

mmPlug: Bringing Millimeter Wave Technology to Any IoT Device

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30 Billion IoT devices by 2030



[\[www.iottechnews.com/news/2021/jun/25/citymesh-acquires-sigfox-iot-network-operator-to-offer-services-from-0g-to-5g\]](http://www.iottechnews.com/news/2021/jun/25/citymesh-acquires-sigfox-iot-network-operator-to-offer-services-from-0g-to-5g)

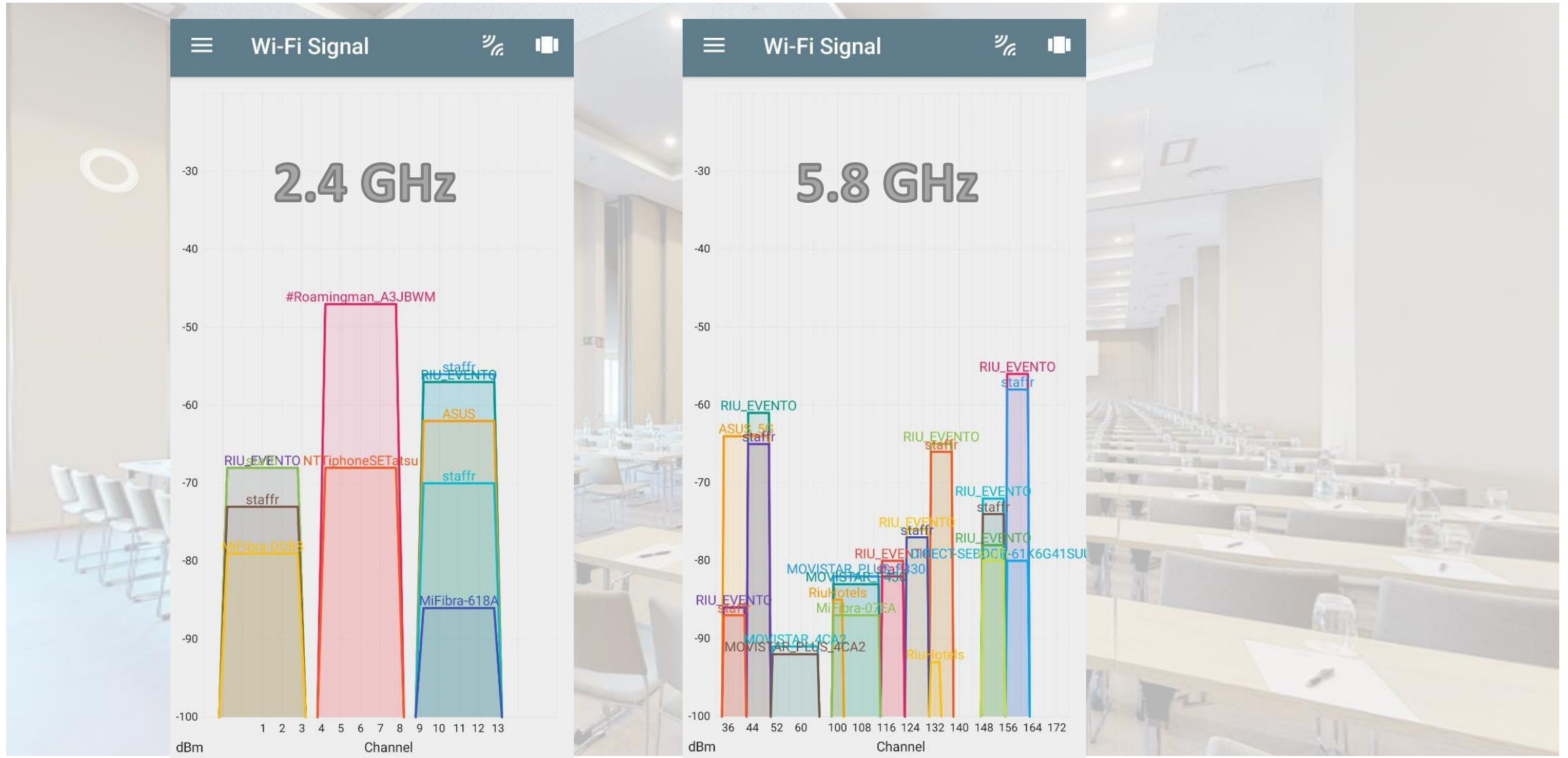
All of these devices connect through WiFi, BLE, ...

Problem: Spectrum congestion

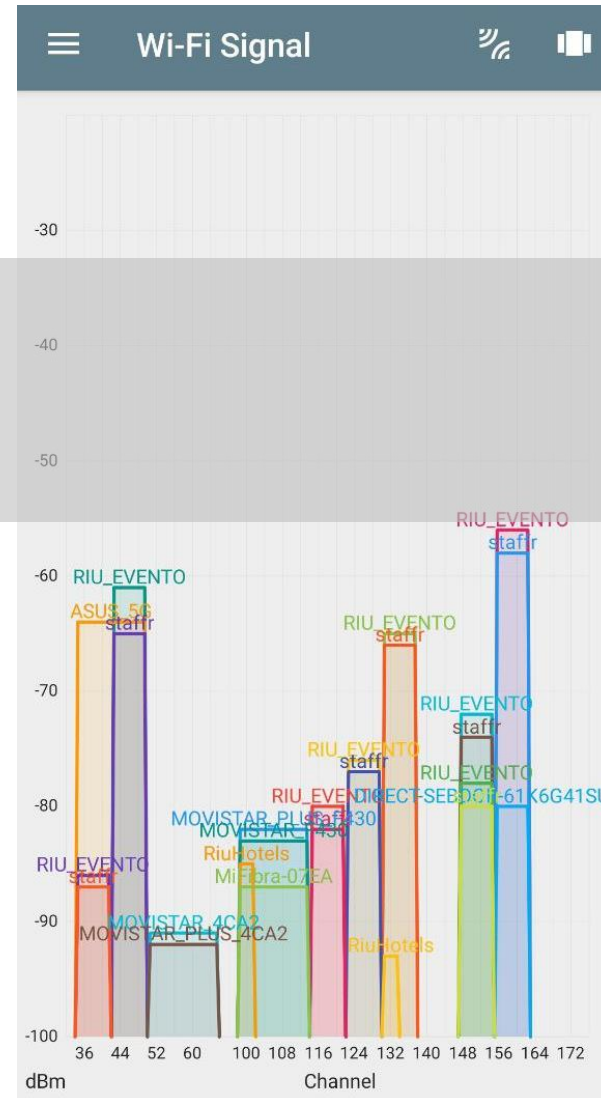
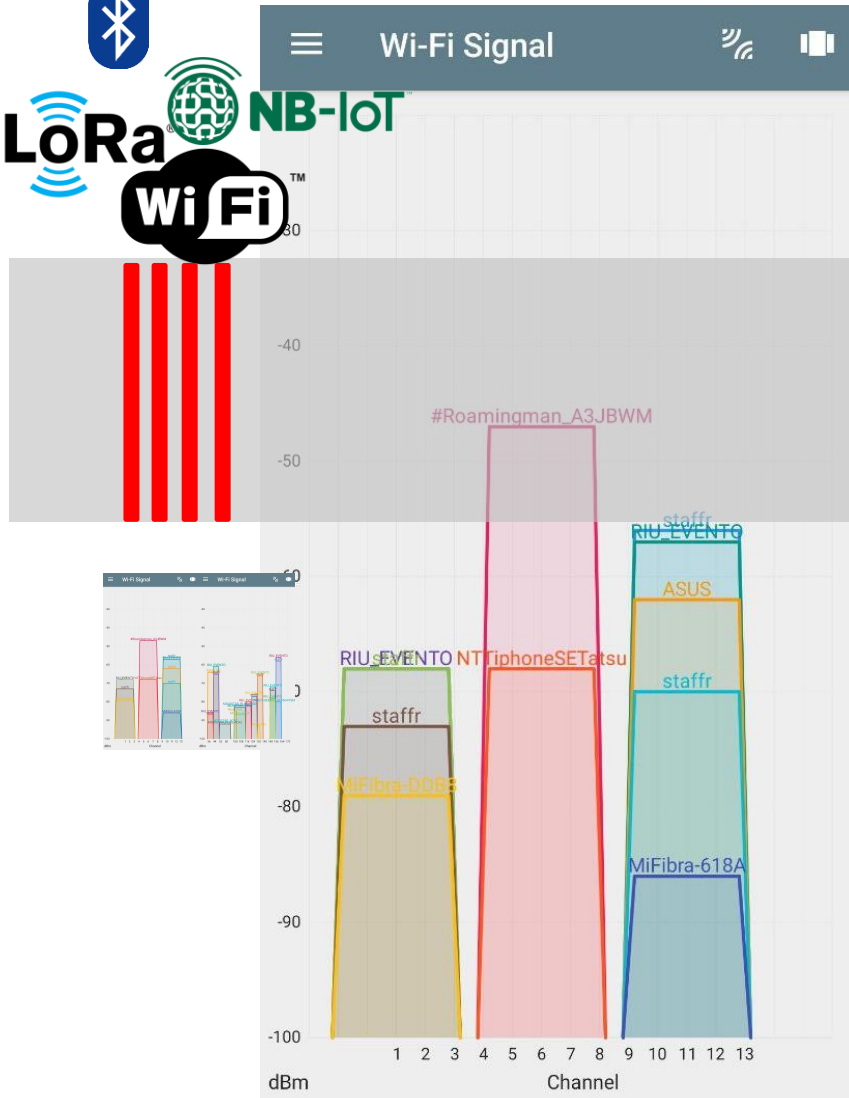
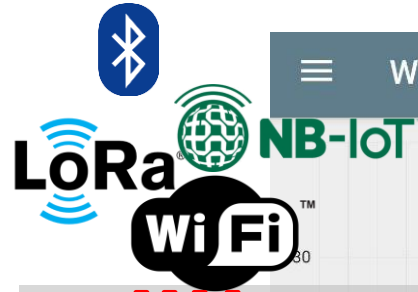


How many WiFi APs are in this room?

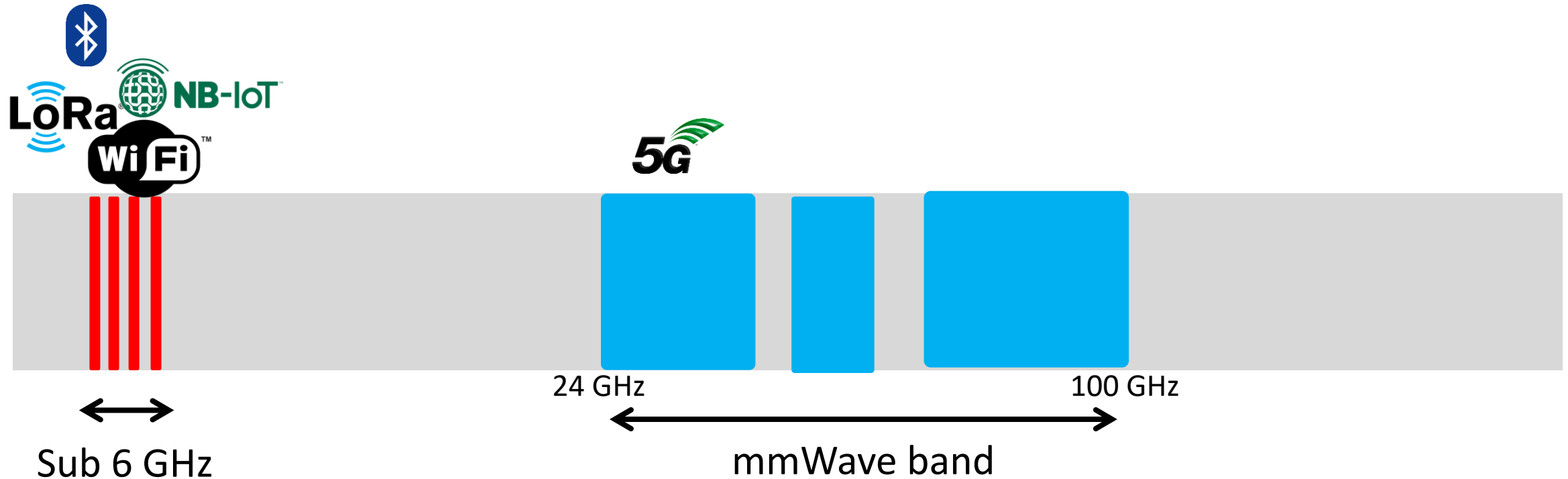
Problem: Spectrum is already congested



Problem: Spectrum congestion



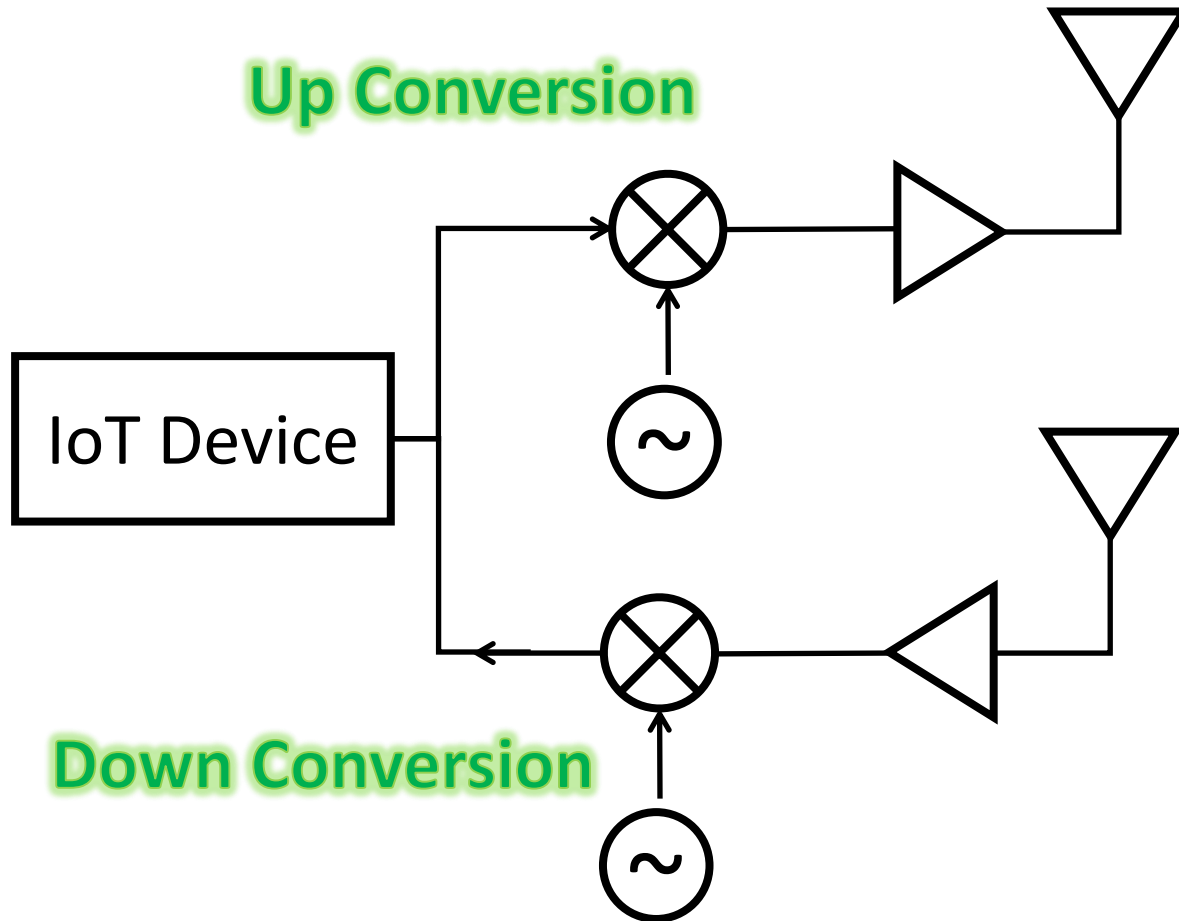
Problem: Spectrum congestion



mmWave supports high number of connected nodes

Can we move an already deployed IoT network to operate at mmWave band?

Naiive approach



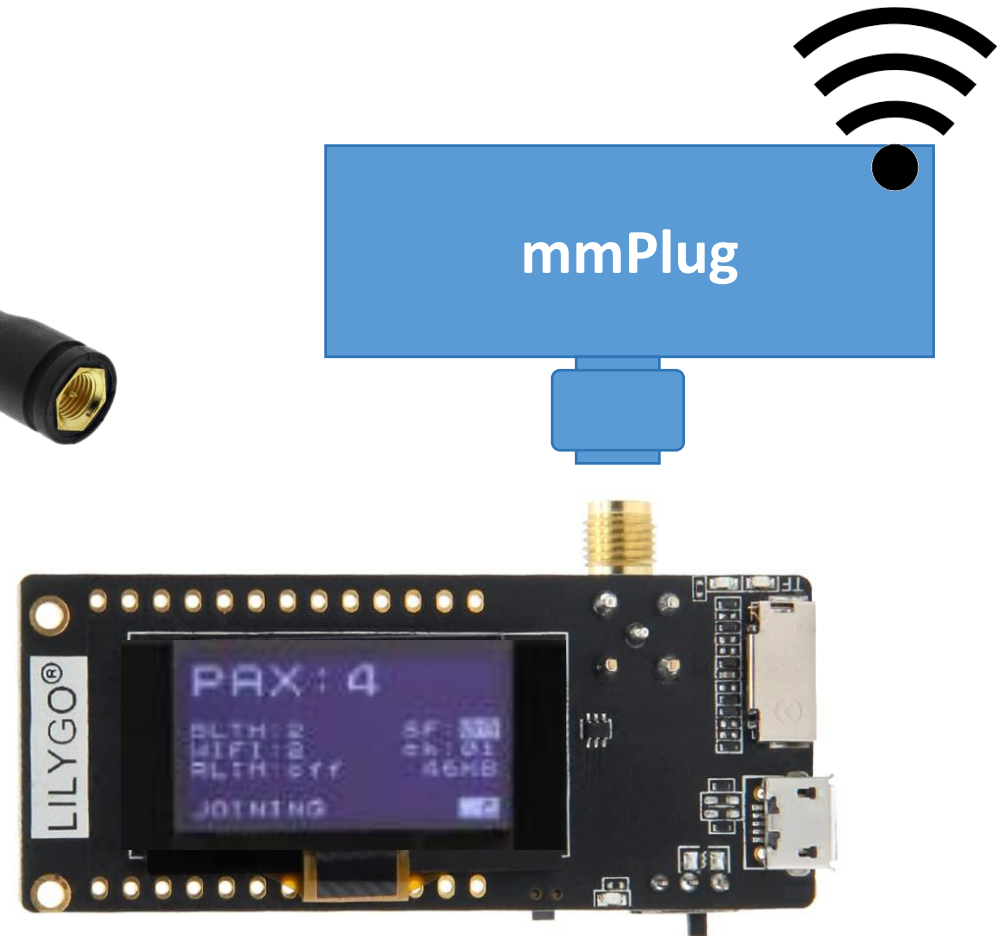
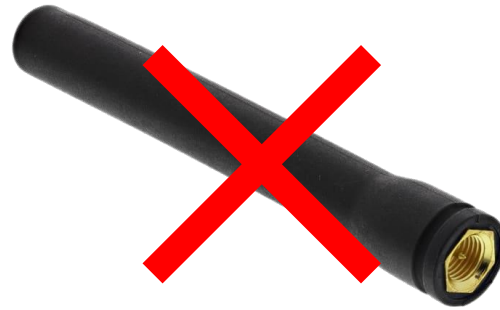
It requires a full mmWave radio

- Complex
- Power hungry
- Expensive

mmPlug

- A simple plug and play module that provides mmWave communication to any sub-6GHz IoT device
- mmPlug is only using a single amplifier component
- Provides accurate device localization

How mmPlug works

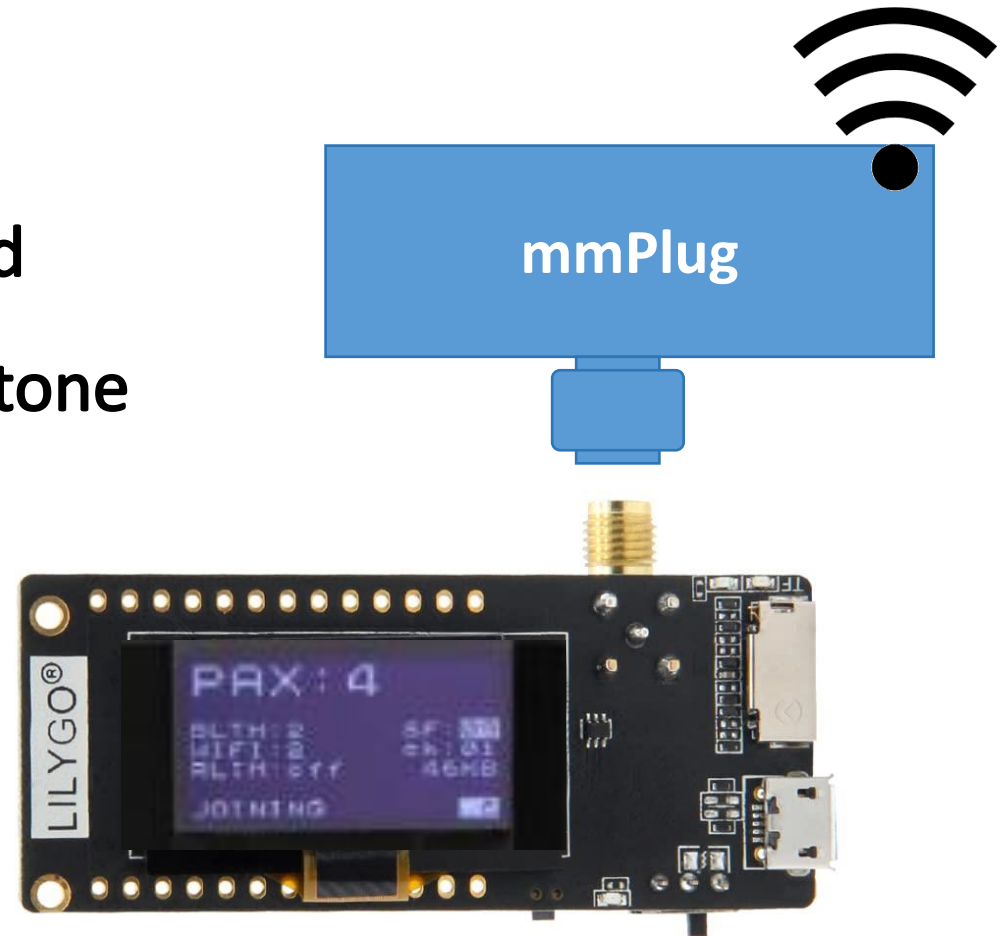


How mmPlug works

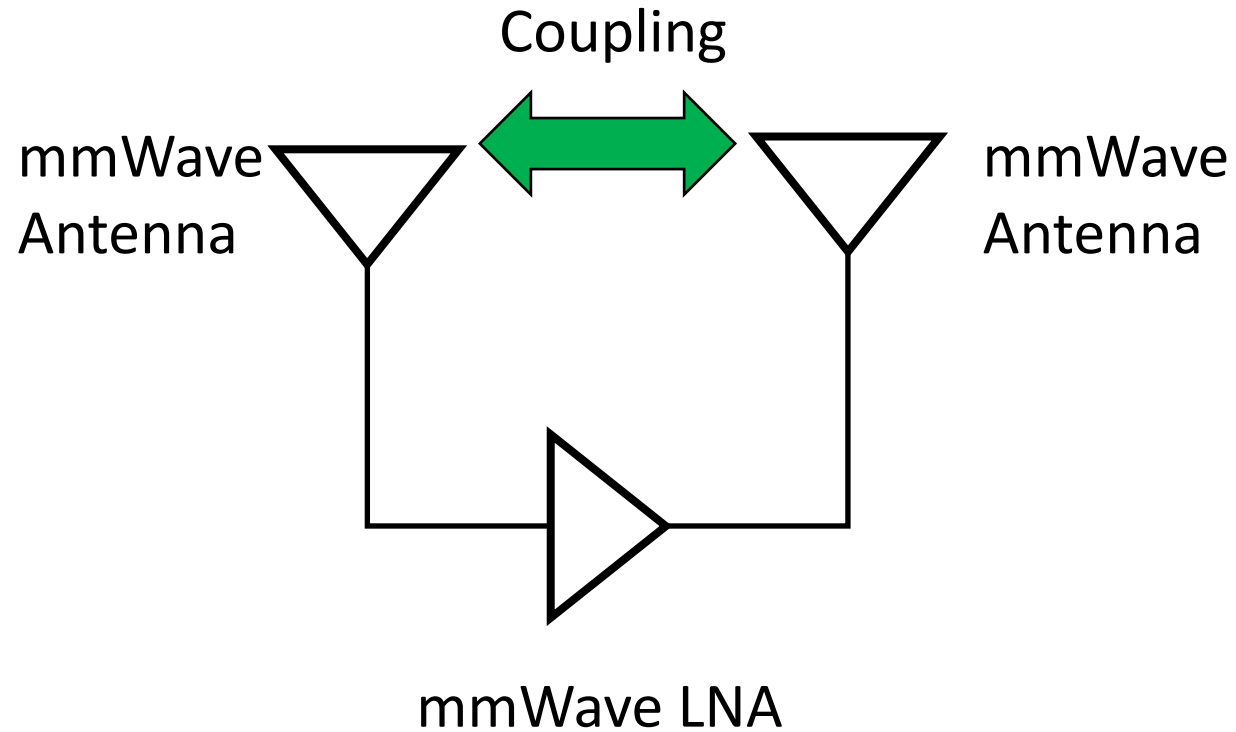
Two main tasks

- Generate a tone at mmWave band
- Mix the IoT signal with mmWave tone

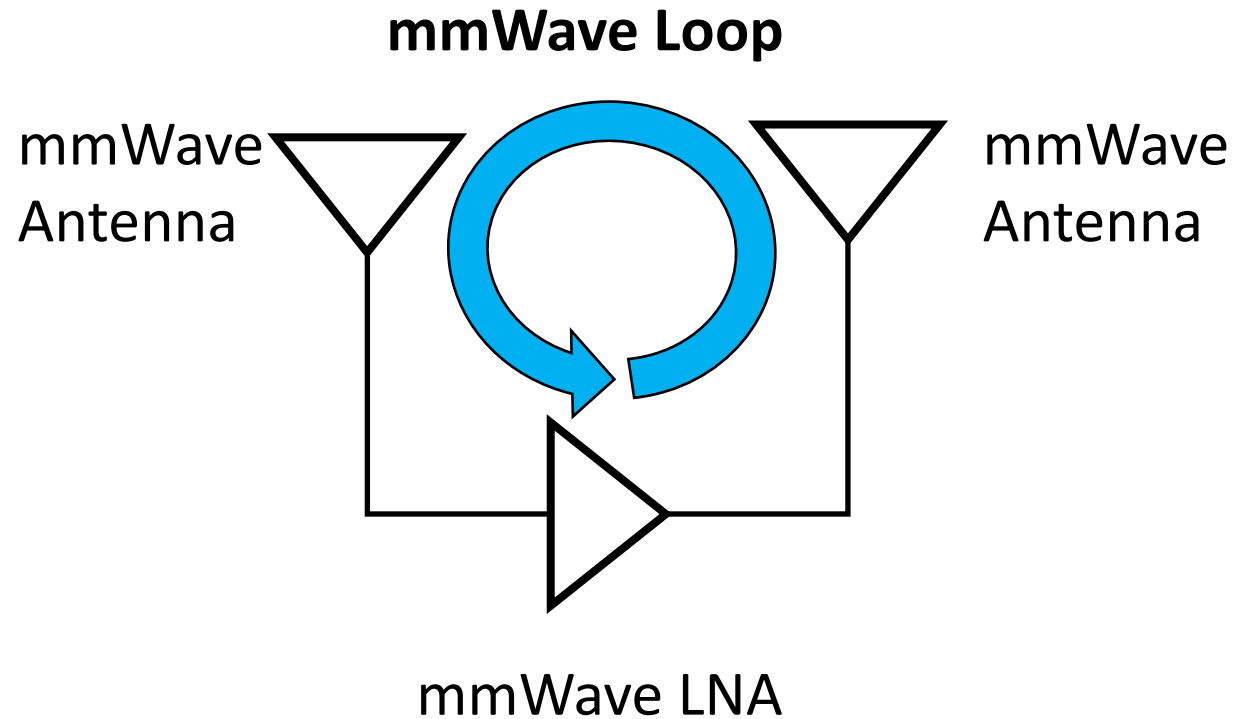
Only with using a single LNA



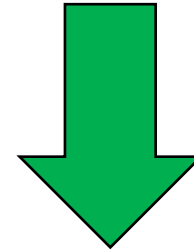
How to generate mmWave tone?



Our approach: Leveraging Mutual Coupling



Loop Gain > 1

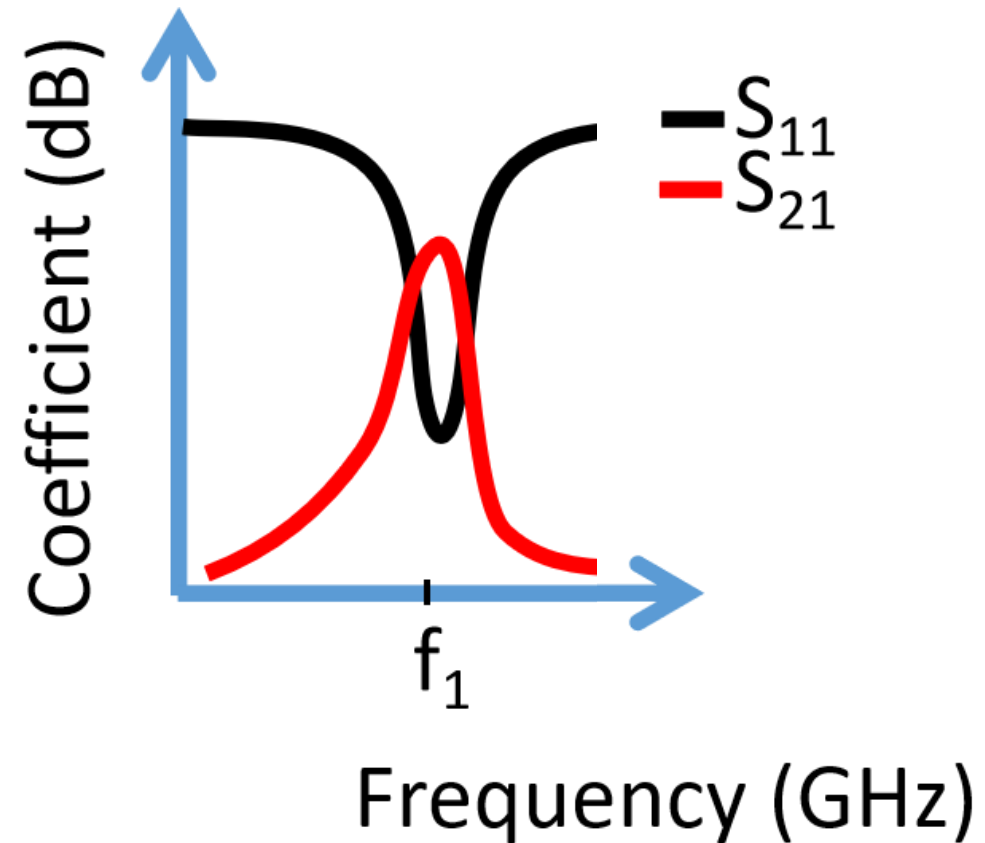
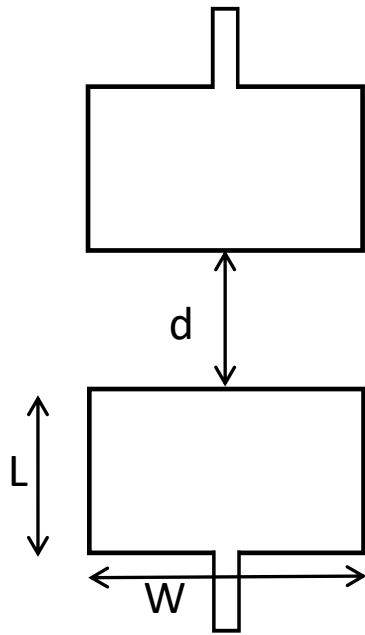


resonance in circuit

How to determine the frequency of resonating signal?

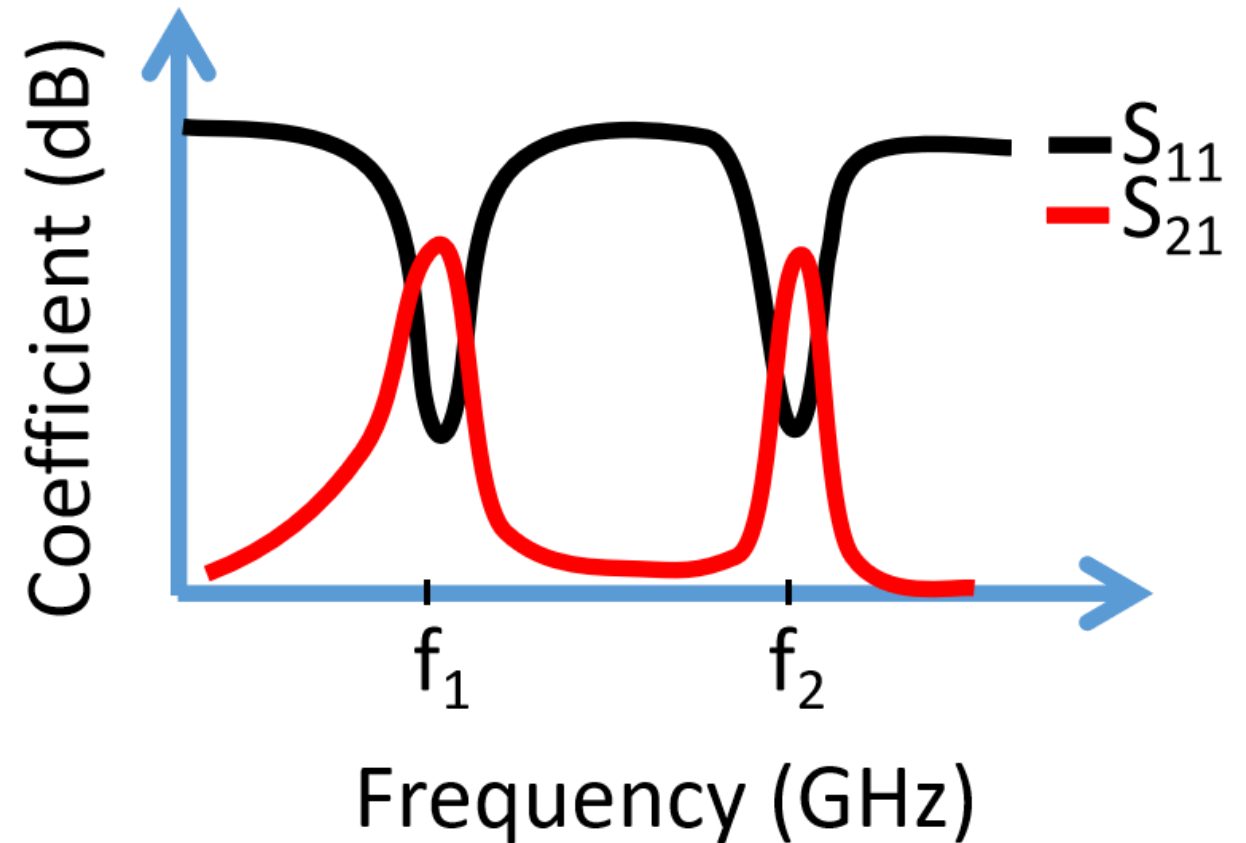
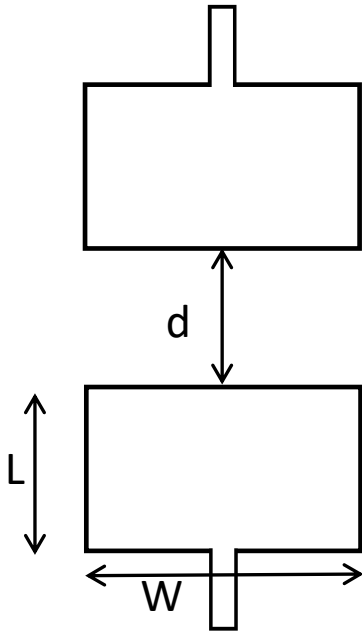
Resonance frequency control

- The antennas act as a 2 port filter



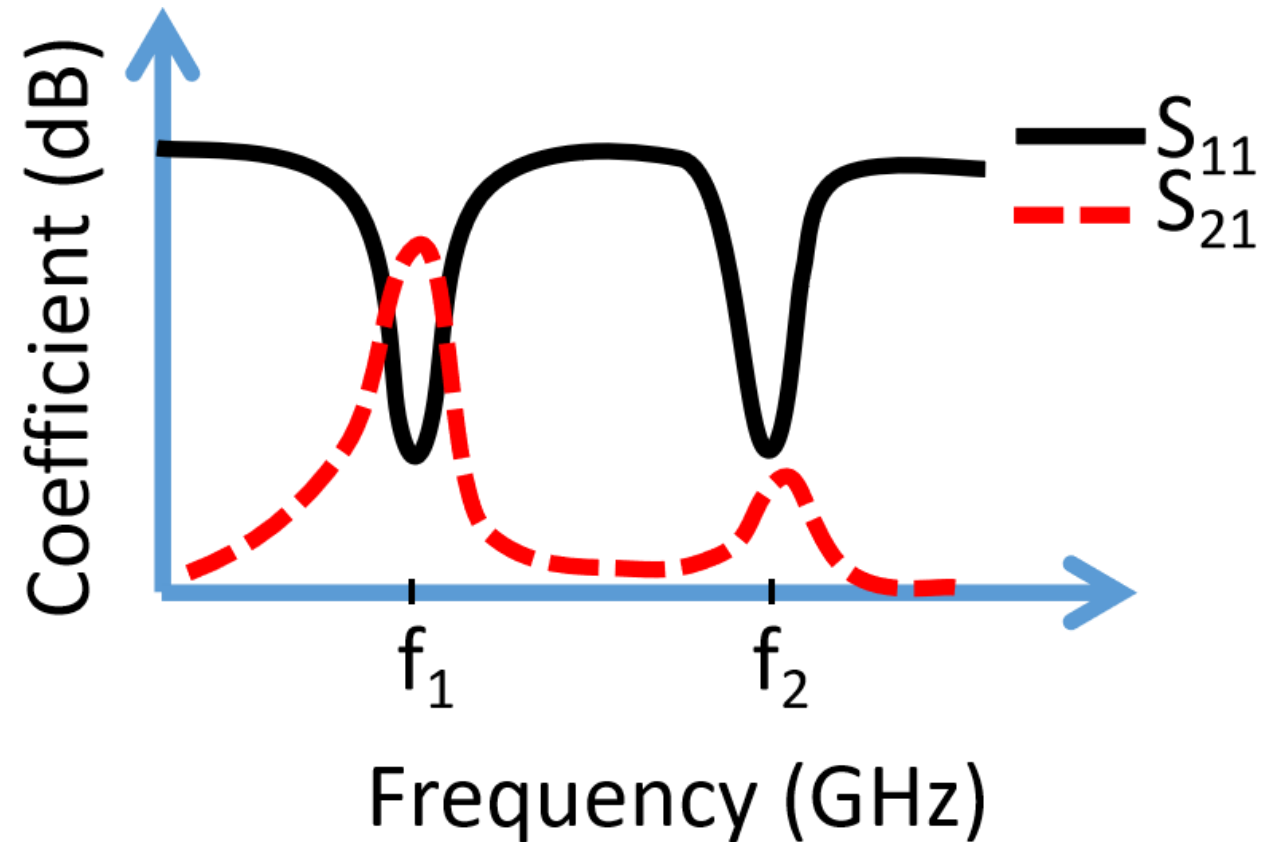
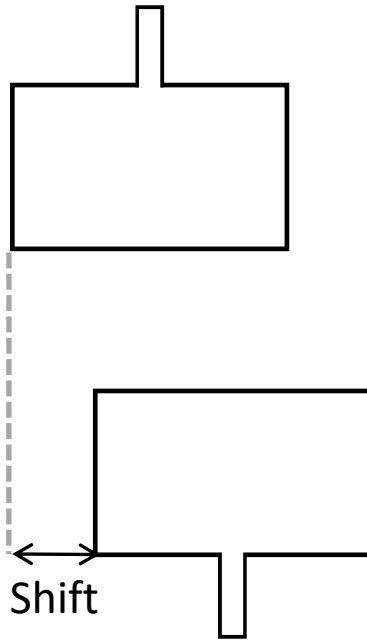
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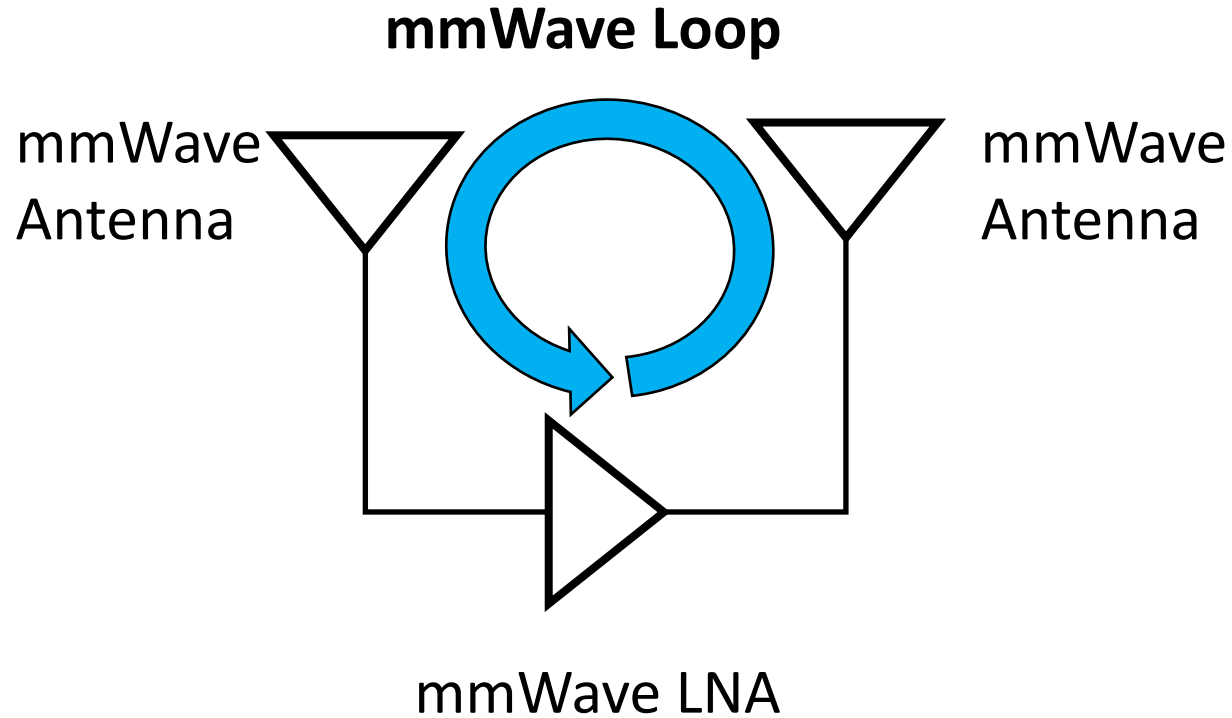


Controlling coupling at harmonics

- The antennas act as a 2 port filter



How to mix the signal using an LNA?



Loop Gain > 1

↓

LNA goes to Saturation

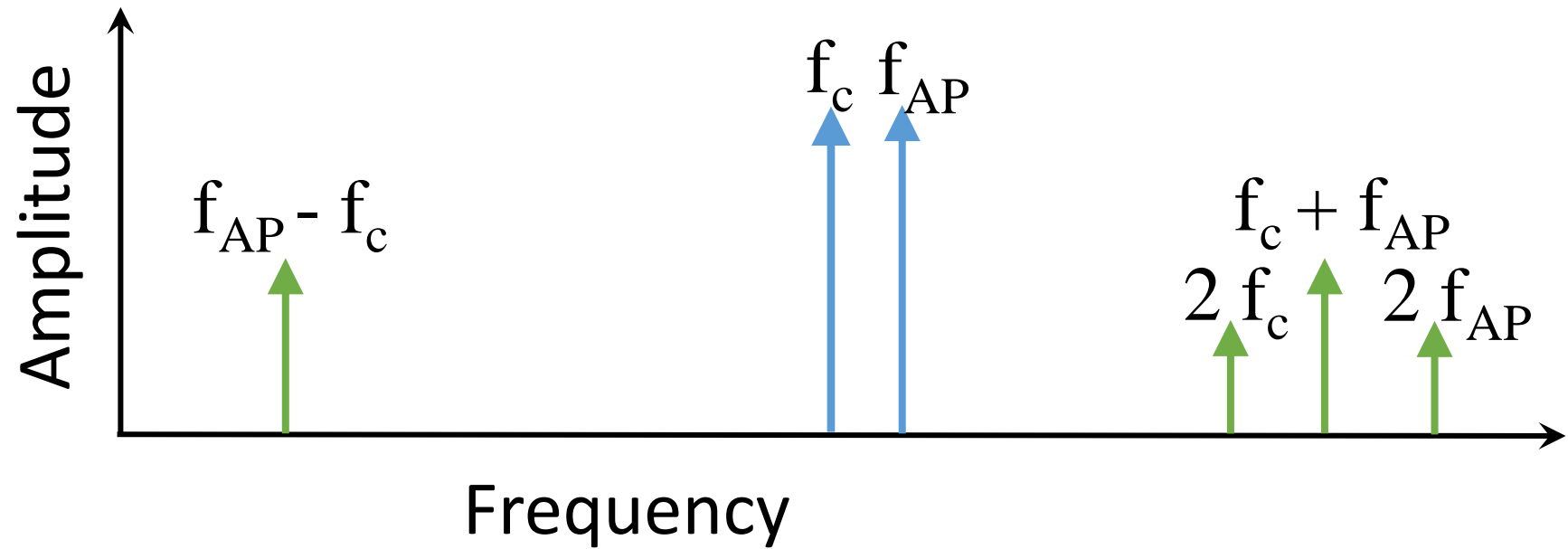
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Non Linearity

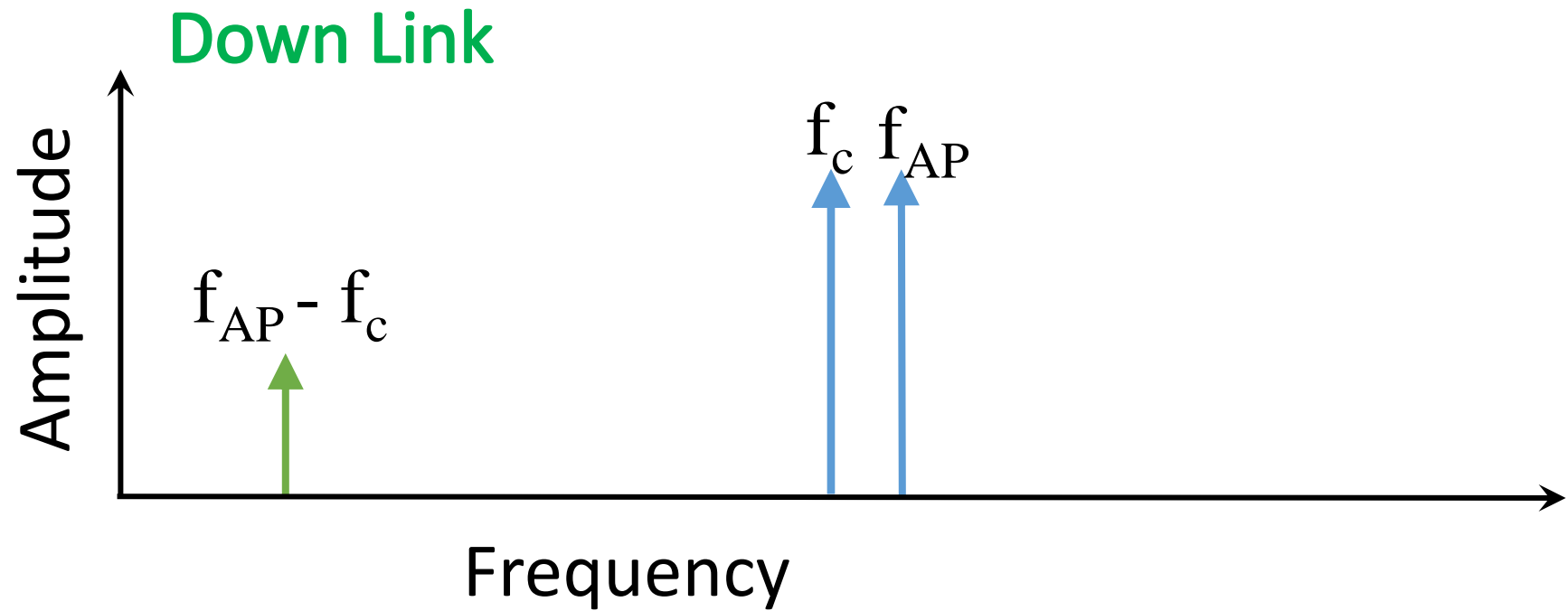
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Intermodulation

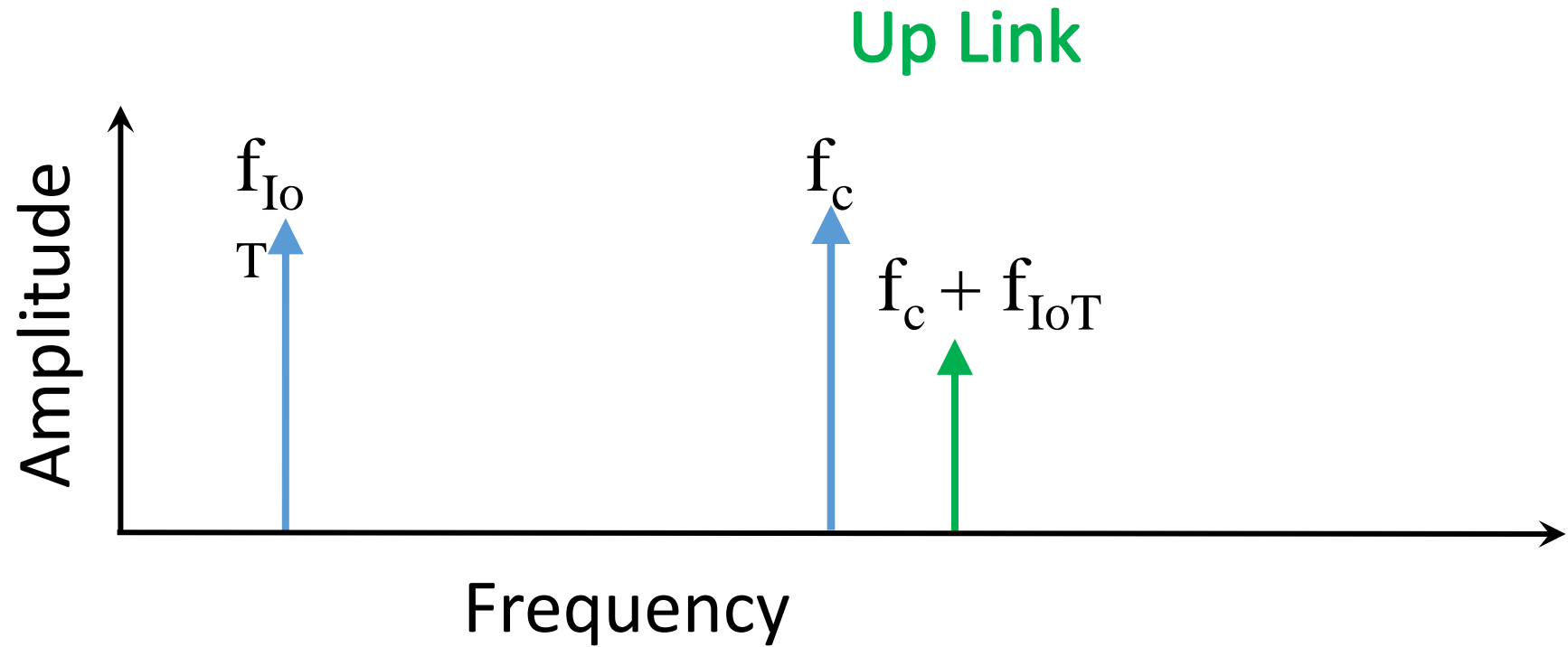
What is intermodulation?



Mixing by the help of Intermodulation

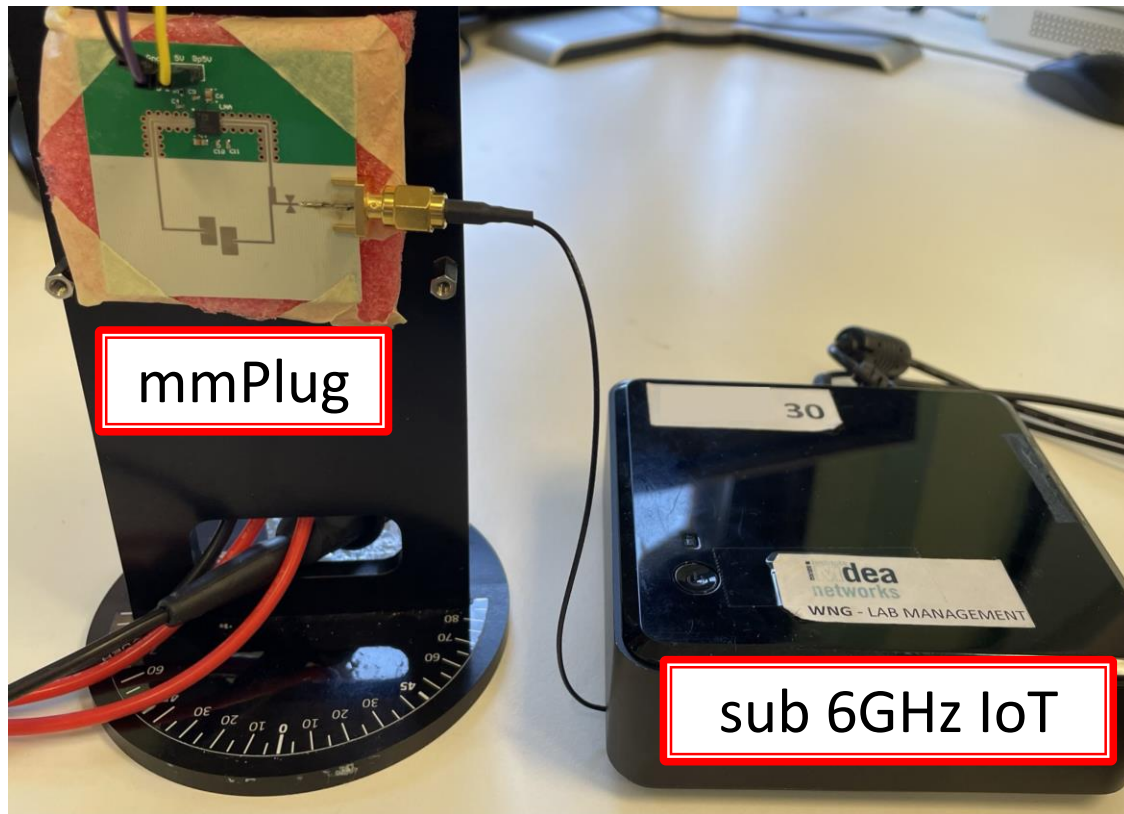


Mixing by the help of Intermodulation

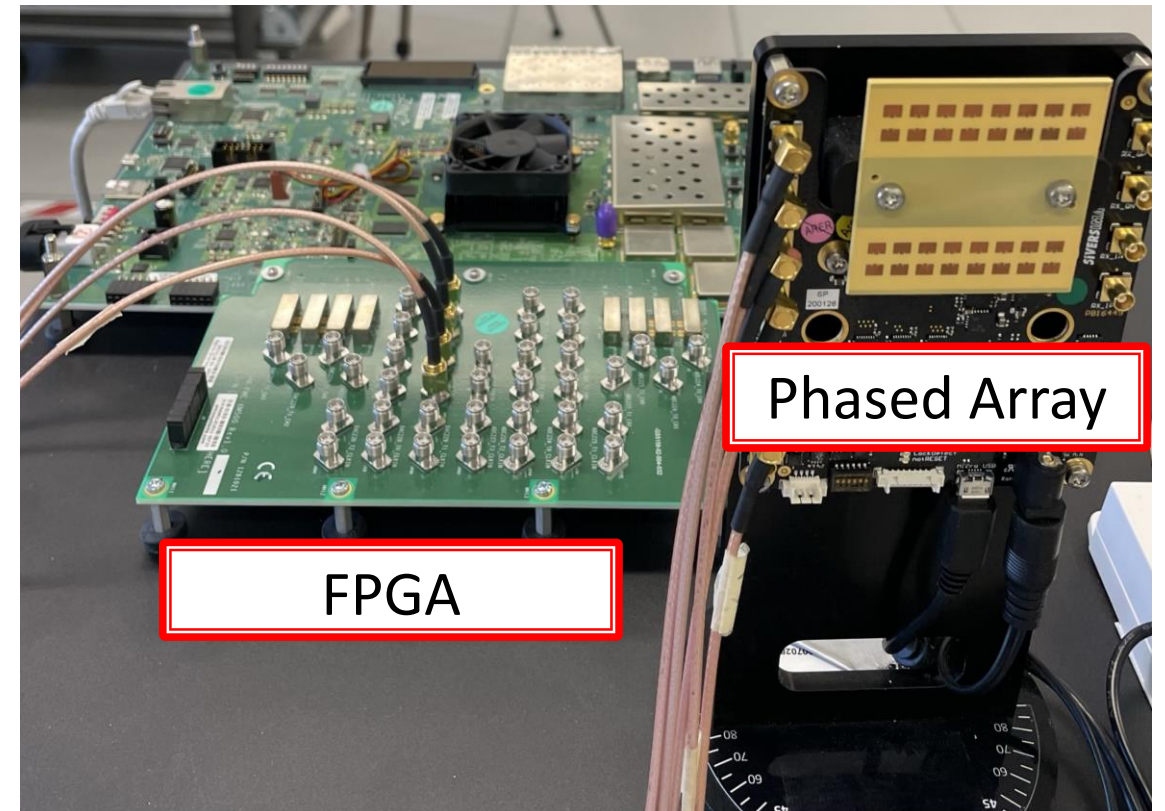


Implementation

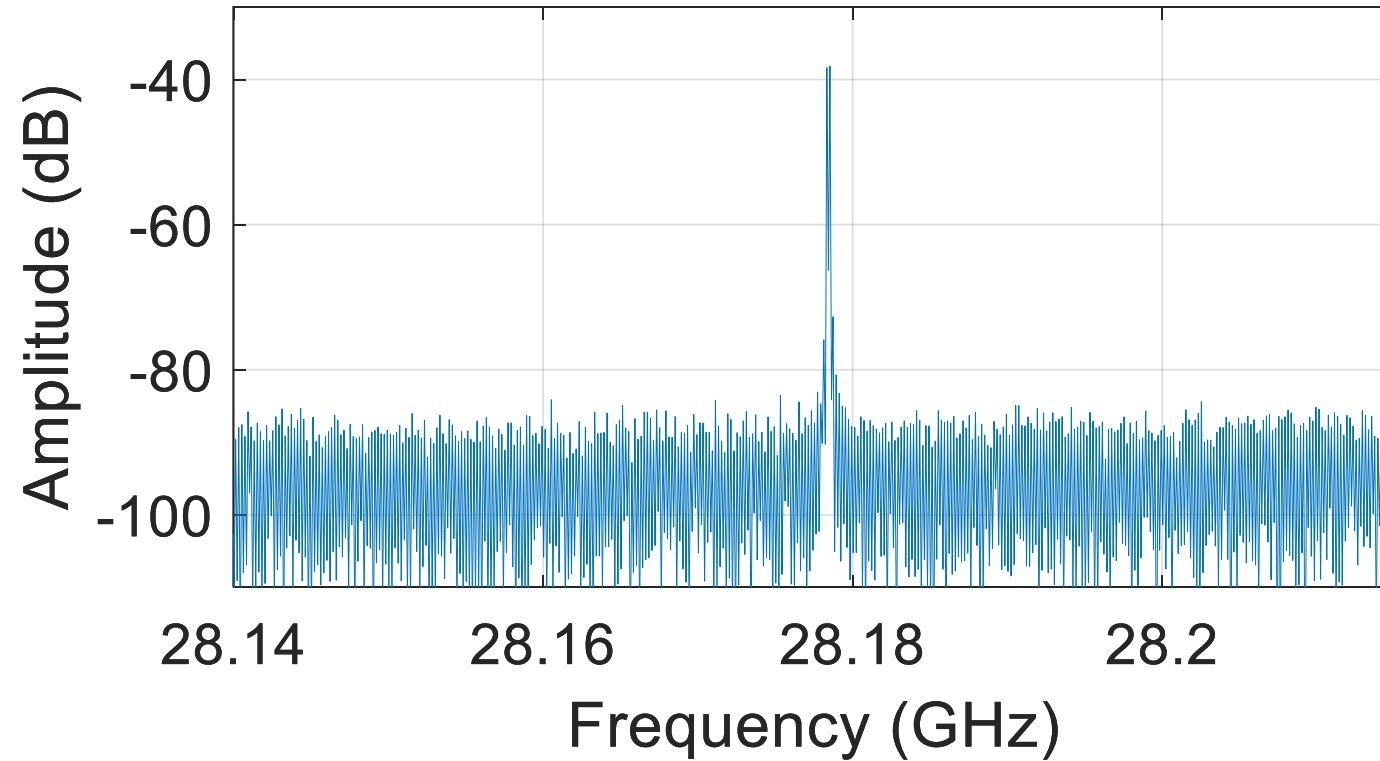
IoT Node



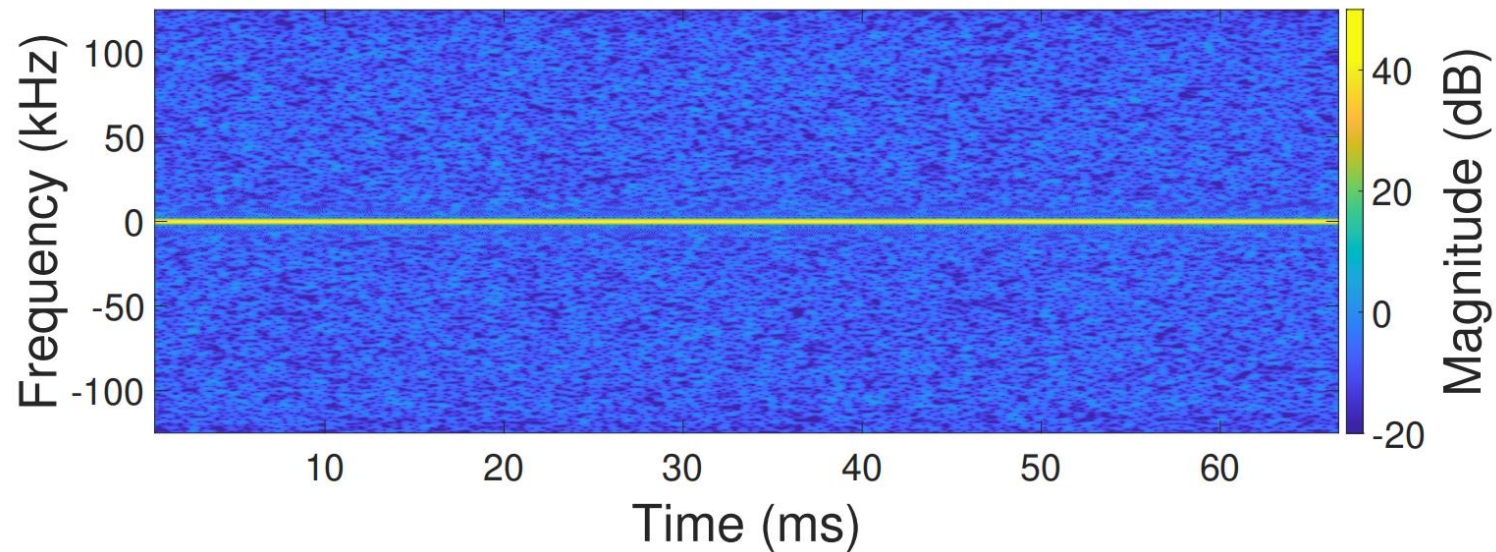
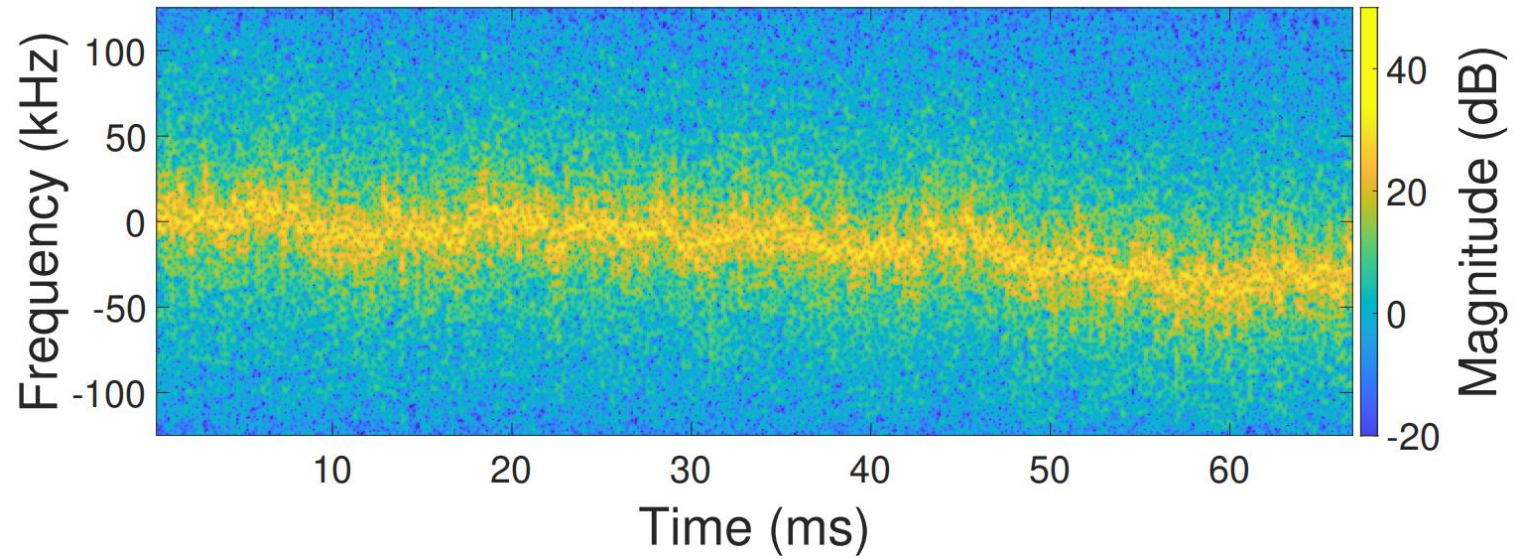
Access Point



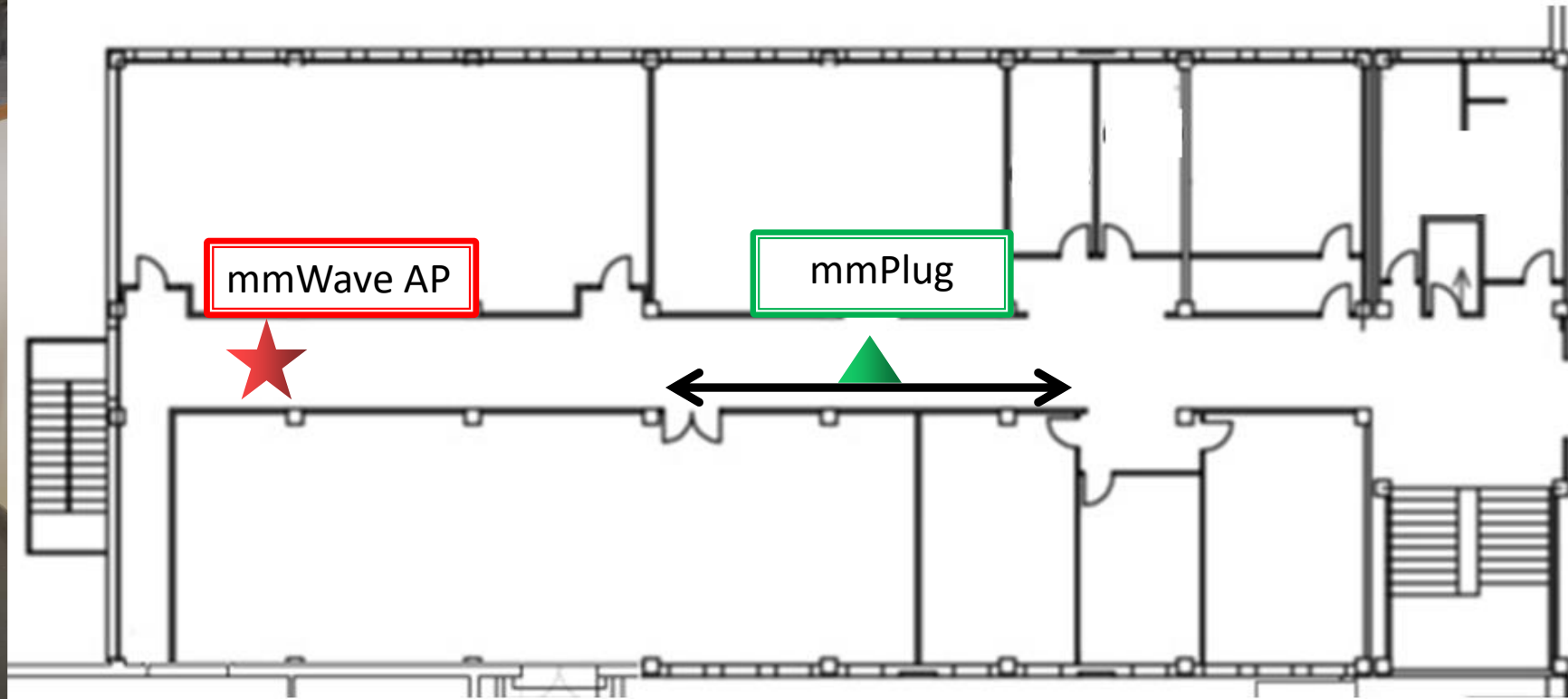
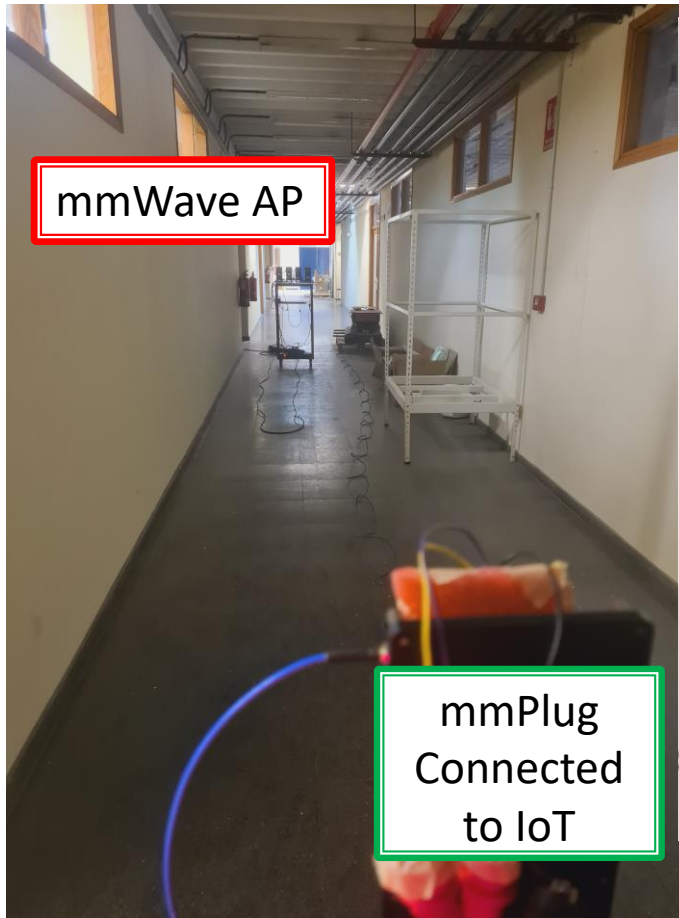
Evaluation: Tone generation



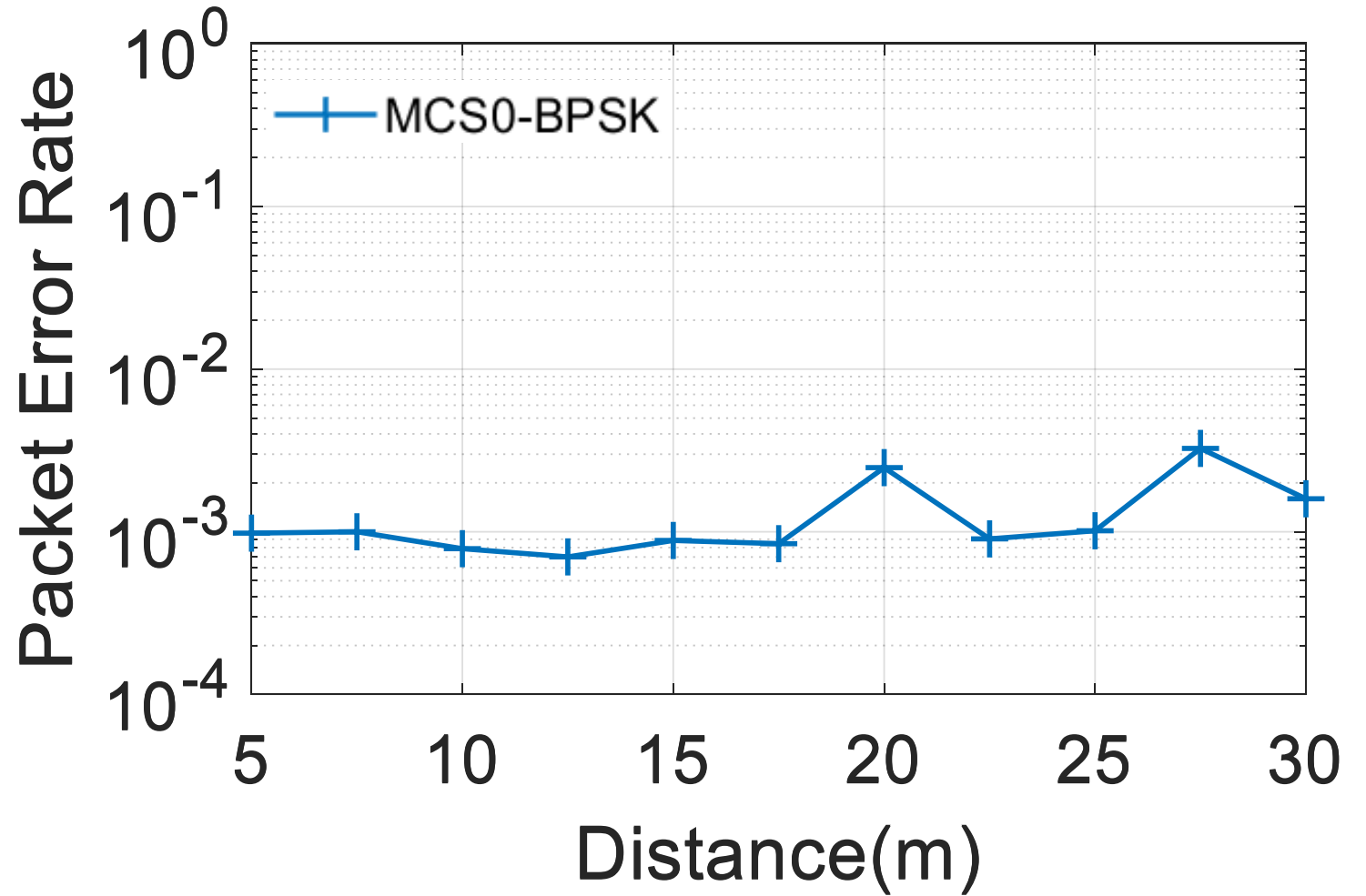
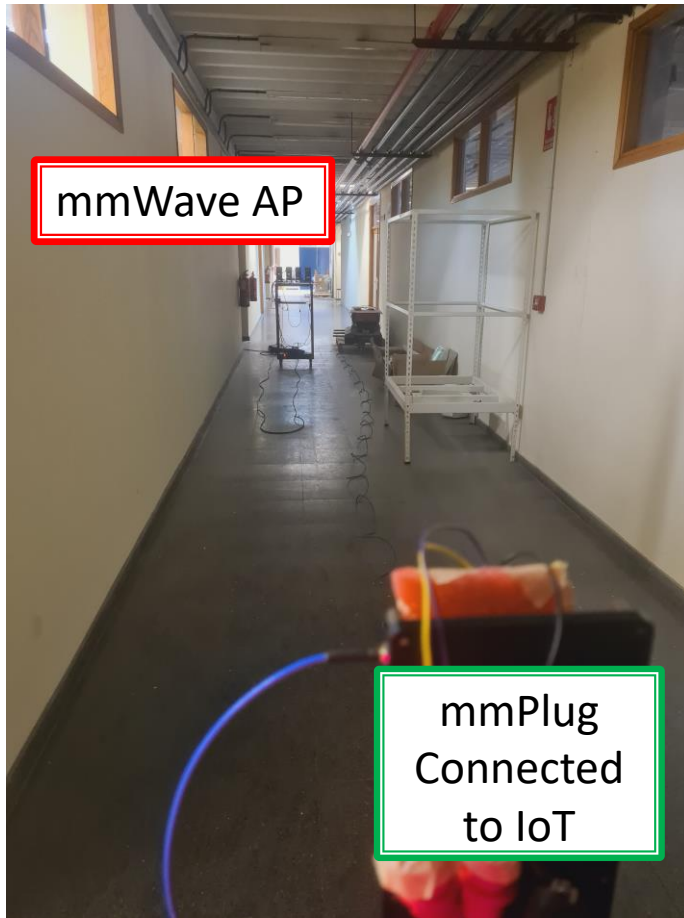
Evaluation: CFO and CFO correction



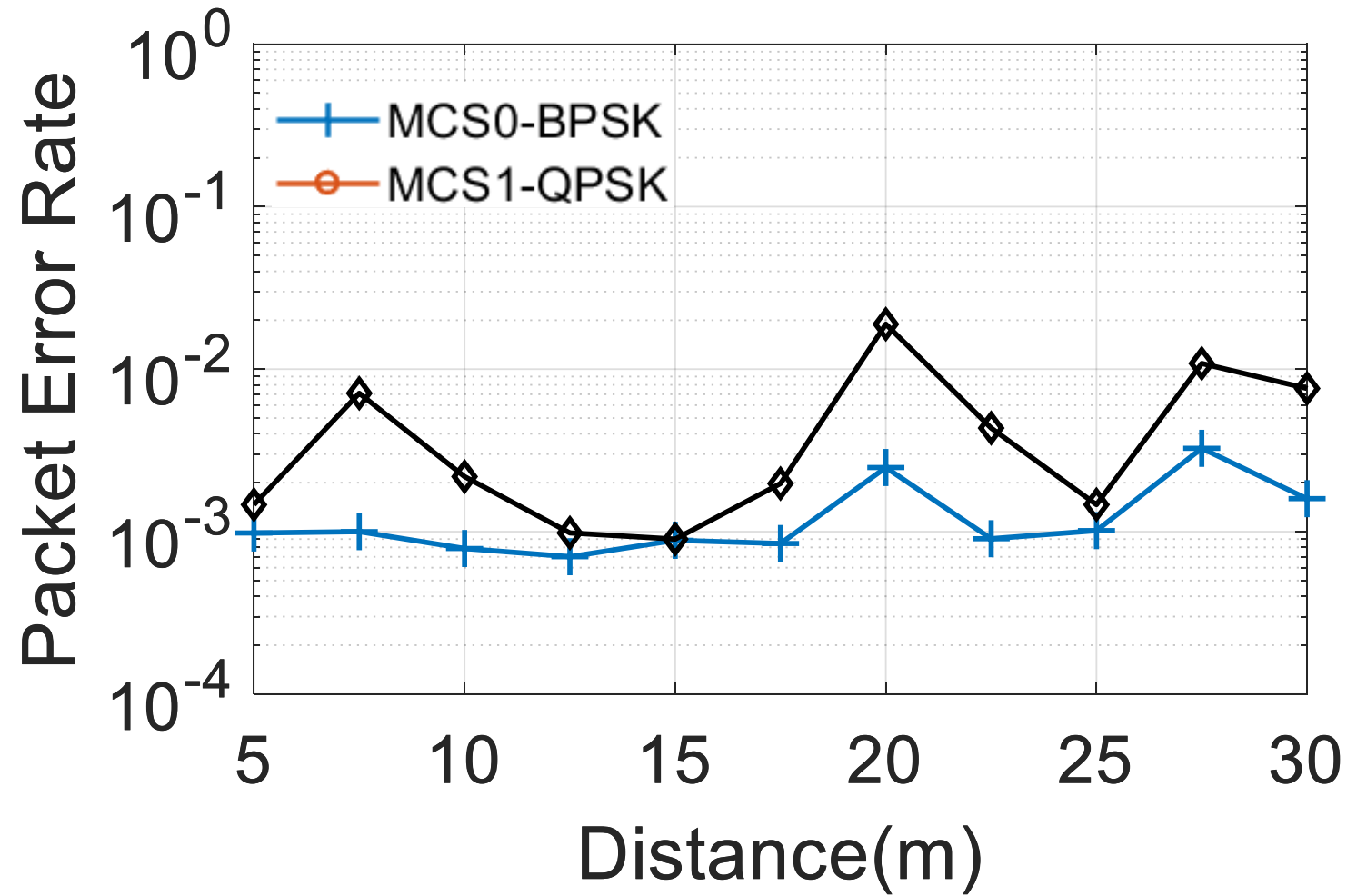
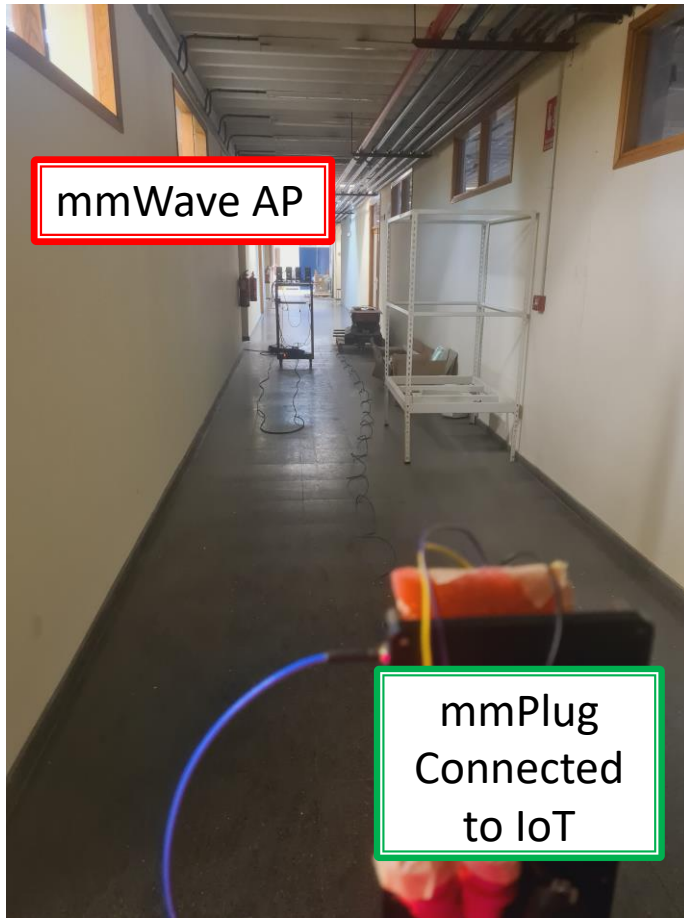
End to End Evaluation: Setup



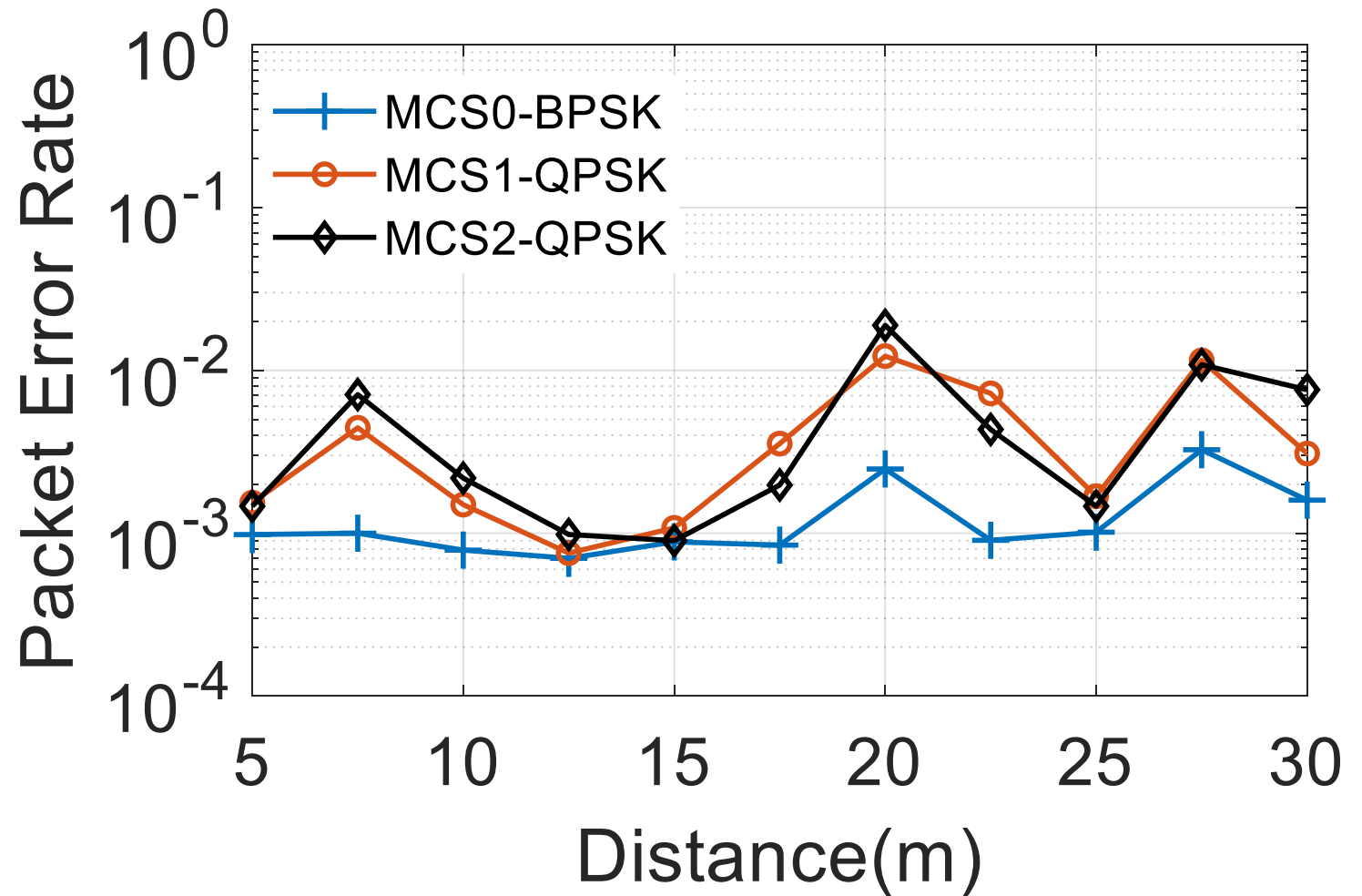
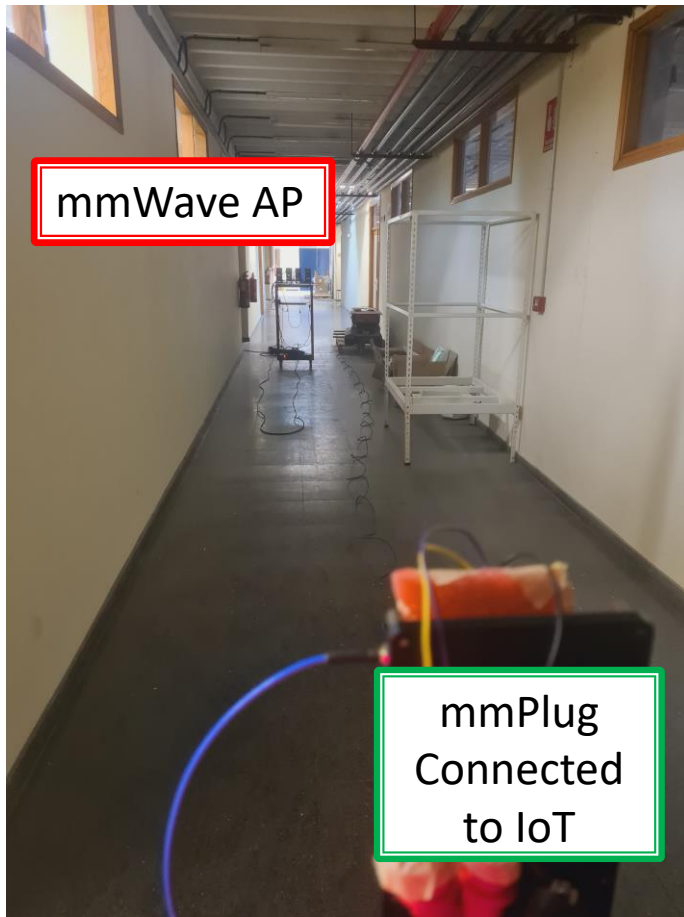
End to End Evaluation: WiFi



End to End Evaluation: WiFi

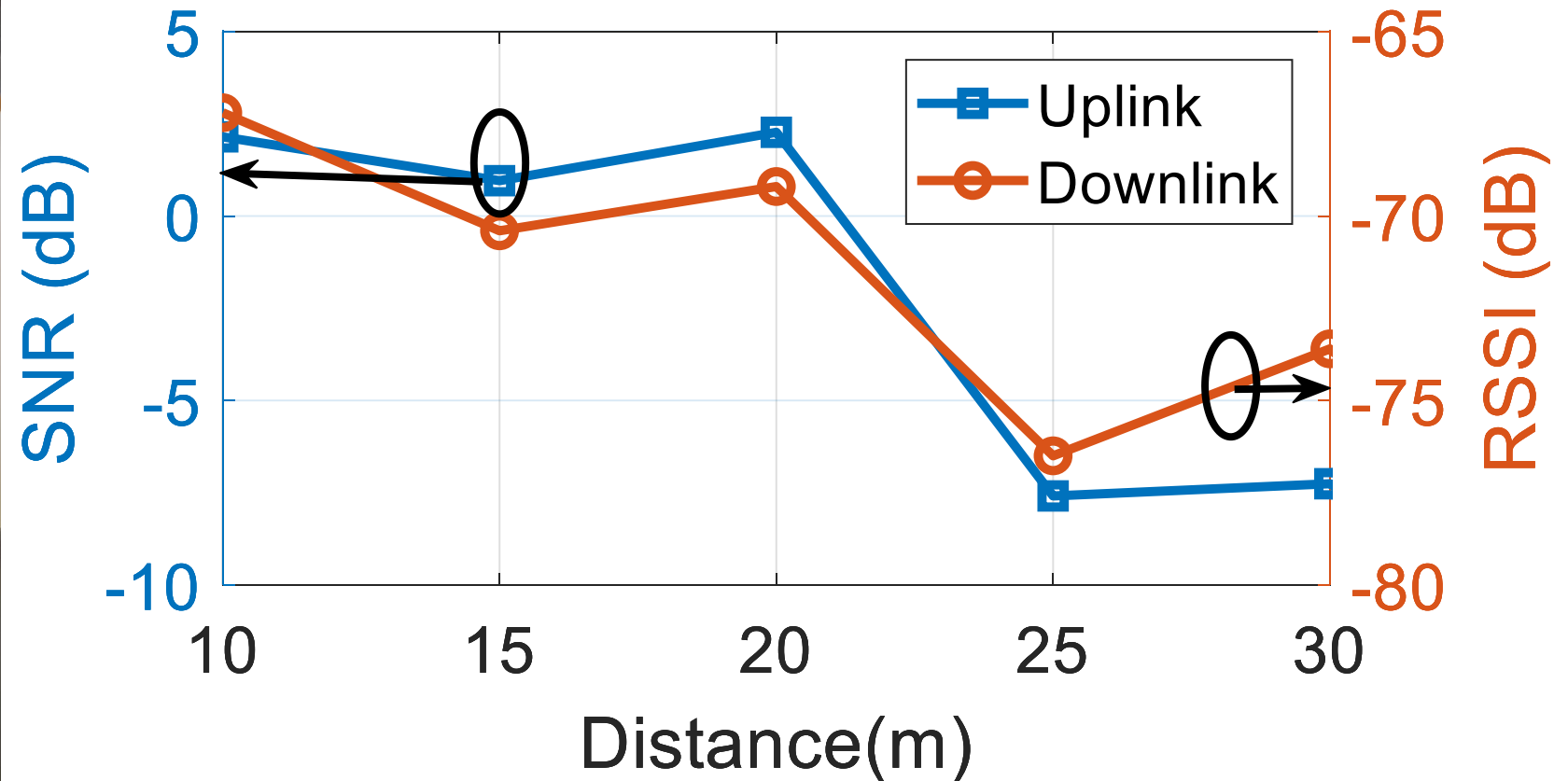
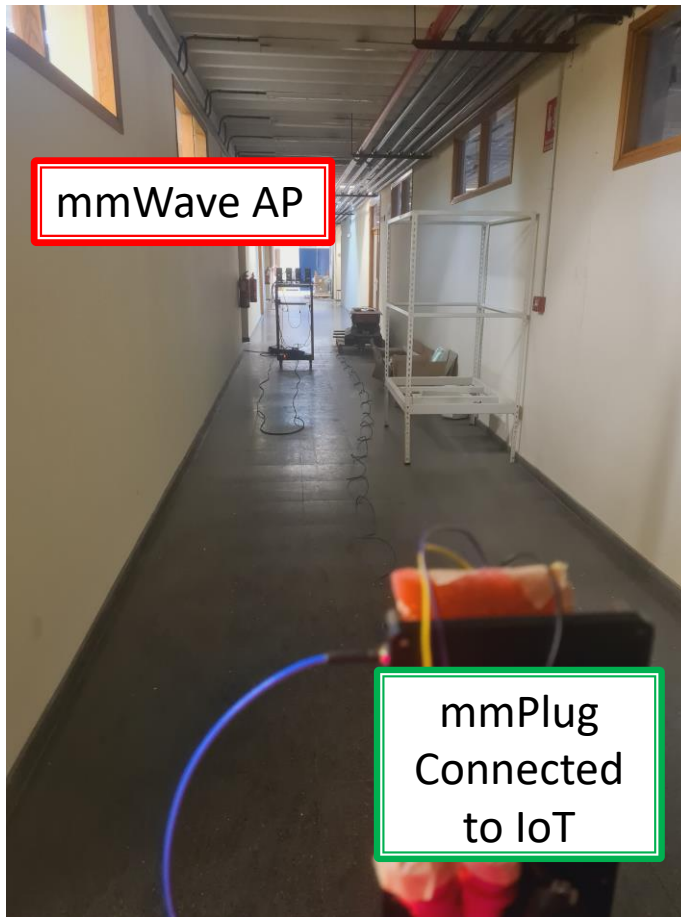


End to End Evaluation: WiFi



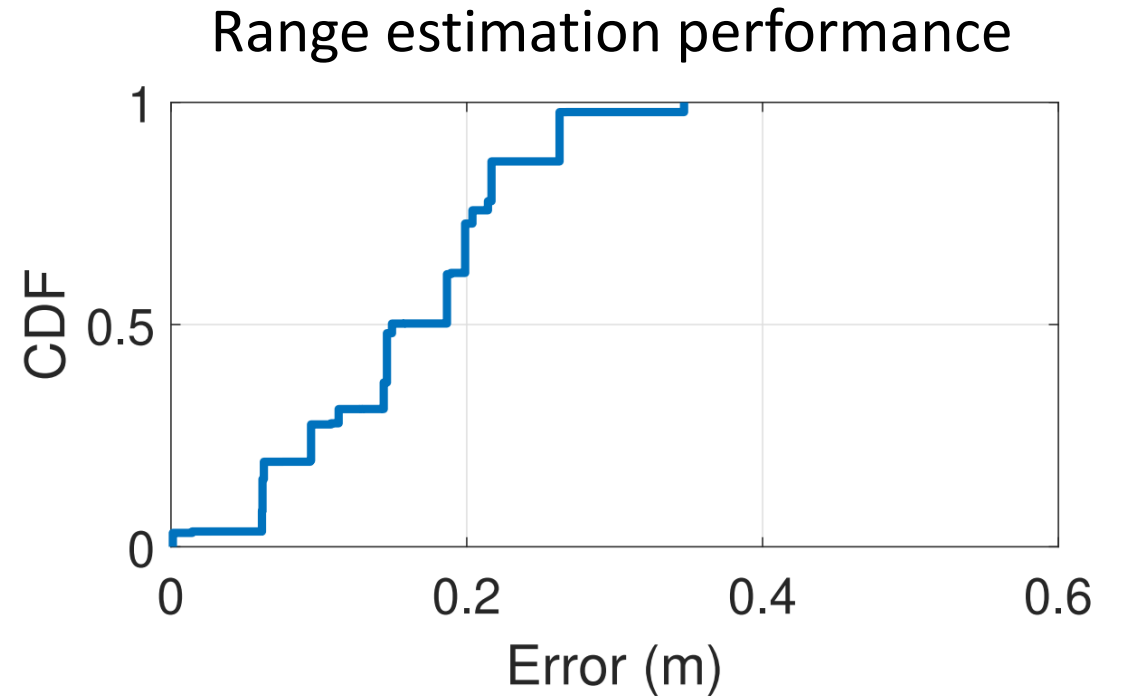
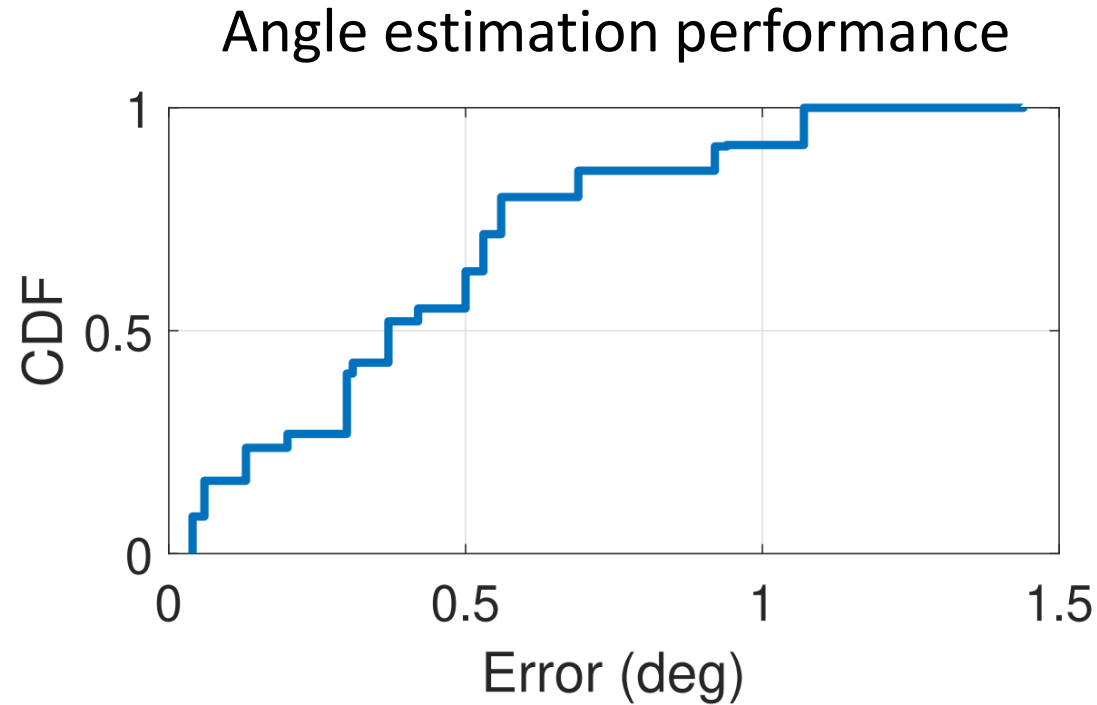
mmPlug seamlessly enables WiFi at mmWave band

End to End Evaluation: LoRa



mmPlug seamlessly enables LoRa at mmWave band

End to End Evaluation: Localization



mmPlug provides accurate localization performance

Comparing with other mmWave IoT platforms

System name	Energy efficiency (nJ/bit)	Range	Uplink	Downlink	Plug and Play
mmPlug	5	>30	✓	✓	✓
mmX	11	18	✓	✗	✗
mmTag	2.4	8	✓	✗	✗

Conclusion

mmPlug A plug and play module

- ✓ **mmPlug** enables IoT devices to send and receive at mmWave band
- ✓ **mmPlug** is very simple; it uses only one active RF component
- ✓ **mmPlug** gives accurate device localization

mmPlug can upgrade current IoT network for massive IoT applications