NSF Award #2128077

SWIFT: Enabling Spectrum Coexistence of 5G mmWave and Passive Weather Sensing

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Motivation & Significance

Motivation

- ❑ mm-wave band (n258)
- ❑ Near water vapor sensing band (23.8 GHz)
- ❑ Risk: 5G Radio Frequency Interference(RFI)

➔ degraded weather forecasts

5G could mean less time to flee a deadly hurricane, heads of NASA and NOAA warn

They're suggesting people could die because we won't have enough evacuation time

By Sean Hollister | @StarFire2258 | May 23, 2019, 3:41pm EDT

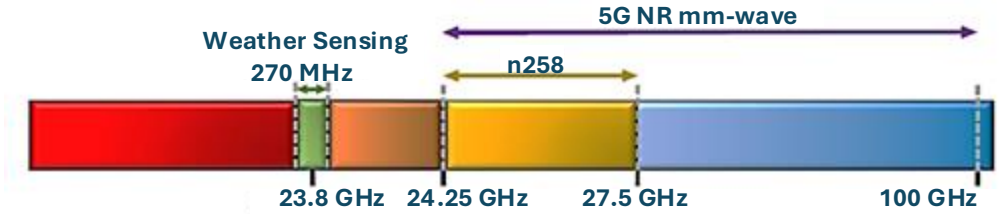
Theverge.com: May 2019

No, 5G Won't Ruin Your Weather Forecasts

The FCC has gotten into a fight with NOAA about 5G disrupting weather forecasting nationwide. The result will likely save your weather forecasts, but it'll weaken 5G coverage.

By Sascha Segan May 23, 2019

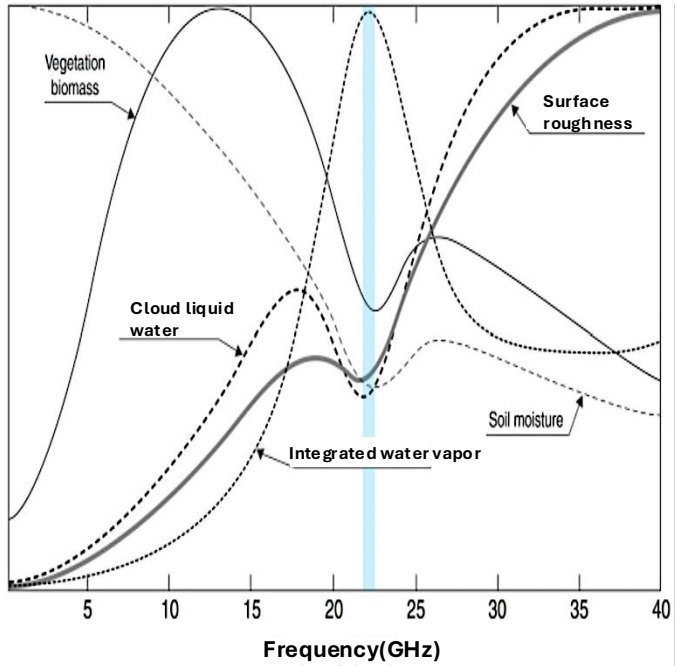
Pcmag.com: May 2019



Research Thrusts

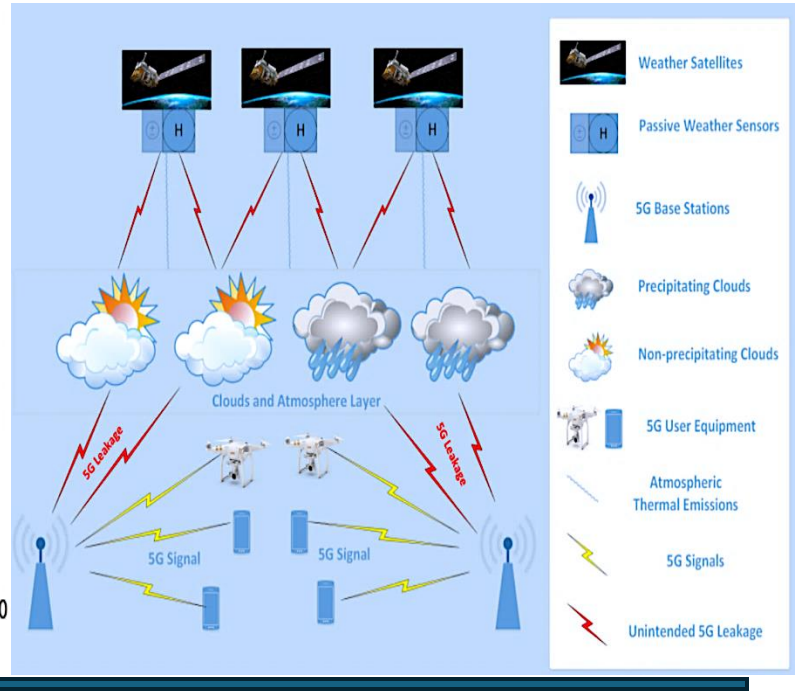
Modeling Impact of 5G Deployment on Numerical Weather Prediction(NWP)

- ❑ RFI characterization
- ❑ RFI effects on NWP



Cross-Layer Mitigation Strategies

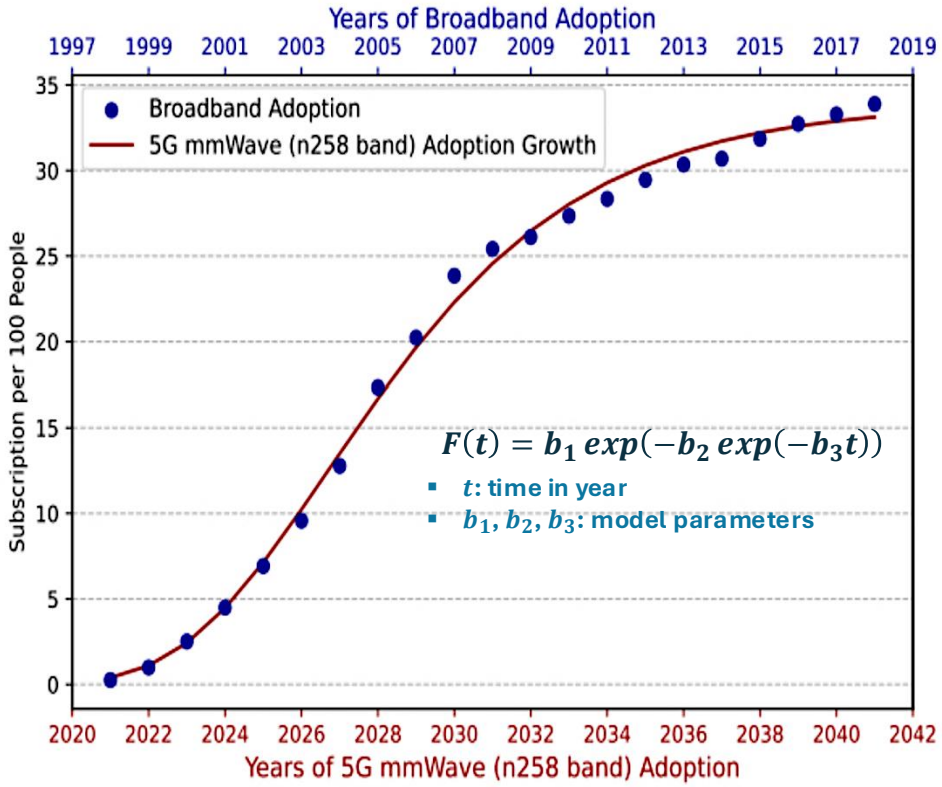
- ❑ Transmission techniques: Filtenna design
- ❑ RFI-aware radio resource management
- ❑ RFI-aware precoder design

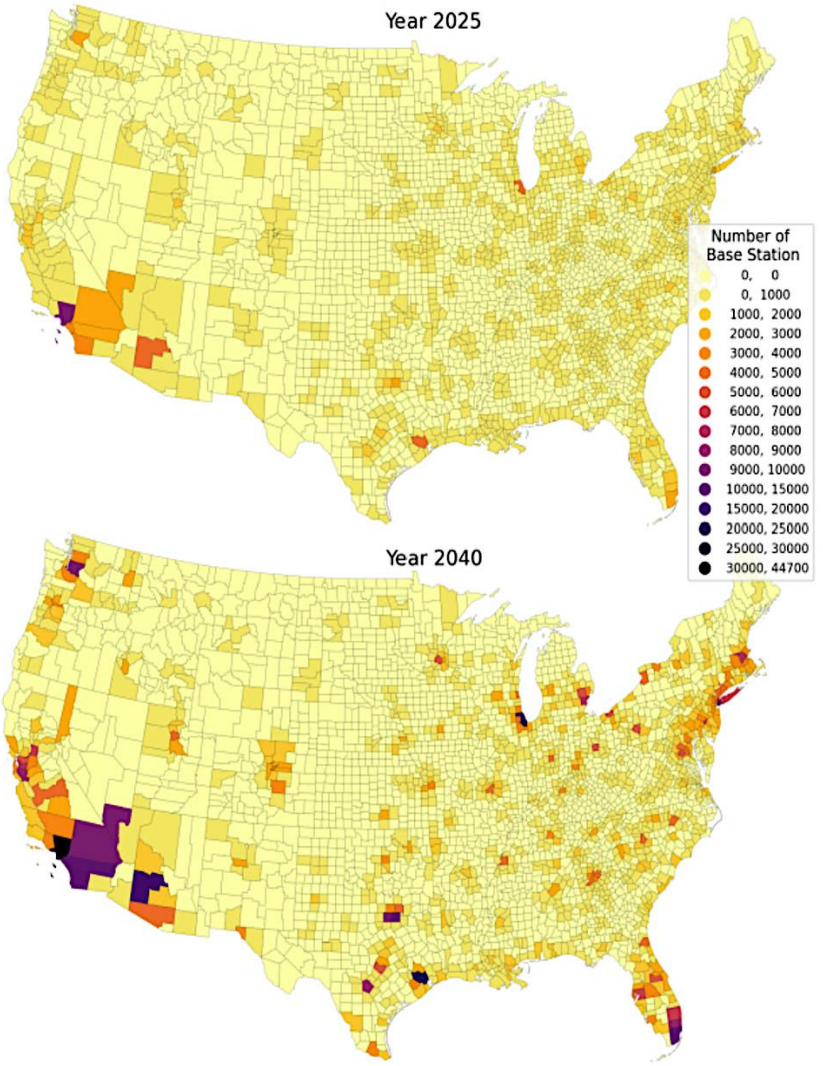


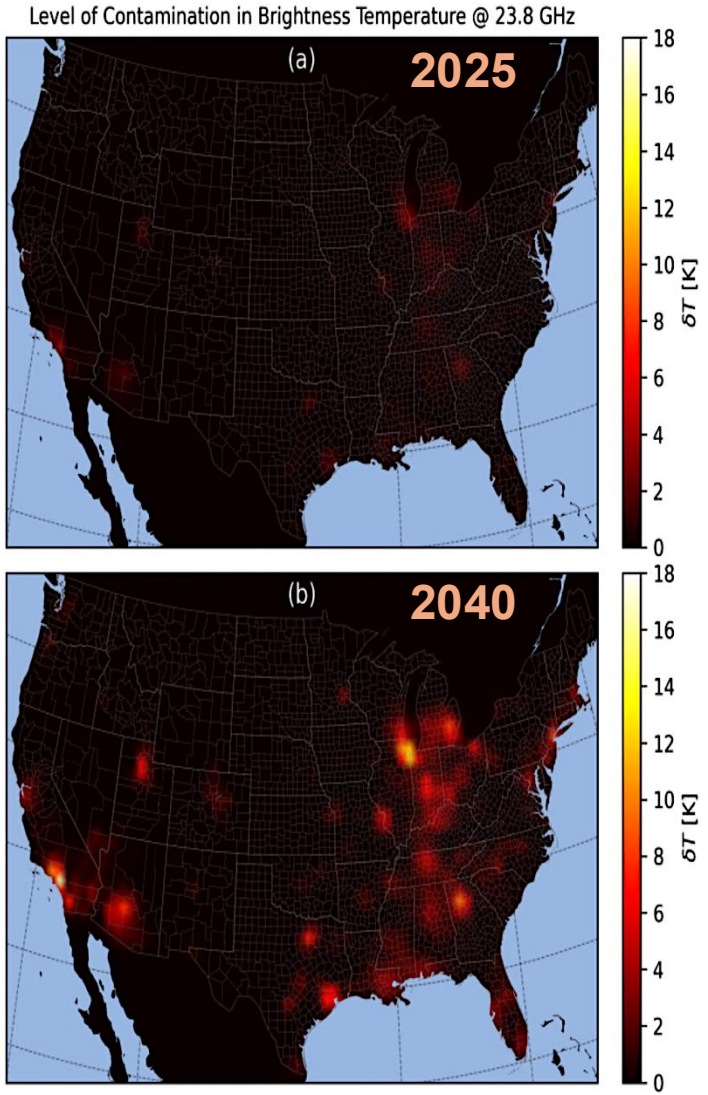
Impact of 5G Deployment on NWP [5]

Approach

- ❑ **5G Base Station Spatial Distribution (Gompertz model)**
- ❑ **Leakage modeling** (filters + Friis)
- ❑ **Aggregate RFI** at AMSU-A footprints
- ❑ **NWP: Weather Research and Forecasting (WRF) Data Assimilation model (WRFDA)**





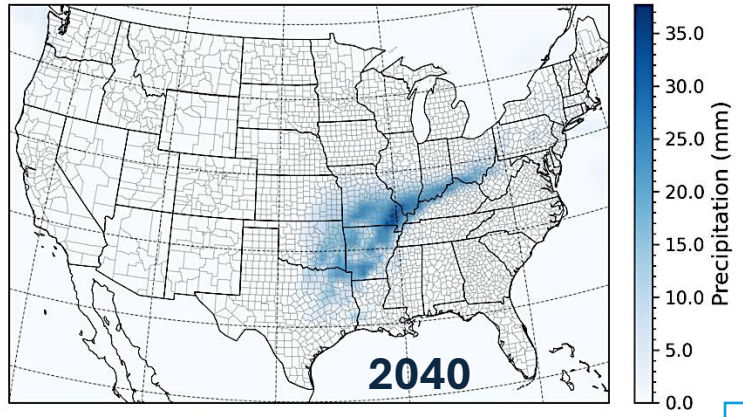


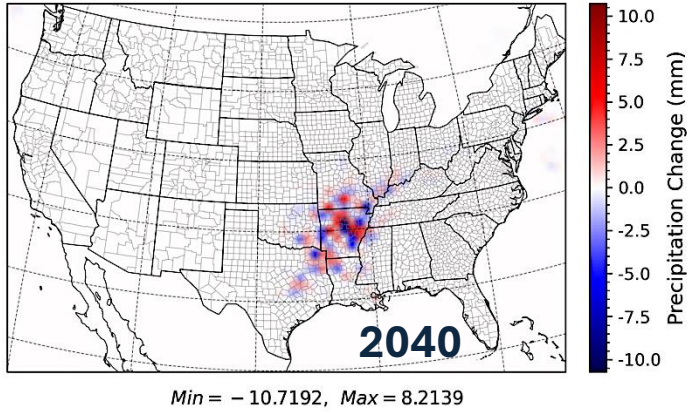
$P^{S}_{\text{RFI}} = -175\ dBW/BS$ and $\eta_{\text{SE}} = 15$ bit/s/Hz/BS

- ❑ **Integrated within the WRF modeling framework**
- ❑ **Utilizes brightness temperature observations from AMSU sensor**

Impact of 5G Deployment on Weather Forecast Accuracy

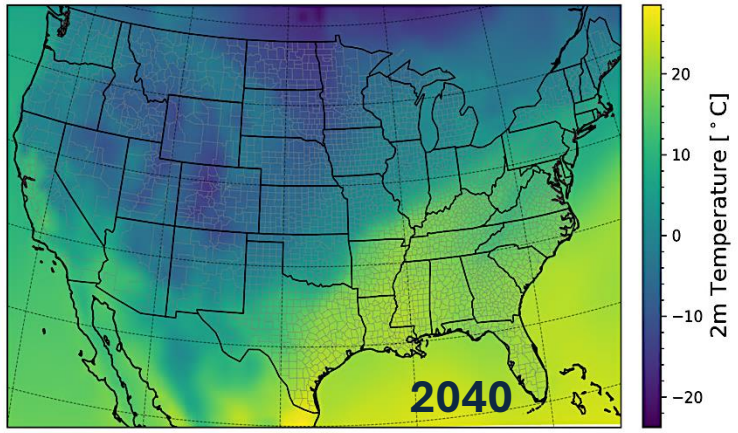
- Dataset: Super Tuesday Tornado Outbreak (February 5, 2008)
- Impact of RFI on 12-hour weather forecasting:
  - Precipitation and 2m Temperature

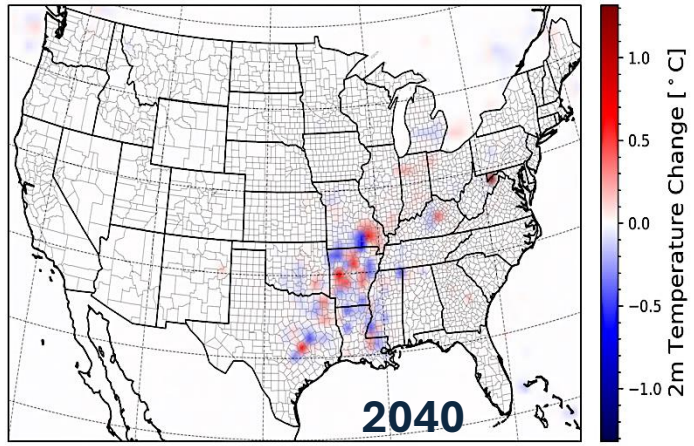




Min = −10.7192, *Max* = 8.2139

With RFI





Min = −0.6543, *Max* = 1.3179

- RFI leakage → biased satellite data → degraded NWP
- RFI effect:
  – Leads to loss of observations in the WRFDA assimilation process

- $P^{S}_{\mathrm{RFI}} = -175\ dBW/BS$ and $\eta_{\mathrm{SE}} = 15$ bit/s/Hz/BS :
  (i) Limited impact in 2025, but up to 17 K brightness temp. by 2040
  (ii) Causes forecast errors: ~10 mm precipitation, 1.75 °C in 2m temperature

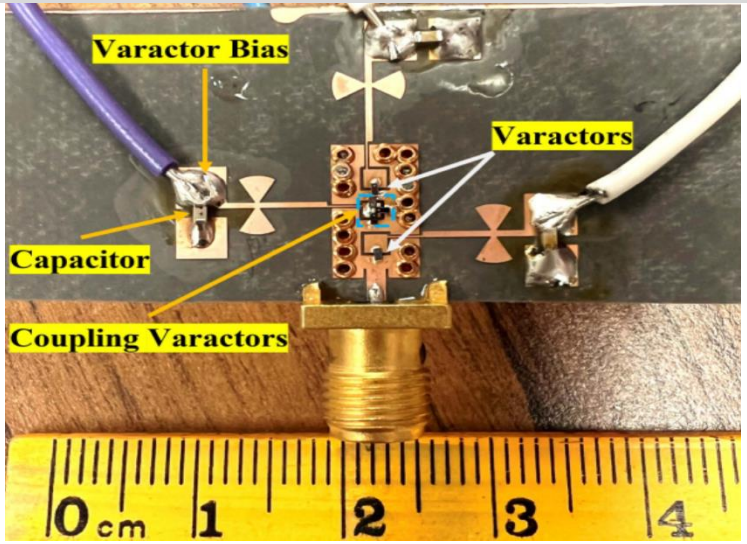
Additional Observation:

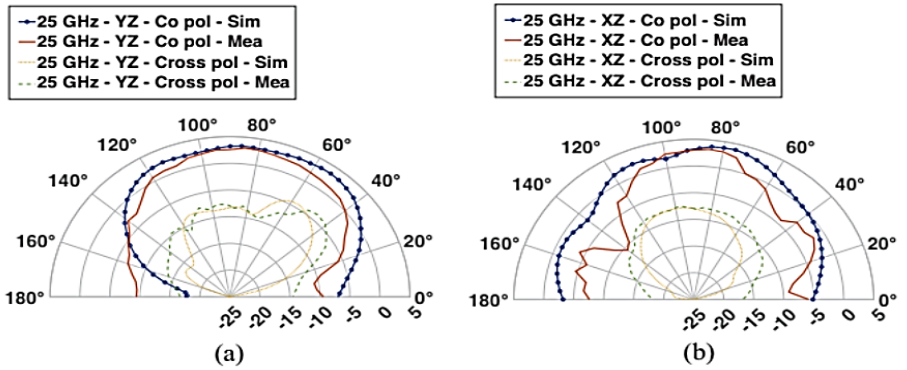
- At $P^{S}_{\mathrm{RFI}} = -200$ dBW/BS and $\eta_{\mathrm{SE}} = 15$ bit/s/Hz/BS: No forecast impact, even in 2040

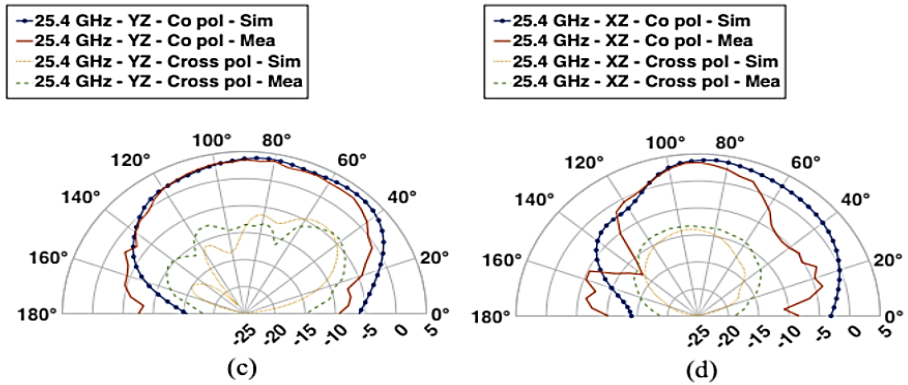
Reconfigurable Filtenna for 5G & Spectrum Coexistence [6]

Proposed Design

- **Reconfigurable Substrate Integrated Waveguide (SIW) Filtenna** with **varactors**
- **Tunable frequency**: 24–27 GHz
- **Constant bandwidth**: ~400 MHz
- **Broadside radiation** pattern
- **Cost-effective, scalable filtenna**
- Enables **5G mmWave performance** + **passive coexistence** with weather sensors.





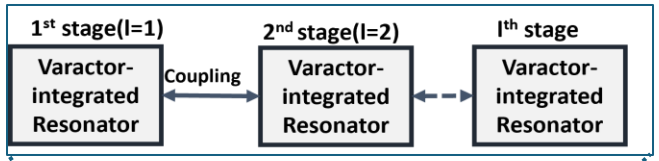


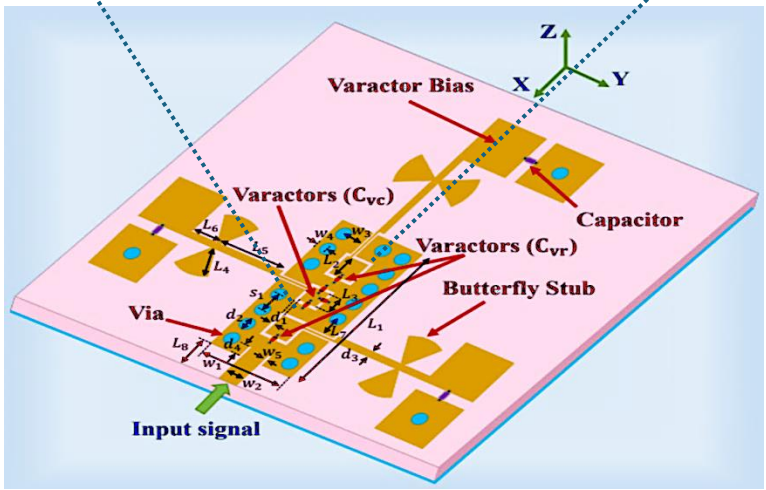
Results

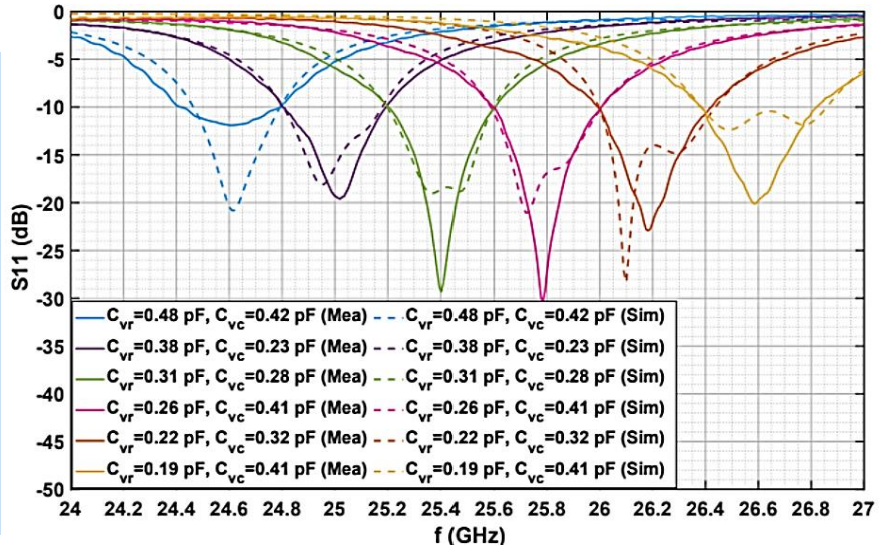
- **Prototype fabricated & tested**
- Measured **S11 & gain** match simulations
- **4.2 dBi gain**, ~60% efficiency
- Effective **out-of-band suppression** → **less RFI to 23.8 GHz**

- **Multi-stage Filtennas** → **better RFI suppression**

- **Tradeoff: RFI Suppression vs Total Power Cost**







Radio Resource Allocation with Filtennas

Goal

- RFI Aware bandwidth and Power Allocation [4]
- MU MIMO Filtenna and Precoder Design [7]

Method

- Iterative RFI-Aware Water-Filling for power and bandwidth allocation [4]
- Minimization of Total Power under Rate and RFI Constraints [7]

Rate Constraint

RFI Constraint

$$\underset{\{\mathbf{P},\tilde{\mathbf{U}}\}}{\text{minimize}} \sum_{k=1}^{K} P_k \|\tilde{\mathbf{u}}_k\|^2$$

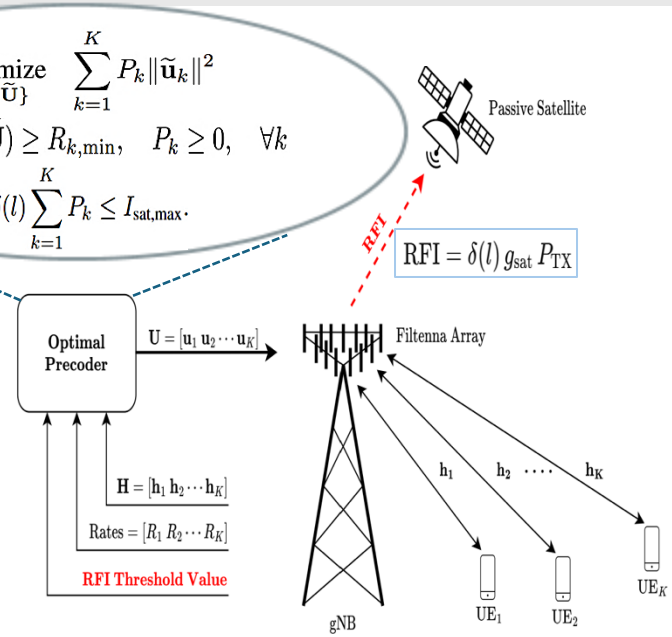
$$\text{s. t.} \quad R_k(\mathbf{P},\tilde{\mathbf{U}}) \geq R_{k,\min}, \quad P_k \geq 0, \quad \forall k$$

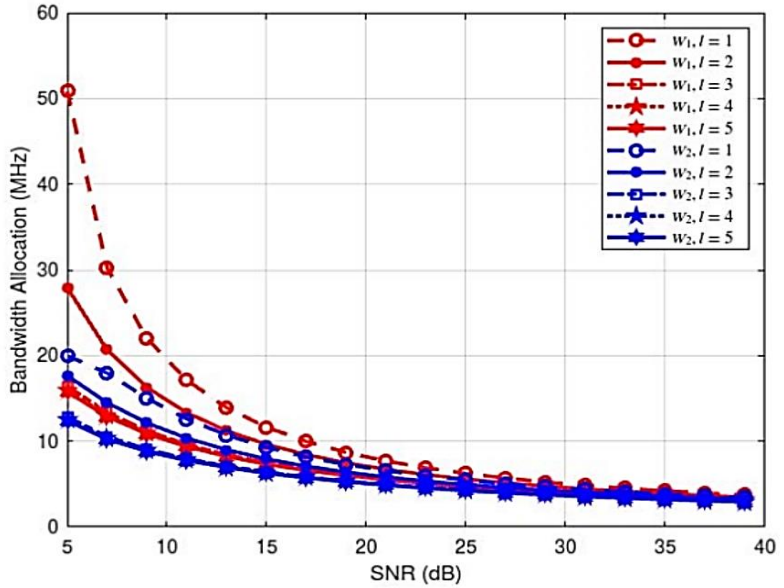
$$g_{\text{sat}}\,\delta(l)\sum_{k=1}^{K} P_k \leq I_{\text{sat,max}}.$$

Total Power | ADC/DAC Power Consumption | RFI Power

$$f_i(P_i, W_i, l) = P_i + \alpha(W_i)P_i + \beta(l)P_i + \delta(W_i, l)P_i$$

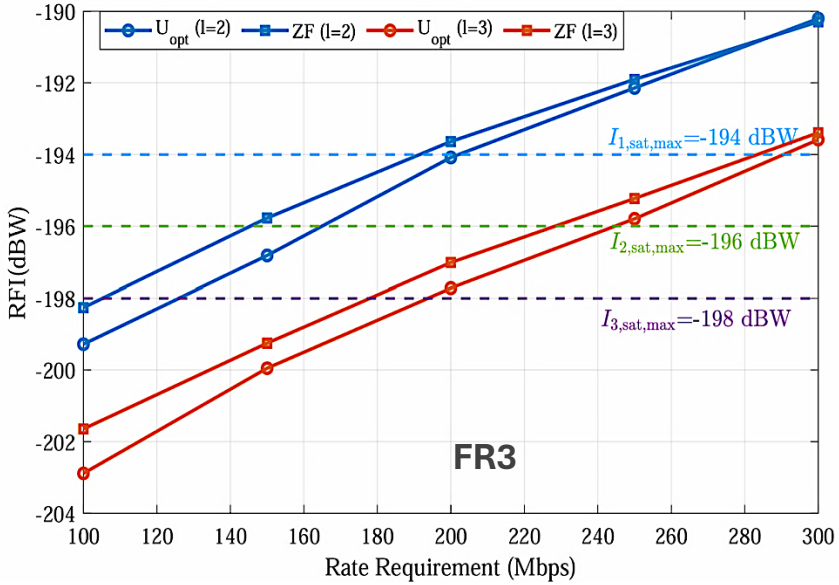
Transmit Power | Filtenna Power Consumption

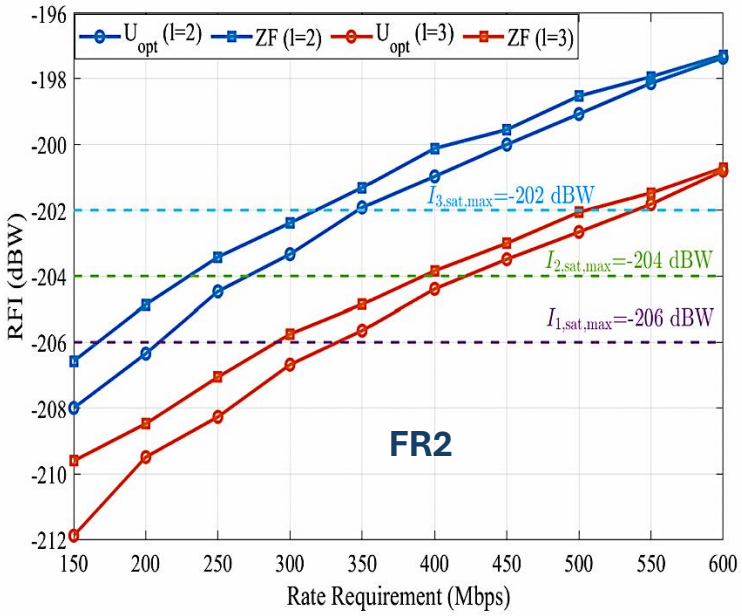




- Bandwidth allocation decreases with increased RFI suppression

- RFI ↑ with a higher user rate requirement





- Average rate loss per 2 dB of RFI suppression:
  - ~40–45 Mbps @ 10.6 GHz
  - ~90–95 Mbps @ 23.8 GHz

Publications

Published:

*[1] Yousefvand, et al. "**Modeling the impact of 5G leakage on weather prediction**." IEEE 3rd 5G World Forum (5GWF), 2020.*

*[2] Golparvar, et al. "**A study on the Impact of Non-Uniform 5G Leakage on the Accuracy of Weather Forecasts**", American Geophysical Union (AGU) Fall Meeting, Dec 2022, Chicago, IL.*

*[3] Golparvar, et al. "**Spatio-temporal analysis of the impact of 5G mm Wave technology deployment on the weather forecast accuracy**", 8th International Symposium on Data Assimilation (ISDA), Jun 2022, Fort Collins, CO.*

*[4] I. B. Majumdar et al., "**Resource Allocation Using Filtennas in the Presence of Leakage**," 2022 IEEE Future Networks World Forum (FNWF), Montreal, QC, Canada, 2022, pp. 591-596.*

*[5] Golparvar, B., Vosoughitabar, S., Bazzett, D., Brodie, J., Wu, C. T. M., Mandayam, N., Wang, R. "**How Does the Growth of 5G mmWave Deployment Affect the Accuracy of Numerical Weather Forecasting?**", (2024) IEEE International Symposium on Dynamic Spectrum Access Networks (DySPAN), May 2024, Washington, DC, USA, 2024, pp. 365-373.*

*[6] S. Vosoughitabar, N. B. Mandayam, J. F. Brodie, B. Golparvar, R. -Q. Wang, and C. -T. M. Wu, "**Design of a Reconfigurable Filtenna with Constant Bandwidth for Enhanced 5G mmWave Communication and Spectrum Coexistence**," 2024 IEEE International Symposium on Dynamic Spectrum Access Networks (DySPAN), Washington, DC, USA, 2024, pp. 517-523.*

Submitted:

*[7] MT. Rahman, H. Venkat, C.-T. M. Wu, and N. B. Mandayam, "**RFI-Aware Downlink Spatial Filtering in Terrestrial Networks for Passive Satellite Coexistence**," in Proc. IEEE Future Networks World Forum (FNWF), Bangalore, India, 2025.*

Future Extensions:

Multi-cell, Uplink/Downlink, Hybrid Precoding, AI Integration, Robust Precoding (Imperfect CSI).