Neighborhood Monitoring in Ad Hoc Networks

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Based on:
Axel Krings, and Stephan Muehlbacher-Karrer,
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Motivation and Background

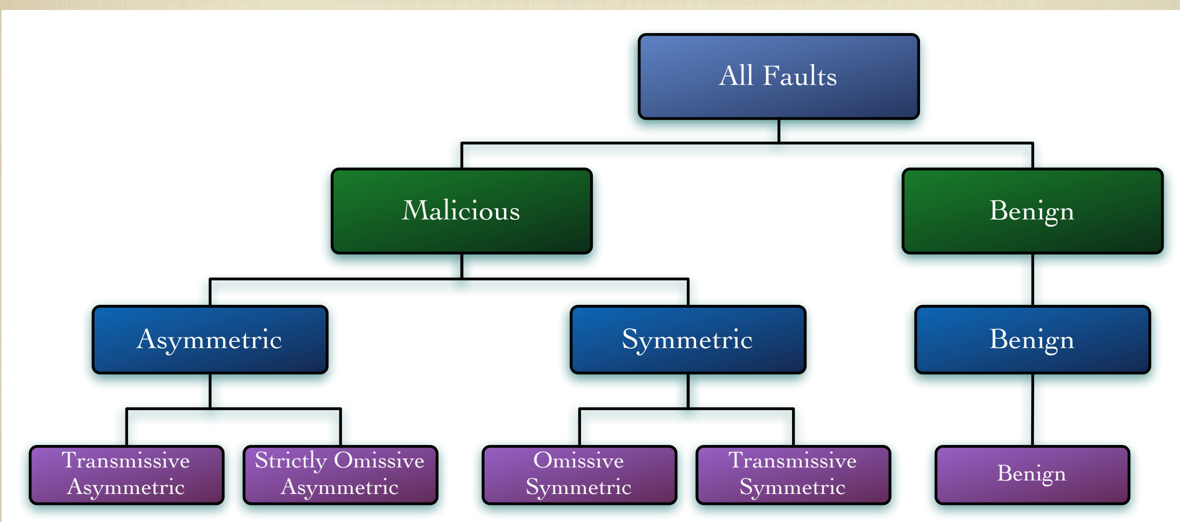
Wireless Networks

- Wireless Networks have gained great popularity
- Special focus: ad hoc nets, MANETs, sensor nets
- Wireless has many potential problems w.r.t.
  - **Security**: broadcast, “everybody can see”, nodes may be captured/impersonated/... many flavors
  - **Reliability**: nodes may be mobile, links and nodes have reliability/availability constraints, external interference, faults range from benign to malicious
  - **Mobility:** dynamic topology

Fault Models

- "Problems" and "Faults", "Errors" and "Failures"
  - in the end it boils down to Fault Models
- What are the assumptions about faults?
  - crash faults, omission faults, etc.
  - independence of faults
  - dependence of faults => common mode fault
  - recovery differs greatly depending on the fault model

Fault Model Overview



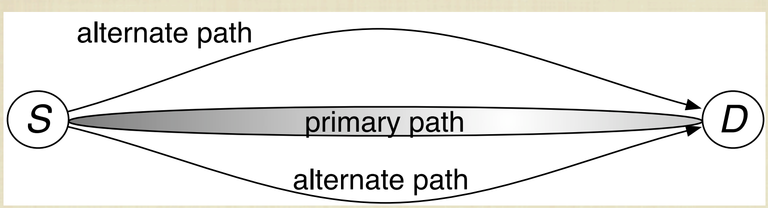
Recovery needs Redundancy

- Time redundancy
- Information redundancy
- Spatial redundancy

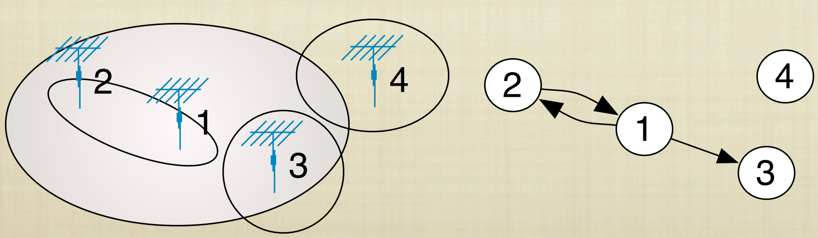
e.g. if one considers *s* symmetric and *b* benign faults, then one needs a redundancy level of $N > 2s + b$ to mask the faults

Network Graph

- General Communication Model



- Network Graph G is a digraph



Network Graph

- General network graph is a flow-graph (packet flow)
- In wireless networks this is different
  - broadcast is NOT point-to-point
  - broadcast implies flow on all outgoing edges of a node
  - if network consists of wireless and wired, then colored graph can be used

Graph Join Operation

- Join graph of two graphs

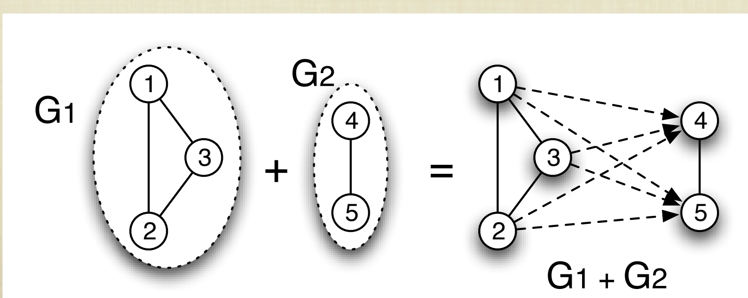
Given $G_i = (V_i,E_i)$ and $G_j = (V_j,E_j)$

$G = (V,E) = G_i + G_j$ where

$V = V_i \cup V_j$

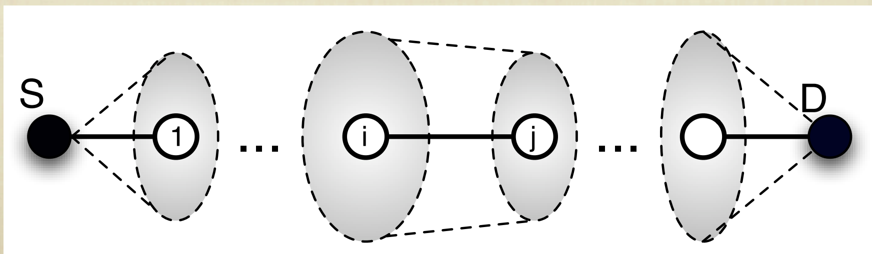
$E = E_i \cup E_j$

and $\forall\ v_i \in V_i,\ v_j \in V_j \quad e_{ij} \in E$



General Join Graph (GJG)

- A path between v_S and v_D defines the primary communication path.
- Let C_1 be a clique of all vertices v_i that is incident from v_S, i.e., for each $v_i \in C_1$ there exists e_{Si}.
- For each v_j in the primary communication path define C_j as a clique of *all* vertices v_i, for which there exists an edge e_{hi} from *all* $v_h \in C_{j-1}$.
- Let C_D be a trivial clique containing only v_D.



Attacks in Ad Hoc Nets

Behind any attack there is an action on the packet which involves

- Delaying packets
- Dropping packets
- Modification of packets
- Fabrication of packets
- and then of course “sniffing” packets

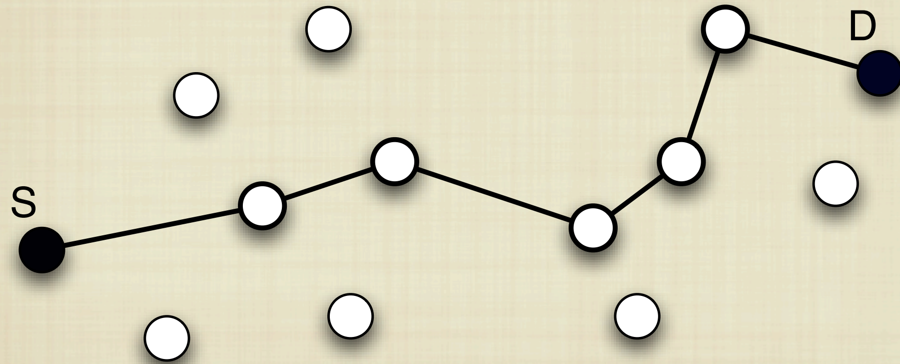
Related Work

Related Work

- One-dimensional monitoring, e.g.,
  - Marti et. al. [2000] Watchdog + Pathrater,
  - Patcha [2003] Watchdog groups, dealing with collusions
  - Buchegger [2004] Limitations on Watchdogs
- Multi-dimensional monitoring, e.g.,
  - Krings and Ma [2006] MILCOM'06 (Join-Graphs)
  - Huang [2008] JICS (Extended Watchdog)
  - Khalil [2009] Ad Hoc Networks (Neighbor Monitoring)

Watchdog a la Marti

- Simple watchdog



Extended Watchdog

- packet ->A-B-C
- is packet for C?
- is B destination?
- what if A is malicious and does not send data to make B look bad?
- what if B drops packet due to congestion?

from Huang & Liu JICS [2008]

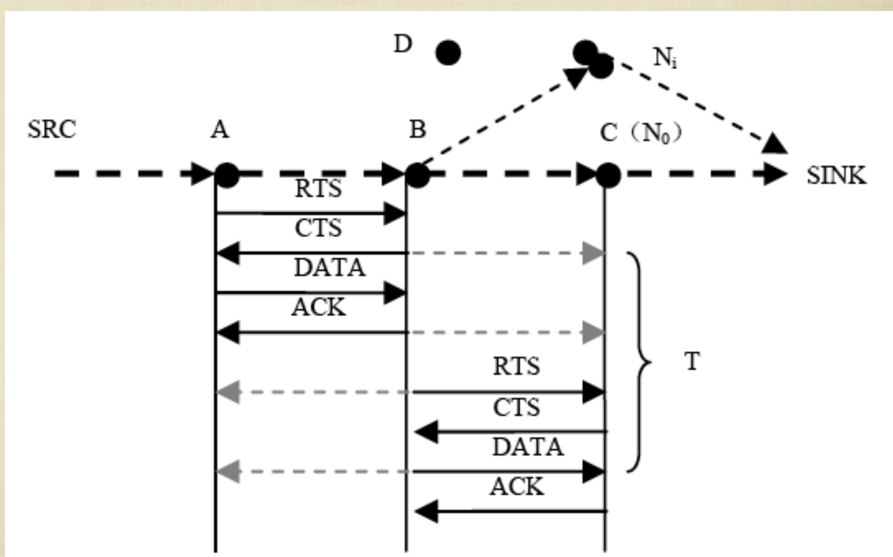
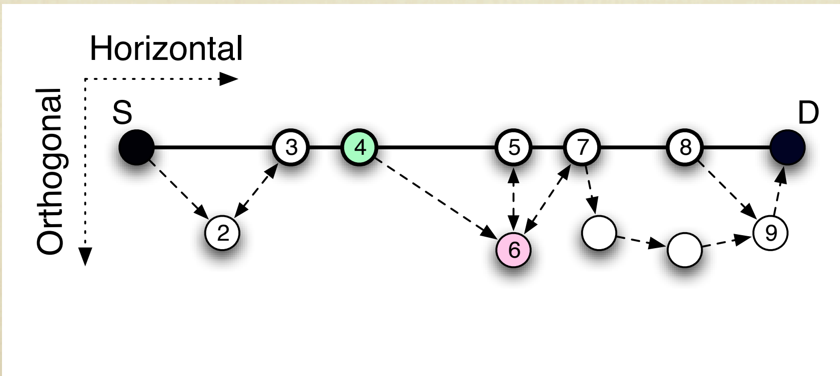


Fig. 1: System Model

Two-Dimensional Monitoring

Krings & Ma 2006

- Horizontal and orthogonal cross-monitoring
- mainly a topology-based argument



[Khalil et.al. 2009] UnMask

- Attack-free environment during neighborhood discovery
- Static wireless network
- Discovery is once in a lifetime only

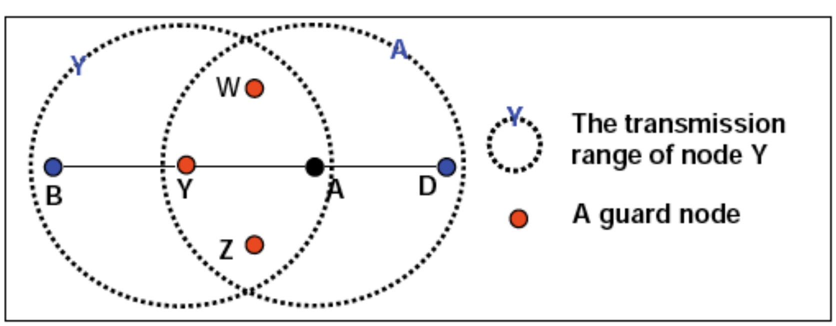


Fig. 1. W, Y, and Z are guards of A over link Y to A.

General Neighborhood Monitoring

Attack Model

- Attack may originate within a node that is part of authenticated neighborhood or not
- Attacks
  - from outside of authenticated neighborhood
  - from good node gone bad
  - from malicious node that joint neighborhood

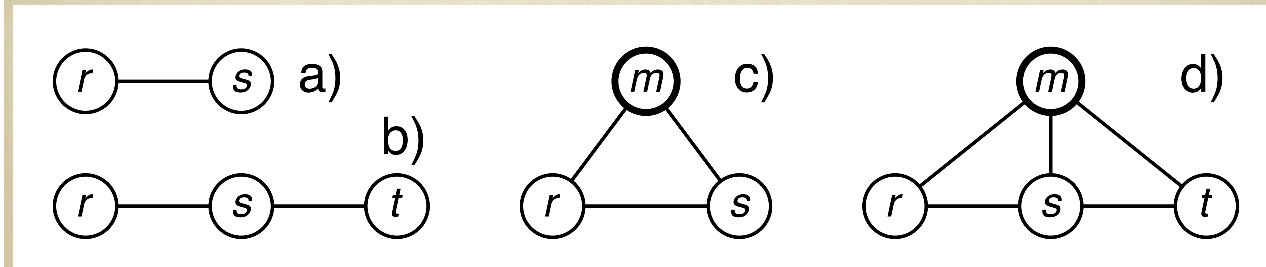
Evolution of Monitoring

a) watchdog

b) extended watchdog

c) UnMask

d) new approach

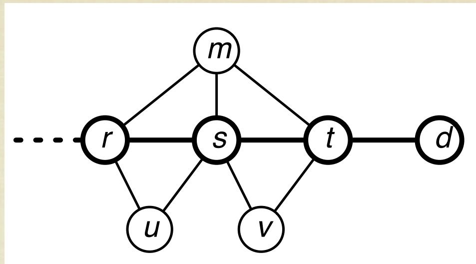


Neighborhood Discovery

- 1-Hop Discovery
  - arriving node v_i broadcasts HELLO message
  - each v_k receiving the message replies to v_i
  - v_i collects the neighbors in neighborhood list N_i
- 2-Hop Discovery
  - each v_k receiving the message replies with its neighborhood list N_k
  - can be used if adopting authentication under the assumptions of [Khalil et.al. 2009]

Neighborhood Discovery

- 1-Hop Discovery



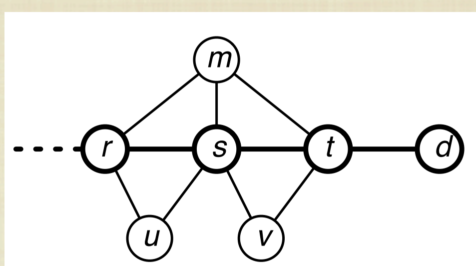
N_u	
r	1
s	1

N_v	
s	1
t	1

N_m	
r	1
s	1
t	1

Neighborhood Discovery

- 2-Hop Discovery



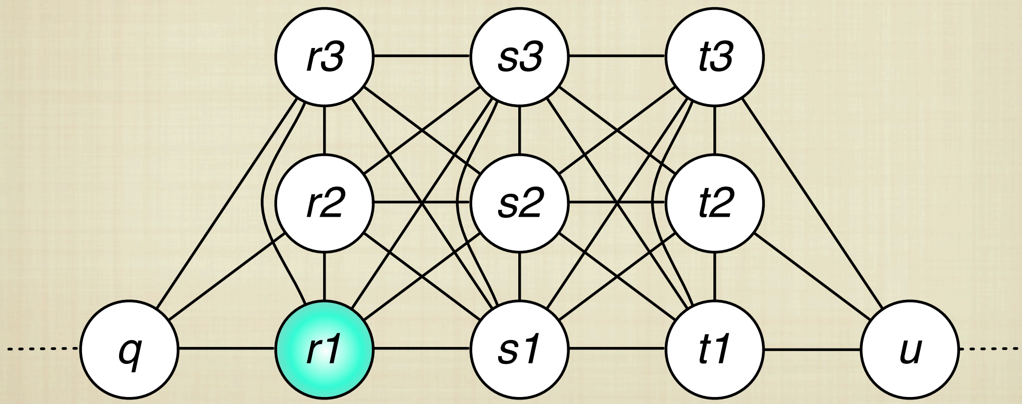
N_u	
r	1
s	1
m	2
v	2
t	2

N_v	
s	1
t	1
m	2
r	2
u	2
d	2

N_m	
r	1
s	1
t	1
u	2
v	2
d	2

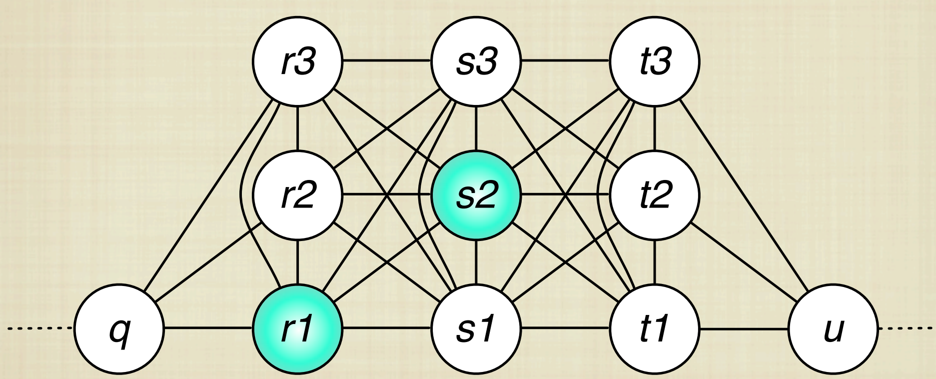
Multi-hop Monitoring

- Example 1: Omission at node r_1
- Example 2: Manipulation at node r_1



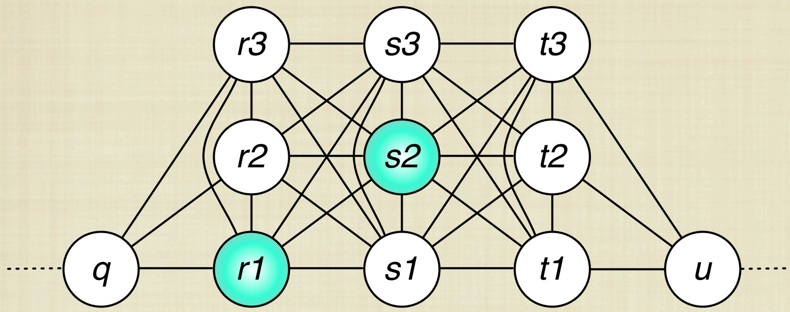
Multi-hop Monitoring

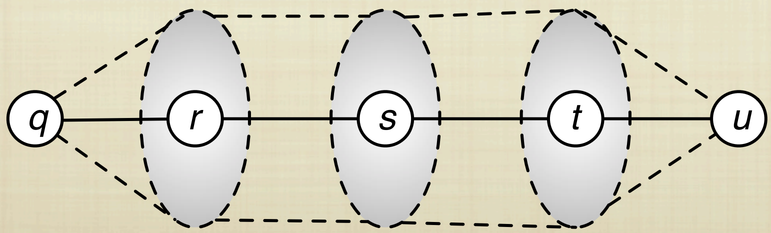
- Example 3: Manipulation at node r_1 collaborating node s_2



Multi-hop Monitoring

- Generalization as Join Graph





Neighborhood Threshold

- Thresholds for fault detection and correction depend on neighborhood awareness or lack thereof
- Type of fault considered: $\mathcal{F} = \{o, d, r, f, m\}$

  o: omission

  d: delay

  r: routing

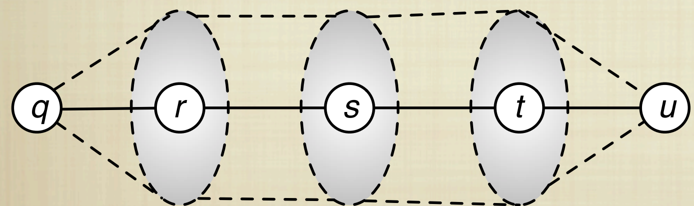
  f: fabrication

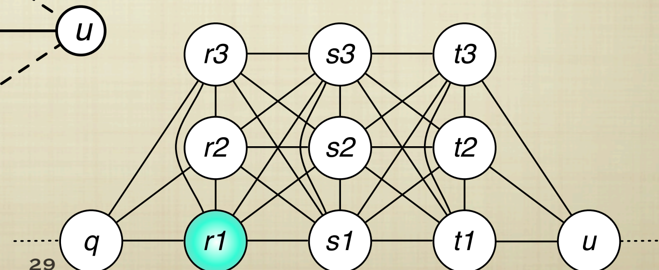
  m: manipulation

Neighborhood Threshold

1. $\mathcal{F}$ = $\{m\}$: Assume the only faults are in C_r. Then a node $s \in C_s$ can recover if it receives $N > e$ identical notifications from clique C_r. N = e + 1.

   True for the topology-aware and tolopogy-unaware cases.



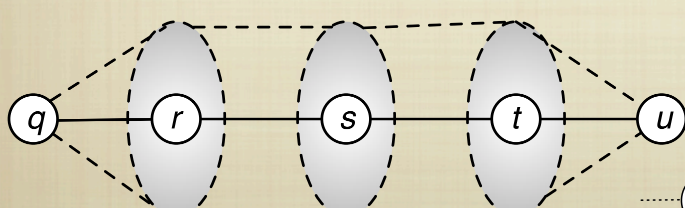


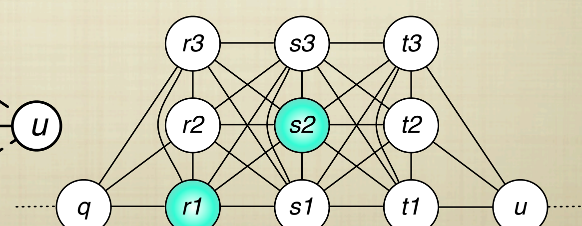
Neighborhood Threshold

2. $\mathcal{F} = \{m\}$: Assume there are e_r faults in C_r and e_s, e_t passive colluders in C_s and C_t respectively.

   Topology-aware case: $s \in C_s$ needs to deal only with faults in C_r, as the others can be ignored. Thus s can recover if it receives $N > e$ identical notifications from clique C_r.

   Topology-unaware case: the passive colluders have to be considered. Therefore, it is the burden of C_r to produce enough notifications to compensate for the notifications for the $e_s + e_t$ colluders. This is only guaranteed if C_r is of size $N > 2e$, with $e = e_r + e_s + e_t$, i.e., at least $e + 1$ monitors in C_r respond.





Neighborhood Threshold

- Threshold for each fault type can be derived

$$\mathcal{F} = \{o, d, r, f, m\}$$

- Big issue becomes buffer size
  - packet ID
  - packet
  - header
  - signature
  - ...

General Neighborhood Watch

- There is **<u>no</u>** snake oil!
- The final model of a neighborhood watch depends on
  - the desired fault model
  - the overhead tolerated by the application
  - this is a trade-off space!

Conclusions

- A cross-monitoring method was presented that:
  - Makes no assumptions about behavior of malicious nodes
  - Establishes the thresholds for detection/correction; any node can be monitor
  - Includes previous work as special case
  - Establishes the connection between fault models and the associated monitoring overhead
- Current efforts focus on overhead analysis

Questions?

Extra Slides

Join Graph Example

- Assume nodes are moved to implement the GJG below