Towards Understanding Source Location Privacy in Wireless Sensor Networks Through Fake Sources

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Monday 25th June 2012

Some Quick Definitions

- Wireless Sensor Network (WSN) is a collection of Wireless Sensor Nodes
- Nodes are equipped with the sensors necessary for the network's application
- Nodes communicate wirelessly
- There are lots of applications for WSNs
  - Tracking
  - **Monitoring**

Introduction

- Privacy threats can be classified as either content-based or **context-based**
- Content-based threats have been widely addressed (using cryptography) [Perrig et al., 2004]
- Context-based threats are varied
- We focus on protecting the location context of broadcasting nodes

Important Considerations

- Wireless Sensor Nodes are energy constrained
- Sending messages is the most expensive task
- Receiving messages is the next most expensive task [Shnayder et al., 2004]

The Problem of Source Location Privacy (SLP)

Given:

- A WSN that detects valuable assets
- A Node detecting a valuable asset broadcasting information

Found:

- An attacker can find the source node by backtracking the messages through the network
- So by deploying a network to monitor a valuable asset we have provided a way for it to be captured

The Problem:

- Panda-Hunter Game
- Difficult

Related Work

- [Ozturk et al., 2004]
- [Kamat et al., 2005]

System Model

- Network modelled as a graph $G = (V, E)$
- A link exists between two nodes m and m' if both can communicate with each other
- Two nodes $m \in V$ and $m' \in V$ are 1-hop neighbours iff $\{m, m'\} \in E$
- There exists a sink node $S \in V$ that collects data
- Other nodes $v \in V \setminus \{S\}$ route data to the sink for collection
- The network is event-triggered when an object of interest is sensed by a node that then begins broadcasting

Attacker Model

- We consider a single mobile *distributed eavesdropping* attacker
- Relevant System Assumptions:
  - Messages sent by a source are encrypted and include node ID
  - Only the sink can tell a nodes location from the ID
- Assumptions:
  - The attacker can tell the direction the message came from
  - The attacker can move at any speed and has no power limitations
  - The attacker knows of (i) sink location (ii) network topology (iii) routing algorithm

Fake Sources

- Select a subset of nodes in the network to act as fake sources that simulate the real source
- Two types: (i) permanent (ii) temporary
- Both modelled using a duration parameter and a rate parameter
- Aim to broadcast messages to lure the attacker away from the real source
- Fake messages are similar to real messages to prevent the attacker distinguishing between them

Contribution 1: Formal Definition of SLP

- A fake source F_i is a determined by the *duration* d_i
- If d_i is (small and) finite, then the fake source is *temporary*, else it is *permanent*

Definition 1 (SLP): Given a graph $G = (V, E)$, a set F of fake source tags $\{F_1 \ldots F_f\}$, each F_i associated with duration d_i, a relation $\prec$ on V, a set N of m nodes $\{n_1 \ldots n_m\} \subset V$, a deadline τ and a routing strategy R, assign tags in T to nodes in N to obtain an m-node schedule σ for T that meets the deadline τ under R and obeys $\prec$.

Contribution 2: SLP Complexity

Theorem 1 (SLP Complexity): The Source Location Privacy problem is NP-complete.

Proof: We reduce the multiprocessor scheduling with precedence constraints (MSPC) to SLP. We first define the MSPC problem, and then identify the mapping between MSPC and SLP.

Contribution 2: SLP Complexity

Instance: The MSPC problem is as follows: Given a set $T = \{T_1 \dots T_n\}$ of tasks, with task T_i having execution time e_i, a set P of $m \in \mathbb{Z}^+$ processors, partial order $\lessdot$ on T, and a deadline $D \in \mathbb{Z}^+$.

Question: Is there an m-processor schedule σ for T that meets the overall deadline D and obeys the precedence constraints, i.e., such that $T_i \lessdot T_j$ implies that $\sigma(T_j) \geq \sigma(T_i) + e_i$.

Contribution 3: Heuristic and Parameters

- Heuristic algorithm developed that uses fake sources
- These fake sources are used to "pull" the attacker towards them
- They need to be created in the direction away from the real source
- Selection of fake sources in the algorithm is important
- Can vary the *duration*, *rate* and *probability* of fake sources
- Heuristic uses temporary fake sources try to first "lure" attacker away, and then permanent fake sources ensure the attacker is kept away from the real source

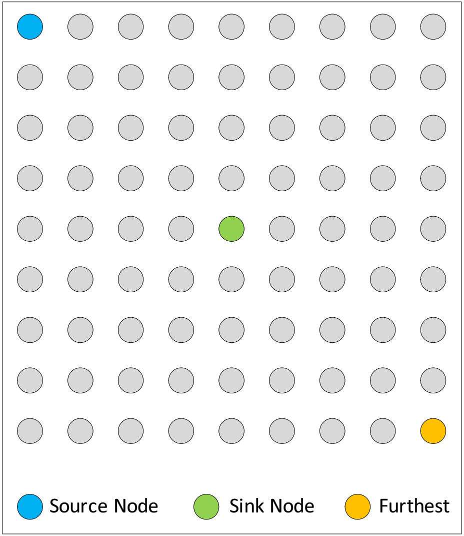
Experimental Setup: Simulation Environment

- JProwler
- Rayleigh Radio model used as it assumes node mobility
- Gaussian Radio model was the alternative

Experimental Setup: Network Configuration I

- Square grid network of 11^2, 15^2 and 21^2 nodes
- Nodes 28 meters apart
- Sink node positioned at the center of the grid
- Source node position in one of the four corners or at a random location along the network edge
- Attacker starts at the location of the sink
- 500 Repeats

Experimental Setup: Network Configuration II



Experimental Setup: Protocol Configuration

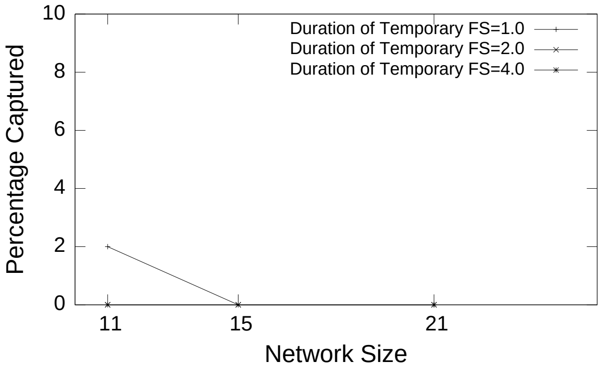
- Flooding Protocol used as a baseline
- Temporary Fake Source Duration $\in \{1, 2, 4\}$ seconds
- Real Source Rates $\in \{1, 2, 4\}$ messages per second
- Fake Source Rates $\in \{2, 4, 8\}$ messages per second
- Simulations never run where real source message rate is greater than fake source message rate

Experimental Setup: Safety Period

- Calculated for each network size and source rate
- Defined as twice the amount of time it took an attacker to capture the source when no protection was in place
- Twice the time allows an attacker to go to the opposite end of the network and back
- A bounded safety period allows bounded simulation time

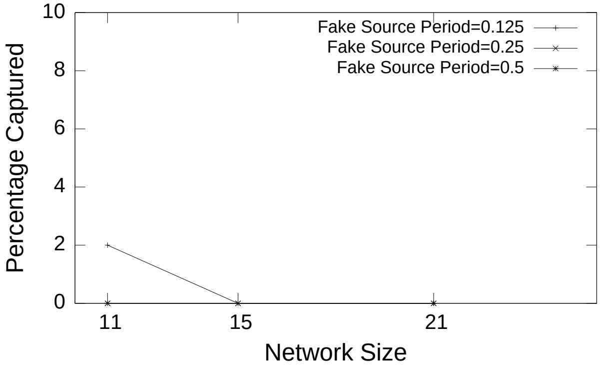
Results: Impact of Temporary Fake Source Duration

- Increasing temporary fake source duration leads to a decreased capture ratio



Results: Impact of Message Rates

- Intuitively, the higher the rate of the fake source , the greater the "pull" it has
- Increasing the message rate of fake sources leads to a decreased capture ratio
- However, with high transmission rates more collisions can occur increasing the capture ratio



Results: Limitations

- Algorithm designed for a grid network structure
- Assumed that attackers follow a message when it has received one

Summary

- Developed a new way of modelling SLP using permanent and temporary fake sources
- Formalised SLP and shown the problem to be NP-complete
- Identified message rates and fake source duration as important parameters
- Provided a heuristic which has been shown provide optimal privacy under certain parameter settings

Further Work

- Investigate other network configurations and shapes
- Consider fake sources in the context of a more perceptive attacker
- Investigate optimising the algorithm to reduce energy usage by making the algorithm adaptive by taking advantage of run-time knowledge

The End

Any Questions?

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