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Making the Link

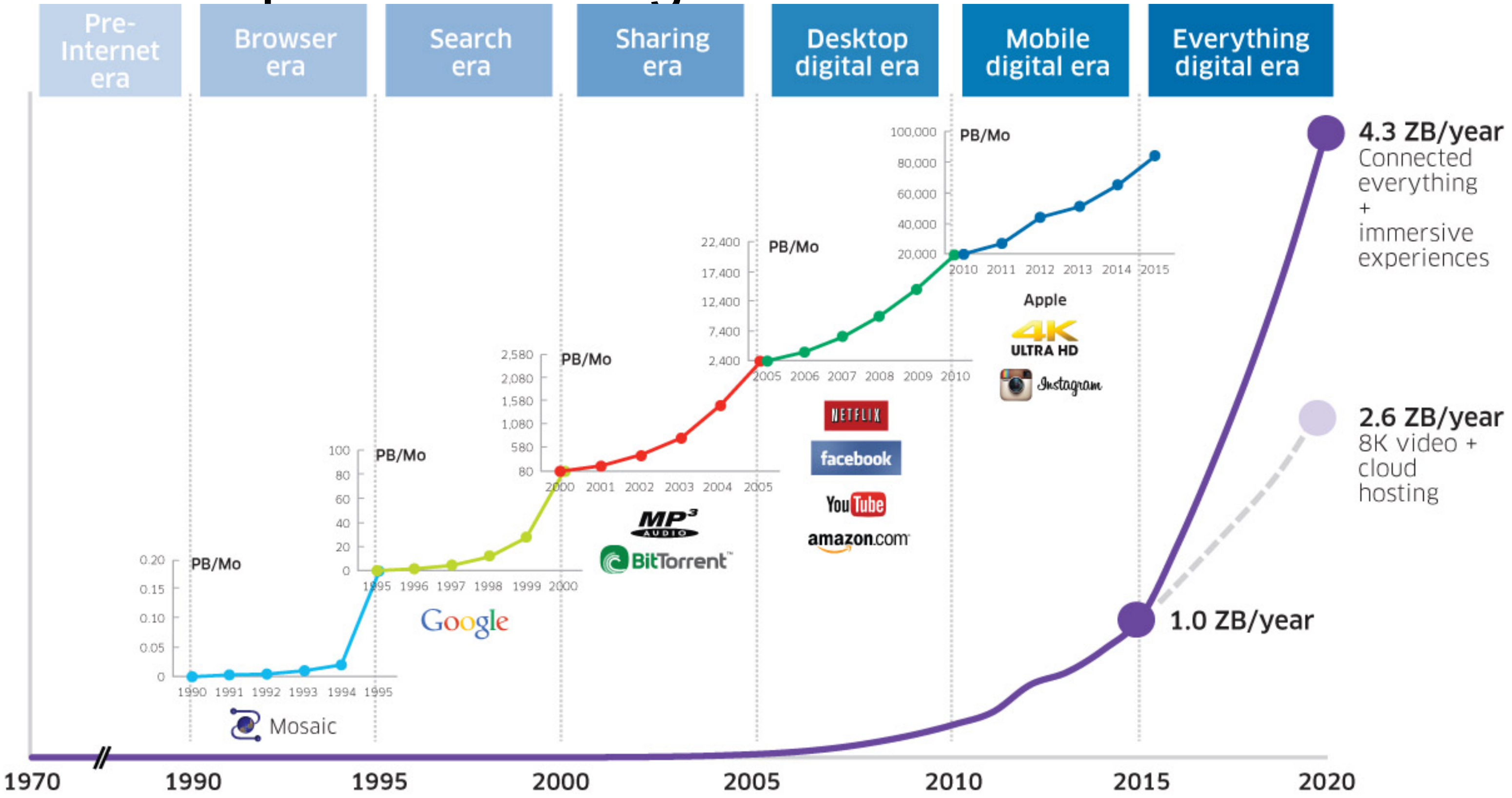
An Introduction to Microwave and Planning Fundamentals

Agenda

- **Configuration and Planning**
- **DEM**
- **Industry Myths – Getting back on track!**
- **It’s all about the System Gaim**
- **Microwave Fundamentals**
  - Transmission Line
  - Pathloss
  - Fresnel Zones
  - Water and Flat Earth!
  - Important Equations
- **Availability and Performance Objectives**
- **Use LINKPlanner to bring it all together!**
- **Q&A - Ask us anything!**

Overall global market trends and opportunities

- <u>Increasing bandwidth demand drives market trends, opportunities and development strategies</u>



Increasing number of sophisticated and bandwidth-hungry devices

Constant increase in high quality and complex web content

NEED

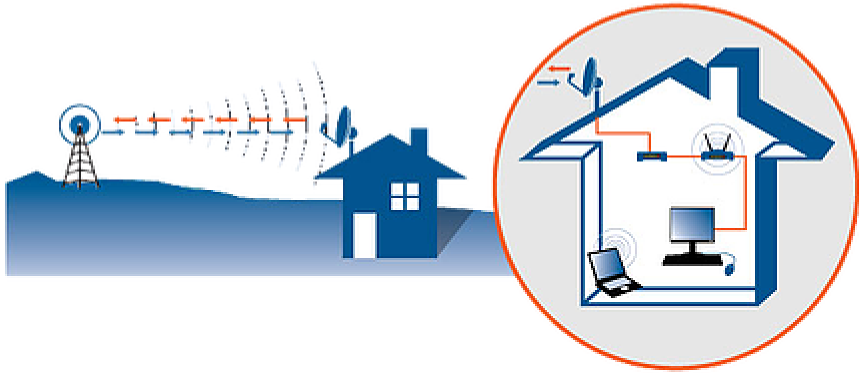
Ultra BroadBand (UBB) high performance network infrastructure

Emerging Global Business Drivers

- **Insatiable broadband speed and this includes the Pacific.**
- **Ubiquitous device (IOT) connectivity**
- **Network as a utility**
- **Doubling capacity demand every few year with no change in ARPU**
- **LAN – WAN convergence wirelessly**

Bridging the Digital Divide - Why Fixed Wireless

- **Tremendously Lower Investment**
  - Cost per home passed is dollars rather than thousands
  - Lower cost per home acquired
- **Quick Construction**
  - Offer service in days rather than months
- **Quickly Connect Customers**
  - No need to trench for every customer
- **Reach**
  - Difficult to reach or remote places can be reached more easily.

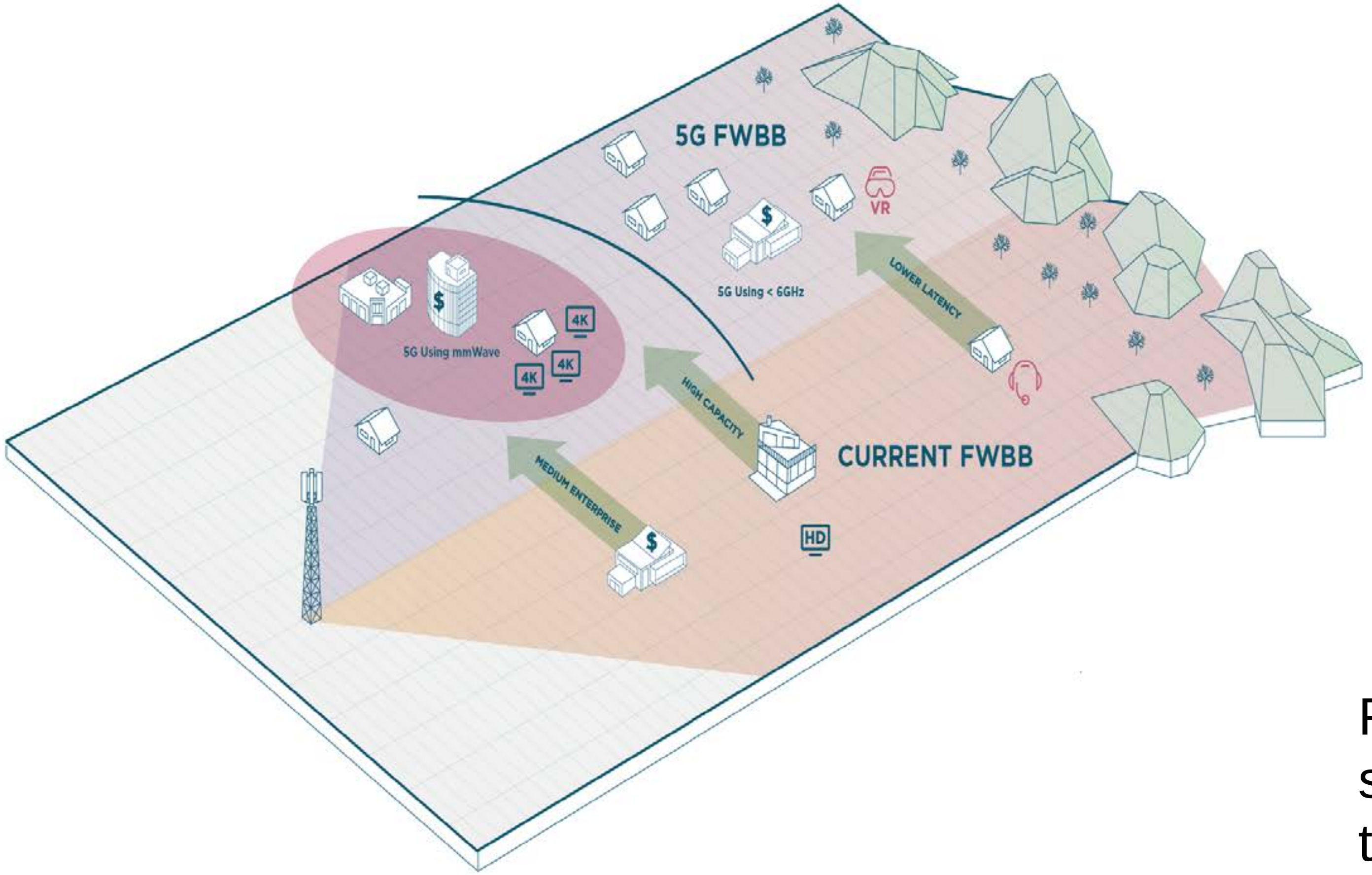


Return On Investment in Months rather than Years

Emerging Technology Drivers

- **Massive MU-MIMO – capacity increase , interference mitigation**
- **Common management framework: Device - LAN - WAN**
- **mmWave – More spectrum and lower cost MU-MIMO**
- **Merchant silicon and standard technologies (802.11ad/ay (WiGig - 60GHz) , 802.11ax (Wi-Fi 6), 802.11be (W-Fi 7) are paving emergence of high throughput communication at affordable price**
- **5G emergence is legitimising FWBB**

How will 5G and 5G like technology change FWBB

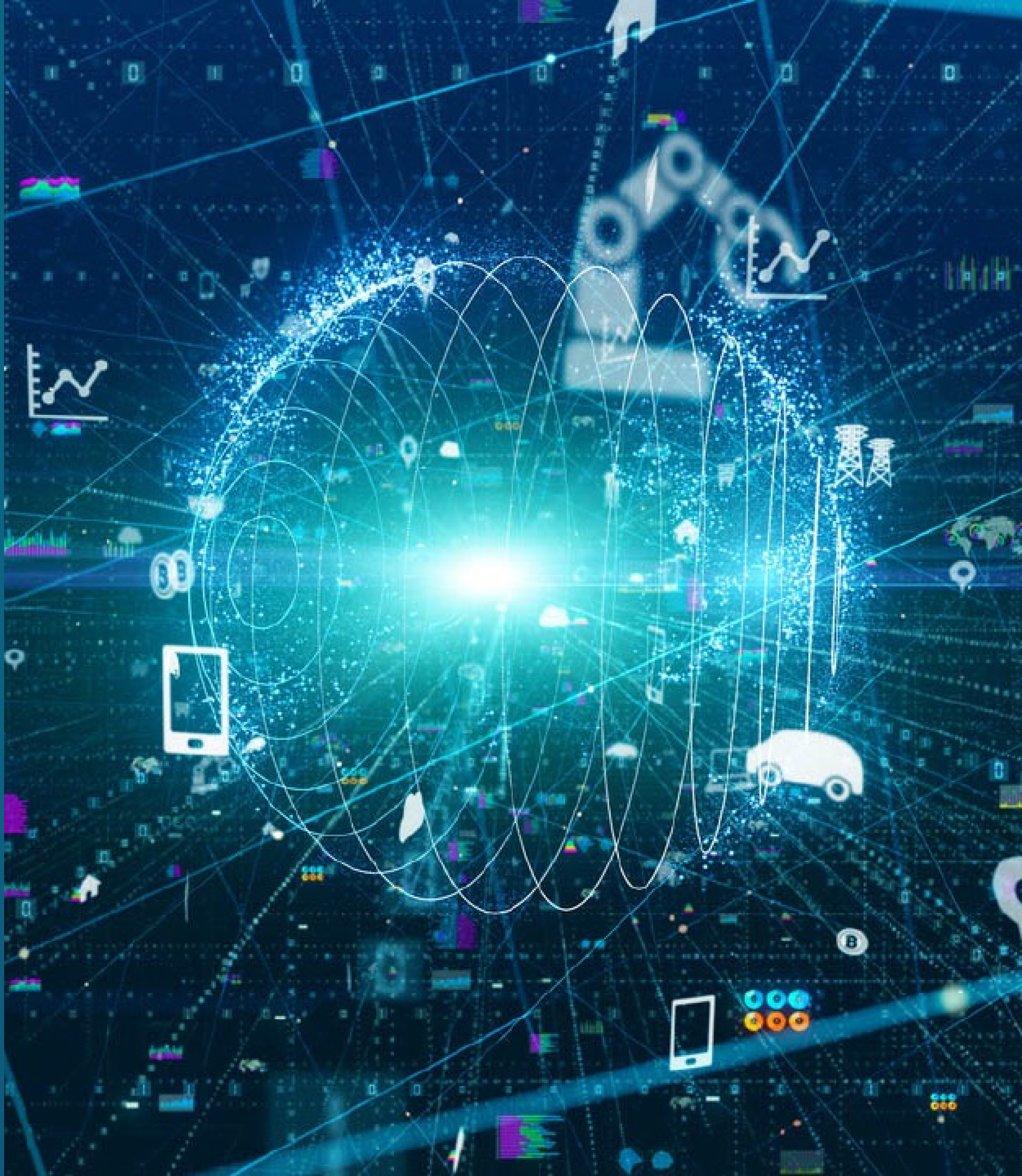


Higher capacity and higher interference tolerance due to MU-MIMO will proliferate use of 100+mbps service plan using wireless. Applications like VR and 4k TVs streaming will become mainstream.

Enterprises in 0- 7Km radius from the AP or cell tower will be using FWBB more prevalently.

FWBB will penetrate more in Urban and suburban area due to higher interference tolerance (due to narrower beams in MU-MIMO).

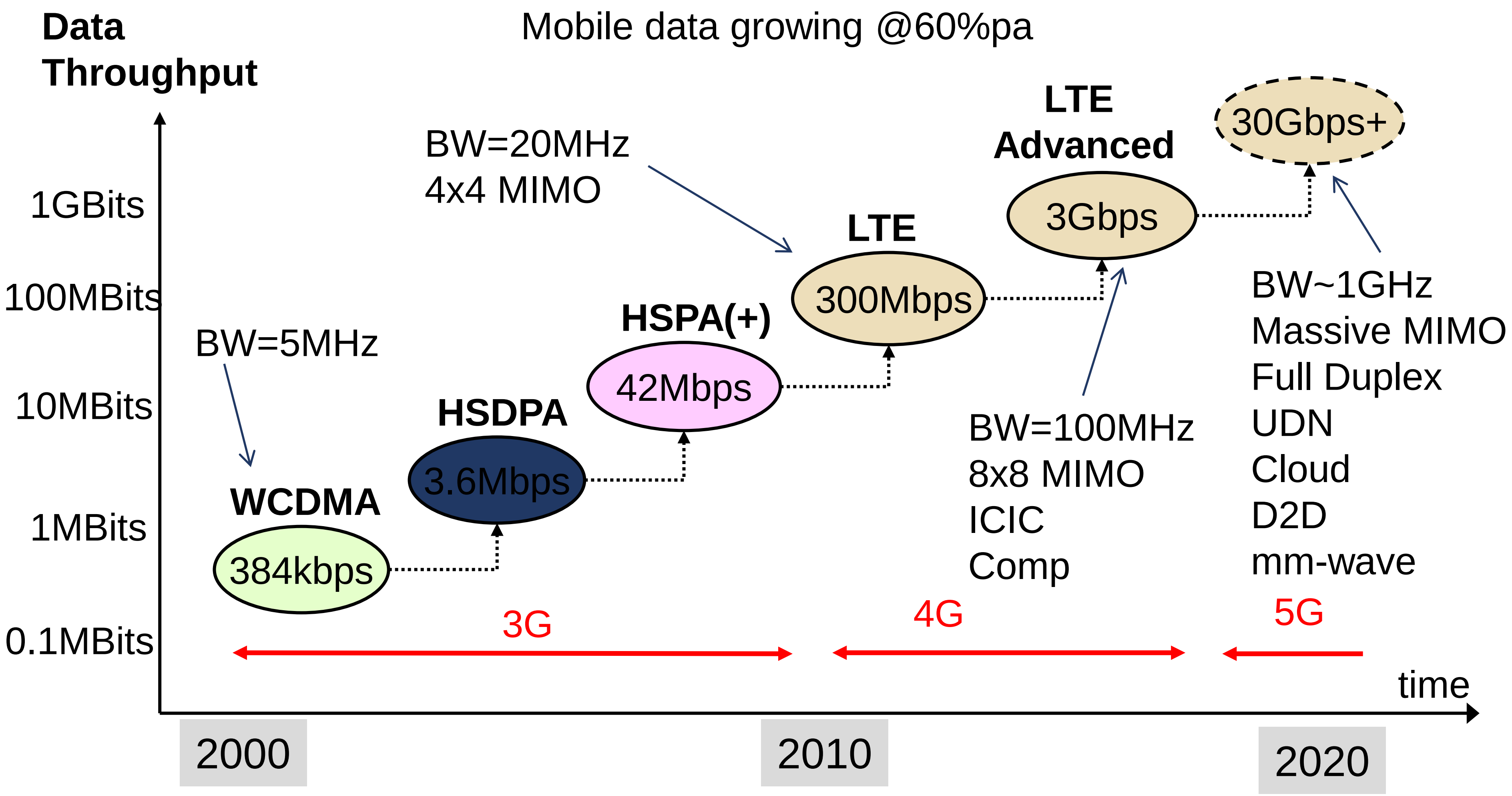
Microwave and Wireless Telecommunications



History of Wireless Telecommunications

- **The birth of telecommunications was in 1876 when Alexander Graham Bell made the world's first telephone call**
- **The history of wireless transmission is attributed James Maxwell, who in 1873 published his famous paper "A Treatise on Electricity and Magnetism," in which he mathematically predicted the existence of electromagnetic waves and deduced the speed of light through his assumption that light traveled as an electromagnetic wave.**
- **In 1888 Heinrich Hertz proved Maxwell's equations when he generated an electromagnetic oscillation using a metal loop with a spark gap at its midpoint, and then detected a similar spark some distance away with a circuit tuned to that frequency.**
  - Hertz verified Maxwell's conclusion on the existence of these waves and the speed they traveled: in other words, the speed of light ($c=\lambda f$)
- **Hertz had effectively invented the first dipole antenna that created radio waves. For that reason, radio waves were originally called Hertzian waves and the frequency - is still measured in hertz!**
- **First commercial Microwave links deployed in the 1950s**
- **Exponential growth from there on – we can apply Moore's Law here!**

"Moore's Law" for Wireless Communications



IEEE_MTT+AP Seminar 29/8/2018. © Professor Mike Faulkner Victoria University

Results of the Studies and Theories

- **Marconi realised the benefits of radios transmission early and in 1897 founded Wireless Telegraph and Signal Company**
- **Commercial terrestrial PTP systems installed in the 1950s**
- **Due to the study of propagation effects, we then discovered:**
  - K-factor
  - Diffraction loss
  - Fresnel clearances
- **Let’s learn again from history and adapt rules**

So Microwave Transmission is now 70 Years old!!!...

… And what do we know?

- **Line of sight is mandatory**
- **Rays travel in elliptical paths called Fresnel zones**
- **The harder it rains the worse the performance**
- **mmWave signals travel as pencil-thin beams**
- **Class 4 ultra-high-performance antennas have high gain**
- **Each path must achieve 99.999% to be carrier grade**

(Hint – these are the myths!!!)

Link Planning - Building the Link

Where do we start?

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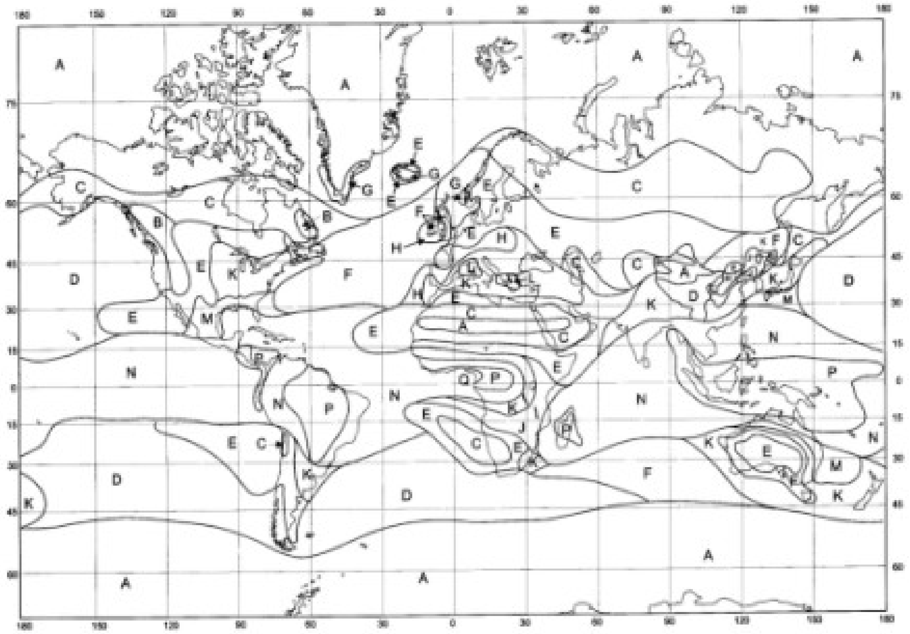
Configuration and Planning Brief

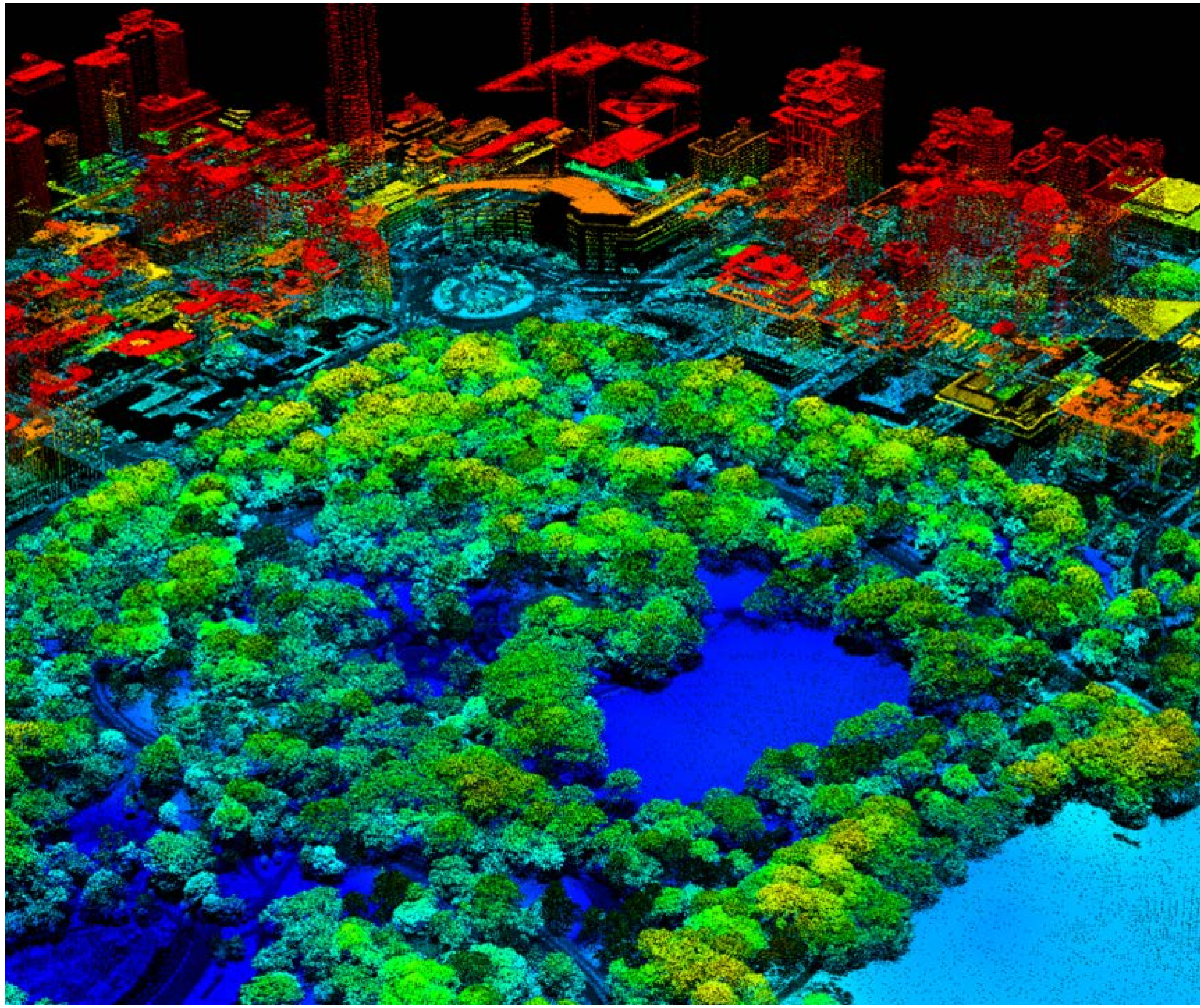
- **Customer locations**
  - Accurate location co-ordinates
  - Connections / Topology
- **Customer Traffic**
  - Importance (voice, data, real-time)
  - Capacity (now and future)
- **Type of protection?**
- **Can we influence the required configuration.**
- **Can we use ACM?**
- **Specific requirements?**
- **Target availability**
- **Fade margin**
- **How to act in case of low performance requirements?**
- **Tower**
  - Do we know what type of tower used?
  - What are the tower heights?
  - Tower loading allowed.
  - What is the Available space on the tower?



0.01%	mm/hour
A	8
B	12
C	15
D	19
E	22
F	28
G	30
H	32
J	35
K	42
L	60
M	63
N	95
P	145

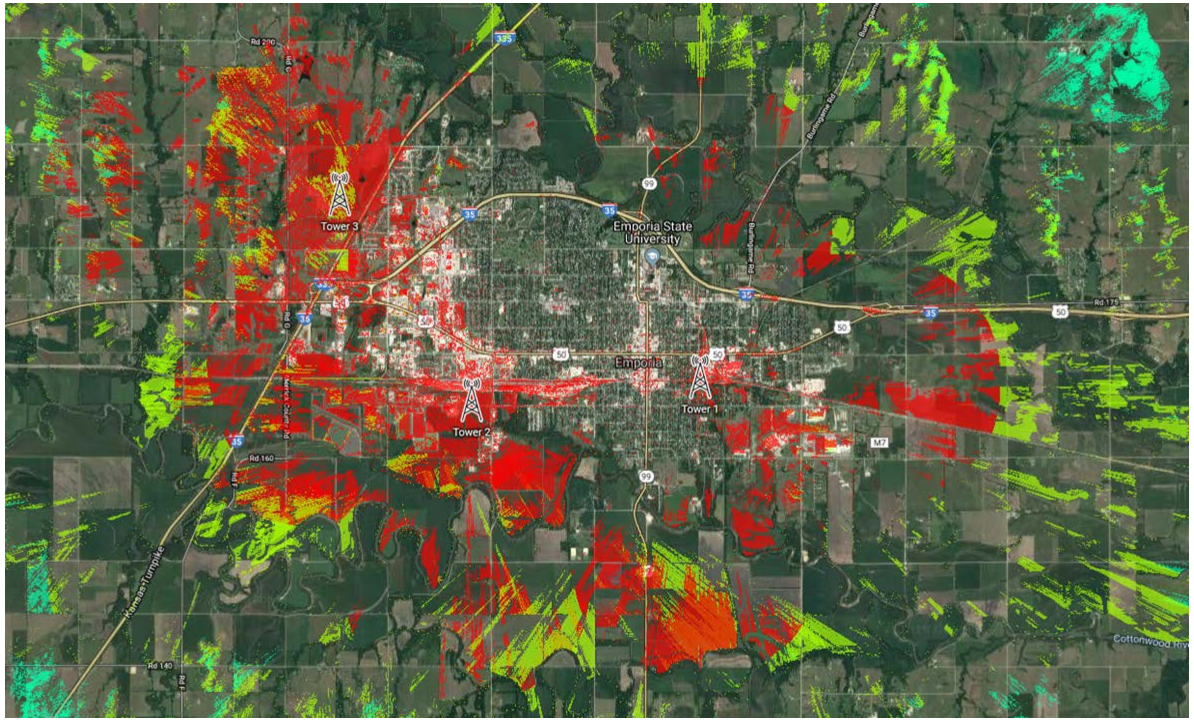
Digital Elevation Models

- **3D Representation of the Earth Surface**
- **How is a DEM derived?**
  - SRTM
    - In our regions this is generally about 1-3 arc second accuracy @ 90% confidence – 90m
  - LiDAR - Light Detection and Ranging
    - Surveyed
    - Acquisition Specifications with a fundamental vertical accuracy of at least 0.30m (95% confidence) and horizontal accuracy of at least 0.80m (95% confidence)



Digital Elevation Models

Heat Map – LiDAR Derived DEM



SRTM and Terrain Data Accuracy

Google and GIS Integration

Propagation

Rain, Friis Equation, mmWave, etc…

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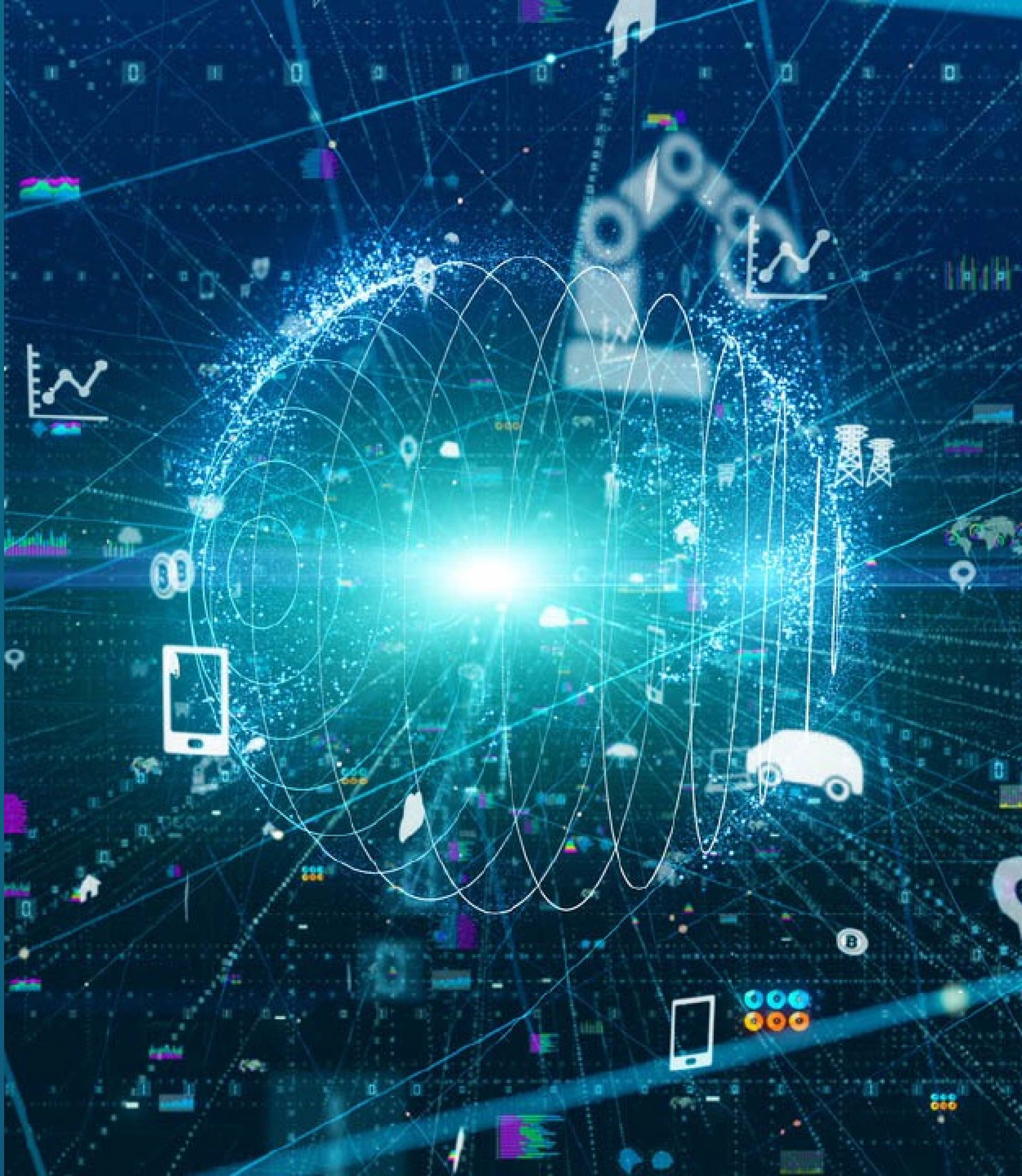
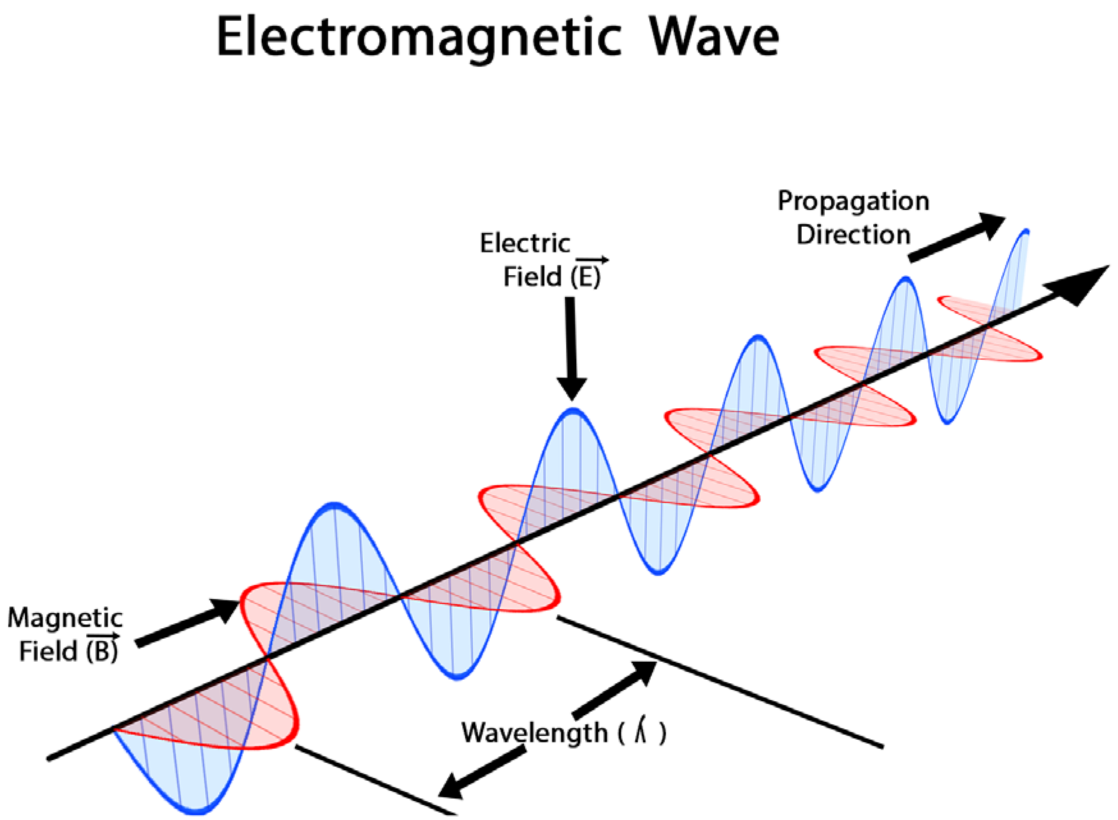


Propagation

- **The transfer of energy between transmit and receive antennas occurs by electromagnetic waves.**
- **Maxwell's equations require that in free space the wave be composed of electric and magnetic waves oriented perpendicular to each other and the direction of propagation**
- **Radio waves are classified by polarization.**
  - If the electric field of the wave is horizontal, the wave is horizontally polarized.
  - If it is vertical, it is vertically polarized.
- **Under unobstructed propagation conditions, the power loss between the transmit and the receive antennas is called the free space loss.**
- **Friis FSL equation:**

$Loss(dB) = 92.4 + 20 \log F_{GHz} + 20 \log D_{km} > 0$

Where F = frequency in GHz, D = distance in km

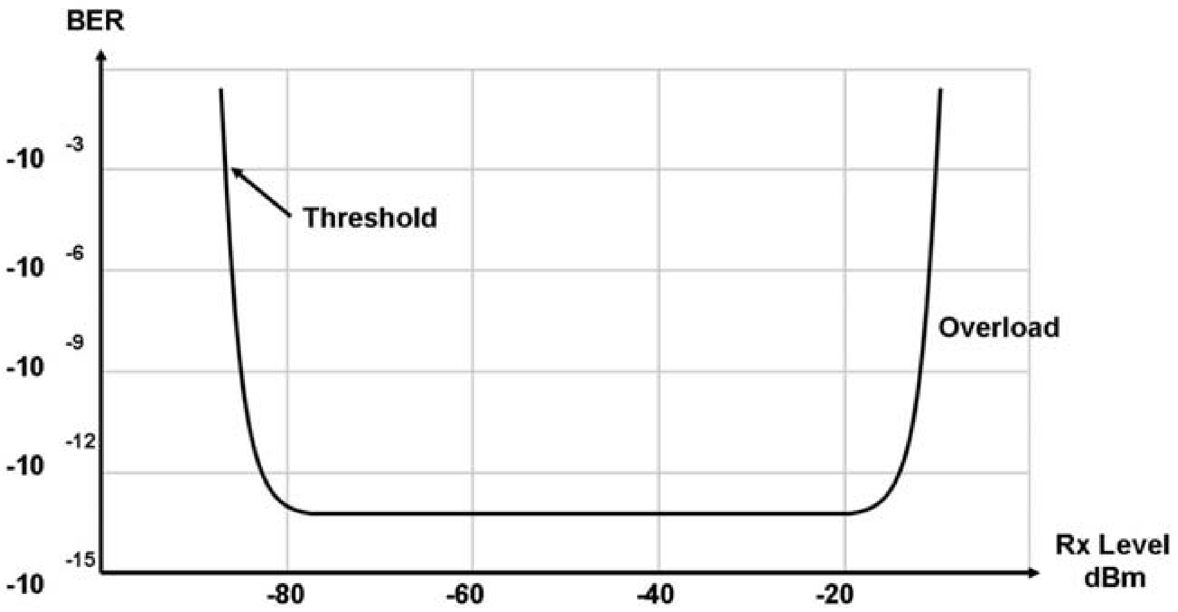


Rain

- **Propagation outage due to rain is proportional to the rain rate of the region.**
- **It is important to realize that it is not dependent on the average rainfall. It is the instantaneous amount of water in the path that is relevant.**
- **Rain attenuation causes flat fading by attenuating the receive signal. The only way to improve the availability is to increase the system gain by using, for example, larger antennas. Diversity techniques (frequency or space) provide no improvement, as both channels would be attenuated equally.**
- **Polarization diversity provides a small improvement on the vertical polarization. The reason for this is that raindrops tend to fall as flattened droplets; thus, the attenuation in the horizontal polarization is greater than vertical polarization.**
- **Attenuation due to rain increases as the frequency increases. Attenuation from rain attenuation is the dominant fading mechanism above 10 GHz.**
- **NOTE - In digital links, rain only impacts quality at the threshold of the radio - and technically speaking does not impact performance (only availability in extreme rain rates)**

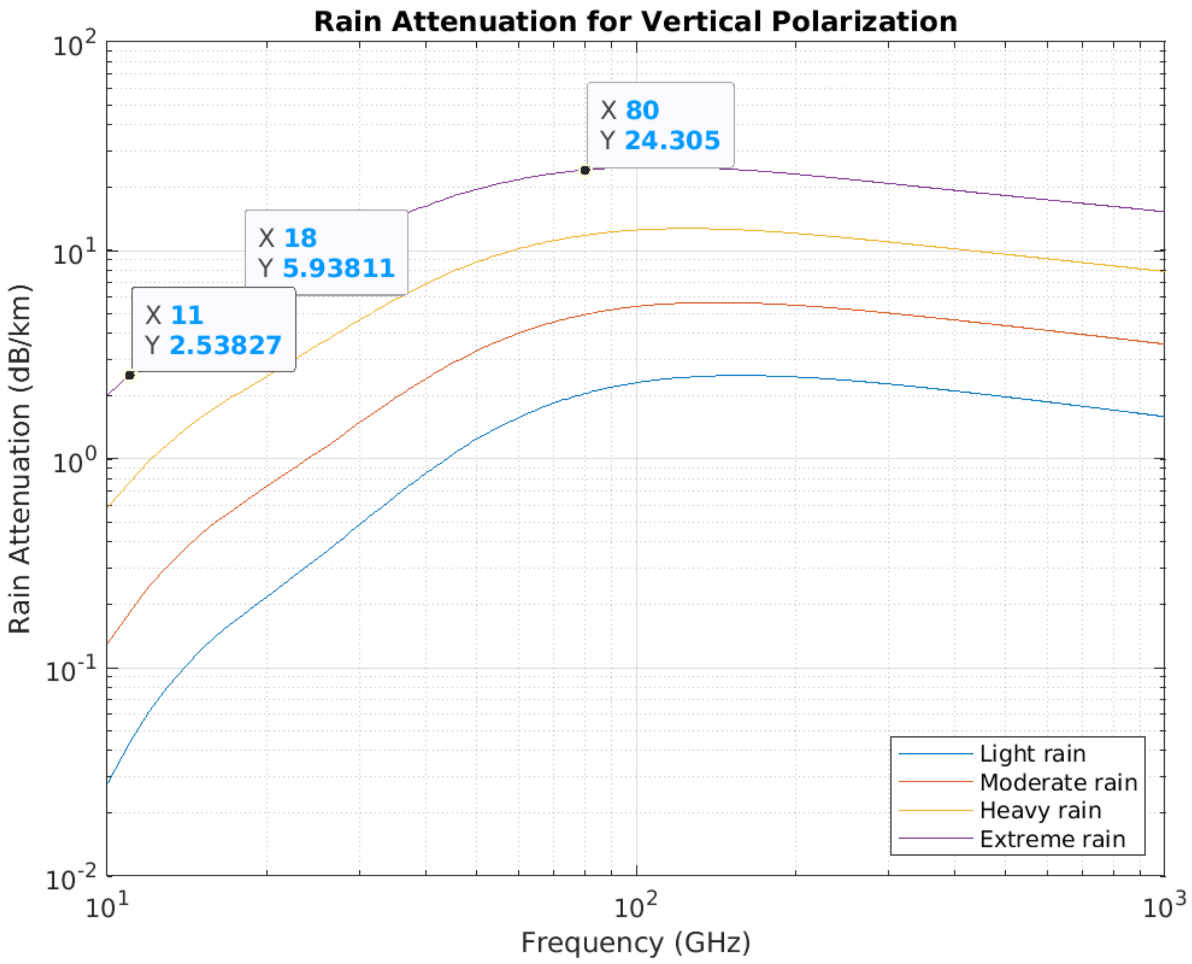
Receiver Threshold Curve

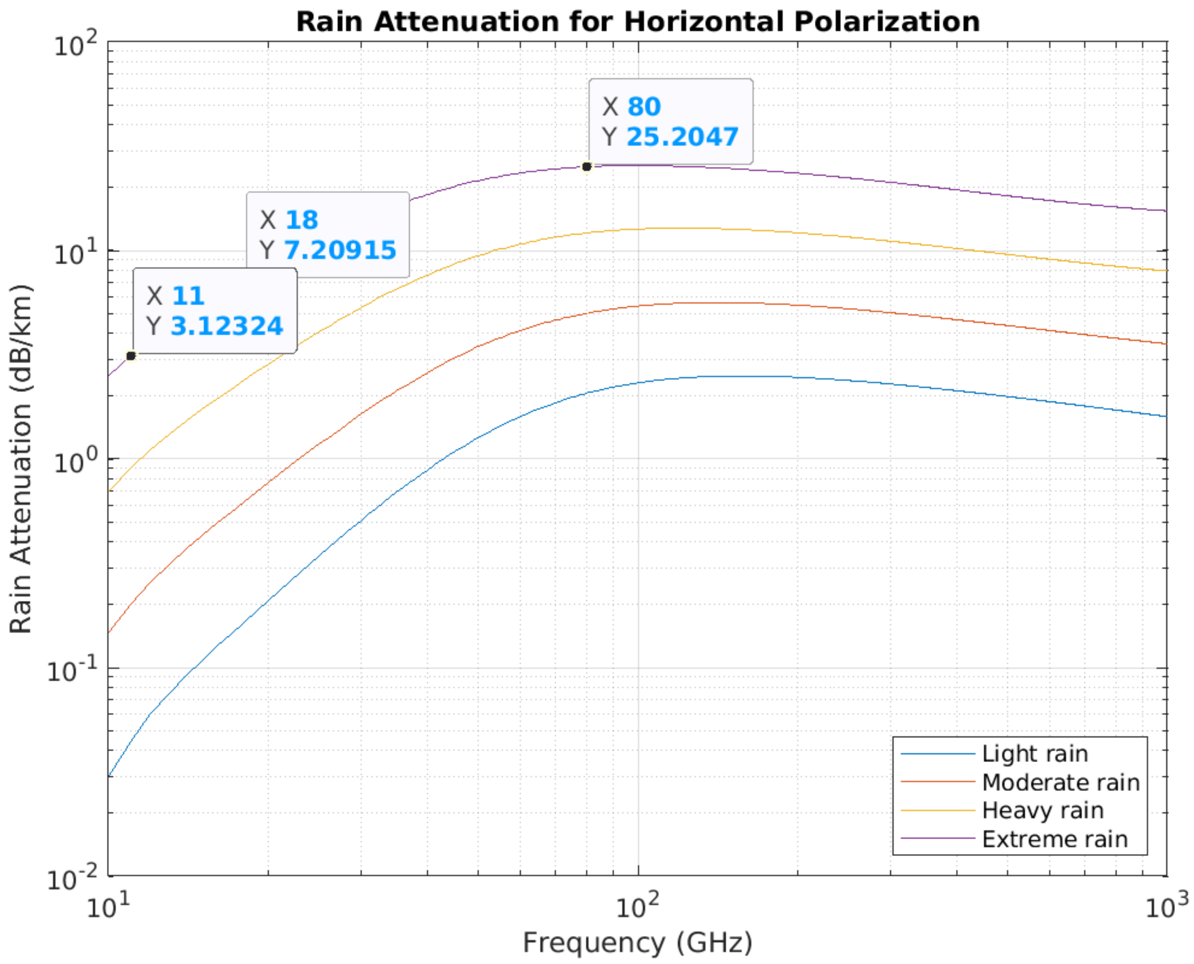
- **In digital systems, due to the threshold effect, the low-level interference has little or no effect on signal quality in an unfaded condition**
- **For small variations around the nominal Rx level the effect on BER is negligible**
- **Quality is only affected when we approach the edges nearest the threshold and overload point**



* Microwave Radio Transmission Guide”, Manning, T.

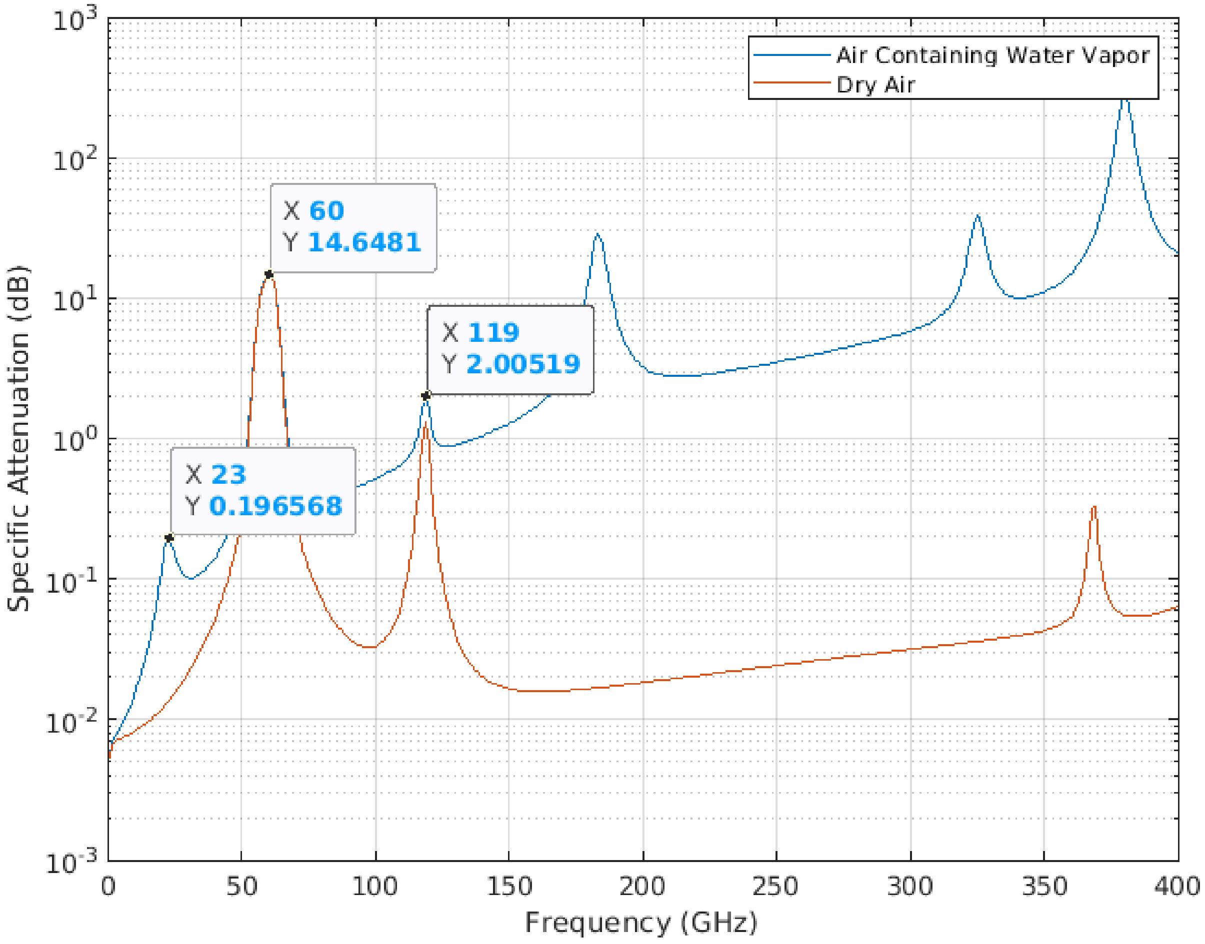
Propagation Loss Due to Rain – V vs H





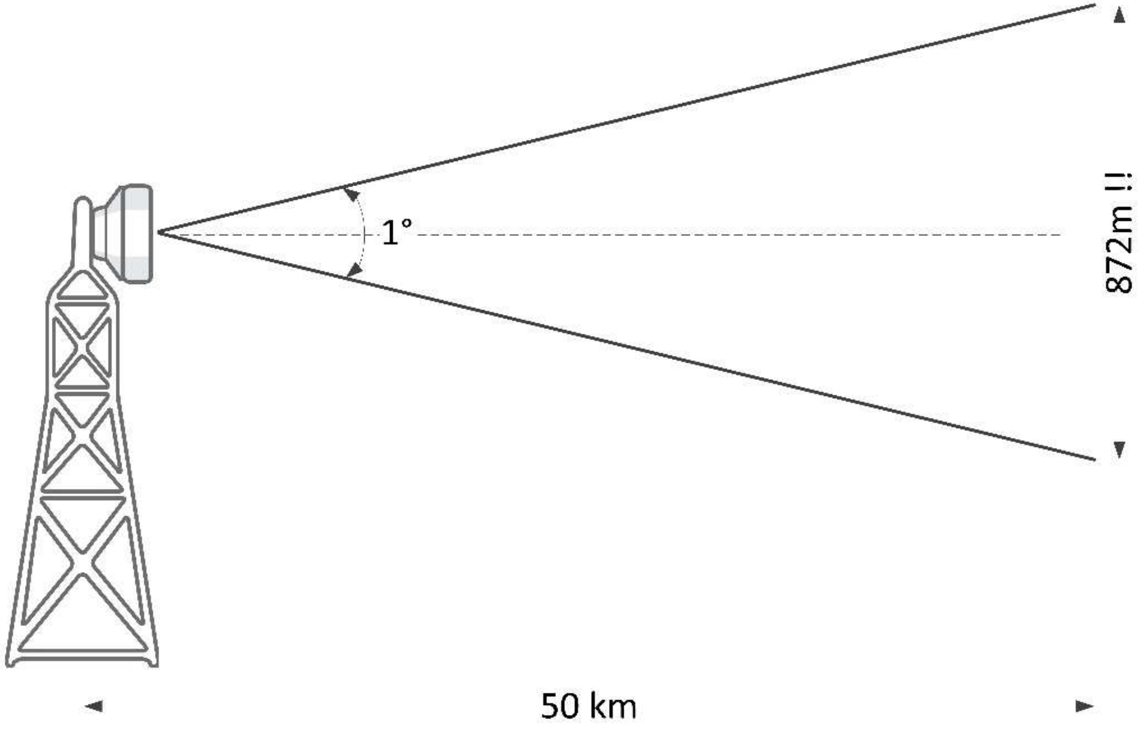
Atmospheric Gas Attenuation Spectrum

- **Absorption due to oxygen, water vapour and other atmospheric gases**
- **Attenuation spectrum from 1 to 400 GHz for an atmospheric % pressure of 101.300 kPa and a temperature of 15degC.**
- **Water vapor density of 7.5 g/m3**
- **% spectrum for dry air (zero water vapor density).**
- **Notable Observations**
  - Resonant Peaks at 23 GHz due to water vapor
  - Resonant Peaks at 60 GHz and 119 GHz for Water Vapor AND Oxygen



Analogue Propagation

- **Common misunderstanding in industry is to assume that radio signal travels as a highly focused pencil-thin bean**
- **The microwave antenna beamwidth is measured by the angle in which it can focus half the energy into a cone, coming out the from of the antenna**



Industry Myths

E-band Frequencies Short Paths Only

- Hence… channel re-use and coordination is very easy
- This statement confuses usable hop lengths (rain attenuated) with interference
- What are the facts?

Frequency	Atten (dB/km)	Atmos Loss (50 km)	Comment
18 GHz	0.1 dB	5 dB	
23 GHz	0.3 dB	15 dB	Nobody says it doesn't go far or is pencil beam
38 GHz	0.15 dB	7.5 dB	
60 GHz	15 dB	750 dB	Yes, it doesn't go very far!
80 GHz	0.4 dB	20 dB	Well within fade margin!!! (excluding interference)

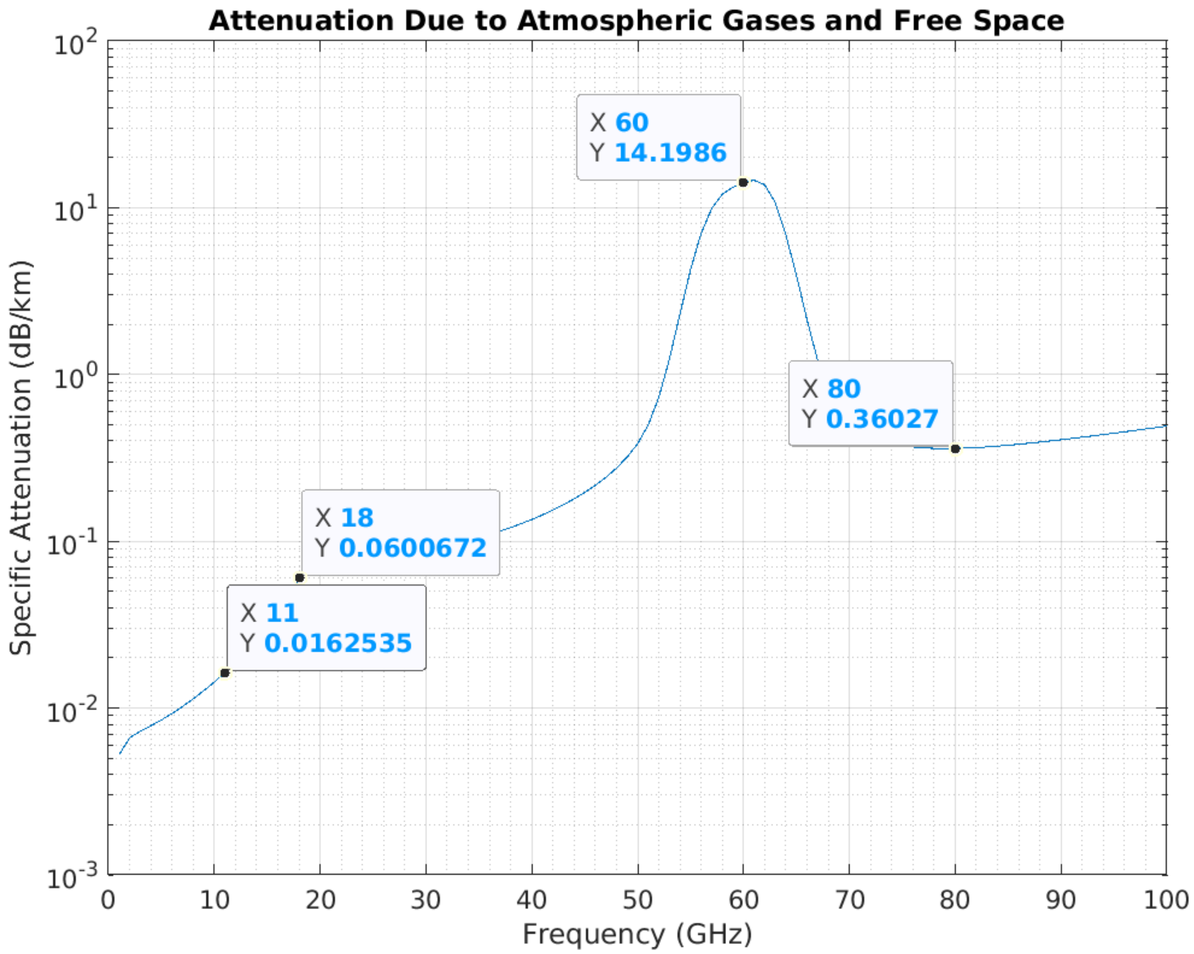
E-Band is "Pencil Thin" ☺

- The antenna pattern, or beam pattern, is as thin as a pencil
- In reality, the beam is an electromagnetic wavefront that is infinitely wide even with high gain antennas [1] (look at this later ☺)
  - The path travelled by the wavefront is dependent on the troposphere encountered
  - In standard atmosphere the average density increases with altitude
  - The upper portion of the wavefront travels faster than the lower portion that is traversing the denser medium

[1] "Microwave Radio Transmission Guide", Manning, T.

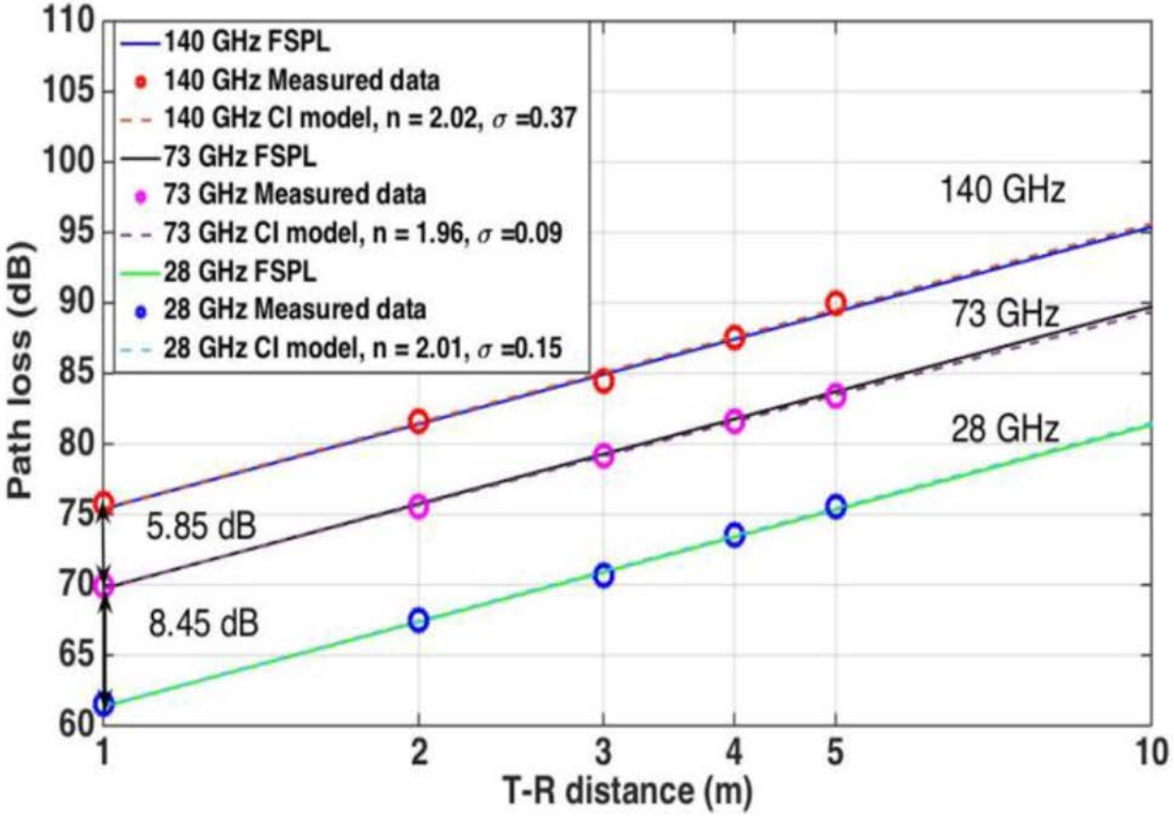
Propagation Characteristics Due to Atmos Gases and FSPL

- **Key Observations?**
  - All frequencies travel!
  - Atmospheric Absorption (oxygen, hydrogen molecules) increases attenuation in addition to Friis' FSPL.



Free Space Path Loss at 28, 73, 140 GHz *

- **As expected, FSPL at 140/73/28 GHz follows the Laws of Physics and satisfies Friis' equations with antenna gains removed.**
- **FSPL verifications following the proposed method at 28, 73, and 140 GHz (after removing antenna gains)**



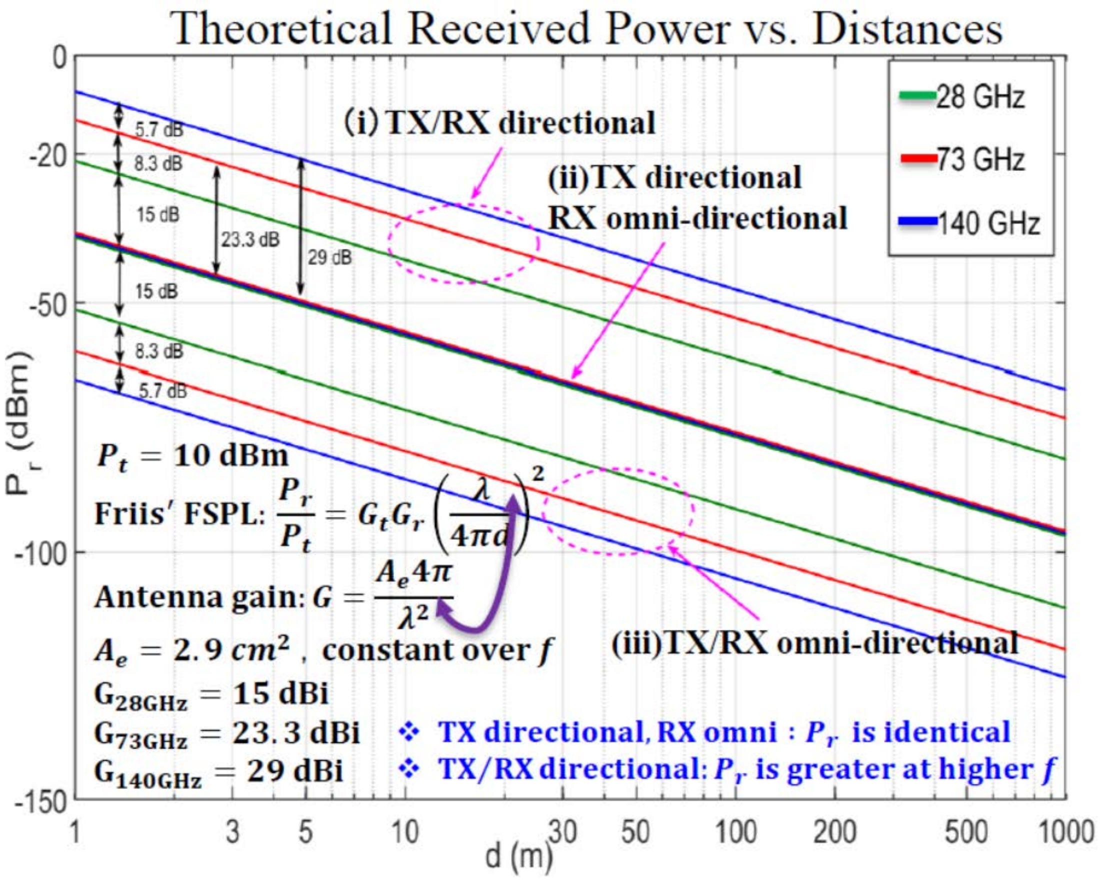
* T. S. Rappaport, et. al., Millimeter Wave Wireless Communications", Pearson/Prentice Hall ; 2015)

Theoretical Received Power vs. Distances

Antennas are not made equal!

- **Directional Antennas with Equal aperture have much less pathloss at higher frequencies.**
- **Here the opposite happens in comparison to the previous!**
- **Why?**
  - If you keep the physical area (with greater directivity) of the antenna the same and up the freq you don't have loss – you have gain!
  - The greater physical area has more gain – more directivity - so you combat the Friis FSPL air loss with a gain factor of both the TX and RX.

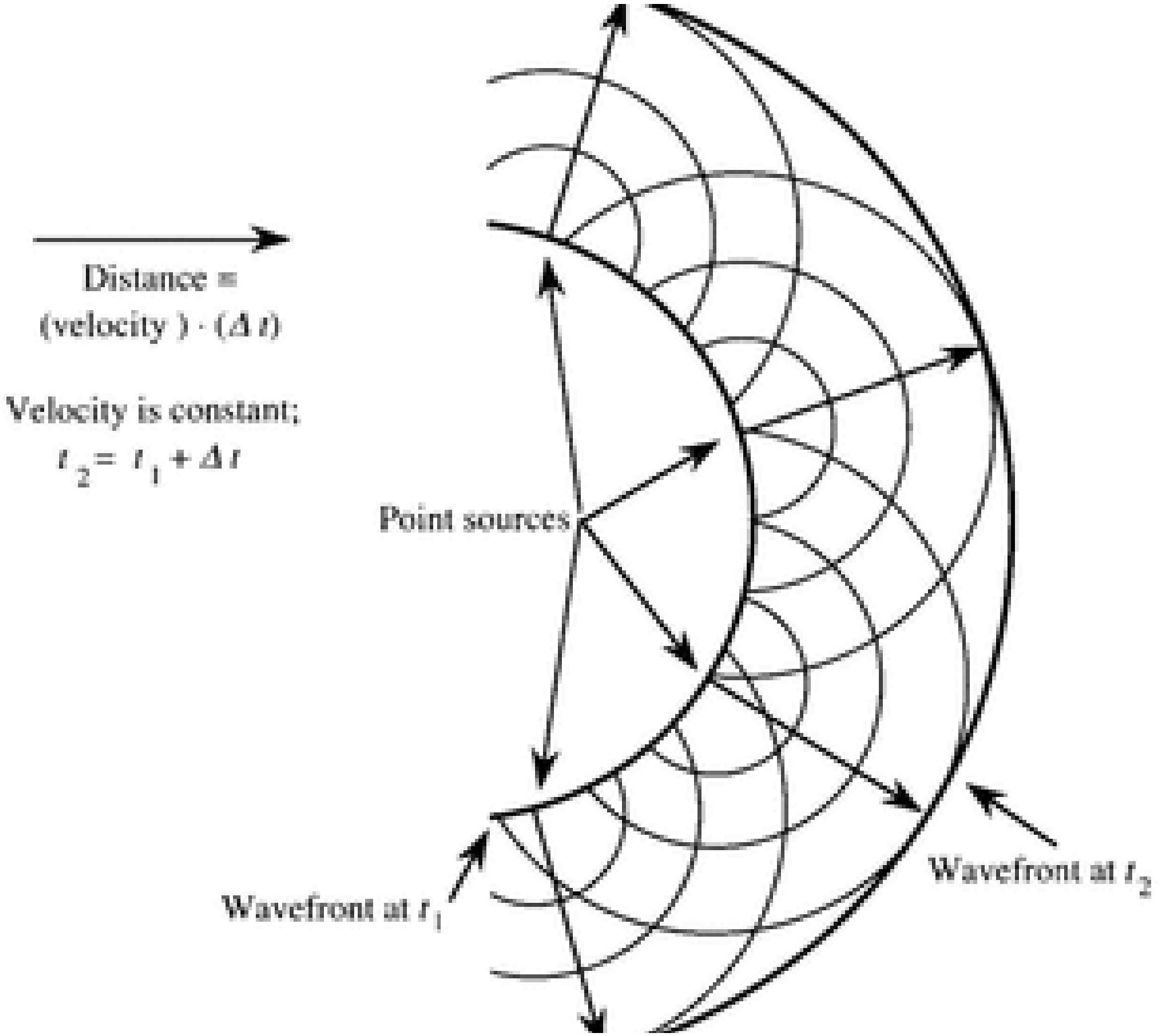
Consider these 3 Scenarios



* T. S. Rappaport, et. al., Millimeter Wave Wireless Communications", Pearson/Prentice Hall ; 2015)

Huygens' Principle

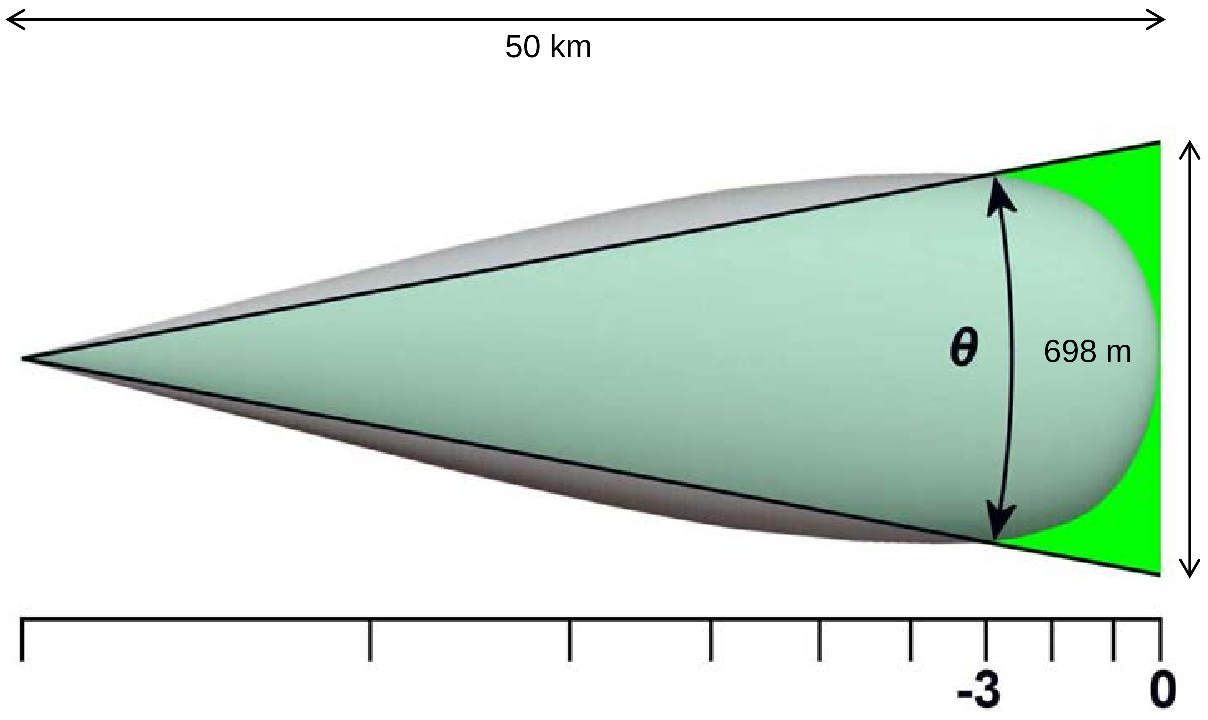
- **Dutch physicist Christiaan Huygens had a very important insight into the nature of wave propagation which is nowadays called Huygens' principle. This principle states that:**
  - [1] Every point on a wave-front may be considered a source of secondary spherical wavelets which spread out in the forward direction at the speed of light. The new wave-front is the tangential surface to all of these secondary wavelets.



[1] "Huygens' Principle". MathPages. Retrieved 2018-04-03.

Antenna 3 dB Beamwidth Dimensioning

Antenna 3 dB Beamwidth



MW signal is NOT a pencil thin beam!

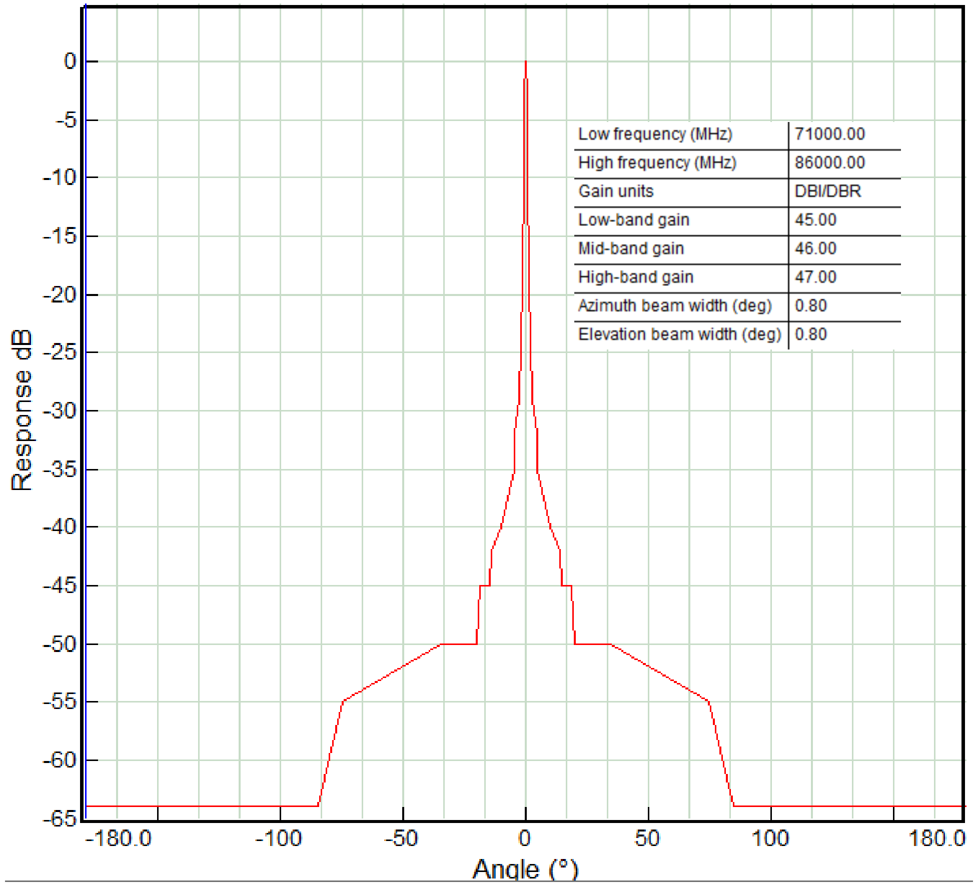
- **The Rx picks up energy from a wide area including outside the main beamwidth**
- **Even within the 3 dB beamwidth this represents a large area**
- **0.8-degree beamwidth**
  - At 50km – 698m
  - At 5km – 70m

Beamwidth(1 deg, 50km) = 2 * tan(0.4) * 50*10^3 = 872m

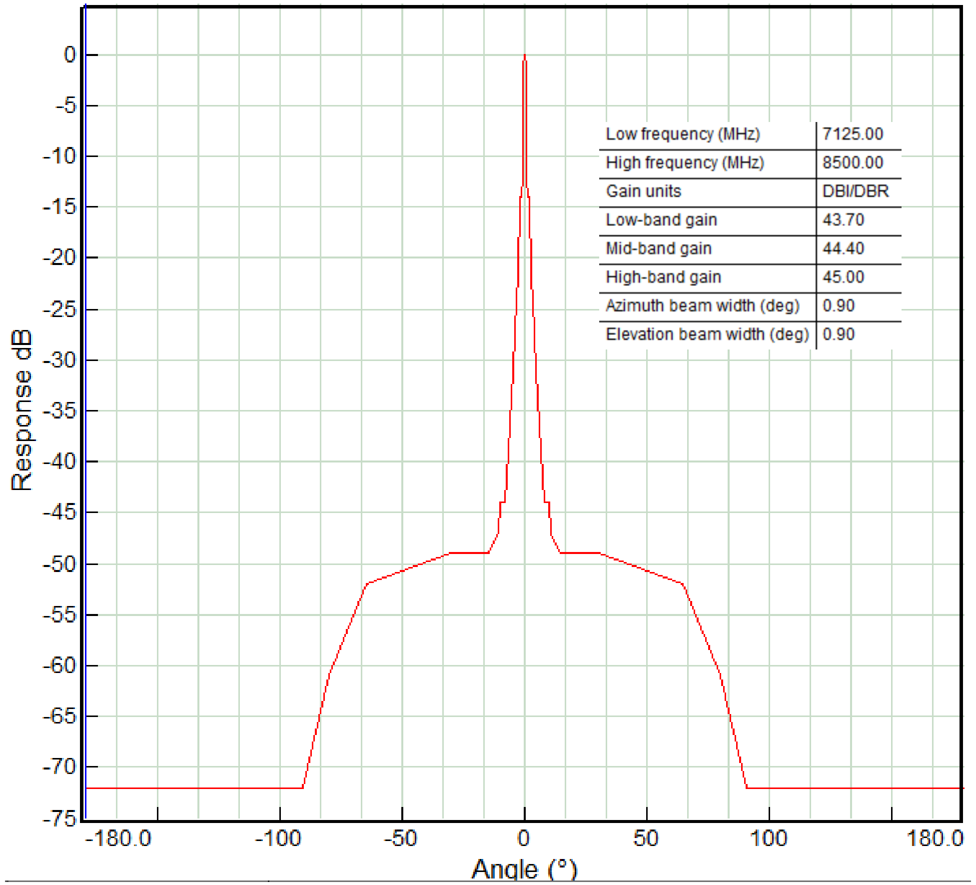
Beamwidth(1 deg, 5km) = 2 * tan(0.4) * 50*10^2 = 70m

Antenna Gain Comparison

Commscope VHLP1-80, 0.3m, 80 GHz



Commscope HP10-7W, 3m, 7 GHz



It's all about the System Gain!

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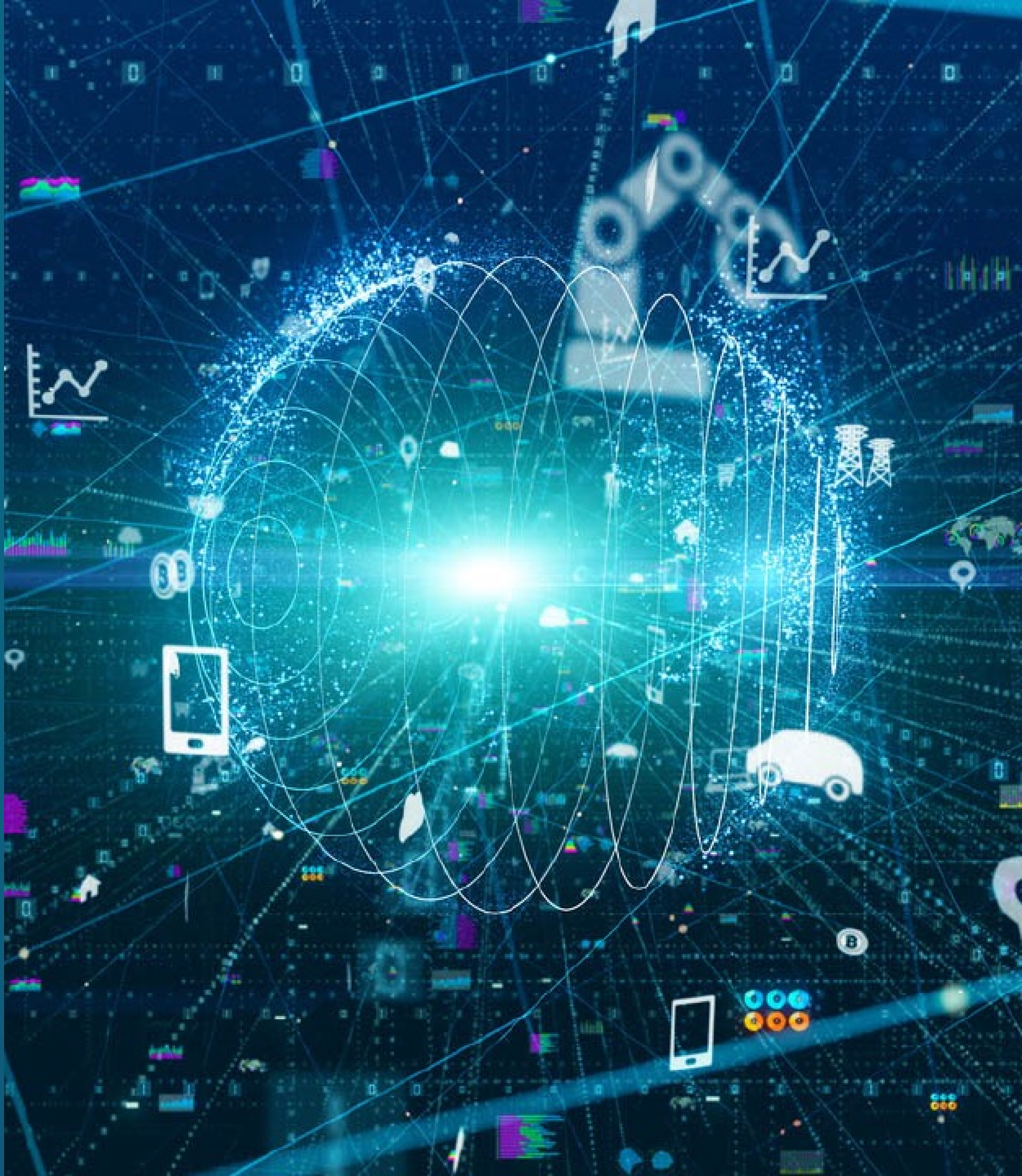
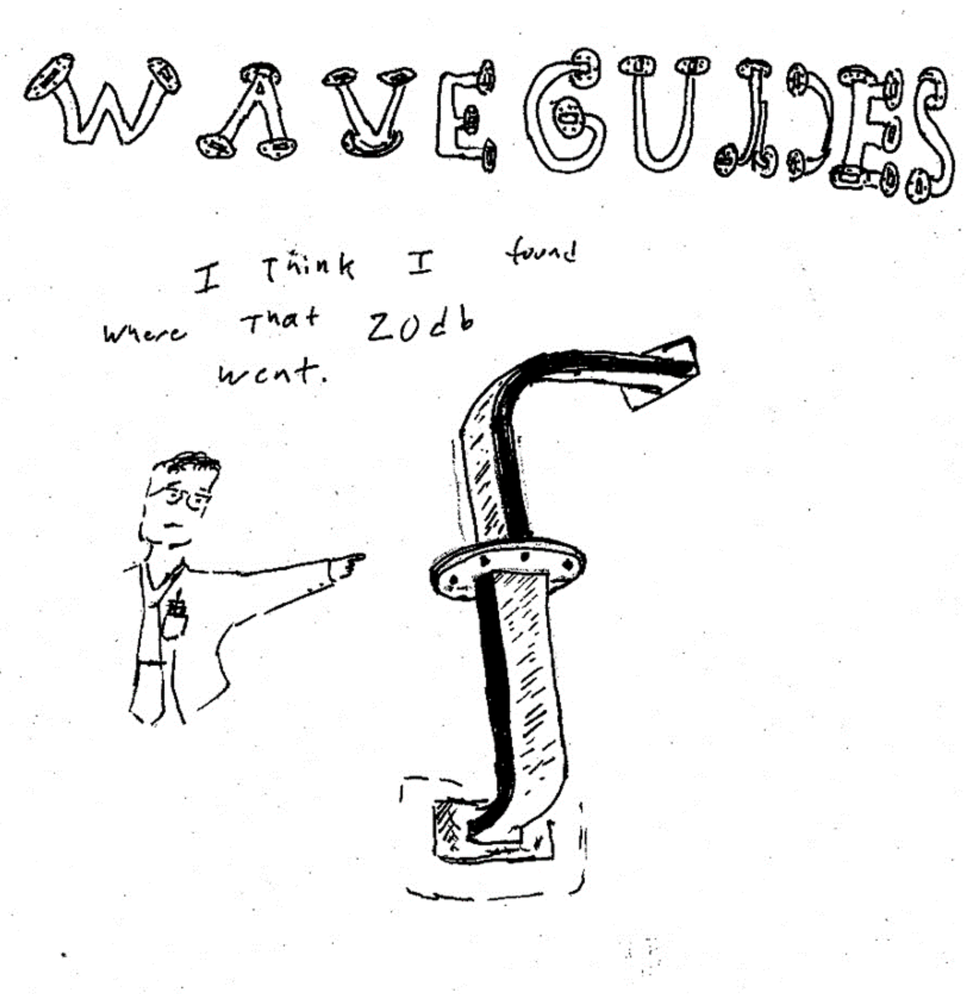


It’s all about the System Gain



EIRP (dBm)	64.60	64.60
Free space loss (dB)	145.11	
Atmospheric absorption loss (dB)		
Main net path loss (dB)		
Diversity net path loss (dB)		
Main receive signal (dBm)		
Diversity receive signal (dBm)		
Thermal fade margin (dB)		
Effective fade margin (dB)		
SD improvement factor		
Worst month multipath availability (%)		
Worst month multipath unavailability (sec)		
Annual multipath availability (%)		
Annual multipath unavailability (sec)		
Annual 2 way multipath availability (%)		
Annual 2 way multipath unavailability (sec)	5.36	
Polarization	Vertical	
0.01% rain rate (mm/hr)	92.08	
Flat fade margin - rain (dB)	33.53	
Rain attenuation (dB)	33.53	
Annual rain availability (%)	99.99742	

Microwave

	Epi	Ambrym
Radio model	PTP08820G	PTP08820G
Emission designator	28M0D1D	28M0D1D
Radio file name	ptp08820g_etsi_29_65_4	ptp08820g_etsi_29_65_4
TX power (watts)	0.25	0.25
TX power (dBm)	24.00	24.00
RX threshold criteria	10-6	10-6
RX threshold level (dBm)	-75.00	-75.00
Maximum receive signal (dBm)	-30.00	-30.00
Dispersive fade margin (dB)	61.60	61.60

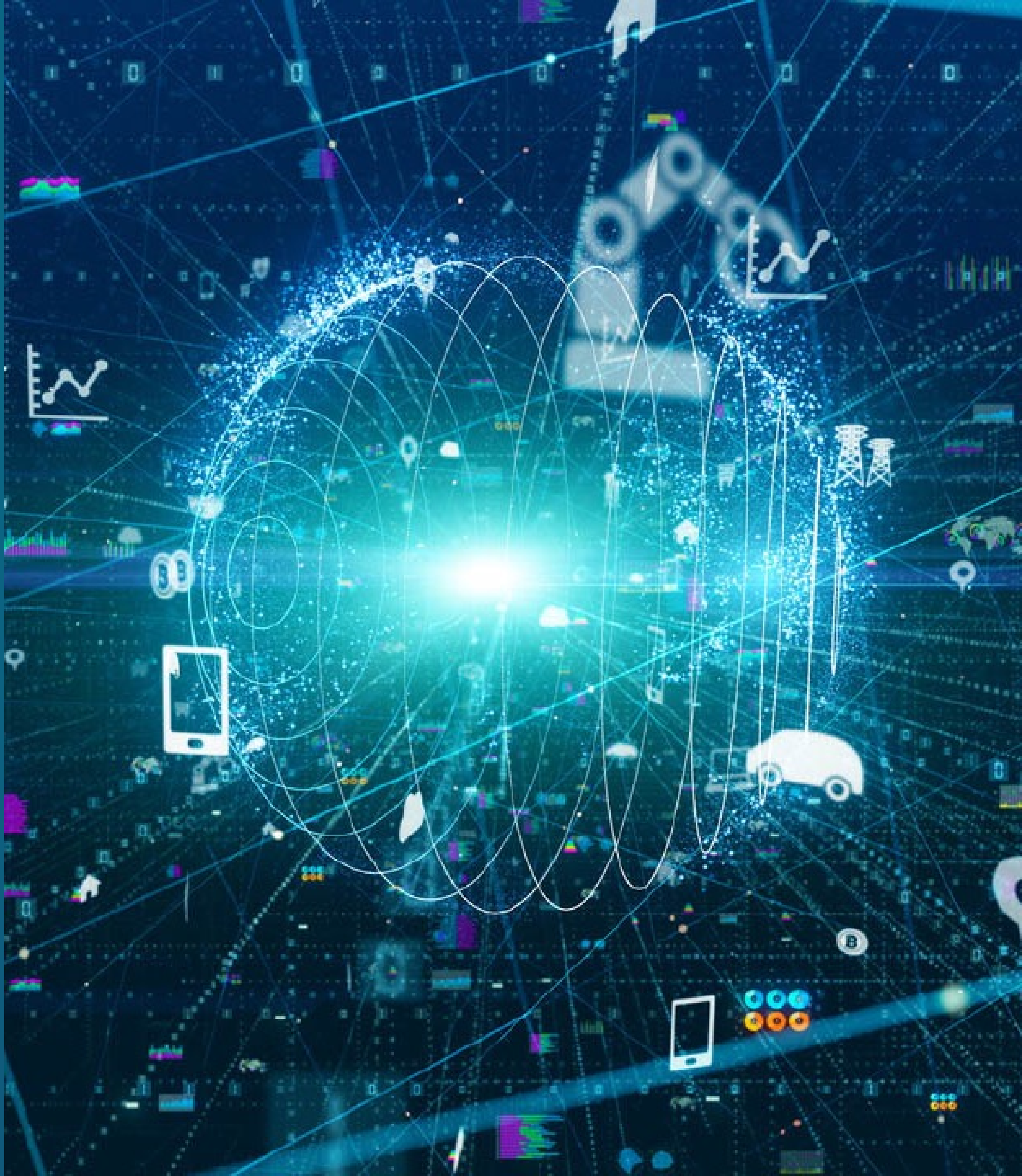
It's all about the System Gain

Parameters	Indoor System (dB)	All-outdoor (dB)
Tx Power dBm	39.0	29.0
Waveguide Loss 100m @ 6.7 GHz	11.2	0.0
Filter Loss dB	2.0	0.0
Rx Threshold (256 QAM-40 MHz) dBm	-67.0	-67.0
Total System Gain	92.8	96.0

In the table above, we see that a 39dBm indoor radio has less system gain than an outdoor radio even when the Outdoor radio power is 10dB less than the indoor system's power level!

- **Lots over the last year on the advancements of transmit power capabilities on microwave radio systems.**
- **Transmit powers values are an important measure of how microwave vendors stack up against each other but definitely not the only piece**
- **The system gain of radio link includes both the Transmit Power, Receiver Threshold, cabling losses, and filtering losses.**
- **With All Outdoor systems, operators can maximize their system gain on the links since there is no waveguide cabling losses or channel filtering losses that must be taken into account in all-indoor systems.**
- **As every RF Network Planner knows, every dB counts these days considering the pressures to drive more capacity on the microwave system while maintaining the same level of up-time.**

Reliability, Rain and Geoclimatic Factors



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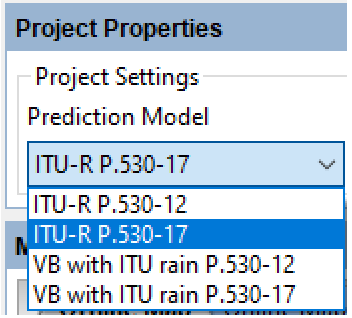
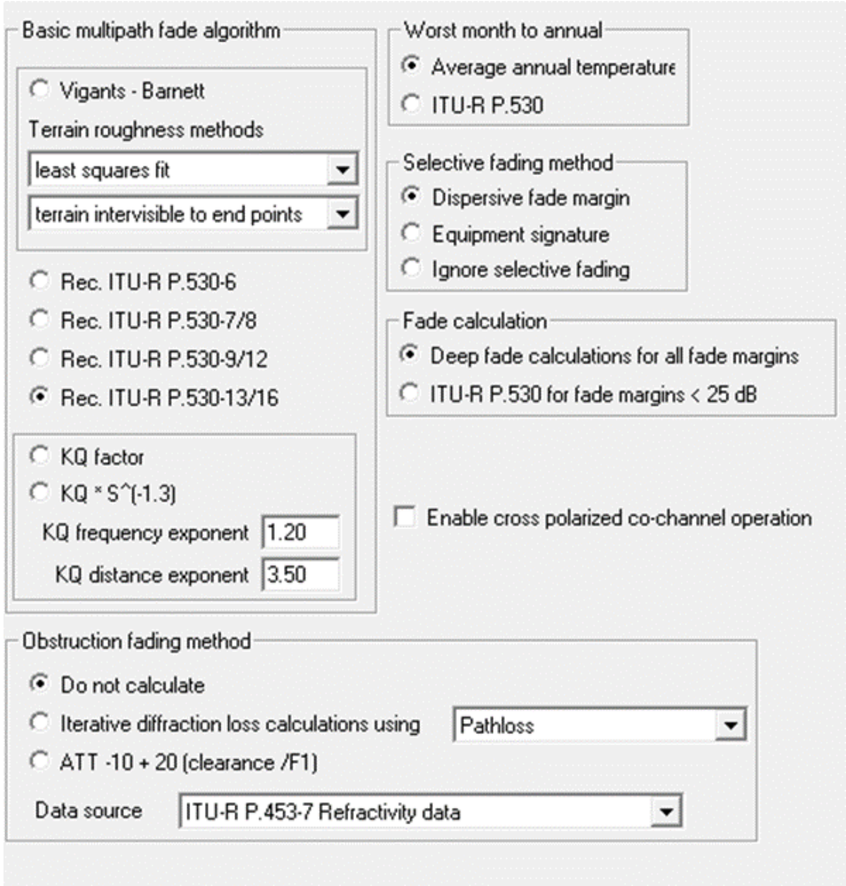
Radio Link Design and Reliability options

Some Guidelines

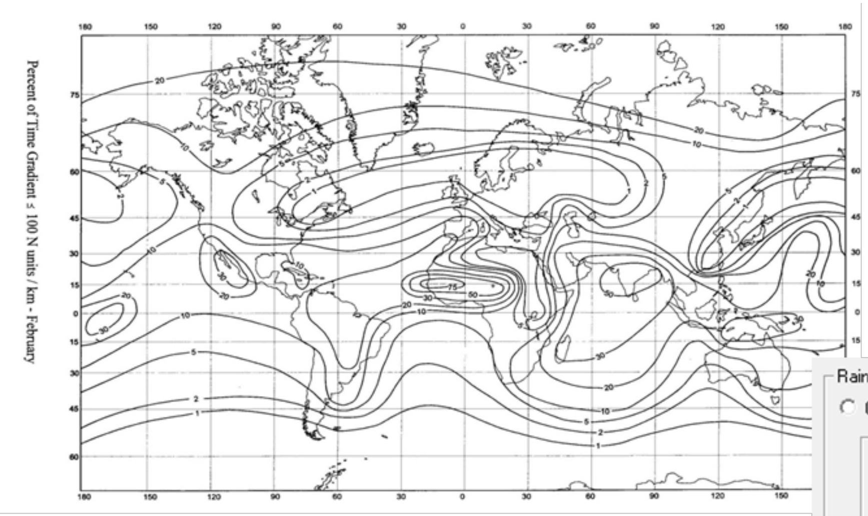
- **Follow customer request if specified.**
- **Vigants-Barnett in the Americas**
- **Outside America, most operators use ITU-R P.530**
- **These take into account**
  - Multipath fading
  - Surface reflection fading
  - Diffraction fading
  - Signal distortion (selective fading) during multipath
  - Scintillation fading

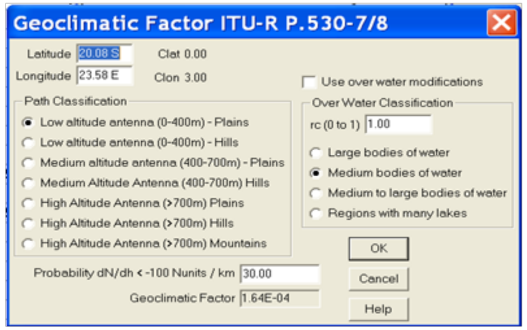


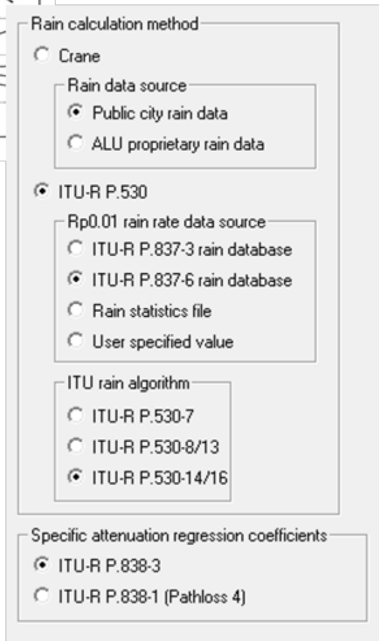
Planning Options (PL5.0)



Link Design - Outage Prediction







- **Outage (availability) on short, high frequency links depends on attenuation from rain**
- **Rain attenuation from absorption and scattering increases with frequency**
- **Should be considered above 5 GHz but significant above 10 GHz**
- **Rain outage limits hop length**
- **Outage depends on instantaneous rate of rain fall**
- **Wet snow / Sleet is significant**
- **Powdery snow is not significant**
- **THESE PREDICTIONS ARE CONSIDERED BY LINKPLANNER**

Calculating Rain Outage

- **Rain rate (mm/hr) is key**
- **Rain cell size reduces with intensity, hence an effective path length is calculated**
- **Use the most accurate local data**
  - Crane (US/Canada)
  - Ofcom (UK)
  - ITU-R (Australia)
- **Formulas are empirical**
  - Beware when applying to long E-band links, etc.

Link Reliability

Availability

- **Propagation (Outages related to propagation that last longer than 10 seconds are due primarily to three causes):**
  - Rain
  - Ducting
  - Diffraction Loss
- **Equipment MTBF and MTTR**
  - The availability (A) of a terminal is given by the formula;
  - A = (MTBF/(MTBF + MTTR)) × 100%
- **Power failure**
- **Catastrophy (fire or tower damage)**
- **Availability objectives, on the other hand, are considered for both directions of transmission and are measured as annual figures**

Performance

- **Flat and selective fading from multipath**
- **Equipment dribble errors (Residual BER)**
- **Interference**
- **Wind**

99.999% is achieved through redundancy, not individual PATH performance. Two 99.1% paths can achieve 99.999% if the causes of outage are non-correlated - a big deal for the new BCA links (Band and Carrier Aggregation)

Diffraction
Fading, Fresnel Zones, Clearance, Reflection

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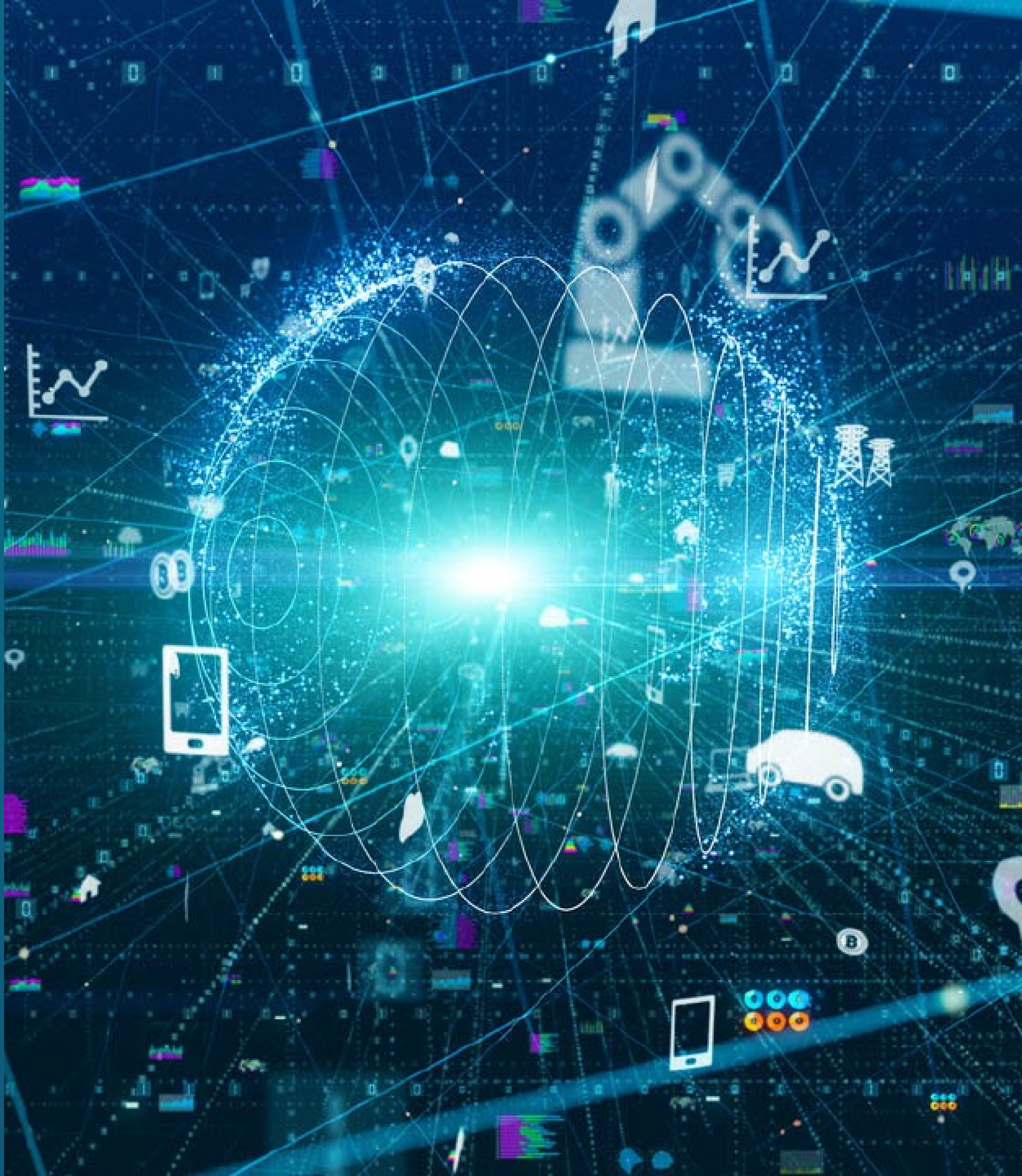


Effective Earth Radius, *k*-Factor

- **Due to refraction of the signal, the radio wave does not travel in a straight line.**
- **Just as the radio ray is not a straight line, the Earth's surface over which it travels is not flat. Even if traveling over a flat surface such as the sea, the curvature of the Earth needs to be taken into account.**
- **We now have a situation where the clearance of the radio beam over the Earth's surface is dependent on the relative distance between two curves.**
  - An analysis of the clearance is made easier if one of the curves is straight and the other is given extra curvature to compensate. It is convenient to imagine that the radio ray travels in a straight line relative to an effective Earth radius, which has been adjusted by the refractivity gradient.
- **This radius is the real Earth radius multiplied by an effective Earth radius factor "k" that is dependent on the refractivity gradient. This is commonly referred to as the k-factor**
- **It's convenient!**

Diffraction Fading and Planning Criteria

Diffraction Fading

- **Variations in atmospheric refractive conditions cause changes in the effective Earth's radius or k-factor from its median value of approximately 4/3 for a standard atmosphere**
  - (see Recommendation ITU-R P.310).
- **When the atmosphere is sufficiently sub-refractive (large positive values of the gradient of refractive index, low k-factor values), the ray paths will be bent in such a way that the Earth appears to obstruct the direct path between transmitter and receiver, giving rise to the kind of fading called diffraction fading.**
- **This fading is the factor that determines the antenna heights.**

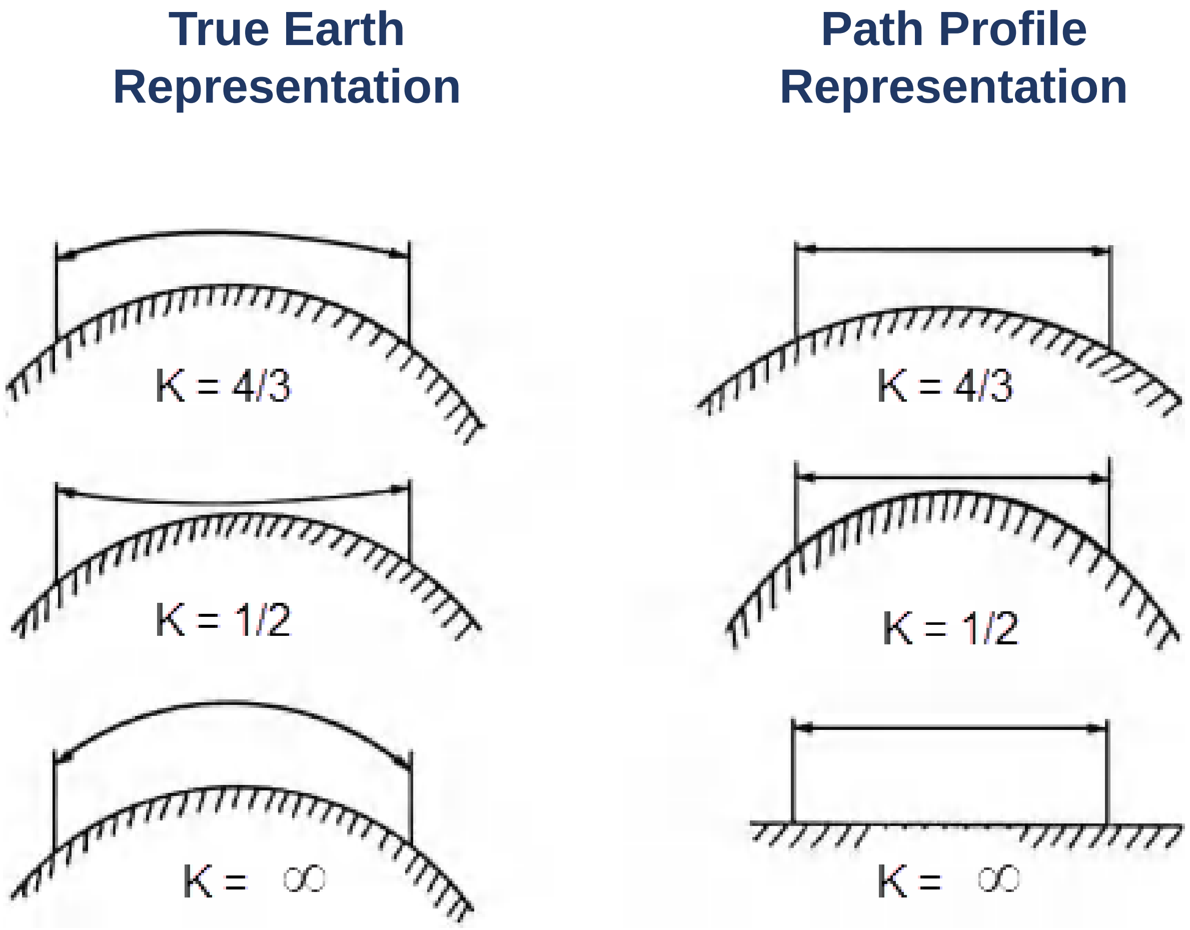
Recommendation ITU-R P.530-18

Planning Criteria

- **Diffraction theory indicates that the direct path between the transmitter and the receiver needs a clearance above ground of at least 60% of the radius of the first Fresnel zone to achieve free-space propagation conditions.**

Clearance Rules for Main Antenna			
	Rule 1	Rule 2 (Temperate)	Rule 2 (Tropical)
Traditional	100% F1 at k = 4/3	60% F1 at k = 2/3	60% F1 at k = 2/3
ITU-R P.530-12	100% F1 at k = 4/3	0% at k_{min}	60% F1 at k_{min}
		(isolated obstacle)	
		30% at k_{min}	
		(extended obstacle)	

Path profiles as a function of atmospheric refractivity



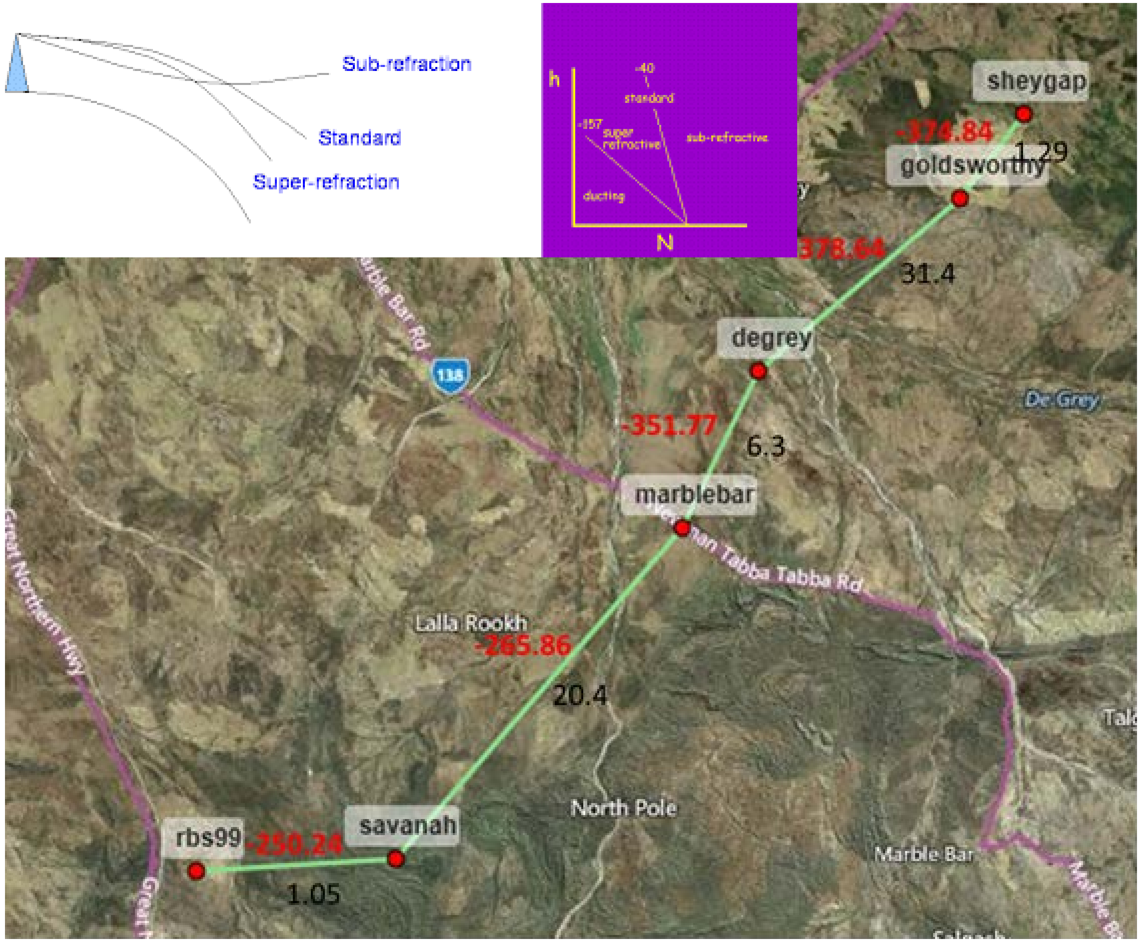
Atmosperic Refractivity

- The radio wave path will bend up or down depending on the K factor (atmospheric refractivity).
- The historical convention is to always plot the radio wave path as a straight line and to move the Earth up or down as a function of the K factor to preserve the vertical distance between the radio wave and the Earth at any location on the path
- For a normal K factor of 4/3 (dN/dh =−40 N units/km), the radio wave bends down slightly (or the Earth bulges slightly) as it moves from transmitter to receiver.
- As the K factor increases (or becomes negative), the radio wave bends down more (or the Earth flattens or becomes concave).
- As the K factor decreases, the radio wave bends up (or the Earth bulges more)

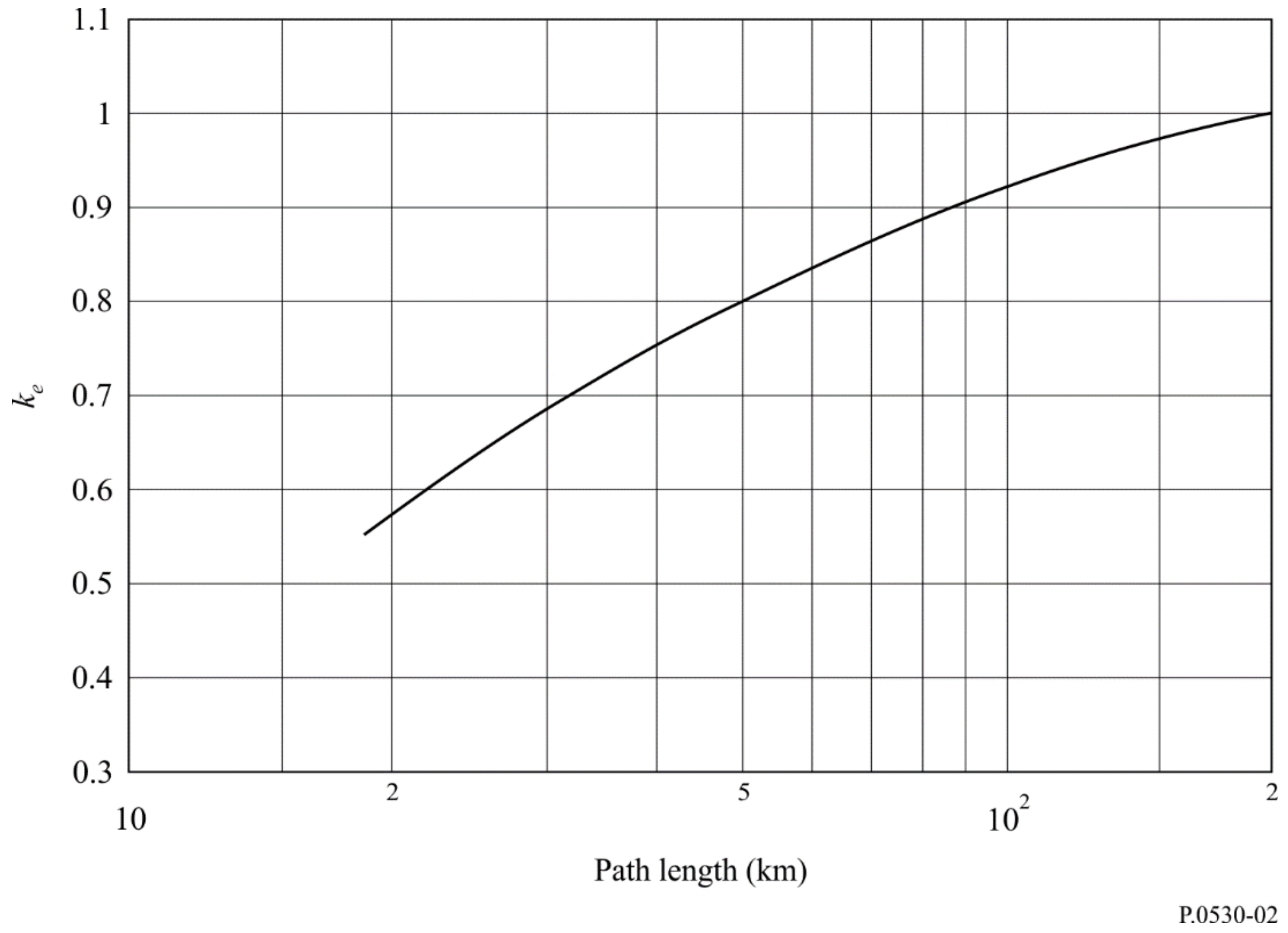
Bean and Dutton, 1966; International Telecommunication Union—Radiocommunication Sector (ITU-R), 2007a; International Telecommunication Union—Radiocommunication Sector (ITU-R), 2005)
DIGITAL MICROWAVE COMMUNICATION, Engineering Point-to-Point, Microwave Systems, GEORGE KIZER, 2013

Diffraction fading – Super and Sub Refraction

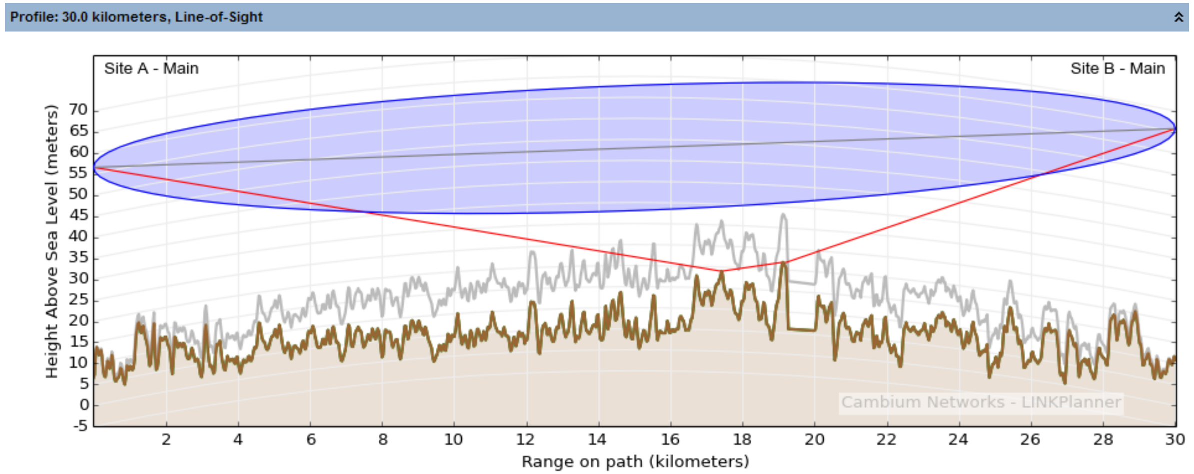
- **If dN/dh exceeds -157 N units, signals will be refracted by more than the curvature of the Earth and be trapped. We call this super-refraction.**
- **When using the ITU models the parameter that is the best indictor of “difficult” propagation areas is the point refractivity gradient (dN1 or dN/dH in LINKPlanner).**
- **Looking at the links in this project we have the following where the red numbers are the dN/dH and the black numbers are the Fade Occurrence Factor**



Value of k_e exceeded for approximately 99.9% of the worst month – Source Rec. ITU-R P.530-18



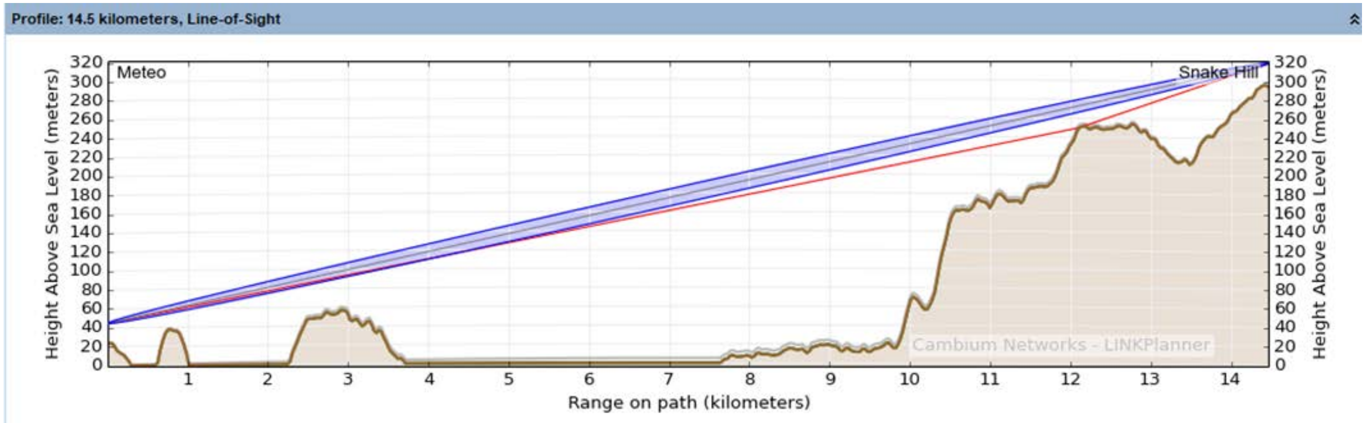
Worst Earth

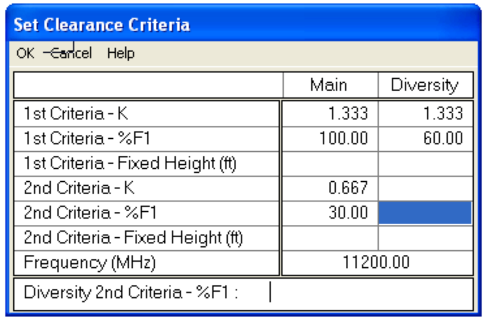


- The grey line in LINKPlanner represents the worst earth curvature – for 99.9% of the time the reflections occur on the terrain.
- The worst earth curvature occurs 0.1% of the time. It is during this time that we will likely suffer excess pathloss as a result.
- Availability will actually be worse than predicted due to this.
- You can see the impact by looking at the "Excess Path Loss at ke" parameter in LINKPlanner.
- If you cannot achieve greater antenna height (or space diversity) to mitigate this worst earth clearance, then an outage may have to be tolerated.

k factor & Clearance Real-world Advice

- **Short Hops (< 20km)**
  - Path Survey
  - Avoid near-field obstructions
- **Longer hops (>20km)**
  - Use Path profile and LOS analysis
  - Fresnel Zones CRITICAL
  - Ideally set at 100% F1 at 4/3
  - Assess risk of min k bending (at least grazing LOS)
- **First Criteria - One for normal atmospheric conditions (K=4/3)**
  - Should meet 100% first Fresnel zone radius over K=4/3.
- **Second Criteria - Substandard atmosphere that uses a minimum value of K.**
  - Should meet 30% to 60% first Fresnel zone radius over a minimum value of K depended on climatic type.
- **For Obstructions in Path**
- **Work out % blocking of F1**
- **If reflective, avoid even FZ**
- **Avoid near field obstructions and reflections**




Set Clearance Criteria
OK Cancel Help

	Main	Diversity
1st Criteria - K	1.333	1.333
1st Criteria - %F1	100.00	60.00
1st Criteria - Fixed Height (ft)		
2nd Criteria - K	0.667	
2nd Criteria - %F1	30.00	
2nd Criteria - Fixed Height (ft)		
Frequency (MHz)	11200.00	

Diversity 2nd Criteria - %F1 :

One major deduction to be made from the theory of Fresnel zones is that, in theory, provided at least **60% of the first zone is clear of any obstruction**, the effect of the Earth can be ignored and the path loss approximated by the **free-space loss**. There will be no diffraction loss.

Practical Example of Worst Earth Clearance

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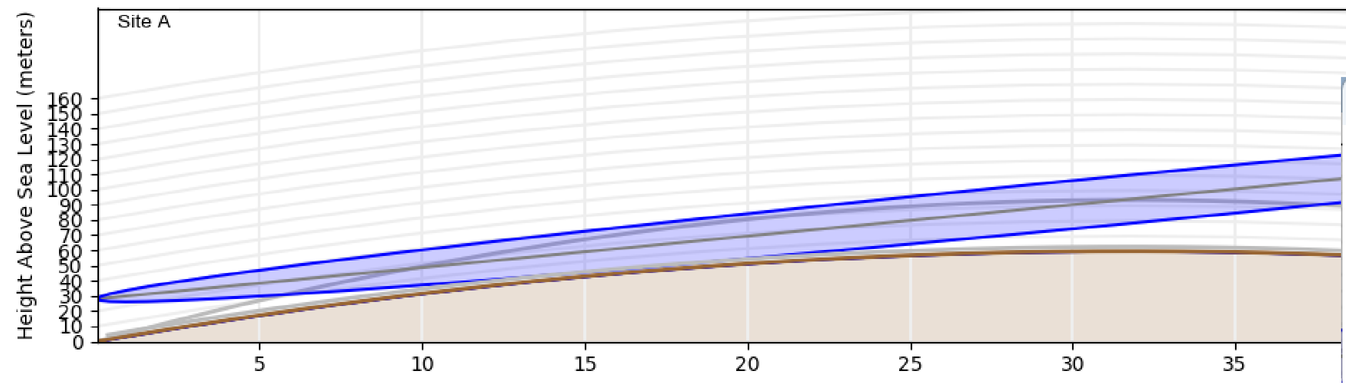
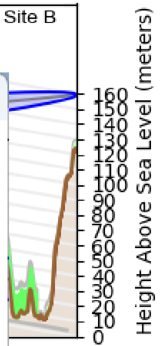
Profile: 63.533 kilometers, Line-of-Sight





Performance Details: Site A to Site B

Common details											
Mode:	2048QAM	1024QAM	1024QAM	512QAM	256QAM	128QAM	64QAM	32QAM	16QAM	8PSK	QPSK
Profile:	10	9	8	7	6	5	4	3	2	1	0
Max Aggregate IP Throughput (Mbps):	679.65	627.16	603.92	534.21	487.23	431.04	365.03	308.48	231.87	163.56	106.73
Performance to Site A											
Max IP Throughput (Mbps):	339.82	313.58	301.96	267.10	243.62	215.52	182.52	154.24	115.93	81.78	53.37
Fade Margin (dB):	16.00	18.50	19.50	24.00	27.00	31.00	35.00	39.00	42.50	45.00	54.25
Mode Availability (%):	99.0888	98.6863	98.9069	99.6950	99.8806	99.9713	99.9933	99.9983	99.9992	99.9996	99.9999
Mode Unavailability (per year):	3.3 days	4.8 days	4.0 days	1.1 days	10.5 hrs	2.5 hrs	35.1 mins	8.8 mins	4.0 mins	2.0 mins	38 secs
Receive Time in Mode (%):	99.0888	-0.4024	0.2206	0.7881	0.1856	0.0907	0.0220	0.0050	0.0009	0.0004	0.0003
Performance to Site B											
Max IP Throughput (Mbps):	339.82	313.58	301.96	267.10	243.62	215.52	182.52	154.24	115.93	81.78	53.37
Fade Margin (dB):	16.00	18.50	19.50	24.00	27.00	31.00	35.00	39.00	42.50	45.00	54.25
Mode Availability (%):	99.1430	98.7750	98.9984	99.7446	99.9048	99.9780	99.9950	99.9987	99.9994	99.9997	99.9999
Mode Unavailability (per year):	3.1 days	4.5 days	3.7 days	22.4 hrs	8.3 hrs	1.9 hrs	26.4 mins	6.6 mins	3.0 mins	1.7 mins	40 secs
Receive Time in Mode (%):	99.1430	-0.3680	0.2234	0.7462	0.1602	0.0733	0.0170	0.0038	0.0007	0.0002	0.0002

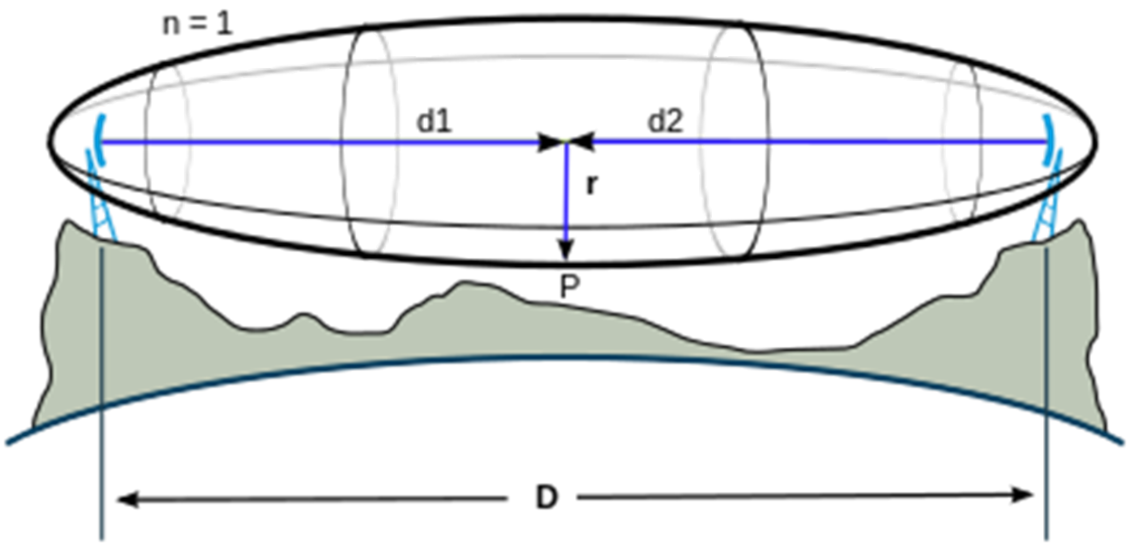
Lowest Mode Availability for Site A to Site B

	Site A	Site B
dN/dH not exceeded for 1% of time	-403.91 N units/km	
Area roughness 110x110km	16 m	
Geoclimatic factor	1.09e-04	
Fade Occurrence Factor (P0)	2.03e+00	2.03e+00
Path inclination	2.07 mr	
Improvement Factor	200.00	200.00
Value of K Exceeded for 99.9% (ke)	0.85	
Free Space Path Loss	145.11 dB	145.11 dB
Gaseous Absorption Loss	0.81 dB	0.81 dB
Excess Path Loss at K = 0.85 (Not included in the availability calculations.)	21.14 dB	21.14 dB
Total Path Loss	145.92 dB	145.92 dB
0.01% Rain rate	37.83 mm/hr	
Rain Attenuation	0.4 dB/km	
Rain Availability	100.00000 %	100.00000 %
Rain Unavailability	1 secs/year	1 secs/year
Annual 1-way Availability (K=1.33)	99.99988 %	99.99988 %
Annual 2-way Availability (K=1.33)	99.99976 %	
Annual 2-way Unavailability	1.3 mins/year	
Annual 2-way Availability Including Rain	99.99975 %	
Annual 2-way Unavailability Including Rain	1.3 mins/year	

OK

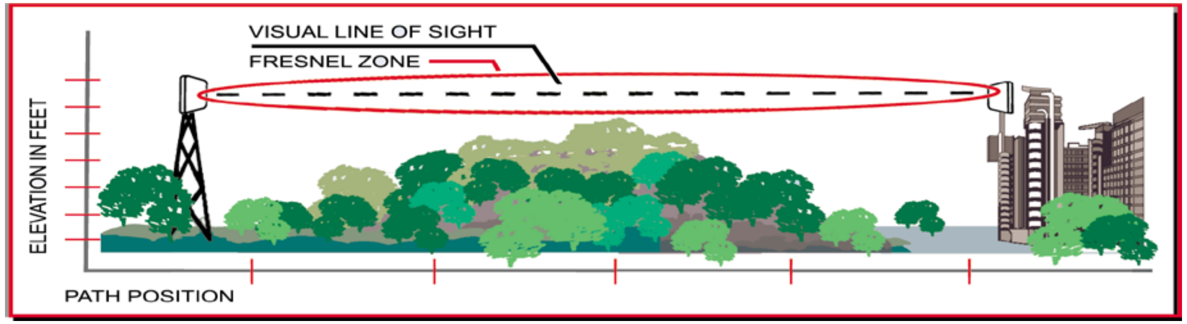
What is a Fresnel Zone?

- **It represents a BOUNDARY condition where the net effect of a Huygens' energy source changes from enhancing the overall signal to depleting it**
  - Nothing to do with antennas
  - Nothing to do with shape of radiowaves (b/c rays travel in straight lines)
  - Are not relevant until an OBSTACLE is introduced and therefore nothing to do with power density
  - Are three dimensional but normally refer to vertical obstruction (hill, tree, building, etc)

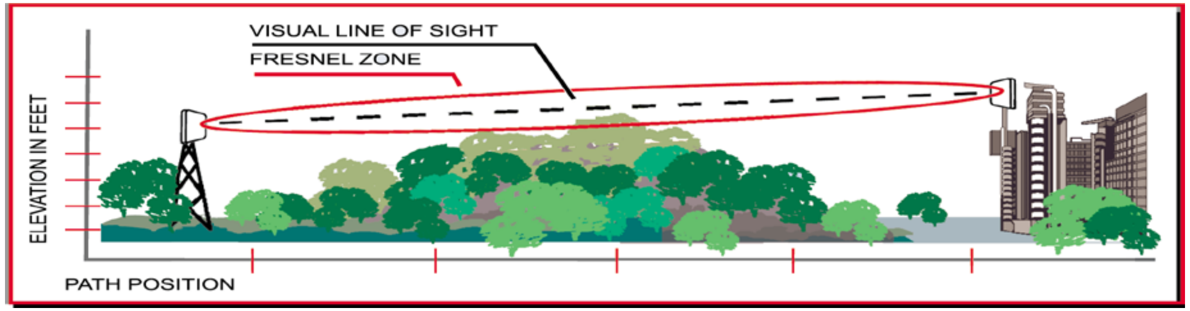


$$F_1 = \sqrt{\lambda \frac{d_1 . d_2}{d_1 + d_2}}$$

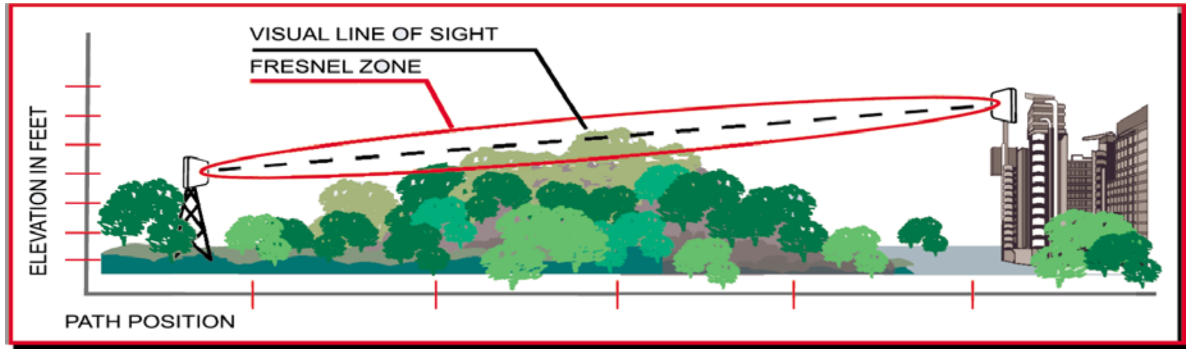
Things to think about - clear path for RF?



Line of Site (LOS)



near Line of Site (nLOS)



Non Line of Site (NLOS)

Radio waves do not travel in straight lines

- **The Fresnel Zone is the additional path clearance required in order to achieve clear line of sight**
- **Size of Fresnel Zone is determined by operating frequency and path distance**
- **Obstacles in Fresnel Zone need to be taken into account**
- **The Cambium PTP LINKPlanner tool includes this in its calculations**

Reflection Analysis

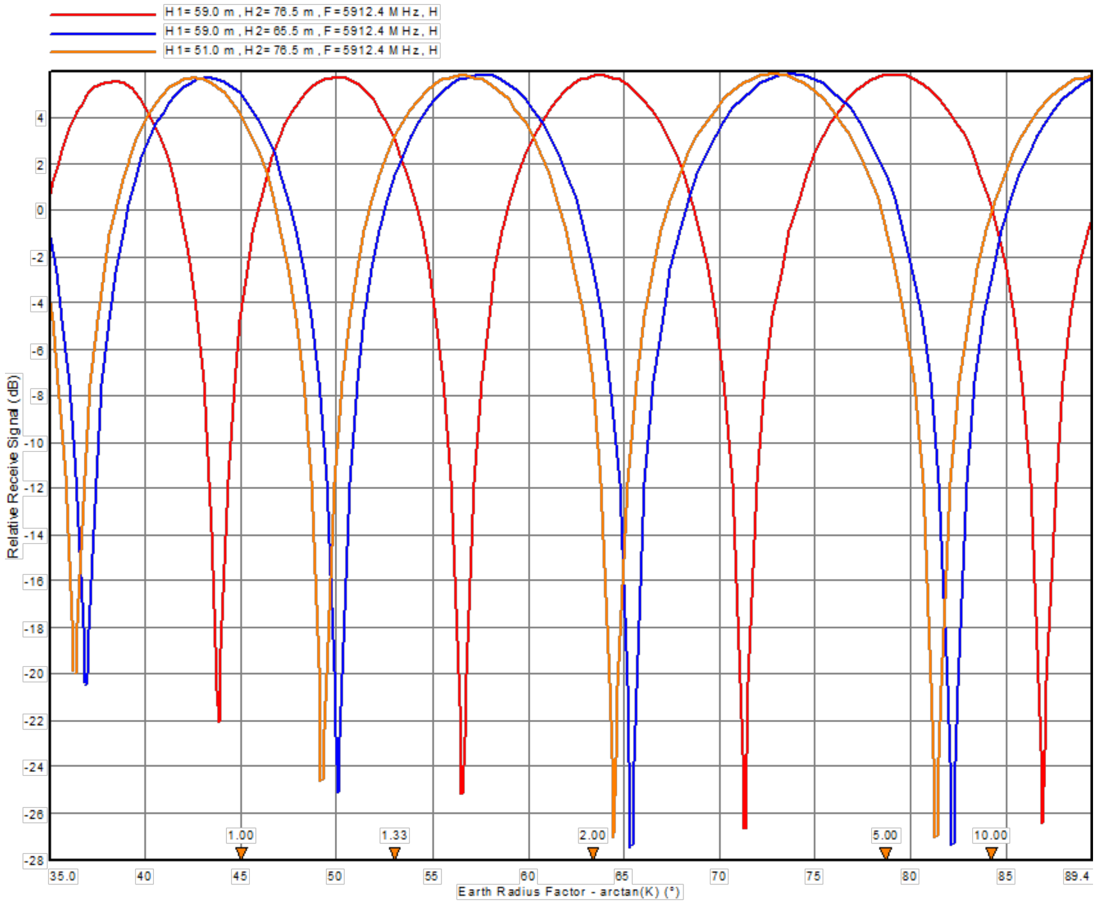
- **Consider adding space diversity to a reflective path, or a path that does not meet the reliability objective using reasonably sized antennas.**
- **Maximise SD Improvement factor - Limit SD improvement factor to 200.**
- **Reflective paths use the Reflection Analysis to optimize separations**

Lowest Mode Availability for Ambrym to Malekula

	Ambrym	Malekula
dN/dH not exceeded for 1% of time	-97.60 N units/km	
Area roughness 110x110km	134 m	
Geoclimatic factor	3.15e-05	
Fade Occurrence Factor (P0)	1.06e-01	
Path inclination	0.67 mr	
Improvement Factor	200.00	200.00
Value of K Exceeded for 99.9% (ke)	0.84	
Excess Path Loss at K = 0.84 (Not included in the availability calculations.)	0.00 dB	
0.01% Rain rate	94.37 mm/hr	
Rain Availability	99.99985 %	
Rain Unavailability	49 secs/year	
Annual 1-way Availability (K=1.33)	100.00000 %	100.00000 %
Annual 2-way Availability (K=1.33)	100.00000 %	
Annual 2-way Unavailability	0 secs/year	
Annual 2-way Availability Including Rain	99.99984 %	
Annual 2-way Unavailability Including Rain	49 secs/year	

Reflection Analysis

- **Typical vertical spacing is 30-ft (10m) depending on meeting clearance requirements. Larger spacing's up to 50-ft (15m).**
- **Important to maintain sufficient clearance between main and diversity antenna**
  - Remove correlation between paths



Create PTP Links using Planning Software

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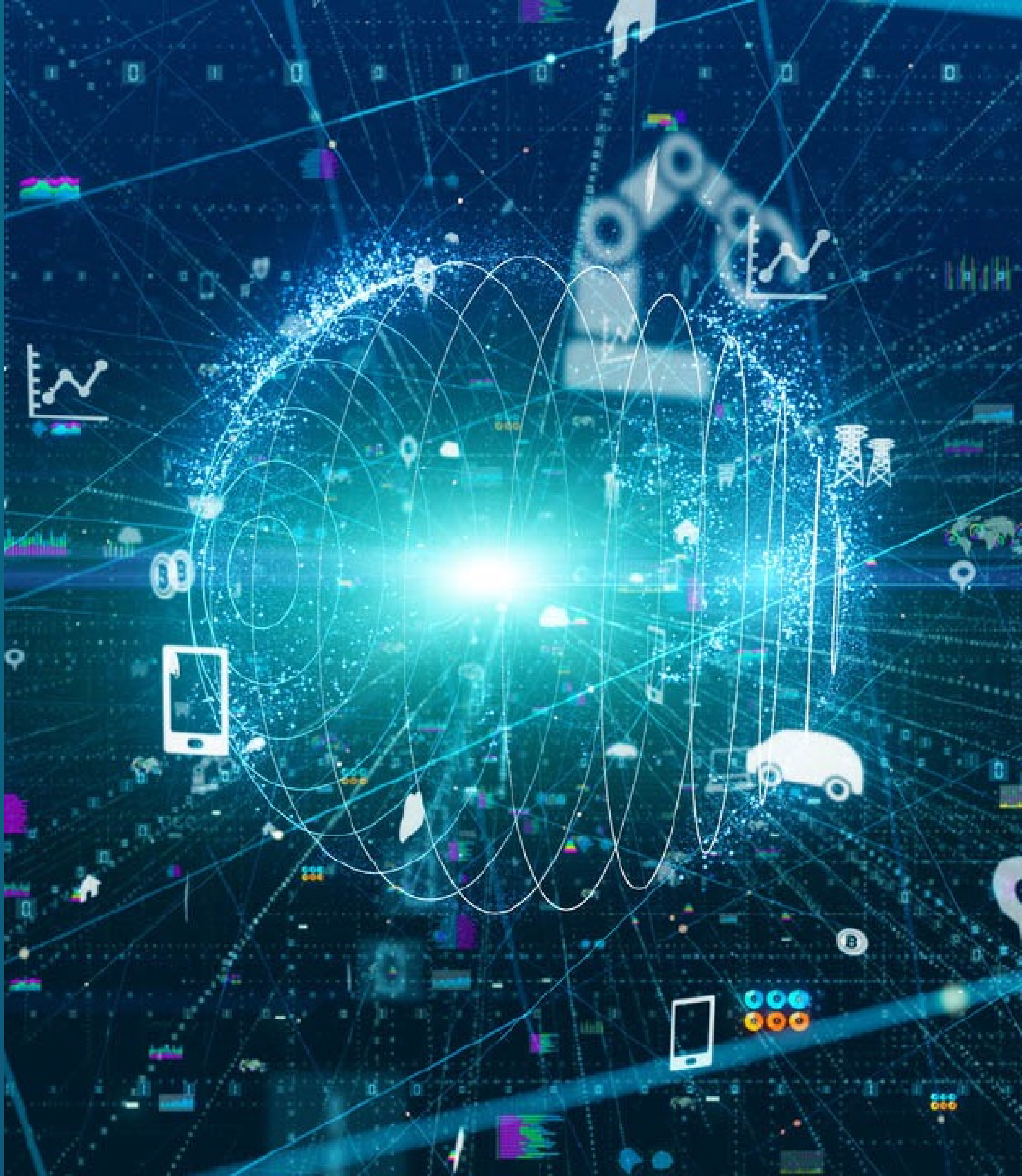

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Pathloss

Google Earth

Atoll
Wireless Network Engineering Software

ATDI

Microwave Radio Link Design and Planning Software

Cambium LINKPlanner

- A free, easy to use link design tool
- Plan and optimize individual links or networks
- Path profiles provided automatically
- Compare performance of our different products before purchase
- Automatically generate Bill of Materials
- Create proposal and installation reports
- Fully supported - simply email linkplanner.ptp@cambiumnetworks.com

Pathloss CTE

- Widely adopted as industry-standard
- The program is intended for experienced telecommunications network designers
- Design of PMP networks and local coverage displays
- Calculates the intra-system interference between any sites in the network
- Comprehensive Multipath fade algorithms
- Automated Link Design
- Thematic Mapping

Cambium LINKPlanner - Multi-sector and Multi-Tower Networks

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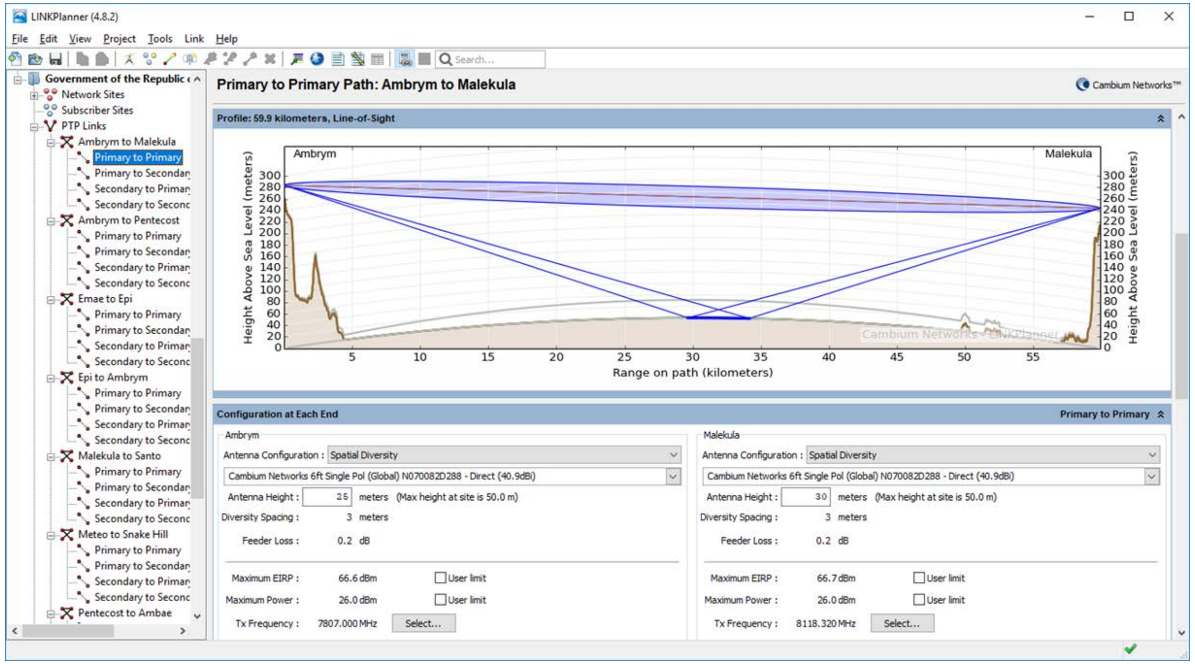
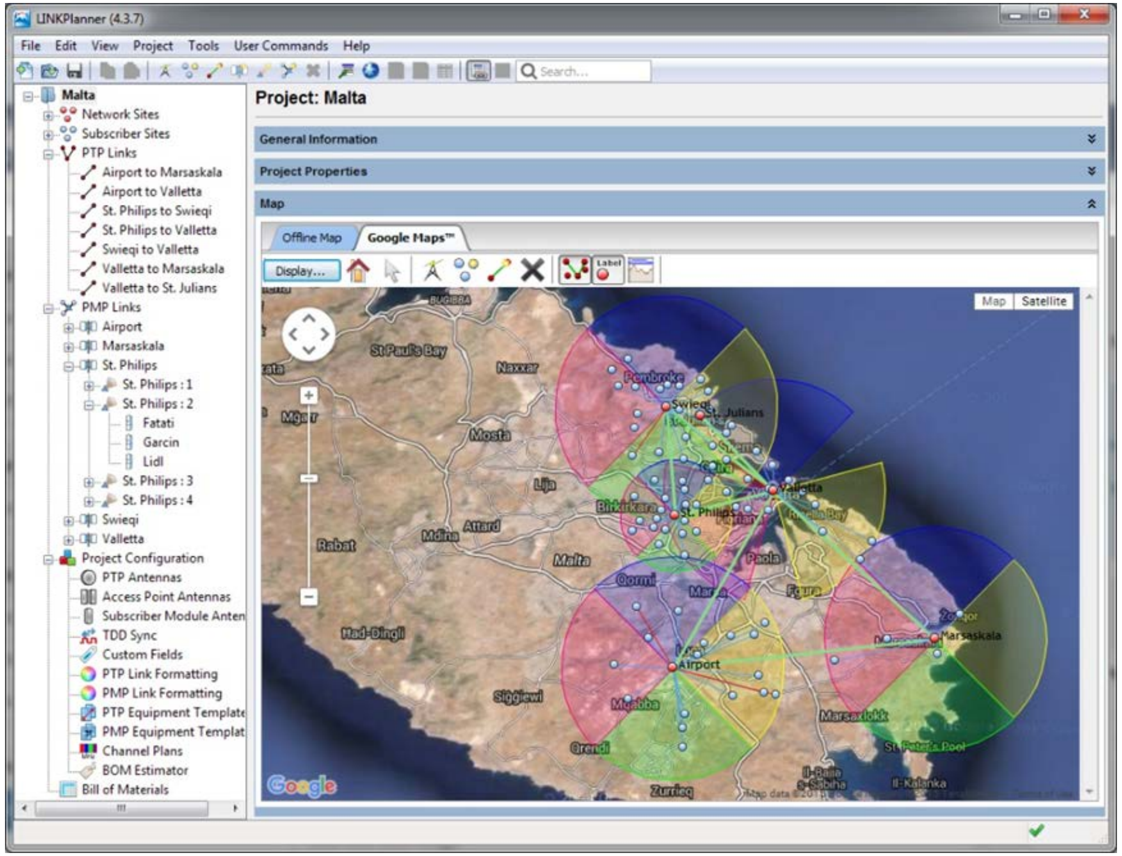


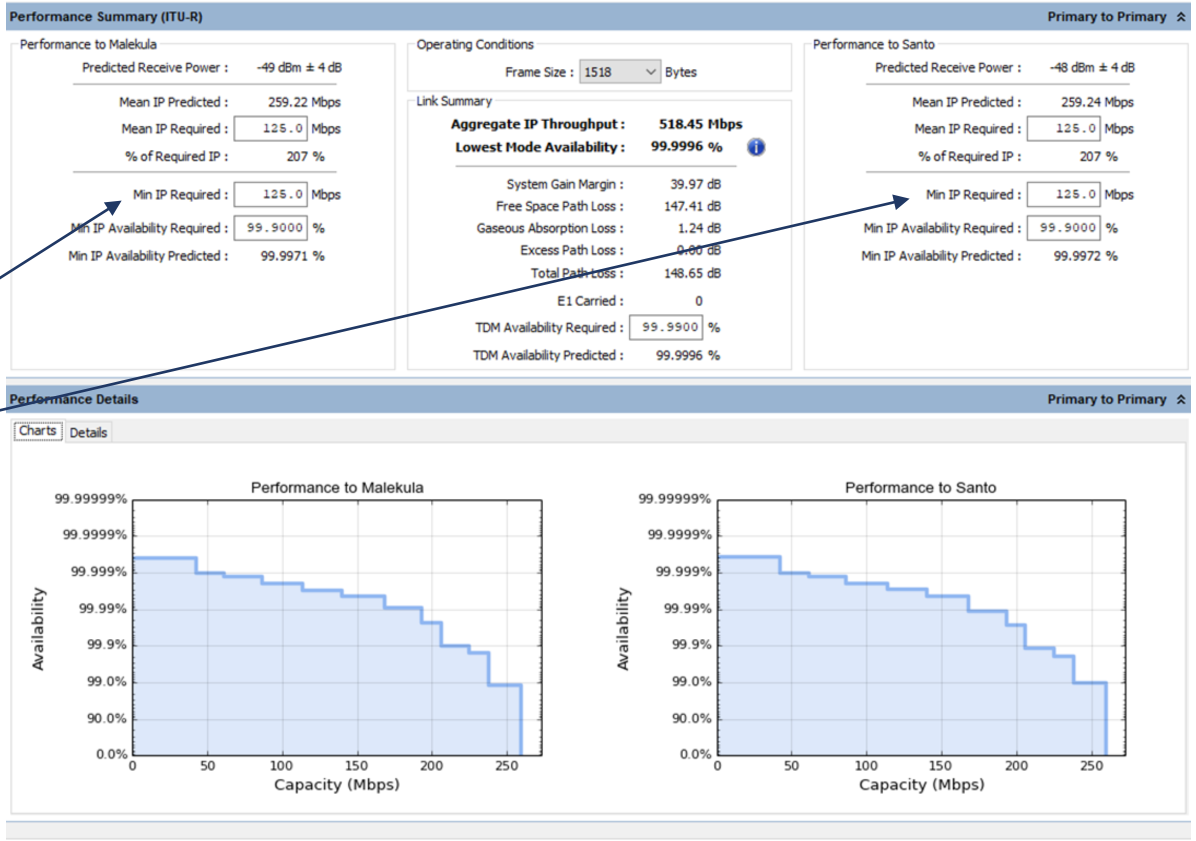


Optimize PTP performance

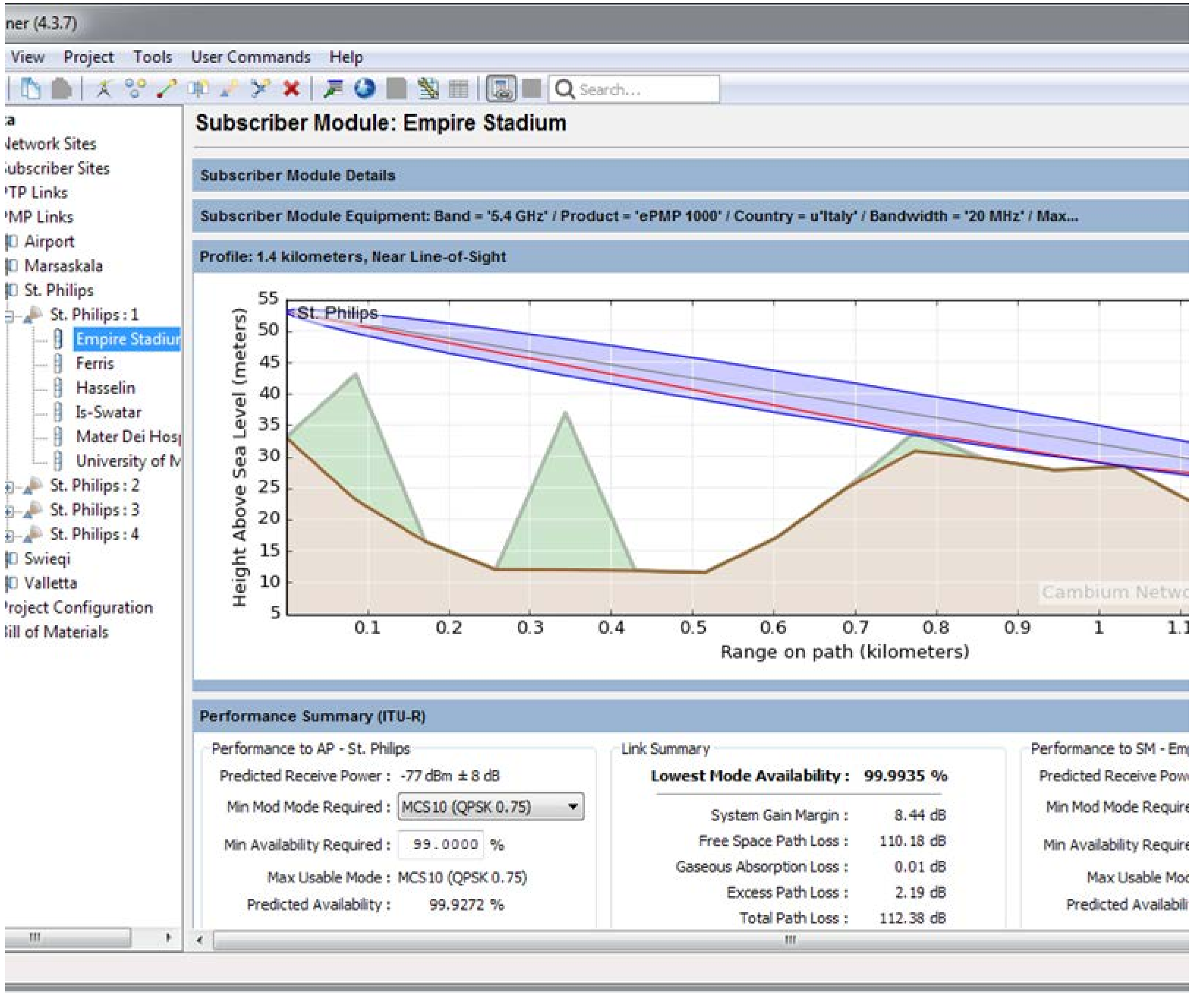
- ***FSPL = 32.45 + 20log(d_{km}) + 20log(f_{MHz}) dB***

- **Where:**
- ***d* is path length in km**
- ***f* is Frequency in MHz**

Set performance requirements



Add Obstructions Detail



- **Once determined, LINKPlanner allows you to input the obstacle details into the path profile.**
- **Note: Using Google Earth can help to determine locations and heights of some obstructions.**
  - Buildings
  - Trees

Establish Requirements and Validate

Common details													
Mode:	4096QAM	2048QAM	1024QAM	1024QAM	512QAM	256QAM	128QAM	64QAM	32QAM	16QAM	8PSK	QPSK	BPSK
Profile:	12	11	10	9	8	7	6	5	4	3	2	1	0
Max Aggregate IP Throughput (Mbps):	1070.58	1040.18	959.62	902.88	829.91	771.15	667.28	551.24	447.89	338.96	242.69	164.67	78.54
Performance to MIC													
Max IP Throughput (Mbps):	535.29	520.09	479.81	451.44	414.95	385.57	333.64	275.62	223.95	169.48	121.35	82.34	39.27
Fade Margin (dB):	13.60	17.60	21.60	22.60	27.10	30.10	33.10	36.10	40.10	44.10	46.10	51.10	56.35
Mode Availability (%):	99.9977	99.9992	99.9997	99.9998	100.0000	100.0000	100.0000	100.0000	100.0000	100.0000	100.0000	100.0000	100.0000
Mode Unavailability (per year):	12.3 mins	4.4 mins	1.5 mins	1.1 mins	11 secs	4 secs	4 secs	4 secs	4 secs	4 secs	4 secs	4 secs	4 secs
Receive Time in Mode (%):	99.9977	0.0015	0.0005	0.0001	0.0002	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
Performance to GNS													
Max IP Throughput (Mbps):	535.29	520.09	479.81	451.44	414.95	385.57	333.64	275.62	223.95	169.48	121.35	82.34	39.27
Fade Margin (dB):	13.60	17.60	21.60	22.60	27.10	30.10	33.10	36.10	40.10	44.10	46.10	51.10	56.35
Mode Availability (%):	99.9977	99.9992	99.9997	99.9998	100.0000	100.0000	100.0000	100.0000	100.0000	100.0000	100.0000	100.0000	100.0000
Mode Unavailability (per year):	12.3 mins	4.4 mins	1.5 mins	1.1 mins	11 secs	4 secs	4 secs	4 secs	4 secs	4 secs	4 secs	4 secs	4 secs
Receive Time in Mode (%):	99.9977	0.0015	0.0005	0.0001	0.0002	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000

Spatial Diversity Reflections

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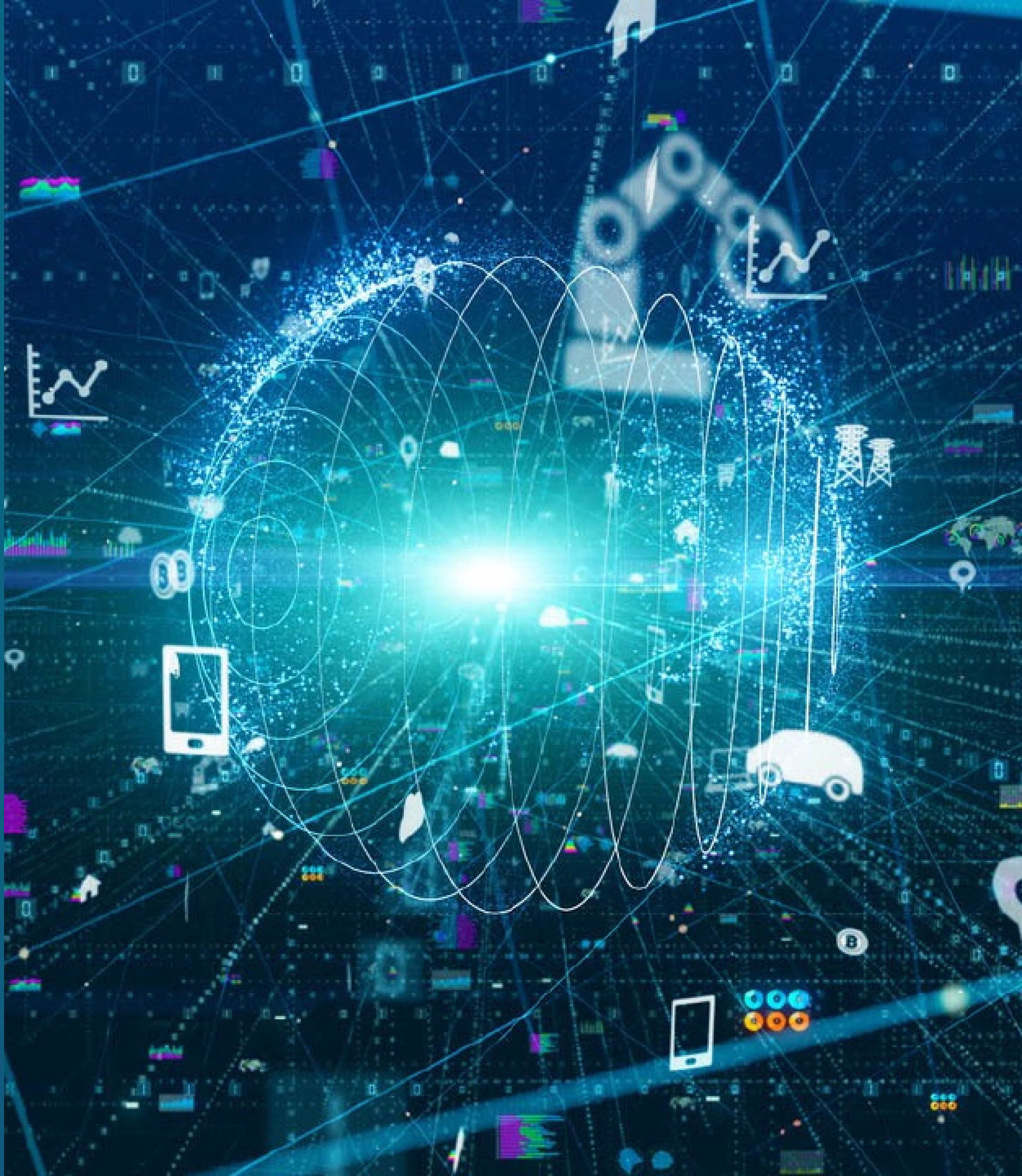
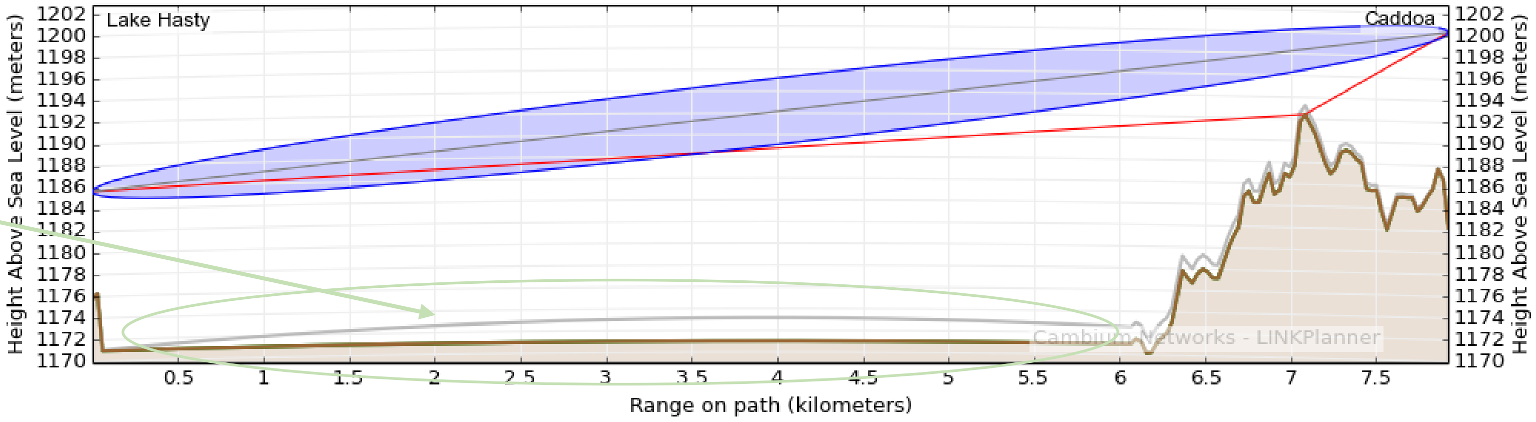
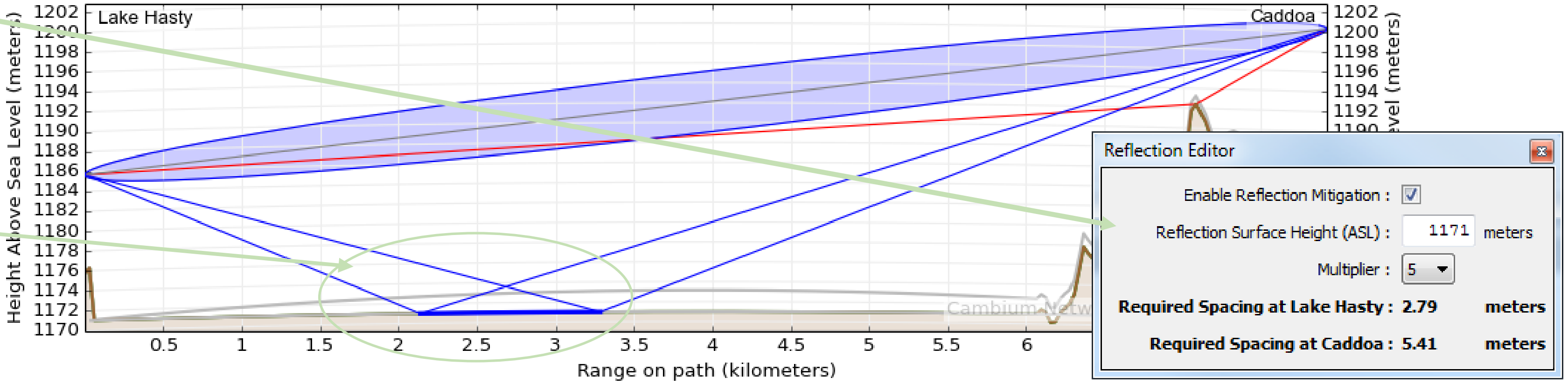


Is there a Reflection Path?

- **Does the path have a large smooth area?**



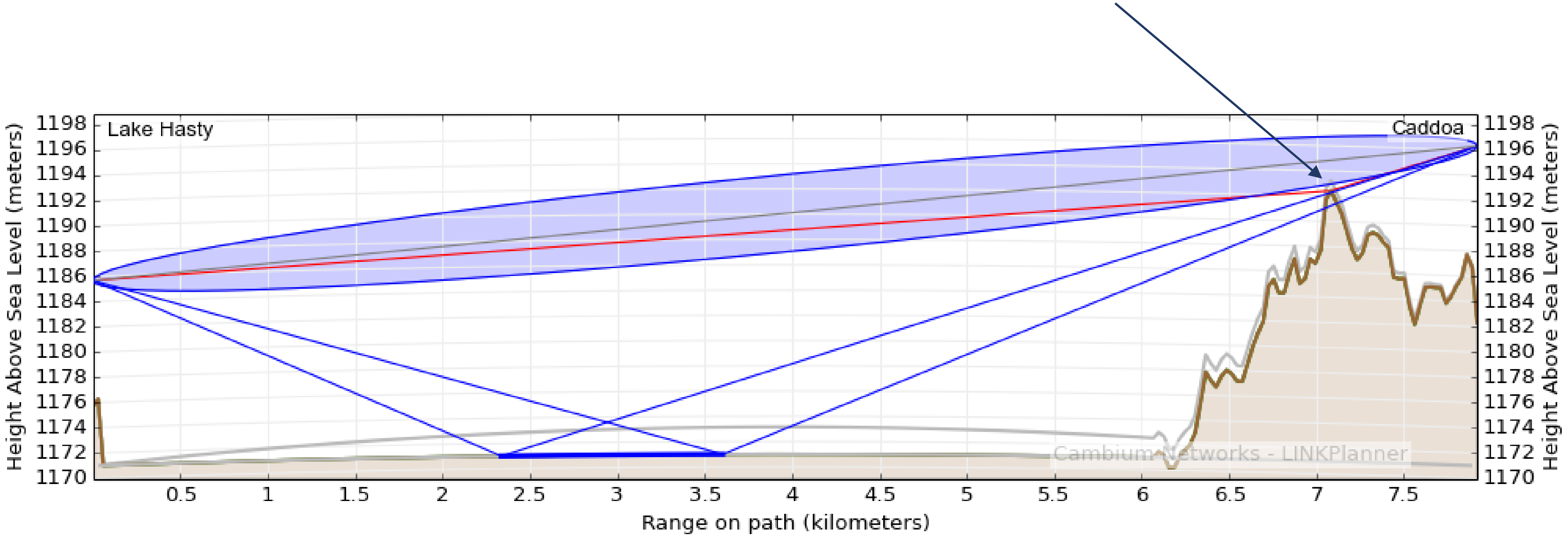
- **Edit Reflection Parameters and Enable Reflection Mitigation – is the reflection point on the smooth area?**



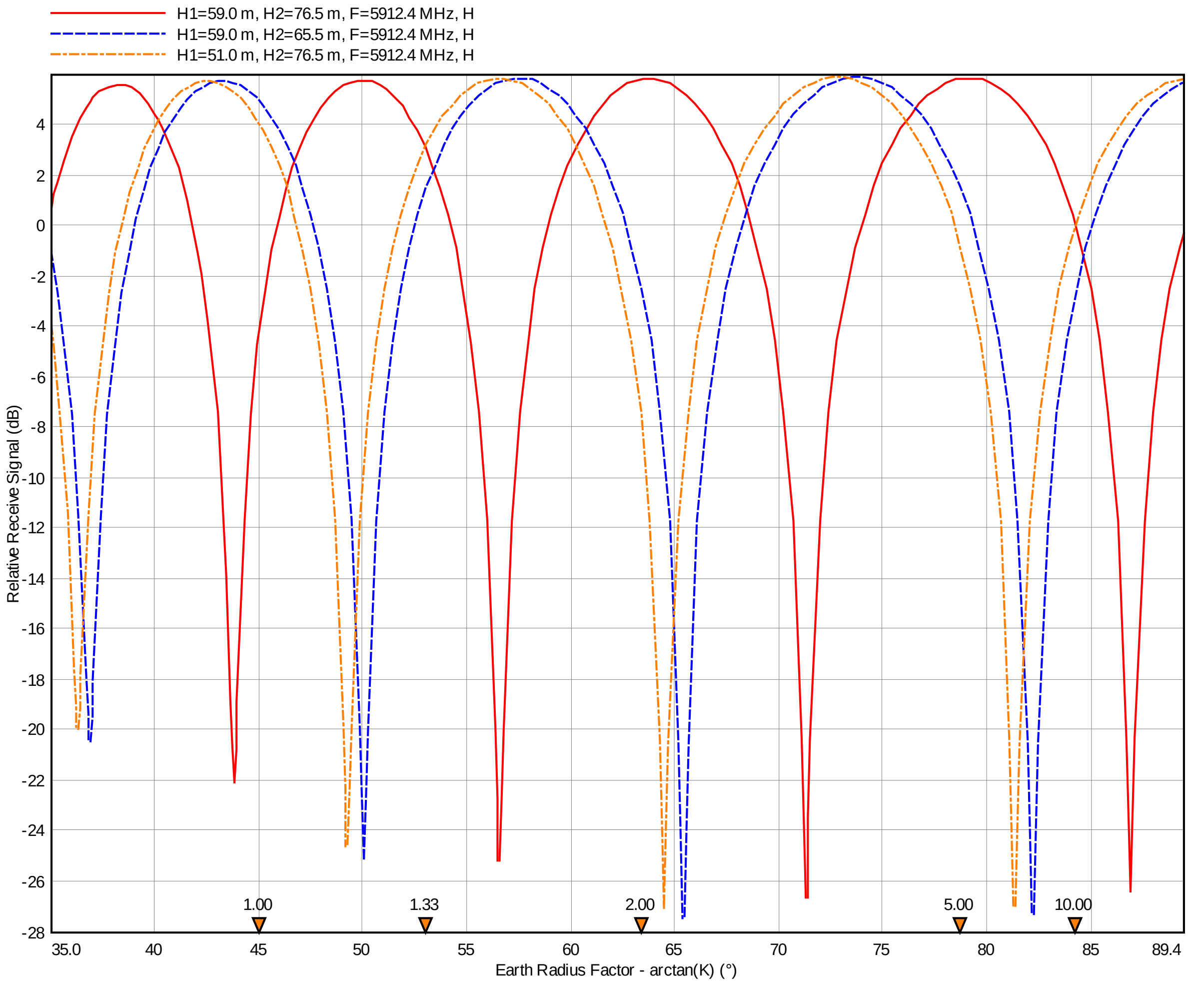
Is it possible to block the reflections?

- **Preferred mitigation method - adjust the antenna height to block the reflection**

- **Only one end of the reflection path needs to be blocked, as this will block the transmitted signal in one direction and the receive signal in the other.**

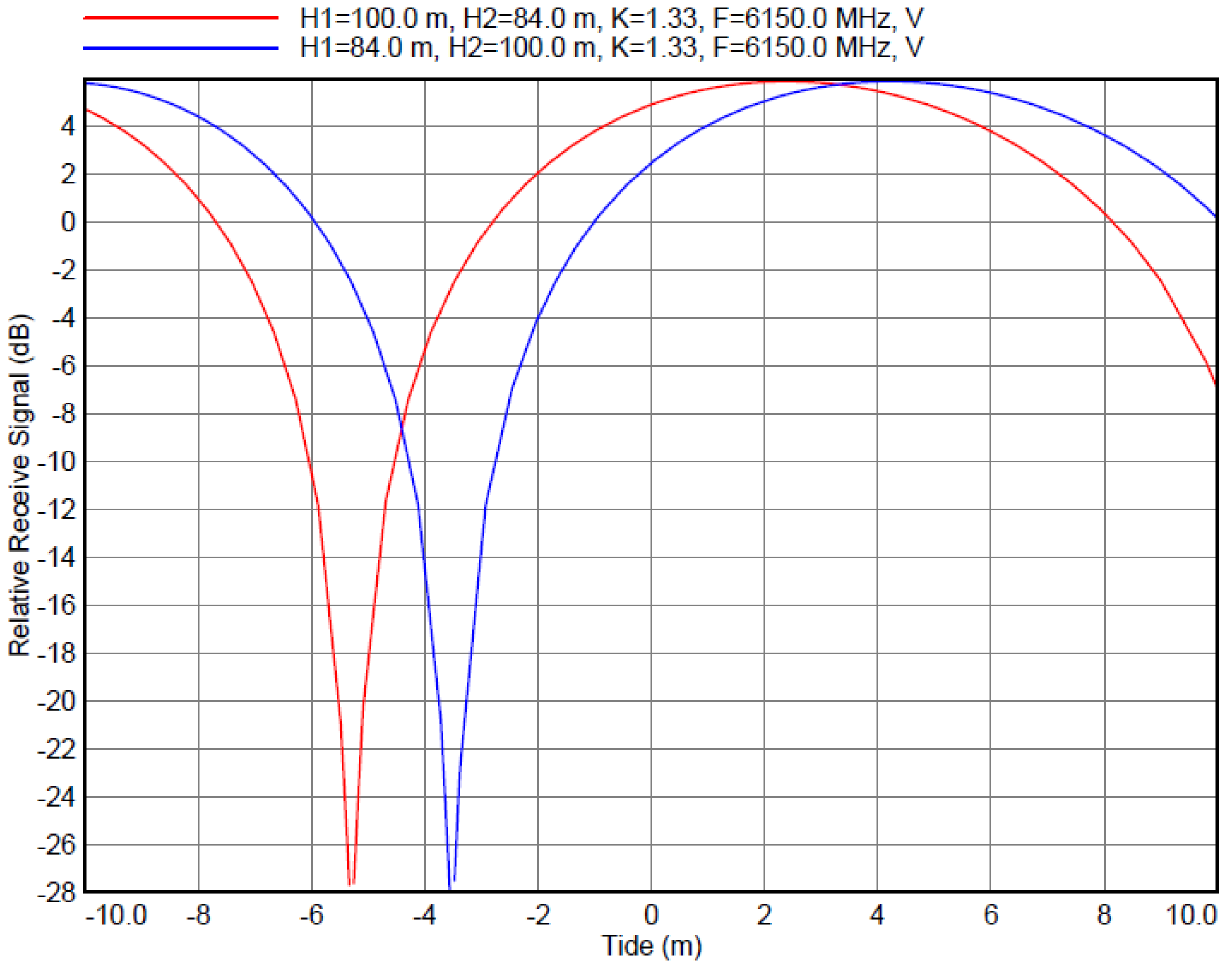


Reflection Analysis using a Reflective Plane definition – Earth Radius

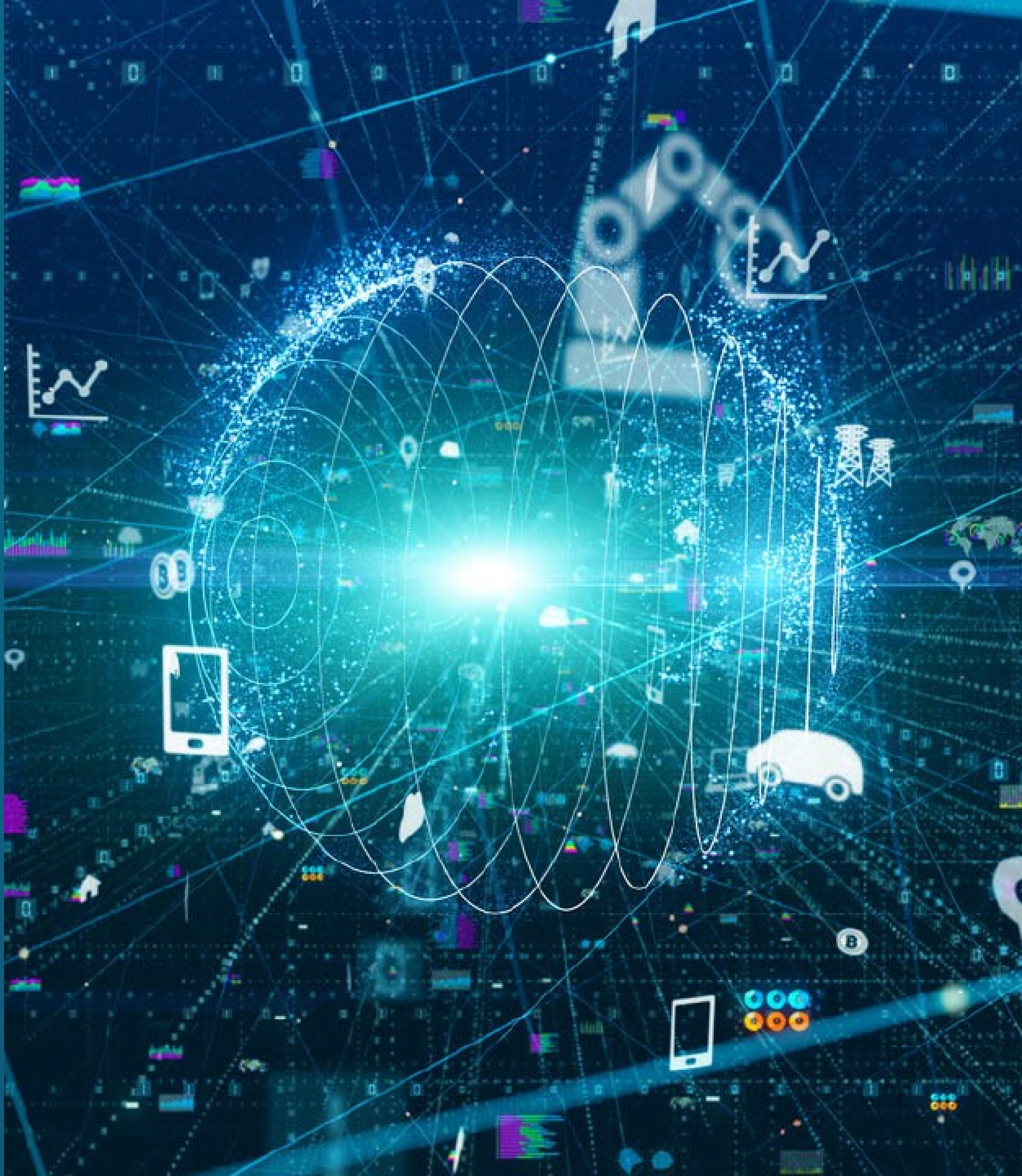


- **Reflection Paths – all about Geometry**
- **Reflected path is longer than the direct path, which means it can be at a different phase.**
- **In worst case this can add an anti-phase signal to direct wave causing complete cancellation.**
- **With the right spacing the two diverse antennas will not be in a null simultaneously**
- **What separation is required ?**
  - General rule is assume 200 * λ

Reflection Analysis using a Reflective Plane definition – Tidal Variation



Link Design Summary



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Link Design - Summary

- **Start with setting a hop reliability objective**
  - Annual availability outage typically between 99.99% (access) and 99.999% (backbone) per hop
  - Lower availability target is OK if link diversity protection (ring/mesh)
- **ACM objective – choose core traffic objective and worst case objective for best effort traffic**
- **Design methodology different between Short Haul and Long Haul**
  - Path surveys
  - Antenna heights
  - Antenna size
  - Equipment configuration and fading countermeasures

Link Design - Summary

Short Haul: (<20km)

- **Frequency Band**
  - >13 GHz
- **Site surveys**
  - Conduct accurate antenna bracket to antenna bracket
  - Path profile not essential other than for initial planning purposes
- **Antenna height**
  - Use size survey results (LOS plus safety margin of 3m – 5m) to take into account Fresnel and K factors
- **Antenna Size**
  - Design for rain outage
  - If antenna size cannot be increased, then drop frequency band
  - Diversity techniques may not yield any improvement

Long Haul: (>= 20km)

- **User low Frequency Band <13 GHz**
- **Site surveys**
  - MUST do accurate path profiles
  - Accurate site locations and key obstructions (Fresnel and K clearance rules)
- **Antenna height**
  - Set using new clearance rules
  - If diversity is required, then diversity antenna needs clearance at median k
- **Antenna Size**
  - Design for rain AND multipath outage
  - Increase antenna size for flat fading
- **Countermeasures**
  - Use diversity techniques to improve performance against multipath fading
  - Can also use Diversity techniques to decrease antenna size (reduces tower loading)

Useful Formulas

Wavelength

$\lambda = c/f$

Free Space Loss (FSL)

FSL = 92.4 + 20 log d (km) + 20 log f (GHz) dB

EIRP

EIRP (dB) = PowerT+TGainAnt-Losses

Receive Power

RxPower (dBm) = EIRP – FSL – AtmosLoss – ExcessLoss + RxAntGain - RxLoss

Valuable Resources and References

- “Wireless Communications Principles and Practice”, Rappaport, T.S.
- “Microwave Radio Transmission Guide”, Manning, T.
- “MICROWAVE RADIO Handy Reference Guide”, Manning, T.
- https://learning.cambiumnetworks.com
- http://linkplanner.cambiumnetworks.com/doc/index.html
- https://www.itu.int

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- Questions