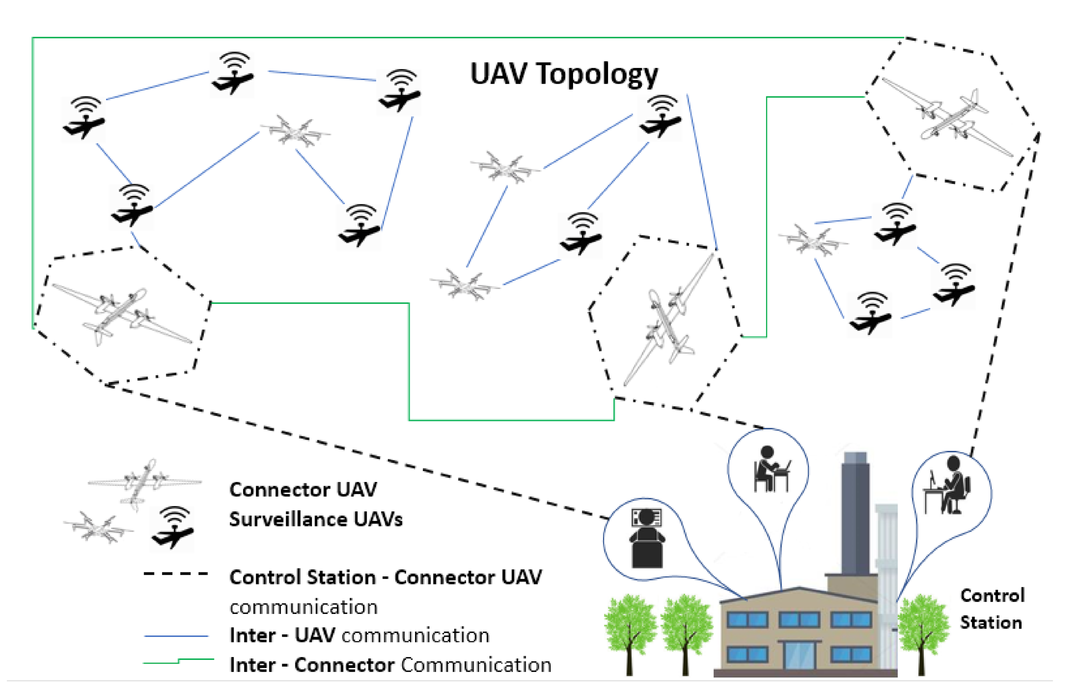
Smart Grid Surveillance With Unmanned Aerial Vehicle Using *K*-Resiliency Modeling

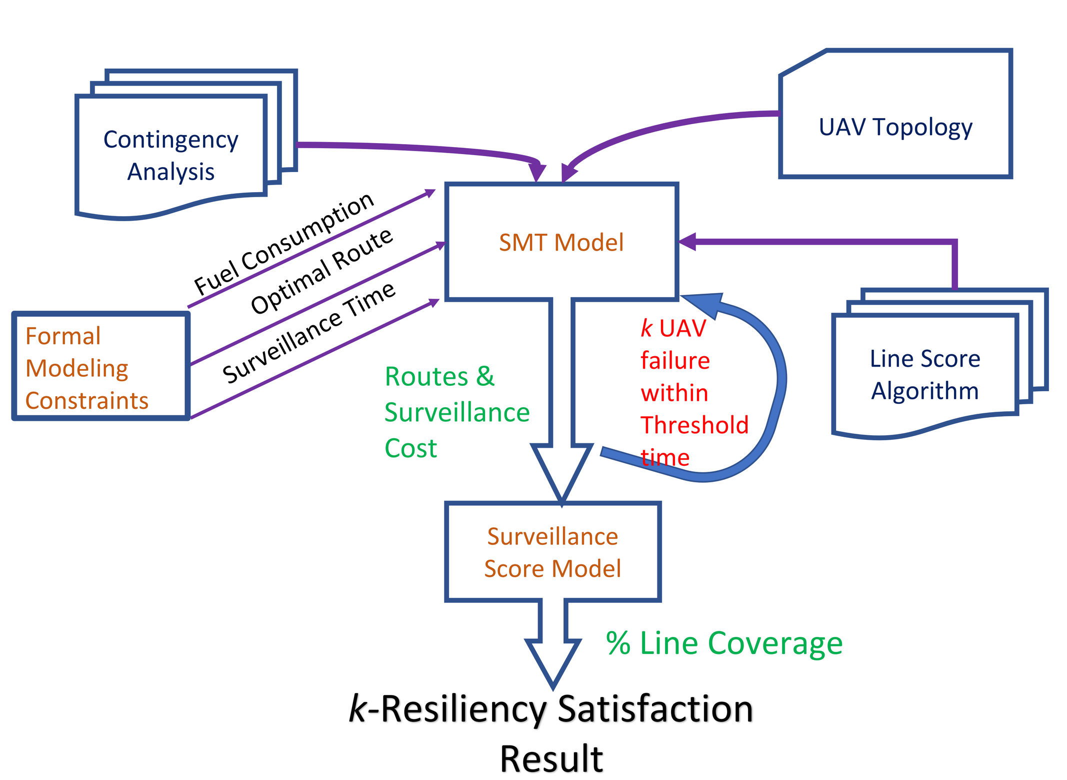
Rahat Masum and Mohammad Ashiqur Rahman
Department of Computer Science

Motivation

- Power line inspection provides a means for the smart grid **surveillance** to ensure the usual operational flow.
- Cyber/physical attacks by adversaries on the control system or natural calamities causing physical damage to the power line will hamper the **functional integrity** of the grid.
- Any damage to the power network can be occurred in **hardly-reachable** remote areas.
- Understanding the amount of impairment will be time consuming whereas control center needs to take **immediate steps** in case of any disturbance.

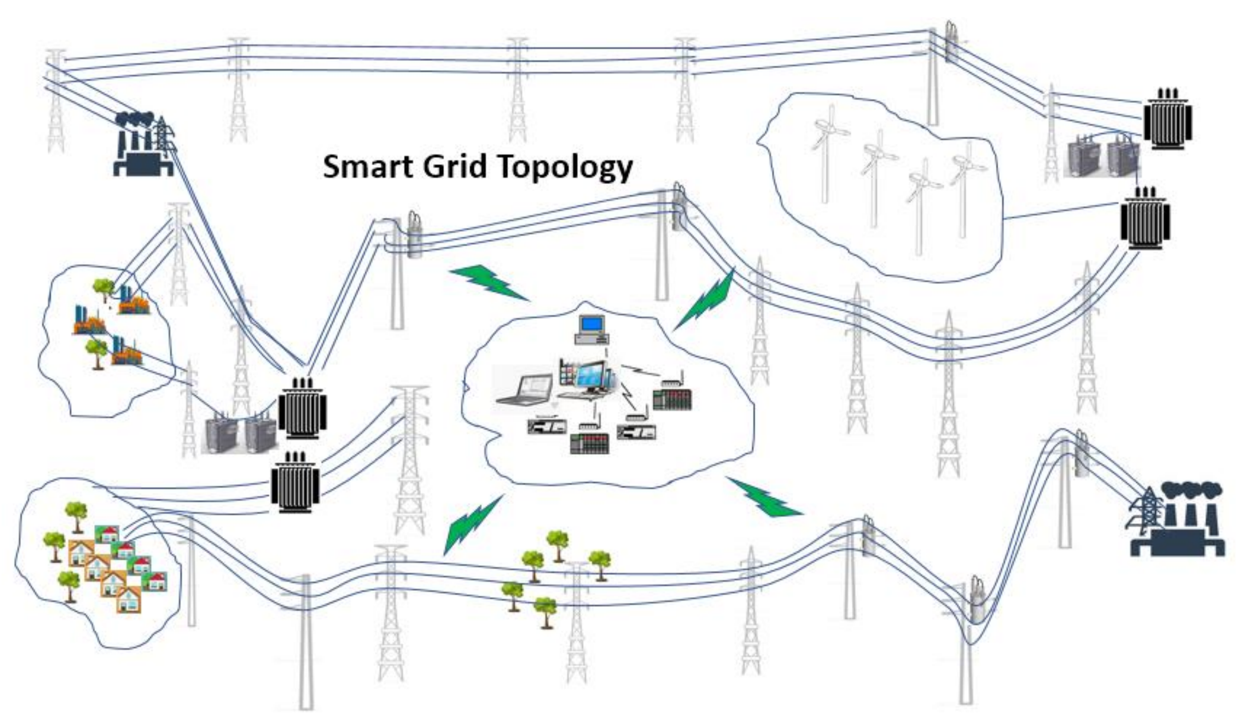
Methodology

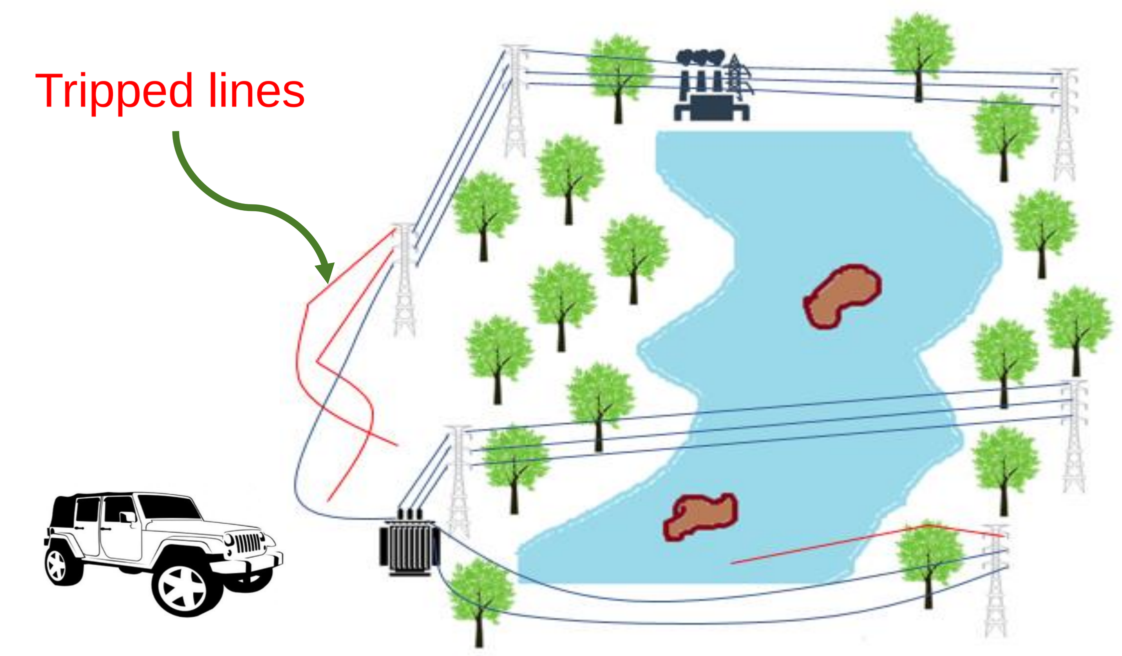




Problem Scenario

- Smart grid being a widely **distributed** engineering system, may run through deep forests to long rivers, costal areas, and over the cities.
- **Breakage** of any line or **outage** in generation on the bus network can not be acknowledged in short duration by occurrence based inspection process.
- **Continuous** monitoring for the **critical** transmission lines costs high maintenance expenses.
- **Emergency** circumstances (natural disasters/intruder attacks) threaten safety for human patrol.
- ***k*-resiliency**[1]: If *k* number of UAVs fails (due to attacks/technical difficulties), the rest of the UAVs still conduct the minimum required surveillance.

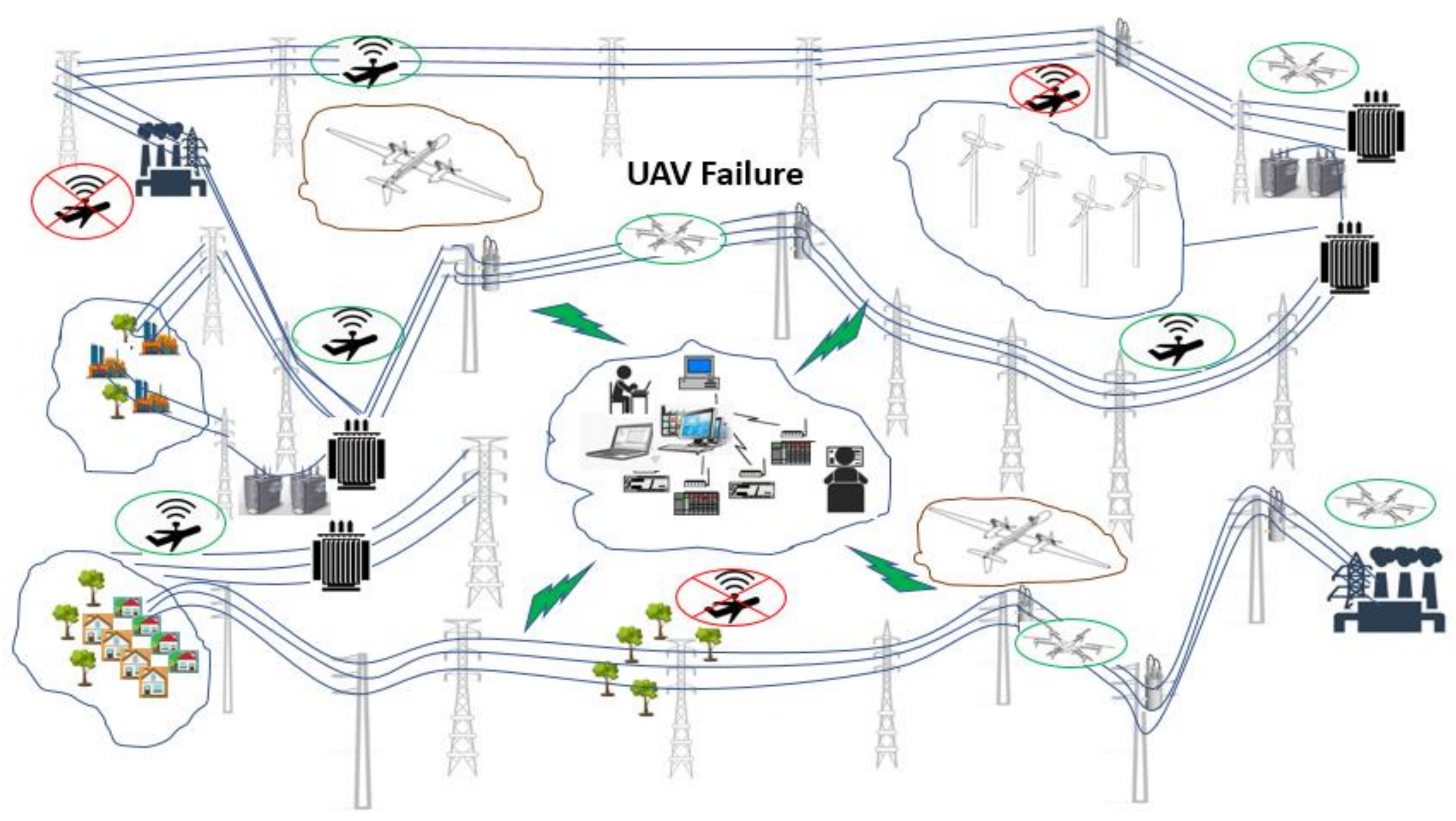




K-Resiliency Solution

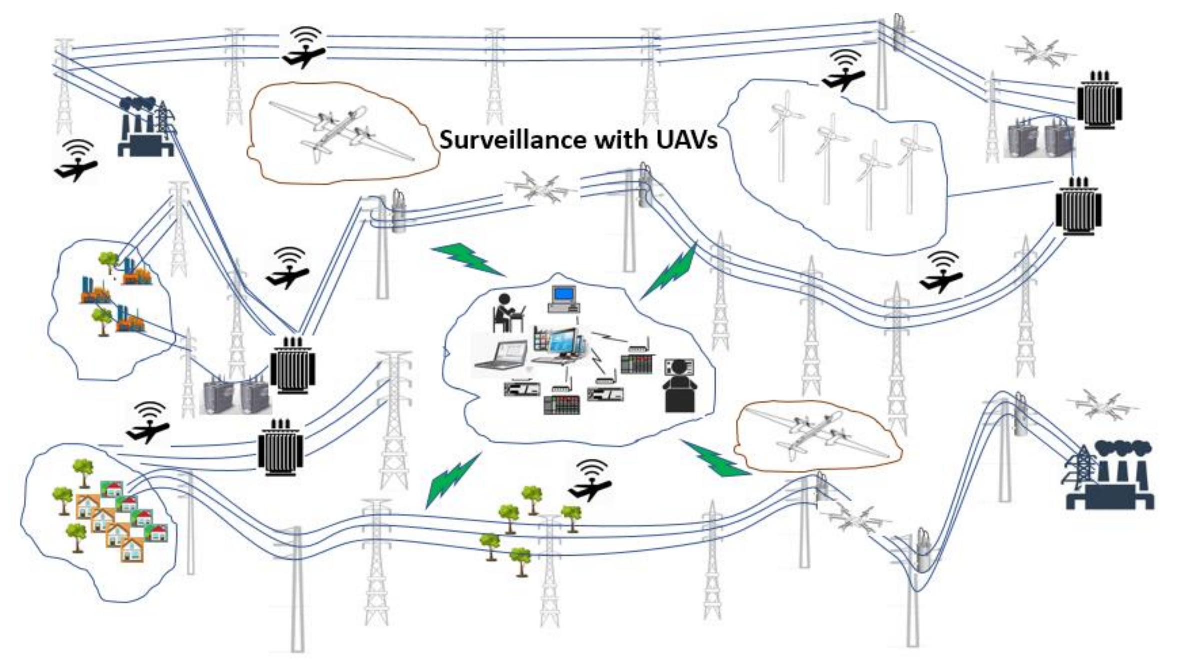
- Bus **contingency analysis** with SF[2] provides selection of critical lines from PI calculation.
- Transmission lines get **critical weights** (descending) applying k-means clustering over PI values.
- UAVs are placed over lines and formal model assigns route[3] to provide surveillance satisfying the threshold **time** and **fuel** constraints for UAV routing paths.
- Inspected lines by the fleet of UAVs add critical weights to the **surveillance score** for analyzing costs.
- **Resiliency** score is calculated from ***k* failed UAVs** in the surveillance based on the % of critical line coverages.

Solution Modules



Proposed Approach

- Instead of the traditional human patrol, **Unmanned Aerial Vehicles** are introduced to enable continuous monitoring[4] of the **safety critical** situations.
- A fleet of UAVs will be sent **over** the **critical lines** to **capture images** deliverable to the control station via **secure** communications channels and protocols to analyze power line situations.



Research Challenges

- Transmission lines in a grid possess critical **overload situation** due to line flow and generation outages.
- Event based surveillance **delays** the immediate decision making process and response time during hazardous situations.
- **Appropriate deployment** of UAVs depends on satisfying the constraints of surveillance time interval, lines to be covered, communication with control, cost effective fuel usage, and data record, making the scenario a ***NP*-hard** problem.
- In case of ***k* failure** from the fleet of UAVs, re-routing needs to be done ensuring ***k*-resilient** surveillance system.

Future Directions

- Apply solution model over real bus dataset if available to solve the surveillance resiliency.
- Optimize cost of UAV deployment and maximize resiliency surveillance coverage.
- Introduce collaborative UAVs for faster data collection and delivery.
- Strengthen encryption methods to ensure security against cyber intrusion.

Abbreviations/Nomenclature:

UAV: Unmanned Aerial Vehicle
SMT: Satisfiability Modulo Theories
PI: Performance Index
SF: Shift Factor for power lines
CA: Contingency Analysis
k-means cluster: Machine Learning algorithm to arrange similar data based on arithmetic mean

References:

[1] Mohammad Ashiqur Rahman, AHM Jakaria, and Ehab Al-Shaer. Formal analysis for dependable supervisory control and data acquisition in smart grids. In *Dependable Systems and Networks (DSN), 2016 46th Annual IEEE/IFIP International Conference on*, pages 263–274. IEEE, 2016.
[2] Robin Berthier, Rakesh Bobba, Matt Davis, Kate Rogers, and Saman Zonouz. State estimation and contingency analysis of the power grid in a cyber-adversarial environment. In NIST Workshop on Cybersecurity for Cyber-Physical Systems, pages 1551–3203, 2012.
[3] Mohammad Ashiqur Rahman, Qi Duan, and Ehab Al-Shaer. Energy efficient navigation management for hybrid electric vehicles on highways. In Cyber-Physical Systems (ICCPS), 2013 ACM/IEEE International Conference on, pages 21–30. IEEE, 2013.
[4] Gino J Lim, Seonjin Kim, Jaeyoung Cho, Yibin Gong, and Amin Khodaei. Multi-uav pre-positioning and routing for power network damage assessment. IEEE Transactions on Smart Grid, 2016.