Link Budget Calculation

Training materials for wireless trainers

United Nations
Educational, Scientific and
Cultural Organization

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 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.

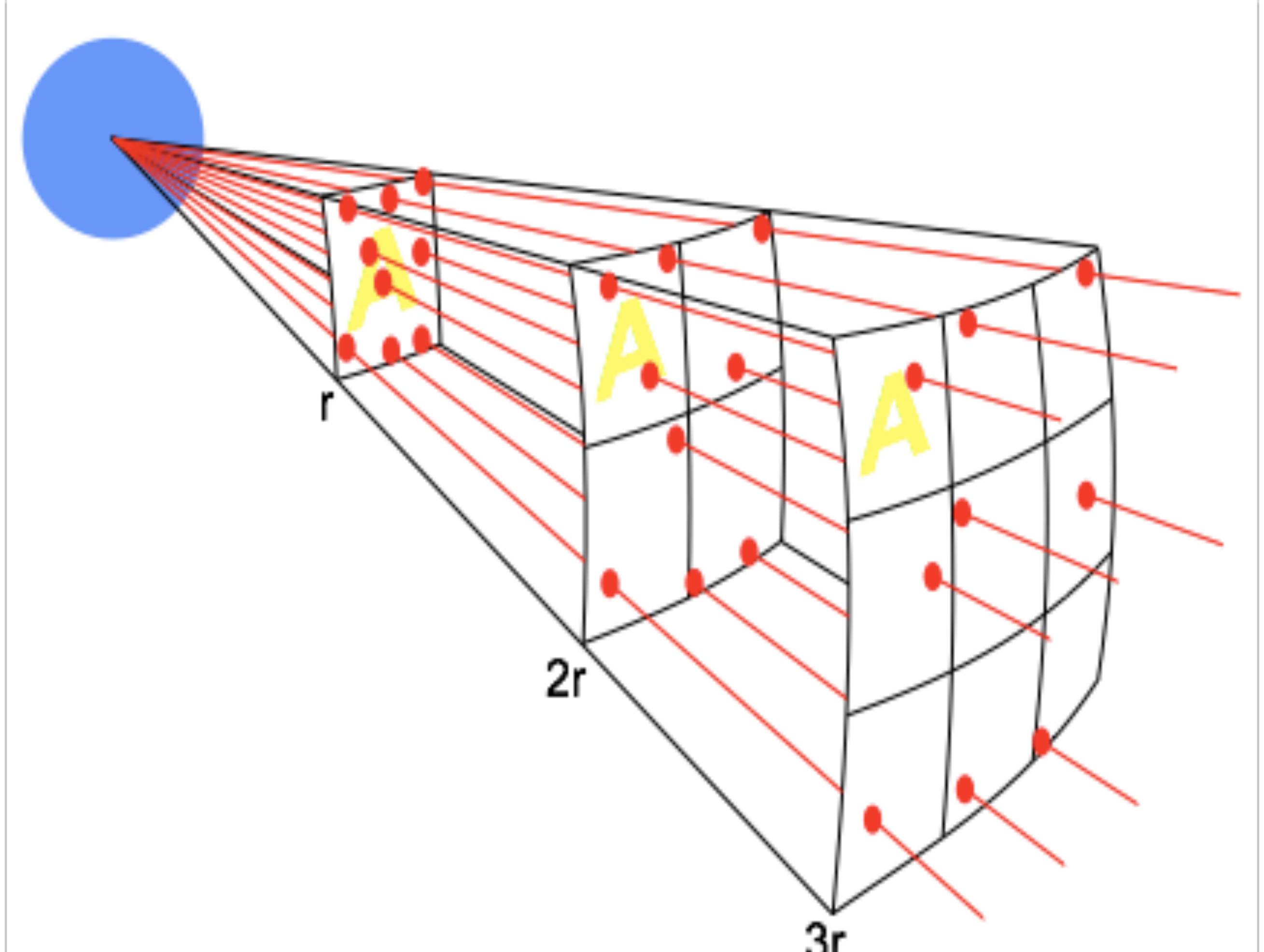


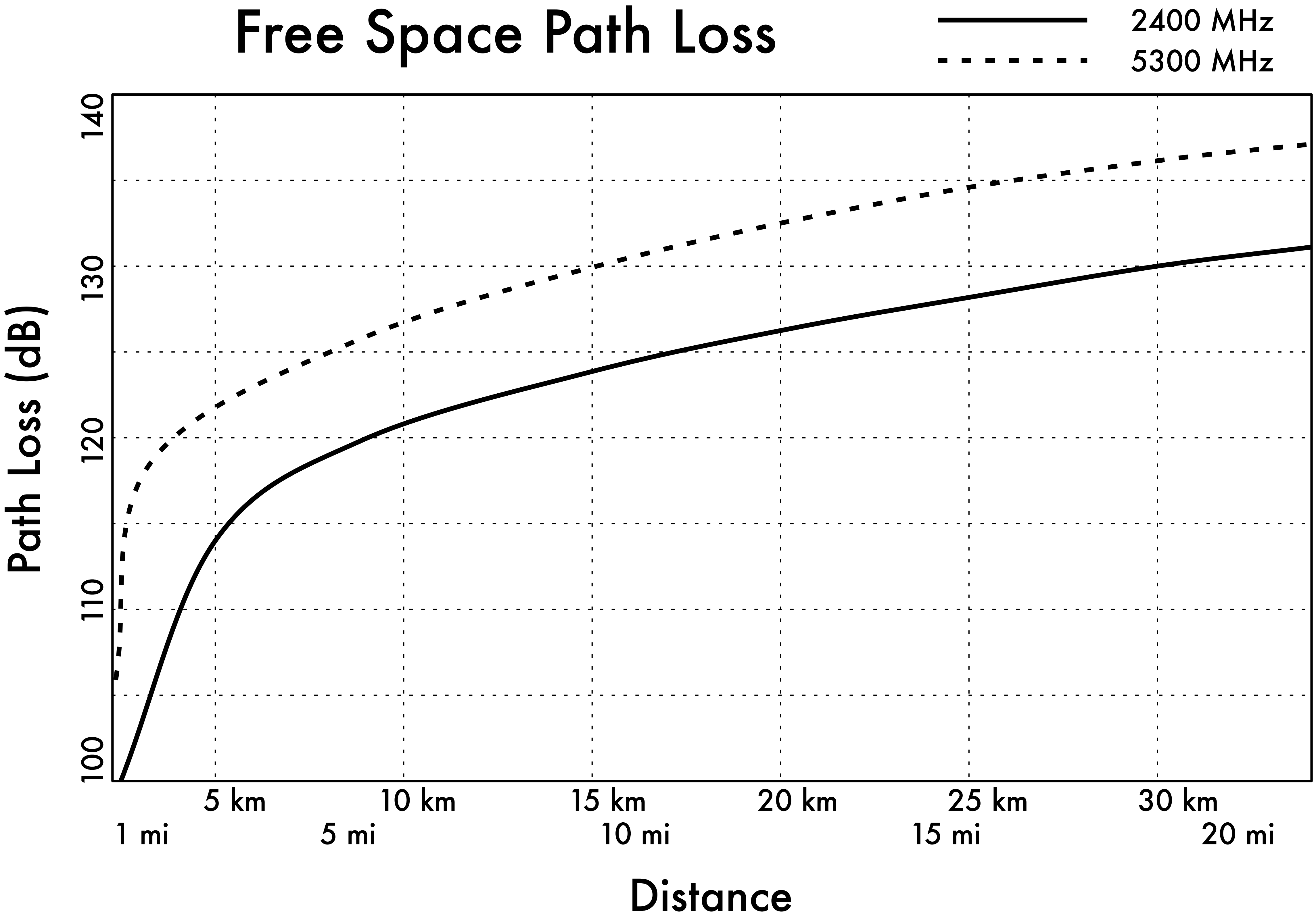
Figure from *http://en.wikipedia.org/wiki/Inverse_square*

Free Space Loss (any frequency)

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

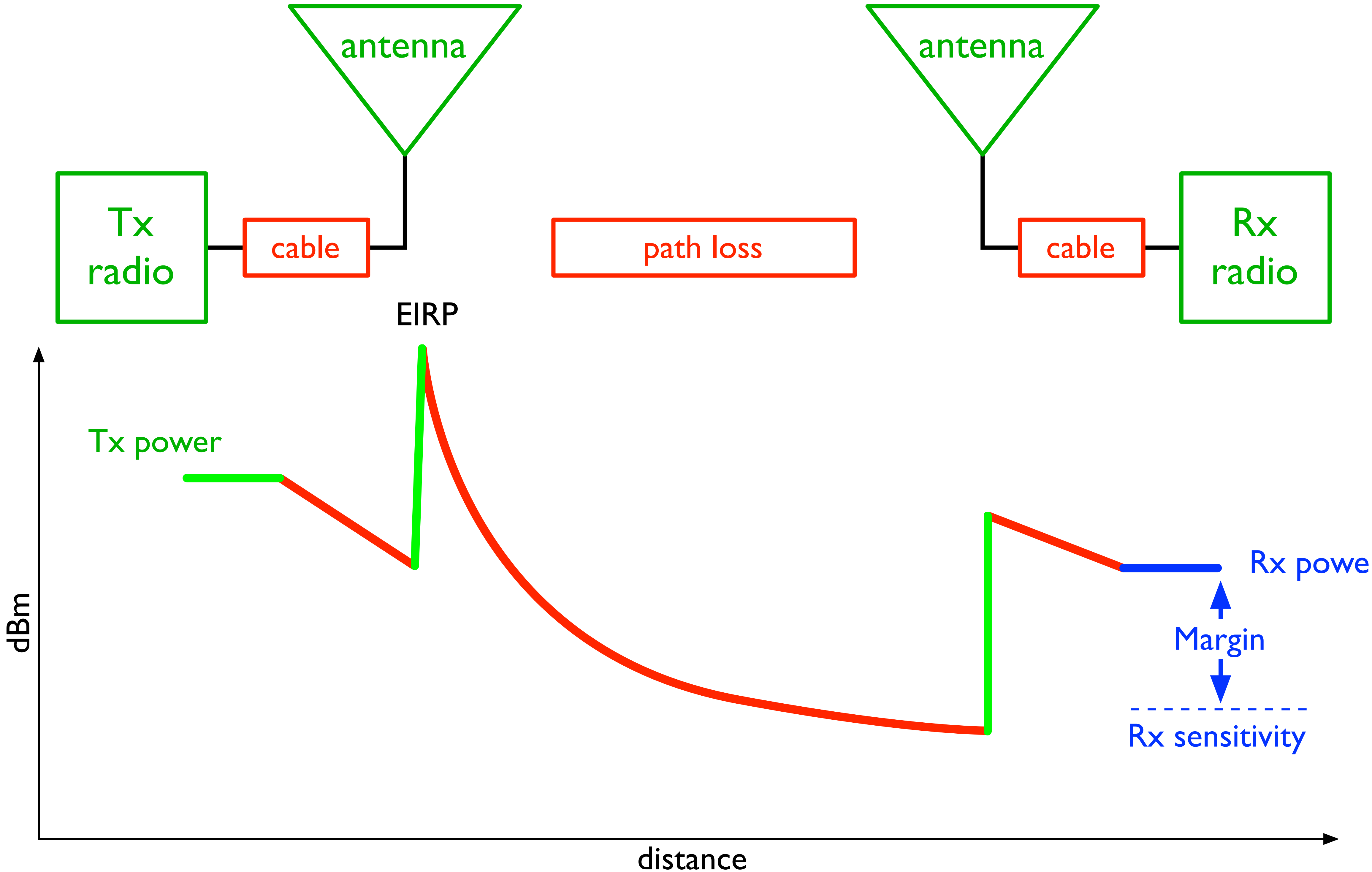
$$L_{fs} = 100 + 20*\log(D) + 20*\log(f)$$

- ...where L_{fs} is expressed in dB, ***D*** is in kilometers and **f** is in GHz.



Free Space Path Loss
2400 MHz
5300 MHz
Path Loss (dB)
140
130
120
110
100
5 km
10 km
15 km
20 km
25 km
30 km
1 mi
5 mi
10 mi
15 mi
20 mi
Distance

Power in a wireless system



Link budget

- The performance of any communication link depends on the quality of the equipment being used.
- ***Link budget*** is a way of quantifying the link performance.
- The received power in a 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 (should be at least 10dB or more for reliable links).

UBIQUITI NETWORKS

Zero Variable Outdoor Wireless Deployment

SYSTEM INFORMATION	
Processor Specs	Atheros MIPS 4KC, 180MHz
Memory Information	16MB SDRAM, 4MB Flash
Networking Interface	1 X 10/100 BASE-TX (Cat. 5, RJ-45) Ethernet Interface

REGULATORY / COMPLIANCE INFORMATION	
Wireless Approvals	FCC Part 15.247, IC RS210, CE
RoHS Compliance	YES

RADIO OPERATING FREQUENCY 2412-2462 MHz

TX SPECIFICATIONS

	DataRate	TX Power	Tolerance
802.11b	1Mbps	20 dBm	+/-1dB
	2Mbps	20 dBm	+/-1dB
	5.5Mbps	20 dBm	+/-1dB
	11Mbps	20 dBm	+/-1dB
802.11g OFDM	6Mbps	20 dBm	+/-1dB
	9Mbps	20 dBm	+/-1dB
	12Mbps	20 dBm	+/-1dB
	18Mbps	20 dBm	+/-1dB
	24Mbps	20 dBm	+/-1dB
	36Mbps	18 dBm	+/-1dB
	48Mbps	16 dBm	+/-1dB
	54Mbps	15 dBm	+/-1dB

RX SPECIFICATIONS

	DataRate	Sensitivity	Tolerance
802.11b	1Mbps	-95 dBm	+/-1dB
	2Mbps	-94 dBm	+/-1dB
	5.5Mbps	-93 dBm	+/-1dB
	11Mbps	-90 dBm	+/-1dB
802.11g OFDM	6Mbps	-92 dBm	+/-1dB
	9Mbps	-91 dBm	+/-1dB
	12Mbps	-89 dBm	+/-1dB
	18Mbps	-88 dBm	+/-1dB
	24Mbps	-84 dBm	+/-1dB
	36Mbps	-81 dBm	+/-1dB
	48Mbps	-75 dBm	+/-1dB
	54Mbps	-72 dBm	+/-1dB

Example link budget calculation

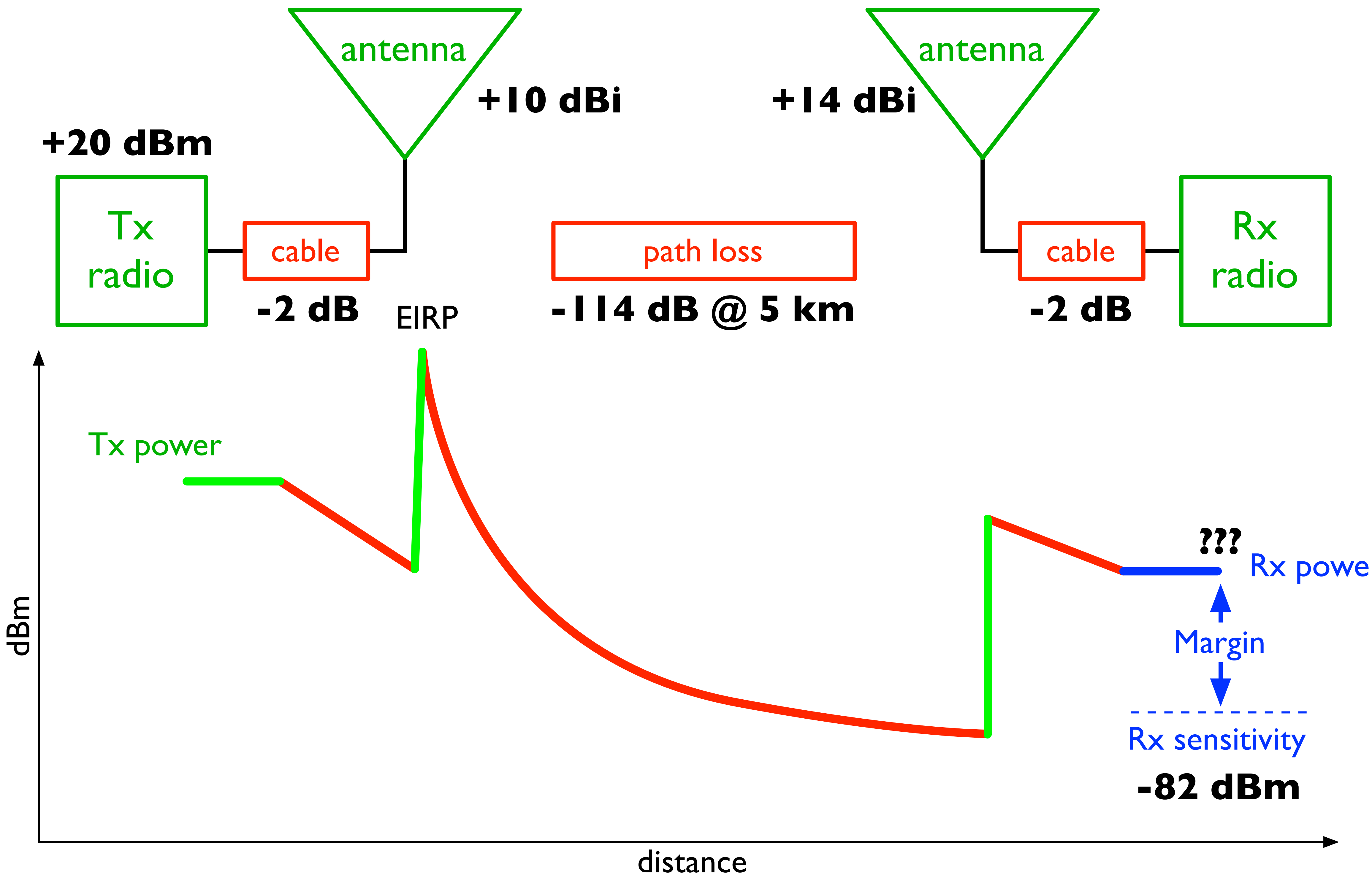
Let's estimate the feasibility of a **5 km** link, with one access point and one client radio, at 2.4 GHz.

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.

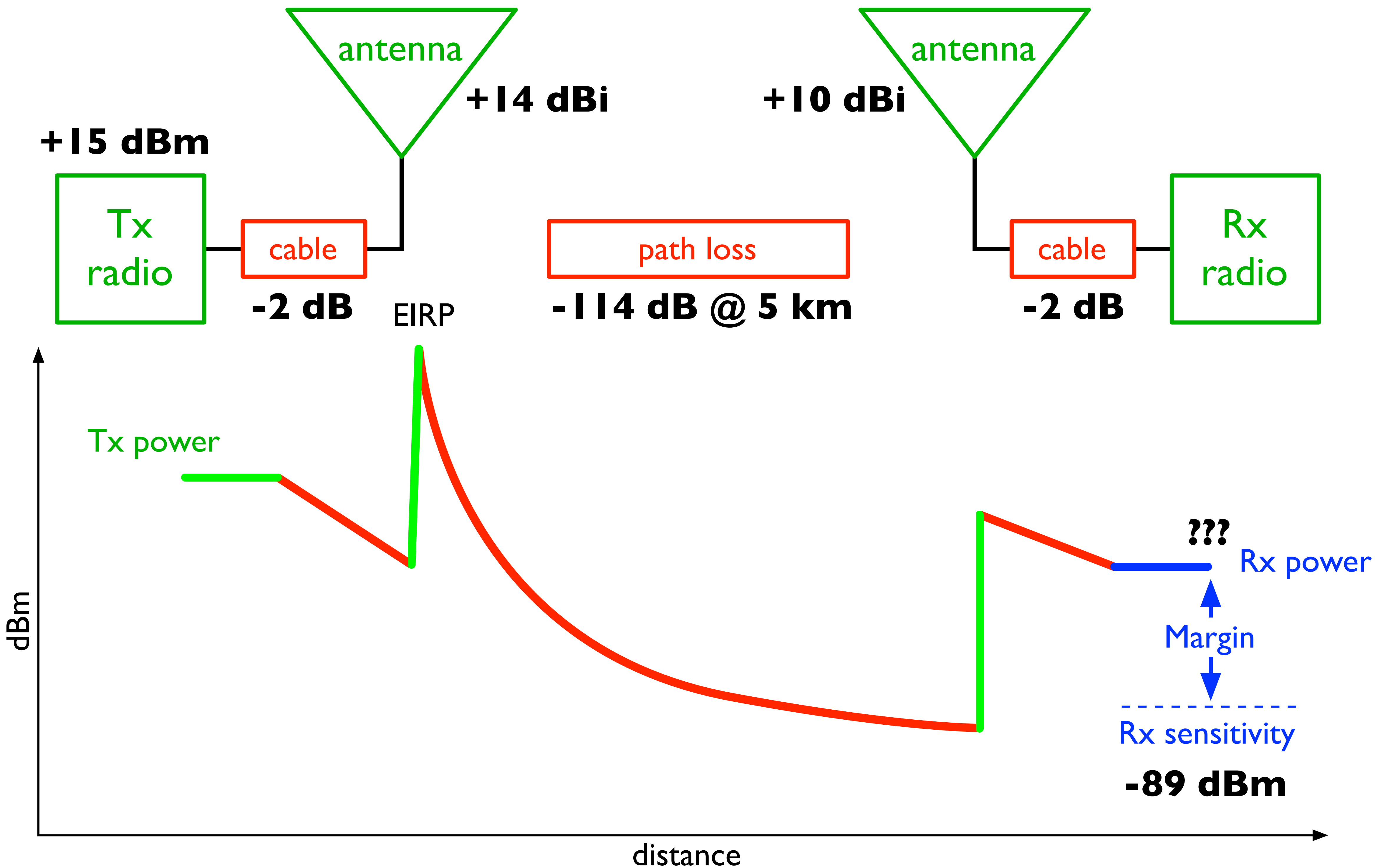
AP to Client link



Link budget: AP to Client link

```
   20 dBm (TX Power AP)
 + 10 dBi (Antenna Gain AP)
 -  2 dB  (Cable Losses AP)
 + 14 dBi (Antenna Gain Client)
 -  2 dB  (Cable Losses Client)
_________
   40 dB  Total Gain
 -114 dB  (free space loss @5 km)
_________
  -73 dBm (expected received signal level)
 --82 dBm (sensitivity of Client)
_________
    8 dB  (link margin)
```

Opposite direction: Client to AP



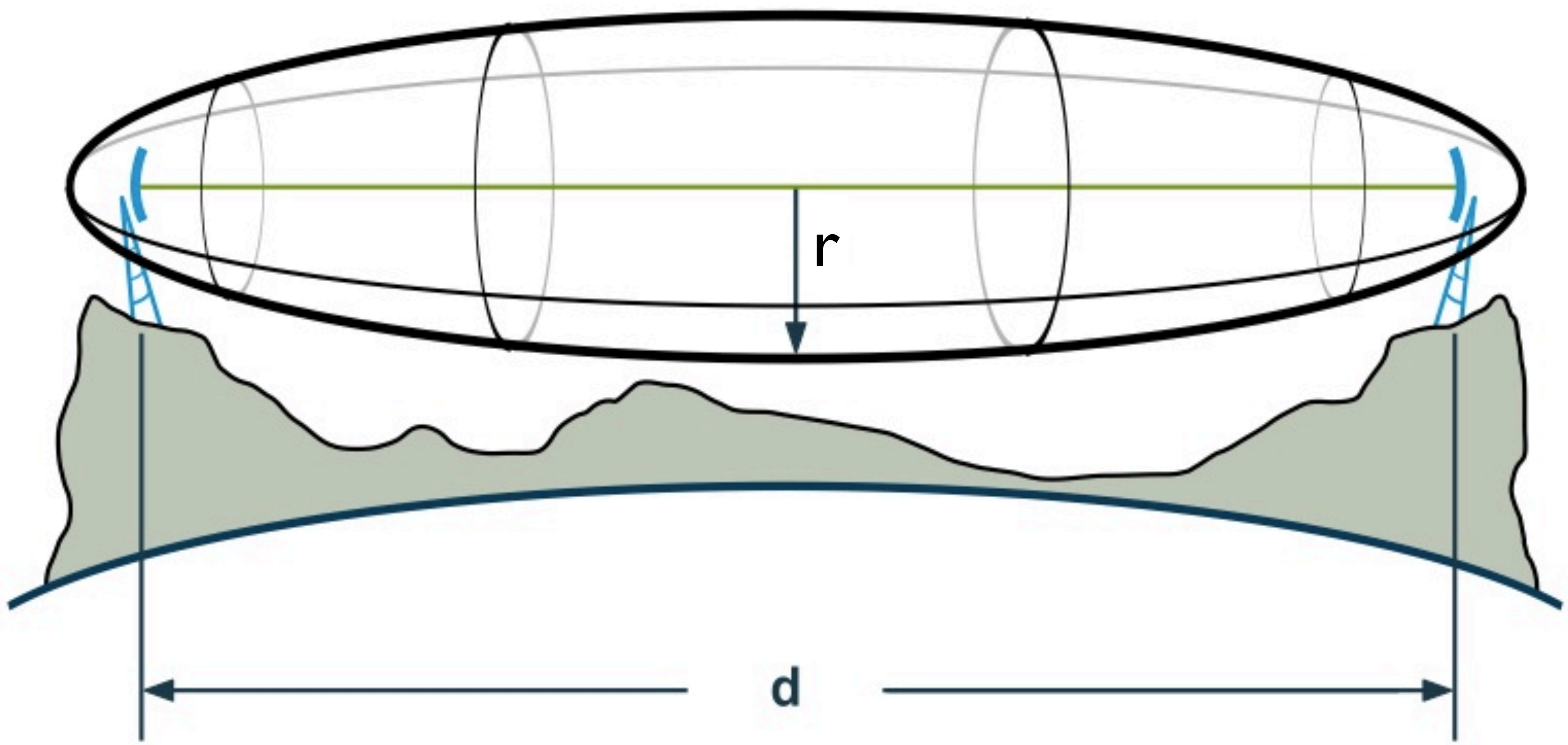
Link budget: Client to AP link

```
   15 dBm (TX Power Client)
 + 14 dBi (Antenna Gain Client)
 -  2 dB  (Cable Losses Client)
 + 10 dBi (Antenna Gain AP)
 -  2 dB  (Cable Losses AP)
_________
   35 dB  Total Gain
 -114 dB  (free space loss @5 km)
_________
  -78 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 path between transmitter and receiver.
- The Fresnel Zone 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.

Line of Sight and Fresnel Zones



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

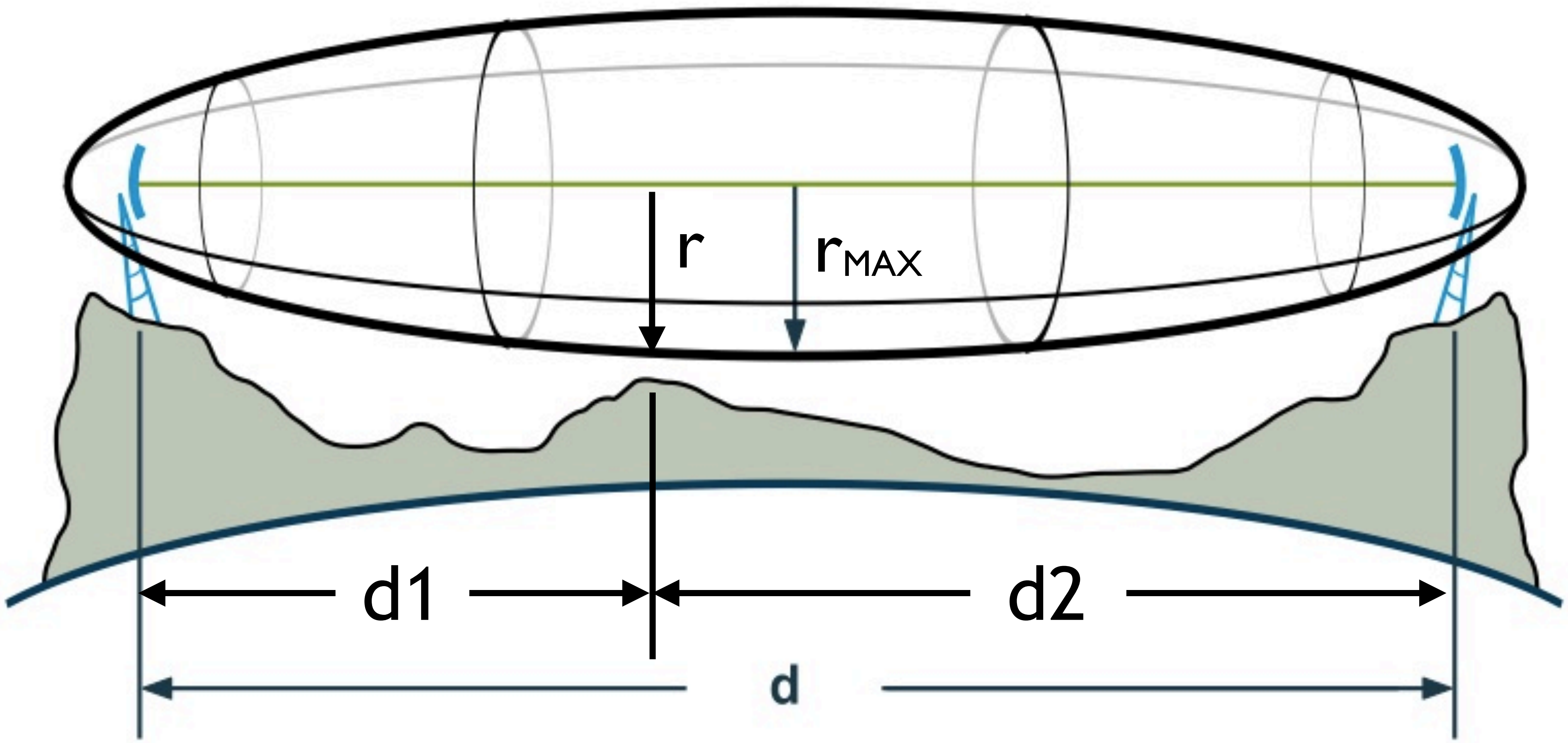
Fresnel Zone

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

```
r = sqrt(d1*d2*λ/d)
```

- ...where **r** is the radius of the zone in meters, **d1** and **d2** are distances from the obstacle to the link end points in meters, **d** is the total link distance in meters, and **λ** is the wavelength.
- 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 = sqrt(d1 * d2 * λ / d)

Clearance of the Fresnel Zone and earth curvature

This table shows the minimum height above flat ground required to clear 70% 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)	70% (m)	Earth curvature (m)	Required height (m)
1	5.5	3.9	0.0	3.9
5	12.4	8.7	0.4	9.1
10	17.5	12.2	1.5	13.7
15	21.4	15.0	3.3	18.3
20	24.7	17.3	5.9	23.2
25	27.7	19.4	9.2	28.6
30	30.3	21.2	13.3	34.5

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 to no interference into the link.
- It is better to err to the conservative side allowing no more than 20% blockage of the Fresnel Zone.

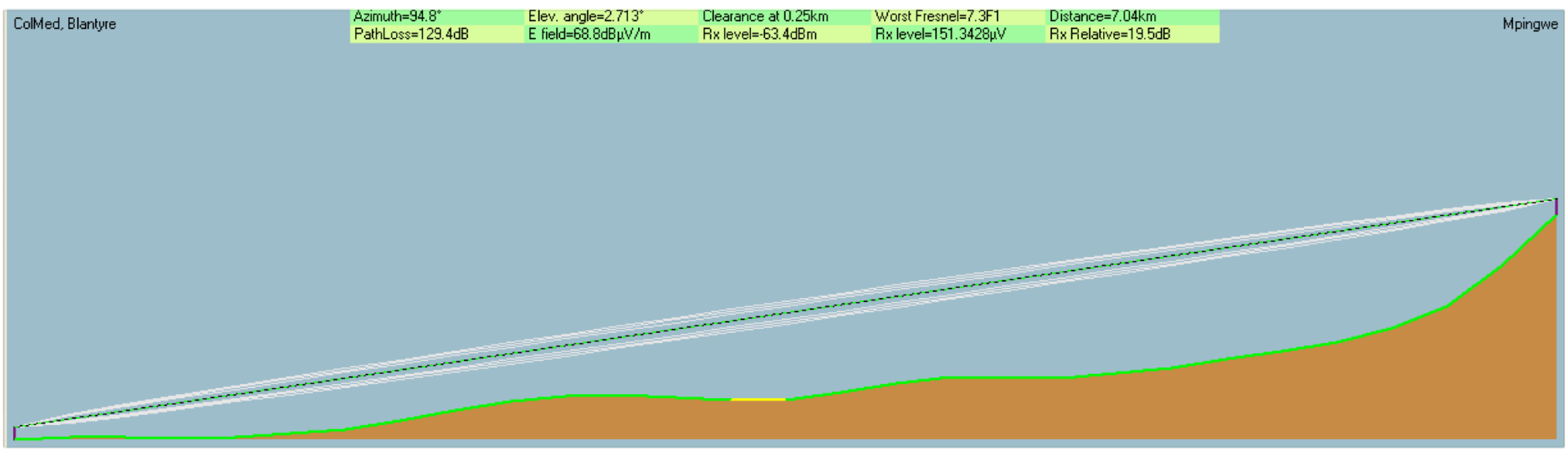
Radio Mobile

- Radio Mobile is a free tool to aid in the design and simulation of wireless systems.
- It can automatically calculate the power budget of a radio link, calculating the Fresnel zone clearance. It can use digital maps, GIS (Geographical Information Systems), or any other digital map, including maps provided by yourself.
- Runs on Windows 95, 98, ME, NT, 2000 and XP.
- There is also an on-line version that can used by any web browser without performing any software installation.

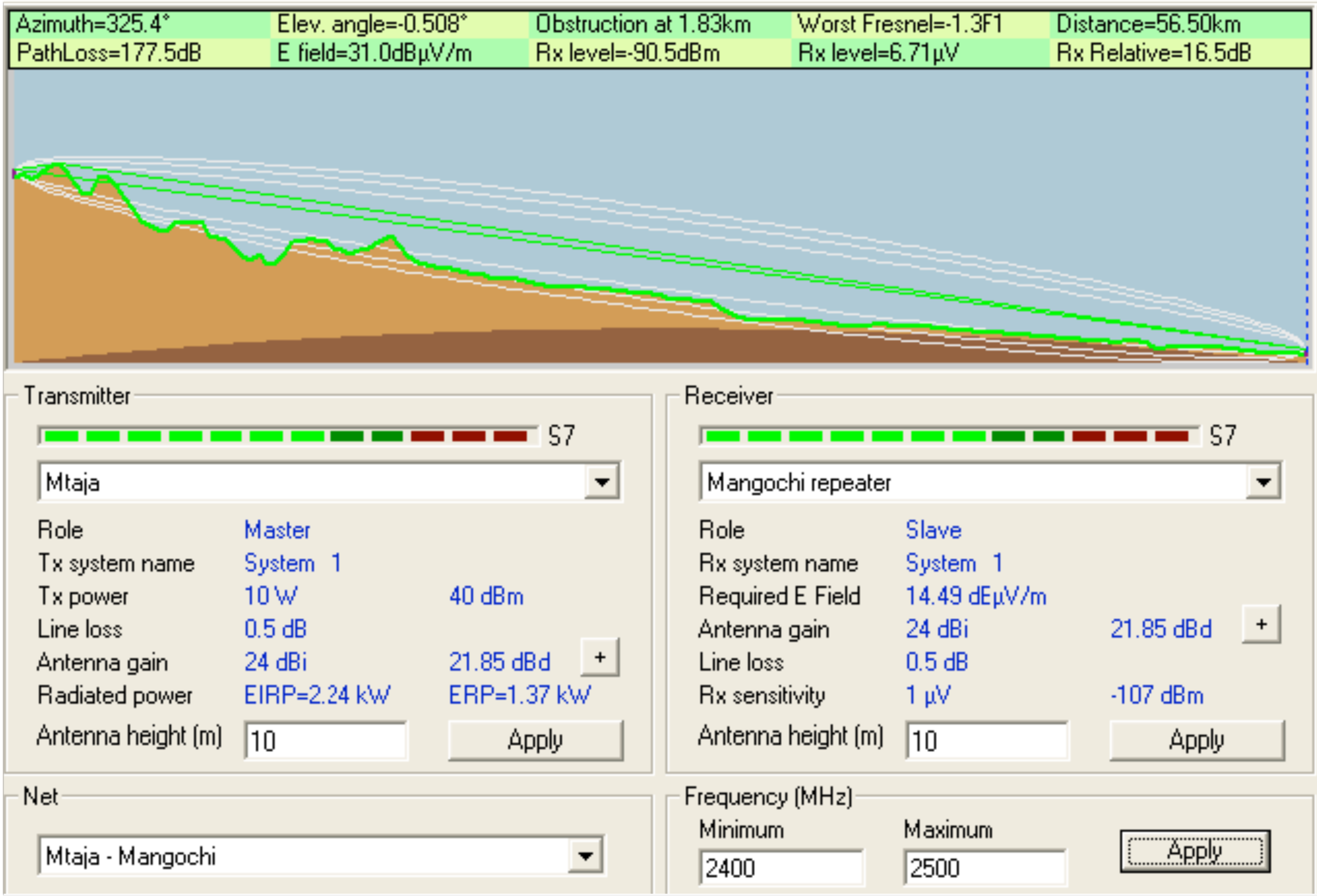
http://www.cplus.org/rmw/english1.html

Radio Mobile

- Uses Digital terrain Elevation Model for the calculation of coverage, indicating received signal strength at various point along the path.
- Radio Mobile automatically builds a profile between two points in the digital map showing the coverage area and 1st Fresnel zone.
- Different antenna heights can be tried to achieve optimum performance.



Radio Mobile



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/