



# *Deaf-Aid:*

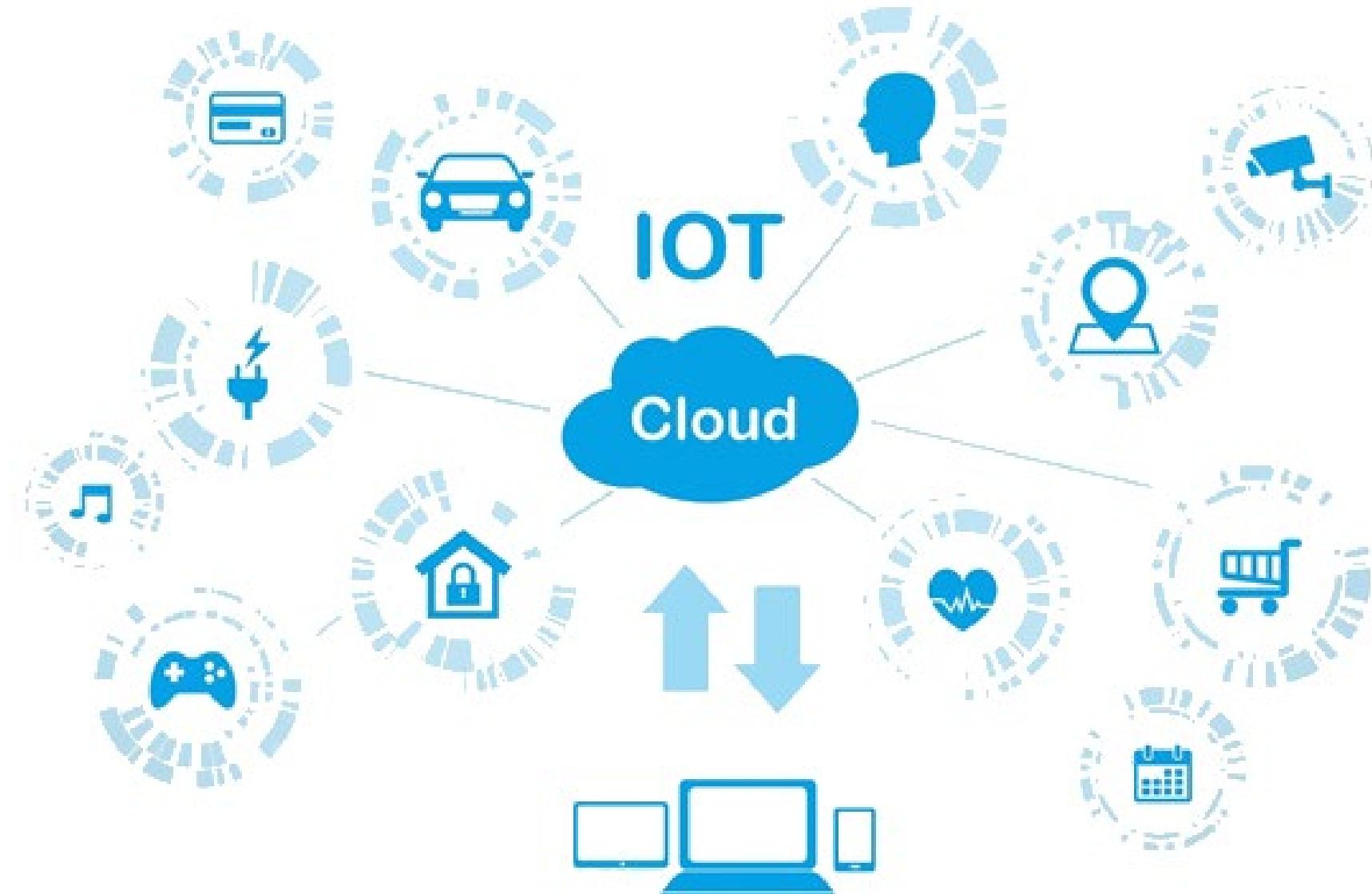
## Mobile IoT Communication Exploiting Stealthy Speaker-to-Gyroscope Channel

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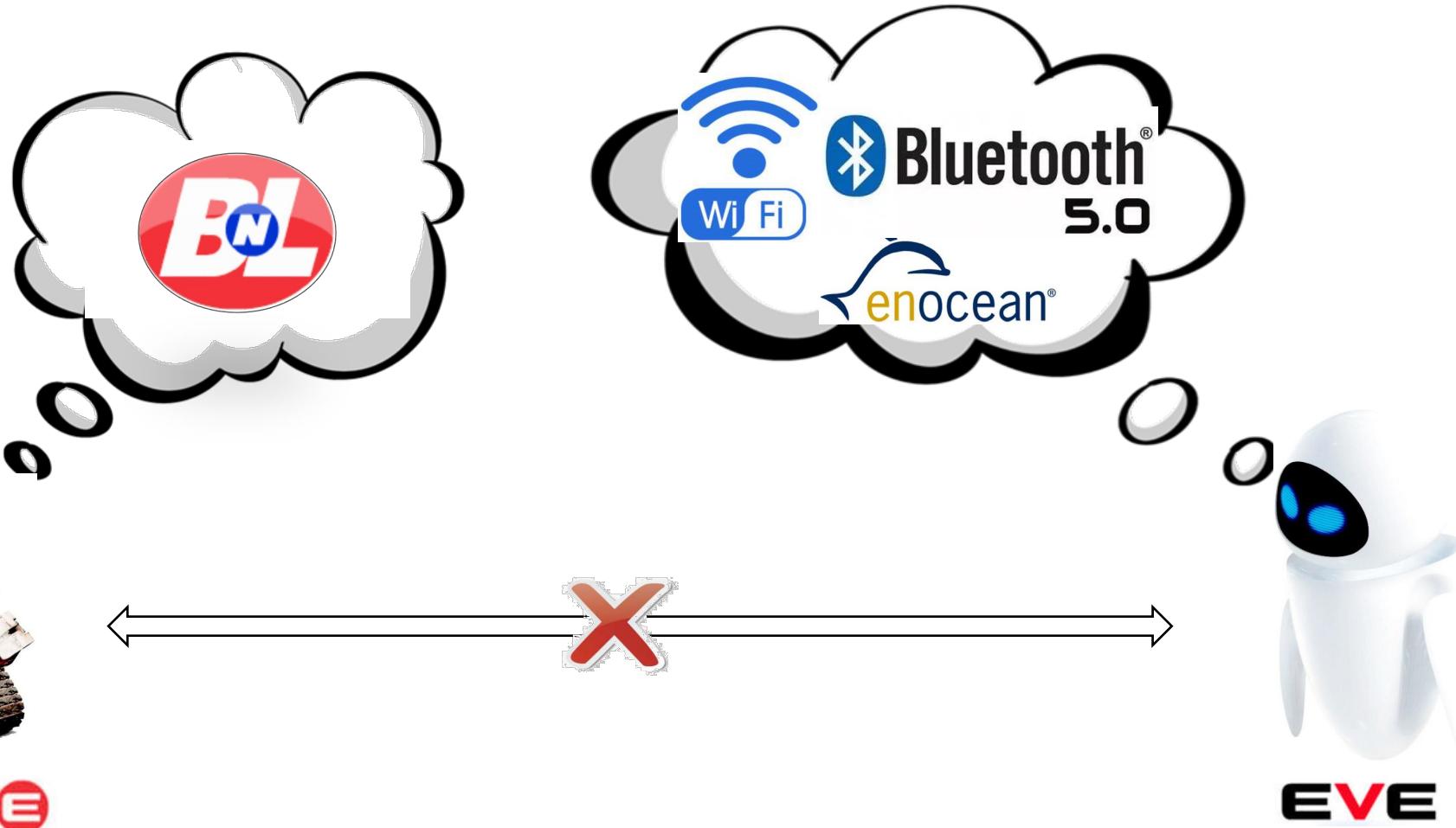


There are still many obstacles to realize such an everything-connected IoT network!

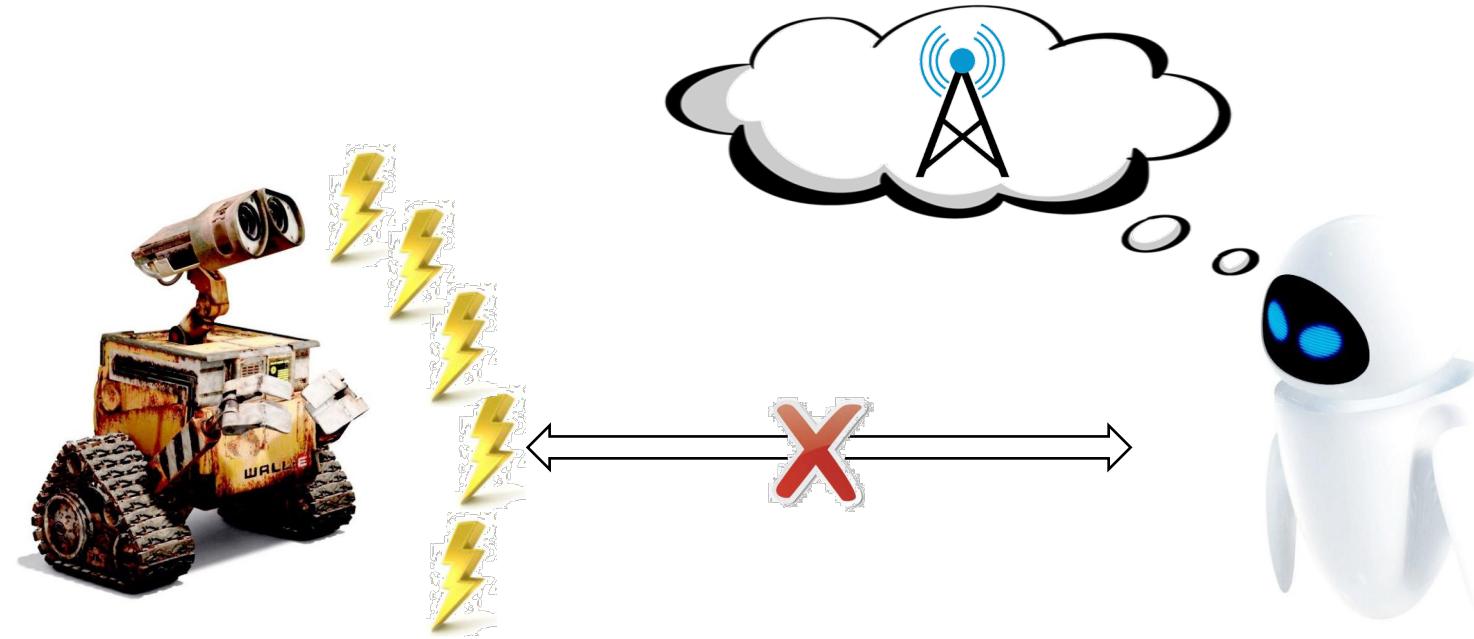
Manufacturers  
develop their own  
protocols



**WALL-E**

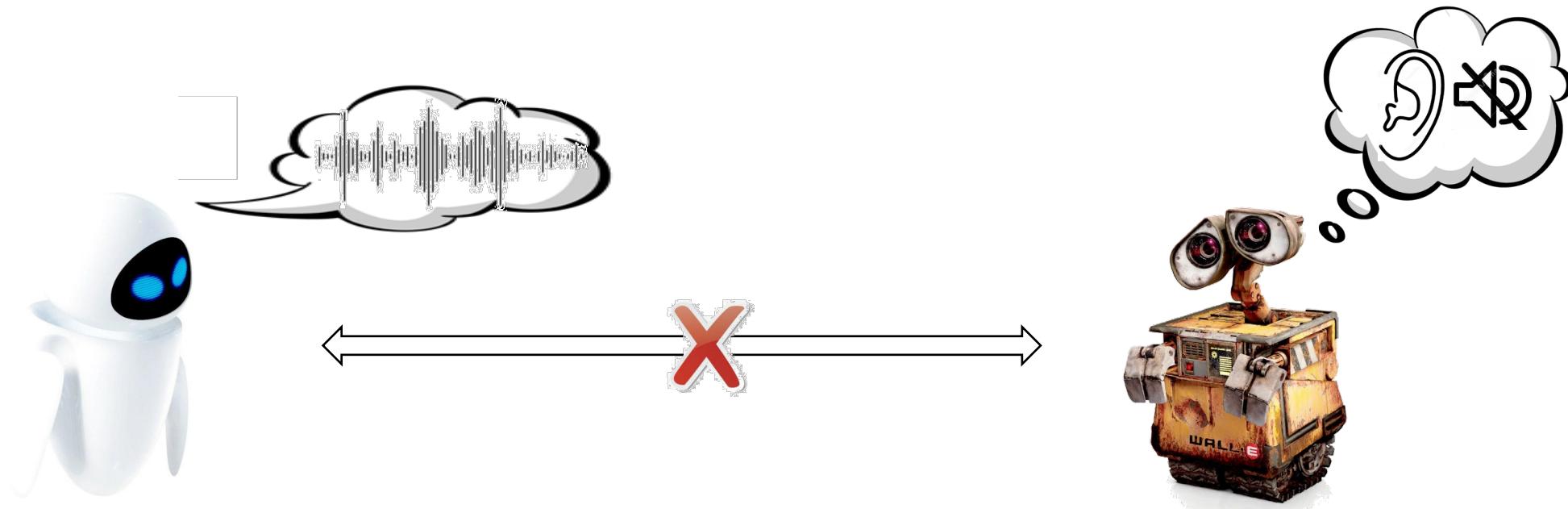


Incompatible protocols make it impossible for  
WALL-E to communicate with EVE!



Communication means based only on the electromagnetic wave would fail upon the electromagnetic interference and shielding!

Paired transmitter-receiver are always required.

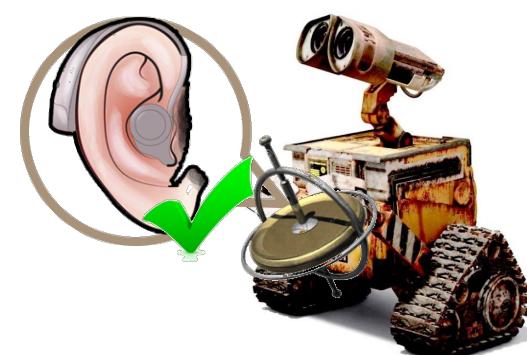
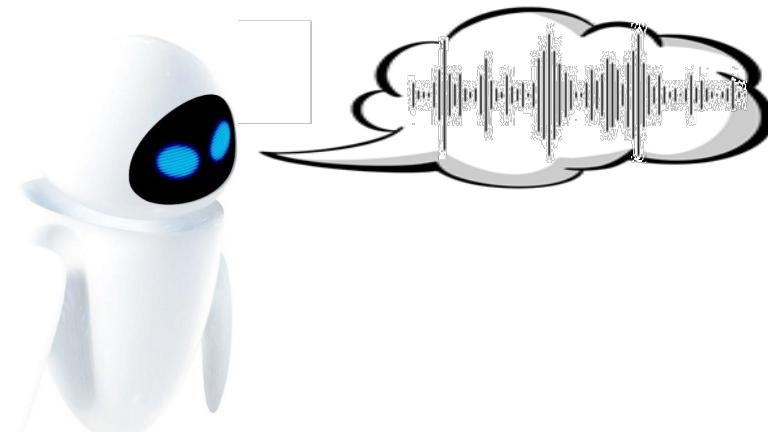


# Our vision

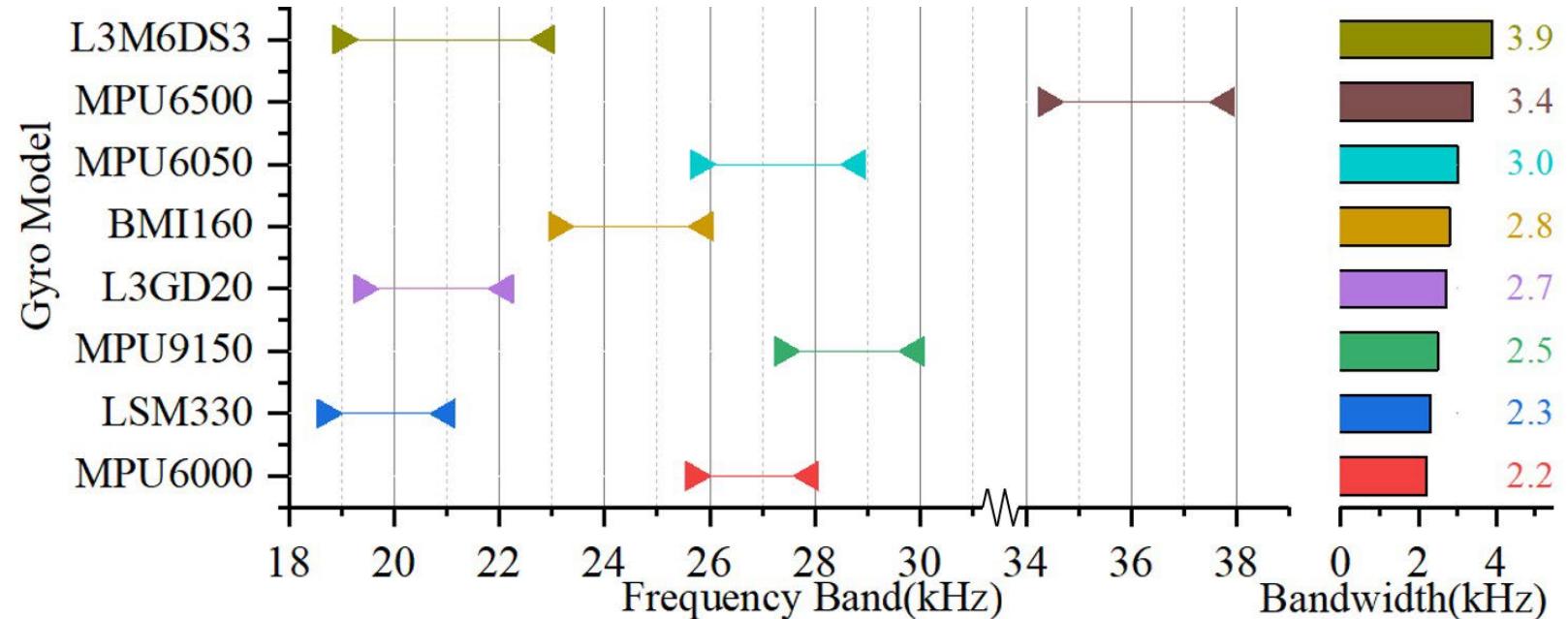
- Protocol-independent
- No Peripheral
- Robust to Movement



It provides a complementary communication channel to current IoT devices.



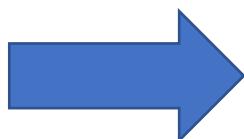
# Feasibility Study



- ✓ Non-contact
- ✓ Inaudibility
- ✓ No peripheral

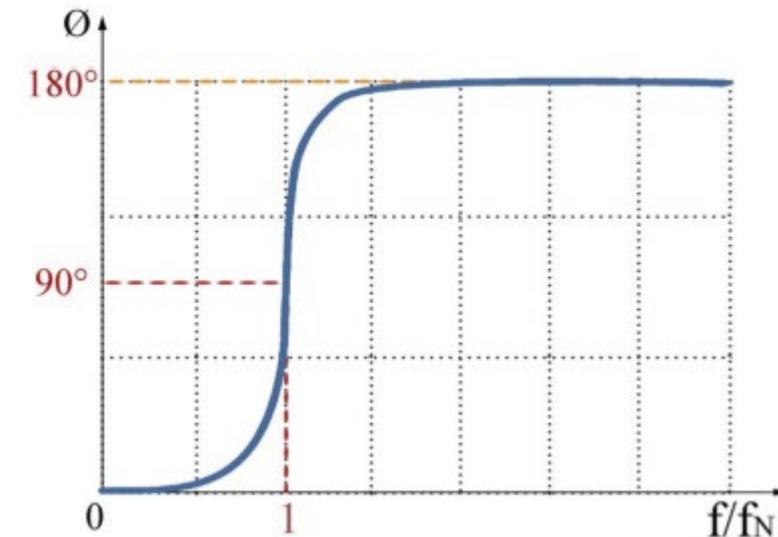
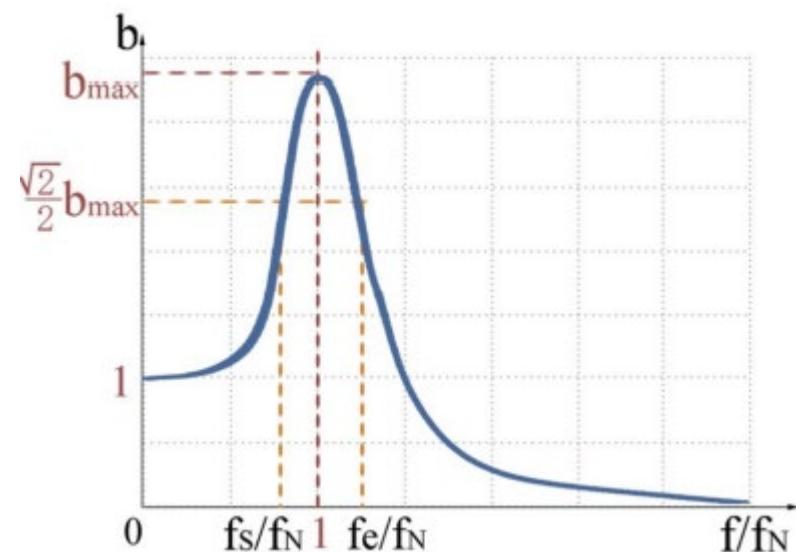


$$F(t) = A \cdot \sin(2\pi f_0 t + \phi_0)$$

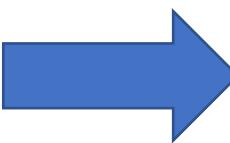


$$M = F(t) - F(t + t_{pw}) \\ + F(t + \Delta t) - F(t + \Delta t + t_{pw})$$

$$R_0(t) = bA \cdot \sin(2\pi f_0 t + \phi_0 + \phi_1)$$

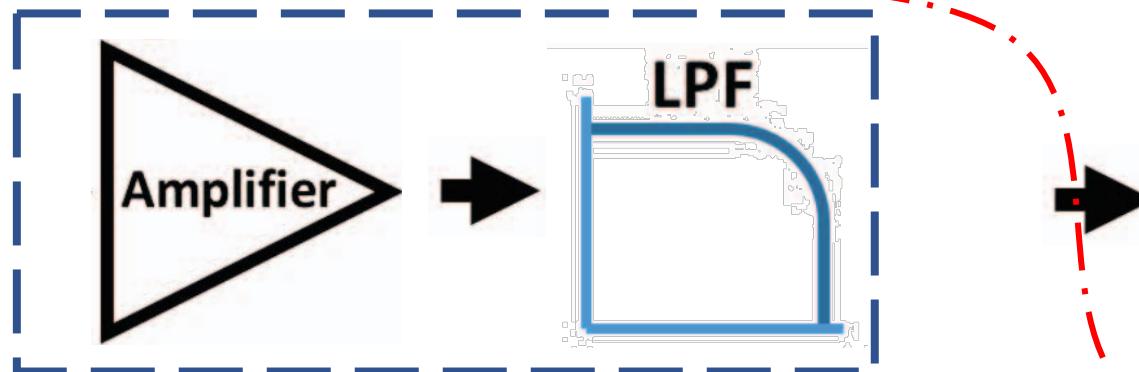


$$F(t) = A \cdot \sin(2\pi f_0 t + \phi_0)$$



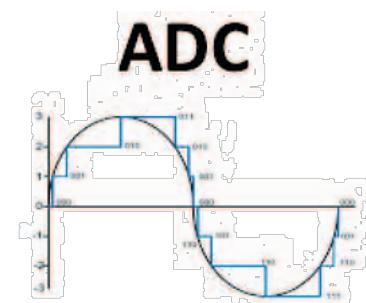
$$M = F(t) - F(t + t_{pw}) \\ + F(t + \Delta t) - F(t + \Delta t + t_{pw})$$

$$R_0(t) = bA \cdot \sin(2\pi f_0 t + \phi_0 + \phi_1)$$



$$R(t) = bLA \cdot \sin(2\pi f_0' t + \Phi)$$

$$\Phi = \phi_0 + \phi_1 + \phi'$$



$$f'_0 = n \times Fs + f_1 \quad \left( -\frac{Fs}{2} < f_1 < \frac{Fs}{2} \right)$$

$$R[k] = bLA \cdot \sin(2\pi f_1 \frac{k}{Fs} + \Phi)$$

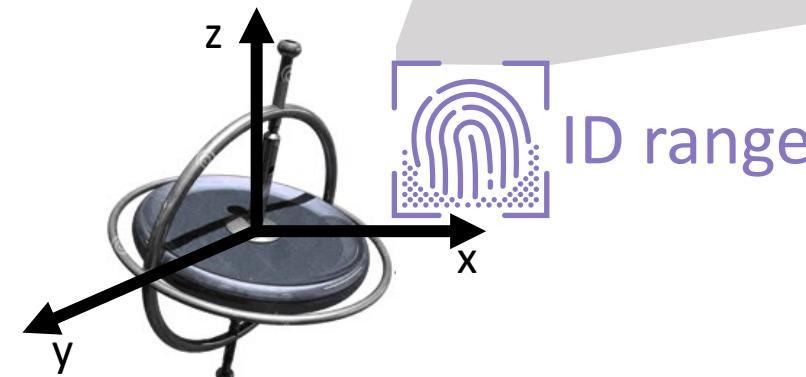
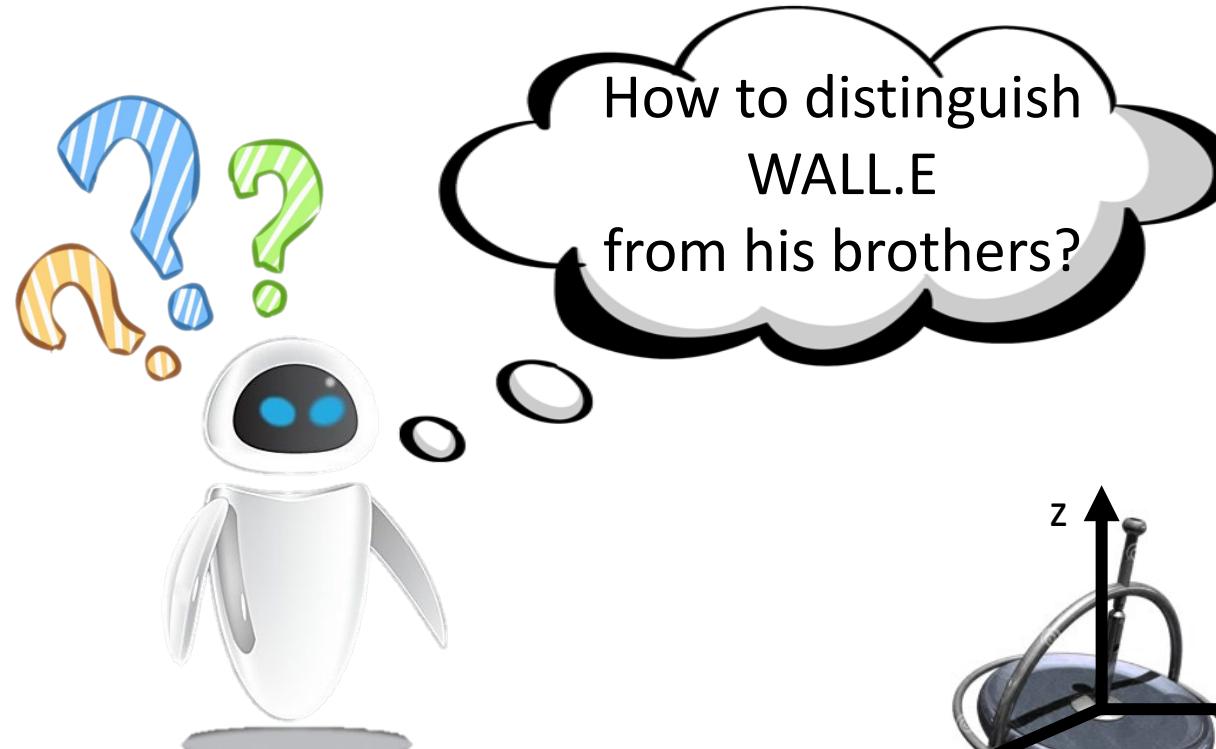


# System Overview

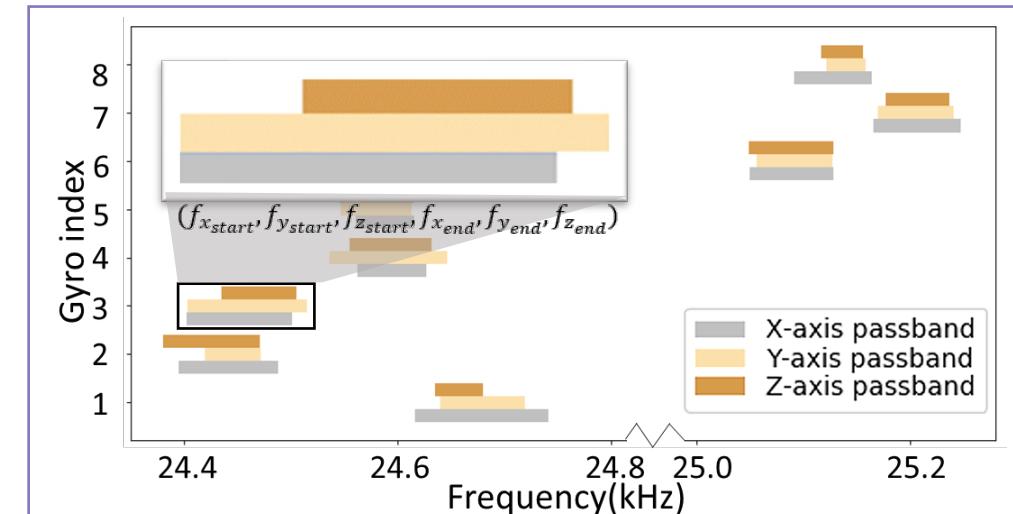
1. How to identify the receiver?

2. How to ensure high-quality communication?

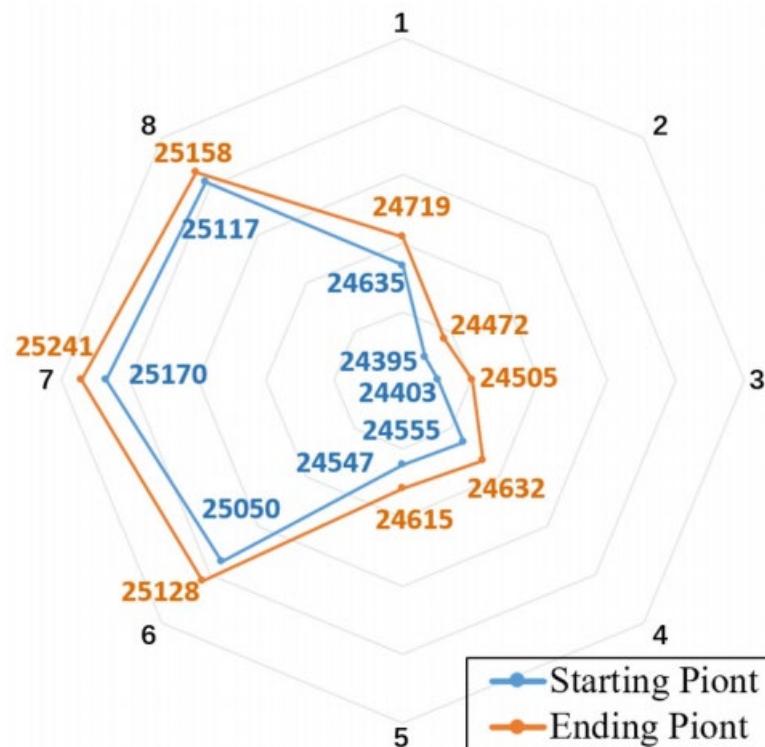
3. How to suppress motion influence?



*Deaf-Aid* leverages **the diversity of resonant passband** of gyroscope as device fingerprint to identify receivers

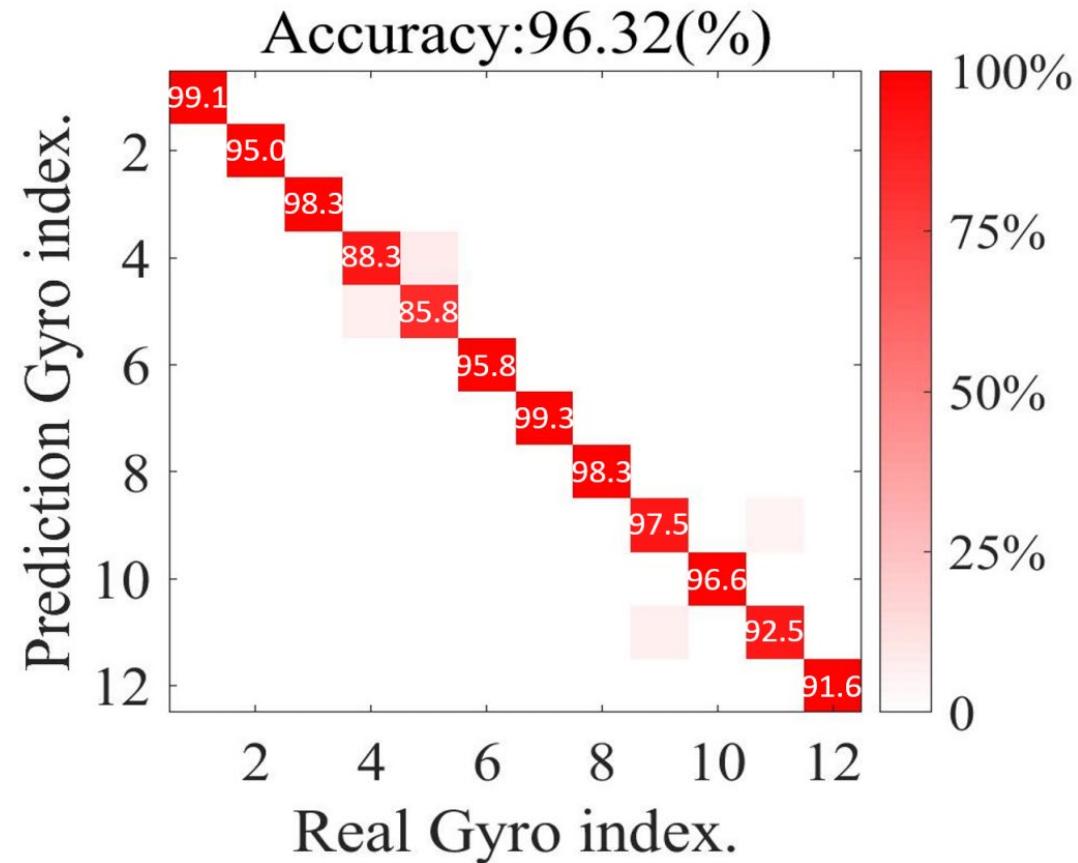


# ID Range



$[\text{Median}(f_{x_{start}}, f_{y_{start}}, f_{z_{start}}), \text{Median}(f_{x_{end}}, f_{y_{end}}, f_{z_{end}})]$

- We tested 6 speakers and 12 gyroscopes
- It achieves an accuracy of **96.32%** totally.



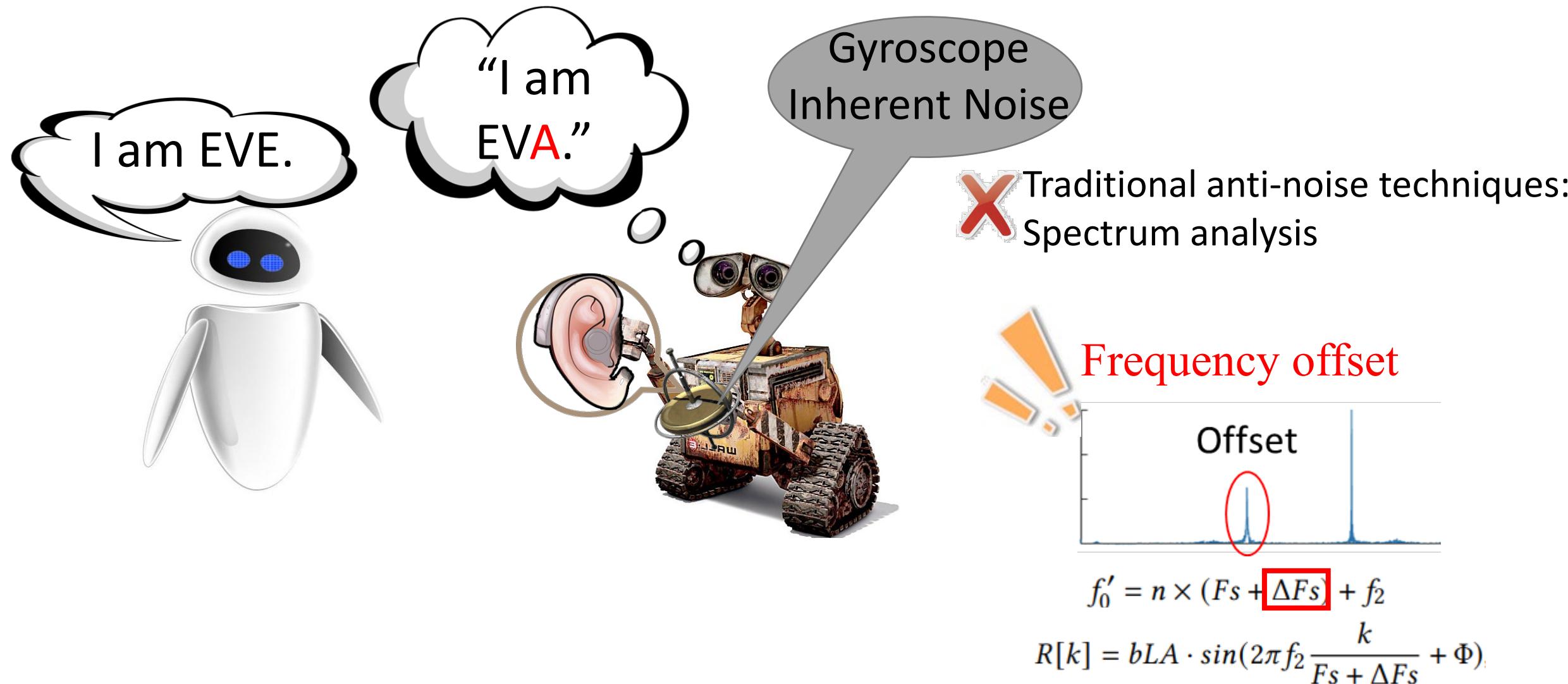


# System Overview

1. How to identify the receiver?

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# Solution: Multiplier-based Correction

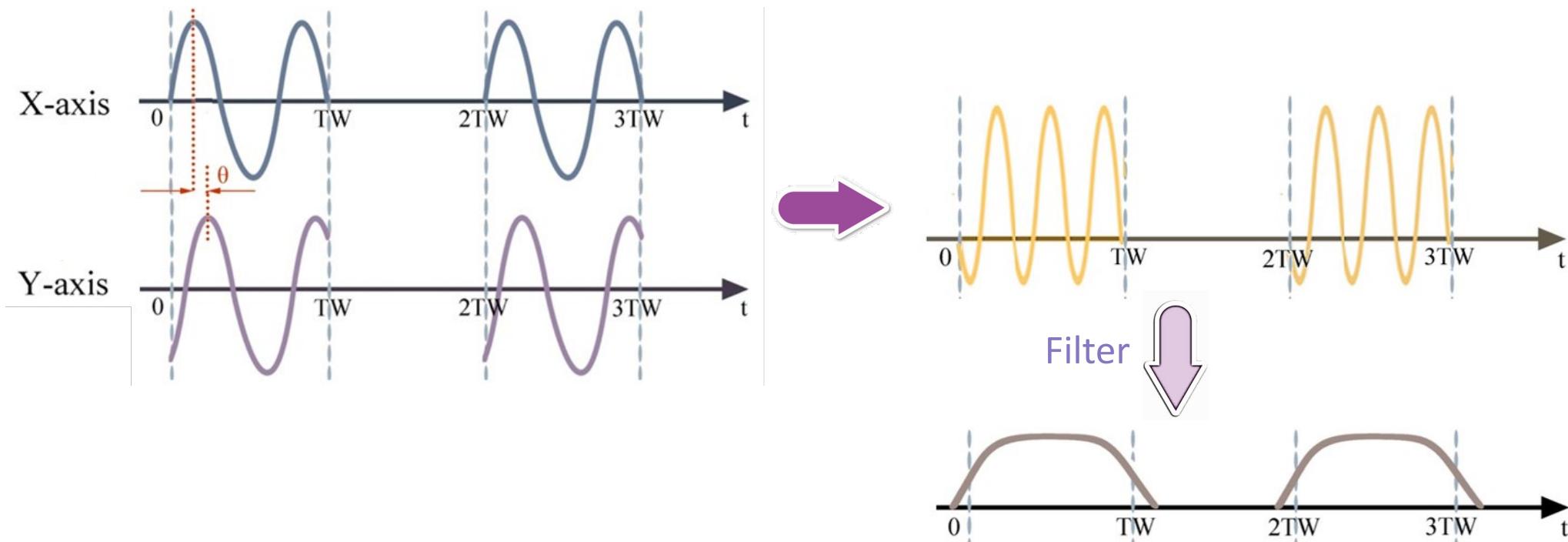
Our Observation:

- Frequency synchronization =  $\frac{1}{2}A_x A_y \cos(\Phi_x - \Phi_y)$
- Fixed phase difference  $\theta$

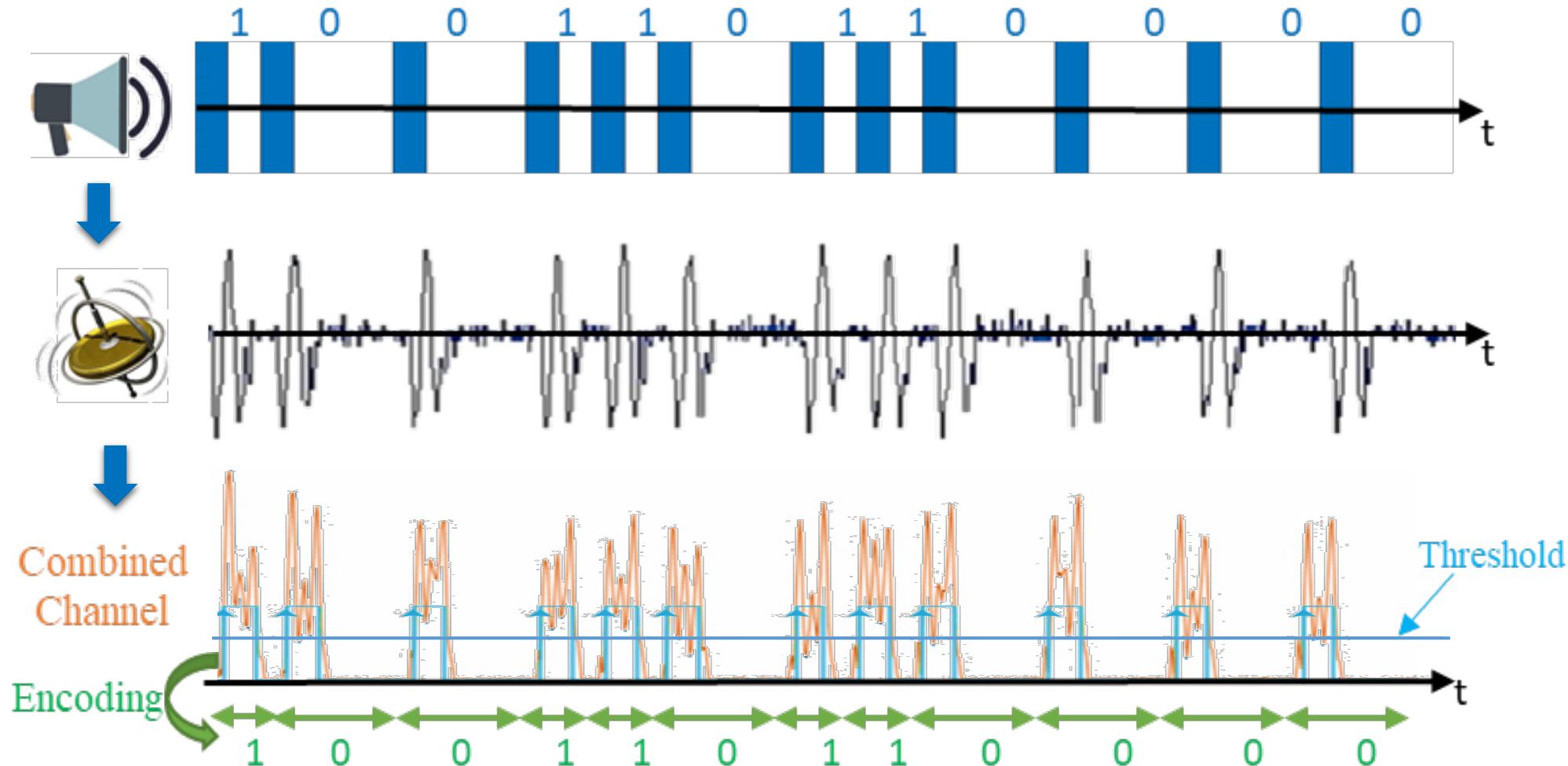
$$S_{cor}[k] = R_x[k] \times R_y[k]$$

Constant!

Noise is removed in an offset-independent way.

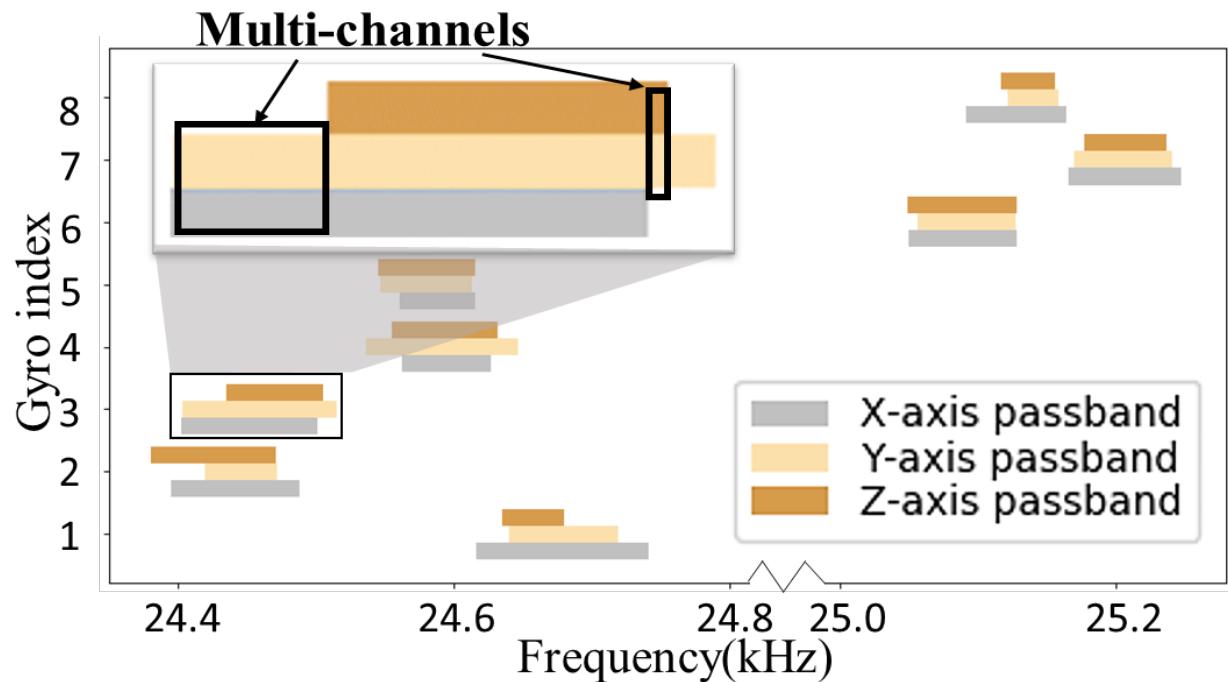


# An example of transmission via *Deaf-Aid*



Signals are received by gyroscope!

# Multi-channel Support



What is  
your mission?



Keep  
secret!

*Deaf-Aid* supports simultaneous communication on multiple channels, even from two transmitters.



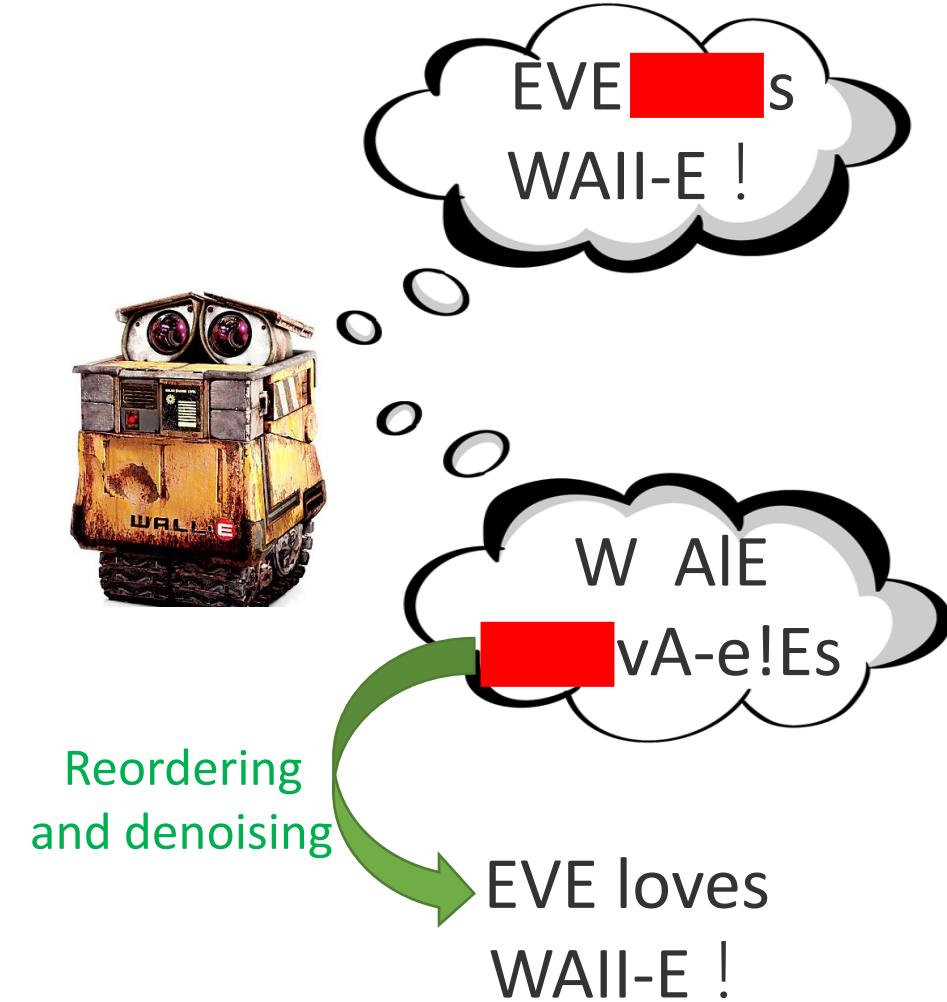
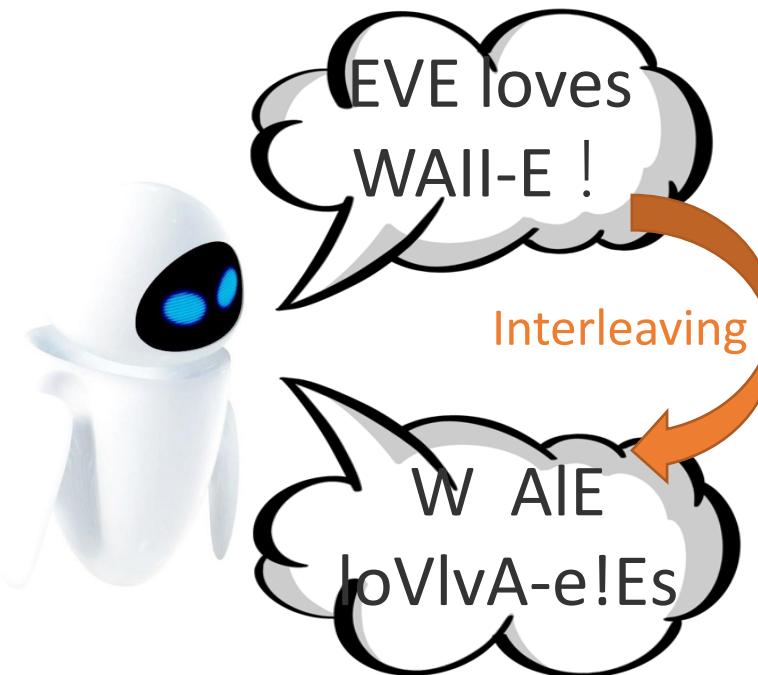
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# Line-of-Sight Blocking



# Transmitter Motion



"I loVe  
yOu!"

A global  
threshold



I Ve  
yOu!

I ve ou!

or

I Ve  
yOu!

In lovnen yonun!

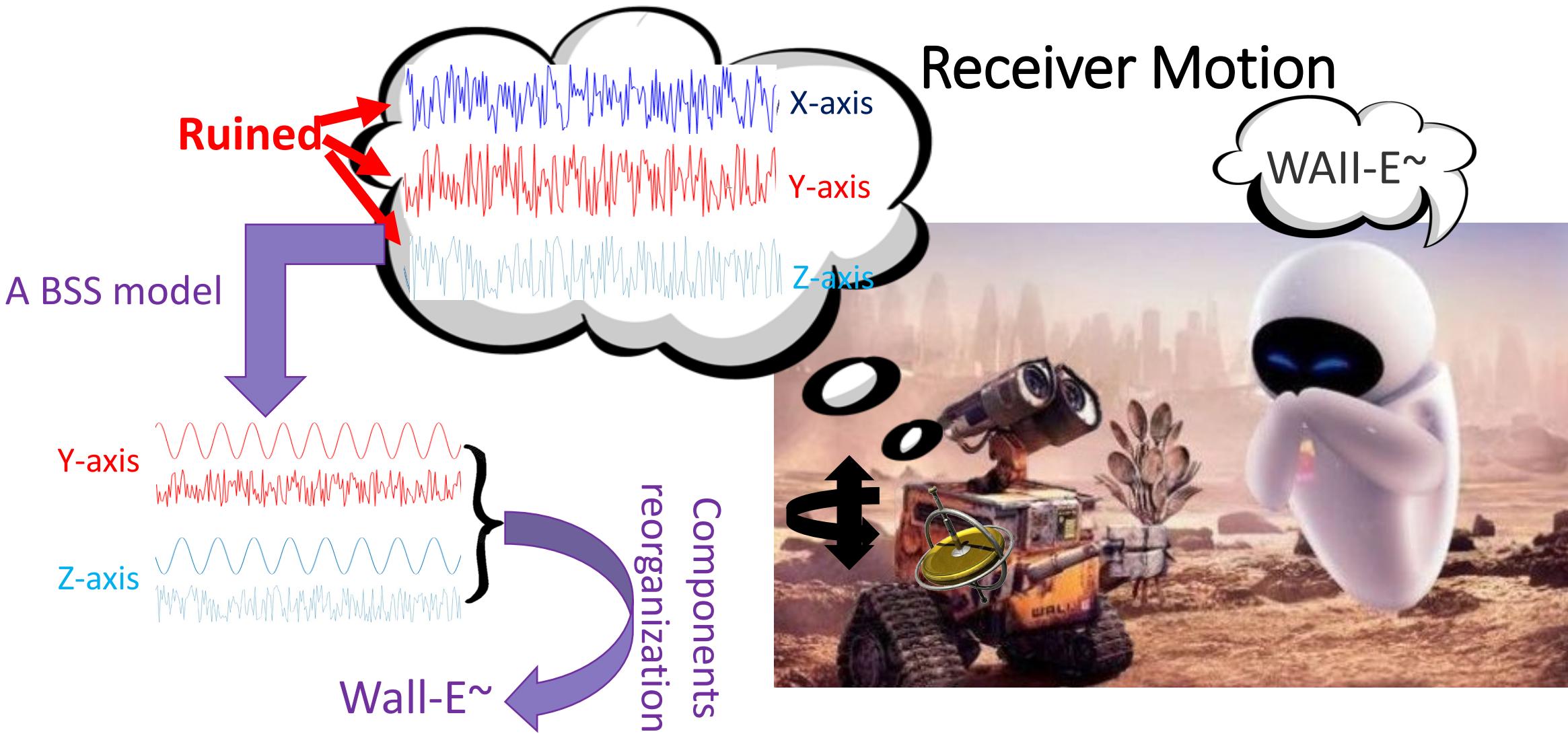
# Transmitter Motion



"I  
Love  
You!"

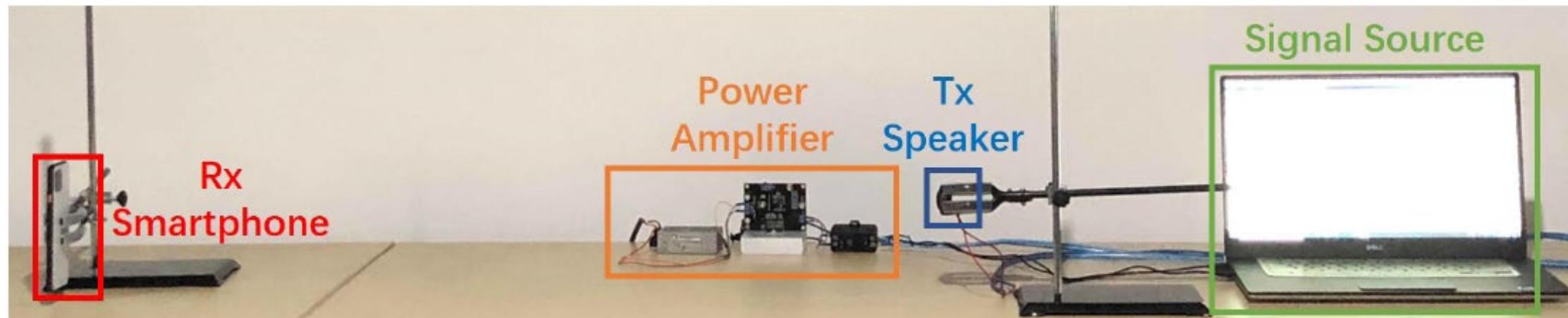
Adaptive threshold segmentation

"H  
Love  
You!" → I love You!

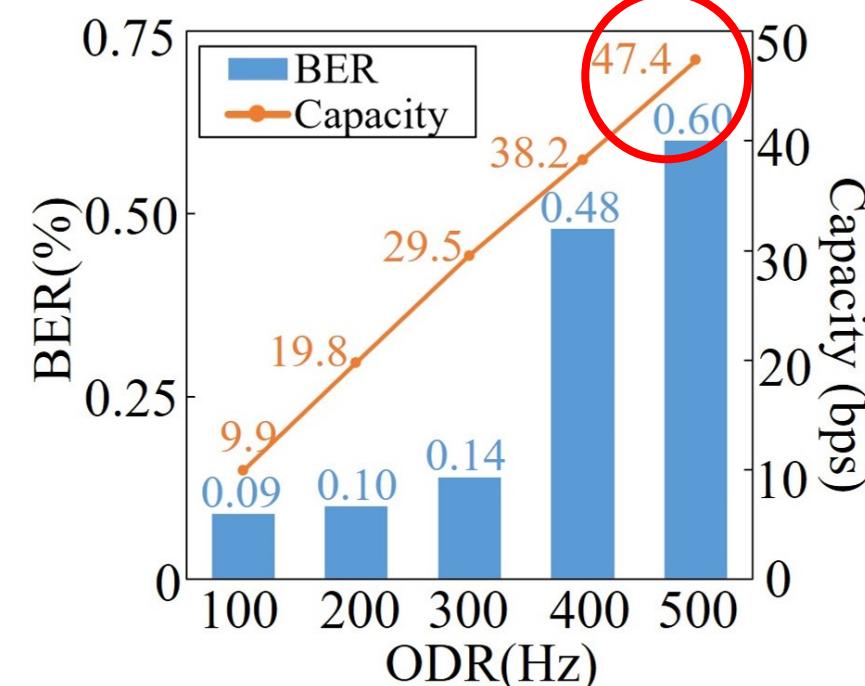
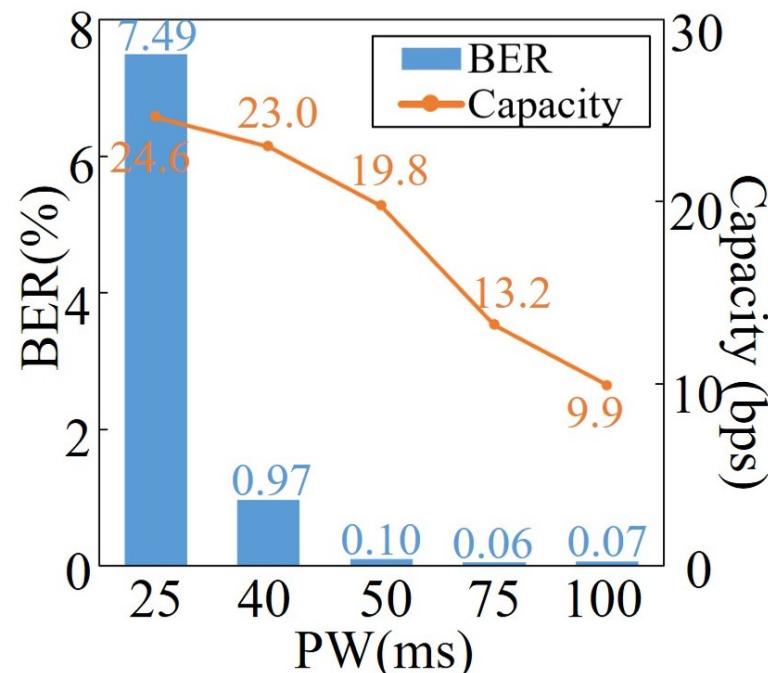


*Deaf-Aid manages to be robust against movements.*

# Experimental Setup



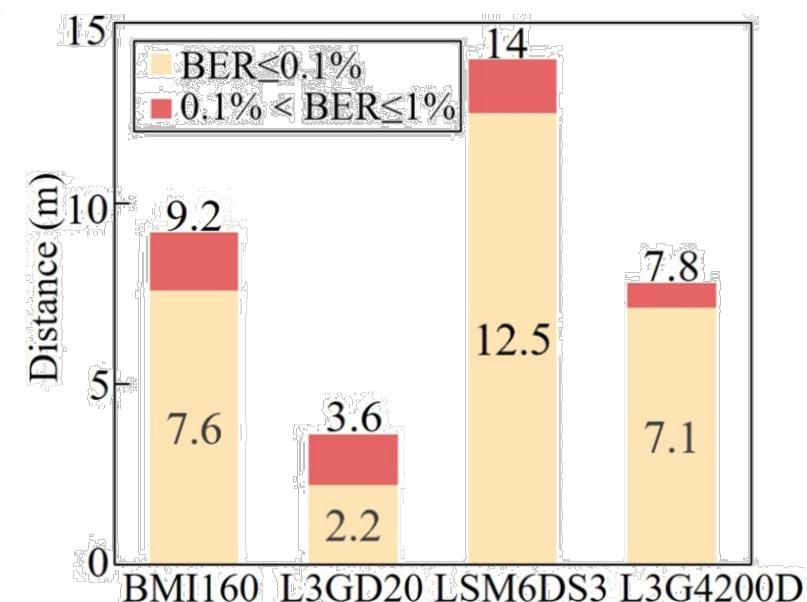
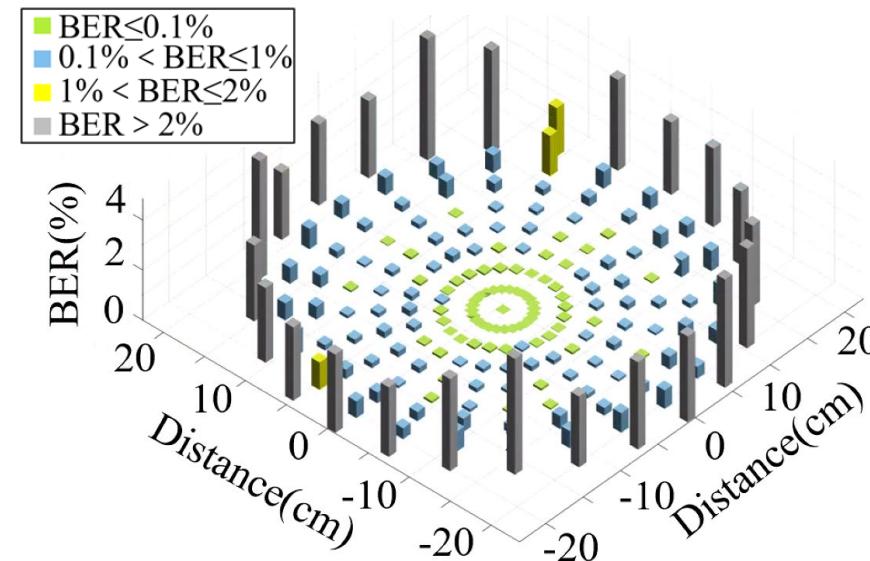
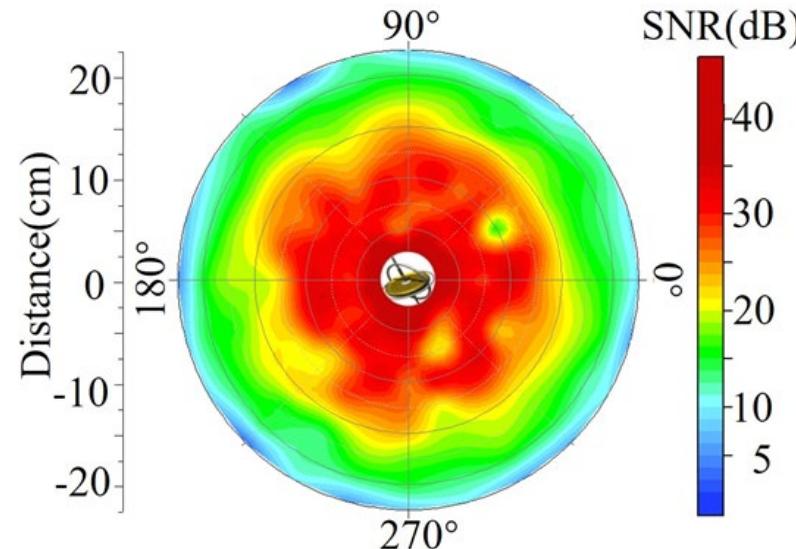
# Transmission Capacity



Error-free and high-speed communication

- Channel capacity reaches 47bps
- BER remains a low level within 0.6%
- *Deaf-Aid* is competent for the different requirements of transmission speed and tolerance of error flexibly in various occasions.

# Orientation and Distance

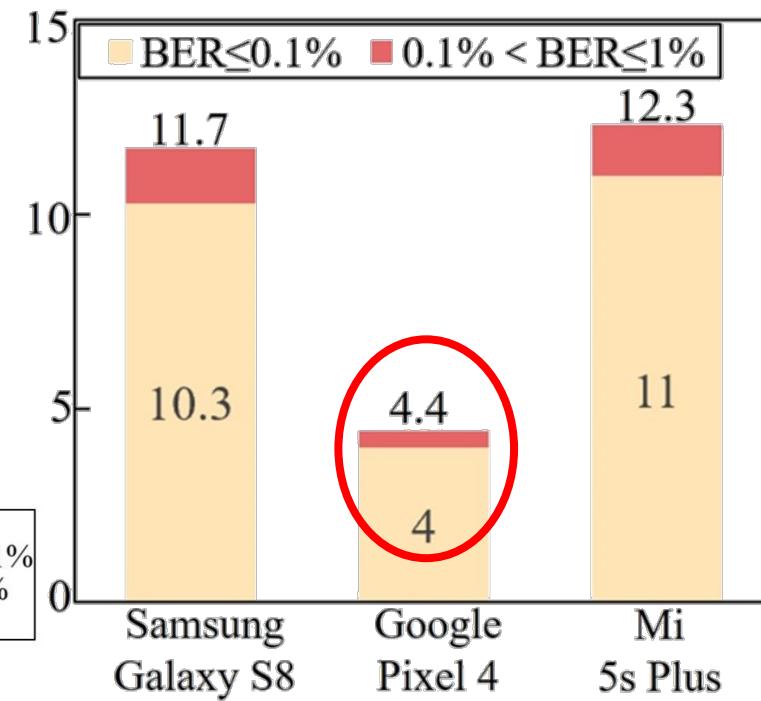
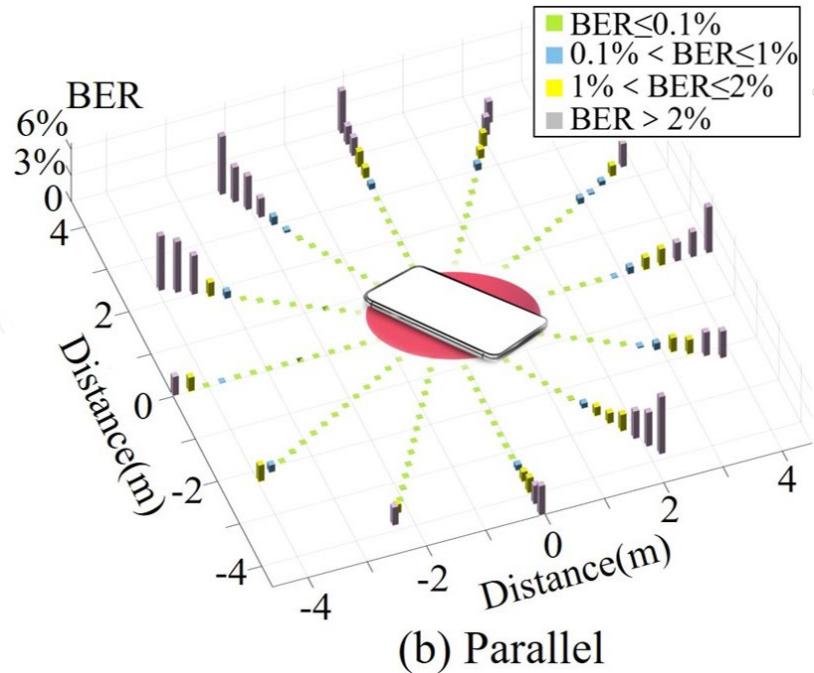
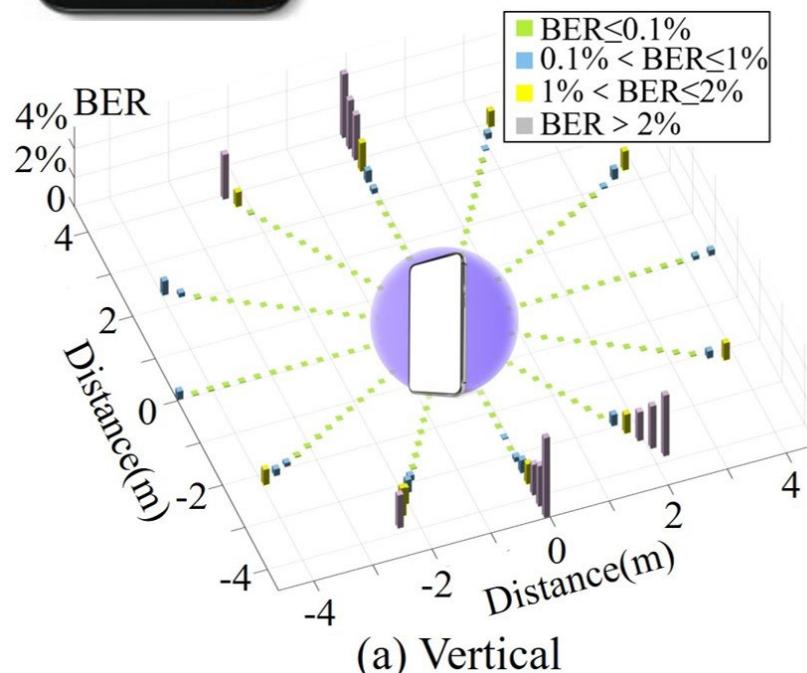


- Scarce constraints on the orientation
- The distance is extended up to **14m**

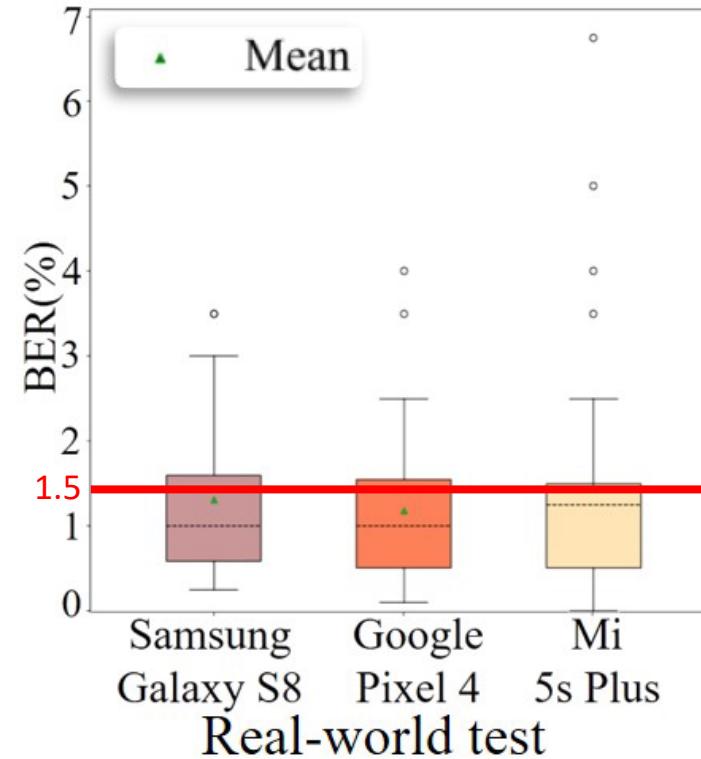
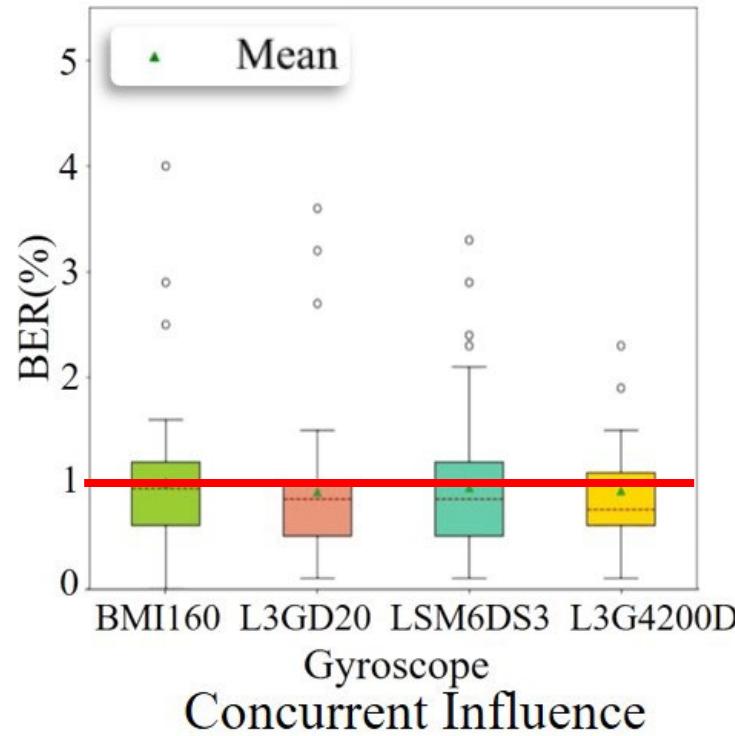


# Smartphone Prototype

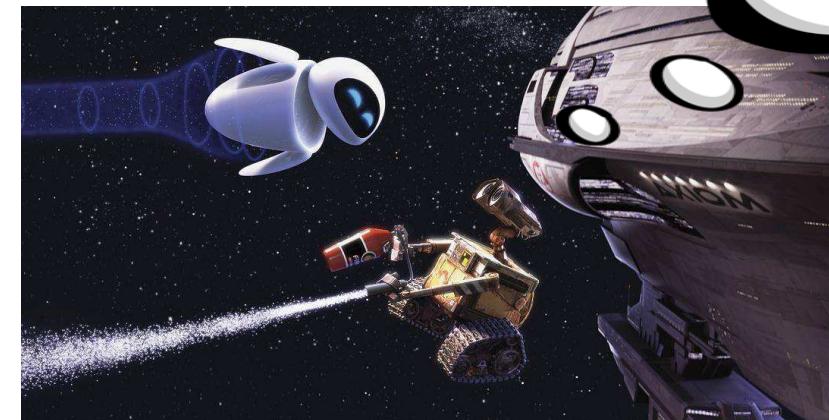
- We rotate a speaker around the fixed phone
- Two different position
- Scarce constraints on the orientation



The communication distance can reach up to **12 meters** among realistic devices.



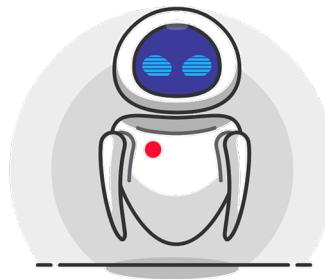
# Motion Influence



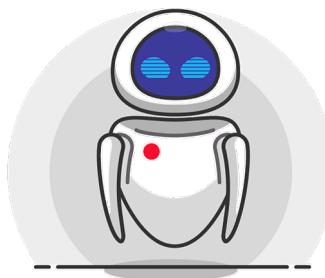
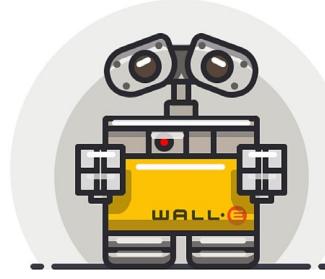


	Ripple [RGC15]	Ripple II [RC16]	BitWhisper [GMME15]	Dhwani [NCPV13]	Deaf-Aid
Speed	200bps	30kbps	1-8 bits per hour	2.4kbps	47bps
Accuracy	BER<1.7%	SNR>15db	Not evaluate	Accuracy>95%	BER<0.6%
Distance	6 inches	Touch based	40cm	10cm	14m
Free Placement	✗	✗	✗	✓	✓
No need for Peripheral	✓	✓	✓	✗	✓
Motion Robustness	✗	✗	✗	✓	✓
Automatic Identification	✗	✗	✗	✗	✓

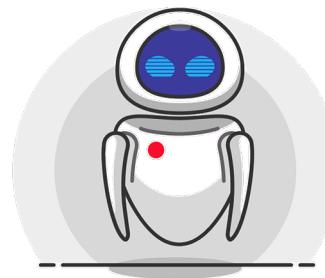
# Implementation Consideration



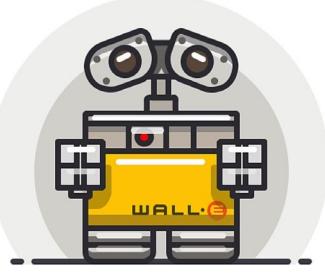
5W  
20cm



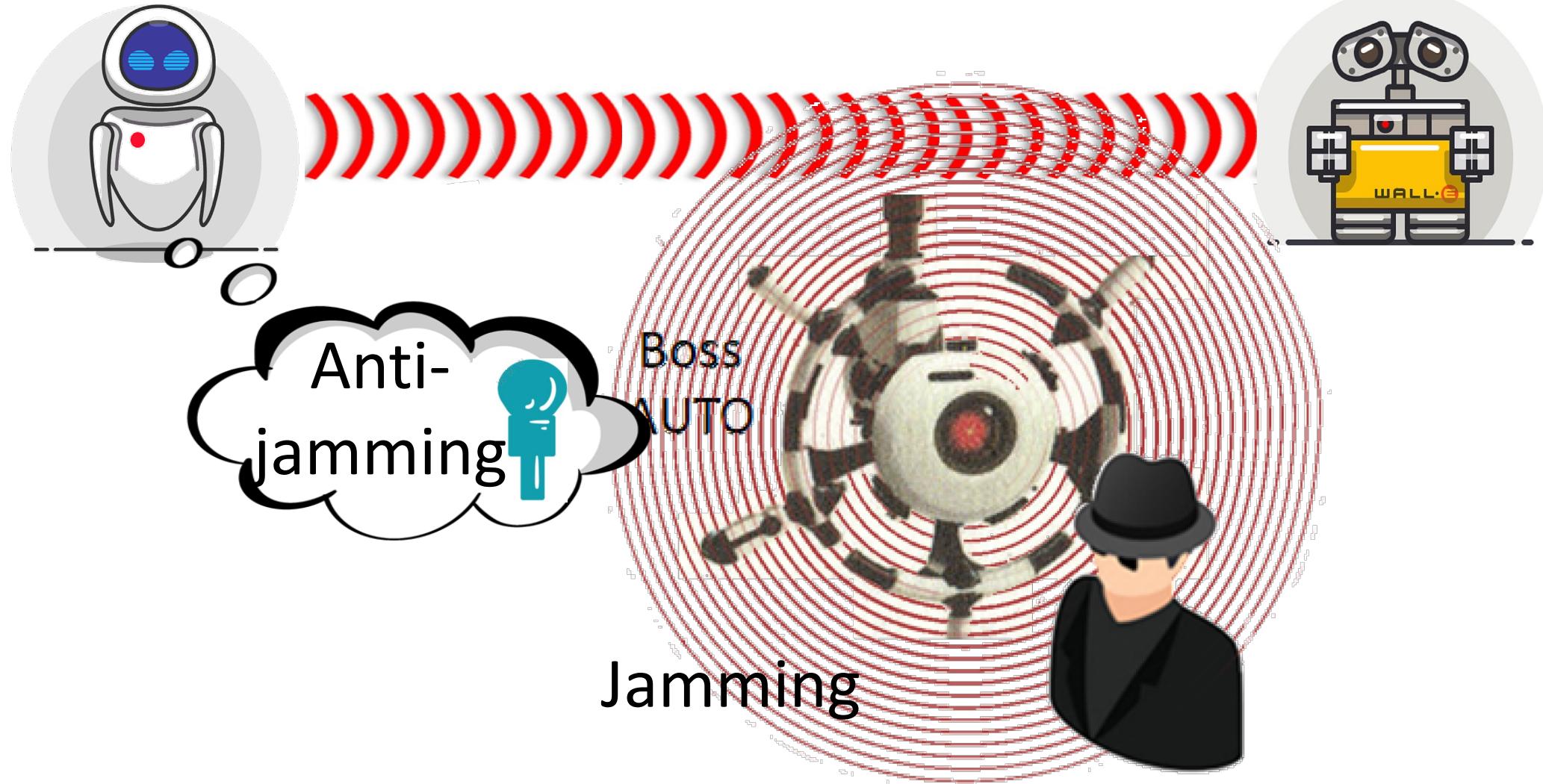
30W  
14m



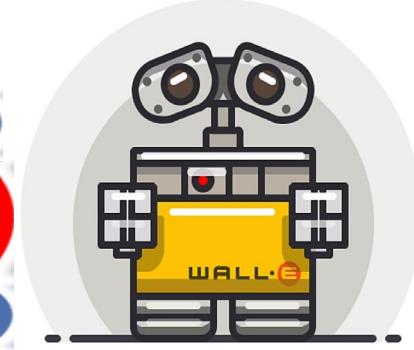
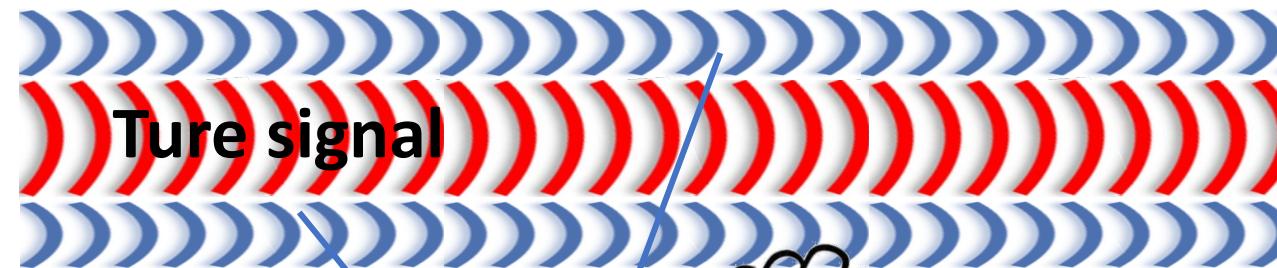
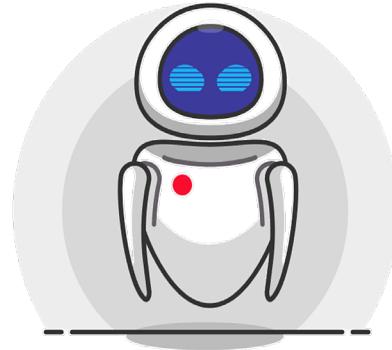
A better speaker  
Up to 37m



# Security



# Security



Eavesdropping



# Conclusions



- We build the speaker-to-gyroscope channel, *Deaf-Aid*, for protocol-independent mobile IoT communication.
- We analyze the inter-axes relationship in a gyroscope under resonance.
- *Deaf-Aid* leverages the diversity of resonant passband of gyroscope as device fingerprint to identify receivers.



# Thank you!

## Contact

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# Reference

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-  [NCPV13] R. Nandakumar, K. K. Chintalapudi, V. Padmanabhan, and R. Venkatesan. 2013. Dhwani: secure peer-to-peer acoustic NFC. *ACM SIGCOMM Computer Communication Review* 43.4 (2013), 63–C74.