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**Submission Title :** Surface-Wave Communication: Rethinking the Future of Wireless Communications

**Date Submitted :** September 17, 2025

**Source :** Kai-Kit Wong (UCL) and Seok-Bong Hyun (ETRI)

**Re :** TG4ad Next Generation SUN PHYs

**Abstract :** This contribution discusses how surface wave communications redefine how wireless connectivity can be provided.

**Purpose:** Discussion

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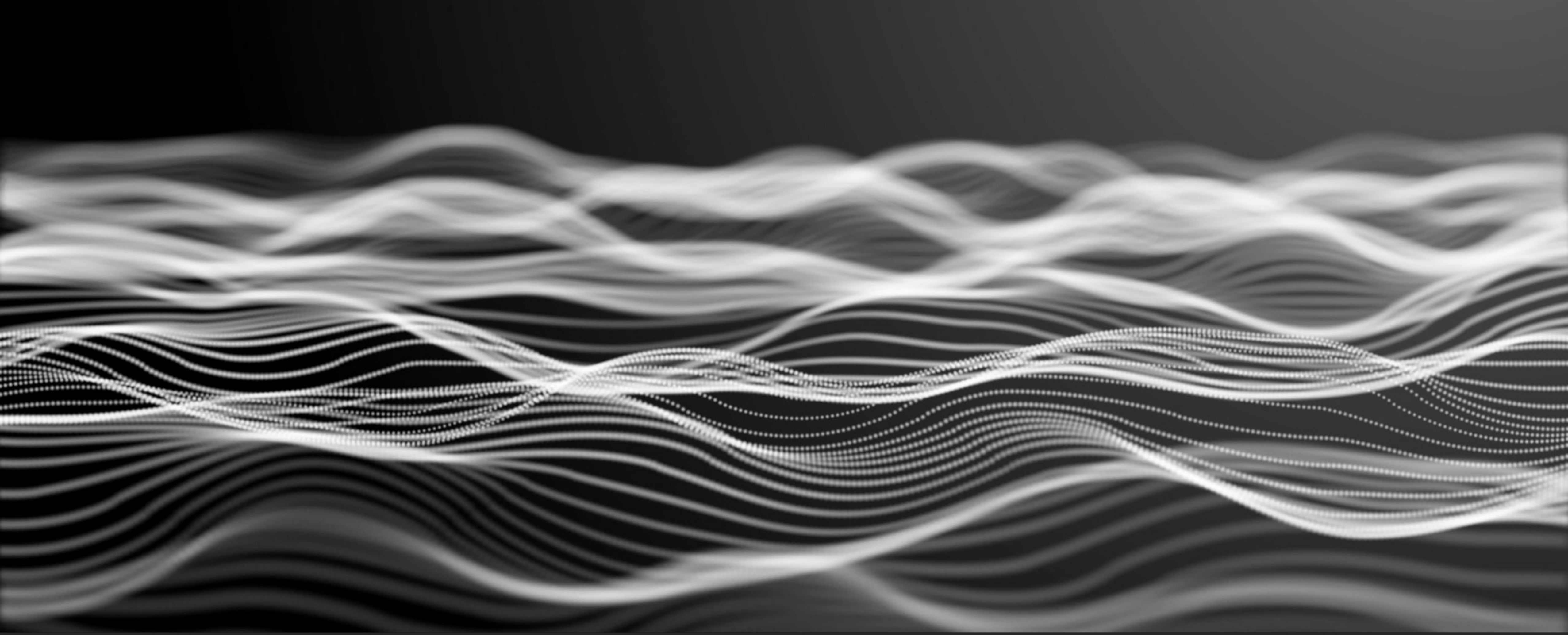


# Surface-Wave Communication : Rethinking the Future of Wireless Communications

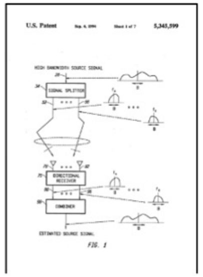
(Kit) Kai-Kit Wong (UCL)
Seok-Bong Hyun (ETRI)

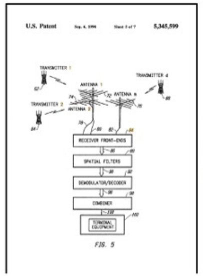
# Wireless Communications?

- Wireless means convenience
  - Without being tethered by cables, users can move freely while staying connected.
  - Users can add, remove, or move devices without re-wiring
  - $\underbrace{\textbf{5G}\text{ (eMBB, mMTC, URLLC)}}_{\text{Infrastructures for Smart Services}} \Rightarrow \underbrace{\textbf{6G}\text{ (AI, ISAC, UC, IC, MC, HRLLC)}}_{\text{Seamless Integration of the Digital and Physical Worlds}}$

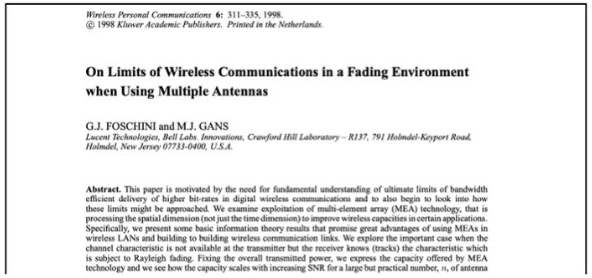
- Wireless means difficulty
  - Propagation loss, shadowing, multipath fading, interference … etc.
  - 6G aims to achieve reliability level at 99.99999%

# MIMO




Emeritus Professor of Stanford University



Wireless Personal Communications 6: 311–335, 1998.
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**On Limits of Wireless Communications in a Fading Environment when Using Multiple Antennas**

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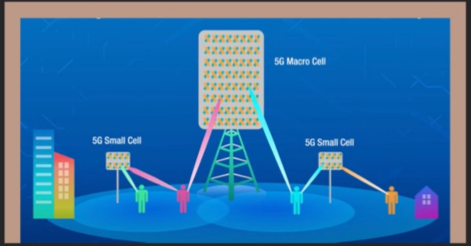
**Abstract.** This paper is motivated by the need for fundamental understanding of ultimate limits of bandwidth efficient delivery of higher bit-rates in digital wireless communications and to also begin to look into how these limits might be approached. We examine exploitation of multi-element array (MEA) technology, that is processing the spatial dimension (not just the time dimension) to improve wireless capacities in certain applications. Specifically, we present some basic information theory results that promise great advantages of using MEAs in wireless LANs and building to building wireless communication links. We explore the important case when the channel characteristic is not available at the transmitter but the receiver knows (tracks) the characteristic which is subject to Rayleigh fading. Fixing the overall transmitted power, we express the capacity offered by MEA technology and we see how the capacity scales with increasing SNR for a large but practical number, $n$, of antenna

Distinguished Inventor of Nokia Bell-Labs

NOKIA Bell Labs

- Professors A. Paulraj and T. Kailath are Fathers of MIMO
  - Patent US5345599A filed 1992, granted 1994, expired 2012
- MIMO research exploded in 1998 after Foschini's work




- MU-MIMO (2000 & 2004) is being used in 802.11ac (Wi-Fi 5), 802.11ax (Wi-Fi 6), 802.11be (Wi-Fi 7), 4G and 5G
  - 5G uses 64 BS antennas to support up to 12 users on the same physical data channel
  - Reliable CSI needed
  - Very expensive
  - Not quite scalable

# Network Densification

- A natural move to accommodate greater speed and capacity is to move to higher frequency bands, e.g., mmWave or even THz
  - Higher attenuation, shorter range

📶 **Base Station Cost vs Frequency**

| Freq. Range (GHz) | Application | Coverage | Cost (USD) |
|---|---|---|---|
| < 1 | 2G/3G, Rural 4G | > 10 km | $30k – $70k |
| 1 – 6 | 4G LTE, 5G Sub-6 GHz | 1 – 5 km | $20k – $60k |
| 24 – 30 | 5G mmWave (dense urban) | 100 – 300 m | $25k – $50k |
| 57 – 71 | WiGig, FWA | 50 – 150 m | $10k – $25k |
| 90 – 110 | THz comms, backhaul | < 100 m | $50k – $120k |
| > 110 | UHF / experimental systems | < 50 m | $100k+ |

# Interesting Observations on LinkedIn

6G Reset
Gustavo Costa • 2nd
2d •
Join

What can we do better in 6G than 5G? Well, it all comes down to complexity.

Generally, when we think of a next generation of technology we tend to focus on “more”: more capacity, more features, more spectrum, more services, more use cases and so on...
We are, however, paying an increasingly steep price for our desire for more: namely, complexity.
It was quite an a-ha moment. One of these days I was comparing the Rel-15 to the Rel-18 versions of TS 38.321 (5G NR MAC specification) and I realized something: Wow! It used to have only about 80 pages! (now at more than 340).
I decided to check and plot (see the graph below) what has been happening to specs. I ´ve chosen these ones as small but representative sample:

The trend is the same for all specifications – their page count has been increasing at a fast pace. And it is not that we have started simple. If you compare 5G NR to 4G LTE – many things which were fixed in 4G have 2, 3 or many options in 5G. Often, initial 5G specs may have double the number of pages of equivalent 4G ones. Also, it is striking that Rel-15 felt incomplete and each spec pretty much doubled for Rel-16.
Naturally, each of these decisions had a story of reasons, discussions and compromises behind it. But cumulatively we have been adding complexity at a higher pace than we can grasp or than we need.
One of the most interesting contributions to

Comments — Most relevant

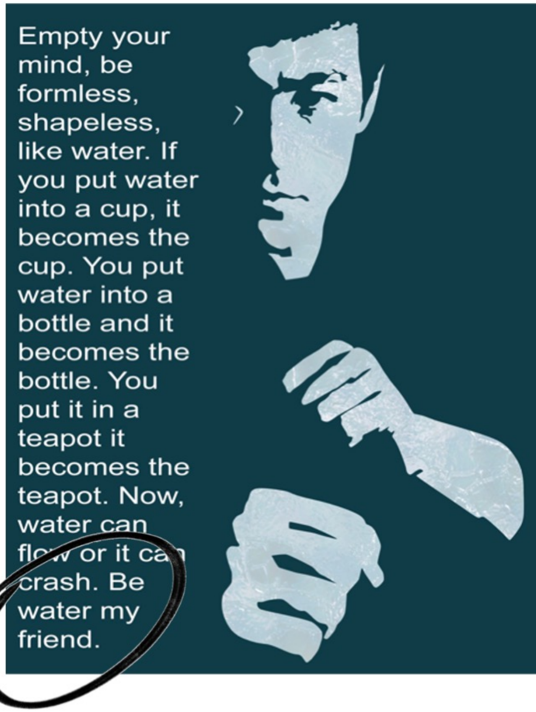
**Robert Heath** • 1st — 1d
Charles Lee Powell Chair in Wireless C...

We had a related discussion at WCNC 2025. Wen Tong made the point that the entire 5G spec if printed would be 22m high. I checked on chatGPT and it seemed that the 802.11 spec if printed is about 22cm. I asked why 80% of wireless Internet traffic goes on 802.11 and the spec is 100x more compressed. Generated some interesting discussion.

Like • 7 | Reply • 2 replies

# Fluid Antenna System (FAS)

- We say *Be Water, My Antenna!*
- To treat antenna (or radiating aperture) as a reconfigurable physical-layer resource, broadening system design and network optimisation and inspiring next-generation reconfigurable antennas (NGRAs)
- Emphasize the feature of **Shape&position-flexibility**





1. K. K. Wong, K.-F. Tong, Y. Zhang, and Z. Zheng, "**Fluid antenna system for 6G: When Bruce Lee inspires wireless communications**," Electronics Letters, vol. 56, no. 24, pp. 1288–1290, November 2020.
2. W. K. New *et al.*, "**A tutorial on fluid antenna system for 6G networks: Encompassing communication theory, optimization methods and hardware designs**," IEEE Communications Surveys and Tutorials, vol. 24, no. 4, pp. 2325–2377, August 2025.

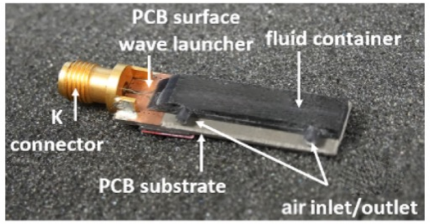
# Prototypes: FAS is REAL

- Liquid-based surface-wave enabled FAS

  Y. Shen *et al.*, "**Design and implementation of mmWave surface wave enabled fluid antennas and experimental results for fluid antenna multiple access**," [Online] arXiv:2405.09663, May 2024.

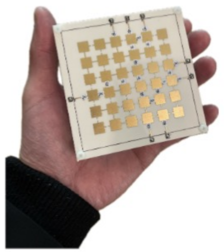
Prof. Steve Hang Wong
CityU

Prof. Kenneth Tong
UCL




- Pixel reconfigurable antenna-based FAS

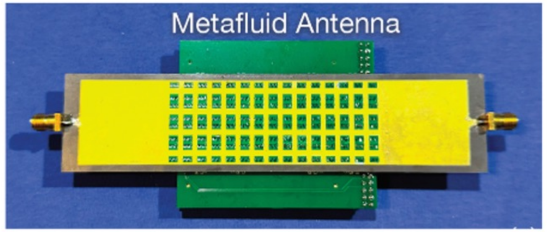
  J. Zhang *et al.*, "**A novel pixel-based reconfigurable antenna applied in fluid antenna systems with high switching speed**," IEEE Open Journal of Antennas and Propagation, Vol. 6, No. 1, pp. 212-228, Feb. 2025.



Prof. Ross Murch
HKUST

- Metamaterial-based FAS

  B. Liu *et al.*, "**Programmable meta-fluid antenna for spatial multiplexing in fast fluctuating radio channels**," Optics Express, Vol. 33, No. 13, pp. 28898-28915, 2025.

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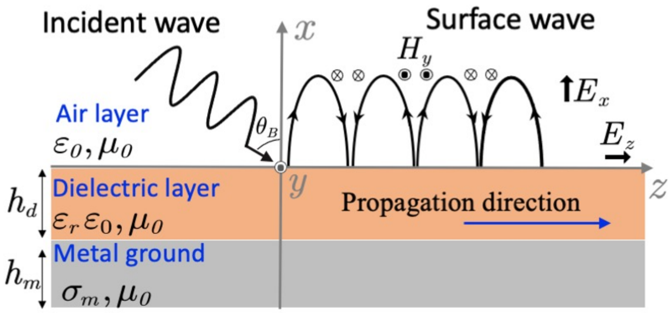
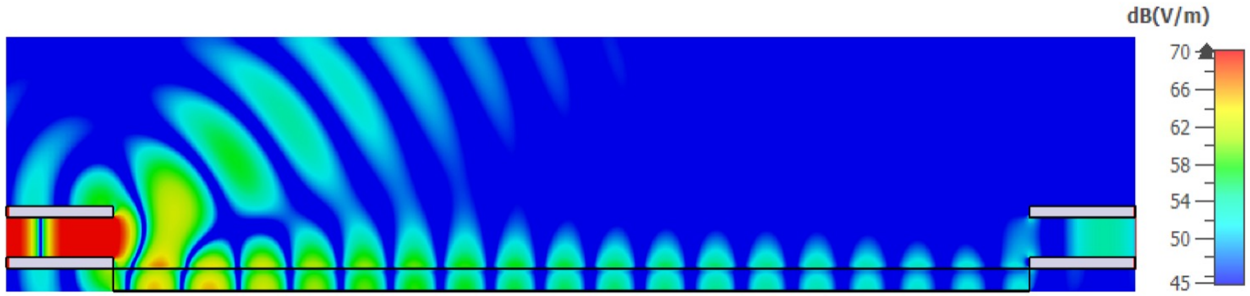
Prof. Steve Wong
CityU

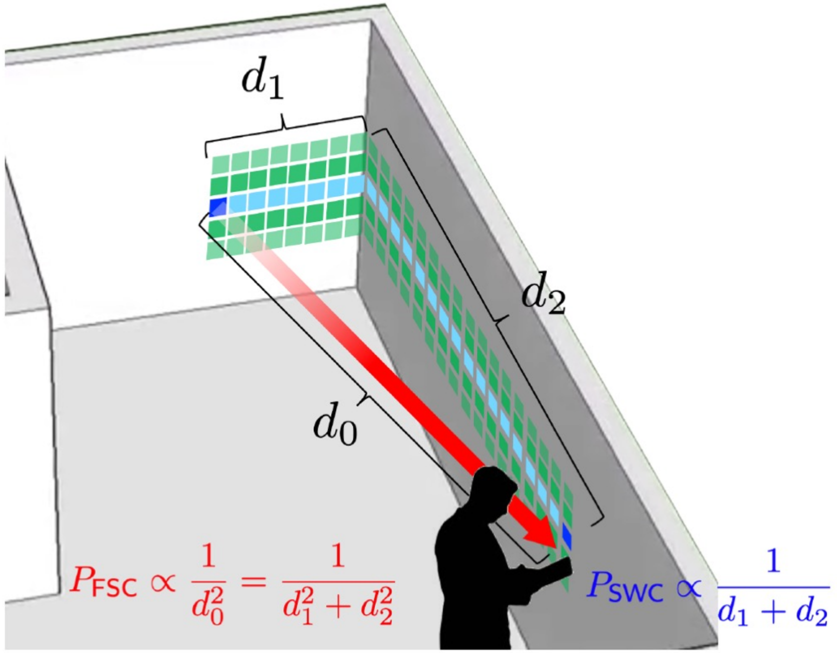
Prof. Kenneth Tong
HKMU

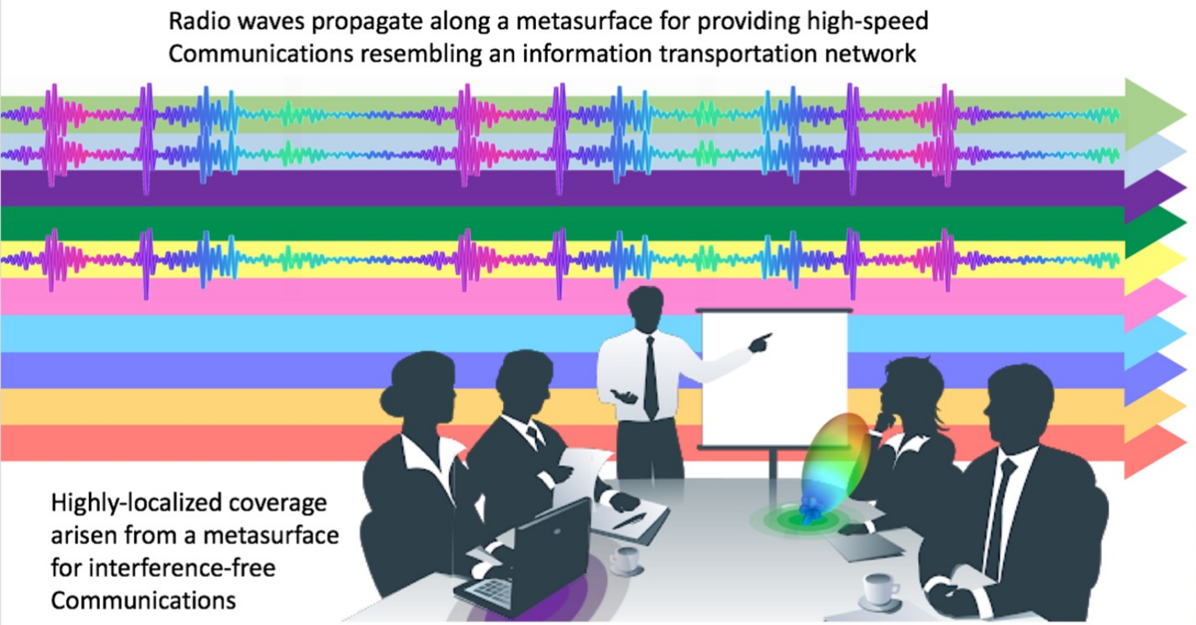
# Surface-Wave Communication

- Surface wave is a non-radiating wave that propagates along the interface between two homogeneous media such as a dielectric-metal surface
  - More controlled
  - Less interference
  - Less attenuation
  - Higher efficiency



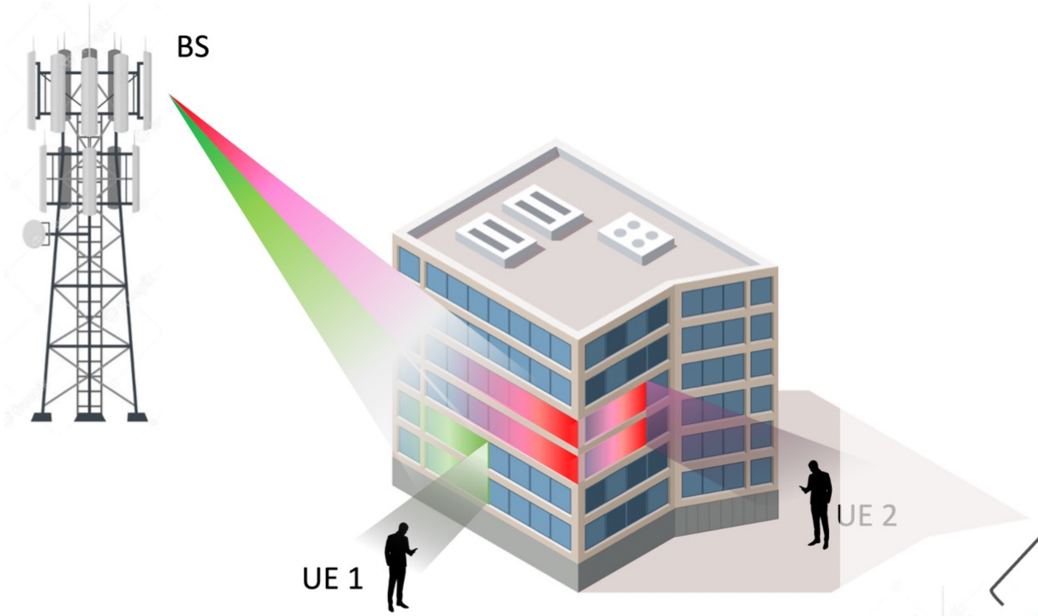



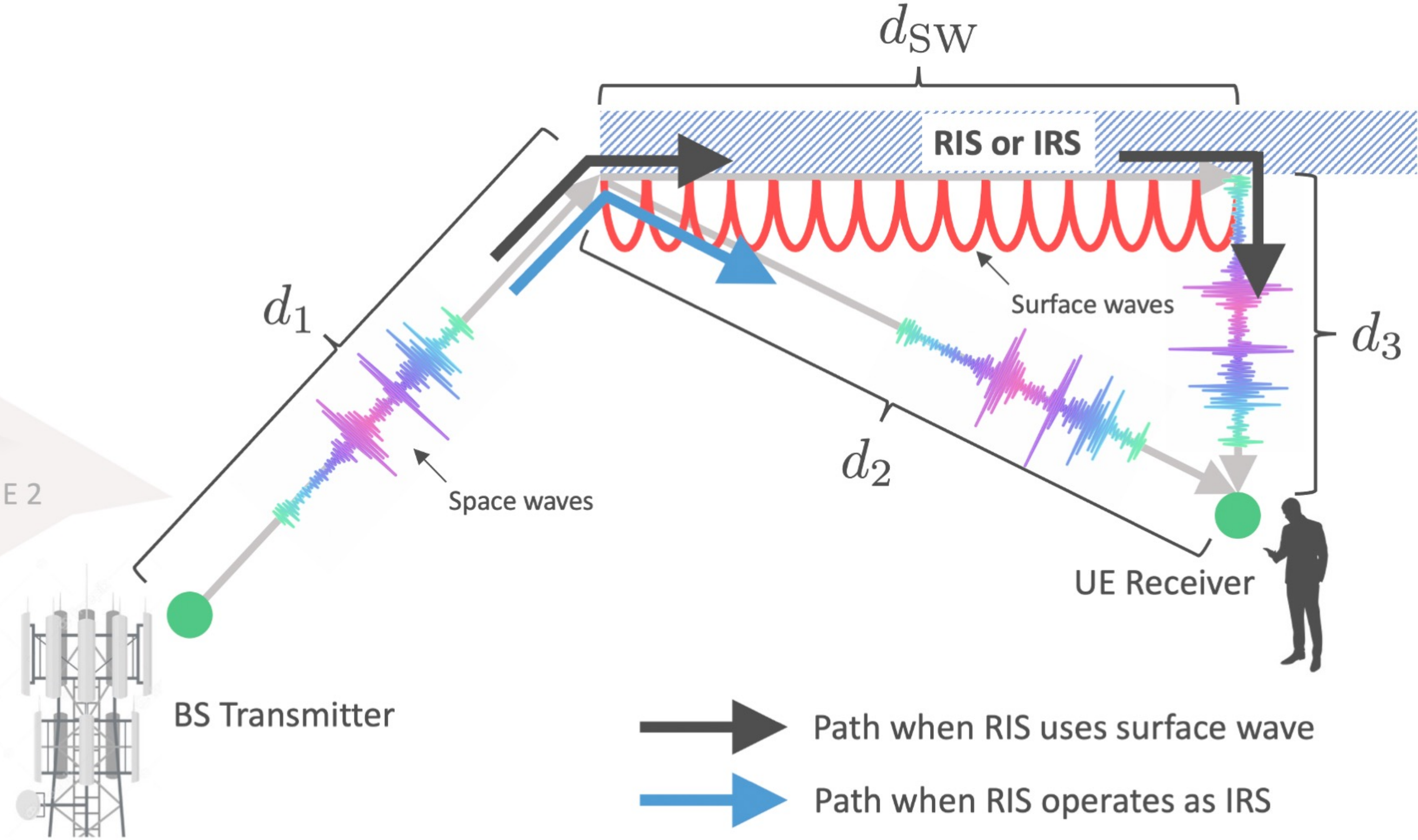



K. K. Wong, K. F. Tong, Z. Chu, and Y. Zhang, "**A vision to smart radio environment: Surface wave communication superhighways**," IEEE Wireless Communications, Vol. 28, No. 1, pp. 112-119, February 2021.

# Enormous FAS (E-FAS)

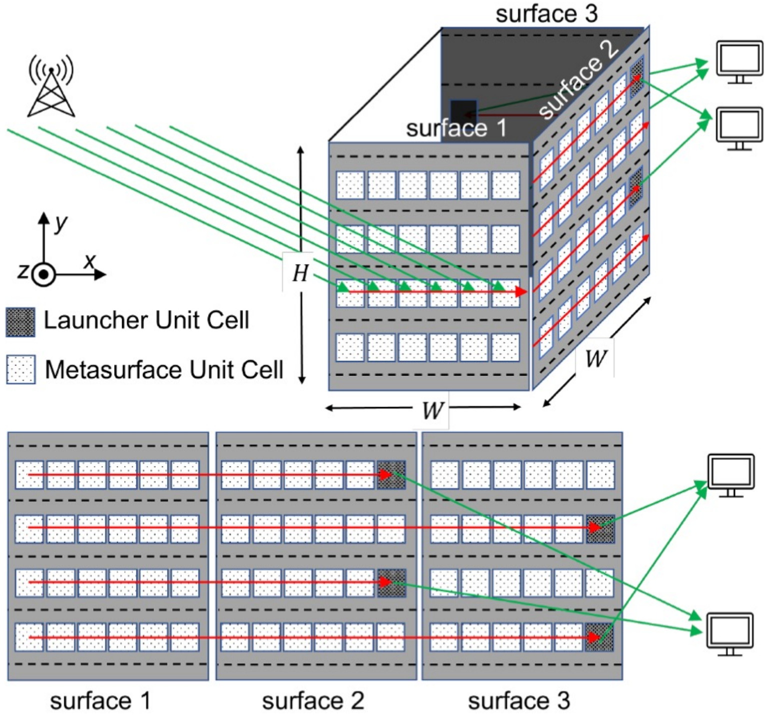
# No More Blocking



# BS Locking

- The surface can be designed to ensure Brewster's angle incidence



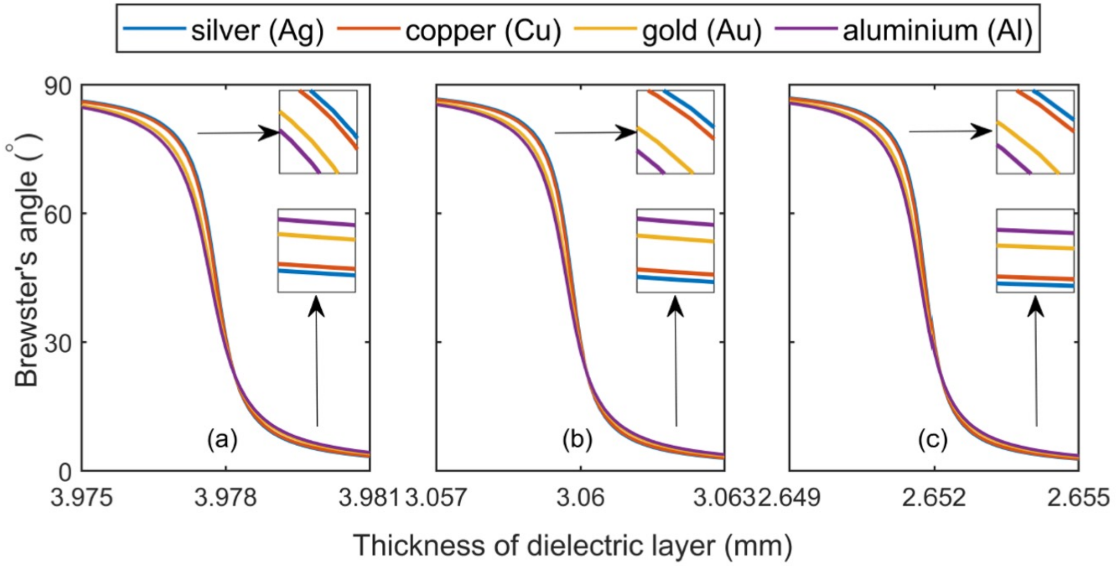




**FIGURE 14. Brewster's angle versus thickness of the dielectric layer using the three-layer media metasurface model: (a) $f$ = 20GHz; (b) $f$ = 26 GHz; (c) $f$ = 30 GHz.**

# Considered Scenarios

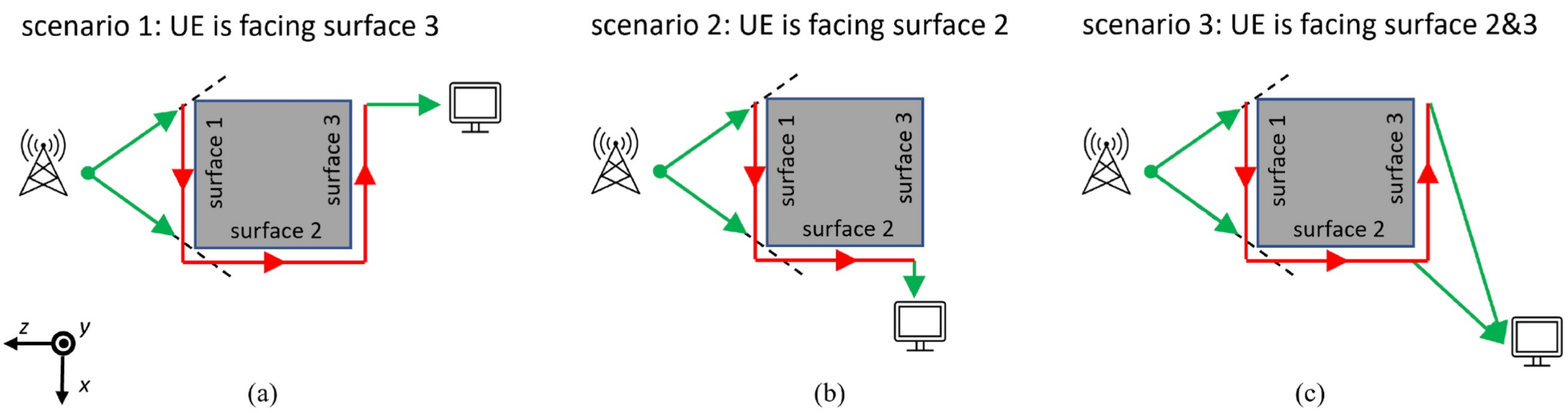



**FIGURE 9.** **SISO surface wave-assisted wireless communication system: (*a*): scenario 1; (*b*): scenario 2; (*c*): scenario 3.**

# Results

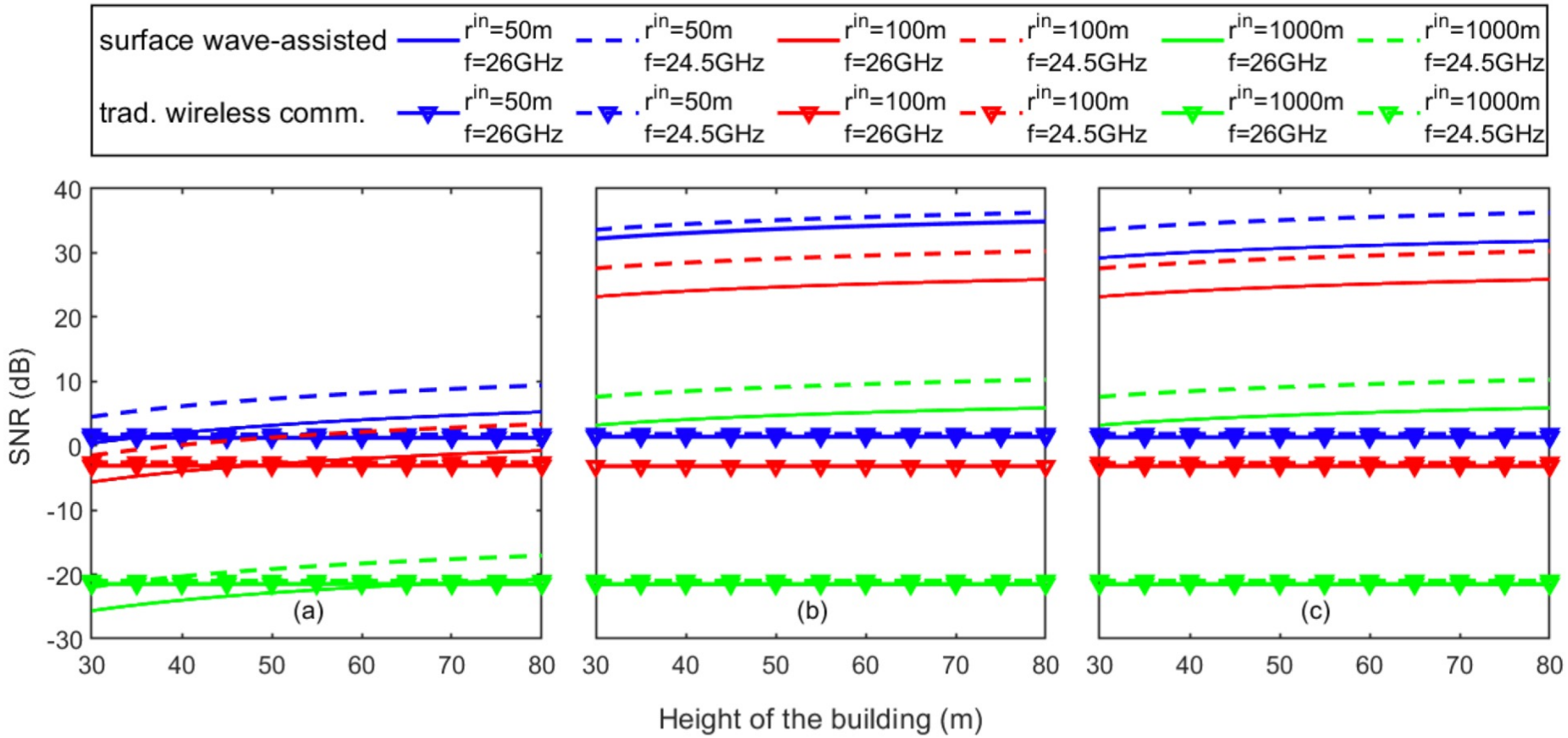
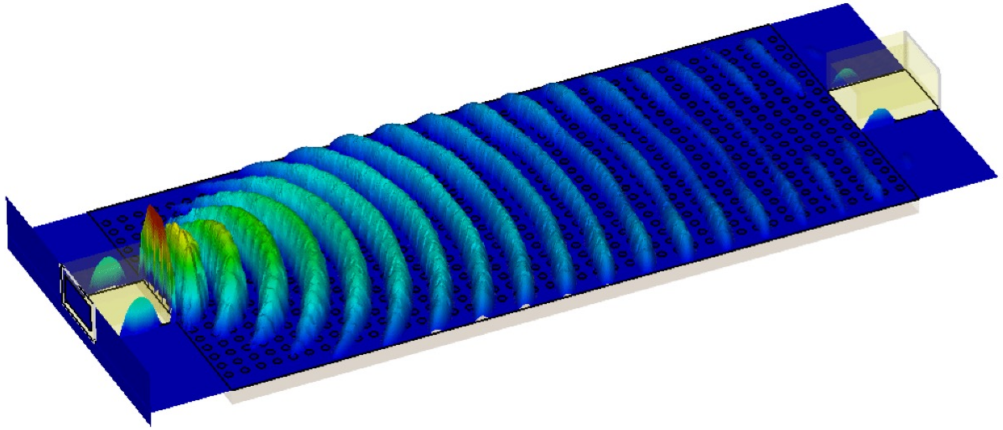
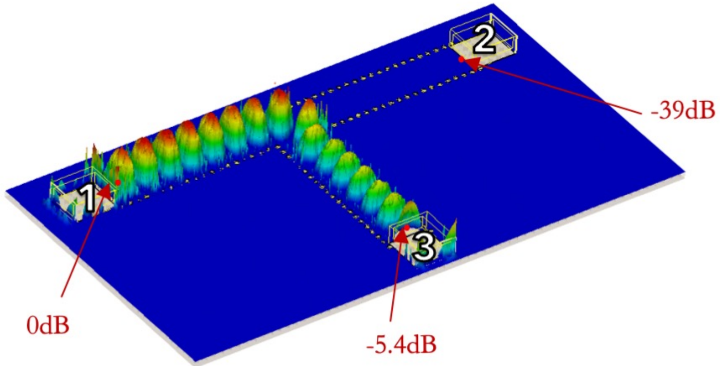
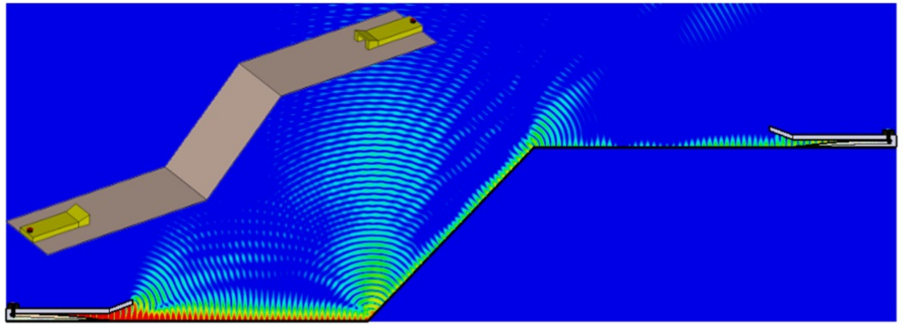


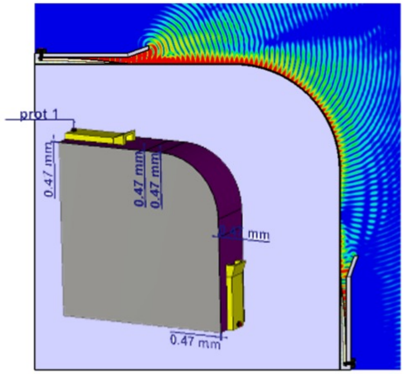

**FIGURE 10.** **SNR of a surface wave-assisted wireless communication system and a traditional wireless communication system across different building heights and $r^{in}$ in (*a*): scenario 1; (*b*): scenario 2; (*c*): scenario 3.**

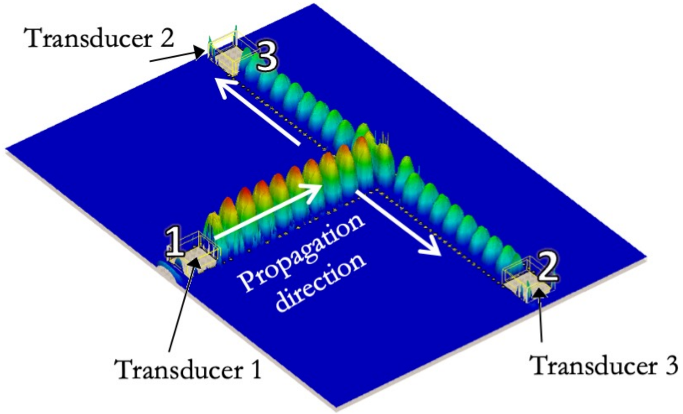
# Reconfigurable Waveguides



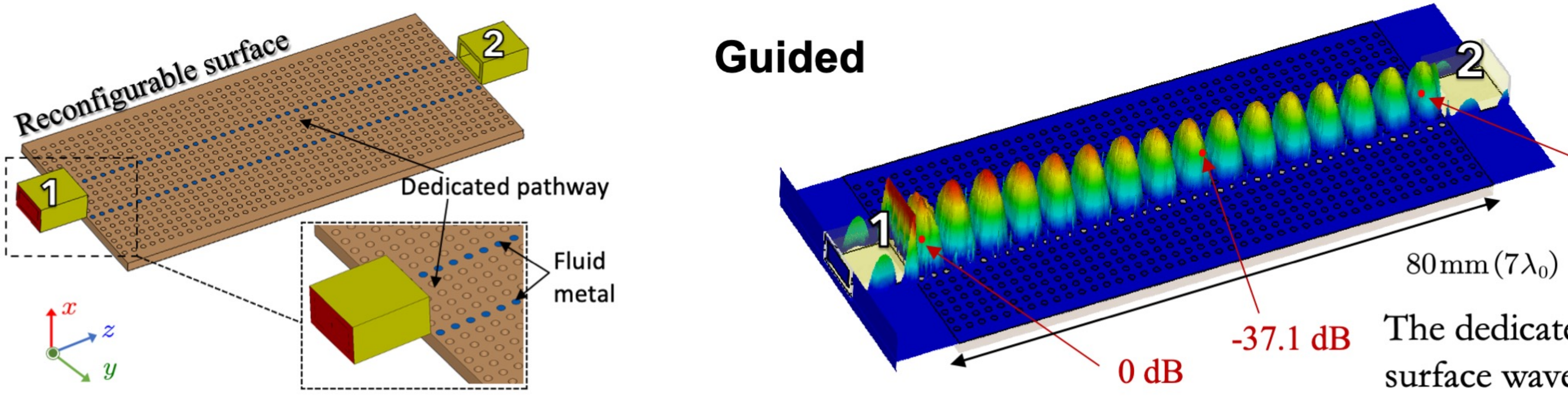




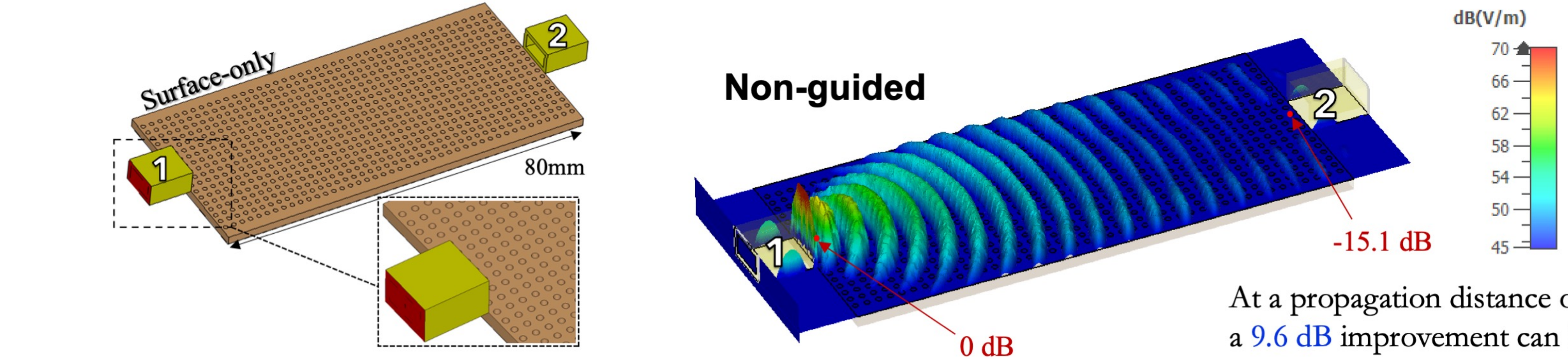



# Guided Pathway



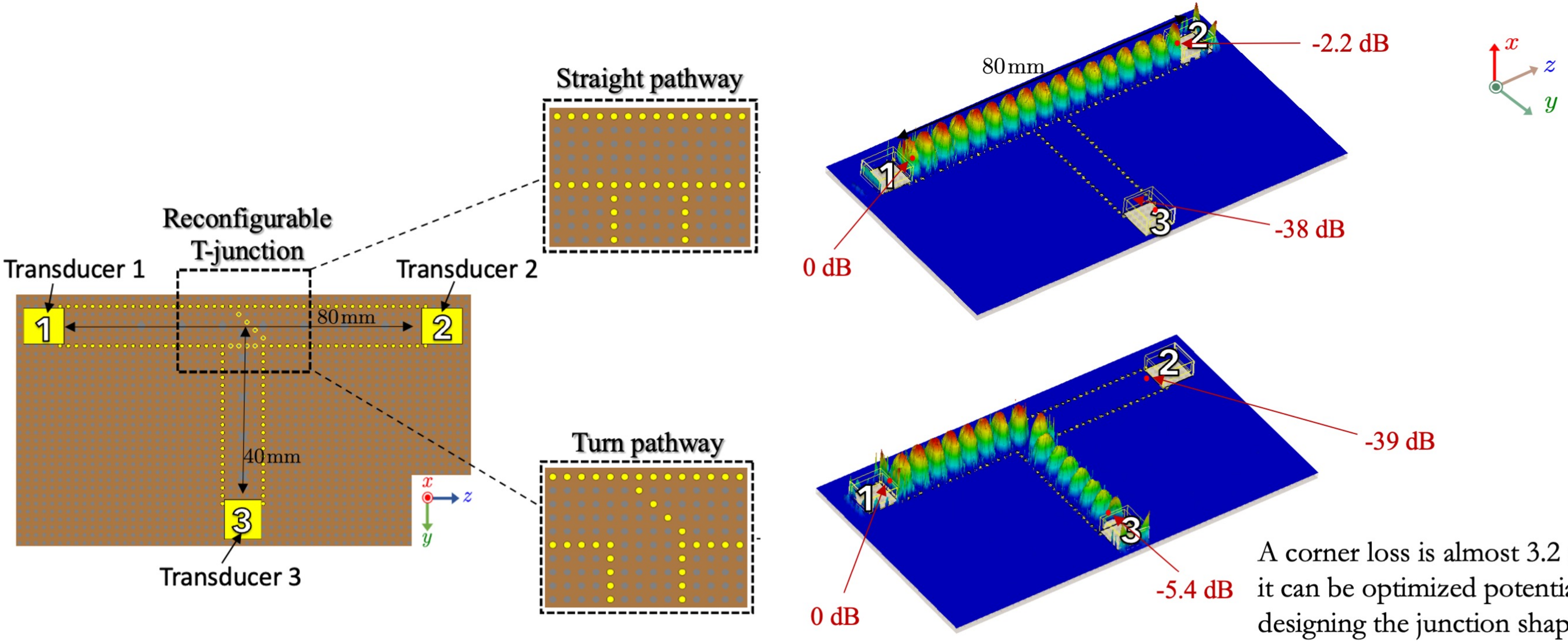

Working frequency $f = 26\,\mathrm{GHz}$
Wavelength $\lambda_0 = 11.5\,\mathrm{mm}$

The dedicated pathway are able to guide surface wave inside the pathway.



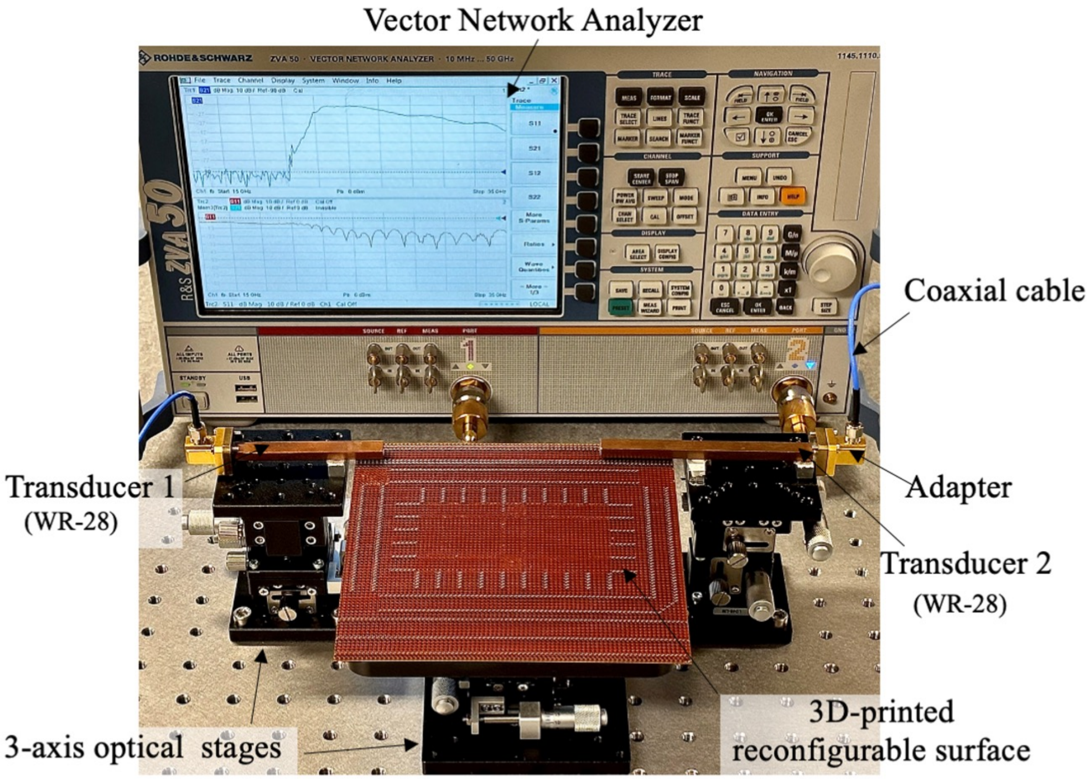

At a propagation distance of 80mm, a 9.6 dB improvement can be obtained.

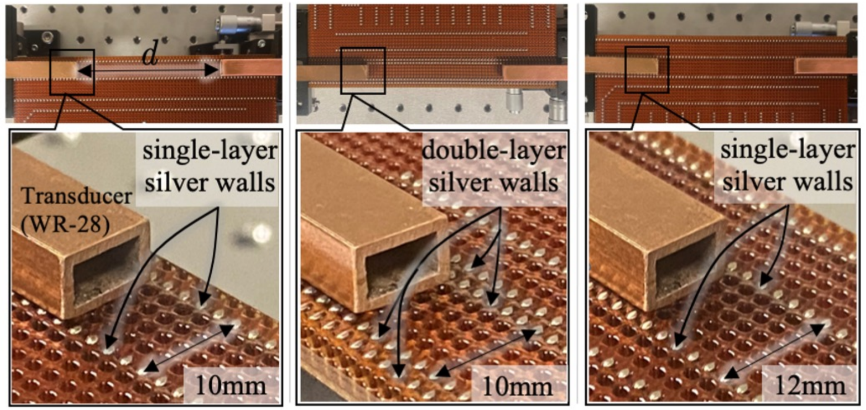
# Reconfigurable Pathways




A corner loss is almost 3.2 dB and it can be optimized potentially by designing the junction shape.

# Reconfigurable Platform Prototype



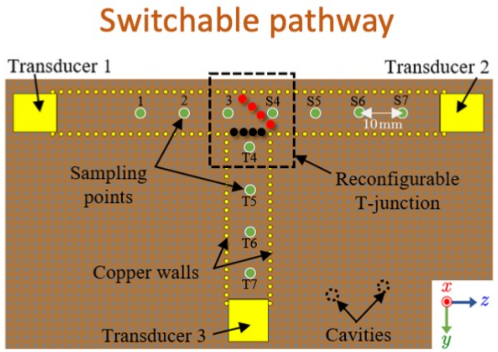



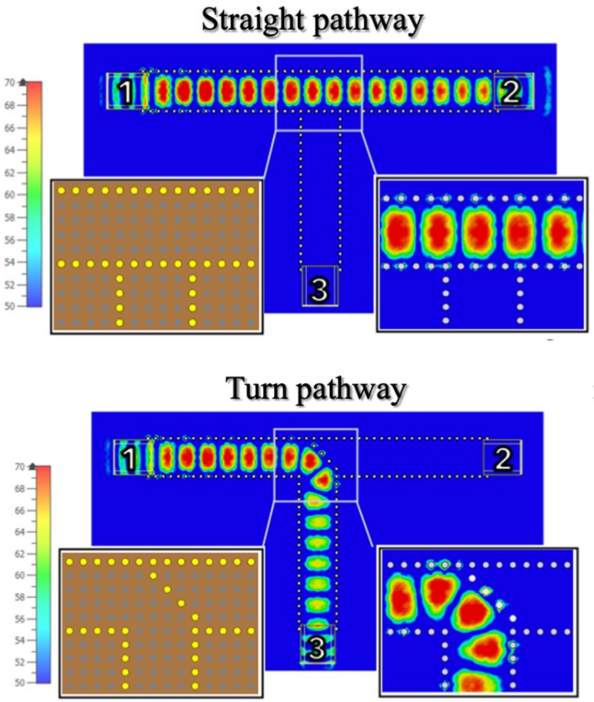

| Parameter | Value |
|---|---|
| transducer (WR-28) frequency band, $f_b$ | $21-42$GHz |
| relative permittivity of the dielectric layer, $\varepsilon_r$ | 2.8 |
| effective permittivity of the dielectric layer, $\varepsilon_r^{\mathrm{eff}}$ | 2.4 |
| surface porosity, $\rho$ | 19.63% |
| tangential loss, $tan\delta$ | 0.0155 |
| channel width, $w_c$ | 10mm |
| thickness of the dielectric layer, $h$ | 2mm |
| thickness of the metal ground, $h_m$ | 0.05mm |
| radius of cavity, $r$ | 0.5mm |
| center-to-center separation between cavity, $w_s$ | 2mm |
| electrical conductivity of silver ink, $\sigma_s$ | $3.15 \times 10^6$ S/m |
| surface impedance, $Z_s$ | $j240\Omega$ at 26GHz |

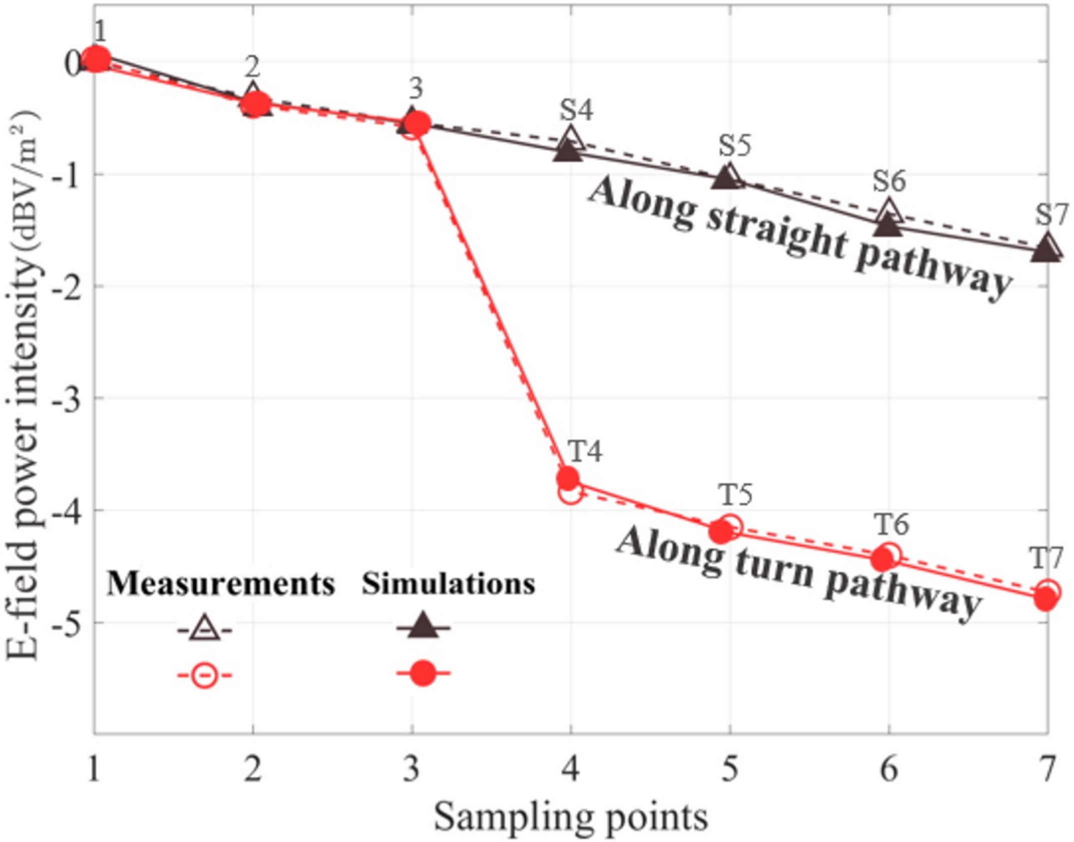
Dielectric resin ink

Silver ink

# Experimental Results



# Conclusion

**Our Vision**

- ✅ E-FAS: transform walls, ceilings, and building surfaces into a massive, reconfigurable antenna
- ✅ Not just reflecting (like RIS) → surfaces guide, route, and emit signals
- ✅ Ensures line-of-sight connectivity indoors and around obstacles

**Relevance to Industry**

- 📡 Reliable indoor & urban coverage.
- ⚡ Energy efficiency → lower OPEX, greener networks
- 🔒 Reduced interference, better QoS
- 🏙 Infrastructure integration → “connectivity by design”

**Potential Applications**

- Telecom operators: 5G/6G deployment & coverage
- Smart buildings & smart cities
- Industry 4.0: automation, robotics, digital twins
- Public safety & defence communications
- Smart homes & IoT ecosystems

# Related Publications

1. Z. Chu, W. K. New, K. F. Tong, K. K. Wong, H. Liu, C.-B. Chae, and Y. Zhang, "**On propagation loss for reconfigurable surface wave communications**," IEEE Transactions on Communications, vol. 73, no. 3, pp. 1547–1559, March 2025.
2. Z. Chu, K. F. Tong, K. K. Wong, C.-B. Chae, and C. H. Chan, "**On propagation characteristics of reconfigurable surface wave platform: Simulation and experimental verification**," IEEE Access, vol. 12, pp. 168744-168754, November 2024.
3. H. Liu, W. K. New, H. Xu, Z. Chu, K.-F. Tong, K. K. Wong, and Y. Zhang, "**Path loss and surface impedance models for surface wave-assisted wireless communication system**," IEEE Access, vol. 12, pp. 125786-125799, August 2024.
4. K. K. Wong, K. F. Tong, Z. Chu, and Y. Zhang, "**A vision to smart radio environment: Surface wave communication superhighways**," IEEE Wireless Communications, vol. 28, no. 1, pp. 112-119, February 2021.