A Schedule Randomization Policy To Mitigate Timing Attacks in WirelessHART Networks

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Background

i. **Components of a WirelessHART network**
   Sensors, actuators, gateway, network manager
ii. **Centralized architecture**
   Network manager generates schedules, allocates resources and decides routes
iii. **Complex mesh topology**

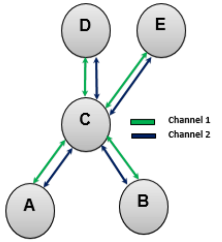
Characteristics of a WirelessHART network

- most reliable standard for real-time communication in time-critical systems
- Time Division Multiple Access (TDMA) based communication
- Channel diversity, route diversity and channel blacklisting
- Spatial re-use of channels

System Model

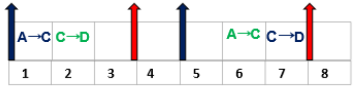
Our system consists of

- a network graph **G = (V , E)** with **m** channels
  V : set of nodes
  E : set of edges
- **n** end-to-end real-time flows
  F = {F_1,F_2,……F_n}



A **real-time flow** in a WSN in CPS is defined as

F = {s,d,p,δ,R}
s: source of a flow
d: destination of a flow
p: period of a flow
δ: deadline of a flow
R: set of routes from s to d
F_1 = {A, D, 4, 3, [A→ C→D]}



Motivation

Scheduling policy in a WirelessHART network is

1. Centralized
2. The same communication schedule repeats over every hyperperiod (L.C.M. of the periods of all the flows)
3. The time slots in a schedule are predictable in nature

Consequence :

- Due to the repetitive nature of the communication schedule over every hyperperiod, the attacker can ***predict*** the time slots in which any two target device communicate
- The attacker can launch ***selective jamming attacks*** targeting specific transmissions

Countermeasure to Attack

We propose ***a schedule randomization policy***, the ***SlotSwapper***, as a countermeasure to attack

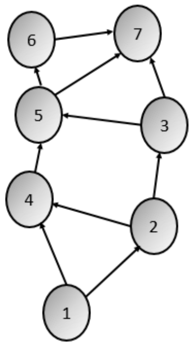
SlotSwapper consists of two phases –

- an **offline randomized Schedule Generation Phase** (runs at the network manager)
- an **online Schedule Selection Phase** (runs at each node in the network)

Offline Schedule Generation Phase

Step 1: Consider a **base schedule B** over a set of three flows

F = {s, d, p, δ, R}
F_1 = {1, 7, 8, 8, [1 → 2 → 3 → 7] }, F_2 = {4, 7, 4, 4, [4 → 5 → 7] },
F_3 = {2, 7, 8, 8, [2 → 3 → 7] }



Base Schedule B

	1	2	3	4	5	6	7	8
Chan 1	1→2		5→7	2→3	4→5			3→7
Chan 2	4→5				2→3	3→7	5→7	

Step 2: Consider the **scheduling window [1,7]** for the first hop **(2→3)** of **F_3**
Step 3: Check for **transmission conflicts, deadline preservation** and **flow sequence preservation** within scheduling window **[1,7]**
Step 4: Generate an **eligible list of slot-channel pairs** that satisfy all the conditions from **Step 3**

	1	2	3	4	5	6	7	8
Chan 1	1→2		5→7	2→3	4→5			3→7
Chan 2	4→5				2→3	3→7	5→7	

Step 5: Select a **random slot-channel pair** from the list of eligible slot-channel pairs
Step 6: Swap the current slot with the randomly selected slot

	1	2	3	4	5	6	7	8
Chan 1	2→3		5→7	1→2	4→5			3→7
Chan 2	4→5				2→3	3→7	5→7	

Step 7: Repeat steps 2 to 6 for every hop of each flow instances in B
Run the offline Schedule Generator for a large number of times to generate a set of feasible randomized schedules

Online Schedule Selection Phase

Each node selects a schedule uniformly at random from the set of feasible schedules at every hyperperiod
All nodes in the network select the same schedule independently
- Each node uses the same pseudo random number generator initialized with the same seed

Base Schedule B

	1	2	3	4	5	6	7	8
Chan 1	1→2		5→7	2→3	4→5			3→7
Chan 2	4→5				2→3	3→7	5→7	

Randomized Schedule S after offline Schedule Generation Phase

	1	2	3	4	5	6	7	8
Chan 1		1→2		5→7	3→7			5→7
Chan 2	2→3	4→5	2→3			4→5	3→7	

Measure of Uncertainty – Kullback Leibler Divergence

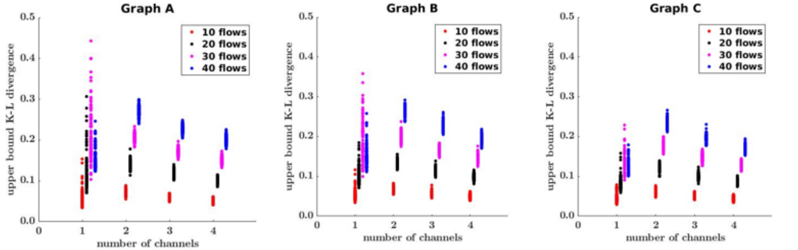
We propose **Kullback Leibler Divergence or K-L Divergence** as a **security metric** to compare the performance of our algorithm w.r.t. a truly random algorithm

- Measures the **divergence** between the probability distribution of the flows in the schedules generated by two algorithms

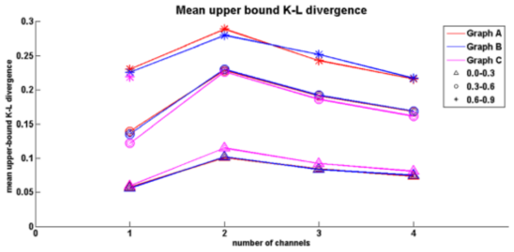
$$\mathcal{D}(\mathbb{A}||\mathbb{A}') = \sum_{i=1}^{l}\sum_{k=1}^{m}\sum_{j=0}^{n} \Pr(g_{ik}=j)\log_2\frac{\Pr(g_{ik}=j)}{\Pr(g'_{ik}=j)}$$

where **Pr($g_{ik=j}$)** and **Pr($g'_{ik=j}$)** are the probability mass functions of the j^{th} flow occurring in the k^{th} channel of the i^{th} slot by algorithm A and A' respectively

Experimental Results



Upper-bound K-L divergence over randomly generated sparse, medium and dense graphs with number of flows varying between 10 to 40 and number of channels between 1 to 4 over a hyperperiod of 1024 slots



Mean upper-bound K-L divergence over randomly generated sparse, medium and dense graphs with utilization varying between 0.0 to 0.9 and number of channels between 1 to 4