

# Link Budget Calculation

Training materials for wireless trainers



*The Abdus Salam*  
**International Centre  
for Theoretical Physics**



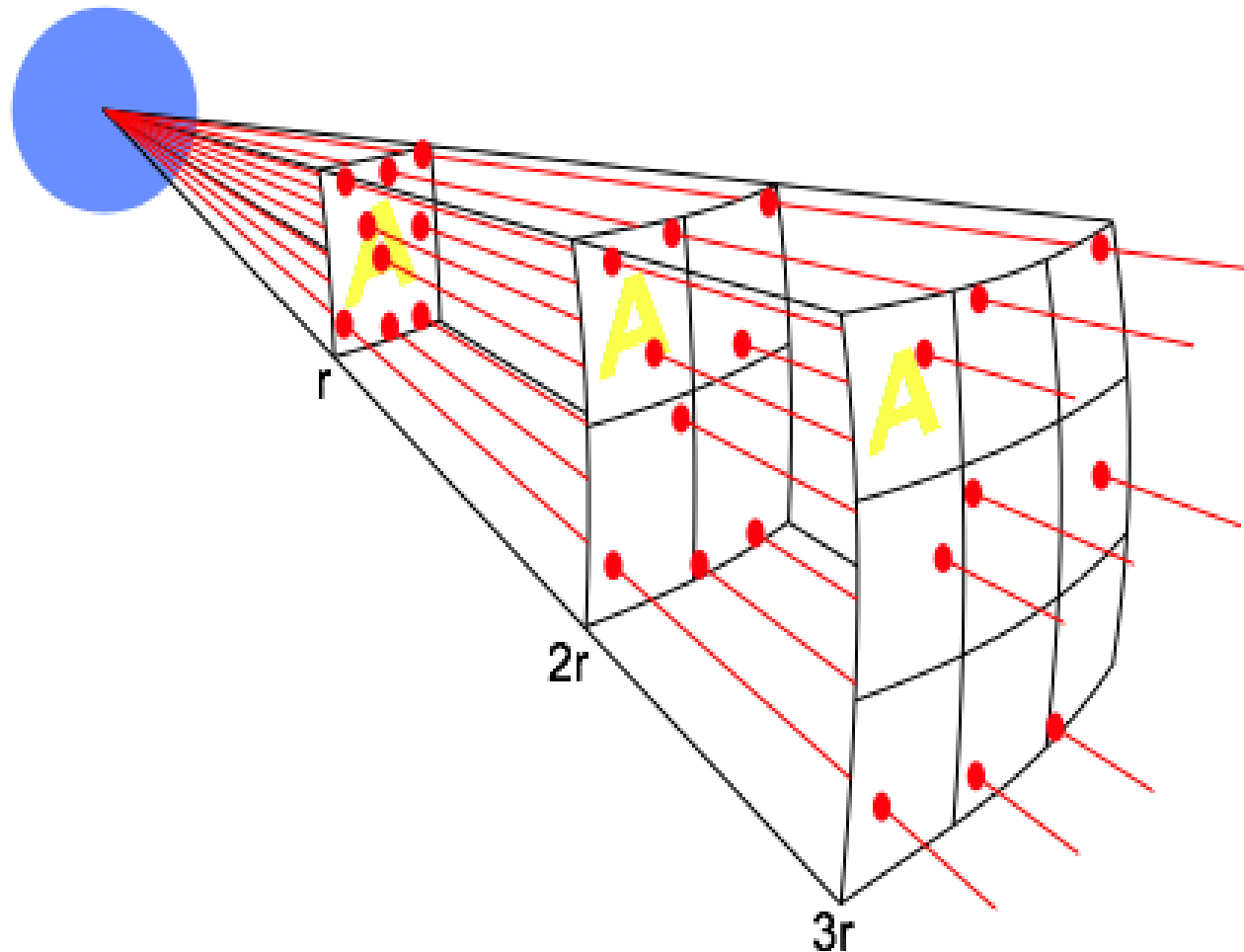
# Goals

- ▶ 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.



# Free Space Loss (@2.45 GHz)

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

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

- ▶ ...where  $L_{fs}$  is expressed in dB and  $D$  is in kilometers.

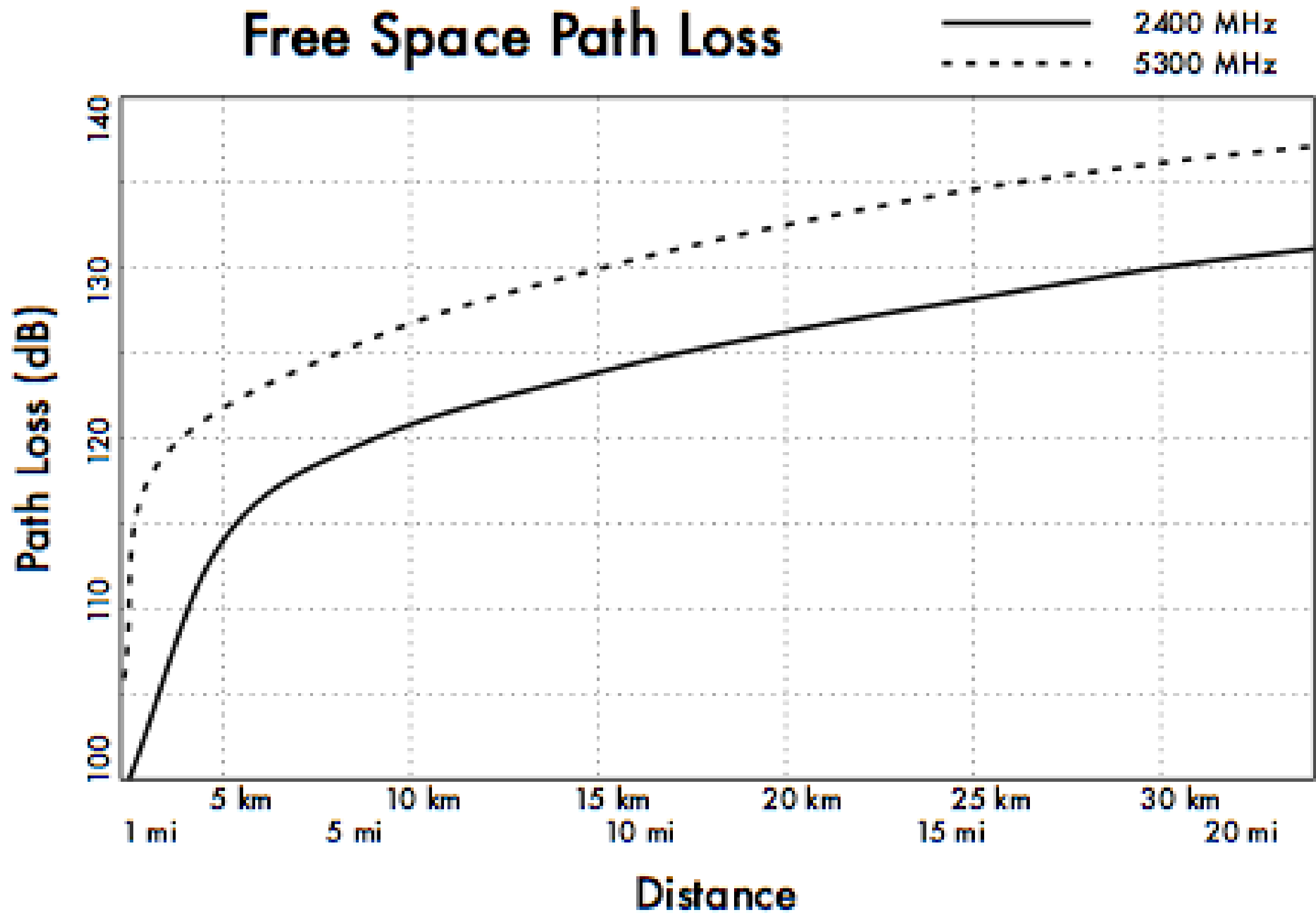
# Free Space Loss (any frequency)

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

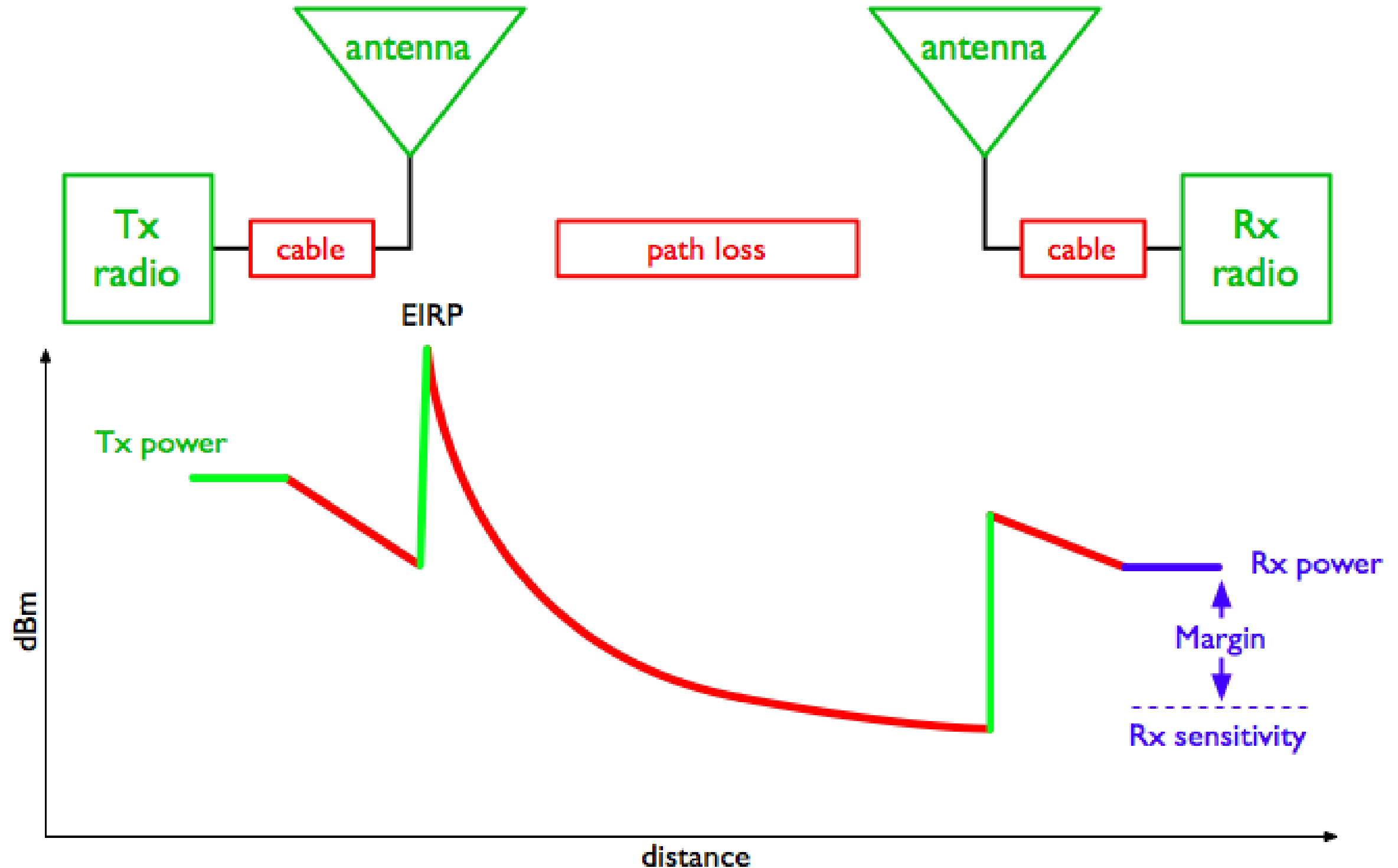
$$L_{fs} = 32,45 + 20 \cdot \log(D) + 20 \cdot \log(f)$$

- ▶ ...where  $L_{fs}$  is expressed in dB,  $D$  is in kilometers and  $f$  is in MHz.

# Free Space Path Loss



# 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 an 802.11 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).



# BULLET<sup>2</sup>

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					RX SPECIFICATIONS			
	DataRate	TX Power	Tolerance			DataRate	Sensitivity	Tolerance
802.11b	1Mbps	20 dBm	+/-1dB		802.11b	1Mbps	-95 dBm	+/-1dB
	2Mbps	20 dBm	+/-1dB			2Mbps	-94 dBm	+/-1dB
	5.5Mbps	20 dBm	+/-1dB			5.5Mbps	-93 dBm	+/-1dB
	11Mbps	20 dBm	+/-1dB			11Mbps	-90 dBm	+/-1dB
802.11g OFDM	6Mbps	20 dBm	+/-1dB		802.11g OFDM	6Mbps	-92 dBm	+/-1dB
	9Mbps	20 dBm	+/-1dB			9Mbps	-91 dBm	+/-1dB
	12Mbps	20 dBm	+/-1dB			12Mbps	-89 dBm	+/-1dB
	18Mbps	20 dBm	+/-1dB			18Mbps	-88 dBm	+/-1dB
	24Mbps	20 dBm	+/-1dB			24Mbps	-84 dBm	+/-1dB
	36Mbps	18 dBm	+/-1dB			36Mbps	-81 dBm	+/-1dB
	48Mbps	16 dBm	+/-1dB			48Mbps	-75 dBm	+/-1dB
	54Mbps	15 dBm	+/-1dB			54Mbps	-72 dBm	+/-1dB

# Example link budget calculation

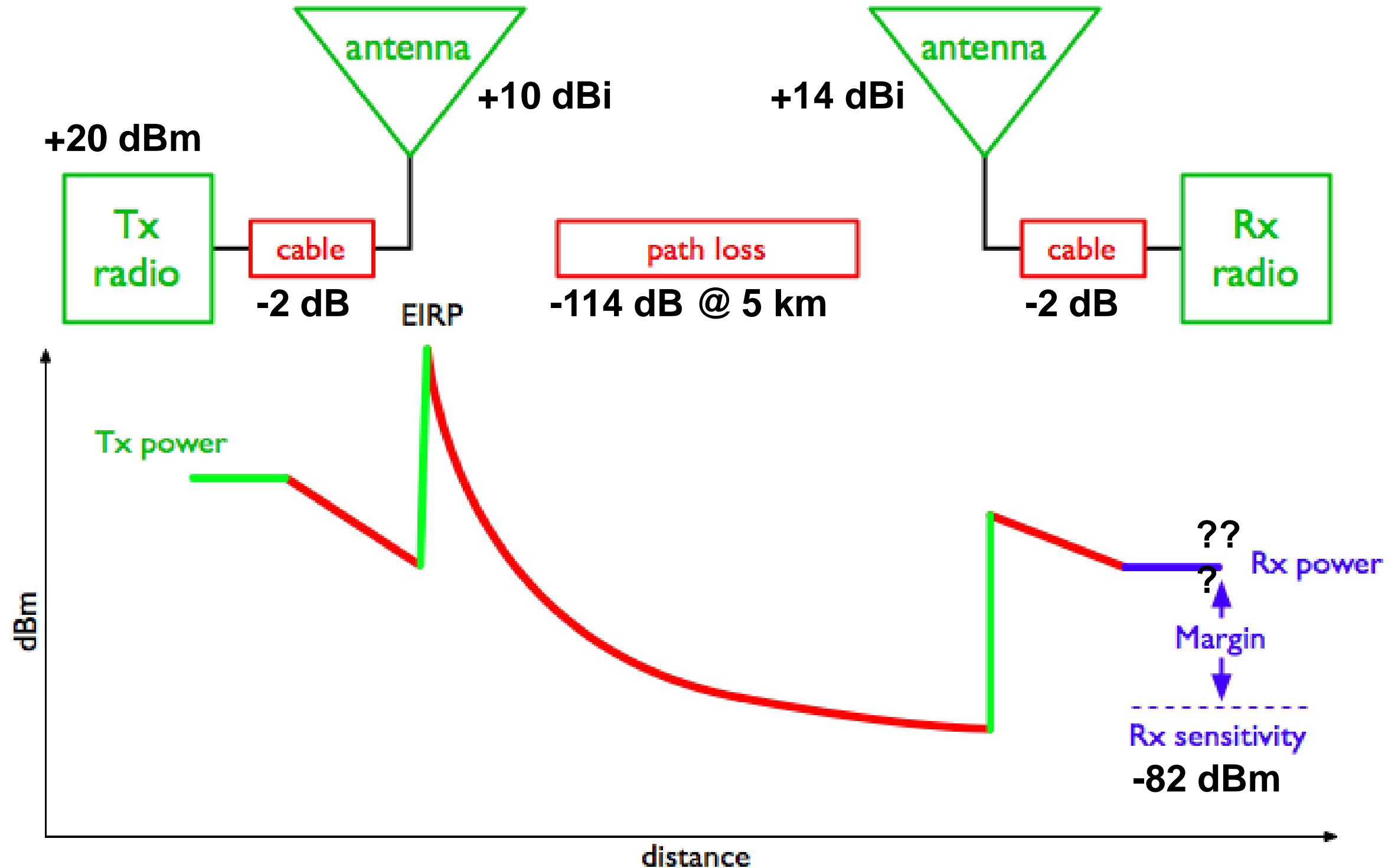
Let's estimate the feasibility of a **5 km** link, with one access point and one client radio.

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)

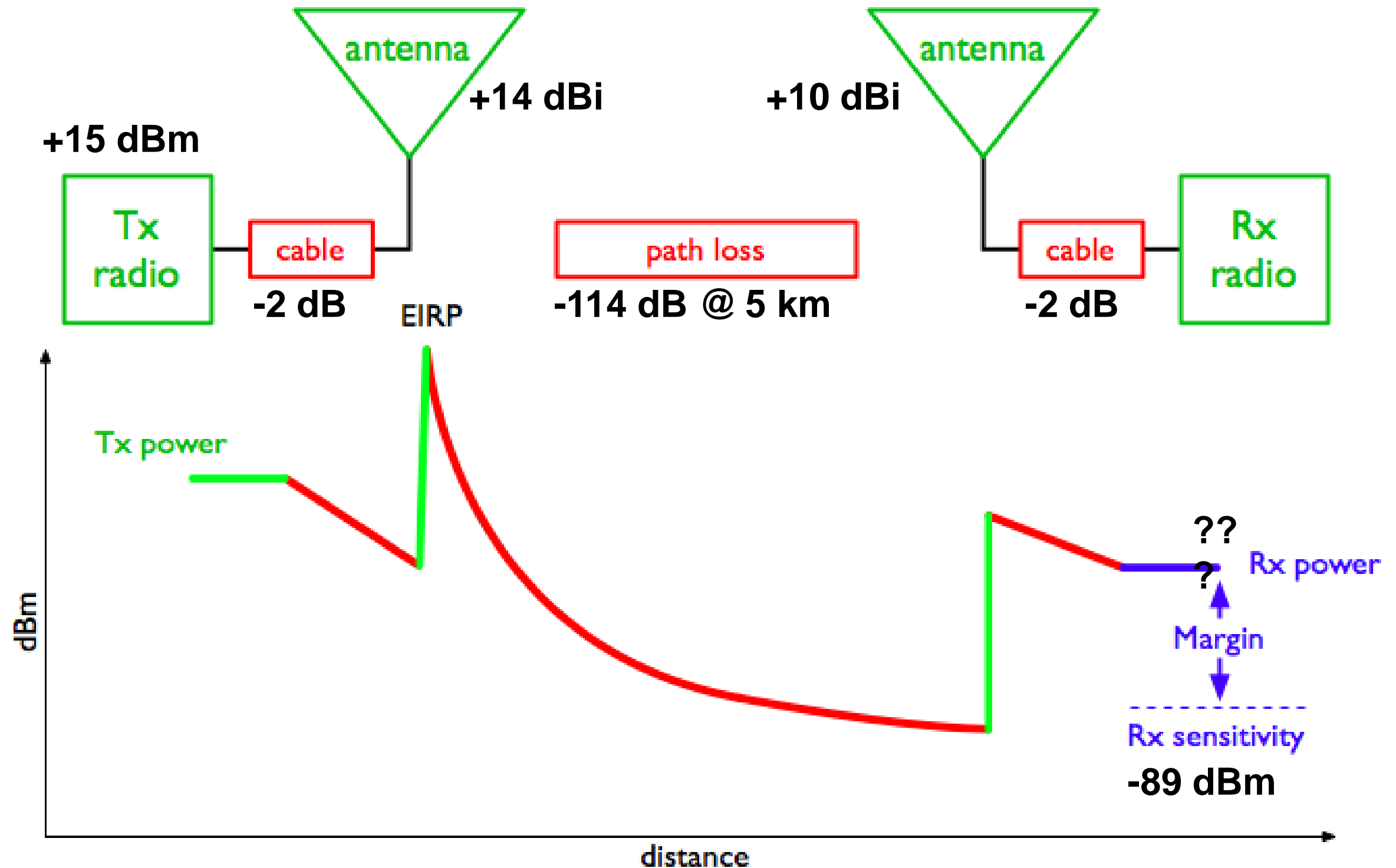
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-73 dBm (expected received signal level)  
--82 dBm (sensitivity of Client)

---

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)

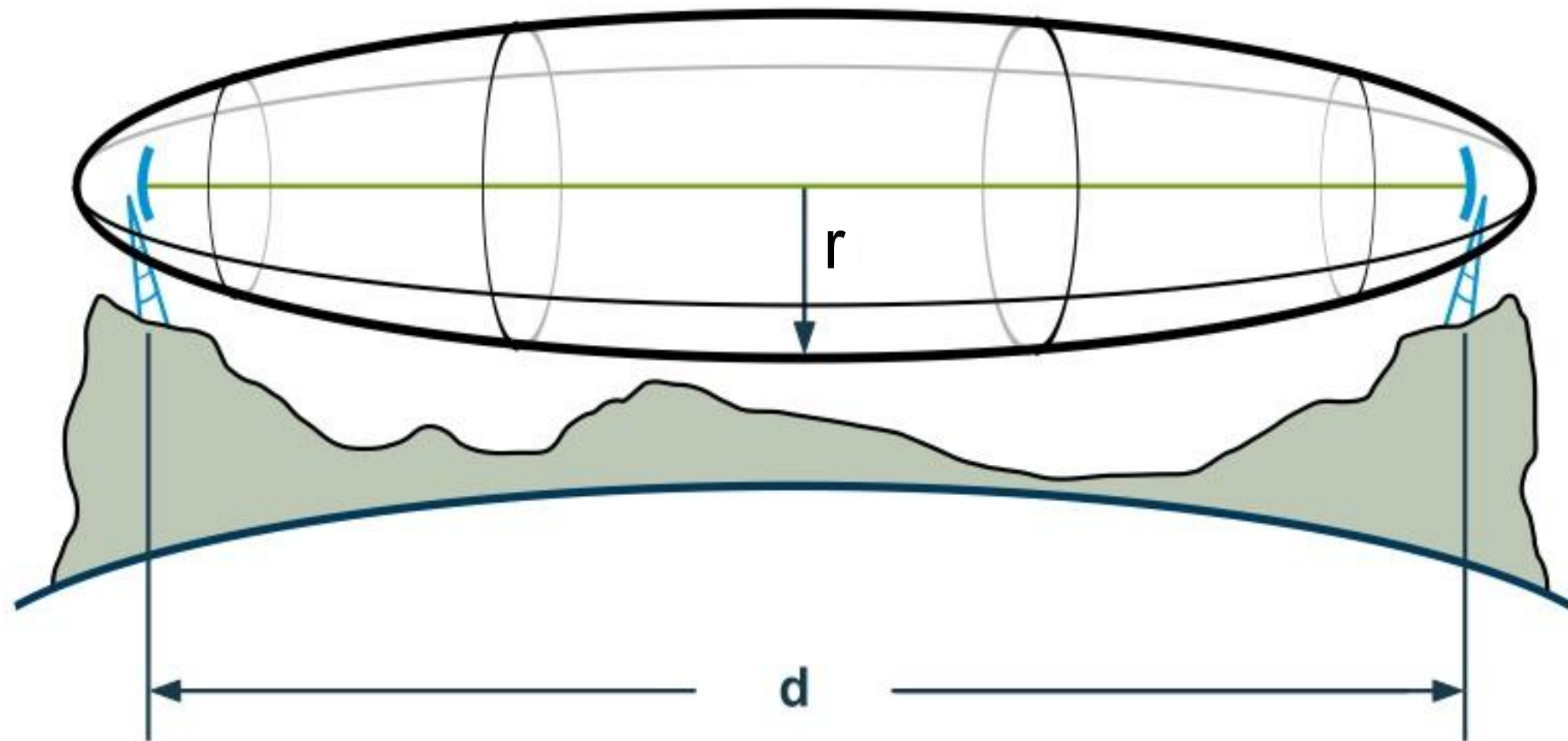
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10 dB (link margin)

# 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



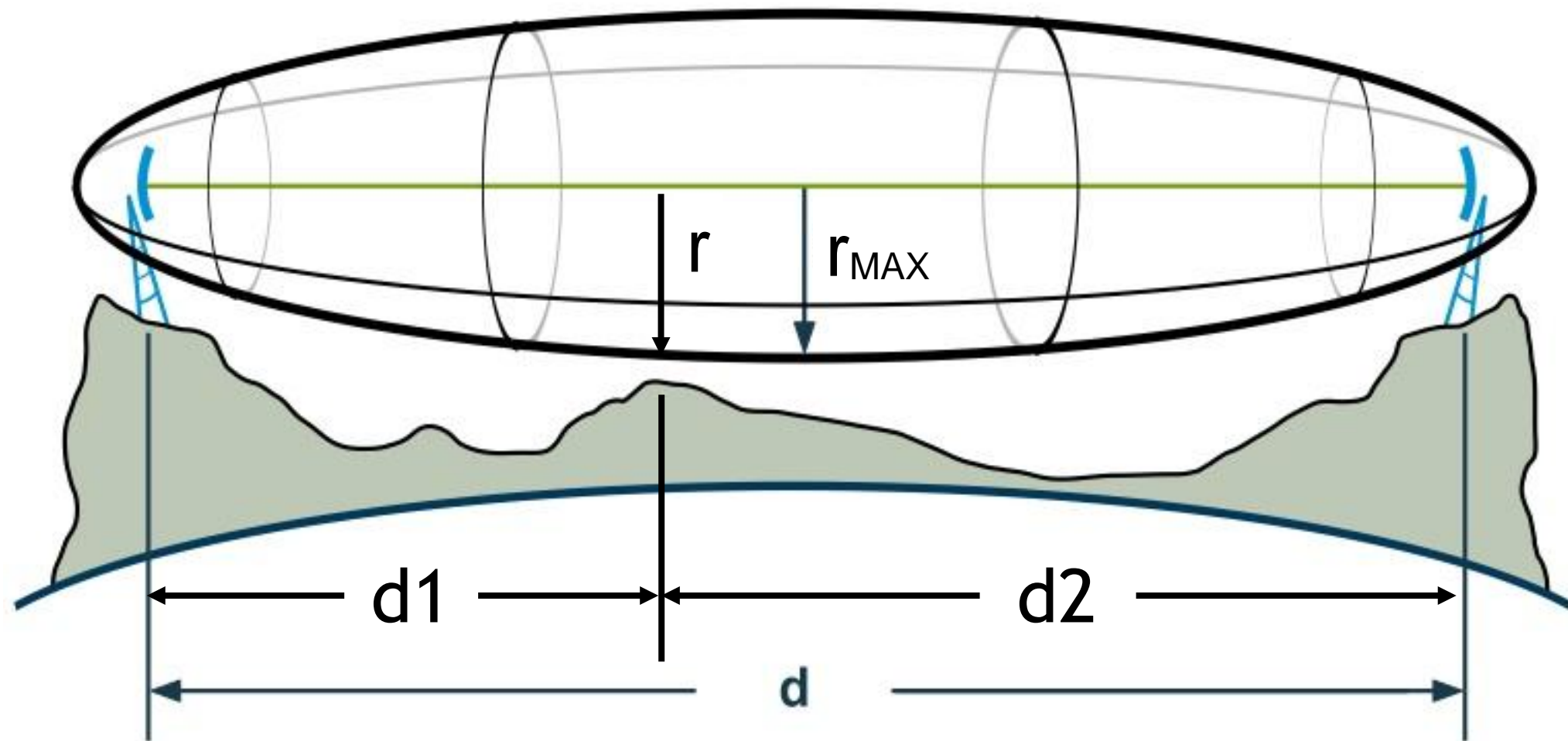
a free line-of-sight **IS NOT EQUAL TO** a free Fresnel Zone



# Fresnel Zone

- ▶ The radius of the first Fresnel Zone at a given point between the transmitter and the receiver can be calculated as:  
$$r = 17.31 * \sqrt{(d1*d2)/(f*d)}$$
- ▶ ...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 **f** is the frequency in MHz.
- ▶ 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



$$r = 17.31 * \text{sqrt}((d_1 * d_2) / (f * d))$$

# 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.

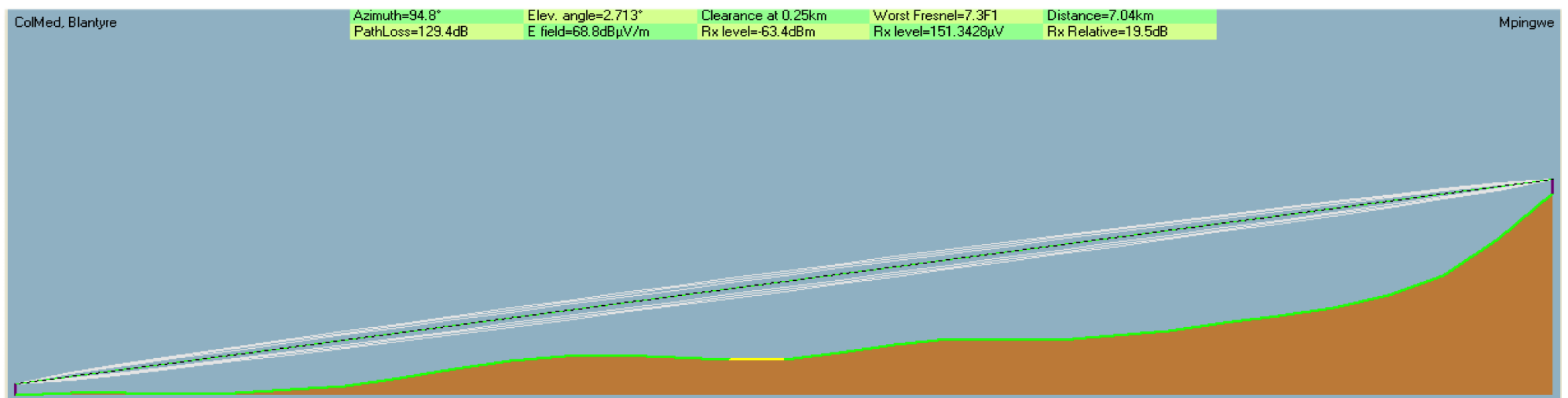
# Radio Mobile

- ▶ 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.

*<http://www.cplus.org/rmw/english1.html>*

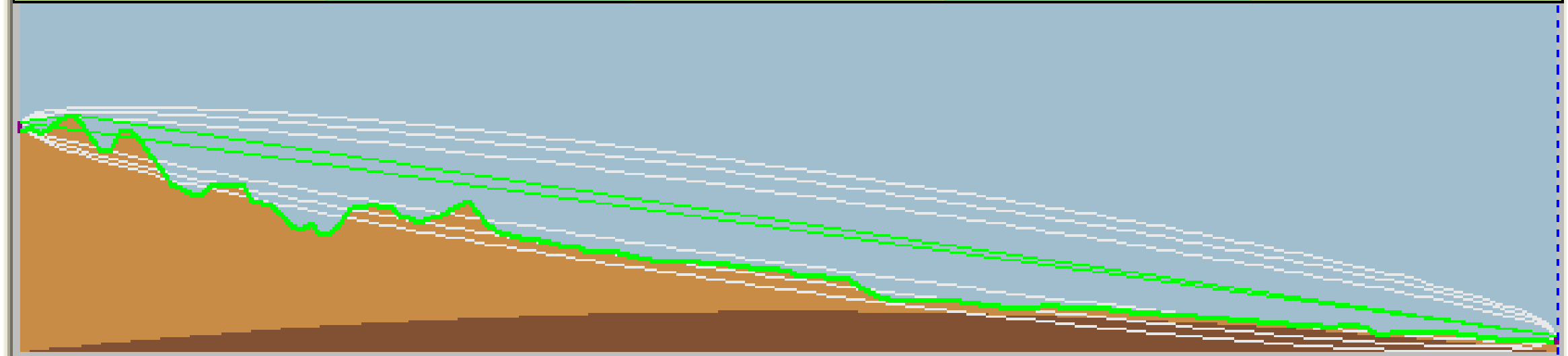
# Radio Mobile

- ▶ 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

Azimuth=325.4°	Elev. angle=-0.508°	Obstruction at 1.83km	Worst Fresnel=-1.3F1	Distance=56.50km
PathLoss=177.5dB	E field=31.0dB $\mu$ V/m	Rx level=-90.5dBm	Rx level=6.71 $\mu$ V	Rx Relative=16.5dB



## Transmitter

 S7

Mtaja

Role Master  
 Tx system name System 1  
 Tx power 10 W 40 dBm  
 Line loss 0.5 dB  
 Antenna gain 24 dBi 21.85 dBd +  
 Radiated power EIRP=2.24 kW ERP=1.37 kW  
 Antenna height (m) 10 Apply

## Receiver

 S7

Mangochi repeater

Role Slave  
 Rx system name System 1  
 Required E Field 14.49 dE $\mu$ V/m  
 Antenna gain 24 dBi 21.85 dBd +  
 Line loss 0.5 dB  
 Rx sensitivity 1  $\mu$ V -107 dBm  
 Antenna height (m) 10 Apply

## Net

Mtaja - Mangochi

## Frequency (MHz)

Minimum 2400 Maximum 2500 Apply

# Win vs Web Radio Mobile

- **Web version**

- Pros: runs on any machine (Linux, Mac, Tablet); does not require big downloads; saves sessions; user friendly
- Cons: requires connectivity; only certain frequencies

- **Windows version**

- Pros: runs offline; can use the GPS
- Cons: runs on Windows only; requires big downloads; hard to learn



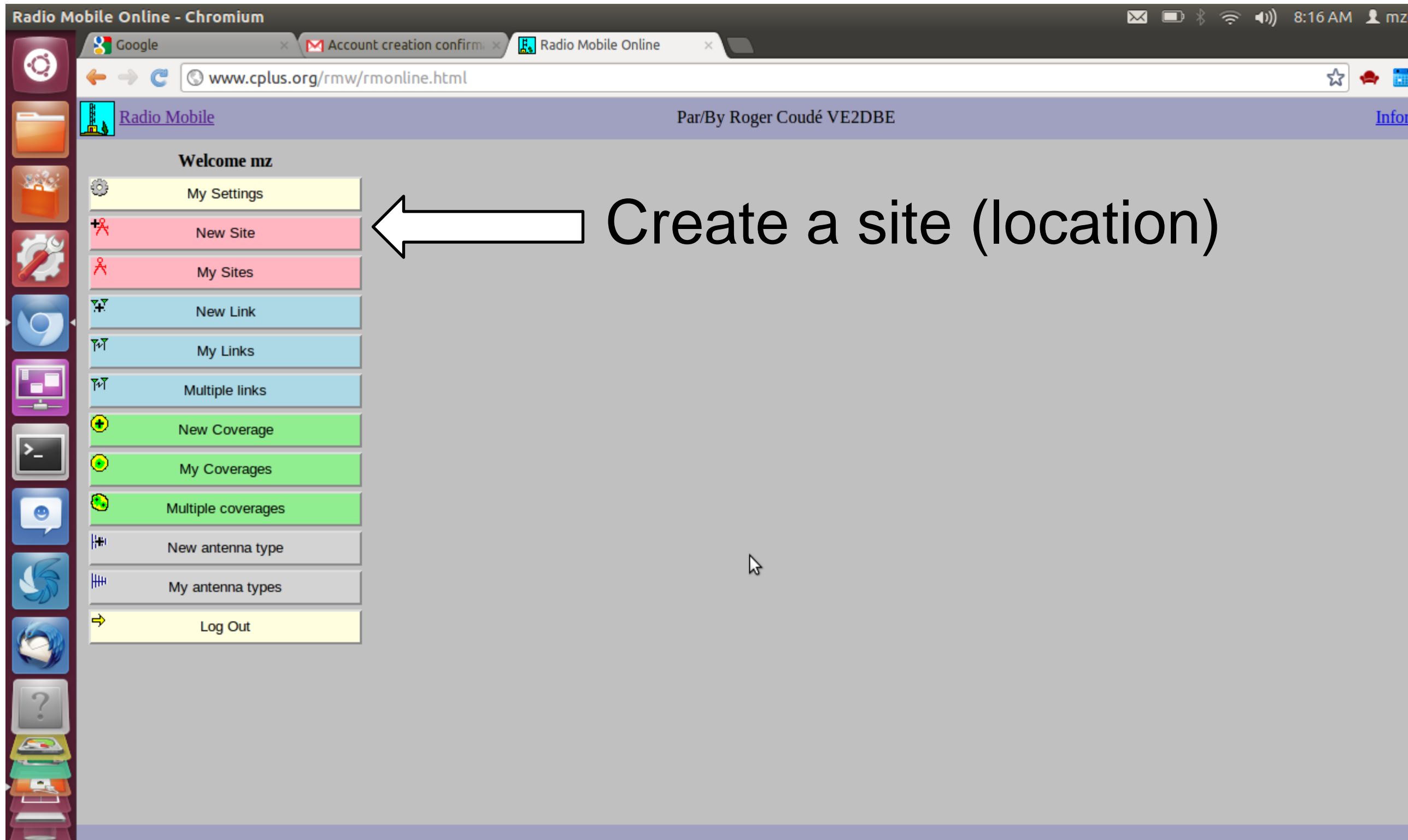
# Web Radio Mobile

Visit

<http://www.cplus.org/rmw/rmonline.html>

and create a new account!

# Web Radio Mobile



# Web Radio Mobile

Radio Mobile Online - Chromium

Google Account creation confirm Radio Mobile Online

www.cplus.org/rmw/rmonline.html

Radio Mobile Par/By Roger Coudé VE2DBE Information

Map Satellite

Google 5 km 5 mi

Map data ©2012 Google - Terms of Use

**New Site 1**

Latitude 0.00000000 00° 00' 00.00" N  
Longitude 0.00000000 000° 00' 00.00" E

Cancel Center at cursor Place cursor at center Submit

# Web Radio Mobile

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Map Satellite

Google 500 m 1000 ft

Map data ©2012 Google Imagery ©2012 DigitalGlobe, GeoEye - Terms of Use

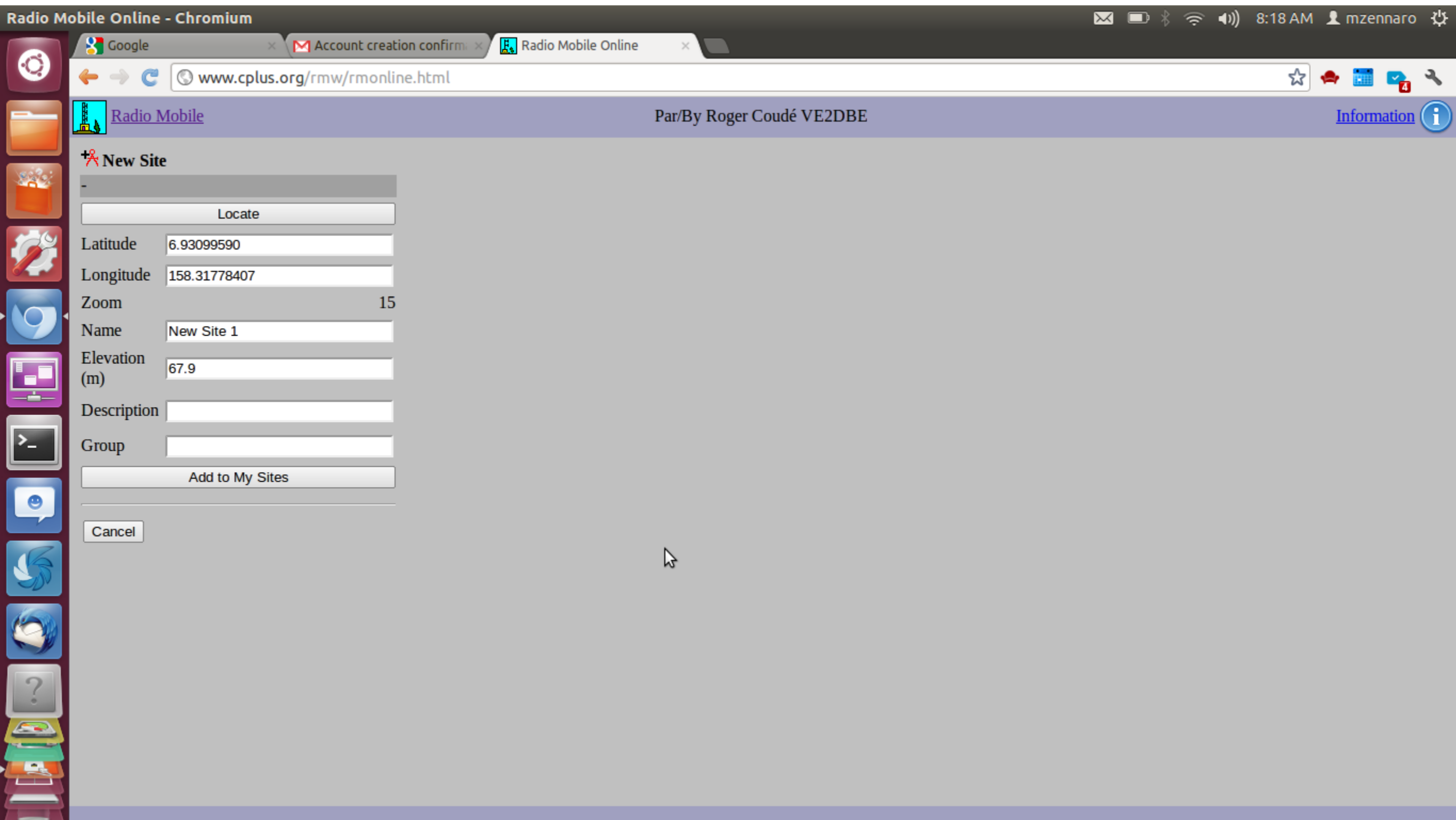
New Site 1

Latitude 6.93099590 06° 55' 51.59" N

Longitude 158.31778407 158° 19' 04.02" E

Cancel Center at cursor Place cursor at center Submit

# Web Radio Mobile





# Web Radio Mobile

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Welcome mz

- My Settings
- New Site
- My Sites
- New Link
- My Links
- Multiple links
- New Coverage
- My Coverages
- Multiple coverages
- New antenna type
- My antenna types
- Log Out

Site Two has been added to my sites

Create a link

# Web Radio Mobile

Radio Mobile Online - Chromium

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www.cplus.org/rmw/rmonline.html

Radio Mobile Par/By Roger Coudé VE2DBE Information

New Link

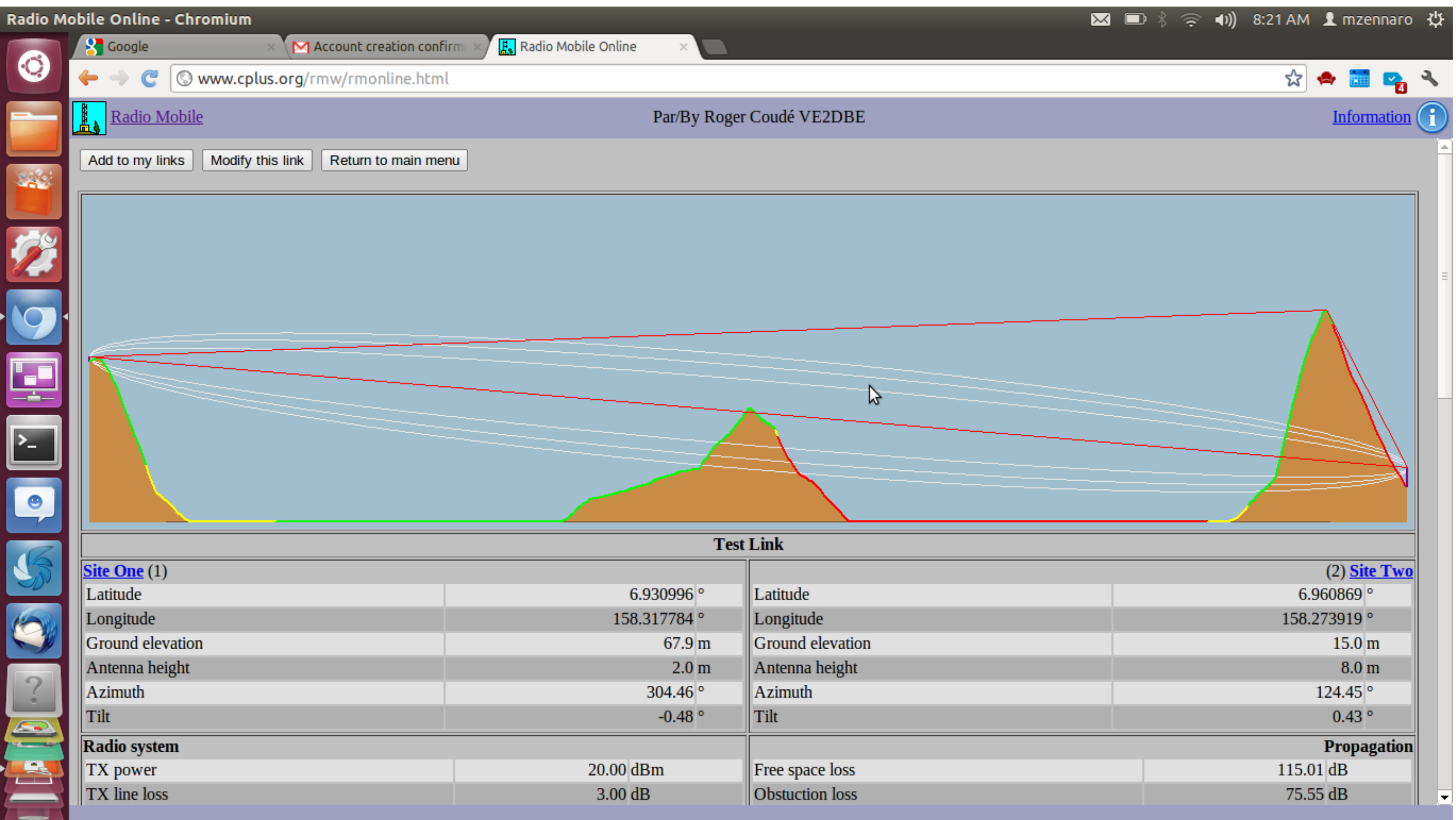
From	Site One
Antenna height (m)	2
To	Site Two
Antenna height (m)	8
Description	Test Link
Frequency (MHz)	2300
Tx power (Watts)	0.1
Tx line loss (dB)	3
Tx antenna gain (dBi)	10
Rx antenna gain (dBi)	10
Rx line loss (dB)	0.5
Rx threshold (µV)	0.5
Required reliability (%)	70
Use land cover	<input checked="" type="checkbox"/>
Use two rays	<input checked="" type="checkbox"/>

Submit

Cancel

← Use 2300 for 2.4 GHz and 5825 for 5.8 GHz

# Web Radio Mobile





# Web Radio Mobile

Radio Mobile Online - Chromium

Google Account creation confirm Radio Mobile Online

www.cplus.org/rmw/rmonline.html

Radio Mobile Par/By Roger Coudé VE2DBE Information

### Test Link

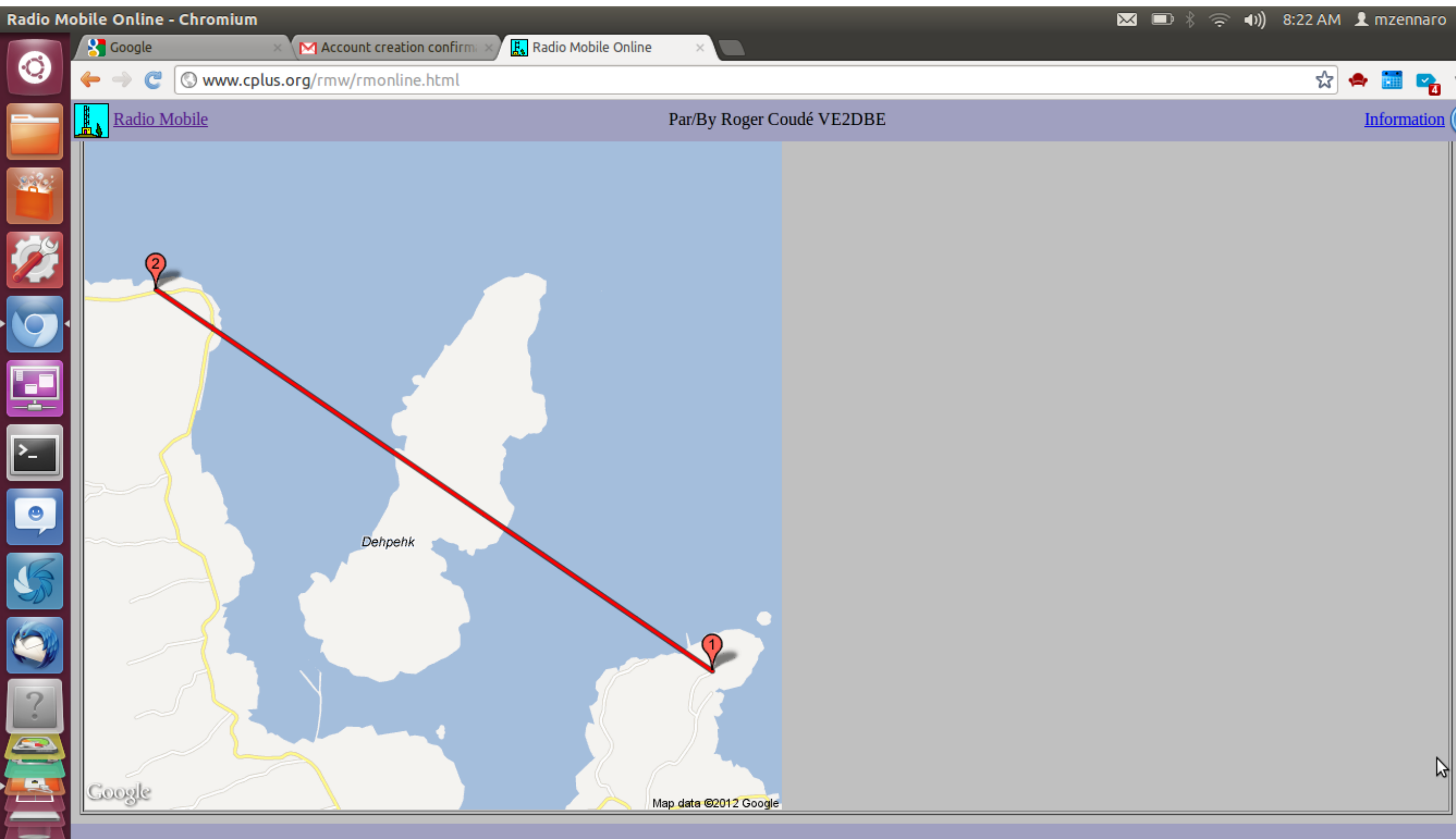
Site One (1)		(2) Site Two	
Latitude	6.930996 °	Latitude	6.960869 °
Longitude	158.317784 °	Longitude	158.273919 °
Ground elevation	67.9 m	Ground elevation	15.0 m
Antenna height	2.0 m	Antenna height	8.0 m
Azimuth	304.46 °	Azimuth	124.45 °
Tilt	-0.48 °	Tilt	0.43 °

Radio system		Propagation	
TX power	20.00 dBm	Free space loss	115.01 dB
TX line loss	3.00 dB	Obstruction loss	75.55 dB
TX antenna gain	10.00 dBi	Forest loss	0.00 dB
RX antenna gain	10.00 dBi	Urban loss	0.00 dB
RX line loss	0.50 dB	Statistical loss	6.60 dB
RX sensitivity	-113.02 dBm	Total path loss	197.17 dB

### Performance

Distance	5.872 km
Precision	10.0 m
Frequency	2300.000 MHz
Equivalent Isotropically Radiated Power	0.501 W
System gain	149.52 dB
Required reliability	70.000 %
Received Signal	-160.67 dBm
Received Signal	0.00 µV
Fade Margin	-47.65 dB

# Web Radio Mobile



# Web Radio Mobile

Radio Mobile Online - Chromium

Google Account creation confirm Radio Mobile Online Radio Mobile Online

www.cplus.org/rmw/rmonline.html

Radio Mobile Par/By Roger Coudé VE2DBE

**New Coverage**

Frequency not allowed for this account

Centre Site	Site One
Antenna Height (m)	10
Antenna Type	Omni
Antenna Azimuth (°)	0
Antenna Tilt (°)	0
Antenna Gain (dBi)	10
Mobile Antenna Height (m)	2
Mobile Antenna Gain (dBi)	2
Description	Site One 2400 MHz*
Frequency (MHz)	2300
Tx power (Watts)	20
Tx line loss (dB)	3
Rx line loss (dB)	0.5
Rx threshold (µV)	0.5
Required reliability (%)	70
Strong Signal Margin (dB)	10
Strong Signal Color	00FF00
Weak Signal Color	FFFF00

# Web Radio Mobile

Radio Mobile Online - Chromium

Google Coordinates for the Chuuk Radio Mobile Online Radio Mobile Online

www.cplus.org/rmw/rmonline.html

Radio Mobile Par/By Roger Coudé VE2DBE Information

Map Satellite

Kolonia Federated States of Micronesia Rontiki

Google

Map data ©2012 Google - Terms of Use

Add to my coverages Modify this coverage Return to main menu

✓ Site One 2300 MHz\* ✓ Site One

Chuuk link

TR's office:

7.452582

151.844061

Udot School:

7.384819

151.718185

# Chuuk link

Questions to answer:

- 1) How high should the masts be?
- 2) How much output power should the radio give?
- 3) What antennas should we use?

Please use the equipment in the lab to answer.

# 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/>*

