Mitigating Routing Misbehavior in the Internet of Drones Environment

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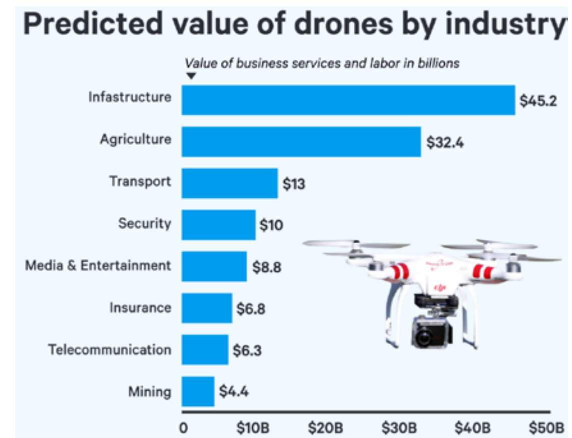
Outline

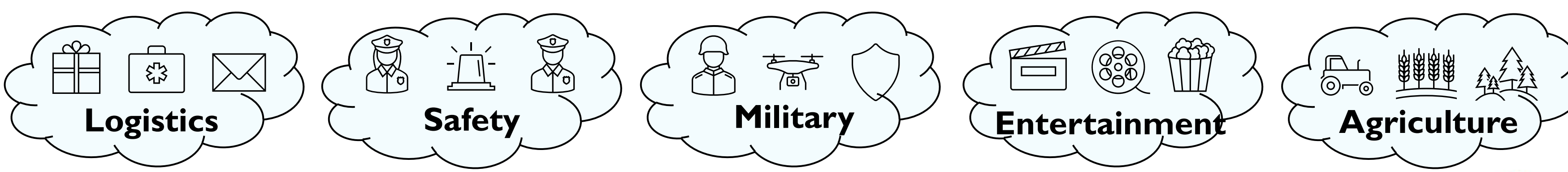
- Introduction & Motivation
- Related Work
- Proposed Routing Misbehavior Detection/Mitigation
  - System Model
  - Distributed Countermeasure
- Performance Evaluation and Analysis
- Concluding Remarks

Introduction

- Initially used as military strike weapons, drones discover a variety of civilian applications
  - goods delivery
  - aerial surveillance
  - combating COVID-19

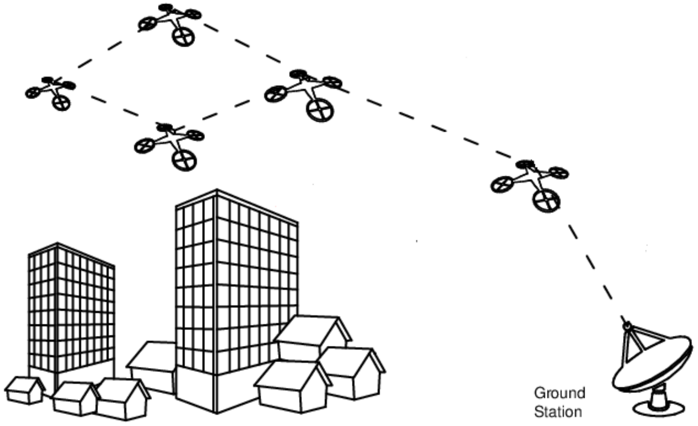
- "Drone Market Report 2020"
  - the drone industry is expected to grow to $43 billion by 2025
- The demand for drones by various unites is high; deployed for a wide range of apps.





Introduction

- To fully exploit drones, Internet of Drones (IoD) is proposed
  - mobile drones
  - stationary ground stations
    - acts as access point
  - drone-to-drone (D2D) comm.
  - drone-to-ground station (D2I) comm.
  - exploiting intermittent connect.



- The IoD is lack of persistent connectivity
  - between drone and drone, and between drone and ground station

store-carry-and-forward strategy

the most promising candidate for delivering data in the IoD

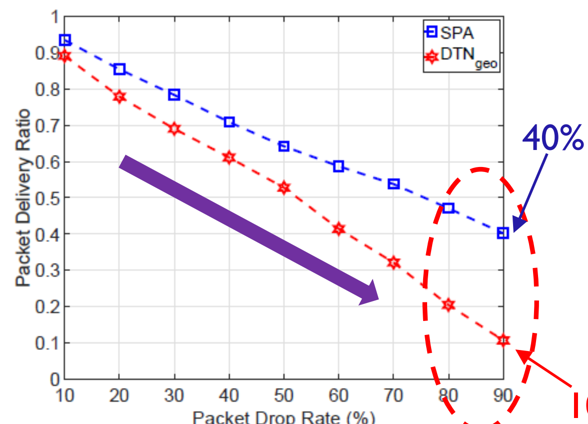
a drone stores the received packets in the storage, carries them while flying around, and forwards them to the next-hop drone or destination (i.e., ground station)

Motivation

- *Routing protocol*: efficient info. sharing and team performance
- As a result of high mobility and resource constraints, the IoD is vulnerable to *routing attacks*
  - an adversary strategically misbehave by dropping the packets
    - saving its energy power or launching attacks
- *Routing attacks/misbehaviors degrade network performance*
  - packet delivery ratio (PDR) reduction; dropped packets increase
  - preliminary experiments (*SPA* [8] and DTN_{geo} [10])

SPA [8]: a stochastic packet forwarding algorithm

DTN_{geo} [10]: a shortest path forwarding algorithm



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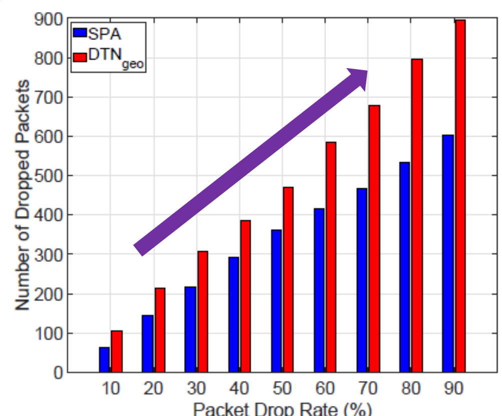

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Motivation (cont.)

- *Routing attacks* are an old research topic in diverse environments
  - traditional computer network
  - mobile ad hoc network
  - wireless ad hoc network
  - vehicular ad hoc network
  - etc.

- existing countermeasures
  - monitoring-based
  - acknowledgment-based
  - bait-based
  - cryptography-based

- no/low mobility is considered
- exiting schemes do not apply in IoD

- In addition, there is no available work concentrating on routing attacks and their countermeasures in the IoD
  - our work fill this research gap in the community

Our Contribution

- This paper
  - proposes a distributed countermeasure (*Counter*^{Romir}) to detect / mitigate routing misbehavior in the IoD environment
    1. a drone keeps the previous signed communication invoice and shares it with the next-hop drone so that the next-hop drone can detect whether the drone has dropped any packets
    2. each drone saves and sends a small number of past communication invoices to the ZSP which can detect the misstating drone who misstates its communication invoices to avoid detection
  - extensive simulation experiments showing *Counter*^{Romir} is an efficient approach to mitigate routing misbehavior in the IoD

Most Countermeasures in the IoD

- monitor-based approach [15,17,18]
  - implicitly monitor the activity of next-hop node
    - determine whether it forwards the recently received packets
  - depends on stable connectivity between sender and receiver
    - difficult to achieve in the IoD environment
- acknowledgment-based approach [16,19,20]
  - explicit acknowledgement packet is required to confirm the receipt of packet from the receiver
  - relies on stable end-to-end routing path
    - not applicable in the IoD environment
- bait-based approach [7,21]
  - lure adversaries to launch attack with fictitious information
  - "fake" packets might get lost during the transmission
    - the high mobility of drones in the IoD environment

Most Countermeasures in the IoD

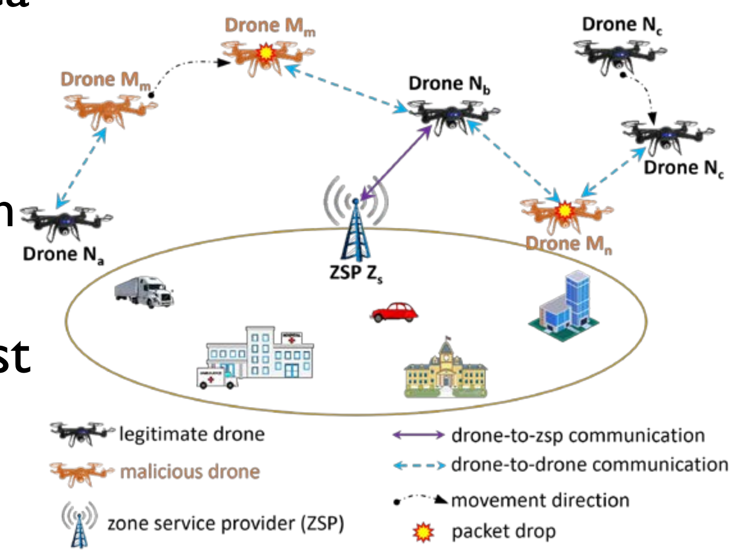
- trust management scheme [22]
  - a fuzzy trust scheme examining node's trustworthiness and converge trust, reward, and punishment values.
  - the trust evaluation process relies on neighbor monitoring
  - the cluster-head selection incurs extra communication overhead
- our approach *Counter*^{Romir} borrows the idea of *store-carry-and-forward mechanism* and *delay tolerant networking technique*
  - for each drone
    1. keeps the previous signed communication invoices
    2. shares them with the next-hop drone or nearby ZSP
    3. detect the routing misbehavior or misstating drones
  - a network-layer approach which can be implemented as an add-on to existing routing protocols (e.g., SPA [8], DTN_{geo} [10], etc.)
  - the *first* distributed approach against routing misbehavior in the IoD

Most Countermeasures in the IoD

- Four important issues should be addressed to detect routing attacks in the IoD
  i. intermittent connectivity in the IoD
     - store-carry-and-forward & delay tolerant networking techniques
  ii. routing attacks/misbehaviors
     - keeps signed communication invoice
  iii. misstating drone (fabricating communication invoice)
     - sharing invoices with ground station
  iv. integration with off-the-shelf routing protocols
     - designing countermeasure as a network layer add-on module
- This paper provides
  - in-depth analysis of routing attacks
  - distributed countermeasure against routing attack
  - bridge the research gap in the community

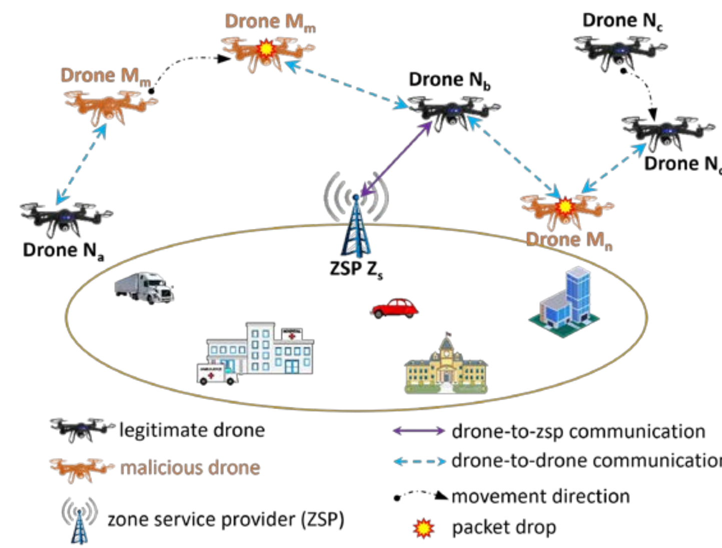
Counter^{Romir}: System Model

- A generic IoD scenario (combating COVID-19 pandemic)
  - a set of drones is deployed in the area
  - when a drone detects an event
    - generates data packets
    - sends them to nearby ground station
      - multi-hop relays
  - end-to-end path does not always exist
    - store-carry-and-forward strategy
      - stores received packets
      - carries them while flying
      - forwards them to next-hop (i.e., drone or ground station)
  - drone has limited storage space
    - a timer is used to purge stale packets
  - public-key cryptography [26,27] is being utilized



Counter^{Romir}: Adversary Model

- In wide-open airspace, drones can be captured ("anti-drone-gun")
  - compromising legitimate drones
  - making them behave maliciously
  - sending it back to the mission area



- The primary goal of adversary
  - degrade the network performance
    - strategically dropping the received packets
      - saving energy power or launching attacks
  - collusive routing attacks are not considered
    - a small number of malicious drones might collude together to drop the packets without being detected

Counter^{Romir}: Distributed Countermeasure

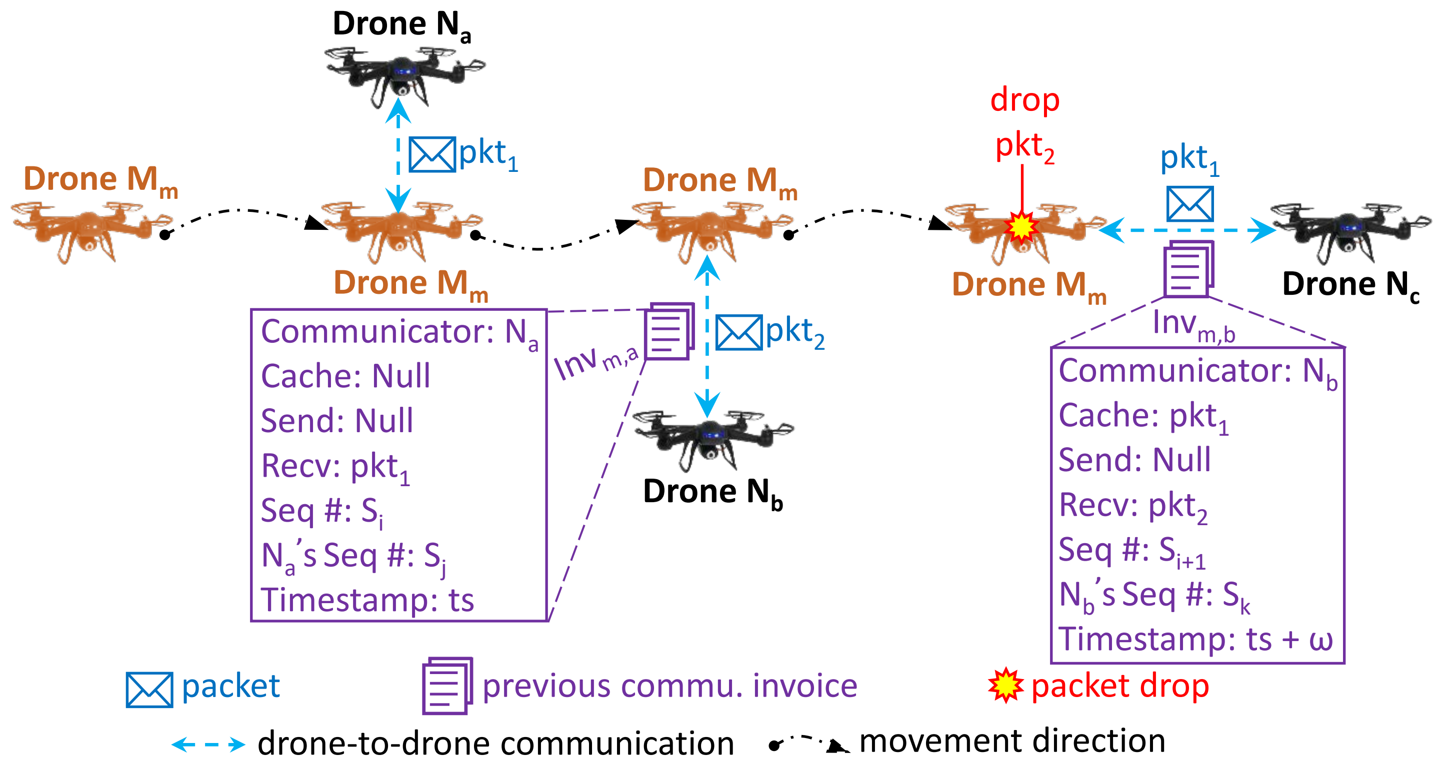
- When two drones contact,
  - exchange packets to be sent to next-hop drone
  - create communication invoice
    - communicators' ID
    - timestamp of communication
    - unique communication sequence number
    - what packets are in their caches before the communication
    - what packets they receive and send during the communication
    - their digital signatures
  - keep previous communication invoice
  - share next-hop drone with the following
    - previous communication invoice; the vector of packets in its cache

communication invoice:
a certified record that contains all communication related information of two drones.

determines whether the sending drone has dropped any packet

Yes, quit sending ← → No, continue sending

$Counter^{Romir}$: Distributed Countermeasure



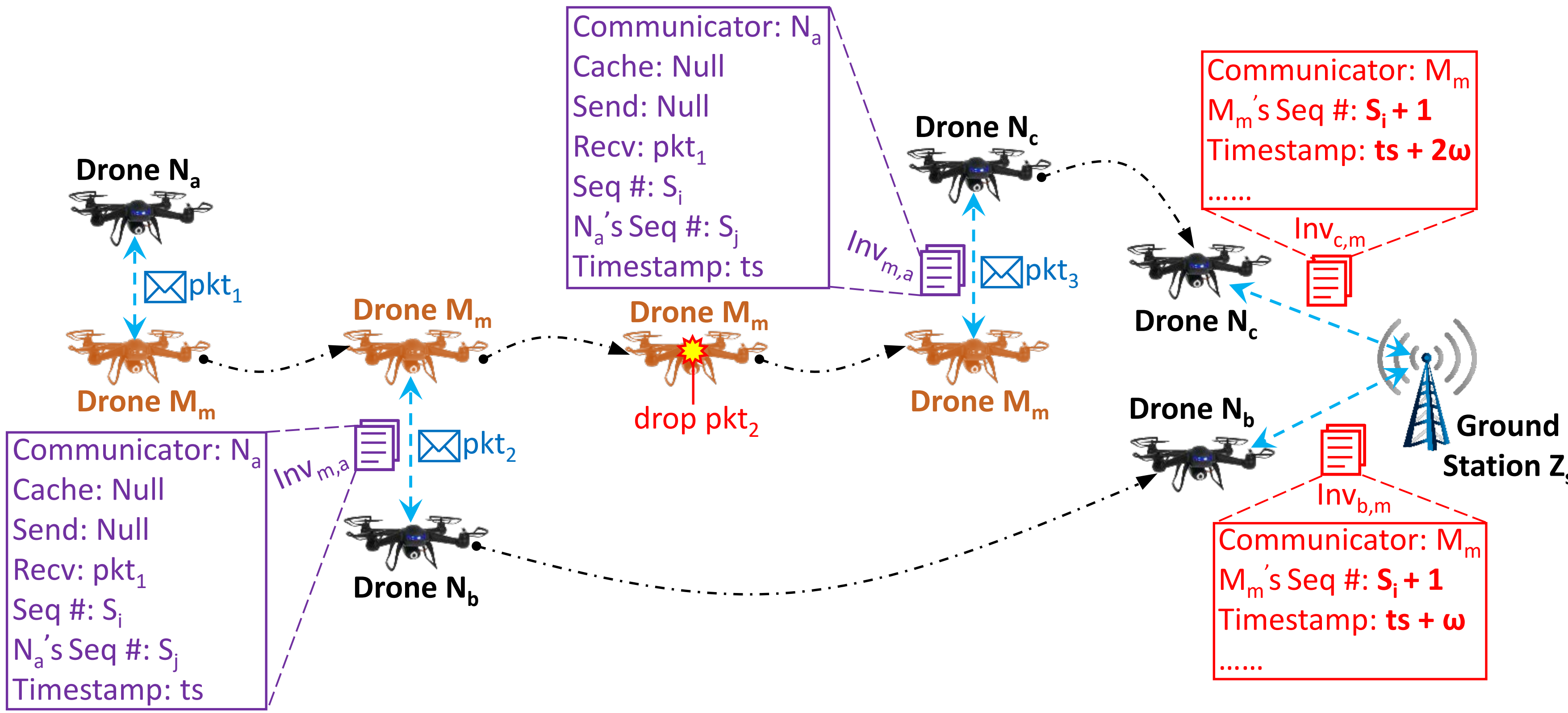
Counter^{Romir}: Distributed Countermeasure

- A malicious drone might share the incorrect communication invoice
  - cover up its packet dropping activity
  - avoid detection

  ⬇ inconsistent communication invoices

- ZSP detects the misstating activity of malicious drone
  - assign a unique comm. seq. number to each communication
  - the same seq. number will not be used twice
    - e.g., 1st seq. #: 1, 2nd seq. #: 2, 3rd seq. #: 3, ……
    - 2^{32} possible seq. # ⟶ large enough for packets
  - basic idea of detecting misstating activity:
    - each drone
      1. saves a small number of invoices of communications with other drones
      2. sends them to ground station for verification
    - ground station identifies inconsistent communication invoices from two different drones ⟶ detecting misstating activity

Counter^{Romir}: Distributed Countermeasure



Performance Evaluation

- Performance metrics
  - detection rate
  - miss/error detection rate
  - packet delivery ratio
  - the number of dropped packets
- Benchmark schemes
  - EYES [15]
    - monitor-based approach
  - SCAD [16]
    - acknowledgement-based approach
- Simulation environment
  - OMNeT++ [8]
    - event-driven network simulator

Algorithm 1: Routing Misbehavior Countermeasure

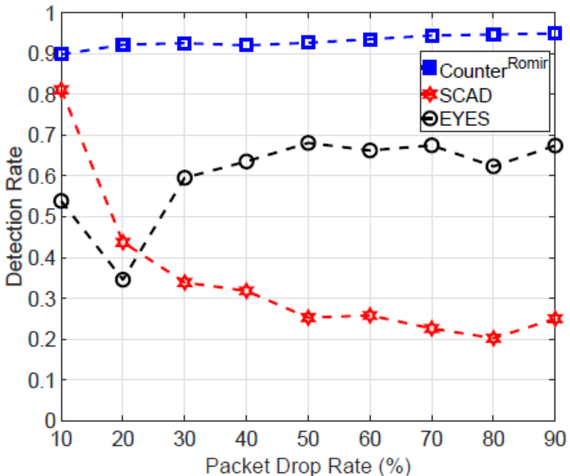
Input: $Inv_{m,a}$, Ca_m, $Inv_{b,m}$, $Inv_{c,m}$

/* drone detects packet dropping attack */
Function DroneDetect ($Inv_{m,a}$, Ca_m):
  /* $Inv_{m,a}[Ca_m]$ is the vector of cached packets at the beginning of previous communication; Ca_m is the vector of cached packets at the beginning of current communication. */
  /* *pkt* indicates the packet. */
  if *pkt* $\in (Inv_{m,a}[Ca_m] \cup Inv_{m,a}[Rec_m])$ **and** *pkt* $\notin Ca_m$ **and** *pkt* $\notin Inv_{m,a}[Sen_m]$ **then**
    detect packet dropping misbehavior;
  else
    exchange packets;
  end

/* ZSP detects commu. invoice misstating */
Function ZSPDetect ($Inv_{b,m}$, $Inv_{c,m}$):
  if $Inv_{b,m}[TS] < Inv_{c,m}[TS]$ **then**
    if $Inv_{b,m}[Seq_m] \geq Inv_{c,m}[Seq_m]$ **then**
      detect communication invoice misstating;
      broadcast *Alarm* packet;
    end
  end
  if $Inv_{b,m}[TS] > Inv_{c,m}[TS]$ **then**
    if $Inv_{b,m}[Seq_m] \leq Inv_{c,m}[Seq_m]$ **then**
      detect communication invoice misstating;
      broadcast *Alarm* packet;
    end
  end

Performance Evaluation (cont.)

Detection Rate



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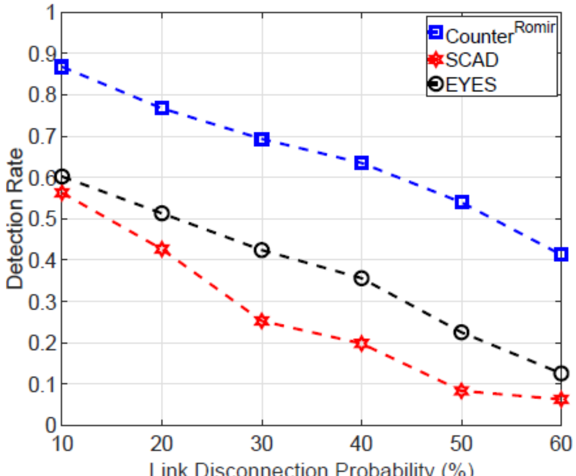

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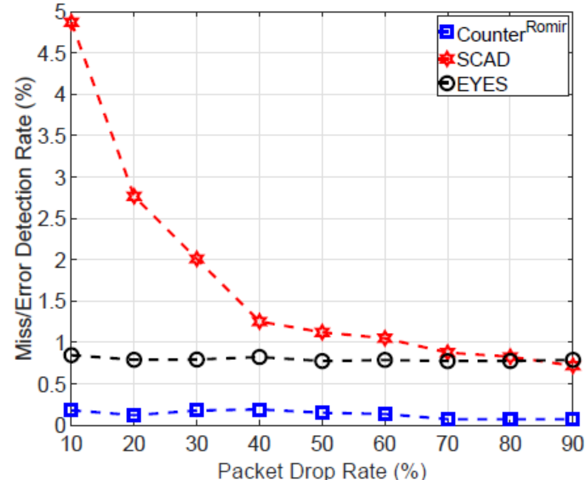
Miss Detection Ratio



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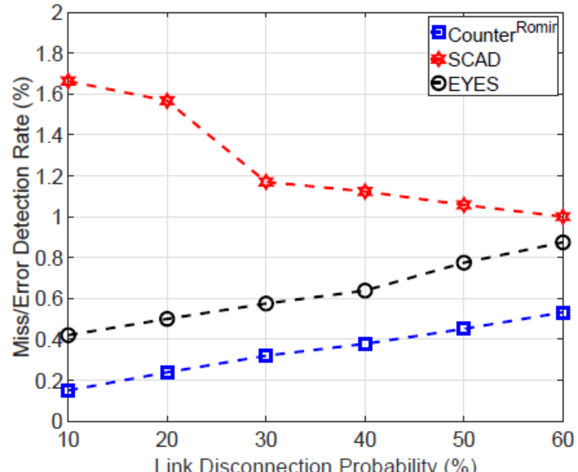

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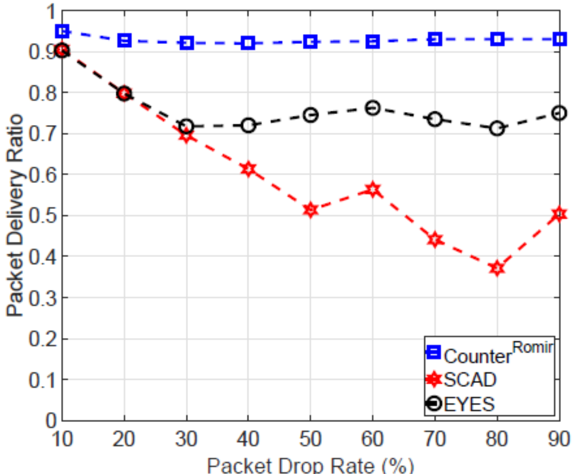
Performance Evaluation (cont.)

Packet Delivery Ratio



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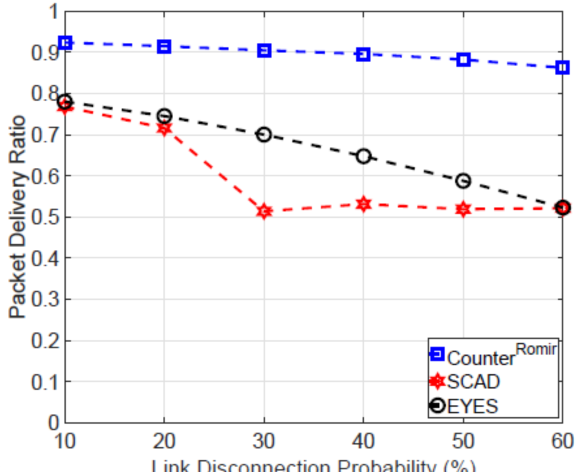

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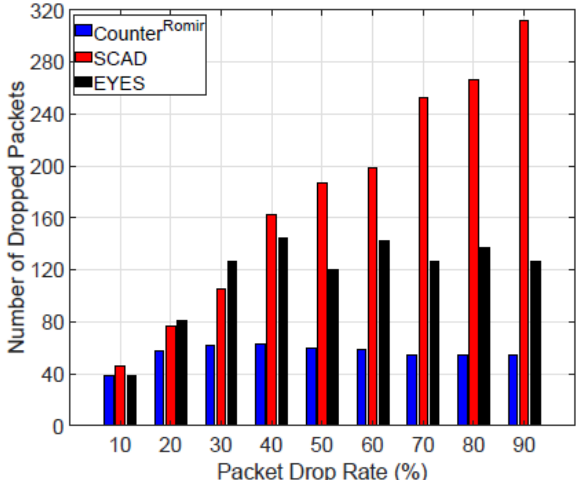
Number of Dropped Packets



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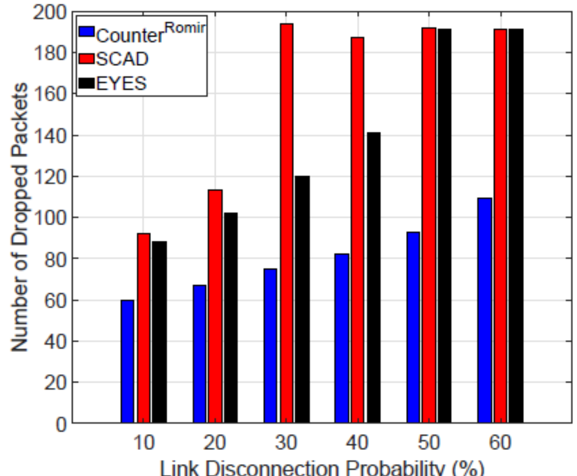

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Concluding Remarks

- Developed a distributed countermeasure (*Counter*^{Romir}) to detect / mitigate routing misbehavior in the IoD.
  - a drone keeps the previous signed communication invoice and shares it with the next-hop drone to detect any packet dropping activity
  - each drone saves and sends a small number of past communication invoices to the ground station which can detect the misstating drone
- *Counter*^{Romir} achieves
  - 90% detection rate
  - packet delivery ratio above 90%,
  - lower miss/error detection rate
- Under investigation…
  - a large number of communication invoices to be exchanged
  - data reduction strategy
  - a real-world testbed to explore the full potential of *Counter*^{Romir}

Any Questions?

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