THz Physical Layer Security

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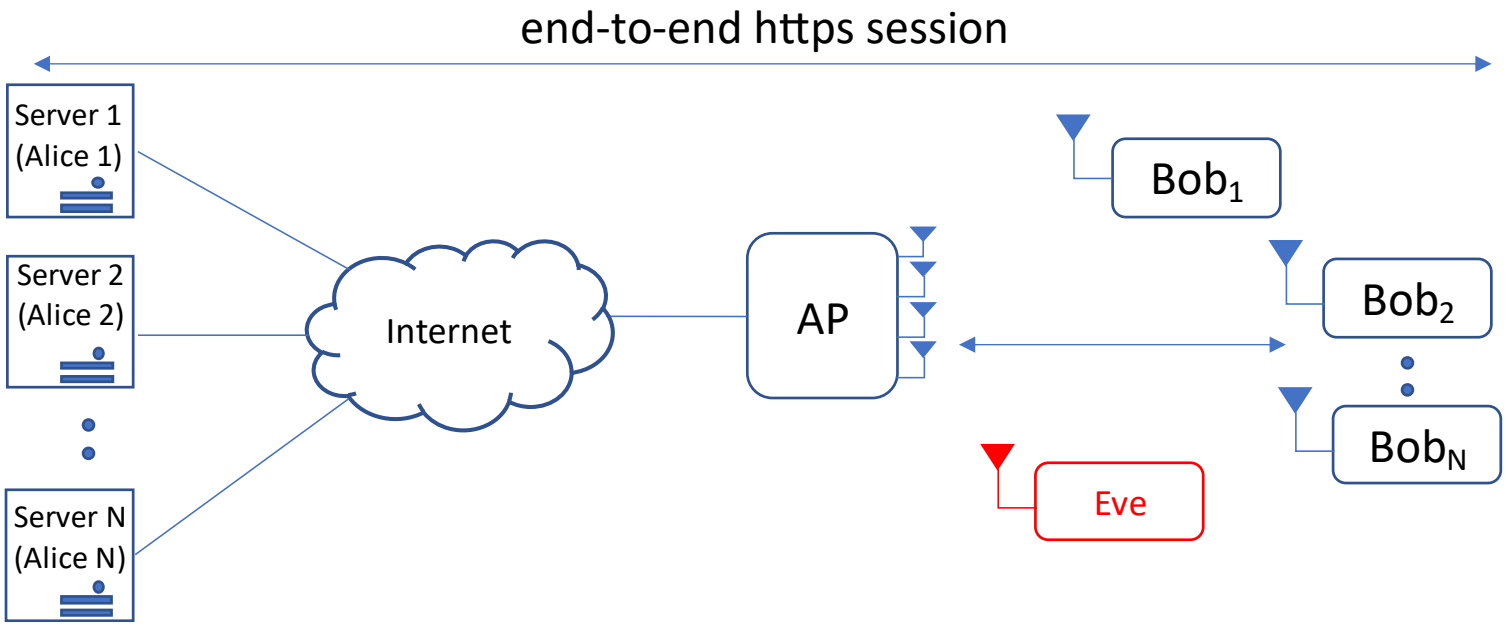
Internet Security

- Confidentiality goal
  - if an Eavesdropper (Eve) intercepts the message, the bits appear to be random.
  - Only Bob can decode the message with the secret key



Multi-Layer Security Today

Application layer end-to-end encryption

Secure Socket Layer (SSL) and https

Network layer

IPSec and VPNs

Wi-Fi link-layer

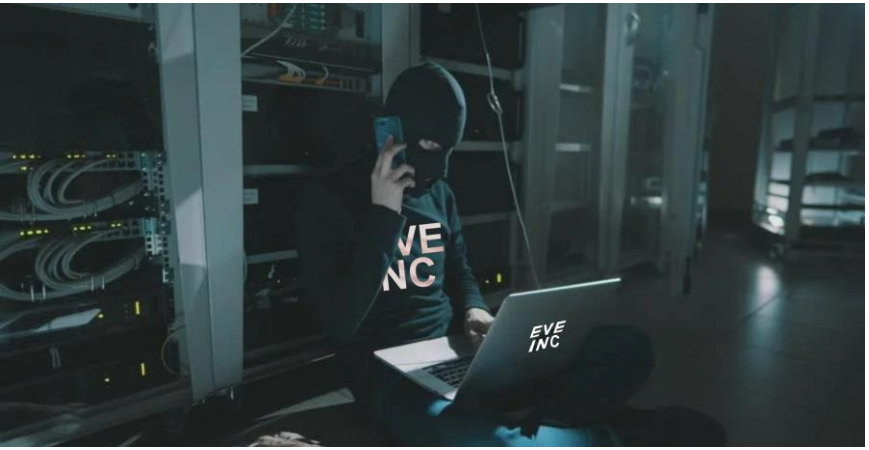
AES 256

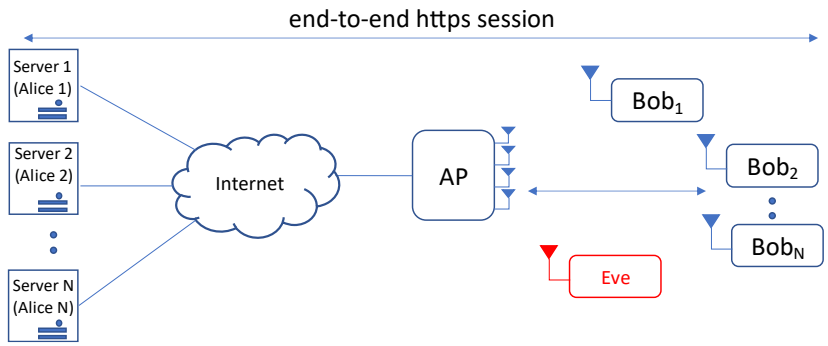
Why Multi-Layer?

- Redundant protection in case of one layer's breach

Physical Layer Security

- Why do we need it?
  - Wireless broadcast is the most vulnerable component
- Goal of PHY security
  - Eavesdropper (Eve) cannot intercept the bits at all
  - A new foundational layer of security





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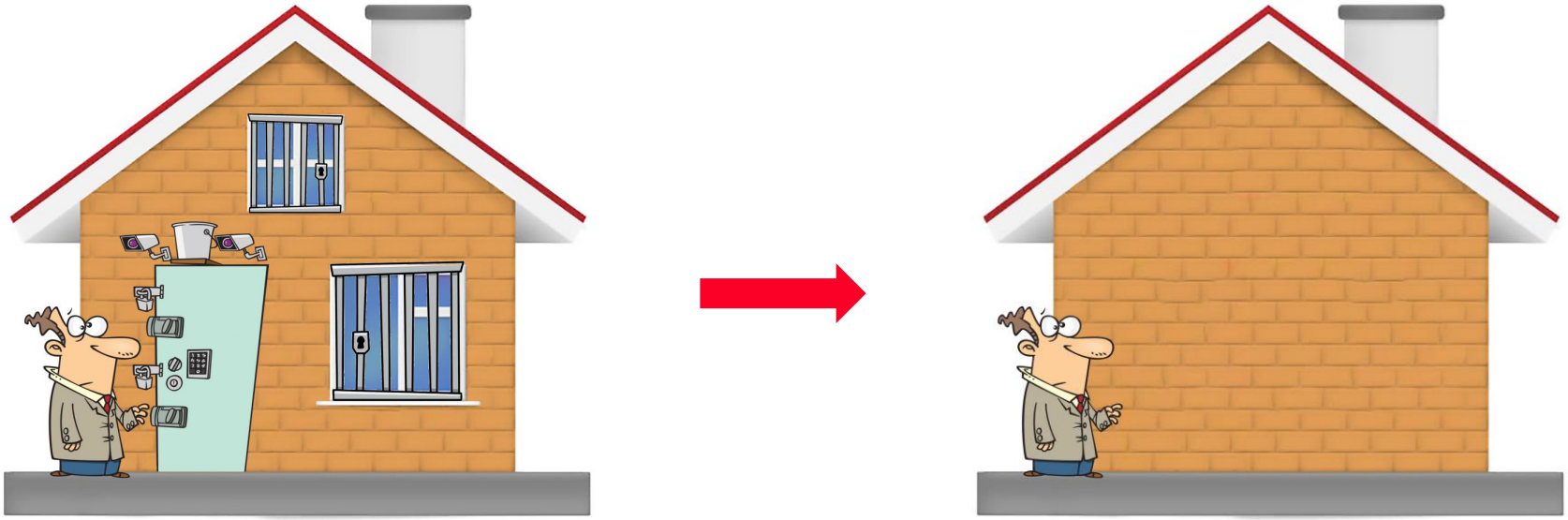


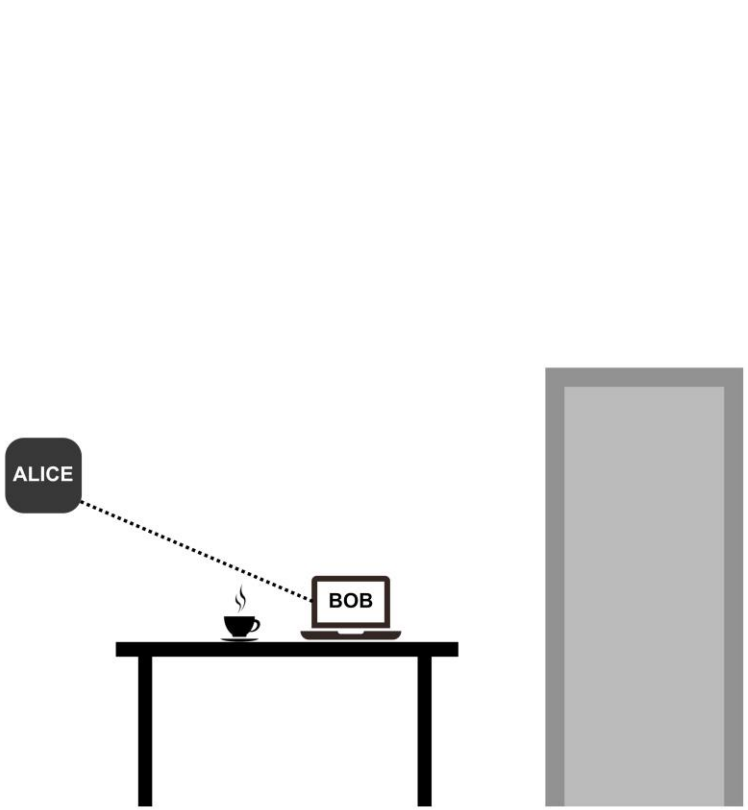
Secure Wireless at mmWave and Beyond

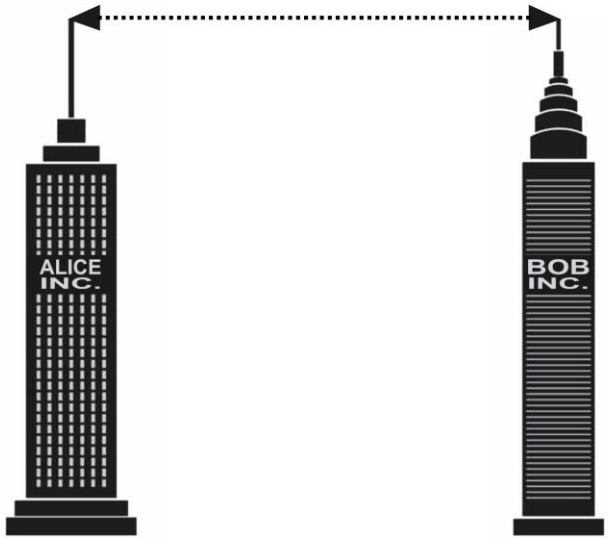
- Can a sufficiently narrow beam thwart eavesdropping?

- Optimism:
  - "At 60 GHz, the signal overshoot is very low and hence it is possible to make this communication link **covert**"
  - "Due to mm-wave's inherently low beam widths … the technology has a low probability of intercept and detection which is vital for the transference of **confidential** material."
  - "Narrow beam antennas **provide security** that prevents signals from being intercepted."

Securing Highly Directional Links

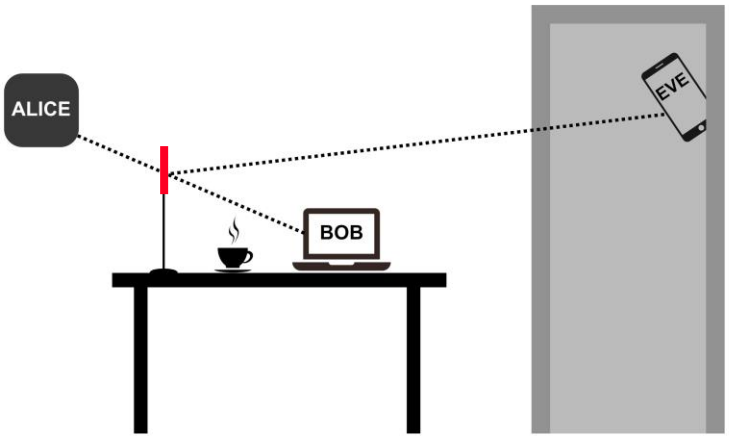
- Alice and Bob have a highly directional link
- Immune from eavesdropping and man-in-the-middle attacks?

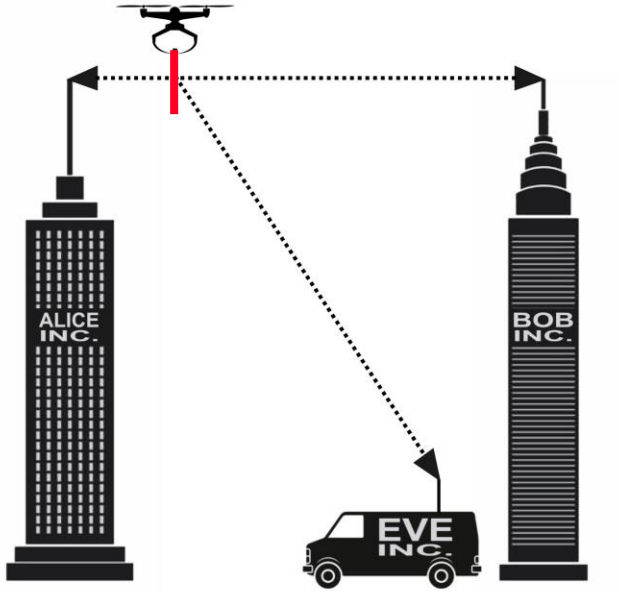




New Threat: MSITM Attack "MetaSurface In The Middle"

- Strong adversary uses a metasurface to manipulate electromagnetic waves
- Eavesdropper lets Alice and Bob communicate while diffracting a portion of energy towards herself





New Threat: MSITM Attack "MetaSurface In The Middle"

- Strong adversary uses a metasurface to manipulate electromagnetic waves
- Eavesdropper lets Alice and Bob communicate while diffracting a portion of energy towards herself

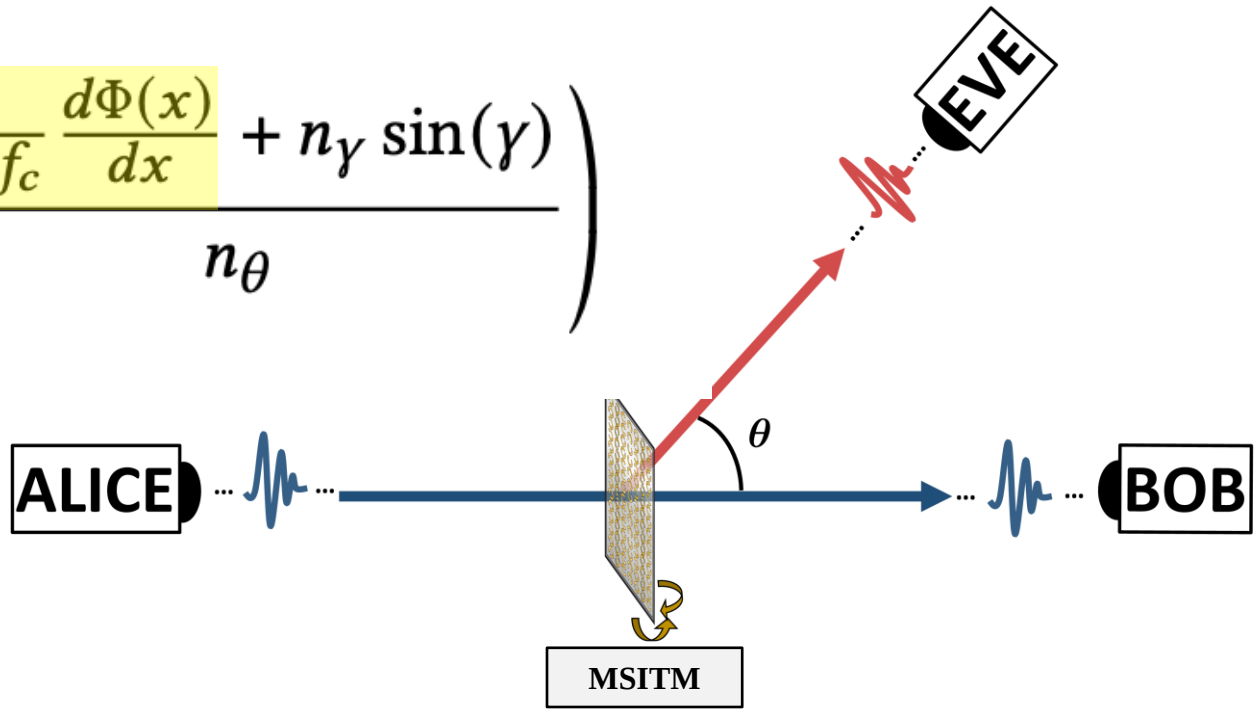
- Research questions
  - Eve's Metasurface design
    - Transmissive substrate
    - Meta atom structure as building block
    - Arrangement of different atoms on surface
  - Fabrication for > 100 GHz
  - Experimental evaluation at Eve and Bob

Z. Shaikhanov et al., "Metasurface-in-the-Middle Attack: from Theory to Experiment," ACM WiSec 2022.

MSITM Design Principle

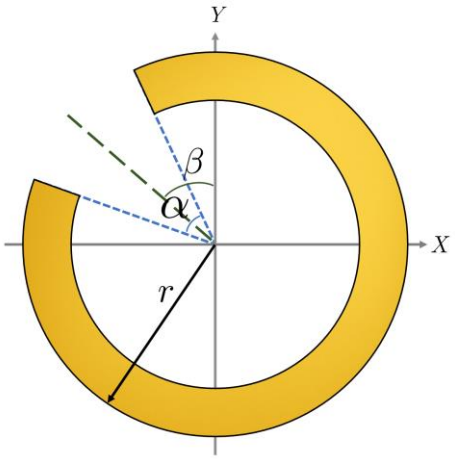
- Eve targets θ towards herself
- Anomalous diffraction via Generalized Snell's Law
  - Position dependent phase discontinuity at surface
- She must design the surface to manipulate the incoming wave's spatial phase profile $\phi(x)$

$$\theta = \sin^{-1}\left(\frac{\frac{c}{2\pi f_c}\frac{d\Phi(x)}{dx} + n_\gamma \sin(\gamma)}{n_\theta}\right)$$



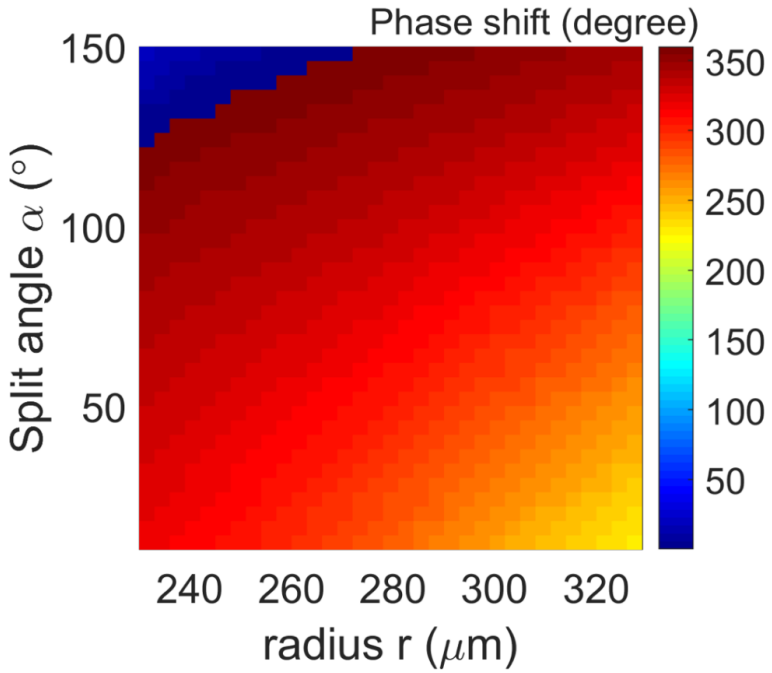
Constructing MSITM (Meta) Atom by Atom

- Material analogy
  - Atomic structure controls refractive index *n*
  - Structure's shape can realize non-uniform phase delay



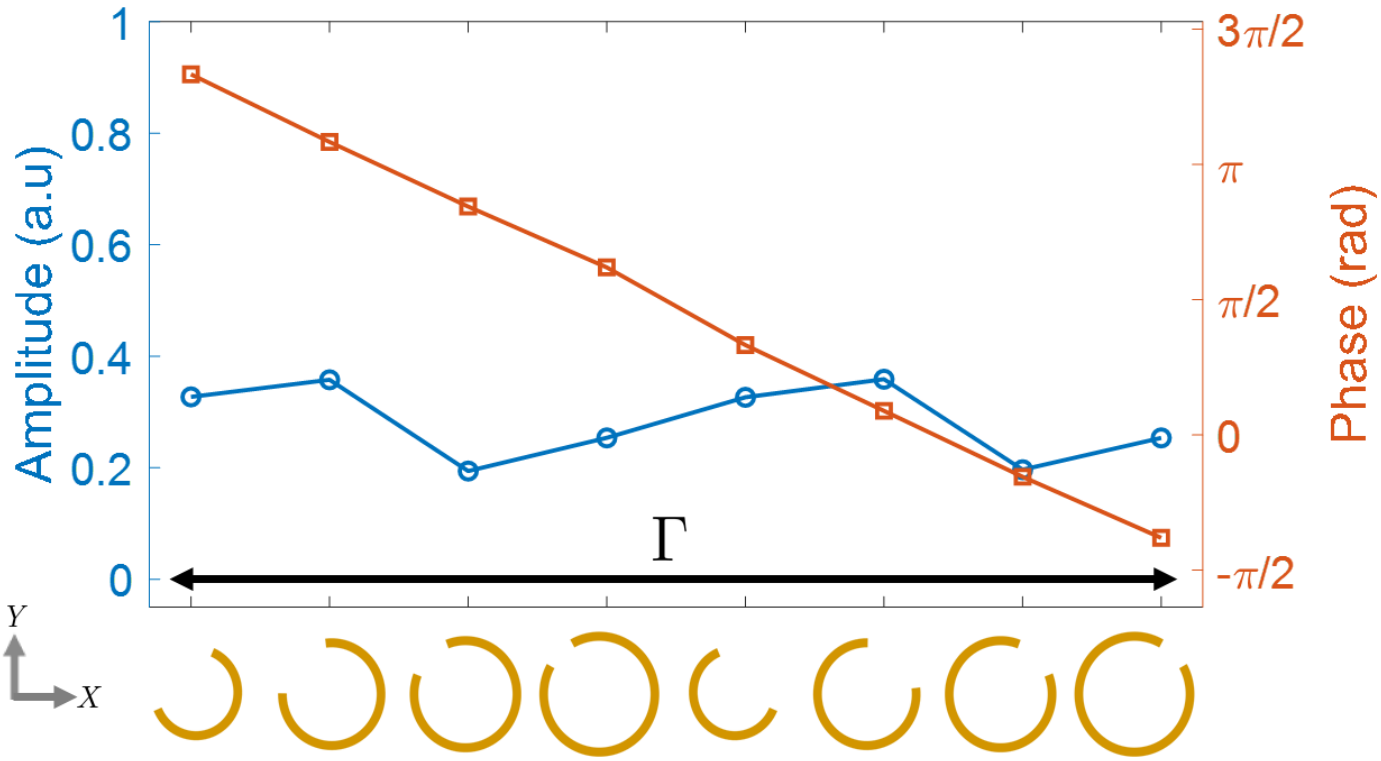
- Meta Atom design
  - Split Ring Resonator
  - Sub-wavelength size metallic structure
  - Parameters: radius r, opening angle α, orientation angle β

- Atom-by-atom selection
  - Eve has full 2π phase control



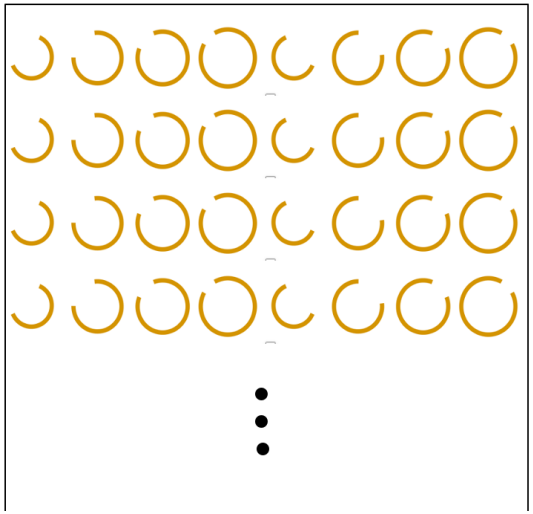
Eve's Supercell and Surface Design

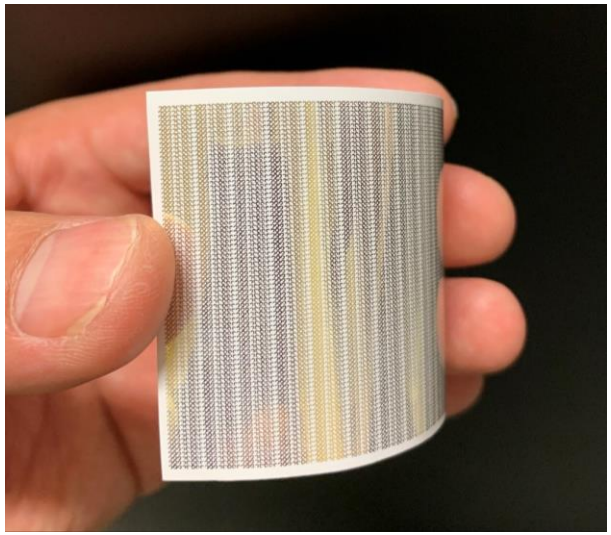
- Constant phase gradient $\frac{d\phi}{dx} = \frac{2\pi}{\Gamma}$ to yield desired θ
- Eve places meta-atoms on surface in periodic columns
  - Spatial period Γ = 8 meta atoms over 6.1 mm
- Imperfect (non-constant) amplitude profile



MSITM Fabrication

- Traditional methods: photolithography
  - Ultrahigh resolution (~100 nm) but high cost and slow
- Eve's method: rapid and inexpensive fabrication
  - Hot stamping on paper substrate
    1. Print pattern on paper substrate (transmissive surface)
    2. Feed metal foil and printed paper through laminator
    3. Heat and pressure bond metallic powder and toner

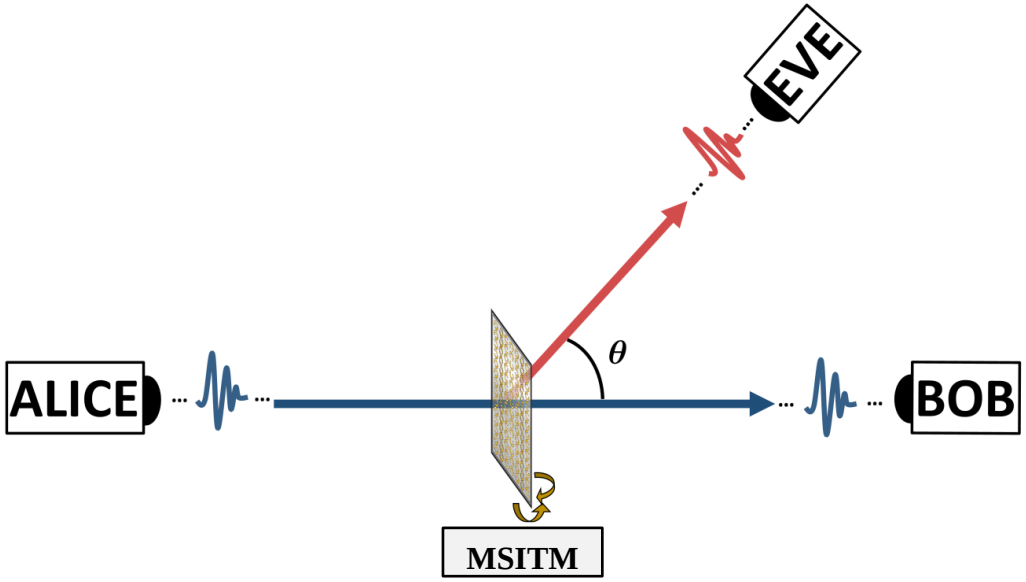


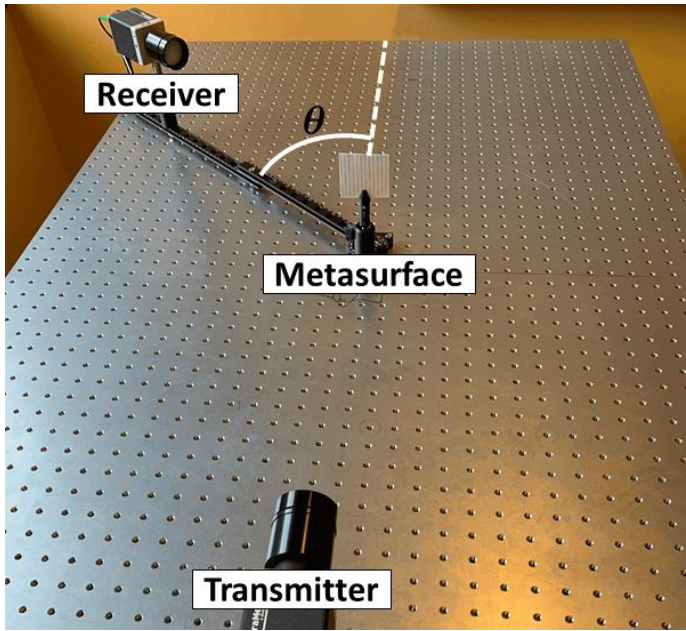


H. Guerboukha et al., "High-volume rapid prototyping technique for terahertz metallic metasurfaces," Optics Express, 29, 13806-13814 (2021).

Experimental Evaluation Scenario

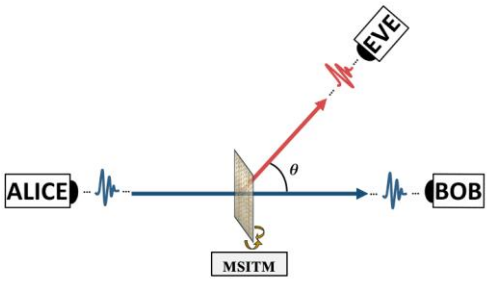
- Table top setup with sub micro-watt transmit power
  - Wideband THz pulses via Terametrix T-Ray 5000
- Eve prototypes hot-stamped MSITM
  - Specs: center frequency 150 GHz, Eve at θ = 22˚
- Bob is broadside to the MSITM

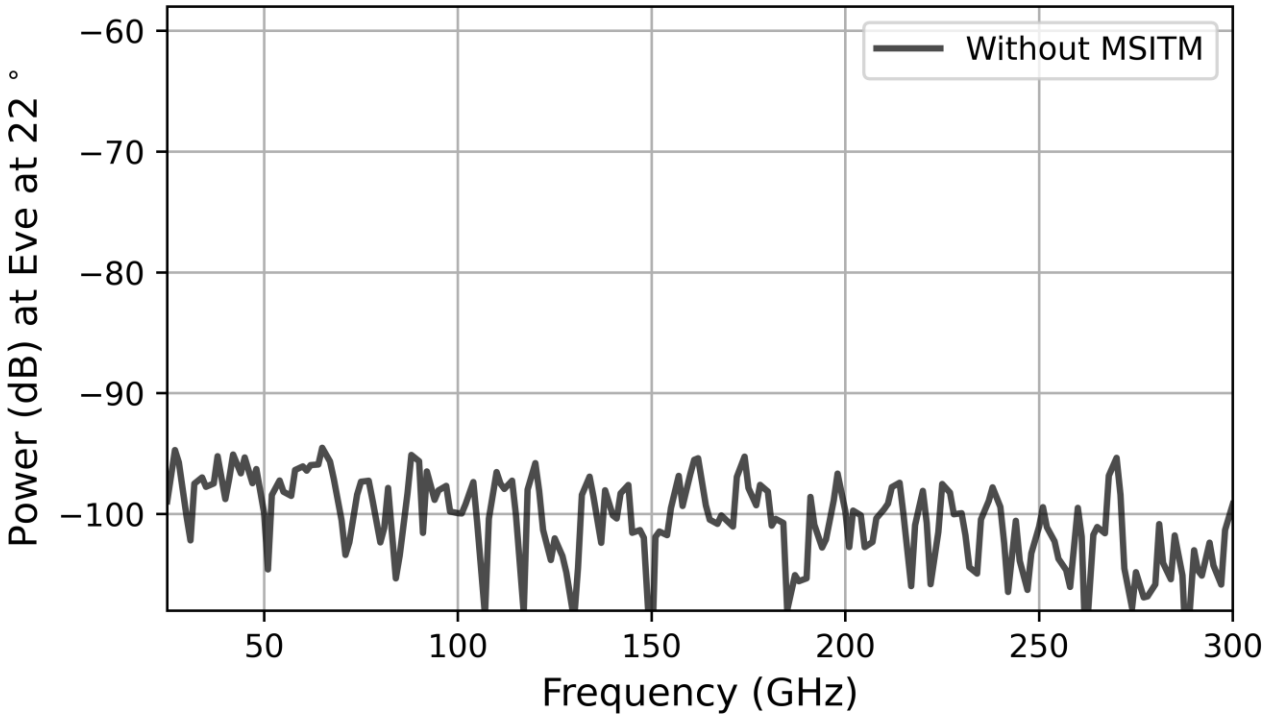




Reception at Eve

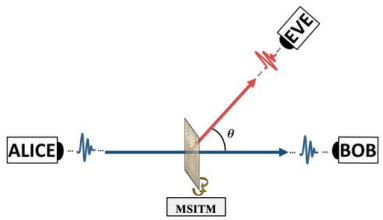
- Eve positions herself $\theta = 22^\circ$ away from Bob
- Without the MSITM, Eve cannot detect Alice

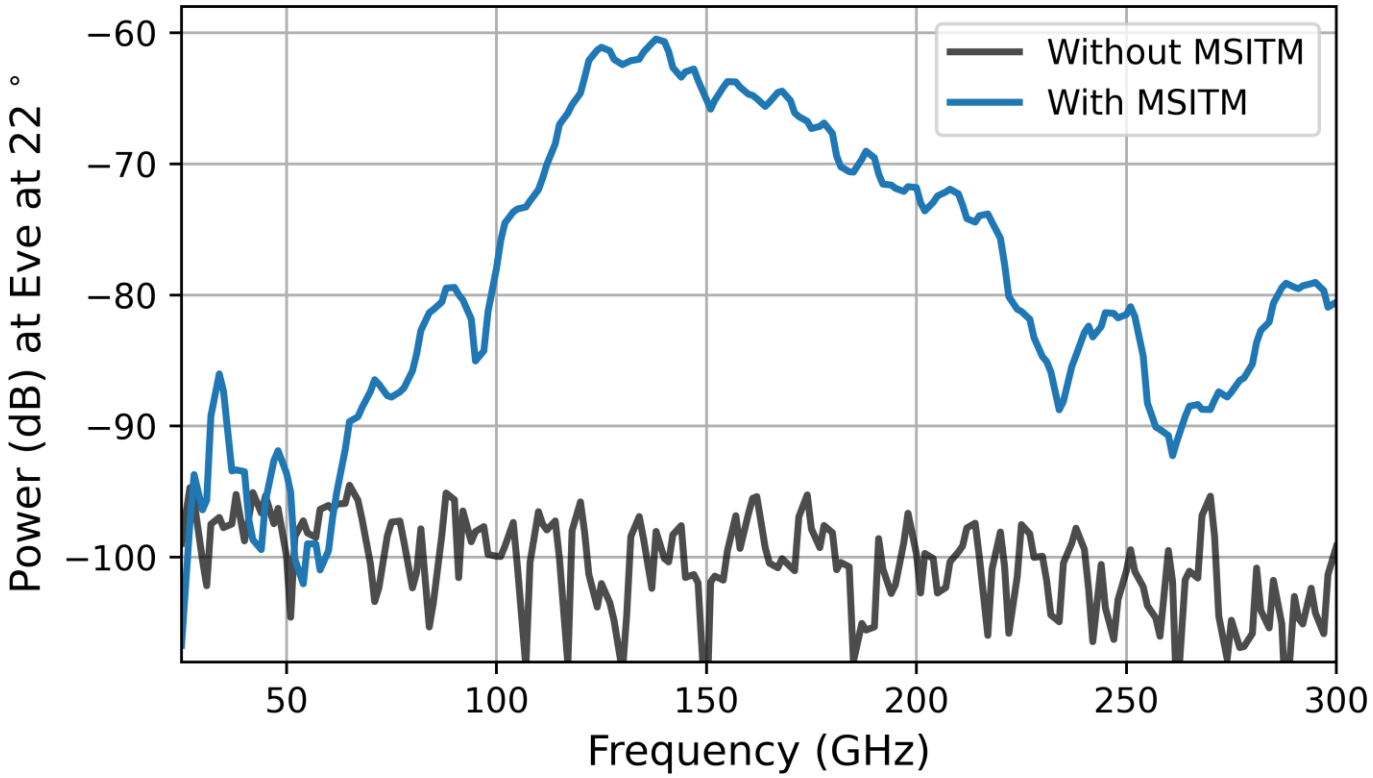




Eve Declares Victory

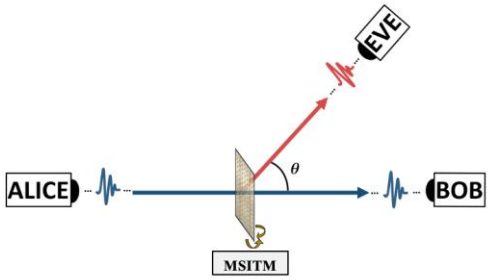
- Eve positions herself $\theta = 22^{\circ}$ away from Bob
- Without the MSITM, Eve cannot detect Alice
- With MSITM 20-40 dB gain, over > 100 GHz

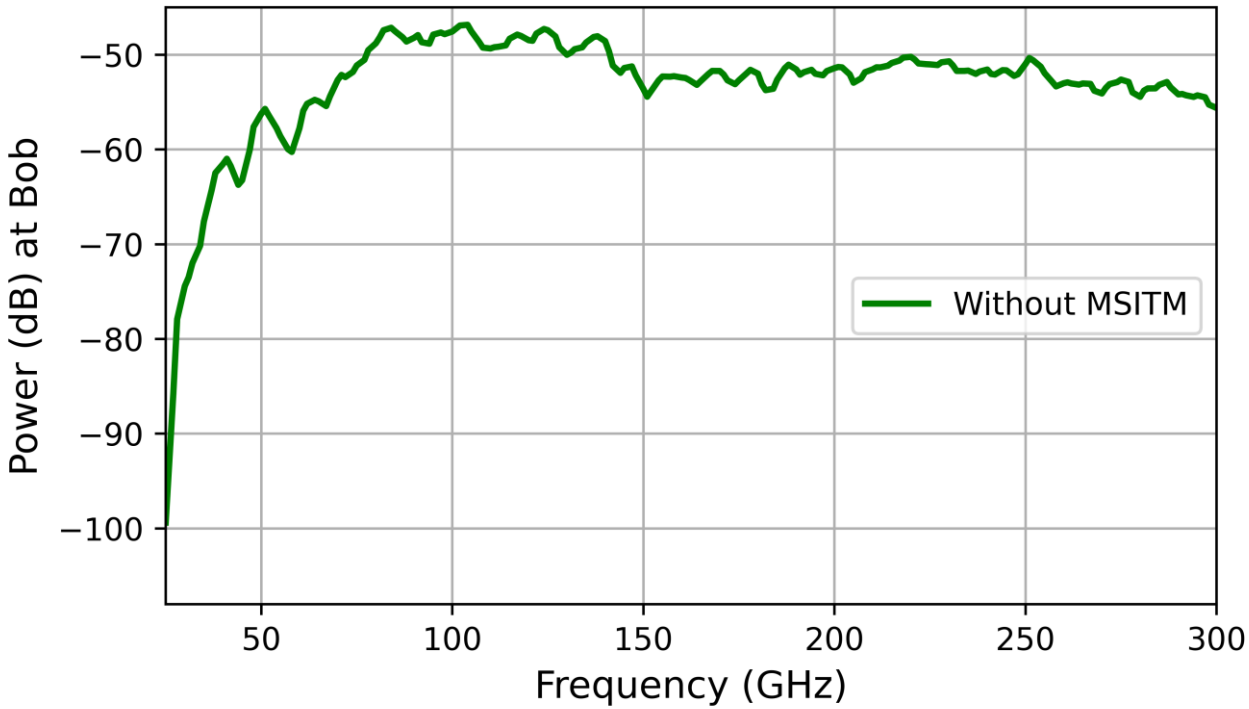




Can Bob Detect the Attack?

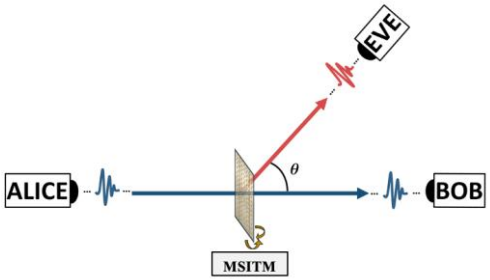
- If the Alice-Bob link is blocked, they will not use it
- If the MSITM leaves a footprint, Bob will discover it

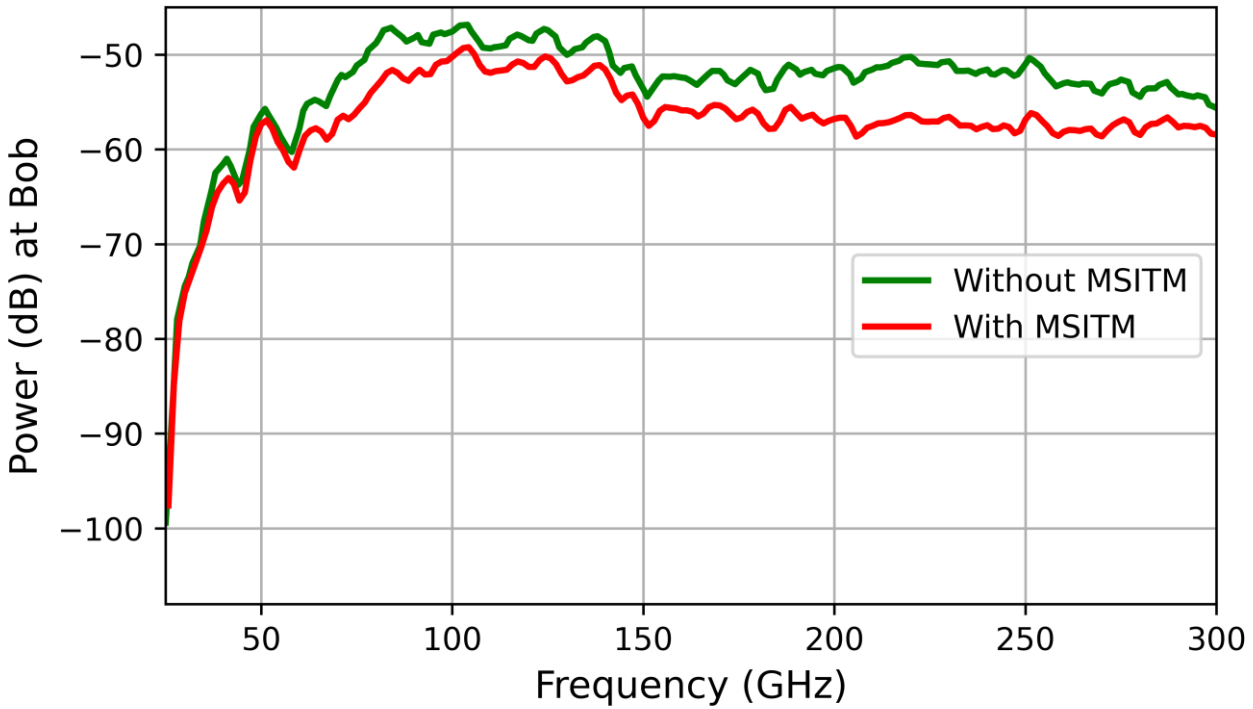




Can Bob Detect the Attack?

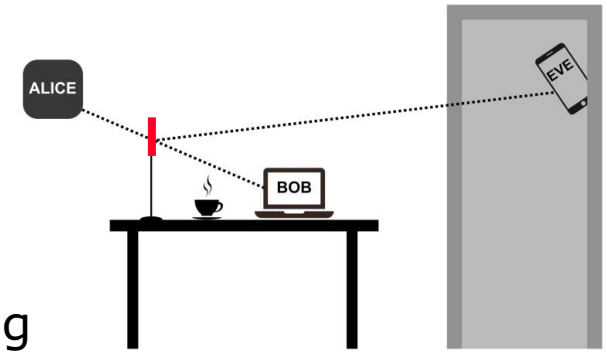
- If the Alice-Bob link is blocked, they will not use it
- If the MSITM leaves a footprint, Bob will discover it
- MSITM attenuates Bob's link by a few dB
  - No sharp resonance
  - The MSITM will be difficult to distinguish from small-scale mobility



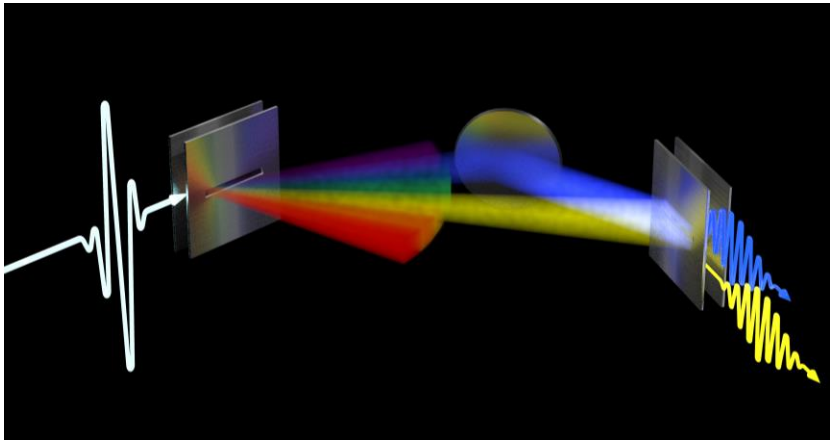


Security Takeaway

- High frequencies and high directivity provide both new security capabilities and threats
- Meta-Surface In The Middle (MSITM) attack
  - New vulnerability above 100 GHz
- Research questions
  - Programmable MSITM
  - Counter mechanisms
    - Sensing at Alice and Bob
    - Security-aware control-plane training
  - Counter-counter strategies
  - Actively securing links with metasurfaces

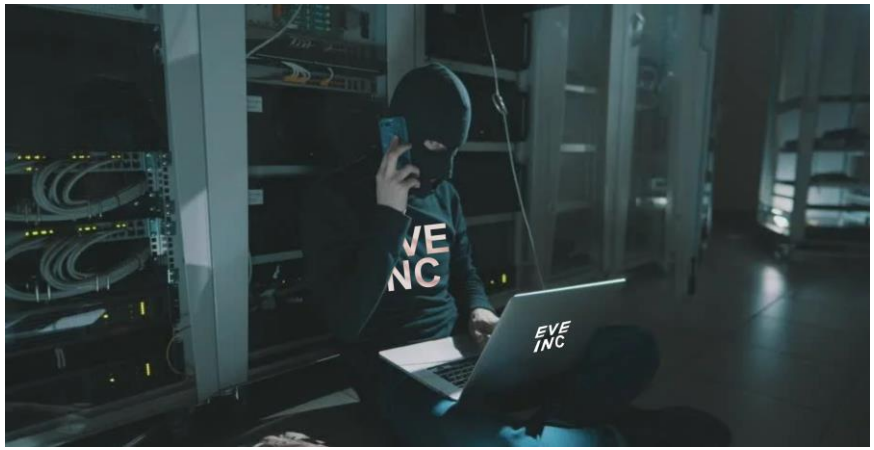


My Research Interests:
Wireless Networking, Sensing, and Security



Network devices, architectures and control

Mobile networks on a mission



Securing networks from eavesdroppers, jammers, and wireless adversaries

Acknowledgements

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  - Dan Mittleman at Brown University
- Sponsors