Towards Instantaneous Collision and Interference Detection using In-Band Full Duplex

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Outline

• In-band full duplex
• Problem formulation: Collision detection at transmitter
• Motivation: Energy and throughput gains
• Feasibility: Sensitivity requirements
• Evaluated detection techniques
• Experiment design and evaluation
• Conclusion
In-band full duplex

- Simultaneous transmit and receive
- Same time and frequency slot
In-band full duplex

• Simultaneous transmit and receive
• Same time and frequency slot

Problem: Self Interference (SI) saturates receiver

Solution: Self Interference cancellation in two forms...
  • Analog cancellation achieves 50 to 70 dB
  • Digital cancellation up to 30dB further
In-band full duplex

- Simultaneous transmit and receive
- Same time and frequency slot

Problem: Self Interference (SI) saturates receiver

Solution: Self Interference cancellation in two forms...
  - Analog cancellation achieves 50 to 70 dB
  - Digital cancellation up to 30dB further ... replaced by our collision detector
Problem formulation
Problem formulation
Problem formulation

\[ Y_n = \begin{cases} 
  h_{tt} X_n + W_n & H_0 \\
  h_{tt} X_n + h_{it} Z_n + W_n & H_1 
\end{cases} \]
Problem formulation

\[ Y_n = \begin{cases} 
  h_{tt}X_n + W_n & \mathcal{H}_0 \\
  h_{tt}X_n + h_{it}Z_n + W_n & \mathcal{H}_1 
\end{cases} \]

Challenge: Detect weak interferers in the presence of stronger self-interference
Motivation: Energy and Throughput Gains

- Half duplex Tx
- Interferer

Wasted Energy

- Collision detecting Tx
- Interferer

Time
Motivation: Energy and Throughput Gains

- Half duplex Tx
- Interferer

Wasted Energy

- Collision detecting Tx
- Interferer

Energy per bit [µJ/bit]

Throughput gain

Number of nodes

Number of nodes
Feasibility: Sensitivity Requirement

\[ d_{ir} \]

\[ \text{Tx} \quad d_{ir} \quad \text{Rx} \]
Feasibility: Sensitivity Requirement
Feasibility: Sensitivity Requirement

Detection at both Rx and Tx
Feasibility: Sensitivity Requirement

Detection at both Rx and Tx

Misdetection

$d_{it}$

$D_{tr}$

$D_{ir}$
Feasibility: Sensitivity Requirement

Detection at both Rx and Tx

False detection at Tx

Misdetection

$d_{it}$

$Tx$

$d_{tr}$

$Rx$

$d_{ir}$
Feasibility: Sensitivity Requirement

Detection at both Rx and Tx
Target > 95%

False detection at Tx

Misdetection

Constraint ≤ 5%
Feasibility: Sensitivity Requirement

Constraint $\leq 5\%$
False detection at Tx
Misdetection

Detection at both Rx and Tx
Target $> 95\%$

$\beta\delta \triangleq$ Detection sensitivity w.r.t self interference power
Feasibility: Sensitivity Requirement

Collision detection at Tx is feasible and useful for indoor environments

Detection at both Rx and Tx
Target > 95%

Constraint ≤ 5%
False detection at Tx
Misdetection

\[ \beta \delta \triangleq \text{Detection sensitivity w.r.t self interference power} \]

\[ d_{it} \]

\[ d_{tr} \]

\[ \text{Prob. of Detection (P_D)} \]

\[ \text{Distance } d_{tr} [\text{m}] \]

\[ \beta \delta = 50\text{dB} \quad \beta \delta = 60\text{dB} \quad \beta \delta = 70\text{dB} \quad \beta \delta = 80\text{dB} \quad \beta \delta = 90\text{dB} \]
Evaluated Detection Techniques

\[ Y_n = \begin{cases} 
    h_{tt}X_n + W_n & \mathcal{H}_0 \\
    h_{tt}X_n + h_{it}Z_n + W_n & \mathcal{H}_1 
\end{cases} \]

Energy detection test statistic:  
\[ T_{ED} = \sum_{n=1}^{N} |Y_n|^2 \]

Two-sample Goodness-of-Fit Test Statistics:

- Kolmogorov-Smirnov:  
  \[ \hat{D}_{KS} = \max \{ d_+, d_- \} \]

- Kuiper:  
  \[ \hat{D}_{KP} = d_+ + d_- \]

- Anderson-Darling:  
  \[ \hat{D}_{AD} = \frac{1}{mn} \sum_{i=1}^{N-1} \frac{(M_i N - n_i)^2}{i(N - i)} \]
  
  - 2-norm difference between combined CDF and \( z_1 \)
  - Weight = \( i(N - i) \) \quad Weights tails

Estimated from \( Y_n \)

Learnt through training
Our measurement setup

- IEEE 802.15.4 signals
- TX power: 0dBm
- Noise floor: -90dBm
- EBD cancellation: 50-70dB

Node with collision detection:

- Receiver oversamples by 8
- Results averaged over 2000 measurements per interfering power
- Threshold trained for each test statistic such that $P_{FA} = 5\%$
Results

Target: $P_D > 95\%, P_{FA} < 5\%$
Results

Target: $P_D > 95\%$, $P_{FA} < 5\%$

2000 samples = 250 μs, i.e., 4 bytes in an 8 times oversampling 802.15.4 receiver
Results

Target: $P_D > 95\%, P_{FA} < 5\%$

Observation duration: 250 $\mu$s
Conclusions

- Collision detection at TX is practical for indoor environments
- Kuiper test + analog SI cancellation can detect interferers up to -75 dBm
- Almost instantaneous: only 250 μs
Thank you!
References
