Security and Cooperation in Wireless Networks

http://secowinet.epfl.ch/

Chapter 4: Naming and addressing

attacks against naming and addressing:

- address stealing
- Sybil attack
- node replication attack;

protection mechanisms:

- Cryptographically Generated Addresses
- witness based detection of node replication

Chapter outline

4.1 The future of naming and addressing in the Internet

4.2 Attacks against naming and addressing

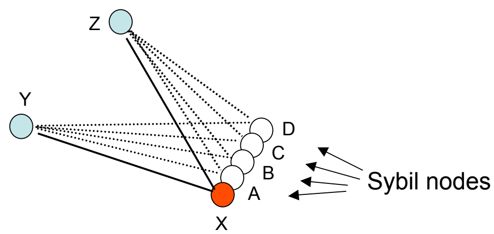
4.3 Protection techniques

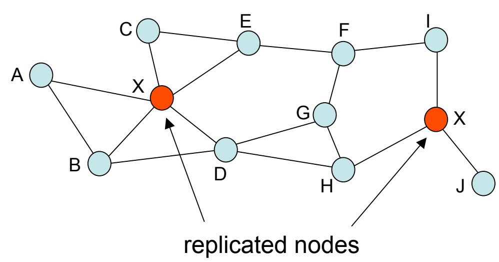
Chapter outline

Introduction

- naming and addressing are fundamental for networking
  - notably, routing protocols need addresses to route packets
  - services need names in order to be identifiable, discoverable, and useable
- attacks against naming and addressing
  - address stealing
    - adversary starts using an address already assigned to and used by a legitimate node
  - Sybil attack
    - a single adversarial node uses several invented addresses
    - makes legitimate nodes believe that there are many other nodes around
  - node replication attack
    - dual of the Sybil attack
    - the adversary introduces replicas of a single compromised node using the same address at different locations of the network

Illustration of the Sybil and node replication attacks



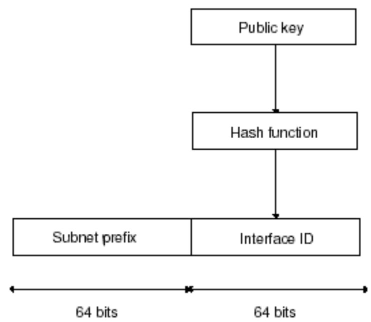


Chapter outline

4.1 The future of naming and addressing in the Internet
4.2 Attacks against naming and addressing
4.3 Protection techniques

Cryptographically Generated Addresses (CGA)

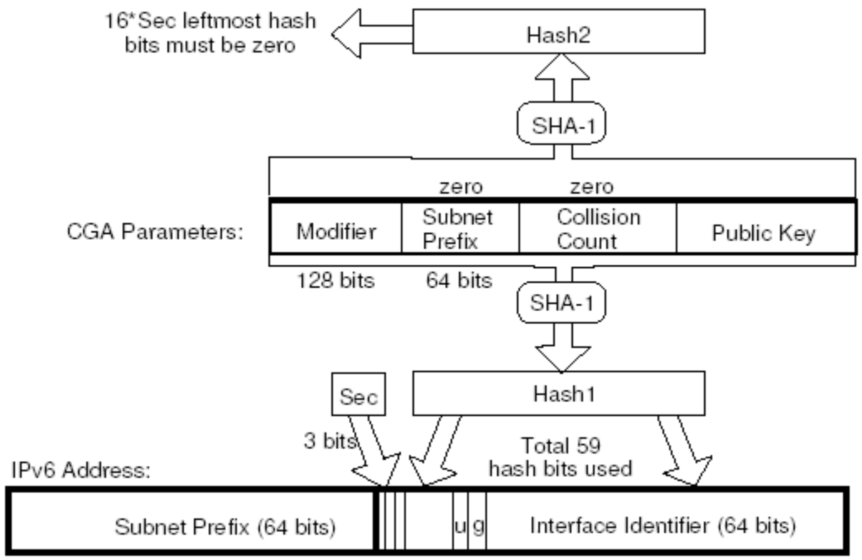
- aims at preventing address stealing
- general idea:
  - generate node address from a public key
  - corresponding private key is known only by the legitimate node
  - prove ownership of the address by proving knowledge of the private key
- example in case of IPv6:



A potential problem with CGA

- often only a limited number of bits of the address can be chosen arbitrarily (64 in our example)
- this number may be too small to guarantee second pre-image resistance
  - an adversary could pre-compute a large database of interface identifiers from public keys generated by himself, and use this database to find matches to victims' addresses
- a solution can be the technique called *hash extension*
  - increase the cost of address generation, and hence the cost of brute-force attacks, while keep constant the cost of address usage and verification

Hash extension



Protocol for CGA generation

1. Set the modifier field to a random 128-bit value.
2. Hash the concatenation of the modifier, 64+8 zero bits, and the encoded public key. The leftmost 112 bits of the result are Hash2.
3. Compare the 16*Sec leftmost bits of Hash2 with zero. If they are all zero (or if Sec=0), continue with Step (4). Otherwise, increment the modifier and go back to Step (2).
4. Set the collision count value to zero.
5. Hash the concatenation of the modifier, subnet prefix, collision count and encoded public key. The leftmost 64 bits of the result are Hash1.
6. Form an interface identifier by setting the two reserved bits in Hash1 both to 1 and the three leftmost bits to the value Sec.
7. Concatenate the subnet prefix and interface identifier to form a 128-bit IPv6 address.
8. If an address collision with another node within the same subnet is detected, increment the collision count and go back to step (5). However, after three collisions, stop and report the error.

Protocol for CGA verification

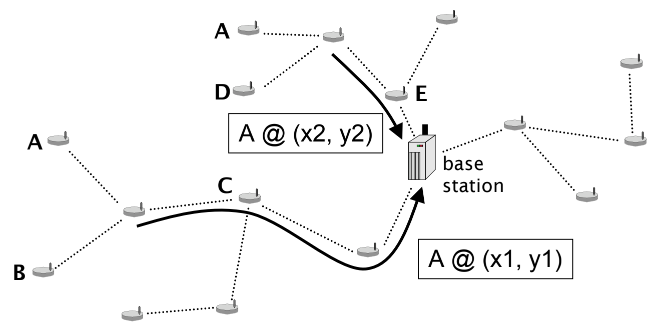
1. Check that the collision count value is 0, 1 or 2, and that the subnet prefix value is equal to the subnet prefix (i.e. leftmost 64 bits) of the address. The CGA verification fails if either check fails.
2. Hash the concatenation of the modifier, subnet prefix, collision count and the public key. The 64 leftmost bits of the result are Hash1.
3. Compare Hash1 with the interface identifier (i.e. the rightmost 64 bits) of the address. Differences in the two reserved bits and in the three leftmost bits are ignored. If the 64-bit values differ (other than in the five ignored bits), the CGA verification fails.
4. Read the security parameter Sec from the three leftmost bits of the interface identifier of the address.
5. Hash the concatenation of the modifier, 64+8 zero bits and the public key. The leftmost 112 bits of the result are Hash2.
6. Compare the 16*Sec leftmost bits of Hash2 with zero. If any one of these is nonzero, CGA verification fails. Otherwise, the verification succeeds.

Thwarting the Sybil attack

- note that CGAs do not prevent the Sybil attack
  - an adversary can still generate addresses for herself
- a solution based on a central and trusted authority
  - the central authority vouches for the one-to-one mapping between an address and a device
  - e.g., a server can respond to requests concerning the legitimacy of a given address
- other solutions take advantage of some physical aspects
  - e.g., identify the same device based on radio fingerprinting

Thwarting the node replication attack (1/2)

- a centralized solution
  - each node reports its neighbors' claimed locations to a central authority (e.g., the base station in sensor networks)
  - the central authority detects if the same address appears at two different locations
  - assumes location awareness of the nodes



Thwarting the node replication attack (2/2)

- a decentralized variant
  - neighbors' claimed location is forwarded to *witnesses*
  - witnesses are randomly selected nodes of the network
  - if a witness detects the same address appearing at two different locations then it broadcast this information and the replicated nodes are revoked

Analysis of the decentralized variant

- total number if nodes is n
- average number of neighbors is d
- each neighbor of A forwards A's location claim with probability p to g randomly selected witnesses
- average number of witnesses receiving A's location claim is p*d*g
- if there are L replicas of A, then for the probability of detection:

$$P_{det} > 1 - \exp(- L(L-1)(pdg)^2 / 2n)$$

- numerical example:

  n = 10000, d = 20, g = 100, p = 0.5
  L = 2 → P_{det} ~ 0.63
  L = 3 → P_{det} ~ 0.95

Summary

- there are various attacks against naming and addressing
  - address stealing
  - Sybil attack
  - node replication attack

- decentralization and lack of a central authority renders the defense against these attacks difficult

- proposed solutions (CGA, node replication detection using witnesses) provide only probabilistic guarantees
  - parameters should be chosen carefully

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Chapter 5: Establishment of security associations

key establishment in sensor networks;

key establishment in ad hoc networks exploiting
- physical contact
- vicinity
- node mobility;

revocation;

Chapter outline

Key establishment in sensor networks

- due to resource constraints, asymmetric key cryptography should be avoided in sensor networks
- we aim at setting up symmetric keys

- requirements for key establishment depend on
  - communication patterns to be supported
    - unicast
    - local broadcast
    - global broadcast
  - need for supporting in-network processing
  - need to allow passive participation

- necessary key types
  - node keys – shared by a node and the base station
  - link keys – pairwise keys shared by neighbors
  - cluster keys – shared by a node and all its neighbors
  - network key – a key shared by all nodes and the base station

Setting up node, cluster, and network keys

- node key
  - can be preloaded into the node before deployment

- cluster key
  - can be generated by the node and sent to each neighbor individually protected by the link key shared with that neighbor

- network key
  - can also be preloaded in the nodes before deployment
  - needs to be refreshed from time to time (due to the possibility of node compromise)
    - neighbors of compromised nodes generate new cluster keys
    - the new cluster keys are distributed to the non-compromised neighbors
    - the base station generates a new network key
    - the new network key is distributed in a hop-by-hop manner protected with the cluster keys

Design constraints for link key establishment

- network lifetime
  - severe constraints on energy consumption
- hardware limits
  - 8-bit CPU, small memory
  - large integer arithmetics are infeasible
- no tamper resistance
  - nodes can be compromised
  - secrets can be leaked
- no a priori knowledge of post-deployment topology
  - it is not known a priori who will be neighbors
- gradual deployment
  - need to add new sensors after deployment

Traditional approaches

- use of public key crypto (e.g., Diffie-Hellman)
  - limited computational and energy resources of sensors
- use of a trusted key distribution server (Kerberos-like)
  - base station could play the role of the server
  - requires routing of key establishment messages to and from the base station
    - routing may already need link keys
    - unequal communication load on the sensors
  - base station becomes single point of failure
- pre-loaded link keys in sensors
  - post-deployment topology is unknown
  - single "mission key" approach
    - vulnerable to single node compromise
  - n -1 keys in each of the n sensors
    - excessive memory requirements
    - gradual deployment is difficult
    - doesn't scale

Link key setup using a short-term master key

- Sensor networks: stationary nodes, neighborhood of a node does not change frequently

- Link key establishment protocol:
  - Master key pre-loading
  - Neighbor discovery
  - Link key computation
  - Master key deletion

- Master key pre-loading:
  - Before deployment
  - Master key K_{init} is loaded into the nodes
  - Each node u computes $K_u = f_{Kinit}(u)$

Link key setup using a short-term master key

- Neighbor discovery:
  - After the deployment
  - Node u initializes a timer
  - Discovers its neighbors: HELLO message
  - Neighbor v responds with ACK
  - ACK: identifier of v, authenticated with K_v
  - u verifies ACK

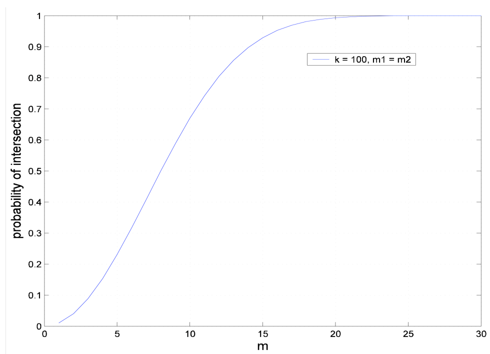
- link key computation:
  - link key: $K_{uv}=f_{Kv}(u)$.

- Master key deletion:
  - When timer expires: u deletes K_{init} and all K_v

Random key pre-distribution – Preliminaries

Given a set *S* of *k* elements, we randomly choose two subsets S_1 and S_2 of m_1 and m_2 elements, respectively, from *S*.
The probability of $S_1 \cap S_2 \neq \emptyset$ is

$$\Pr\{S_1 \cap S_2 \neq \emptyset\} = 1 - \frac{(k-m_1)!(k-m_2)!}{k!(k-m_1-m_2)!}$$



The basic random key pre-distribution scheme

- initialization phase
  - a large pool S of unique keys are picked at random
  - for each node, m keys are selected randomly from S and pre-loaded in the node (key ring)
- direct key establishment phase
  - after deployment, each node finds out with which of its neighbors it shares a key (e.g., each node may broadcast the list of its key IDs)
  - two nodes that discover that they share a key verify that they both actually posses the key (e.g., execute a challenge-response protocol)
- path key establishment phase
  - neighboring nodes that do not have a common key in their key rings establish a shared key through a path of intermediaries
  - each link of the path is secured in the direct key establishment phase

Setting the parameters

- connectivity of the graph resulting after the direct key establishment phase is crucial
- a result from random graph theory [Erdős-Rényi]:
  in order for a random graph to be connected with probability *c* (e.g., *c* = 0.9999), the expected degree *d* of the vertices should be:

$$d = \frac{n-1}{n}(\ln(n) - \ln(-\ln(c))) \qquad (1)$$

- in our case, $d = pn'$ (2), where *p* is the probability that two nodes have a common key in their key rings, and *n'* is the expected number of neighbors (for a given deployment density)
- *p* depends on the size *k* of the pool and the size *m* of the key ring

$$p = 1 - \frac{((k-m)!)^2}{k!(k-2m)!} \qquad (3)$$

- $c \xrightarrow{(1)} d \xrightarrow{(2)} p \xrightarrow{(3)}$,

Setting the parameters – an example

- number of nodes: n = 10000
- expected number of neighbors: n' = 40
- required probability of connectivity after direct key establishment: c = 0.9999

- using (1):
  required node degree after direct key establishment: d = 18.42
- using (2):
  required probability of sharing a key: p = 0.46
- using (3):
  appropriate key pool and key ring sizes:
  k = 100000, m = 250
  k = 10000, m = 75
  …

Qualitative analysis

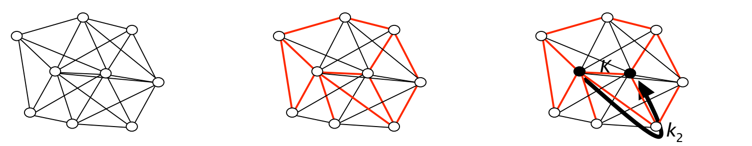
- advantages:
  - parameters can be adopted to special requirements
  - no need for intensive computation
  - path key establishment have some overhead …
    - decryption and re-encryption at intermediate nodes
    - communication overhead
  - but simulation results show that paths are not very long (2-3 hops)
  - no assumption on topology
  - easy addition of new nodes
- disadvantages:
  - node capture affects the security of non-captured nodes too
    - if a node is captured, then its keys are compromised
    - these keys may be used by other nodes too
  - if a path key is established through captured nodes, then the path key is compromised
  - no authentication is provided

Improvements: q-composite rand key pre-distribution

- basic idea:
  - two nodes can set up a shared key if they have at least q common keys in their key rings
  - the pairwise key is computed as the hash of all common keys
- advantage:
  - in order to compromise a link key, all keys that have been hashed together must be compromised
- disadvantage:
  - probability of being able to establish a shared key directly is smaller (it is less likely to have q common keys, than to have one)
  - key ring size should be increased (but: memory constraints) or key pool size should be decreased (but: effect of captured nodes)

Improvements: Multipath key reinforcement

- basic idea:
  - establish link keys through multiple disjoint paths
  - assume two nodes have a common key K in their key rings
  - one of the nodes sends key shares k_1, …, k_j to the other through j disjoint paths
  - the key shares are protected during transit by keys that have been discovered in the direct key establishment phase
  - the link key is computed as $K + k_1 + \ldots + k_j$



radio connectivity — shared key connectivity — multipath key reinforcement

Improvements: Multipath key reinforcement

- advantages:
  - in order to compromise a link key, at least one link on each path must be compromised → increased resilience to node capture
- disadvantages:
  - increased overhead
- note:
  - multipath key reinforcement can be used for path key setup too

Polynomial based key pre-distribution

- let f be a bivariate t-degree polynomial over a finite field GF(q), where q is a large prime number, such that f(x, y) = f(y, x)

$$f(x,y) = \sum_{i,j=0}^{t} a_{ij} x^i y^j$$

- each node is pre-loaded with a polynomial share f(i, y), where i is the ID of the node
- any two nodes i and j can compute a shared key by
  - i evaluating f(i, y) at point j and obtaining f(i, j), and
  - j evaluating f(j, y) at point i and obtaining f(j, i) = f(i, j)
- this scheme is unconditionally secure and t-collision resistant
  - any coalition of at most t compromised nodes knows nothing about the shared keys computed by any pair of non-compromised nodes
- any pair of nodes can establish a shared key without communication overhead (if they know each other's ID)
- memory requirement of the nodes is (t +1) log(q)
- problem: t is limited by the memory constraints of the sensors

Polynomial based random key pre-distribution

- operation:
  - let S be a pool of bivariate t-degree polynomials
  - for each node i, we pick a subset of m polynomials from the pool
  - we pre-load into node i the polynomial shares of these m polynomials computed at point i
  - two nodes that have polynomial shares of the same polynomial f can establish a shared key f(i, j)
  - if two nodes have no common polynomials, they can establish a shared key through a path of intermediaries
- advantage:
  - can tolerate the capture of much more than t nodes (t can be smaller, but each node needs to store m polynomials)
    - in order to compromise a polynomial, the adversary needs to obtain t + 1 shares of that polynomial
    - it is very unlikely that t + 1 randomly captured nodes have all selected the same polynomial from the pool

Matrix based key pre-distribution (Blom's scheme)

- let G be a $(t + 1)\times n$ matrix over a finite field GF(q) (where n is the size of the network)
- let D be a random $(t+1)\times(t+1)$ symmetric matrix over GF(q)
- G is public, D is secret
- let $A = (DG)^T$ and $K = AG$
  - K is a symmetric matrix, because $K = AG = (DG)^TG = G^TD^TG = G^TDG = G^TA^T = (AG)^T = K^T$
- each node i stores the i-th row of A
- any two nodes i and j can compute a shared key K_{ij}
  - i computes $A(i,.)G(.,j) = K_{ij}$
  - j computes $A(j,.)G(.,i) = K_{ji} = K_{ij}$

Matrix based random key pre-distribution

- G is as before
- $D_1, \ldots, D_k$ are random $(t+1)\times(t+1)$ symmetric matrices
- $A_v = (D_vG)^T$ and $\{A_v\}$ is the pool (of spaces)
- for each node i, we pick a random subset of the pool and pre-load in the node the i-th row of the selected matrices (i.e., $A_v(i,.)$ for each selected v)
- if two nodes i and j both selected a common matrix A_v, then they can compute a shared key using Blom's scheme
- if two nodes don't have a common space, they can setup a key through intermediaries

Chapter outline

Exploiting physical contact

- target scenarios
  - modern home with multiple remotely controlled devices
    - DVD, VHS, HiFi, doors, air condition, lights, alarm, …
  - modern hospital
    - mobile personal assistants and medical devices, such as thermometers, blood pressure meters, …
- common in these scenarios
  - transient associations between devices
  - physical contact is possible for initialization purposes
- the ***resurrecting duckling*** security policy
  - at the beginning, each device has an empty *soul*
  - each empty device accepts the first device to which it is physically connected as its master (imprinting)
  - during the physical contact, a device key is established
  - the master uses the device key to execute commands on the device, including the *suicide* command
  - after suicide, the device returns to its empty state and it is ready to be imprinted again

Chapter outline

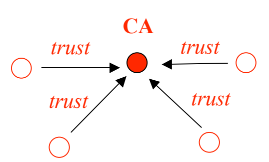
Does mobility increase or reduce security ?

- Mobility is usually perceived as a major security challenge
  - Wireless communications
  - Unpredictable location of the user/node
  - Sporadic availability of the user/node
  - Higher vulnerability of the device
  - Reduced computing capability of the devices
- However, very often, people *gather and move* to increase security
  - Face to face meetings
  - Transport of assets and documents
  - Authentication by physical presence
- In spite of the popularity of PDAs and mobile phones, this mobility has not been exploited to provide digital security
- So far, client-server security has been considered as a priority (e-business)
- Peer-to-peer security is still in its infancy

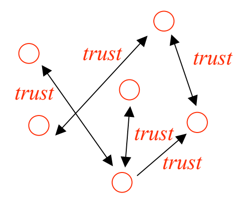
Two scenarios

- Mobile ad hoc networks with a central authority
  - off-line or on-line authority
  - nodes or authorities generate keys
  - authorities certify keys and node ids
  - authorities control network security settings and membership

- Fully self-organized mobile ad hoc networks
  - no central authority *(not even in the initialization phase !)*
  - each user/node generates its own keys and negotiates keys with other users
  - membership and security controlled by users themselves



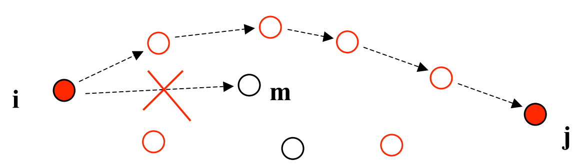
Authority-based



Fully self organized

Secure routing requirements and assumptions

- A network controlled by a **central authority**
- All security associations established between all nodes prior to protocol execution
- **The most stringent assumption:** Routes are established exclusively between nodes with which the source and the destination have security associations



- **Secure routing proposals**
  - **Securing Ad Hoc Routing Protocols**, Zappata, Asokan, WiSe, 2002
  - **Ariadne**, Hu, Perrig, Johnson, MobiCom 2002
  - **Secure Routing for Ad Hoc Networks**, Papadimitratos, Haas CNDS, 2002
  - **A Secure Routing Protocol for Ad Hoc Networks**, Sanzgiri et al. ICNP, 2002
  - **SEAD**, Hu, Perrig, Johnson, WMCSA 2002

Routing – security interdependence

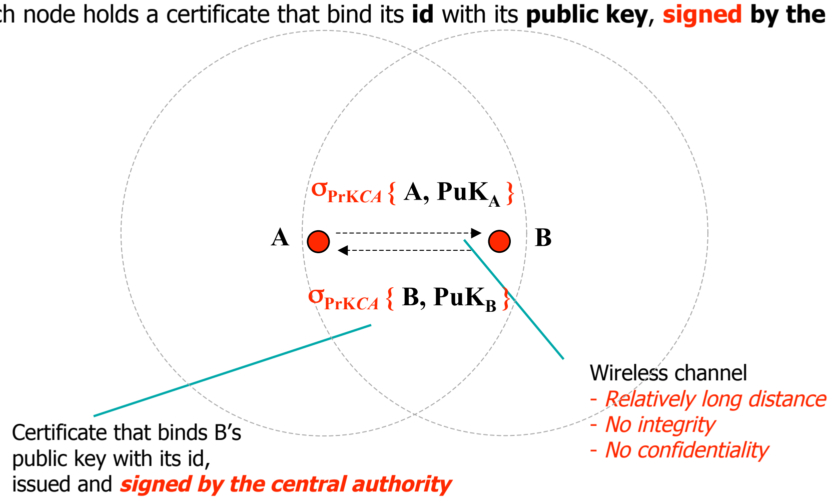
Routing cannot work until security associations are set up

Security associations cannot be set up via
multi-hop routes because routing does not work

- Existing solutions:
  - **Preloading all pairs of keys into nodes** (it makes it difficult to introduce new keys and to perform rekeying)
  - **On-line authentication servers** (problematic availability and in some cases routing-security inter-dependence, rekeying)
  - **CAM, SUCV**

Mobility helps security of routing

Each node holds a certificate that bind its **id** with its **public key**, **signed by the CA**

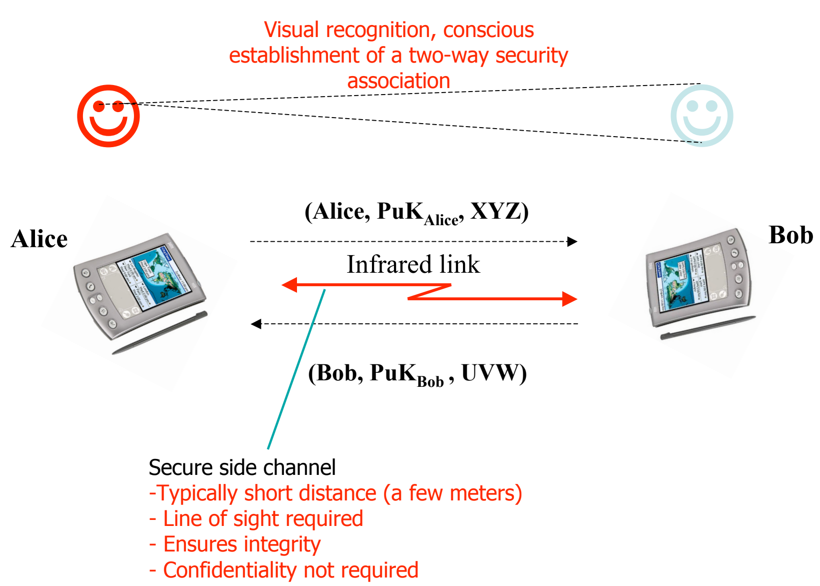


The establishment of security associations within power range breaks the routing-security interdependence cycle

Advantages of the mobility approach (1/2)

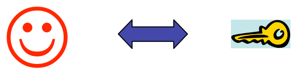
- Mobile ad hoc networks with authority-based security systems
  - breaks the routing-security dependence circle
  - automatic establishment of security associations
  - no user involvement
  - associations can be established in power range
  - only off-line authorities are needed
  - straightforward re-keying

Fully self-organized scenario



Two binding techniques

Binding of the face or person name with his/her public key



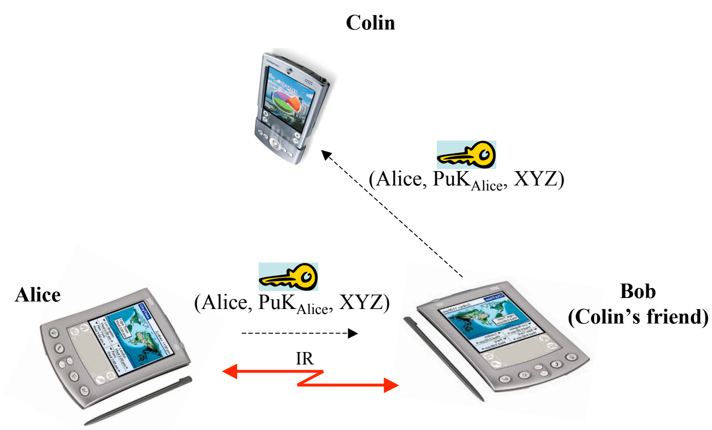
: by the Secure Side Channel, the Friend mechanism and the appropriate protocols

Binding of the public key with the NodeId

XYZ

: by Cryptographically Generated Addresses
Assumption: *static* allocation of the NodeId:
NodeId = h(PuK)

Friends mechanism



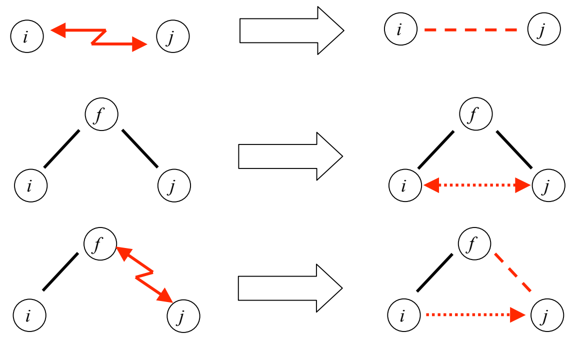
Colin and Bob are *friends*:
- They have established a Security Association at initialisation
- They faithfully share with each other the Security Associations they have set up with other users

Mechanisms to establish Security Associations

a) Encounter and activation of the SSC

b) Mutual friend

c) Friend + encounter



Exchange of triplets over the secure side channel
Two-way SA resulting from a physical encounter
Friendship : nodes know each others' triplets
i ⋯▸ j — *i* knows the triplet of *j* ; the triplet has been obtained from a friend of *i*

Note: there is no transitivity of trust (beyond your friends)

Protocols

Protocol 1: Direct Establishment of a Security Association

msg1	$i \rightarrow j :$	$r_i \mid u_i \mid k_i \mid a_i$
msg2	$j \rightarrow i :$	$r_j \mid u_j \mid k_j \mid a_j$
	$i :$	$u_j?;\ match(k_j, a_j)?$
	$j :$	$u_i?;\ match(k_i, a_i)?$
msg3	$i \rightarrow j :$	$\sigma_i(r_j \mid u_i \mid u_j)$
msg4	$j \rightarrow i :$	$\sigma_j(r_i \mid u_j \mid u_i)$

Protocol 1': Direct Establishment of a Security Association (variant)

msg1 (secure side ch.)	$i \rightarrow j :$	$a_i \mid \xi_i = h(r_i \mid u_i \mid k_i \mid a_i)$
msg2 (secure side ch.)	$j \rightarrow i :$	$a_j \mid \xi_j = h(r_j \mid u_j \mid k_j \mid a_j)$
msg3 (radio ch.)	$i \rightarrow j :$	$r_i \mid u_i \mid k_i \mid a_i$
msg4 (radio ch.)	$j \rightarrow i :$	$r_j \mid u_j \mid k_j \mid a_j$
	$i :$	$h(r_j \mid u_j \mid k_j \mid a_j) = \xi_j?;\ u_j?;\ match(k_j, a_j)?$
	$j :$	$h(r_i \mid u_i \mid k_i \mid a_i) = \xi_i?;\ u_i?;\ match(k_i, a_i)?$
msg5 (radio ch.)	$i \rightarrow j :$	$\sigma_i(r_j \mid u_i \mid u_j)$
msg6 (radio ch.)	$j \rightarrow i :$	$\sigma_j(r_i \mid u_j \mid u_i)$

Protocol 2: Friend-Assisted Establishment of a Security Association

msg1	$i \rightarrow f :$	$req : u_j \mid r_i$
msg2	$f \rightarrow i :$	$u_j \mid k_j \mid a_j \mid \sigma_f(r_i \mid u_j \mid k_j \mid a_j)$

Advantages of the mobility approach (2/2)

- Fully self-organized mobile ad hoc networks
  - There are no central authorities
  - Each user/node generates its own public/private key pairs
  - (No) trust transitivity
  - Intuitive for users
  - Can be easily implemented (vCard)
  - Useful for setting up security associations for secure routing in smaller networks or peer-to-peer applications
  - Requires some time until network is fully secure
  - User/application oriented

Pace of establishment of the security associations

- **Depends on several factors:**
  - Area size
  - Number of communication partners: *s*
  - Number of nodes: *n*
  - Number of friends
  - Mobility model and its parameters (speed, pause times, …)

Desired security associations :

$$p_{ij} = \begin{cases} 1 & \text{if } i \text{ wants to know the public key and address of node } j \\ 0 & \text{otherwise} \end{cases}$$

Established security associations :

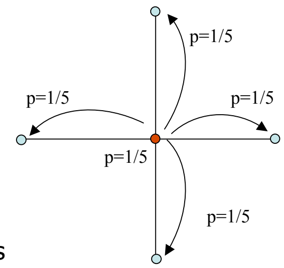
$$e_{ij}(t) = \begin{cases} 1 & \text{if, at time } t\text{, } i \text{ knows the public key and address of node } j \\ 0 & \text{otherwise} \end{cases}$$

Convergence : $$r(t) = \frac{\sum_{i,j} e_{ij}(t) \cdot p_{ij}}{\sum_{i,j} p_{ij}}$$

and the convergence time t_M is the earliest time at which $r(t) = 1$.

Mobility models

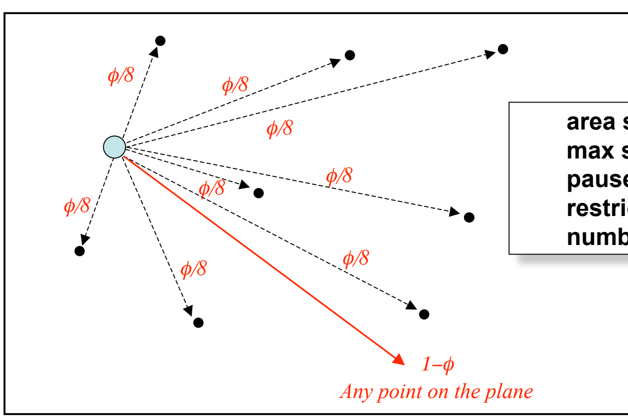
- Random walk
  - discrete time
  - simple, symmetric random walk
  - **area:** Bounded and toroid grids (33x33, 100x100, 333x333)
  - **number of nodes:** 100



- Random waypoint
  - most commonly used in mobile ad hoc networks
  - continuous time
  - **area size:** 1000m x1000m
  - **max speed:** 5m/s, 20m/s
  - **pause time:** 5s, 100s, 200s
  - **security power range**: 5m (SSC), 50m 100m (radio)
- Common simulation settings
  - simulations are run 20 times
  - confidence interval: 95%

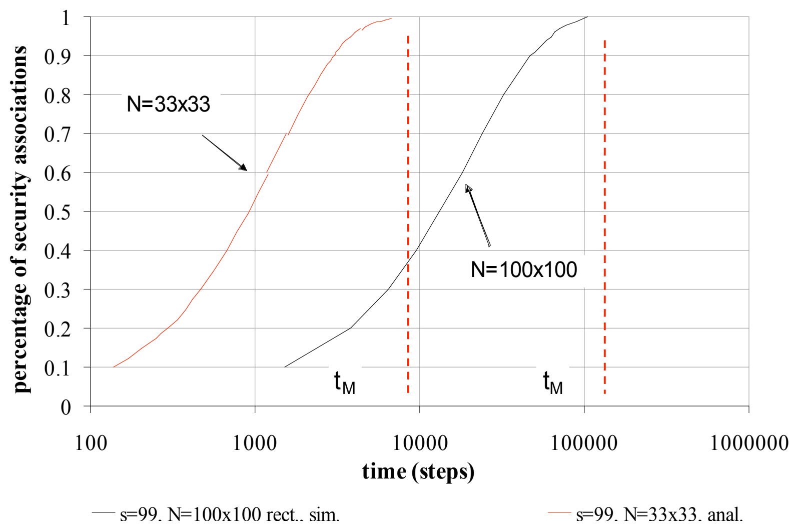
(Restricted) random waypoint

- Restricts the movement of nodes to a set of points with a predefined probability
- Regular random waypoint is a special case (ϕ = 0)



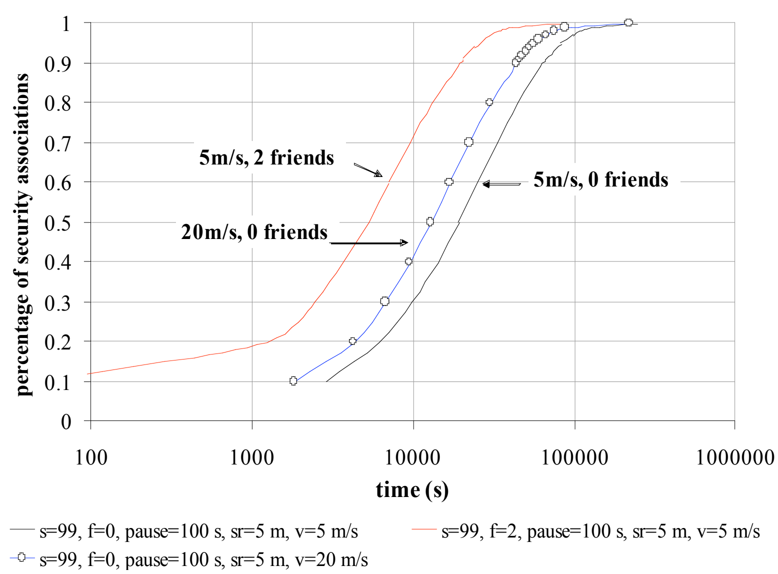
area size: 1000m x1000 m
max speed: 5m/s, 20m/s
pause time: 5s, 100s, 200s
restriction probability: 0.1, 0.5, 1
number of restriction points: 20

Size matters

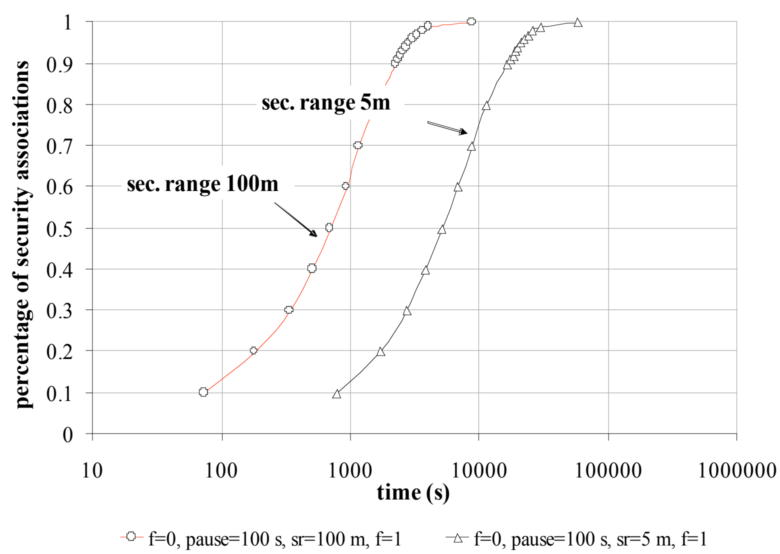


$t_M=O(N\log N)$

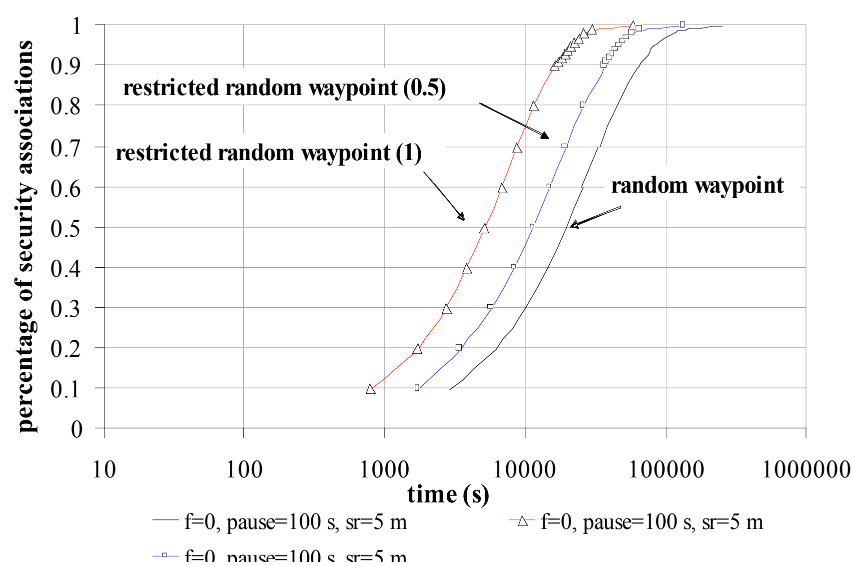
Friends help (f+1)



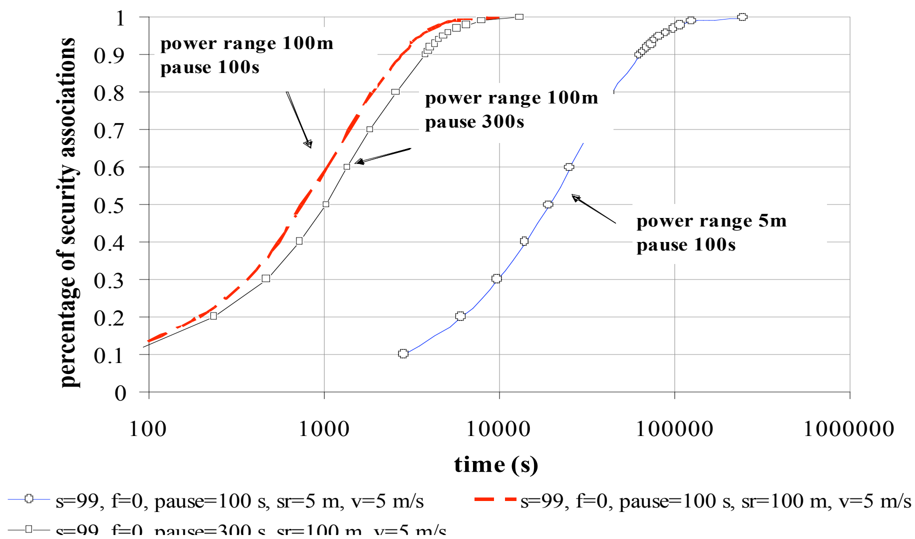
Security range matters



Meeting points help



Pause time



Conclusion on Section 5.3

- Mobility can help security in mobile ad hoc networks, from the networking layer up to the applications
- Mobility "breaks" the security-routing interdependence cycle
- The pace of establishment of the security associations is strongly influenced by the area size, the number of friends, and the speed of the nodes
- The proposed solution also supports re-keying
- The proposed solution can easily be implemented with both symmetric and asymmetric crypto

Chapter outline

Exploiting vicinity

- problem
  - how to establish a shared key between two PDAs?
- assumptions
  - no CA, no KDC
  - PDAs can use short range radio communications (e.g., Bluetooth)
  - PDAs have a display
  - PDAs are held by human users
- idea
  - use the Diffie-Hellman key agreement protocol
  - ensure key authentication by the human users

Diffie-Hellman with String Comparison

Alice		Bob
Given ID_A, g^{X_A}		Given ID_B, g^{X_B}
Pick $N_A \in_U \{0,1\}^k$		Pick $N_B \in_U \{0,1\}^k$
$m_A \leftarrow 0 \Vert ID_A \Vert g^{X_A} \Vert N_A$		$m_B \leftarrow 1 \Vert ID_B \Vert g^{X_B} \Vert N_B$
$(c_A, d_A) \leftarrow \text{commit}(m_A)$		$(c_B, d_B) \leftarrow \text{commit}(m_B)$
	$\xrightarrow{c_A}$	
	$\xleftarrow{c_B}$	
	$\xrightarrow{d_A}$	$\widehat{m}_A \leftarrow \text{open}(\hat{c}_A, \hat{d}_A)$
$\widehat{m}_B \leftarrow \text{open}(\hat{c}_B, \hat{d}_B)$	$\xleftarrow{d_B}$	Verify 0 in $\widehat{m}_A$; $i_B \leftarrow N_B \oplus \hat{N}_A$
Verify 1 in $\widehat{m}_B$; $i_A \leftarrow N_A \oplus \hat{N}_B$		

If $i_A = i_B$, Alice and Bob output "Accept" $\widehat{m}_B$ and $\widehat{m}_A$, respectively.

<u>theorem</u>: the probability that an attacker succeeds against the above protocol is bounded by $n\gamma 2^{-k}$, where n is the total number of users, γ is the maximum number of sessions that any party can participate in, and k is the security parameter

Integrity Codes

- is it possible to rely on the radio channel only?
- assumption
  - it is possible to implement a channel with the following property:
    - bit 0 can be turned into bit 1
    - bit 1 cannot be turned into bit 0
  - an example:
    - bit 1 = presence of random signal (~noise)
    - bit 0 = no signal at all
- i(ntegrity)-codes
  - each codeword has the same number of 0s and 1s
  - such a codeword cannot be modified in an unnoticeable way
  - encoding messages with i-codes ensures the integrity of the communications → Man-in-the-Middle is excluded

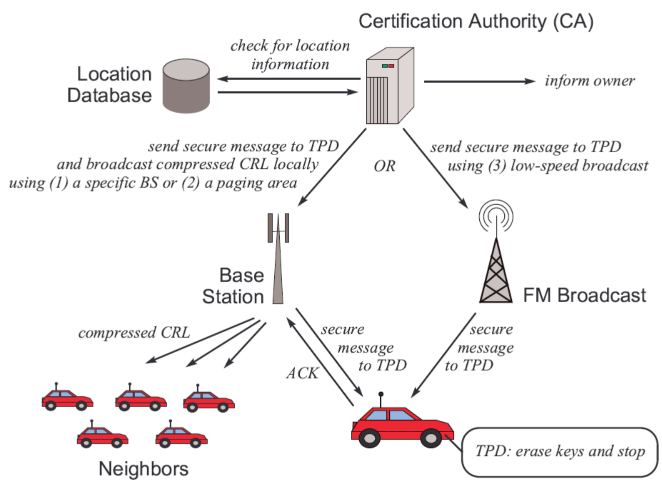
Chapter outline

Revocation

- methods of revocation proposed in the IEEE P1609.2:
  - distribution of CRLs (Certificate Revocation Lists)
  - Using short-lived certificates
- Drawbacks:
  - CRLs can be very long
  - Short lifetime creates a vulnerability window
- Solution: based on
  - RTPD (Revocation Protocol of the Tamper-Proof Device)
  - RCCRL (Revocation protocol using Compressed Certificate Revocation Lists)
  - DRP (Distributed Revocation Protocol).

Revocation

- Revocation protocol of the Tamper-Proof Device (RTPD):



Revocation

- RCCRL:
  - when the CA wants to revoke only a subset of a vehicle's keys
  - or when the TPD of the target vehicle is unreachable
- Using Bloom filters

- DRP:
  - Is used in the pure ad hoc mode
  - Vehicles accumulate accusations against misbehaving vehicles, evaluate them using a reputation system
  - If misbehavior: report them to the CA

Summary

- it is possible to establish pairwise shared keys in ad hoc networks without a globally trusted third party
- mobility, secure side channels, and friends are helpful
- in sensor networks, we need different types of keys
  - node keys, cluster keys, and network keys can be established relatively easily using the technique of key pre-loading and using already established link keys
  - link keys can be established using a short-term master key or with the technique of random key pre-distribution

Chapter 7: Secure routing in multi-hop wireless networks

ad hoc network routing protocols;
routing security in sensor networks;

Chapter outline

7.1 Routing protocols for mobile ad hoc networks

7.5 Secure routing in sensor networks

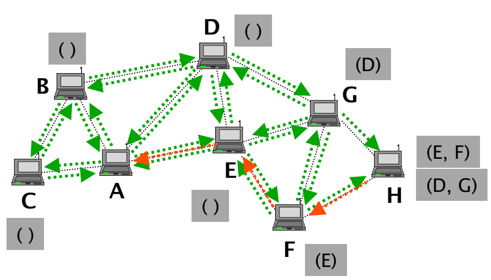
Ad hoc network routing protocols

- topology-based protocols
  - proactive
    - distance vector based (e.g., DSDV)
    - link-state (e.g., OLSR)
  - reactive (on-demand)
    - distance vector based (e.g., AODV)
    - source routing (e.g., DSR)
- position-based protocols
    - greedy forwarding (e.g., GPSR, GOAFR)
    - restricted directional flooding (e.g., DREAM, LAR)
- hybrid approaches

Example: Dynamic Source Routing (DSR)

- on-demand source routing protocol
- two components:
  - route discovery
    - used only when source S attempts to send a packet to destination D
    - based on flooding of Route Requests (RREQ) and returning Route Replies (RREP)
  - route maintenance
    - makes S able to detect route errors (e.g., if a link along that route no longer works)

DSR Route Discovery illustrated



A → *: [RREQ, id, A, H; ()]
B → *: [RREQ, id, A, H; (B)]
C → *: [RREQ, id, A, H; (C)]
D → *: [RREQ, id, A, H; (D)]
E → *: [RREQ, id, A, H; (E)]
F → *: [RREQ, id, A, H; (E, F)]
G → *: [RREQ, id, A, H; (D,G)]

H → A: [RREP, <source route>; (E, F)]

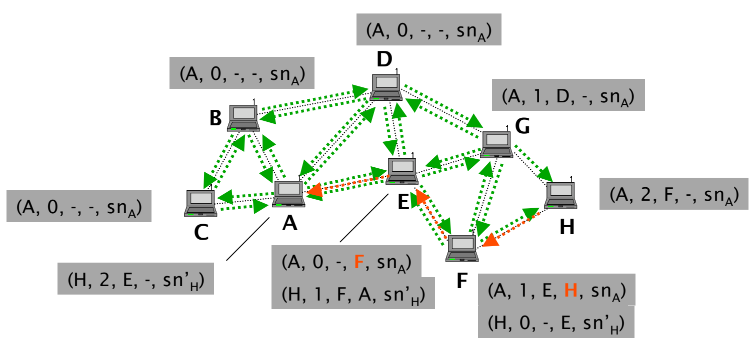
where <source route> is obtained

- from the route cache of H
- by reversing the route received in the RREQ
  - works only if all the links along the discovered route are bidirectional
  - IEEE 802.11 assumes that links are bidirectional
- by executing a route discovery from H to A
  - discovered route from A to H is piggy backed to avoid infite recursion

Example: Ad-hoc On-demand Distance Vector routing (AODV)

- on-demand distance vector routing
- uses sequence numbers to ensure loop-freedom and to detect out-of-date routing information
- operation is similar to that of DSR but the nodes maintain routing tables instead of route caches
- a routing table entry contains the following:
  - destination identifier
  - number of hops needed to reach the destination
  - identifier of the next hop towards the destination
  - list of precursor nodes (that may forward packets to the destination via this node)
  - destination sequence number

AODV Route Discovery illustrated

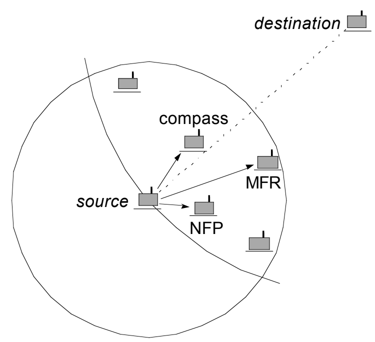


A → *: [RREQ, id, A, H, 0, sn_A, sn_H]
B → *: [RREQ, id, A, H, 1, sn_A, sn_H]
C → *: [RREQ, id, A, H, 1, sn_A, sn_H]
D → *: [RREQ, id, A, H, 1, sn_A, sn_H]
E → *: [RREQ, id, A, H, 1, sn_A, sn_H]
F → *: [RREQ, id, A, H, 2, sn_A, sn_H]
G → *: [RREQ, id, A, H, 2, sn_A, sn_H]

H → F: [RREP, A, H, 0, sn'_H]
F → E: [RREP, A, H, 1, sn'_H]
E → A: [RREP, A, H, 2, sn'_H]

Example: Position-based greedy forwarding

- assumptions
  - nodes are aware of their own positions and that of their neighbors
  - packet header contains the position of the destination
- packet is forwarded to a neighbor that is closer to the destination than the forwarding node
  - Most Forward within Radius (MFR)
  - Nearest with Forward Progress (NFP)
  - Compass forwarding
  - Random forwarding
- additional mechanisms are needed to cope with local minimums (dead-ends)



Chapter outline

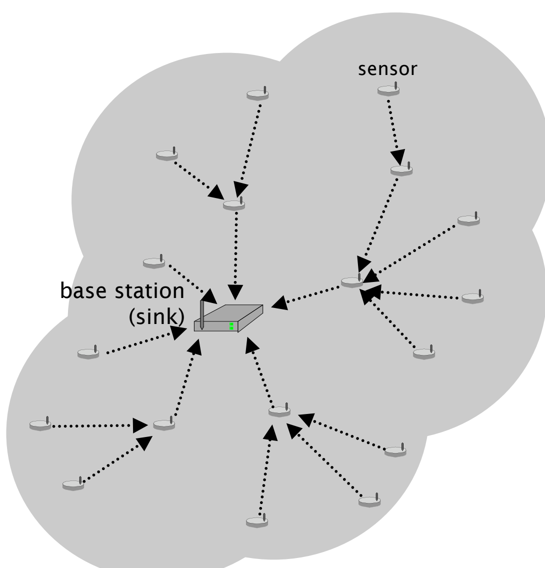
7.1 Routing protocols for mobile ad hoc networks

7.5 Secure routing in sensor networks

How are sensor networks different?

- communication patterns
  - sensors to base station (many-to-one)
  - base station to sensors (one-to-many)
- limited mobility
  - sensor nodes are mainly static
  - topology can change due to node and link failures
  - much less dynamicity than in ad hoc networks of mobile computers
- resource constraints
  - sensor nodes are much more constrained in terms of resources
- infrastructure support
  - the base station can act as a trusted entity

TinyOS beaconing

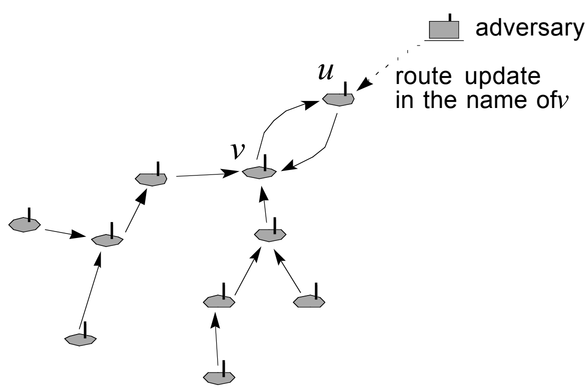


Authenticated TinyOS beaconing

- since beacon messages are not authenticated, an adversary can initiate the route update process and become the root of the established tree
- in order to prevent this, the base station should authenticate the beacon
  - needs broadcast authentication
  - due to resource constraints, symmetric key crypto should be used
  - a possible solution is TESLA
- this does not entirely solve the problem …

Authenticated TinyOS beaconing

- intermediate nodes are not authenticated
- an adversary can use spoofing to create a routing loop



Summary

- routing is a fundamental function in networking, hence, an ideal target for attacks
- attacks against routing aim at
  - increasing adversarial control over the communications between some nodes;
  - degrading the quality of the service provided by the network;
  - increasing the resource consumption of some nodes (e.g., CPU, memory, or energy)
- many attacks (but not all!) can be prevented by authenticating routing control messages
- it is difficult to protect the mutable parts of control messages
- special attacks (e.g., tunnels and rushing) needs special protection mechanisms
- several secured ad hoc network routing protocols have been proposed
- some of them have weaknesses that are exploitable by attacks