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Vulnerability of Fixed-Time Control of Signalized Intersections to Cyber-Tampering

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Sensor Vulnerabilities in Transportation Networks

- 200,000 vulnerable traffic control sensors in important cities around the world such as New York, San Francisco, London, and Melbourne
- Traffic signal control
  - Feedback control such as max-pressure
  - Periodic cycle such as fixed-time control
- 90 percent of all traffic signals in the US follow fixed-time control policy.

A. Ghafouri, W. Abbas, Y. Vorobeychik, and X. Koutsoukos, "Vulnerability of fixed-time control of signalized intersections to cyber-tampering." Submitted to the 9th International Symposium on Resilient Control Systems (ISRCS), Chicago, Illinois, 2016.

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Fixed-Time Control

- Deterministic vehicle flows subject to 1) conservation constraints, 2) constraints on saturation flows, and 3) simultaneous turn movements.

Total duration

$$\min \sum_{S \in \mathbb{S}} \lambda_S$$

$$\text{s.t.} \quad \sum_{S \in \mathbb{S}} \lambda_S c(i,j) S(i,j) \geq f(i,j), \text{all } (i,j)$$

$$\lambda_S \geq 0 \text{ all } S \in \mathbb{S}$$

Sensor attack on flow measurement

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Attacker Model

1. **Network accumulation:** destabilizing the overall network as much as possible
2. **Lane accumulation:** causing worst-case accumulation on some target lanes
3. **Risk-averse target accumulation:** reaching a target accumulation by making the minimum perturbation

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Attacker Model

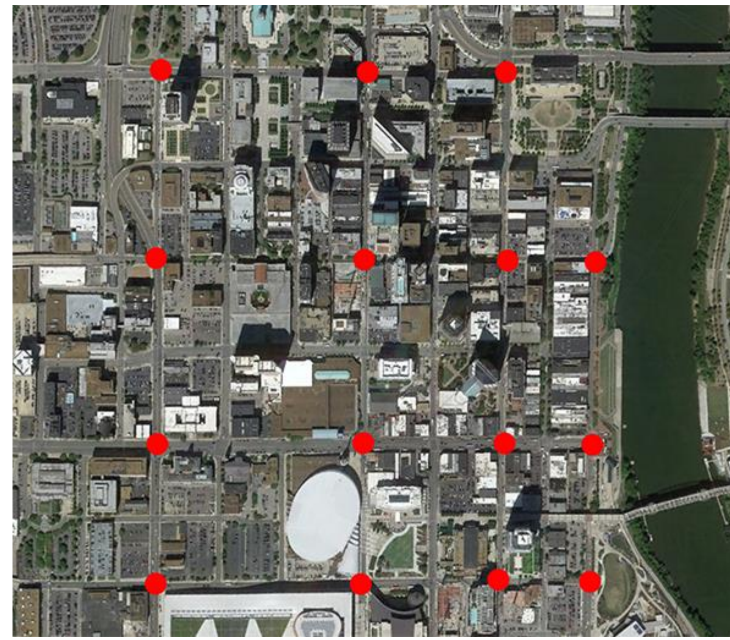
- All attacker problems are Bilevel Mixed Integer Quadratic Programs (BMIQP).
- Solution using branch-and-bound and cutting planes. GUROBI OPTIMIZATION
- Metrics: $\mathrm{NV} = \dfrac{\text{Accumulation Rate}}{\text{Total Flow}}$ and $\mathrm{LV} = \dfrac{\text{Lane Accumulation Rate}}{\text{Lane Total Flow}}$

Total accumulation rate	$\max_{\tilde{Q},\tilde{F}} \quad \sum_{ij} \max(0, (f_{ij} - \sum_{S} \tilde{\lambda}_S c_{ij} S_{ij}))$
Fixed-Time sub-problem	$\text{s.t.} \quad \tilde{\lambda}_S \in \mathrm{FT}(\tilde{F})$
Feasibility constraint	$\sum \tilde{\lambda}_S < 1$
Flow conservation	$\sum_h \tilde{f}(h,i) = \sum_j \tilde{f}(i,j)$
Attacker's budget	$\lvert\tilde{Q}\rvert \leq B$
	$\tilde{f}(i,j) \geq 0, \ \text{all } (i,j)$

Worst-case Network Accumulation

Case Study – Nashville Downtown

- Real traffic history data provided by Tennessee Department Of Transportation (TDOT)
- Area between 1st Ave, 8th Ave, Demonbreun St, and Charlotte Ave.
- 15 intersections (12 four-way and 3 three-way), and 104 phases
- Total demand approximately 15000 vehicles per hour



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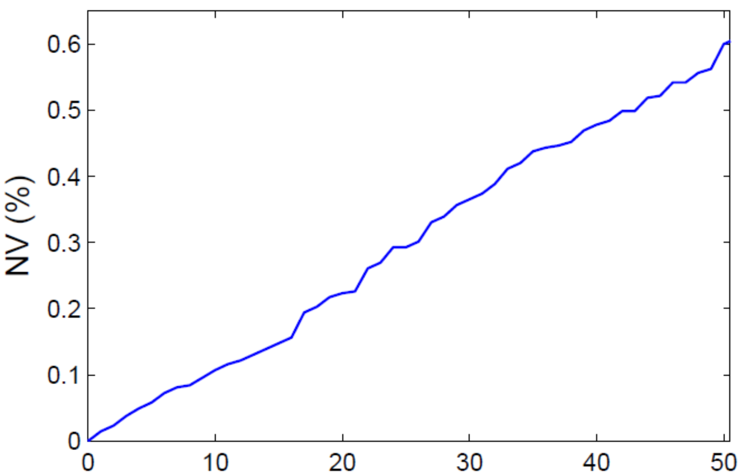
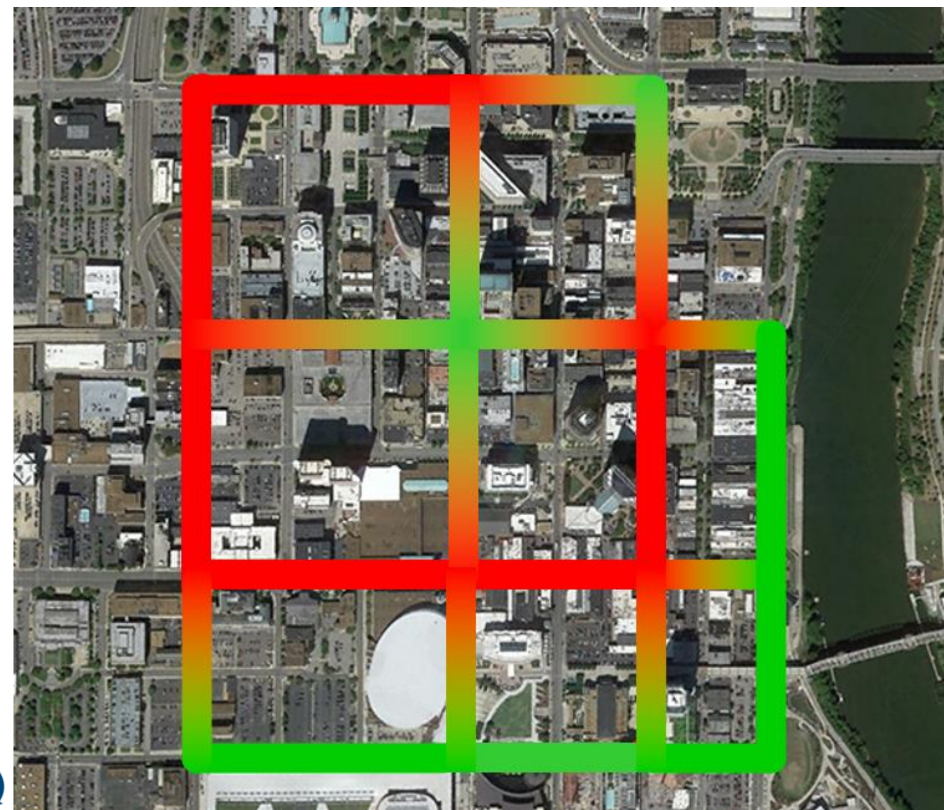
Worst-Case Network Accumulation

1. Accumulation of 4000 vehicles per hour by compromising 20% of sensors (~21 sensors)



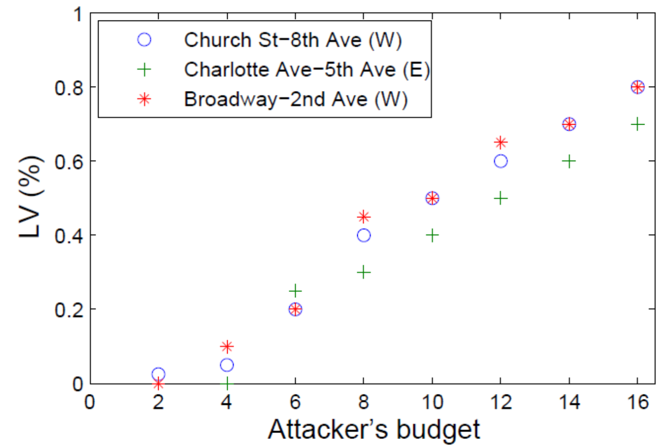
Sensor measurement	Frequency
Charlotte Ave-8th Ave (WE)	98%
Broadway-8th Ave (NW)	97%
Charlotte Ave-8th Ave (SE)	95%
Demonbreun St-8th Ave (NE)	95%
Charlotte Ave-5th Ave (WE)	94%
Charlotte Ave-3rd Ave (NE)	94%
Broadway-8th Ave (WE)	91%
Broadway-5th Ave (WE)	83%

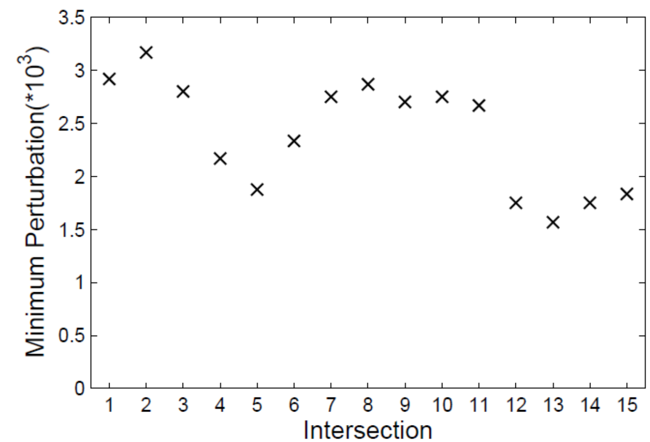


Worst-Case Lane Accumulation and Risk-Averse Target Accumulation

2. **Lane accumulation:** easier to cause a disastrous congestions on Broadway-2nd Ave.

3. **Risk-averse target accumulation:**
   - highest perturbation: Charlotte Ave-5th Ave
   - lowest perturbation: Demonbreun St-3rd Ave and





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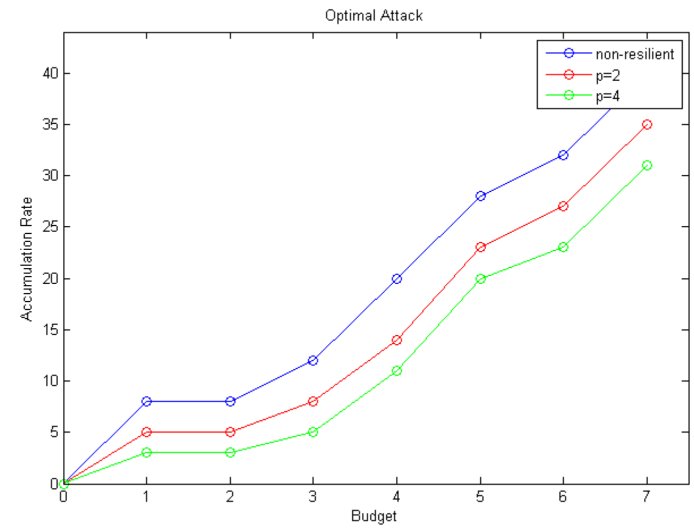
Ongoing Work

1. Resilient Fixed-time Control
   - Worst-case attack is mitigated by %20 if cycle length is quadrupled.
2. Analysis of Max-Pressure Control
3. Implementation
   - Vulnerability analysis incorporating real-time user data provided by Transit-Hub
   - Transit-Hub: public transit route finder app powered by real-time data from the Nashville MTA



Nashville MTA

Available on the App Store

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Thank you for your attention!

Questions?