Robust Location Distinction Using Temporal Link Signatures

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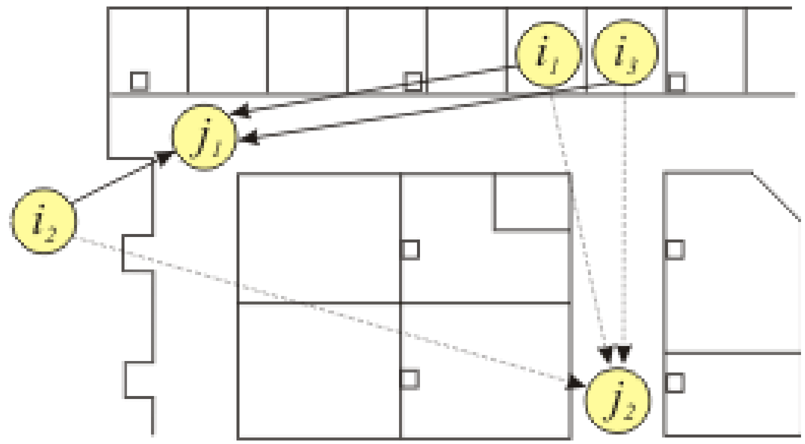
What is location distinction?

- Ability to know when a transmitter has changed position
- Enabled by the physical layer only
- Compared to localization
  - no coordinates
  - benefits from multipath
  - more sensitive, needs less coverage



Each transmitter (i_1, i_2, i_3) is distinguished at the two receivers (j_1, j_2)

Neal Patwari and Sneha Kasera, “Robust Location Distinction Using Temporal Link Signatures”, ACM MobiCom 2007.

Applications

- Efficient location estimation in WSN
- Physical security, management of objects
- Prevent impersonation in wireless networks

Location Estimation in WSNs

- Network self-localization expensive
  - Ranging energy, bandwidth
  - Communication
- Only re-localize when sensor moves

  How do you know? Collaboration?
- WSN low-energy location distinction: detect movement w/o collaboration

Real-Time Location Service

- Applications in Logistics
  - Healthcare, distribution, manufacturing, mining, military, …
- Idea: Detect Movement of Objects
  - most assets should be stationary
  - focus resources on rare moving assets
- However, existing methods are costly!
  - Accelerometers: add $3 to each tag
  - Doppler: require continuous transmission
  - both: energy, cost, communication inefficient
- Localization Issues: Coverage, Accuracy, Security

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Wireless LAN Security

- Impersonation
- MAC-address spoofing [1]
- Traditional crypto methods subject to node compromise

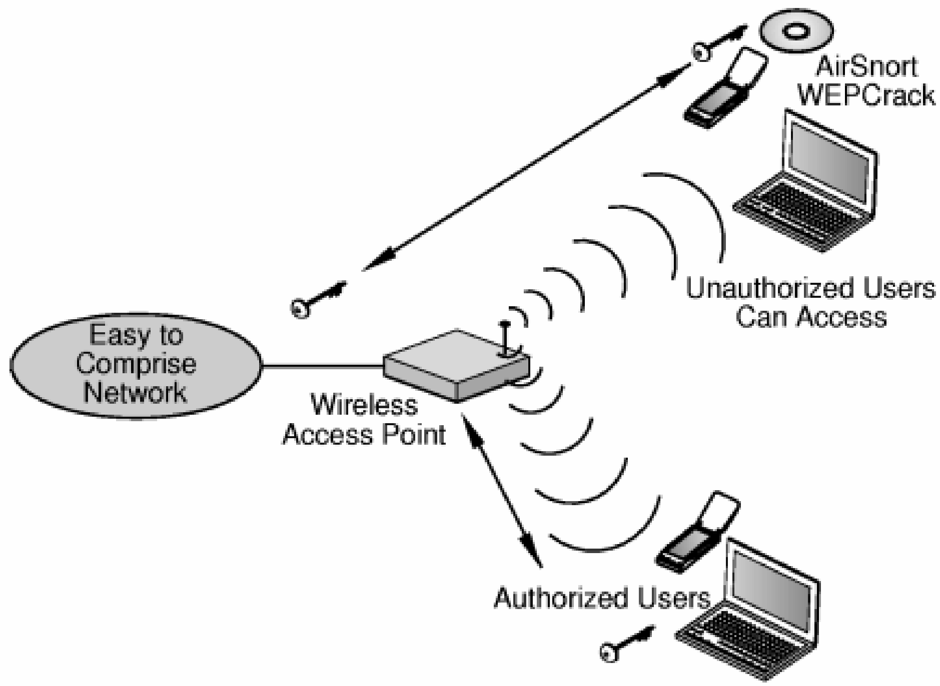


Image from HP, http://docs.hp.com/en/T1428-90017/img/gfx2.gif, "Three Levels of Wireless Security"

[1] D. B. Faria and D. R. Cheriton. Radio-layer security: Detecting identity-based attacks in wireless networks using signalprints. In *Proc. 5th ACM Workshop on Wireless Security (WiSe'06)*, pages 43-52, Sept. 2006.

Goals & Challenges

- Develop link signatures with key properties
  - uniqueness: as function of tx, rx locations
  - non-measurement: can't read from another place
  - spoof-proof: can't create from another place
- Efficiency: receivers, time
- Do not change transmitter
- Validate with real measurements

Outline

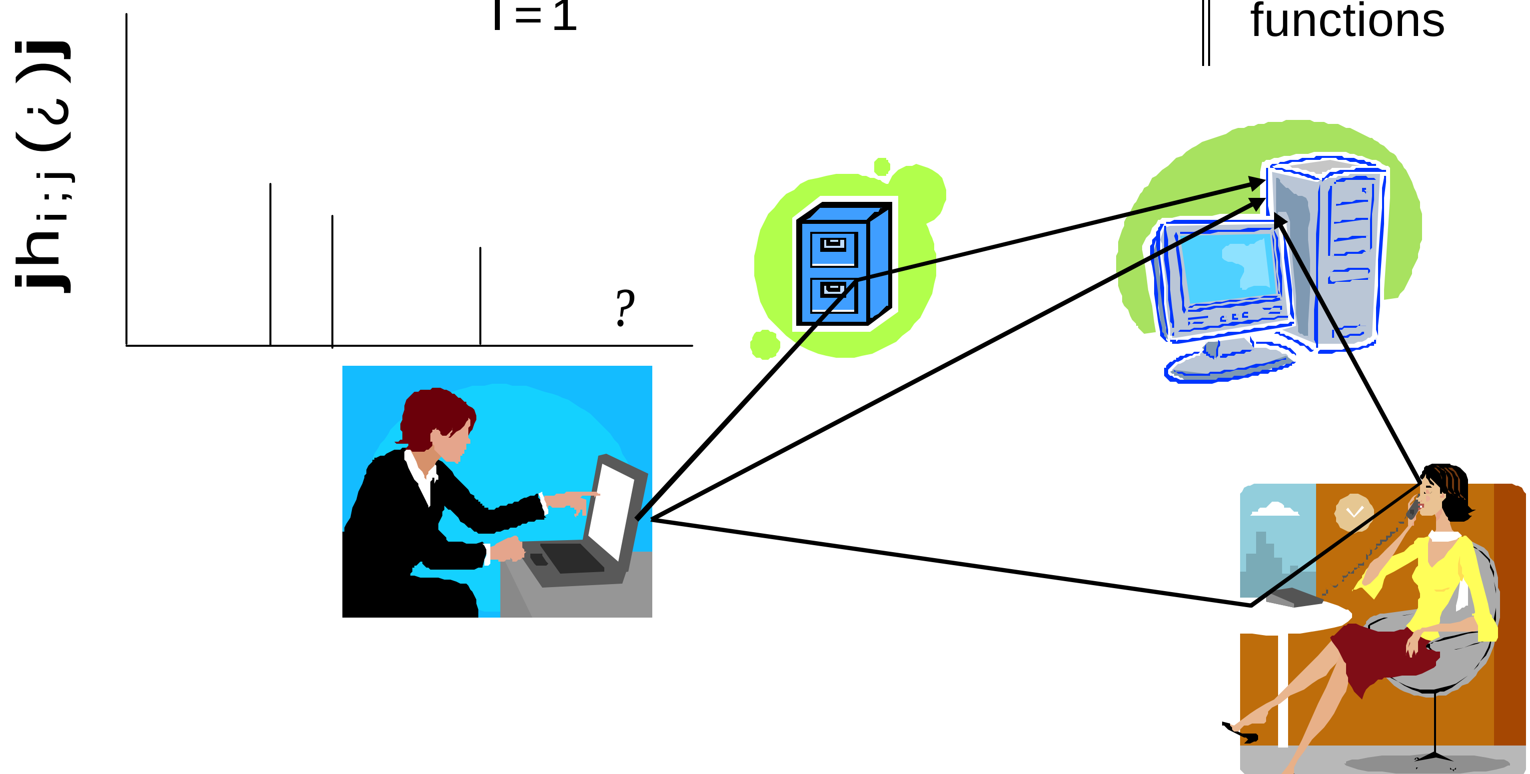
- Temporal link signatures
- Related work
- Methodology
- Measurement apparatus
- Quantitative evaluation
- Summary

Physical Layer Filter

Wireless channel from *i* to *j* is a filter $h_{i,j}(\tau)$

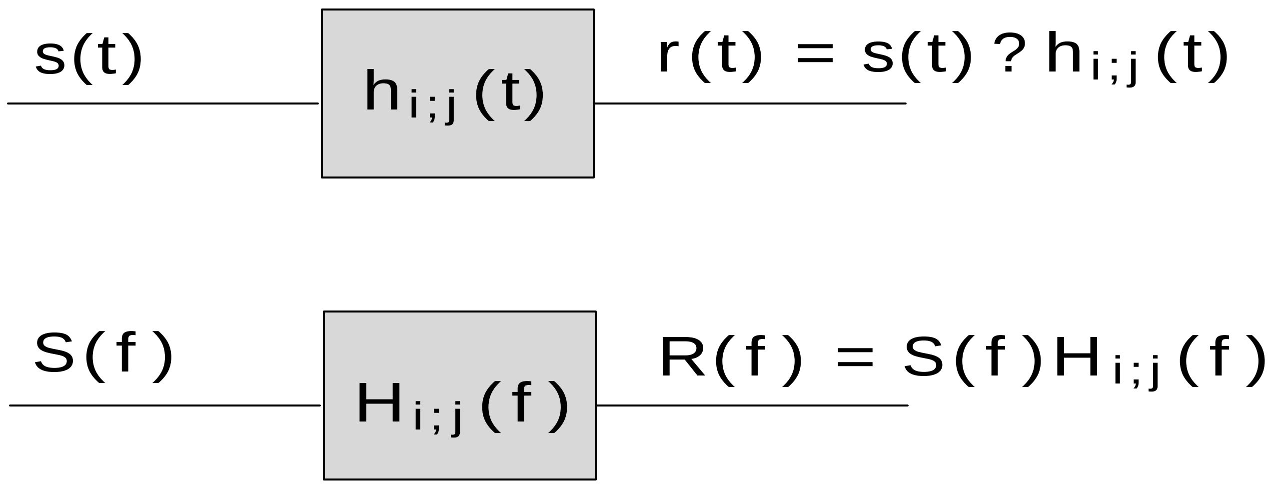
$$h_{i,j}(\tau) = \sum_{l=1} \alpha_l e^{j\phi_l} \delta(\tau - \tau_l)$$

Sum of attenuated, delayed impulse functions



Received Signal

- The signal is filtered by the channel



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Calculation in Receiver

- Further convolve with known tx signal

$$r(t) \longrightarrow \boxed{s^{*}(t)} \longrightarrow h^{(n)}_{i,j}(t) = s(t) \star h_{i,j}(t) \star s^{*}(t)$$

$$R(f) \longrightarrow \boxed{S^{*}(f)} \longrightarrow H^{(n)}_{i,j}(f) = |S(f)|^{2} H_{i,j}(f)$$

Estimate of the Channel

- Typically $|S(f)|^2$ largely flat in-band, very low out of band. (spectral efficiency)

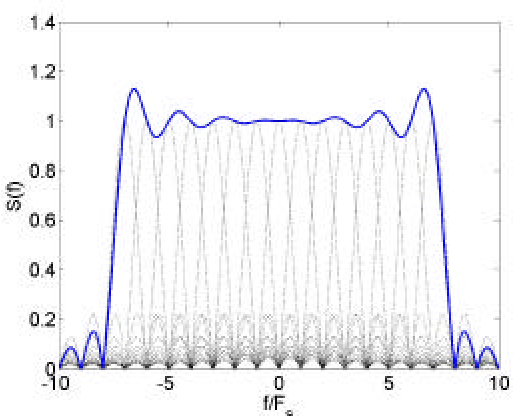

Figure: Spectral characteristic of an OFDM signal

$$H^{(n)}_{i,j}(f) = |S(f)|^2 H_{i,j}(f)$$

$$H^{(n)}_{i,j}(f) \approx H_{i,j}(f)$$

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Temporal Link Signature

- In time domain, *temporal* link signature

$$h^{(n)}_{i;j}(t) ¼ h_{i;j}(t)$$

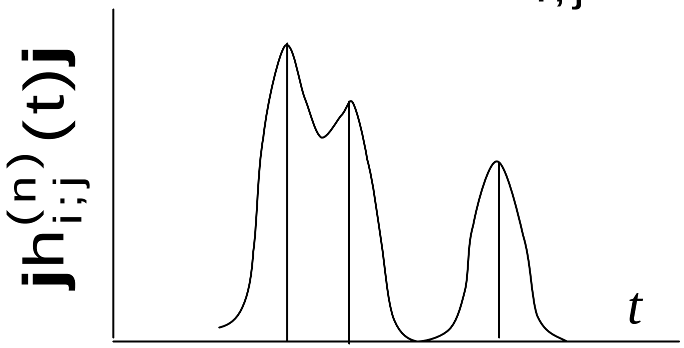

Figure: Multipath (?) are approximated in the measurement (?) $h_{i;j}(t)$

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Related Work

- Use RSS only (multiple receivers) [1]
  - Power in received signal $r(t)$
- Use frequency-domain estimate [2]
  - Equivalent to $H_{i,j}^{(n)}(f)$ at selected frequencies $\{f\}$

[1] D. B. Faria and D. R. Cheriton. Radio-layer security: Detecting identity-based attacks in wireless networks using signalprints. In *Proc. 5th ACM Workshop on Wireless Security (WiSe'06)*, pages 43-52, Sept. 2006.

[2] Z. Li, W. Xu, R. Miller, and W. Trappe. Securing wireless systems via lower layer enforcements. In *Proc. 5th ACM Workshop on Wireless Security (WiSe'06)*, pages 33-42, Sept. 2006.

Temporal Link Sig. Methodology

- Sampled temporal link signature

$$h_{i,j}^{(n)} = [h_{i,j}^{(n)}(0), \ldots, h_{i,j}^{(n)}(\cdot T_r)]^T$$

- Normalized link signature (NLS)

$$\bar{h}_{i,j}^{(n)} = \frac{h_{i,j}^{(n)}}{\|h_{i,j}^{(n)}\|}$$

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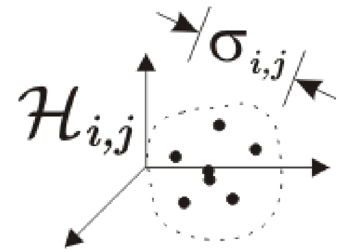
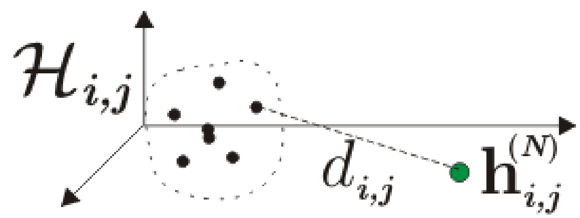
Distance Between Signatures

- History for $\{\mathbf{h}_{i,j}^{(n)}\}_{n=1,\ldots,N-1}$



- Size of history $\sigma_{i,j}$: avg. distance between points
- New measurement $\mathbf{h}_{i,j}^{(N)}$



- Distance: normalized Euclidean (l_2) to closest point

$$d_{i,j} = \frac{1}{\sigma_{i,j}} \min_{\mathbf{h} \in \mathcal{H}_{i,j}} \|\mathbf{h} - \mathbf{h}_{i,j}^{(N)}\|$$

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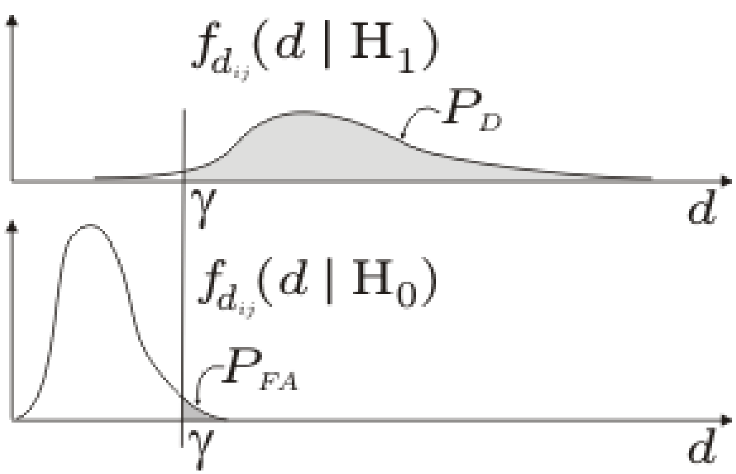
Detection of Different Location

- Want to test two cases

  H_0: New Meas't at same location

  H_1: New Meas't at different location

- Two conditional densities for distance d



- Choose a threshold ?

P_{FA} = Probability of false alarm
P_D = Probability of detection

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Measurement Experiment

- Meas't set from Motorola office area
- Using 40 MHz direct sequence spread-spectrum (DSSS) Tx and Rx

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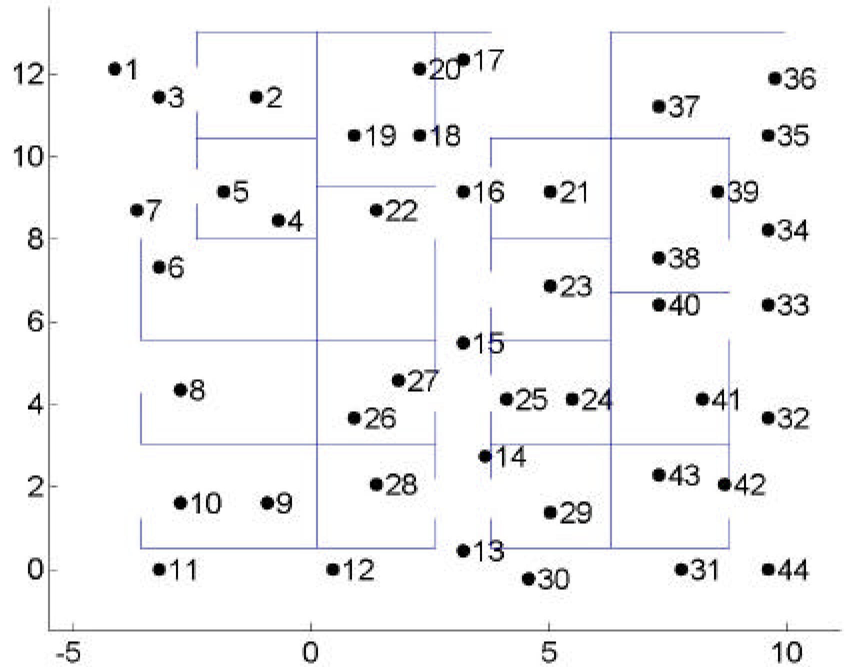
Measurement Experiment



- Node locations measured

Cubicle Partitions

- 13 by 15 m area, and 44 devices
- 5 meas'ts per link (over 30 sec)
- 44 x 43 x 5 = 9460 measurements
- 'Manual' procedure, Mostly stationary

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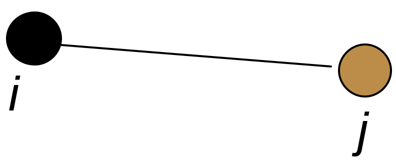
Leave-one-out Comparison

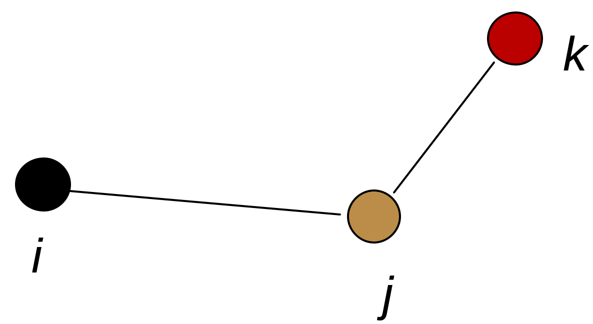
Temporal Differences:

- Compare N = 5 meas't from same link (i,j) to History for (i,j)

Spatial Differences:

- Compare N = 5 meas't from different link (k,j) to History for (i,j)





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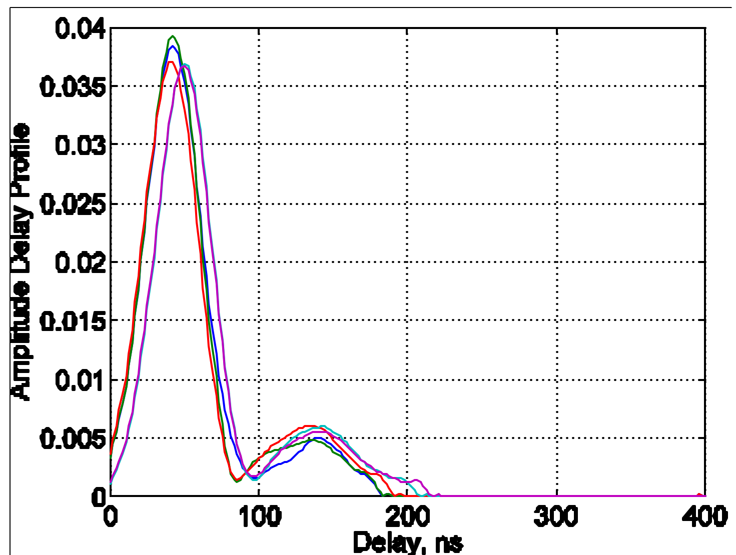
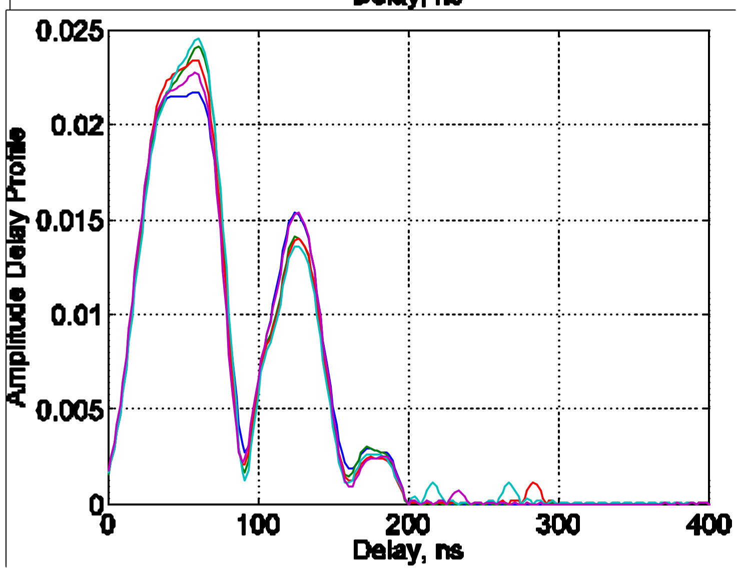
Example Link Signatures

Link 13 to 43



Link 14 to 43



- Each plot: 5 meas'ts

$$h_{i;j}^{(n)} \quad n = 1;:::;5$$

- How different are they?
  - Temporal Differences: 0.18, 0.76
  - Spatial Differences: 3.6, 10.0

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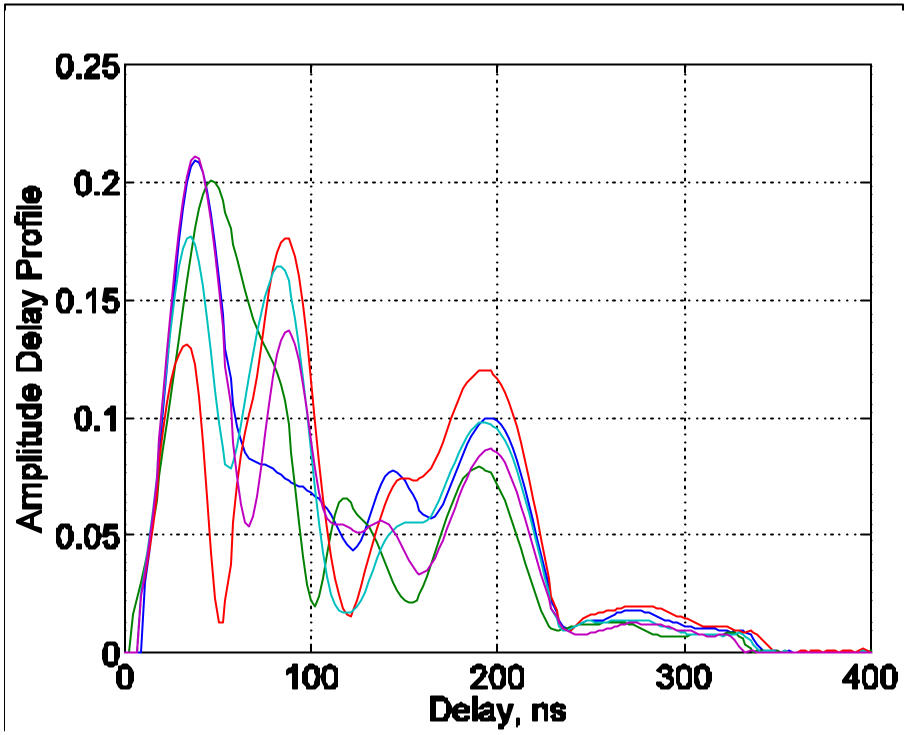
Link Signatures: Worst Case

- Temporal channel changes can cause changes
  - most widely varying set



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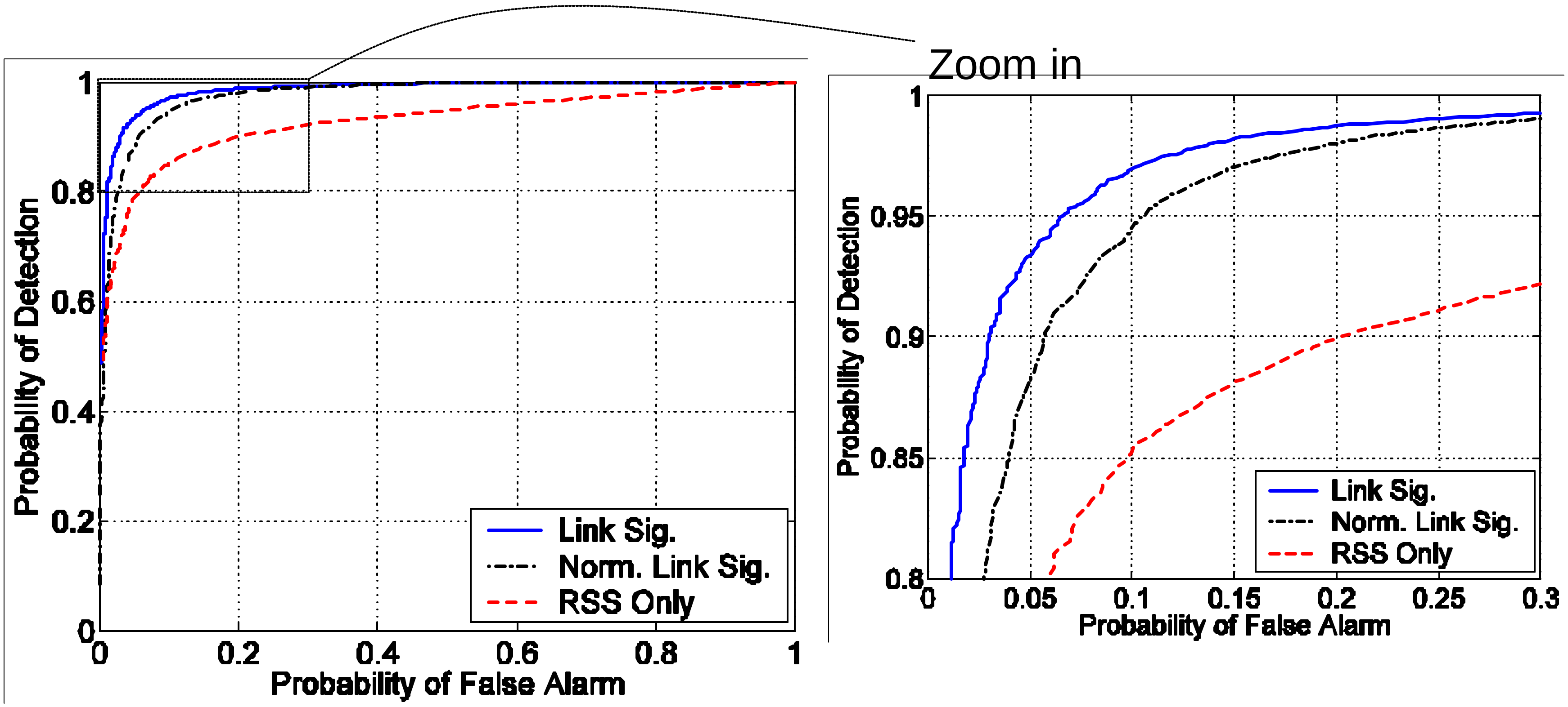
Comparing Results

- Three methods
  - RSS [Faria 2006]
  - Link Signature
  - Amplitude-Normalized Link Signature

Performance with one Rx

- Adjustable results based on threshold



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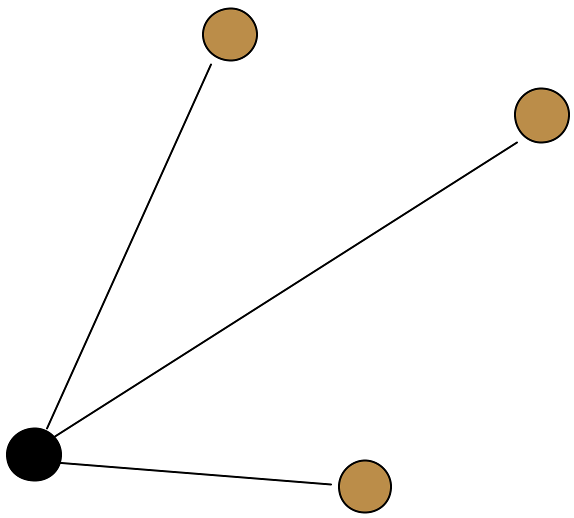
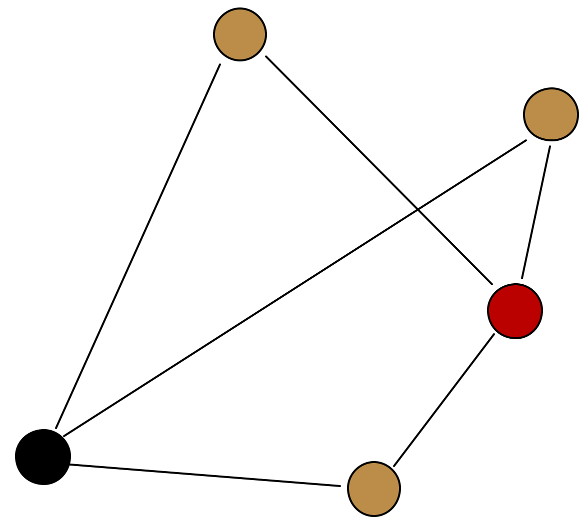
Heavy Tail on Worst Links

- Worst 5% of links cause 46% of missed detections
  - System could disable link signatures for highly varying links

Multiple Receivers

- Can employ more than one receiver (access point)





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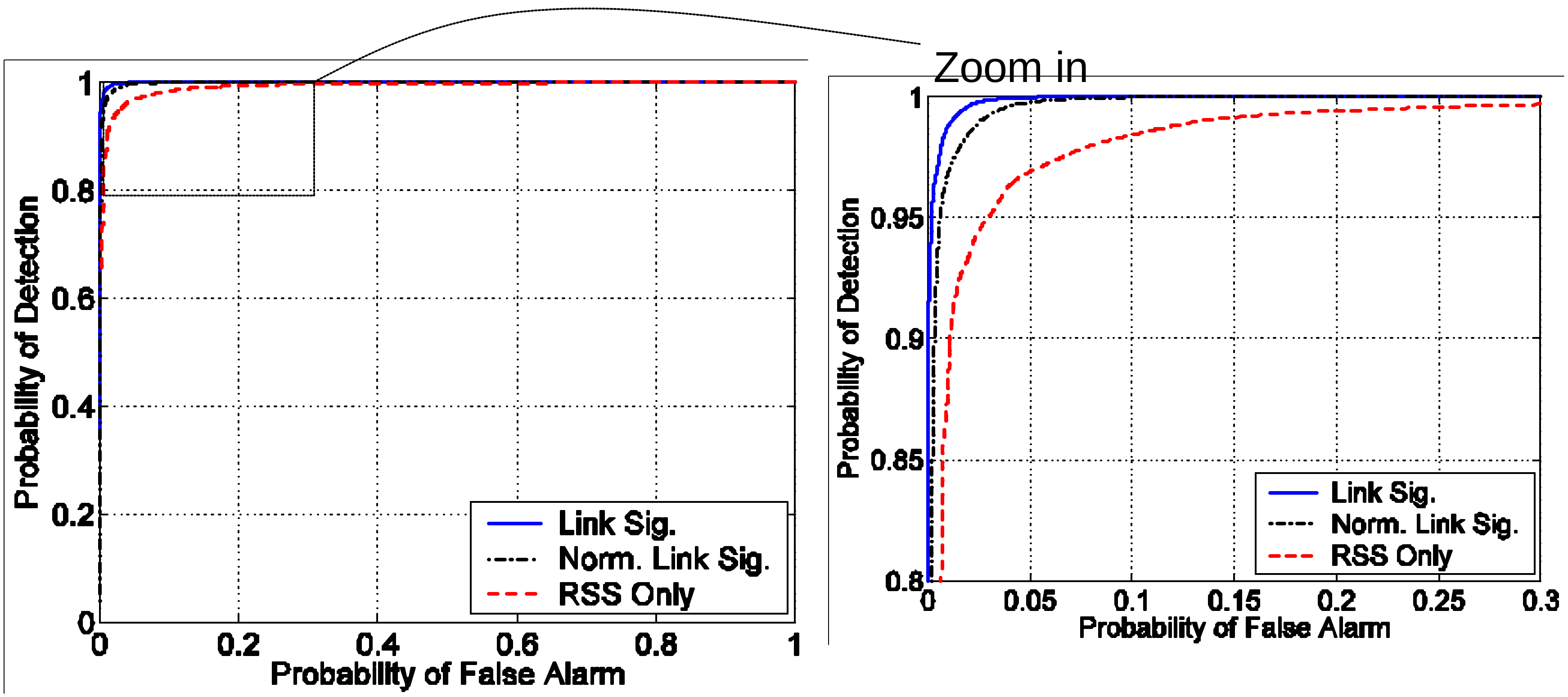
Performance with Three Rx

- Significantly higher reliability compared to one Rx



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Multiple RX Summary

- Table 1: False Alarm Rates for Constant 95% Detection Rate

Method	1 RX	3 RX
LS	0.0655	0.0019
RSS	0.5164	0.0295

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Summary

- Robust location distinction can be achieved using temporal link signatures
- Significant improvement over RSS-only signature methods
- Future work
  - Comparison w/ freq-domain link signatures [Li '06]
  - Study other link characteristics, metrics
  - Real-time Implementation

Measurement Data Access

- SPAN Website
  - http://span.ece.utah.edu/
  - Under "Data & Tools"
- To appear in CRAWDAD

Threat Model

- Attacker can
  - listen to all wireless traffic
  - compromise encryption
  - use attenuators, amplifiers, directional antennas, software radios
- Attacker cannot
  - be at location of user
  - be at location of access points
- System deployment must have multiple coverage

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