Enabling Spectrum Coexistence of 5G mmWave and Passive Weather Sensing

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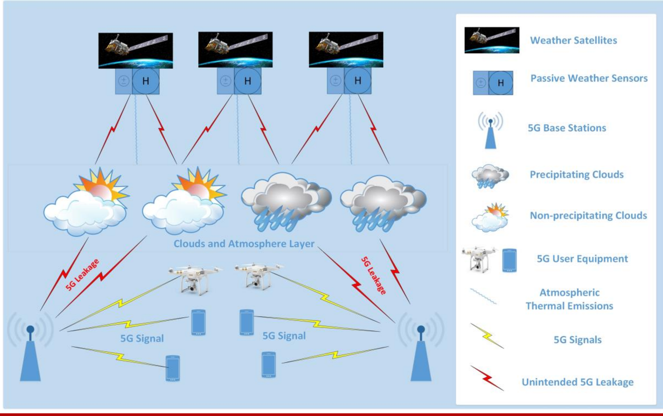
Project #: 2128077

Project Website

Summary

The 5G mmWave band allocated in the 26 GHz spectrum referred to as 3GPP band n258 has generated anxiety and concern in the meteorological data forecasting community. This issue stems from 5G transmissions impacting the observations of passive sensors on weather satellites used to detect the amount of water vapor in the atmosphere, which in turn affects weather forecasting and predictions. To this end, the proposed research project aims to tackle this issue by characterizing the impact of 5G transmissions on weather data measurements and prediction, and then design cross layer mitigation strategies needed to enable coexistence between 5G services and weather prediction, as well as improved weather prediction algorithms. The project will lead to algorithm designs, reference architectures, and testbed experiments that will provide pointers to engineering methodology for the design of spectrally and system power-efficient 5G/B5G networks that can peacefully coexist with passive weather sensors. It will also enable the development of improved weather forecasting algorithms that are cognizant of the potential impact of unintended interference.



Research Progress

Spatio-Temporal Impact of RFI from 5G mmWave on Weather Forecast

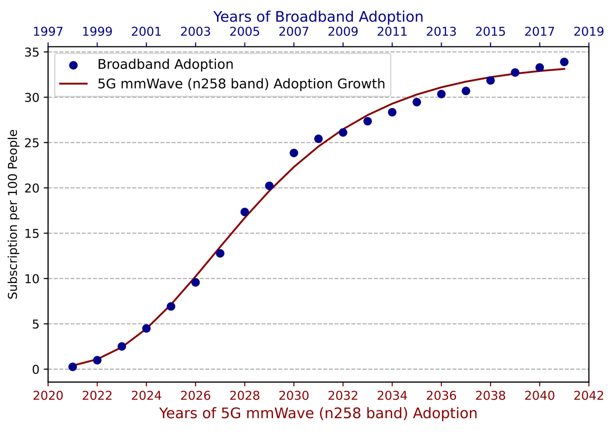


Fig. 1 5G mmWave adoption growth rate predicted using Gompertz model

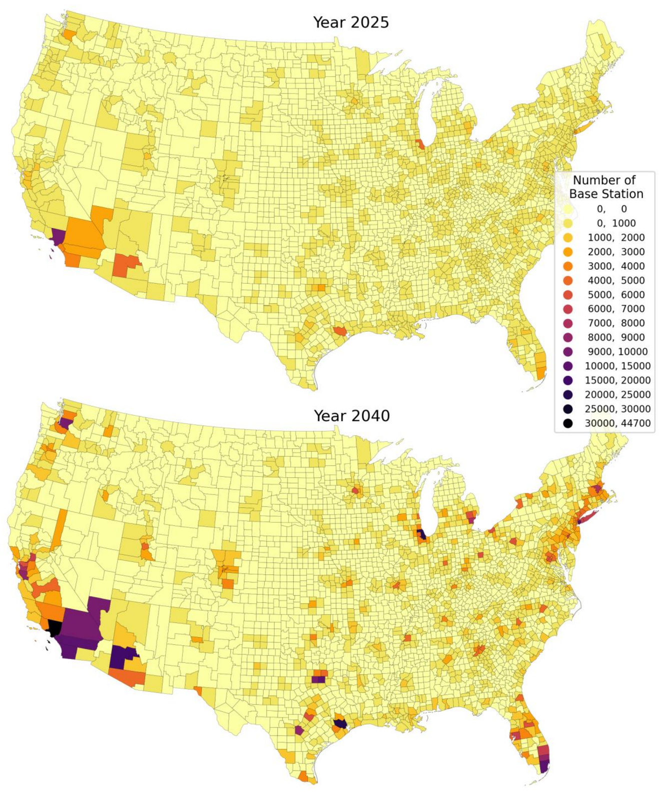


Fig. 2 Predicted number of base stations in each county for $\eta_{sp} = 15$ bit/s/Hz/BS in years 2025 and 2040

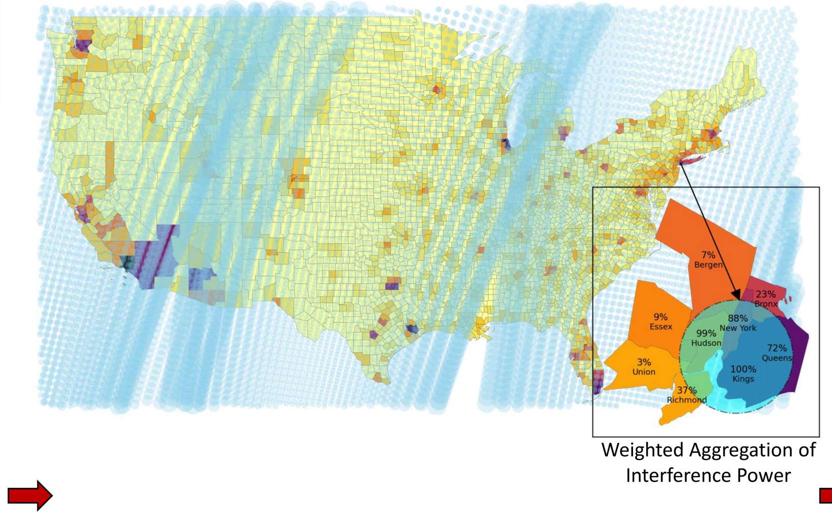


Fig. 3 AMSU-A observations from Metop-A, NOAA-15, 16, and 18 satellites depicted as blue circles. Similar to Fig. 2(b) is in the background.

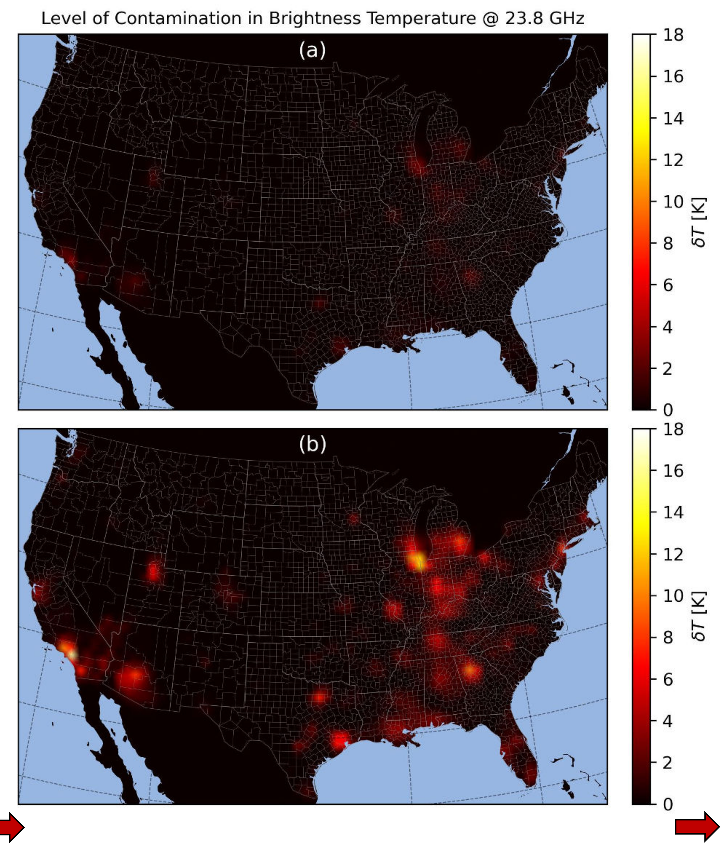


Fig. 4 Predicted RFI in terms of induced noise in brightness temperature (contamination) for $P^S_{\mathrm{RFI}} = -175$ dBW and $\eta_{sp} = 15$ bit/s/Hz/BS in year (a) 2025, and (b) 2040

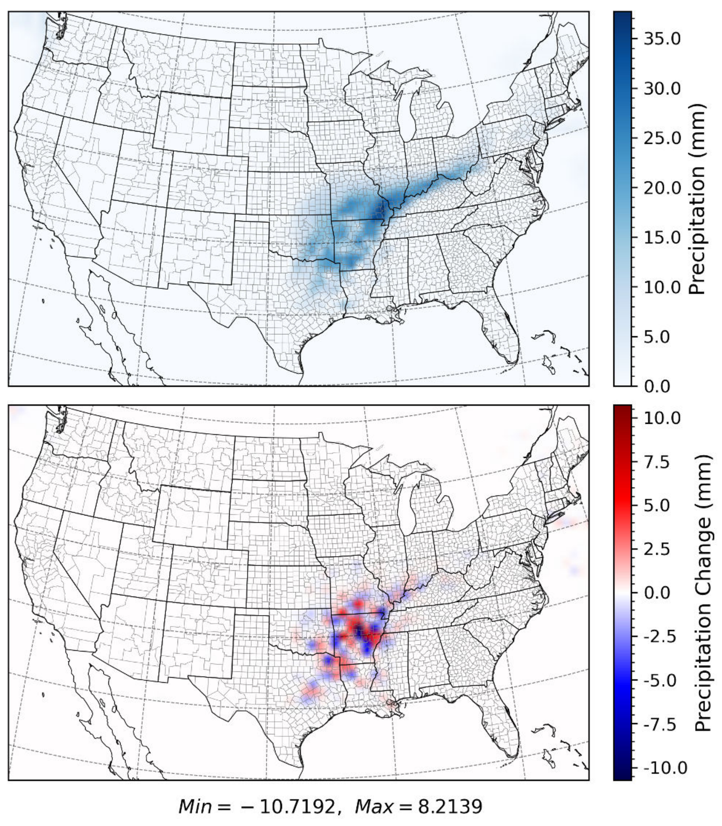


Fig. 5 12-hour forecast of accumulated total precipitation without any RFI, (b) deviation in accumulated total precipitation forecast for $P^S_{\mathrm{RFI}} = -175$ dBW, $\eta_{sp} = 15$ bit/s/Hz/BS, and year 2040

- Assuming that the temporal trend of 5G mmWave adoption can be somewhat similar to the growth patterns of broadband adoption because of their advantages compared with predecessors [1], the future base station deployments can be predicted using diffusion of a new technology model trained on broadband adoption data. (Fig. 1)
- The spatio-temporal distribution of base stations can be predicted using the estimated total demand and certain spectral efficiencies (η_{sp}) only for counties classified as metropolitan or dense urban. (Fig. 2)
- Aggregated interference power is estimated for each observation using geo-spatial data analysis and aggregation weights calculated based on area covered by satellite observations. (Fig. 3)
- Interference power received by the AMSU-A radiometer from a single base station (P^S_{RFI}) can vary depending on the transmitted power, orientations of the satellite's receiver and base station's transmitter, filtering response, and atmospheric attenuation.
- A parametric study is conducted for a wide range of -210 to -165 dBW for P^S_{RFI} [2], and 7 to 25 bit/s/Hz/BS for η_{sp}
- The induced noise in brightness temperature can be estimated using the aggregated interference power received by the radiometer ($\delta T = P^A_{RFI}/kB$), where B is the channel bandwidth and k is the Boltzmann constant. (Fig. 4)
- Modeling of 5G mmWave leakage impact on prediction of rainfall and other atmospheric parameters using the open-source packages of Weather Research and Forecasting (WRF) and Data Assimilation (WRFDA) for the data set of "Super Tuesday Tornado Outbreak" happened in Feb. 2008. (Figs. 5 and 6)

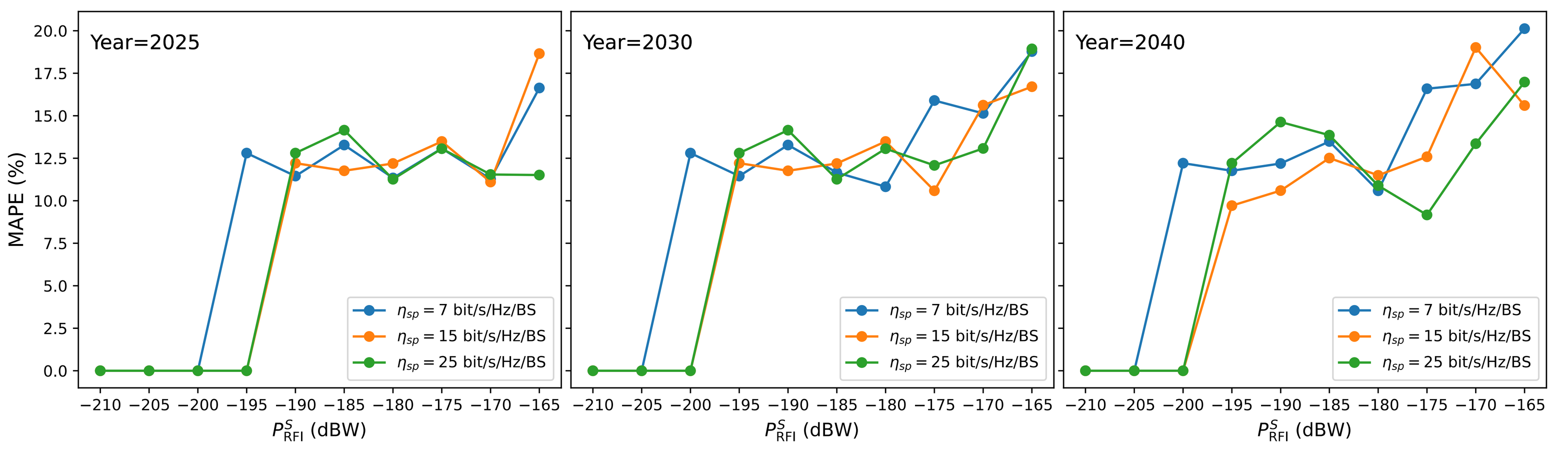
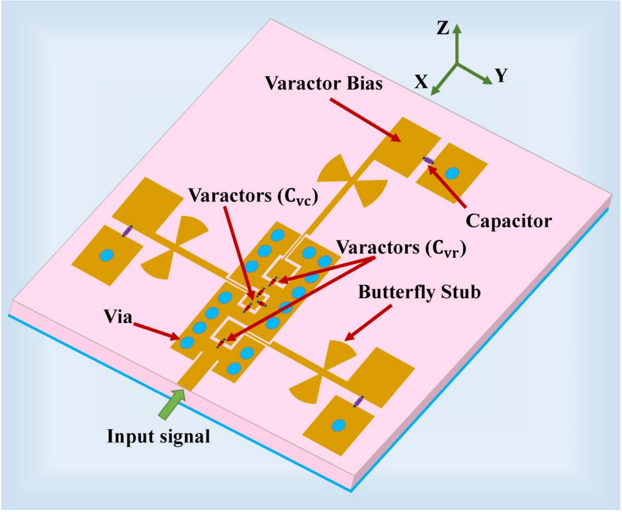


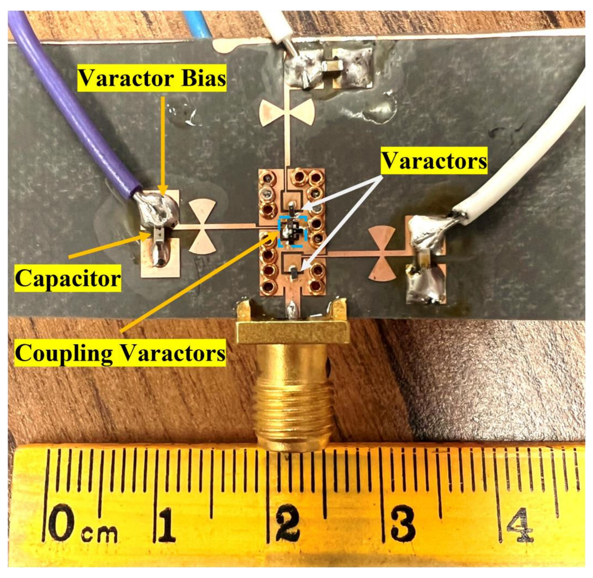
Fig. 6 Mean absolute percentage error of accumulated total precipitation forecast versus P^S_{RFI} for different spectral efficiencies and deployment year

A Reconfigurable mm-Wave Substrate-Integrated-Waveguide filtenna

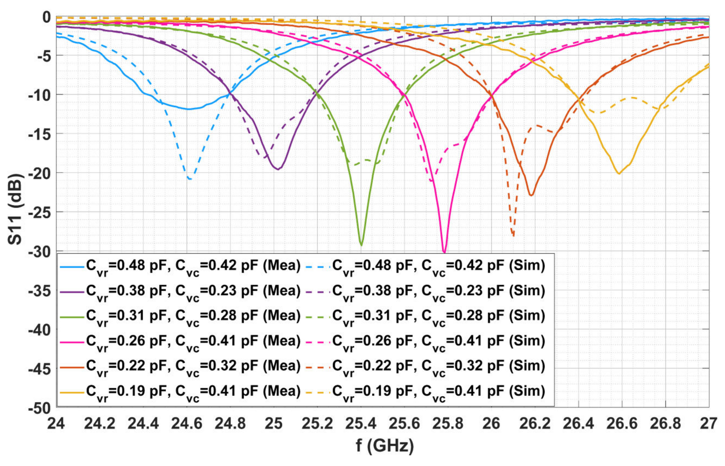
- Tunability with integrated varactors
- Cost-effective and scalable

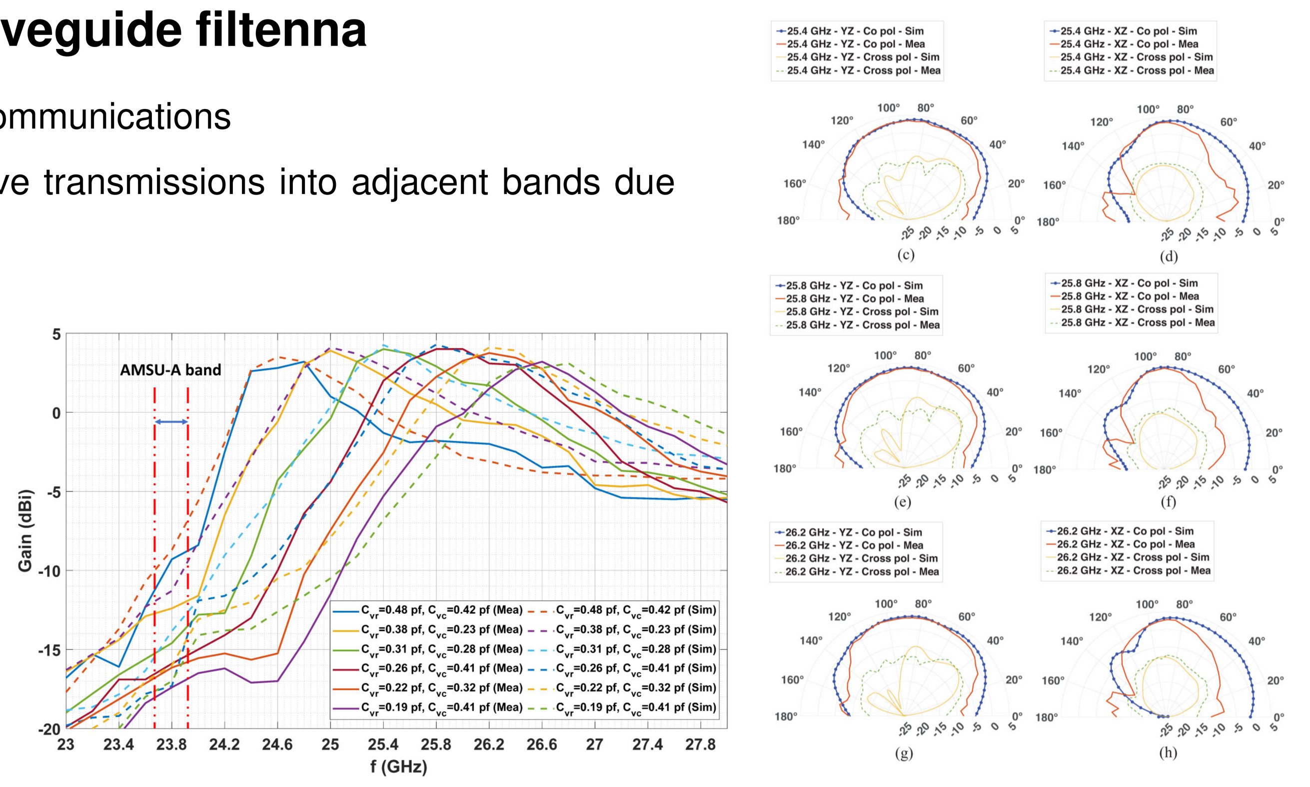


- Fabrication of a prototype with 2 stages



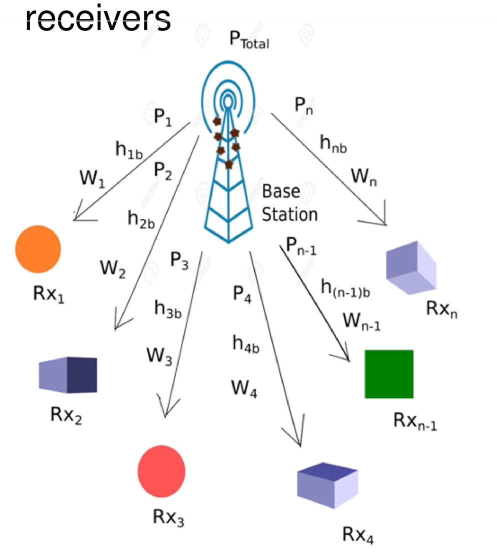
- Constant bandwidth for 5G NR Communications
- Decrease the RFI of 5G mm-Wave transmissions into adjacent bands due to the filtering property



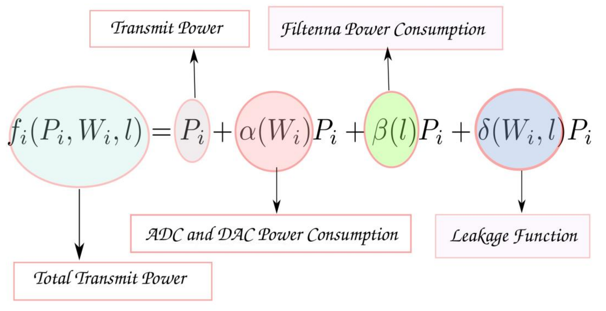


Radio Resource Allocation

- Downlink of SISO system with transmitters using filtennas
- Filtennas with l varactor stages transmitting to n receivers



- Minimize total transmit power subject to bandwidth, rate, and filtenna constraints
- Optimal power and bandwidth allocation via iterative waterfilling to reduce leakage



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

$$f(P_1, P_2, \cdots, P_n, W_1, W_2, \cdots, W_n, l) = \sum_{i=1}^{n} f_i(P_i, W_i, l)$$

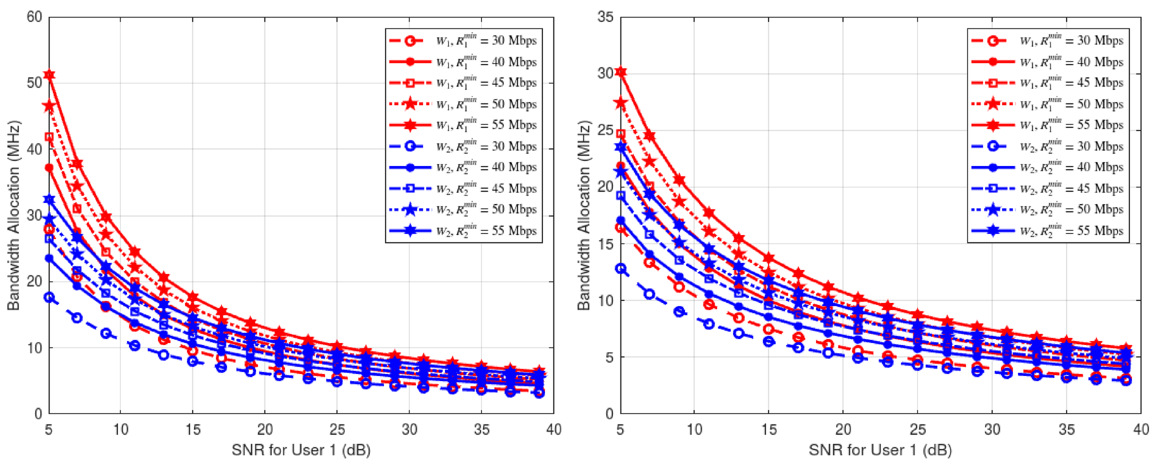
$$\min_{P_1, P_2, \cdots, P_n, W_1, W_2, \cdots, W_n, l} f(P_1, P_2, \cdots, P_n, W_1, W_2, \cdots, W_n, l)$$

$$W_1 + W_2 + \cdots + W_n = W \text{ (Total bandwidth constraint)}$$

$$W_1 \ln\left(1 + \frac{h_{11}P_1}{\sigma^2 + \sum_{i\neq 1}\delta(W_i, l)P_i}\right) \geq R_1^{min}, \cdots, W_n \ln\left(1 + \frac{h_{nn}P_n}{\sigma^2 + \sum_{i\neq n}\delta(W_i, l)P_i}\right) \geq R_n^{min}$$

$$W_1^* \ln\left(1 + \frac{h_{11}P_1^*}{\sigma^2 + \sum_{m\neq 1}\delta(W_m^*, l^*)P_m^*}\right) = R_1^{min}, \cdots, W_n^* \ln\left(1 + \frac{h_{nn}P_n^*}{\sigma^2 + \sum_{m\neq 1}\delta(W_m^*, l^*)P_m^*}\right) = R_n^{min}$$

- Modeling the leakage function
- Bandwidth allocation decreases with increased leakage suppression



Bandwidth allocation for n = 2 users versus SNR for different minimum rates for (a) l = 2 (b) l = 3. The blue lines correspond to user 1 and red lines correspond to user 2.

Future Directions

- Resource management for multiple-input multiple-output (MIMO) systems
- Filtennas with sharper out of band rejection including more stages
- Studying other extreme weather events using JEDI and UFS
- Incorporating a correction method in WRFDA to assimilate 5G RFI/bias-informed weather observations
- Studying the impact using the state-of-the-art operational models using Joint Effort for Data Assimilation Integration (JEDI) and Unified Forecast System (UFS)

Publications

- Yousefvand, et al. "Modeling the impact of 5G leakage on weather prediction." IEEE 3rd 5G World Forum (5GWF), 2020.
- Golparvar, et al. "A study on the Impact of Non-Uniform 5G Leakage on the Accuracy of Weather Forecasts", AGU Fall Meeting, Dec 2022, Chicago, IL.
- 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.
- Majumdar, et al. "Resource Allocation Using Filtennas in the Presence of Leakage." IEEE Future Networks World Forum (FNWF), 2022.
- 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
- Vosoughitabar, S., Mandayam, N., Brodie, J., Golparvar, B., Wang, R., Wu, C. T. M. "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), May 2024, Washington, DC

References

[1] Palade, A., et al. "Will Emerging Millimeter-Wave Cellular Networks Cause Harmful Interference to Weather Satellites?". IEEE Transactions on Cognitive Communications and Networking, 2023.

[2] A. Jha and D. Saha, "Techno-economic analysis of 5g deployment scenarios involving massive mimo hetnets over mmwave: A case study on the us state of texas," 2018