MOBIWORP: Mitigation of the Wormhole Attacks in Mobile Multi-hop Wireless Networks (MANET)

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Outline

- Introduction
  - What is a MANET network?
  - Attacks against MANET networks
  - The wormhole attack
  - The goals of the paper
- Primitive Building Blocks
- Mitigating Wormhole Attack in Mobile Networks
- Conclusion

MANET networks

- **M**obile **A**d **H**oc **NET**works (MANET)
- Autonomous system of nodes with no static infrastructure
- All or subset of nodes may move
- Nodes communicate wirelessly in multi-hop fashion
- Often subject to rapid deployment in environments where natural or malicious errors are likely

Security Attacks

Two classes of attacks

1. Attacks that can be defeated by crypto mechanisms
   - Eavesdropping: Solved by encryption
   - Message tampering: Solved by authentication
2. Attacks that subvert the functionality of the network
   - Control attacks: Manipulating control traffic (e.g., routing traffic) to disrupt data traffic
     - Examples: ID spoofing and Sybil, sinkhole, rushing, wormhole
   - Data Attacks: Directly manipulate data traffic
     - Examples: Blackhole, grayhole
   - This class cannot be prevented by cryptographic mechanisms alone

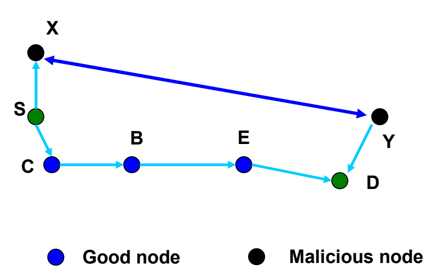
What is the Wormhole Attack?

- A control traffic attack that enables an attacker node to draw many routes through it
- Attacker tunnels packets received in one part of the network and replays in another part giving the illusion that optimal routes pass through it
- Tunneled packets look legitimate thus crypto mechanisms cannot detect them
- Puts the attacker in a powerful position to disrupt network functionality
  - Insinuate attacker in a route and then manipulate data traffic
    - Example: Selectively drop data packets
  - Routing disruptions
    - Example: Prevent discovery of legitimate route
  - Traffic analysis
    - Example: Observe traffic patterns as a way of leaking information
- Particularly insidious because can be launched without possessing any cryptographic keys

How can a Wormhole Attack be Launched?

- A simple way to launch the wormhole attack is through an out-of-band channel [1]
- Collusion is required for the attack to succeed

- S-C-B-E-D is a 4-hop legitimate route
- S-X-Y-D is a 3-hop wormhole route



[1] "LITEWORP: A Lightweight Countermeasure for the Wormhole Attack in Multihop Wireless Networks," I. Khalil, S. Bagchi, N. B. Shroff. In the International Conference on Dependable Systems and Networks (DSN), Yokohama, Japan, June 28 - July 1, 2005.

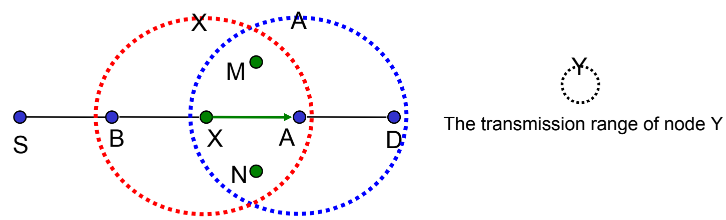
Goals

- Mitigate the wormhole attack in MANET networks with mobile attacker by
  - Detecting nodes involved in the attack
  - Diagnosing attacker nodes
  - Isolating attacker nodes from the network
- All previous approaches
  - Either, use expensive hardware, such as tight time synchronization among all nodes, directional antennas, etc.
  - Or, rely on all nodes being static and therefore their neighbors are unchanging

Outline

- Introduction
- The Wormhole Attack
- Primitive Building Blocks
  - Local Monitoring
  - Detection using local monitoring
  - Why detection is imperfect
- Mitigating Wormhole Attack in Mobile Networks
- Conclusion

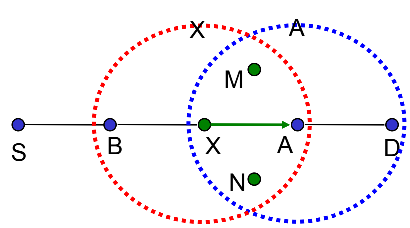
Local Monitoring



- A collaborative detection strategy in which a node monitors the traffic going in and out of its neighbors.
- Assumptions
  - Each node knows its first-hop and second-hop neighbors
  - Requires each node to include the ID of the prev-hop in the forwarded packet
- ***A guard*** of a node A for the link from X to A is any node that lies within the transmission range of both X and A
  - Example: M, X, and N are the guards of node A for the link from X to A
- A guard saves information about incoming packets in a watch buffer
- Matches an output packet with information in buffer

Local monitoring: Details

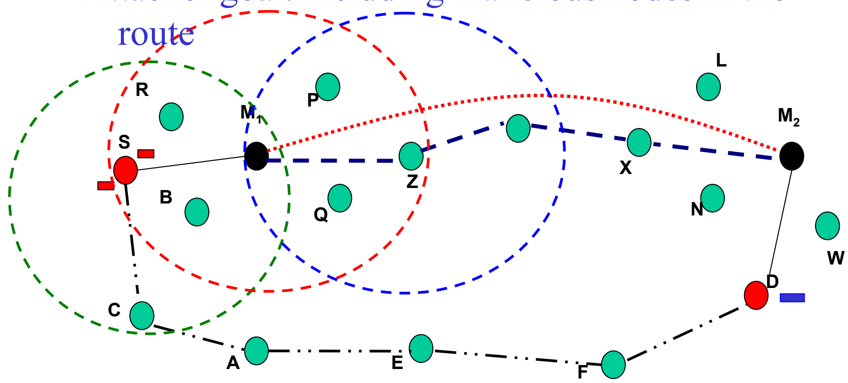
- Local monitoring can be used to detect different kinds of control attacks by changing the information maintained in the buffer and the kind of checking that goes on
- The different kinds of malicious activity that can be done by a node
  - Fabrication
  - Modification
  - Delay
  - Drop



- Correspondingly the kind of checking that needs to be done are:
  - An outgoing packet that has no matching packet in watch buffer
  - Difference between incoming and outgoing packet fields
  - Forwards after a threshold time
  - Not forwarding within a maximum acceptable timeout threshold

Detection Using Local Monitoring

Attacker goal: including malicious nodes in the route



Choice#1

Choice#2

M_1 claims that the R_{REP} is from M_2

M_1 claims that R_{REP} is from one of its neighbors, say Z

These detection approaches require the guards to monitor the route reply (R_{REP}) packets

Detection strategy

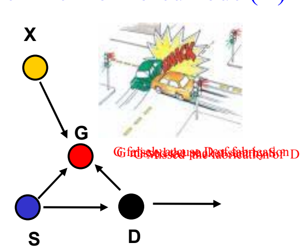
All the neighbors of M_1 (S,R,B,Z,Q) detect this malicious activity, because they know that M_2 is not a neighbor of M_1

The guards of the link (Z→M_1) (P,Z,Q) detect this malicious activity, because they have nothing in their watch buffers about R_{REP} coming from Z

Why Detection is Imperfect

Due to collision the following may occur

- *Missed detection*: A malicious event goes undetected
  - Collision at the guard (G) when the node (D) forwards a packet
- *False detection*: A normal event is detected as a malicious event
  - Collision at the guard (G) when the sender (S) transmits a packet
  - Detection at the guard when the monitored node (D) forwards the packet



Outline

- Introduction
- Primitive Building Blocks
- Mitigating Wormhole Attack in Mobile Networks
  - The mobility challenge
  - System assumptions and attack model
  - Data structures
  - The selfish move protocol (SMP)
  - The connectivity-aided protocol with constant velocity (CAP_CV)
  - Detection & isolation of malicious nods
  - Results
- Conclusion

The Mobility Challenge

- No fixed neighborhood membership
- Need two-hop neighbor verification that is
  - Efficient in time and energy
  - Secure
  - Not relying on expensive hardware
- No existing solution satisfies these requirements
- In MobiWorp, we provide
  - Two-hop neighbor verification whenever there is the possibility of launching a wormhole attack
  - Use this information to mitigate the wormhole attack with mobile attackers

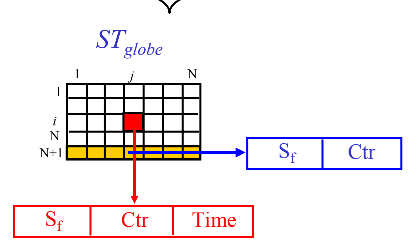
Assumptions & Model

- System assumptions
  - Existing key distribution mechanism
  - Mix of mobile and static nodes
  - Bi-directional links
  - Network has unconstrained trusted central authority (*CA*)
  - Ability to verify CA signatures
  - The maximum number of nodes in the network that can be compromised is known *a priori*
  - Loose time synchronization
- Attack model
  - Links may be subjected to eavesdropping and message tampering
  - Attacker node may be external or internal (i.e., compromised node)
  - Attacker node may be more powerful than legitimate network nodes
  - Attacker can arbitrarily delay, drop, modify, or fabricate subset of packets
  - Attacker nodes can collude among one another
  - Brute force denial of service attacks are not considered

Data Structures

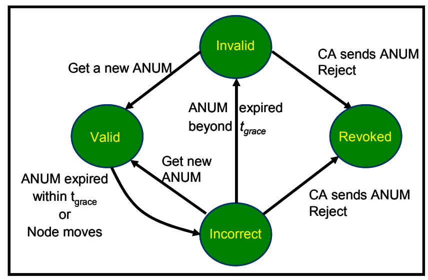
- A node *B* maintains
  - *MalC(B,i)* about each neighbor *i*
  - *Neighbor list* (Nb_{List})
  - *Black List* (B_{List}) of known revoked nodes

- The CA suspicion table (ST_{globe})
  - N+1×N table, N = number of nodes
  - $ST_{globe}[i,j].s_f$ = 1 if *i* revokes *j*, 0 otherwise
  - $ST_{globe}[i,j].ctr = MalC(i,j)$
  - $ST_{globe}[i,j]$.Time= the aggregated continuous time during which *i* & *j* are neighbors
  - $ST_{globe}[N+1,j].s_f$= 1 if *j* has been globally revoked
  - $ST_{globe}[N+1,j].ctr$ = number of nodes locally revoke *j*



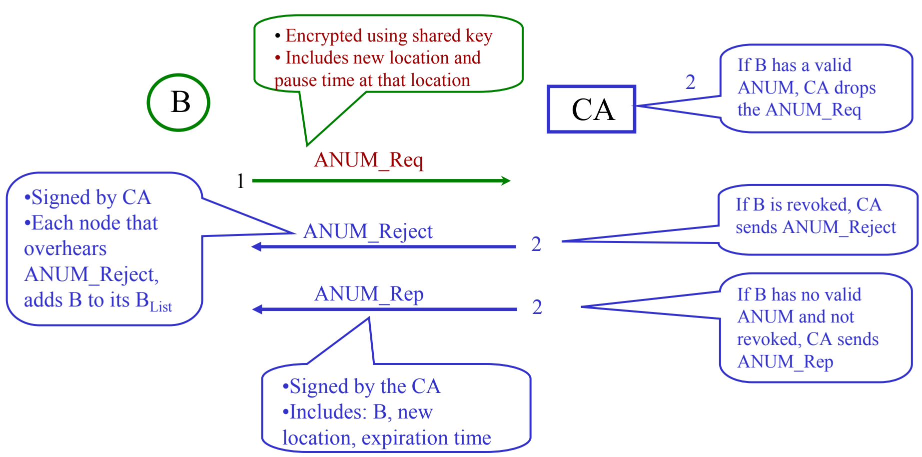
ANUM & Node States

- Authentication Neighbor Update Message (ANUM)
  - A certificate given by CA to a node (signed using CA's private key)
  - Used to convince other nodes of location ANUM.Loc
  - Has an expiration time ANUM.T_{expire}
- Grace Period (T_{grace}): the max time a node can send and recv after the expiration of its ANUM
- Node States: based on the functionality allowed to the node
  - Valid (send, recv, relay)
    - Claimed Loc = ANUM.Loc and
    - Cur_Time < ANUM.T_{expire}
  - Incorrect (send, recv)
    - Claimed Loc != ANUM.Loc or
    - ANUM.T_{expire} < Cur_Time < T_{grace}
  - Invalid (only Handshake packets)
    - Cur_Time > T_{grace}
  - Revoked (no allowable functionality)



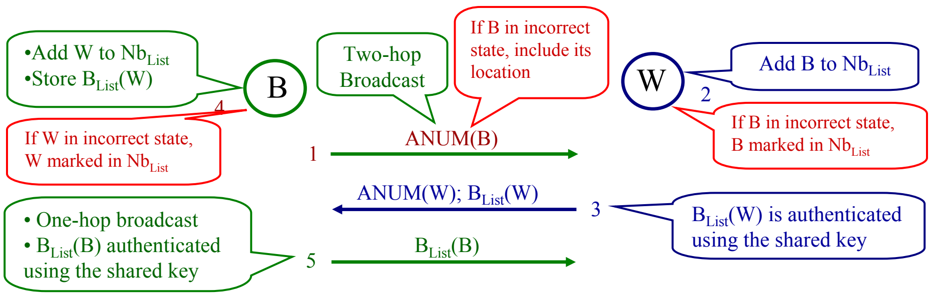
Selfish Move Protocol (SMP): Getting ANUM

Used for scenarios in which a mobile node is not allowed to relay packets while moving



SMP: Using the ANUM

Initiated by a node when it reaches its new location



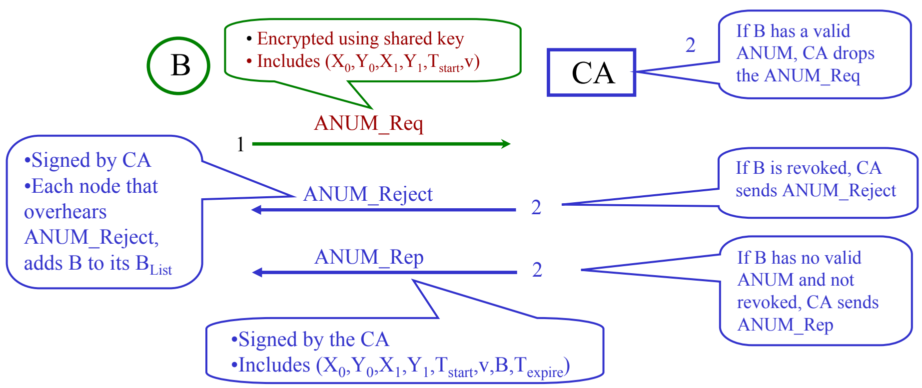
- A malicious node directly detected in B_{List}(B) serves as a partial detection evidence to W and vice-versa
- At min(T_{expire}(W), T_{expire}(B)), B removes W from Nb_{List}(B), so does W

Connectivity Aided protocol with Constant Velocity (CAP_CV)

- Problems with SMP
  - Network may get disconnected in high mobility scenario
  - A moving node can not communicate beyond T_{grace}
- Goals
  - Preserve the same network connectivity conditions as the insecure network
  - Allow moving nodes to travel any distance
- Assumptions
  - Each mobile node knows its location and trajectory of motion
  - Moving with fixed velocity (*v*)

CAP_CV: Getting and Using the ANUM

- Getting the ANUM (retry if fail)



- Secure neighbor discovery: same as SMP except that B computes the difference between actual position and computed one and refrain from broadcast if greater than a threshold

Local Isolation

- Goals
  - Propagate detection knowledge among the first-hop neighbors of the attacker
  - Isolate the malicious node from its local neighborhood
- When a guard G detects a malicious event by node M
  - G increments *MalC(M,G)*
  - Different malicious activities can be considered at different levels of criticality
- When the *MalC(M,G)* crosses a threshold
  - G removes M from its neighbor list
  - G sends an authenticated alert to the neighbors of M
- When W receives an alert about a neighbor M
  - Collects alert information from multiple guards
  - When the number of alerts reaches detection threhsold γ, W removes M from its neighbor list
- Local isolation is not sufficient for mobile attacker nodes
  - A malicious node leaves the current neighborhood to a new one

Global Isolation

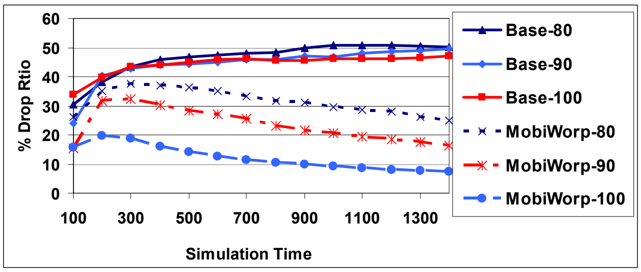
- Upon detection of a malicious node, M, a guard G sends an alert to the CA
  - I directly detect M behaving maliciously, or
  - This is the *MalC(G,M)* and the length of the monitoring round
- The CA updates its data structure (ST_{globe}) accordingly
  - $ST_{globe}[G,M].s_f = 1$, $ST_{globe}[N+1,M]$++ or
  - Update $ST_{globe}[G,M]$.Ctr and $ST_{globe}[G,M]$.Time
- CA takes decision about M
  - If $ST_{globe}[N+1,M]$ = the bound on the number of compromised nodes + false alarm safety factor, mark M as malicious

Simulation Setup

- Use ns-2 network simulator
- Data communication model: any node to any node, uses AODV for routing
- *Node distribution*: Randomly on a fixed-size field
  - Increasing number of nodes increases the density
- *Node movement*: Random waypoint model with velocity picked randomly from a uniform distribution (v_{min},v_{max})
- *Attacker nodes*: Internal compromised nodes randomly selected from network
- *Attack model* for wormhole attack: Out-of-band channel emulated by allowing instantaneous packet forwarding among attacker nodes
  - Attacker nodes drop all data packets through them
  - Attacker nodes have perfect collusion
- We simulate two scenarios
  - Baseline: insecure network
  - MobiWorp
- The output parameters are measured at the end of simulation time (1500 s)

Results: Drop Ratio

The output here is Drop ratio = % (Packets dropped/Packets sent)



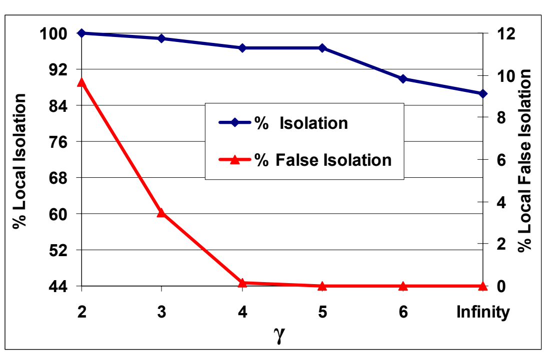
Input parameters

- $\gamma = 3$
- # mal. = 4
- #nodes= 80,90,100

- Drop ratio in Baseline is higher and reaches a steady state with time
- In MOBIWORP, drop ratio goes to zero with time due to isolation
- The higher the number of nodes, the smaller is the fraction of malicious nodes and therefore the lower the drop ratio

Results: Local Isolation

- % Isolation = %(#mal. nodes isolated locally/total number of mal. nodes)
- % False isolation = %(#good nodes isolated locally/total number of nodes)



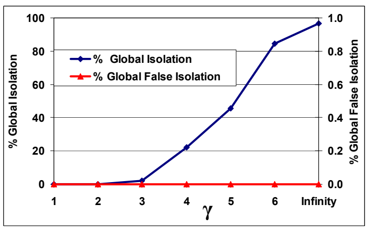
Input Parameters

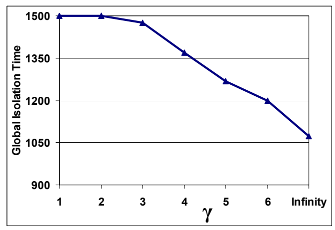
- # mal. Nodes = 4
- # of nodes = 60

- Both isolation and false isolation decrease with increasing γ since it becomes more difficult to get consensus among guards
- Why do we go for infinite γ if $\gamma = 4$ is good enough?

Results: Global Properties

- %Global Isolation = %(the # mal. nodes revoked by CA / total of mal. nodes)
- %Global False Isolation = %(the # nodes falsely revoked by CA / total # nodes)
- %Global Isolation time = average of global isolation time of each isolated malicious node
- Isolation time of a malicious node = the time from which the node starts attacking the network to the time when the node is revoked by the CA.



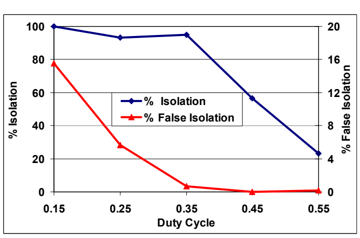


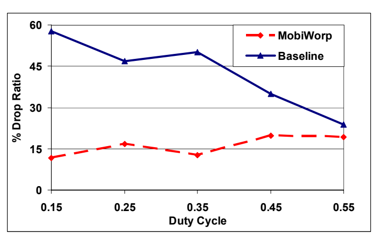
- Inputs
- # mal. = 4
- # Nodes = 60
- # Max mal. = 15

- Low γ requires contribution of many neighborhoods and thus low isolation and false isolation percentages
- Global latency decreases even though local latency increases with γ

Results: Effect of Motion

Duty cycle = motion time/simulation time





Input parameters
- γ = 3
- #Max mal. = 3
- # mal. = 4
- #nodes= 60

- Increasing frequency of motion causes malicious nodes to escape before the MalC reaches the threshold. CA does not aggregate across guards. This decreases both detection and false detection
- In Base case increasing motion frequency causes wormholes to break faster and thus the drop ratio decreases

Conclusion

- Proposed a generic strategy for cooperative distributed detection of the wormhole attack in mobile ad-hoc networks (MOBIWORP)
- Proposed a generic strategy for locally isolating the malicious nodes
- Proposed a global strategy for mitigating the wormhole in face of mobile malicious nodes through the CA
- Study the efficiency of MOBIWORP under different network conditions and mobility patterns
- Future Work:
  - Extension to aggregate across multiple guards
  - Scheduling of guards to reduce collision

Thanks

Questions?