Trident: Interference Avoidance in Multi-reader Backscatter Network via Frequency-space Division

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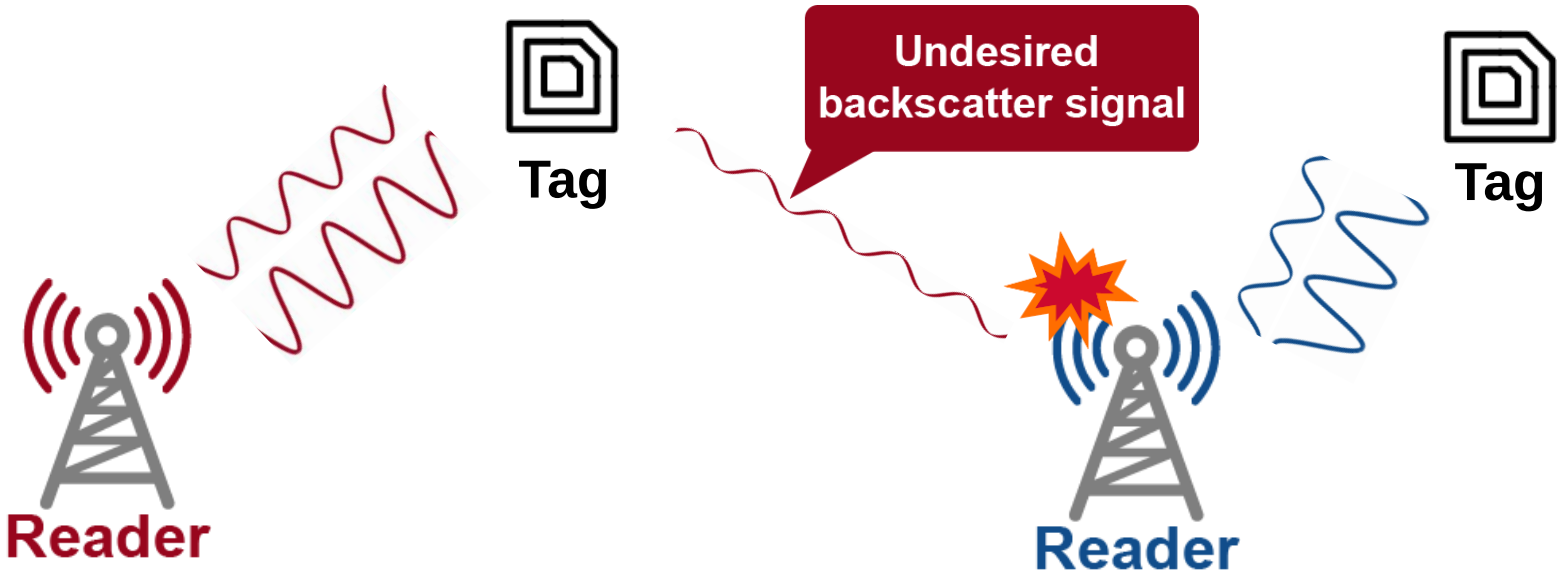
Dense reader deployment

Deploying a backscatter network in a large area requires a dense deployment of readers for full coverage.

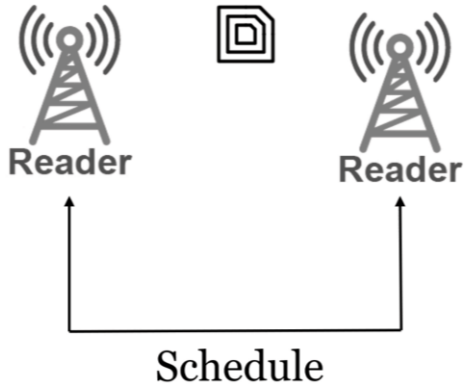
Interference in the multi-reader network



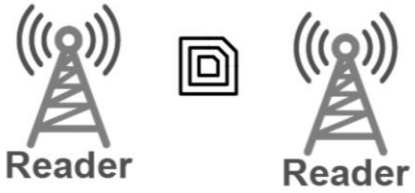
The backscattered signals from a tag are likely to reach another reader and induce undesired interference.

Avoid interference in the time domain

TDMA-based method



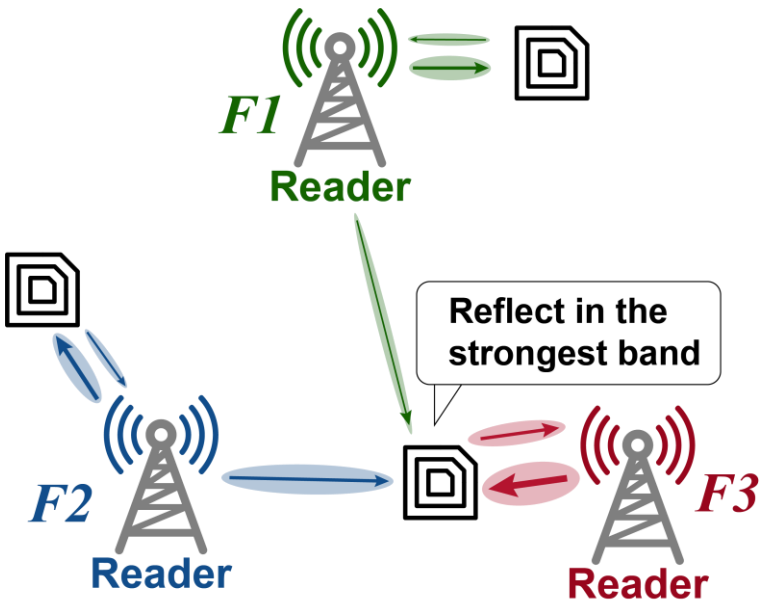
CSMA-based method



These methods avoid interference in the time domain, however, at the cost of the **network throughput**.

Trident

Frequency division



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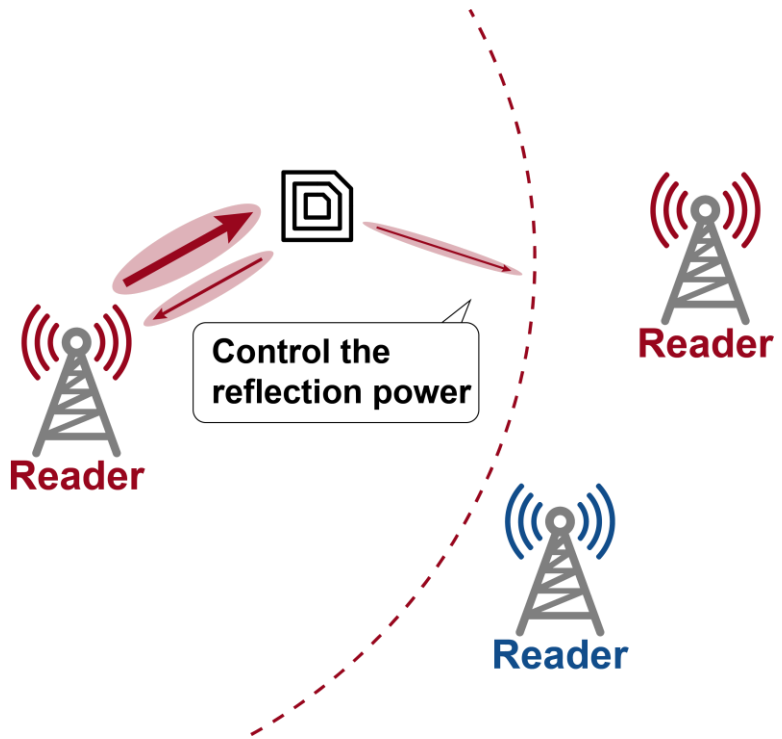
Space division

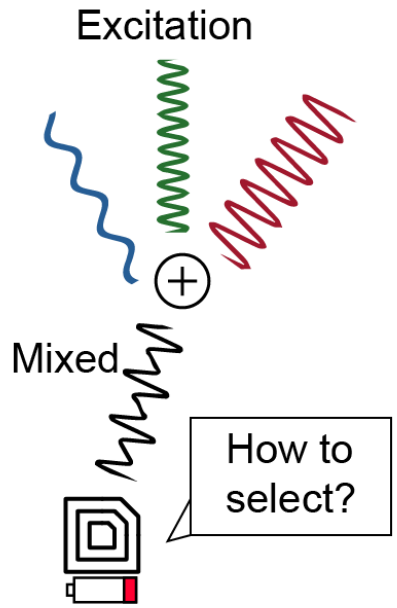


Enable the tag to avoid interference in the frequency-space domain.

Challenge

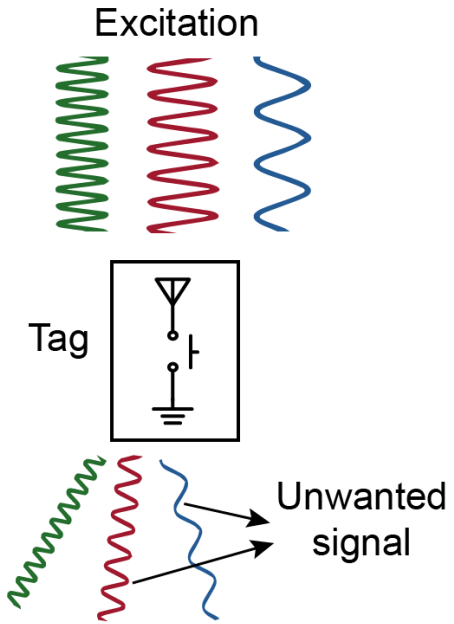
Challenge 1

How to select the strongest band with limited power?



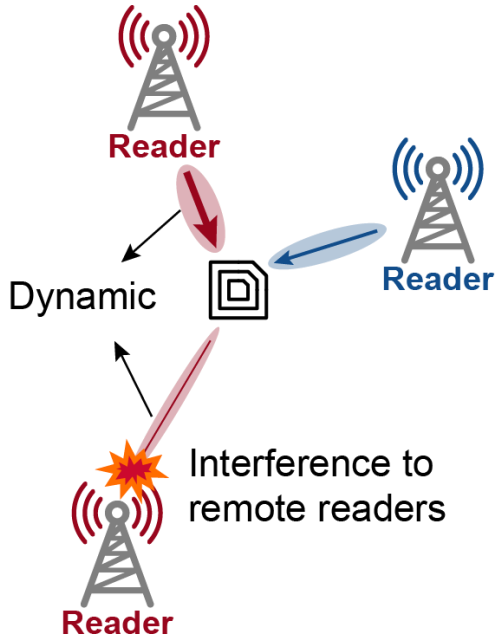
Challenge 2

How to generate reflection signals in a specific band?



Challenge 3

How to control the reflection power in a dynamic channel?



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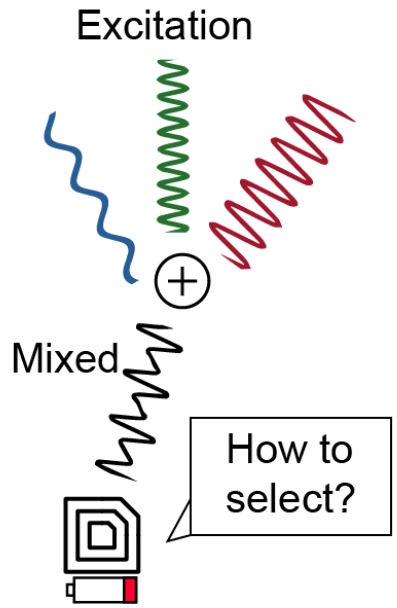

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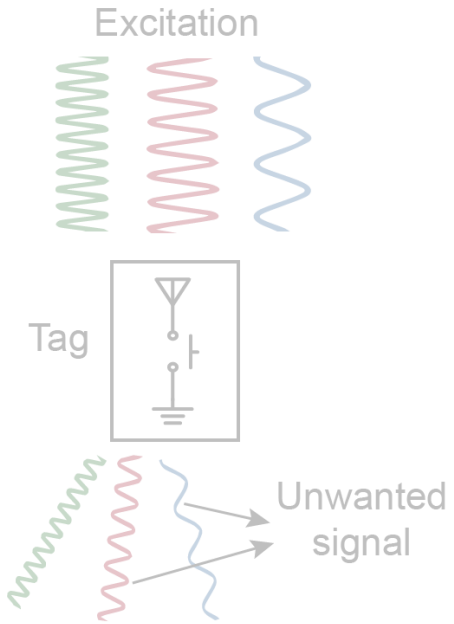

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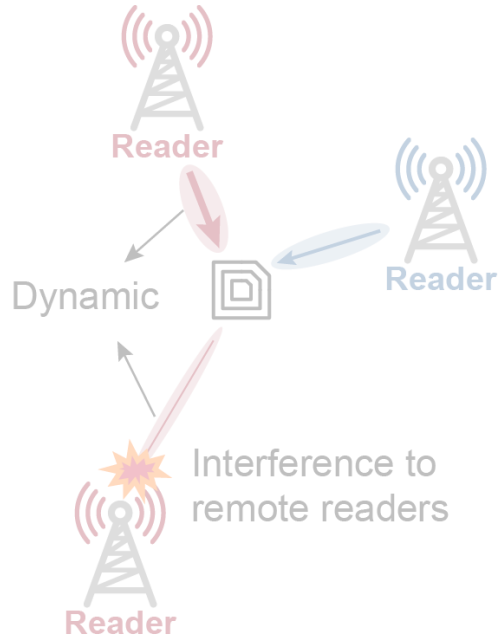
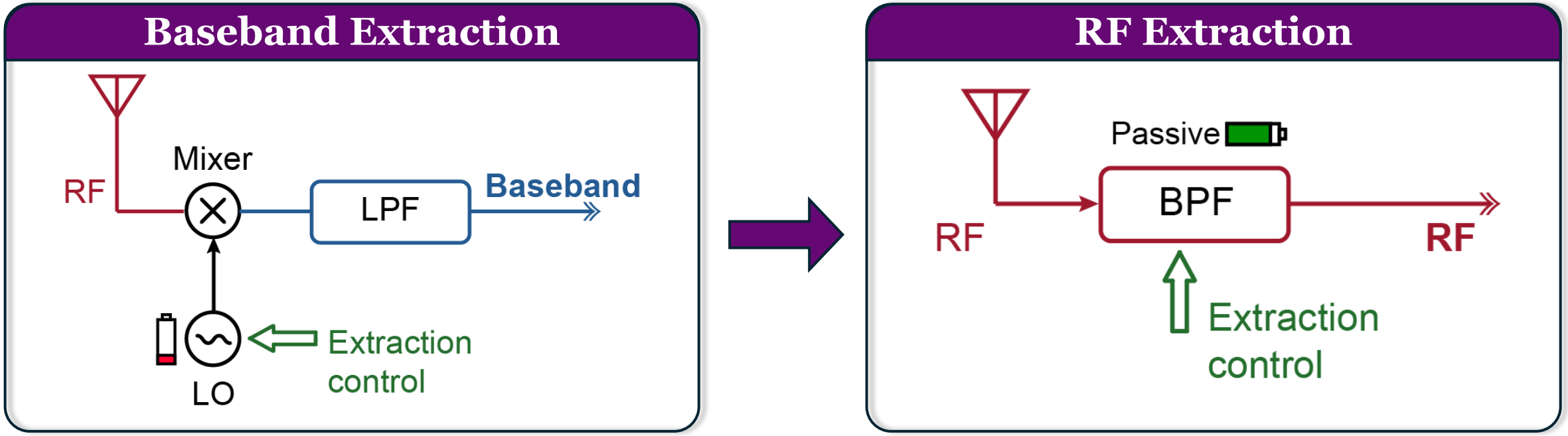
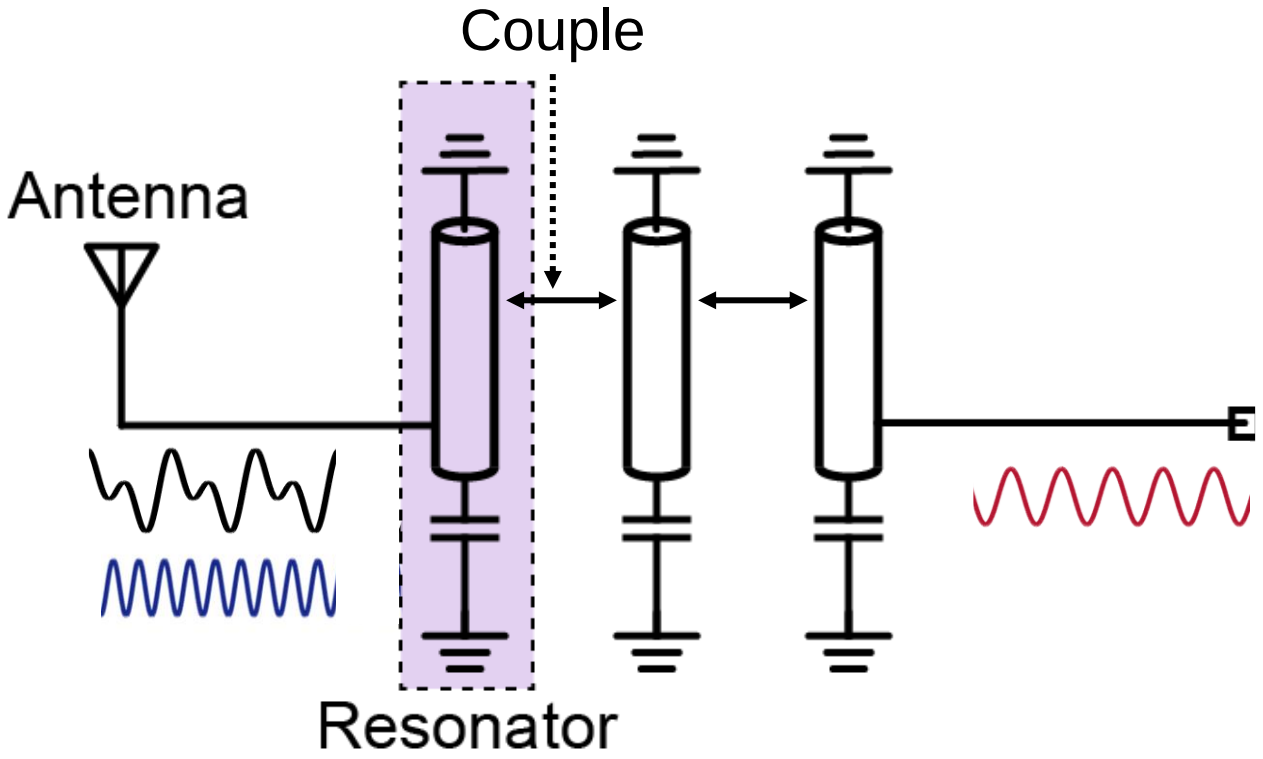


Signal extraction



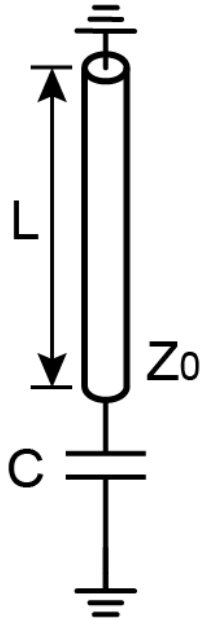
Innovation: avoid using baseband signals and instead perform the signal extraction directly in the RF domain.

Comb-line filter



Comb-line filter: extract the signal whose frequency is near the resonance point.

Resonator



$$L = \frac{Z_0 \tan(2\pi fl / v)}{2\pi f}$$

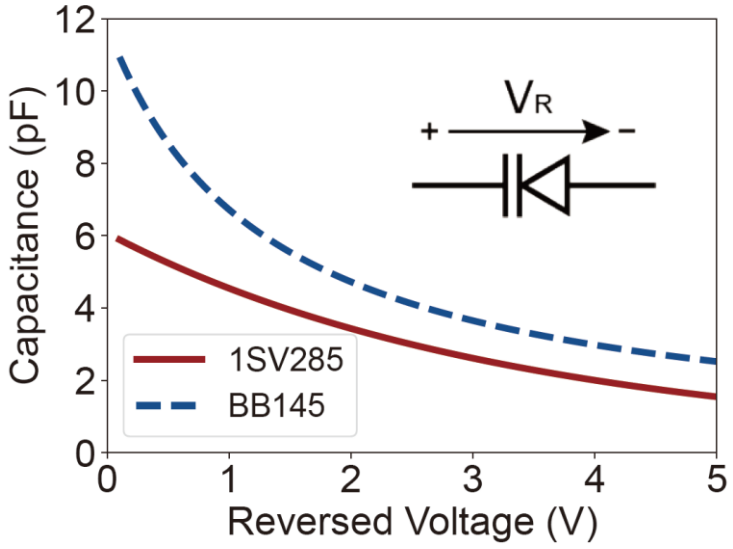
$$f = \frac{1}{2\pi \tan(2\pi fl / v) Z_0 C}$$

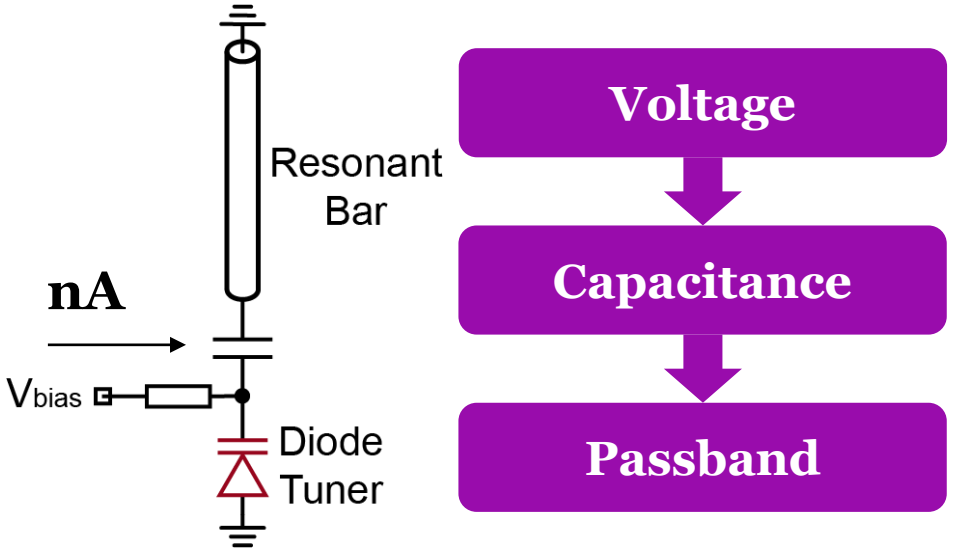
Speed of light

Characteristic impedance

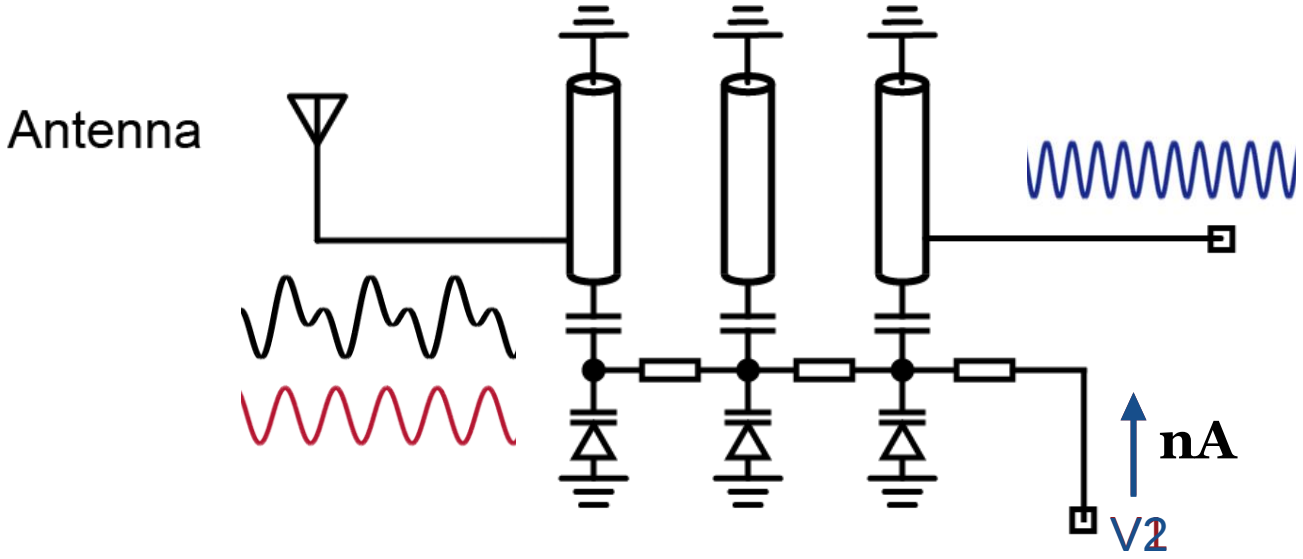
Load Capacitor

Comb-line filter





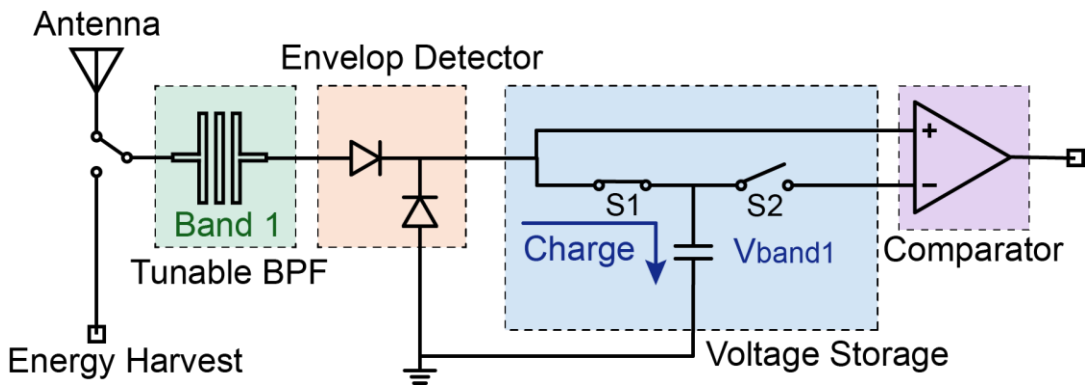
Voltage → Capacitance → Passband



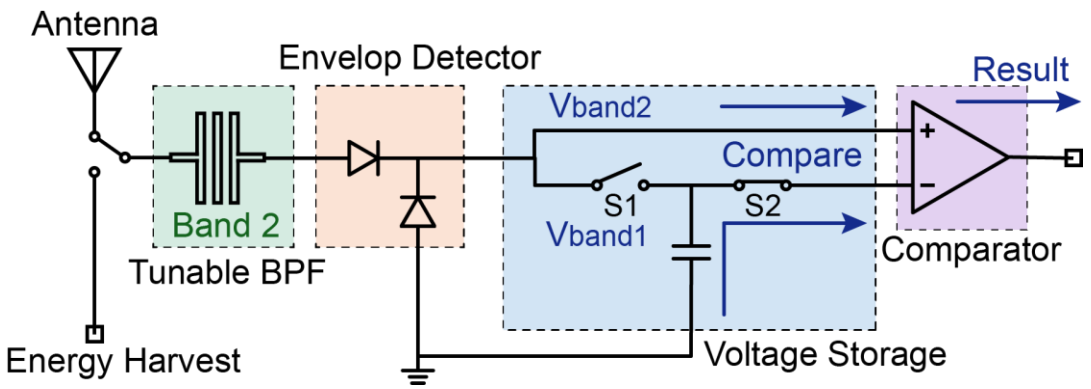
Voltage tuning comb-line filter: Adjust the bias voltage to extract signals in different bands.

Signal comparison

Step 1: Charge



Step2: Compare

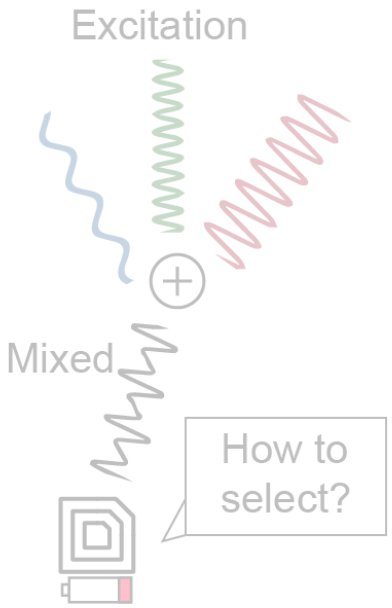


Two-step comparison: extract signals from two bands, store the detection voltage of the previous one and compare it with the next one.

Challenge

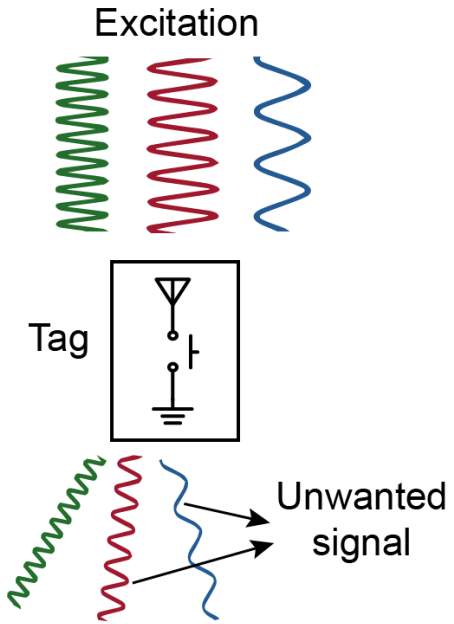
Challenge 1

How to select the strongest band with limited power?



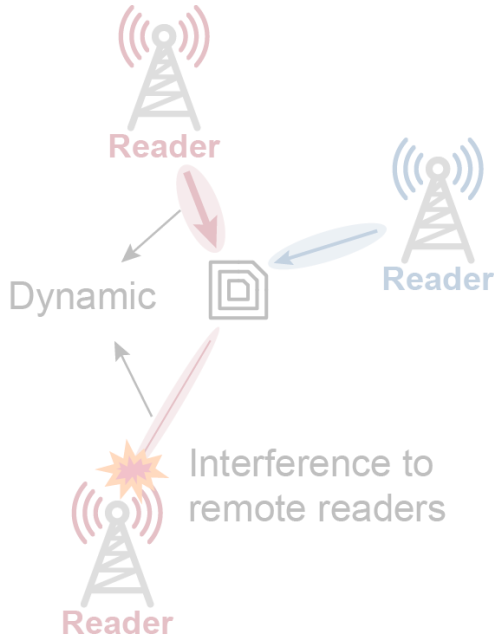
Challenge 2

How to generate reflection signals in a specific band?



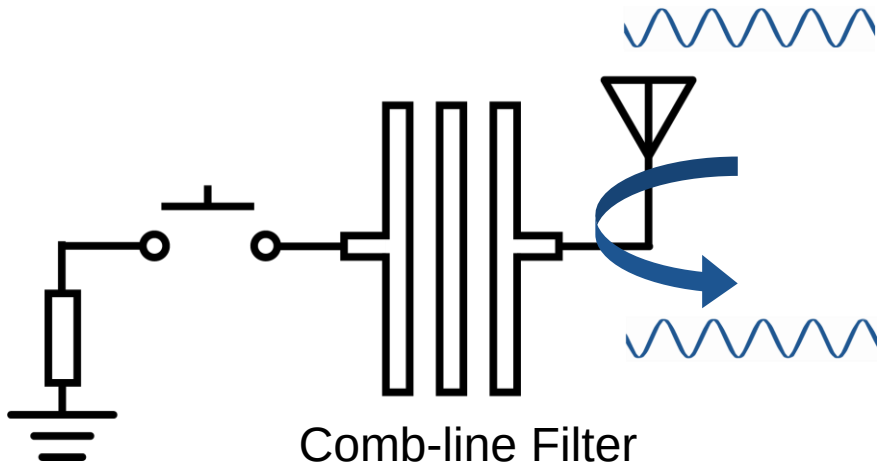
Challenge 3

How to control the reflection power in a dynamic channel?

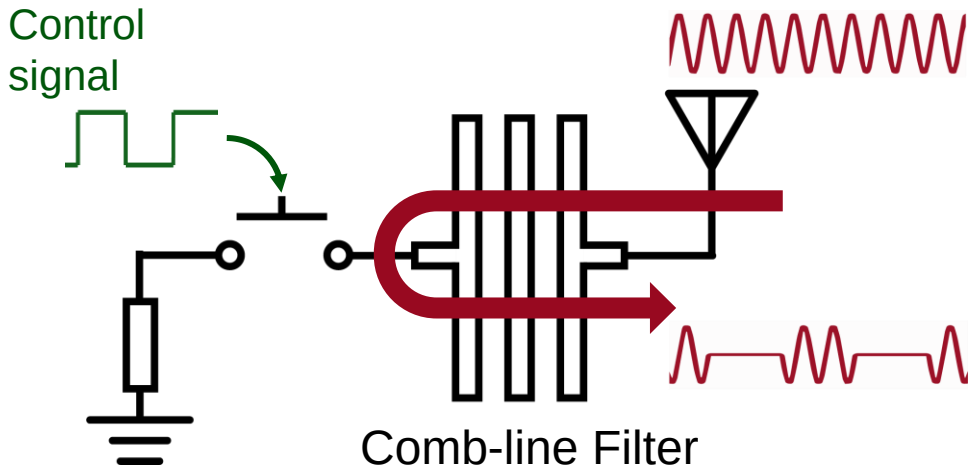


Frequency-selective backscatter

Out of band: Reflect directly



In band: Modulate & reflect



Apply distinct RF operations to signals in different frequency bands to achieve the frequency-selective reflection.

Challenge

Challenge 1

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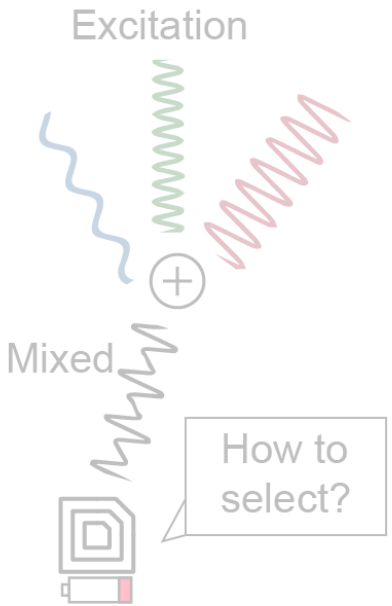

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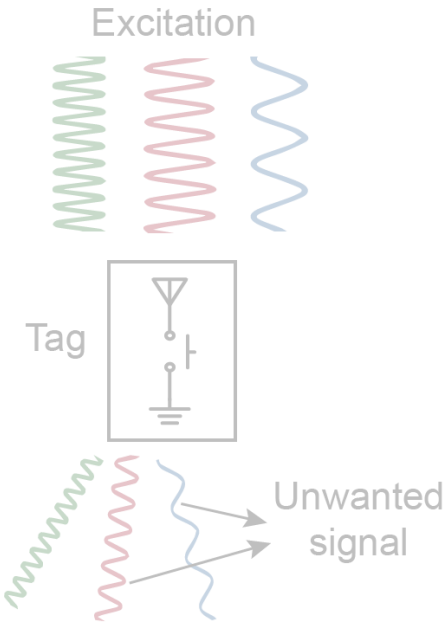

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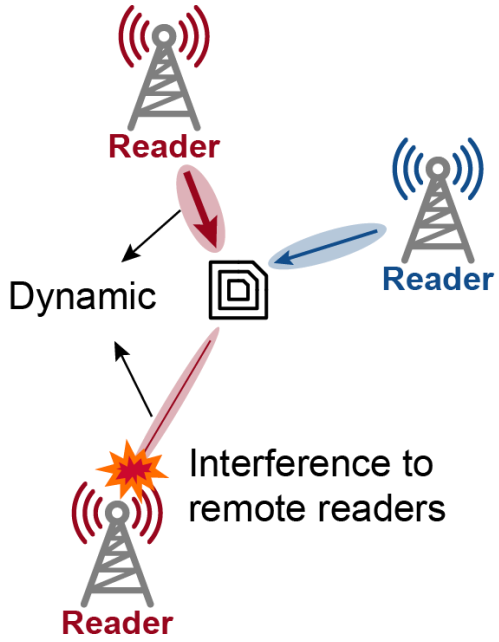
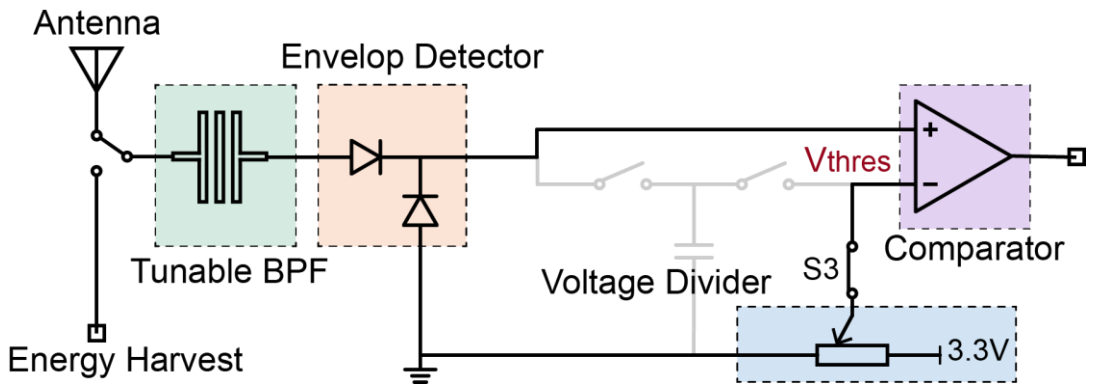
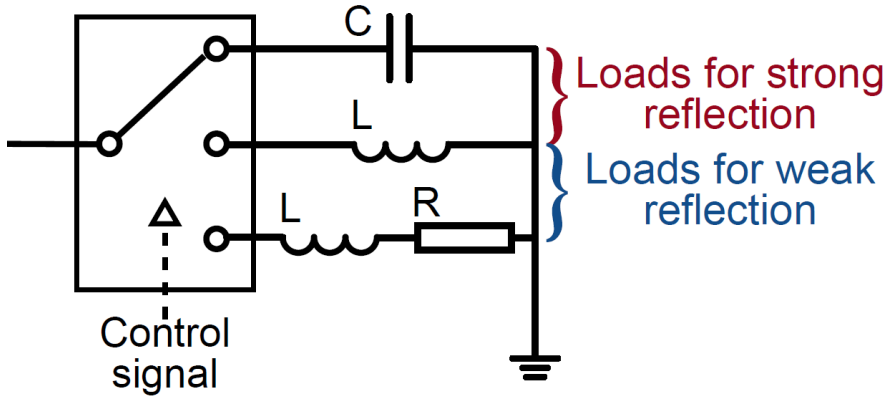


Reflection power adjuster

Step 1: Detect power



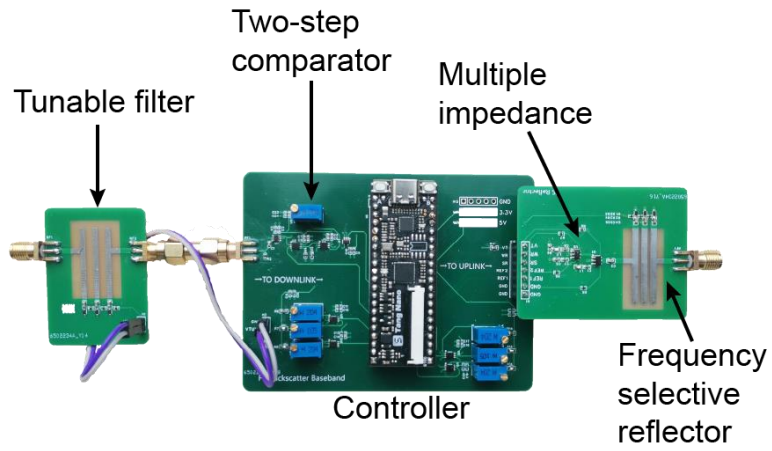
Step 2: Select loads



Reflection power adjuster: Detect excessively strong excitation and select proper loads to control the reflection strength.

Implementation

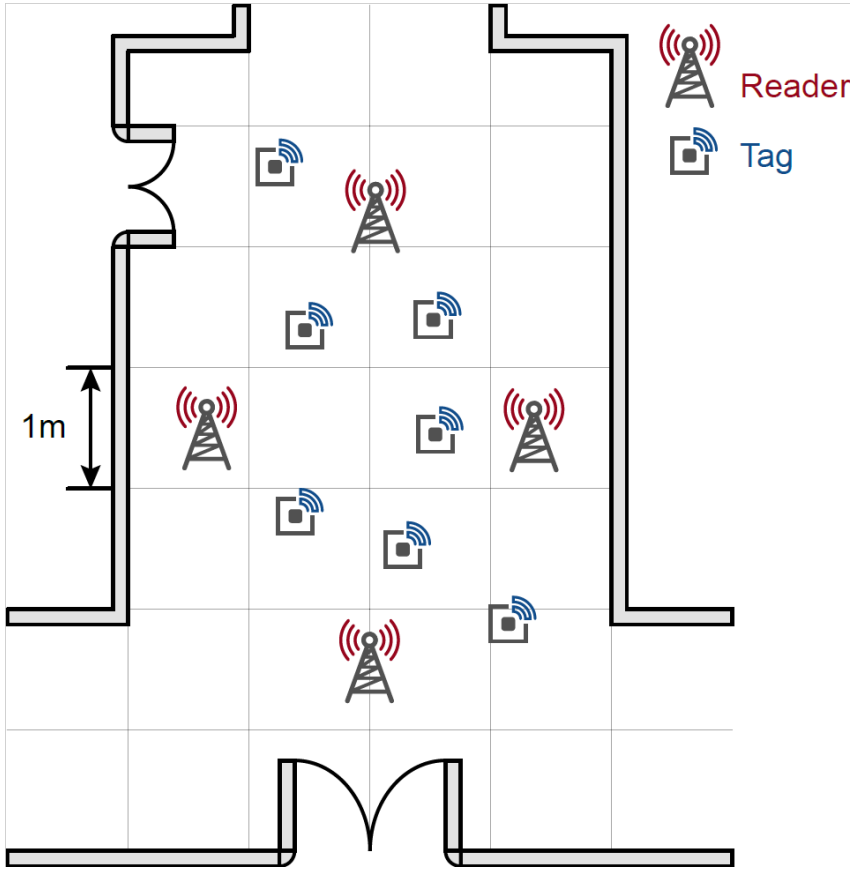
Trident tag



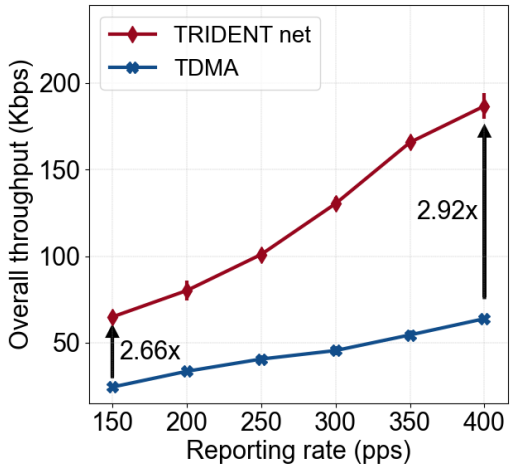
Power consumption

Implementation	Power
PCB prototype	30mW
ASIC simulation	16μW

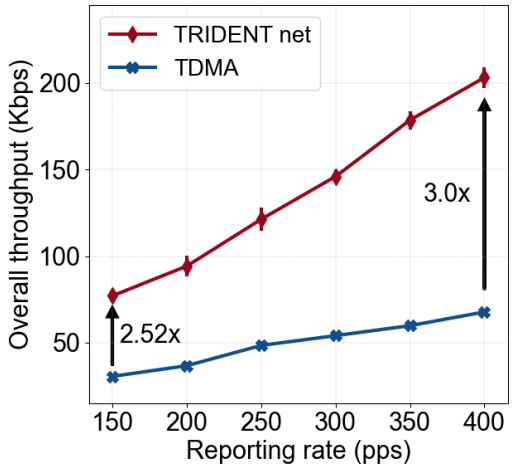
The network deployment



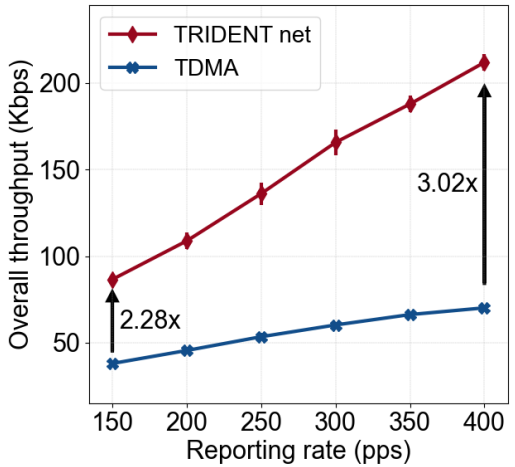
Overall performance



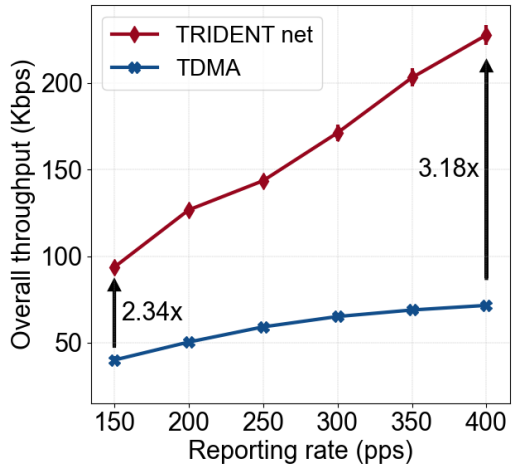
Deploy 4 tags



Deploy 5 tags



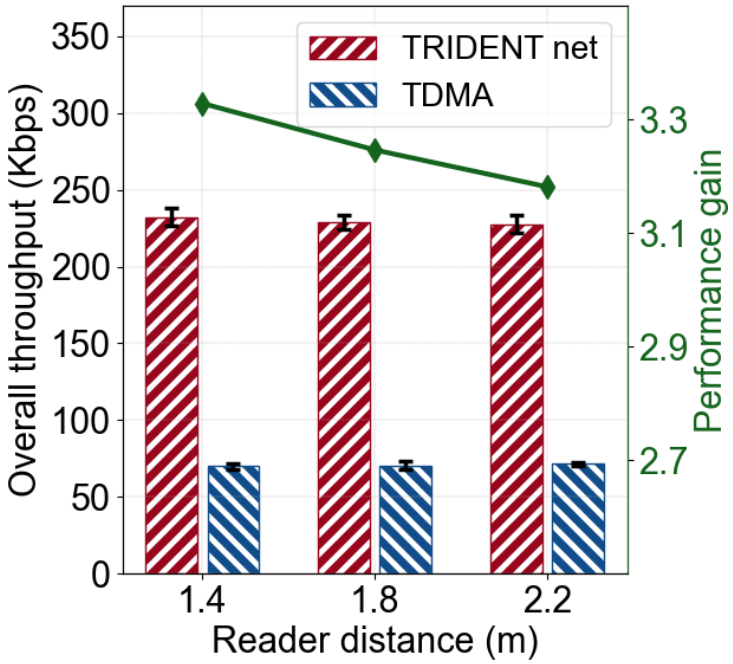
Deploy 5 tags



Deploy 7 tags

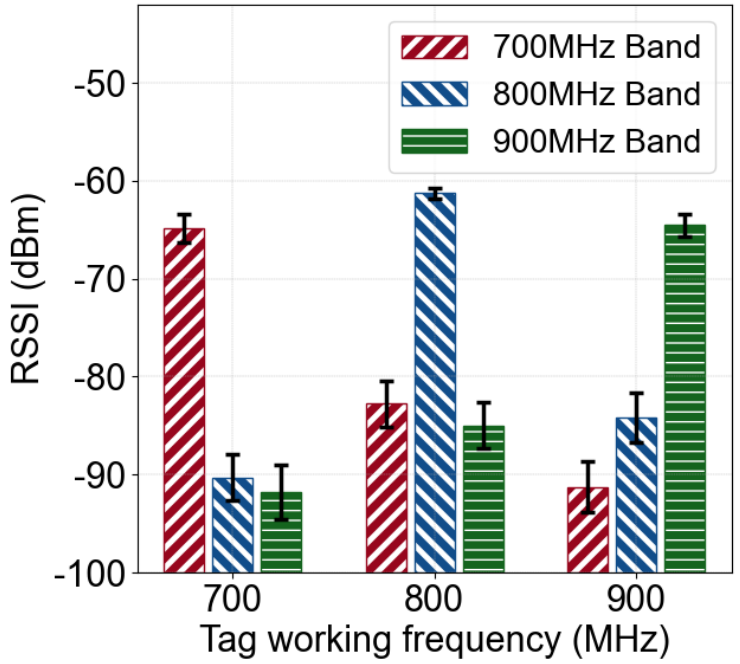
Trident demonstrates a throughput improvement of **2.28x-3.18x** across various numbers of tags and reporting rates compared to the TDMA method.

Overall performance



Trident is more suitable for dense deployment, with a performance gain of **3.33x** when distance of readers is shorter (1.4m).

Frequency selectivity of reflector



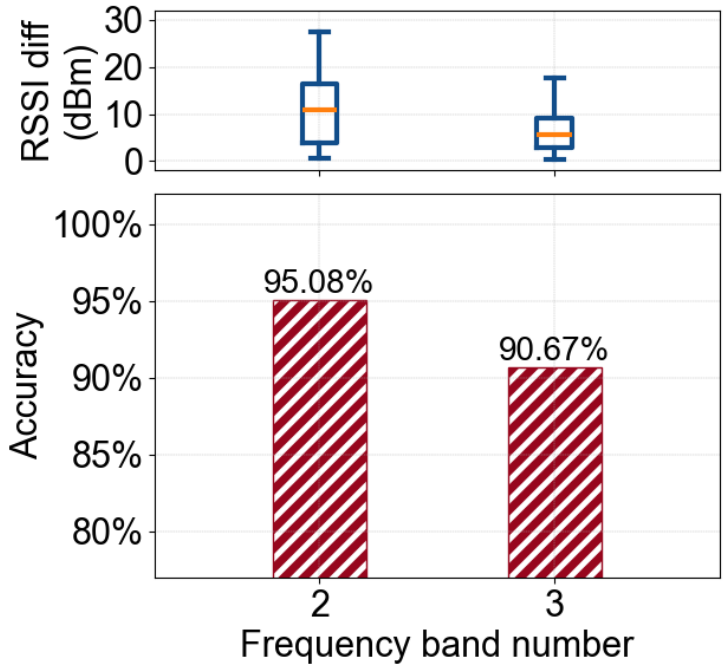
Settings:

1. set the operating frequency bands of the tag;

2. measure the strength of the backscattered signal received by the reader in different bands.

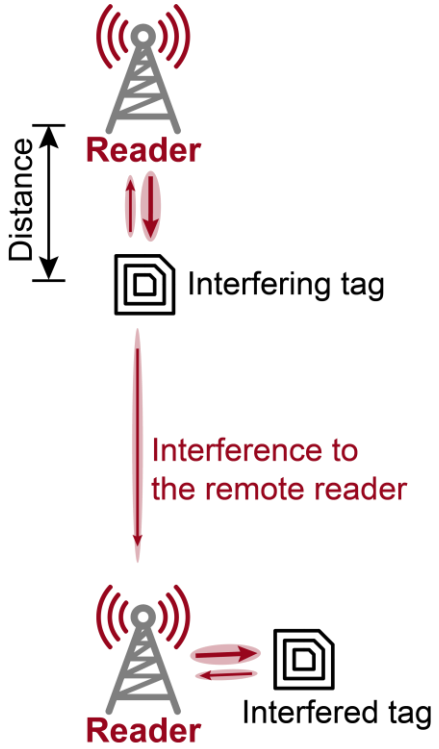
The out-of-band suppression is more than **18dB**, which demonstrates the good frequency selectivity of Trident's reflector.

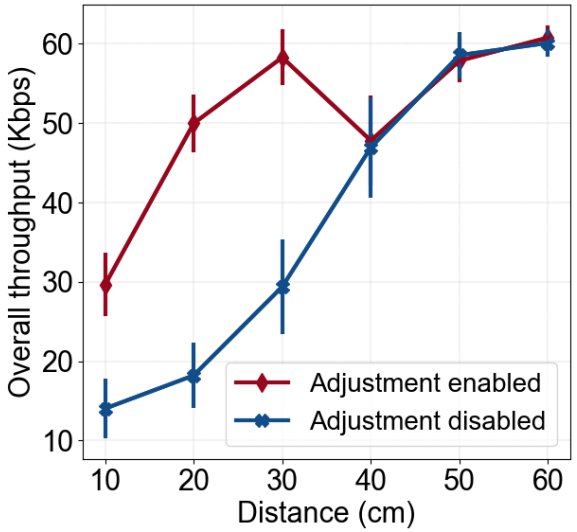
Accuracy of band selection



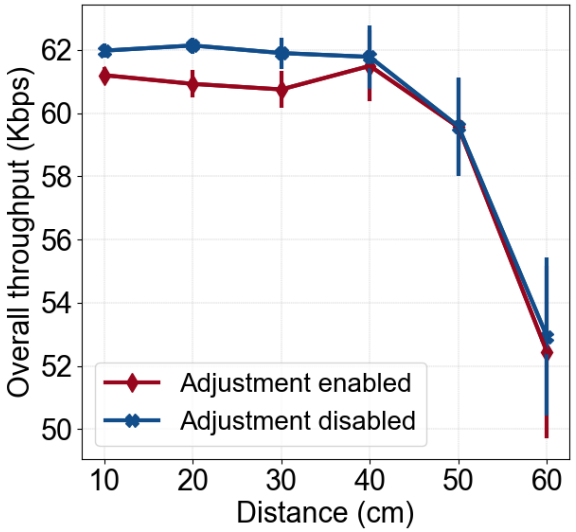
Trident can identify the frequency band with the strongest excitation signal with the accuracy of **95.08%**.

Throughput increment by adjusting power





Throughput of the interfered tag



Throughput of the interfering tag

Power adjustment can alleviate the interference significantly, while causing negligible throughput loss.

Conclusion

- We propose **Trident**, a backscatter tag design which avoids interference in the multi-reader backscatter network via **frequency-space division** to enhance the throughput of the whole network.
- The key innovation is the exploration of the direct RF signal processing on the tag, enabling the **signal extraction** and **frequency-selective backscatter.**
- Trident demonstrates **throughput improvement of 2.28x-3.18x** compared to the traditional TDMA-based scheme, without consuming more energy.

清華大學 Tsinghua University

Thank You!

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