This project is co-funded by

Horizon 2020

NICT National Institute of Information and Communications Technology

THOR

FWS link performance degradation in Millimeter-wave and Terahertz due to severe weather conditions

H2020 EU-Japan Project ThoR Final Workshop

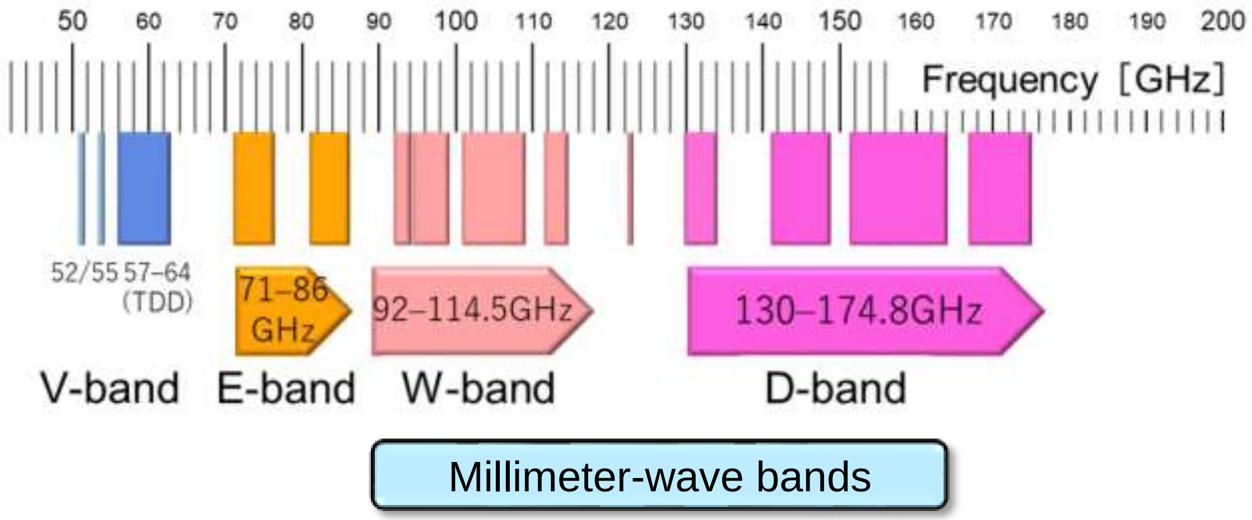
Eisaku Sasaki, NEC Corporation, Braunschweig, 29-30 June 2022

Agenda

Millimeter-wave Radio

- Millimeter-wave (mmW) bands are now used for FWS.
  - E-band is already in service.
  - W-band and D-band are under standardization.

FWS : Fixed Wireless System



- Link budget is severer than microwave bands.
  - Low Tx power due to device performance.
  - Large FSL and rain attenuation, narrow beam-width due to high frequency.

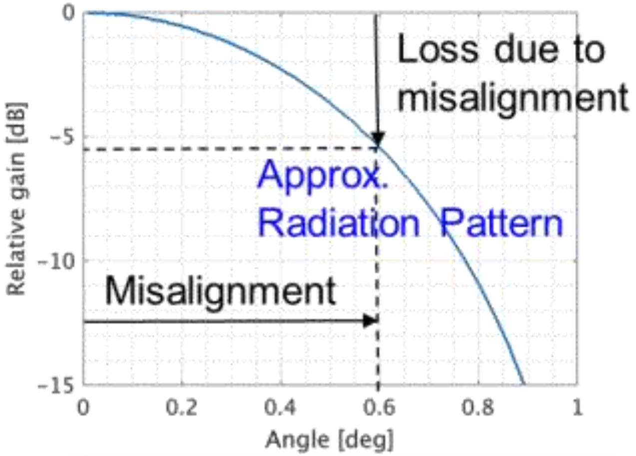
FSL : Free Space Loss

Effect of Strong Wind

- Susceptible to wind
  - From BB to RF circuits are implemented in one box.
  - Small antenna is connected with the box directly.
  - Pencil beam.
  - Expected to be installed on a tower or a pole.

E-band Radio

- Effect of Strong Wind
  - Fluctuation of beam-direction due to wind causes RSL reduction.
  - No ITU-R Rec. for strong wind.
  - Development of new Rec. for strong wind was proposed in AWG.
  - Now, the Rec. is under approval process.

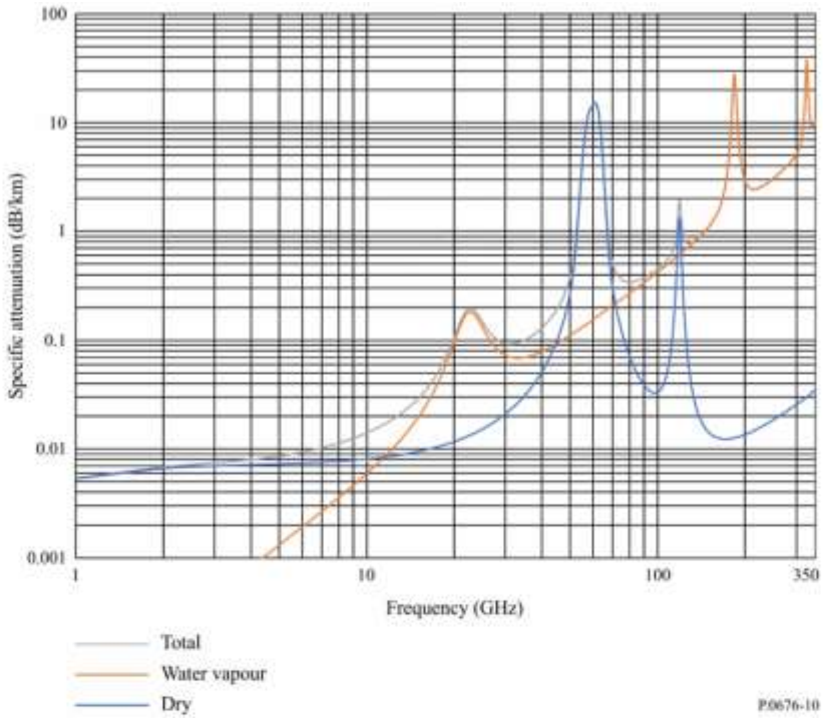


Loss due to misalignment

RSL : Received Signal Level
AWG : APT Wireless Group
APT : Asia-Pacific Telecommunity

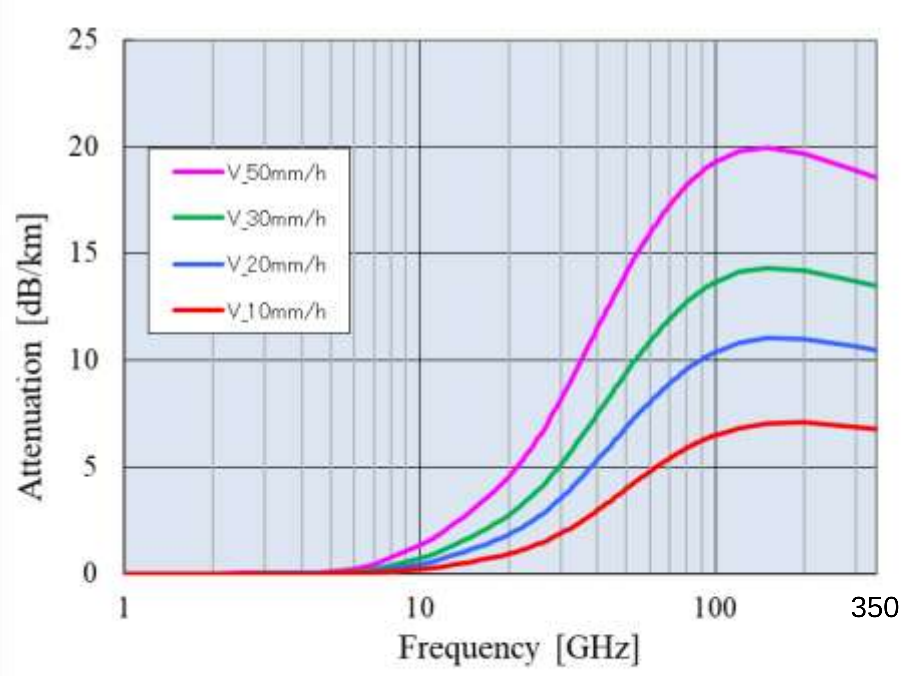
Gas and Rain Attenuation

- Gas Attenuation
  - ITU-R Rec. P.676-12
  - 0.2 to 1.0dB/km loss for fine day.



Gas Attenuation

- Rain Attenuation
  - ITU-R Rec. P.838-3
  - 20dB/km or more loss in rainy weather.

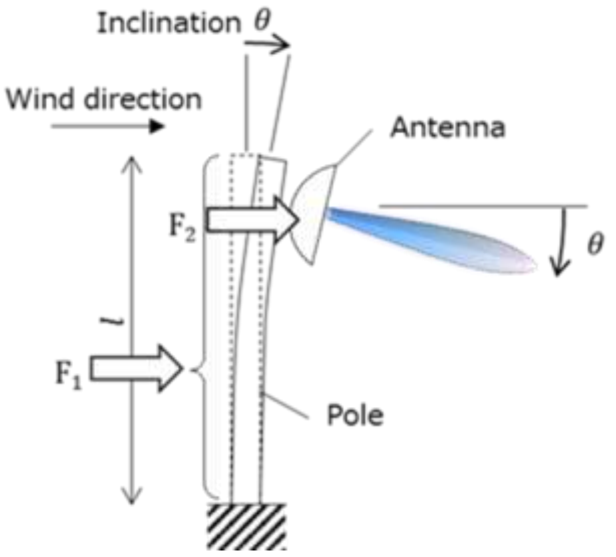


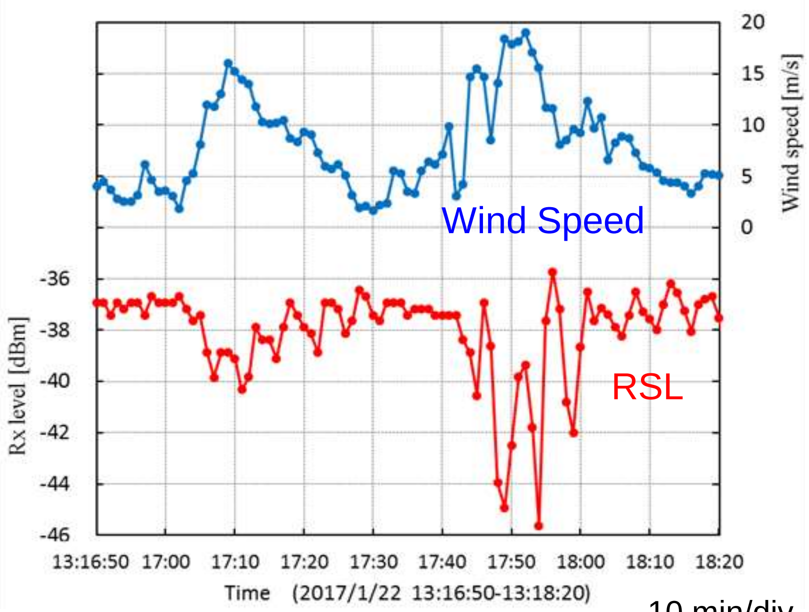
Rain Attenuation

Field Evaluations (1)

- A field evaluation was conducted using actual equipment.
  - Radio performance and weather data were recorded simultaneously.
  - Conditions
    - Radio : 85.5GHz, ϕ300mm Ant., 13.4kg
    - Pole : height=5m, ϕ89mm, steel
    - Measurement : 6months, 320m link

Source :
AWG-29/OUT-25





10 min/div

Site Configuration

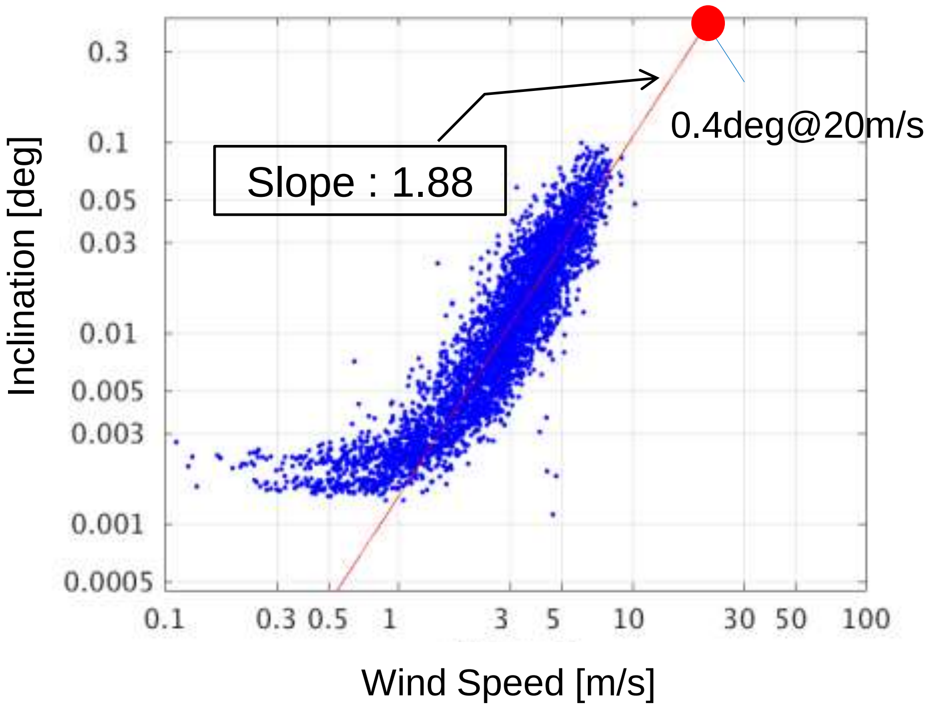
Calculation model

Wind speed vs. RSL

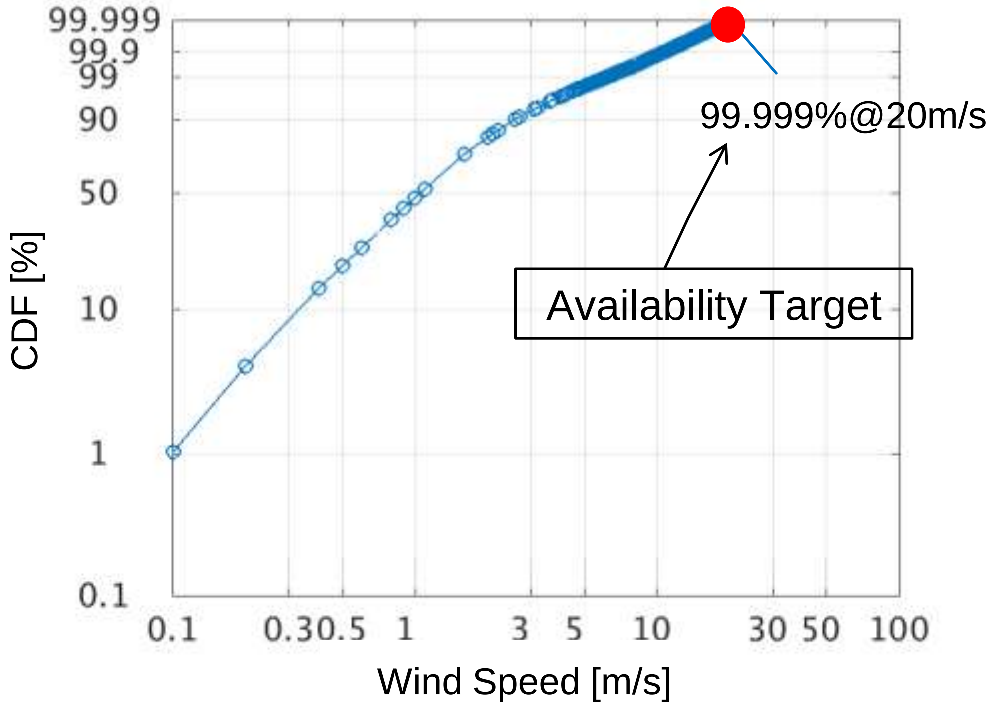
Field Evaluations (2)

- Statistical Data Analysis
  - Average wind speed at CDF=99.999% is 20m/s, with corresponding pole inclination and loss of 0.4deg and 2.2dB respectively.
  - The impact of static load is small.

CDF : Cumulative Distribution Function



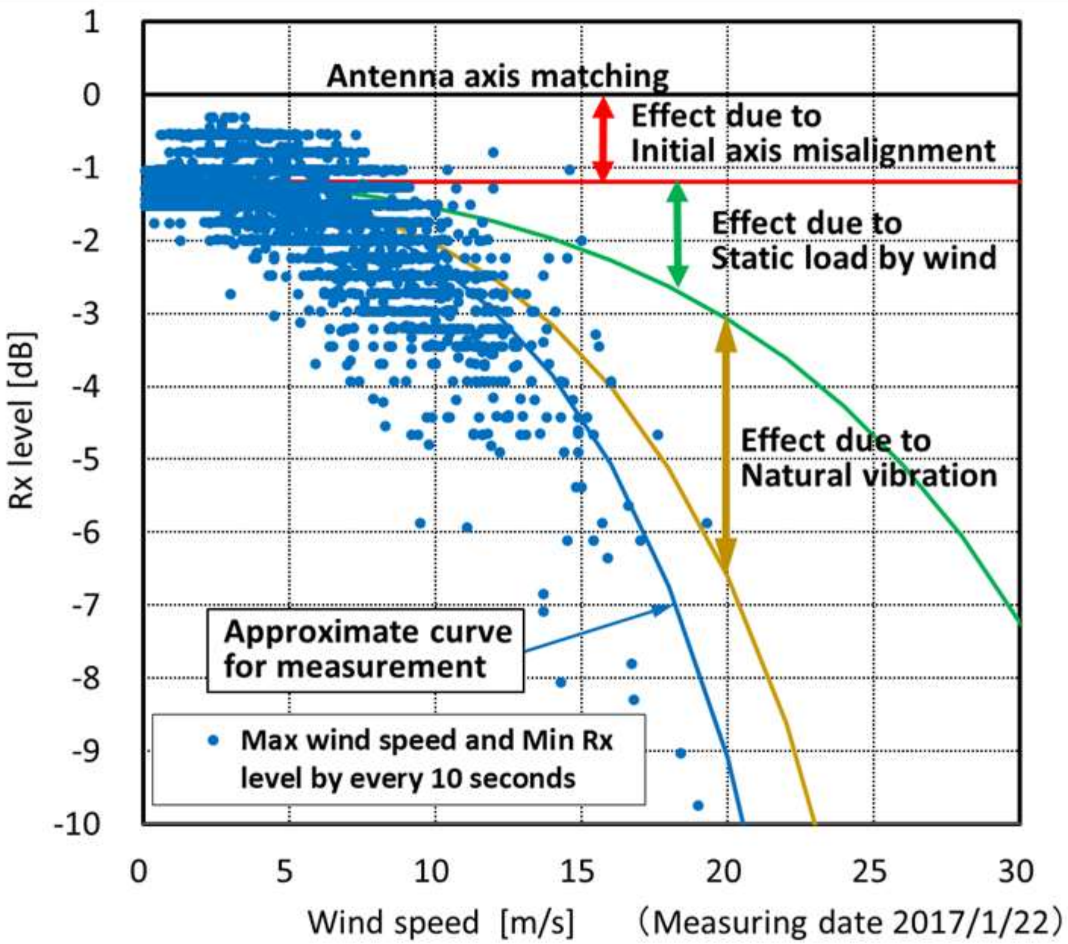
Distribution of Wind speed vs. Inclination



CDF of Wind speed

Field Evaluations (3)

- Distribution of Maximum wind speed vs. Minimum RSL was measured.
  - The result suggests that both static and dynamic load should be considered.



Source : AWG-29/OUT-25

Distribution of Max. Wind speed vs. Min. RSL

Theoretical Study (1)

- The inclination angle of the pole by the static wind load is derived as follows. (Assuming a radio system installed at the top of pole.)

  - The velocity pressure q for a wind velocity v is shown as follows:

    $$q = \frac{1}{2}\rho v^2 \quad (1)$$

    where, q: Velocity pressure [N/m^2], ρ: Air density [kg/m^3], v: Wind speed [m/s]

  - The static load F applied to the pole or the antenna is calculated by

    $$F = qCA \quad (2)$$

    where, C: Drag coefficient, A: Wind receiving area [m^2]

  - Static inclination angle θ_s $[deg]$ is calculated by

    $$\theta_s = \frac{F_1 l^2}{6EI} + \frac{F_2 l^2}{2EI} = (F_1 + 3F_2)\frac{l^2}{6EI}[rad] = (C_1 A_1 + 3C_2 A_2)\frac{\rho l^2}{12EI} v^2 \frac{180}{\pi} \quad (3)$$

    where, E: Young's modulus [Pa], I: Second moment of area [m^4], l: Pole Length [m]
    suffix 1 is for a pole and suffix 2 is for an antenna.

$$\theta_s = (C_1 A_1 + 3C_2 A_2)\frac{\rho l^2}{12EI} v^2 \frac{180}{\pi} \equiv C_s \cdot v^2 \ [deg] \quad (4)$$

where, C_s: static wind load coefficient

Theoretical Study (2)

- The inclination angle of the pole by the dynamic wind load is derived as follows. (Assuming a radio system installed at the top of pole.)
  - Vibration of the pole is analyzed based on the measurement results.
  - The relation between wind speed and dynamic inclination is expressed as (5).
    - The dynamic inclination angle θ_d of the pole is proportional to square of wind speed same as static wind load.

$$\theta_d \equiv C_d \cdot v^2 \; [deg] \quad (5)$$

where, C_d: dynamic wind load coefficient

  - The C_d is derived from the measured data.
    - The value was 4.6 × 10^{-4} deg/(m/s)^2 in the measurement, it is close to C_s.

Theoretical Study (3)

- Probability of RSL-Loss can be calculated as below.
  - CDF of wind speed $p(v)$ is expressed by Weibull distribution.
    - Coefficients k and c depend on the region.

$$p(v) = 1 - exp\left\{-\left(\frac{v}{c}\right)^k\right\} \quad (6)$$

  - Converted to probability of wind speed.

$$v(p) = c\{-\log_e(1-p)\}^{1/k}\ [m/s] \quad (7)$$

  - Probability of inclination $\theta(p)$ is expressed as below using a dynamic and a static coefficient C_d and C_s respectively and initial misalignment θ_0.
    - Both coefficients depend on the structure of the pole.

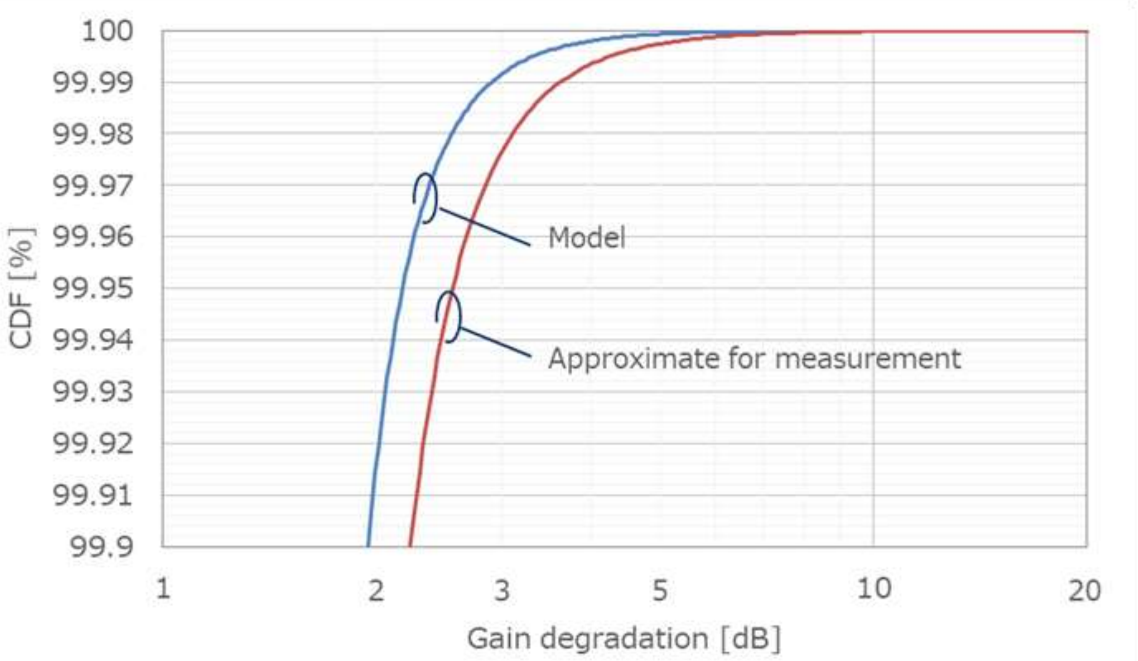
$$\theta(p) = \theta_0 + (C_s + C_d)v^2(p)\ [deg] \quad (8)$$

  - Probability of RSL-Loss $R(\theta)$ is expressed as below using the radiation pattern $g(\theta)$.

$$R(\theta) = g\{\theta(p)\}\ [dB] \quad (9)$$

Comparison of Mathematical Model and Measured data

- A model of radio system for strong wind was proposed.
  1. Parameterized system installed at the top of pole.
  2. Calculation method for the probability of RSL-Loss.
- Calculated performance by the model is well coincident with the measured data as below.
  - The validity of the model was confirmed.

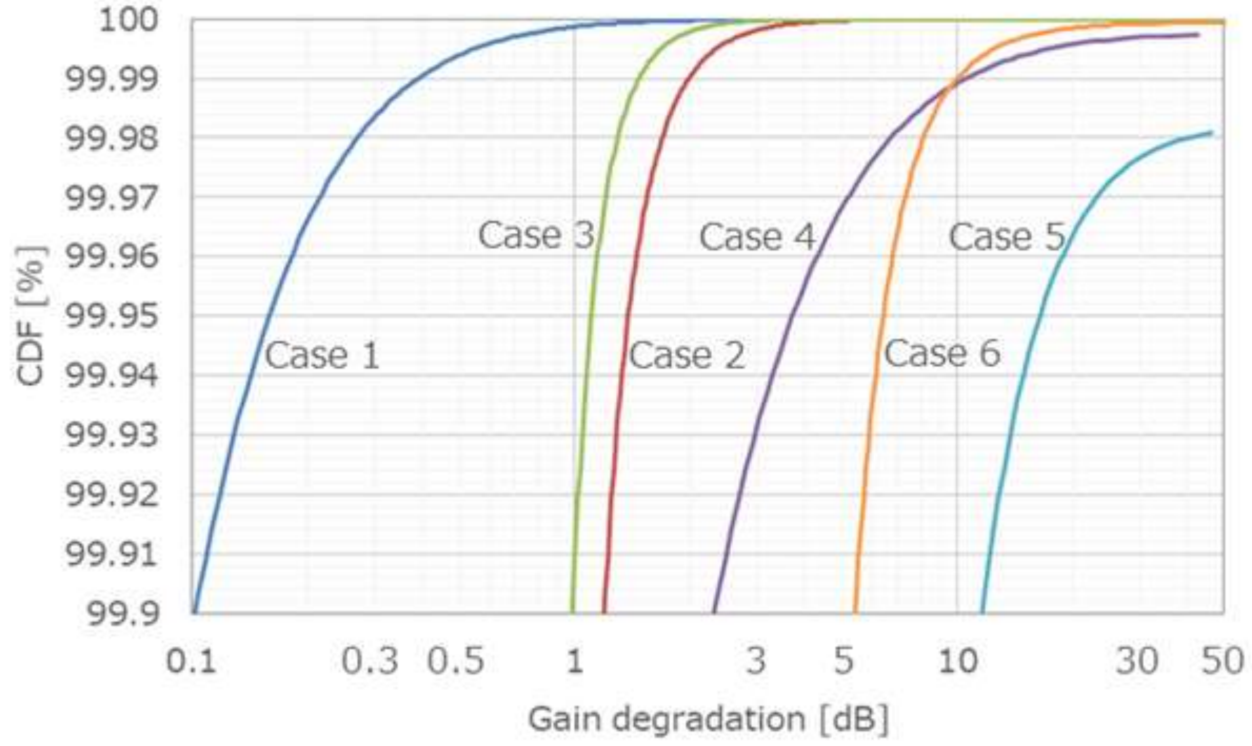


CDF of Gain Degradation

Source :
AWG-29/OUT-25

Examples of Calculation

- CDF performance of gain degradation for some cases are shown in the figure below.
  - Based on the wind-characteristics in Japan.
  - Possible to estimate the performance before actual installation.



	Antenna diameter	Pole length	Initial alignment error
Case 1	0.3m	5m	0deg
Case 2	0.3m	5m	0.2deg
Case 3	0.3m	10m	0.2deg
Case 4	0.6m	5m	0deg
Case 5	0.6m	5m	0.2deg
Case 6	0.6m	10m	0.2deg

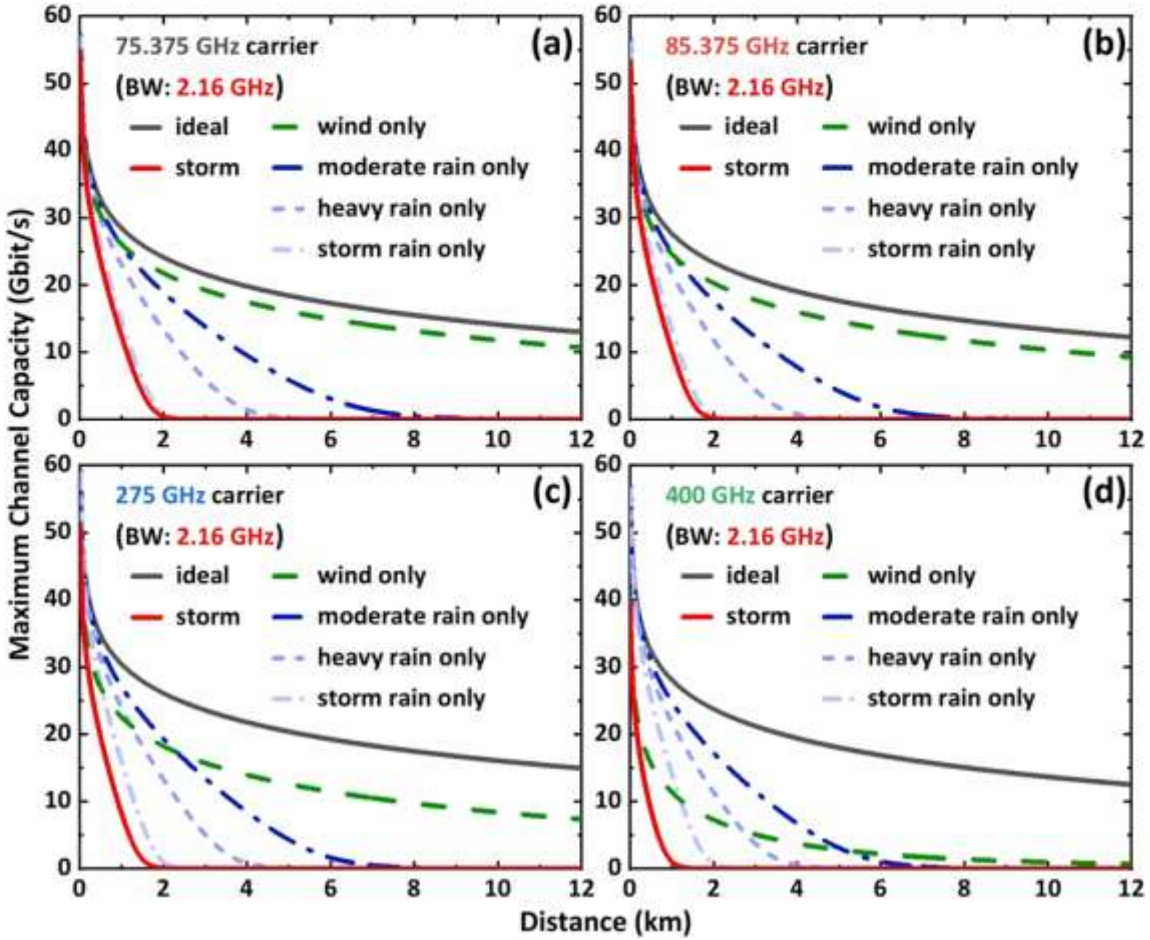
Source :
AWG-29/OUT-25

Examples of Calculation

Performance against Combination of Rain and Wind

- Possible to calculate the link performance under a combination of rain and wind.
  - In E-band (a) and (b), Rain effect is dominant, wind effect shortens the link distance slightly.
  - TeraHertz (c) and (d) are more sensitive against wind.

Source : Zu-Kai Weng et al. ,"Millimeter-wave and Terahertz Fixed Wireless Link Budget Evaluation for Extreme Weather Conditions," IEEE Access, vol.9, Dec. 2021.

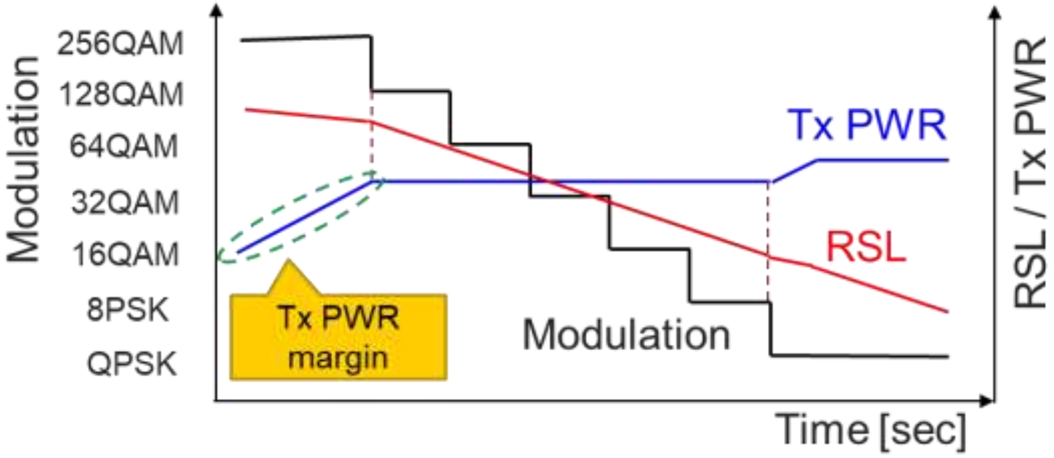


Examples of Calculated Performance

Mitigation Technologies

1. ATPC (Automatic Transmit Power Control)
2. ACM (Adaptive Coding & Modulation)

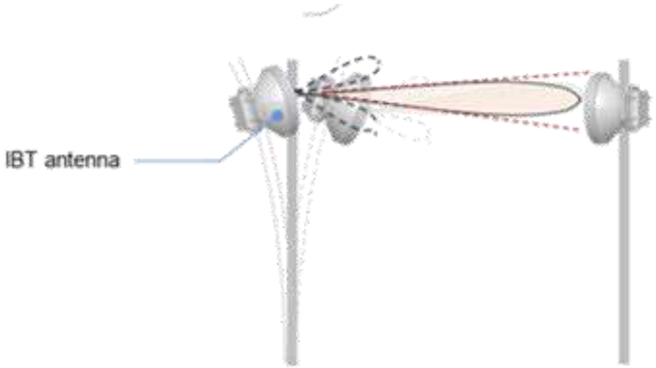
- Depending on the RSL, modulation scheme is shifted to maintain the link.
- By using both together, the link becomes harder to be outage.



Operation of ATPC & ACM

3. IBT (Intelligent Beam Tracking)

- Fluctuations due to pole sway are cancelled by beam tracking.
- The radio includes a sensor that detects misalignment.



Concept of IBT

Source : AWG-29/OUT-25

Summary

- The effects of severe weather conditions, especially wind, on millimeter-wave links were presented.

- A mathematical model for considerations of wind-effect was developed, based on field evaluations in E-band. A new APT Rec. including this model is under approval process.

- The model is also applicable to terahertz bands.

- The model will contribute to the accurate calculation of link budgets in over millimeter-wave bands.

This work was conducted as part of “Research and development of carrier converter technologies having high-environmental tolerance" under a contract with NICT, Japan.

Thank you for your attention!

ご清聴ありがとうございました

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