SMART: A SVM-based Misbehavior Detection and Trust Management Framework for MANETs

Wenjia Li
Anupam Joshi
Tim Finin

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UMBC
AN HONORS UNIVERSITY IN MARYLAND

ebiquity group

Outline

- Introduction and Motivation
- Related Work
- Outlier Detection Algorithm
- Performance Evaluation
- Conclusion and Future Work

Introduction

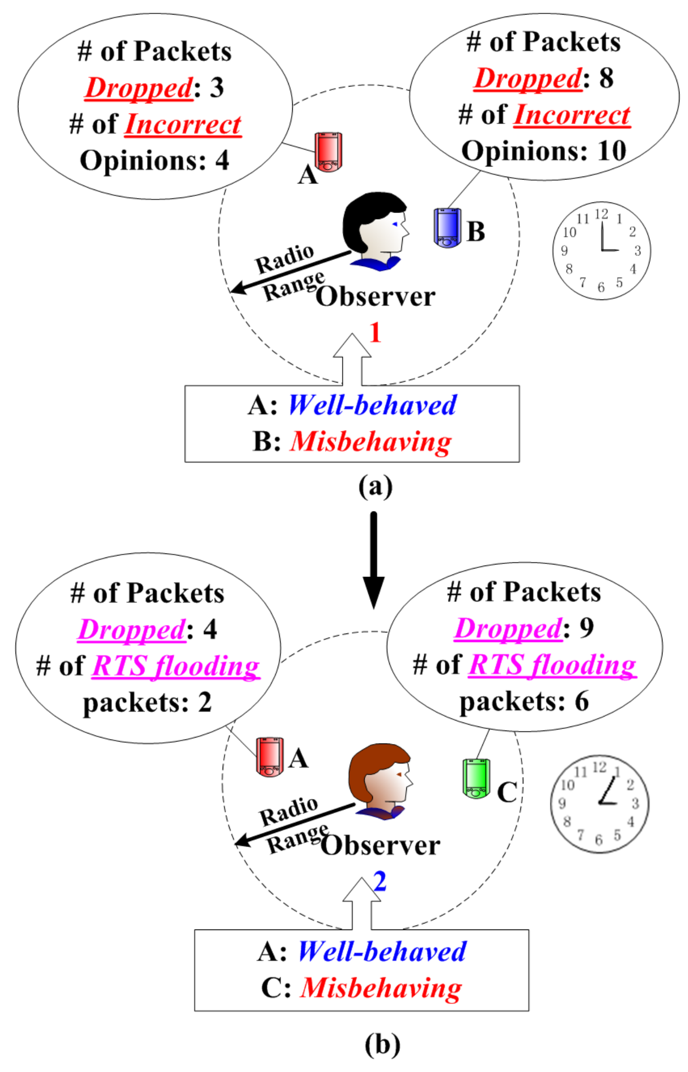
- **Basic features of mobile ad hoc networks**
  - **Open and unreliable transmission medium**
    - **Data are *easily* disclosed to unwanted third parties**
  - **Node mobility and constantly changing topology**
    - **Data communication may be *frequently* disrupted**
  - **Absence of pre-deployed infrastructure**
    - ***Selfish* nodes refuse to forward packets for others → System performance severely downgraded**
  - **Limited power supply for each node**
    - **Consequence: *SHORT* transmission range and *LIMITED* computation capability**

⇒ *Ad Hoc Networks* are extremely vulnerable to various misbehaviors

Misbehavior Detection

- An important method to protect MANETs from BOTH *external* attackers AND *internal* compromised nodes
- Current misbehavior detection mainly relies on a *predefined threshold* to detect misbehaviors
  - Threshold-based intrusion detection: set a threshold for each kind of misbehavior, and alert only when the number of misbehaviors exceeds the threshold
- Drawbacks of threshold
  - Hard to define beforehand
    - How can we accurately predict an adversary's attack pattern?
  - Need to adjust frequently
    - Adjust according to the changing topology and node mobility
  - Easy to exploit
    - A *smart* adversary reduces its misbehaviors *JUST* below the threshold

Motivating Scenario I



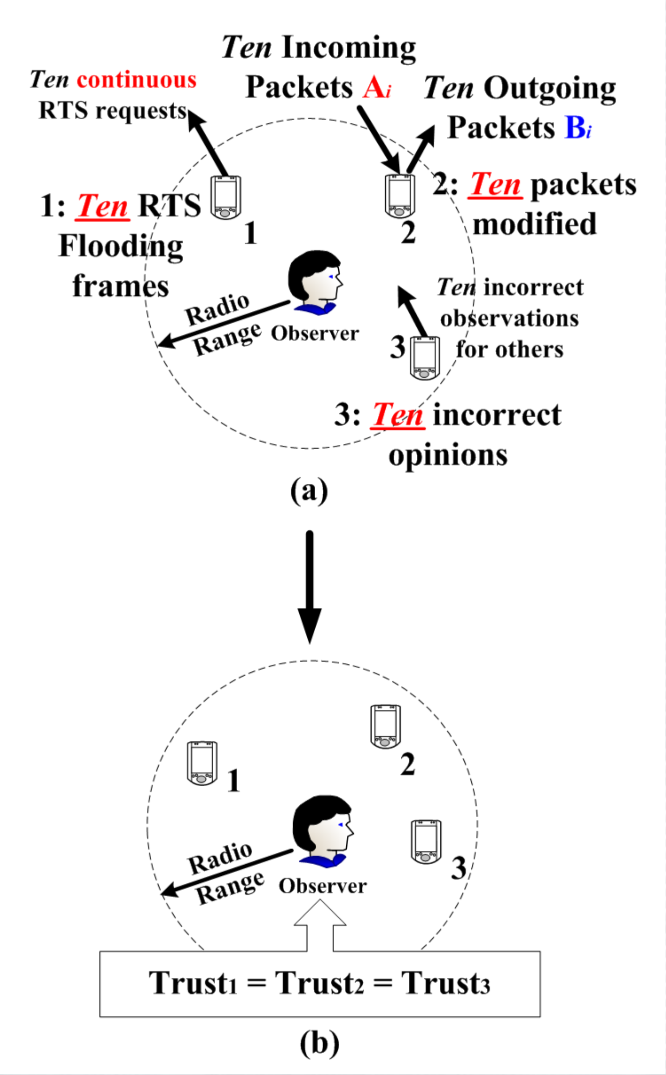
Trust Management

- Evaluation of how *trustworthy* a node will be based on the *observations* to its previous behaviors

- Two types of observations
  - *Direct* observation (First-hand information)
    - Observations made by a node ITSELF
  - *Indirect* observation (Second-hand information)
    - Observations obtained from OTHER nodes

- Majority of current trust management schemes model trust in form of *ONE single scalar*
  - Observations to all types of misbehaviors are used to derive ONE single trust value for each node
  - Neither expressive nor accurate in complicated scenarios

Motivating Scenario II



SMART

- **SVM-based misbehavior detection and trust manage -ment framework**
  - ***Outlier detection*** **technique is used for behavioral data collection**
    - **Misbehaviors generally *deviate* from normal behaviors → misbehaving nodes can be viewed as *outliers***
  - ***SVM*** **technique is used to identify misbehaving nodes**
    - **Incorporate previous knowledge on misbehaviors to detect *unknown* misbehaviors**
  - ***Multi-dimensional*** **trust management**
    - **Divide trustworthiness into several dimensions (for example 3)**
    - **Each dimension of trustworthiness is derived by a subset of misbehaviors**

Related Work

- **Misbehavior detection in MANETs**
  - ***Selfish*** **node VS.** ***malicious*** **node**
    - **Selfishness: Merely want to preserve resource (battery power, bandwidth), so may deny forwarding packets or route requests**
    - **Maliciousness: Intentionally want to disrupt the network services, so may take any action to meet this goal**
      - **Packet drop, modification, misroute, fake RTS requests, etc.**
  - **Intrusion detection system (IDS) for MANETs**
    - **IDS sensor deployed on each node**
      - **NOT energy-efficient**
    - **Cluster-based IDS by Huang et al.**
  - **Efforts to identify routing misbehaviors**
    - **"Watchdog" & "Pathrater" by Marti et al.**

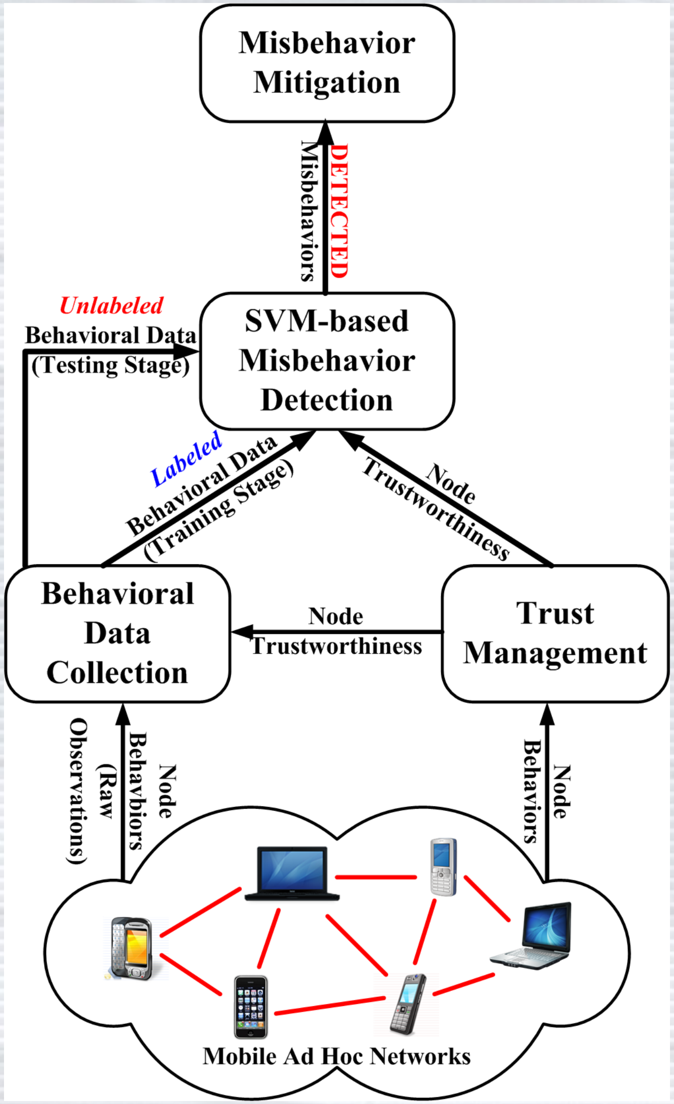
Related Work (Cont.)

- **Trust management for MANETs**
  - **Goal: to evaluate behaviors of other nodes and consequently decide the *trustworthiness* for each node based on the behavior assessment**
  - **Various trust management schemes**
    - **CONFIDANT by Buchegger et al.**
      - **Four components: a Monitor, a Reputation System, a Trust Manager, and a Path Manager**
    - **CORE by Michiardi et al.**
      - **Identifies *selfish* nodes and forces them to cooperate**
      - **Only *positive* observations are exchanged**
    - **Node evaluation scheme by Ren et al.**
      - **Second-hand observations only shared by a subset of neighbors ("trustworthy neighbors")**

Framework Overview

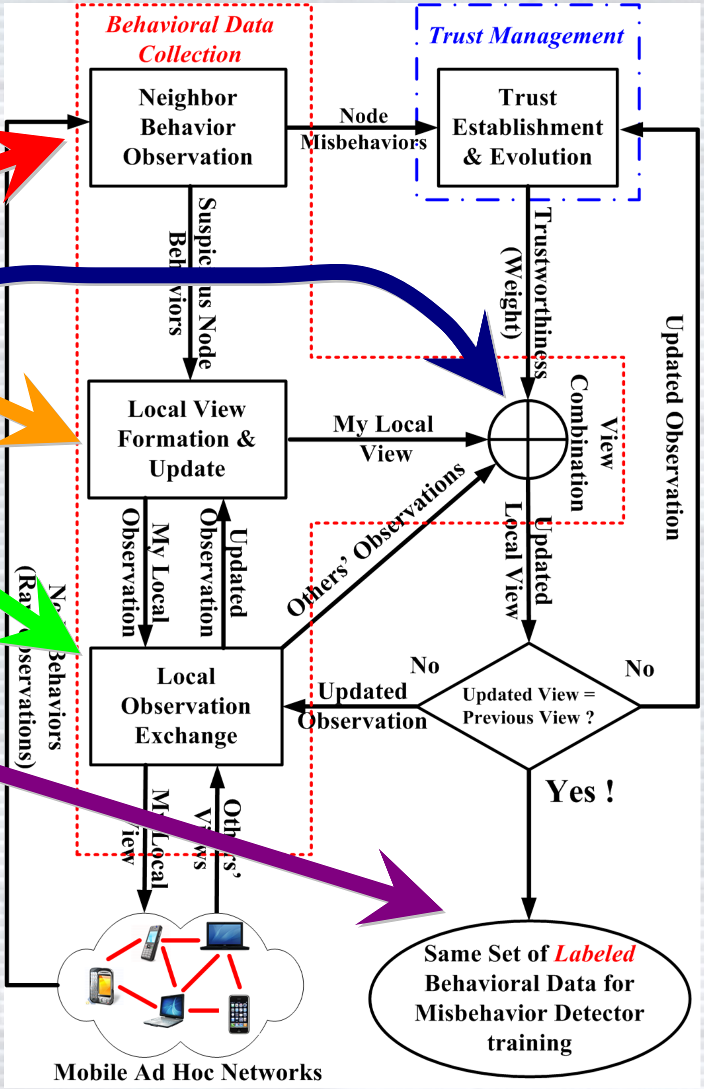
- Four components
  - Behavioral data collection
  - Trust management
  - SVM-based misbehavior detection
  - Misbehavior mitigation

- Two stages
  - Training stage
  - Detection stage

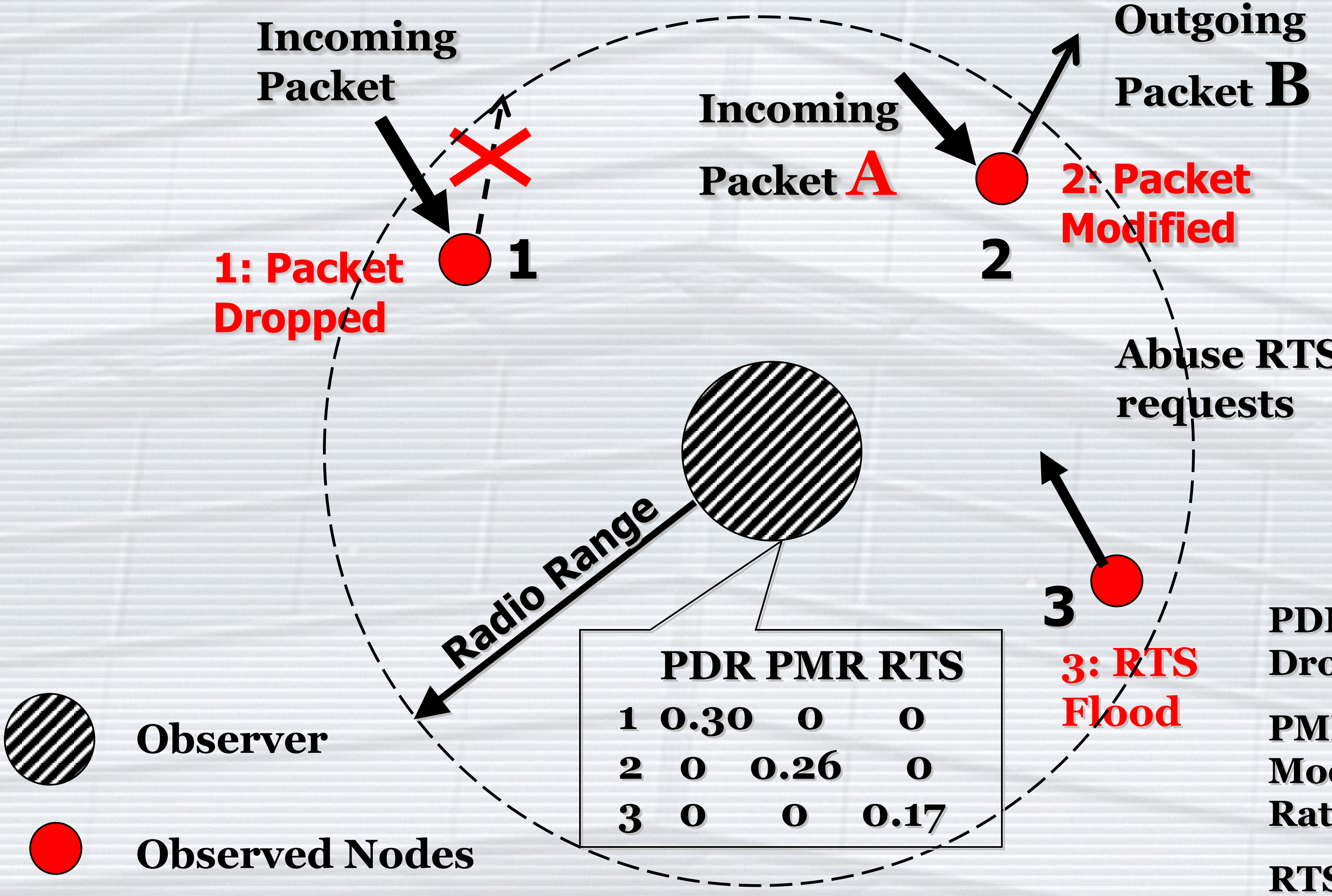


Behavioral Data Collection

- Five steps for the *training* stage
  - Neighbor observation
  - Local view formation
  - Local observation exchange
  - View combination
  - Global view formation and data labeling
- One step for *detection* stage
  - Neighbor observation



Local observation and view formation



	PDR	PMR	RTS
1	0.30	0	0
2	0	0.26	0
3	0	0	0.17

Notes:

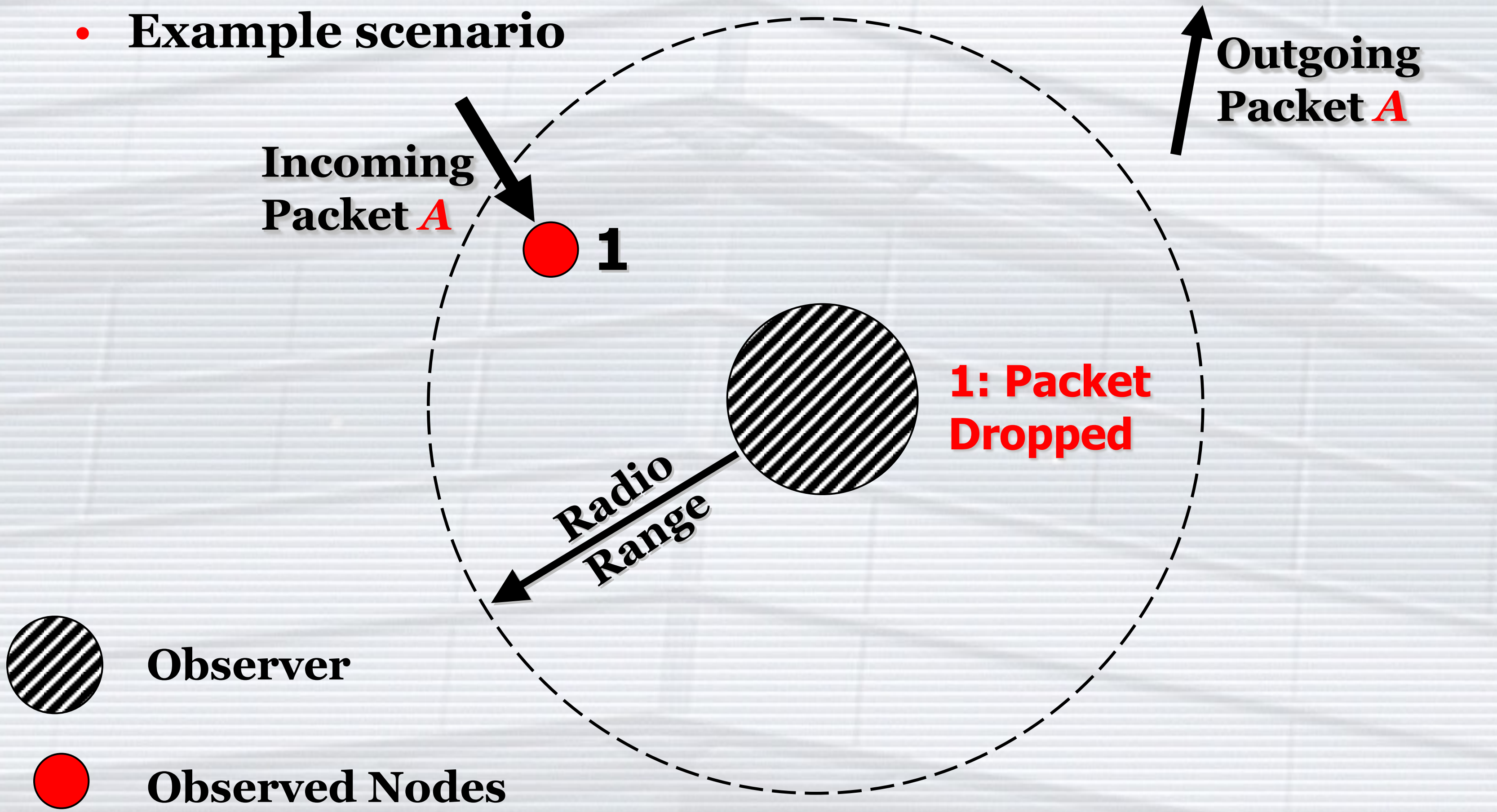
PDR – Packet Drop Rate

PMR – Packet Modification Rate

RTS – RTS Rate

View Combination

- **Motivation: Node mobility and channel collision can make the neighbor observation results *inaccurate***
  - Example scenario



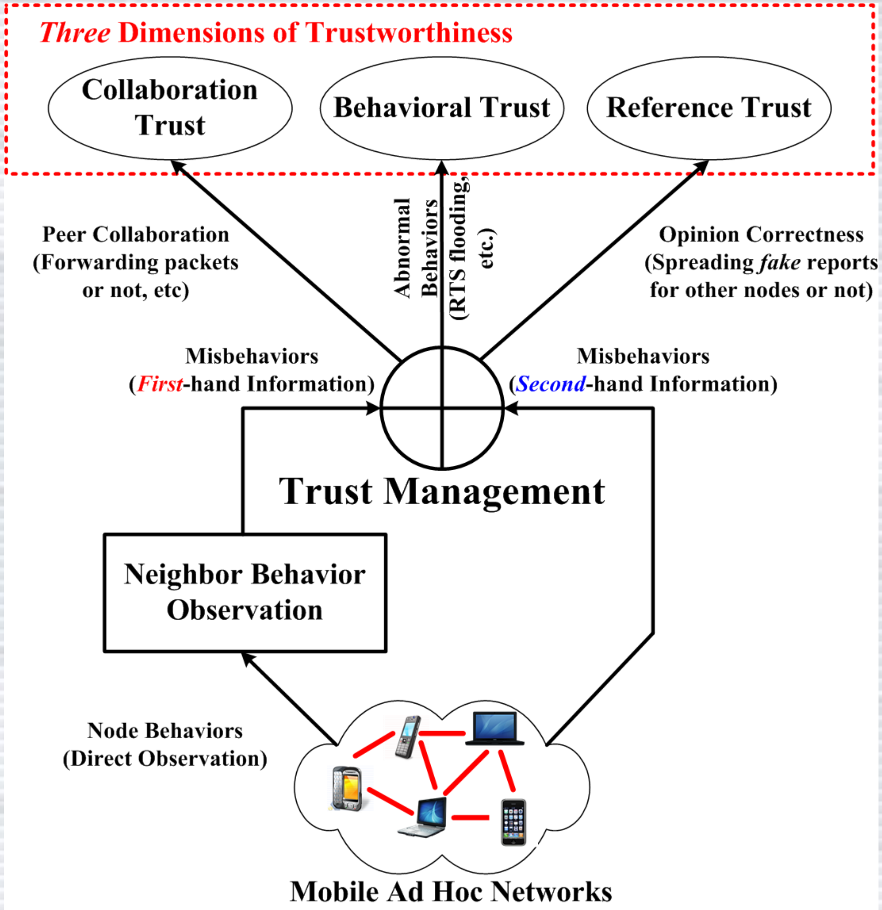
View Combination (Cont.)

- **Dempster-Shafer Theory (DST): combine separate pieces of observations (evidences) to calculate the probability of malicious behaviors**
  - **Basics: lack of evidence can *NOT* be viewed as the *refutal* to this evidence**
  - **Solution: a node can either hold a *positive* opinion or have *no* opinion to the misbehavior of its neighbor**
  - ***NO* opinion is called "Environment" in this case (Θ)**
  - **How to combine separate pieces of evidences – *Dempster's Rule of combination***

$$m_B(A) \oplus m_C(A) = \frac{\sum_{q,r:\alpha_q \cap \alpha_r = A} m_B(\alpha_q) m_C(\alpha_r)}{1 - \sum_{q,r:\alpha_q \cap \alpha_r = \Phi} m_B(\alpha_q) m_C(\alpha_r)}$$

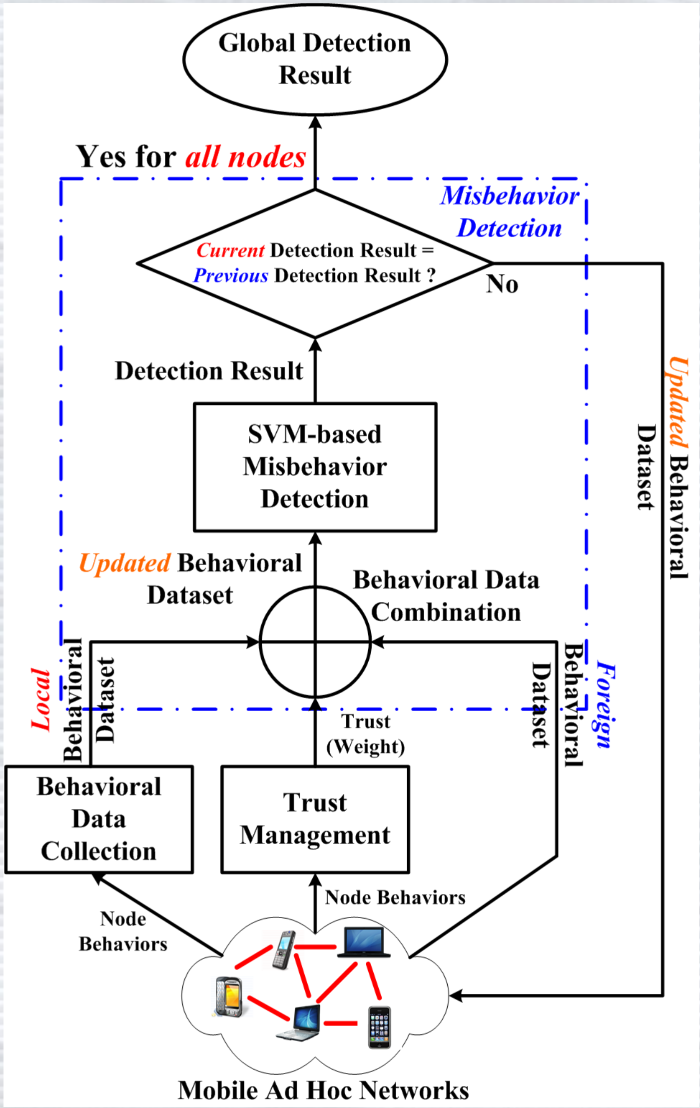
Multi-dimensional Trust Management

- **All trust values initialized to be 1 (trust value ∈ [0, 1])**
- **Trust values adjusted based on observation results**
  - **Both *first-hand* information and *second-hand* information**
- **Three dimensions of trust**
  - **Collaboration trust**
  - **Behavioral trust**
  - **Reference trust**



SVM-based Misbehavior Detection

- Three steps in ***detection*** stage
  - Behavioral data combination
  - Misbehavior detection
  - Behavioral data update and exchange



Performance Evaluation

- **Simulation setup**

Parameter	Value
Simulation area	600m × 600m
Number of nodes	50, 100, 200
Transmission range	60m, 90m, 120m
Simulation Duration	900s
Mobility pattern of nodes	Random waypoint
Number of bad nodes	5, 10, 20
Node motion speed	5m/s, 10m/s, 20m/s

Performance Metrics

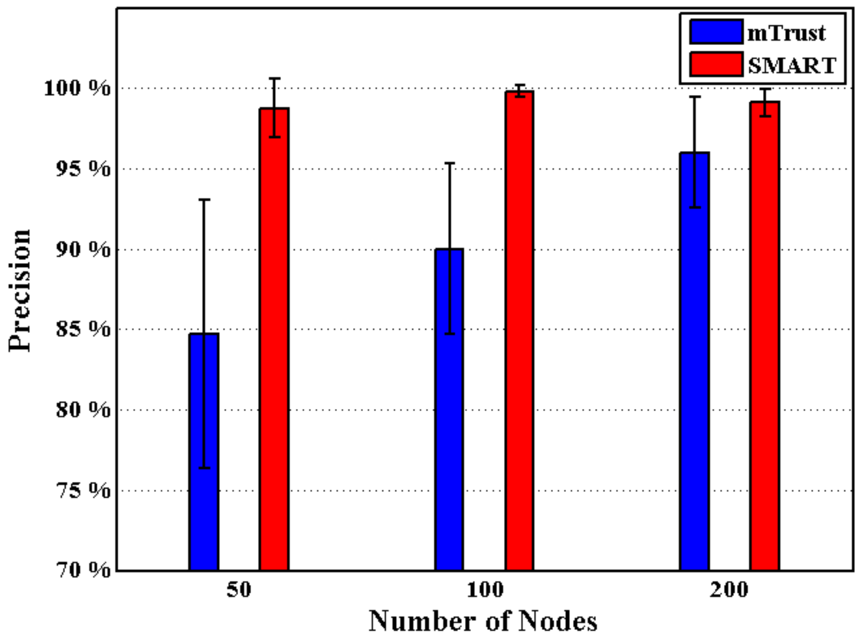
- **Four metrics**
  - **Precision**
  - **Recall**
  - **Communication Overhead (CO)**
  - **Convergence Time (CT)**

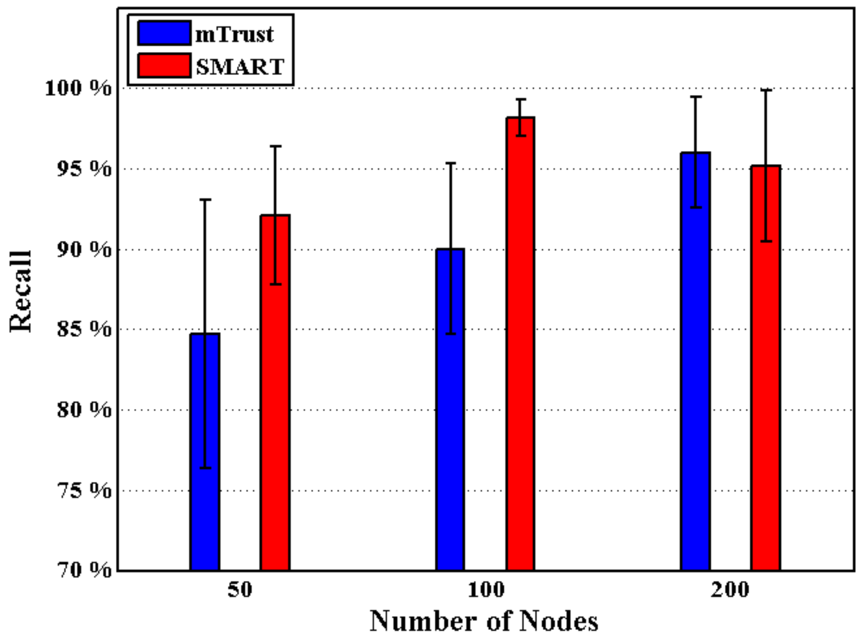
$$TNPOD = Total\ Number \text{ of Packets for Outlier Detection}$$

$$CO = \frac{TNPOD}{Total \text{ Number of Packets in the network}}$$

$$CT = Time \text{ taken to form a } consistent \text{ global view of outliers}$$

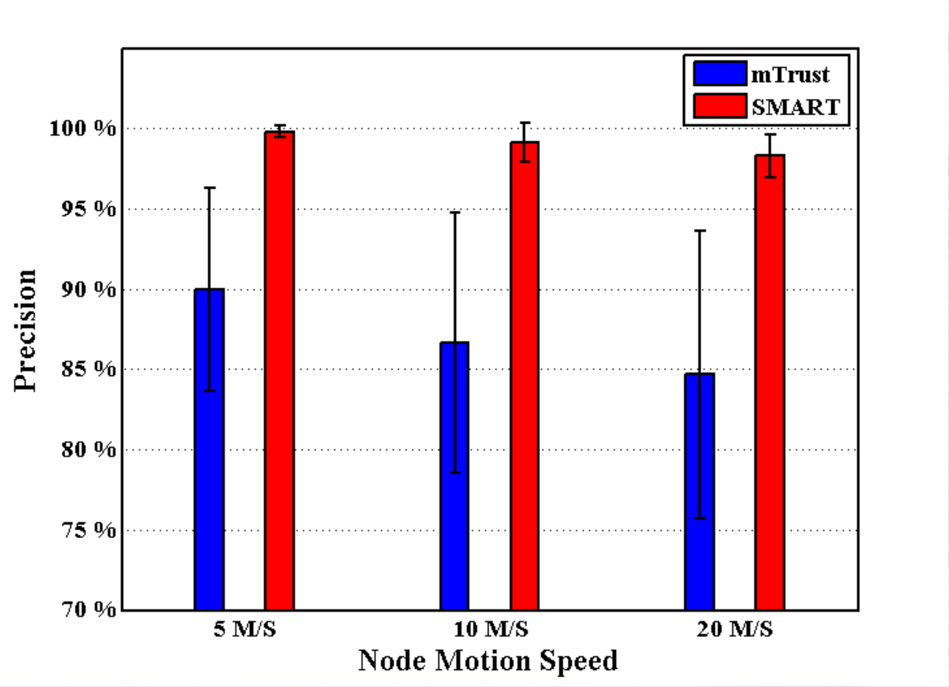
Simulation Scenario I

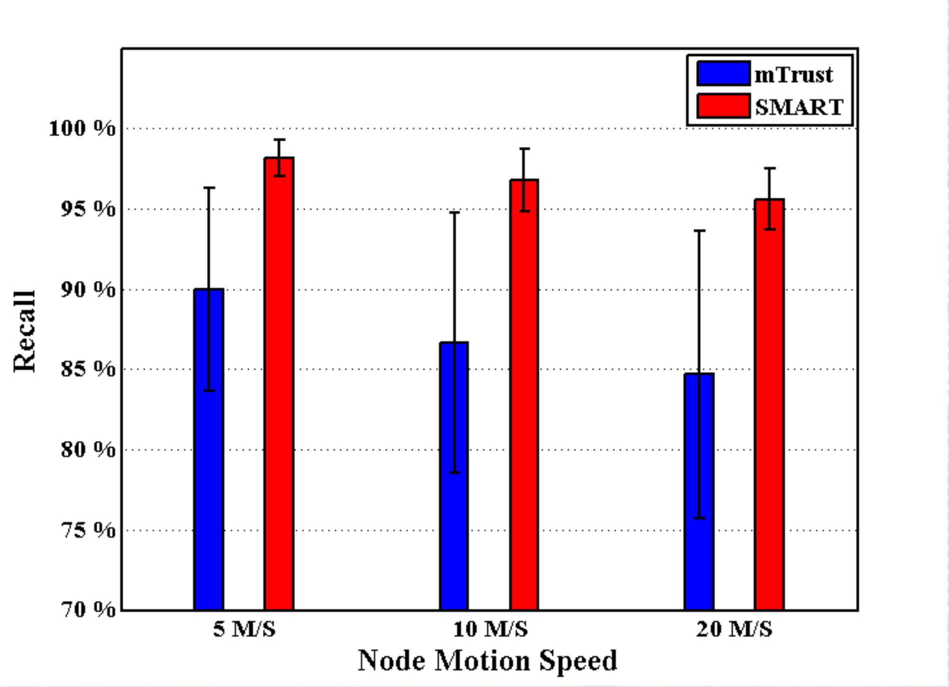




Precision and Recall with Different Number of Nodes
(Area: 600m ×600m, Radio Range: 120m, Speed: 5m/s)

Simulation Scenario II

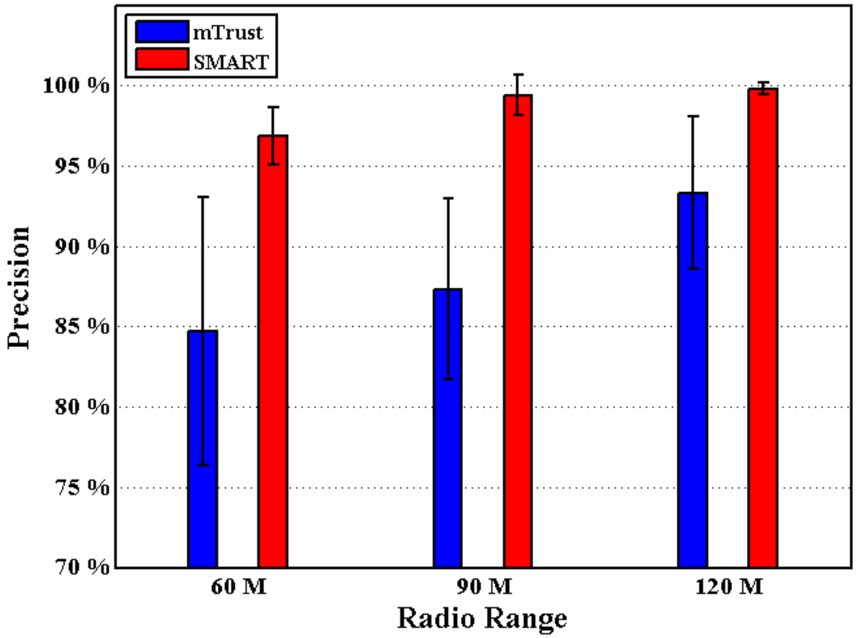


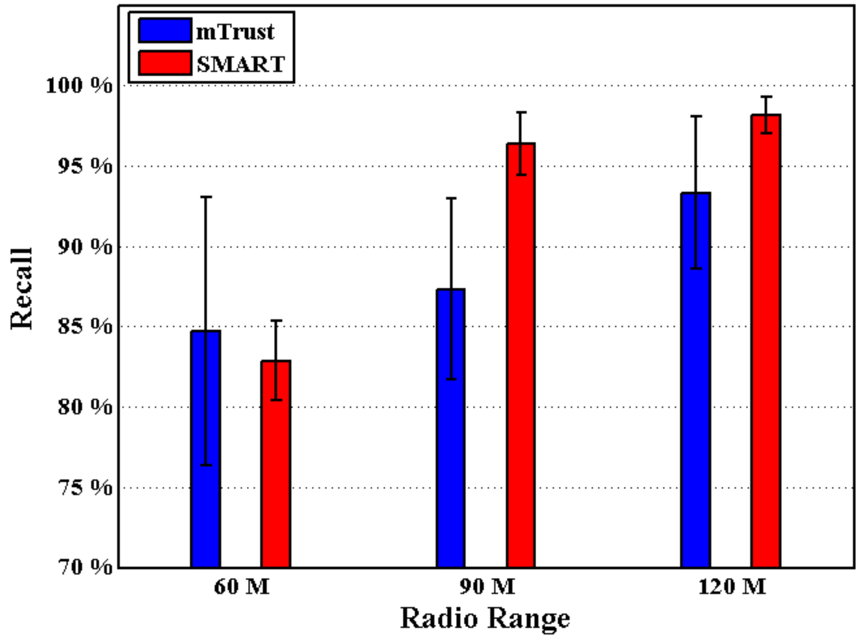


Precision and Recall with Different Motion Speed

(Area: 600m ×600m, Radio Range: 120m, Num of Nodes: 100)

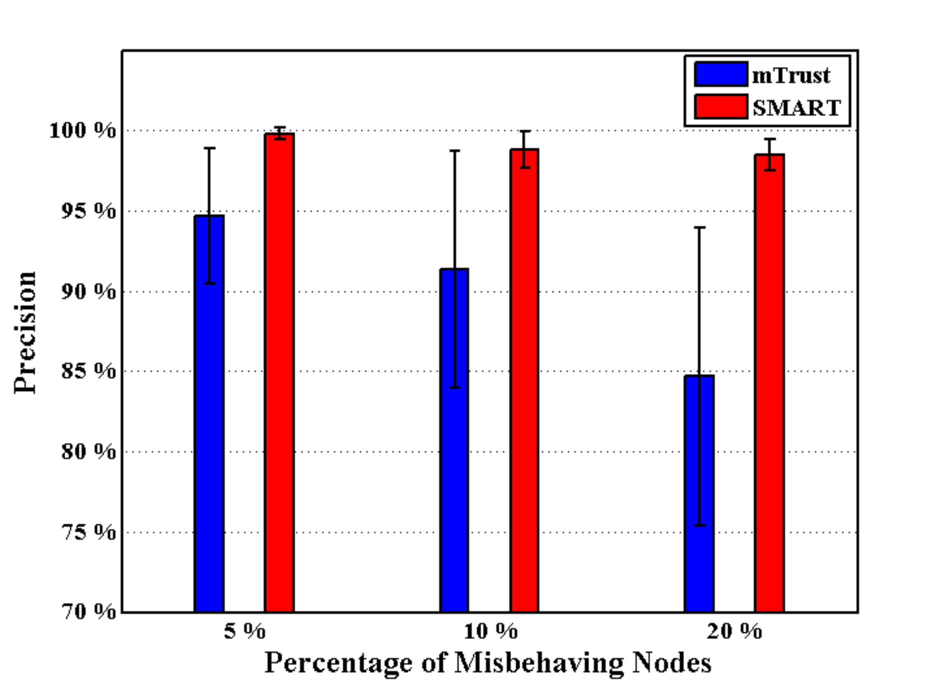
Simulation Scenario III

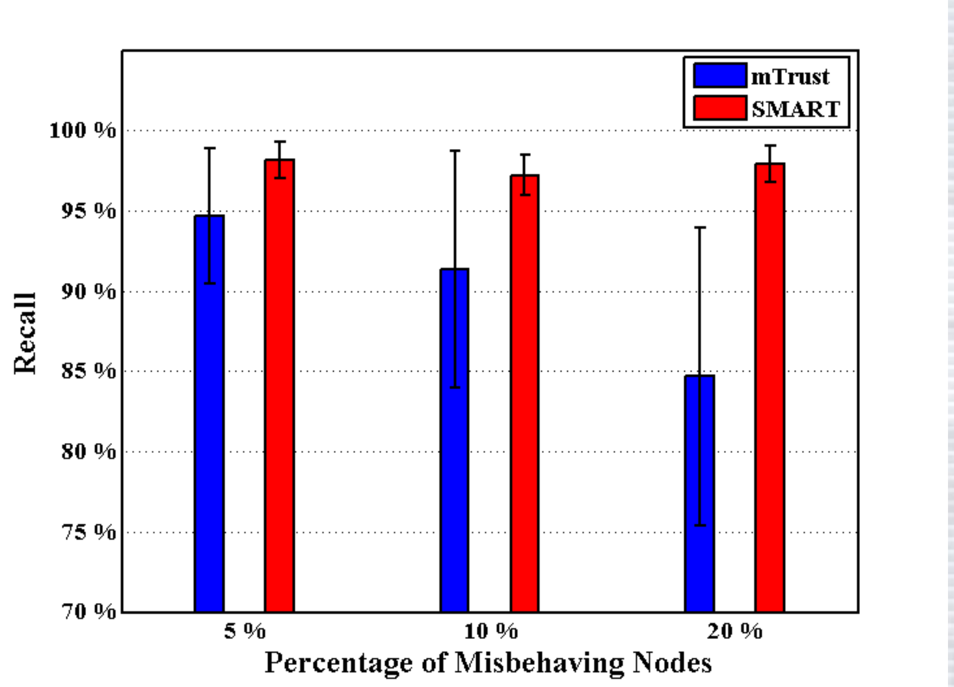




Precision and Recall with Different Radio Ranges
(Area: 600m ×600m, Num of Nodes: 100, Node Speed: 5m/s)

Simulation Scenario IV





CR with Different Percentage of Bad Nodes

(Num. of Nodes: 100, Area: 600m ×600m, Range: 120m, Speed: 5m/s)

Adversary Model

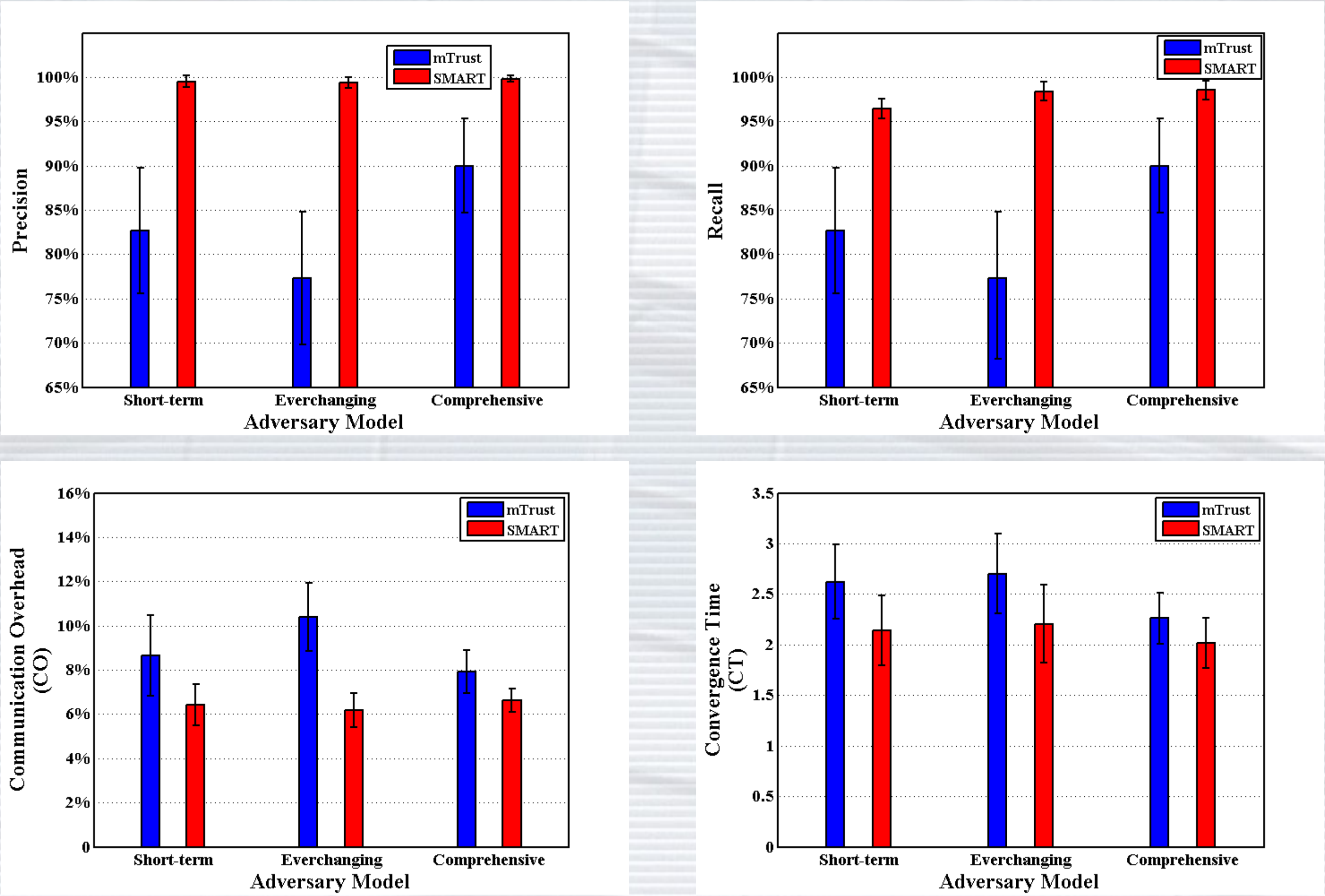
- **Three adversary models**
  - **Short-term**
  - **Ever-changing**
  - **Comprehensive**

$Node\ ID$	$Start$	End	$Drop$	$Modify$	RTS
16	$10s$	$180s$	90%	10%	0
33	$100s$	$400s$	0	30%	70%
34	$50s$	$200s$	40%	30%	30%
44	$400s$	$660s$	0%	50%	50%
45	$350s$	$600s$	20%	0	80%

$Node\ ID$	$Start$	End	$Drop$	$Modify$	RTS
16	$0s$	$200s$	10%	70%	20%
16	$200s$	$400s$	50%	0%	50%
16	$400s$	$900s$	90%	10%	0
33	$0s$	$400s$	0	40%	60%
33	$400s$	$900s$	30%	30%	40%
...	...	...	...	...	...

$Node\ ID$	$Start$	End	$Drop$	$Modify$	RTS
1	$0s$	$900s$	80%	20%	0
2	$0s$	$900s$	0	50%	50%
3	$0s$	$900s$	30%	30%	40%
4	$0s$	$900s$	20%	10%	70%
5	$0s$	$900s$	10%	0	90%

Simulation Scenario V



Effect of Different Adversary Models

Conclusion and Future Work

- SVM-based misbehavior detection and trust management framework for MANETs
  - Outlier detection for behavioral data collection
  - SVM for misbehavior detection
  - Multi-dimensional trust management
- Several simulation scenarios have validated the correctness and efficiency of our approach
- Future work
  - How to properly determine trustworthiness DIRECTLY from the SVM classifier
  - Incorporation of context information to SVM classifier

The End

- Questions
- Comments☺