2 AND 5 GHZ REAL WORLD PROPAGATION

FINDING PATHS THAT WORK

KE2N

PATH MODELING BEYOND TOPOGRAPHY:
TREES AND BUILDINGS

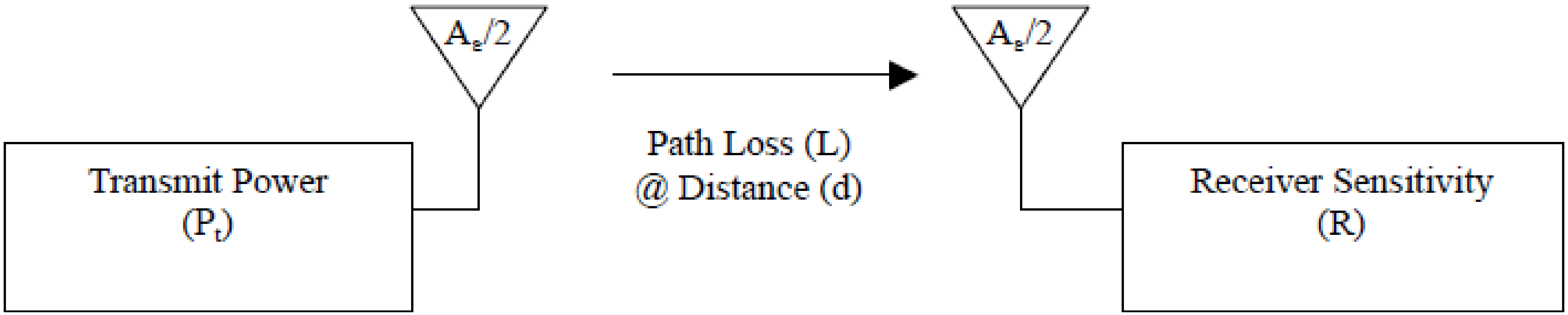
- RADIO MOBILE: "When prediction over small distances are required to be accurate it is important that the influence of local buildings (clutter) is taken in account. When predictions are performed over bigger distances the dominance of clutter decreases and eventually can be left out of the calculations. This simplifies the formula for calculating RF propagation."
- "Accurate RF predictions require detailed clutter and height data but this data is generally expensive and only affordable when income out of the exploitation of a radio network is high. For amateur radio, emergency services, and students for example it is not realistic to have this accurate data available. Therefore low budget and easy accessible data must be [used]. Radio Mobile uses geodata that is available on the internet for free."
- "Land Cover data has a focus on vegetation and not urban area's. This has influence on the usability of Land Cover for radio planning purposes".
- NOTE: RADIOMOBILE is Longley Rice "irregular terrain model" with obstructions.

INTRODUCTION - CONTINUED

- Extensive studies have been done of tree (vegetation) attenuation (e.g., ITU-R P.833-8)
- For buildings, diffraction-based path models require each structure in the path to be modeled. Due to complexity, empirical models have been developed for urban and suburban environments and specific equipment arrangements – while not exactly like BBHN these are instructive.
- This presentation summarizes some of that information and looks at one RadioMobile analysis.

HOW MUCH ATTENUATION CAN WE STAND?

Typical RF Transmission System



Where:

P_t = Transmitter power in dBm
A_g = Total antenna gain in dB
C_l = Total connection loss in dB
G_{tot} = (A_g - C_l) Total gain in dB
L = Transmission path loss in dB
R = Receiver sensitivity in dBm
d = Distance between transmitter and receiver in meters

ALLOWABLE LOSS

$L = P_t + G_{tot} - R$

ATTENUATION FOR "HAMNET"

- ALLOWABLE LOSS
- $L = P_t + G_{tot} - R$

Point to Point Backbone
Desired operation: MCS15
Radio: M5
Pt = 21 – 2 dBm
R = -75 + 2 dBm
Antenna 28 dBi x 2
Connector/cable loss 1 dB

L = 19 + 54 - (- 73)
L = 146 dB
(minus desired fade margin)

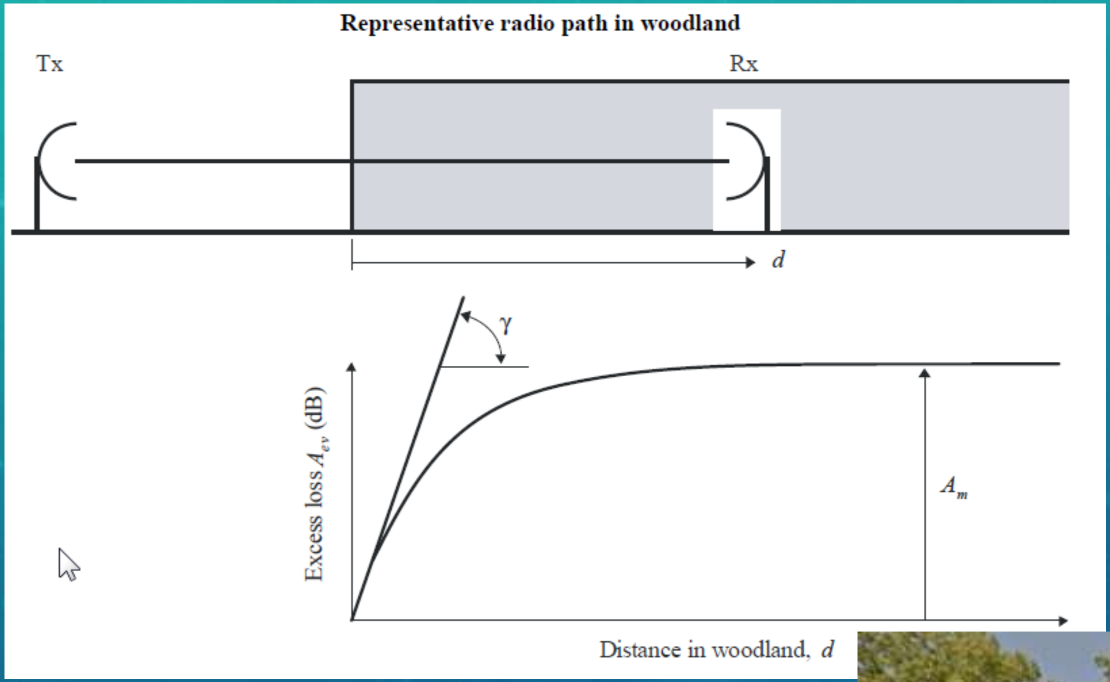
Mesh
Desired operation: MCS10
Radio: M5
Pt = 27 – 2 dBm
R = -90 + 2 dBm (~10 dB NF)
Antenna 10 dBi x 2
Connector/cable loss 1 dB

L = 25 + 18 - (- 88)
L = 131 dB (!)

"Free Space" loss
$L_{fs} = 32.45 + 20Log_{10}(d_{km}) + 20Log_{10}(f_{MHz})$
= 110 dB @ 2.4 GHz 10 km

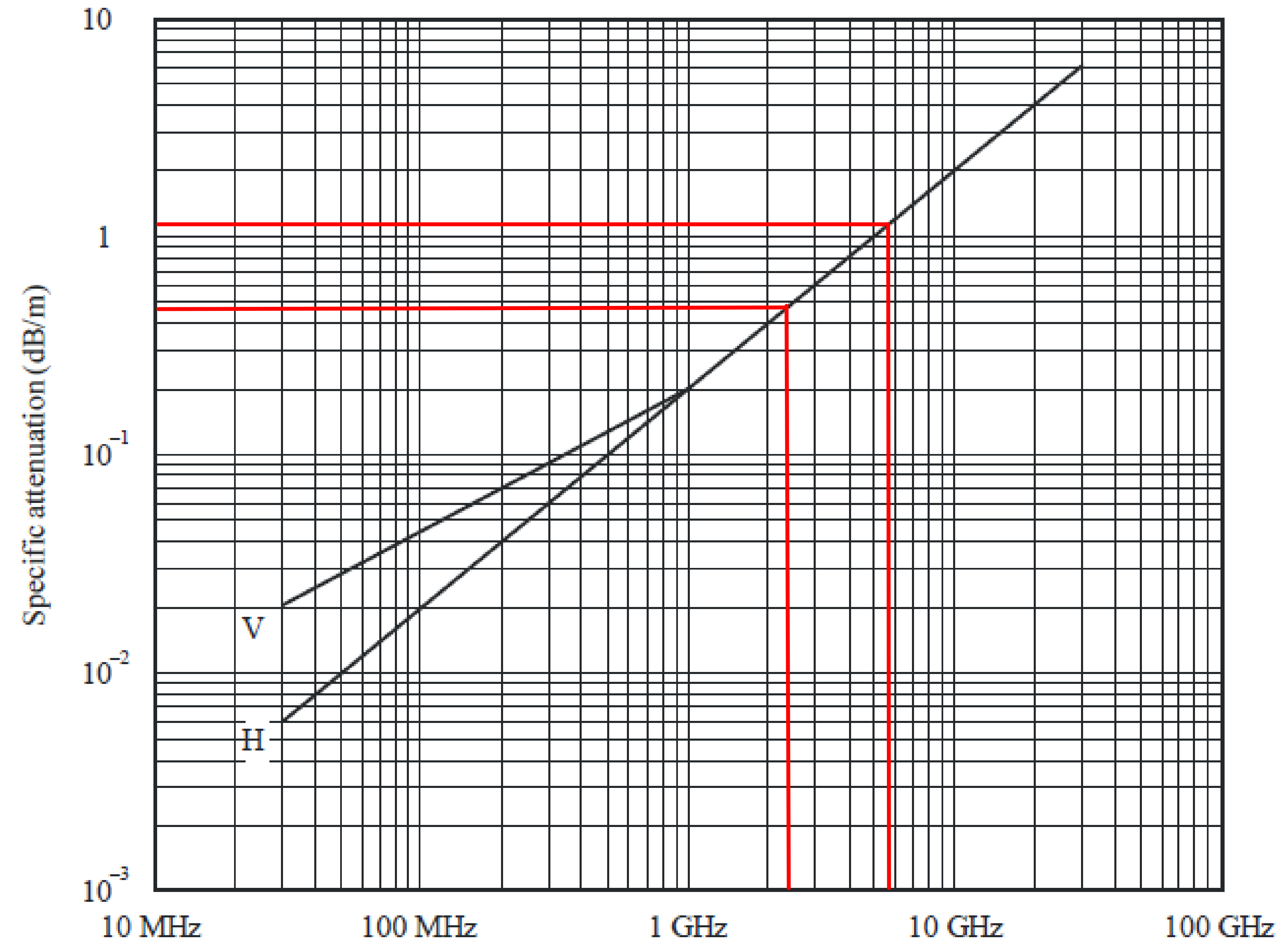
SPECS ASSUME 20 MHZ B/W

LOST IN THE WOODS (100m OR MORE)

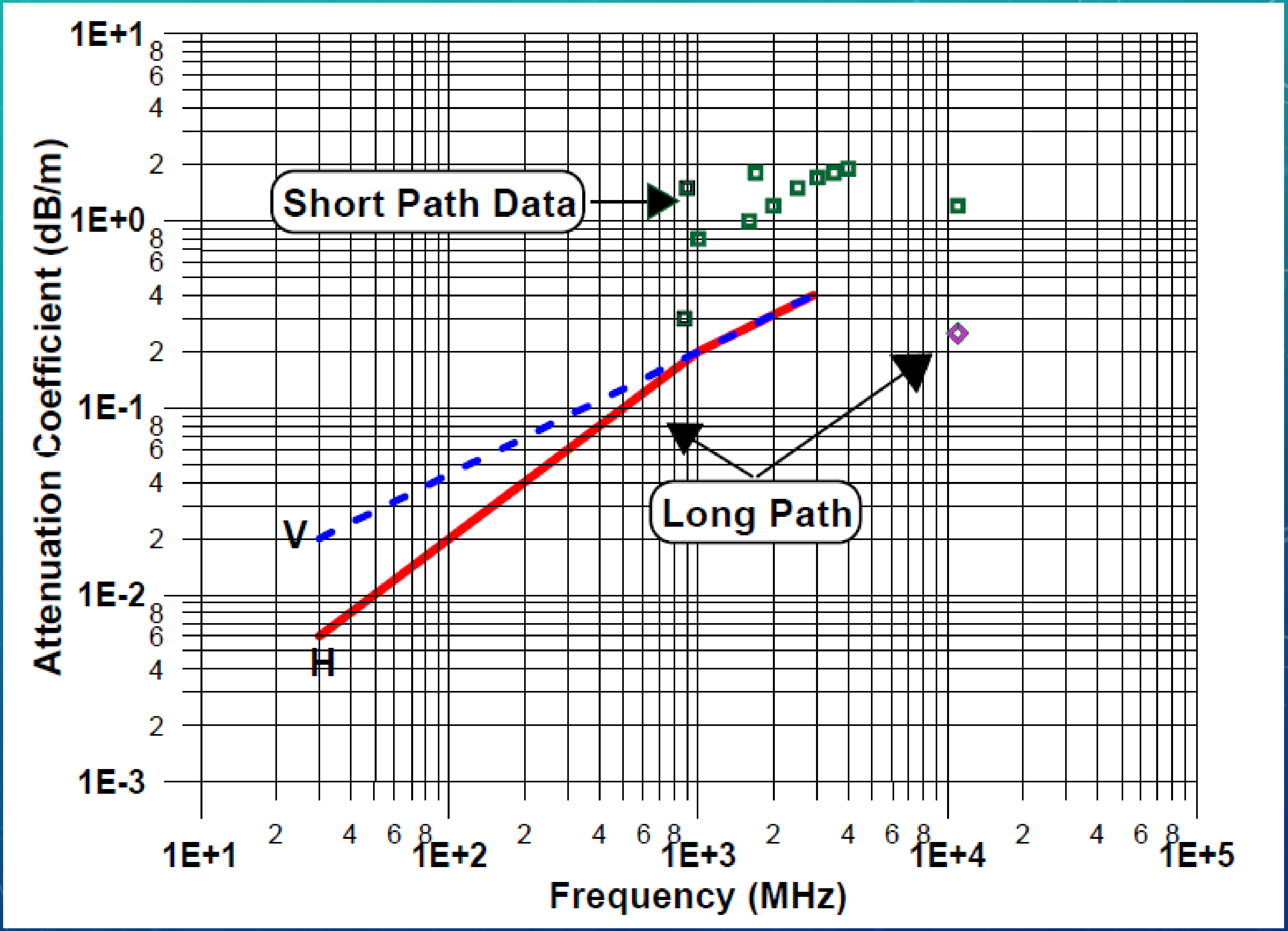


Burke Lake Park, Ox Road, Fairfax

EXCESS LOSS DUE TO “WOODLAND” –LONG PATH



"SHORT PATH" EXCESS LOSS (10-15 m)



TREE LOSSES - SUMMARY

For short paths through trees, excess path loss due to trees are on the order of 1-2 dB/m for 2.4 GHz and 2-3 dB/m for 5 GHz depending on tree species. For long paths through multiple trees (a canopy) the losses are usually too high (>30 dB) to be feasible. Lower loss diffraction paths may exist over or around the trees.

Another source (CCIR 236-2) suggests
$L = 0.2\ f^{0.3}\ R^{0.6}$ dB (MHz, meters)
Where R<400 meters – a grove of trees.

Loss variation between species may be related of the size of the physical components of the tree compared to a wavelength (leaves, needles, twigs and stems).

Table below:
Data measured at 1.6 GHz:

Tree Type	Average Attenuation (dB)	Attenuation Coefficient (dB/m)
Willow	10.45	1.1
Pine	18.0	1.8
Linden	9.1	1.4
European Alder	7.0	1.0
Acacia	6.75	0.9
Poplar	3.5	0.7
Elm	9.0	1.2
Hazelnut	2.75	1.1
Maple	16.25	1.25
White Spruce	20.1	1.75
Laurel Cherry	12.0	2.0
Plane	16.9	1.35
Fir	12.75	1.5
Fruit	9.6	1.2
Average	11.0	1.3

EXAMPLE AT 5 GHZ: SIGNAL AND NO SIGNAL

100 meters or
20,000 meters
Same antenna

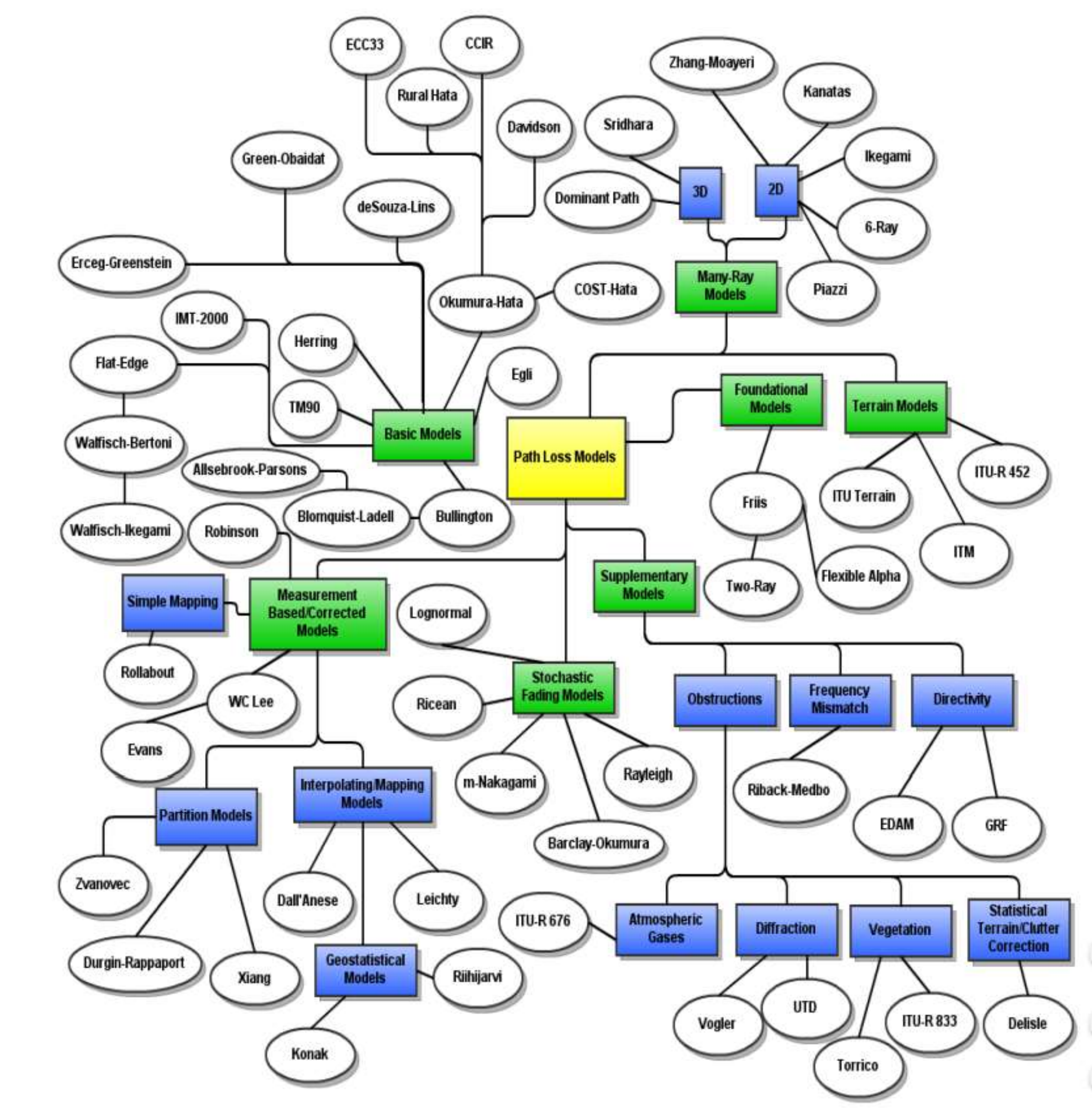
EMPIRICAL MODELS THAT TAKE INTO ACCOUNT BUILDINGS (ETC.)

National Institute of Standards and Technology (NIST) compared several loss models including:

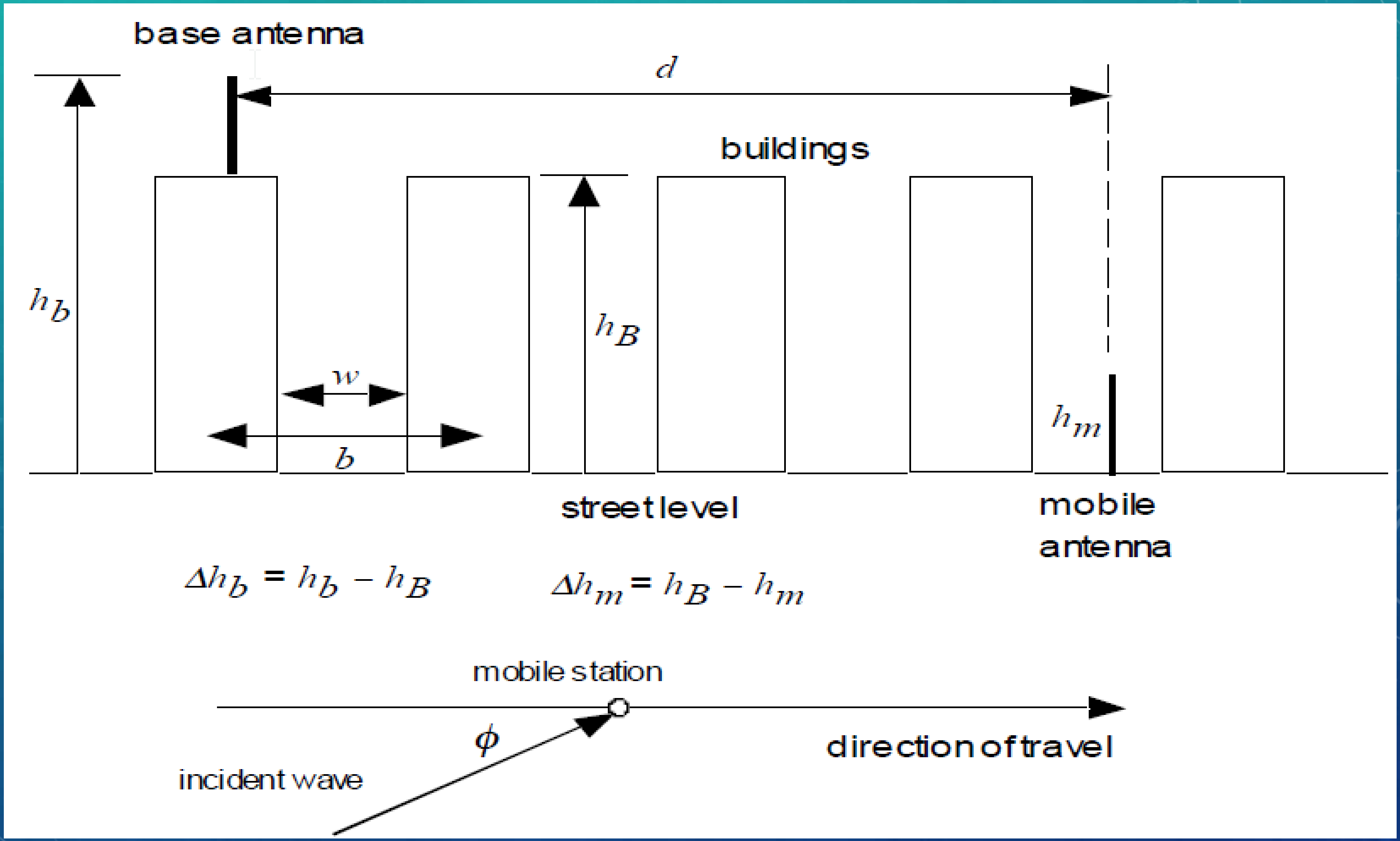
- Free Space Model (for comparison)
- CCIR Model
- Hata Models
- Walfisch-Ikegami Models (WIM)
- (more!)

Reference for following - http://w3.antd.nist.gov/wctg/manet/calcmodels_dstlr.pdf

"MORE"


ECC33
CCIR
Rural Hata
Zhang-Moayeri
Kanatas
Davidson
Sridhara
Green-Obaidat
Ikegami
3D
2D
Dominant Path
deSouza-Lins
6-Ray
Erceg-Greenstein
Many-Ray Models
Piazzi
COST-Hata
Okumura-Hata
IMT-2000
Herring
Flat-Edge
Egli
Foundational Models
Terrain Models
TM90
Basic Models
Path Loss Models
Walfisch-Bertoni
ITU-R 452
Allsebrook-Parsons
ITU Terrain
Friis
Blomquist-Ladell
Bullington
Walfisch-Ikegami
Robinson
ITM
Supplementary Models
Two-Ray
Flexible Alpha
Simple Mapping
Measurement Based/Corrected Models
Lognormal
Rollabout
Stochastic Fading Models
WC Lee
Ricean
Obstructions
Frequency Mismatch
Directivity
Evans
Rayleigh
m-Nakagami
Interpolating/Mapping Models
Riback-Medbo
Partition Models
EDAM
GRF
Barclay-Okumura
Zvanovec
Dall'Anese
Leichty
ITU-R 676
Atmospheric Gases
Diffraction
Vegetation
Statistical Terrain/Clutter Correction
Durgin-Rappaport
Xiang
Geostatistical Models
Riihijarvi
UTD
Vogler
ITU-R 833
Delisle
Torrico
Konak

PHYSICAL ENVIRONMENT PATH LOSS VARIABLES



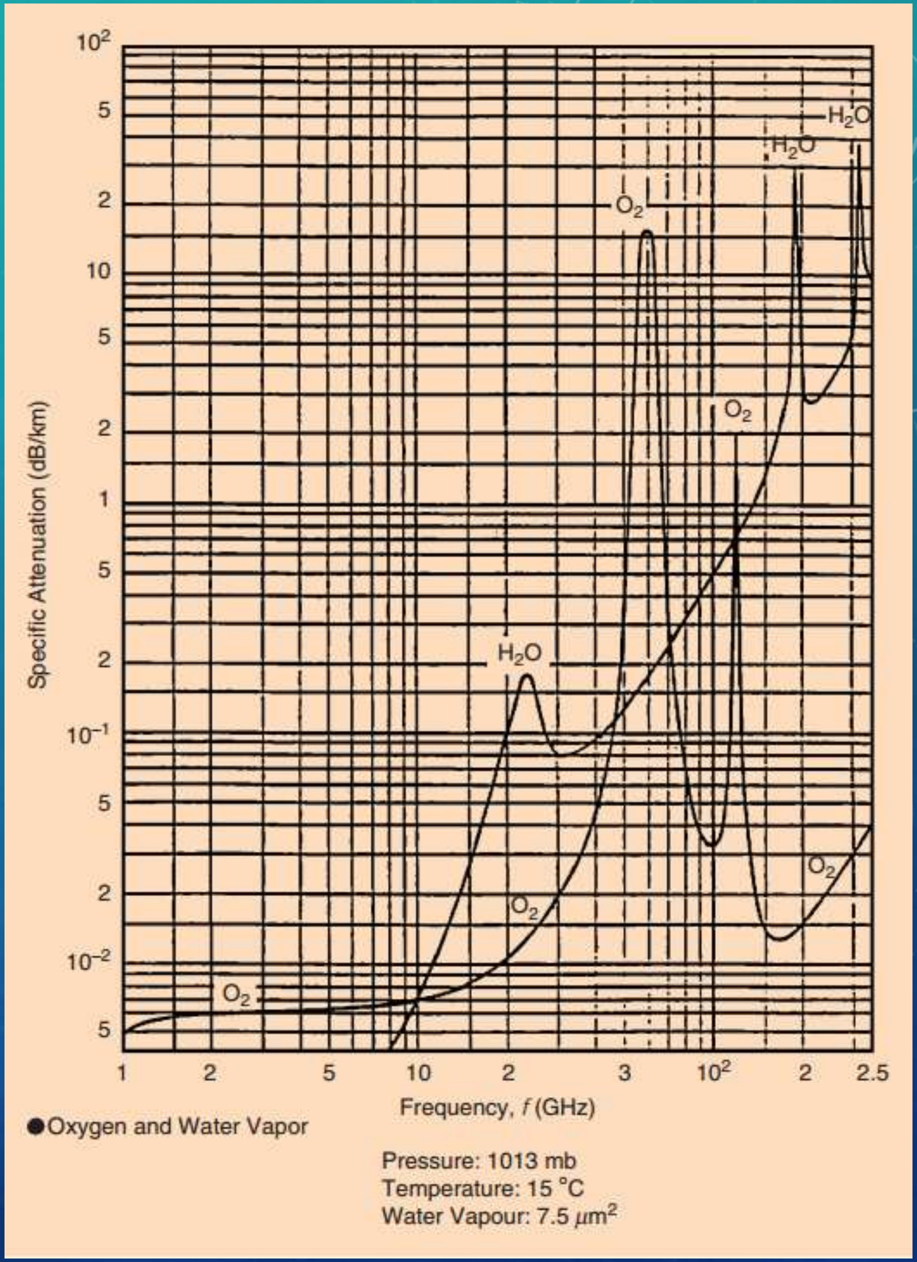
No trees in this model?

FREE SPACE PATH LOSS (FAR FIELD)

FSPL = 10 LOG(d) +20 LOG(f) + 32.45

LOG –> BASE 10 LOG AND UNITS OF km AND METERS

NOTE: FREQUENCY DEPENDENCY IS DUE TO THE DERIVATION OF THE FORMULA (CONSTANT RECEIVE ANTENNA GAIN) AND NOT PROPAGATION EFFECTS



CCIR PATH LOSS MODEL (L_{CCIR})

An empirical formula for the combined effects of free-space path loss and terrain-induced path loss was published by the CCIR (Comite' Consultatif International des Radio-Communication, now ITU-R):

$$Lccir = 69.55 + 26.16Log_{10}(f_{MHz}) - 13.82Log_{10}(h_b) - a(h_m) + [44.9 - 6.55Log_{10}(h_b)]Log_{10}(d_{km}) - B$$

- Where:
- $a(h_m) = [1.1Log_{10}(f_{MHz}) - 0.7]h_m - [1.56Log_{10}(f_{Mhz}) - 0.8]$
- $B = 30 - 25Log_{10}$(% of area covered by buildings)

Note: B = 0 when 15% covered

OKUMURA-HATA PATH LOSS MODELS (L_{HATA})

based on the CCIR model and following extensive measurements of urban and suburban radio propagation losses, published as sets of curves (150-1500/3000 MHz).

Empirical curves were subsequently reduced to a set of formulas known as the Hata models that are widely used in the industry. The CCIR and Hata models differ only in the effects of the mobile antenna and area coverage. There are four Hata models: Open, Suburban, Small City, and Large City.

$L_{hata} = 69.55 + 26.16Log_{10}(f_{MHz}) - 13.82Log_{10}(h_b) - a(h_m) + [44.9 - 6.55Log_{10}(h_b)]Log_{10}(d_{km}) - K$ where

Type of Area	$a(h_m)$	K
Open	$[1.1Log_{10}(f_{MHz})-0.7]h_m - [1.56Log_{10}(f_{Mhz})-0.8]$	$4.78[Log_{10}(f_{MHz})]^2 - 18.33Log_{10}(f_{MHz}) + 40.94$
Suburban		$2[Log_{10}(f_{MHz}/28)]^2 + 5.4$
Small City		0
Large City	$3.2[Log_{10}(11.75h_m)]^2 - 4.97$	0

Note – original data from H_b > 30 m

WALFISCH-IKEGAMI PATH LOSS MODELS (L_{WIM})

- WIM has been shown to be a good fit to measured propagation data for frequencies in the range of 800 to 2000 MHz and path distances in the range up to 5 km.
- The WIM distinguishes between Line Of Sight (LOS) and NLOS propagation situations.

In a LOS situation where the base antenna height is greater the 30 meters ($h_b \geq 30$) and there is no obstruction in the direct path between the transmitter and the receiver, the WIM path loss model for LOS is:

$$L_{wim\text{-}los} = 42.64 + 26Log_{10}(d_{km}) + 20Log_{10}(f_{MHz})$$

WIM (CONTINUED) – FOR NLOS PATHS

For non-LOS paths the total transmission loss equals the sum of:

- Free space loss
- Diffraction loss from rooftop to street
- Multiple screen diffraction past rows of buildings

The first two are independent of “base station” antenna height while the last component depends on whether the antenna is at, below, or above, the building height. Formula has several “it depends” factors.

There is another factor K_f that depends on whether it is a “Small City” or a “Large City”

(Detailed formulas can be found in the references)

PATH LOSS CALCULATOR "PROPCALC" FROM NIST

	Link distance (km)	10						
	Propagation model	CCIR	Hata-l. city	Hata-s. city	Hata-suburb	Hata-open	WI-LOS	WI-NLOS
	Loss (dB)	144.8	166.8	149.8	136.9	116.2	136.2	222.4
INPUT PARAMETERS (see diagram below)								
Frequency in MHz		*fMHz*	2400	Enter these	parameters or accept			
Physical antenna height 1 in m		*hb*	22		the default values			
Physical antenna height 2 in m		*hm*	10		already given.			
Percentage of buildings		%	10	for CCIR model				
WIM building height		*hB*	40	for Walfisch-Ikegami non-line-of-sight (NLOS) model				
WIM building separation		*b*	40	"				
WIM street width		*w*	20	"				
WIM angle		phi	28	"				
WIM NLOS environment			Other	Enter either "Large City" or "Other" (without the quotes)				

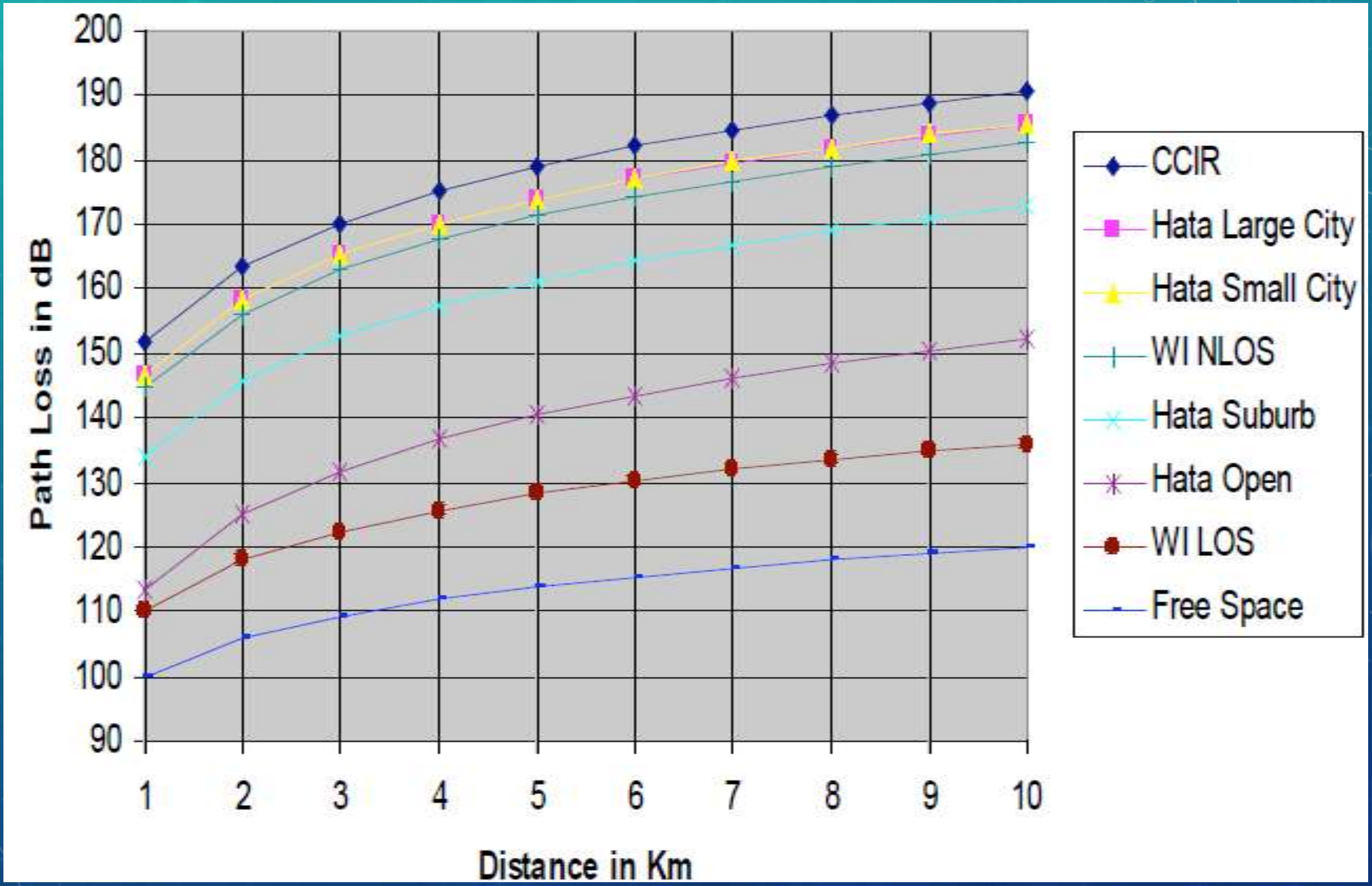
RAISING THE LOWER ONE OF THE TWO ANTENNAS HAS A MAJOR EFFECT ON PATH LOSS

HEIGHT 2	HATA-S.
5	152
10	137
15	122
20	107

Quad copter drone application!

CALCULATED LOSS FOR DIFFERENT MODELS

2350 MHz Hb=8m, Hm=1m, 25% BUILDINGS



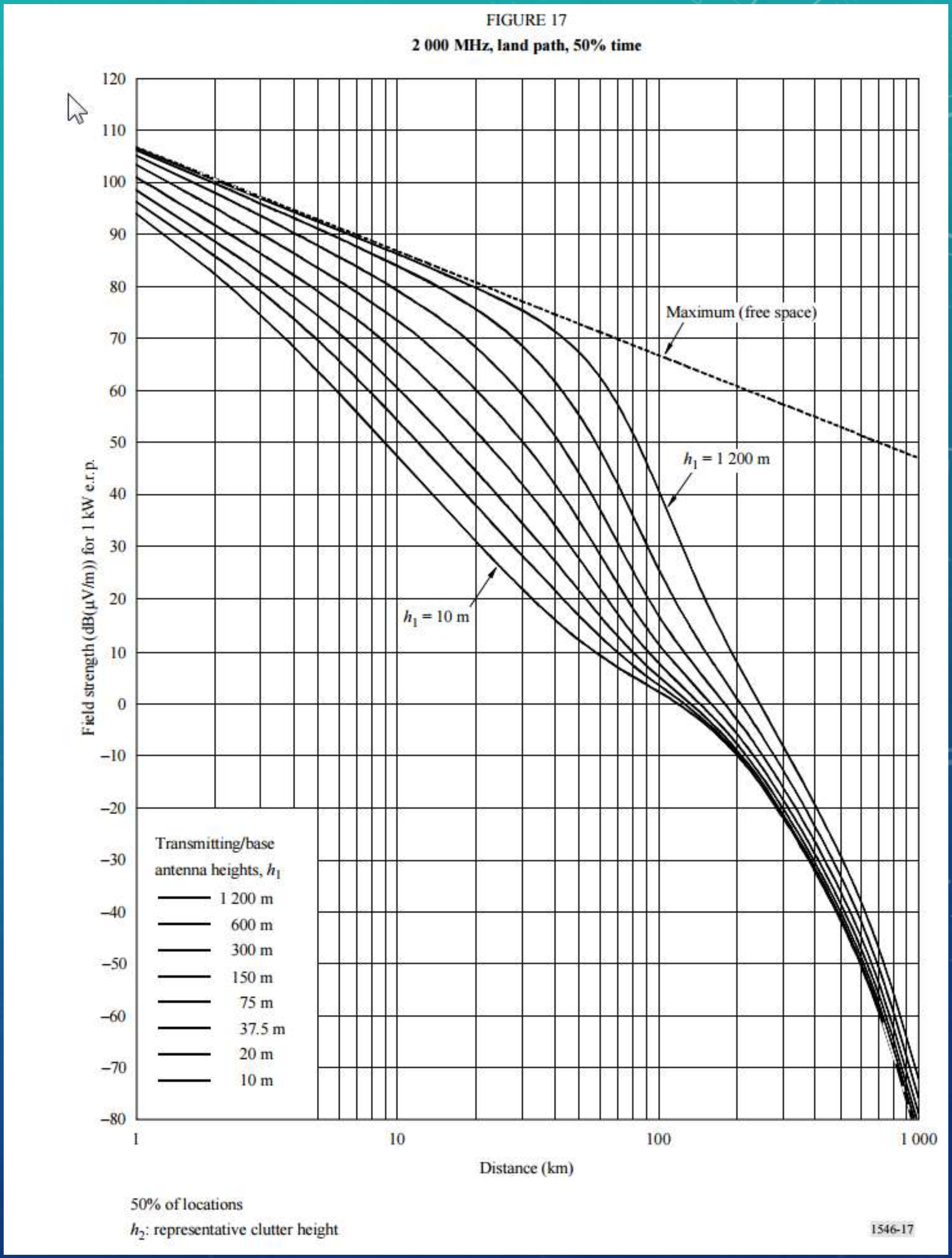
CAUTION- THESE CALCS BY “OTHERS”

ONE MORE REFERENCE: ITU-R P.1546-1

Calculating equivalent loss for 10 km and 20 m high 'base' antenna (h_1) the curve indicates about 101 dB loss @ 2 GHz or about 110 dB at 2.4 GHz (plus and minus a standard deviation).

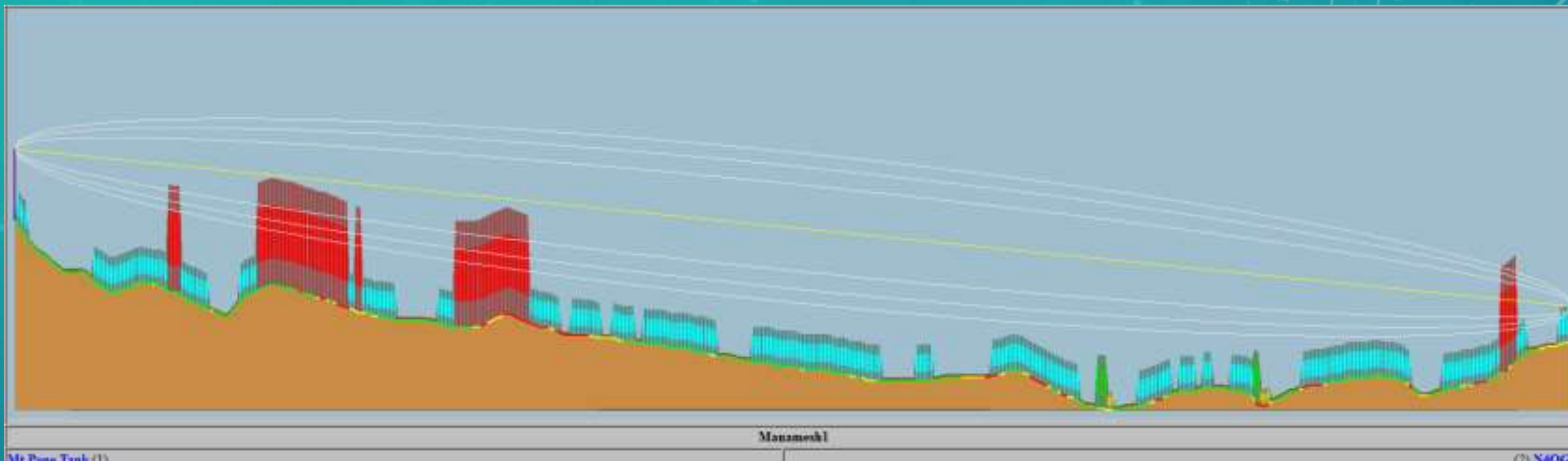
Mountain-top "base station" can buy you a lot of gain.

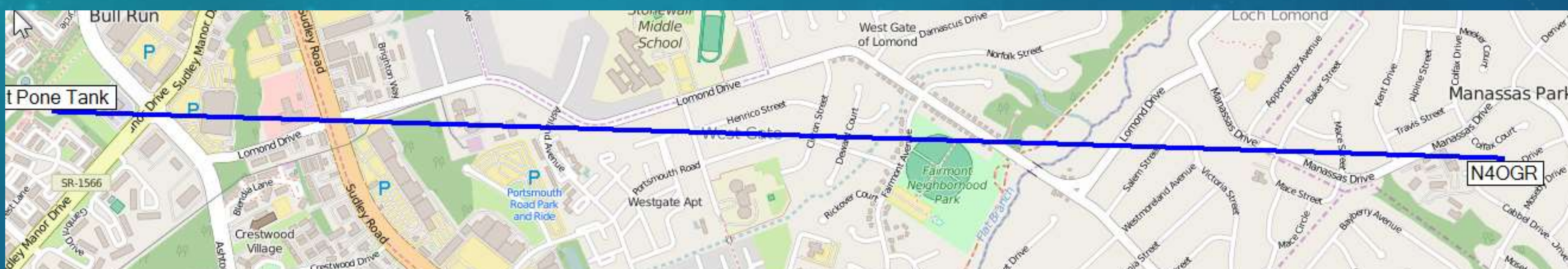
h_2 is at 'clutter' height which is 10-30 m depending on environs
'Gently rolling terrain' is assumed.

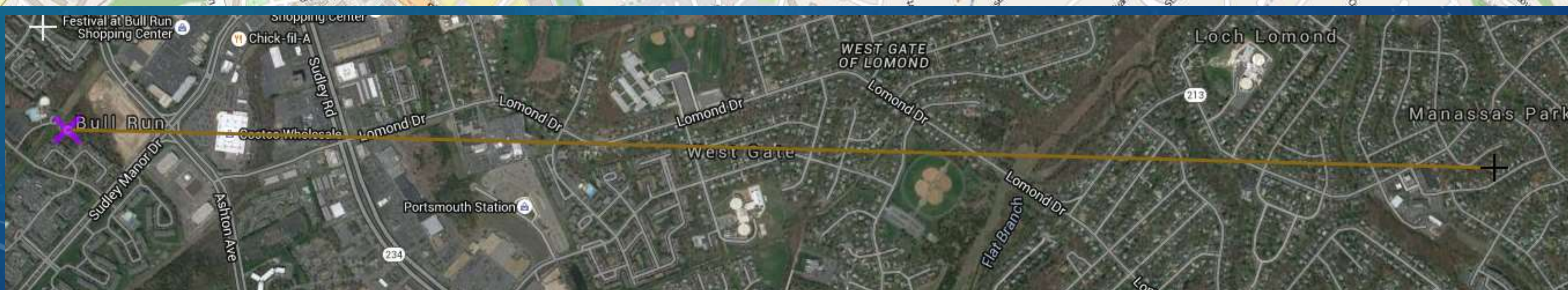


RADIOMOBILE ONLINE – MT. PONE TO N4OGR

Plot is for h2=10 m.







MT PONE – N4OGR: ONLINE RM RESULTS

h_2 m.	RM 2ray	RM 1ray	PC h.s.
5	125	126	140
10	129	123	125
15	118	122	110
20	127	121	95
25	118	120	80

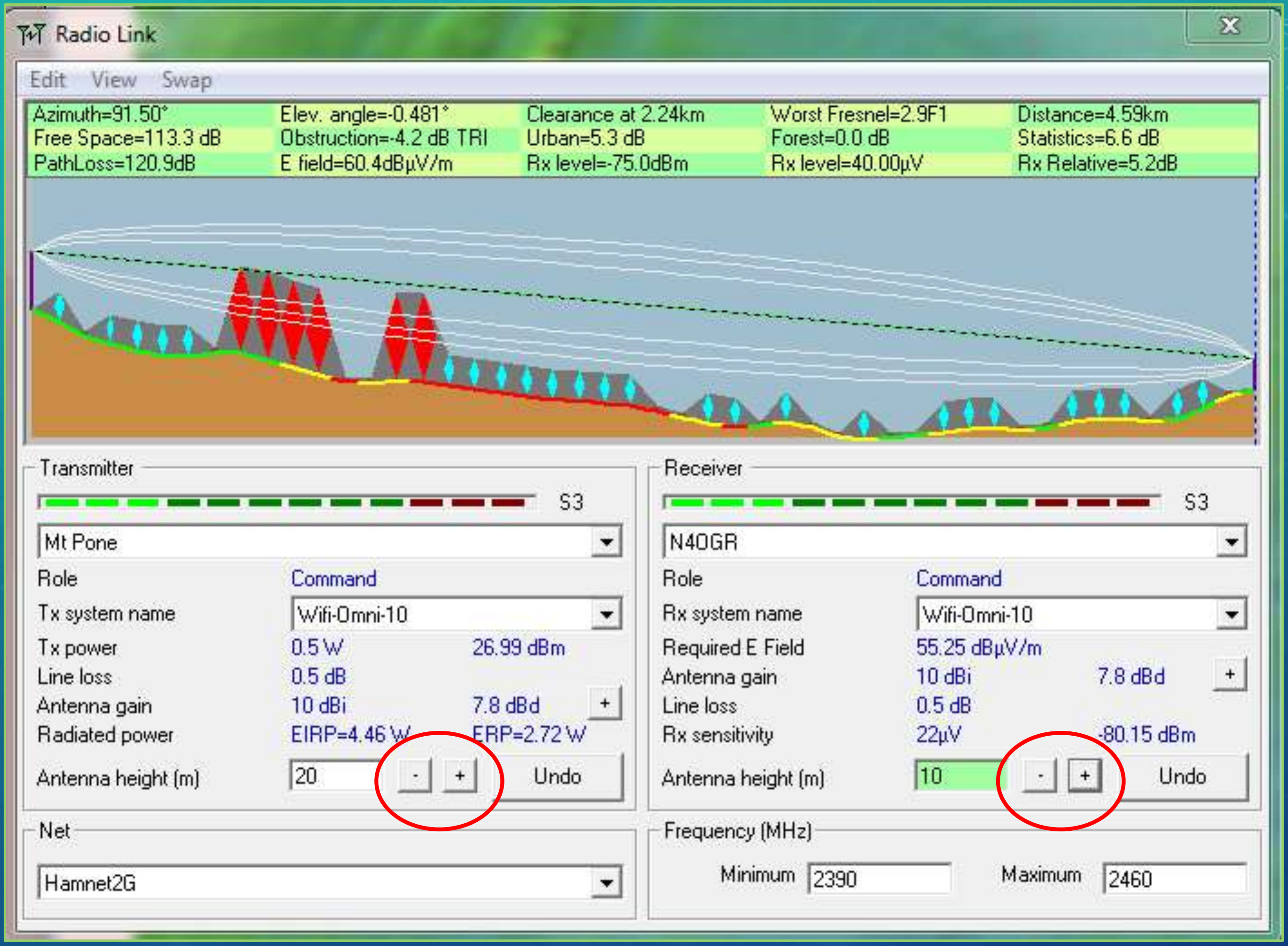
h.s. = Hata Suburban

'118' dB CASE:

Free space loss	112.80	dB
Obstruction loss	-4.25	dB
Forest loss	0.00	dB
Urban loss	2.61	dB
Statistical loss	6.57	dB
Total path loss	117.73	dB

Negative obstruction loss comes from 2-ray/normal model
Can also result in some very deep nulls over small height changes

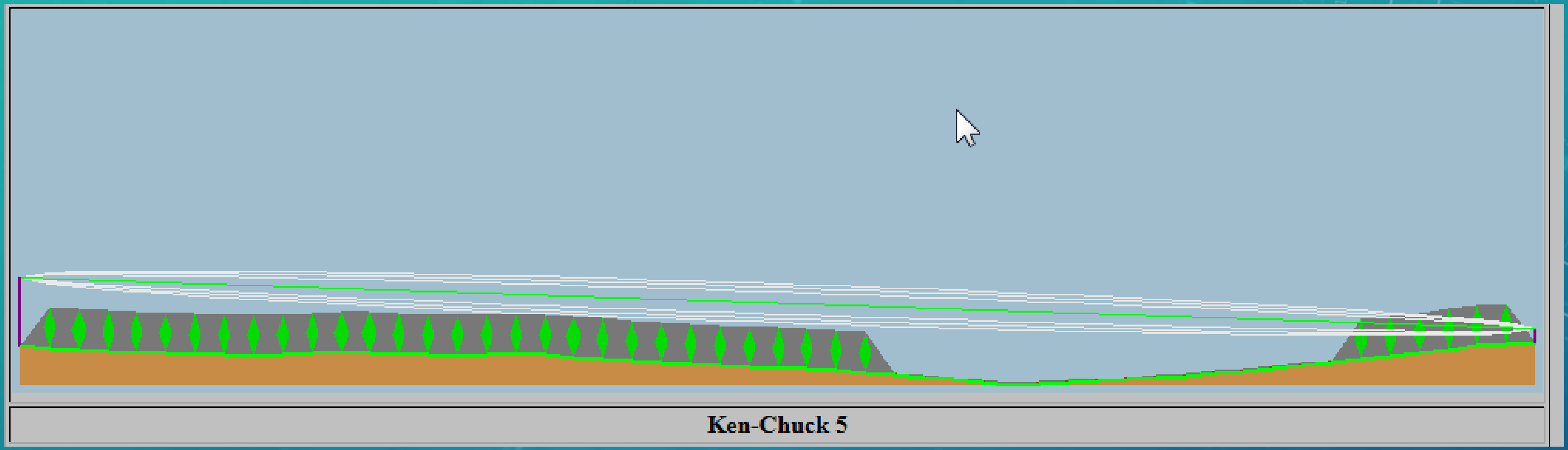
FOR COMPARISON – OFF LINE (PC) MODEL



NICE FEAURE: UP/DOWN BUTTON FOR ANTENNA HEIGHT

Manassas has no forest or woodland – only urban lo/hi – in this path

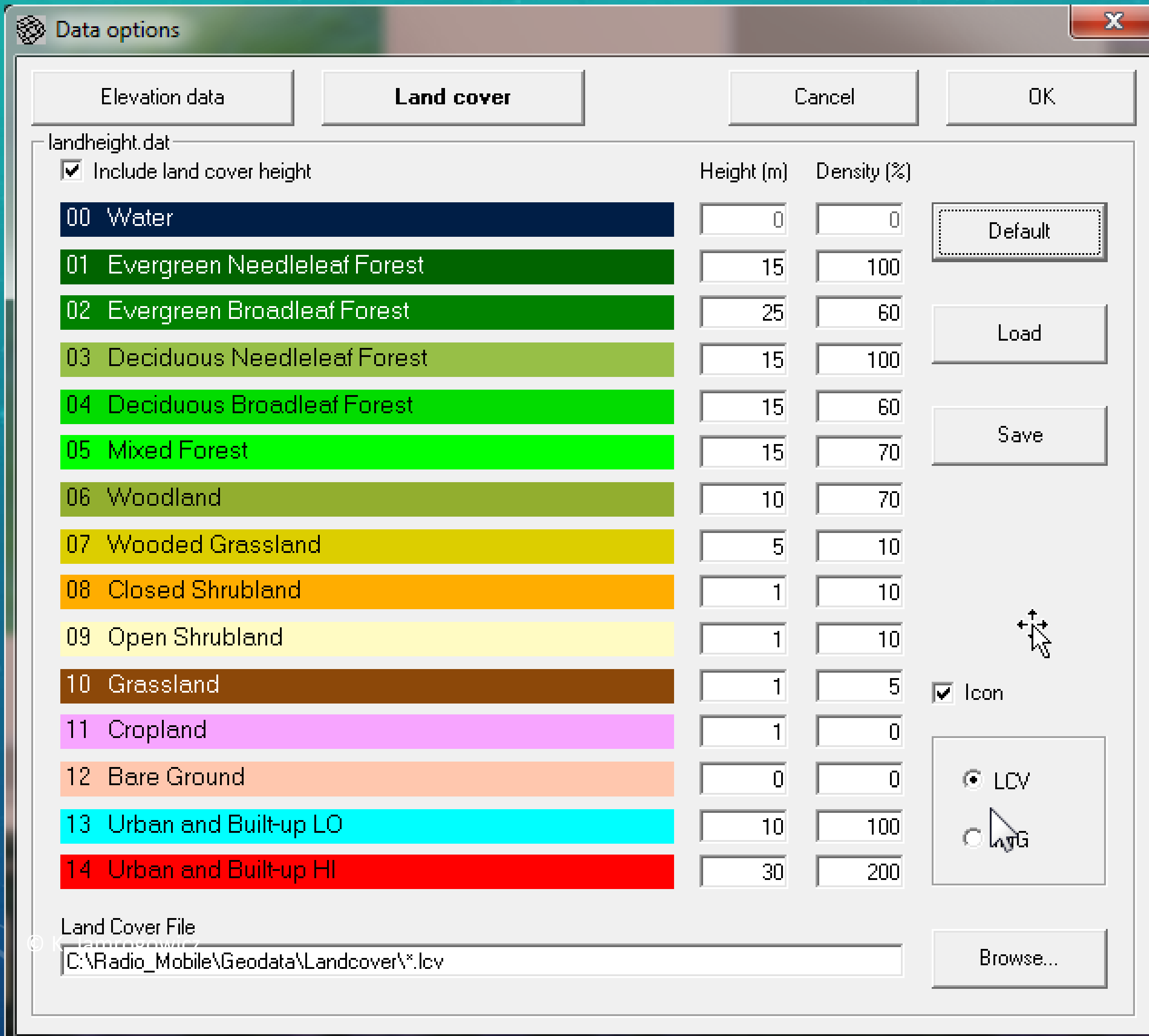
ANOTHER: RADIOMOBILE KE2N-W4XP



h_2	loss	Forest
5	103.46	2.96
10	102.68	2.18
15	100.5	0
20	100.5	0
25	100.5	0

DISTANCE = 0.515. Km
FREQ 2310 MHZ

LANDCOVER DATA – PC VERSION



DETAILED DATA AVAILABLE FOR USA.

BUT RESOLUTION IS STILL LIMITED AND CHOICES ARE “EITHER/OR”

But you can ADJUST

THE INSTALLED VERSION (AS OPPOSED TO ON LINE) ALLOWS TWEAKING ABSORPTION VALUES BUT…

“ field test results (3.5 GHz):

- #1 : LOS 5km -50 RSSI
- #2 : 165m broadleaf trees -80 RSSI (forest = 30 db)
- #3 : 365m broadleaf trees -95 RSSI (forest = 45 db)
- Here is what RM gives me with density set at 1000%:
- #1 : 0 db
- #2 : 15.1 db
- #3 : 20.8 db
- Our calculation shows that we have to boost the density over 2000% to represent the real forest attenuation.
- The problem : Radio Mobile won't accept density over 1000%.”

Recent RM yahoo group posting

FINAL NOTE: CHECKING FOR OBSTRUCTIONS

- IN 'HEYWHATSTHAT' CLICKING ON THE PROFILE TAKES YOU TO THAT POINT ON A SATELLITE MAP WHERE YOU CAN DO A VISUAL EXAMINATION. THIS CAN BE VERY IMPORTANT – NOT AVAILABLE IN RADIOMOBILE

MURPHY'S LAW: WATER TANKS AND HIGH RISE BUILDINGS TEND TO BE LOCATED ON LOCAL HIGH SPOTS

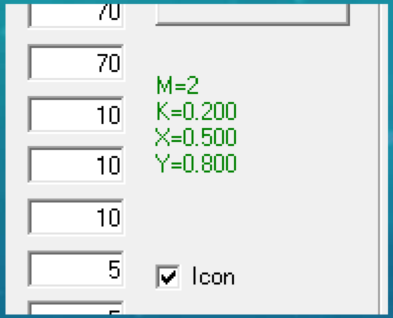
SUMMARY

- RADIOMOBILE UNDERESTIMATES THE EXCESS PATH LOSS DUE TO LOCAL CLUTTER (AS STATED IN THE INSTRUCTIONS).
- THE TWO-RAY MODEL SHOULD BE USED WITH CARE (I.E. ONLY IN CASES WHERE A SINGLE GROUND REFLECTION PREDOMINATES). “INTERFERENCE” MODE MORE REALISTIC THAN “NORMAL” MODE. (2-ray is default for LOS but can be de-selected).
- THE HATA MODELS DO NOT CONSIDER TOPOGRAPHY, BUT SEEMS TO TAKE INTO ACCOUNT GROUND CLUTTER IN A MORE REALISTIC WAY THAN THE DEFAULTS IN RM.
- RADIOMOBILE DOES NOT FACILITATE EXAMINATION OF THE SATELLITE MAP
- “HEYWHATSTHAT” PROVIDES AN EASY WAY TO IDENTIFY OBSTRUCTIONS FROM SATELLITE PHOTOGRAPHS. IF BASE PHOTOGRAPHY IS SUMMER SEASON (AND ESPECIALLY IF 3D) THEN A BETTER ASSESSMENT OF FOLIAGE IS POSSIBLE.

$\Rightarrow$ A COMBINATION OF TOOLS IS NEEDED TO GET A GOOD PATH EVALUATION

- COMMON SENSE ANSWER: DIRECT RAY BETWEEN ANTENNAS MUST BE CLEAR OF TREES FOR PATHS > 100 m FOR 2.4/3.4/5.9 GHZ.

POST MEETING NOTE:

- There is a hidden function in Radio Mobile allowing use of the CCIR 236-2 model for attenuation in obstructions. It is activated by adding one line at the end of the "landcover.dat" file.
- 

The parameters are type, multiplier, frequency exponent and distance exponent, respectively.
In this example:

Type (M) = 2 (CCIR)
Multiplier (k) = 0.2
Frequency exponent (x) = 0.5
Distance exponent (y) = 0.8

This formula applies to ALL obstructions. You can set a separate height (meters) and % number for each type of clutter, but not a different model.

Preliminary testing shows that much higher absorption can easily be simulated using this feature. But determination of the k, x, m factors is not straightforward.

EMPIRICAL FOLIAGE LOSS MODELS OF THE MODIFIED EXPONENTIAL DECAY (MED) TYPE

Model	Expression
Weissberger model [10]	$L_W\,(\text{dB}) = \begin{cases} 1.33 \times f^{0.284} d^{0.588} & 14\,\text{m} < d \leq 400\,\text{m} \\ 0.45 \times f^{0.284} d & 0\,\text{m} \leq d < 14\,\text{m} \end{cases}$ f is frequency in GHz, and d is the tree depth in meter
ITU-R model [11]	$L_{ITU\text{-}R}\,(\text{dB}) = 0.2 \times f^{0.3} d^{0.6}$ f is frequency in MHz, and d is the tree depth in meter ($d < 400\,\text{m}$)
COST235 model [12]	$L_{COST}\,(\text{dB}) = \begin{cases} 26.6 \times f^{-0.2} d^{0.5} & \text{out-of-leaf} \\ 15.6 \times f^{-0.009} d^{0.26} & \text{in-leaf} \end{cases}$ f is frequency in MHz, and d is the tree depth in meter
FITU-R model [13]	$L_{FITU\text{-}R}\,(\text{dB}) = \begin{cases} 0.37 \times f^{0.18} d^{0.59} & \text{out-of-leaf} \\ 0.39 \times f^{0.39} d^{0.25} & \text{in-leaf} \end{cases}$ f is frequency in MHz, and d is the tree depth in meter

"The generation of an accurate model, either empirical or analytical, requires input parameters that are difficult to acquire. These parameters include any combination of the following: height of vegetation, leaf state, vegetation density, trunk size, leaf size, and canopy height"

http://www3.ntu.edu.sg/home/eyhlee/Prof%20Lee/PIER%20foliage%20review%202010.pdf

ON LINE REFERENCES

- http://www.utexas.edu/research/mopro/papercopy/chapter02.pdf
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- https://www.itu.int/rec/R-REC-P.833-8-201309-I/en
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- http://w3.antd.nist.gov/wctg/manet/calcmodels_dstlr.pdf
- http://radiomobile.pe1mew.nl/
- http://radiomobile.pe1mew.nl/?The_program:Options_menu:Elevation_data_%26gt%3B_Land_cover
- https://help.ubnt.com/hc/en-us/articles/204952114-airMAX-Where-can-I-find-antenna-pattern-data-