Project	**IEEE 802.16 Broadband Wireless Access Working Group <http://ieee802.org/16>**
Title	**Propagation in the frequency range 2-11 GHz**
Date Submitted	**2001-11-15**
Source(s)	G. Jack Garrison Harris Corporation #409-1230 Quayside Drive New Westminster B.C. Canada V3M 6H1 Voice: +1 604 524 6980 Fax: +1 604 524 6980 mailto:gjg@telus.net
Re:	Analysis of propagation and fading mechanisms in systems operating in the frequency range 2-11 GHz.
Abstract	This paper provides an analysis of the important propagation and fading mechanisms for systems operating in 2.5 GHz, 3.5 GHz and 10.5 GHz bands. It identifies the dominant fading mechanism in each type of system and provides examples of link budget calculations.
Purpose	To assist in the decision process for TG2 system parameters used in coexistence analysis and to provide source material for TG3 system designeres.
Notice	
Release	
Patent Policy and Procedures	

Propagation in the frequency range 2-11 GHz.

Some Notes on Sub-11 GHz
Transmission Link Considerations

Objectives

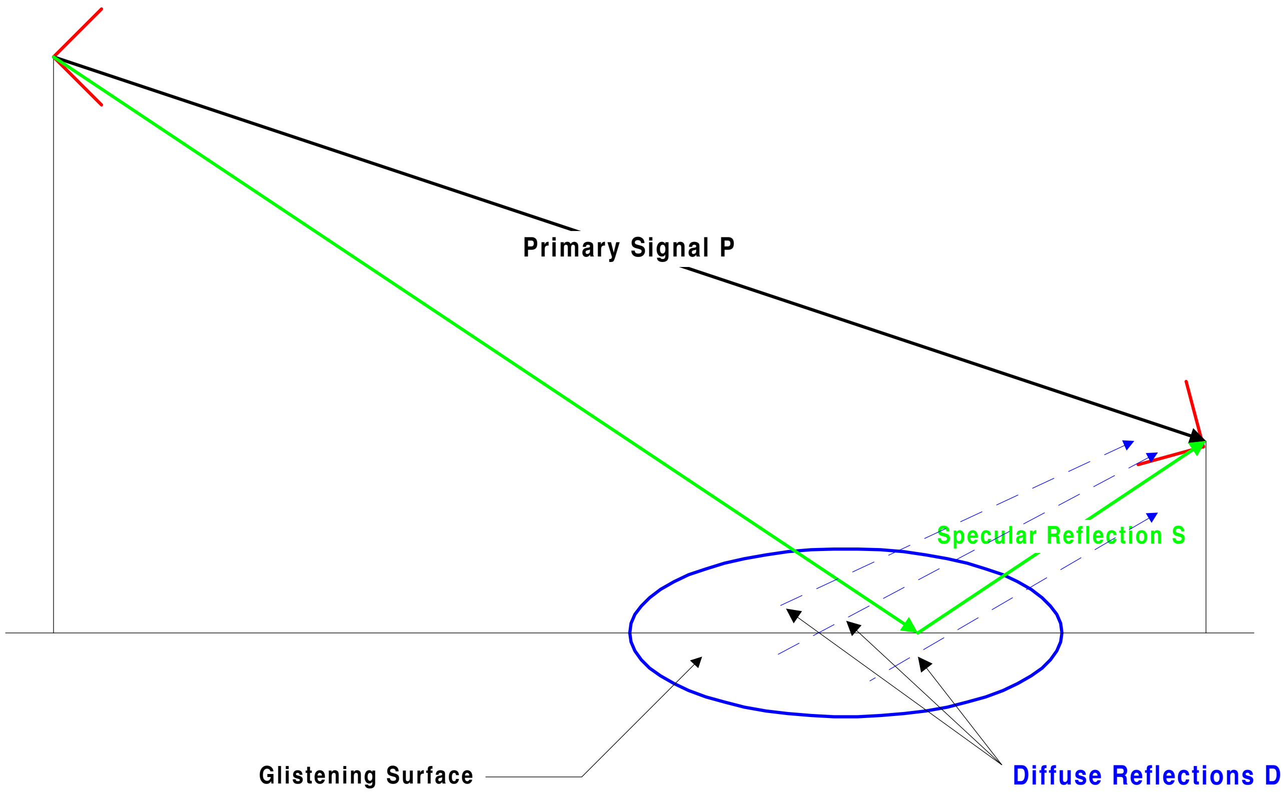
- **Identify Constraints on Channel Models to Ensure that TG3 Link Availability Objectives are Achieved (99.9/99.99 %)**
- **Establish Link Margin Limits so that Coexistence C/I Objectives can be Defined**

Rician Fading
(Tutorial Review)

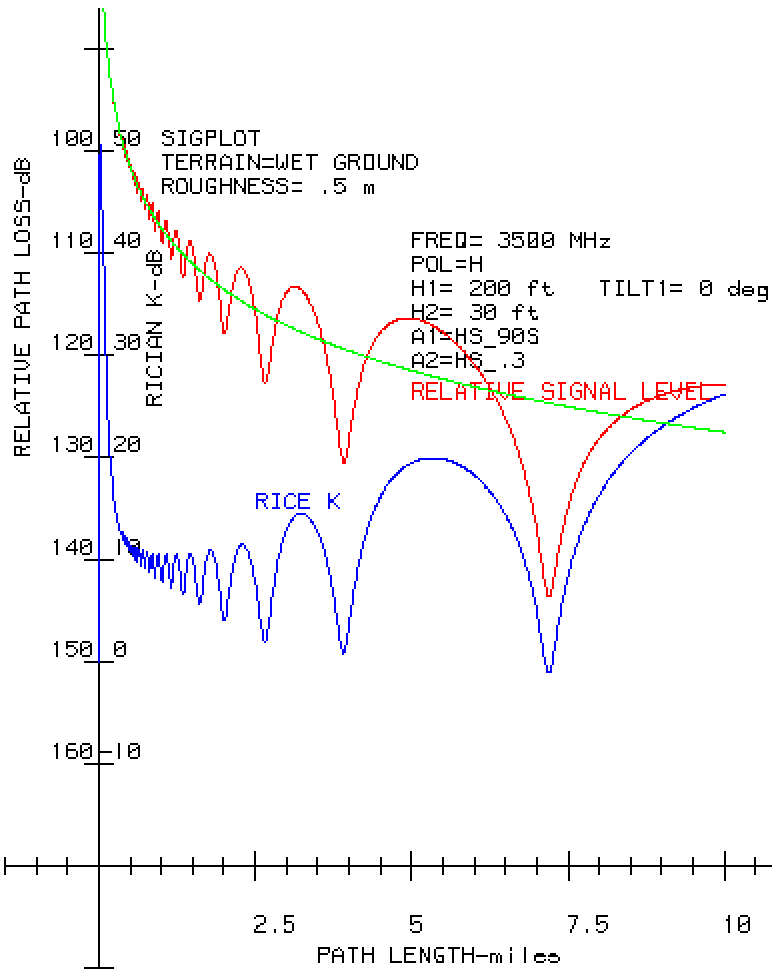
Example 1

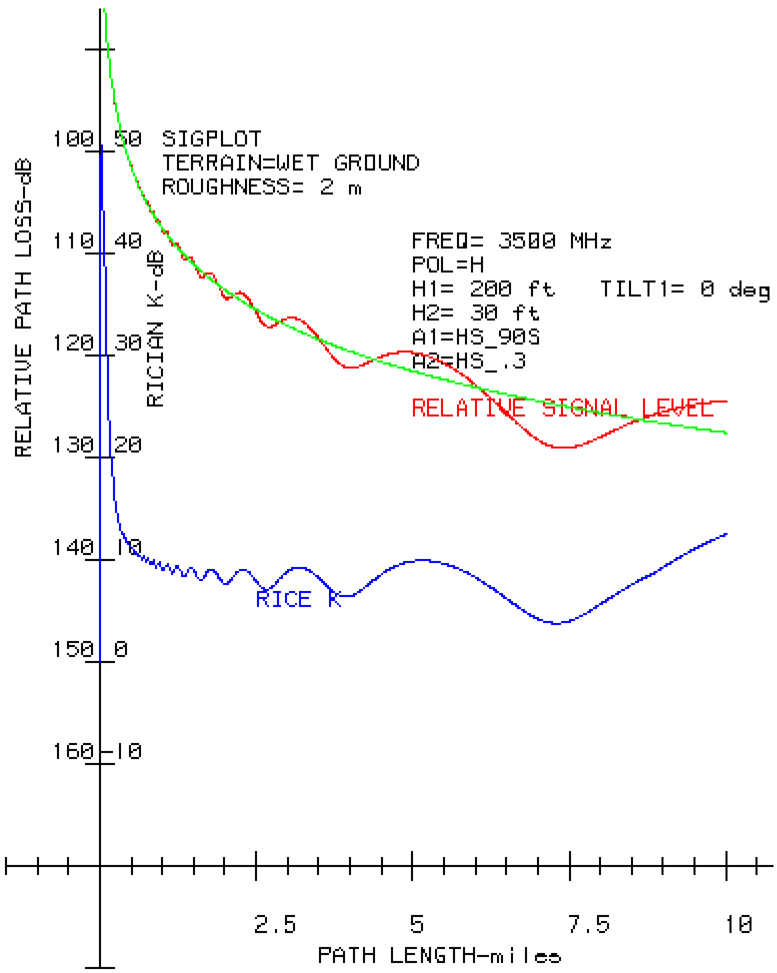
Reflections from a Spherical Earth

- Analytical Method
- Geometry and Antenna Patterns
- Terrain Type and Reflection Coefficient
- Terrain Roughness to Compute Specular and Diffuse Reflections

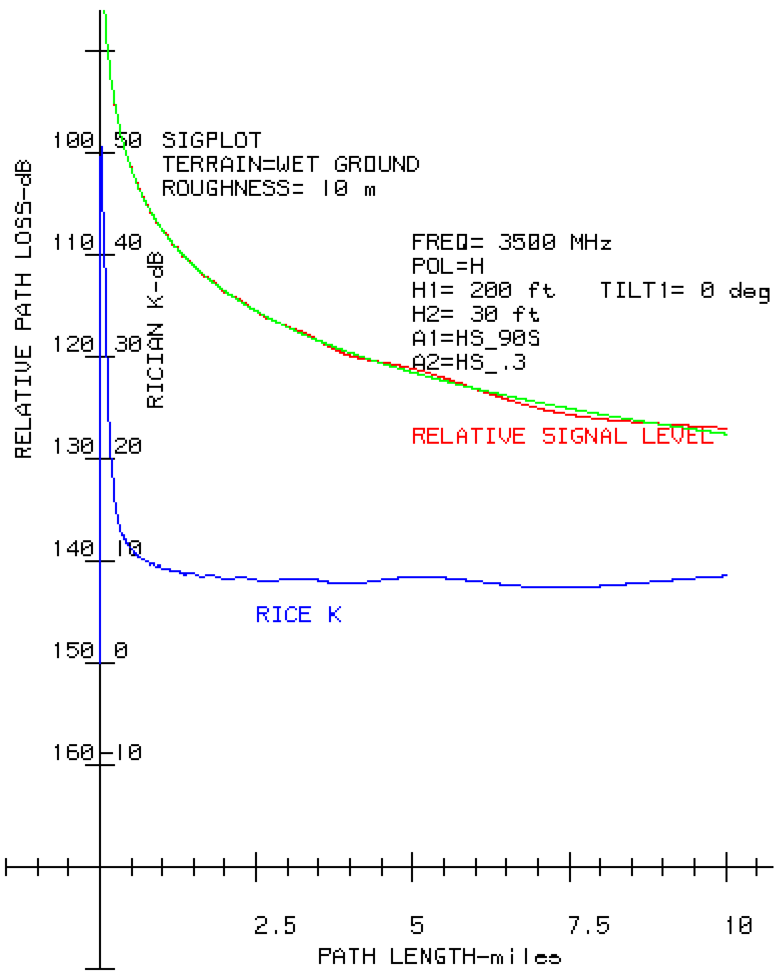


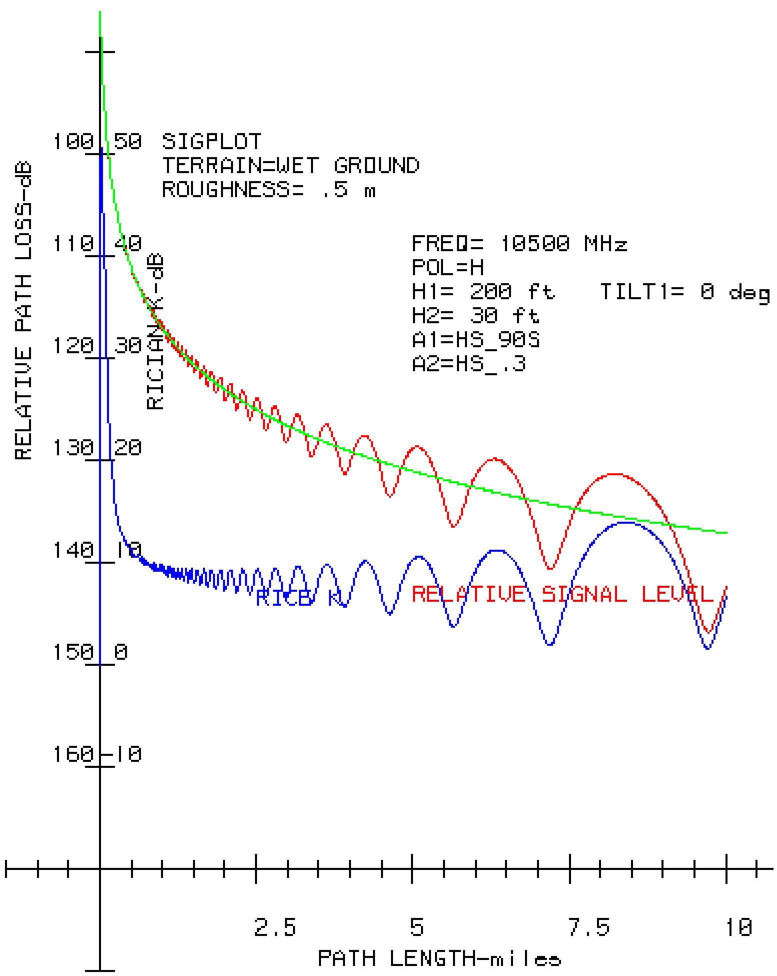
$$\text{Rice } K = \frac{(P+S)^2}{\sum_{j=1}^{j_{\max}} D(j)^2} \qquad \text{(power ratio)}$$

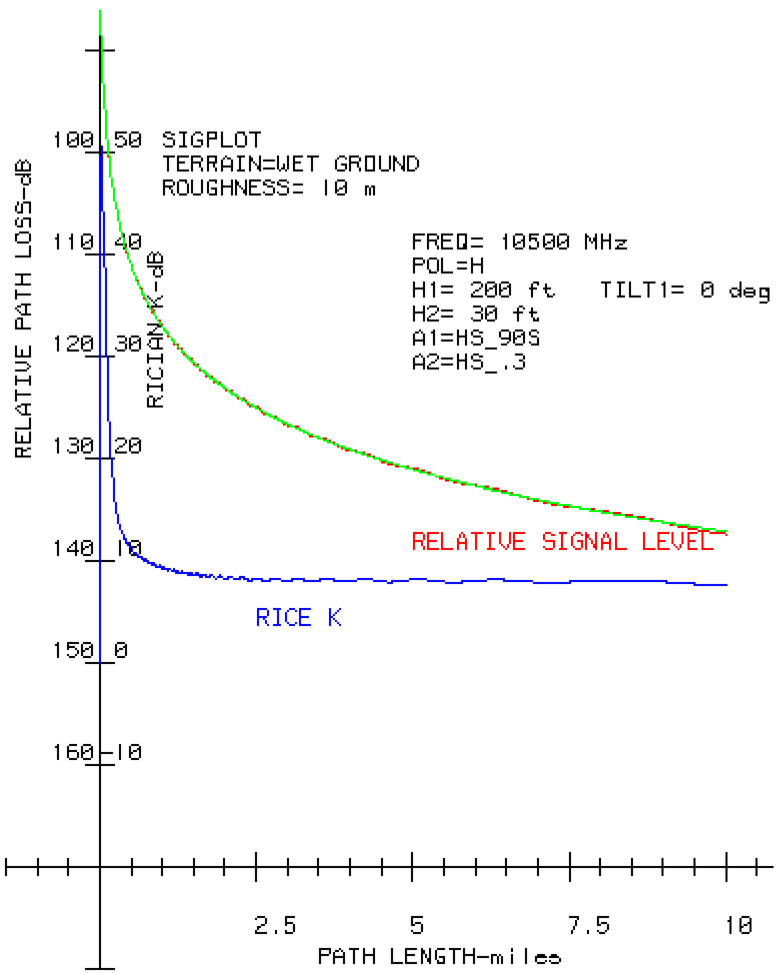

SIGPLOT
TERRAIN=WET GROUND
ROUGHNESS= .5 m
FREQ= 3500 MHz
POL=H
H1= 200 ft TILT1= 0 deg
H2= 30 ft
A1=HS_90S
A2=HS_.3
RELATIVE SIGNAL LEVEL
RICE K
RELATIVE PATH LOSS-dB
RICIAN K-dB
100 50
110 40
120 30
130 20
140 10
150 0
160 -10
2.5
5
7.5
10
PATH LENGTH-miles



SIGPLOT
TERRAIN=WET GROUND
ROUGHNESS= 2 m
FREQ= 3500 MHz
POL=H
H1= 200 ft TILT1= 0 deg
H2= 30 ft
A1=HS_90S
A2=HS_.3
RELATIVE SIGNAL LEVEL
RICE K
RELATIVE PATH LOSS-dB
RICIAN K-dB
100 50
110 40
120 30
130 20
140 10
150 0
160 -10
2.5
5
7.5
10
PATH LENGTH-miles


SIGPLOT
TERRAIN=WET GROUND
ROUGHNESS= 10 m
FREQ= 3500 MHz
POL=H
H1= 200 ft TILT1= 0 deg
H2= 30 ft
A1=HS_90S
A2=HS_.3
RELATIVE SIGNAL LEVEL
RICE K
RELATIVE PATH LOSS-dB
RICIAN K-dB
100 50
110 40
120 30
130 20
140 10
150 0
160 -10
2.5
5
7.5
10
PATH LENGTH-miles


SIGPLOT
TERRAIN=WET GROUND
ROUGHNESS= .5 m
FREQ= 10500 MHz
POL=H
H1= 200 ft TILT1= 0 deg
H2= 30 ft
A1=HS_90S
A2=HS_.3
RELATIVE PATH LOSS-dB
RICIAN K-dB
RICE K
RELATIVE SIGNAL LEVEL
PATH LENGTH-miles
100 50
110 40
120 30
130 20
140 10
150 0
160 -10
2.5
5
7.5
10


SIGPLOT
TERRAIN=WET GROUND
ROUGHNESS= 10 m
FREQ= 10500 MHz
POL=H
H1= 200 ft TILT1= 0 deg
H2= 30 ft
A1=HS_90S
A2=HS_.3
RELATIVE PATH LOSS-dB
RICIAN K-dB
100 50
110 40
120 30
130 20
140 10
150 0
160 -10
RELATIVE SIGNAL LEVEL
RICE K
2.5
5
7.5
10
PATH LENGTH-miles

Example 2

Shooting Through the Urban Canopy

- TG3 Method
- Measurement Data
- Empirical Equation

$$K = F_s F_h F_b K_0 d^{\gamma} u$$

where

$F_s =$ seasonal factor, 1 in summer and 2.5 in winter

$F_h = \left(h_{rx} / 3\right)^{.46}$, receive antenna height factor, h_{rx} in meters

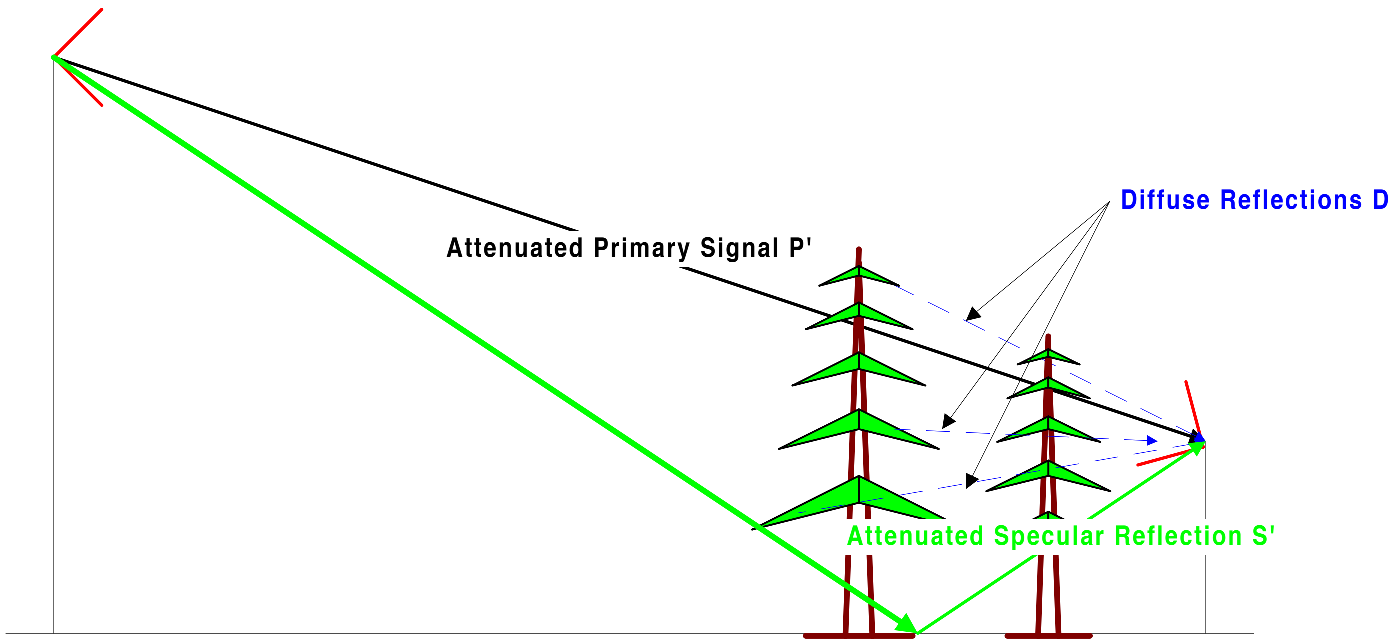
$F_b = \left(b / 17\right)^{0.62}$, antenna beamwidth factor, b in degrees

$d =$ distance in km

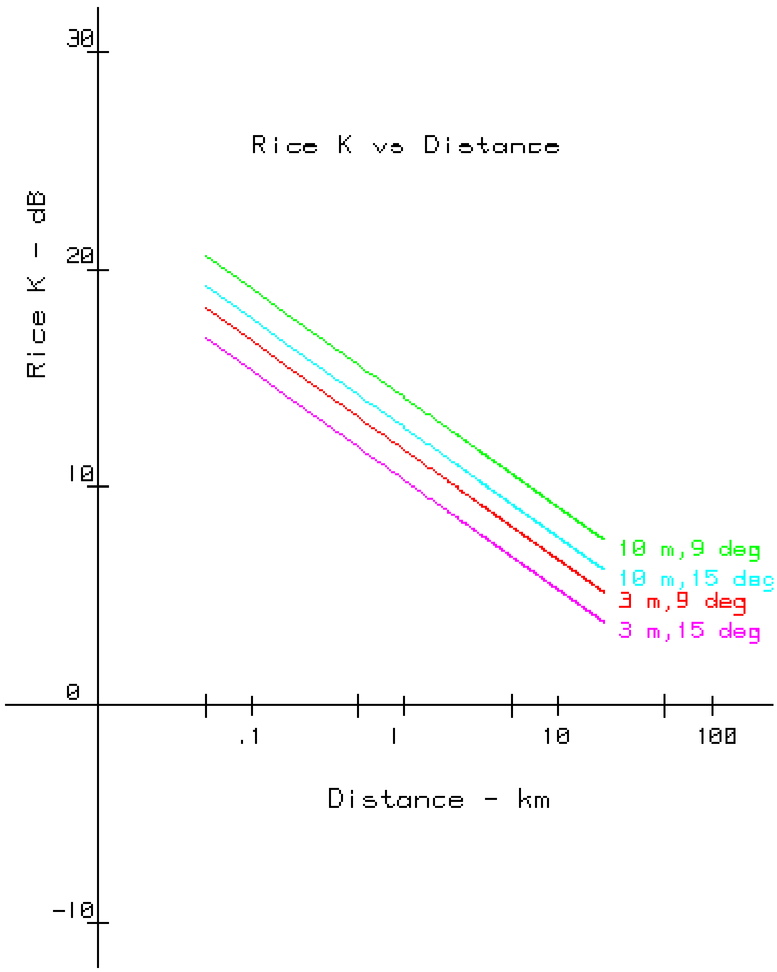
$\gamma = -0.5$

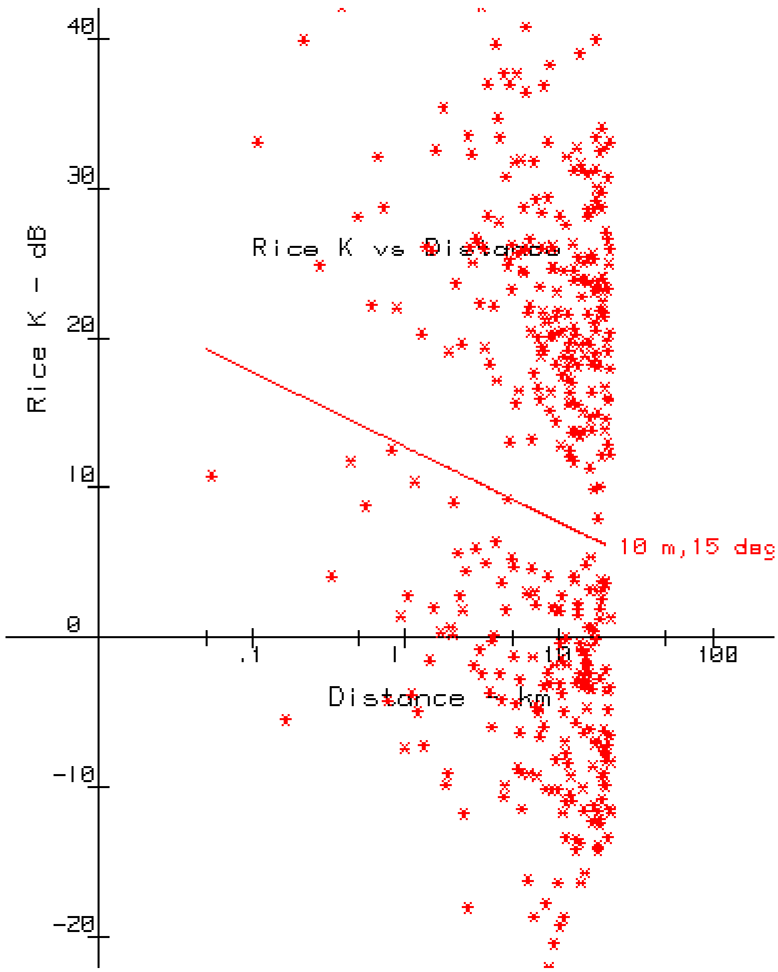
$K_0 = 10$ dB, 1 km intercept

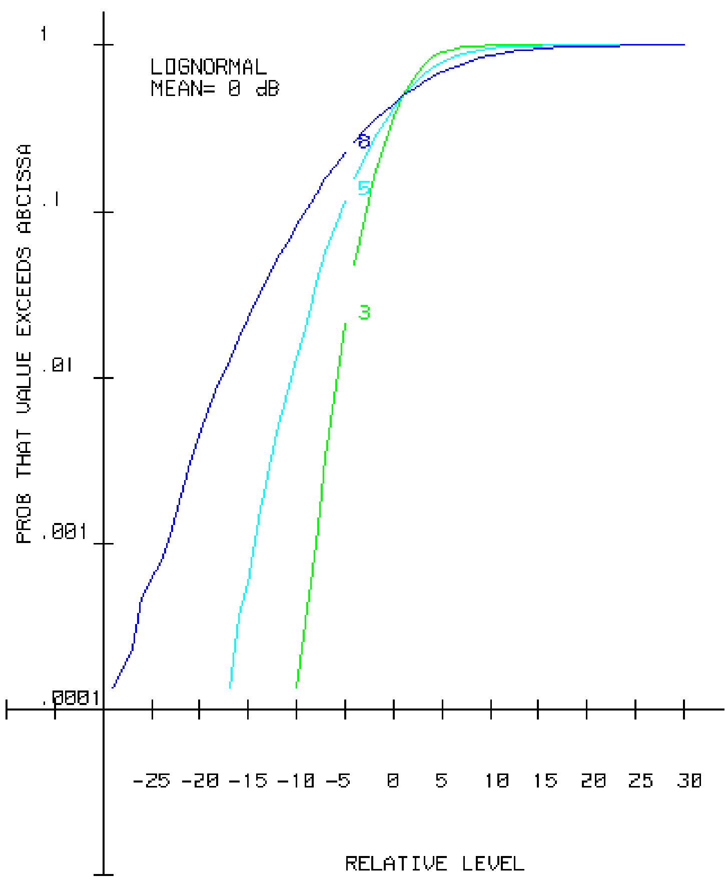
$u =$ zero - mean lognormal variate, 8 dB standard deviation over the cell area



$$\text{Rice } K = \frac{(P' + S')^2}{\sum_{j=1}^{j_{\max}} D(j)^2} \qquad \text{(power ratio)}$$


Rice K vs Distance
Rice K - dB
30
20
10
0
-10
.1
1
10
100
Distance - km
10 m,9 deg
10 m,15 deg
3 m,9 deg
3 m,15 deg


Rice K vs Distance
Rice K - dB
Distance - km
10 m,15 deg
40
30
20
10
0
-10
-20
.1
1
10
100


1
.1
.01
.001
.0001
LOGNORMAL
MEAN= 0 dB
8
5
3
PROB THAT VALUE EXCEEDS ABCISSA
-25 -20 -15 -10 -5 0 5 10 15 20 25 30
RELATIVE LEVEL

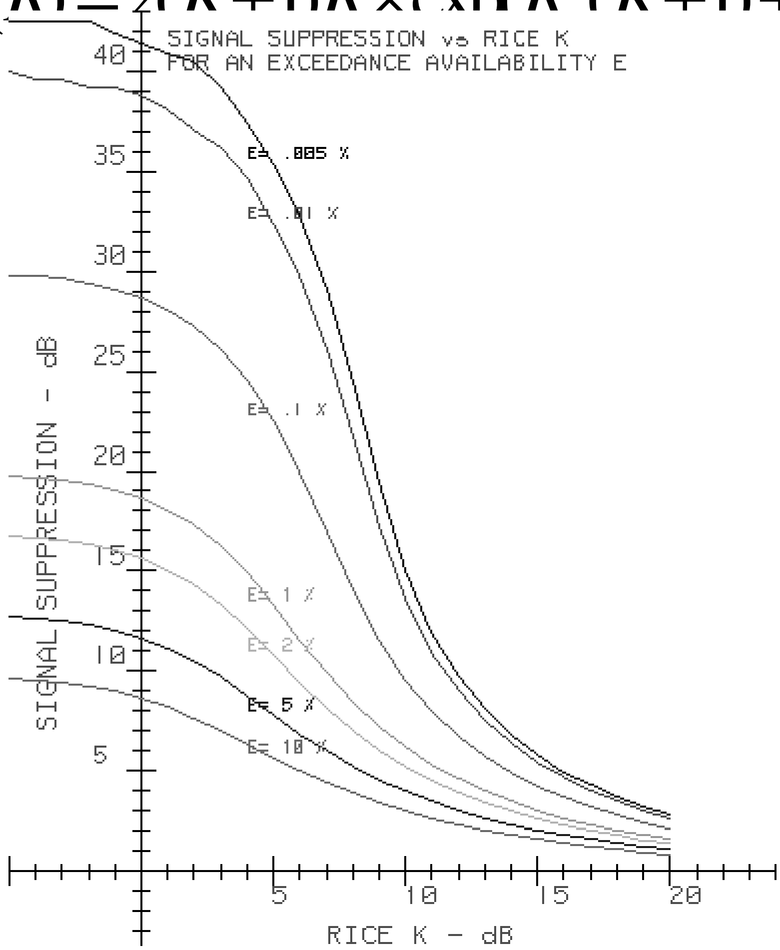
Signal Suppression vs K

R = Signal Suppression Ratio (voltage)

IF R = 0.1, this is a 20 dB fade

K = Rice Value (power)

$$p_r(R) = 2(K+1)R \times \exp(R^2(K+1)+K) \times I_0(2(R^2K(K+1))^{.5})$$



K (dB)	0	3	5	8	10	12	15	18	20	% Outage
	18	16.2	13.3	8.4	6.2	4.6	3	2	1.6	1
	19.1	16.7	13.7	8.6	6.3	4.7	3.1	2.1	1.6	0.9
	19.6	17.2	14.1	8.9	6.5	4.8	3.1	2.1	1.6	0.8
	20.2	17.8	14.6	9.2	6.7	4.9	3.2	2.2	1.7	0.7
	20.9	18.4	15.2	9.5	6.9	5.1	3.3	2.2	1.7	0.6
	21.7	19.2	15.9	9.9	7.1	5.2	3.4	2.3	1.8	0.5
	22.7	20.1	16.8	10.4	7.5	5.4	3.5	2.4	1.8	0.4
	23.9	21.4	18	11.1	7.9	5.7	3.7	2.5	1.9	0.3
	25.7	23.1	19.7	12.1	8.5	6.1	3.9	2.6	2	0.2
	28.6	26.1	22.6	14	9.5	6.7	4.3	2.8	2.1	0.1
	29.1	26.6	23	14.3	9.7	6.8	4.3	2.8	2.2	0.09
	29.6	27	23.5	14.6	9.9	7	4.4	2.9	2.2	0.08
	30.2	27.6	24.1	15	10.1	7.1	4.4	2.9	2.2	0.07
	30.9	28.3	24.7	15.5	10.3	7.2	4.5	3	2.3	0.06
	31.7	29.1	25.5	16.1	10.6	7.4	4.6	3	2.3	0.05
	32.6	30	26.5	16.8	11	7.6	4.7	3.1	2.4	0.04
	34	31.4	27.7	17.7	11.5	7.9	4.9	3.2	2.4	0.03
	35.7	33.2	29.5	19.1	12.2	8.3	5.1	3.3	2.5	0.02
	38.8	36.2	32.9	21.7	13.6	9	5.4	3.5	2.6	0.01
	39.2	36.5	33	22.2	13.8	9.1	5.5	3.5	2.7	0.009
	39.6	37.1	33.4	22.6	14	9.2	5.5	3.6	2.7	0.008
	40	37.7	34	23.1	14.3	9.4	5.6	3.6	2.7	0.007
	40.9	38.4	34.7	23.7	14.7	9.6	5.7	3.6	2.8	0.006
	41.4	39.2	35.4	24.4	15	9.7	5.8	3.7	2.8	0.005
	42.5	40	36.5	25.4	15.6	10	5.9	3.8	2.8	0.004
	43.7	41.4	37.7	26.6	16.2	10.3	6	3.8	2.9	0.003
	45.2	43.1	39.6	28.3	17.3	10.8	6.2	3.9	3	0.002
	48	46	42.5	31.2	19.2	11.6	6.6	4.1	3.1	0.001
	52	49.1	45.2	34.2	21.4	12.5	7	4.3	3.3	0.0005
	56.5	56.5	52	41.4	27.3	14.7	7.8	4.8	3.6	0.0001

Conclusions

- **TG3 systems cannot operate at a Rice K=0 dB and still achieve acceptable availability objectives.**
- **NLOS TG3 systems face a number of attenuation and fading mechanisms that are interrelated and require careful examination referenced to desired availability objectives.**
- **To maintain Rice K at acceptable values, TG3 criteria for link distance, excess link loss, antenna beam width, minimum antenna elevation and urban canopy type needs to be reviewed.**
- **A Rice K=0 dB is not equivalent to Rayleigh.**

Atmospheric Multipath

Consideration Rationale

- **Not Currently Included in TG3 Channel Models**
- **Fade Unavailability Not Insignificant for Long Paths**
- **Needs to be Included in Link Budgets**

Fading Mechanism

- **A Result of Multiple Refractive Paths in the Atmosphere**
- **Most Severe if the Atmosphere is not "Well Mixed" (Summer)**
- **Impacted by Terrain Type**
- **Excludes Ground Reflections**
- **Rayleigh Fade Distribution**
- **Empirical Outage Equations (decades of measurements)**

Fade Model

- **Modified Two - Ray Model**
- **Two Components:**

  Flat Fade Component

  Dispersive Frequency Selective Component

- **Various Estimation Models**
  - **KQ Factor**
  - **KQ plus Terrain S**
  - **ITU Rec. P-530**
  - **Vigants Barnett**

Vigants Barnett Method

- **Computes the Probability of a Rayleigh Fade p_r(Ray)**
- **Outage = p_r(Ray) times Rayleigh Fade Prob to Margin FM**
- **Includes Terrain Factor C where C equals:**

  C=0.25 - good propagation conditions (mountains/dry climates)

  C=1 - average propagation conditions (avr. terrain/climate)

  C=4 - difficult propagation conditions (over water/gulf coast)

- **Alternative Definition for C:**

  $C = C_f(S/15.2)^{-1.3}$

  where

  C_f **= 0.25, 1, 4 and S = terrain roughness in m**

Unavailability Equation

$$P = 6.0 \times 10^{-7} \times C \times f \times d^{3} \times 10^{-FM/10}$$

where

$f =$ frequency in GHz

$d =$ path length in km

$FM =$ effective fade margin in dB

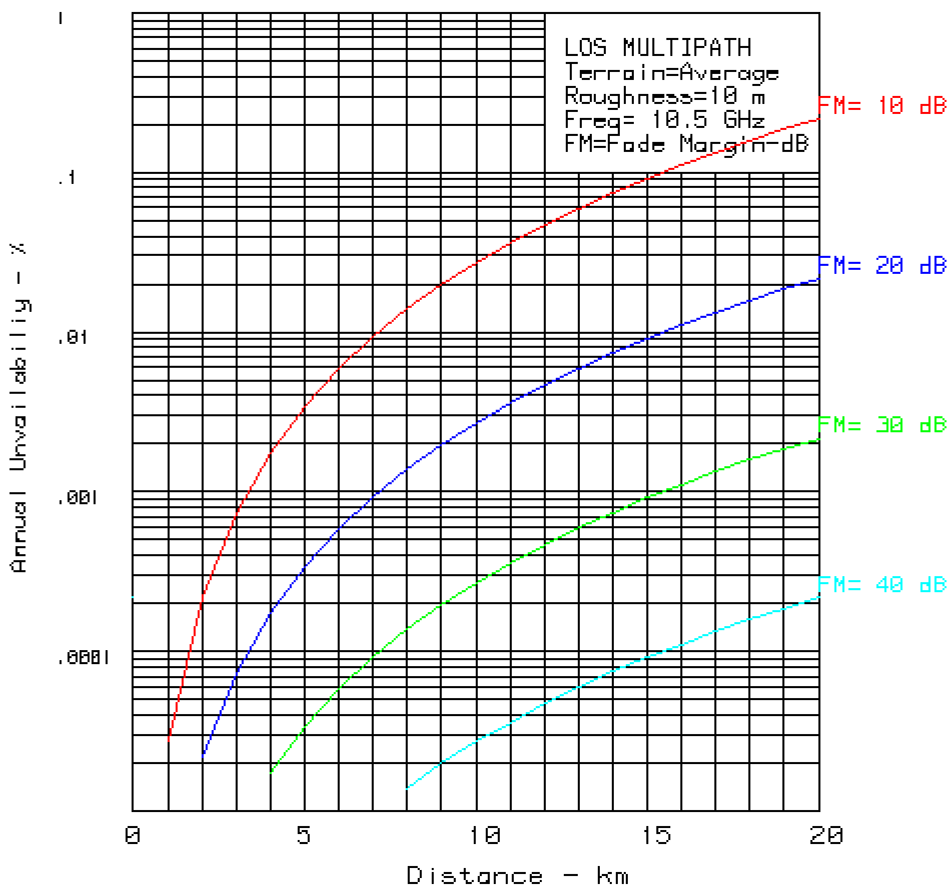
- **Valid for FM> 15 dB**

The effective fade margin is composed of the flat fade margin and the dispersive fade margin.

- **Flat fade margin = thermal plus interference.**

- **Dispersive fade margin = selective fade depth causing an outage. This is a measured equipment parameter for the average outage level of a selective frequency notch moved across the channel passband.**

Flat Fade Example



Conclusions

- **Atmospheric Multipath is not Negligible on Long Paths.**

- **The impact on availability is directly related to the fade margin available to withstand a Rayleigh fade.**

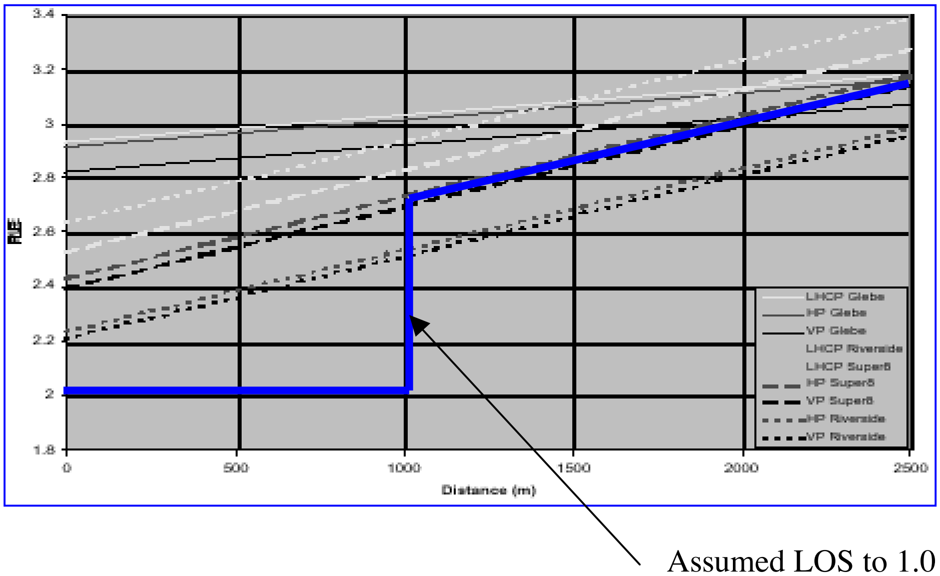
- **Even for paths of 10 km or less, atmospheric multipath is finite and will reduce the margin available for other excess loss, interference or fade mechanisms.**

TG3 Link Budget Examples (16-QAM)

PARAMETER	NAME	V-POL	H-POL	UNITS
Location	**New York**			
Frequency	f0	3.5		GHz
Path Length	r0	7		km

CCIR .01% Rain Rate	rr01ccir	42		mm/hr
Rice Factor	Kr	20		dB
TX Pwr/Cxr (clear sky)	ptx	35.00	35.00	dBm
Power Control	pcr	0.00	0.00	dB
TX Transmission Line Loss		0.00	0.00	dB
TX Branching Network Loss		-3.00	-3.00	dB
TX Antenna Gain	gbase	14.50	14.50	dBi
EIRP (clear sky)		46.50	46.50	dBm
EIRP (rain)		46.50	46.50	dbm
FSL to Distance R0		-120.18	-120.18	dB
Excess Loss to edge of coverage Rmax		0.00	0.00	dB
Atmospheric Absorption	aabsorb	-0.05	-0.05	dB
Foliage Loss		0.00	0.00	dB
Structure Loss		0.00	0.00	dB
Rx Antenna Gain	gsub	18.00	18.00	dBi
RX RF Losses		-3.00	-3.00	dB
RX Signal Level (clear sky)		-58.73	-58.73	dBm
RX Noise Level	n0	-101.52	-101.52	dBm
C/N (clear sky)	cnrcsv/h	42.79	42.79	dB
Required C/(N+I) for BER=E-6	cnir_E6	18.00	18.00	dB
C/I (HPA Intermod -clear sky)	hpaim	100.00	100.00	dB
C/I (adj-channel)	ciadjcs	100.00	100.00	dB
C/I (co-channel)	cicocs	100.00	100.00	dB
C/I Total	citotalcsv/h	95.23	95.23	dB
C/(N+I) (clear sky)	cnircsv/h	42.79	42.79	dB
Allowed C/N at Threshold	cnthreshv/h	18.00	18.00	dB
Fade Margin (clear sky)	margincsv/h	24.79	24.79	dB
C/I (HPA Intermod -rain)	hpaim	100.00	100.00	dB
C/I(adj-channel) plus Rain XPD	ciadjr	100.00	100.00	dB
C/I(co-channel plus Rain XPD)	cicor	100.00		dB
C/I Total	citotalv/h	96.99	96.99	dB
C/(N+I) (rain)	cnirrv/h	42.79	42.79	dB
Allowed C/N at Threshold	cnthreshrv/h	18.00	18.00	dB
Fade Margin (rain)	marginrainv/h	24.79	24.79	dB
Annual Availability (clear sky)-2 Way	availcsv_a_	99.99979	99.99979	%
Annual Availability (rain)	availrv/h_a	99.99999	99.99999	%
Annual Availability (Rice)-2 Way	avail_rice	100.00000	100.00000	%
Total Annual Availability		99.99978	99.99978	%
Outage		0.01893	0.01893	hrs

F1. 3.5 GHz link budget without impairments



Assumed LOS to 1.0 km for Link Budgets

Figure 5. Propagation Path Loss Exponent Variation through the Urban Canopy;
Height of Receiving antenna is 11 Meters

(CRC Measurement Data - Sydor)

PARAMETER	NAME	V-POL	H-POL	UNITS
Location	**New York**			
Frequency	f0	3.5		GHz
Path Length	rmax	6.4		km

Free Space Path Distance	r0	1			km
Excess Path Loss Coefficient	obsprop	4.32			
CCIR .01% Rain Rate	rr01ccir	42			mm/hr
Rice Factor	Kr	20			dB
TX Pwr/Cxr (clear sky)	ptx		35.00	35.00	dBm
Power Control	pcr		0.00	0.00	dB
TX Transmission Line Loss			0.00	0.00	dB
TX Branching Network Loss			-3.00	-3.00	dB
TX Antenna Gain	gbase		14.50	14.50	dBi
EIRP (clear sky)			46.50	46.50	dBm
EIRP (rain)			46.50	46.50	dbm
FSL to Distance R0			-103.28	-103.28	dB
Excess Loss to edge of coverage Rmax			-34.83	-34.83	dB
Atmospheric Absorption	aabsorb		-0.04	-0.04	dB
Foliage Loss			0.00	0.00	dB
Structure Loss			0.00	0.00	dB
Rx Antenna Gain	gsub		18.00	18.00	dBi
RX RF Losses			-3.00	-3.00	dB
RX Signal Level (clear sky)			-76.65	-76.65	dBm
RX Noise Level	n0		-101.52	-101.52	dBm
C/N (clear sky)	cnrcsv/h		24.87	24.87	dB
Required C/(N+I) for BER=E-6	cnir_E6		18.00	18.00	dB
C/I (HPA Intermod -clear sky)	hpaim		100.00	100.00	dB
C/I (adj-channel)	ciadjcs		100.00	100.00	dB
C/I (co-channel)	cicocs		100.00	100.00	dB
C/I Total	citotalcsv/h		95.23	95.23	dB
C/(N+I) (clear sky)	cnircsv/h		24.87	24.87	dB
Allowed C/N at Threshold	cnthreshv/h		18.00	18.00	dB
Fade Margin (clear sky)	margincsv/h		6.87	6.87	dB
C/I (HPA Intermod -rain)	hpaim		100.00	100.00	dB
C/I(adj-channel) plus Rain XPD	ciadjr		100.00	100.00	dB
C/I(co-channel plus Rain XPD)	cicor		100.00		dB
C/I Total	citotalv/h		96.99	96.99	dB
C/(N+I) (rain)	cnirrv/h		24.87	24.87	dB
Allowed C/N at Threshold	cnthreshrv/h		18.00	18.00	dB
Fade Margin (rain)	marginrainv/h		6.87	6.87	dB
Annual Availability (clear sky)-2 Way	availcsv_a_		99.99024	99.99024	%
Annual Availability (rain)	availrv/h_a		99.99999	99.99999	%
Annual Availability (Rice)-2 Way	avail_rice		100.00000	100.00000	%
Total Annual Availability			99.99023	99.99023	%
Outage			0.85593	0.85593	hrs

F2. 4-9' Availability/Distance with Diffraction Loss

PARAMETER	NAME		V-POL	H-POL	UNITS
Location	**New York**				
Frequency	f0	3.5			GHz
Path Length	rmax	6.8			km
Free Space Path Distance	r0	1			km

Excess Path Loss Coefficient	obsprop	4.44			
CCIR .01% Rain Rate	rr01ccir	42			mm/hr
Rice Factor	Kr	15			dB
TX Pwr/Cxr (clear sky)	ptx		35.00	35.00	dBm
Power Control	pcr		0.00	0.00	dB
TX Transmission Line Loss			0.00	0.00	dB
TX Branching Network Loss			-3.00	-3.00	dB
TX Antenna Gain	gbase		14.50	14.50	dBi
EIRP (clear sky)			46.50	46.50	dBm
EIRP (rain)			46.50	46.50	dbm
FSL to Distance R0			-103.28	-103.28	dB
Excess Loss to edge of coverage Rmax			-36.96	-36.96	dB
Atmospheric Absorption	aabsorb		-0.05	-0.05	dB
Foliage Loss			0.00	0.00	dB
Structure Loss			0.00	0.00	dB
Rx Antenna Gain	gsub		18.00	18.00	dBi
RX RF Losses			-3.00	-3.00	dB
RX Signal Level (clear sky)			-78.79	-78.79	dBm
RX Noise Level	n0		-101.52	-101.52	dBm
C/N (clear sky)	cnrcsv/h		22.73	22.73	dB
Required C/(N+I) for BER=E-6	cnir_E6		18.00	18.00	dB
C/I (HPA Intermod -clear sky)	hpaim		100.00	100.00	dB
C/I (adj-channel)	ciadjcs		100.00	100.00	dB
C/I (co-channel)	cicocs		100.00	100.00	dB
C/I Total	citotalcsv/h		95.23	95.23	dB
C/(N+I) (clear sky)	cnircsv/h		22.73	22.73	dB
Allowed C/N at Threshold	cnthreshv/h		18.00	18.00	dB
Fade Margin (clear sky)	margincsv/h		4.73	4.73	dB
C/I (HPA Intermod -rain)	hpaim		100.00	100.00	dB
C/I(adj-channel) plus Rain XPD	ciadjr		100.00	100.00	dB
C/I(co-channel plus Rain XPD)	cicor		100.00		dB
C/I Total	citotalv/h		96.99	96.99	dB
C/(N+I) (rain)	cnirrv/h		22.73	22.73	dB
Allowed C/N at Threshold	cnthreshrv/h		18.00	18.00	dB
Fade Margin (rain)	marginrainv/h		4.73	4.73	dB
Annual Availability (clear sky)-2 Way	availcsv_a_		99.98084	99.98084	%
Annual Availability (rain)	availrv/h_a		99.99999	99.99999	%
Annual Availability (Rice)-2 Way	avail_rice		99.92000	99.92000	%
Total Annual Availability			99.90083	99.90083	%
Outage			8.68728	8.68728	hrs

F3. Example Link Budget for 3-9's Availability/Distance

PARAMETER	NAME		V-POL	H-POL	UNITS
Location	**New York**				
Frequency	f0	3.5			GHz
Path Length	rmax	1			km
Free Space Path Distance	r0	1			km
Excess Path Loss Coefficient	obsprop	2.7			

CCIR .01% Rain Rate	rr01ccir	42		mm/hr
Rice Factor	Kr	0		dB
TX Pwr/Cxr (clear sky)	ptx	35.00	35.00	dBm
Power Control	pcr	0.00	0.00	dB
TX Transmission Line Loss		0.00	0.00	dB
TX Branching Network Loss		-3.00	-3.00	dB
TX Antenna Gain	gbase	14.50	14.50	dBi
EIRP (clear sky)		46.50	46.50	dBm
EIRP (rain)		46.50	46.50	dbm
FSL to Distance R0		-103.28	-103.28	dB
Excess Loss to edge of coverage Rmax		0.00	0.00	dB
Atmospheric Absorption	aabsorb	-0.01	-0.01	dB
Foliage Loss		0.00	0.00	dB
Structure Loss		0.00	0.00	dB
Rx Antenna Gain	gsub	18.00	18.00	dBi
RX RF Losses		-3.00	-3.00	dB
RX Signal Level (clear sky)		-41.79	-41.79	dBm
RX Noise Level	n0	-101.52	-101.52	dBm
C/N (clear sky)	cnrcsv/h	59.73	59.73	dB
Required C/(N+I) for BER=E-6	cnir_E6	18.00	18.00	dB
C/I (HPA Intermod -clear sky)	hpaim	100.00	100.00	dB
C/I (adj-channel)	ciadjcs	100.00	100.00	dB
C/I (co-channel)	cicocs	100.00	100.00	dB
C/I Total	citotalcsv/h	95.23	95.23	dB
C/(N+I) (clear sky)	cnircsv/h	59.73	59.73	dB
Allowed C/N at Threshold	cnthreshv/h	18.00	18.00	dB
Fade Margin (clear sky)	margincsv/h	41.73	41.73	dB
C/I (HPA Intermod -rain)	hpaim	100.00	100.00	dB
C/I(adj-channel) plus Rain XPD	ciadjr	100.00	100.00	dB
C/I(co-channel plus Rain XPD)	cicor	100.00		dB
C/I Total	citotalv/h	96.99	96.99	dB
C/(N+I) (rain)	cnirrv/h	59.73	59.73	dB
Allowed C/N at Threshold	cnthreshrv/h	18.00	18.00	dB
Fade Margin (rain)	marginrainv/h	41.73	41.73	dB
Annual Availability (clear sky)-2 Way	availcsv_a_	100.00000	100.00000	%
Annual Availability (rain)	availrv/h_a	99.99999	99.99999	%
Annual Availability (Rice)-2 Way	avail_rice	99.99000	99.99000	%
Total Annual Availability		99.98999	99.98999	%
Outage		0.87688	0.87688	hrs

F4. What can we do if K= 0 dB for 4-9's Availability. Try 0.1 km!

Availability	Distance	Rice K	TX Pwr	Fade Margin	Controlling Impairment
3-9's	7 km	6 dB	+50 dBm (100 watts)	19 dB	Rician Fading

4-9's	**7 km**	**9 dB**	**+50 dBm (100 watts)**	**19 dB**	**Rician Fading**
4-9's	**22 km**	**20 dB**	**+44 dBm (25 watts)**	**24 dB**	**Atmospheric Multipath**

Conclusions

- **Significant Constraints on the Values for Rice K**
- **Beating it to Death with Power is not a Valid Mitigation Technique**
- **Long Paths are Controlled by Atmospheric Multipath. Diffraction Loss and any Significant Rician Fading cannot be Tolerated**

Cell Area Space/Time Availability

- **TG3 Objectives: 90% of Cell Area to Exceed 99.9% Availability**

F_0 = 3.5 GHz

R_{max} = 7 km

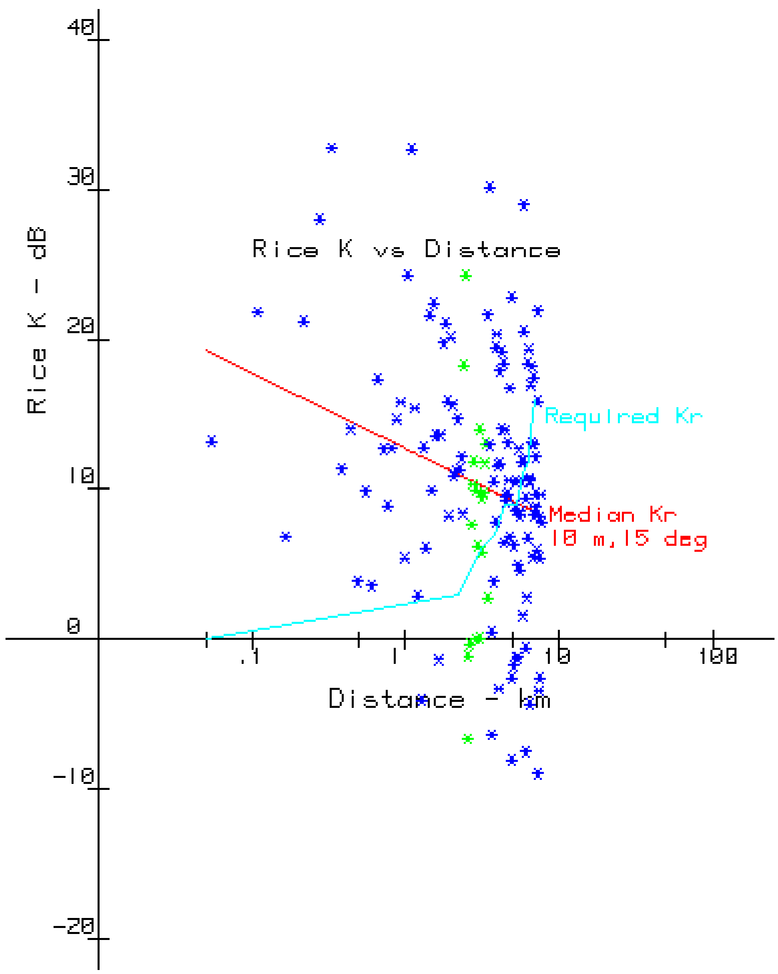
Availability = 99.9 %

Rice K:

- **Erceg Equation for log-normal distribution of K**
- **Mean = 0 dB**
- **Sigma = 8 dB**

Simulation Methodology:

- **Set up cell in 10 annular rings, each corresponding to 10% of area**
- **Compute allowed value of K_a vs distance r (link budget for 99.9%)**
- **Compute expected value of K_e at a random distance within each annular ring (30,000 random deviates based on Erceg)**
- **Compare K_e with K_a and compute probability that 99.9% objective will not be met**



Red: Median Value of Expected K vs Distance (Erceg)

Light Blue: Required Value of K vs Distance (from link budgets)

Dark Blue: Variation of Expected K vs Distance (Erceg -log normal, Sigma =8 dB)

Green: Variation of Expected K within a 10% annular area ring

% Cell Area	Distance r - km	Allowed Rice K -dB to Availability Limit	Median Rice K to Distance r	Excess K Relative to Median	Prob that K is Less than Allowed Within Annular Ring - %
.1	2.2	3	11	8	8-9
.2	3.1	6	10	4	14-15.5
.3	3.8	7	10	3	21-22.5
.4	4.4	9	10	1	27-28
.5	5	9	9	0	31-32.5
.6	5.5	9	9	0	31.5-32
.7	5.9	11	9	-2	35-37
.8	6.3	12	9	-3	43-46
.9	6.6	14	9	-5	50-52
1.0	7	16	8	-8	60-62

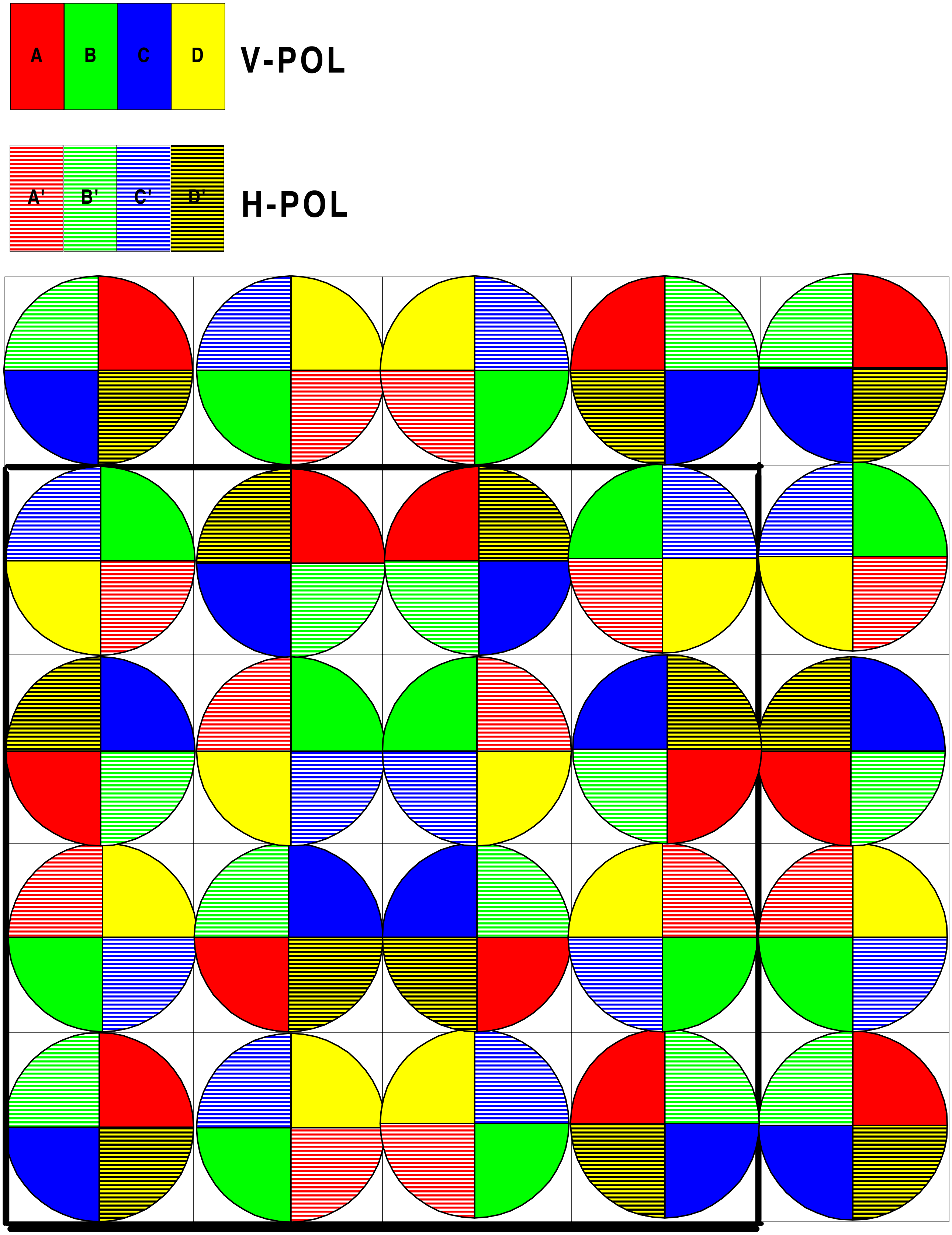
Conclusions

- **TG3 Space/Time Availability Objectives are not Achievable in the Presence of any Significant Rician Fading**

- **TG2a Systems Model Should Assume a Link Design that Allows for Only Diffraction Loss and a Very Modest Amount of Foliage Penetration. This is the only Systems Model that will Allow for Inter-System C/I**

Minimal Frequency Re-Use Plan

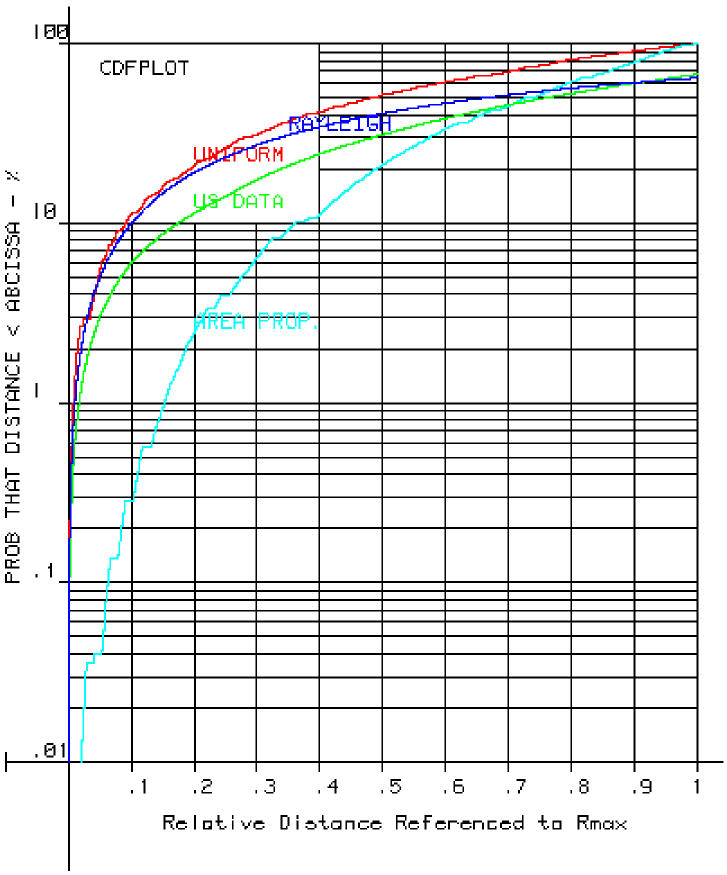
- **Cannot Repeat Frequency Assignments Within a Cell due to Limits of Antenna F/B Ratio (25 dB). This Would Not Support 64-QAM Transmission.**
- **Care Required in Assignment of Adjacent Sector Assignments due to XPD Reduction if Shooting Through Trees**
- **Likely Require 4 Frequencies/2-Polarizations for FDD**

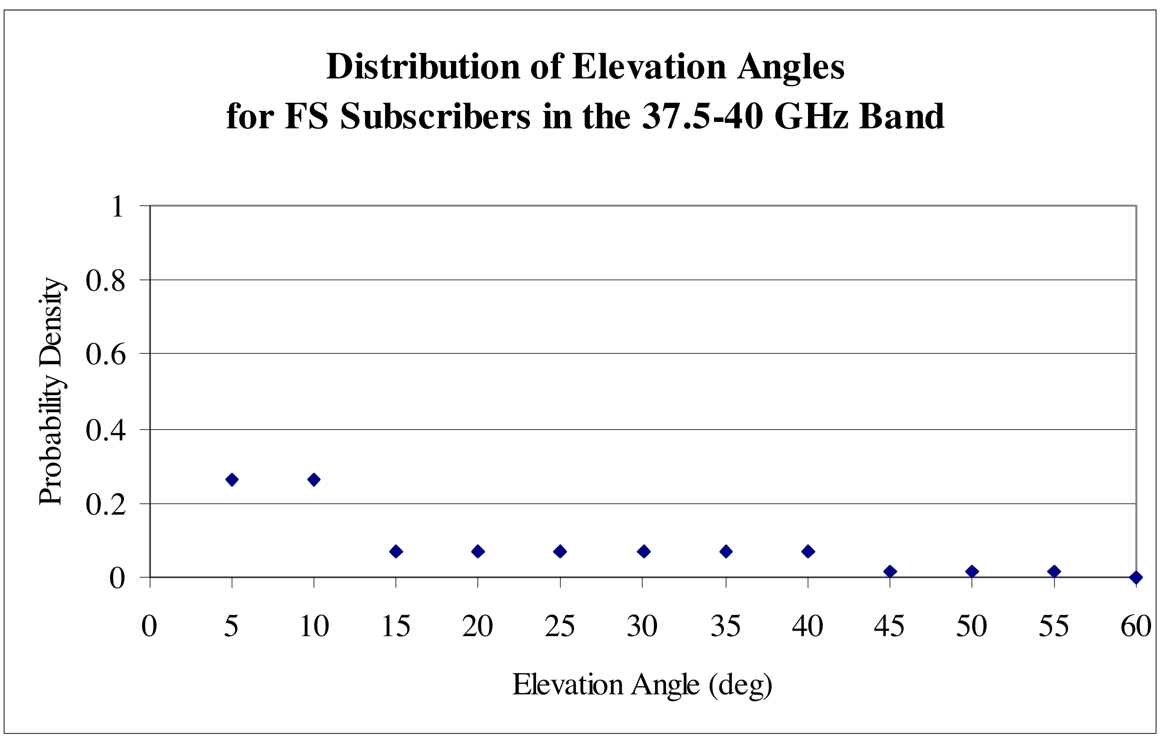

A
B
C
D
V-POL
A'
B'
C'
D'
H-POL

Subscriber Path Length and Vertical Elevation Angle Distributions

- **Randomly Uniform vs Distance**
- **Area Proportional**
- **Rayleigh Rooftops**
- **Compiled US Statistics (38 GHz)**

-Major Impact on Coexistence Due to Vertical Antenna Pattern Discrimination - Need to Select a Distribution for Simulation Studies


CDFPLOT
UNIFORM
RAYLEIGH
US DATA
AREA PROP.
PROB THAT DISTANCE < ABCISSA - %
100
10
1
.1
.01
.1 .2 .3 .4 .5 .6 .7 .8 .9 1
Relative Distance Referenced to Rmax


Distribution of Elevation Angles
for FS Subscribers in the 37.5-40 GHz Band
Probability Density
1
0.8
0.6
0.4
0.2
0
0 5 10 15 20 25 30 35 40 45 50 55 60
Elevation Angle (deg)

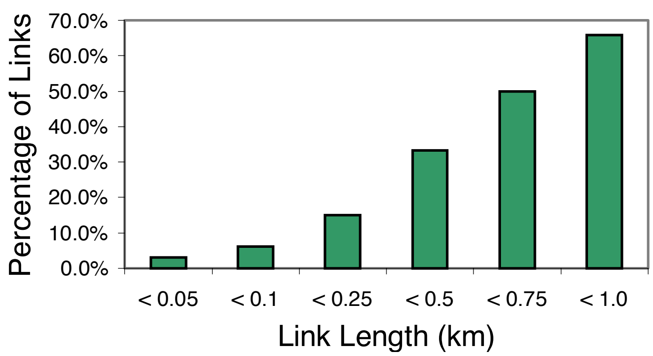


FIGURE 5

38 GHz link length distribution statistics in the United States
for subscriber-based HDFS networks

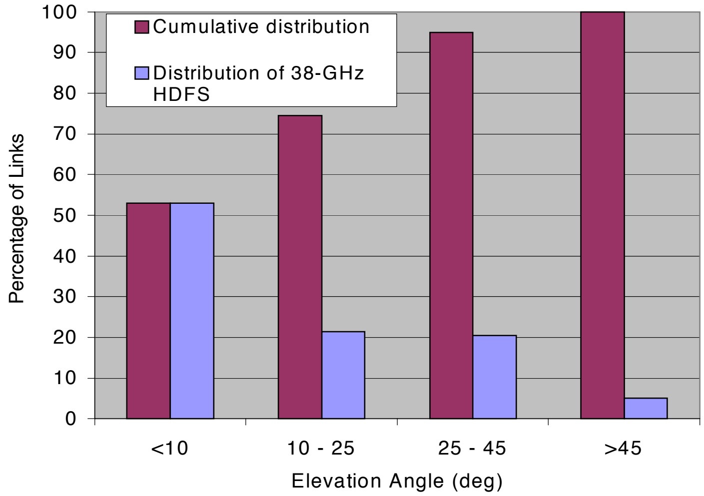
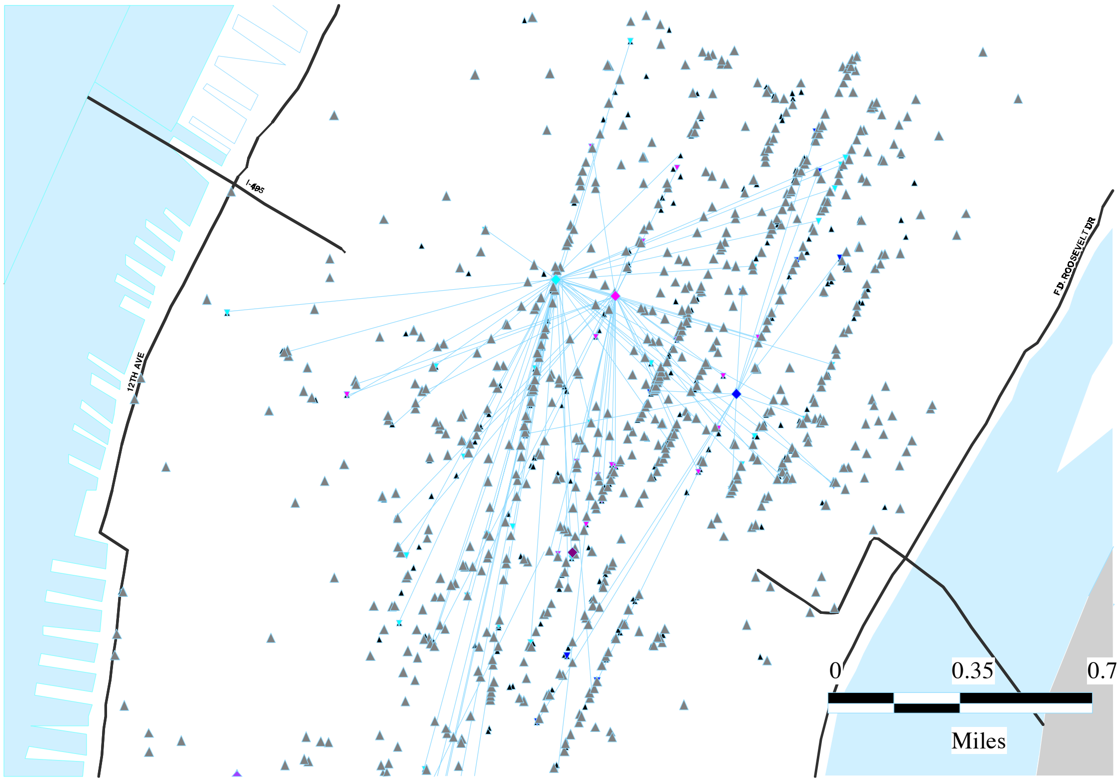


FIGURE 6

38 GHz HDFS elevation angle distribution in the United States

FIGURE ~~2~~ 4

Deployment pattern in an urban area in the United States of America



Rose 9/1015-02

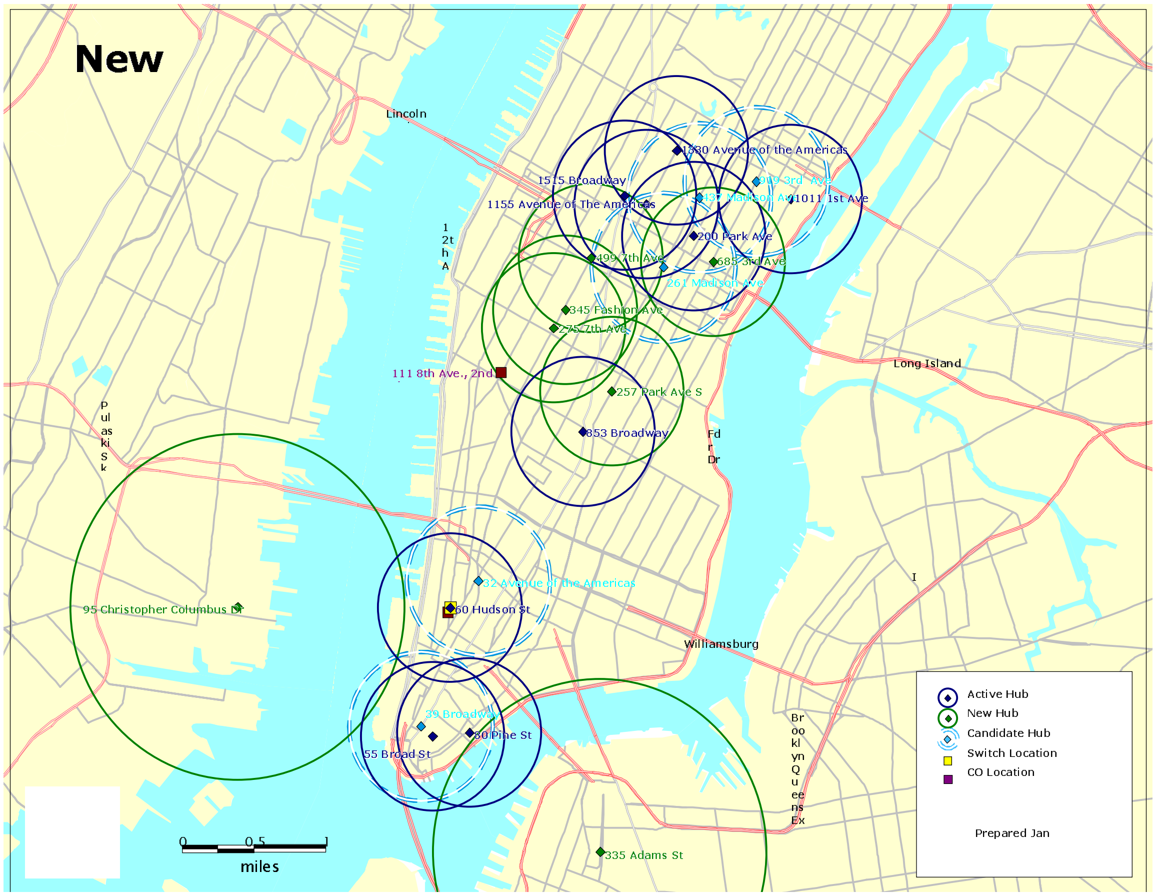


FIGURE 4

Hub deployment in urban area, United States