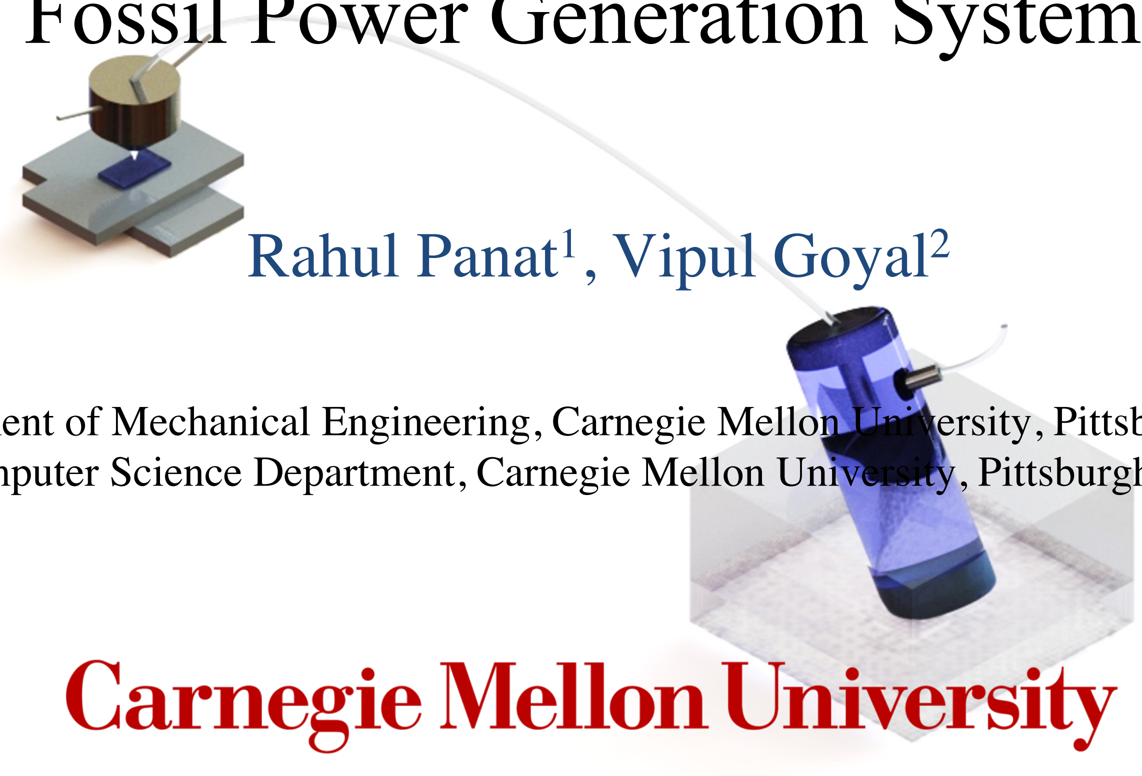
AOI 2: A Novel Access Control Blockchain Paradigm for Cybersecure Sensor Infrastructure in Fossil Power Generation Systems



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Carnegie Mellon University

Outline

- Introduction and Background
  - Team
  - Project Goals and Objectives
  - Tasks and Timelines
- Building Cybersecure Sensor Networks
  - Strain Sensors
  - Temperature Sensors
- Private Access Controlled Blockchain
- Progress on Deliverables and Conclusions

The Team

Lab-scale Sensor Network

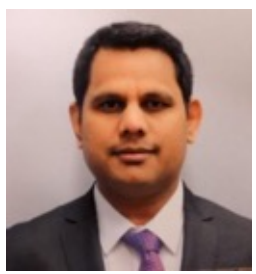
Rahul Panat
Project Lead PI

Blockchain Design and Coding

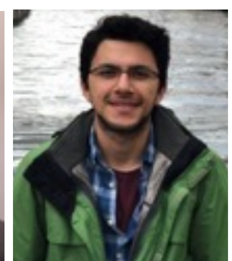
Vipul Goyal
Project Co-PI

Mrunal Vaze
(MS)
Joined a Robotics
Company in
Pittsburgh, PA

Sandra Ritchie (PhD)



Dr. Ali (Postdoc)-
now Asst Prof at
Virginia Tech
working on
sensors

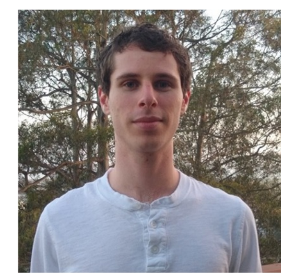


Mert
(PhD)

Elisaweta Masserova
(PhD)

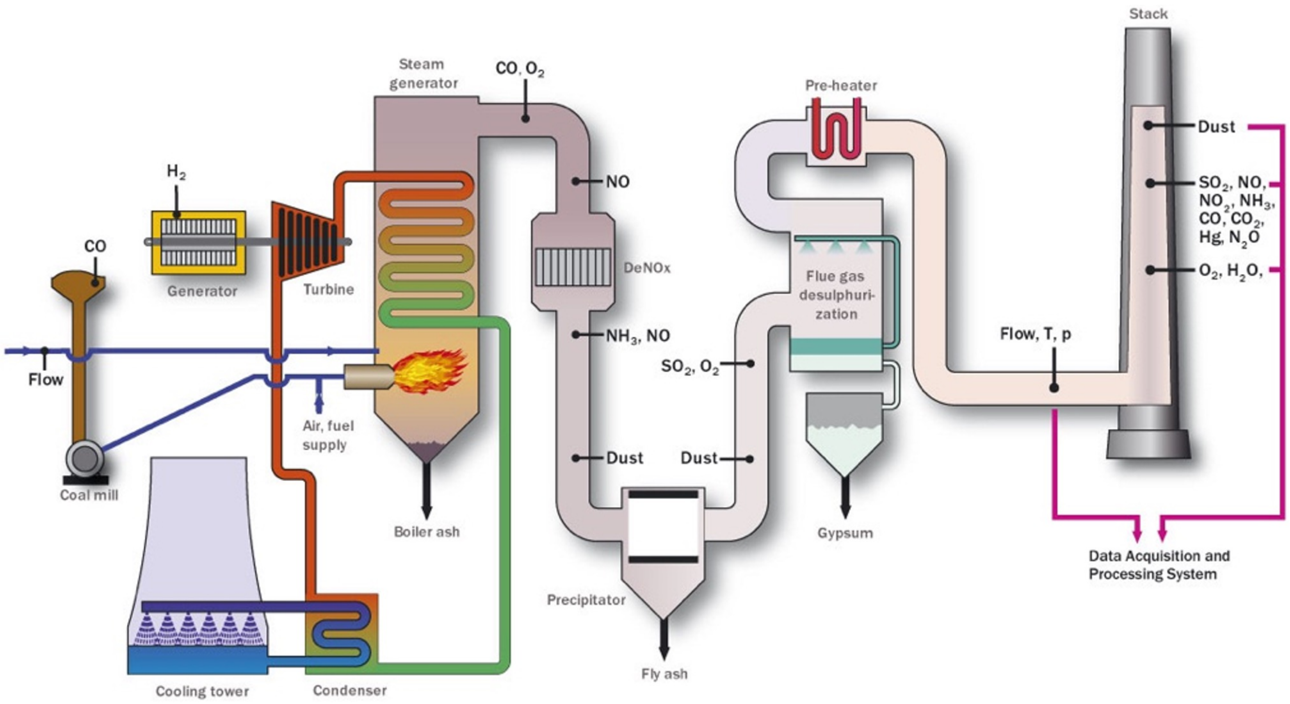
Anirudh Baddepudi
(MS)

Joining Google Inc



Justin Raizes
(PhD)

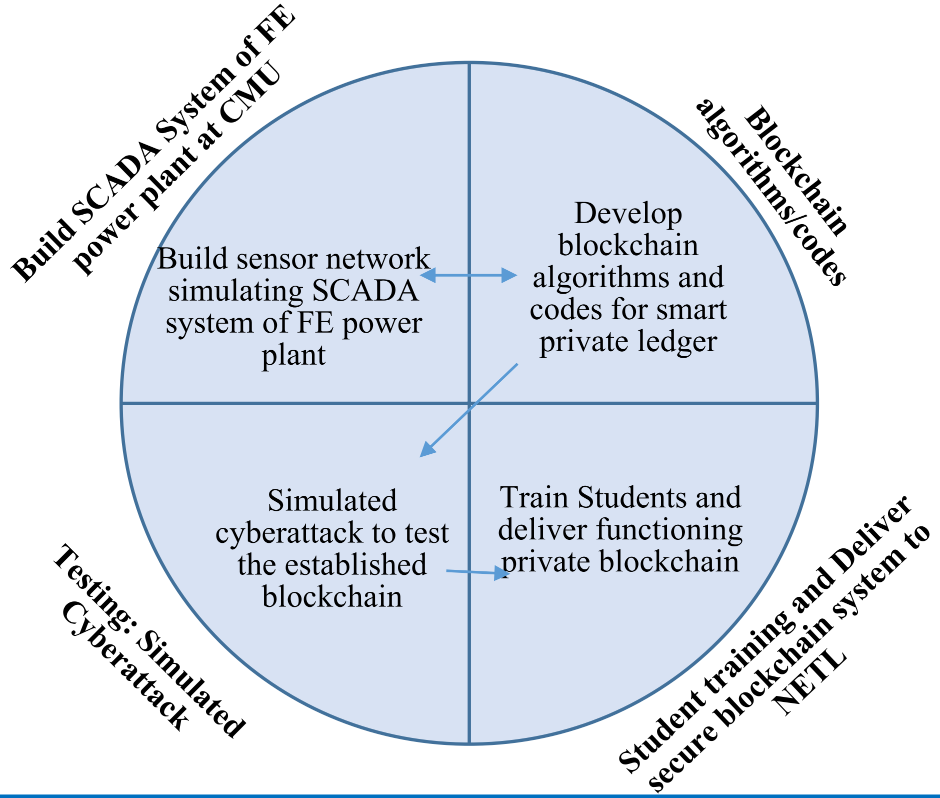
Sensing Applications



- Power generation and distribution infrastructure can experience both external or internal cyberattacks
- Novel methods are required to secure the data, while also controlling its access

Objective of the Project

To design, characterize, and demonstrate a breakthrough secure blockchain protocol, namely smart private ledger with hierarchical access control for fossil power generation systems



Project Timelines and Deliverables

Tasks and Timelines

Tasks	Owner	Year-1				Year-2			
		Q1	Q2	Q3	Q4	Q5	Q6	Q7	Q8
Task 1.0: Project Management and Planning	Panat								
Task 2.0: Create a Sensor Network to Generate Data	Panat								
Task 3.0: Data Transmission to Blockchain Nodes	Panat								
Task 4.0: Development of Blockchain with Computers as Simulated Nodes	Goyal								
Task 5.0: Create Hierarchical Access Control for Data Retrieval	Goyal								
Task 6.0: Simulated Cyberattacks and Demonstration of Robustness of the Blockchain	Panat/Goyal								

- Project period: 2 years + 1year NCE
  - Data acquisition and transmission system
  - Creation of blockchain protocols
  - Simulate cyberattacks and demonstration lab-scale system

Task-1

- Project Management and Planning
  - The PIs will shall manage and direct the project in accordance with a Project Management Plan to meet all technical, schedule and budget objectives and requirements. The PIs will coordinate activities in order to effectively accomplish the work. The PIs will ensure that project plans, results, and decisions are appropriately documented and project reporting and briefing requirements are satisfied.

Tasks	Owner	Year-1				Year-2			
		Q1	Q2	Q3	Q4	Q5	Q6	Q7	Q8
Task 1.0: Project Management and Planning	Panat								
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Task 6.0: Simulated Cyberattacks and Demonstration of Robustness of the Blockchain	Panat/Goyal								

ONGOING

Task-2

- Create a Sensor Network to Generate Data
  - This task will involve the development of sensor networks for the development of the proposed technology. The task will be performed by Panat group

Tasks	Owner	Year-1				Year-2			
		Q1	Q2	Q3	Q4	Q5	Q6	Q7	Q8
Task 1.0: Project Management and Planning	Panat								
Task 2.0: Create a Sensor Network to Generate Data	Panat								
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Task 5.0: Create Hierarchical Access Control for Data Retrieval	Goyal								
Task 6.0: Simulated Cyberattacks and Demonstration of Robustness of the Blockchain	Panat/Goyal								

Task-3

- Data Transmission to Blockchain Nodes
  - This task will involve the development of wireless transmission of the signal to the blockchain nodes. The task will be performed by Panat group

Tasks	Owner	Year-1				Year-2			
		Q1	Q2	Q3	Q4	Q5	Q6	Q7	Q8
Task 1.0: Project Management and Planning	Panat								
Task 2.0: Create a Sensor Network to Generate Data	Panat								
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Task 5.0: Create Hierarchical Access Control for Data Retrieval	Goyal								
Task 6.0: Simulated Cyberattacks and Demonstration of Robustness of the Blockchain	Panat/Goyal								

Task-4

- Development of Blockchain with Computers as Simulated Nodes
  - This task will involve the development of the smart private ledger blockchain with hierarchical access control and secret sharing protocols and will be performed by the Goyal group.

Tasks	Owner	Year-1				Year-2			
		Q1	Q2	Q3	Q4	Q5	Q6	Q7	Q8
Task 1.0: Project Management and Planning	Panat								
Task 2.0: Create a Sensor Network to Generate Data	Panat								
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Task 5.0: Create Hierarchical Access Control for Data Retrieval	Goyal								
Task 6.0: Simulated Cyberattacks and Demonstration of Robustness of the Blockchain	Panat/Goyal								

Task-5

- Create Hierarchical Access Control for Data Retrieval
  - This task will develop algorithms to retrieve the data from the blockchain and will be performed by the Goyal group

Tasks	Owner	Year-1				Year-2			
		Q1	Q2	Q3	Q4	Q5	Q6	Q7	Q8
Task 1.0: Project Management and Planning	Panat								
Task 2.0: Create a Sensor Network to Generate Data	Panat								
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Task 5.0: Create Hierarchical Access Control for Data Retrieval	Goyal								
Task 6.0: Simulated Cyberattacks and Demonstration of Robustness of the Blockchain	Panat/Goyal								

Completed

Task-6

- Simulated Cyberattacks and Demonstration of Robustness of the Blockchain
  - PIs will simulate cyberattacks to harden the blockchain system for real world secure deployment
  - Common strategies such as those used during the Ukranian power grid attack will be studied and the blockchain system will be subjected to similar attacks.
  - Any changes if needed will be made and the entire process will be repeated. We expect our system to provide very high level of security against such attacks by eliminating a single point of failure.

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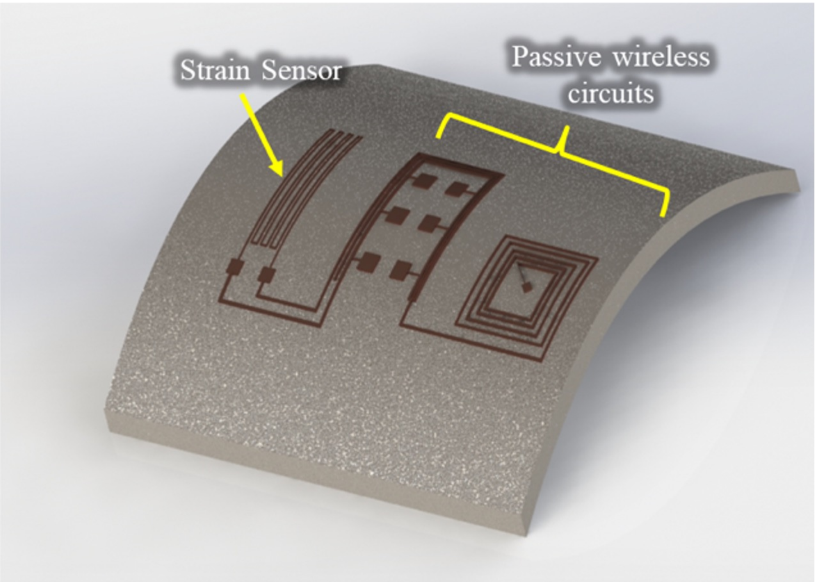
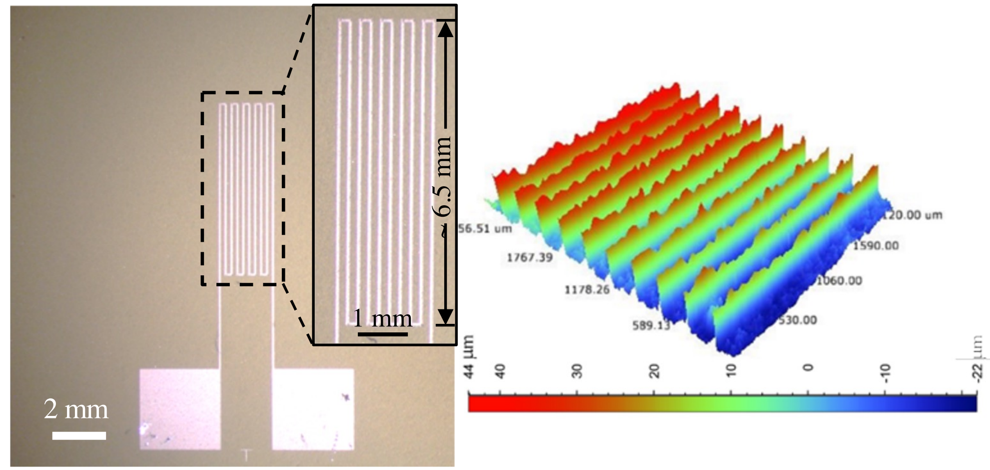
✓ Ongoing

Building Sensor Network

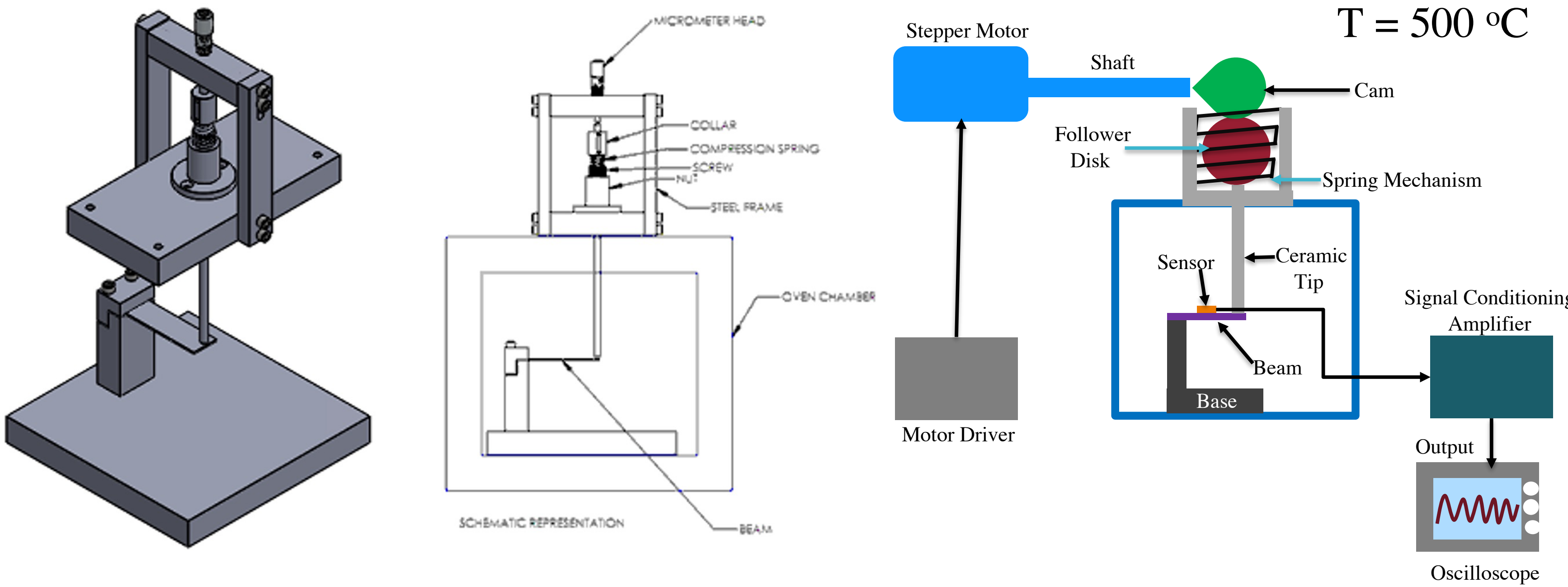
High Temperature Sensor Fabrication





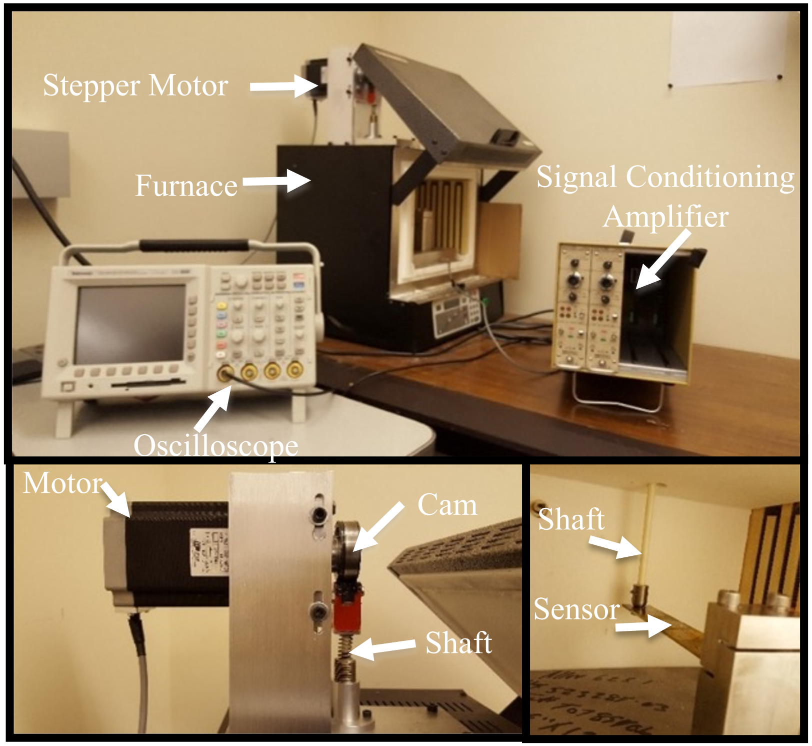
CMU has developed sensor fabrication methods and testing systems for fossil power plants that can work at temperatures up to 500 C

High Temperature Sensor Testing

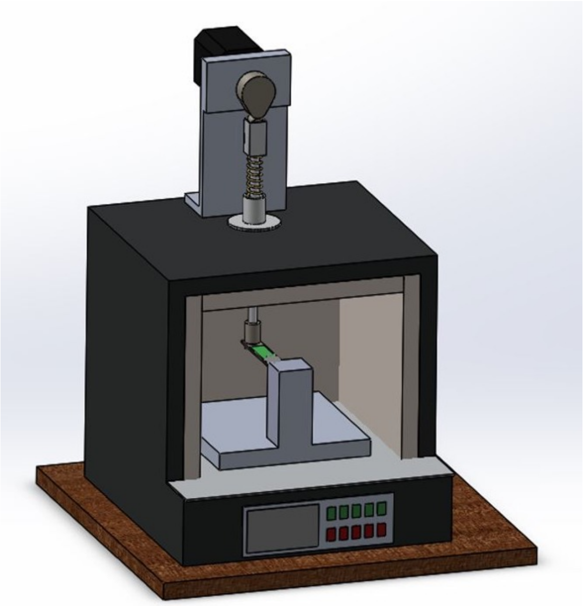


Schematic of the Strain Sensing Apparatus

High Temperature Data Acquisition System



High Temperature Dynamic
Strain Sensor Test Set up



- Able to provide 1000 micro strain on the beam
- Deflection frequency: up to 10 Hz

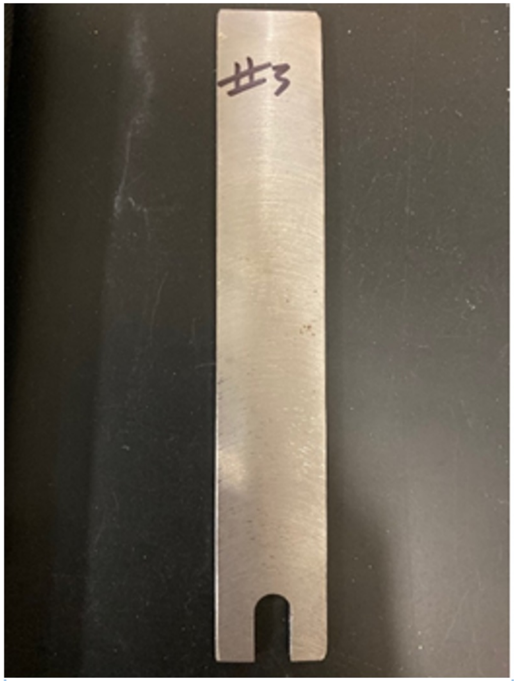
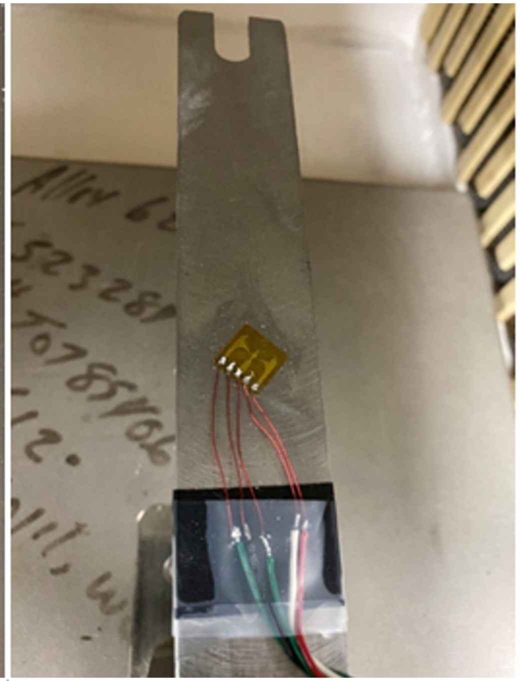
Strain Measurement Apparatus

Strain Measurement

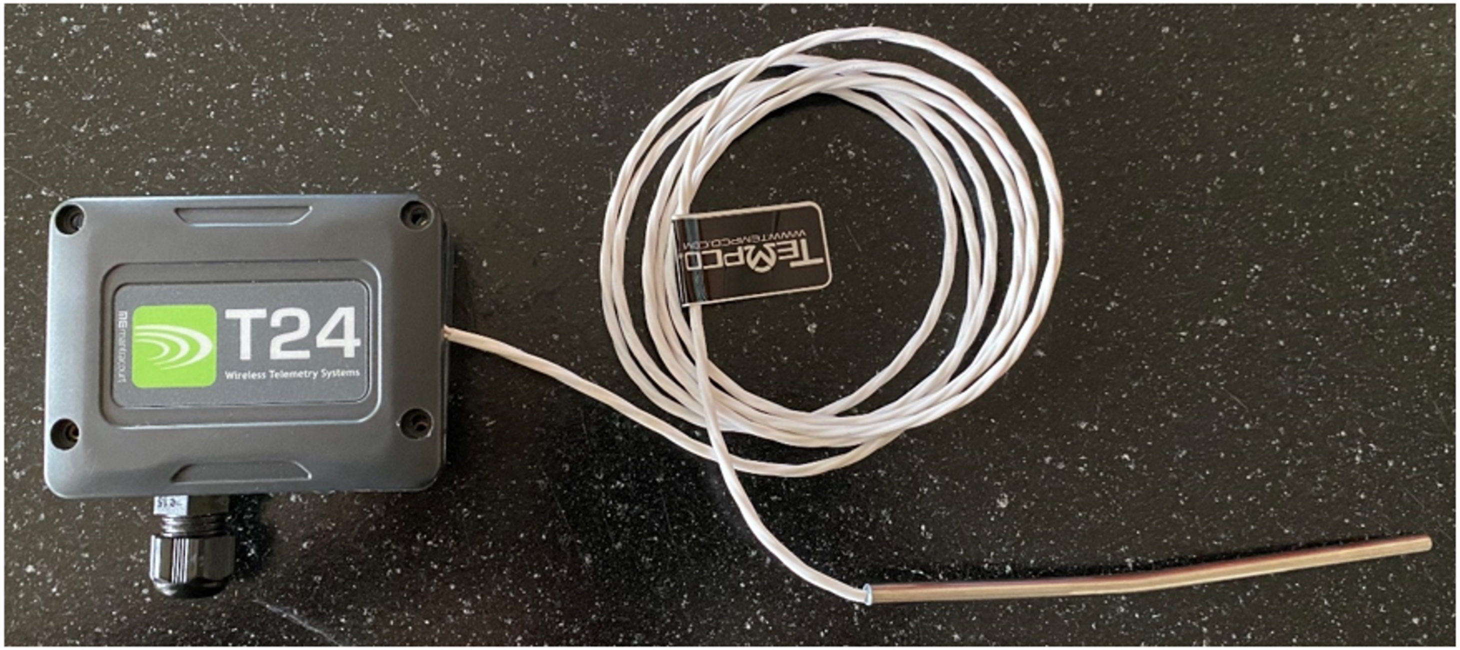
Successfully demonstrated strain measurement using Mantracourt T24 telemetry system

- Installed a commercial strain sensor (VY4 Shear/Torsion full bridge strain gauge) acquired from HBM, USA
- Integrated the strain sensor with transmitter and base station
- Data acquisition at 3 readings/sec – compatible with power plant sensing systems

Strain Measurement

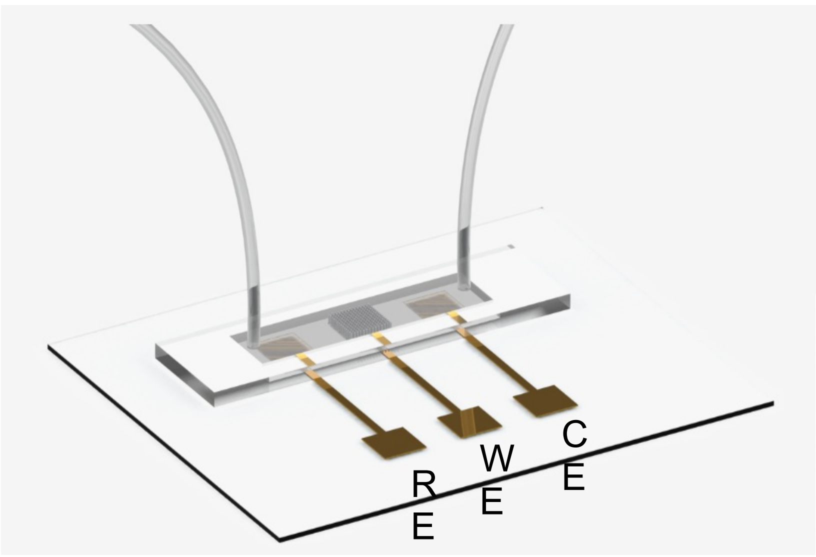
		
Stainless steel beam	Strain sensor showing good adhesion to beam surface	Strain sensor integrated with transmitter module

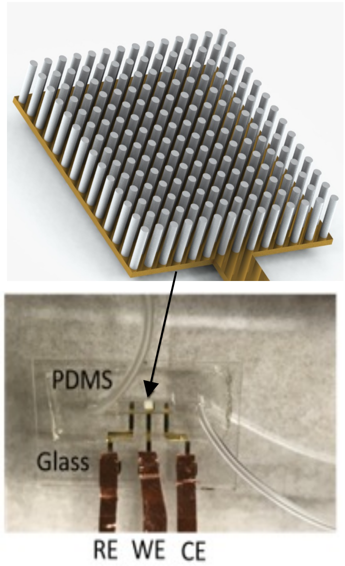
Temperature Measurement

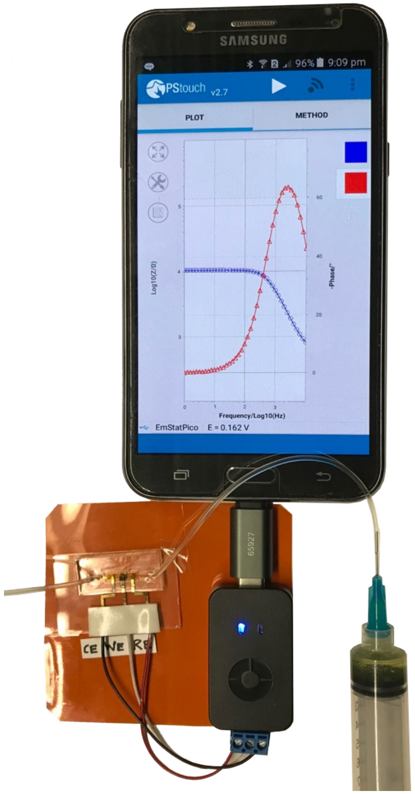


- We chose commercial RTD temperature sensor for the project
- Temperature sensor integrated with Mantracourt T24 acquisition and wireless transmission system

Electrochemical Sensors

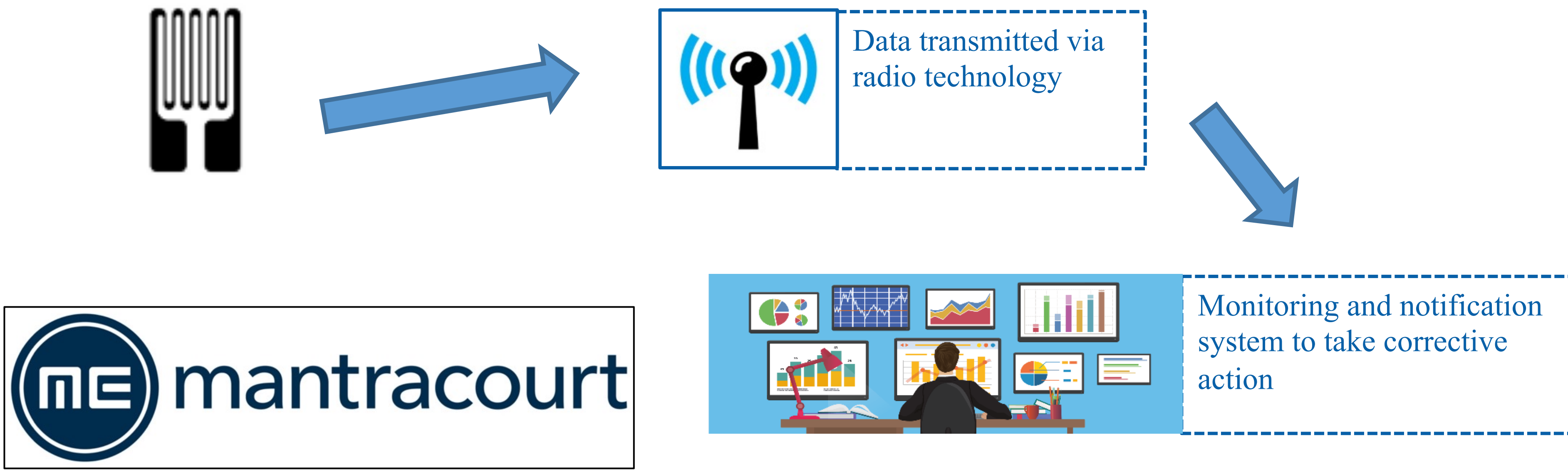






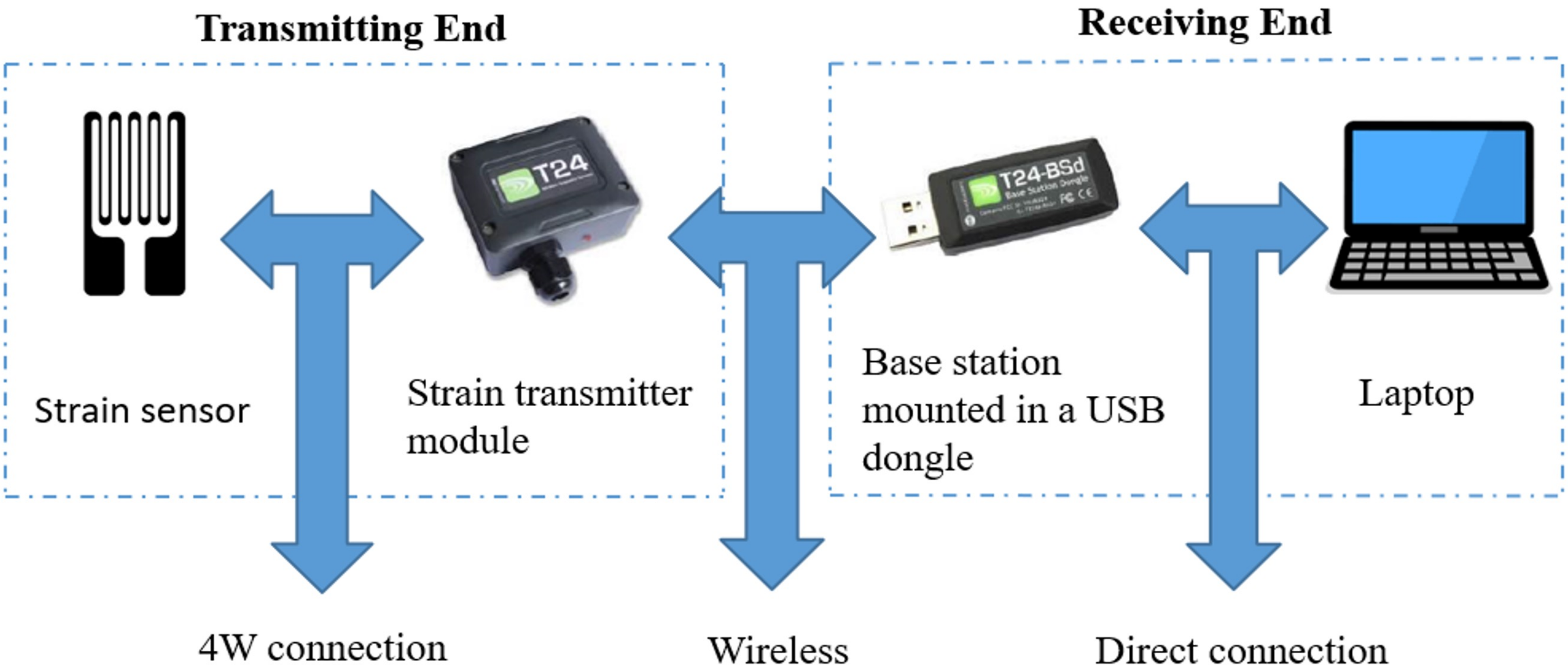
- A third type of sensor was electrochemical sensor for high throughput data collection
- Sensor signal was captured and sent to a cell phone-based interface

Data Transmission: Mantracourt System



- Chose mantracourt system for secure data transmission
- Commercially available system with low cost
- Aim was to create software compatible with commercial technologies for adaptability and lowering of cost

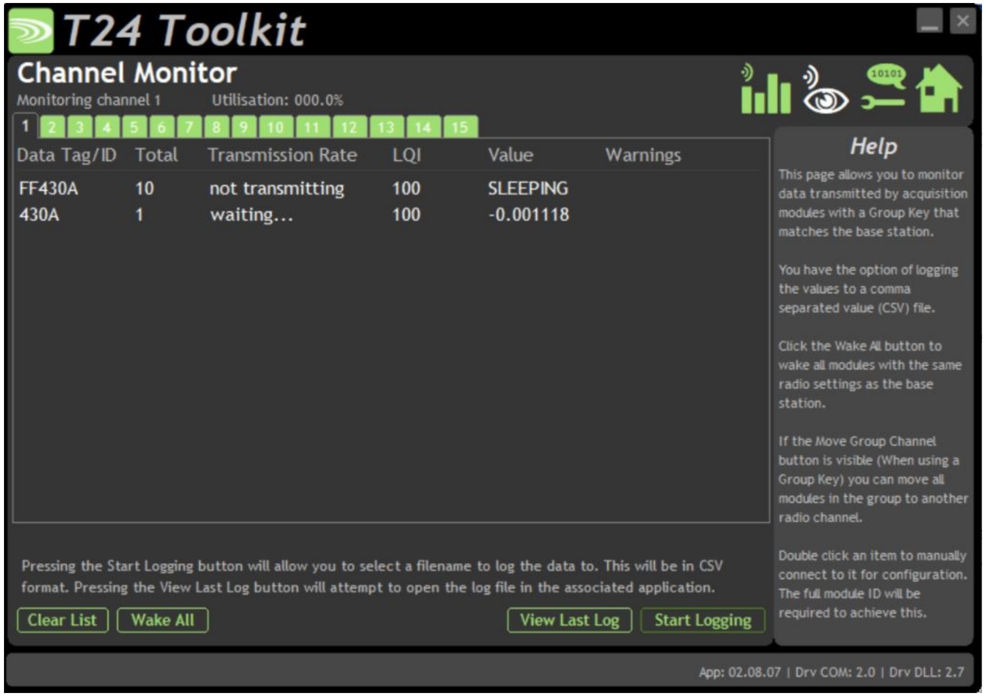
Data Transmission: Mantracourt System



- All types of sensors can be attached to the system reading voltage or current
- 600 m range in an open field site w/ license free 2.4 GHz direct sequence spread spectrum (DSSS) radio technology
- Data Encryption for complete security (128-bit AES)
- Proprietary protocol based on 802.15.4 chip allowing T24 range to co-exist with Bluetooth, Zigbee & Wi-Fi devices w/o conflicts

Data Transmission

- Blockchain coding required the data to be in readable txt format
- One transmitter can be connected to up to 15 sensors – data transmitted to a USB base station connected to a computer in .csv file
- Frequency control to save power with this platform



Example: Temperature Measurement

DataTag	ms Elapse	Value	Time Stamp		
CE3A	255	28.60511	Sunday	April 12	2020 10:56:26 AM:860
CE3A	592	28.58919	Sunday	April 12	2020 10:56:27 AM:197
CE3A	927	28.62245	Sunday	April 12	2020 10:56:27 AM:533
CE3A	1263	28.58334	Sunday	April 12	2020 10:56:27 AM:868
CE3A	1598	28.62991	Sunday	April 12	2020 10:56:28 AM:203
CE3A	1935	28.61842	Sunday	April 12	2020 10:56:28 AM:540
CE3A	2271	28.59906	Sunday	April 12	2020 10:56:28 AM:876
CE3A	2607	28.60068	Sunday	April 12	2020 10:56:29 AM:212
CE3A	2941	28.62083	Sunday	April 12	2020 10:56:29 AM:546
CE3A	3279	28.62991	Sunday	April 12	2020 10:56:29 AM:884
CE3A	3614	28.61963	Sunday	April 12	2020 10:56:30 AM:220
CE3A	3951	28.62547	Sunday	April 12	2020 10:56:30 AM:557
CE3A	4286	28.64886	Sunday	April 12	2020 10:56:30 AM:891
CE3A	4621	28.65369	Sunday	April 12	2020 10:56:31 AM:226
CE3A	4957	28.62849	Sunday	April 12	2020 10:56:31 AM:563
CE3A	5291	28.61842	Sunday	April 12	2020 10:56:31 AM:897
CE3A	5627	28.63736	Sunday	April 12	2020 10:56:32 AM:232
CE3A	5963	28.63595	Sunday	April 12	2020 10:56:32 AM:568
CE3A	6300	28.64301	Sunday	April 12	2020 10:56:32 AM:905
CE3A	6637	28.64764	Sunday	April 12	2020 10:56:33 AM:243
CE3A	6970	28.66216	Sunday	April 12	2020 10:56:33 AM:575
CE3A	7308	28.68111	Sunday	April 12	2020 10:56:33 AM:913
CE3A	7644	28.64603	Sunday	April 12	2020 10:56:34 AM:249
CE3A	7979	28.66337	Sunday	April 12	2020 10:56:34 AM:584
CE3A	8314	28.63998	Sunday	April 12	2020 10:56:34 AM:919
CE3A	8649	28.65047	Sunday	April 12	2020 10:56:35 AM:254
CE3A	8984	28.65369	Sunday	April 12	2020 10:56:35 AM:589

DataTag	ms Elapse	Value	Time Stamp		
CE3A	255	28.60511	Sunday	April 12	2020 10:56:26 AM:860
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CE3A	3614	28.61963	Sunday	April 12	2020 10:56:30 AM:220
CE3A	3951	28.62547	Sunday	April 12	2020 10:56:30 AM:557

- Snapshot of temperature data collected in a .csv file
- This data directly feeds into the smart private ledger blockchain as discussed next

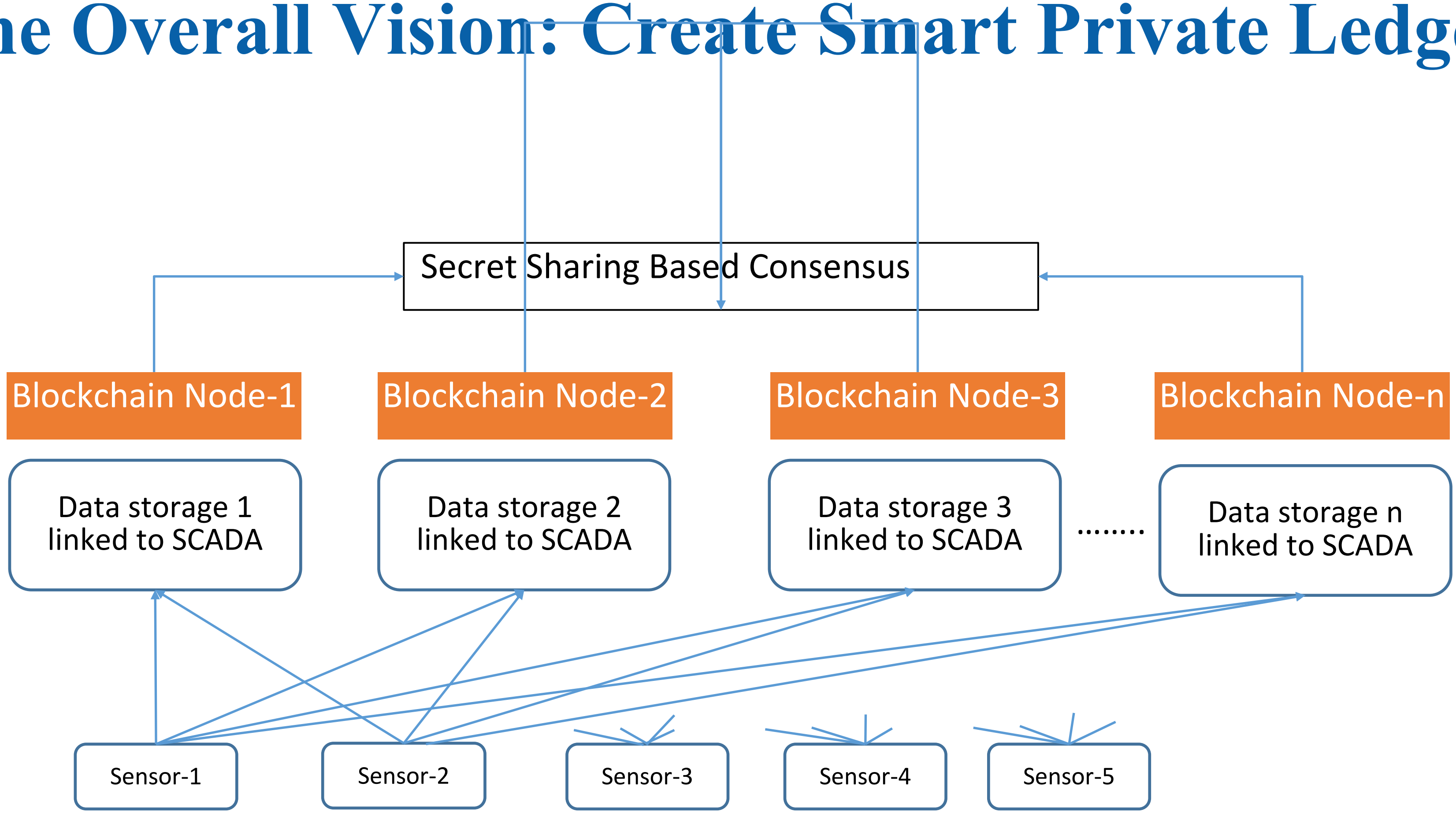
Example: Temperature Measurement

Sensor1		Sensor 2	Sensor 3	Sensor 4	Sensor 5	Sensor 6	Sensor 7	Sensor 8	Sensor 9	Sensor 10
Voltage (V)	Current (A)	Current (A)	Current (A)	Current (A)	Current (A)	Current (A)	Current (A)	Current (A)	Current (A)	Current (A)
-0.4	7.45E-14	7.47E-14	7.57E-14	8.66E-14	9.19E-14	9.46E-14	9.71E-14	9.79E-14	1.00E-13	1.00E-13
-0.39	1.11E-13	1.11E-13	1.13E-13	1.29E-13	1.37E-13	1.41E-13	1.44E-13	1.45E-13	1.49E-13	1.49E-13
-0.38	1.64E-13	1.65E-13	1.67E-13	1.91E-13	2.03E-13	2.09E-13	2.14E-13	2.16E-13	2.21E-13	2.21E-13
-0.37	2.44E-13	2.45E-13	2.48E-13	2.84E-13	3.01E-13	3.10E-13	3.18E-13	3.21E-13	3.28E-13	3.28E-13
-0.36	3.63E-13	3.64E-13	3.69E-13	4.22E-13	4.48E-13	4.61E-13	4.73E-13	4.77E-13	4.87E-13	4.88E-13
-0.35	5.39E-13	5.40E-13	5.48E-13	6.27E-13	6.65E-13	6.85E-13	7.03E-13	7.08E-13	7.24E-13	7.24E-13
-0.34	8.01E-13	8.03E-13	8.14E-13	9.31E-13	9.88E-13	1.02E-12	1.04E-12	1.05E-12	1.08E-12	1.08E-12
-0.33	1.19E-12	1.19E-12	1.21E-12	1.38E-12	1.47E-12	1.51E-12	1.55E-12	1.56E-12	1.60E-12	1.60E-12
-0.32	1.77E-12	1.77E-12	1.80E-12	2.06E-12	2.18E-12	2.25E-12	2.30E-12	2.32E-12	2.37E-12	2.38E-12
-0.31	2.63E-12	2.63E-12	2.67E-12	3.05E-12	3.24E-12	3.34E-12	3.42E-12	3.45E-12	3.53E-12	3.53E-12
-0.3	3.90E-12	3.91E-12	3.97E-12	4.54E-12	4.81E-12	4.96E-12	5.09E-12	5.13E-12	5.24E-12	5.24E-12
-0.29	5.79E-12	5.81E-12	5.89E-12	6.74E-12	7.15E-12	7.36E-12	7.56E-12	7.62E-12	7.78E-12	7.79E-12
-0.28	8.61E-12	8.63E-12	8.76E-12	1.00E-11	1.06E-11	1.09E-11	1.12E-11	1.13E-11	1.16E-11	1.16E-11
-0.27	1.28E-11	1.28E-11	1.30E-11	1.49E-11	1.58E-11	1.63E-11	1.67E-11	1.68E-11	1.72E-11	1.72E-11
-0.26	1.90E-11	1.90E-11	1.93E-11	2.21E-11	2.35E-11	2.41E-11	2.48E-11	2.50E-11	2.55E-11	2.55E-11
-0.25	2.82E-11	2.83E-11	2.87E-11	3.28E-11	3.48E-11	3.59E-11	3.68E-11	3.71E-11	3.79E-11	3.79E-11
-0.24	4.19E-11	4.20E-11	4.27E-11	4.88E-11	5.18E-11	5.33E-11	5.47E-11	5.51E-11	5.63E-11	5.64E-11
-0.23	6.23E-11	6.25E-11	6.34E-11	7.25E-11	7.69E-11	7.92E-11	8.13E-11	8.19E-11	8.36E-11	8.37E-11
-0.22	9.26E-11	9.28E-11	9.41E-11	1.08E-10	1.14E-10	1.18E-10	1.21E-10	1.22E-10	1.24E-10	1.24E-10
-0.21	1.37E-10	1.38E-10	1.40E-10	1.60E-10	1.70E-10	1.75E-10	1.79E-10	1.81E-10	1.85E-10	1.85E-10
-0.2	2.04E-10	2.05E-10	2.08E-10	2.38E-10	2.52E-10	2.60E-10	2.66E-10	2.68E-10	2.74E-10	2.74E-10

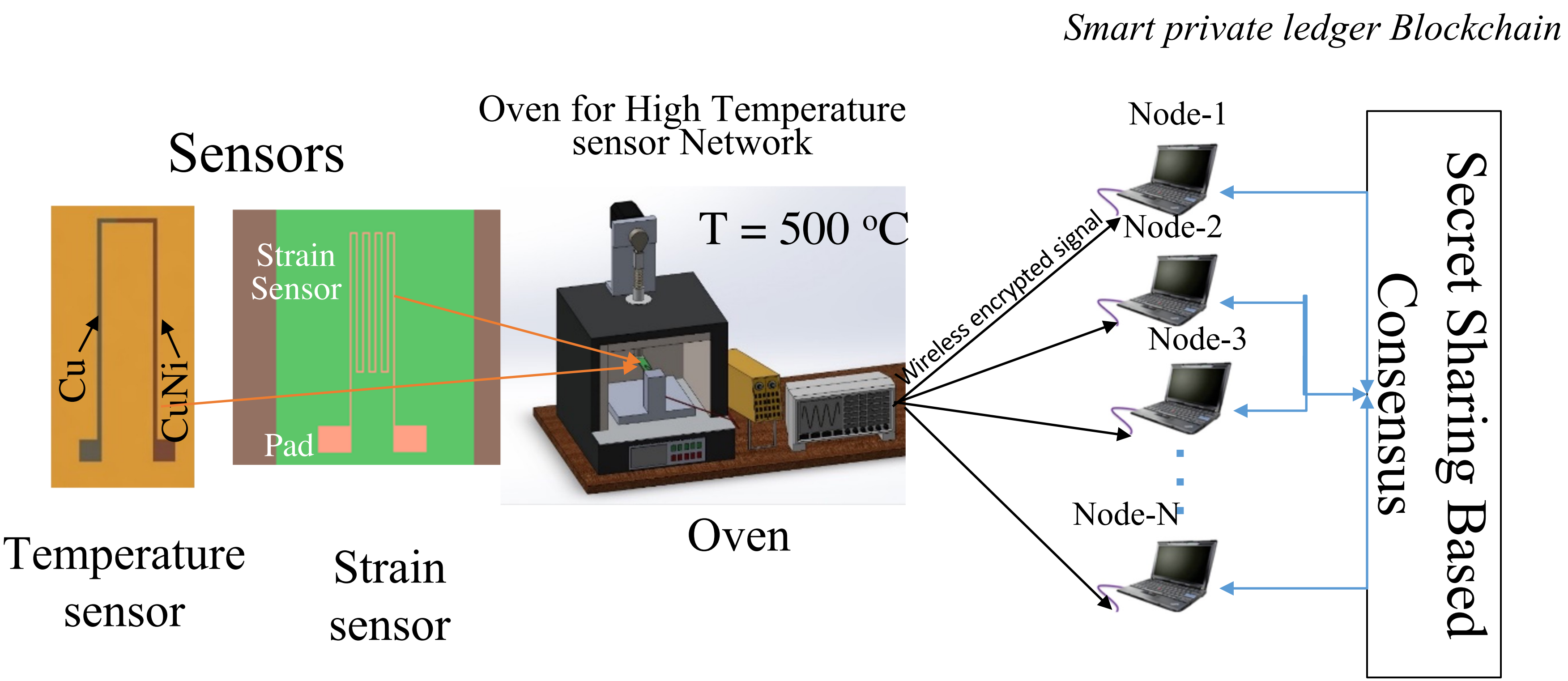
- Data collected in a .csv file
- Directly feeds into the smart private ledger blockchain as discussed next

Smart Private Ledger: Blockchains with Private Computation

The Overall Vision: Create Smart Private Ledger



Integration in Data Acquisition System



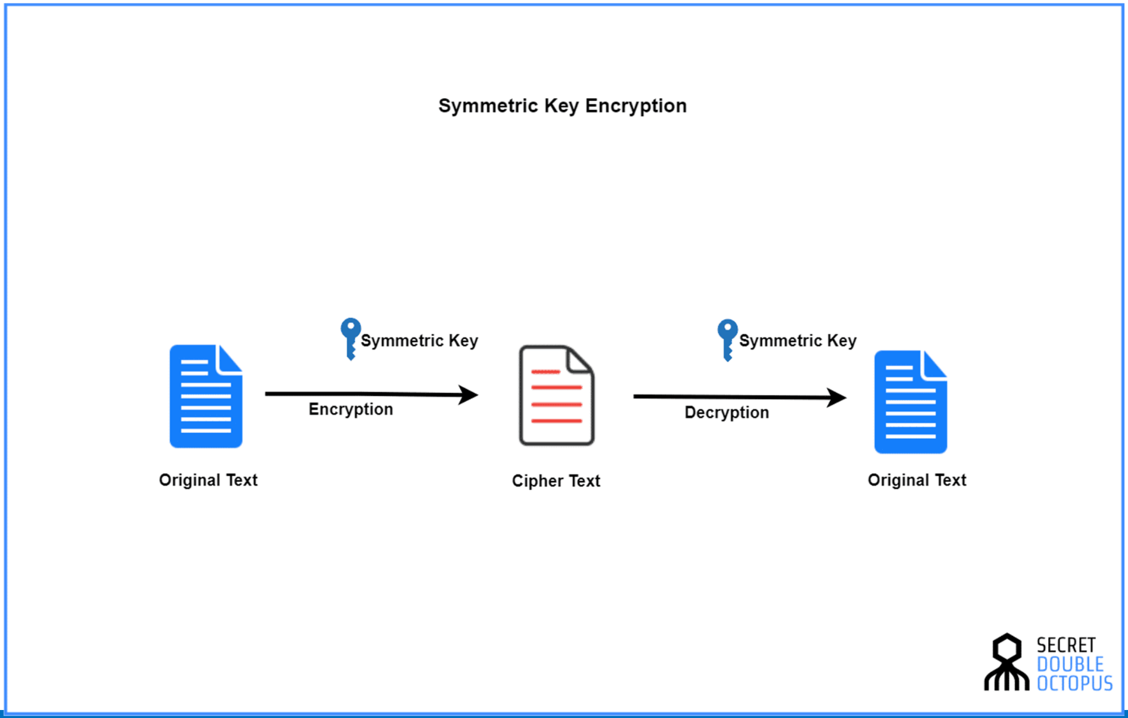
Need for Private Data

- As of today:
  - *All data on public ledger = public*
  - Private, access controlled data?
- Build an intelligent access controlled ledger
  - Different data visible to different parties
  - Even do computation on private data
  - 3rd gen Blockchain tech

Development of Smart Private Ledger

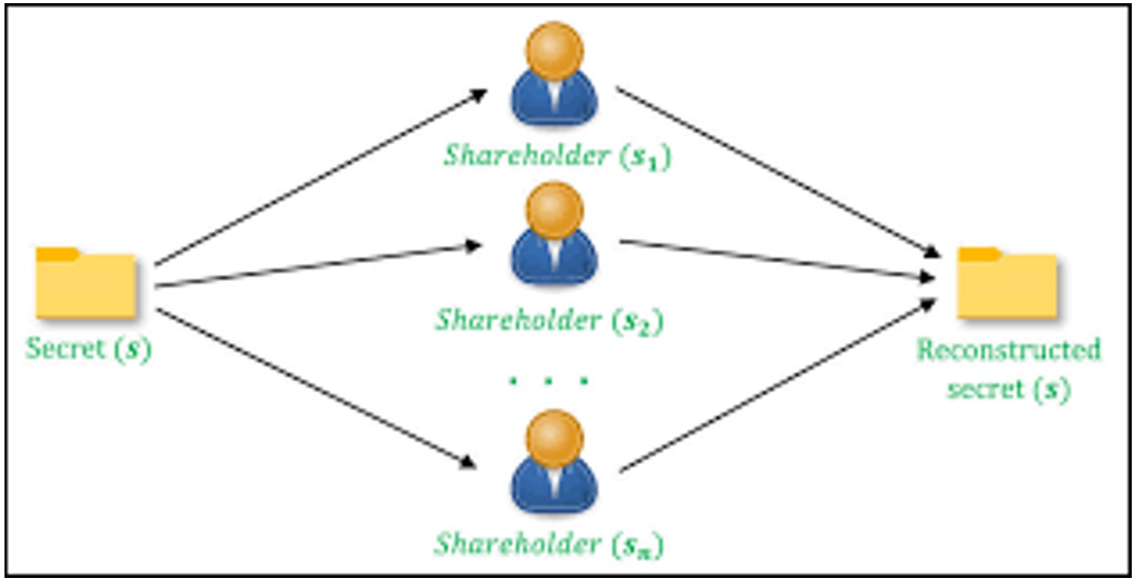
Our system flow is as follows:

- Generating secret key (for efficiency)
- Loading and encrypting csv file containing the data from sensor network (using AES)



Development of Smart Private Ledger

- Generating secret key shares
- Encrypting shares (using RSA) under miner public keys
- Later: decrypting secret key shares
- Reconstructing secret key
- Decrypting ciphertext to obtain original file containing data
- Smart contract to store/retrieve data from blockchain



System Design

- Secret sharing and file encryption is implemented to be run locally on a given miner’s machine.
- Once this data is generated, it is stored in the smart contract which is deployed on the blockchain (Ethereum).
- Any miner is then able to access the data from the smart contract, decrypt their respective shares

Loading in the CSV File

- We first load in the CSV file and convert it to byte[] form. Pictures of this are shown below:

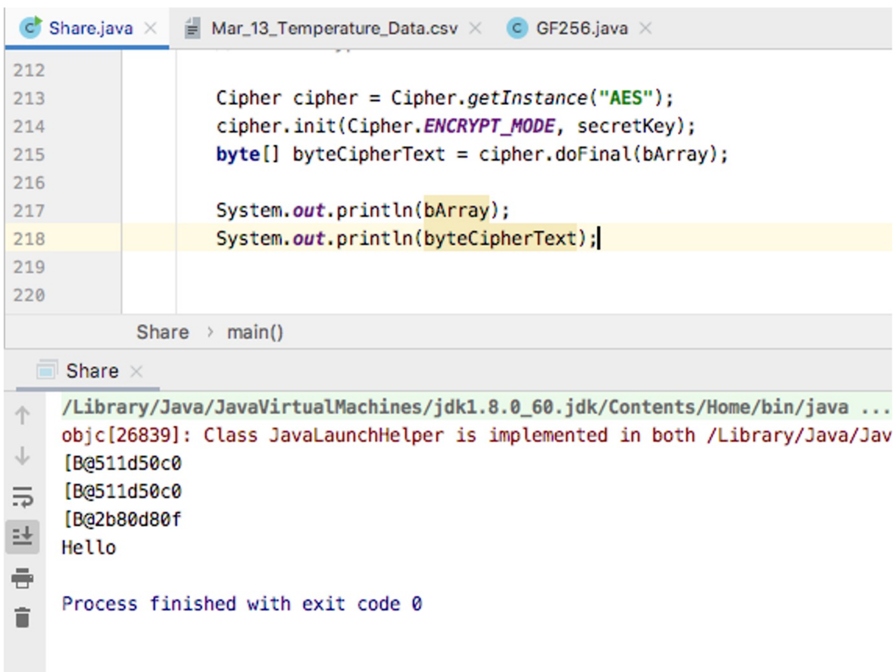
```
CE3A,10133102,127.9730,Friday, March 13, 2020 6:15:25 PM:689
CE3A,10133436,127.9682,Friday, March 13, 2020 6:15:26 PM:24
CE3A,10133771,127.9411,Friday, March 13, 2020 6:15:26 PM:359
CE3A,10134108,127.9202,Friday, March 13, 2020 6:15:26 PM:696
CE3A,10134445,127.9365,Friday, March 13, 2020 6:15:27 PM:32
CE3A,10134781,127.9551,Friday, March 13, 2020 6:15:27 PM:368
CE3A,10135118,127.9278,Friday, March 13, 2020 6:15:27 PM:705
CE3A,10135453,127.9365,Friday, March 13, 2020 6:15:28 PM:41
CE3A,10135786,127.9202,Friday, March 13, 2020 6:15:28 PM:374
CE3A,10136125,127.9411,Friday, March 13, 2020 6:15:28 PM:712
CE3A,10136460,127.9020,Friday, March 13, 2020 6:15:29 PM:47
CE3A,10136795,127.9305,Friday, March 13, 2020 6:15:29 PM:383
CE3A,10137132,127.9232,Friday, March 13, 2020 6:15:29 PM:720
CE3A,10137469,127.9051,Friday, March 13, 2020 6:15:30 PM:57
CE3A,10137804,127.8869,Friday, March 13, 2020 6:15:30 PM:391
CE3A,10138140,127.8946,Friday, March 13, 2020 6:15:30 PM:727
CE3A,10138475,127.8674,Friday, March 13, 2020 6:15:31 PM:62

[B@511d50c0
```

- Above is the CSV file, and below is the converted byte[] form. We require the file to be in this format for encryption/decryption, and will be able to convert back as shown later.

Generating the secret key

- The next step is to generate the secret key and encrypt the CSV file (converted to byte[] form) using the secret key. A picture of this code execution is shown below:
- We use the AES symmetric encryption scheme for file encryption/decryption.



The first two byte[] values are the original file (bArray), and the third is the encrypted version (byteCipherText).

Secret Sharing

- We implement a function that generates the shares and reconstructs the secret key given the shares. The shares are output as a HashMap.

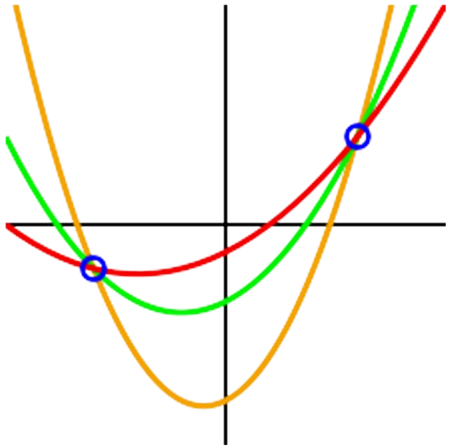
- The Dealer (person who owns the secret) does the following in order:
  1) Encrypts the data file using a generated secret key
  2) Generates the shares of the secret key using the Shamir secret sharing scheme
  3) Signs the shares so that we are able to identify dishonest miners
  4) Encrypts the shares using the corresponding miner public keys
  5) Posts the encrypted data file and shares on the blockchain (currently implemented using a smart contract).

Overview of Shamir Secret Sharing

- Mathematically, a (K,N) threshold Shamir Secret Sharing scheme is implemented using polynomial interpolation. Let the secret be S. We then construct a random polynomial, $f(x) = S + S_1x + S_2x^2 + ... + S_{K-1}x^{K-1}$ where the secret is the constant term.

- A share is defined as a tuple (i,f(i)) for some i ℤ. Note that the degree of the polynomial is K-1, it is a known result that we require k+1 points to uniquely recover a k-degree polynomial, and we require K out of the N shares to recover the secret S.

- Each participant is given a unique share (i,f(i)), done by assigning a unique i to each participant.



Overview of Shamir Secret Sharing

Given K shares, polynomial interpolation (Lagrange interpolation) is used to recover the constructed polynomial f. Let the K shares be (x_1, y_1),..., (x_K, y_K). Define the Lagrange basis functions f_j

$$f_j(x) = \prod_{m=1,\ m \neq j}^{m=K} y_j \frac{x - x_m}{x_j - x_m}$$

Then, the originally generated polynomial f is

$$f(x) = \sum_{j=1}^{K} f_j(x)$$

Overview of Shamir Secret Sharing

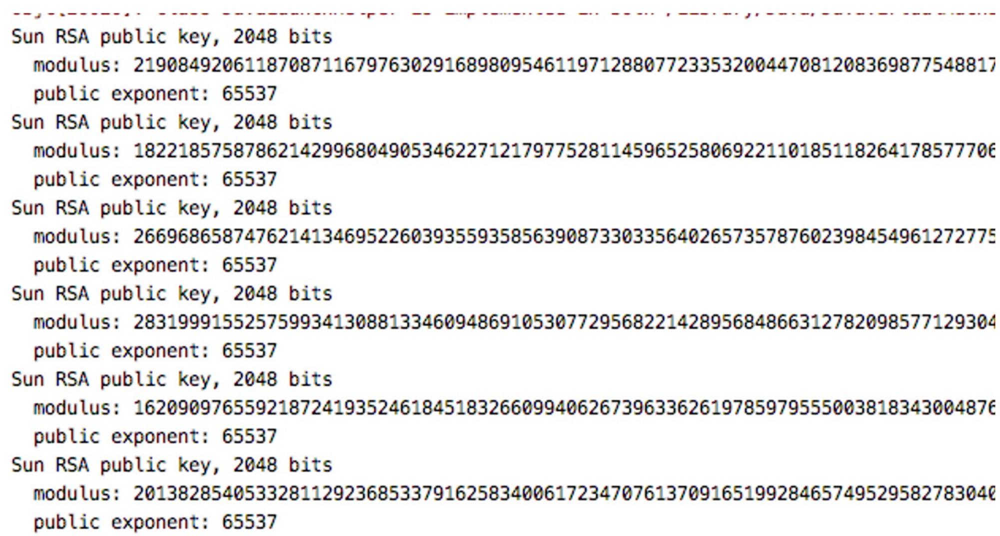
- Now that we are able to uniquely interpolate the polynomial f with the K shares, the secret is recovered as the constant term in f. Note that the dealer uses the K threshold to generate the random polynomial, which is then used to create the secret shares.
- The security of this scheme is dependent on the random generation of the sharing polynomial and that the polynomial is generated uniquely each time secret shares are created.
- The result that K shares uniquely generate a polynomial in a finite field ensures that if an adversary had access to fewer than Kshares (assume K-1 shares), then all viable values of the secret are possible and equally likely to be the constant term in the interpolated polynomial. This therefore provides the adversary with no additional information regarding the secret.

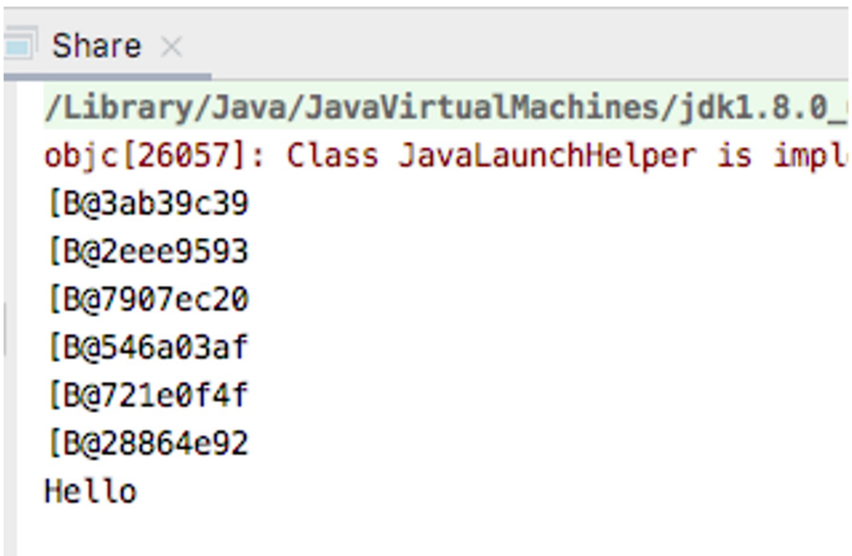
Share Generation Output

- A screenshot of the secret sharing map printed (after execution) is shown below. We map index to polynomial evaluated at that index:

Encrypting Miner shares with Public Keys

We encrypt the miner public keys using RSA encryption scheme. A screenshot of the public keys and encrypted shares when the code is executed is shown below (Where n=6):

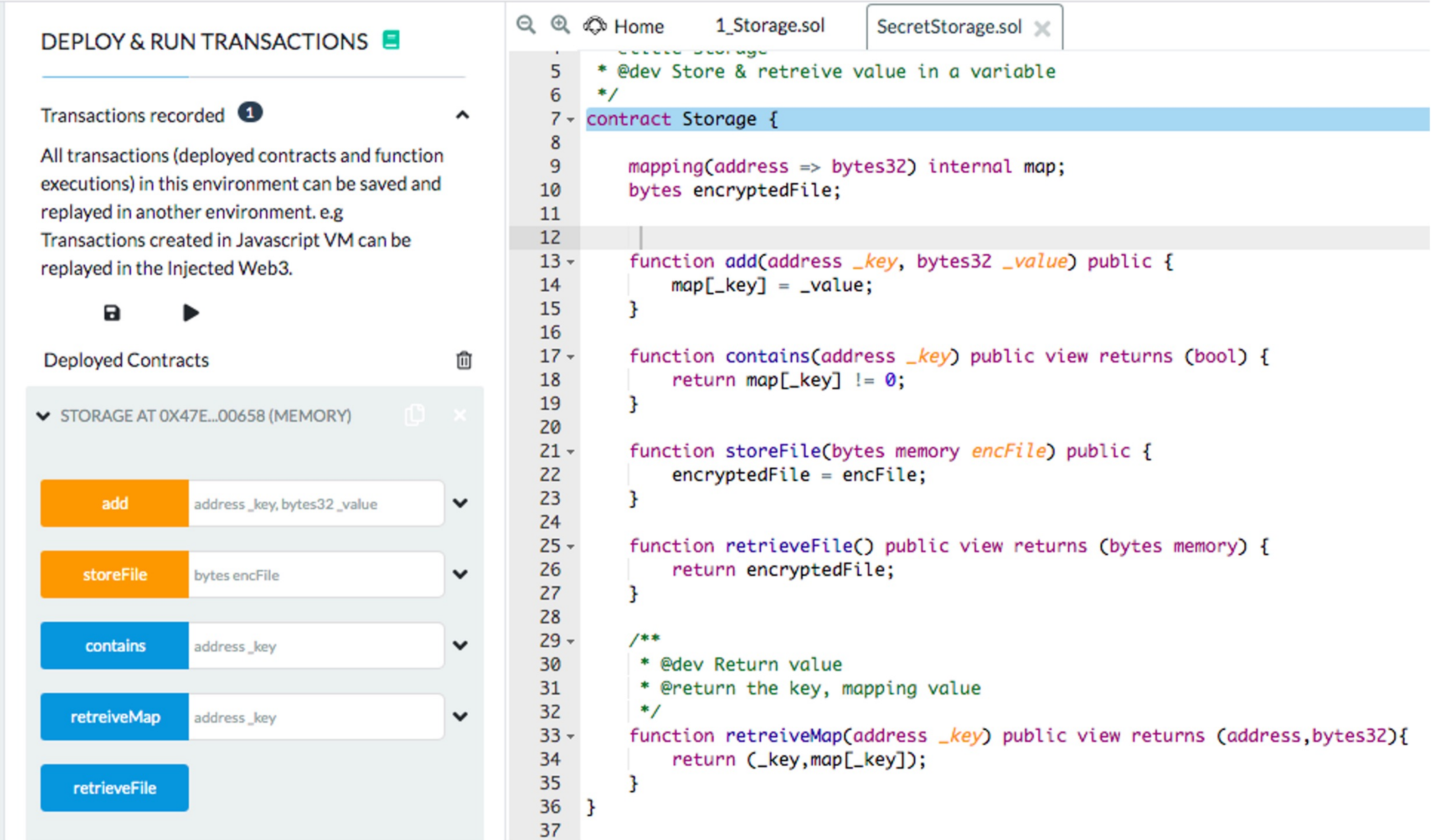




Encrypting Miner shares with Public Keys

- We create a smart contract which stores a mapping from miner address to secret key share (of type bytes) with the following functions:
  - Add a share to the map
  - Store the encrypted file
  - Retrieve the share of a given miner address
  - Check if an address is in the map

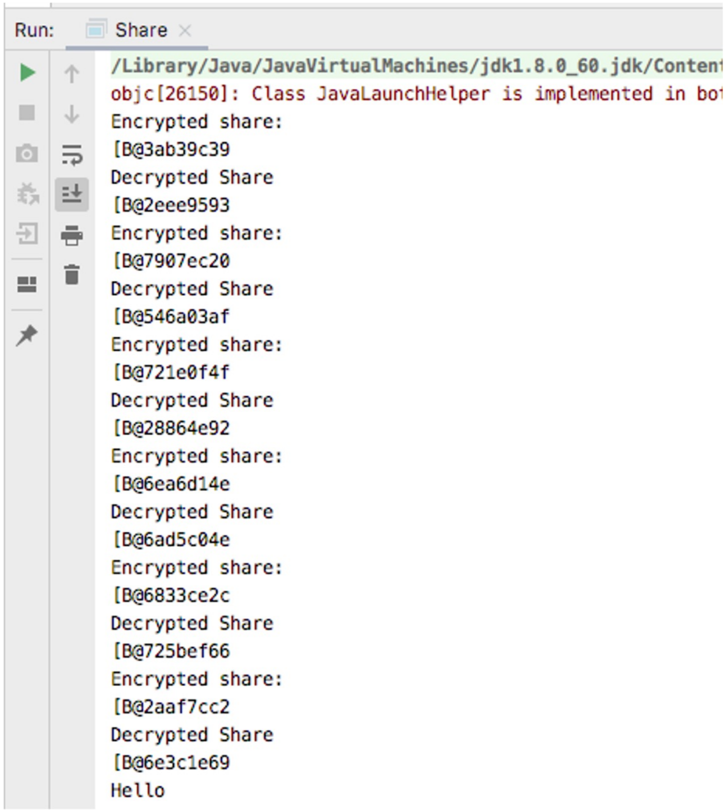
Smart Contract:



- We use the RemixIDE to test the smart contract. We are able to run these functions implemented in the smart contract using the user interface on the left of the picture.

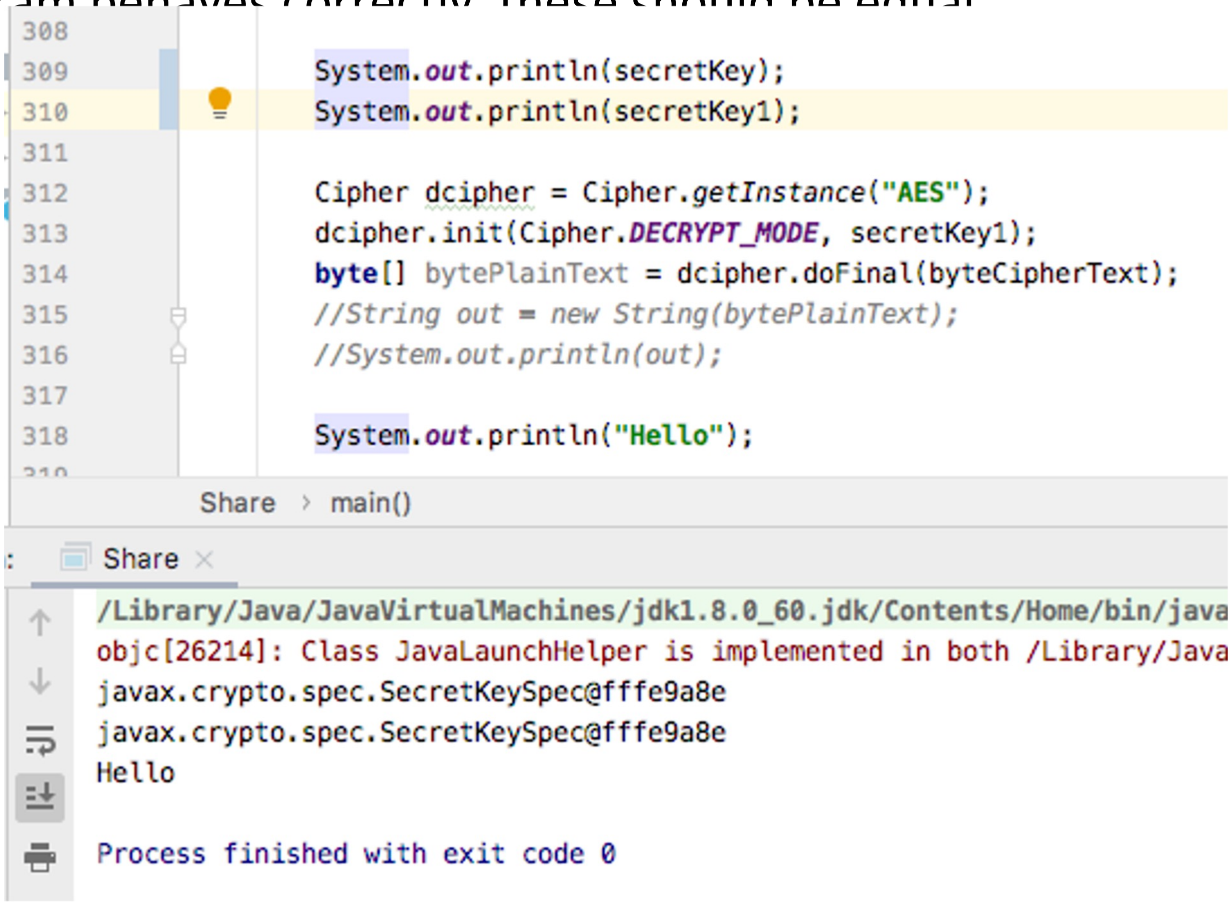
Miner Share Decryption

- Once miners take their shares from the blockchain, they are able to decrypt them using their private key. A picture of this code execution is shown below, with the encrypted share and then original share for each miner. In reality, each miner will only have to do this for their own share, but we implement for all for testing purposes.



Recovering the Secret Key

- We then use this these decrypted miner shares to recover the secret key. Proof of working program is shown below, where we first print the original secret key (secretKey) and then the reconstructed secret key (secretKey1). If the program behaves correctly, these should be equal



Decrypting ciphertext to retrieve private data

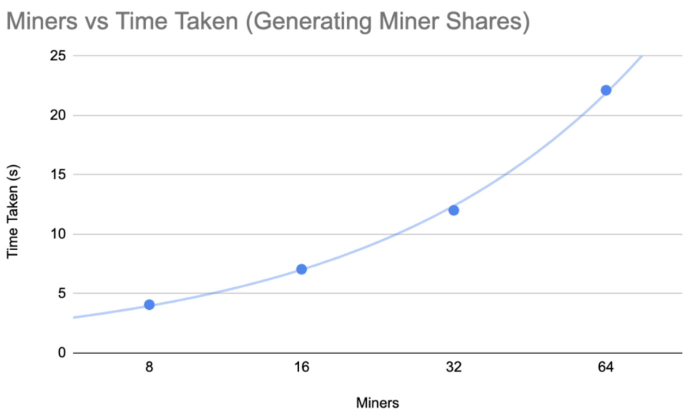
- With the secret key recovered, we are able to then decrypt the data and recover the original CSV file. A picture of the code execution is shown below. We first print the decrypted file (CSV) and then the encrypted byte[] version.

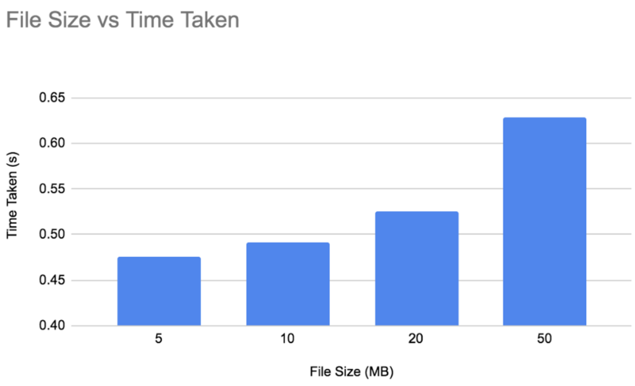
```
CE3A,10131423,127.9819,Friday, March 13, 2020 6:15:24 PM:10
CE3A,10131758,127.9863,Friday, March 13, 2020 6:15:24 PM:345
CE3A,10132096,127.9730,Friday, March 13, 2020 6:15:24 PM:683
CE3A,10132431,127.9744,Friday, March 13, 2020 6:15:25 PM:19
CE3A,10132766,127.9488,Friday, March 13, 2020 6:15:25 PM:353
CE3A,10133102,127.9730,Friday, March 13, 2020 6:15:25 PM:689
CE3A,10133436,127.9682,Friday, March 13, 2020 6:15:26 PM:24
CE3A,10133771,127.9411,Friday, March 13, 2020 6:15:26 PM:359
CE3A,10134108,127.9202,Friday, March 13, 2020 6:15:26 PM:696
CE3A,10134445,127.9365,Friday, March 13, 2020 6:15:27 PM:32
CE3A,10134781,127.9551,Friday, March 13, 2020 6:15:27 PM:368
CE3A,10135118,127.9278,Friday, March 13, 2020 6:15:27 PM:705
CE3A,10135453,127.9365,Friday, March 13, 2020 6:15:28 PM:41
CE3A,10135786,127.9202,Friday, March 13, 2020 6:15:28 PM:374
CE3A,10136125,127.9411,Friday, March 13, 2020 6:15:28 PM:712
CE3A,10136460,127.9020,Friday, March 13, 2020 6:15:29 PM:47
CE3A,10136795,127.9305,Friday, March 13, 2020 6:15:29 PM:383
CE3A,10137132,127.9232,Friday, March 13, 2020 6:15:29 PM:720
CE3A,10137469,127.9051,Friday, March 13, 2020 6:15:30 PM:57
CE3A,10137804,127.8869,Friday, March 13, 2020 6:15:30 PM:391
CE3A,10138140,127.8946,Friday, March 13, 2020 6:15:30 PM:727
CE3A,10138475,127.8674,Friday, March 13, 2020 6:15:31 PM:62

[B@2b80d80f
Hello
```

Further Completed Work

- Smart contract development with the Remix IDE
- User interface development
- Efficiency measurements





Deliverables and Timelines

Task / Subtask Number	Deliverable Title	Due Date
1.0	Project Management Plan	Update due 30 days after award. Revisions to the PMP shall be submitted as requested by the NETL Project Manager.
2.0	Sensor Networks for Fossil Power Generation System	Delivery to NETL 6 months after the start of the project.
3.0	Secure transmission of sensors to blockchain nodes	Delivery to NETL 3 months after Task-2.0, i.e., 9 months after the start of the project.
4.0	Smart Private Ledger Blockchain (codes and algorithms)	Delivery to NETL 12 months after the start of the project.
5.0	Hierarchical Access Control for Data Retrieval (codes and algorithms)	Delivery to NETL 3 months after the Task-4.0, i.e., 15 months after the start of the project
6.0	Robust Blockchain Including Necessary Modifications Ready to be Implemented in the Field	Delivery to NETL 9 months after the Task-5.0, i.e.,24 months after the start of the project

Challenges and Risks

No	Risks	Probability	Impact	Mitigation
i.	Delay in the formation of sensor networks: The PIs propose to create high temperature sensor networks at CMU by leveraging a prior NETL project on sensors and using aerosol jet printing technology. There is a risk for equipment breakdown and the sensor networks not being ready by the end of the third quarter	Low	High	1. Warranties/service agreements with the manufacturers are in place for the equipment. 2. The PIs will use individual commercial temperature sensors in case the sensor network fabrication is delayed.
ii.	Risk for wireless transmission: There is a low probability that the sensor networks cannot send the signal wirelessly to the blockchain nodes.	Low	Moderate	1. The PIs will use commercial wireless sensors (two) as a back-up to demonstrate the concept 2. Multiple suppliers are available in the market with wireless sensors and will be utilized as necessary.
iii.	Risk for formation of Blockchains: there is a small probability that the continuous stream of data coming from sensor readings will cause scalability issues in the blockchain	Low	Moderate	1. The PIs will increase the block size to handle a larger number of transactions per second 2. The number of new blocks per unit time could also be increased to improve the scalability of the system
iv.	Risk for data retrieval: there is a risk that if a number of nodes on the Blockchain go offline, the data stored could become inaccessible	Low	Moderate	1. This risk can be mitigated by increasing the number of nodes. The higher the number of nodes, the better the availability of the system would be. In any case, compared to a centralized data storage, the system will provide much higher level of anonymity.

Acknowledgements

- Mary Underwood, Robie Lewis, Dr. Vito Cedro, and Dr. Sydni Credle for help on guidance of the project

Acknowledgement and Disclaimer

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Questions?