Diversity Benefits for Millimeter Wave Satellite Communications, with Cloud Correlation Functions

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Outline

• Barbaliscia’s 49/22 GHz Worldwide Attenuation maps
• New 6 to 100 GHz Function, for new maps
• Compare GEO, Molniya Att’n at 30 GHz
• Examine MolniyaGEO at 30-45, 90-100 GHz for Iceland, NY, and Rio.
• Discuss Soviet Cloud Correlation Functions
  - Use to predict site diversity advantages, with modest attenuation, good reliability at 90 GHz
(Rain Correlation Functions, Appendix)
Barbaliscia’s 99% Non Rainy Zenith Attenuation at 22.2 GHz World Wide (note ROME, Miami, S.America)
Barbaliscia’s 99% Non Rainy Zenith Attenuation at 49.5 GHz vs LON, LAT

49.5 GHz Zenith Attenuation for N. Hemisphere
3 Phased Molniya for Continuous Coverage
MolniyaGEO Attenuation at 30 GHz

MolniyaGEO Attenuation for N. Hemisphere at F = GHz, by Barbaliscia, LIEBE.
MolniyaGEO Attenuation at Rio, NY, Iceland

dB

GHz

Dan

MolniyaGEO with LIEBE Vapor Att 'n
**Soviet Cloud Autocorrelation Function v. Distance (km)**

Boldyref and Tulupov

Equation: $R_{\text{Boldyrev and Tulupov}} = 0.2 \frac{x}{x_g} + 0.8 \frac{x}{x_a} \cos \theta$

Graph showing the correlation function $R_x$ over distance (km) with a logarithmic scale on the y-axis and a linear scale on the x-axis.
Observations on Soviet Cloud Autocorrelation Function

• \( R(x) \) drops to ZERO at 200 km
  --and NEGATIVE at 300 km
  -- as observed by strong switched diversity results against rain
    (Hatsuda, Baltimore APS, 96)
  --Not accounted for with ITU diversity attenuation

• \( R(x) \) drops to 0.4 at 32-40 km
  --Good cloud relief for Millimeter Wave Satellite Systems
Availability from Boldyrev and Tulupov
Cloud Correlation Function

Availability with 2 sites=
AV2=

\[ 1 - (1 - av1)^2 - 0.2e^{-x} - 0.036x + 0.015 \cdot 0.8e^{-0.003x} \cos(0.0075x) \]

Where \( x = \) site separation, km

with \( av1 = \) availability with 1 site = 0.90 for typical 90 GHz satellite link
\( av2 = \) availability with 2 separated, switched diversity sites
--b. and Much Higher Availability with 0.99 Single Link
Superior Availability with 4 Sites

1 - \((1 - ax1)^2 - 0.2 e^{-x_1 - 0.036 x_2 - 0.015 x_3 - 0.8 e^{-0.003 x} \cos(0.0075 x)}\)^2 - 0.2 e^{-x_1 - 0.036 x_2 - 0.015 x_3 - 0.8 e^{-0.003 x}}
--and Much Higher Availability with 0.99 Single Link
as 3dB at 45 GHz; 9dB at 90 GHz
Conclusions for Diversity Discussion

• Barbaliscia’s non-rainy attenuation results were invaluable, as basis for deriving estimates of zenith attenuation for 6-100 GHz.
• Constellations with high elevation allow the low attenuation to be realized.
  - both Molniya and GEO are well understood, and behaved.
• Boldyrev and Tulupov’s cloud correlation function (Slide 7) allowed high availability (>0.999) to be achieved with modest diversity
  - e.g., 45 GHz, 25 km dual sites, 3 dB; 90 GHz, 25 km, 9 dB
  - and, the site separation combats rain; R(x) as 8 km (Appendix)
• Your cloud correlation functions will be of interest.