Data Security in Unattended Wireless Sensor Network

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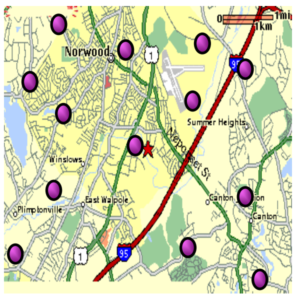
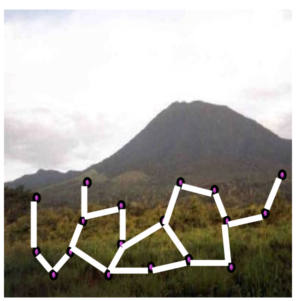
Agenda

1. Introduction to UWSN
2. ADV model
3. POSH
   a. Preliminaries and assumptions
   b. The protocol
   c. Analysis
4. Conclusions

A "Typical" Wireless Sensor Network





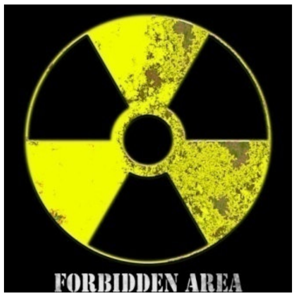
Many real, alleged and imagined applications

- Networking
  - Sensor-to-sink communication (opt. sink-to-sensors)
- Collection method
  - Periodic collection
    or
  - Event driven
    or
  - Query based = on-demand
- Online Sink
  - Real-time off-loading of data

<u>Unattended</u> Wireless Sensor Network (UWSN)

- Nodes operate in hostile environment
  - Initial deployment might be ad-hoc
- No ever-present sink
  - Itinerant
- Periodic data sensing (on-demand, event-driven– N/A)
  - Nodes might retain data for a long time
  - Data might be valuable
- Nodes are left on their own
  - Adversary roams around
  - **Challenge: Data Security in UWSNs**

Examples



- WSN deployed in a recalcitrant country to monitor any potential nuclear activity

- Underground WSN monitoring sound and vibration produced by troop movements or border crossings

- Anti-poaching WSN

New kind of Adversary (ADV)

- Previous adversaries would corrupt a fixed threshold of the nodes in the network
  - Security protocols were aimed at attack detection
  - The online sink can then mitigate the attack
    - Excluding compromised nodes

- Our adversary is ***MOBILE***
  - Roams the network and compromises different sets of sensors
    - Given enough time it can subvert the whole network
  - The sink is offline: real-time detection does not help
    - Adv can reach its goal and leave with impunity

Does this sound familiar?

- ADV shares many feature with the well known Crypto Mobile Adversary
  - Ostrovsky &Yung: How to Withstand Mobile Virus Attacks, PODC'91
  - Proactive Cryptography: Decryption and Signatures
  - Adversary aimed at learning some shared secret
- Now the problem is different
  - No such secret to hide
  - Less resources (power, storage, …)
  - Brand new solutions required

UWSN Mobile Adversary

ADV defined by: goal / operation / visibility

Goal:
- Search-and-erase
- Search-and-replace
- Curious

Operation:
- Reactive
- Proactive

Visibility:
- Stealthy
- Visible

The journey so far…

- Search-and-erase
  - No Crypto
    - Nodes collaborate to hide data location

      Catch Me (if you can): Data Survival in Unattended Sensor Networks (IEEE PerCom'08)
  - Crypto-enabled sensors
    - Design and evaluation of cryptographic protocol to protect target data

      in submission…

- Search-and-replace
  - Collaborative authentication
  - ongoing work…

- Curious
  - Co-operative self healing

    POSH (IEEE SRDS'08)

POSH
Proactive co-Operative Self Healing
in Unattended Wireless Sensor Networks

Motivation

- Curious adversary aims at reading sensor-collected data

- Encryption does not help
  - Symmetric keys are exposed with node compromise
  - w/ Public Key encryption, the adversary can GUESS the cleartext
    - Randomized encryption helps but only with a TRNG
      - Not currently available (nor foreseeable)

- Sensor-collected data can be partitioned based on compromise
  - Before Compromise (1)
    - Requires Forward Secure Encryption Scheme
  - During Compromise (2)
    - Not much can be done!
  - After compromise (3)
    - Requires Backward Secure Encryption Scheme

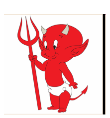
Can we protect category (1) and (3) data?

Forward Secrecy

- Even if ADV learns current key, it is not able to derive PREVIOUS round keys
- Based on per-round key evolution
  - At the end of round r, the next round key is computed through a one-way function (and the current round key is securely erased)
    - $K^{r+1}=H(K^r)$
- Suitable UWSNs
  - But after compromise, ADV can mimic key evolution process
  - Anyway we will use it…

$K^1 \rightarrow K^2 \rightarrow K^3 \rightarrow K^4 \rightarrow K^5 \rightarrow K^6 \rightarrow K^7 \rightarrow \ldots$

Sensor compromised at round 4 and then released



$\leftarrow K^4 \rightarrow K^5 \rightarrow K^6 \rightarrow K^7 \rightarrow \ldots$

Backward Secrecy

- Even if ADV learns current key, it is not able to derive FUTURE round keys

- Based on per-round key evolution
  - In the literature so far, it requires an online trusted authority

- Not suitable for UWSNs
  - The sink is offline
  - Sensor can not act as a trusted authority for their peers as any sensor can be easily compromised

$K^1 \rightarrow K^2 \rightarrow K^3 \rightarrow K^4 \rightarrow K^5 \rightarrow K^6 \rightarrow K^7 \rightarrow \ldots$

Sensor compromised at round 4 and then released

$K^1 \leftarrow K^2 \leftarrow K^3 \leftarrow K^4 \rightarrow$

Key Insulated schemes

- Encryption Schemes that are both BACKWARD and FORWARD secure are known as KEY INSULATED schemes
  - Unfortunately no such scheme is currently available for UWSNs
  - Require online trusted third party
  - Expensive computation

$K^1 \rightarrow K^2 \rightarrow K^3 \rightarrow K^4 \rightarrow K^5 \rightarrow K^6 \rightarrow K^7 \rightarrow \ldots$

Sensor compromised at round 4 and then released

$\leftarrow K^4 \rightarrow$

POSH: Main Idea

- Forward secrecy is achieved through key evolution

- Backward secrecy is achieved through sensor cooperation
  - A sensor can securely regenerate a key unknown to ADV, if it obtains at least one *contribution* from a non compromised peer sensor

Network Assumptions 1/2

- **Periodic data collection**
  - Time divided in equal and fixed collection rounds and each of the ***n*** sensor collects a single data unit per round
- **Unattended Operation**
  - An itinerant sink periodically visits the UWSN to collect sensed data.
  - ***v*** is the maximum number of collection rounds between successive sink visits.
- **Communication**
  - The UWSN is always connected
  - Any two sensors can communicate either directly or through peers

Network Assumptions 2/2

- **Storage**
  - Each sensor has enough storage for O(v) data units
- **Cryptographic Capabilities**
  - Cryptographic hashing
  - Symmetric key encryption (unique secret key shared with the sink)
  - Pseudo-Random Number Generator (PRNG) (unique secret seed shared with the sink)
- **Re-initialization**
  - At each visit, the sink re-initializes the sensors (secrets refreshing)
    - New secret key
    - New secret seed
    - Empty storage

Adversarial model 1/2

- **Goal**
  - ADV's main goal is to learn from nodes as many secrets as possible (keys or other keying material).
- **Compromise Power**
  - ADV can compromise at most $0 < k < n/2$ sensors at any round.
  - It reads all storage/memory and listens to all communication of each compromised sensor.
- **Periodic Operation**
  - At the end of each compromise round, ADV picks a subset of up to k sensors to compromise in the following round.
  - At the start of each round, the adversary atomically releases the subset from the previous round and compromises the new subset.

Adversarial model 2/2

- **Topology Knowledge**
  - ADV knows the entire topology of the UWSN.
- **Minimal Disruption**
  - ADV does not interfere with sensors’ behavior, in order to remain undetected
- **Defense Awareness**
  - ADV is fully aware of any scheme or algorithm used by the UWSN.

POSH algorithm

Contributions to be sent

Generic node protocol run (**round i**):

Contributed nodes

1. Generate t random values $\{R_{i_1}, \ldots, R_{i_t}\}$
2. Select $\{s_{i_1}, \ldots, s_{i_t}\} \leftarrow_R \{s_1, \ldots, s_{i-1}, s_{i+1}, \ldots, s_n\}$
3. Send R_{i_j} to s_{i_j}, $1 \leq j \leq t$
4. Receive contributions $\{c_{i_1}, \ldots, c_{i_{t'}}\}$
5. Sensing, encryption, authentication...
6. Compute $K_i^{r+1} = H(K_i^r || c_{i_1} || \ldots || c_{i_{t'}})$
7. Erase K_i^r

Normal operating activities

Key refresh

$\{s_1, \ldots, s_n\}$ = set of sensors in the network
K_i^r = key used by s_i at round r
$\{s_1, \ldots, s_n\}$ = set of sensors in the network
K_i^r = key used by s_i at round r

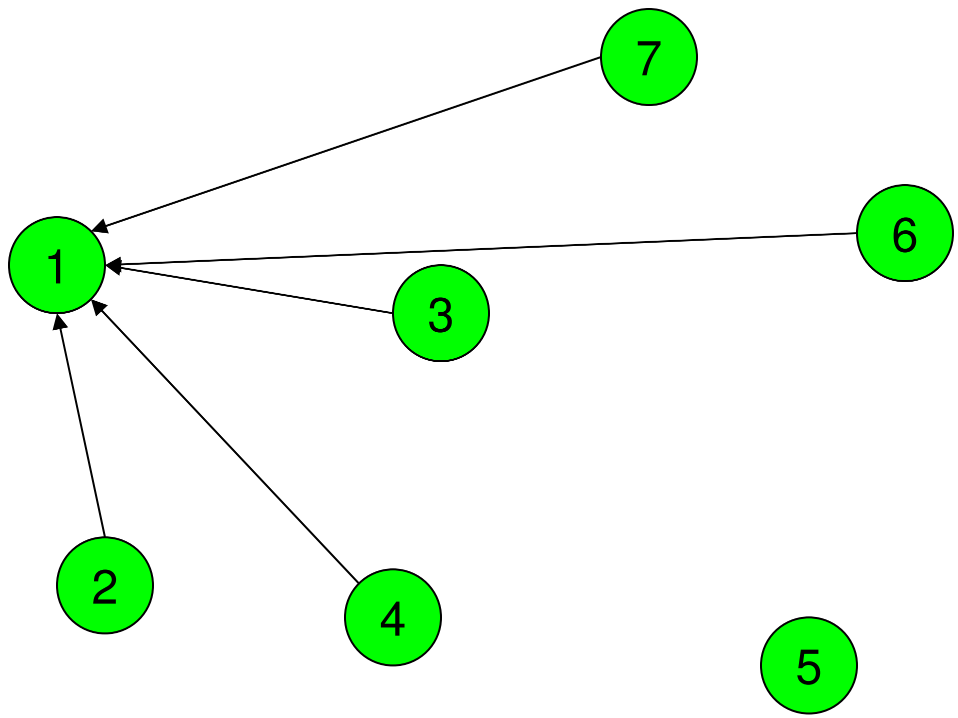
Analysis (aka Sensor Coloring)

Starting from round 1, ADV compromises k sensors per round:

- Red sensors (R^r)
  - currently controlled by ADV
- Yellow sensors (Y^r)
  - have been compromised in some previous round and their current keys are known to ADV
- Green sensors (G^r)
  - Either they have never been compromised
  - **Or** they have recovered through POSH

Example

r = 4



Sensor 1

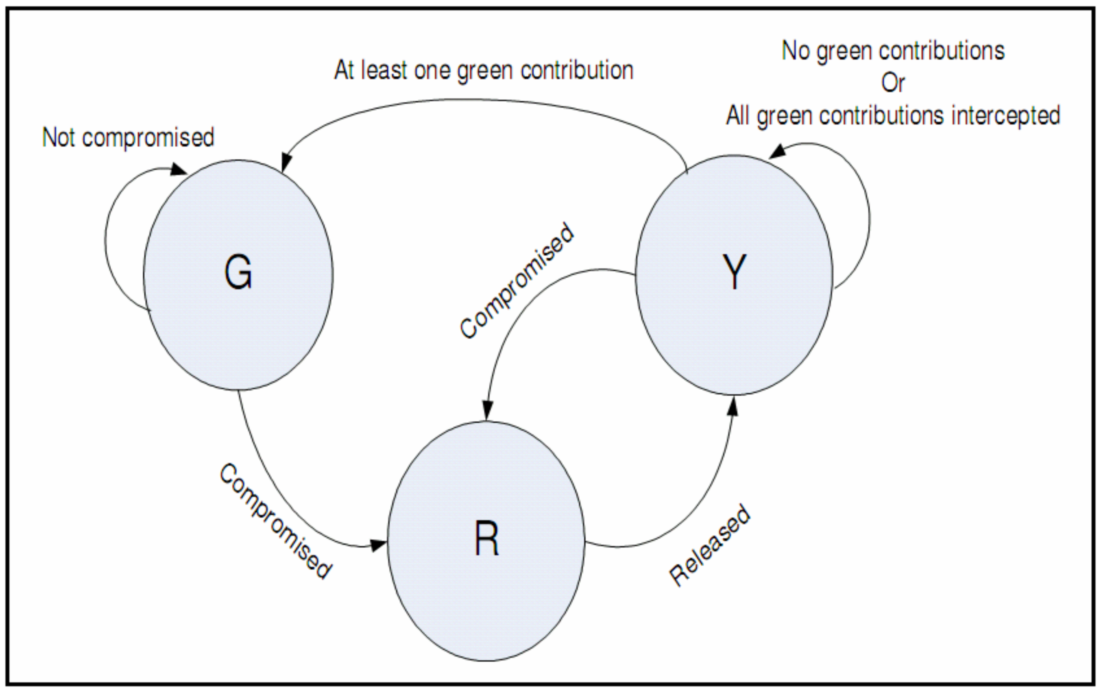
K^1

$K^2 = H(K^1 \mid\mid c_3 \mid\mid c_6)$

$K^3 = H(K^2 \mid\mid c_2)$

$K^4 = H(K^2 \mid\mid c_4 \mid\mid c_7)$

Sensor transition diagram

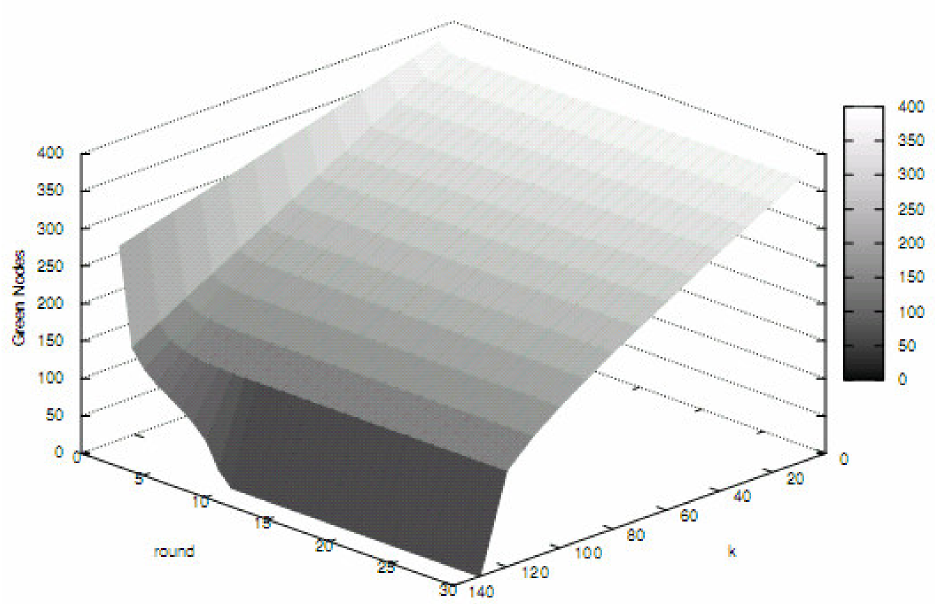


- |R|=k
- ADV's goal it to maximize |Y|+|R|
- Network goal: |G|=n-2k

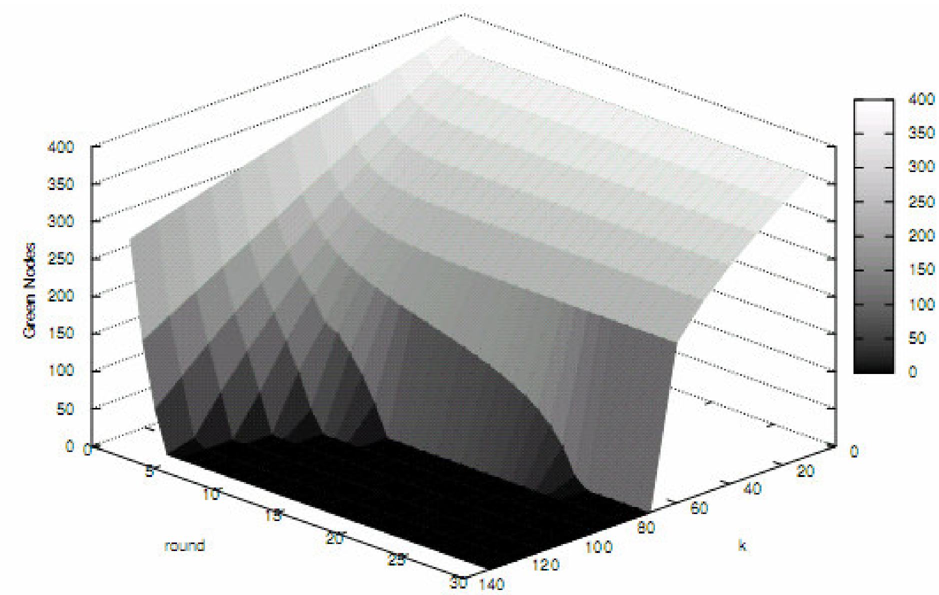
Two kinds of ADV

- INF-ADV is always aware of G
  - Unrealistic but very powerful
  - Used as benchmark
- RR-ADV moves through set of nodes in a round-robin fashion
  - Time based heuristic…nodes in Y for a long time could have moved G
  - Realistic but possibly weak
    - Might choose to compromise a yellow sensor

Results (|G| against INF-ADV)



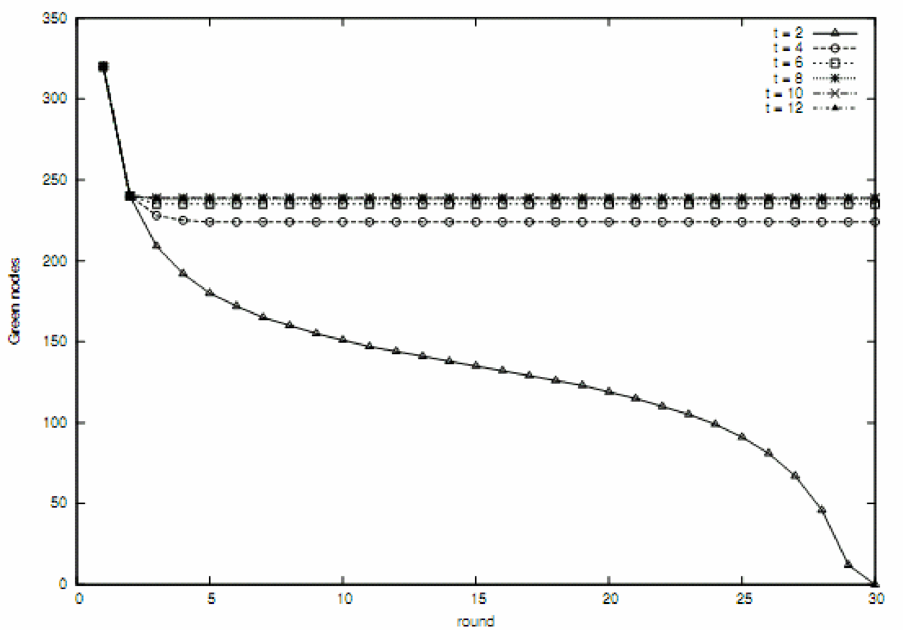
(a) $n = 400, t = 6, p = 0.2$



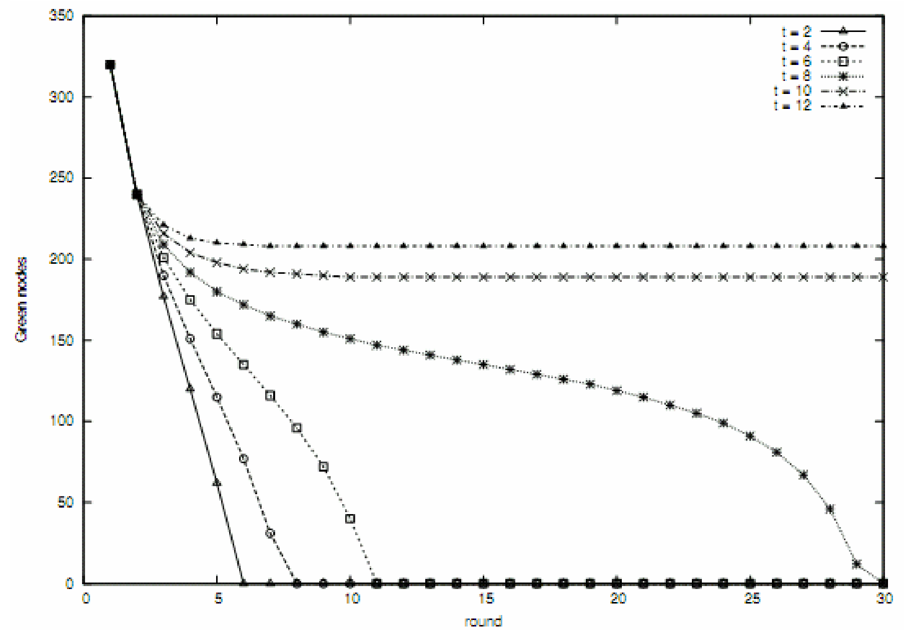
(b) $n = 400, t = 6, p = 0.8$

- p = ADV eavesdropping prob.
- t = 6 results in each sensor receiving at least one contribution on the average
- Threshold phenomena:
  - e.g. for p=0.2, |G| remains stable for k/n < 80/400
  - That is 20% per round!!!

Effect of “t”



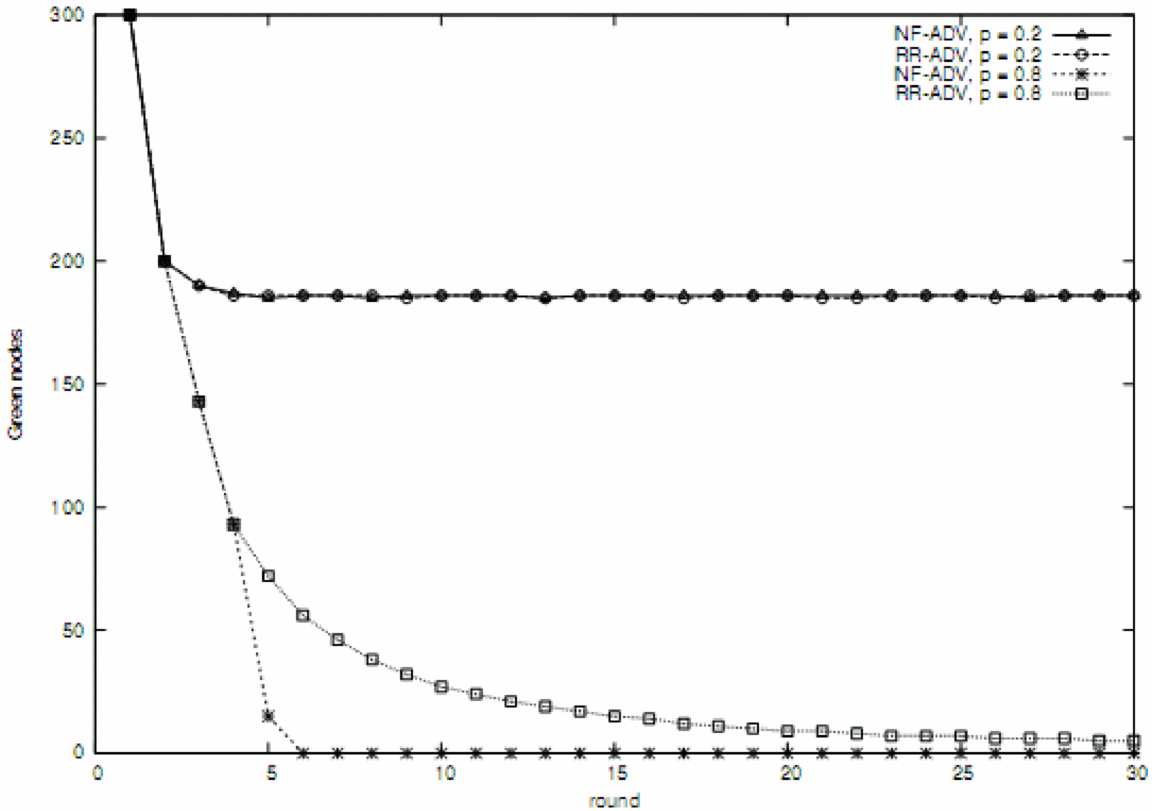
(a) $n = 400, k = 80, p = 0.2$



(b) $n = 400, k = 80, p = 0.8$

- Increasing t when |G| ~ n-2k does not help
  - Further, messages are expensive!

INF-ADV vs RR-ADV



No difference if |G| is close to its optimal value

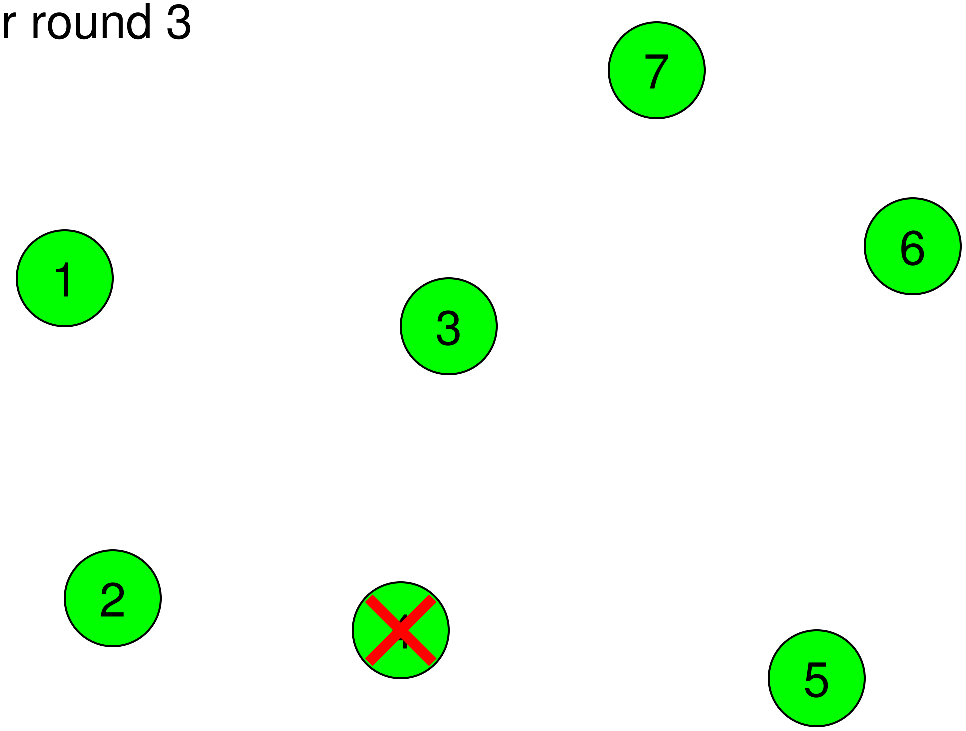
$$n = 400,\ k = 100,\ t = 6$$

Dealing w/ real world

- Message delivery failure
  - Sink synchronization
  - Sensor must store the ID of their contributors
- Sensor failure
  - If storage becomes unavailable key sensor history cannot be reconstructed
  - Other sensors might depend on the failed one
- Publik Key Crypto
  - Encrypt round key under the sink PK
    - Use round key for everything else

Example

Sensor 4 fails after round 3



Sensor 1

K^1

$K^2=H(K^1 \,||\, c_3 \,||\, c_6)$

$K^3=H(K^2 \,||\, c_2)$

$K^4=H(K^2 \,||\, c_4 \,||\, c_7\,)$

K^4 requires sensors 4 and 7

K^1 is shared

Sensor 1 will have contribute to other peers…

Sink

K^1

$K^2=H(K^1 \,||\, c_3 \,||\, c_6)$

$K^3=H(K^2 \,||\, c_2)$

$K^4=H(K^2 \,||\, ? \,||\, c_7\,)$

Conclusion

- UWSN is a new, exciting field that calls for innovative security solutions
- No crypto no means no security
- But….
- Crypto helps!
- Role of randomization in UWSN not completely characterized yet

References

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