Self-Interference Cancellation Towards Real-Time Spectrum Sensing in Vehicular Dynamic Spectrum Access Systems

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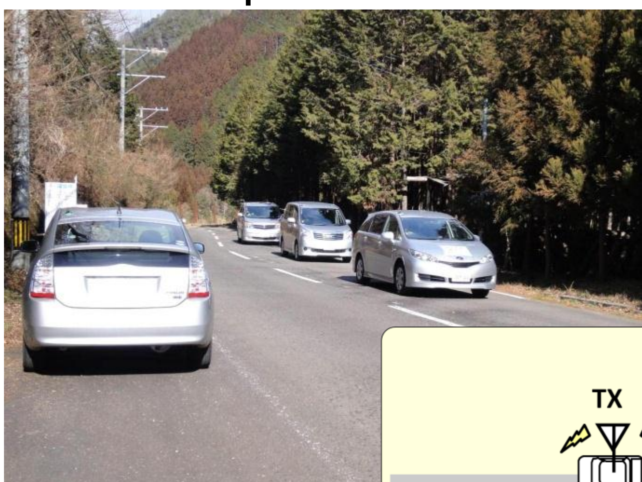
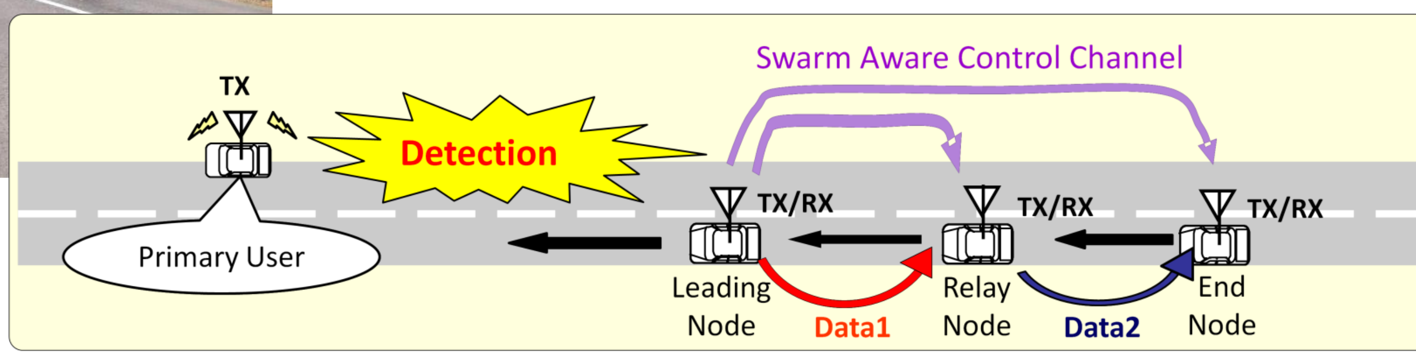
Outline

- Motivation
- Sensing with self-interference cancellation
  - Cancellation in analog domain
  - Cancellation in digital domain
- Performance evaluation
  - Experimental setup
  - Results
- Conclusion

Objective

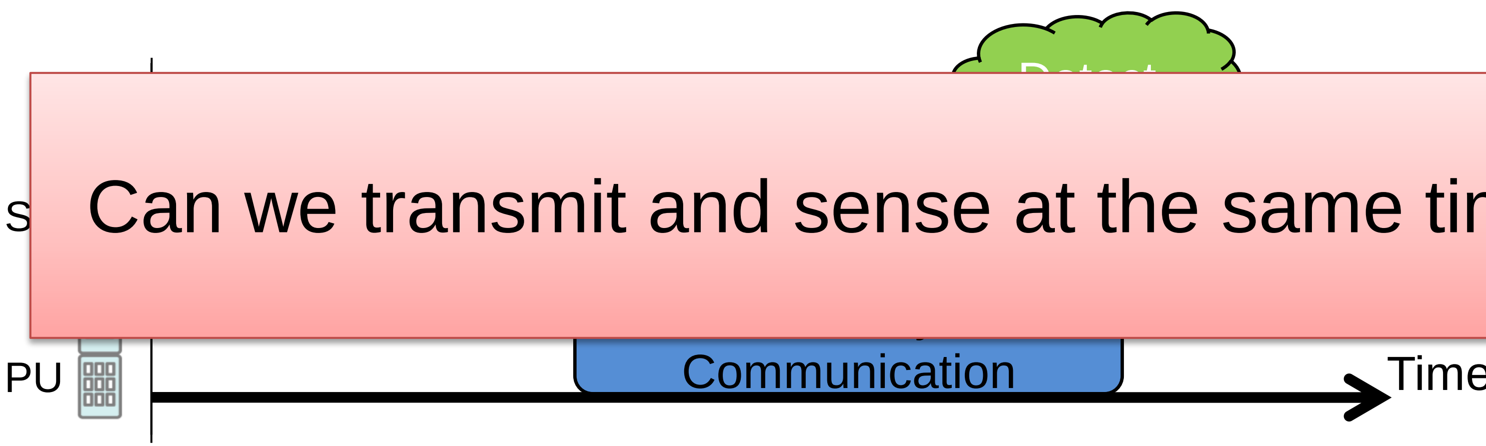
- Dynamic spectrum access (DSA) in the vehicular environment
  - We developed proof of concept demo
  - Ad-hoc vehicular network in TV white space
    [Altintas et al, Mobicom ’12], [Ihara et al, CCNC ’13]
  - Spectrum awareness is achieved through sensing





Conventional sensing approach

- Alternate between sensing and communication intervals
- Drawbacks of quiet periods:
  - Lower channel utilization
  - Possible delay in detection of PUs
    - ✓ In the vehicular environment spectrum occupancy changes faster
  - Mobility creates difficulties in time synchronization of sensors
    - ✓ GPS signal can be lost
    - ✓ Connectivity between nodes can be lost



Can we transmit and sense at the same time?

Related work

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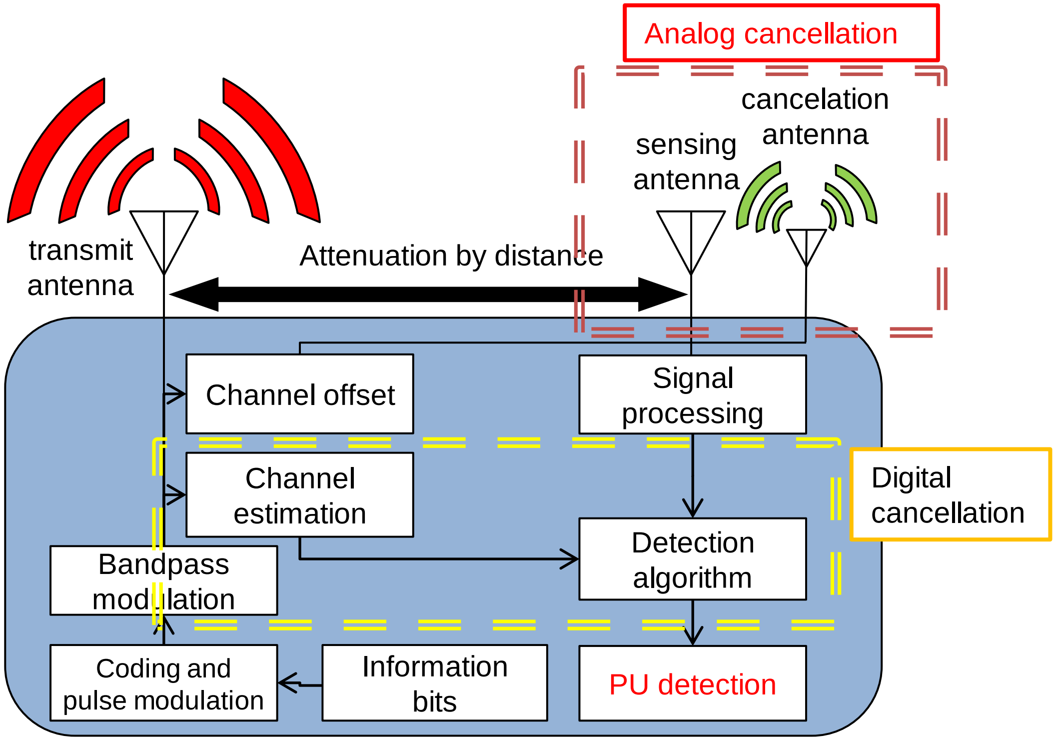
- Full duplex wireless communication [Choi et al ‘10]
  - Cancel self-interference to transmit and receive at the same time
  - We use similar approach for different purpose
- Detecting a PU by observing interference it creates to SUs [Boyd et al ‘12]
  - The same purpose but different approach
- Self-interference cancellation using MIMO [Hua et al ‘12]
  - Use beamforming to achieve full duplex communication
  - Assumes the channel between Tx and Rx (sensor) is known

Two stage self-interference cancellation

- Analog domain
  - Separate antenna injects opposite phase SU Tx signal into sensor
- Digital domain
  - Subtraction of self-interference from sensing signal

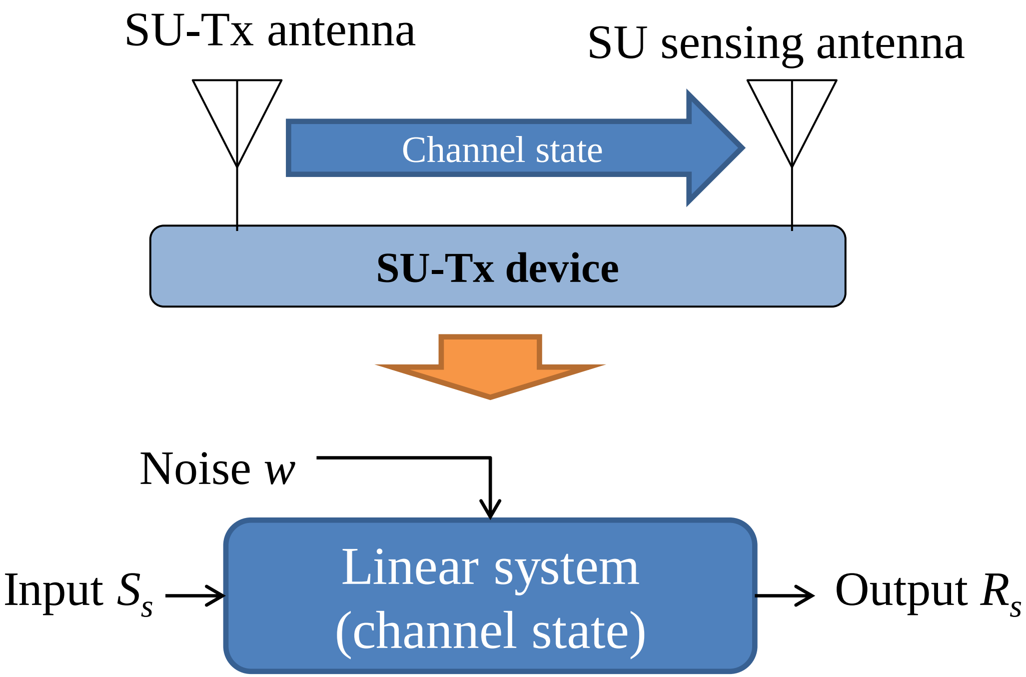


Analog domain cancellation

- Preconditions the signal for digital cancellation
  - Prevents DAC saturation due to strong SU Tx signal
  - Reduces dynamic range of the sensing signal
    - Reduces DAC quantization error of weak PU signal in presence of strong SU signal
- Vehicles present favorable platforms for antenna cancellation
  - Some SU attenuation is achieved through distance between the Tx and the sensing antenna on the car roof
- Cancellation antenna is much closer to sensing antenna
  - Low cancellation power affects SU signal only in the proximity of the sensing antenna

Digital domain cancellation

- Subtract Tx signal replica from the output of analog cancellation
  - Includes RLS MMSE estimation of the channel between the Tx and sensing antennas



$$R_{s,N+1} = z_N^T \hat{\theta}_N = h'_{s,N+1} s_{s,N+1}$$

$$\hat{\theta}_N = \hat{\theta}_{N-1} + L_N \varepsilon_N$$

$$\varepsilon_N = R_{s,N} - z_N^T \hat{\theta}_{N-1}$$

$$L_N = \frac{P_{N-1} z_N}{\rho_N + z_N^T P_{N-1} z_N}$$

$$P_N = \frac{1}{\rho_N}\left[P_{N-1} - \frac{P_{N-1} z_N z_N^T P_{N-1}}{\rho_N + z_N^T P_{N-1} z_N}\right]$$

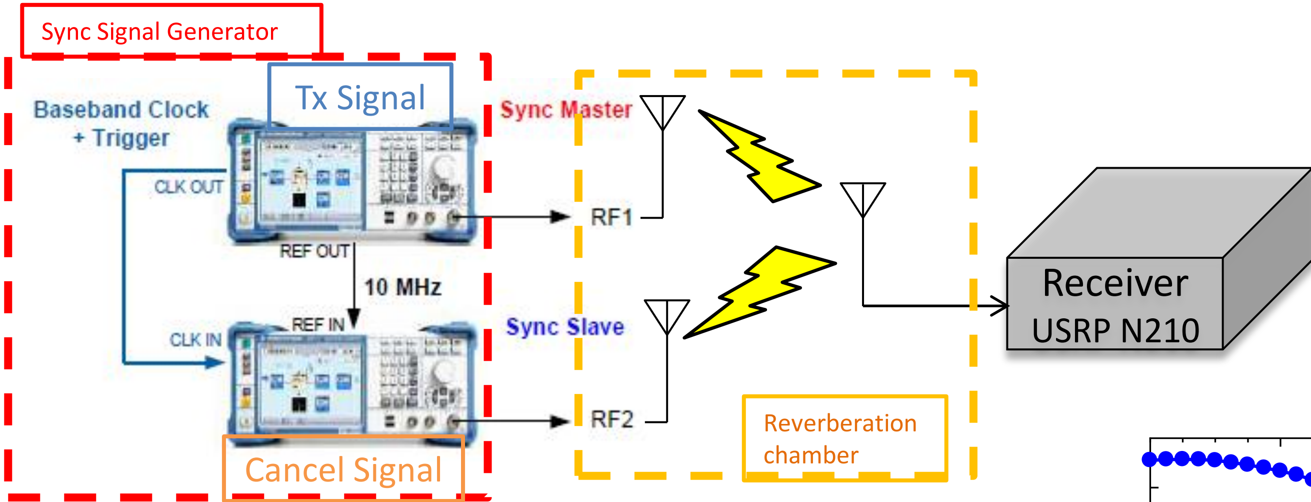
Linear system estimator

Performance evaluation

- Analog domain cancellation is evaluated experimentally
  - In controlled laboratory conditions
    - With sophisticated signal generators
    - In a reverberation chamber
    - Achieved **25 dB** reduction
  - Outdoors
    - On a stationary vehicle
    - Using Ettus USRP N210
    - Achieved **20 dB** reduction

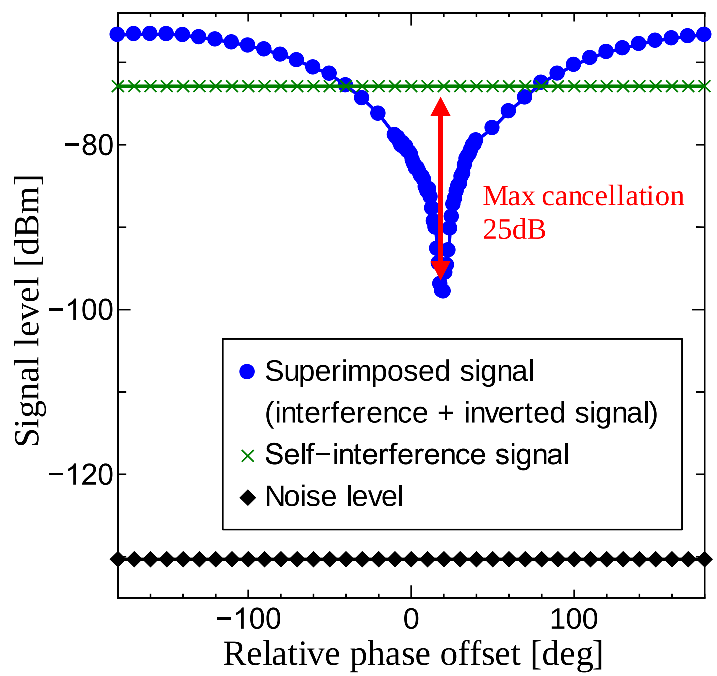
- Digital domain cancellation is evaluated numerically
  - Achieved **40 dB** reduction

Analog cancellation in lab environment



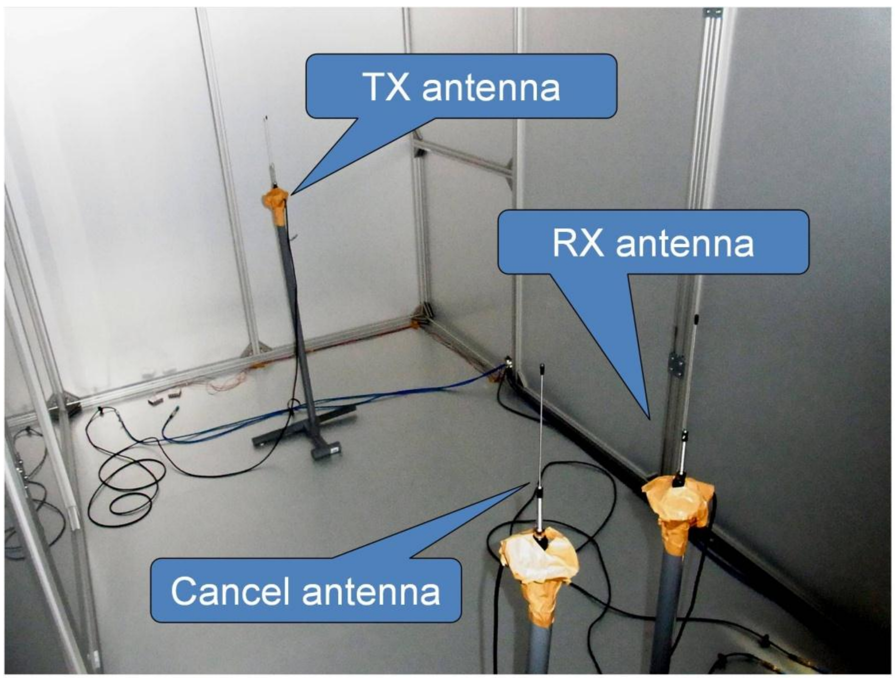
We adjust **phase offset** of the cancelation signal **in baseband** to achieve maximum suppression.

Result

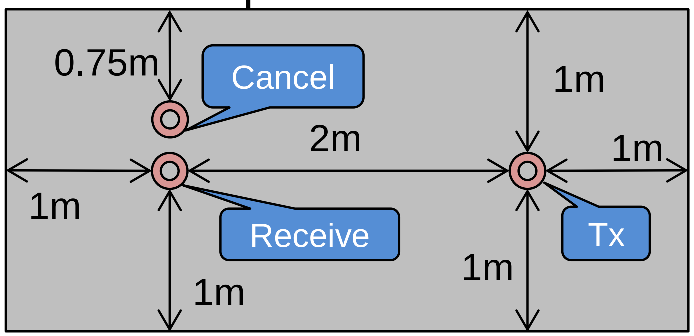


Reverberation chamber

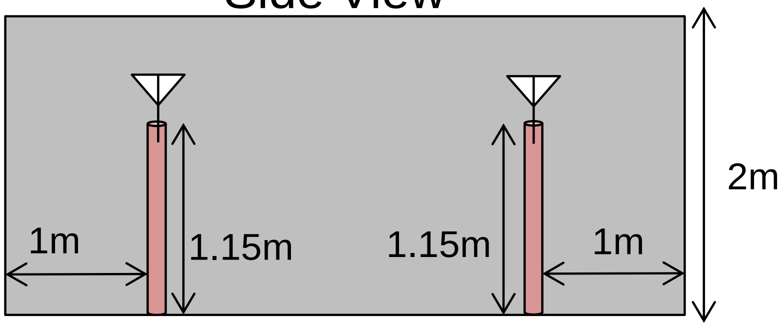
- Enables experimenting in the licensed TV band
- Provides rich multipath Rayleigh-like environment
  - Testing under unfavorable conditions



Top View

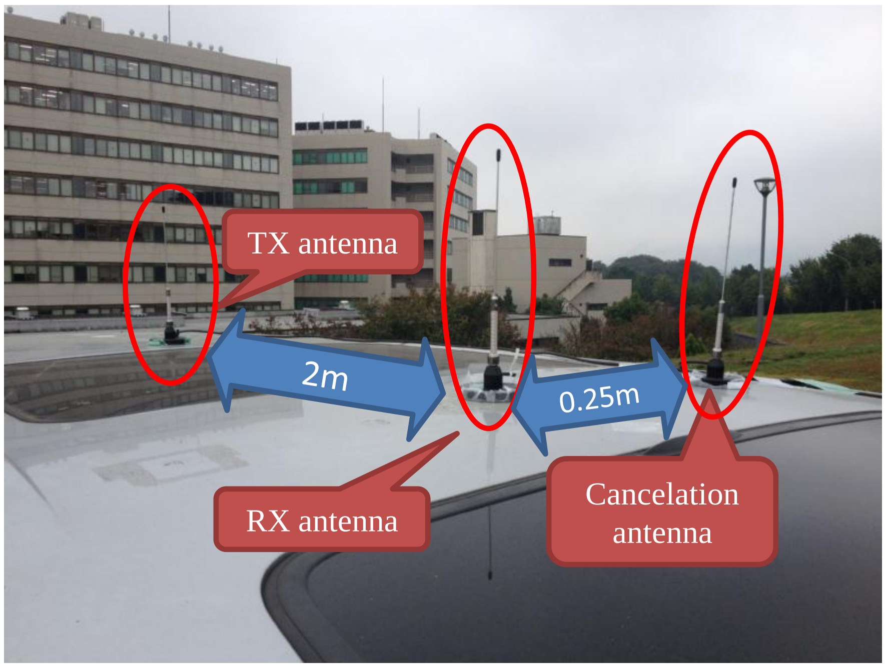


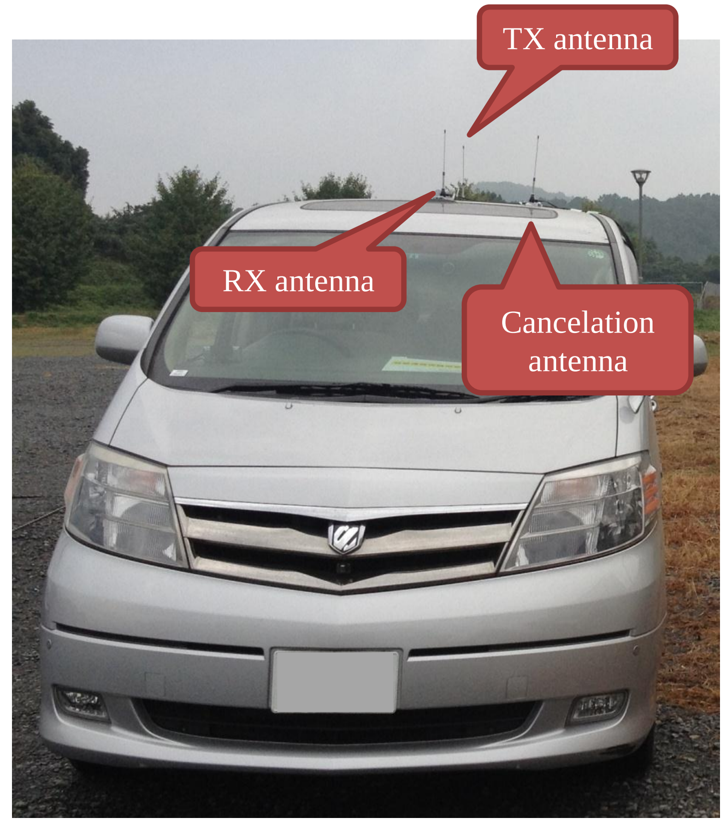
Side View



Analog cancellation outdoors

- With an experimental license valid in Iizuka, Kyushu
- Using synchronized USRP N210 radios





Sensing performance

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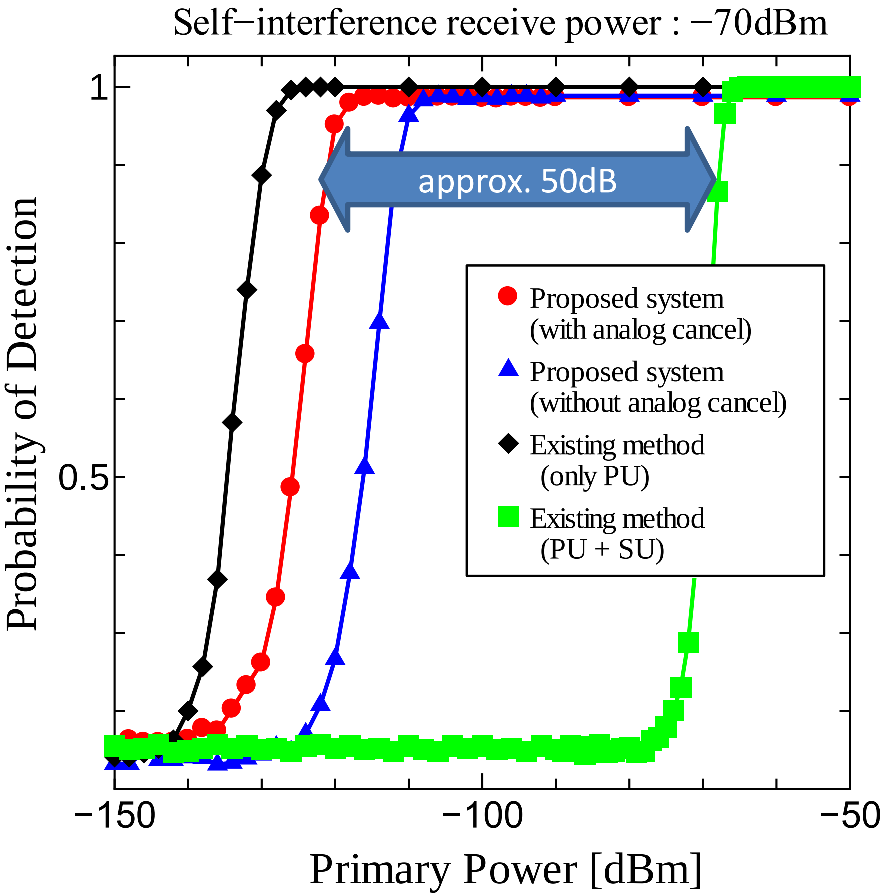
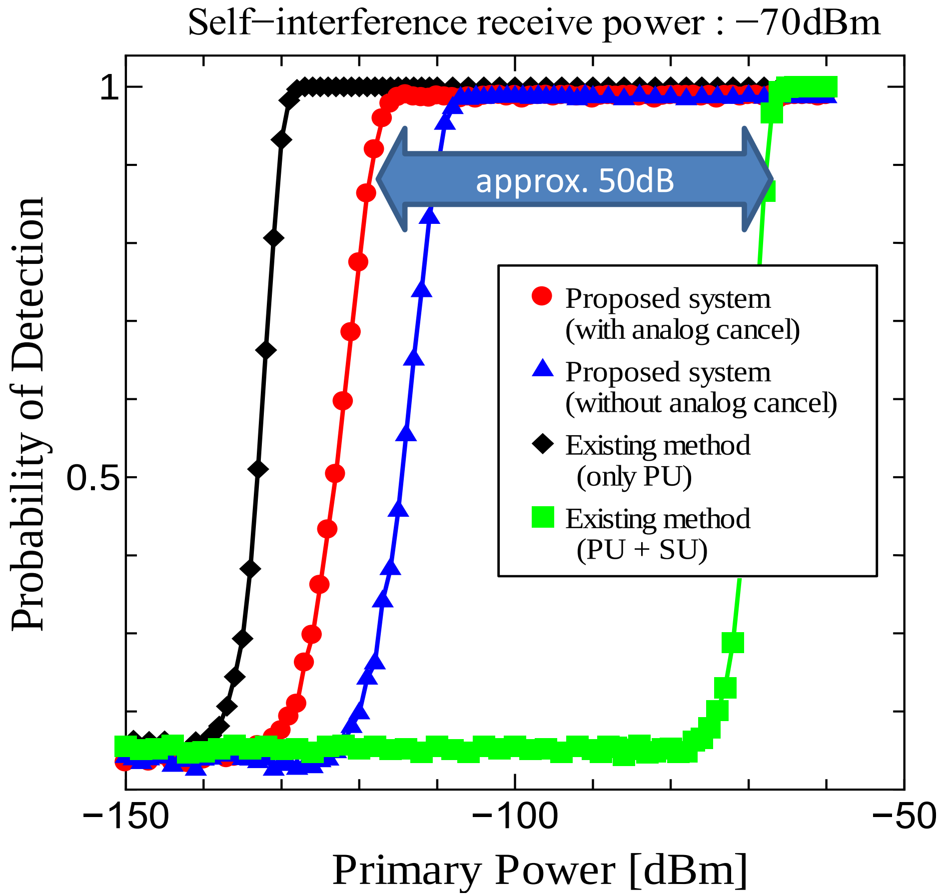
Energy Detection Threshold is set to satisfy probability of false alarm $P_{FA} = 0.15$



25dB analog cancellation



20dB analog cancellation

Conclusion

- We presented and evaluated first step towards simultaneous sensing and transmitting in the vehicular environment

- Two-stage SU self-interference cancellation
  - Analog domain cancellation achieves 20 to 25 dB rejection
  - Digital domain cancellation achieves 40 dB rejection

- Results:
  - Around 50 dB improvement in detection performance
  - Around 10 dB penalty in detection performance in comparison to sensing during quiet periods

Appendix

- Parameter settings for analog cancellation in the lab
- Parameter settings for digital cancellation
- Example of RLS-MMSE cancellation
- Detailed system block diagram

Settings for analog cancellation in the lab

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TABLE 1 Experimental Evaluation Parameters

Parameter	Value
Sequence Length	10000 symbols
Data Source	PRBS, PRBS 9
Symbol Rate	100.0 ksym/s
Filter type	Gaussian
Filter coefficient	0.30
Number of samples	320000
Sample Rate	3.20 MHz

Simulation parameters for digital cancellation

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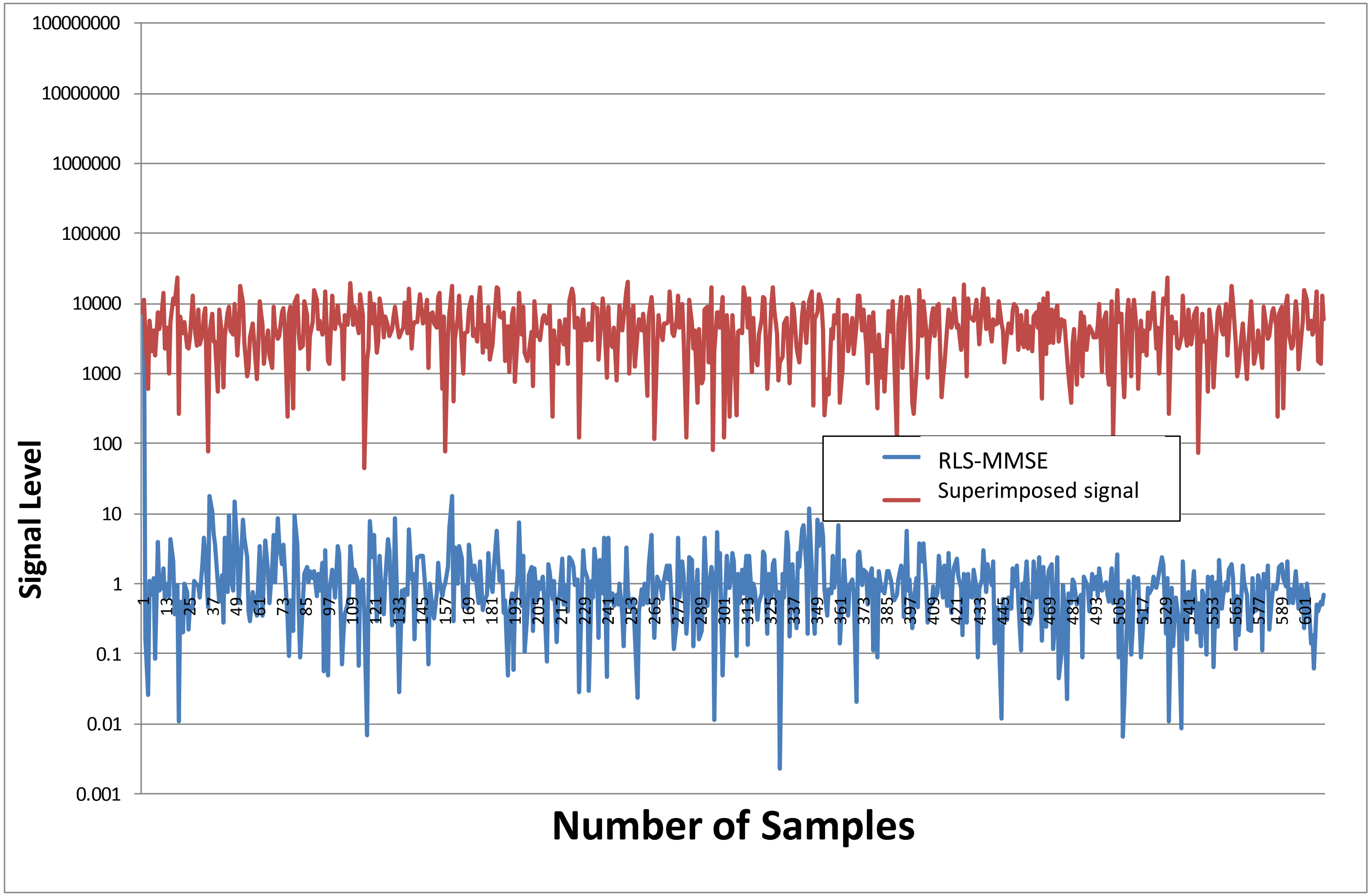
TABLE 2 Computer Simulation Parameters

Parameter	Value
Modulation	OFDM,QPSK
Number of symbols at OFDM	10
Number of pilot symbols at OFDM	2
Number of FFT points (per symbol)	512
Number of guard intervals	100
Fading environment	Rayleigh fading
Number of channel taps	8
Number of trials	5000

RLS-MMSE cancellation

- Secondary SNR 40 dB



Detailed system block diagram