PURDUE AERONAUTICS & ASTRONAUTICS

UAV-Traffic Information Exchange Network

Blockchain-inspired Data Transmission Mechanism

Hsun Chao, Apoorv Maheshwari, Varun Sudarsanan,
Dr. Shashank Tamaskar, Prof. Dengfung Sun, and Prof. Daniel DeLaurentis

Presenter: Prof. Dengfeng Sun (dsun@purdue.edu)
Associate Professor
School of Aeronautics and Astronautics, Purdue University

Outline

- Research Motivation
- What is UAV-TIEN?
  - What is blockchain?
  - TIEN Framework
- What are the properties of UAV-TIEN?
  - Simulation Setup
  - Simulation Results & Discussion
- Conclusion & Future Work

Research Motivation

- Several forecasts show the increasing demand of operations of commercial UAVs in metropolitan area in the future

- A reliable traffic data source is the fundamental assumption for all of collision avoidance algorithms but…
  - Performance of ADS-B type data transmission mechanism is shadowed in cities due to skyscrapers/obstacles
  - Distributed radar system is too expansive
  - Antenna of cellular towers are directed to ground
  - Low altitude operation is more prone to cyber-attacks

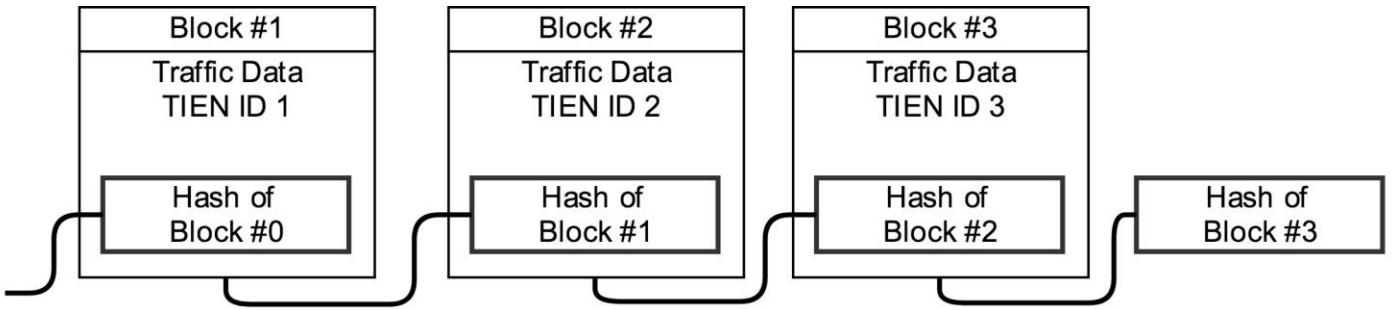
- The six requirements for an open, safe, spontaneous traffic information sharing system are:
  1. Ad-hoc network
  2. High Data Refresh Rate
  3. Secure Data Transmission
  4. Economical Data Distribution
  5. Compatible with third party detect-and-avoid systems
  6. Ability to deliver information in presence of large number of obstacles

Traffic Information Exchange Network (TIEN) & Blockchain

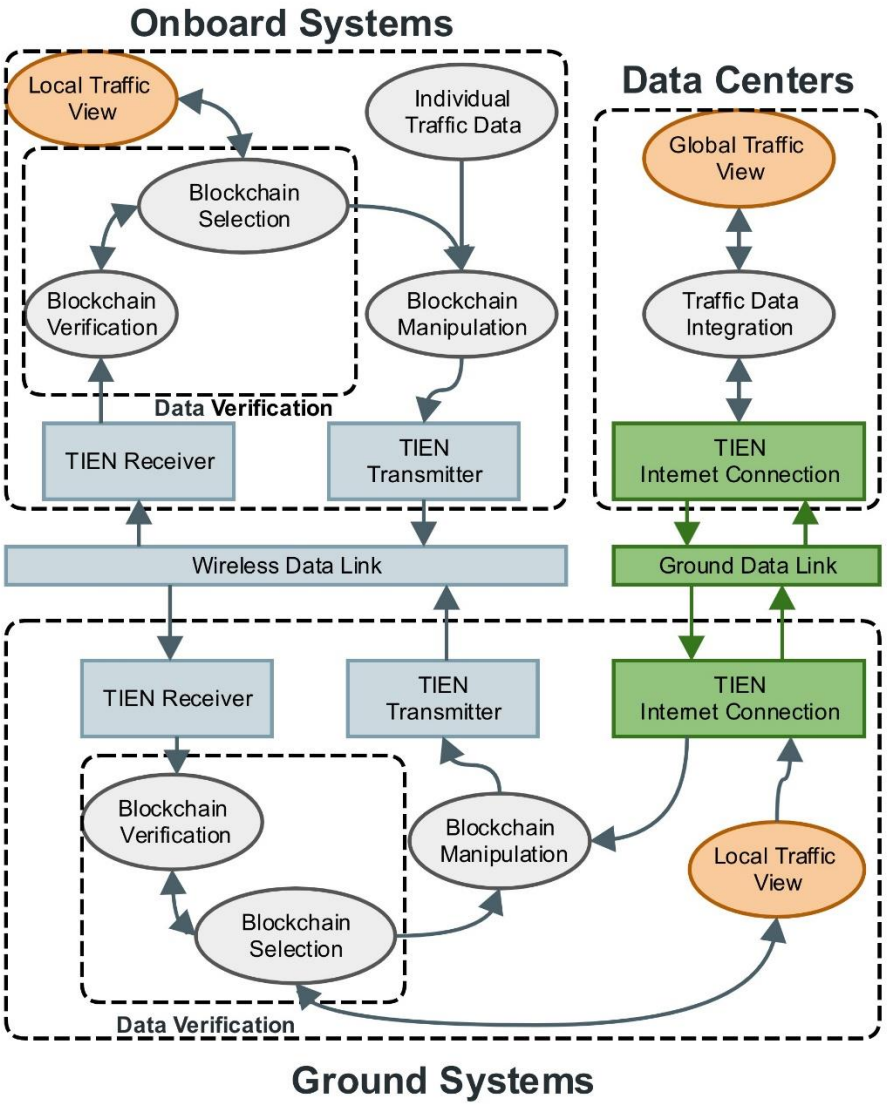
What is blockchain? – Hash Function 101

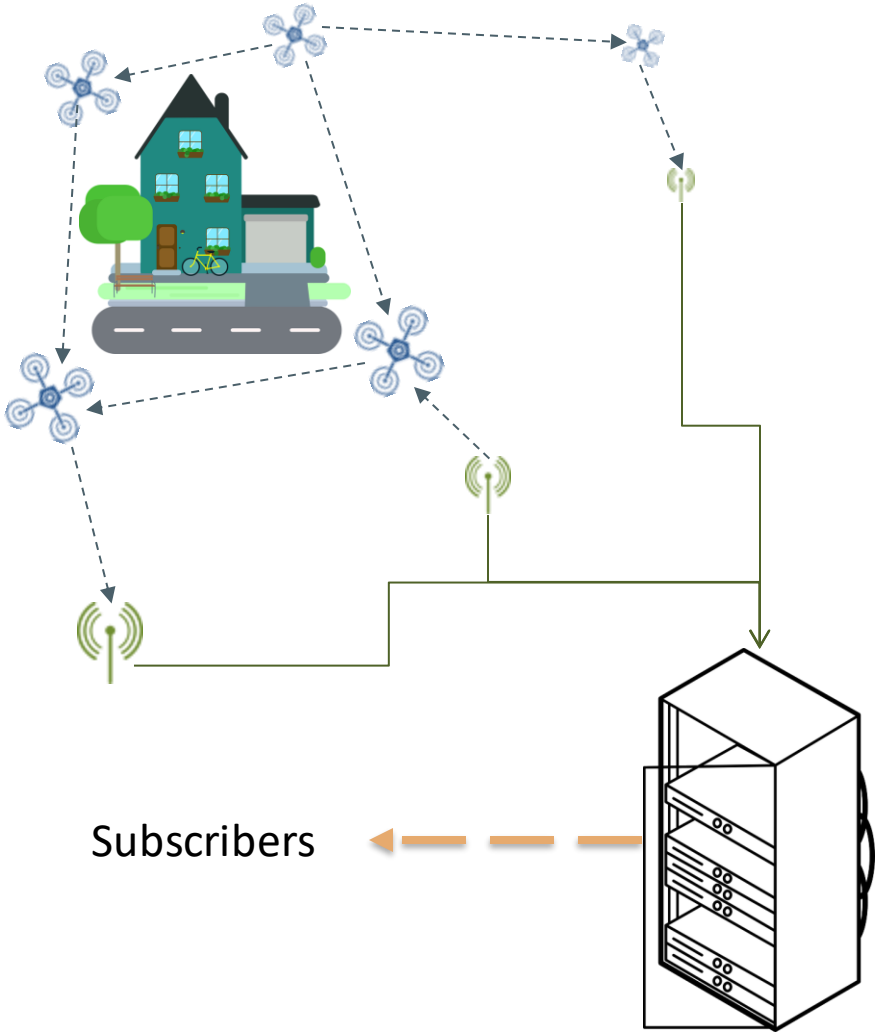
- Properties of Hash Function
  - **Pseudo-random**: A specific "output" according to the input
  - **No inverse function**: Extremely hard to find a reversed function
  - **Uniqueness**: Almost no two sets of input have the same output

- Example: (SHA3-256 hash function)
  - H('**TIEN**') = hex'ac9b93c166f5c8661908bcbe1eaca1f67cec943f82b080a75d13cb4f47d66f39'
  - H('**TIEN.**') = hex'b96c3cc063177621792829a6a4d2a3ac0d93e53abed452976d82f67929918476'



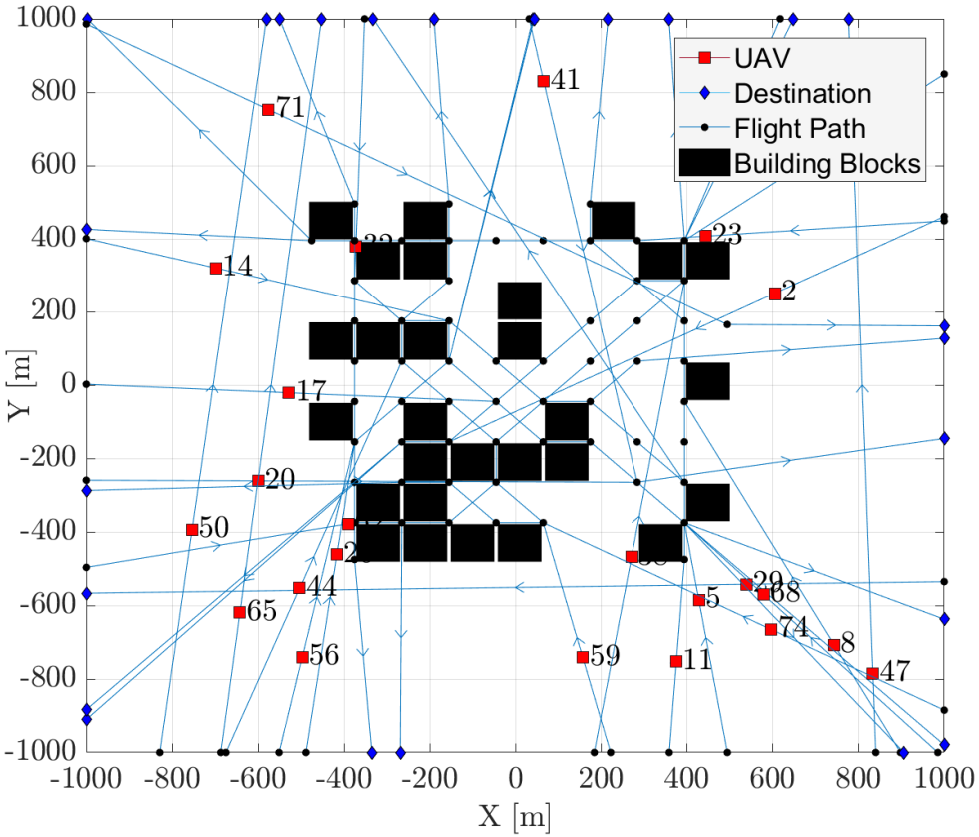
Framework


Onboard Systems
Local Traffic View
Individual Traffic Data
Blockchain Selection
Blockchain Verification
Blockchain Manipulation
Data Verification
TIEN Receiver
TIEN Transmitter
Wireless Data Link
Data Centers
Global Traffic View
Traffic Data Integration
TIEN Internet Connection
Ground Data Link
TIEN Receiver
TIEN Transmitter
TIEN Internet Connection
Blockchain Verification
Blockchain Manipulation
Local Traffic View
Blockchain Selection
Data Verification
Ground Systems


Subscribers
Ground Communication
Air Communication
Provided Information

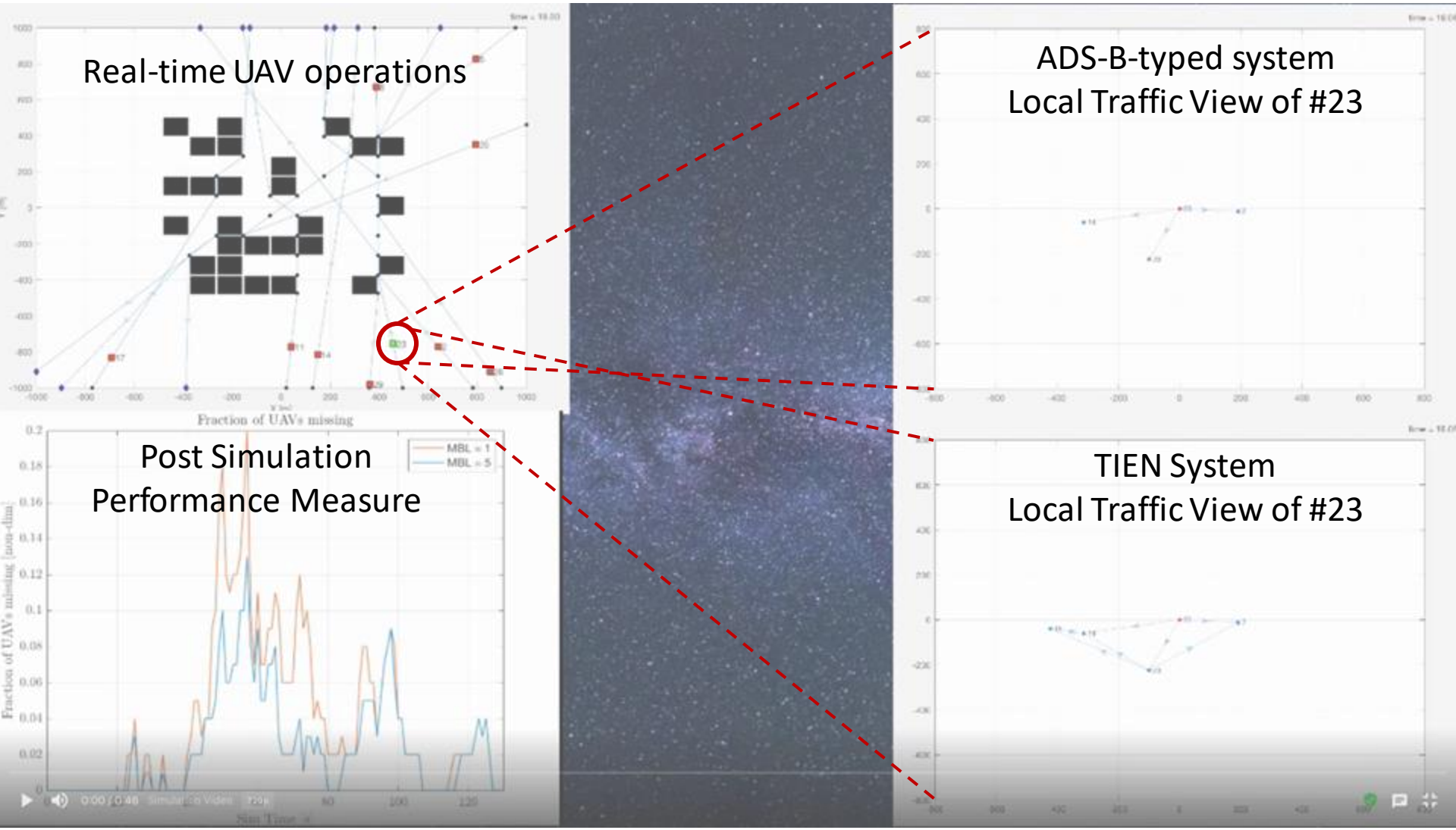
Simulation Setup

- Goal: Proof-of-concept
  - Evaluate properties of the blockchain-inspired data transmission mechanism
  - The ground systems and data centers are not modeled in the simulation yet
- Environment:
  - A virtual world
  - A virtual city
  - Building Blocks
- TIEN and UAV Operation Assumptions:
  - No collision avoidance
  - Start and finish points of a flight are at the edges of virtual world
  - Only deploy onboard systems
  - Data transmission rate is 110 kbps; average block size is roughly 800 bits
- ADS-B can be regarded as a special case of the data transmission with only 1 block

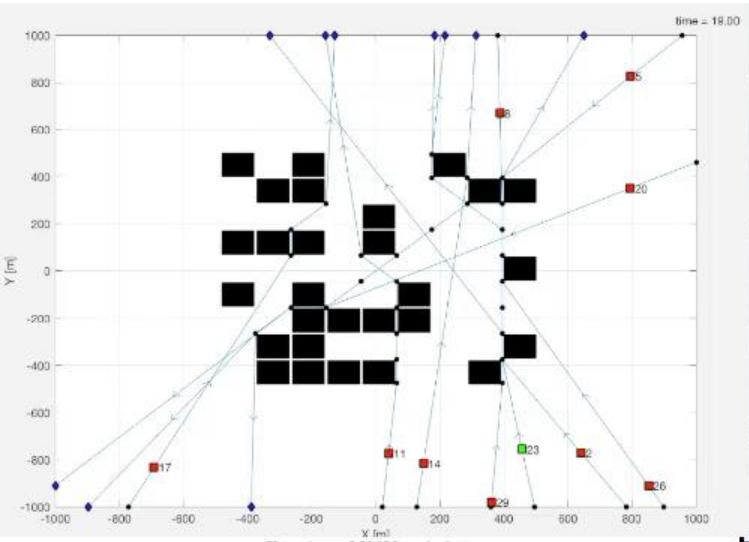


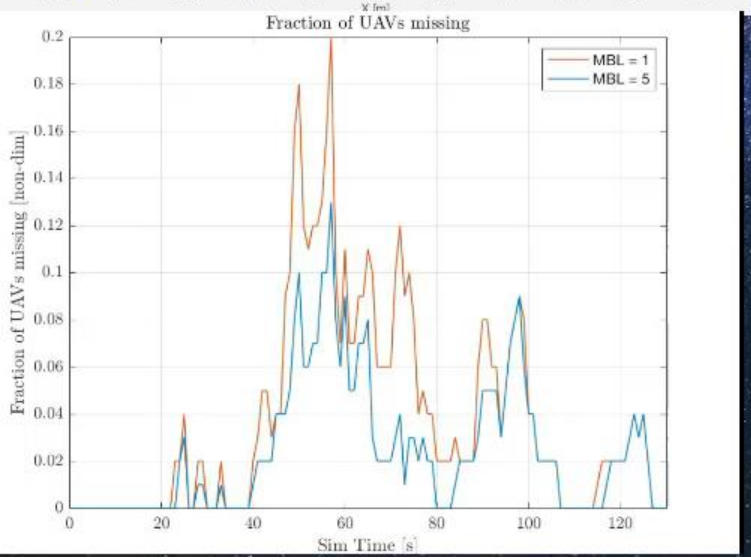
Snapshot of the simulation with 25 UAV operations

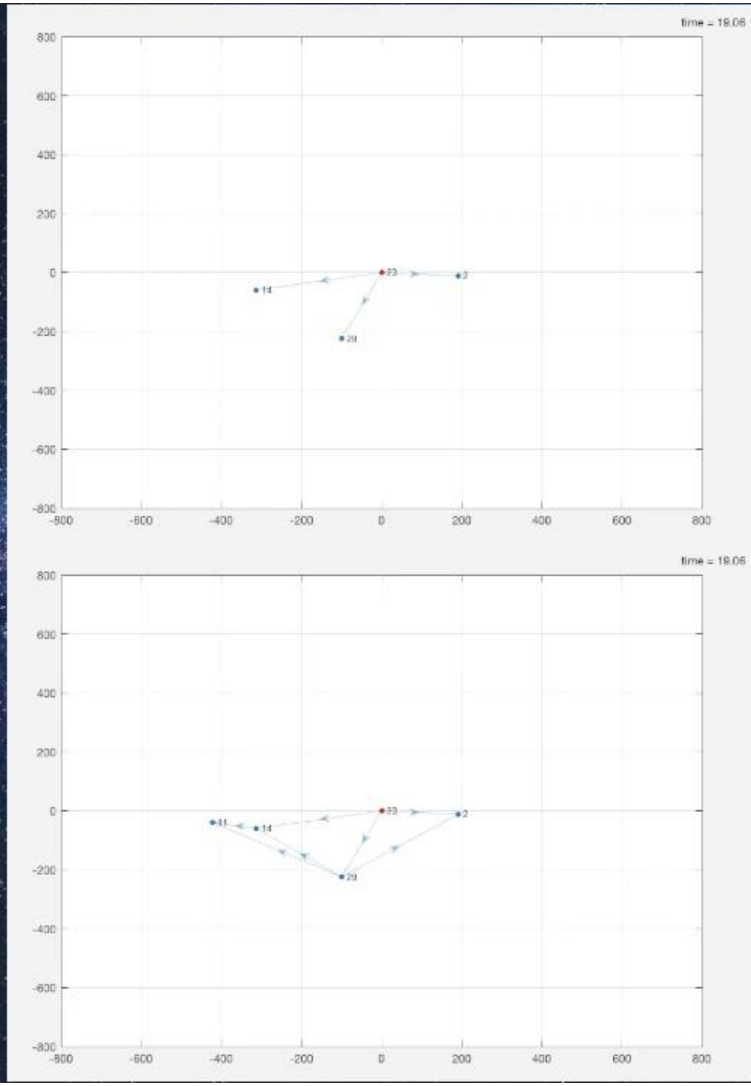
Simulation Demonstration



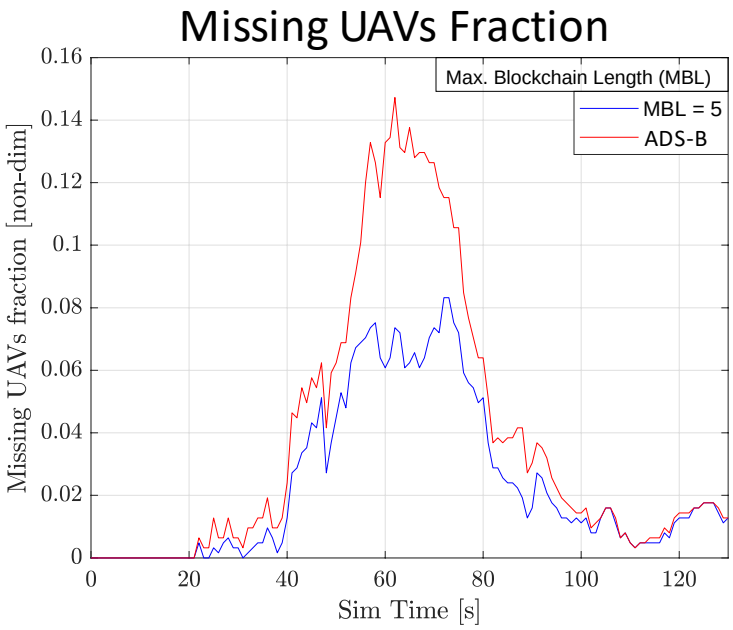
Simulation Demonstration







Results and Discussion



- Randomly generated:
  - City layout
  - UAV flight plan and OD pair
  - UAV cruise speed
- Study the impacts of:
  - Number of UAVs in the simulation
  - Broadcasting Frequency
  - Maximum number of relayed blocks

- Missing UAVs Fraction:
  - Measure the fraction of UAVs which are in the broadcasting range but are not seen by others
  - TIEN has lower Missing UAVs Fraction value throughout the simulation than ADS-B-like system
- Effective broadcasting range:
  - UAVs with TIEN can broadcast their position further than its broadcasting range
  - We observed that the effective broadcasting range can be as high as 5 times the broadcasting range
  - The broadcasting range can be reduced to reduce power consumption while maintaining good coverage
- System scalability
  - TIEN is a distributed system, so its performance increases with higher number of UAVs, which is verified by the simulation results

Conclusion & Future Work

- Conclusions:
  - UAV-TIEN system is a data transmission system to provide free and secured traffic information for everyone
  - Simulation results confirm the robustness and scalability of TIEN system in urban areas with dense traffic environment

- Future Work
  - Prototype TIEN system and test its performances in the real world.
  - Investigate how ground system affects TIEN onboard system performance and qualities of the global traffic view
    - Select a case study city, such as Washington D.C., Chicago, Manhattan
    - Investigate ground system deployment strategies
  - Demonstrate the robustness against the several types of cyber-attacks

NASA University Student Research Challenge Competition

- This project has won the NASA University Student Research Challenge (USRC) proposal competition
  - This project gets funding from NASA to build and test the prototyping system.
  - Per the proposal requirements, one third of the directed cost has to be raised through crowdfunding campaign.

- Learn more about this project or subscribe for the future updates
  - https://goo.gl/DWks9L

Backup slides

Simulation Setup

Parameter	Type of Variable	Values
Virtual World & Virtual City		
Boundary	Deterministic	2 km (1.24 mile)
City Boundary	Deterministic	1 km (0.62 mile)
Block Boundary	Deterministic	100 m (328 ft)
Block has buildings	Binomial	0.4
UAV		
Origin	Uniform	
Destination	Uniform	
Cruise Speed	Gaussian	μ: 70 kmh, σ: 5 kmh (μ: 43 mph, σ: 3 mph)

Parameter	Type of Variable	Values
Onboard System		
Maximum Blockchain Length	Deterministic	(1, 5, 10)
Broadcasting Frequency	Deterministic	(1, 2) Hz
Broadcasting Range	Deterministic	400 m (1312 ft)
Data Transmission Rate	Deterministic	110 kbps

- Investigate the impacts from the following parameters
  - Maximum Blockchain Length (MBL)
  - Broadcasting Frequency
  - Number of UAVs (25, 50, 100)
- Setting with 1 MBL and 1 Hz broadcasting frequency can be regarded as an ADS-B type system

System Performance Metrics

- Weighted Position Error (WPE):

$$WPE = \frac{1}{N}\sum_{i=1}^{N}\left(\frac{1}{N_i}\sum_{j=1}^{N_i}\sum_{t}\frac{\overbrace{\left\|x_j(t) - x_j^*(t)\right\|}^{\text{Position Errors}}}{\underbrace{d_{ij}(t)}_{\text{Relative Distance}}}\right)$$

- Weighted Data Age (WDA):

$$WDA = \frac{1}{N}\sum_{i=1}^{N}\left(\frac{1}{N_i}\sum_{j=1}^{N_i}\sum_{t}\frac{\overbrace{\left\|t - T_j^{i0}(t)\right\|}^{\text{Data age}}}{d_{ij}(t)}\right)$$

- Missing UAV Fraction (η):

$$\eta(t) = \frac{1}{N}\sum_{i=1}^{N}\frac{N_{in}^{i}(t)}{N_{br}^{i}(t)}$$

$N_{in}^{i}(t)$: # of invisible UAVs

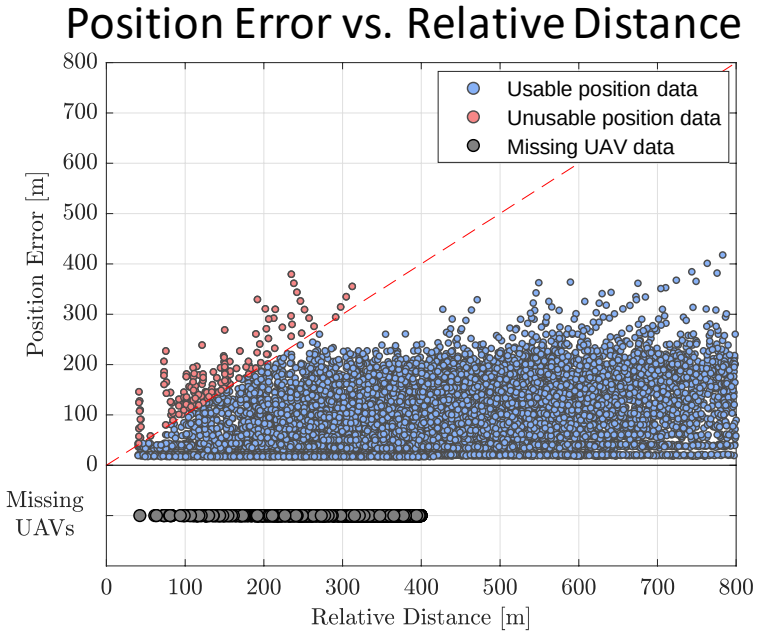
$N_{br}^{i}(t)$: # of UAVs in the broadcasting range

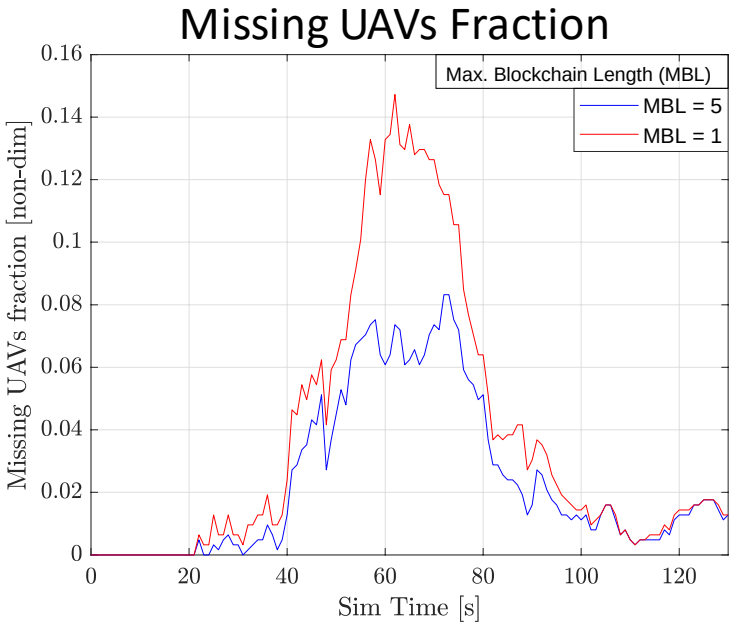
- Effective Broadcast Range (BR_{eff}):

$$BR_{eff} = \frac{1}{BR}\max_{i,j,t}\left\{d_{ij}(t) \times \underbrace{I_{\epsilon_{ij}(t)\leq\epsilon_{th}}}_{\text{Check whether the position error is within the threshold}}\right\}$$

Simulation Results & Discussion

- Simulation settings for the results shown on left:
  - 25 UAVs
  - 1 Hz Broadcasting Frequency
  - (1, 5) MBL
- Position Error vs. Relative Distance:
  - A data point is unusable if the position error is more than the relative distance.
  - Most of data points are usable.
  - There are more missing UAVs at the edge of broadcasting range.
- Missing UAVs Fraction:
  - ADS-B type system has 14~15% missing UAVs fraction.
  - The MBL can reduce the missing UAV fraction to 8~9%.





Simulation Results & Discussion

- Statistical Analysis:
  - Linear cell effect model w/o interaction terms
- Impacts of MBL
  - Improve the accuracy of traffic data (Decrease the WPE)
  - Decrease the missing UAV fraction
  - Increase effective broadcasting range
- Impacts of BF
  - Improve the accuracy of traffic data
  - Decrease the effective broadcasting range.
  - TIEN broadcast the latest received blockchain; this hurts the information propagation when number of received blockchain increased.
- Impacts of number of UAVs
  - This has not significant effects on WPE and WDA
  - Increase the effective broadcasting range.
  - TIEN system has higher chances to find a relay to propagate information

Simulation Scenario Counting

		nUAVs & Broadcasting Frequency (BF)					
		1 Hz			2 Hz		
		25	50	100	25	50	100
MBL	1	19	18	5	22	15	2
	5	19	14	6	19	7	3
	10	14	18	10	14	15	2

Linear Regression Analysis Results

	WPE	WDA	η_{avg}	BR_{eff}
Intercept	0.3329	0.0152	0.0423	1.1553
MBL = 5	-0.0229	-0.007	-0.0157	1.8878
MBL = 10	-0.0408	-0.0016	-0.0209	2.3690
BF = 2 Hz	-0.0737	-0.0039	0.0133	-0.1983
nUAVs = 50	NS	NS	NS	0.5692
nUAVs = 100	NS	NS	NS	1.0453