Privacy- and Data-Aware Smart Grid Communication

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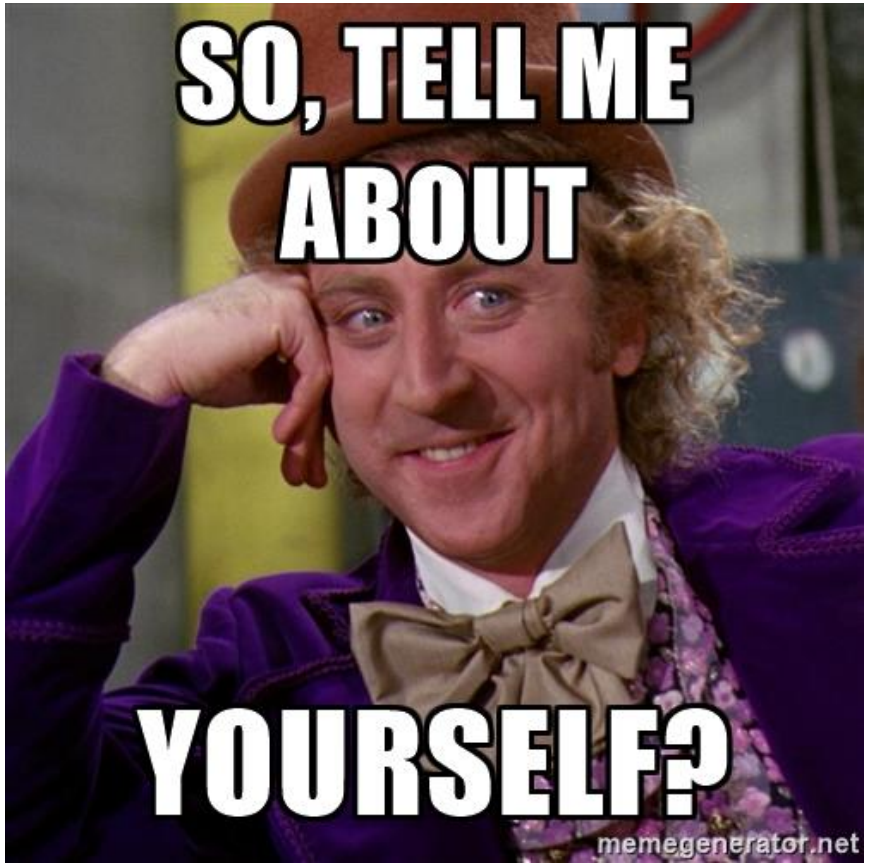
- Smart Grid security and cybersecurity education researcher
- Instructor: Principles of Computing
- Coach Southeast Collegiate Cyber Defense Competition and Collegiate Penetration Testing Competition
  - SE CCDC participant: 2014, 2015
  - Capture the Flag participant since 2012
- CyberEagles Club founder
- Mentor for undergraduate/graduate students



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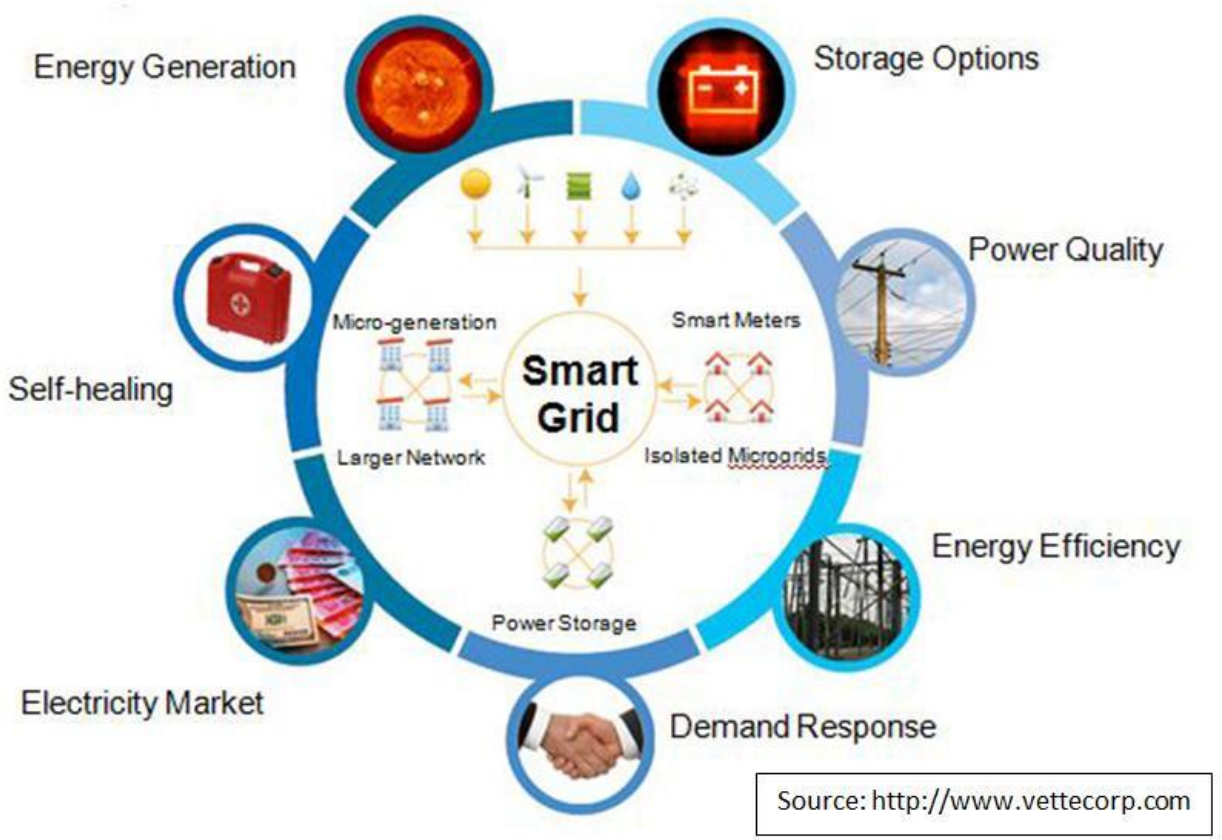
Outline

- Smart Grid
  - Advanced Metering Infrastructure (AMI)
  - Smart Meter
  - Characteristics
- Privacy and Security Issues
- Existing Solutions
- Privacy- and Data-Aware Scheme



Source: http://www.vettecorp.com

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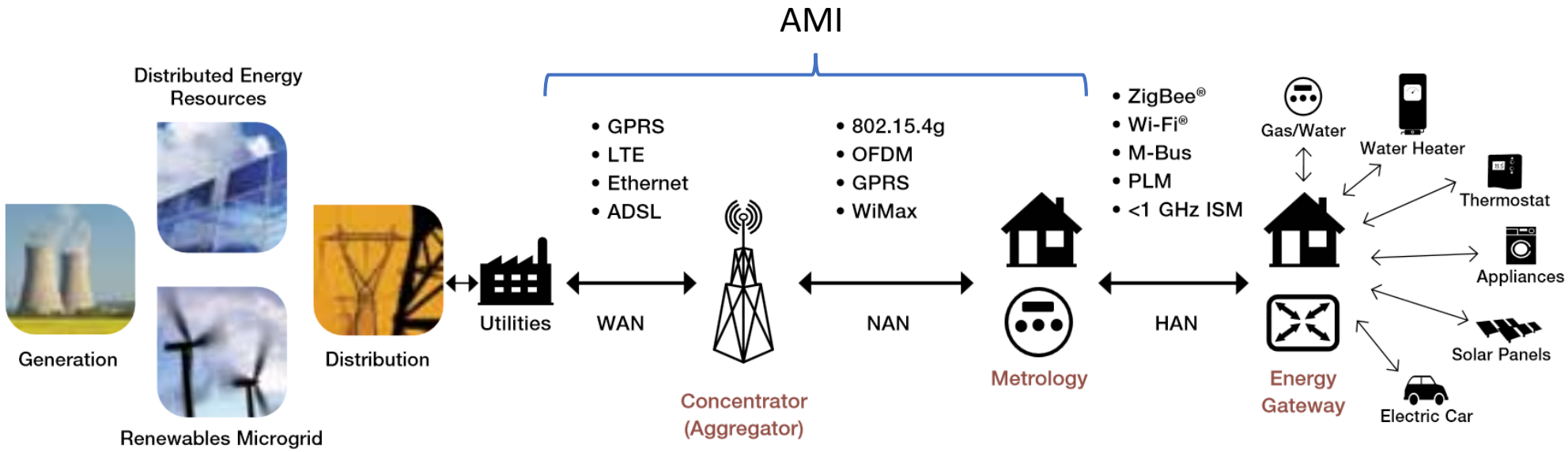
Smart Grid Network Model: Big Picture



- Smart meters receive info about appliances from the hub at the house
- Smart meters send data to the aggregator
- Aggregator forwards data to the utility company

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Advanced Metering Infrastructure (AMI)

- Meters gather data every second
- Two network models:
  - One-hop
  - Multi-hop

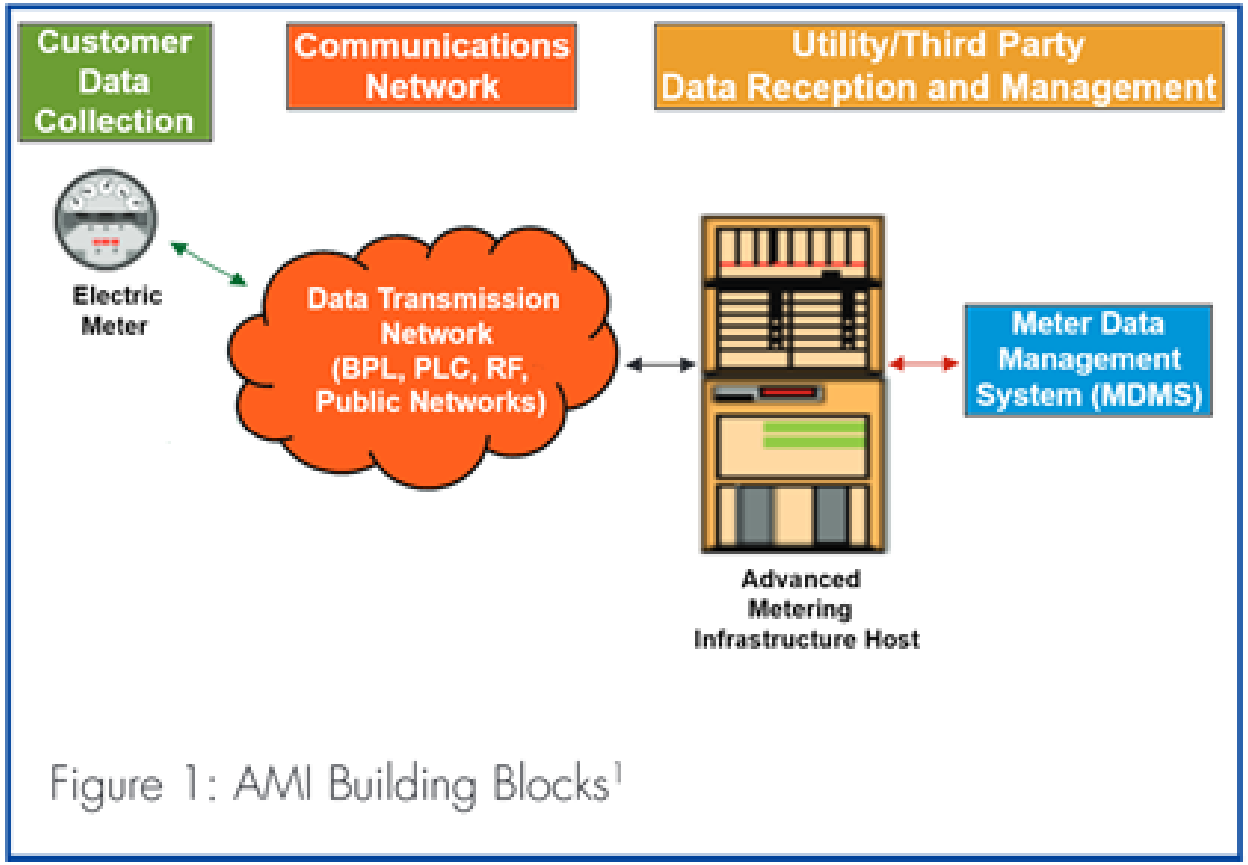

Figure 1: AMI Building Blocks[1]

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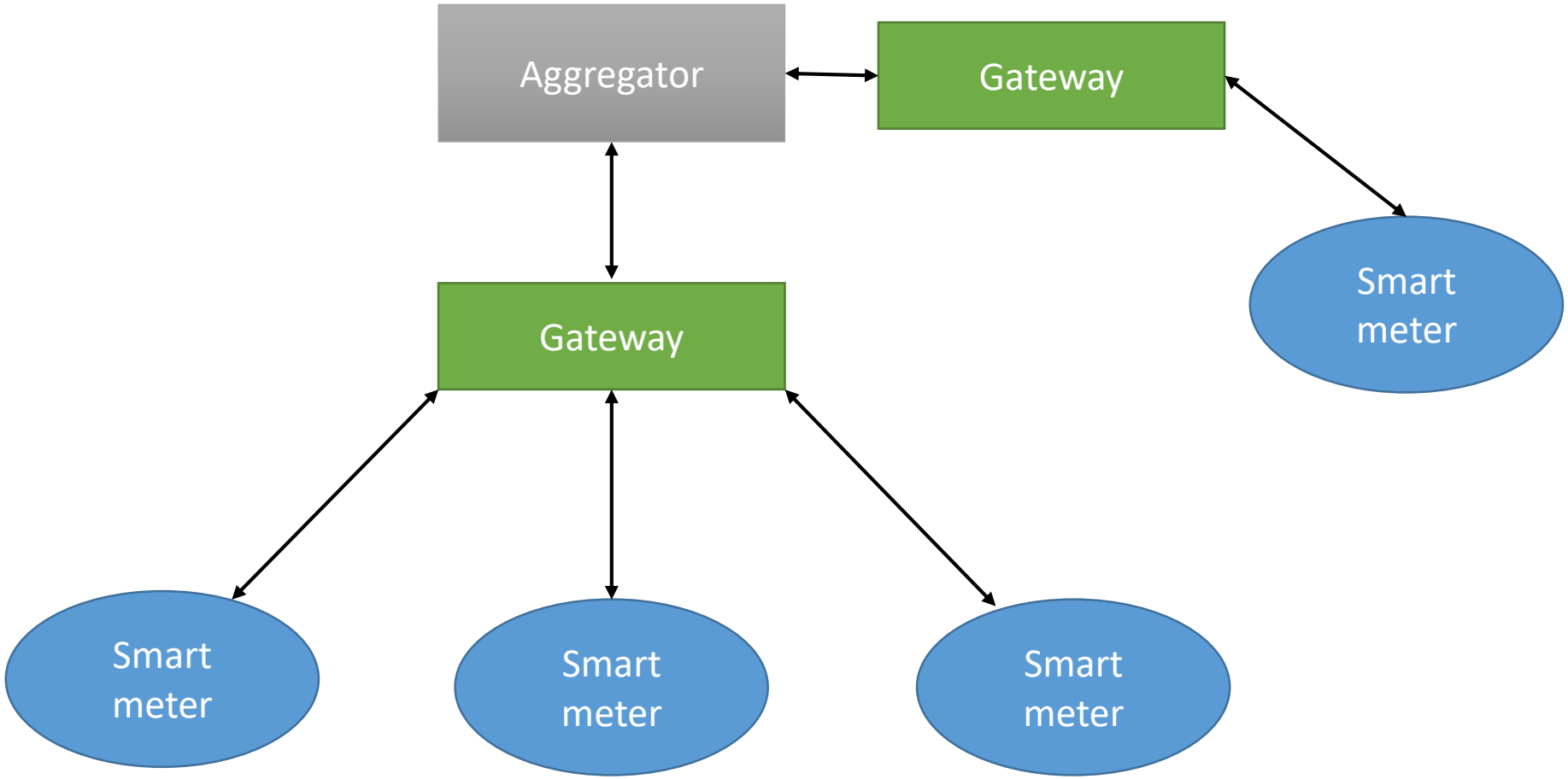
One-Hop AMI



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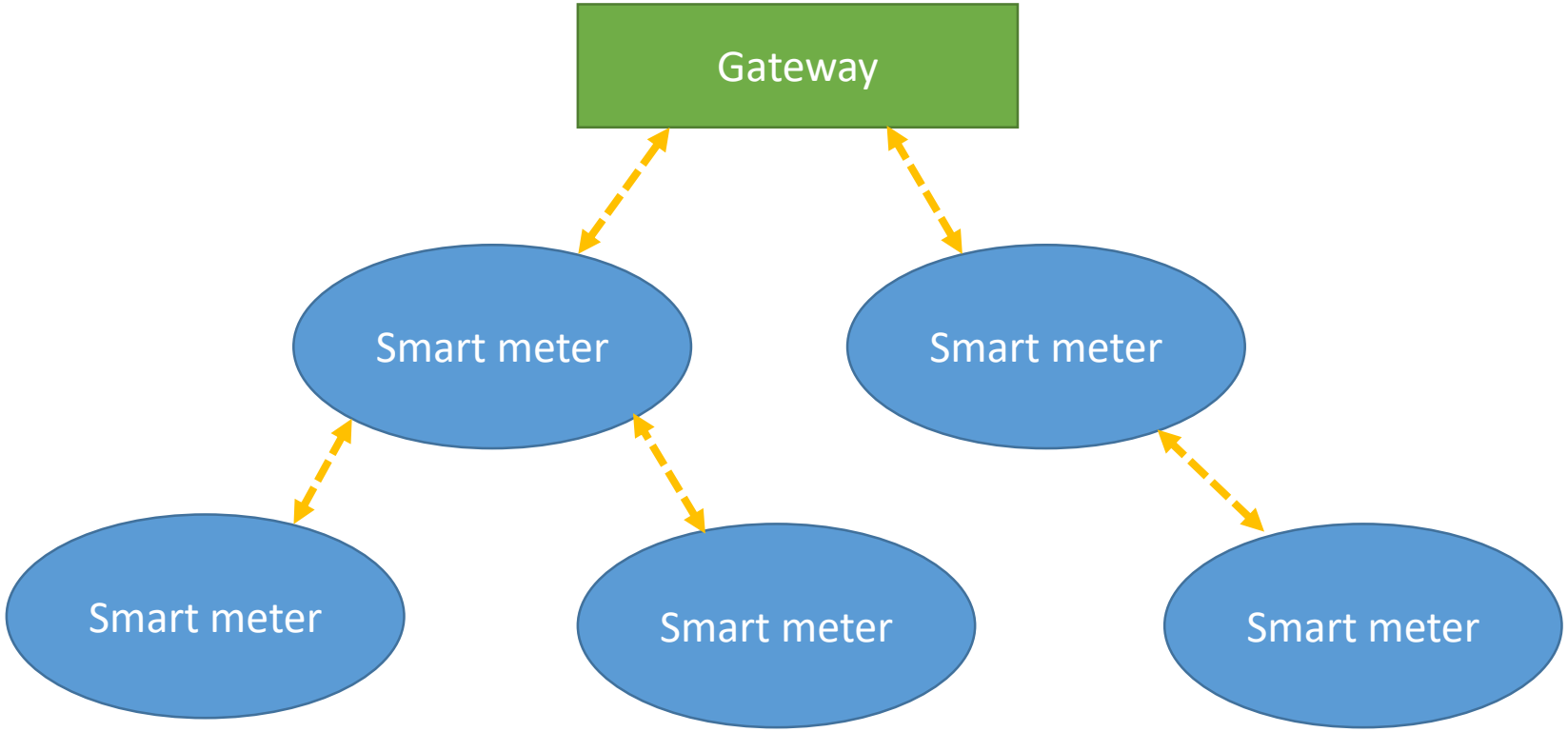
Multi-Hop AMI



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AMI Benefits

System Operation

Customer Service

Financial

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AMI Benefits: System Operation

- Increased meter reading accuracy
- Easier energy theft detection due to real-time energy consumption data
  - Providing service to 3.3 million people, $65 million was lost to fraud, 2015

https://www.sas.com/content/dam/SAS/en_us/doc/solutionbrief/utilities-detect-reduce-energy-theft-106064.pdf

- Easier outage management

  due to two-way communication

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AMI Benefits: Customer Service

- Early detection of meter failures
  - Due to two-way communication, utilities can monitor the meter status
- Variety of time-based rate options
  - Utility companies can change electricity price in real-time
  - Consumers can decrease their bills by using appliances when the cost is less
- Customer energy profiles
  - Access to energy profiles to see how we can utilize appliances more efficiently
  - Industries can detect if their big machines consume more energy due to failure

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AMI Benefits: Financial Benefits for Utilities

- Reduced equipment maintenance cost
  - Most maintenance can be done remotely
- Faster restoration and shorter outages
  - Meters and smart devices provide real-time status information and locality so that utilities can easily pinpoint the problem and resolve it

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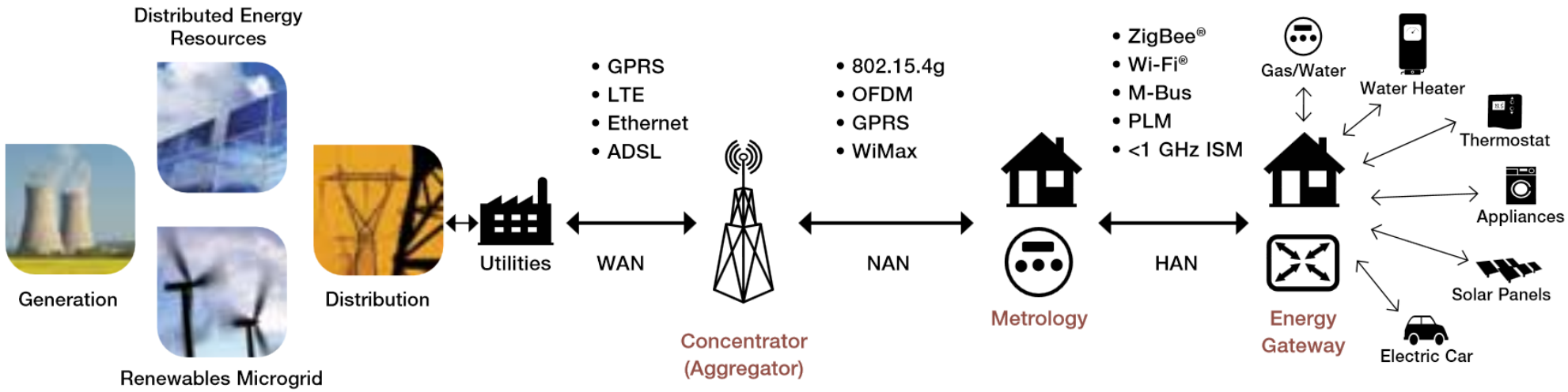

Home Area Network (HAN)

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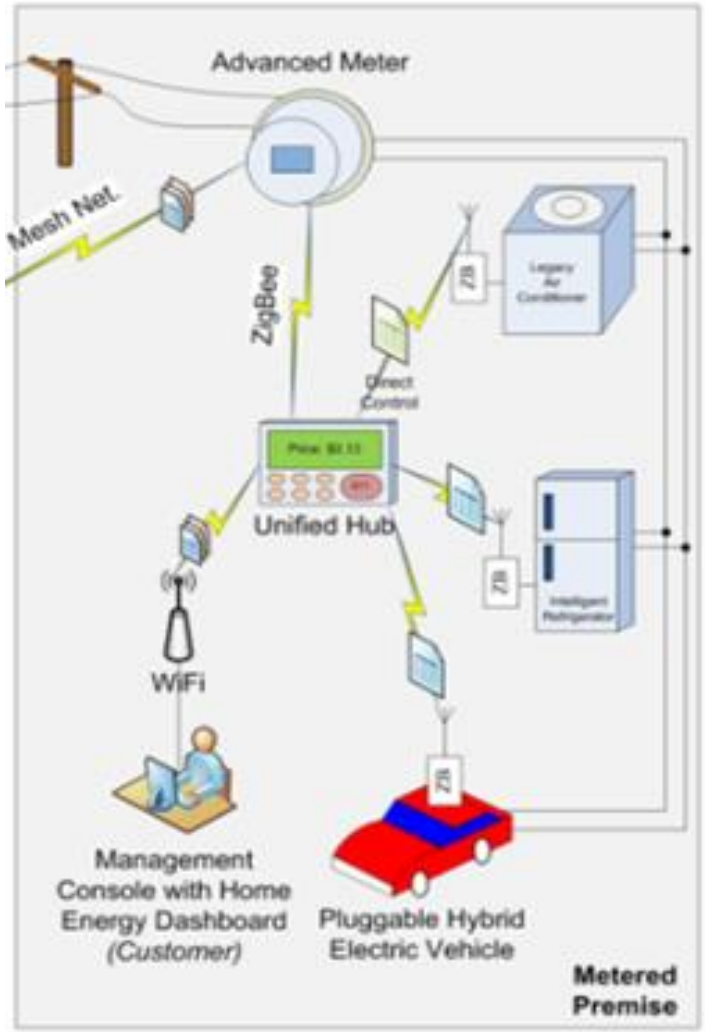
HAN Model

- A unified hub collects data from home appliances and sends to a smart meter
- Each meter reads energy consumption, connecting to a unified hub via ZigBee
- Smart meters are organized in a mesh network connected to the meter data management service
- **Example**: if utility can turn air conditioners in the whole neighborhood at the same time, then it can decrease electricity fluctuations



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Smart Meter

- Energy monitoring device
- Wireless technologies
- Two-way communication
  - Send granular data in real-time
  - Remote maintenance
  - **Real-time pricing**

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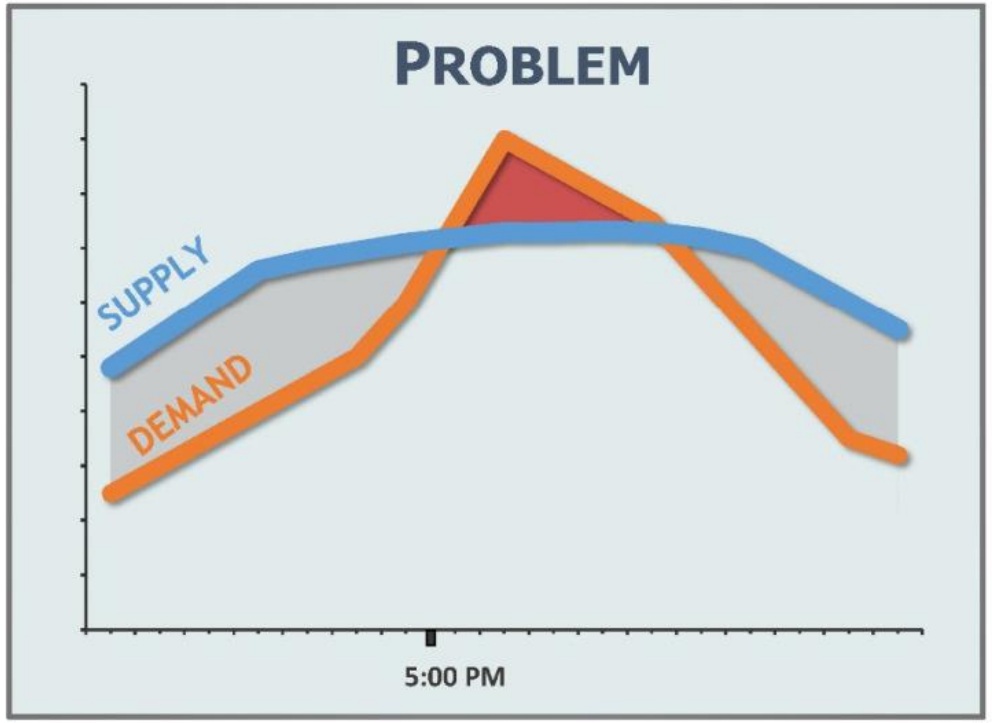
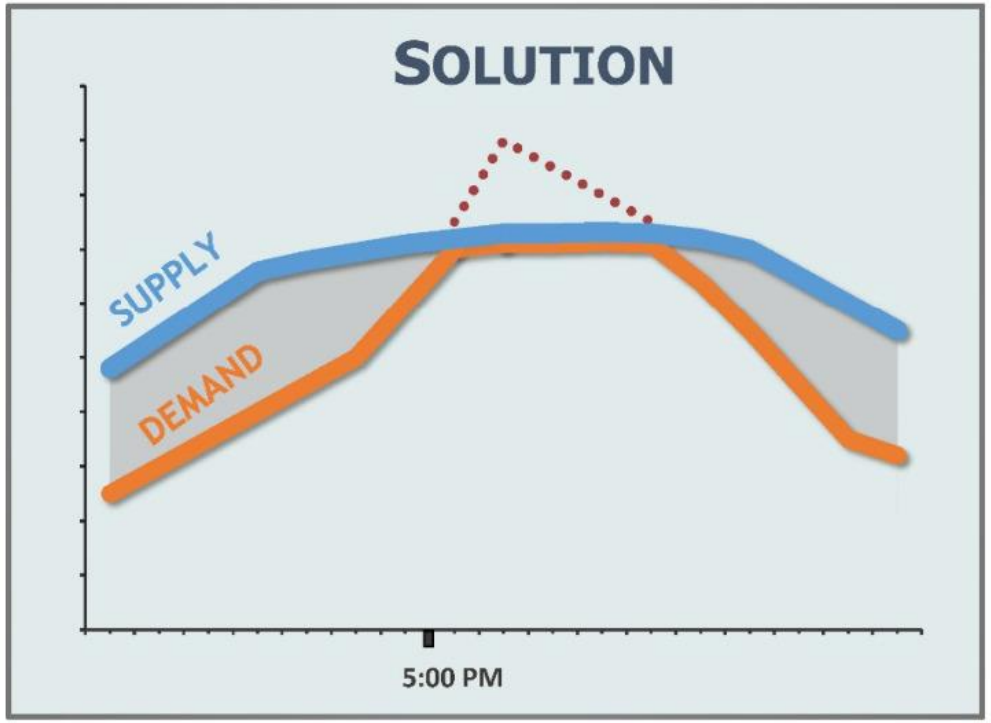
Supply-Demand Problem





https://jasmasenergy.files.wordpress.com/2016/02/demand-response-graphic.jpg?w=1620

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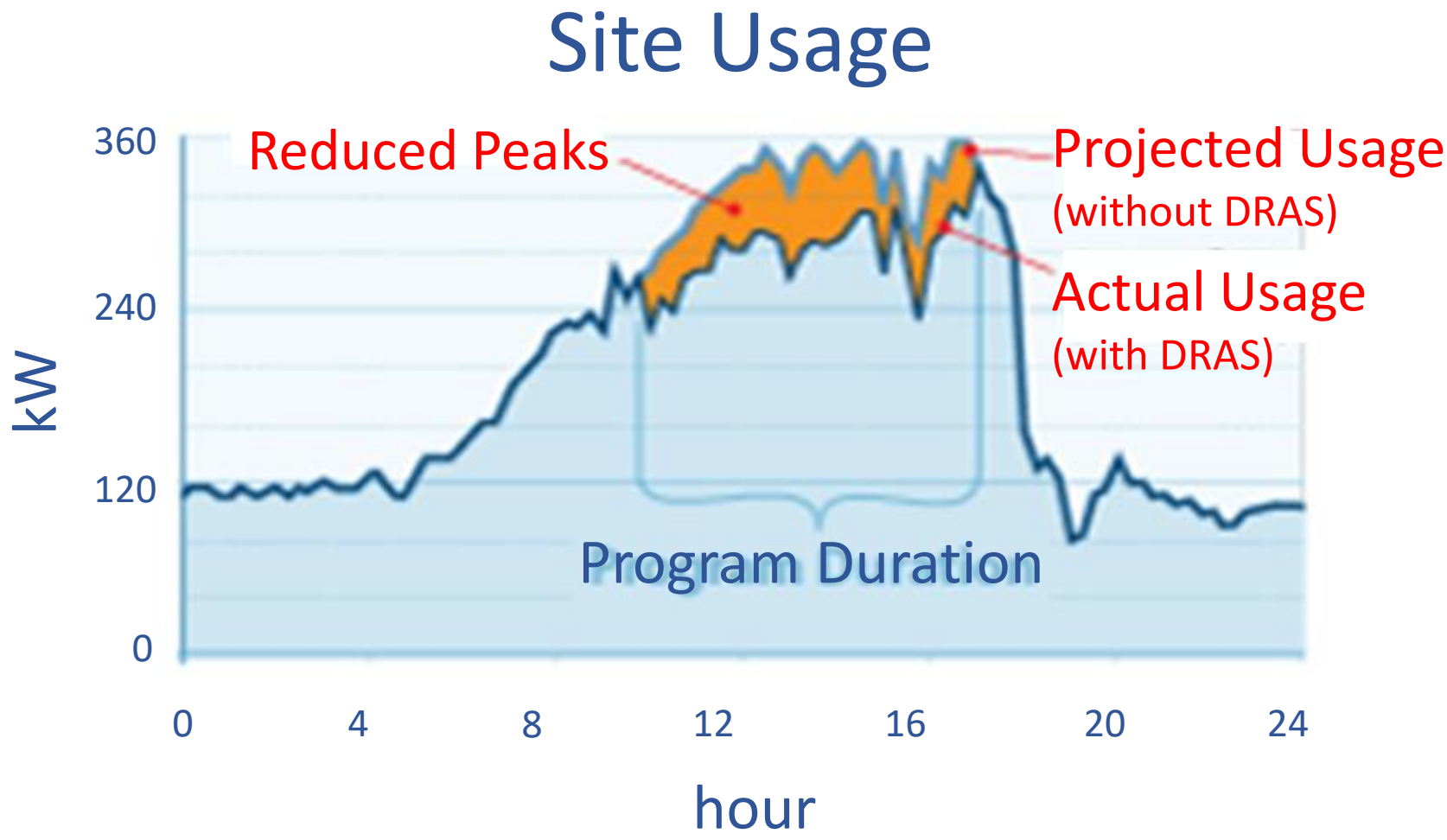
Demand-Response



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Demand-Response Outlook (cont.)

- Direct load control
  - Allows utilities to turn specific appliances on and off during peak demand periods and critical events
  - Load management saves money for both utilities and customers by reducing the need for the generation capacity and minimizing the amount of energy a utility must purchase on the open market at peak demand periods

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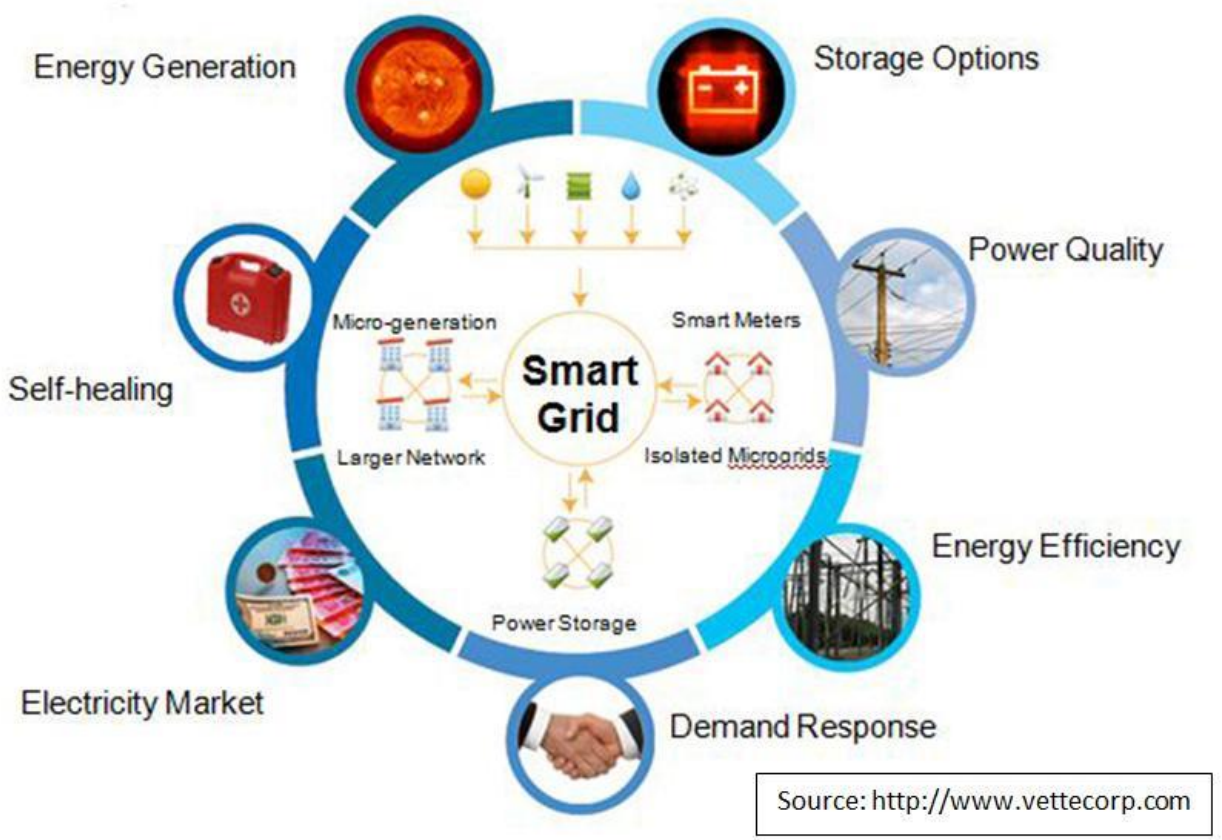

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Security Issues

- Denial of Service Attacks
- False-data Injections
- Man-in-the-middle Attacks
- Energy Fraud Attacks
- Authentication Attacks
- Disaggregation Attacks

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Consumer Privacy Violation

- Burglary preparation
- Targeted advertising
- Stalkers may exploit the data to discover victim’s home occupancy
- Risk assessment for insurance companies
- Parents “spying” on their children
- Landlords may determine if tenants violate the renting agreement
- Law enforcement agencies to discover illegal activities
- Businesses may analyze their competitors
- An employer can learn sleeping and eating habits of their employees

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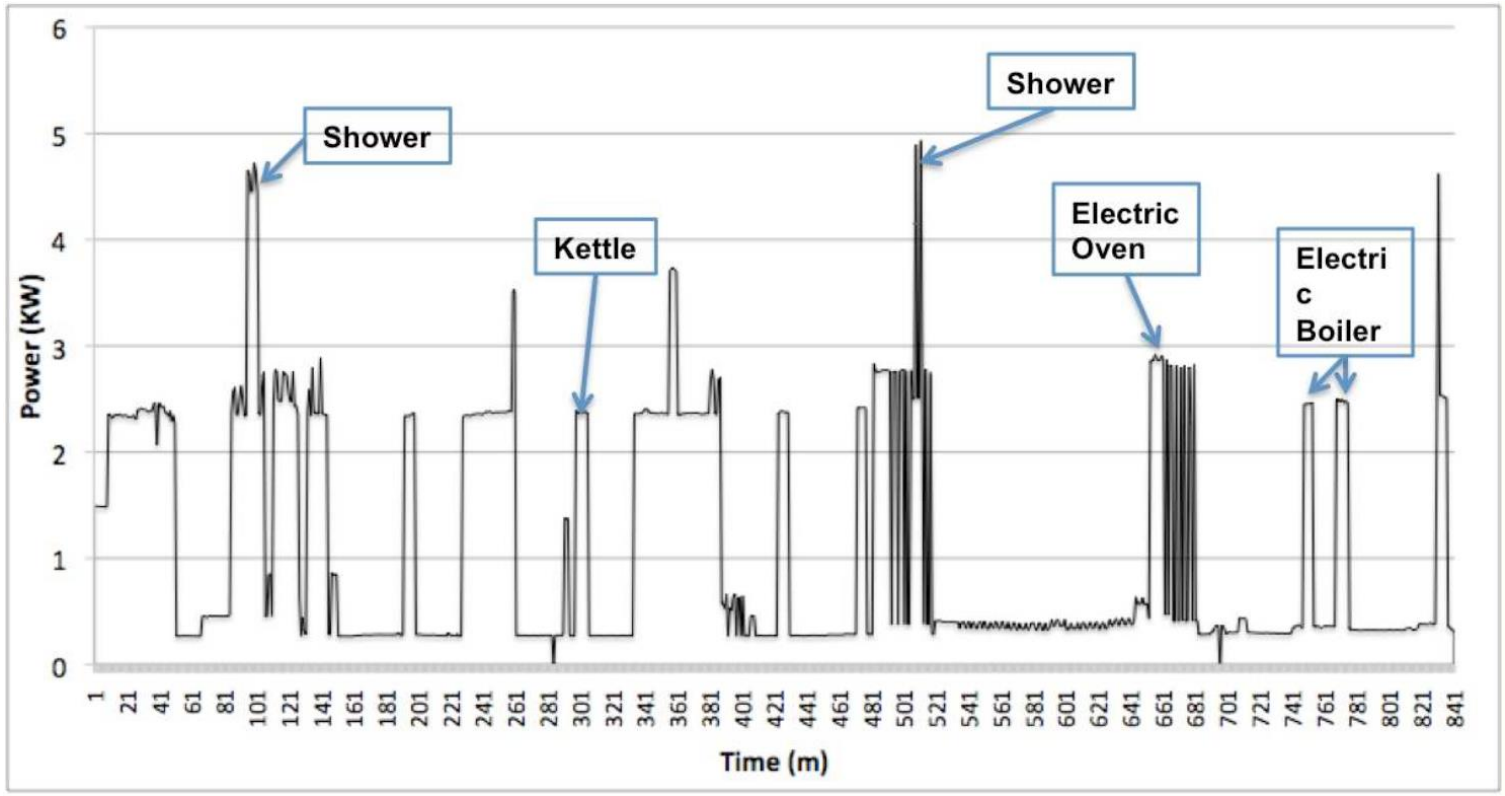
Profiling Consumer Energy Consumption



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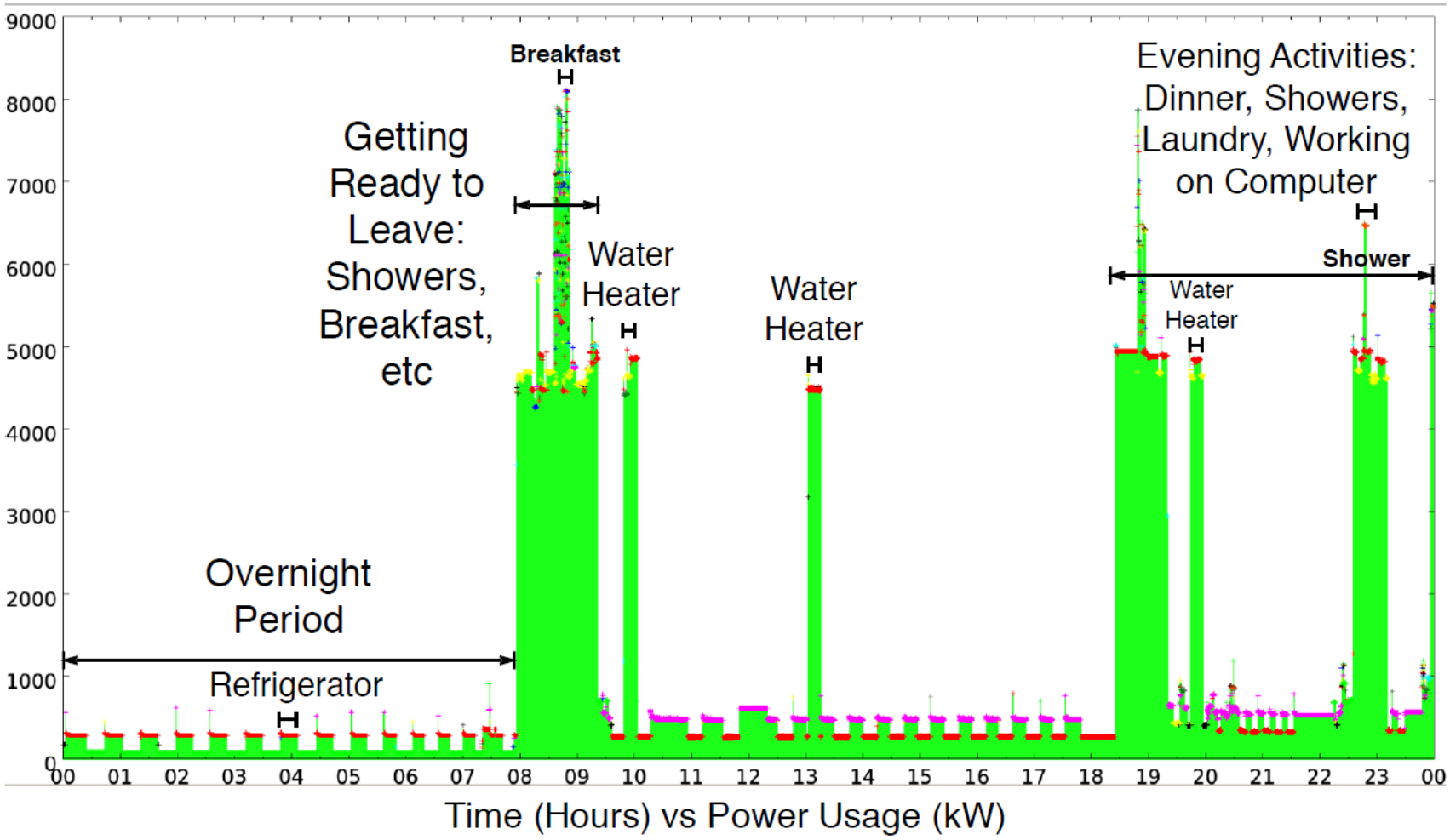
Granular Energy Consumption Data



Molina-Markham, Andrés, et al. "Private memoirs of a smart meter."*Proceedings of the 2nd ACM workshop on embedded sensing systems for energy-efficiency in building*. ACM, 2010.

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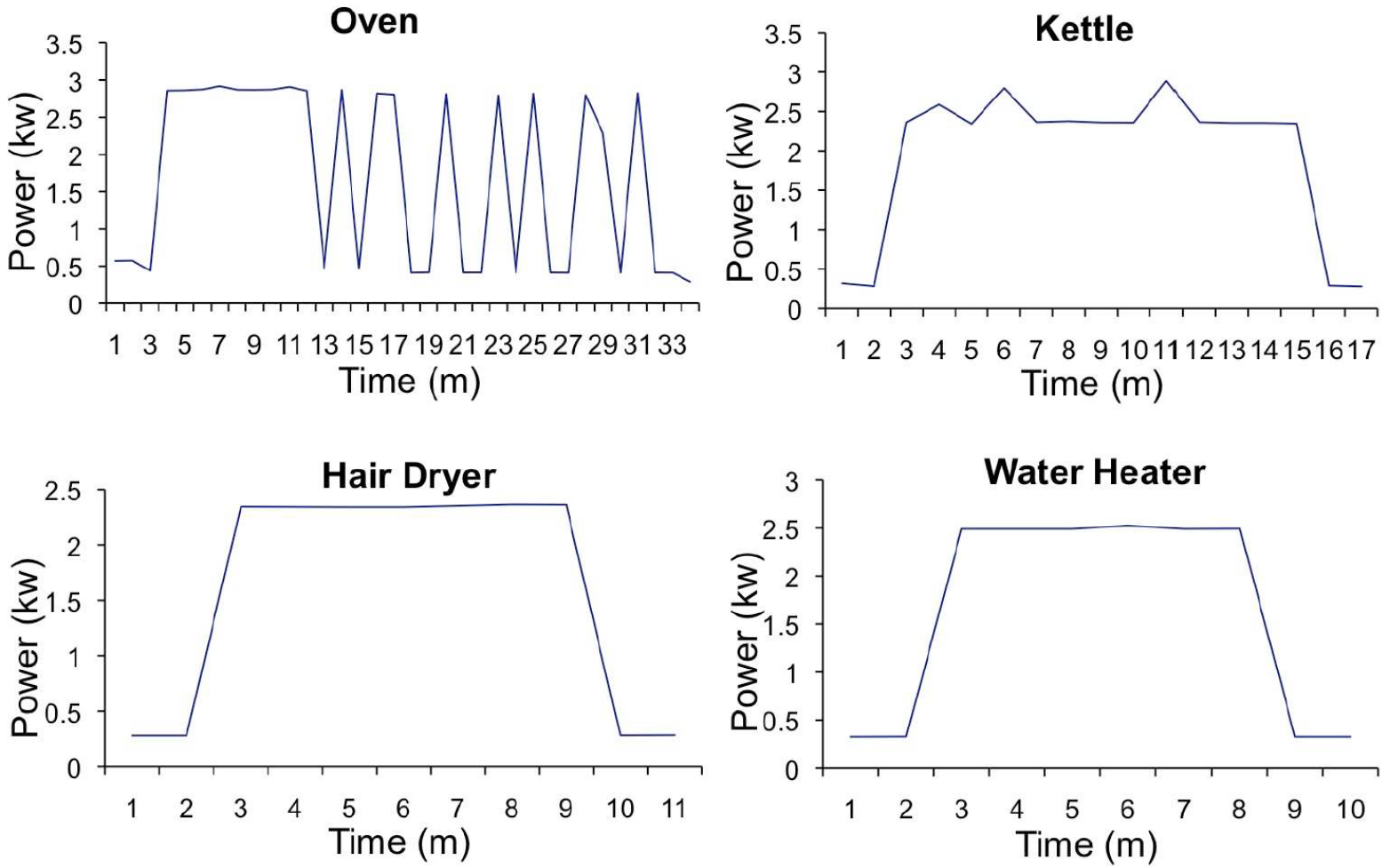
Active Power Signatures for 4 Appliances



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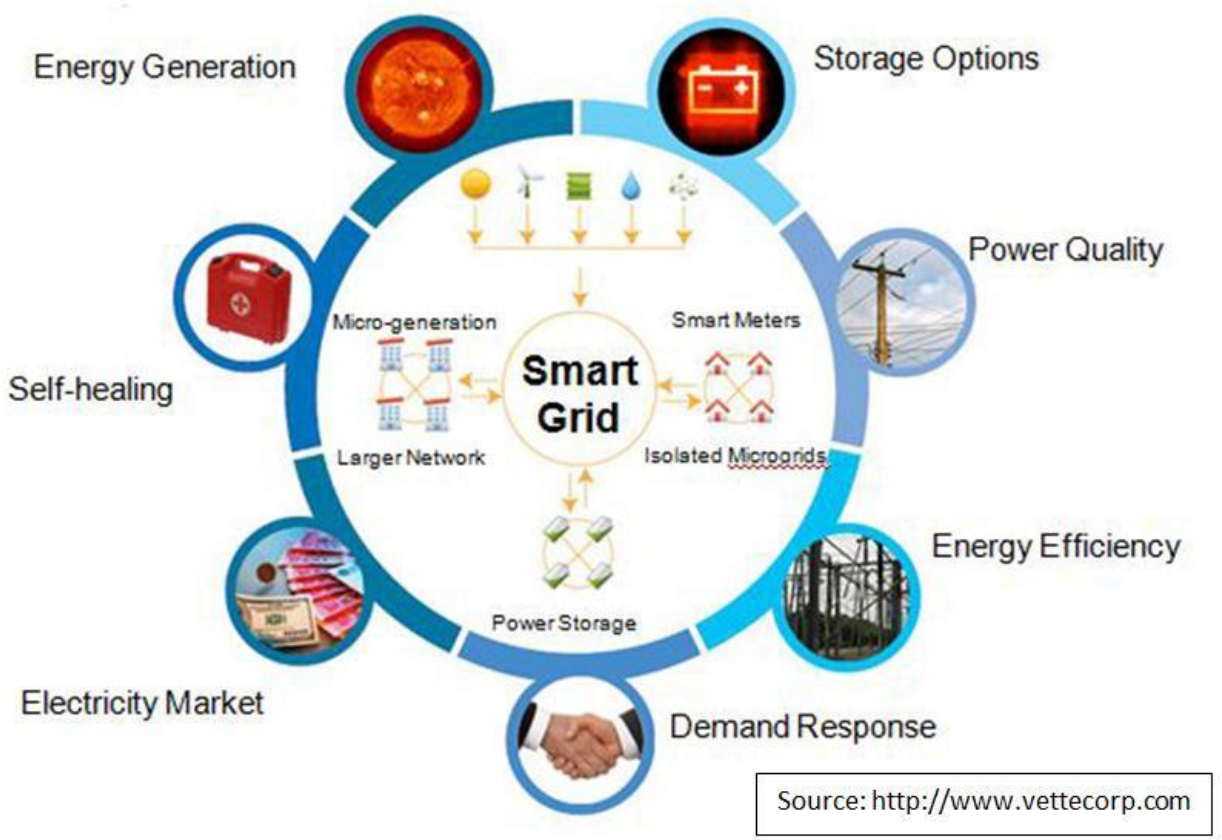

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Consumer's Wish List

- Reduce bill
- Better service
- Manage energy consumption
- Select utility company that best fits their energy needs
- Preserve privacy

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Utility's Wish List

- Meet consumer needs
- Bill consumers correctly
- Employ load monitoring
- Process fine-grained data for further analysis
- Manage and control smart meters
- Minimize outages

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AMI Challenges

- Fine-grained data: transfer, storage, and analysis
- Limited computational resources
- Consumer privacy preservation
- Scalability
- Multiple energy providers

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Existing Solutions

- Utility companies (UCs) utilize:
  - Collectors
  - Aggregators
  - Storage units
  - Trusted Third Party (TTP)

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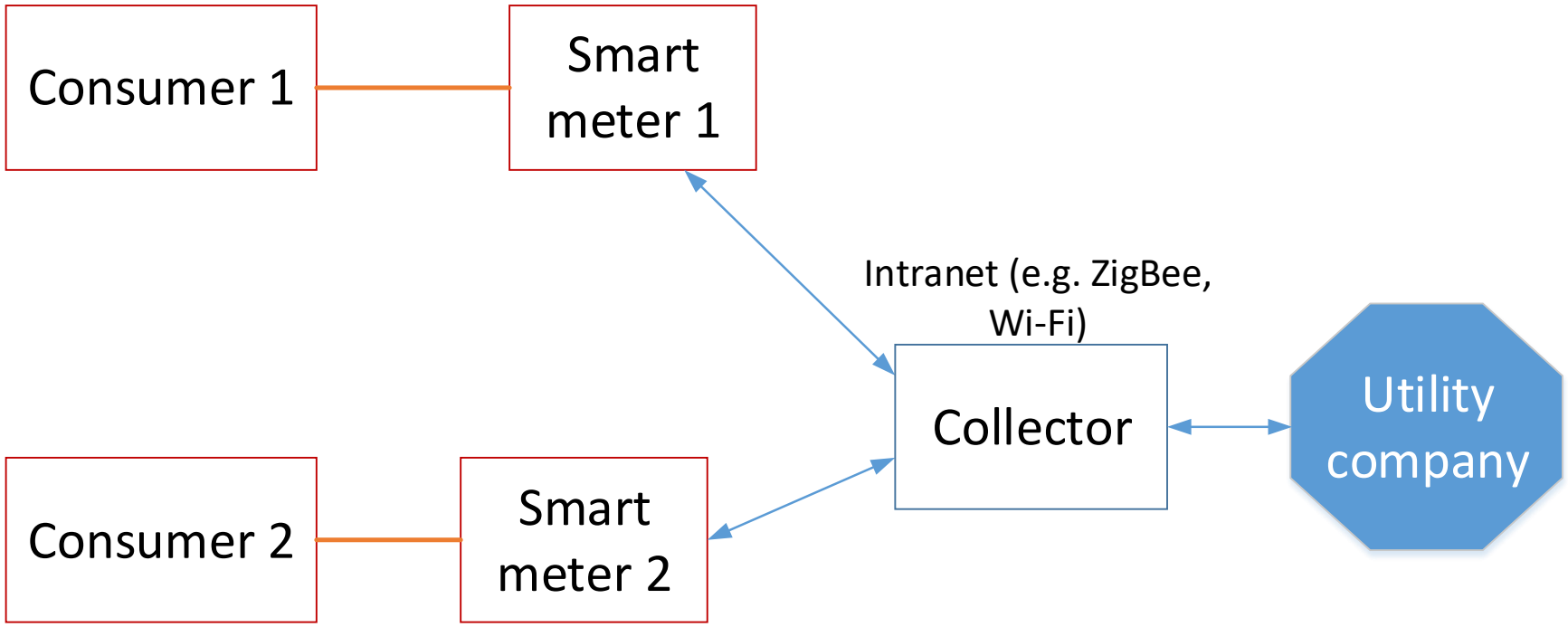
Standard Infrastructure



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Disadvantages Associated with Standard Infrastructure

- Fine-grained data are directly stored at UC
- Privacy issues
- No scalability in case of several electricity providers (data will not be transferrable among providers)
- UC controls the data and can do whatever they want with them besides load monitoring, fraud detection, energy efficiency

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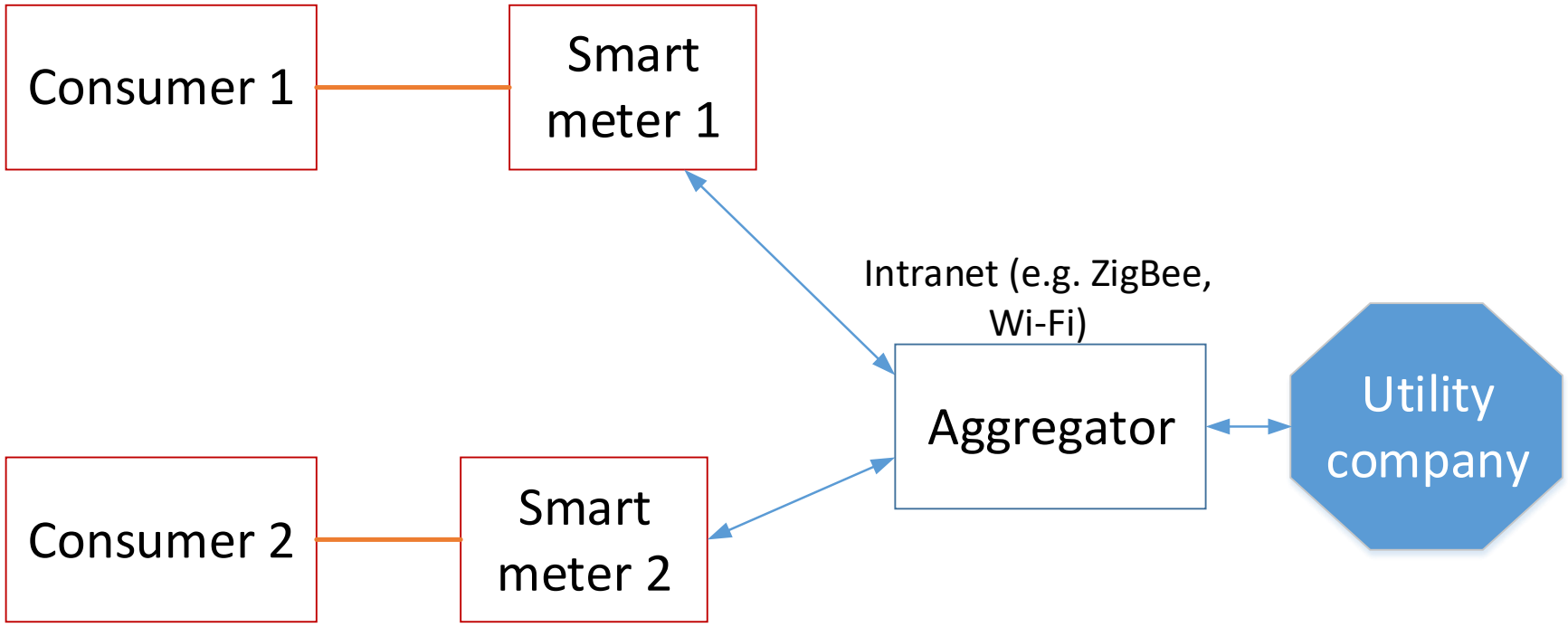
Aggregation-based Infrastructure



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Disadvantages Associated with Aggregation-based Infrastructure

- No fine-grained data storage
- No fine-grained data applications
- No analysis of consumer energy consumption

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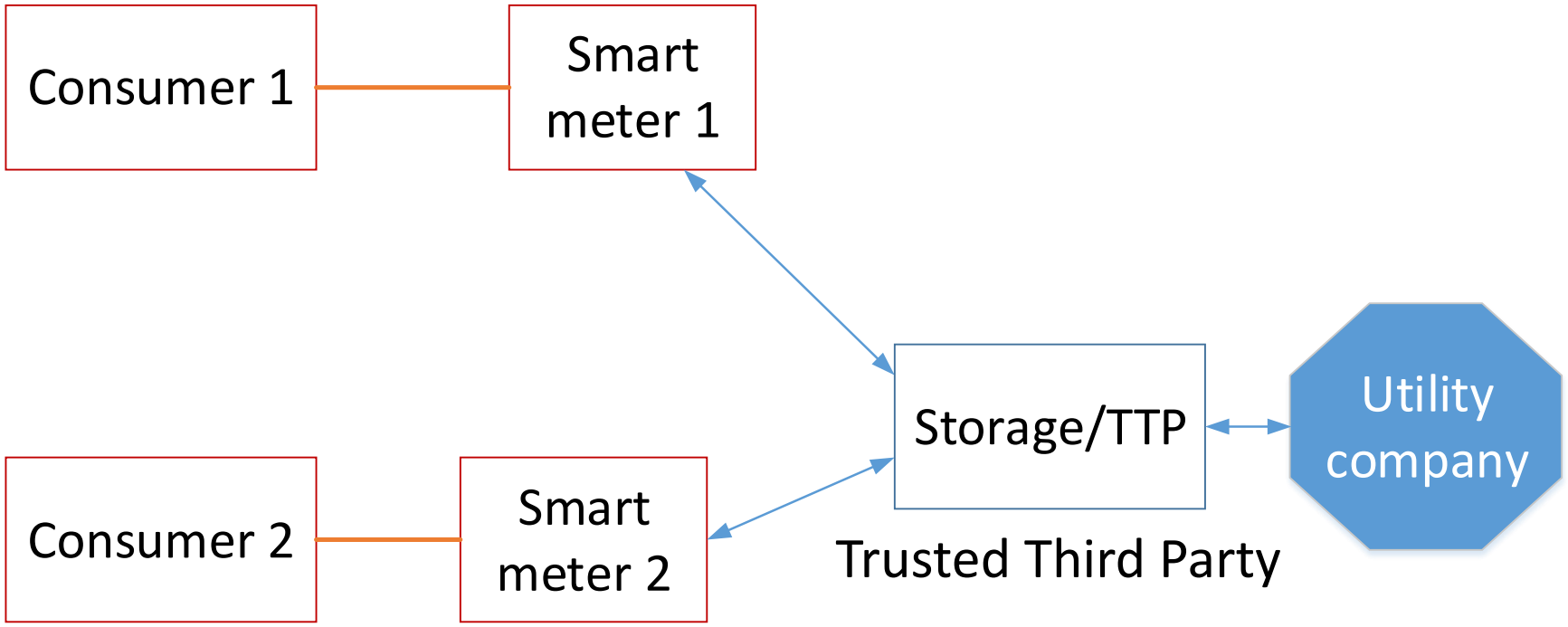
Infrastructure with a Storage Unit



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Disadvantages Associated with Infrastructure with a Storage Unit

- Two parties (Storage/TTP & UC) have direct access to Smart Meter (SM)s
- To support scalability, Storage/TTP has to use the same connection lines to SMs as UC, increasing network load
- Storage is deployed by UC
- Consumers cannot see their historical energy consumption
- Not scalable for multiple providers

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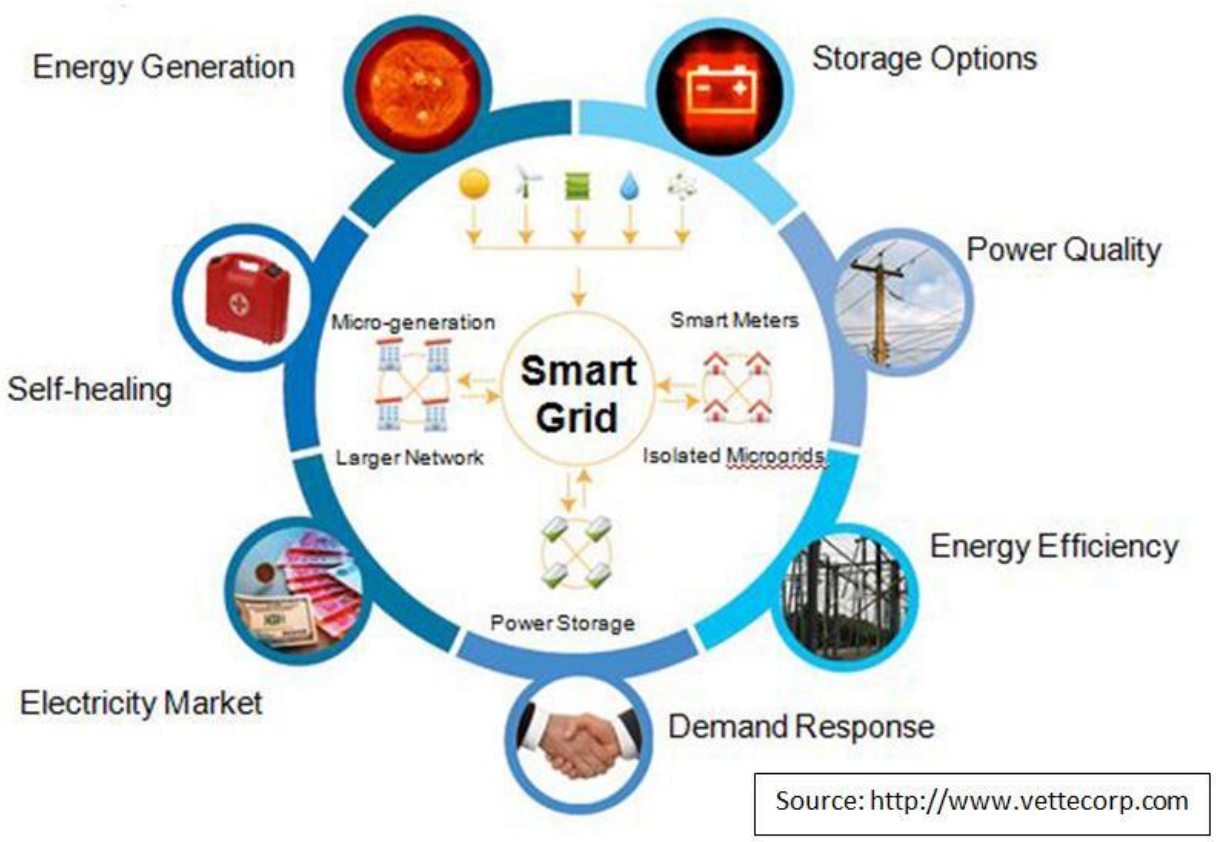

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Proposed Solution

- Apart from use of lightweight cryptography and consumer privacy preservation, other unique features
  - Scalability, no significant changes to the current grid
  - Fine-grained data analysis
  - Network load reduction
  - Only UC has a direct access to smart meters
  - Different consumer-oriented applications
    - Comparison of energy providers' prices
    - Variable price rates for energy, reducing smart meter computational load
  - Aggregation is made out of AMI

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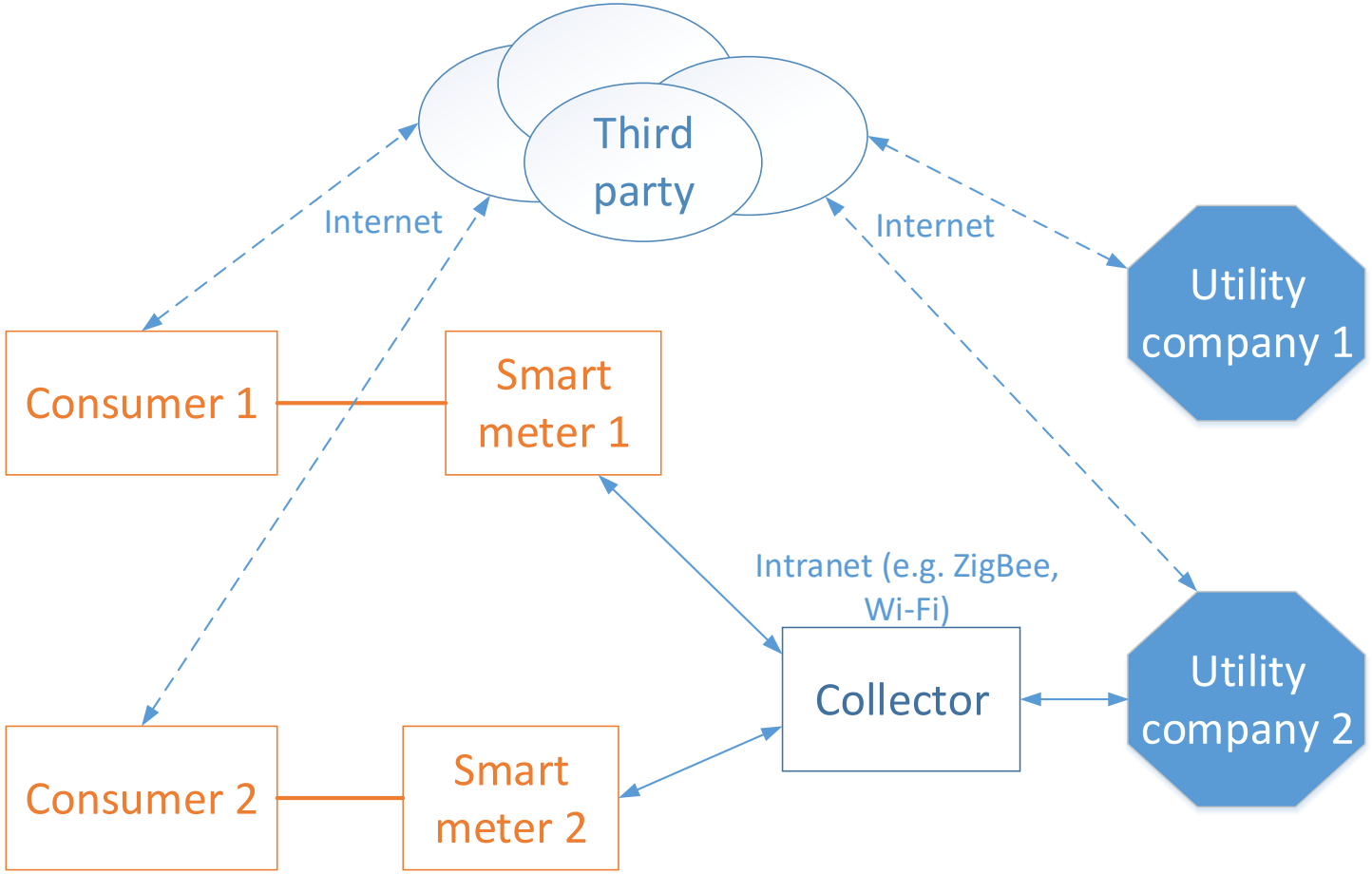
Proposed Infrastructure



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Role of Trusted Third Party

- Independent commercial cloud-based organization
- Responsibility
  - Store and analyze fine-grained data
  - Calculate the bill
  - Provide detailed analysis to consumers
  - Provide privacy-preserving analysis for utilities

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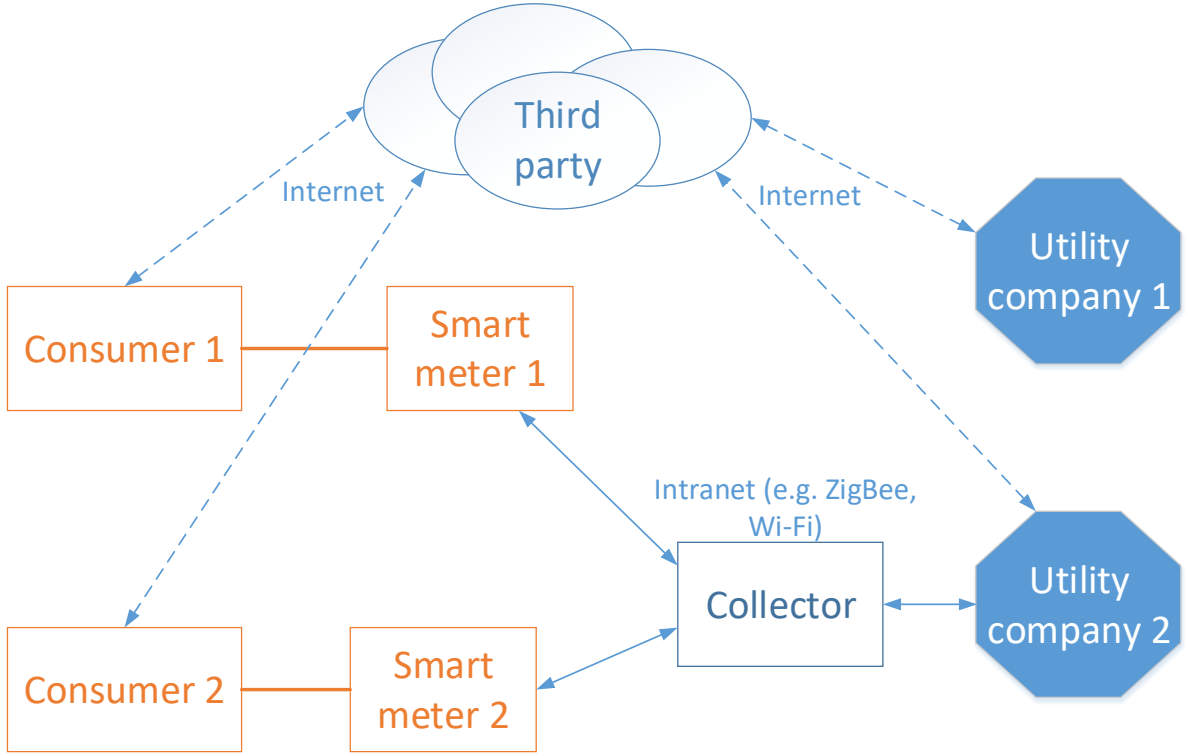
UC-TTP and Consumer-TTP Interaction

- Utility company
  - Billing
  - Load monitoring
  - Support of different price ranges
  - Fraud detection
- Consumers
  - Consumption analysis
  - Comparison of UC’s



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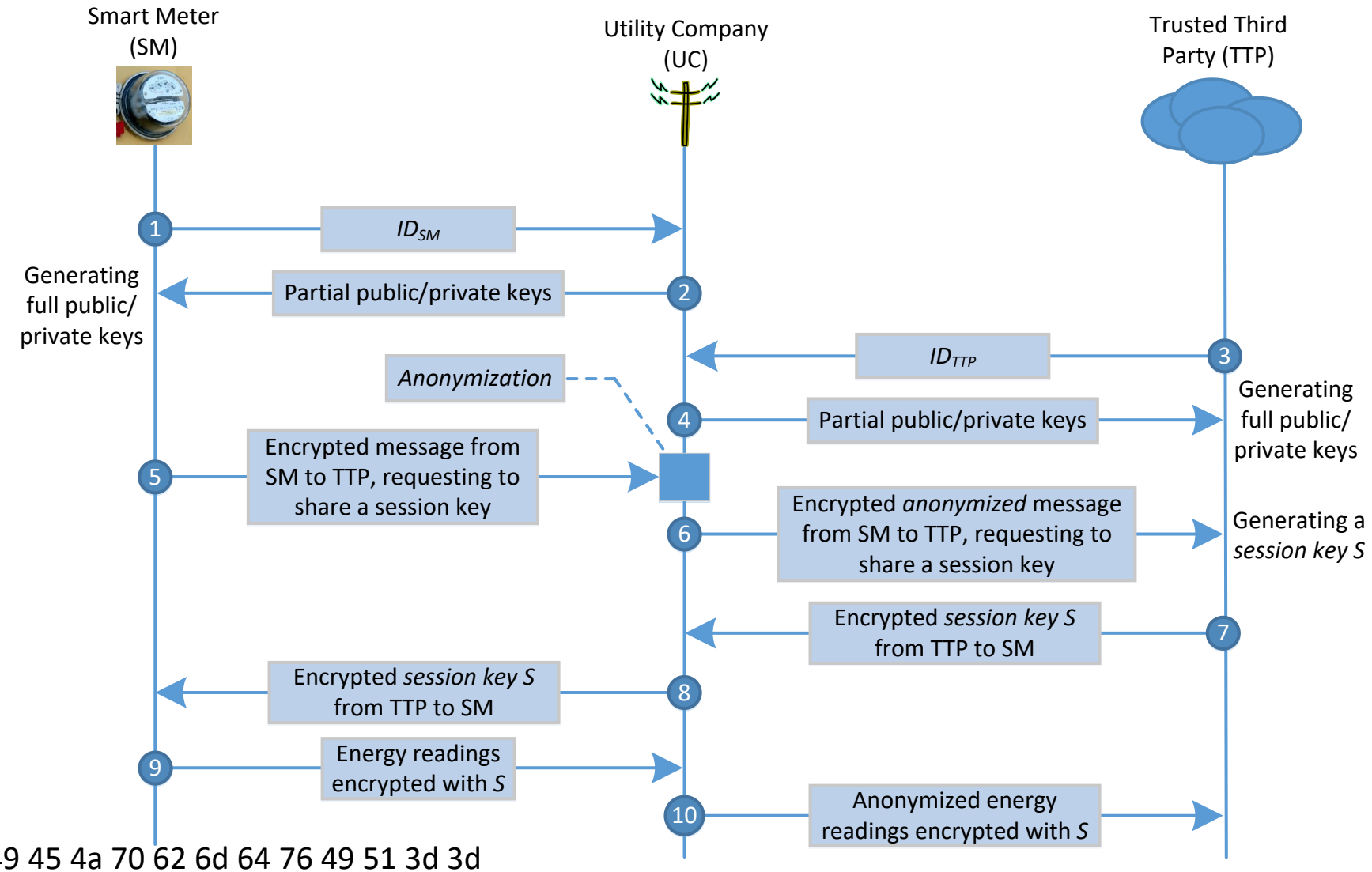
Proposed Protocol



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Communication Phases

- Registration phase
  - Utility Company (UC) serves as a key generation center
  - Smart meters and the Trusted Third Party (TTP) communicate to the utility company to obtain partial public/private keys
- Session key exchange phase
  - Smart meters and TTP exchange a session key
- Data transmission phase
  - Smart meters send encrypted energy readings to TTP via UC

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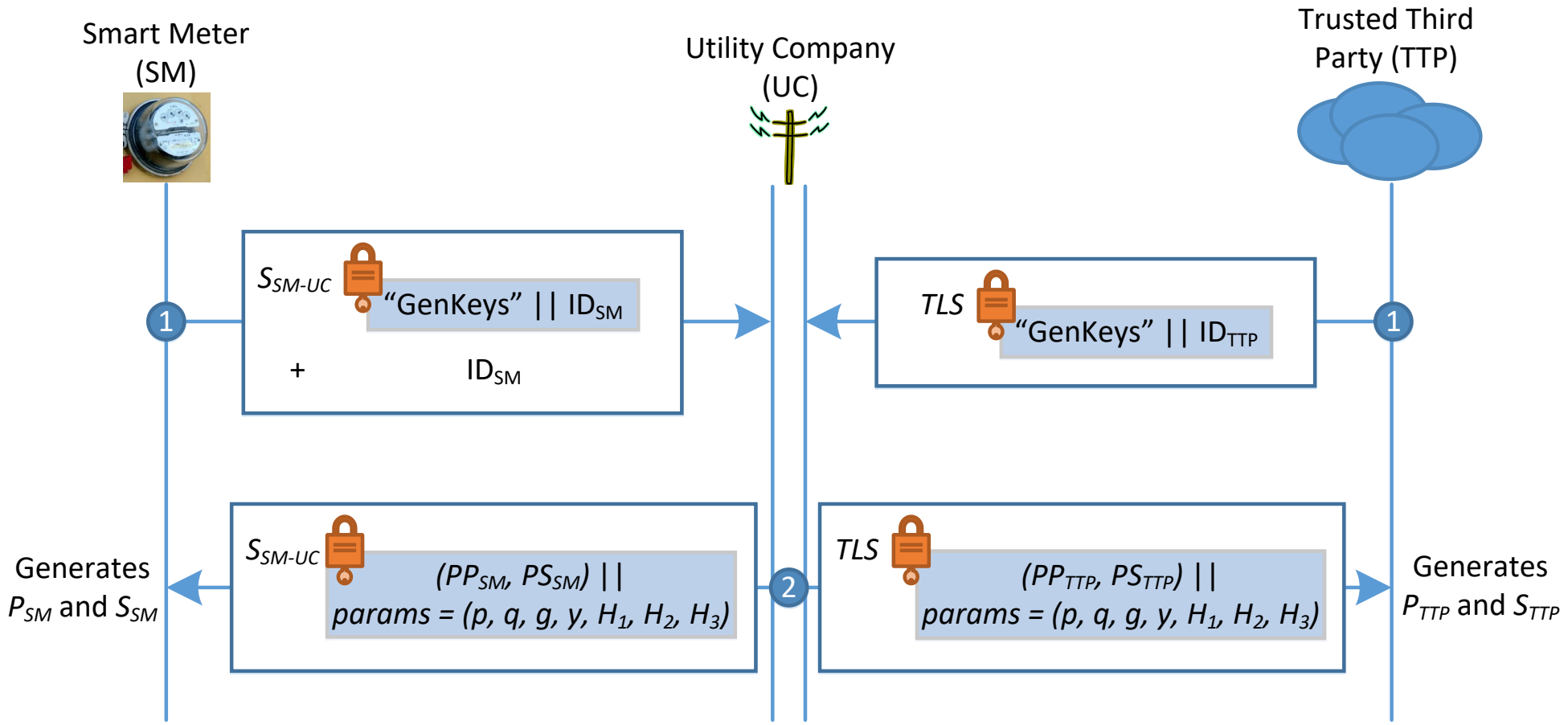
Registration Phase



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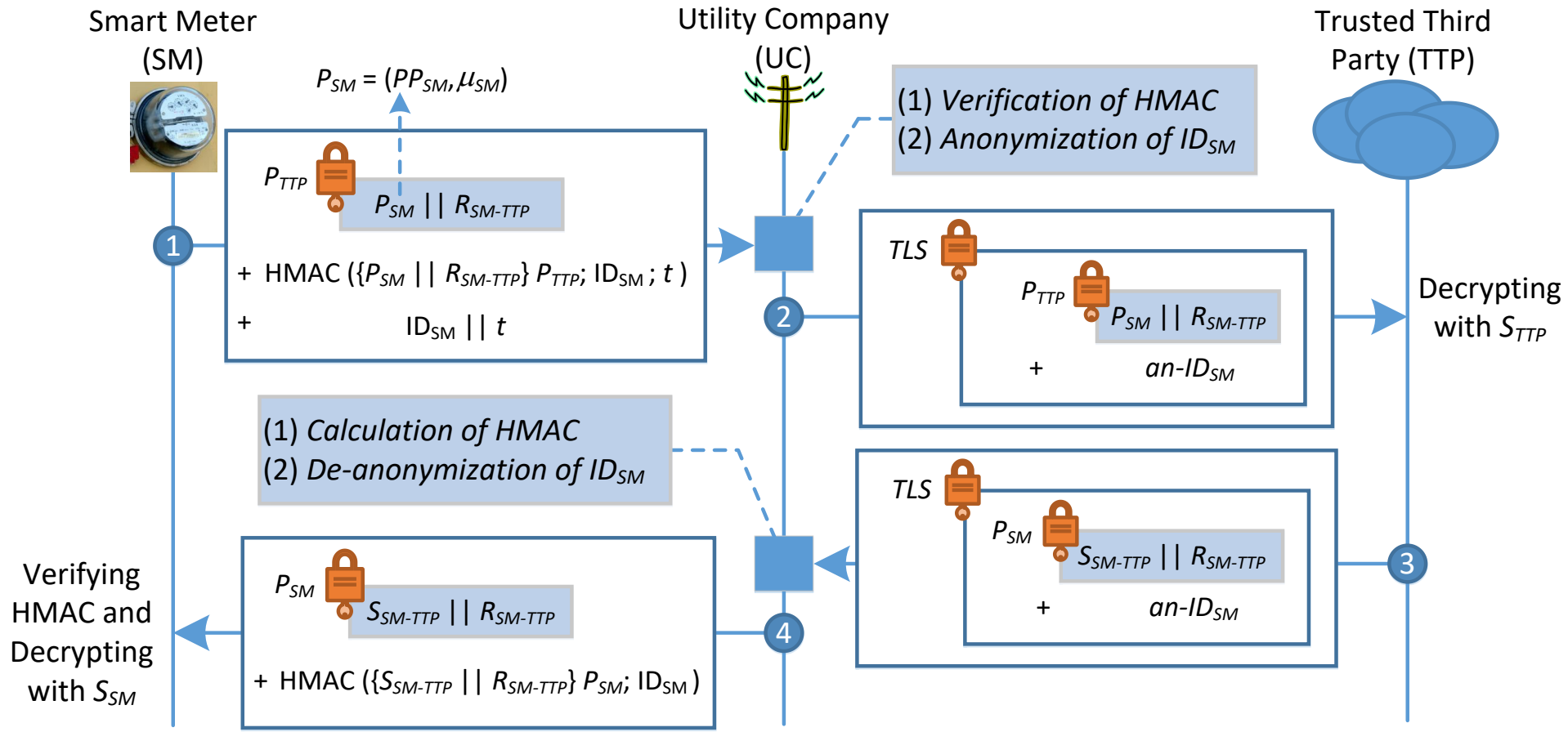
Session Key Exchange Phase



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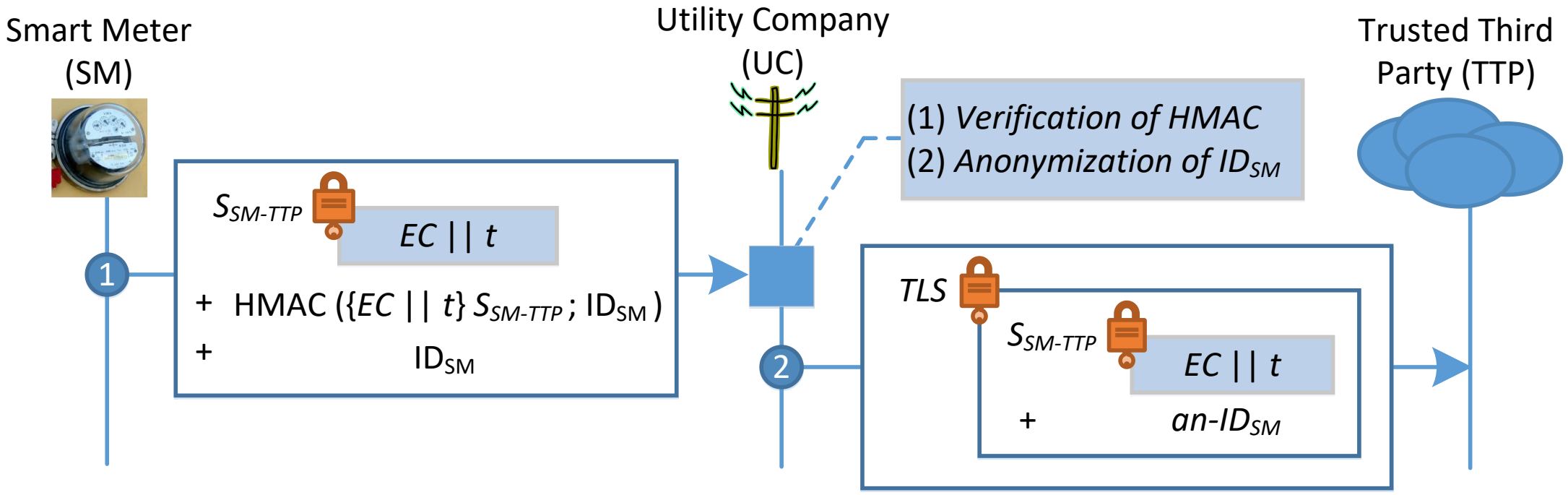
Data Transmission Phase



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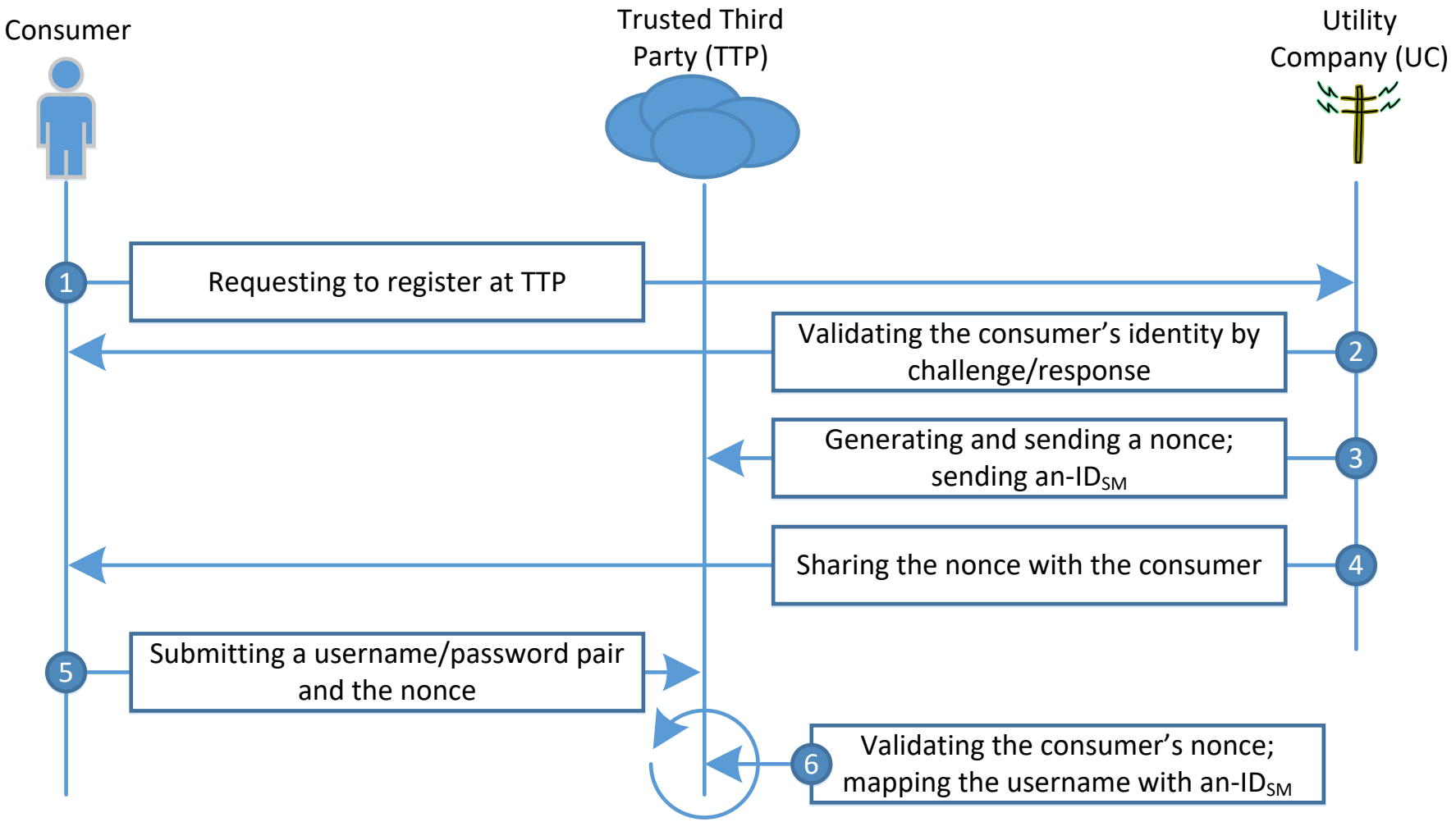
Consumer Authentication



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Attack Vectors

- Utility company as an *honest-but-curious* adversary
- Wait-for-response attack by a utility company
- Trusted third party as an *honest-but-curious* adversary
- Man-in-the-middle attacks

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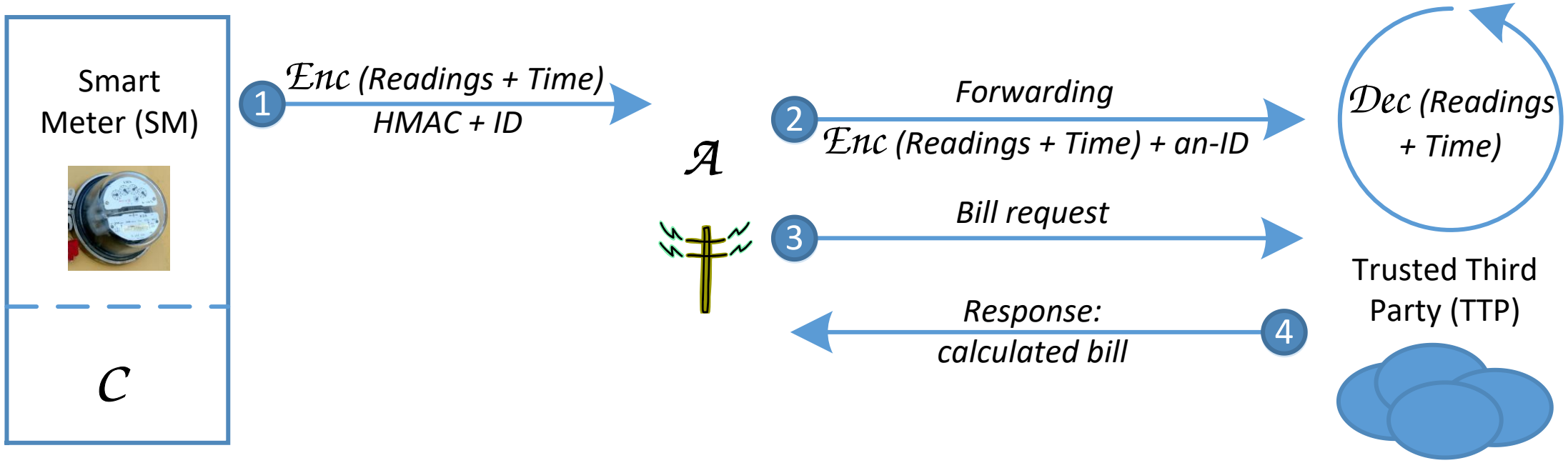
Attacker: Utility Company



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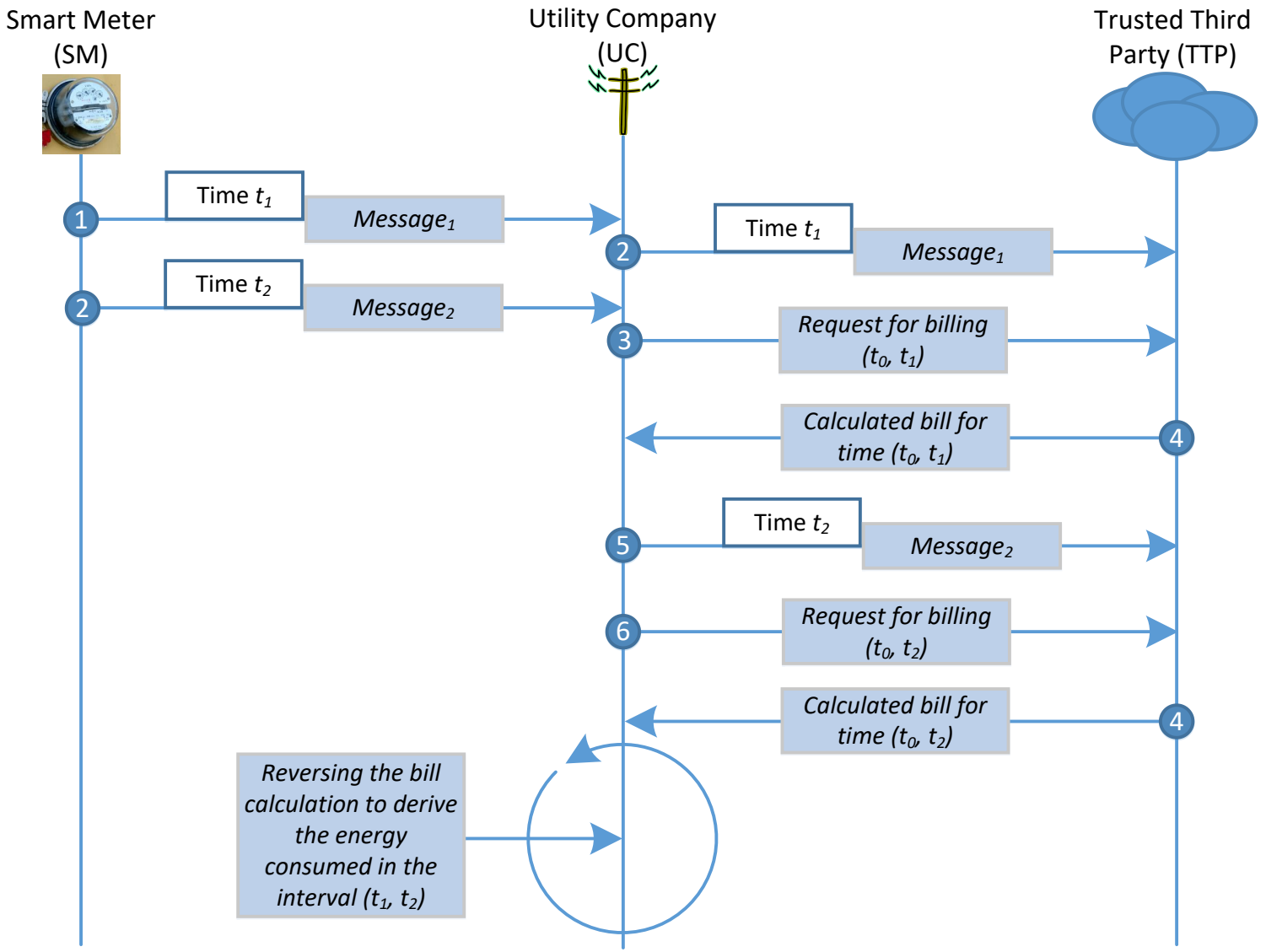
Wait-for-Response Attack



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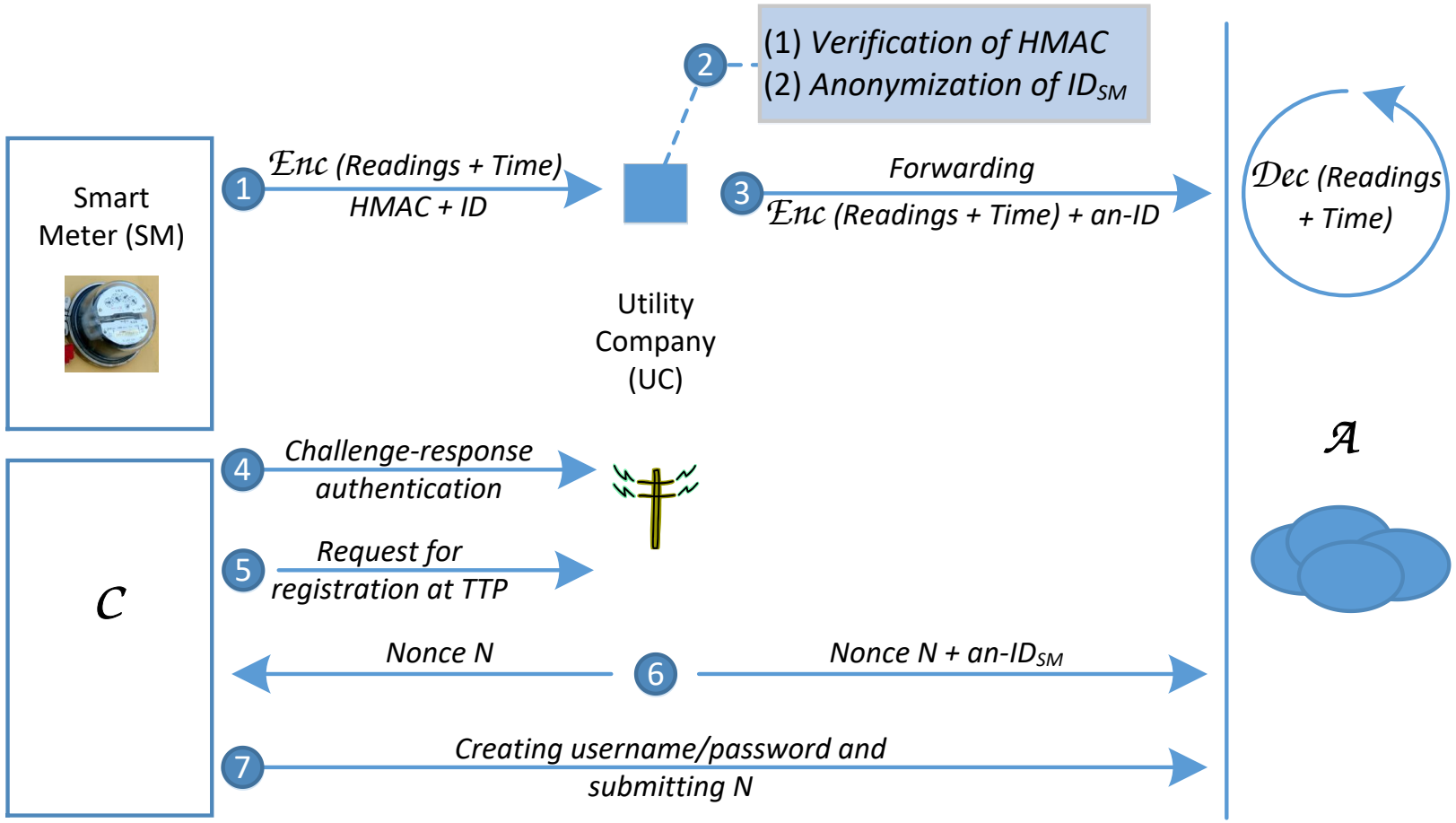
Attacker: Trusted Third Party



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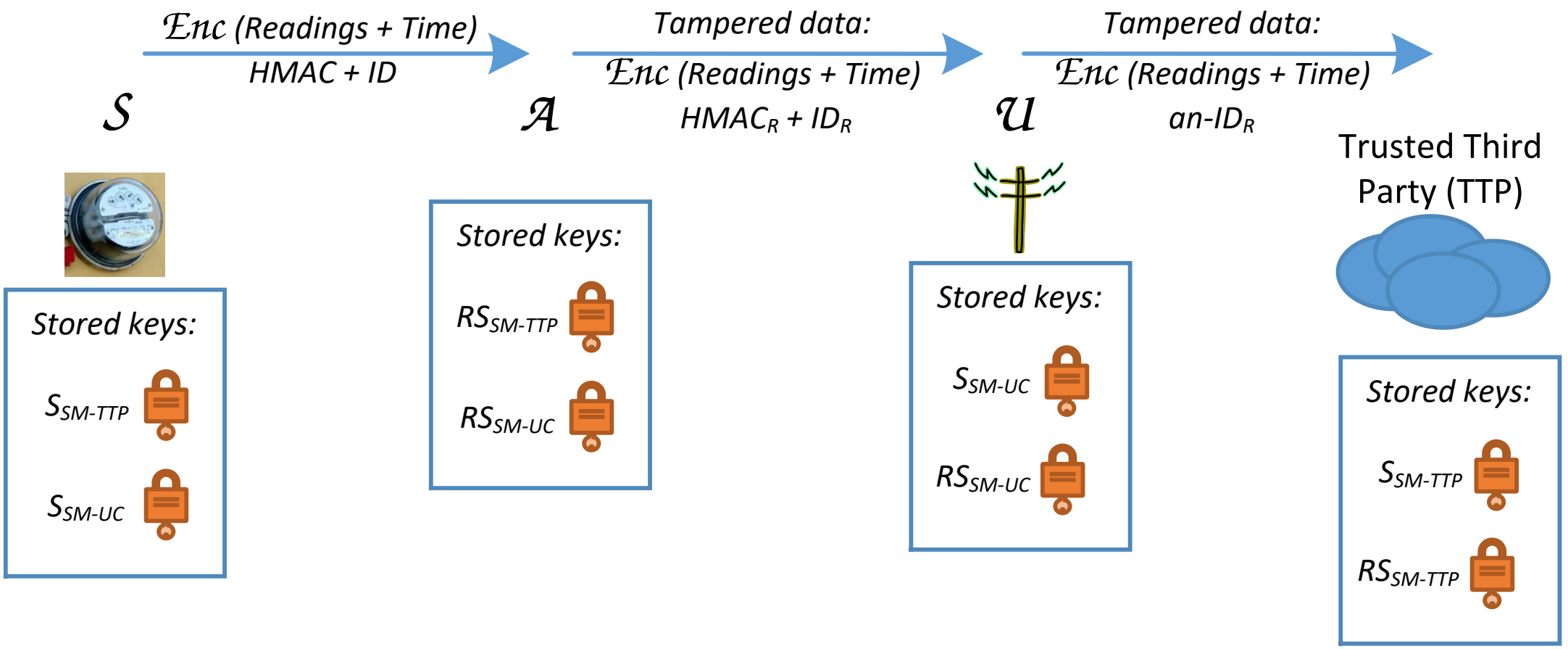
Attacker: MITM



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Conclusion and Future Research

- Cyber-Physical Systems research: security, privacy, data mining
- Unified AMI Simulation Framework
- Vehicular Network Integration
- Relax the assumption that the utility company and TTP do not collude

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Education: CTF Unplugged

- Mission 000: Background
- Mission 001: Reconnaissance
- Mission 010: Forensics
- Mission 011: Cryptography
- Mission 100: Reverse Engineering
- Mission 101: Steganography
- Mission 110: Web

V. Ford, A. Siraj, A. Haynes, and E. L. Brown, “Capture the Flag Unplugged: An Offline Cyber Competition”, accepted at ACM SIGCSE 2017.

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CyberEagles

- Cybersecurity Club at Tennessee Tech
- Seminars, speakers, competitions, conferences
- http://blogs.cae.tntech.edu/cybereagles/
- https://forum.cybereagles.club/

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References

1. V. Ford, A. Siraj, and M. A. Rahman, “Secure and Efficient Protection of Consumer Privacy in Advanced Metering Infrastructure Supporting Fine-grained Data Analysis,” *Journal of Computer and System Sciences* 83.1 (2017): 84-100.
2. V. Ford, A. Siraj, and W. Eberle, “Smart Grid Energy Fraud Detection Using Artificial Neural Networks,” in *Proceedings of the 2014 IEEE Symposium Series on Computational Intelligence*, December 9-12, 2014.
3. V. Ford and A. Siraj, “Clustering of smart meter data for disaggregation,” in *Proceedings of IEEE Global Conference on Signal and Information Processing*, December 3-5, 2013.
4. V. Ford, A. Siraj, A. Haynes, and E. L. Brown, “Capture the Flag Unplugged: An Offline Cyber Competition”, accepted at ACM SIGCSE 2017.

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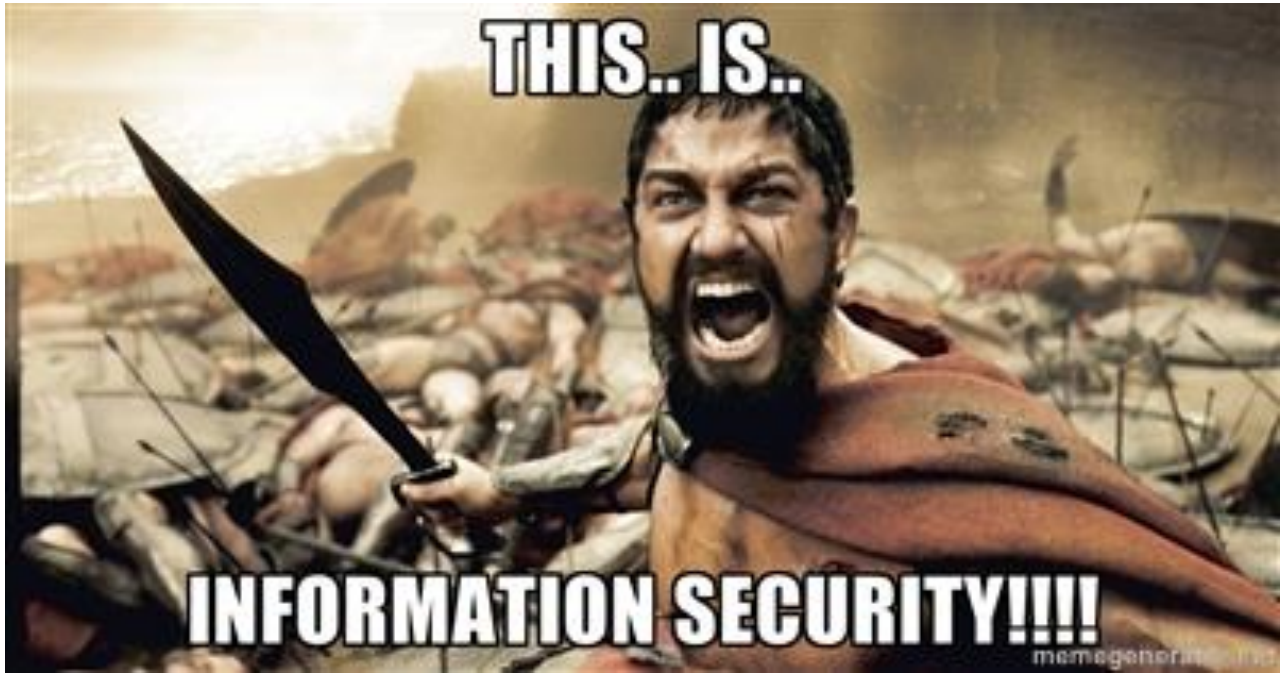
Thank you!



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