

OmniScatter: Extreme Sensitivity mmWave Backscattering Using Commodity FMCW Radar

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Parth Pathak, Sung-Min Sohn, and **Song Min Kim**

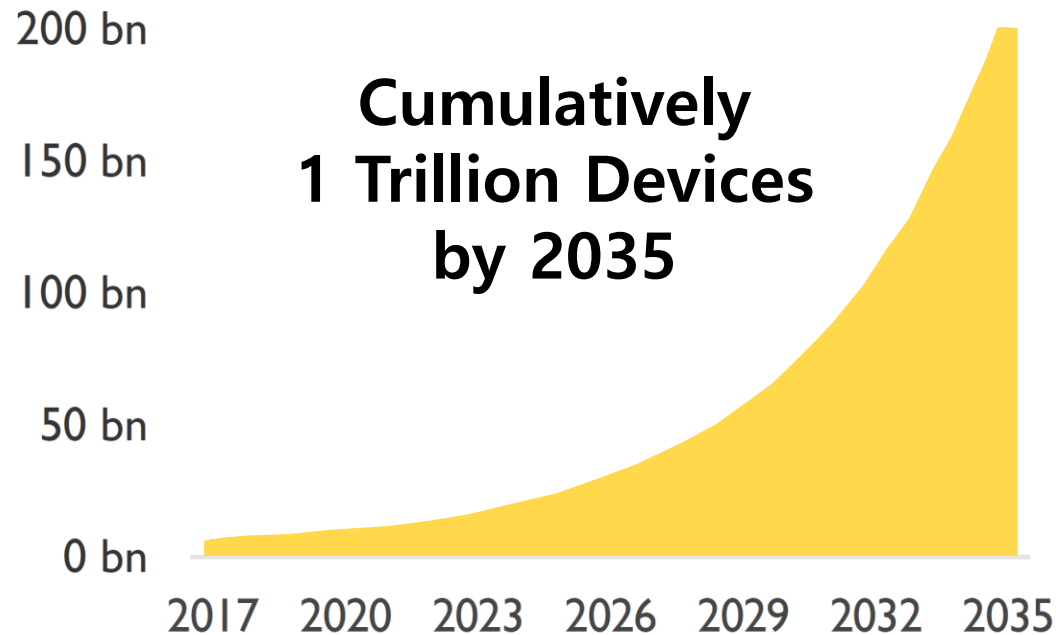
Massive Connectivity is key for IoT



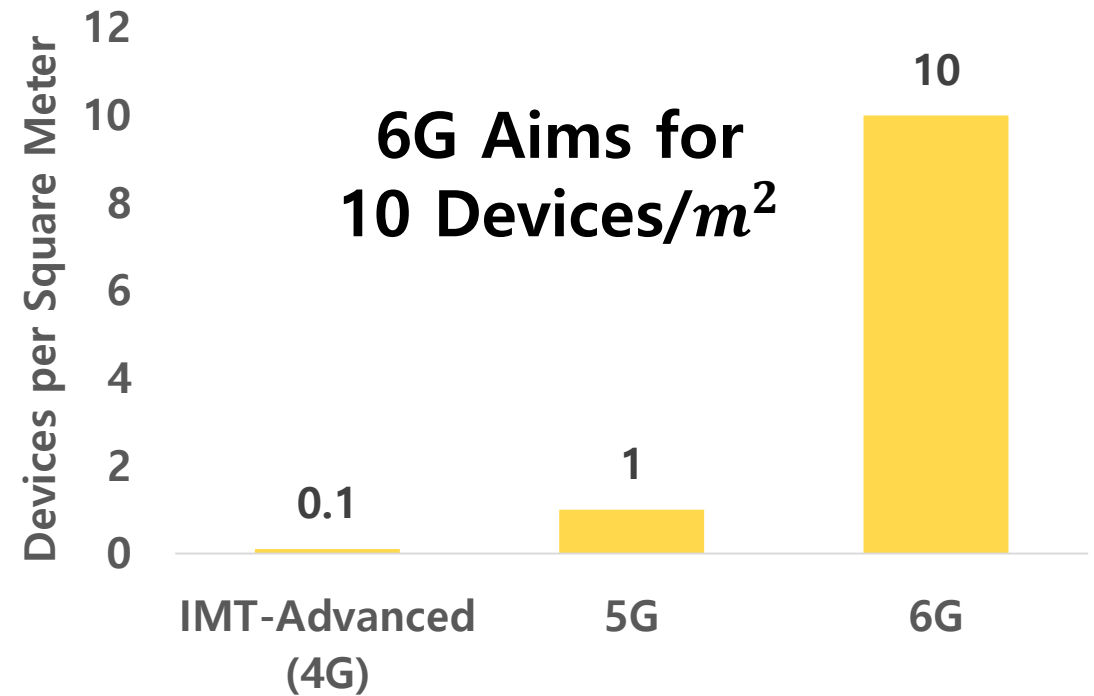
Vector Image from <https://videoplasty.com/>, Factory image is from Adobe Stock.

But are we ready for this future?

Annual Production of IoT devices

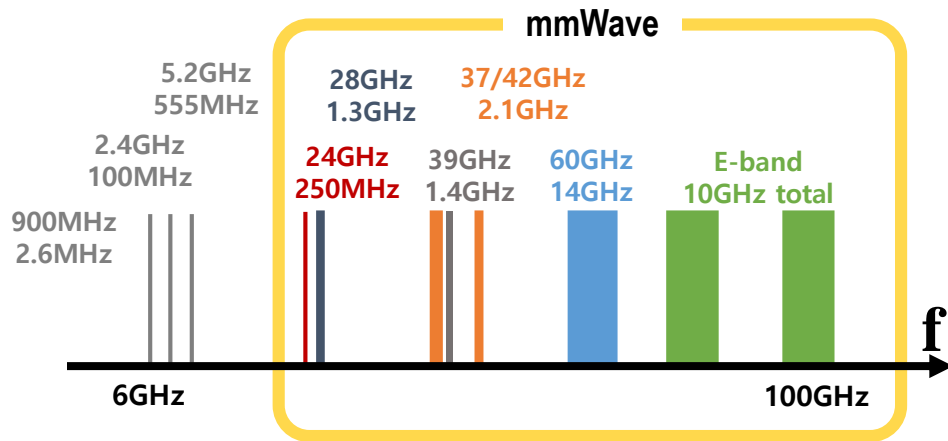


Source: SoftBank and ARM estimates



Source: Samsung 6G White Paper

mmWave Backscatter for Massive

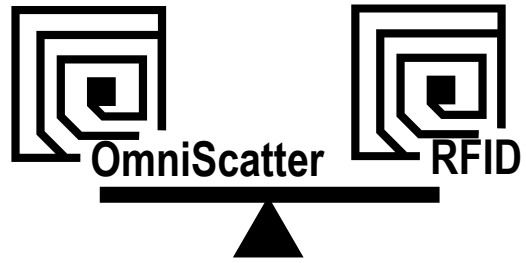


**Large Bandwidth of
mmWave**

**Low power consumption
backscatter**

= Massive Connectivity

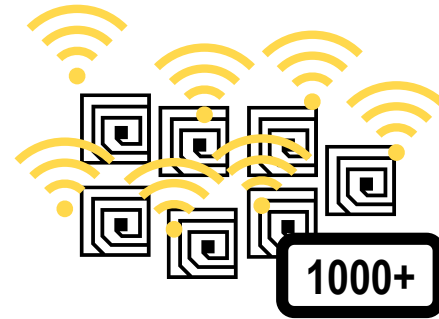
We present: **OmniScatter**



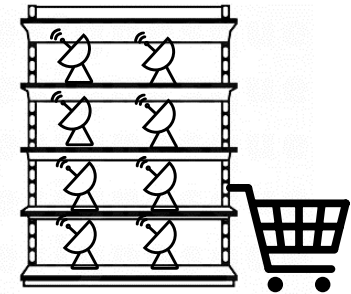
Comparable robustness
to 900MHz RFID



Communication range up to 50m
Without beamforming

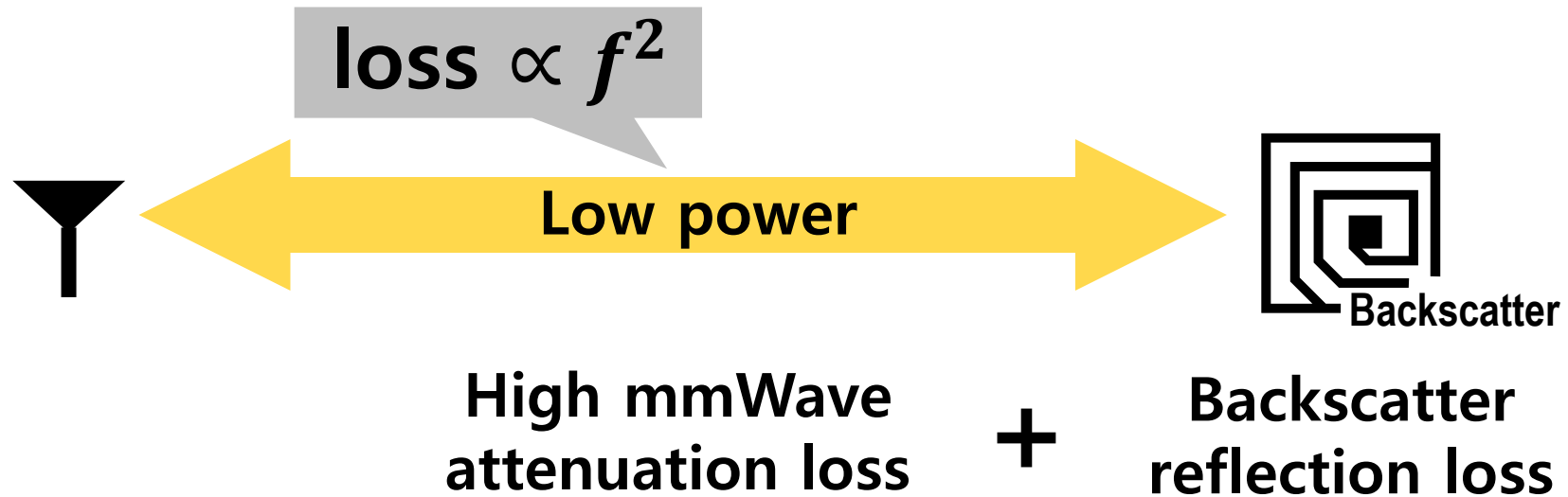


1000+ concurrent comm.
at practical settings

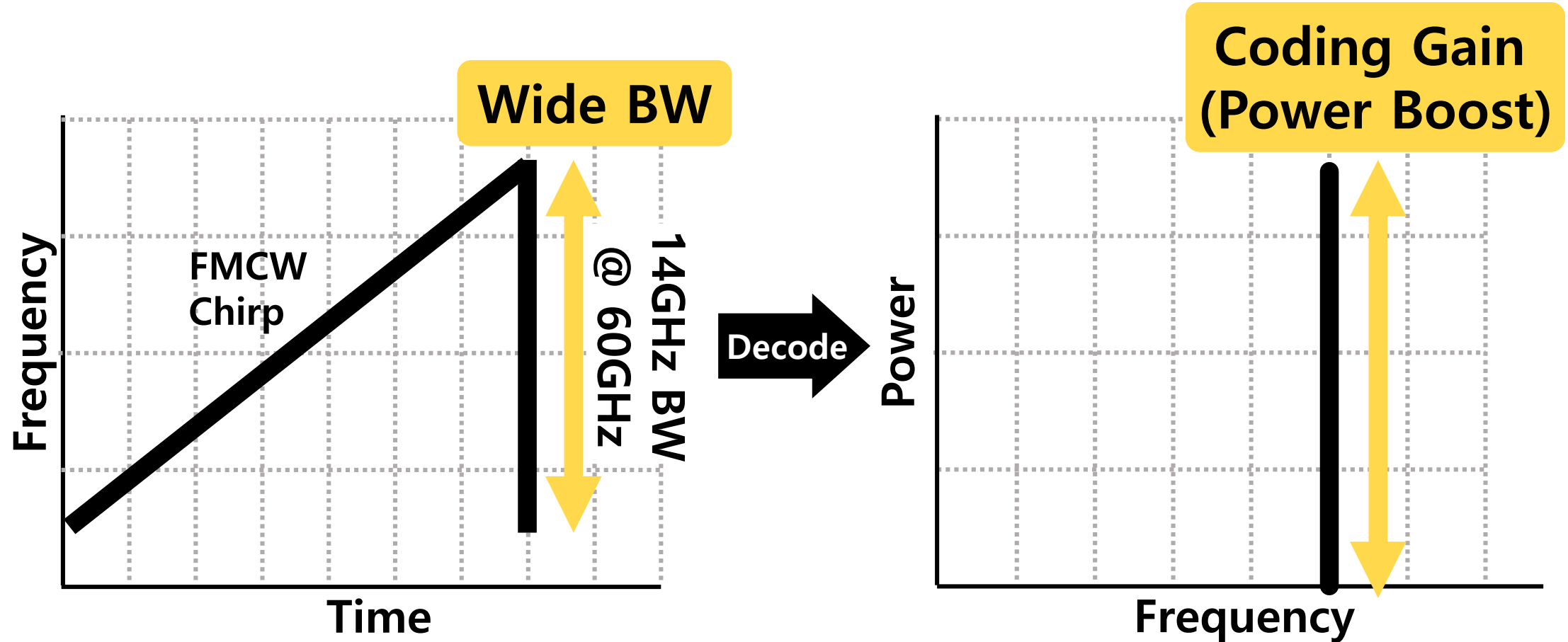


Compatible with commodity radars
(24 and 60Ghz)

Challenge: High loss

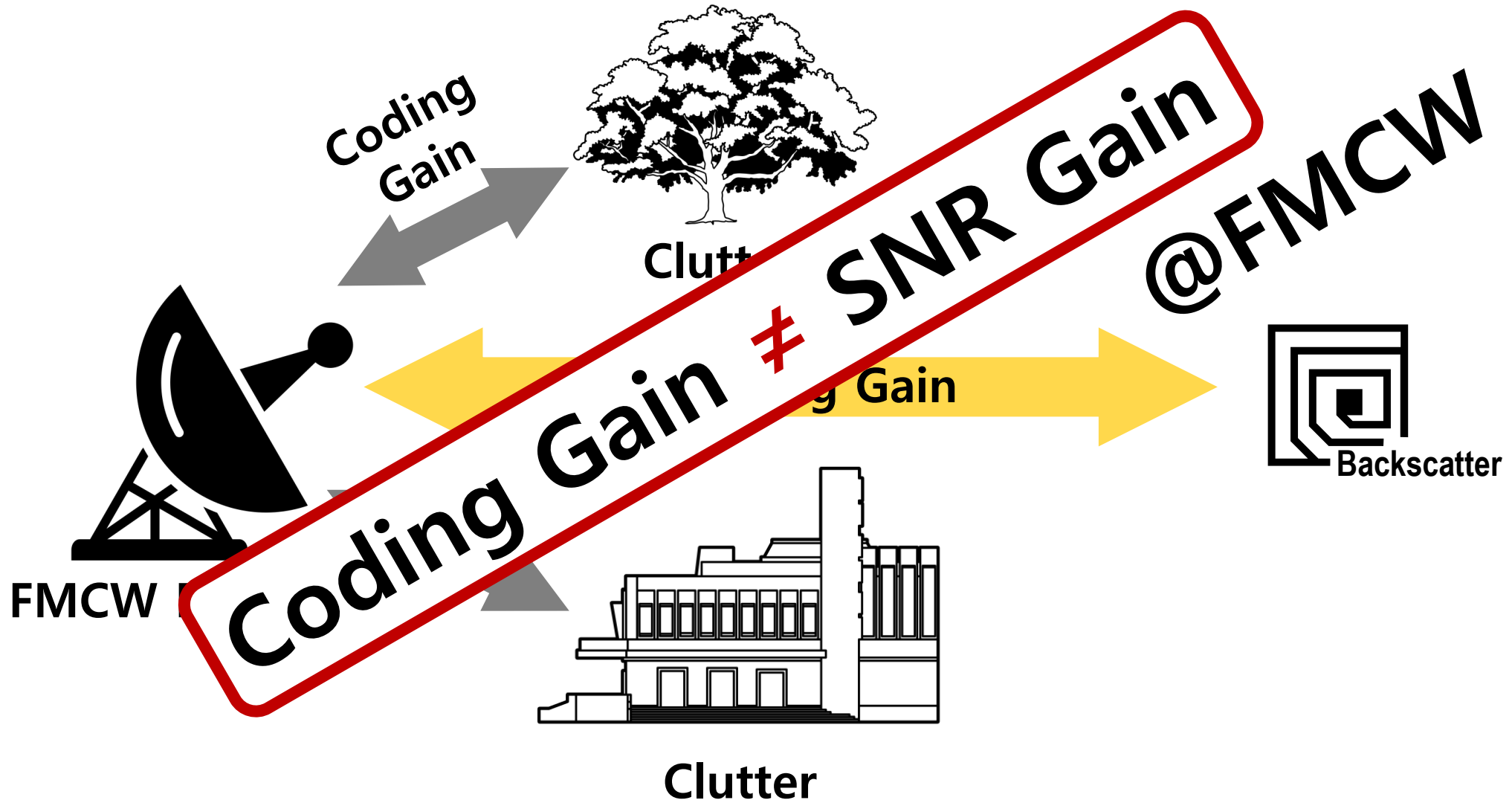


FMCW Radar has the **Potential**

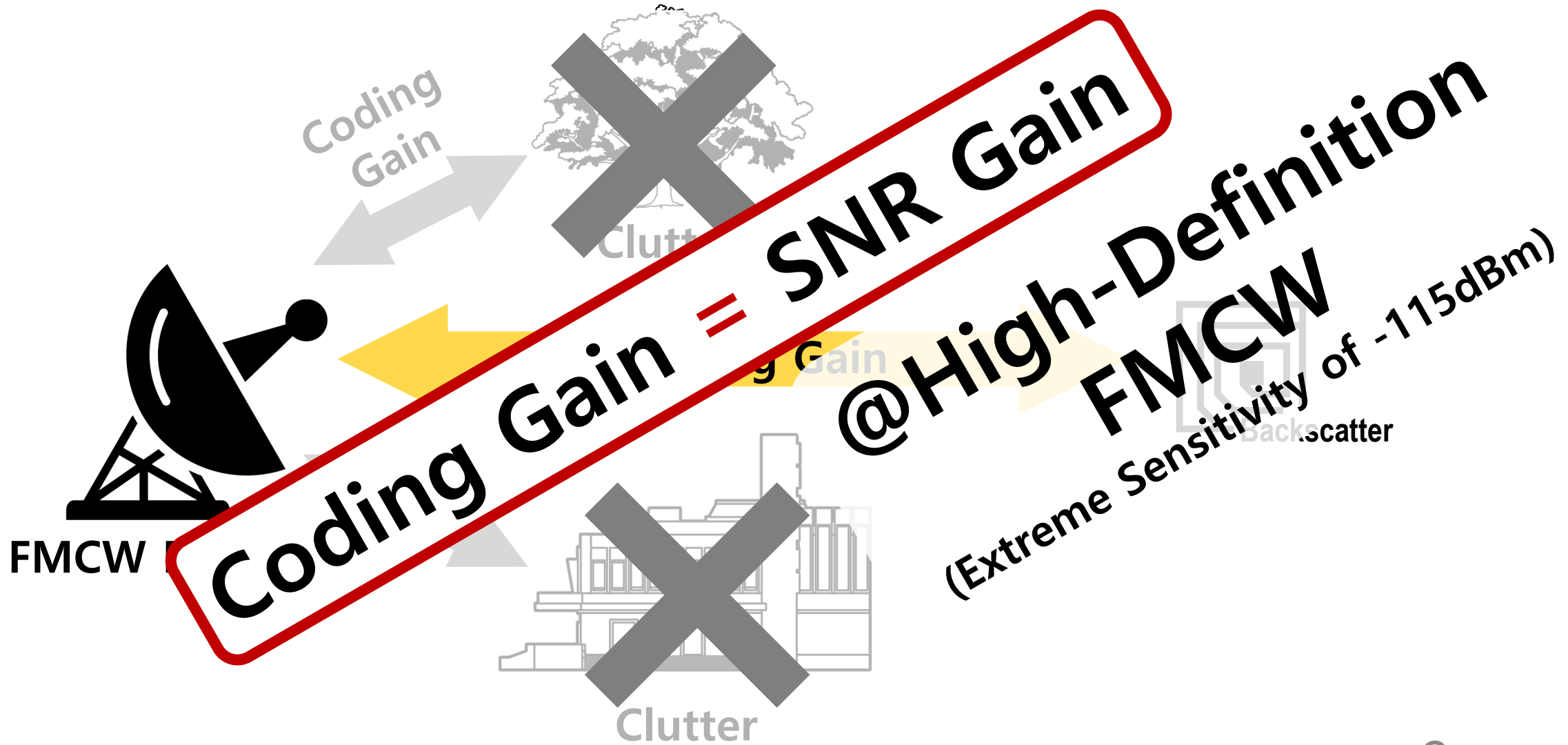


FMCW radar boosts power \propto bandwidth

FMCW Limitations

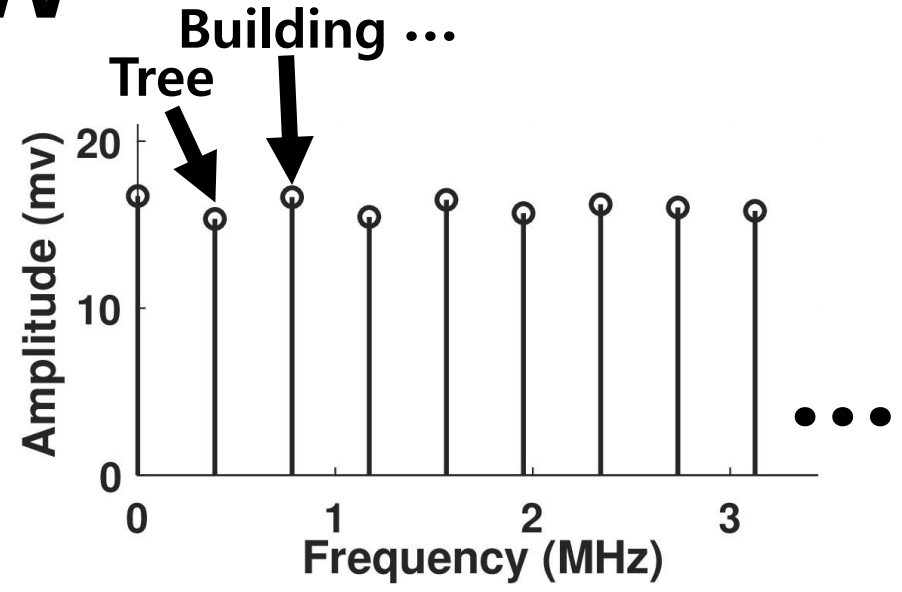
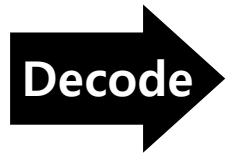
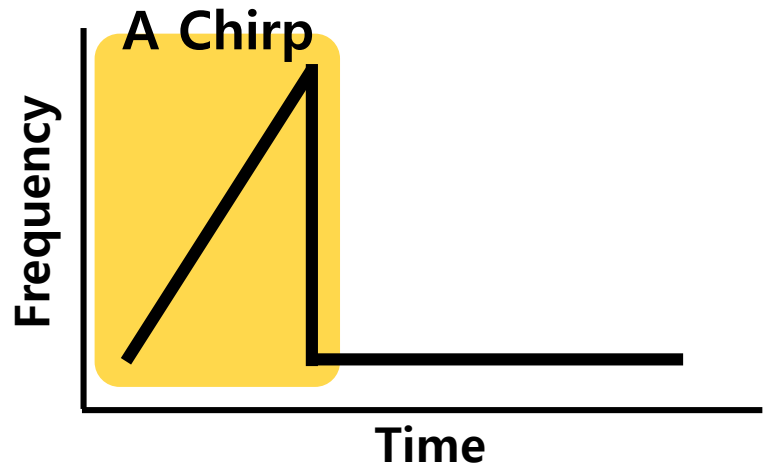


Our Contribution



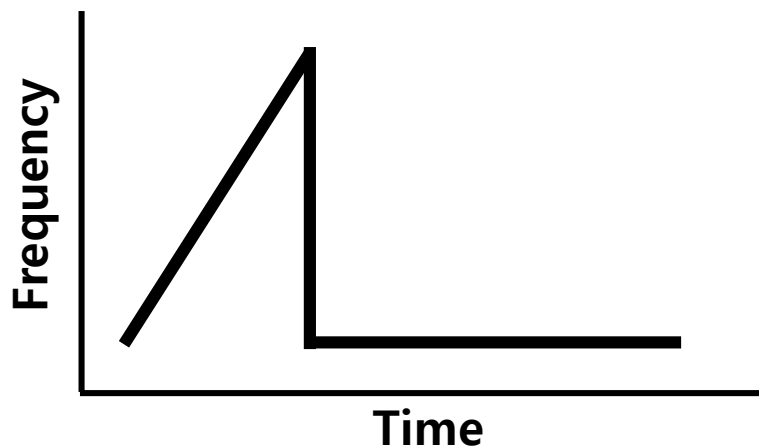
HD-FMCW vs. FMCW

FMCW

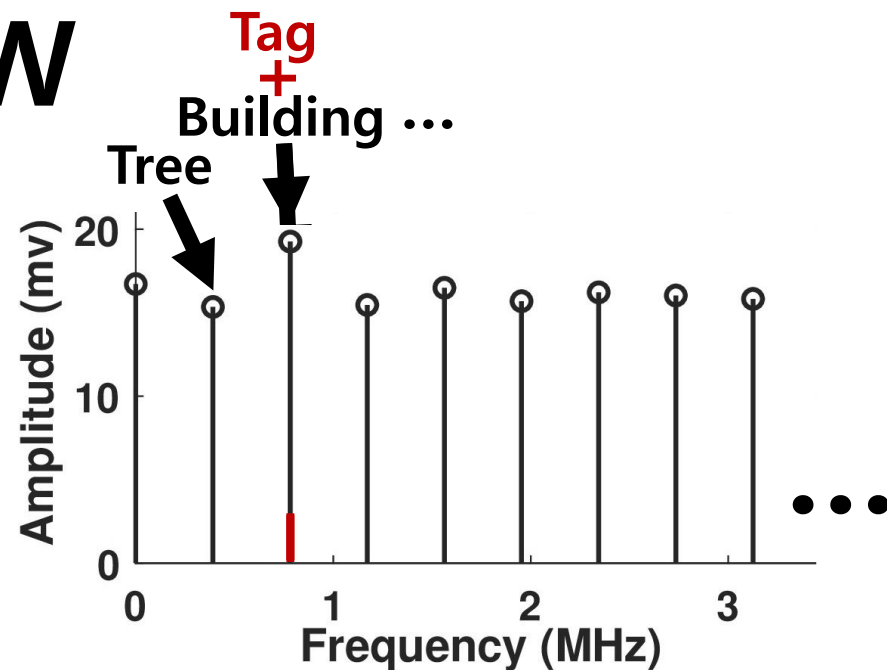


HD-FMCW vs. FMCW

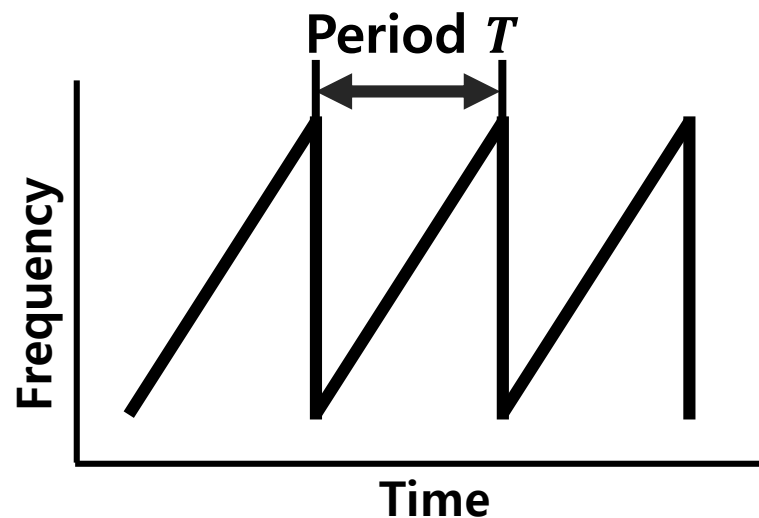
FMCW



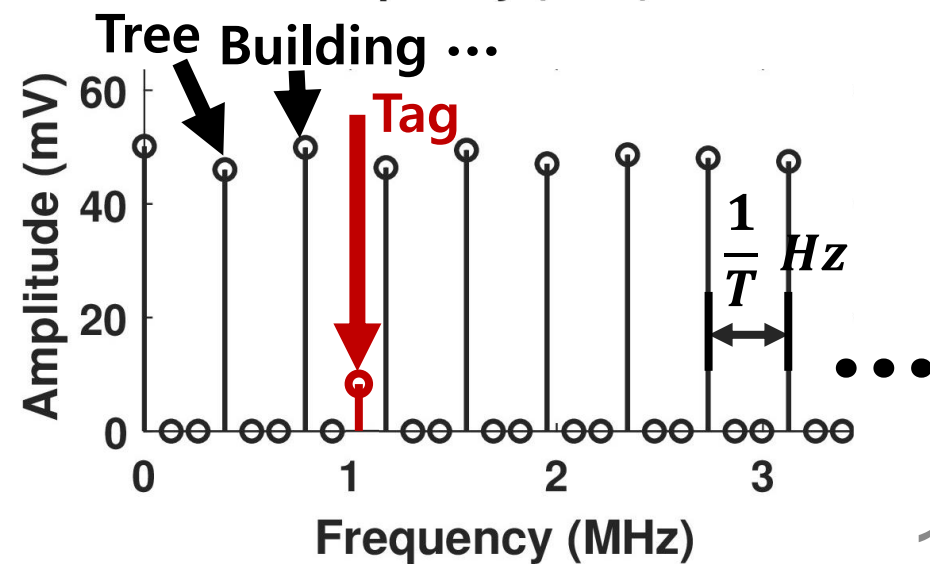
Decode



HD-FMCW

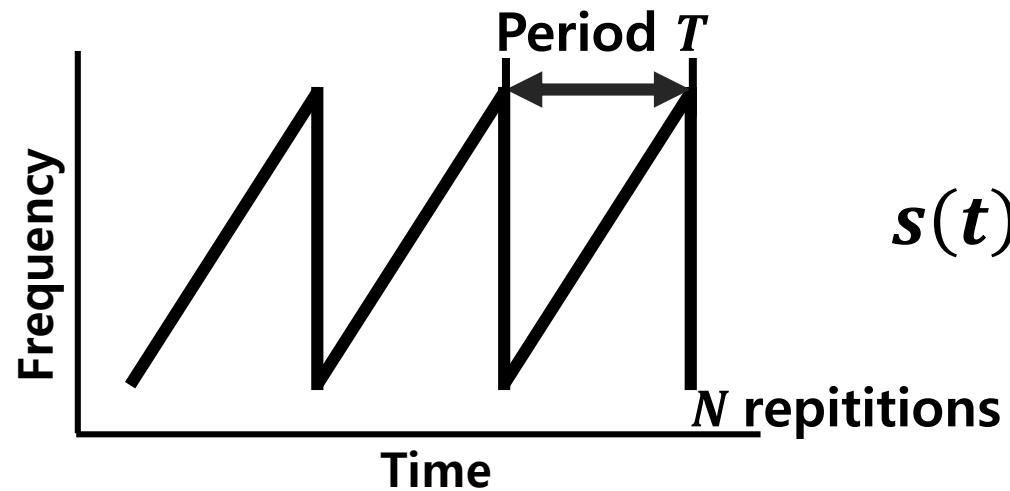


Decode



HD-FMCW vs. FMCW

HD-FMCW



$$s(t) = c(t) * \sum_{n=1}^N \delta(t - nT)$$

HD-FMCW vs. FMCW

HD-FMCW

$$s(t) = c(t) * \sum_{n=1}^N \delta(t - nT)$$

Clutter Noise

$$s(t - \Delta t)$$

Period T

Peaks on
multiples of $\frac{1}{T} Hz$

Tag Signal

HD-FMCW vs. FMCW

HD-FMCW

$$s(t) = c(t) * \sum_{n=1}^N \delta(t - nT)$$

Clutter Noise

$$s(t - \Delta t)$$

Period T

Tag Signal

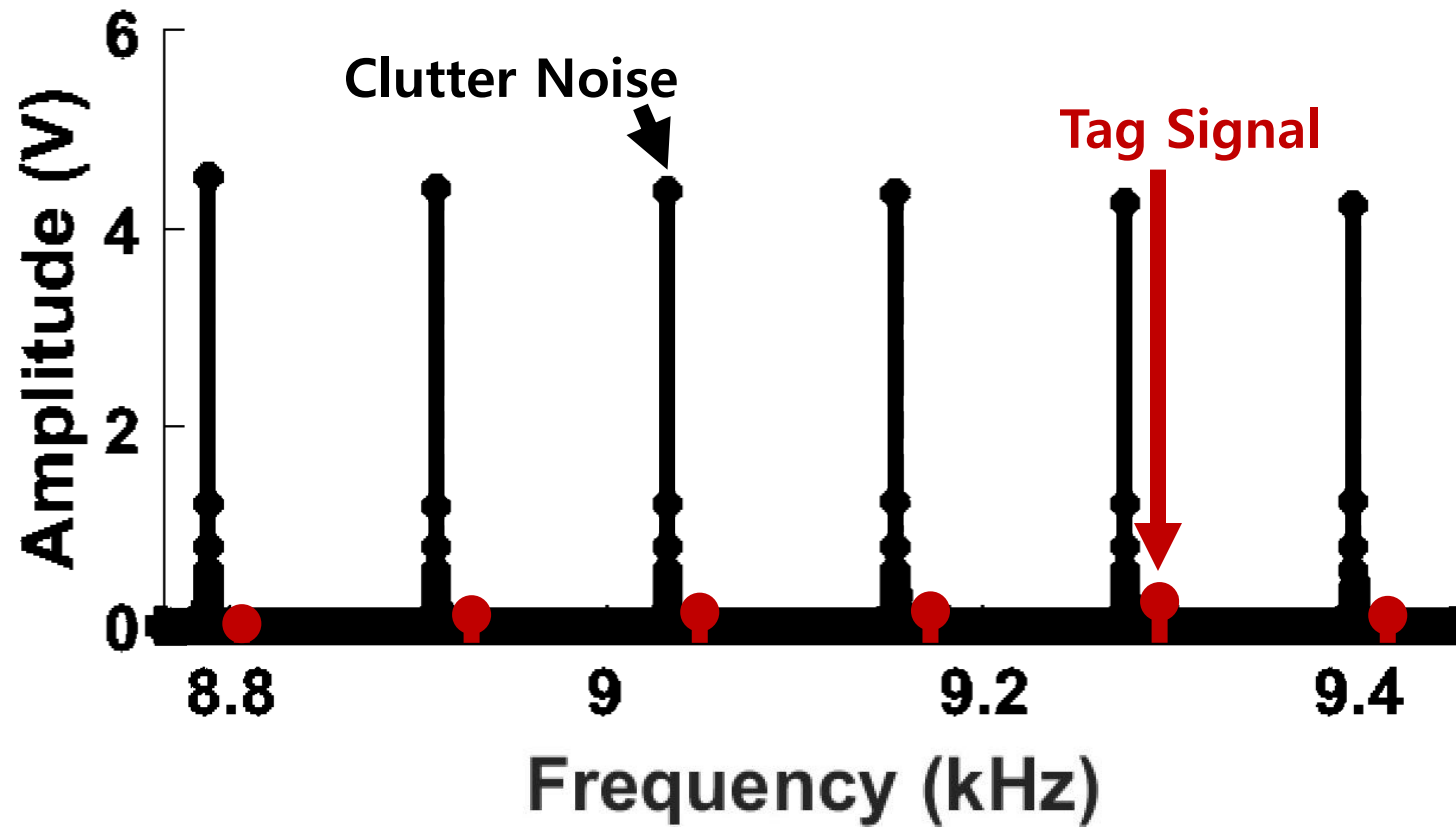
$$s(t - \Delta t) \cdot e^{j2\pi f_{tag} t}$$

Period T

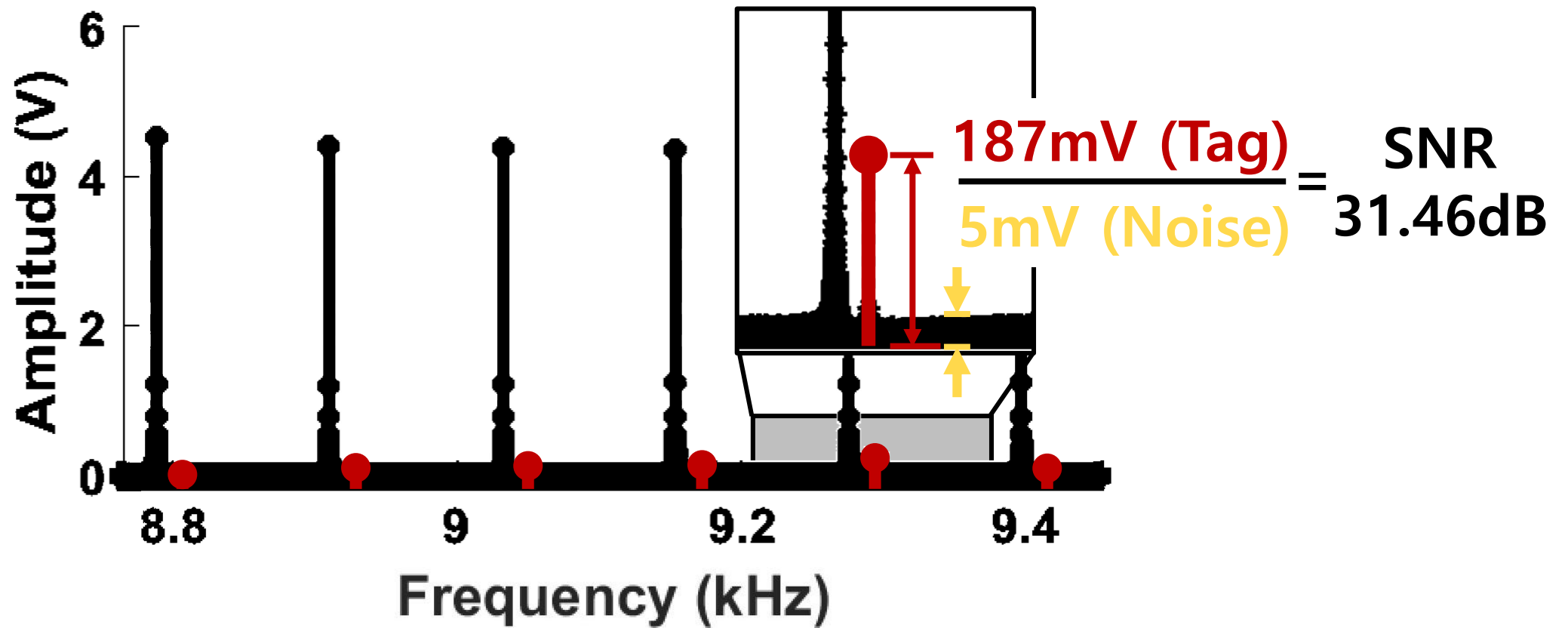
Period $\frac{1}{f_{tag}}$

No longer period T

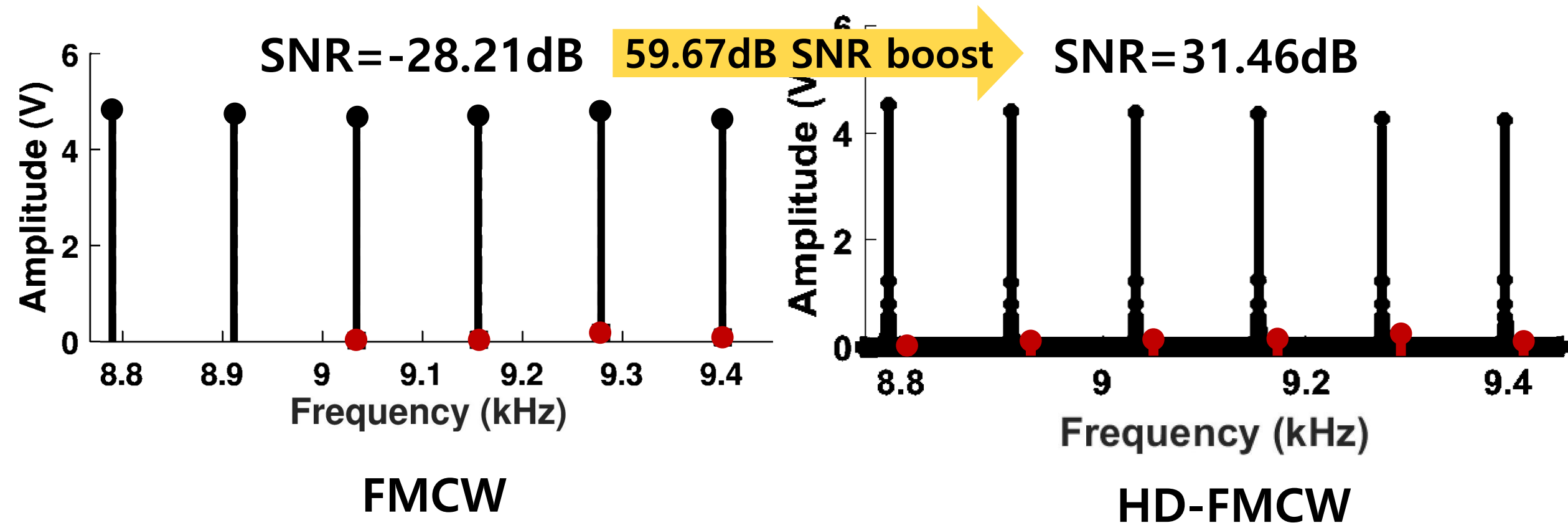
HD-FMCW vs. FMCW



HD-FMCW vs. FMCW



HD-FMCW vs. FMCW

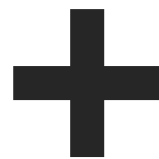


Are we there yet?

Our Goal
Massive Connectivity

**High Definition-
FMCW**

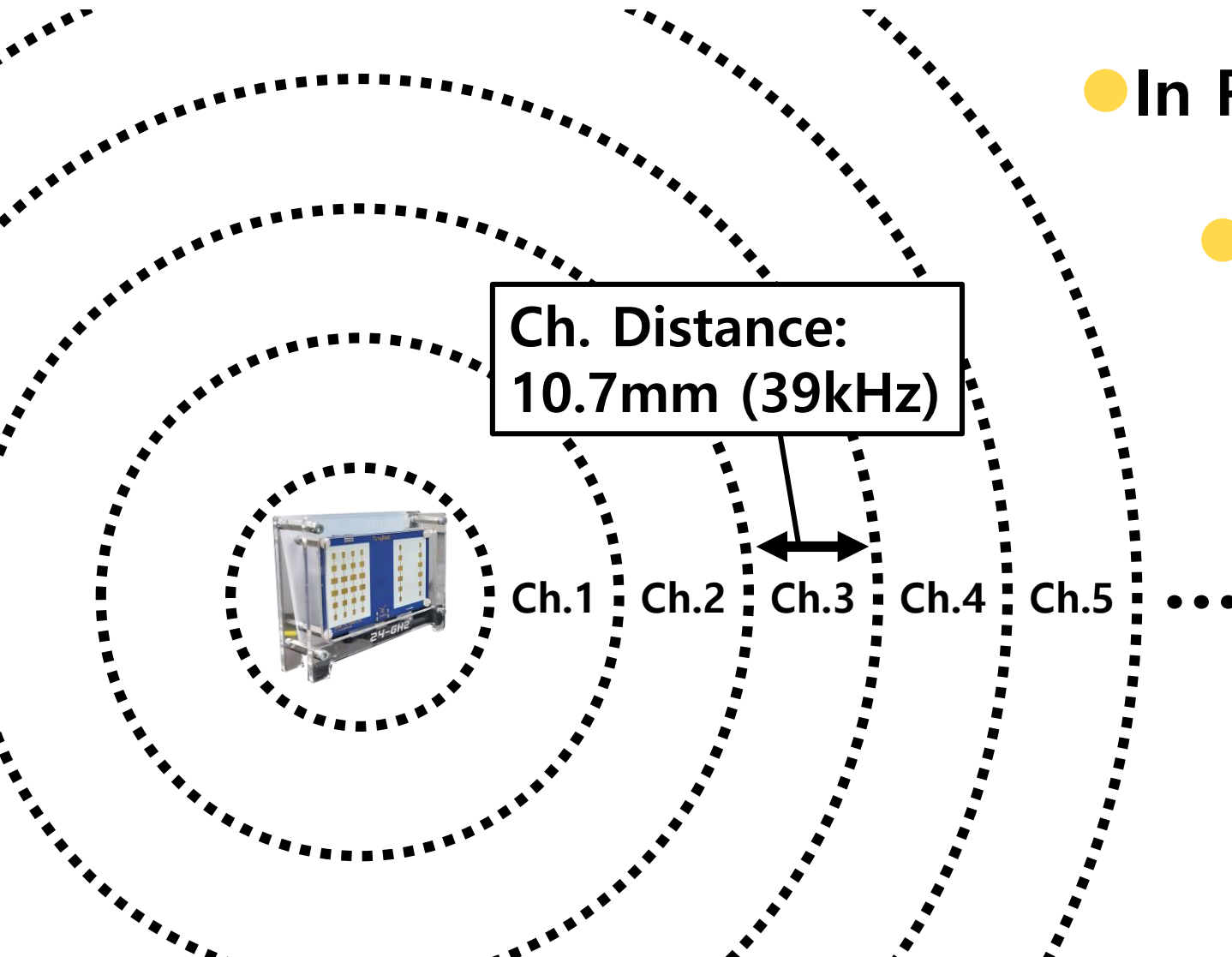
-115dBm Sensitivity



**Coordination-free
FDMA**

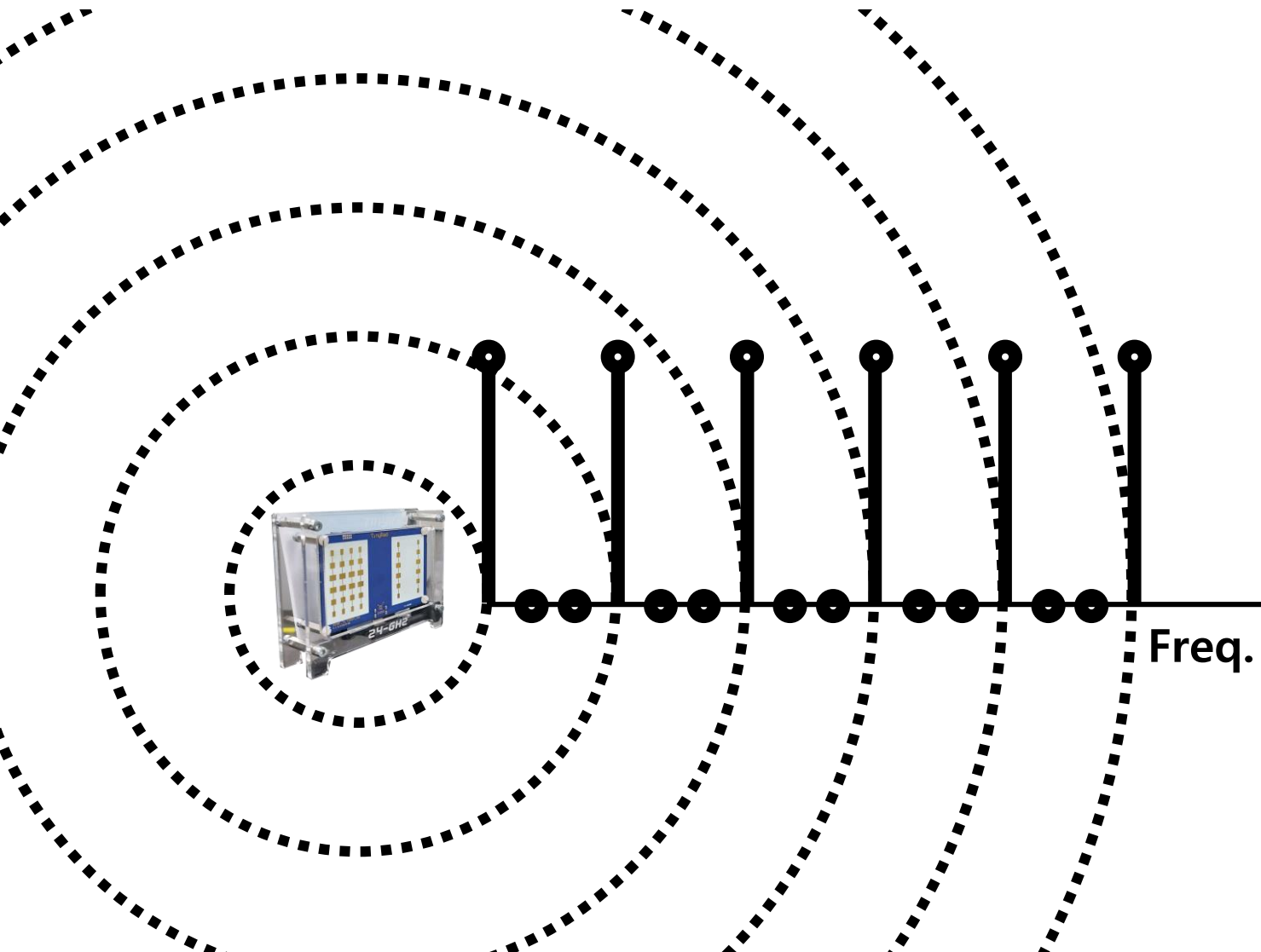
Scale to 1000+ tags

Coordination-free FDMA

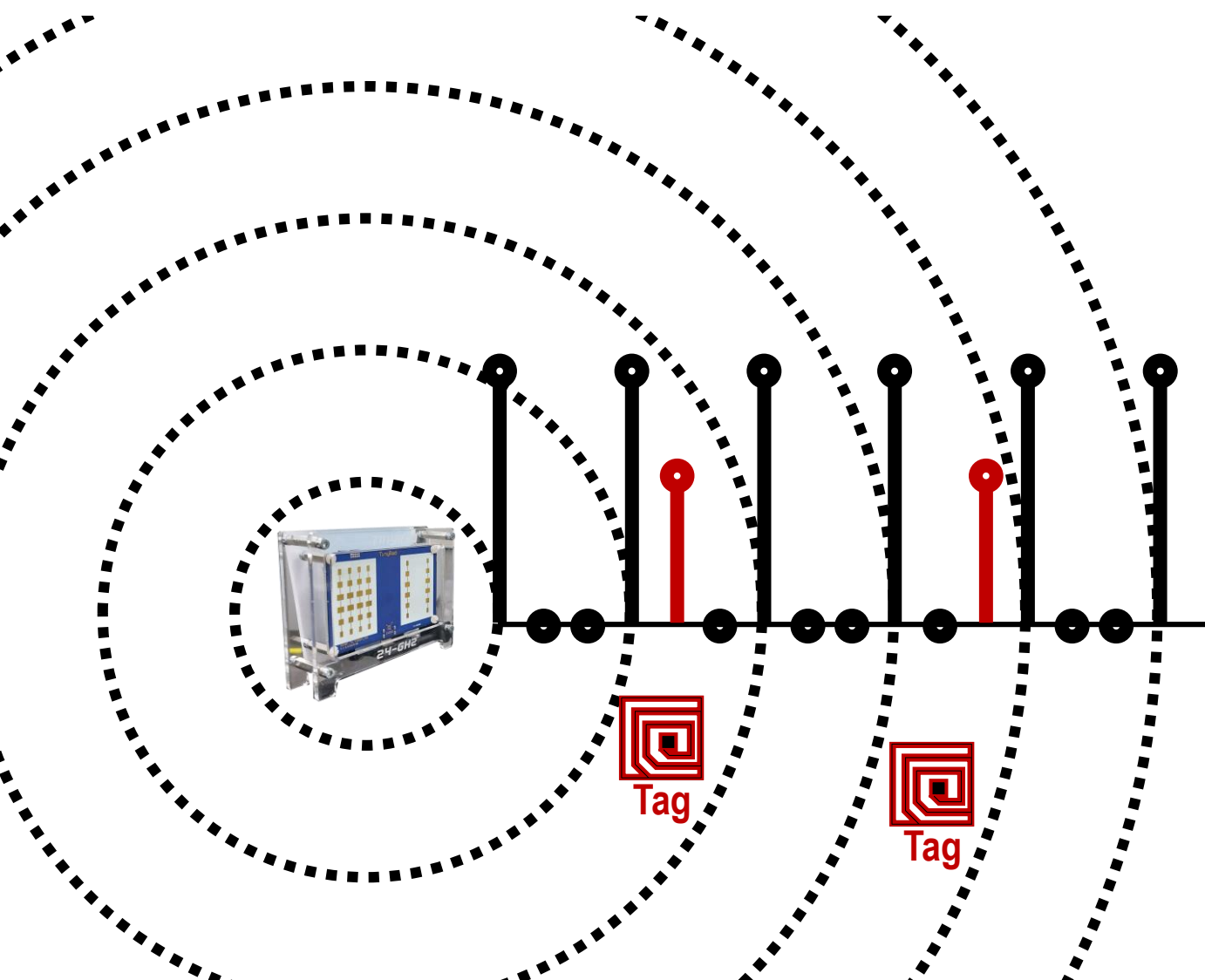


- In Radar: Distance ↔ Frequency
- Channel assignment by physical position
- Utilize wide BW with low power oscillator

Coordination-free FDMA

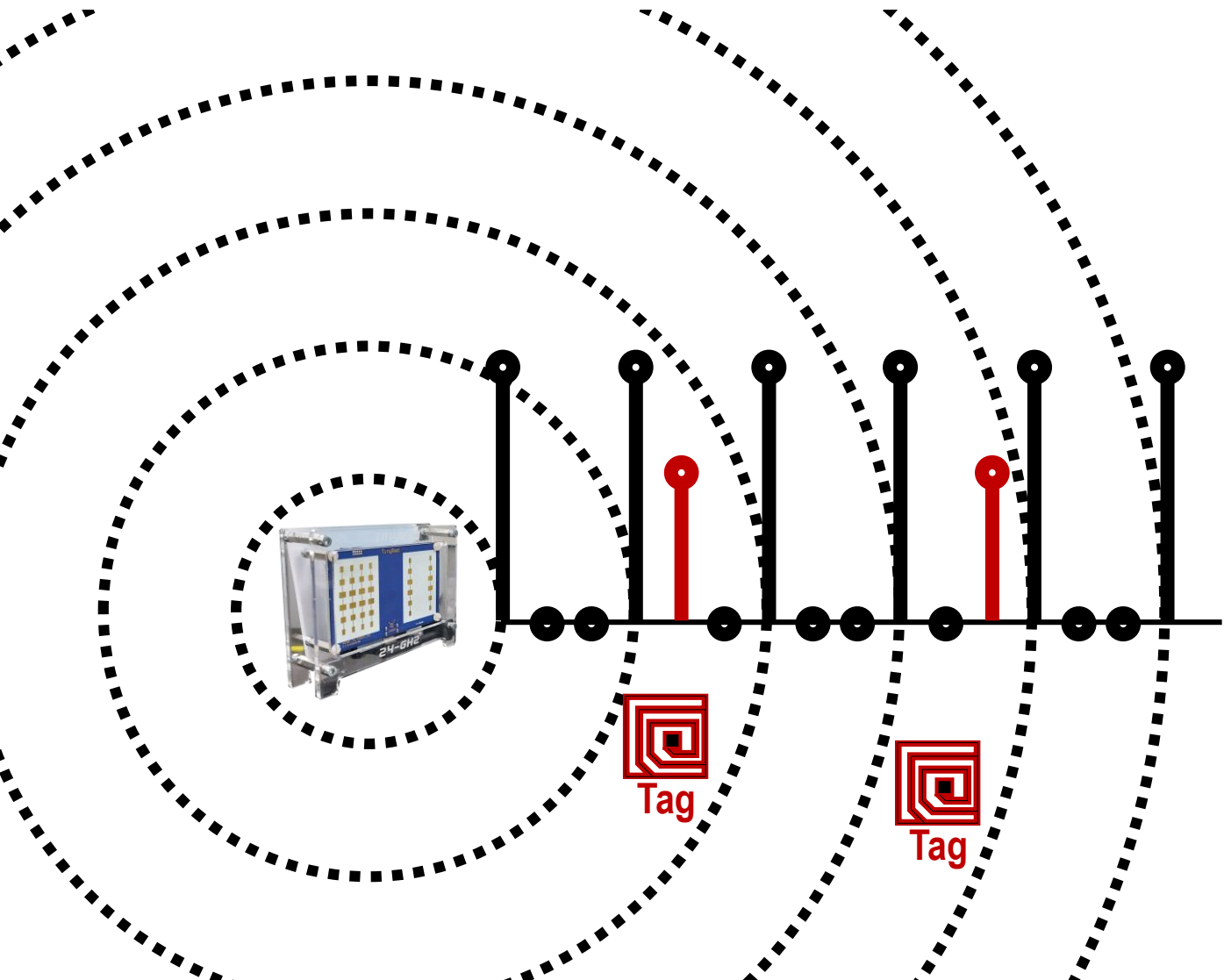


Coordination-free FDMA



Tags a different distance
↓
Assigned to different channel

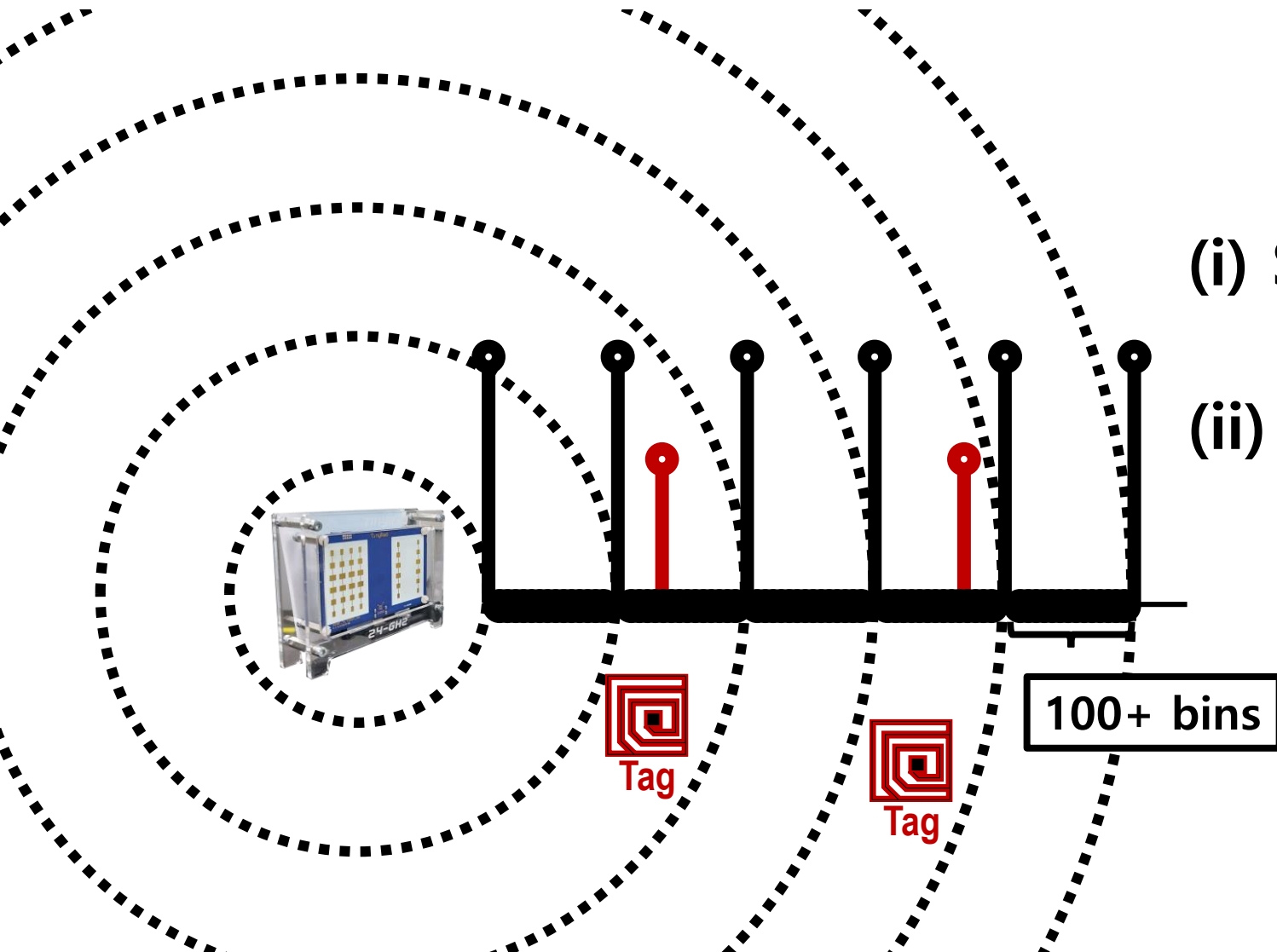
Coordination-free FDMA



Collision? - Unlikely!

**(i) Short channel distance
(10.7mm)**

Coordination-free FDMA

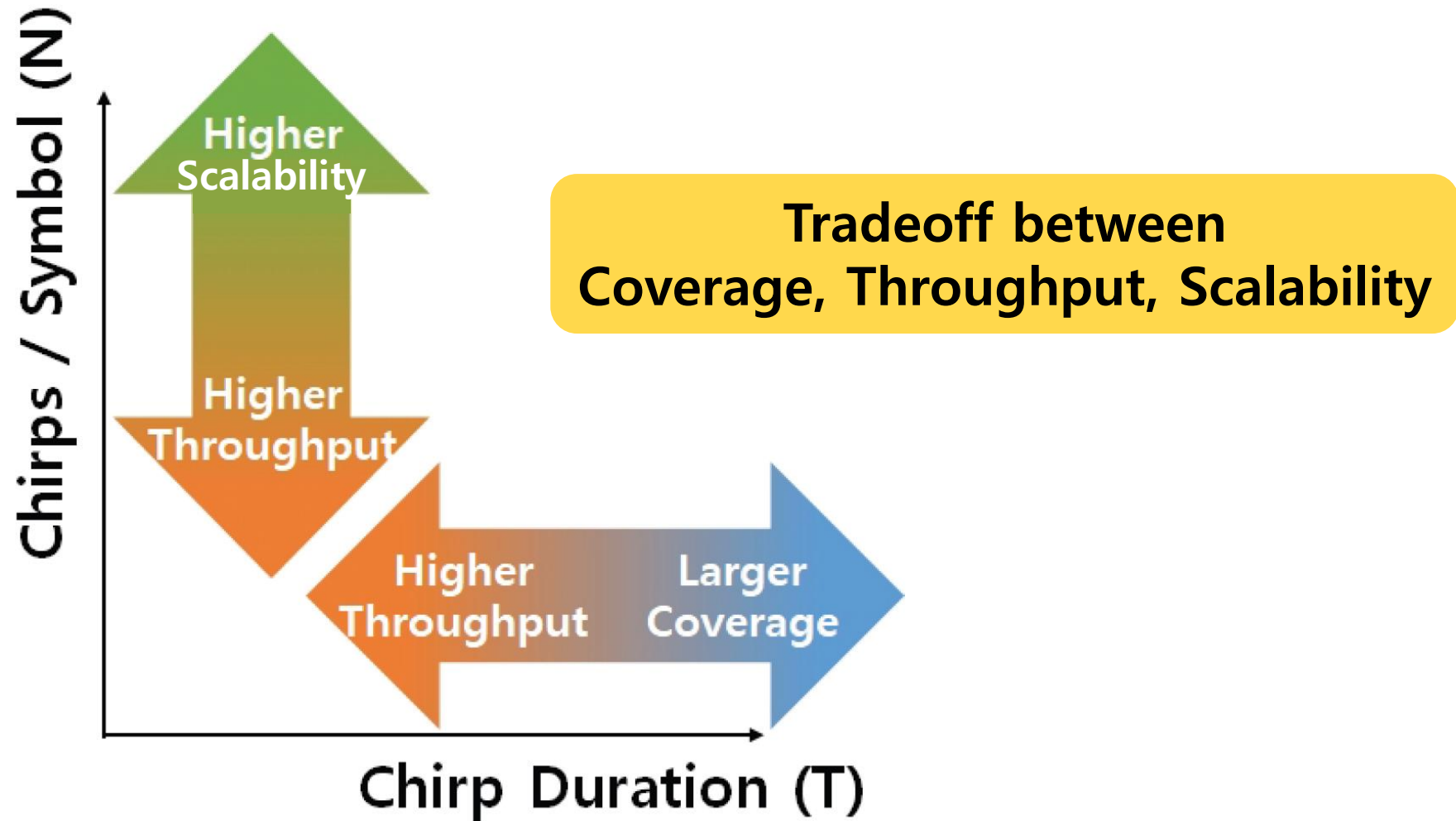


Collision? - Unlikely!

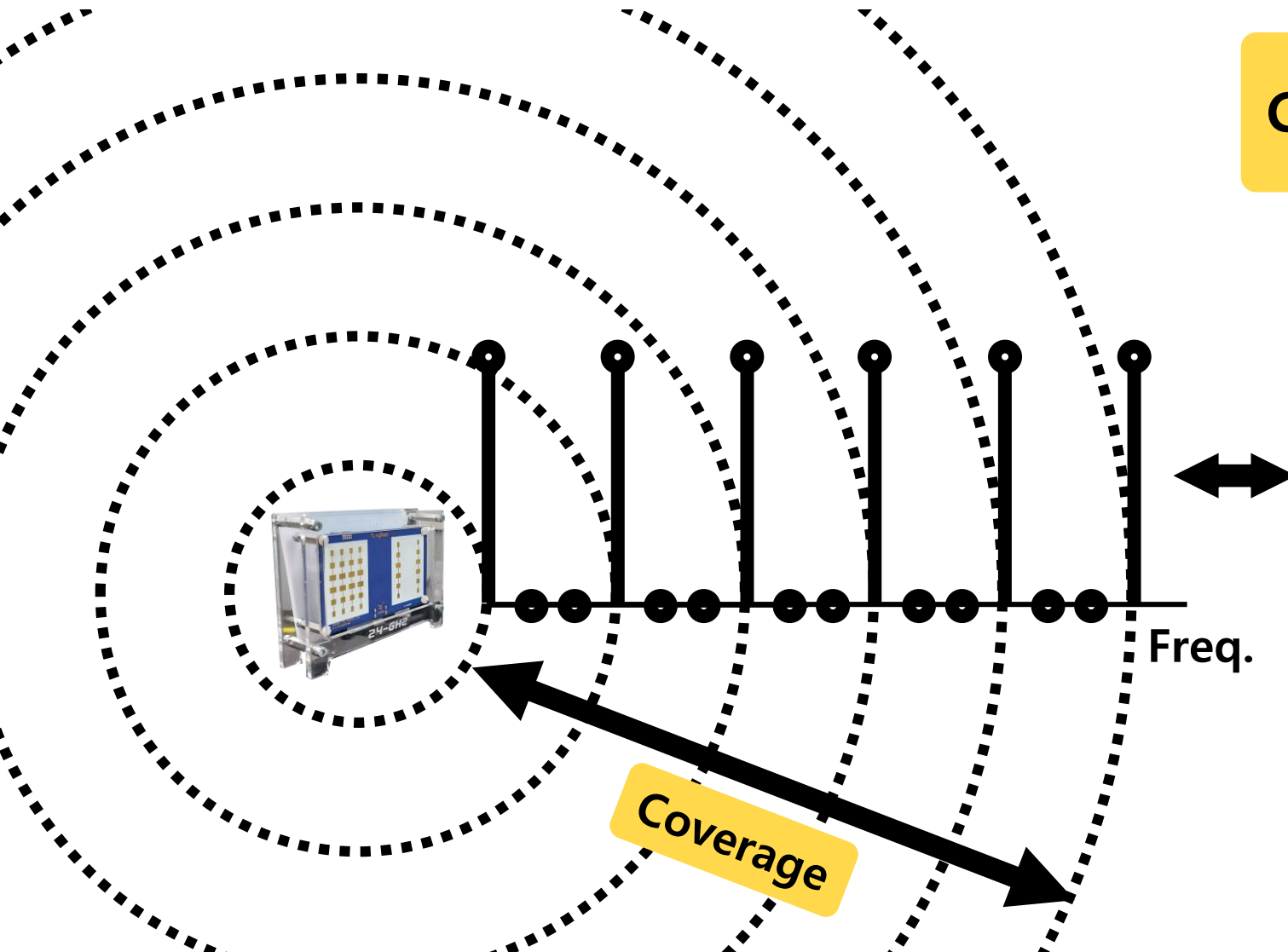
**(i) Short channel distance
(10.7mm)**

(ii) 100+ bins in each channel

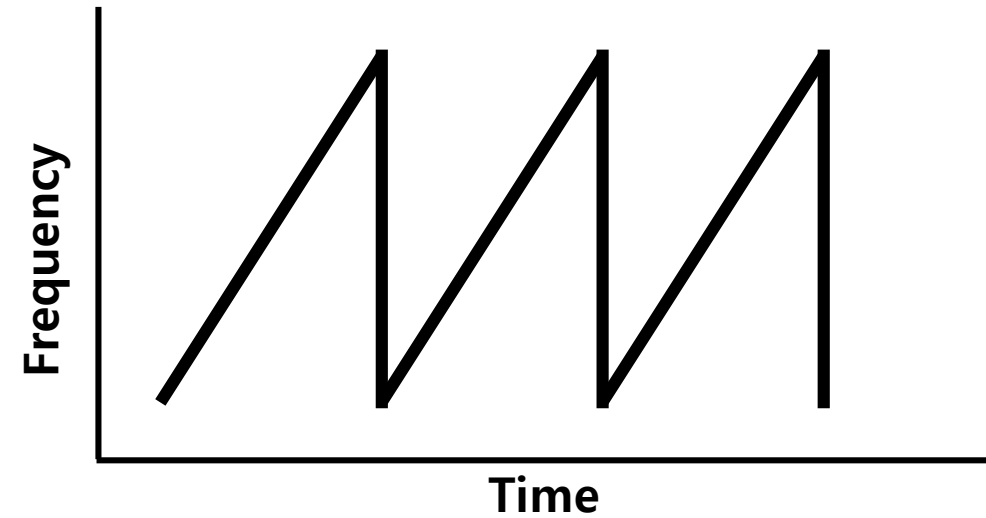
OmniScatter Network Configuration



OmniScatter Network Configuration

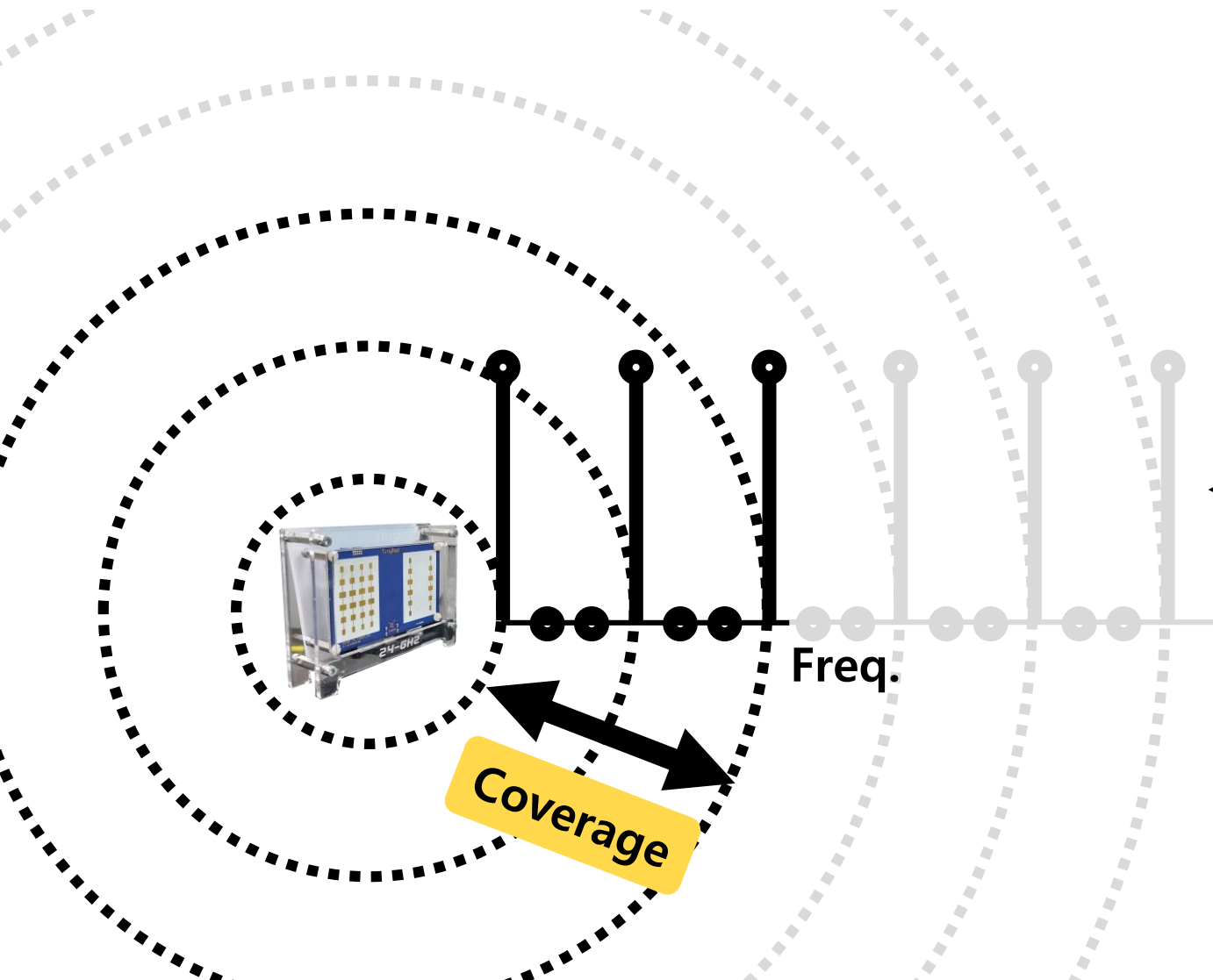


Chirp duration ↓ : Throughput ↑
Coverage ↓

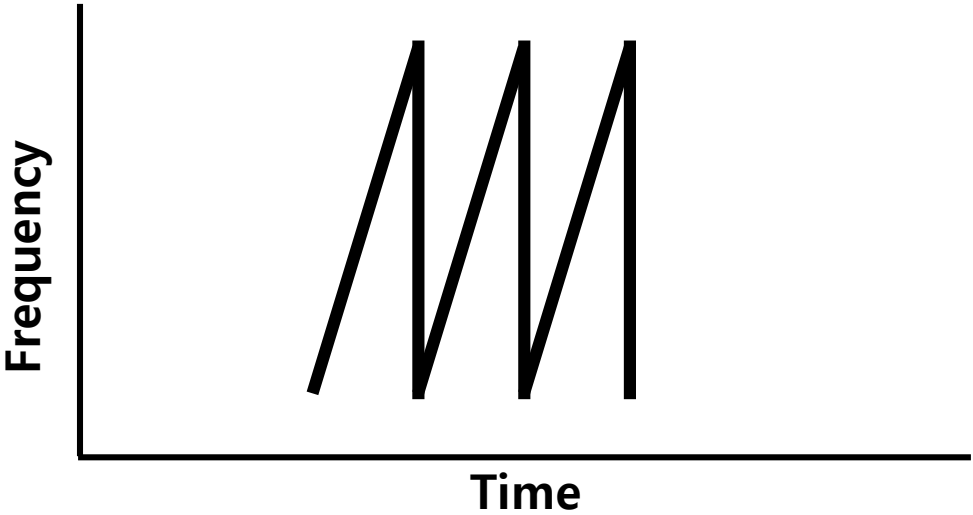
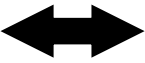


Coverage

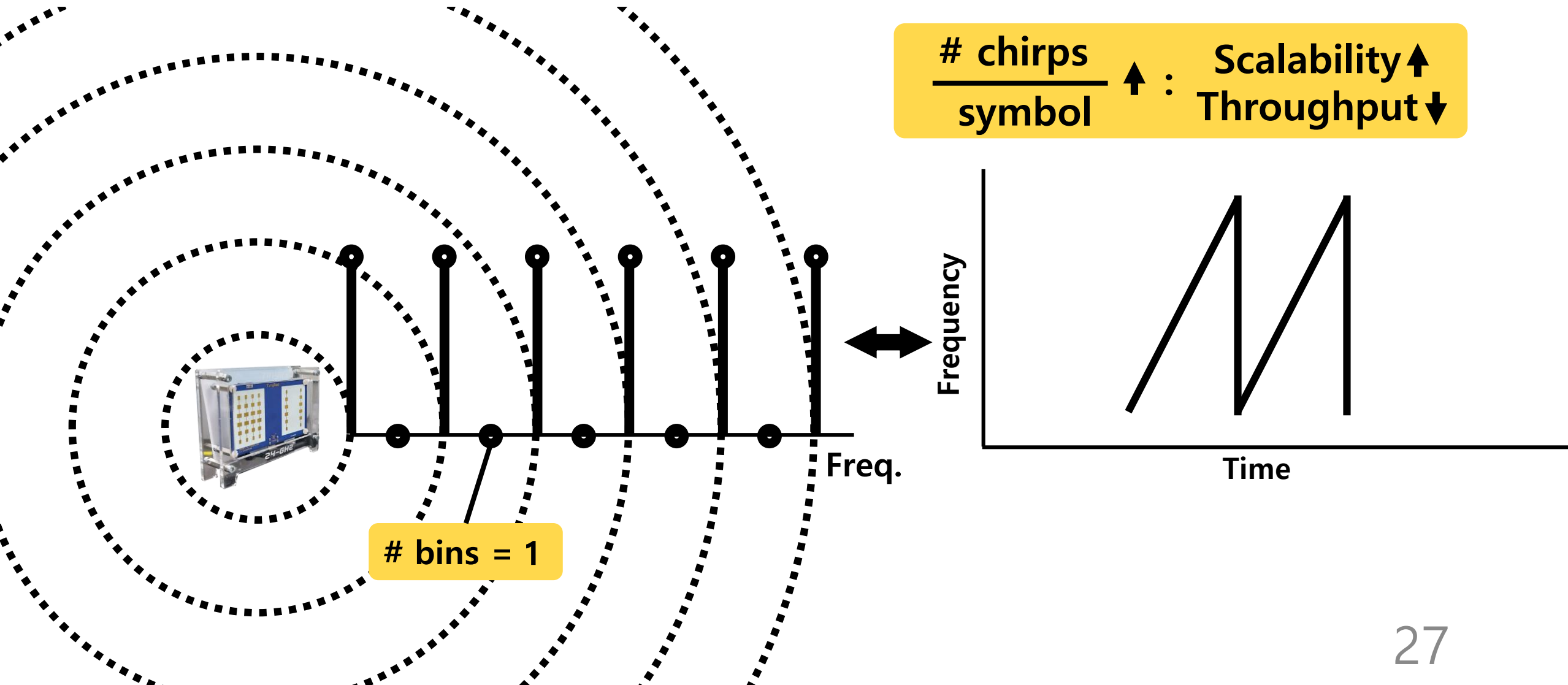
OmniScatter Network Configuration



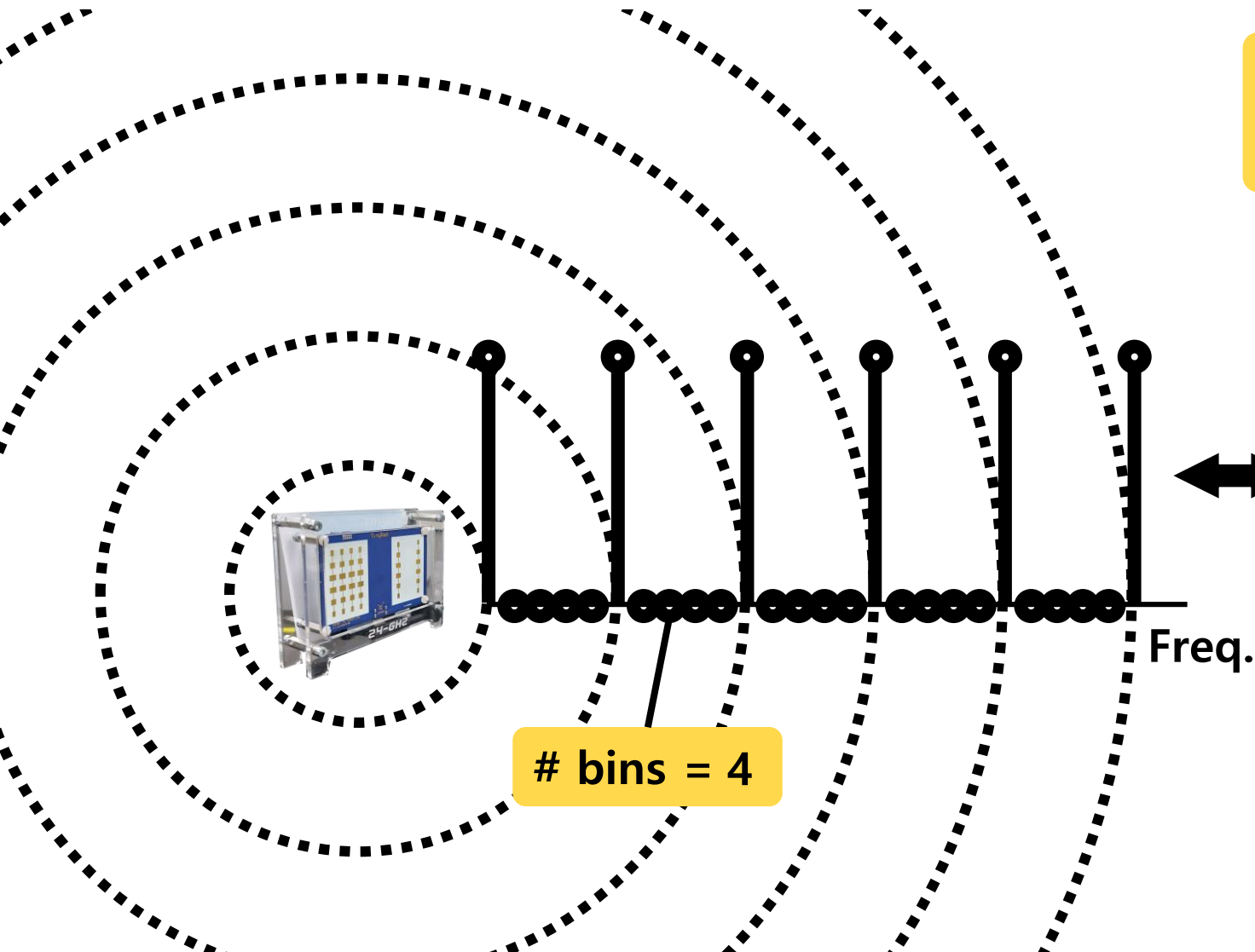
Chirp duration ↓ : Throughput ↑
Coverage ↓



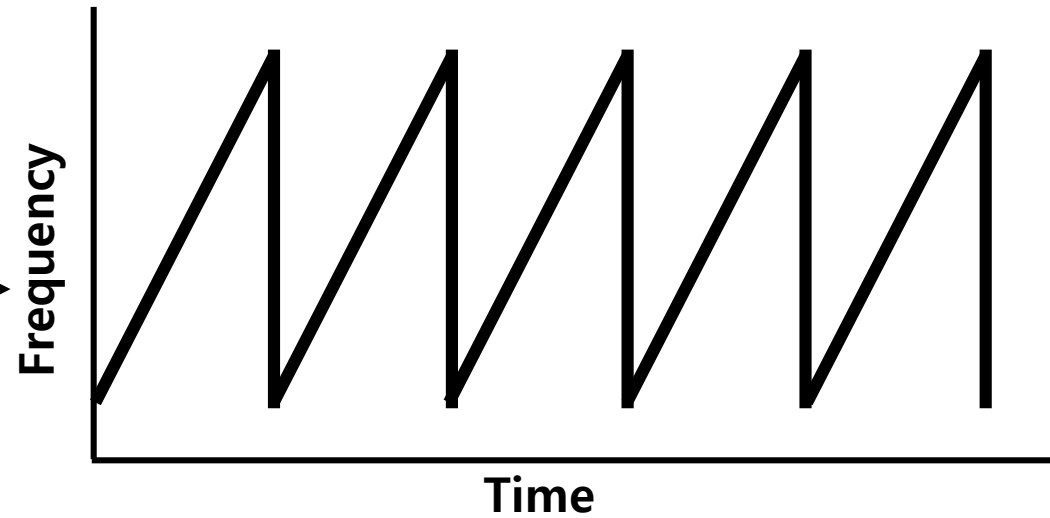
OmniScatter Network Configuration



OmniScatter Network Configuration



$\frac{\# \text{ chirps}}{\text{symbol}} \uparrow : \text{Scalability} \uparrow$
 $\text{Throughput} \downarrow$

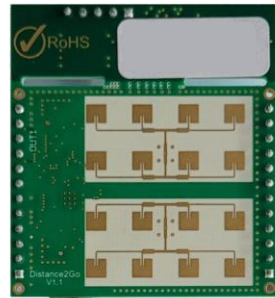


Omniscatter Implementation

Commodity Radar (24 GHz)

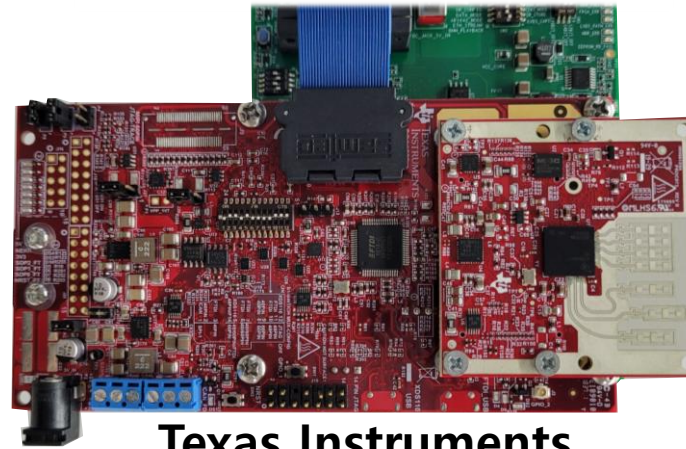


Analog Devices
EVAL-Tinyrad



Infineon
Distance2Go

Commodity Radar (60 GHz)



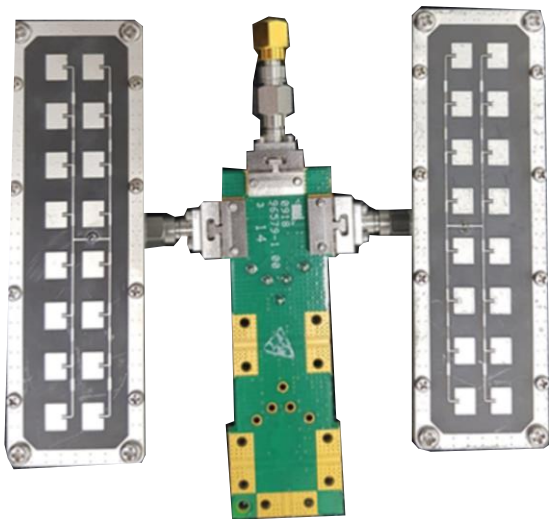
Texas Instruments
mmWaveICBoost

USRP Testbed



Omniscatter Implementation

**Custom Tag
(24 GHz)**



Retroreflective Tag



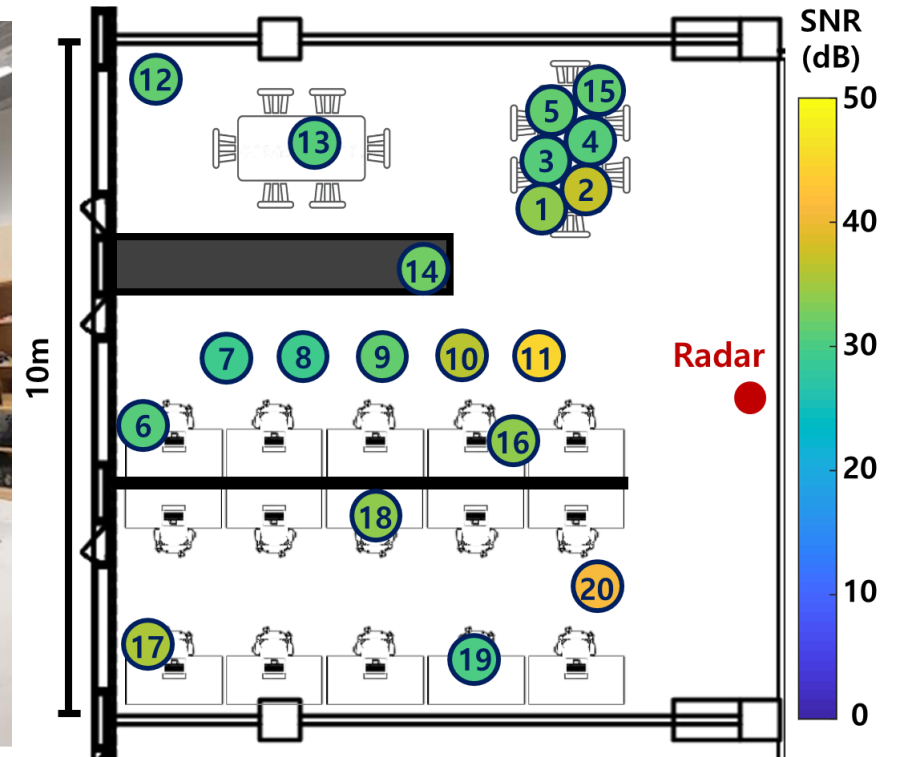
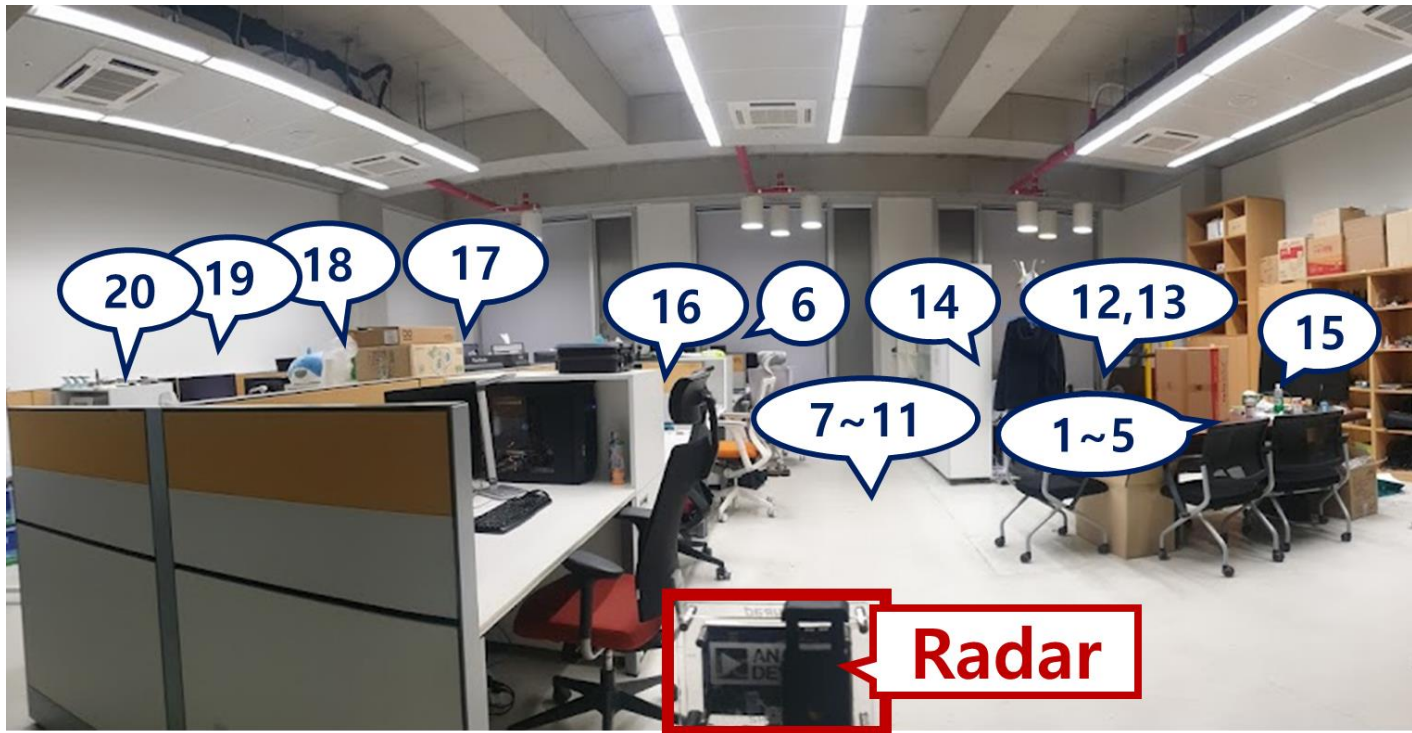
Prototype Tag

**Custom Tag
(60 GHz)**

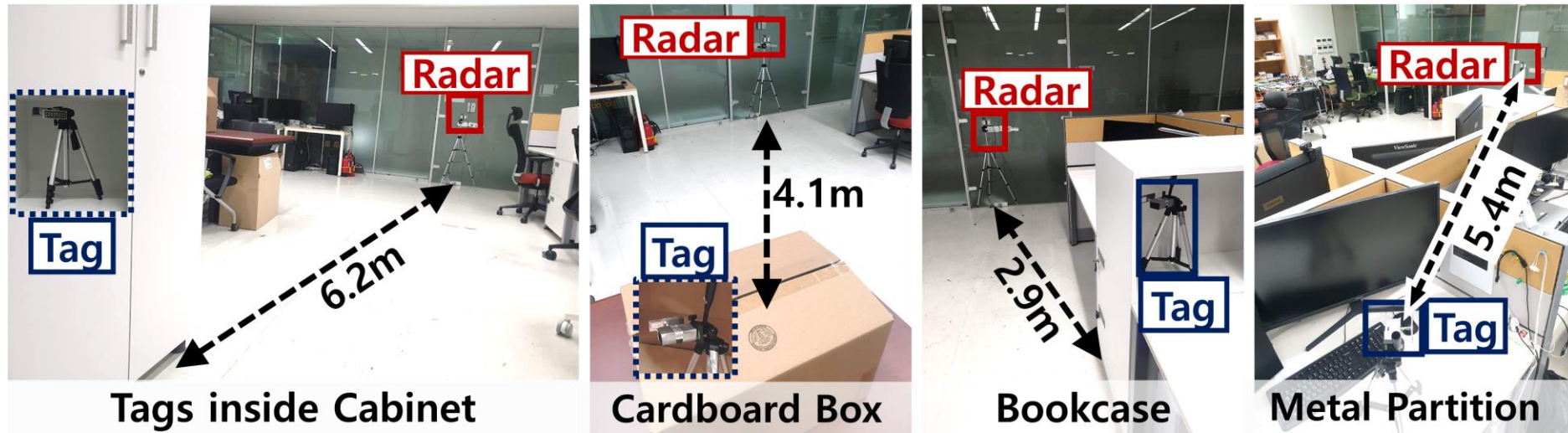


Waveguide Tag

Evaluation: Practical Office Deployment



Evaluation: Practical Office Deployment



SNR: 28.8 dB

31.8 dB

30.9 dB

28.1 dB

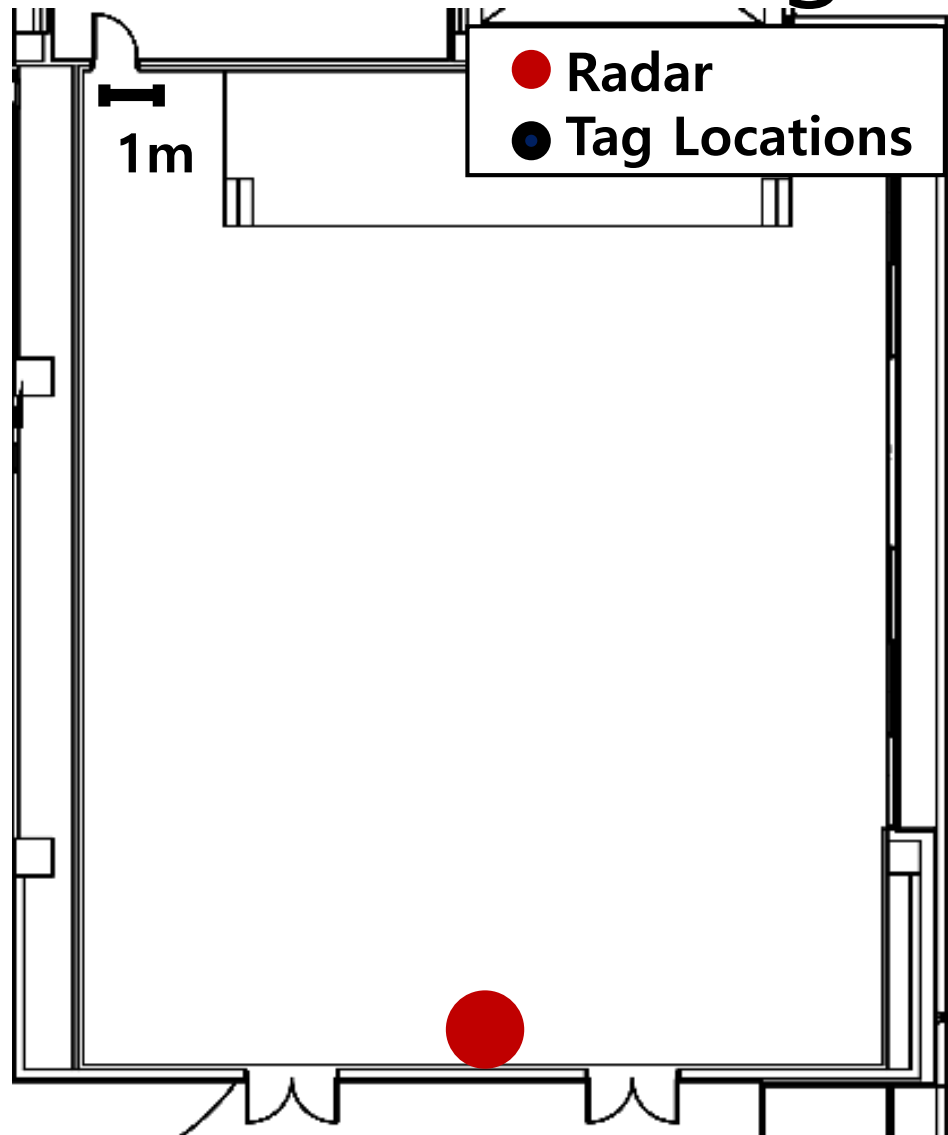
BER: $<1 \times 10^{-4}$

4×10^{-4}

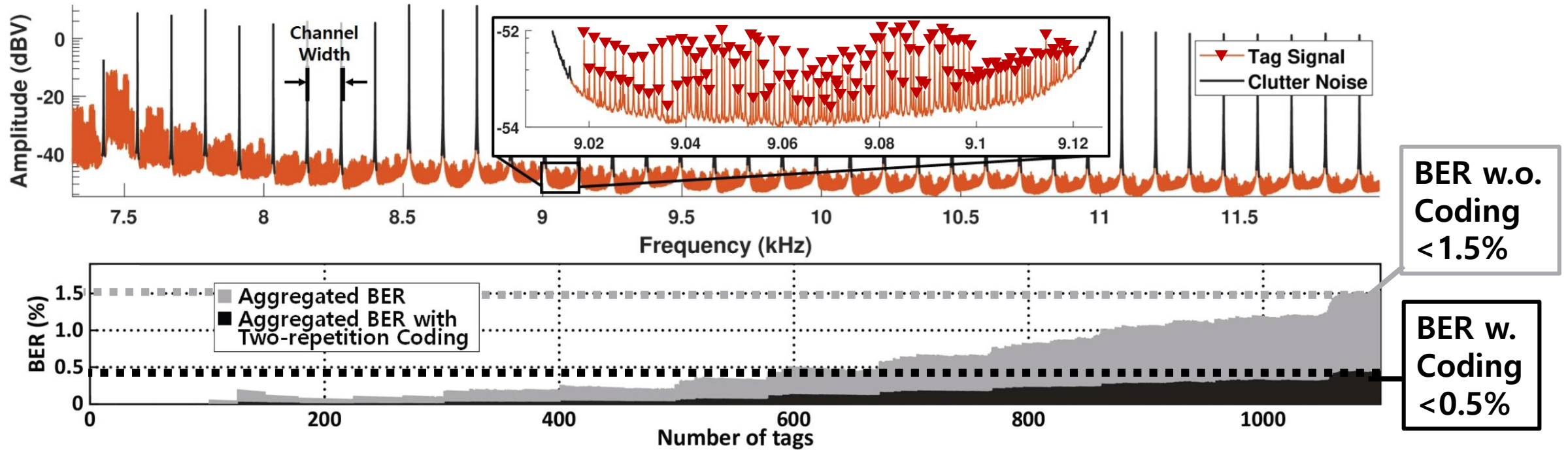
64×10^{-3}

57×10^{-3}

Evaluation: Large scale (1,100 tags)



Evaluation: Large scale (1,100 tags)



Conclusion

- We introduce **Omniscatter**, practical mmWave backscatter
- **Extreme sensitivity of -115 dBm**
 - Works in practical, complex environments
 - No beamforming/alignment
- **Scales to thousands** of concurrency
 - 1100 tags @BER ~1.5% (trace driven)

 **Thank you!**