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Massive MIMO for 5G and Beyond: Challenges and Opportunities

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For IEEE INGR Panel: Millimeter Wave and Massive MIMO – Deployment Challenges and New Trends

Power Consumption in Wireless Communications

- Power consumption poses a serious challenge: network and base station level

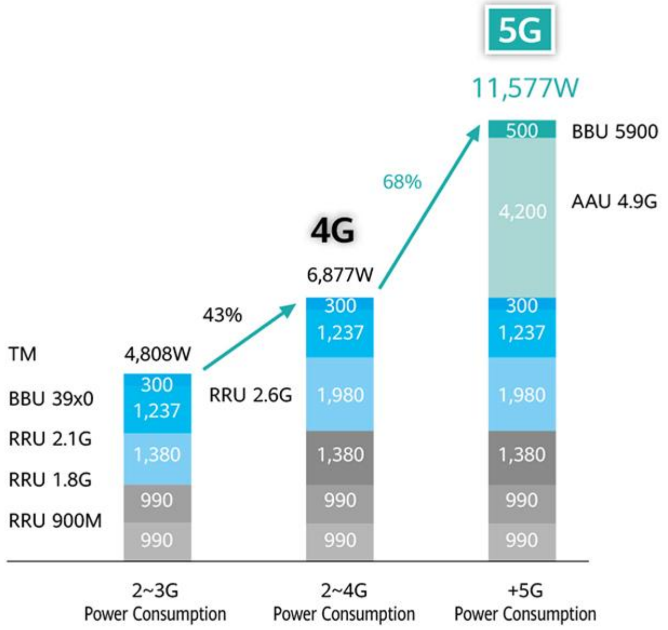


Fig. 1. Typical maximum power consumption of a single 5G base station

courtesy: [1] R. Saracco, "6G does not exist, yet it is already there!" IEEE Future Directions, 2020.

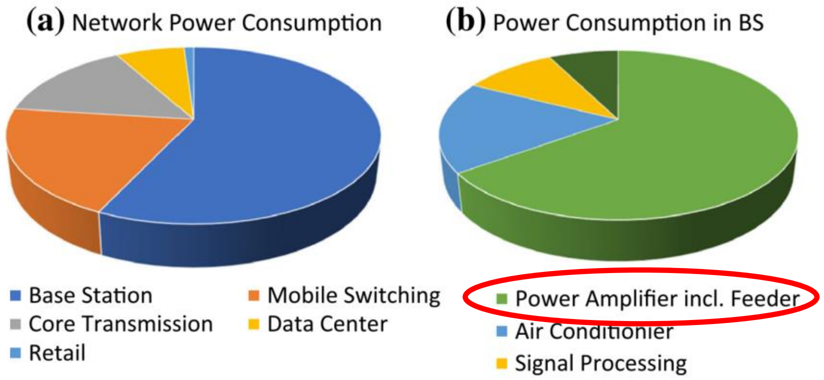


Fig. 2. Power consumption in cellular networks.

courtesy: [2] V. Poirot, et al., "Energy efficient multi-connectivity algorithms for ultra-dense 5G networks," Wireless Netw., vol. 26, pp. 2207–2222, Jun. 2019.

Power Consumption and Global Energy Transition

❖ Semiconductor industry may experience power shortrage issue that worses the chip shortage

The global chip shortage is going from bad to worse. Here's why you should care

By Hanna Ziady, CNN Business

Updated 12:07 PM ET, Tue May 4, 2021

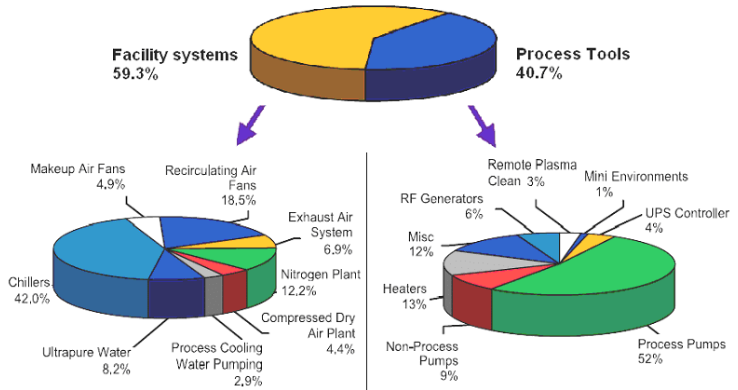


Fig. 3. Distribution of energy consumption in semiconductor fab.
courtesy: [3] A. Plepys,"Environmental Implications of Product Servicing. The Case of Outsourced Computing Utilities", thesis, 2004.

The energy consumption for manufacturing per unit (wafer) over last decades decreases slowly while the demand on chips grows exponentially.
courtesy: [4] S. Hu and Y.K. Chuah, "Power consumption of semiconductor fabs in Taiwan", Energy, 2003.

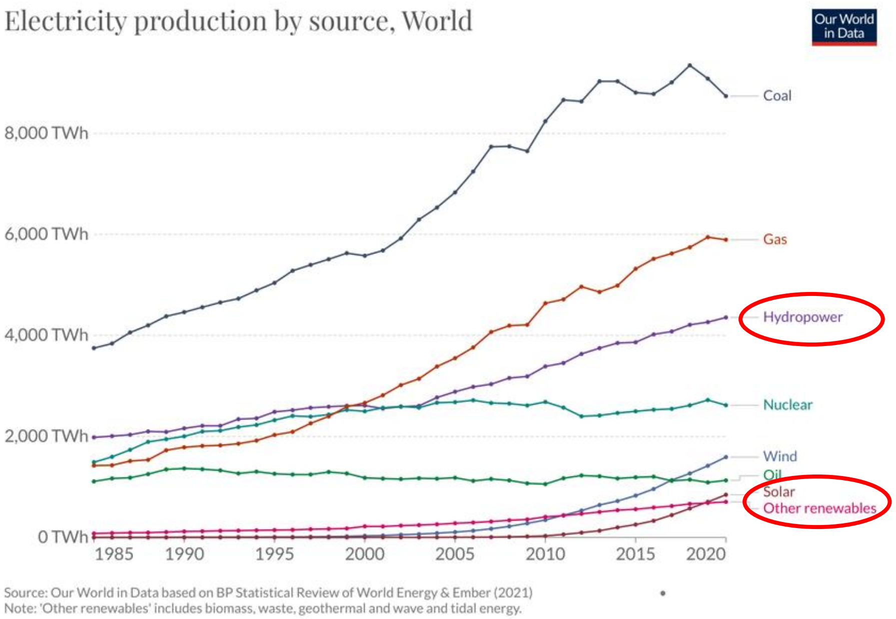


Fig. 4. Electricity production by source.
courtesy: [5] our world in data, 2021.

Renewable energy to reach about **22.5%** share in global power mix in 2020

Vision and Possible Solutions from Massive MIMO B5G

- Higher Energy/Spectrum Efficiency Leading to Being Envrionmentally Fridenly
- Reconfigurable Intelligent Surfaces (RIS) Assited Massive MIMO
- Hardware and Futional Blocks Reuse
- Spatial Multiplexing/Reuse and Licensed/Unlicensed Bands Coexistence
- Machine-learning Enhanced Massvie MIMO

Why RIS Is A Critical Game-Changer

- Alternative names: Intelligent Reflecting Surface (IRS), Software-controlled Metasurfaces
- Significant capability of tailoring the EM waves

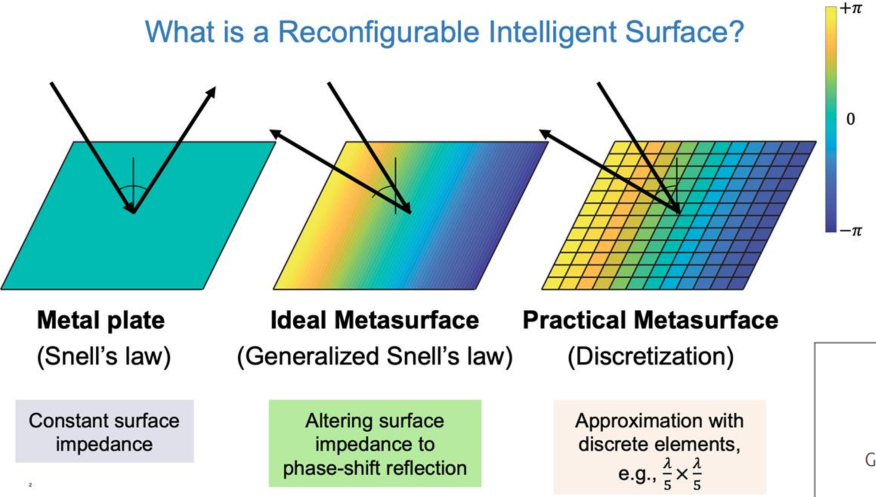


Fig. 5. what is RIS and how it works [6].

courtesy: [6] E. Björnson, "IRS Myths and Realities," https://github.com/emilbjornson/presentation_slides/blob/master/IRS_myths_and_realities.pdf. 2020

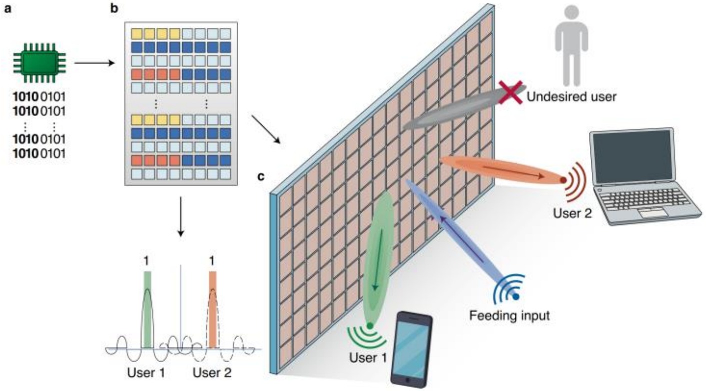


Fig. 6. Metasurface design for signal multiplexing in space and frequency

Courtesy: [7] S. Nie, et al., "metasurfaces for multiplexed communication ," Nature Electronics, 2021.

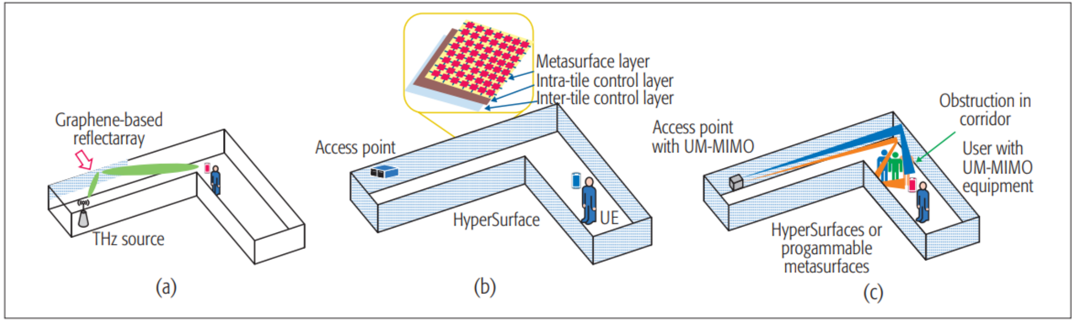


Fig. 7. Illustrations of proposed techniques: a) a use case of graphene-based reflectarrays; b) HyperSurfaces; c) the joint design based on UM-MIMO communication, HyperSurface, and the distance-adapative modulation technique. [8]

courtesy: [8] I. F. Akyildiz, et al. "Combating the Distance Problem in the Millimeter Wave and Terahertz Frequency Bands," IEEE Communications Magazine, 2018.

A Small Design Demo and Analysis

- Based on a realistic meeting room 3D design and 60 GHz carrier frequency

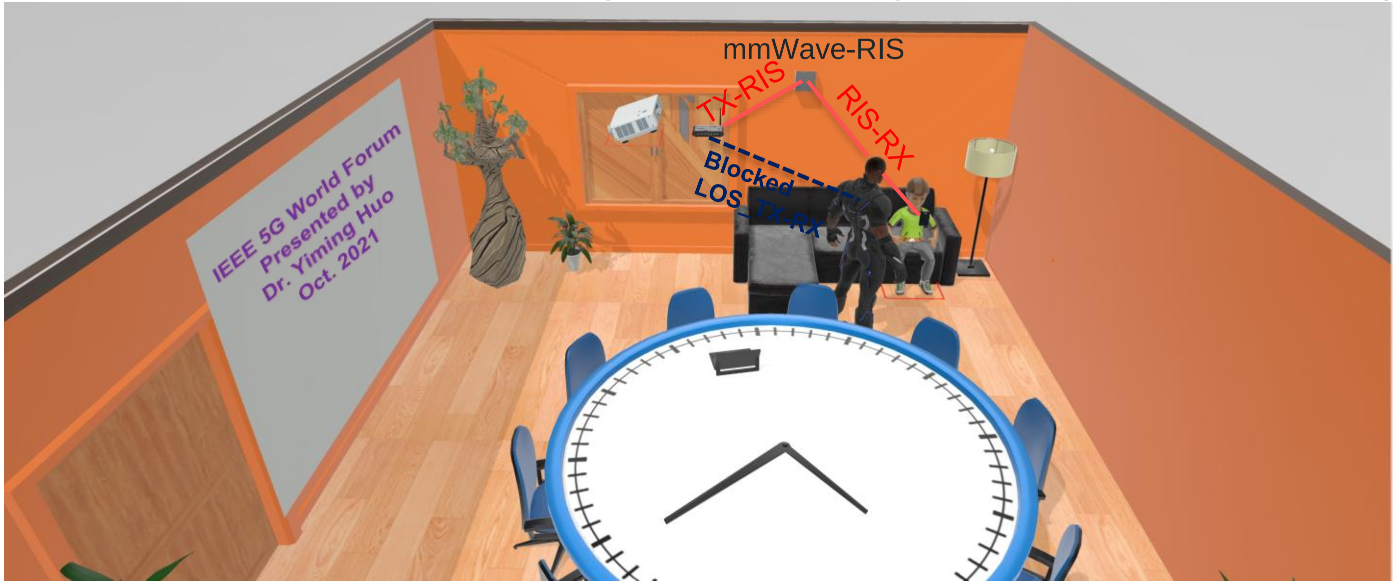


Fig. 8. 3D transparent view of RIS-Assisted mmWave Communication with A Realistic Environment and Human Blockage.

Human Blockage can exceed 40 dB (*R. J. Weiler, IEEE ICUWB, 2014*), causing LOS comm. Blocked and a series of side effects.

- RIS enables another **'ARTIFICIAL'** reflection link to overcome the human blockage issue
- Path Loss (with atmospheric atten. and real RIS refl. coeff.) of mmWave-RIS is <u>**11.8 dB**</u> lower (better) than the best NLOS link (situation without RIS)
- RIS is consisted of <u>**80 * 80**</u> unit cells, occupying a total hardware area <u>< 0.14 m * 0.14 m</u> (2 * iPhone-12-mini)
- **Artificial reflection link outperforms 'natural' reflection** where the atten. depends on building materials and roughness factor. Plasterboard material is used in the simulation.

A Small Design Demo and Analysis II

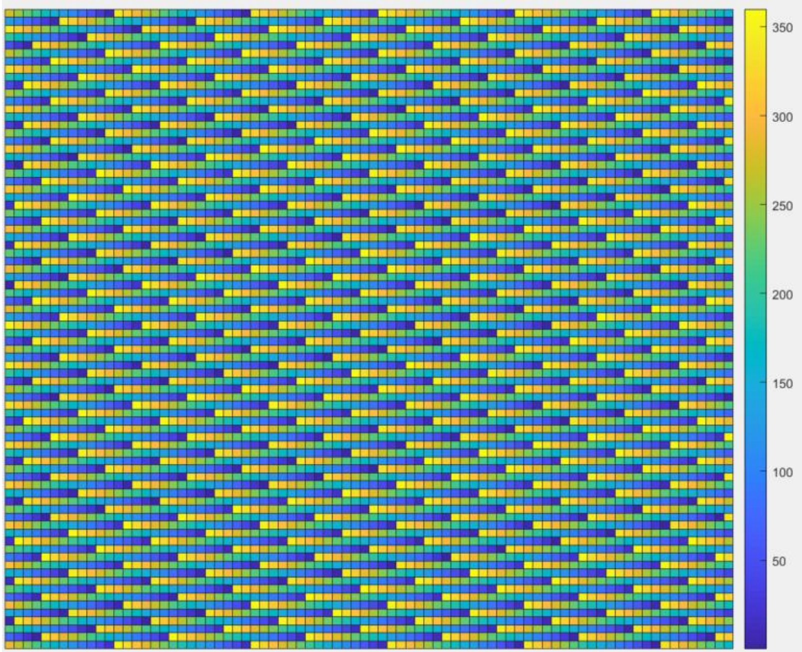


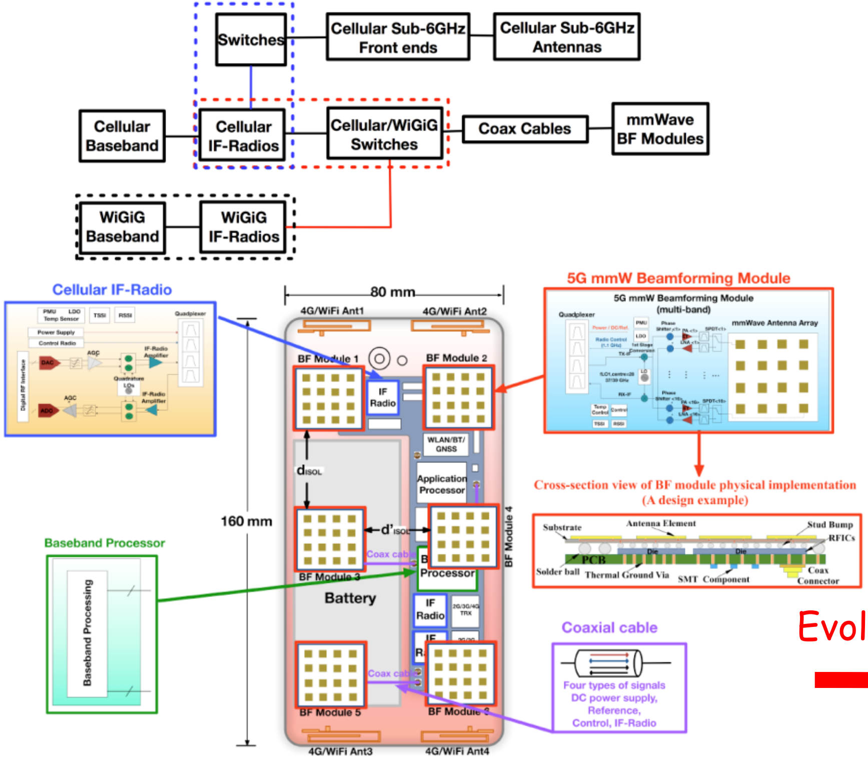
Fig. 9. Phase shifts matrix design for 80 * 80 sized RIS system operating at 60 GHz and in the application scenario of Fig. 8.

Opportunies and Future Challenges for RIS

- RIS-assisted wireless communication at higher frequencies significantly improves the QoS and **energy efficiency (saving power)** for both BS & UE
- Chip-level design and hardware implementation require more creative designs to mitigate the cost (SoC & PCB) and to improve the speed and energy efficiency
- More advanced algorithms and framework are needed to design and deploy, and to optimize the performance, e.g. the machine learning (reinforcement learning)
- Integrating RIS into UAV/Satellite/Vehicular comm. networks may hold great potential

User Equipment

- Enabling Hardware Reuse and Overcoming Human Blockage



Evolution !

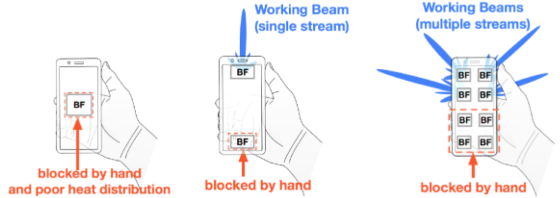


Fig. 11. Possible mmWave UE design strategies comparison [10].

Courtesy [10] Y. Huo, at al., "5G Cellular User Equipment: From Theory to Practical Hardware Design," IEEE Access, 2017.

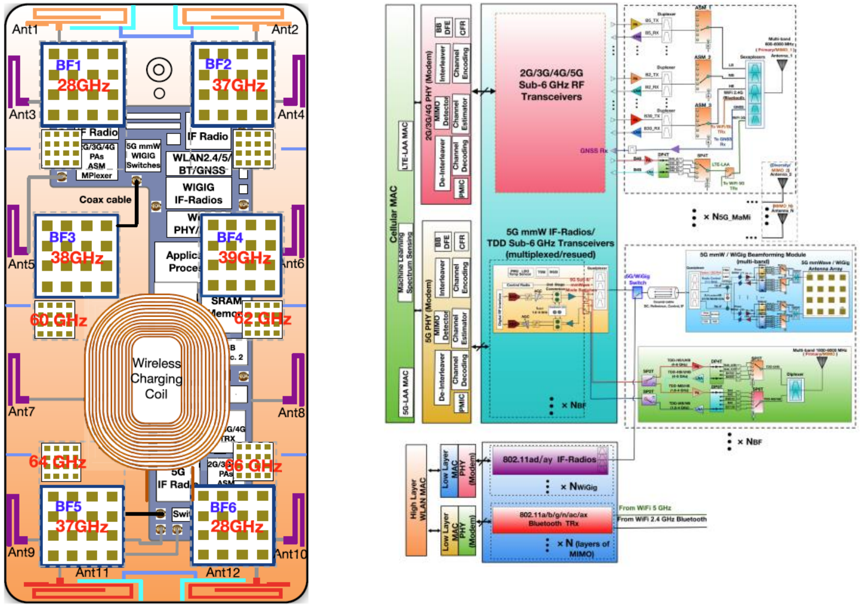


Fig. 10. System block diagram of Sub-6 GHz/WiFi/WigGig co-design for user equipment design [9].

Courtesy [9] Y. Huo, et al. "Cellular and WiFi Co-design for 5G User Equipment," 2018 IEEE 5GWF.

Fig. 12. Hardware-reuse cellular and WiFi/WigGig co-design for 5G and Beyond UE with Frequency/Spatial Multiplexing [11].

Courtesy [11] Y. Huo, at al., "Enabling Multi-Functional 5G and Beyond User Equipment: A Survey and Tutorial," IEEE Access, 2019.

Conclusions

- Global Power Shortage, Energy Transition and Supply Chain Issues Require More Energy/Spectrum Efficiency for B5G Networks Design and Deployment

- RIS-Assisted B5G Massive MIMO Is Effective to Reduce the Unecessary Energy Dissipation and Absorption (either by building materials or human/animals)

- Overcoming Human Blockage Needs both BS, UE and Network Co-design/deployment and Co-optimization

- Hardware Reuse and Licensed/Unlicensed Co-op Can Reduce the Cost and Mitigate Global Supply Chain Pressure

- More Advanced/Fittable Machine-learning Algorithms are Needed to Enhance the B5G Massvie MIMO Overall System Performance