A Distributed Framework for Resource Availability Tracking and Decision Making for Power Systems During Natural Disasters

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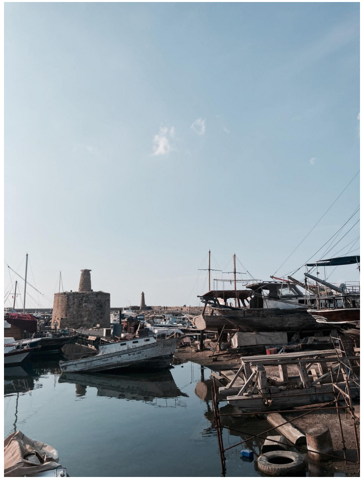
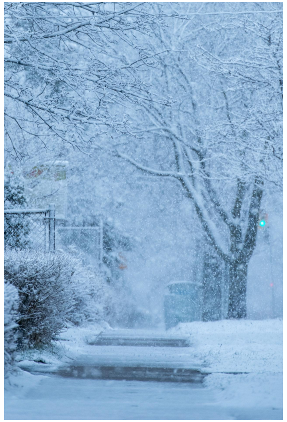
Introduction

Natural Disaster: Weather phenomena that have the potential to threaten human health and safety, property, infrastructure, and security [1].

Fires, flooding, hurricanes, snow storms





[1] U.S. Department of Energy, Infrastructure Security and Energy Restoration, Hurricanes Maria, Irma, and Harvey September 22, 2017 Afternoon Event Summary (Report 43).

Introduction (cont.)

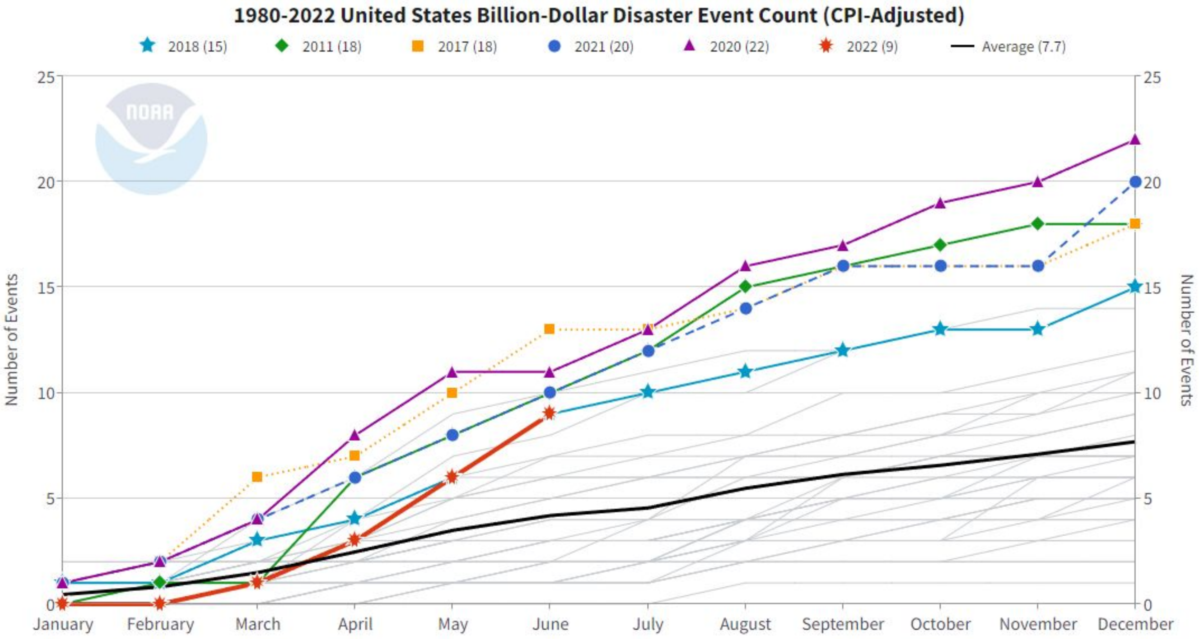
The frequency and intensity of natural disasters have been increasing which in turn increase the economic impact in the affected areas [2,3]

- From 1980 to present day there has been a total of 332 events (around 7.7 per year)
- The total cost from these events have been $2.275 trillion ($53.0 billion per year)
- During 2021 there were over 20 events and their aftermath resulted in a cost of $152.6 billion

[2] M. Coronese, F. Lamperti, K. Keller, F. Chiaromonte and A. Roventini, "Evidence for sharp increase in the economic damages of extreme natural disasters", Proceedings of the National Academy of Sciences, vol. 116, no. 43, pp. 21450-21455, 2019.

[3] NOAA, “Billion-Dollar Weather and Climate Disasters: Overview,” National Centers for Environmental Information. https://www.ncdc.noaa.gov/billions/

Introduction (cont.)



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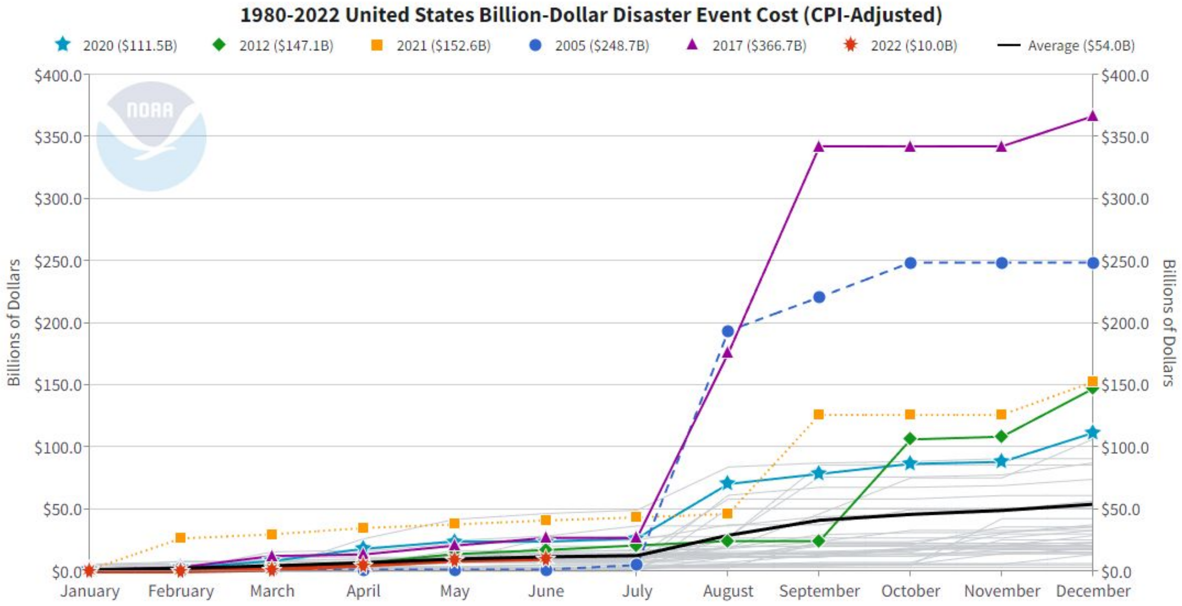
Introduction (cont.)



[from [2]]

Introduction (cont.)

When power lines are affected by natural disasters they become unstable or can be destroyed thus leading to small- or large-scale power outages which threatens the safety of people.

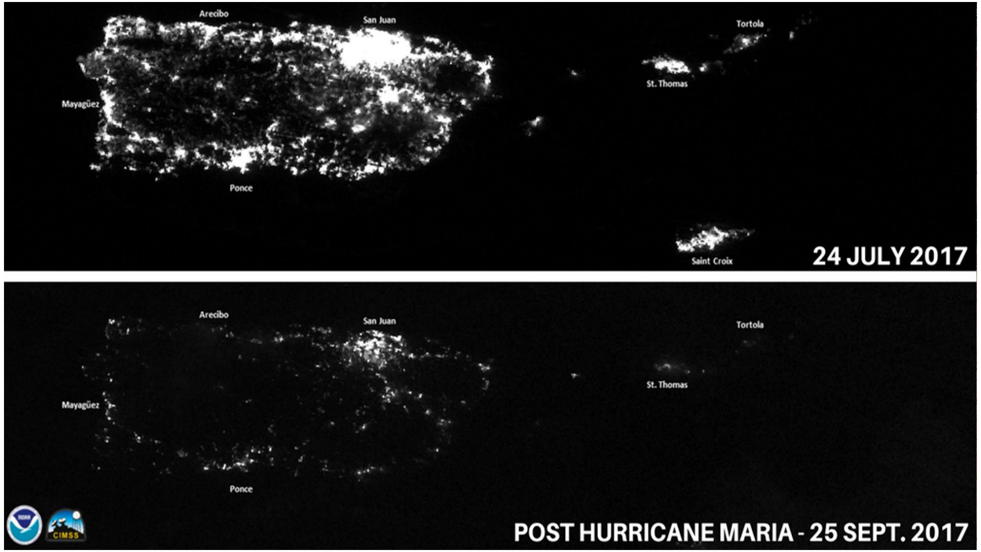
Economic losses

From [3]

Introduction (cont.)

A large-scale power outage example is when Hurricane Maria passed through Puerto Rico. During this event the electric grid went down and the island experience one of the worst power outages in the history of Puerto Rico and the US.

- 80% of the Electric Grid went down
- Took 11 month to get all the power back
- Left the electric grid vulnerable



https://edition.cnn.com/2017/10/26/us/puerto-rico-power-outage/index.html and [4-5]

Background: Electric Grids

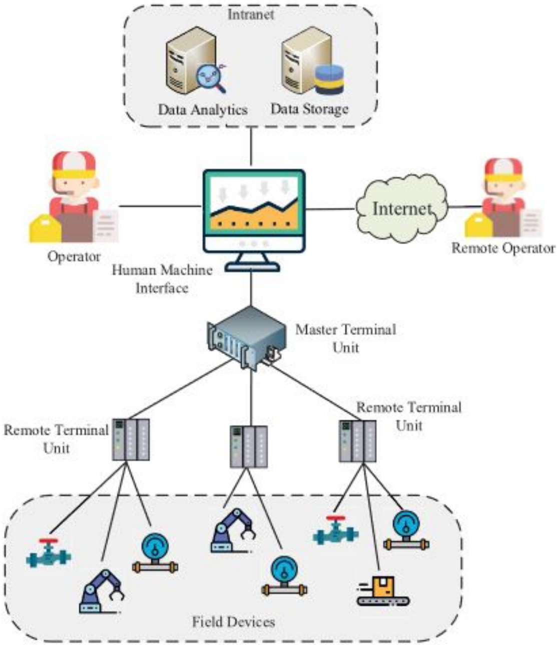
Composition of the Power Grid

- Generation: It can be one of two types: Centralized and Decentralized. Centralized being a larger scale of power generation and farther away from the user and Decentralized being closer to the to the end-user
- Transmission: Includes Transformers, substations and power lines that transport electricity from the generators towards the consumers
- Distribution: Reduces power to consumer-usable levels to every user on the grid

Background: SCADA

Supervisory Control and Data Acquisition (SCADA) systems are the backbone of monitoring and control for the infrastructure of the power grid and other critical infrastructure.

- SCADA is centralized system
- It is also used in the following infrastructure:
  - Energy Management
  - Water, Wastewater and Sewage
  - Manufacturing Industries
  - Oil and Gas Industries



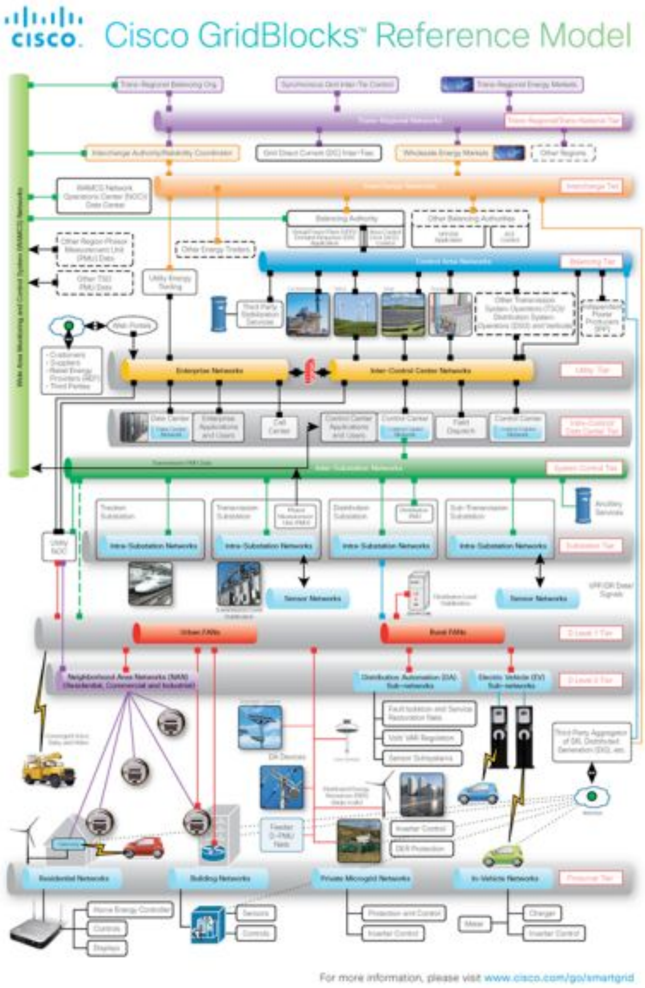
[1]

Background: Smart Grids

Smart grids are a new type of power grids in which the flow of power and information is two-way aided by the use of advanced automatic and distributed energy delivery networks.

Components in a Smart Grid:

- Electric Power Generators
- Electric Power Substations
- Transmission and Distribution Lines
- Controllers
- Smart Meters
- Collector Nodes
- Distribution and Transmission Control Centers



CISCO Smart Grid Reference Model

From: Cisco GridBlocks Architecture: A Reference for Utility Network Design, reference note C22-705941-00

Problem Statement

Due to damages to the power grid causing certain sections of the power grid to become islanded and the difficulty of maintaining track of the resources available during these events this project's main focus is on the development of the following:

- Blockchain-based decentralized resource availability tracking mechanism
- Hierarchical real-time preventive operation mechanism

Hypothesis

By giving the power grid infrastructure the following capabilities:

- Ability to sense the status of the power grid at many different levels
- Ability to make decisions in a distributed manner

It could be possible to reduce system downtime after natural disaster and improve recovery time.

Proposed Solution

- Implementation of an IoT based sensor network using blockchain technology to keep track of the grids status at different points
- ICT
    - Create a network of sensors that are able to detect faults.
    - Use of a decentralized communication protocol, which allows for the information about the grid to be uninterrupted in partial fault events.
    - Blockchain based
- Restore power after a natural phenomena by using a distributed decision making algorithm.

Design considerations

- Sensors, Endpoints and Power Systems
  - Sensing Devices
  - Power Management and Storage
- Data Communication
  - Information theory
    - Bitrate limits
    - Error rates
    - Narrowband vs wideband
  - Communication theory
    - Range and interference
  - Spectrum
  - Standards
  - Networking considerations
    - Topology, addressing modes, stack, range
- Edge Computing
  - Processors, Memory, Storage, Partitioning
  - ISA and processor characteristics
  - Abstraction level
  - Power Consumption
  - Speed
  - OS, Virtualization, Containers
  - Edge Routing and Networking
  - Edge to Cloud Protocols
- Cloud and Fog Topologies
- Data Analytics and ML
- Security and Threats
  - Attack Surface
  - Physical Security
  - Regulations
  - Blockchain

Concerns

Concerns

- What is the Data Priority?
- What is the delay required for messages?
- Can blockchain meet the speeds required for data transmission?
    - PoA vs PoW vs PoI
- What communication protocol is used in the Generation Stage?
- What happens when a Natural Disaster destroys the Wire Connections?
- How often do we need to sense and send data?
- Where will the Blockchain run?
- What hardware will be used for the Blockchain?
- Private Blockchain, Public Blockchain or Hybrid Blockchain?
    - Hybrid
- What type of consensus protocol will be used in the Blockchain?
- What kind of Blockchain Structure will be used?
    - Chain vs DAG vs GHOST
- What size will the packets that are being sent be?
- What is the best network Topology?
- Where and When should we aggregate the data?
- How should we power the sensors?

Communication Protocols

Communication Protocols: What are they?

A communication protocol can be defined as the following:

- A set of rules that describe how to transmit or exchange data across a network.

There exist multiple types of communication protocols but they can be classified into three categories:

- Wired Networks
- Wireless Networks
- Internet Communications

Communication Protocols: Currently Used

Currently in the modern power grid systems the following communication protocols are some of the currently used:

- Generation Stage: Broadband Power Line Communication (PLC), Narrowband PLC, Ethernet
- Transmission Stage: Ethernet
- Distribution Stage: Wi-Fi, 3G, 4G/LTE

Communication Protocols: Comparison

Wired vs Wireless communication:

Wired Advantages:
- Data Rate
- Power Consumption
- Reliability
- Security

Wired Disadvantages:
- Range
- Scalability
- Flexibility
- Installation Speed

Wireless Advantages:
- Range
- Scalability
- Flexibility
- Installation Speed

Wireless Disadvantages:
- Data Rate
- Power Consumption
- Reliability
- Security

Communication Protocols: Considerations

One of the most important things about the communication protocol is that it must meet the 3 ms message delay that is required in the electric power grid (IEC 61850). The following list of communication protocols are some of the ones being considered:

- DNP3 Distributed Network Protocol 3 (**DNP3**) is a set of communications protocols used between components in process automation systems.
- TCP/IP TCP/IP stands for Transmission Control Protocol/Internet Protocol and is a suite of communication protocols used to interconnect network devices on the internet.
- Ethernet Ethernet is the traditional technology for connecting devices in a wired local area network (LAN) or wide area network (WAN).
- IEC -The International Electrotechnical Commission is an international standards organization that prepares and publishes international standards for all electrical, electronic and related technologies – collectively known as "electrotechnology"
- 5G 5th generation mobile network.
- WiMax Worldwide Interoperability for Microwave Access (WiMAX) is a family of wireless broadband communication standards based on the IEEE 802.16 set of standards

Hardware and Sensing

Hardware Platform

For the project a hardware platform is needed, therefore some of the platforms that are being considered are the following:

- Raspberry Pi 4
- Arduino
- NVIDIA Jetson Nano
- FPGA
- Atmega328p

Sensing Devices

For sensing power in the electric grid and monitor the grid the technology that is being considered will be the devices called Smart Meters.

With the use of the smart meter it will be possible to measure the power that the grid has in a specific spot.

Blockchain

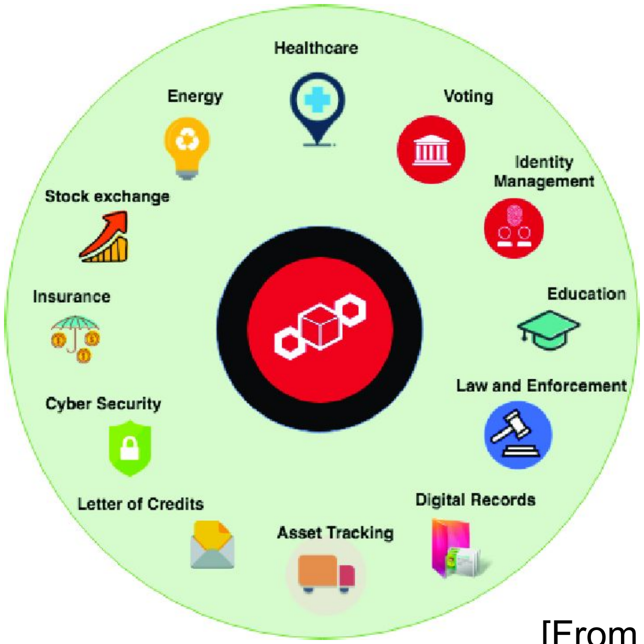
What is and Why Blockchain

What is Blockchain:

- A distributed digital ledger that stores data of any kind across a network.

Why Blockchain:

- Allows us to decentralize the distribution of information throughout the system.

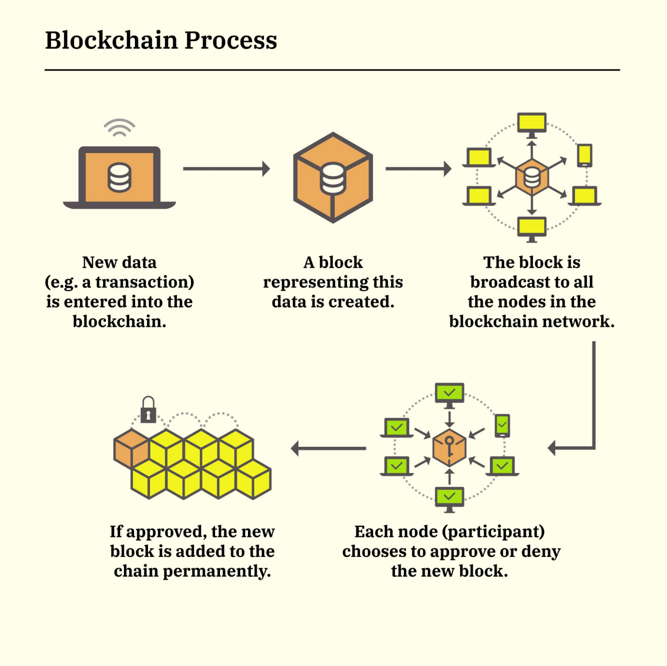


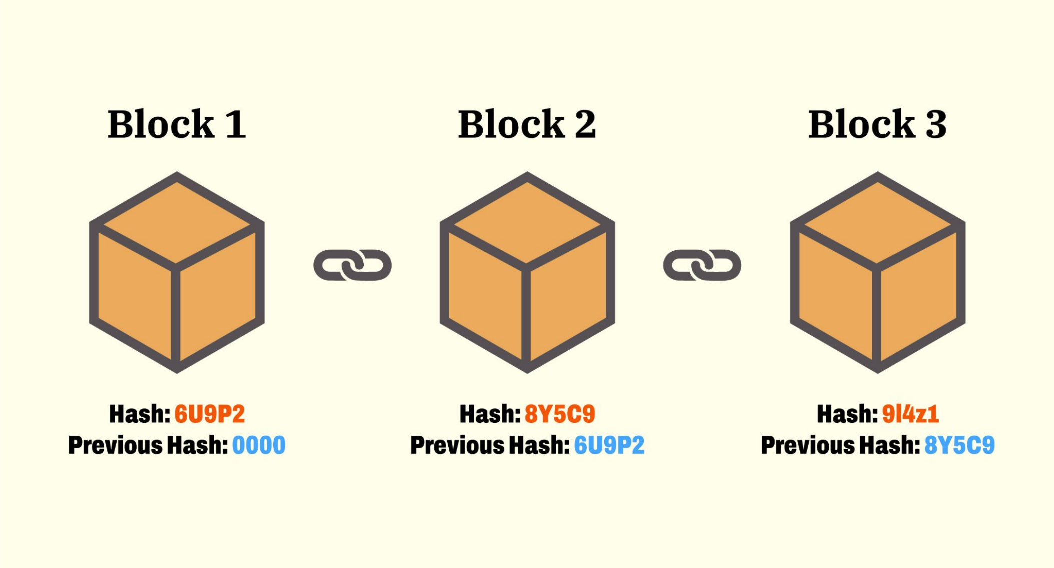
[From [6]]

Blockchain Components

- Consensus Mechanism - Fault-Tolerance Mechanism that determines if the transaction is valid or not.
- Blocks - Data Structure.
- Miners - Specific blocks that performs the block verification process.
- Transactions -
- Nodes - Users, Computers, Servers.

How Does Blockchain Works





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Blockchain Design Decisions

For the design of the Blockchain Network multiple things must be decided beforehand:

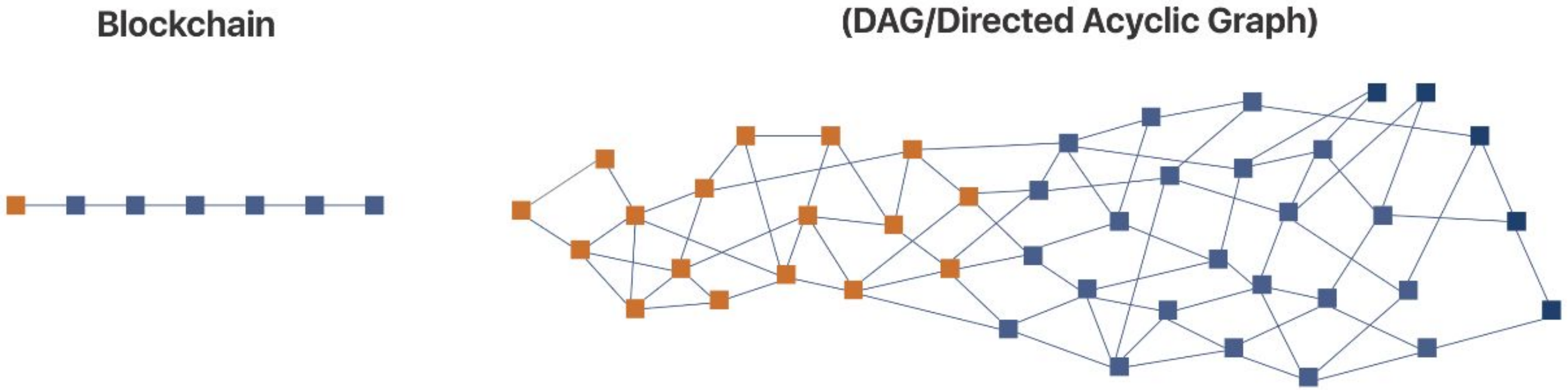
- Consensus Mechanism
- Blockchain Data Structure
- Type of network
- Blockchain Platform

Blockchain: Consensus Mechanism

To choose the consensus mechanism the following things must be considered:

Consensus Mechanism	Proof of Work	Proof of Stake	Practical Byzantine Fault Tolerance	Proof of Identity
Energy Consumption	High	Low	Very Low	
Scalability	Strong	Strong	Weak	
Block Creation Speed	Slow	Fast	Fast	
Consensus Confirmation Speed	High	High	Low	

Blockchain: Data Structure



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Blockchain: Type of Network

Blockchain networks vary between types and each of them have different capabilities:

Type of Network	Public	Hibrid	Private
Efficiency	Low	High	High
Scalability	High	Low	High
Energy Consumption	High	Low	Low
Transaction Approval Frequency	Long (10 minutes or more)	Short	Short

Blockchain: Platform

Platform	Ethereum	Hyperledger Fabric	Tendermint
Energy Consumption	High	Very Low	Very Low
Scalability	Strong	Weak	Strong
Consensus Confirmation Time	High	High	Low
Identity Management of Node	Open	Permissioned	Permissioned

Blockchain: Cybersecurity

Blockchain's security is higher than other technologies but it is still susceptible to different attacks, specially the following attacks:

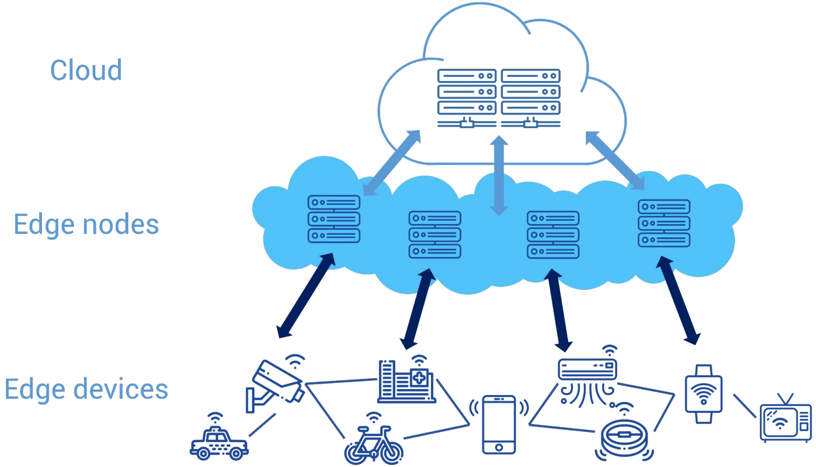
- Phishing
- Routing
- Sybil
- 51% Attacks

Edge Computing

Edge Computing

Edge Computing can be defined as the following:

- The idea of pushing applications, data and computing power to the edge of the internet, in close proximity to mobile devices, sensors, and end users.



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Edge Computing (Cont.)

For the design of the project multiple things must be considered on the area of Edge Computing. Some of the things that must be considered and explored are the following:

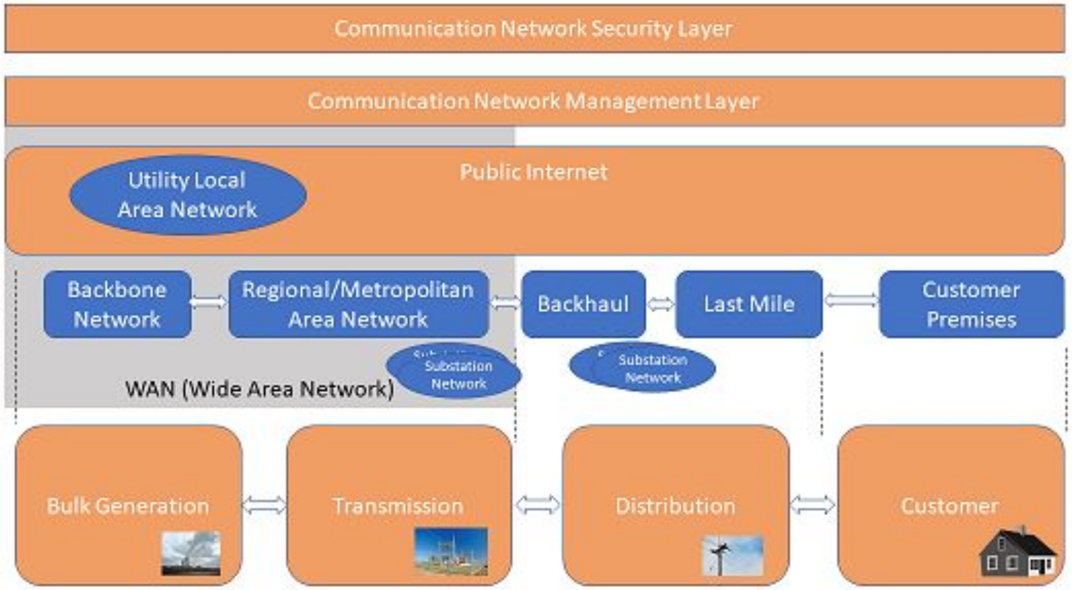
- Processors, Memory, Storage, Partitioning
- ISA and processor characteristics
- Abstraction level
- Power Consumption
- Speed
- OS, Virtualization, Containers
- Edge Routing and Networking
- Edge to Cloud Protocols

Digital Twin and Software Defined Radios

Two technologies that are going to be explored are the following:

- Digital Twins:
  - A real-time digital representation of a real-world physical system or process. This could be used to do simulations and tests.
- Software Defined Radios:
  - A radio communication system that uses software to modulate and demodulate radio signals.

Preliminary Diagram - Smart Grid



Status and Future Work

Status

- Working on Literature Review on the Communication Network, Endpoints, and Blockchain aspects of the Project.
- Design constraints report.
- Design Documentation phase.

Future

- Blockchain - proof of identity
- Interfacing with endpoints
- Networking and power considerations decisions











Acknowledgements

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Project Title: CISE-MSI: RCBP-RF: S&CC: A Distributed Framework for Resource Availability Tracking and Decision Making for Power Systems During Natural Disasters
Managing Division Abbreviation: CNS
Award Period of Performance: Start Date: 01/01/2022 End Date: 12/31/2023

- Ezequiel Mendez and Alejandro Puente

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Questions

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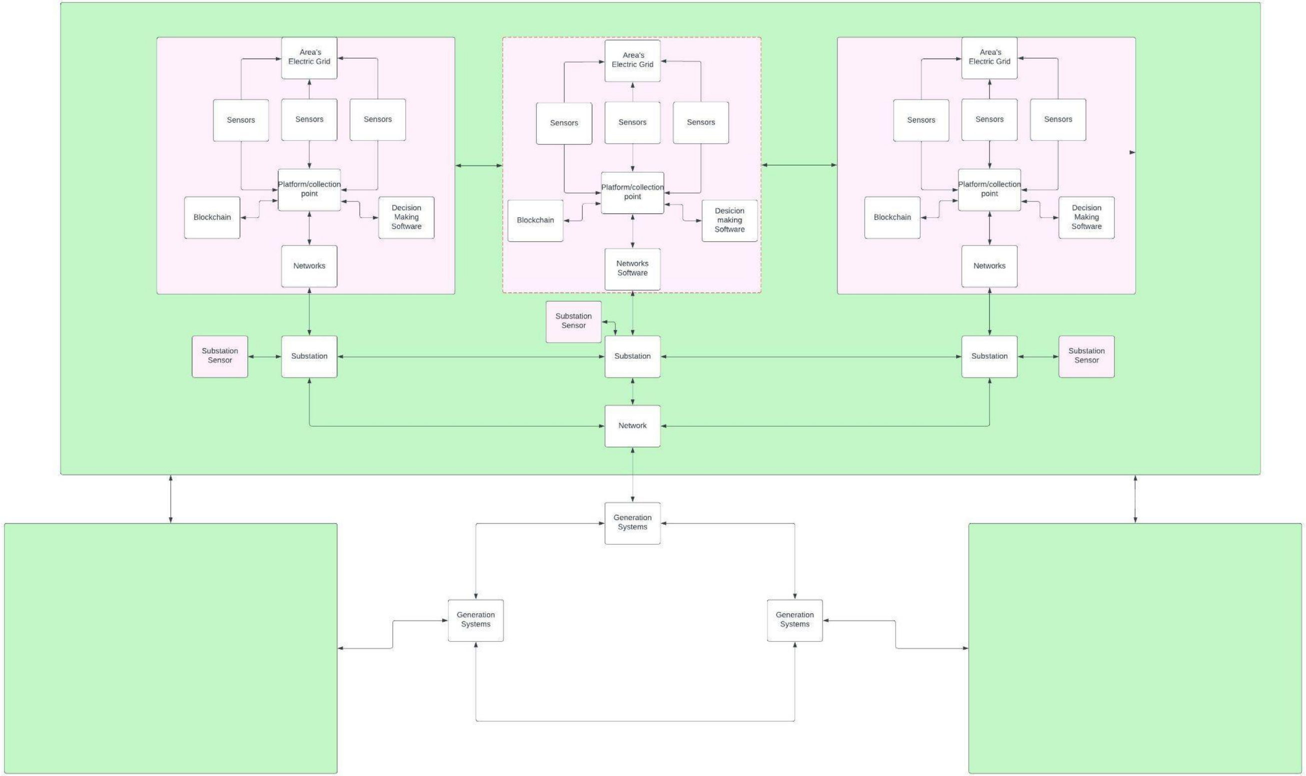
Preliminary Block Diagram



Future work & Project needs

UPRM

- Implementation Phase
  - Blockchain
    - Proof of work → Proof of Identity
  - Sensing Units
  - Network topology and protocols
  - Power considerations (of sensors)
  - Keep the current system unaltered