt}(\lambda * d)$$

where all the dimensions are in meters

Clearance of the Fresnel Zone and earth curvature

This table shows the minimum height above flat ground required to clear 60% of the first Fresnel zone for various link distances at 2.4 GHz.

Notice that earth curvature plays a small role at short distances, but becomes more important as the distance increases.

Distance (km)	1st zone (m)	60% (m)	Earth curvature (m)	Required height (m)
1	5.5	3.3	0.0	3.9
5	12.4	7.44	0.4	7.84
10	17.5	10.5	1.5	12
15	21.4	12.84	3.3	16.13
20	24.7	15.82	5.9	21.72
25	27.7	16.62	9.2	25.82
30	30.3	18.18	13.3	32.5

Fresnel Zone

- Considering the importance of the Fresnel Zone, it is important to quantify the degree to which it can be blocked.
- Typically, 20% - 40% Fresnel Zone blockage introduces little attenuation into the link.
- It is better to err to the conservative side allowing no more than 20% blockage of the Fresnel Zone.

Thank you for your attention

For more details about the topics presented in this lecture, please see the book ***Wireless Networking in the Developing World***, available as free download in many languages at:

http://wndw.net/