Using Classification to Protect the Integrity of Spectrum Measurements in White Space Networks

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Network and Distributed System Security Symposium (NDSS)

Feb 17, 2011

Opportunistic Spectrum Access

- Spectrum crunch
  - Increased demand
  - Limited supply
  - Inefficiencies of fixed and long term spectrum assignment (*licenses*)
- Emerging solution: opportunistic access to unused portions of licensed bands

Opportunistic Spectrum Access

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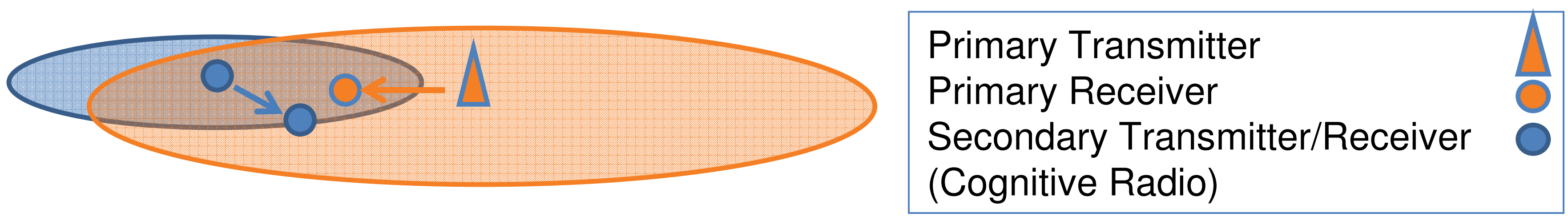
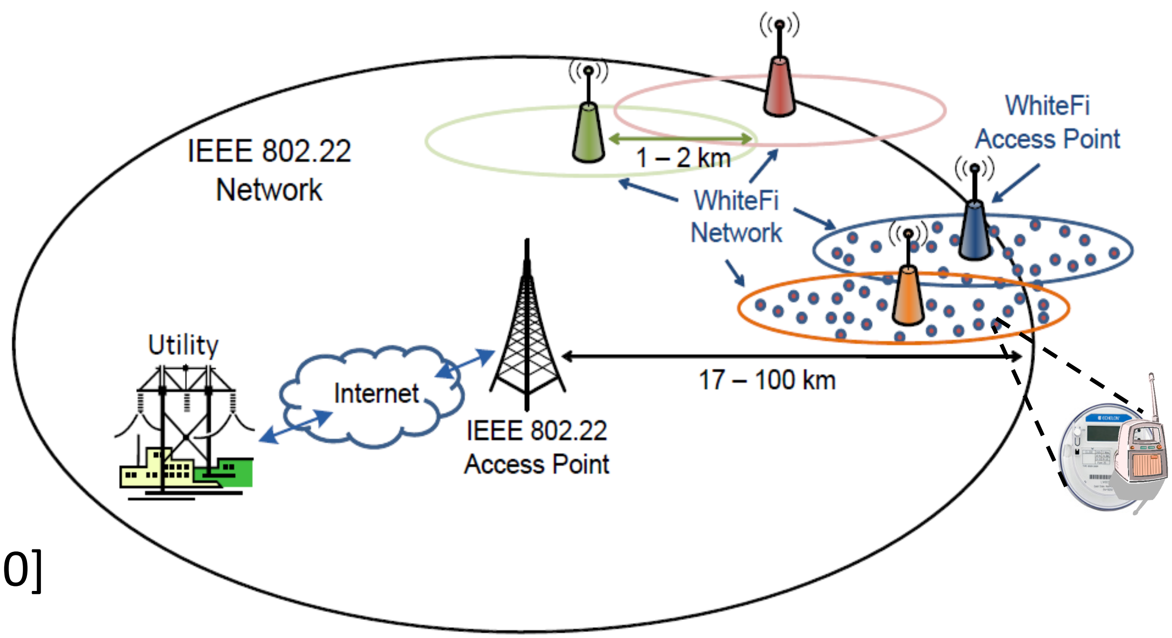
  - Inefficiencies of fixed and long term spectrum assignment (*licenses*)
- Emerging solution: opportunistic access to WHITE SPACES



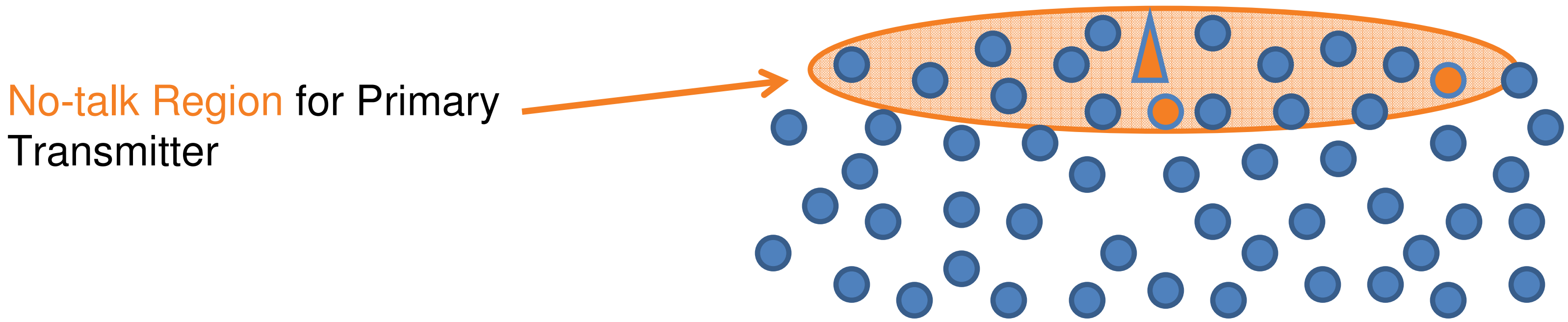
- Cognitive Radio: A radio that interacts with the environment and changes its transmitter parameters accordingly

White Space Networks

- Allowed by FCC in Nov 2008 (and Sep 2010)
  - TV White Spaces: unused TV channels 2-51 (54 MHz-698MHz)
  - Much spectrum freed up in transition to Digital Television (DTV) in 2009
  - Excellent penetration and range properties
- Applications
  - Super Wi-Fi
  - Campus-wide Internet (*e.g.* Microsoft)
  - Rural broadband (*e.g.* Claudville, VA)
  - Advanced Meter Infrastructure (AMI) [FatemiehCG – ISRCS '10]



How to Identify Unused Spectrum?



- Spectrum Sensing – Energy Detection
  - Requires sensing-capable devices -> cognitive radios
  - Signal is variable due to terrain, shadowing and fading
  - Sensing is challenging at low thresholds

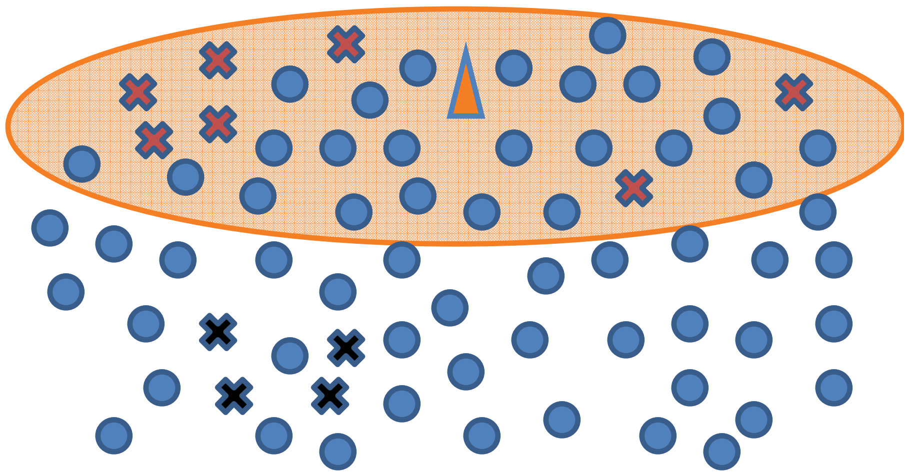
Collaborative Sensing

- Central aggregation of spectrum measurement data
  - Base station (e.g. IEEE 802.22)
  - Spectrum availability database (required by the FCC)

Problem: Detecting Malicious Misreporting Attacks

- Malicious misreporting attacks
  - Exploitation: falsely declare a frequency occupied
  - Vandalism: falsely declare a frequency free

- Why challenging to detect?
  - *Spatial variations* of primary signal due to signal attenuation
  - *Natural differences* due to shadow-fading, *etc.*
  - *Temporal variations* of primary
  - Compromised nodes may *collude* and employ smart strategies to hide under legitimate variations



Compromised Secondary – Vandalism
Compromised Secondary – Exploitation

Setting and Attacker Model

- Network of cognitive radios (nodes) in large area
- Node *i* periodically reports measurement p_i to aggregation center to build a spectrum availability map
- End-to-end secure channel between nodes and aggregation center
- Geo-location for nodes
- Problem: How to protect against malicious attackers that may perform exploitation or vandalism
  1. Uncoordinated
  2. Coordinated
  3. Omniscient

p_i higher than threshold

p_i lower than threshold

Limitations of Existing Work

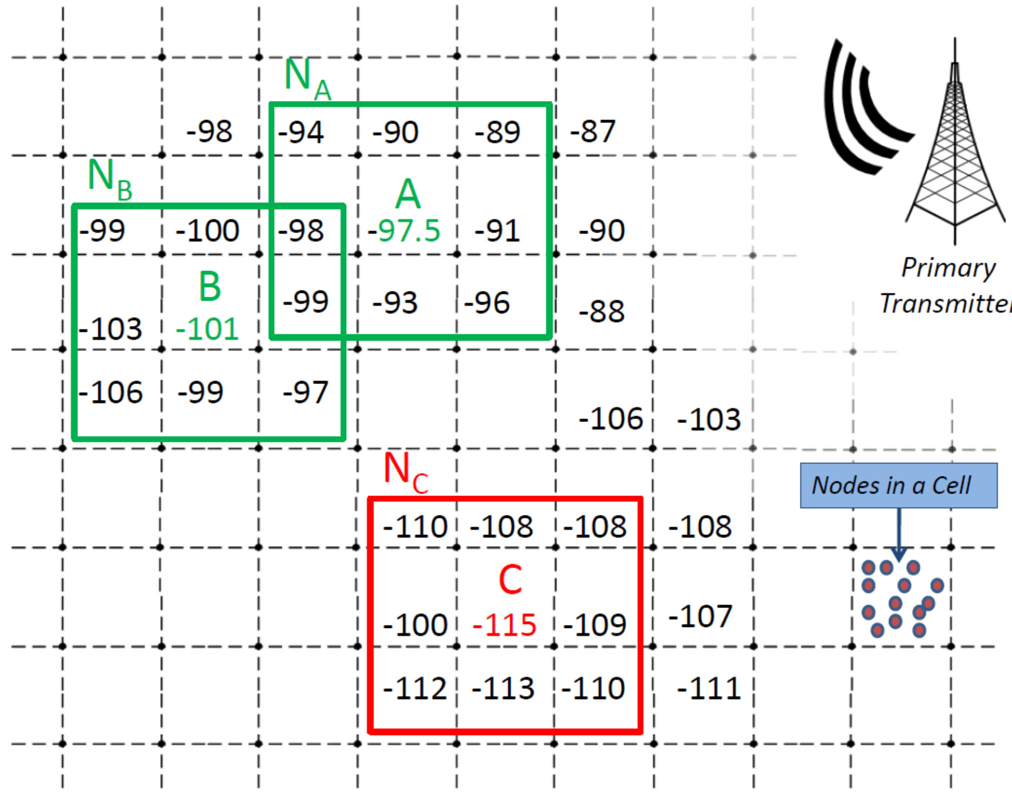
- [ChenPB – INFOCOM ‘08] [KaligineediKB – ICC ‘08] [MinSH – ICNP ‘09]
  - Consider detection in a small area with a common ground truth
  - Attackers constitute a small fraction of nodes (*e.g.* up to 1/3 [MinSH 09])
  - Not designed to detect areas dominated by attackers
  - Attackers use unsophisticated misreporting strategies

- [FatemiehCG – DySPAN ‘10]
  - Arbitrary assumptions about models and parameters of signal propagation
  - Rely on outlier detection threshold parameters that
    - Depend on propagation models and parameters

      or
    - Must be manually tuned

Solution Idea and Overview

- let *data* speak for itself
- Use natural signal propagation patterns to train a (machine learning) classifier
- Subsequently use classifier to detect unnatural propagation patterns -> *attacker-dominated* cells



Classification Background

- Widely used in spam detection, fraud detection, etc.

- Identifying patients with high risk of heart attack
  - Represent each patient as an *example* = < *label* , *features* >

    + or -

    blood pressure
    cholesterol level
    body mass index

  - Goal: predict label for examples with known features (test examples) using examples with known features *and* labels (training examples)

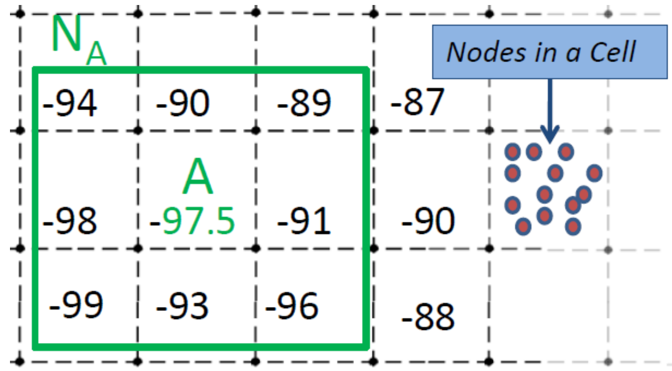
  - Approach: building a classifier using training examples

- How to build classifiers? Winnow, Decision Trees, Naïve Bayes, Support Vector Machines (SVM), *etc.*

- Important factors: data representation, feature selection, choice of classifier

Attacker-Dominated Cell Detection

- The *local neighborhood* of any cell A: N_A
- Neighborhood (feature) representation of A
  - <+/-, -97.5, -98, -94, -90, -89, -91, -96, -93, -99>

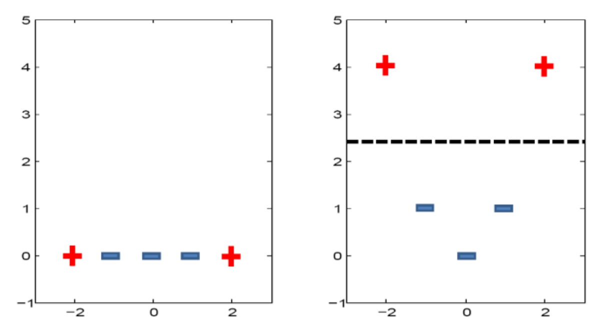


- How to get training examples?
  - Negative (normal): A one-time process using war-driving or a trusted set of sensors
  - Positive (attacker-dominated): Randomized approach to inject *uncoordinated*, *coordinated*, and *omniscient* attacks

- To build a unified classifier for each region, we use SVM with quadratic kernels

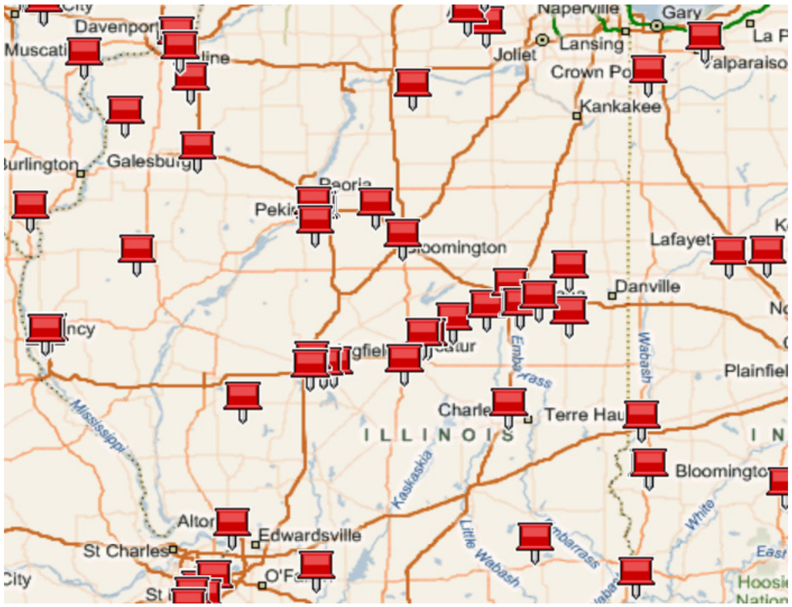
$$\min \frac{1}{2}\|\overrightarrow{W}\|^2 + \gamma \sum_{i=1}^{N} \xi_i$$

$$\text{subject to } y_i(\overrightarrow{W}.\Phi(\overrightarrow{x}) + W_0) \geq 1 - \xi_i \quad \forall i$$

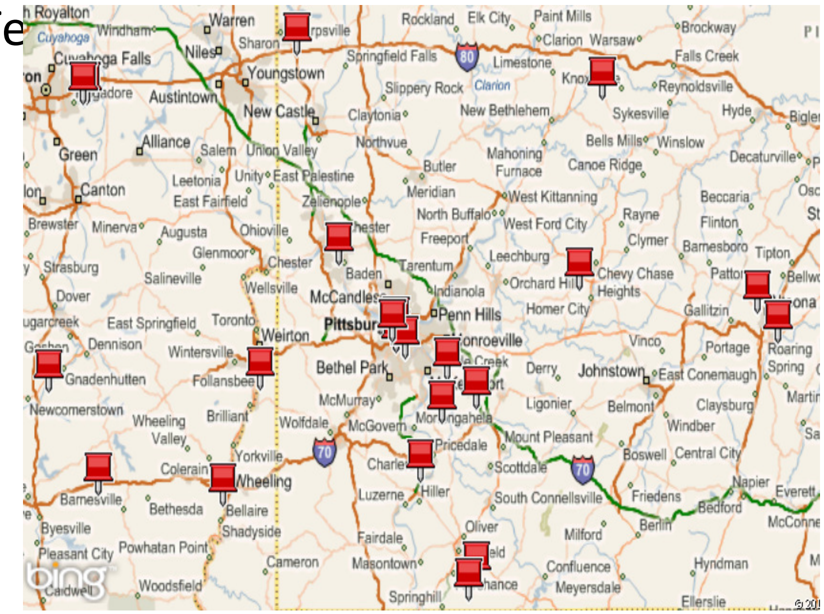


Evaluation

Flat East-Central Illinois



Hilly Southwest Pennsylvania (Stress Te



- TV transmitter data from FCC
- Terrain data from NASA
- House density data from US Census Bureau
- Ground truth: predicted signal propagation using empirical Longley-Rice model

Pennsylvania (Stress Test) Results

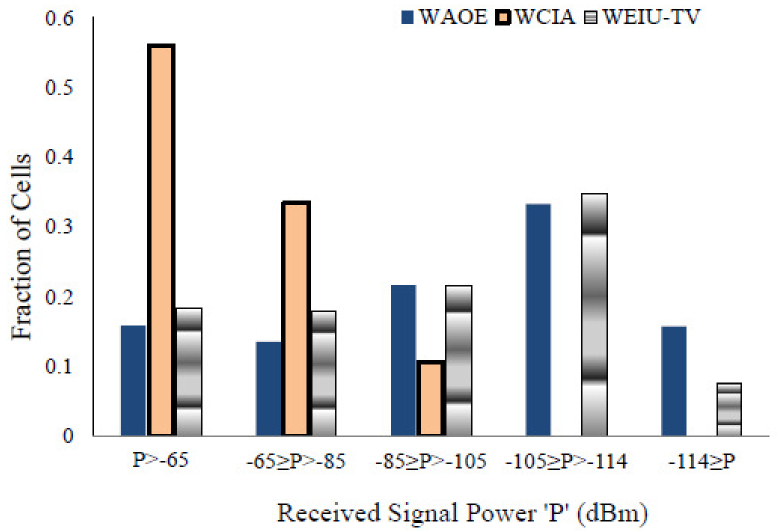
- 20km by 20km area
- Data from 37 transmitters within 150km
- Train classifier using data from 29
- Test classifier on data from 8
- Represent unaccounted uncertainties by Gaussian variations with mean 0 and std dev (σ) up to 6 (dB-spread) only to test data
- Worst-case results (σ=6)
  - Attacker detection rate
    - Uncoordinated: 97%
    - Coordinated: 95%
    - Omniscient: 94%
  - False positive rate: 7%

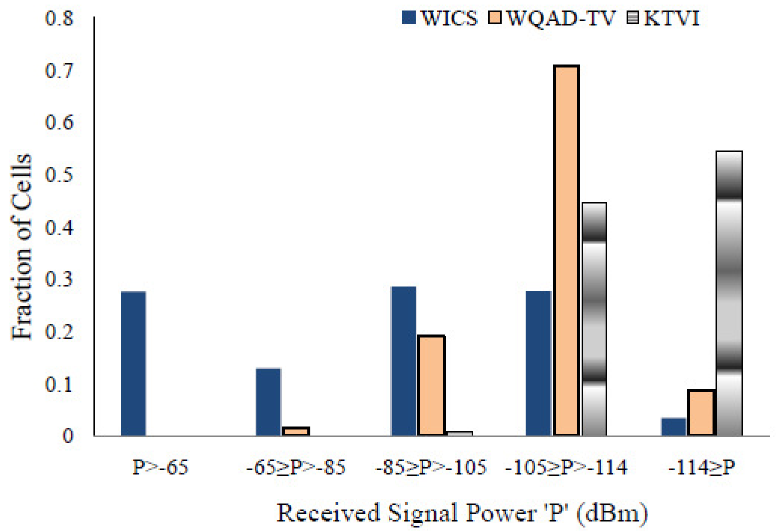
Conclusions and Future Work

- Motivated and formulated exploitation and vandalism attacks
- Showed how to build a classification-based defense using location-tagged signal propagation data
- Showed the effectiveness of approach against uncoordinated, coordinated, and omniscient attacks
- Future work
  - Additional features used for classification, *e.g. elevation, building density/height*
  - Building a crowdsourced nationwide spectrum availability map using *participatory sensing* data
  - Use a small subset of attestation-capable nodes as trust foundation [submitted to SECON '11]

Thanks

Illinois Results





- Train a **unified classifier** with WEIU-TV (PBS) and KTVI (Fox)
- Test on the following four

	WAOE		WCIA		WICS		WQAD-TV	
	D.A. (%)	F.P. (%)	D.A.	F.P.	D.A.	F.P.	D.A.	F.P.
$P > -65$	100	0	99.8	0	100	0	-	-
$-65 \geq P > -85$	100	0	100	0	99.7	0	100	0
$-85 \geq P > -105$	100	0	100	0	99.9	0	100	0
$-105 \geq P > -114$	99.1	.9	-	-	99.7	1.6	99.6	.8
$-114 \geq P$	97.3	3.2	-	-	97	2.4	95.1	7.6
Overall	**99.3**	**.8**	**99.9**	**0**	**99.7**	**.5**	**99.3**	**1.3**

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False Positive Rates	Standard Deviation of Added Variations in Test Data			
	σ=0	**σ=2**	**σ=4**	**σ=6**
P > - 65	0	0	0	0
-65 ≥ P > -85	0	0	0	0
-85 ≥ P > -105	.5	.5	.8	1.5
-105 ≥ P > -114	6.8	8.3	12	17
-114 ≥ P	9	9.8	15	21
Overall	2.9	3.4	5.2	7.3

Related Work – White Space Networks

- Limitations of existing work
  - Consider detection in a small region with a common ground truth
  - Attackers constitute a small fraction of nodes (*e.g.* up to 1/3 [MinSH 09])
  - Not able to detect regions dominated by attackers
  - Attackers use unsophisticated misreporting strategies
- [ChenPB – INFOCOM '08]
  - Weighted likelihood ratio test using similarity to final outcome as reputation
  - Uses 0/1 results: low overhead but Ignores measurement details
  - Bases the decisions on accurate knowledge of P_{FA} and P_{MD}
- [KaligineediKB – ICC '08]
  - Assign (low) trust factors based on (an arbitrary) outlier detection
  - Use trust factors as weights in the averaging
- [MinSH – ICNP '09]
  - Shadow-fading correlation filters to exclude abnormal reports

Related Work – Sensor Networks (1)

- Major differences with sensor networks
  - More capable nodes
  - Long communication ranges

- Differences enable:
  - Centralized solutions with global view
  - Attestation, primary emulation, etc.

Related Work – Sensor Networks (2)

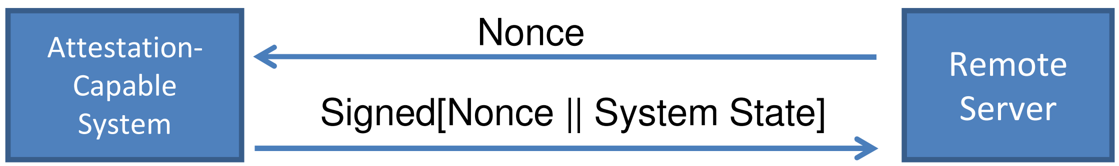
- Resilient data aggregation
  - [Wagner 04] Statistical analysis techniques for various aggregators
    - (+) Could be used to analyze our grid-based scheme
    - (-) Limited to small regions
  - [HurLHY 05] A trust-based framework in a grid: each sensor builds trust values for neighbors and reports them to the local aggregator
    - (sim) Similar to our grid-based scheme
    - (diff) No global view for a centralized aggregator
    - (-) Cannot identify compromised *regions*
    - (-) Does not consider statistical propagation / uncertainties
  - [ZhangDL 06] Identifies readings not statistically consistent with the distribution of readings in a cluster
    - (-) Local: only works for a small region
    - (+) Considers statistical distribution for readings
    - (-) Assumes data comes from distribution in the *time* domain

Related Work – Sensor Networks (3)

- Reputation/trust frameworks
  - [GaneriwalBS 04 & 08] A general reputation-based trust framework, where each sensor maintains a local reputation and trust for its neighbors
    - (diff) Local and P2P: reputation based on the quality of each interaction/report
    - (diff) Very general framework, focused on local decision making at each sensor
- Insider attacker detection
  - [LiuCC 07] Each node builds a distribution of the observed measurements around it and flags deviating neighbors as insider attackers
    - (diff) Local and P2P: voting among neighboring sensors to detect insiders
    - (-) Does not work in areas with more than 25% attackers
- Event region detection
  - [Krishnamachari 04] Fault tolerant event region detection
    - (diff) Only considers faulty nodes (not malicious); uniformly spread
    - (-) Node itself participates in detection

A Small Subset of Trusted Nodes

- Previous solutions
  - Used reported sensor measurements for inferring (dis)trust
- Remote attestation: A technique to provide certified information about software, firmware, or configuration to a remote party
  - Detect compromise
  - Establish trust



- Root of trust for remote attestation
  - Trusted hardware: TPM on PCs or MTM on mobile devices
  - Software on chip [LeMay, Gunter - ESORICS ‘09]
- Why a subset?