Data Security in Unattended Wireless Sensor Network

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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
Unattended 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…

![Key Evolution Diagram]

Sensor compromised at round 4 and then released
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
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**

Generic node protocol run (round $i$):

1. Generate $t$ random values $\{R_{i1}, \ldots, R_{it}\}$
2. Select $\{s_{i1}, \ldots, s_{it}\} \leftarrow R \{s_1, \ldots, s_{i-1}, s_{i+1}, \ldots, s_n\}$
3. Send $R_{ij}$ to $s_{ij}$, $1 \leq j \leq t$
4. Receive contributions $\{c_{i1}, \ldots, c_{it'}\}$
5. Sensing, encryption, authentication...
6. Compute $K_{i}^{r+1} = H(K_{i}^{r} || c_{i1} || \ldots || c_{it'})$
7. Erase $K_{i}^{r}$

Contributions to be sent

Contributed nodes

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 $r$
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

Sensor 1

\[ K^1 \]
\[ K^2 = H(K^1 \parallel c_3 \parallel c_6) \]
\[ K^3 = H(K^2 \parallel c_2) \]
\[ K^4 = H(K^2 \parallel c_4 \parallel c_7) \]
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)

- $p$ = 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”

- Increasing t when $|G| \sim n-2k$ 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
\[ K^1 \]
\[ K^2 = \text{H}(K^1 \ || \ c_3 \ || \ c_6) \]
\[ K^3 = \text{H}(K^2 \ || \ c_2) \]
\[ K^4 = \text{H}(K^2 \ || \ c_4 \ || \ c_7) \]

Sink
\[ K^1 \]
\[ K^2 = \text{H}(K^1 \ || \ c_3 \ || \ c_6) \]
\[ K^3 = \text{H}(K^2 \ || \ c_2) \]
\[ K^4 = \text{H}(K^2 \ || \ ? \ || \ c_7) \]

Sensor 1 will have contribute to other peers…
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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