Understanding the Security of Traffic Signal Infrastructure

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Outline

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- Introduction
- Background
- Security Analysis
- Attacks and Mitigations
- Conclusion

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Introduction

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Traffic signal systems have introduced large regional networks and operation centers to help alleviate traffic congestion.

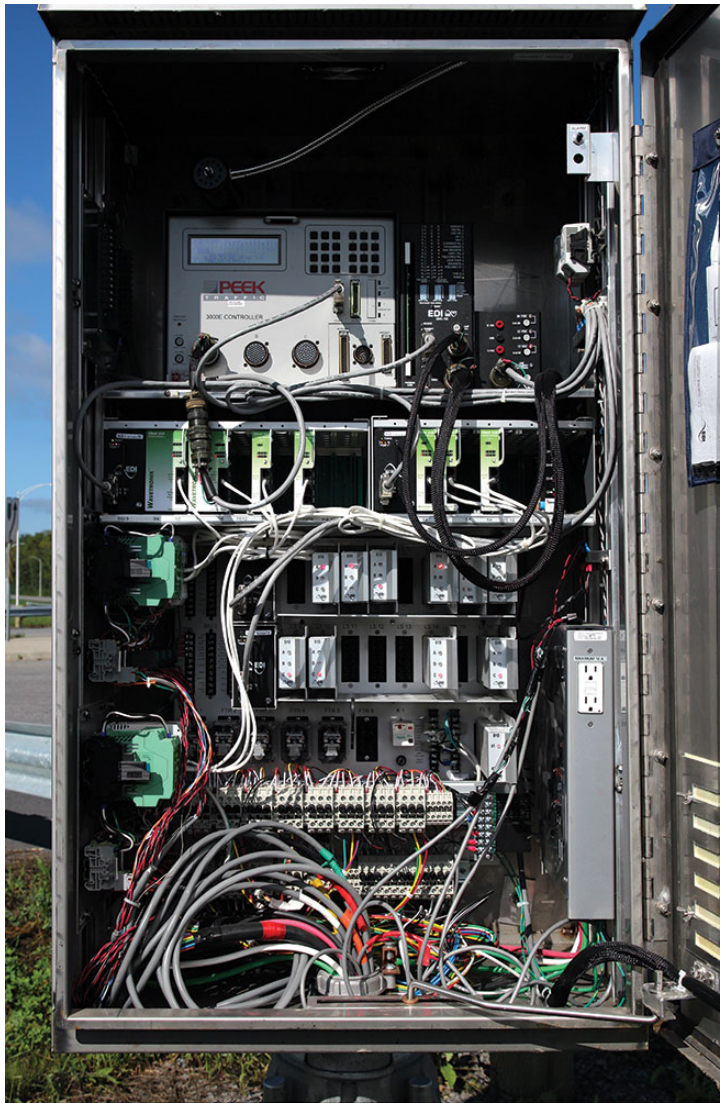
- Traditional traffic signal systems use rotating gears and wheels to control the traffic bulbs.
  - Simple, but lack of flexibility.

- Modern traffic signal systems have achieved a efficient control over the vehicle traffic via numerous technologies.

Modern Traffic Signal System

source: https://www.orangetraffic.com/product/mtq-traffic-light-distribution-and-control-cabinet/

Modern Traffic Signal System



source: https://www.orangetraffic.com/product/mtq-traffic-light-distribution-and-control-cabinet/

Introduction

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Is it secure?

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Is the traffic signal system secure?

- Previous research mainly focus on the traffic controller and network vulnerabilities.
  - [1, 2, 3]

- However, traffic signal systems are actually comprised of many components!
  - E.g., traffic controller, fail-safe systems, surveillance cameras, et, al.

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Roadside Cabinets

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- A modern traffic signal systems is comprised of many hardware components.
- These components are normally placed in a roadside cabinet.
- Cabinet standards are applied to the components inside the cabinet.
  - TS-2 cabinet standard and ITS cabinet standard.

Cabinet Standards

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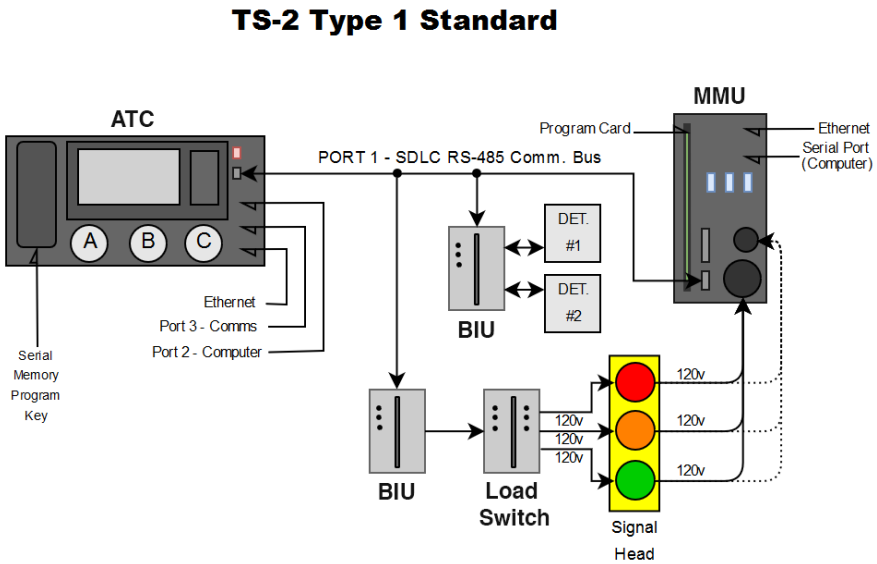
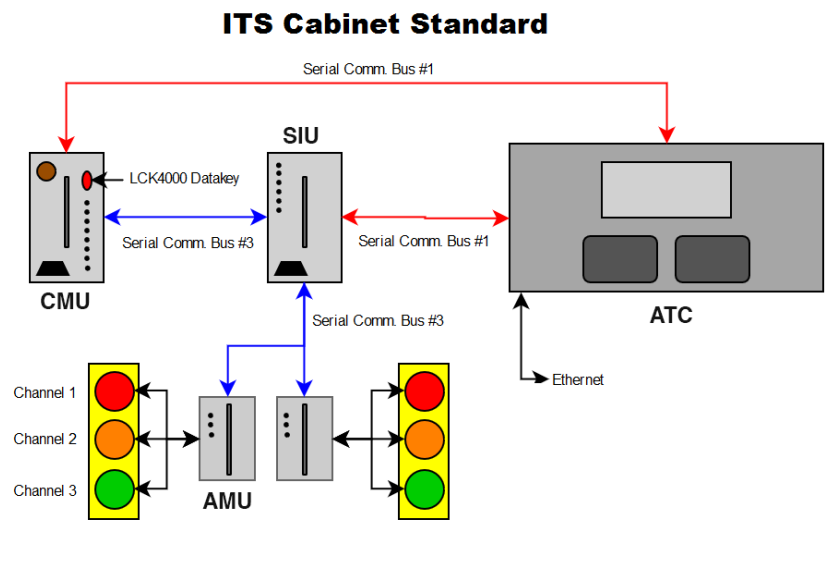
- The **TS-2 Cabinet Standard** was initially commissioned by National Electrical Manufacturers Association (NEMA) in 1998.
  - A replacement of NEMA TS-1 standard.
  - Using serial communication to replace hardwired I/O.
- The **ITS Cabinet Standard** is designed to supersede the NEMA TS-2 standard.
  - Published by American Association of State Highway and Transportation Officials (AASHTO), Institute of Transportation Engineers (ITE), and NEMA.

Cabinet Standards





Advanced Transportation Controller

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The Advanced Transportation Controller (ATC) is the core part for a traffic signal control system.

- Build upon a Linux kernel with BusyBox.
- Directly controls the traffic signals with specific software.
- E.g., Intelight Model 2070 ATCs and Siemens Model 60 ATCs.

Fail-safe Components

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The fail-safe components are used to guarantee that the traffic signals would not turn to a dangerous state even when the ATC is malfunctional.

- Malfunction Management Unit (MMU) in TS-2 Standard.
- Cabinet Monitor Unit (CMU) in ITS Standard.

Fail-safe Components

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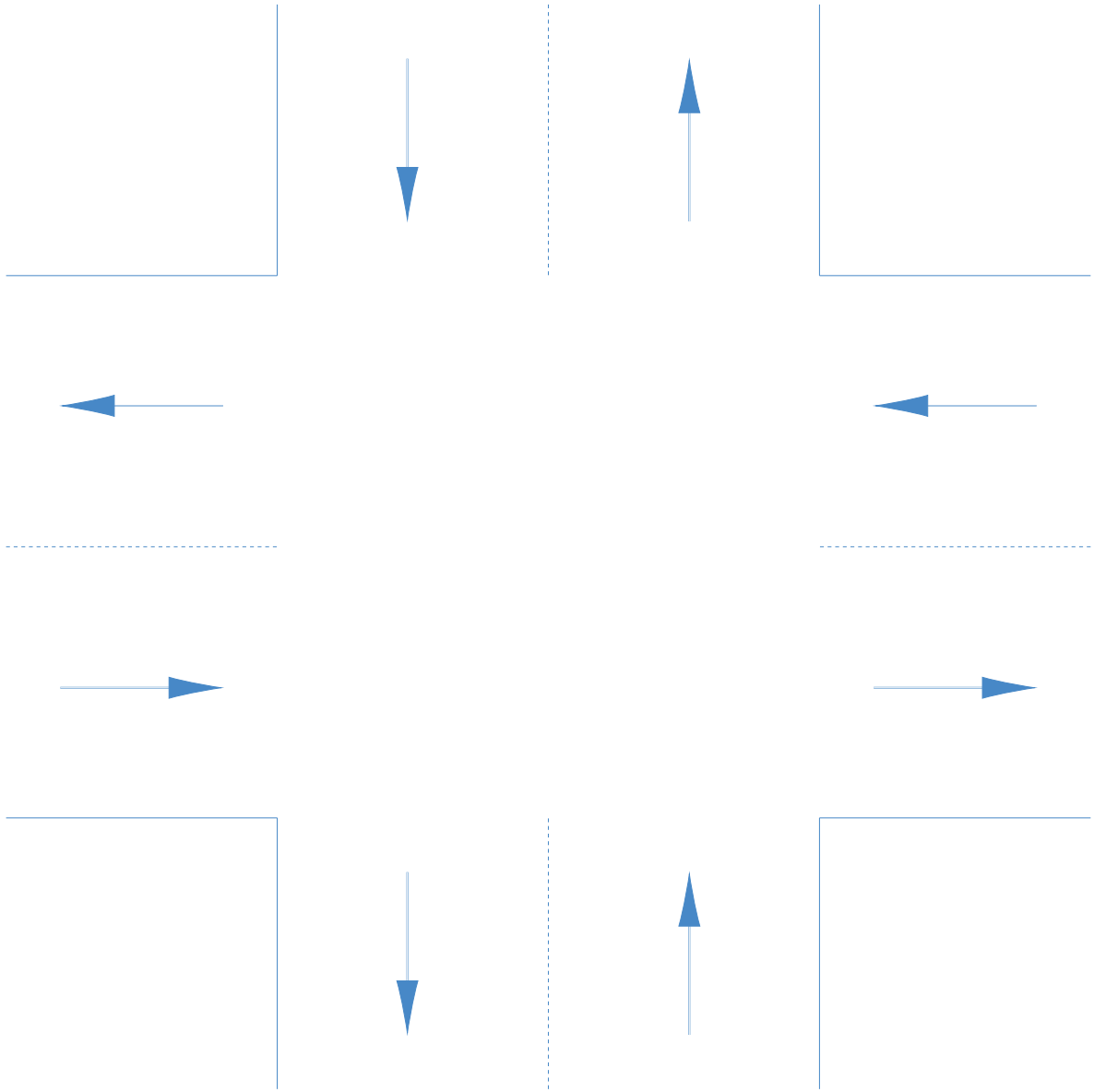
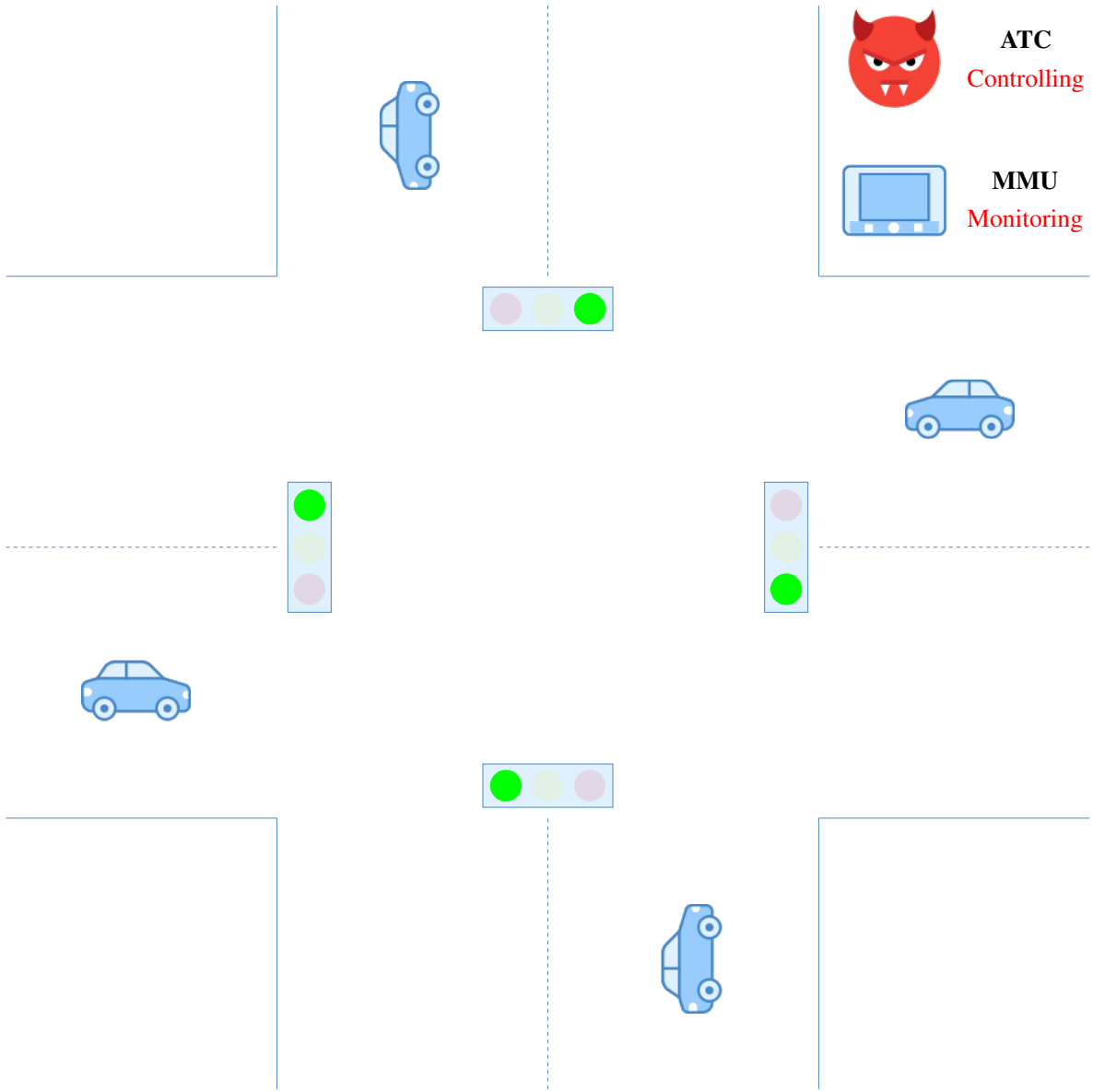


Fail-safe Components

Fail-safe Components



Fail-safe Components

Fail-safe Components

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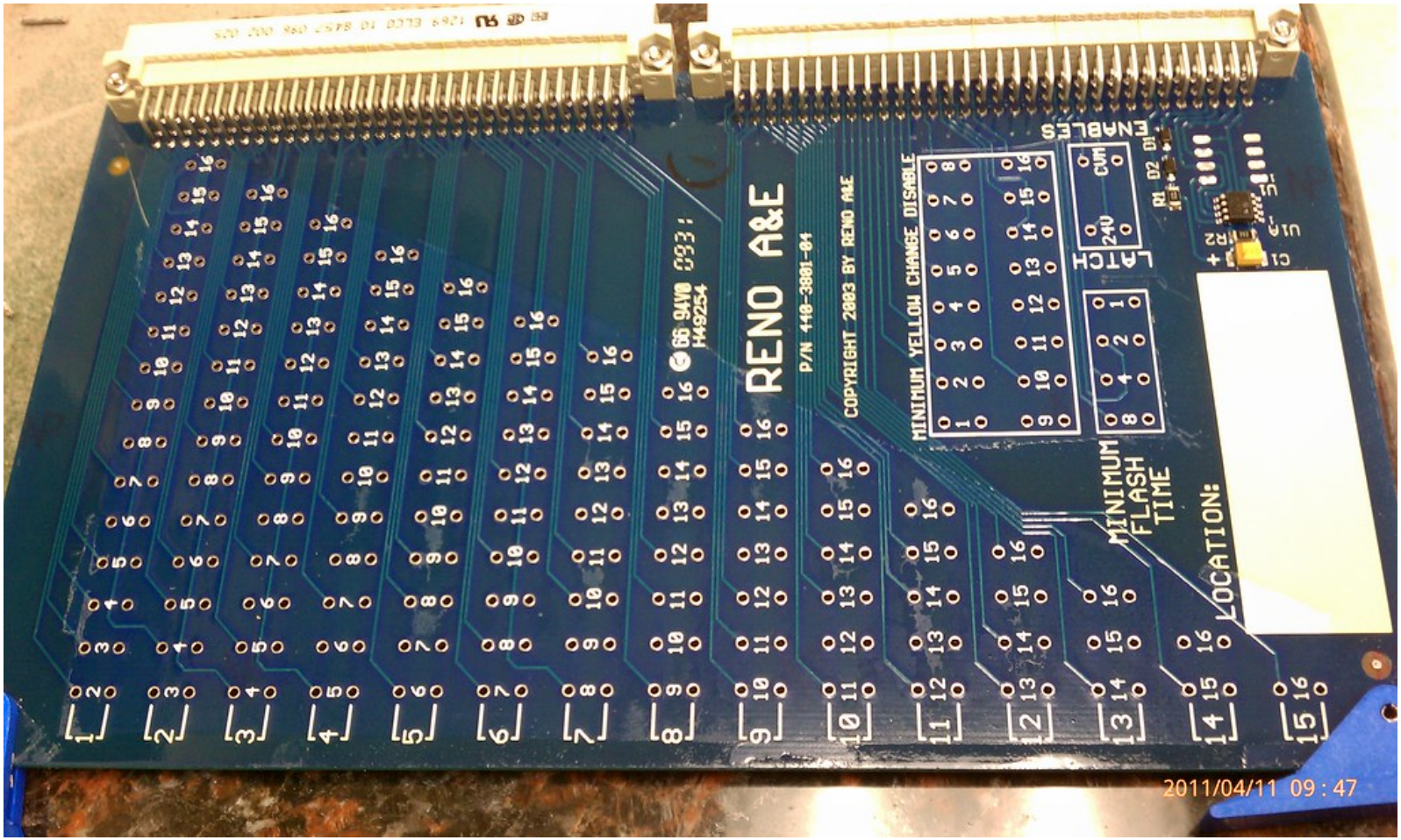
The conflict status is predefined by **Programming Card** in MMU and **Datakey** in CMU.

- In Programming Card, the conflict status is defined by soldered wire jumpers.
- Datakey is an EEPROM memory device.

MMU Programming Card



source: https://www.flickr.com/photos/robklug/5617557995/in/photostream/

CMU Datakey

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source: https://manualzz.com/doc/8353064/888-1212-001-monitorkey-operation-manual

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Security Analysis

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- Methodology: Partnering with a municipality in USA.
- Analysis Environment:
  - A standard traffic signal system in our lab.
  - The traffic signal system lab in the municipality.
  - The deployed traffic signal system in the municipality.
- Devices:
  - TS-2 cabinets with Siemens Model 60 ATC and EDI MMU-16LE.
  - ITS cabinets with Intelight Model 2070 ATC and CMU-212.

Security Analysis

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How to attack the system?

Security Analysis

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How to attack the traffic signal system?

- Step 1 – Access the Traffic Signal System
- Step 2 – Control the Traffic Signals
- Step 3 – Bypass Fail-Safe Components
- Step 4 – Hide Yourself

Security Analysis

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Physical Access

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Obstacles for accessing the traffic signal system physically:

- Surveillance Camera
- Cabinet Lock
- Cabinet Door Status Monitoring

Surveillance Camera

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According to the municipality officials,

- There are 750 vehicle intersections in the municipality.
- 275 vehicle intersections are covered by traffic cameras.
- More than 60% of the intersections are out of surveillance.

Cabinet Lock

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According to the cabinet specifications, both TS-2 and ITS cabinets shall be provided with a Corbin #2 key.

- However, the Corbin #2 master key is sold online.
- The sold key is marked with the ability to open most traffic signal cabinets in the United States.
- With $5 USD, we are able to open all cabinets in the municipality lab.

Cabinet Door Status Monitoring

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In the ITS cabinets, the status of the door can be monitored by the CMU.

- ATC send query message to CMU to get the door status.
- In real-world deployment,
  - The door alarm message is saved to log file by ATC.
  - The log file is forwarded to the municipality every one-to-five minute.

Physical Access

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Obstacles for accessing the traffic signal system physically:

- ~~Surveillance Camera~~
  60% intersections are out of surveillance
- ~~Cabinet Lock~~
  $5 USD for the master key
- ~~Cabinet Door Status Monitoring~~
  Non-real-time alarm

Remote Access

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- Previous work [3] has shown that the wireless communication network is vulnerable.
- We find that the both type of ATCs use default credentials for the SSH and Telnet.
  - The municipality were not aware of the ability to login to the ATC over SSH.
- The public IP addresses of a number of ATCs can be identified on Shodan [4] website.

Security Analysis

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Control the Traffic Signals

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With physical access,

- The signal pattern can be configured by the control buttons on the front panel.
- No authentication is activated in analyzed ATCs.
  - Access code can be set to control the access, but the partnering municipality didn't do so.

Control the Traffic Signals

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Normally, the traffic signals are controlled by specific software running in the Linux kernel via several serial ports. With remote access,

- Directly write commands to the serial ports.
  - Command specification is publicly available.
  - Communication is unencrypted.
  - No authentication is required.
- Manipulate the driver of the front panel.

Security Analysis

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Bypass Fail-Safe Components

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With physical access,

- For MMU, resolder the wire jumpers of the programming card.
- For CMU, reconfigure the parameters stored in the Datakey.
  - The configuration is unencrypted.
  - A customized Datakey access tool can be built by an Arduino Uno starter-kit.

Bypass Fail-Safe Components

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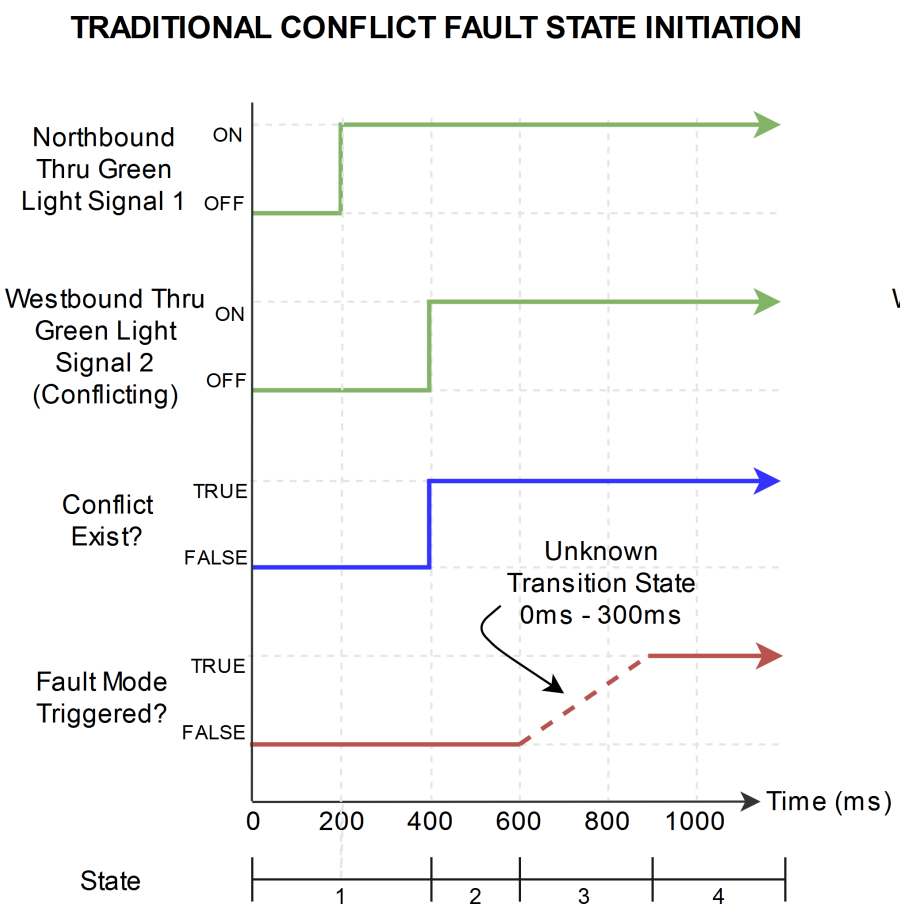
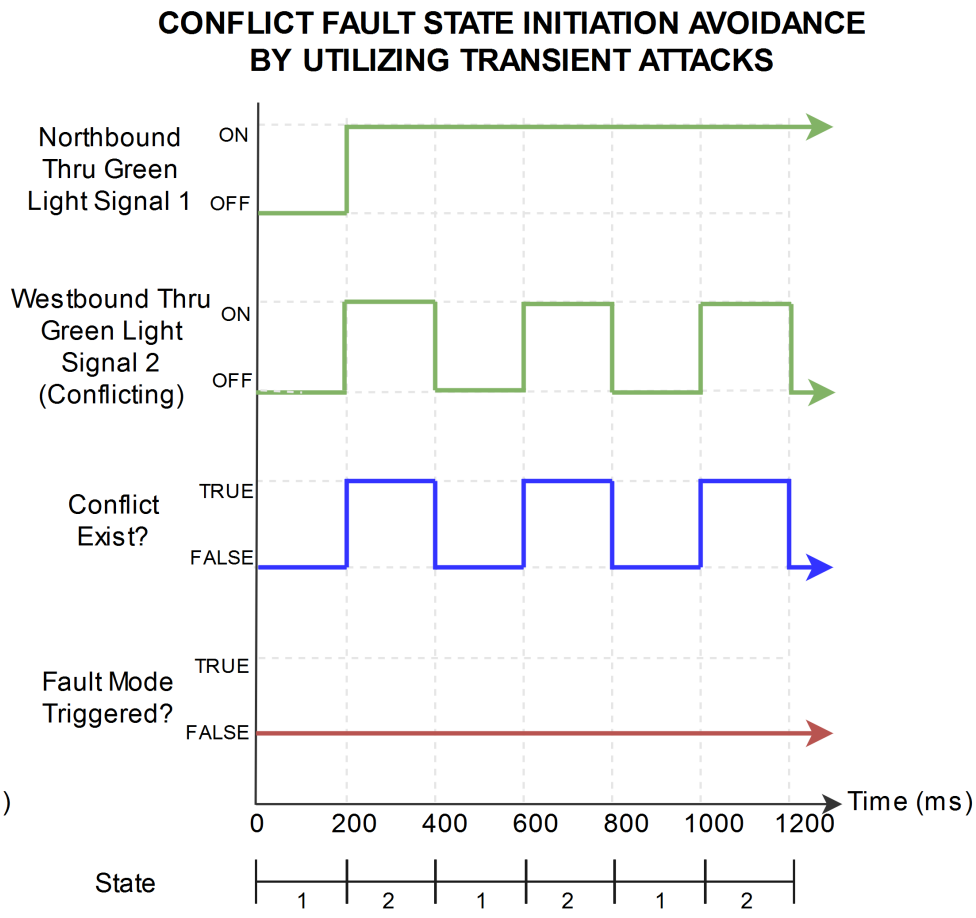
- With remote only access, we are not able to bypass the fail-safe components completely.
- We design a transient avoidance tactic to fight the fail-safe components.

Transient Avoidance Tactic





Security Analysis

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Traffic Network

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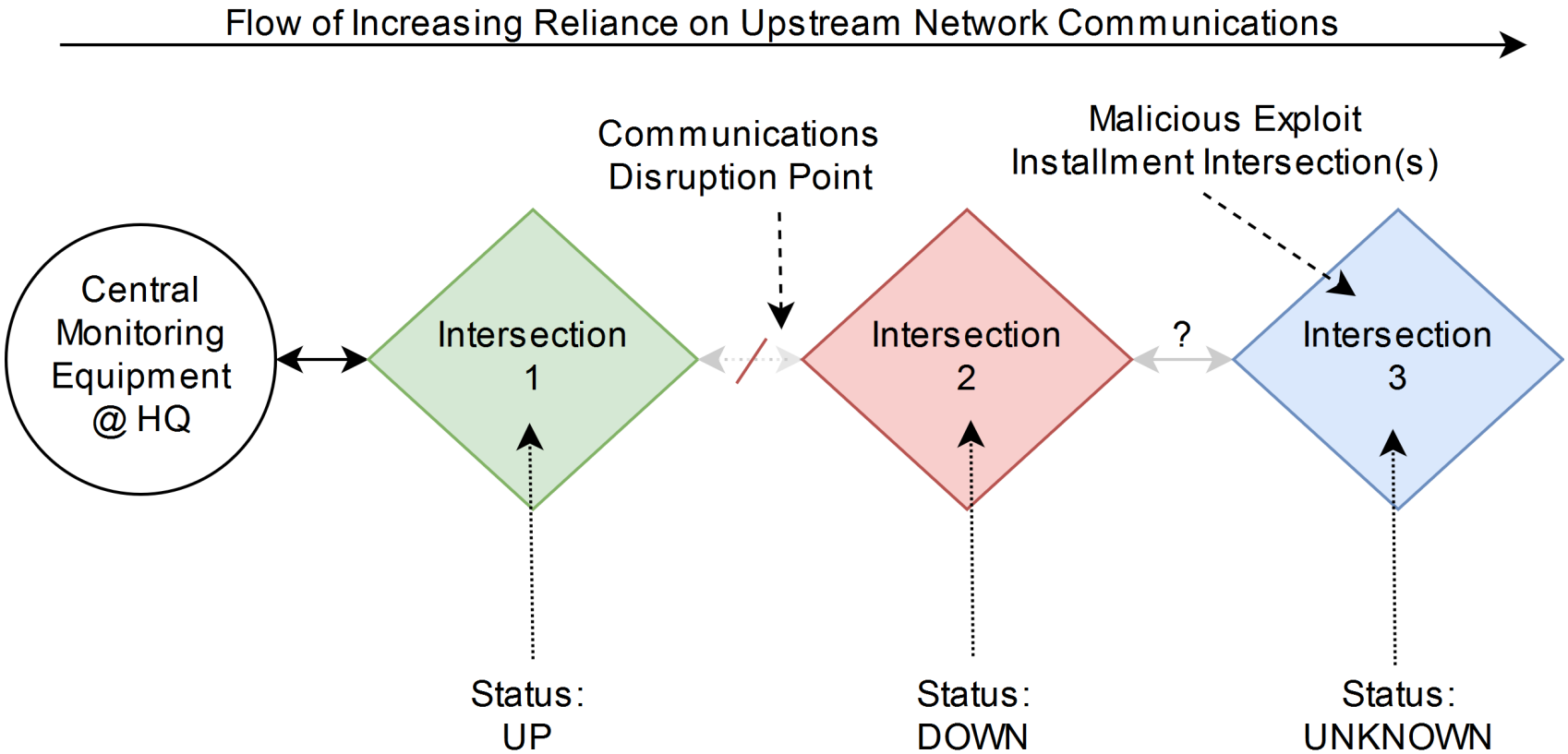
According to the municipality officials,

- Due to the geography that must be covered, the deployed traffic network are generally linear in communication flows.
- Redundant protocols are not used due to extra cost of additional equipment.
- Troubleshooting process of the traffic system mainly focus on the down point.

Diversionary Tactic



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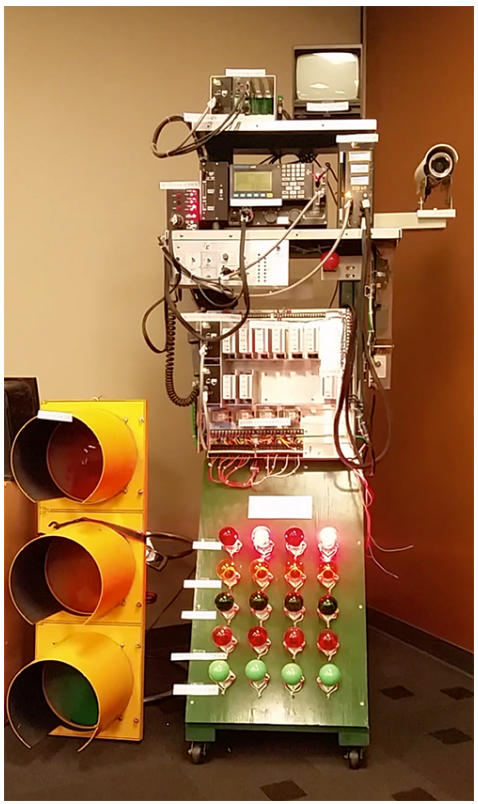
Attacks and Mitigations



Test environment in the municipality lab and our lab

Attack Scenarios

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- Stealthy Manipulation and Control
  - Stealthy control the traffic signal to introduce congestion.
- Ransomware Deployment
  - Change login credentials and lock ATC block startup process.
- All-Direction Green Lights
  - Transient avoidance tactic helps to make green light flashing.
  - Increase the flicker frequency to introduce optical illusion.

Recurrent Pulse Detection

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The Recurrent Pulse Detection (RPD) looks for voltage leaks lasting 1ms to 200ms and triggers a conflict state if a certain criteria level is met.

- In a certain time window, the duration of green light is cumulative.
- In practice, 24ms green light on-time with 17ms off-time will bypass the RPD.

Mitigations

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- Avoid default password and master key.
- The design should put security in mind.
  - Secure communication
  - Encrypted configuration
- Open access to the related software and specification with strict verification.

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Conclusion

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- We present a comprehensive vulnerability analysis of the traffic signal system and identify a number of vulnerabilities.
- Attackers can conduct a variety of attacks including all-direction green lights to the traffic system.
- More attention should be paid to the security threats in the transportation community.

References I

[1] C. Cerrudo, "Hacking US (and UK, Australia, France, etc.) traffic control systems," 2014.

[2] Q. A. Chen, Y. Yin, Y. Feng, Z. M. Mao, and H. X. Liu, "Exposing congestion attack on emerging connected vehicle based traffic signal control," in Proceedings of 25th Network and Distributed System Security Symposium (NDSS'18), 2018.

[3] B. Ghena, W. Beyer, A. Hillaker, J. Pevarnek, and J. A. Halderman, "Green lights forever: Analyzing the security of traffic infrastructure," in Proceedings of the 8th USENIX Workshop on Offensive Technologies (WOOT'14), 2014.

[4] Shodan, "Search engine for Internet-connected devices," https://www.shodan.io/.

Thank you!

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Questions?

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http://compass.cs.wayne.edu