Secure Cyber-Physical Systems by Design

Keynote – International Conference on Control, Automation, Power and Signal Processing (CAPS-2021)

10th December 2021

Saraju P. Mohanty

University of North Texas, USA.

Email: saraju.mohanty@unt.edu Website: http://www.smohanty.org

The Big Picture

Issues Challenging City Sustainability

Pollution

Water Crisis

Energy Crisis

Traffic

Smart City Technology - As a Solution

- Smart Cities: For effective management of limited resource to serve largest possible population to improve:
  - Livability
  - Workability
  - Sustainability

At Different Levels:
- Smart Village
- Smart State
- Smart Country

- Year 2050: 70% of world population will be urban

July 2016

Source: S. P. Mohanty, U. Choppali, and E. Kougianos, “Everything You wanted to Know about Smart Cities”, *IEEE Consumer Electronics Magazine*, Vol. 5, No. 3, July 2016, pp. 60--70.

Smart Cities Vs Smart Villages

City - An inhabited place of greater size, population, or importance than a town or village

-- Merriam-Webster

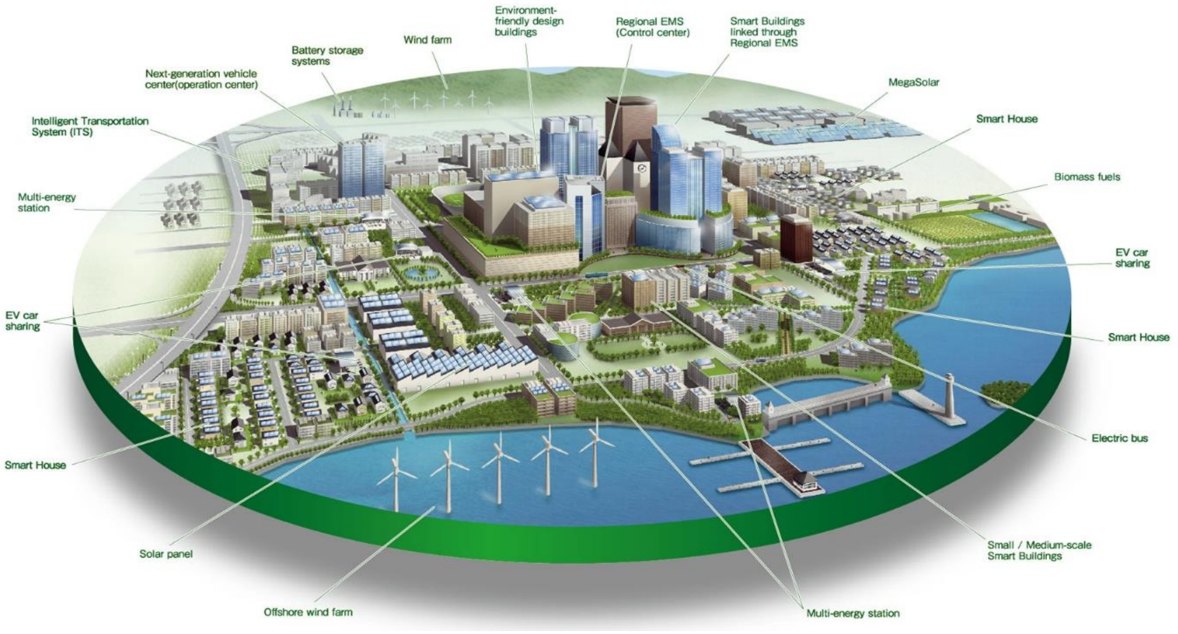
Smart City: A city "connecting the physical infrastructure, the information-technology infrastructure, the social infrastructure, and the business infrastructure to leverage the collective intelligence of the city".

Source: S. P. Mohanty, U. Choppali, and E. Kougianos, "Everything You wanted to Know about Smart Cities", *IEEE Consumer Electronics Magazine*, Vol. 5, No. 3, July 2016, pp. 60--70.

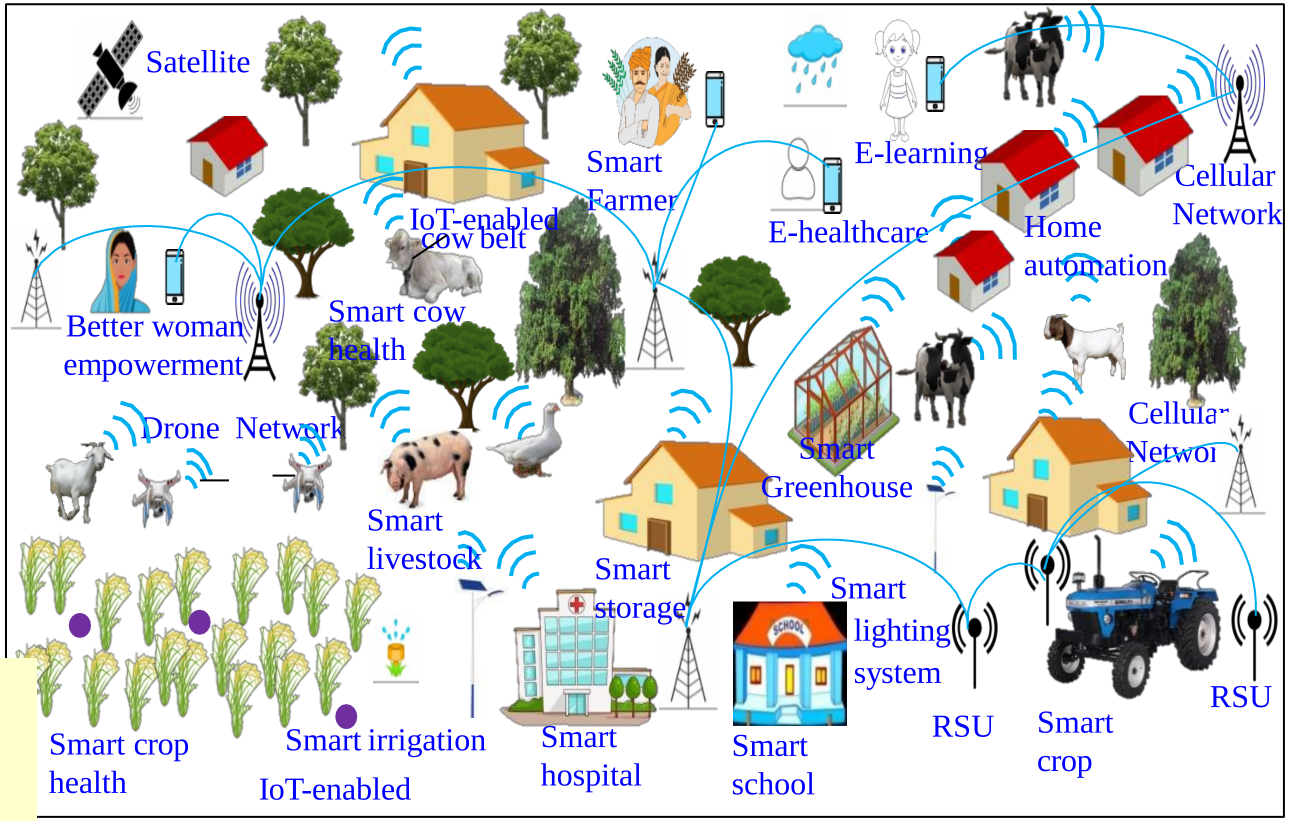
Smart Village: A village that uses information and communication technologies (ICT) for advancing economic and social development to make villages sustainable.

Source: S. K. Ram, B. B. Das, K. K. Mahapatra, S. P. Mohanty, and U. Choppali, "Energy Perspectives in IoT Driven Smart Villages and Smart Cities", *IEEE Consumer Electronics Magazine (MCE)*, Vol. 10, No. 03, May 2021, pp. 19-28.

Smart Cities Vs Smart Villages



Source: http://edwingarcia.info/2014/04/26/principal/



Source; P. Chanak and I. Banerjee, "Internet of Things-enabled Smart Villages: Recent Advances and Challenges," *IEEE Consumer Electronics Magazine*, DOI: 10.1109/MCE.2020.3013244.

Smart Villages
- CPS Types - Less
- Design Cost - Low
- Operation Cost – Low
- Energy Requirement - Low

Smart Cities
- CPS Types - More
- Design Cost - High
- Operation Cost – High
- Energy Requirement - High

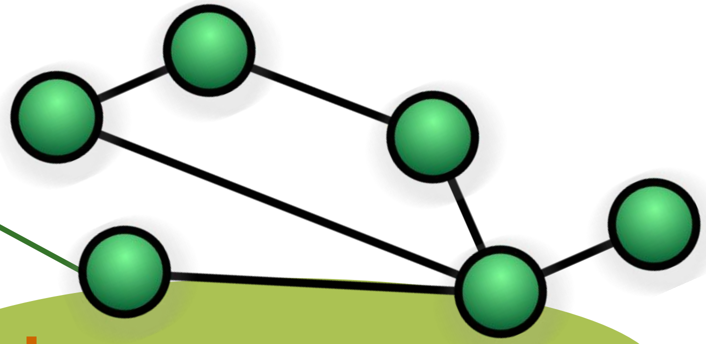
Smart Cities or Smart Villages - 3 Is

Instrumentation

The 3Is are provided by the Internet of Things (IoT).

Smart Cities

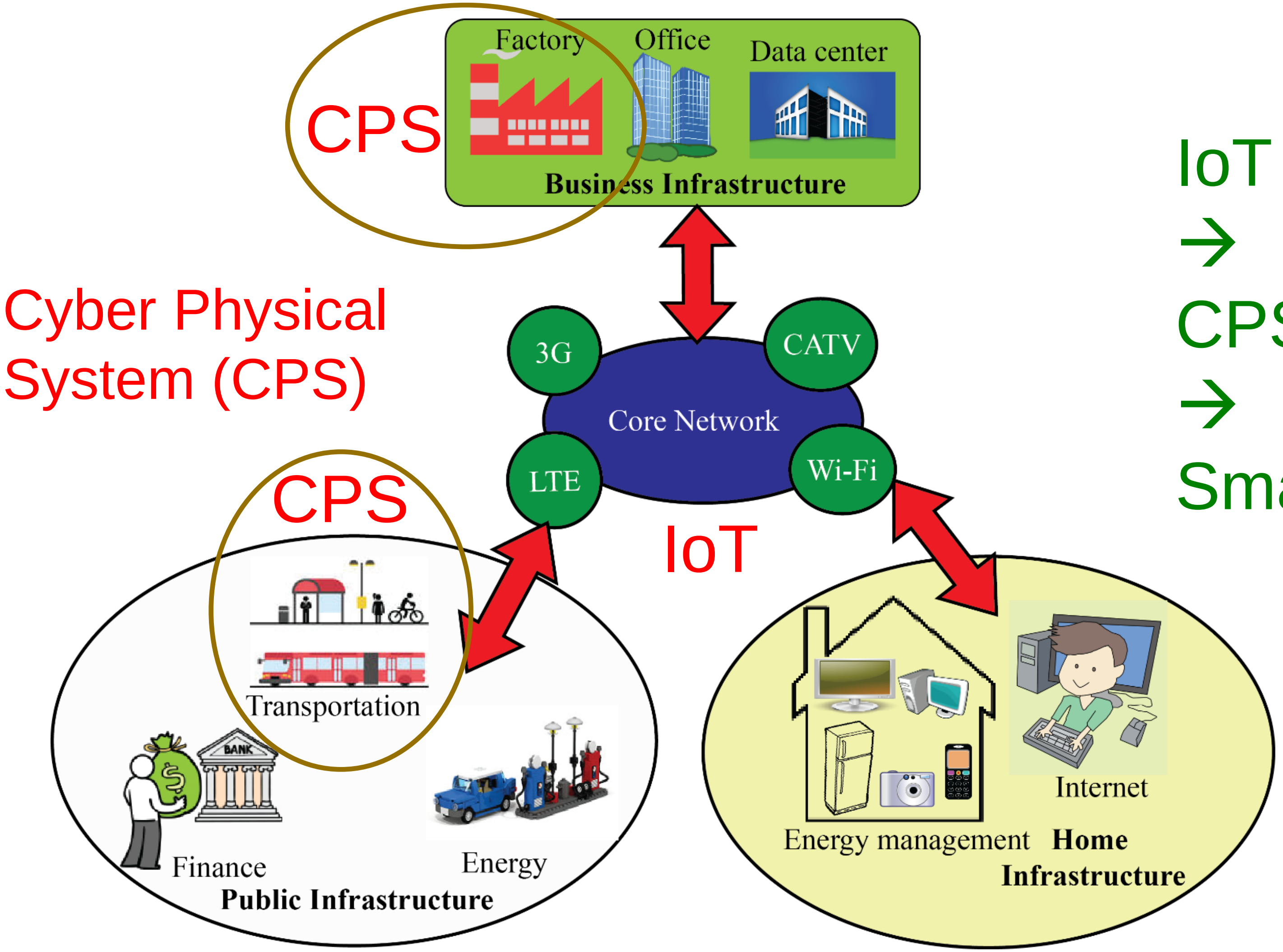
Intelligence



Interconnection

Source: Mohanty ISC2 2019 Keynote

IoT → CPS → Smart Cities or Smart Villages

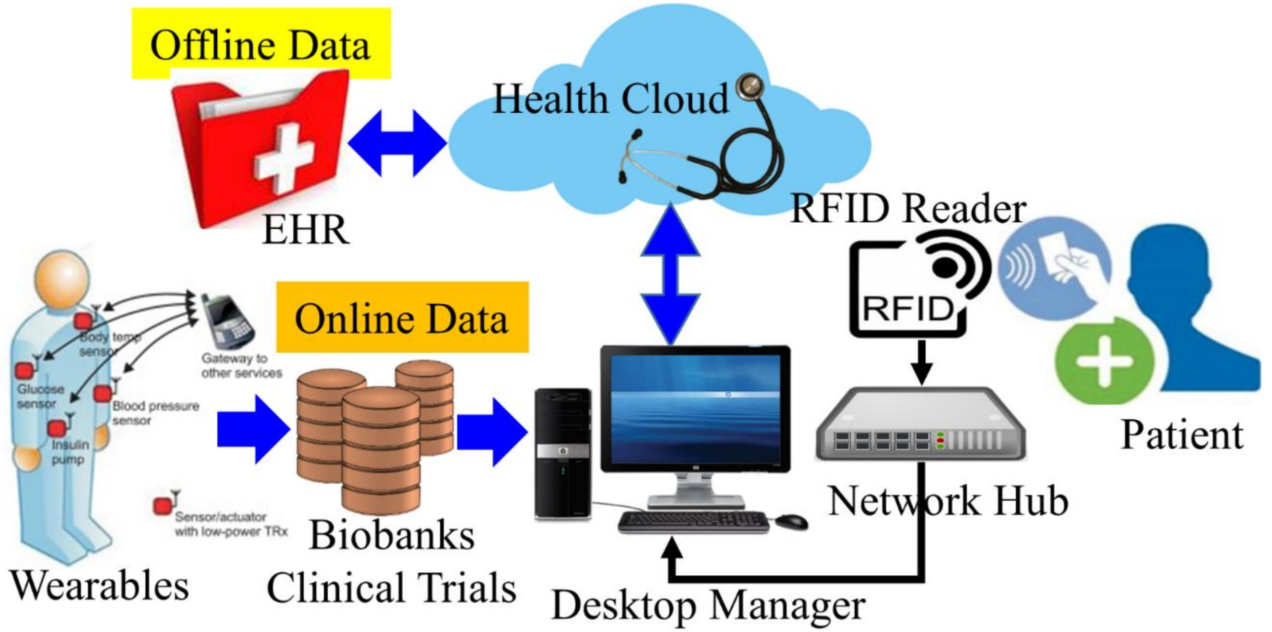


IoT
→
CPS (Smart Components)
→
Smart Cities or Smart Villages

IoT is the backbone

Source: S. P. Mohanty, U. Choppali, and E. Kougianos, "Everything You wanted to Know about Smart Cities", *IEEE Consumer Electronics Magazine*, Vol. 5, No. 3, July 2016, pp. 60--70.

Healthcare Cyber-Physical System (H-CPS)



Internet-of-Medical-Things (IoMT)

OR

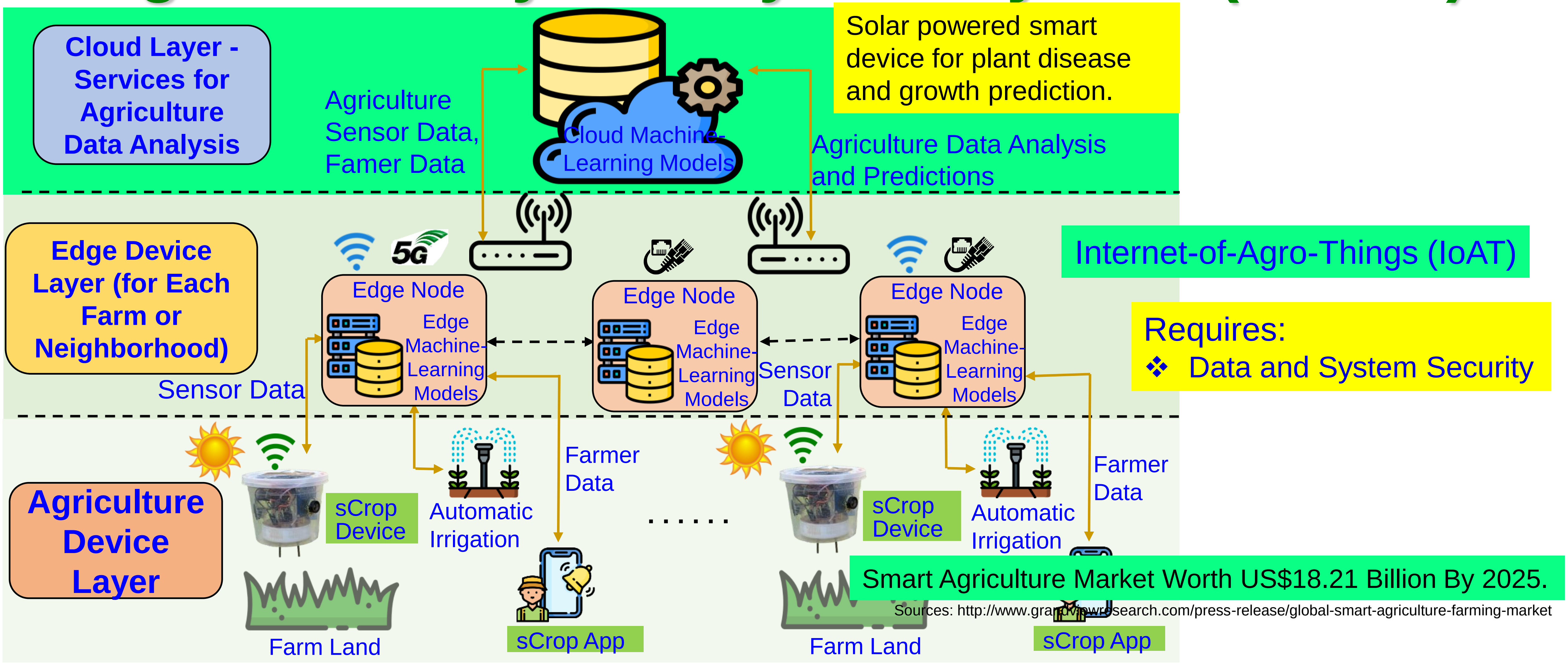
Internet-of-Health-Things (IoHT)

H-CPS ← Biosensors + Medical Devices + Wearable Medical Devices (WMDs) + Implantable Medical Devices (IMDs) + Internet + Healthcare database + AI/ML + Applications that connected through Internet.

Requires:
- ❖ Data and Device Security
- ❖ Data Privacy

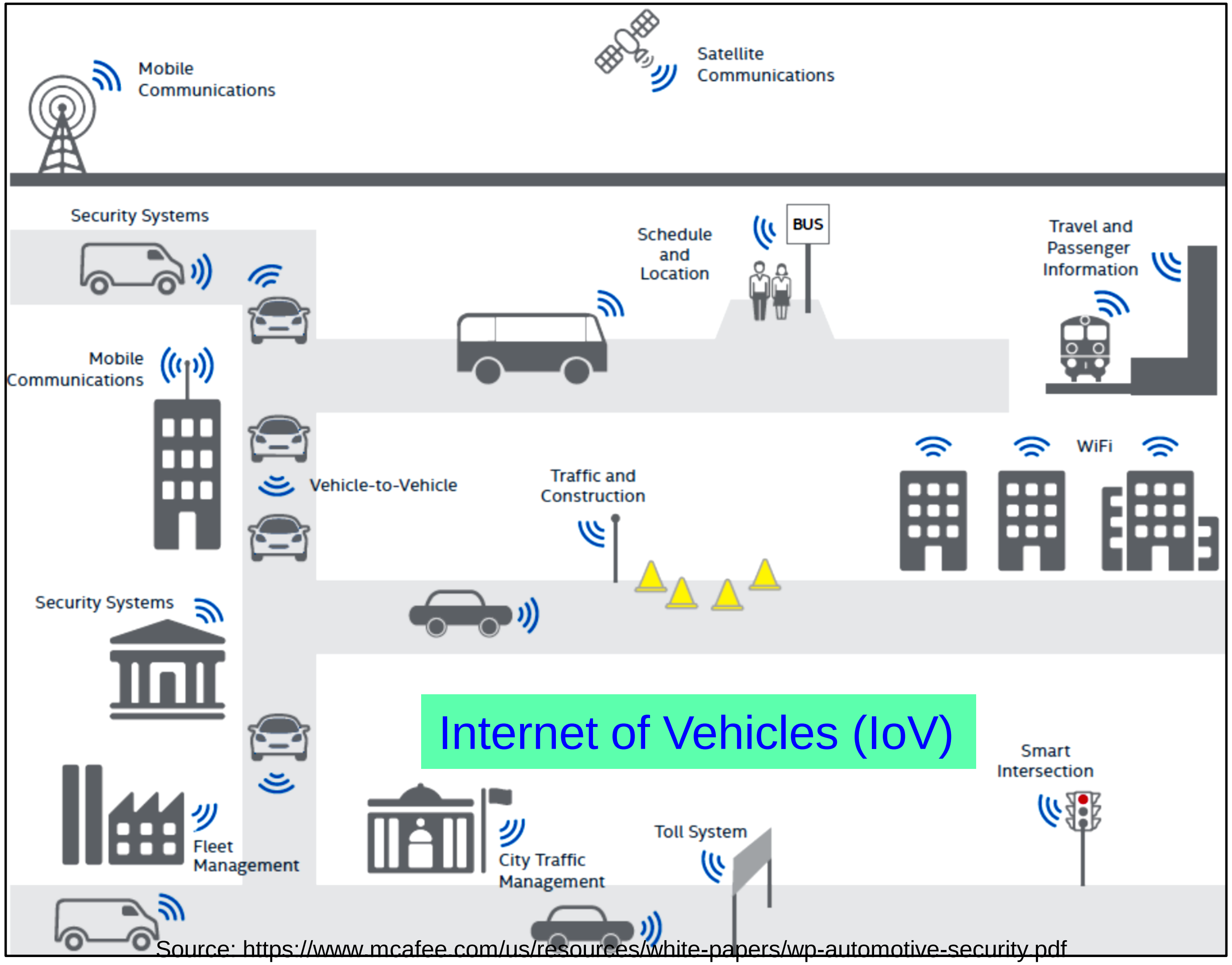
Frost and Sullivan predicts smart healthcare market value to reach US$348.5 billion by 2025.

Agriculture Cyber-Physical System (A-CPS)



Source: V. Udutalapally, S. P. Mohanty, V. Pallagani, and V. Khandelwal, “sCrop: A Novel Device for Sustainable Automatic Disease Prediction, Crop Selection, and Irrigation in Internet-of-Agro-Things for Smart Agriculture”, *IEEE Sensors Journal*, Vol. 21, No. 16, August 2021, pp. 17525--17538, DOI: 10.1109/JSEN.2020.3032438.

Transportation Cyber-Physical System (T-CPS)



Source: https://www.mcafee.com/us/resources/white-papers/wp-automotive-security.pdf

IoT Role Includes:

- Traffic management
- Real-time vehicle tracking
- Vehicle-to-Vehicle communication
- Scheduling of train, aircraft
- Automatic payment/ticket system
- Automatic toll collection

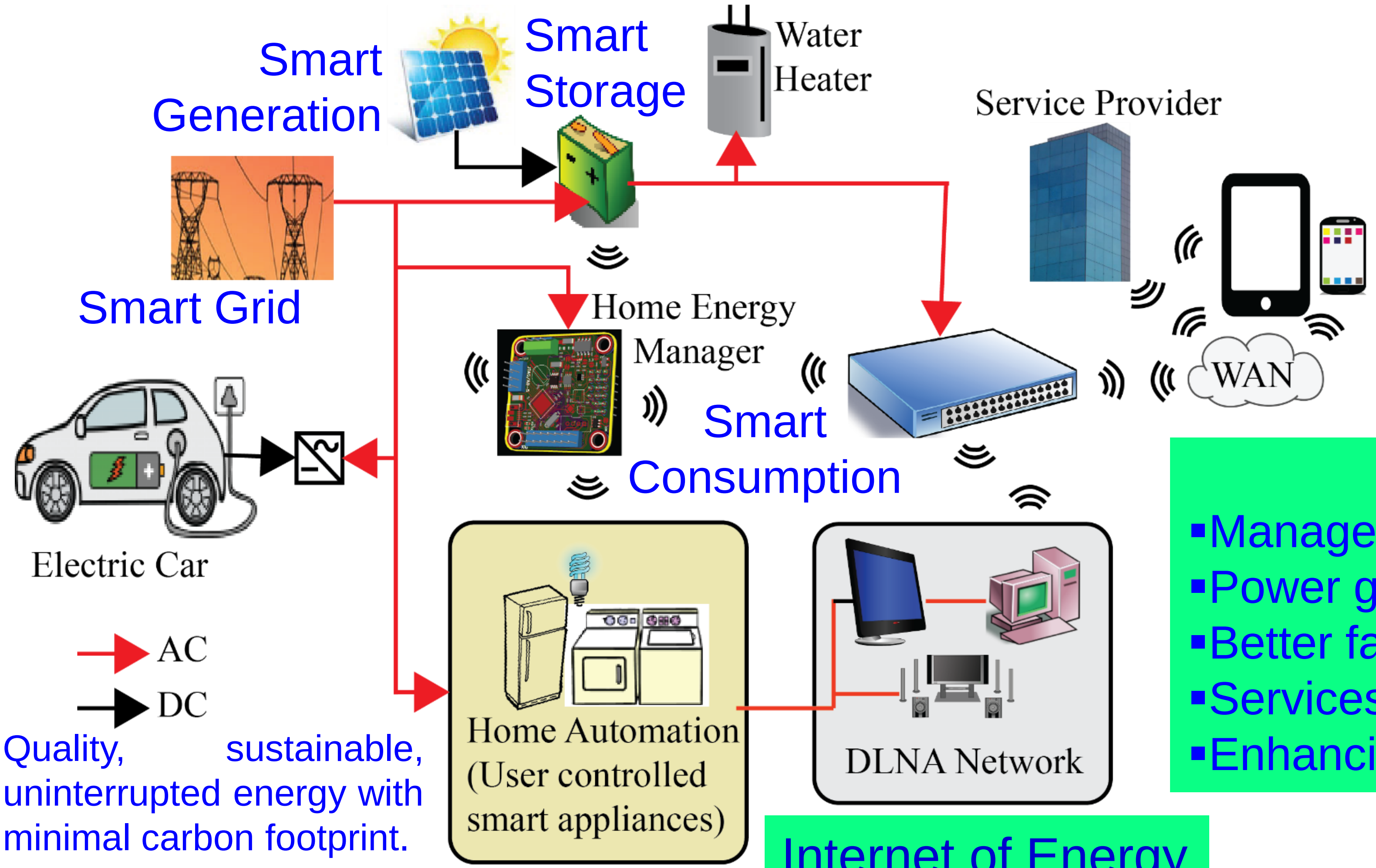
Requires:

- ❖ Data, Device, and System Security
- ❖ Location Privacy

"The global market of IoT based connected cars is expected to reach $46 Billion by 2020."

Source: Datta 2017, CE Magazine Oct 2017

Energy Cyber-Physical System (E-CPS)



Quality, sustainable, uninterrupted energy with minimal carbon footprint.

Internet of Energy

Requires:
- Data, Device, and System Security

IoT Role:
- Management of energy usage
- Power generation dispatch for solar, wind, etc.
- Better fault-tolerance of the grid
- Services for plug-in electric vehicles (PEV)
- Enhancing consumer relationships

Source: S. P. Mohanty, U. Choppali, and E. Kougianos, “Everything You wanted to Know about Smart Cities”, *IEEE Consumer Electronics Magazine*, Vol. 5, No. 3, July 2016, pp. 60--70.

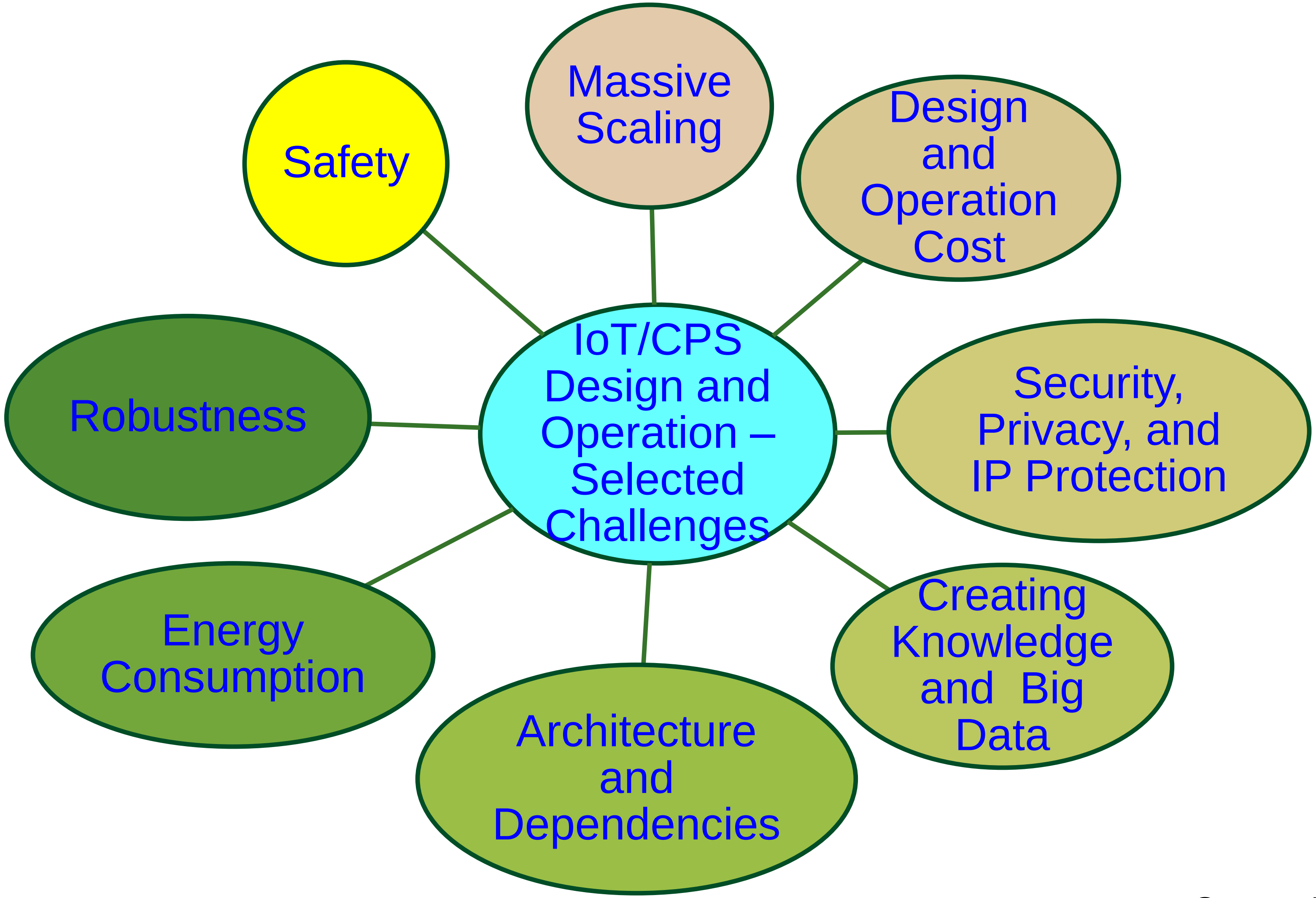
Services in Smart Cities and Smart Village

In Smart Cities	In Smart Village	Communication Type	Energy Source	Feasibility
Waste Management	Waste Management	WiFi, Sigfox, Neul, LoRaWAN	Battery Powered and Energy Harvesting	Feasible but smart containers adds in cost
Air Quality Monitoring	Smart Weather and Irrigation	BLE, ZigBee, 6LoWPAN, WiFi, Cellular, Sigfox, LoRaWAN	Solar Panels, Battery Power and Energy Harvesting	Feasible
Smart Surveillance	NA	BLE, WiFi, ZigBee, Cellular, Sigfox, LoRaWAN	Battery Power and Energy Harvesting	Feasible but additional sensors needed
Smart Energy	Smart Energy	ZigBee, Z-Wave, 6LoWPAN, Sigfox, LoRaWAN	PowerGrid, Solar Power, Wind Power, Energy Harvesting	Feasible
Smart Lighting	Smart Lighting	WiFi, ZigBee, Z-Wave, Sigfox, LoRaWAN	Power Grid, Solar Power, Energy Harvesting	Feasible
Smart Healthcare	Smart Healthcare	BLE, Bluetooth, WiFi, Cellular, Sigfox	Power Grid, Battery Power, and Energy Harvesting	Feasible
Smart Education	Smart Education	LR-WPAN, WiFi and Ethernet	Power Grid, Battery Power, and Energy Harvesting	Feasible
Smart Parking	NA	Z-Wave, WiFi, Cellular, Sigfox, LoRaWAN	Power Grid, Solar Power, Energy Harvesting	Feasible
Structural Health Monitoring	NA	BLE, WiFi, ZigBee, 6LoW-PAN, Sigfox	Power Grid, Solar Power, Battery Power, Energy Harvesting	Energy harvesting can be useful for power specs
Noise Monitoring	NA	6LoWPAN, WiFi, Cellular	Battery Power, Energy Harvesting, and Energy Scavenging	Sound pattern identification is a bottleneck
NA	Smart Farming	BLE, Bluetooth, WiFi, 6LoW-PAN, Sigfox, LoRaWAN	Power Grid, Battery Power and Energy Harvesting	Feasible
NA	Smart Diary	Bluetooth, WiFi, ZigBee, 6LoWPAN, LoRaWAN	Power Grid, Battery Power and Energy Harvesting	Feasible

Source: S. K. Ram, B. B. Das, K. K. Mahapatra, S. P. Mohanty, and U. Choppali, "Energy Perspectives in IoT Driven Smart Villages and Smart Cities", *IEEE Consumer Electronics Magazine (MCE)*, Vol. 10, No. 03, May 2021, pp. 19-28, DOI: 10.1109/MCE.2020.3023293.

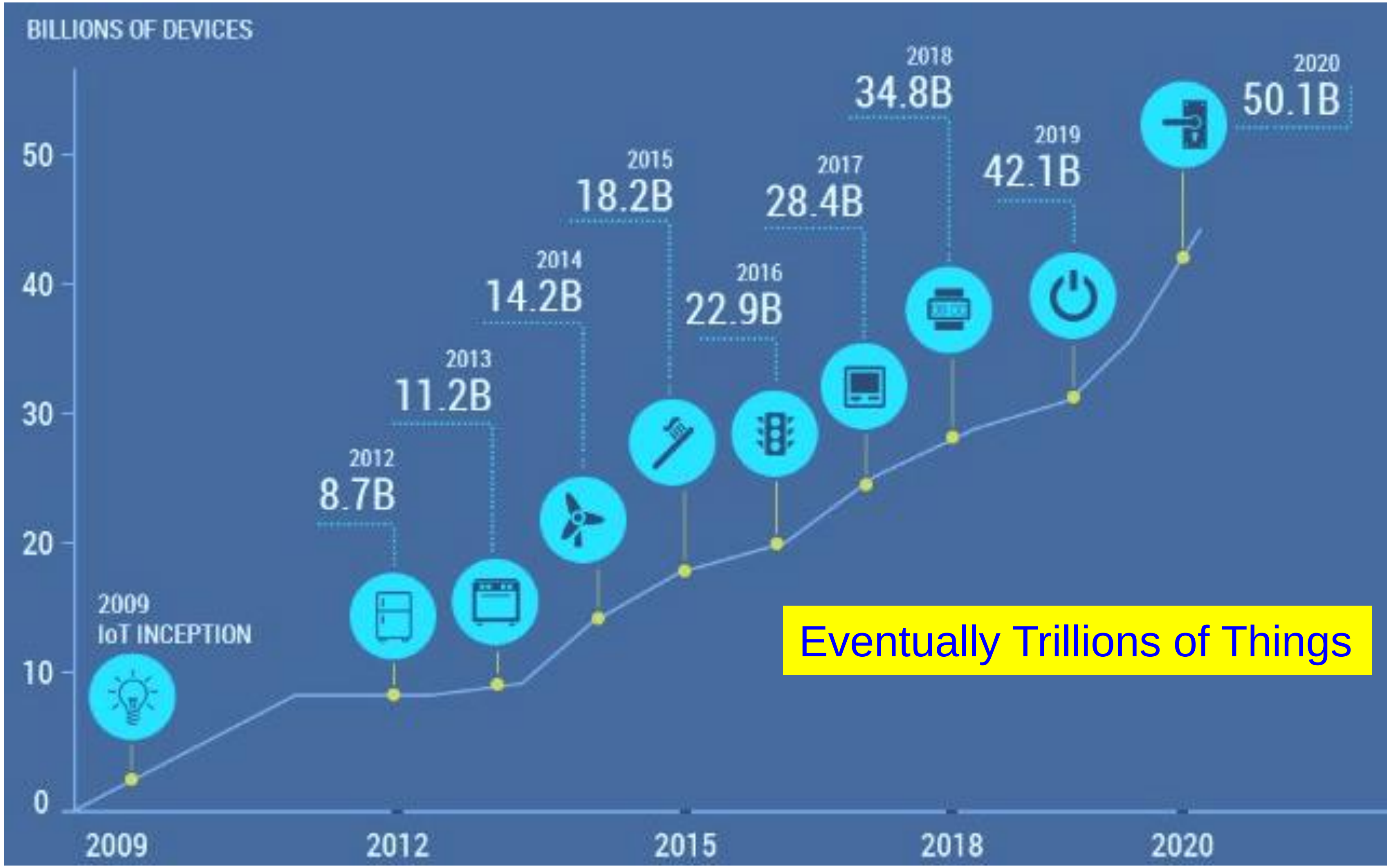
Challenges in CPS Design

CPS – Selected Challenges



Source: Mohanty ICIT 2017 Keynote

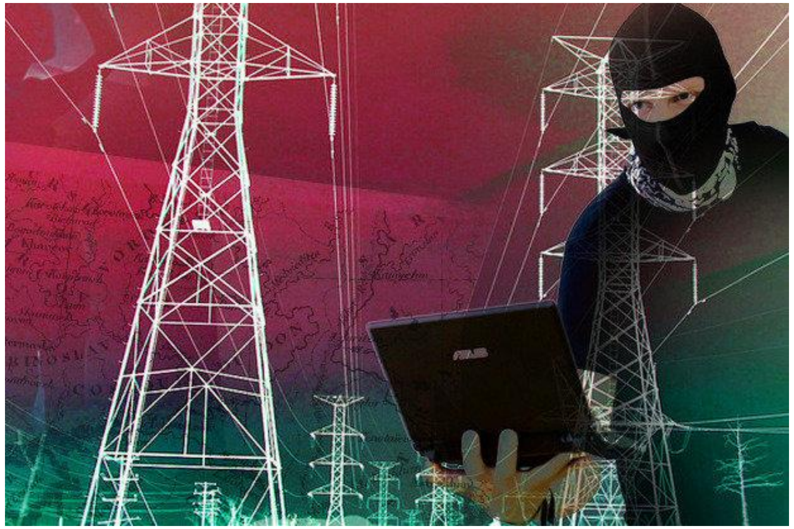
Massive Growth of Sensors/Things



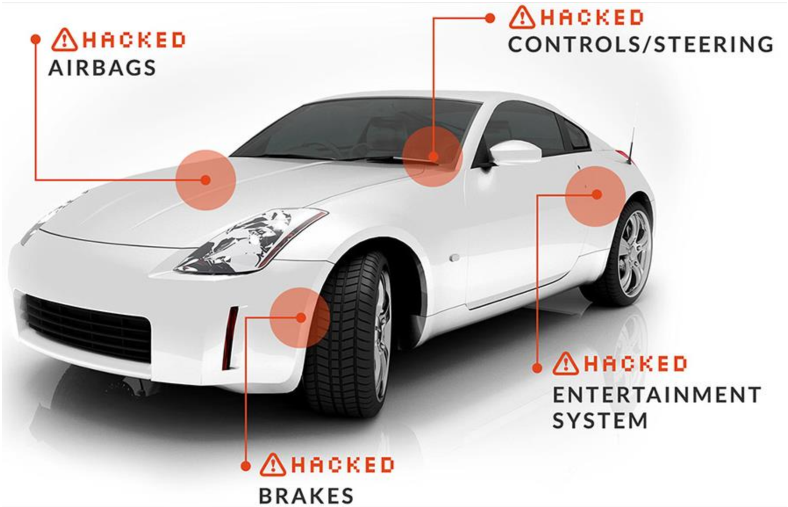
Source: https://www.linkedin.com/pulse/history-iot-industrial-internet-sensors-data-lakes-0-downtime

Cybersecurity Challenges - System

Power Grid Attack



Source: http://www.csoonline.com/article/3177209/security/why-the-ukraine-power-grid-attacks-should-raise-alarm.html



Source: http://money.cnn.com/2014/06/01/technology/security/car-hack/

Source: http://politicalblindspot.com/u-s-drone-hacked-and-hijacked-with-ease/

Smart Healthcare - Cybersecurity and Privacy Issue

Selected Smart Healthcare Security/Privacy Challenges

- Data Eavesdropping
- Data Confidentiality
- Data Privacy
- Location Privacy
- Identity Threats
- Access Control
- Unique Identification
- Data Integrity
- Device Security

Impersonation Attacks

Eavesdropping Attacks

Smart Healthcare

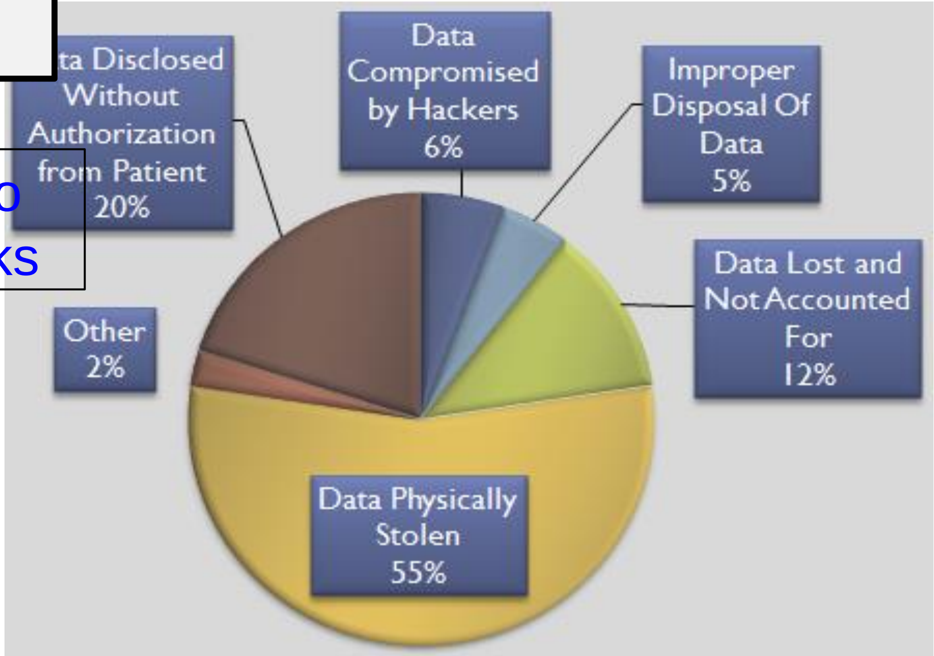
Reverse Engineering Attacks

Radio Attacks

HIPAA

Health Insurance Portability and Accountability Act

HIPPA Privacy Violation by Types



Implantable Medical Devices - Attacks

- The vulnerabilities affect implantable cardiac devices and the external equipment used to communicate with them.
- The devices emit RF signals that can be detected up to several meters from the body.
- A malicious individual nearby could conceivably hack into the signal to jam it, alter it, or snoop on it.

Source: Emily Waltz, Can "Internet-of-Body" Thwart Cyber Attacks on Implanted Medical Devices?, *IEEE Spectrum*, 28 Mar 2019, https://spectrum.ieee.org/the-human-os/biomedical/devices/thwart-cyber-attacks-on-implanted-medical-devices.amp.html.

IoMT/H-CPS Security Issue is Real and Scary

- Insulin pumps are vulnerable to hacking, FDA warns amid recall:

https://www.washingtonpost.com/health/2019/06/28/insulin-pumps-are-vulnerable-hacking-fda-warns-amid-recall/

- Software vulnerabilities in some medical devices could leave them susceptible to hackers, FDA warns:

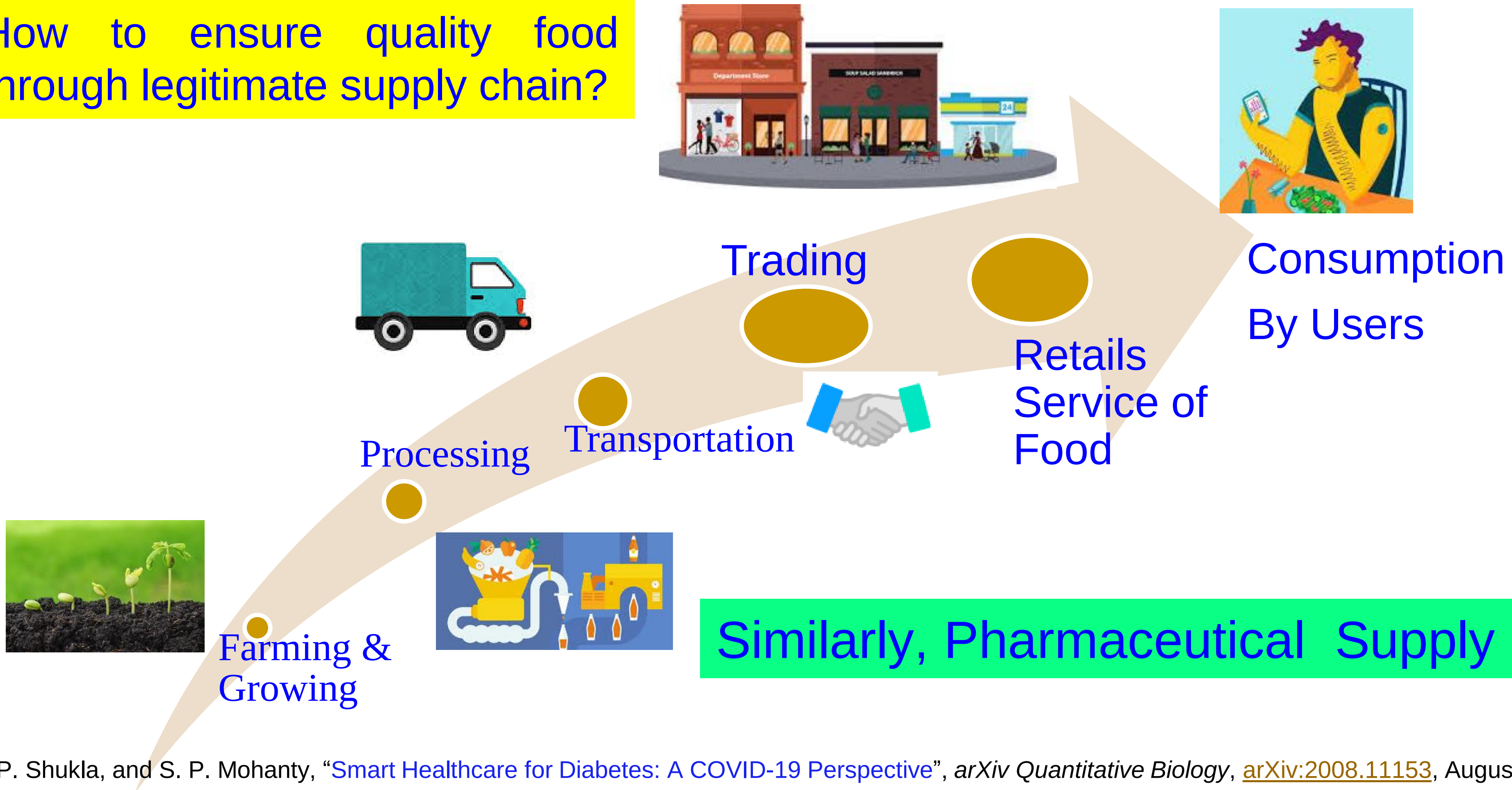
https://www.cnn.com/2019/10/02/health/fda-medical-devices-hackers-trnd/index.html

- FDA Issues Recall For Medtronic mHealth Devices Over Hacking Concerns:

https://mhealthintelligence.com/news/fda-issues-recall-for-medtronic-mhealth-devices-over-hacking-concerns

Reliable Supply Chain: Food Supply Chain: Farm → Dinning

How to ensure quality food through legitimate supply chain?

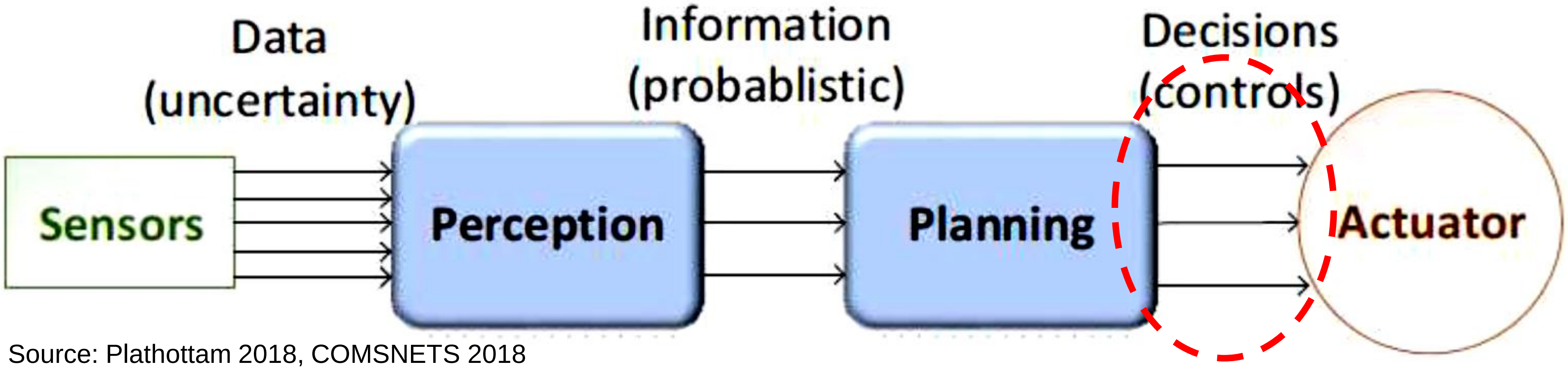


Similarly, Pharmaceutical Supply Chain

Source: A. M. Joshi, U. P. Shukla, and S. P. Mohanty, "Smart Healthcare for Diabetes: A COVID-19 Perspective", *arXiv Quantitative Biology*, arXiv:2008.11153, August 2020, 18-pages.

Smart Car – Modification of Input Signal of Control Can be Dangerous

- Typically vehicles are controlled by human drivers
- Designing an Autonomous Vehicle (AV) requires decision chains.
- AV actuators controlled by algorithms.
- Decision chain involves sensor data, perception, planning and actuation.
- Perception transforms sensory data to useful information.
- Planning involves decision making.



Source: Plathottam 2018, COMSNETS 2018

Smart Grid Attacks can be Catastrophic

Threats

Vulnerabilities

Security group knowledge
- Management deficiencies of network access rules
- Inaccurate critical assests documentation

Information leakage
- Unencrypted services in IT
- Weak protection credentials

Access point
- Improper access point
- Remote access deficiency
- Firewall filtering deficiency

Unpatched System
- Unpatched operating system
- Unpatched third party application

Weak cyber security
- Buffer overflow in control system services
- SQL injection vulnerability

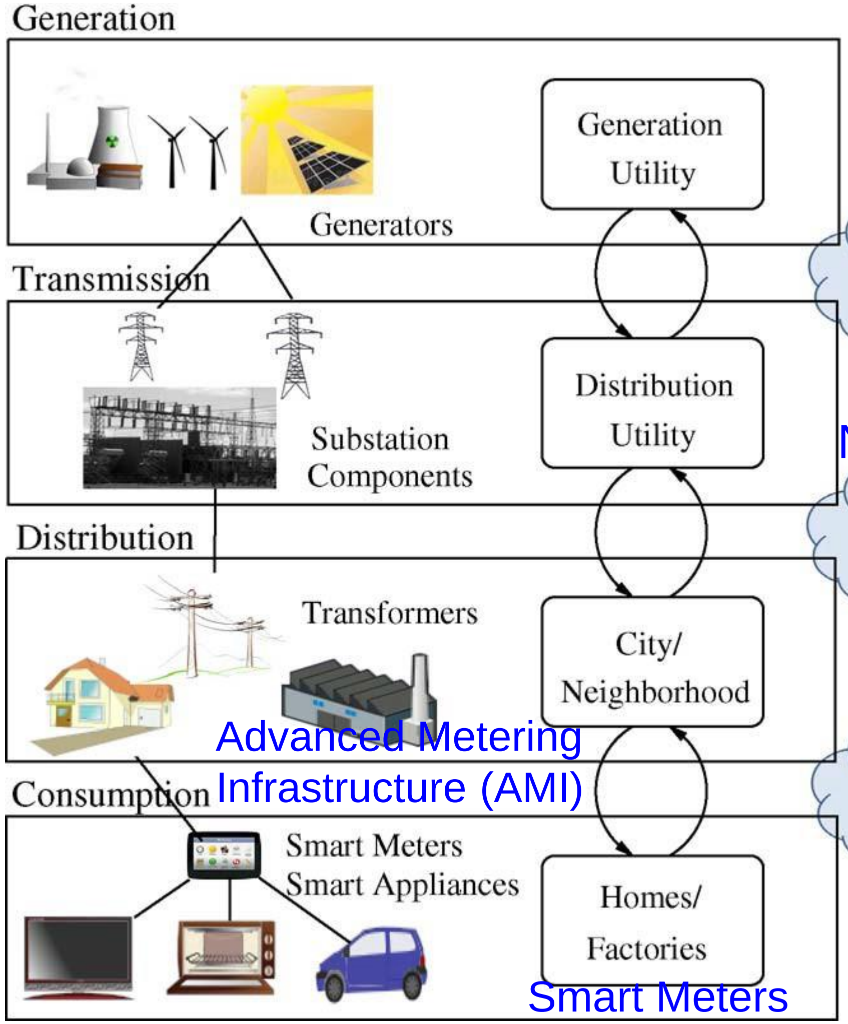
Source of Threats
- Phishers
- Nation
- Hacker
- Insider
- Terrorist
- Spammers
- Spyware / Malware authors

Attacks
- Stuxnet
- Night Dragon
- Virus
- Denial of service
- Trojan horse
- Worm
- Zero day exploit
- Logical bomb
- Phishing
- Distributed DoS
- False data Injection

Impacts
- Ukraine power attack, 2015
- Stuxnet attack in Iran, 2010
- Browns Ferry plant, Alabama 2006
- Emergency shut down of Hatch Nuclear Power Plant, 2008
- Slammer attack at Davis-Besse power plant, 2001
- Attacks at South Korea NPP, 2015

Source: R. K. Kaur, L. K. Singh and B. Pandey, "Security Analysis of Smart Grids: Successes and Challenges," *IEEE Consumer Electronics Magazine*, vol. 8, no. 2, pp. 10-15, Mar 2019.

Smart Grid - Vulnerability



Advanced Metering Infrastructure (AMI)

Smart Meters

Wide-Area Network (WAN)

Neighbor-Area Network (NAN)

Home-Area Network (HAN)

Control Center

Supervisory Control and Data Acquisition (SCADA)

Information and Communication Technology (ICT) components of smart grid is cyber vulnerable.

Data, Application/System Software, Firmware of Embedded System are the loop holes for security/privacy.

Network/Communication Components

Phasor Measurement Units (PMU)

Phasor Data Concentrators (PDC)

Energy Storage Systems (ESS)

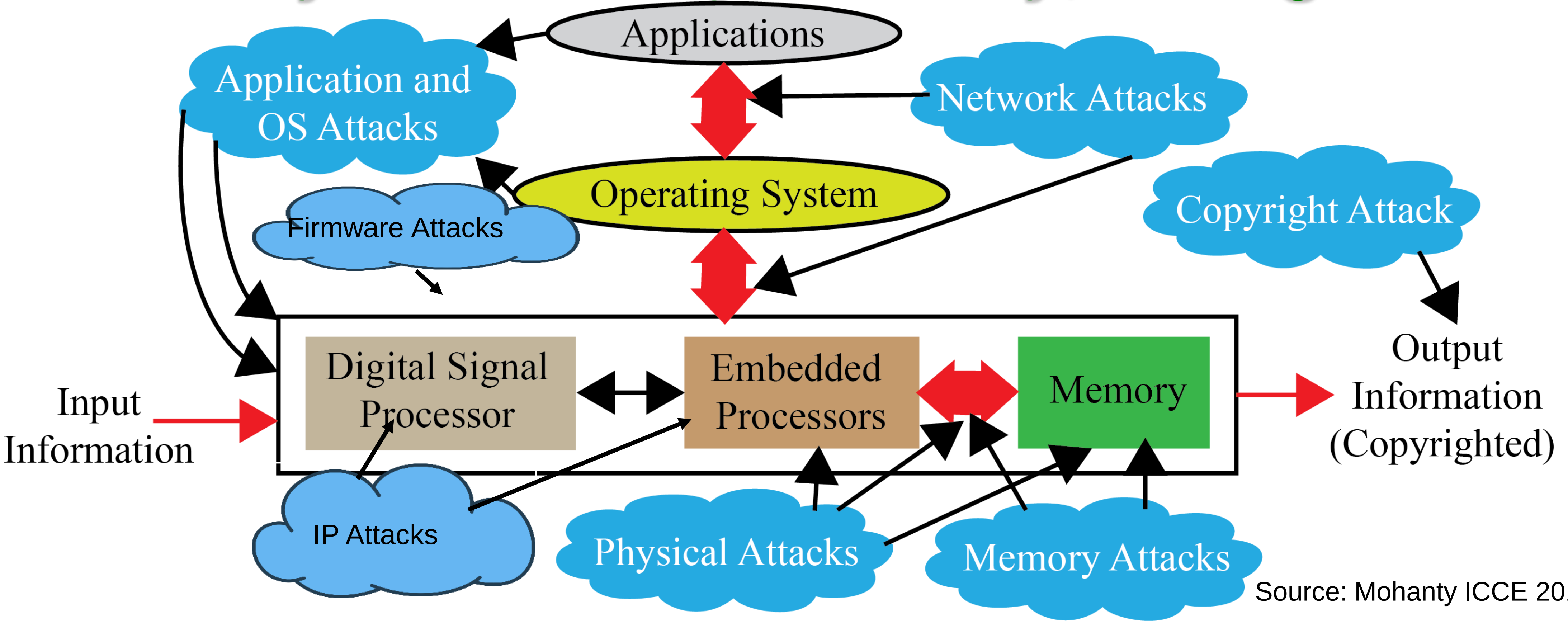
Programmable Logic Controllers (PLCs)

Smart Meters

Smart Grid Model – CPS Security Perspective

Source: Y. Mo *et al*., "Cyber–Physical Security of a Smart Grid Infrastructure“, *Proceedings of the IEEE*, vol. 100, no. 1, pp. 195-209, Jan. 2012.

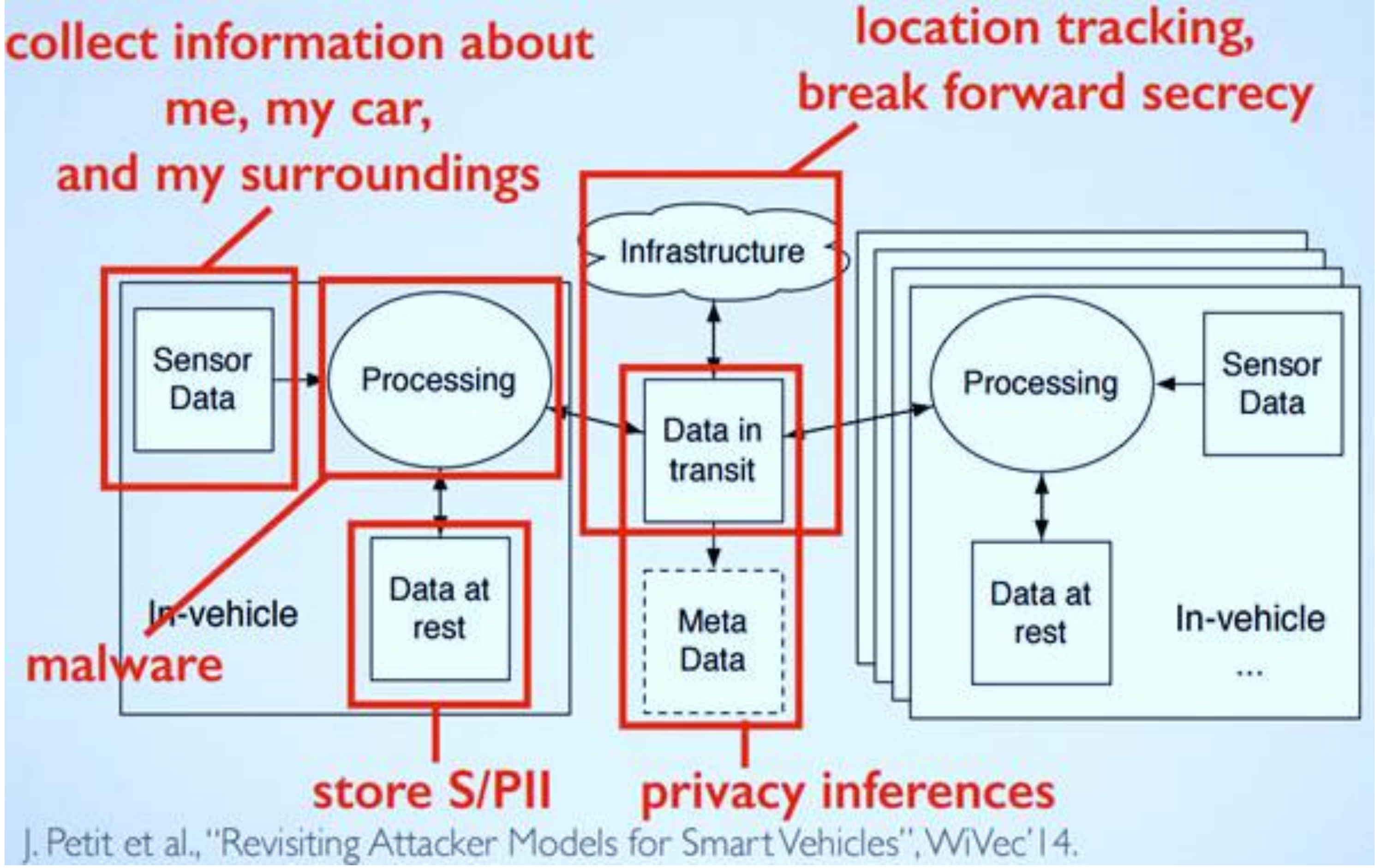
Selected Attacks on Smart Electronics – Cybersecurity, Privacy, IP Rights



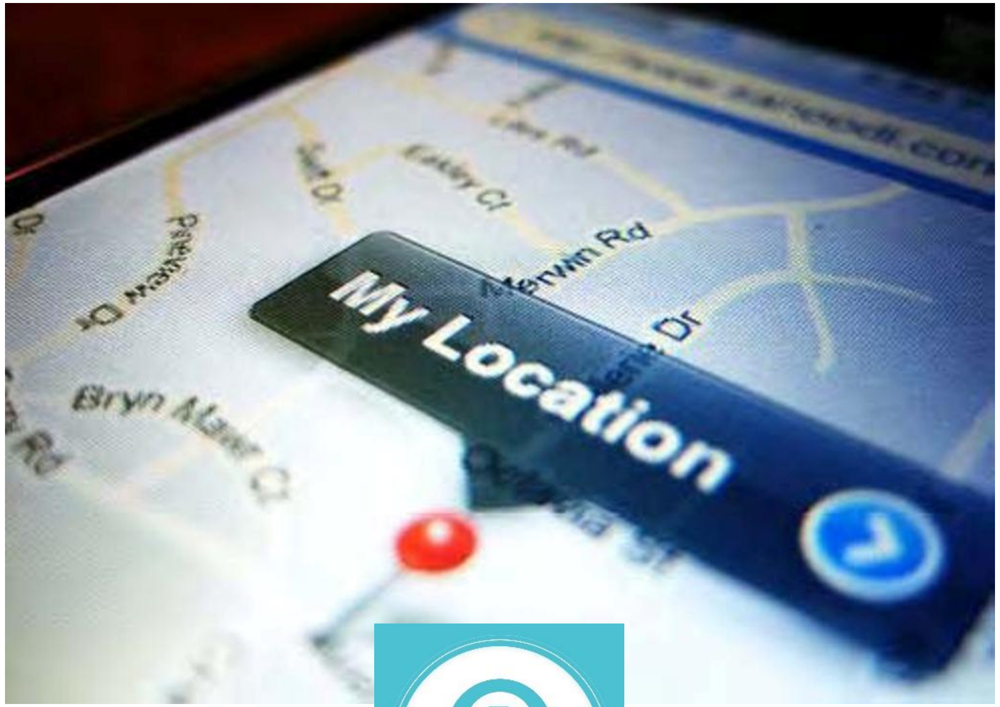
Source: Mohanty ICCE 2018 Keynote

Diverse forms of Attacks, following are not the same: System Security, Device Security, Information Security, Information Privacy, System Trustworthiness, Hardware IP protection, Information Copyright Protection.

Privacy Challenge – System, Location



Source: http://www.computerworld.com/article/3005436/cybercrime-hacking/black-hat-europe-it-s-easy-and-costs-only-60-to-hack-self-driving-car-sensors.html



Challenges of Data in IoT/CPS are Multifold

Lots of Data

Data Curation

Data Storage

Data Modeling

Data Quality

Data Ownership

Data Cost

Fake Data and Fake Hardware – Both are Equally Dangerous in CPS

AI can be fooled by fake data

AI can create fake data (Deepfake)

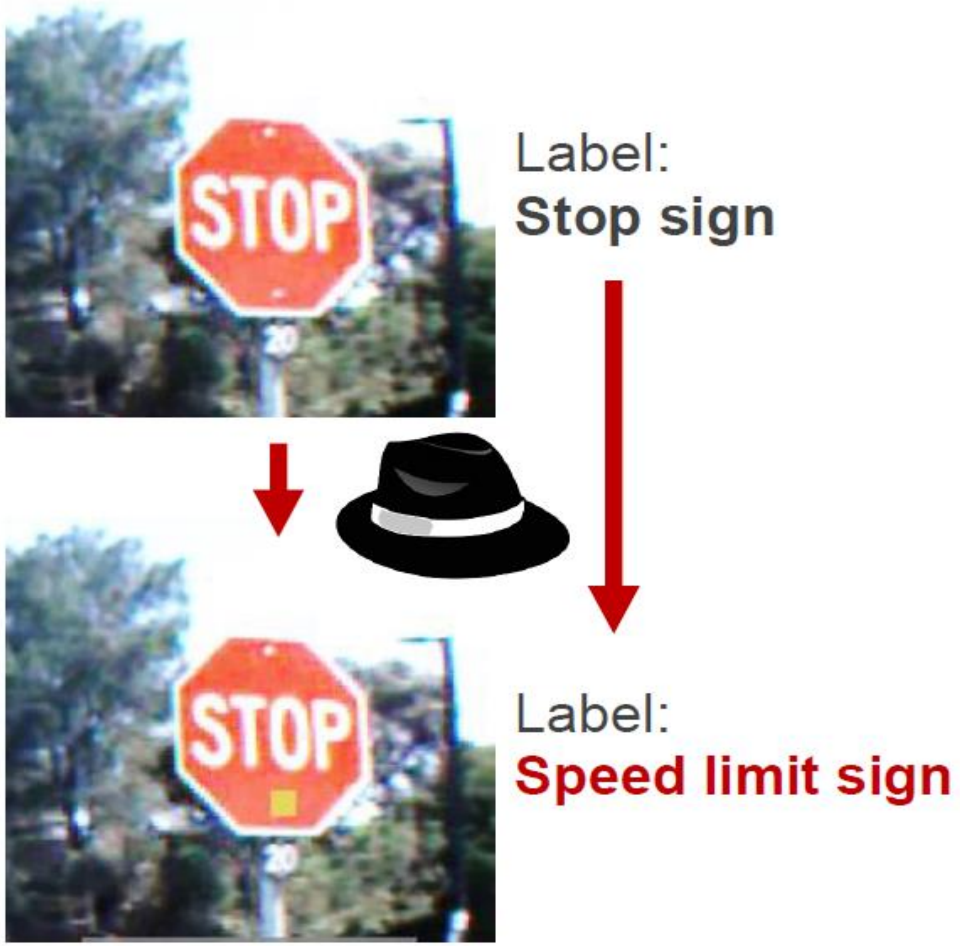
Authentic Fake

An implantable medical device

Authentic Fake

A plug-in for car-engine computers

AI Security - Trojans in Artificial Intelligence (TrojAI)

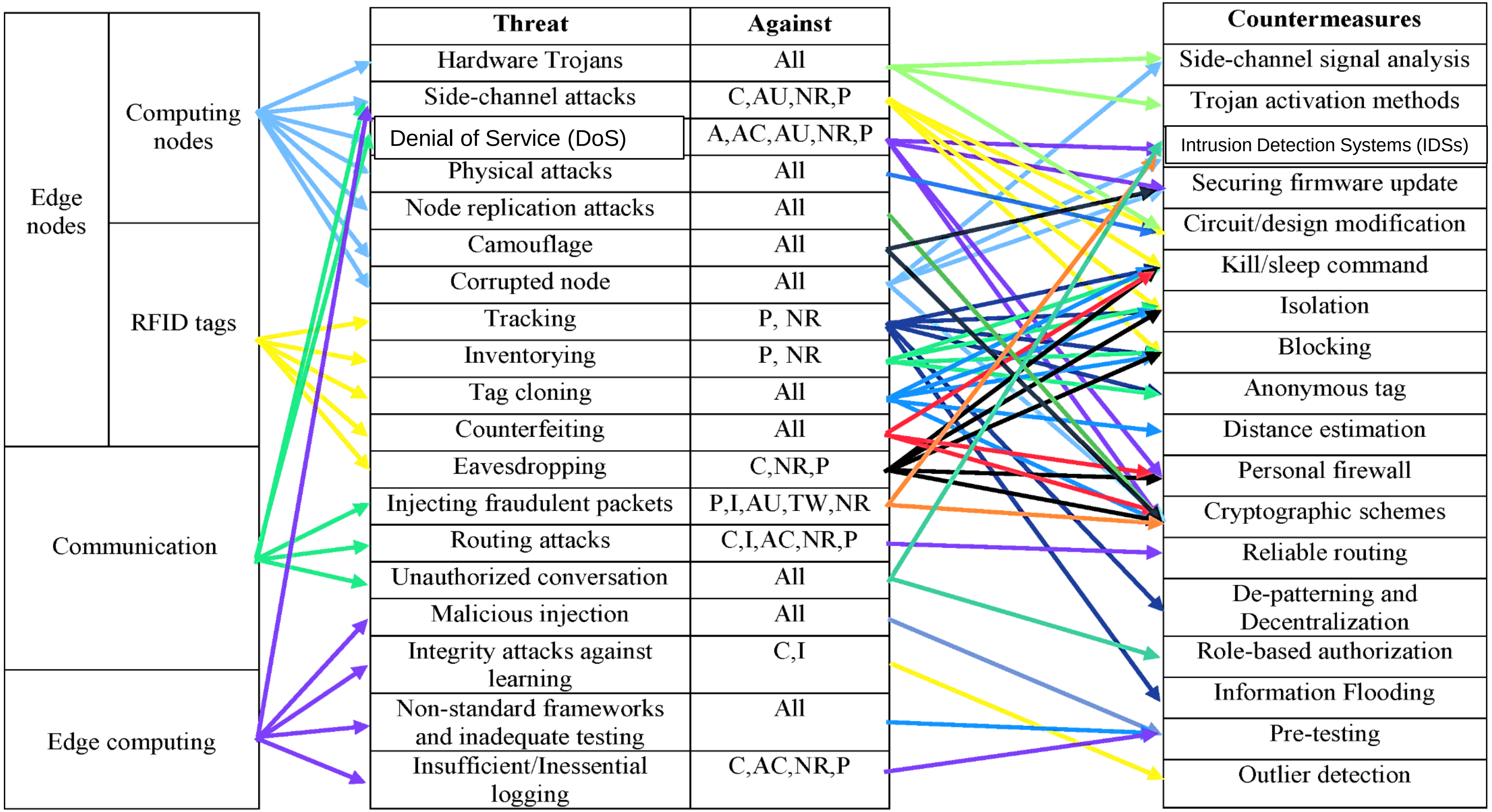


Adversaries can insert **Trojans** into AIs, leaving a trigger for bad behavior that they can activate during the AI's operations

Source: https://www.iarpa.gov/index.php?option=com_content&view=article&id=1150&Itemid=448

Cybrsecurity Solution for CPS

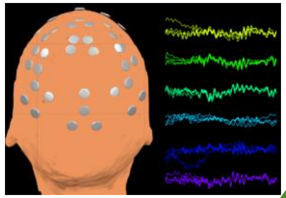
IoT Cybersecurity - Attacks and Countermeasures

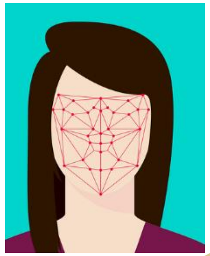


C- Confidentiality, I – Integrity, A - Availability, AC – Accountability, AU – Auditability, TW – Trustworthiness, NR - Non-repudiation, P - Privacy

Source: A. Mosenia, and Niraj K. Jha. "A Comprehensive Study of Security of Internet-of-Things", *IEEE Transactions on Emerging Topics in Computing*, 5(4), 2016, pp. 586-602.

Security, Authentication, Access Control – Home, Facilities, ...



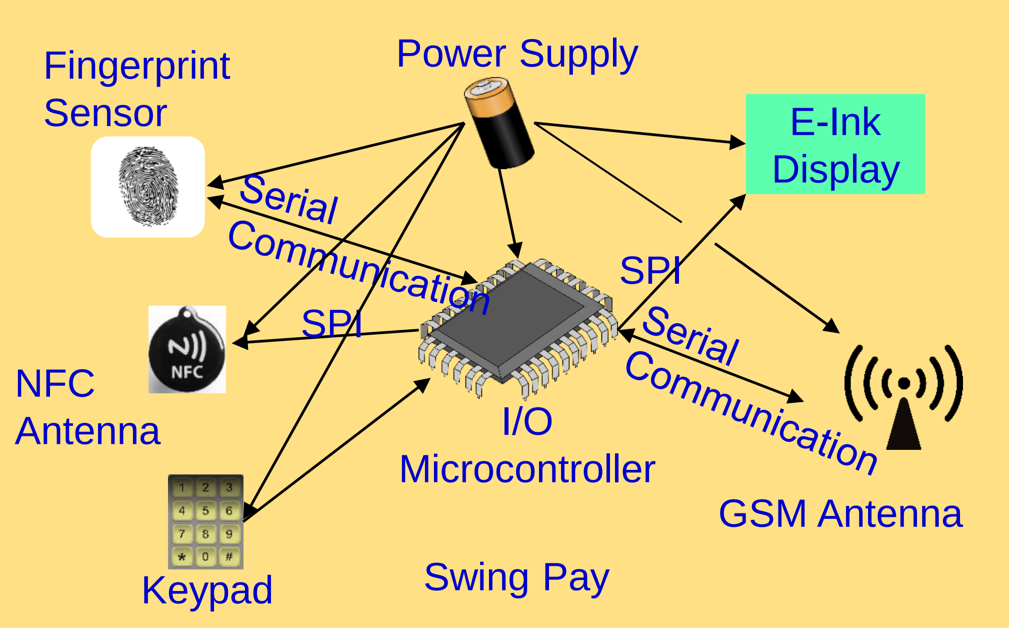


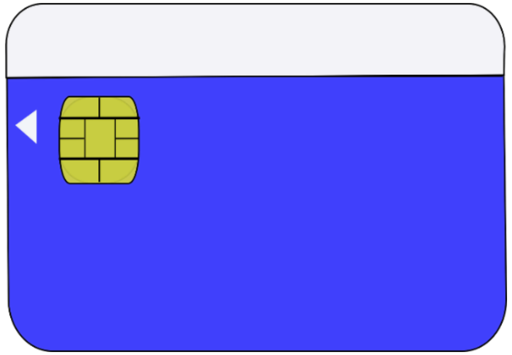
Security Methods (Authentication)

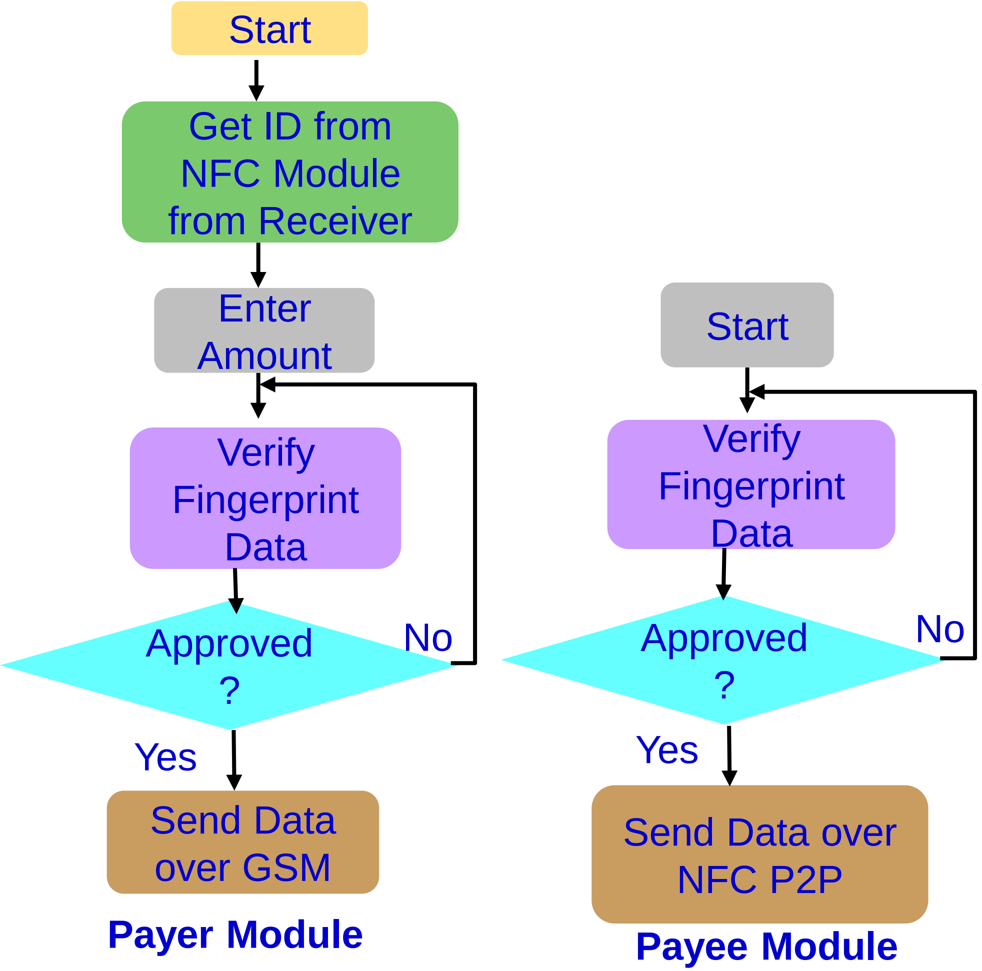
- Finger Vein
- Facial Recognition
- Fingerprint
- Personal Identification Number (PIN)
- Password
- Touch-Screen Pattern
- Online Signature
- Electrocardiography (ECG)
- Electroencephalography (EEG)

Source: Mohanty ISCT 2019 Keynote

Our Swing-Pay: NFC Cybersecurity Solution







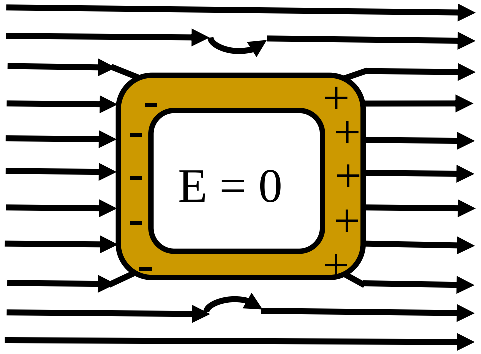
Source: S. Ghosh, J. Goswami, A. Majumder, A. Kumar, **S. P. Mohanty**, and B. K. Bhattacharyya, "Swing-Pay: One Card Meets All User Payment and Identity Needs", *IEEE Consumer Electronics Magazine (MCE)*, Volume 6, Issue 1, January 2017, pp. 82--93.

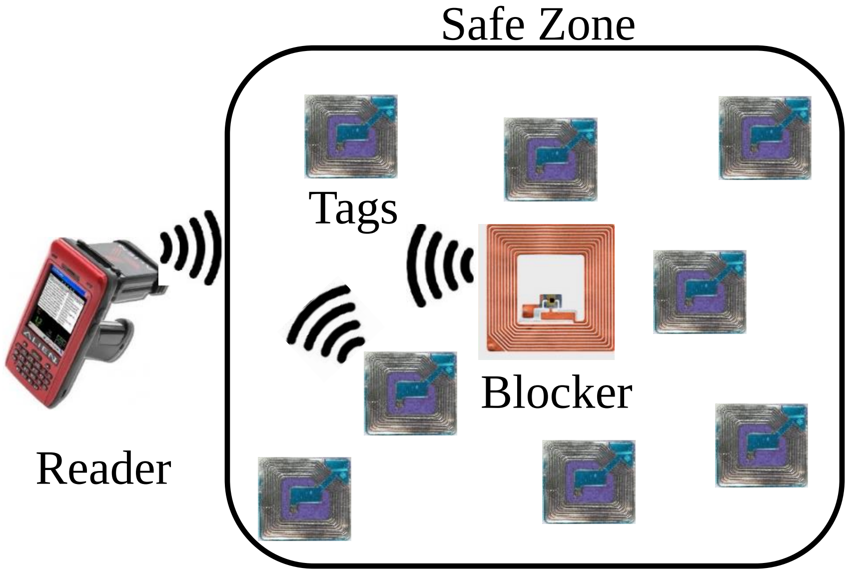
RFID Cybersecurity - Solutions

Selected RFID Security Methods

- Killing Tags
- Sleeping Tags
- Faraday Cage
- Blocker Tags
- Tag Relabeling
- Minimalist Cryptography
- Proxy Privacy Devices

Faraday Cage

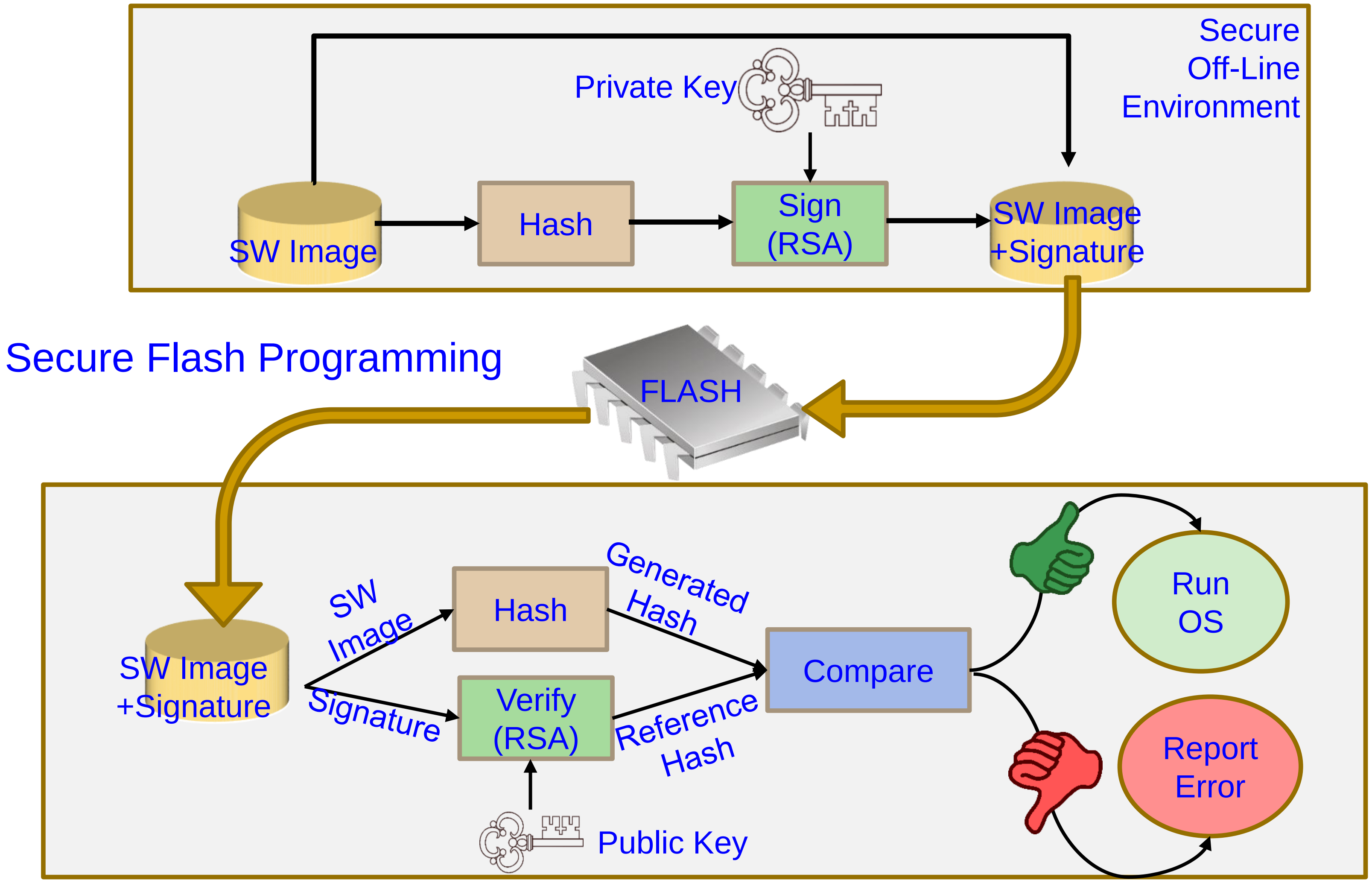




Blocker Tags

Source: Khattab 2017, Springer 2017 RFID Security

Firmware Cybersecurity - Solution



Source: https://www.nxp.com/docs/en/white-paper/AUTOSECURITYWP.pdf

Nonvolatile Memory Security and Protection

Source: http://datalocker.com

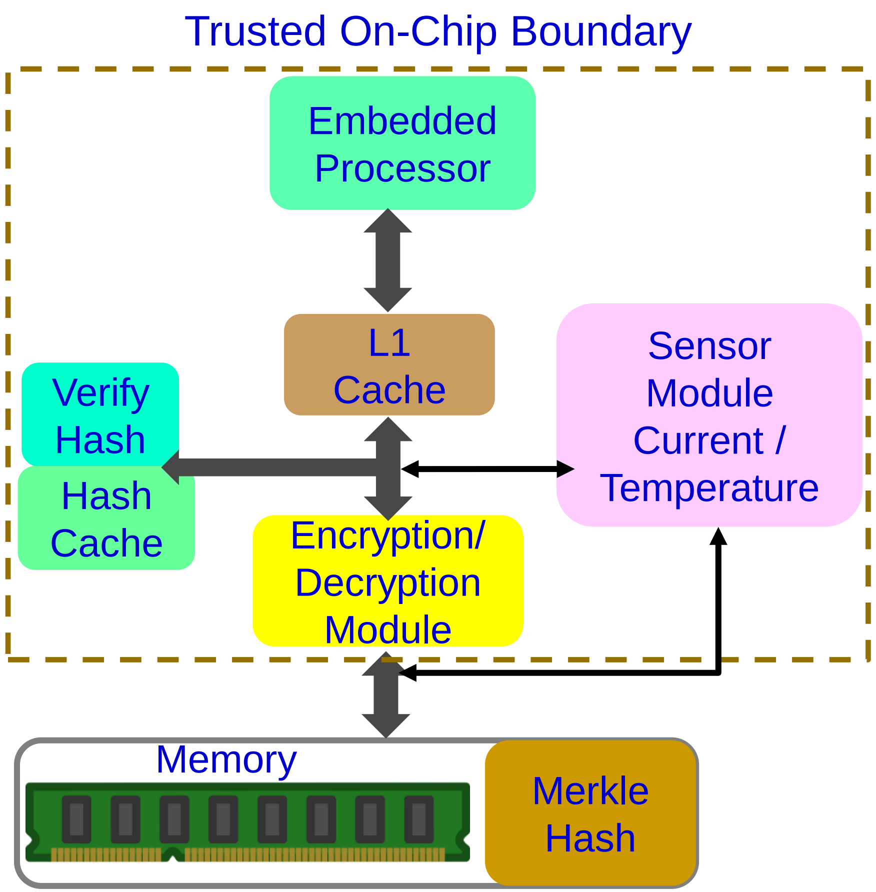
Nonvolatile / Harddrive Storage

Hardware-based encryption of data secured/protected by strong password/PIN authentication.

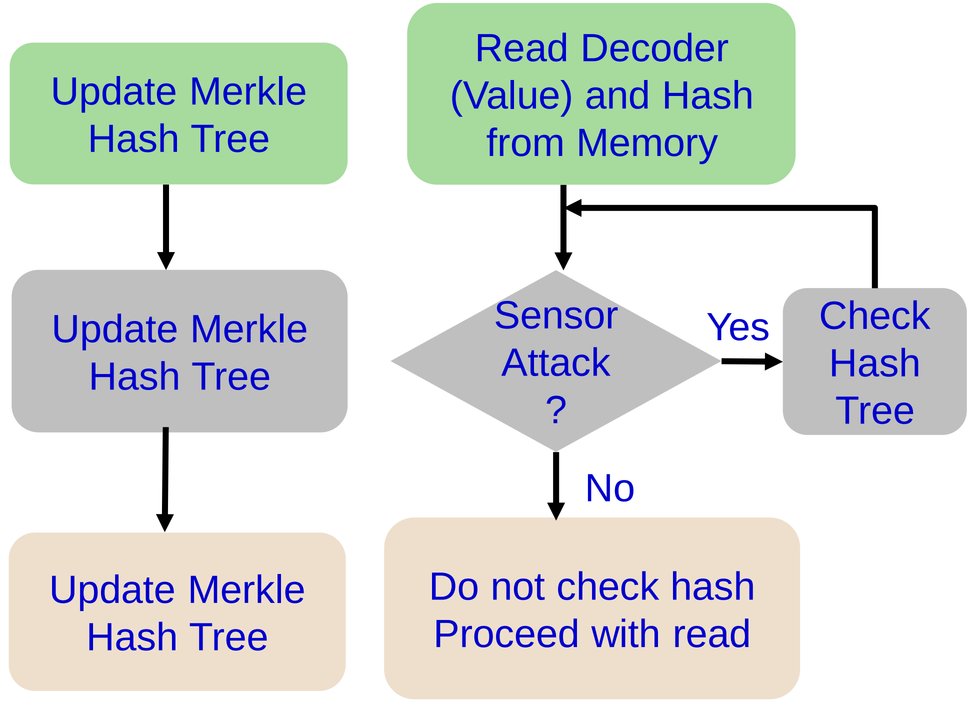
Software-based encryption to secure systems and partitions of hard drive.

Some performance penalty due to increase in latency!

Embedded Memory Security



On-Chip/On-Board Memory Protection



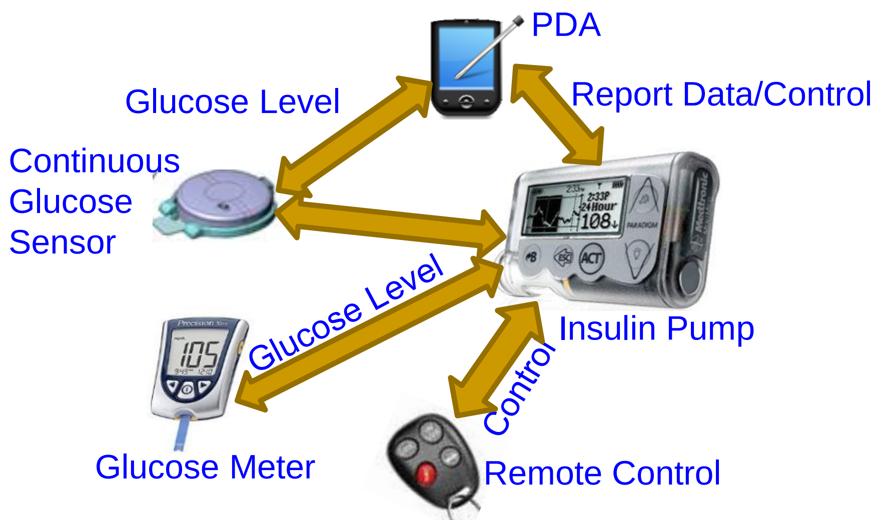
Write Operation

Read Operation

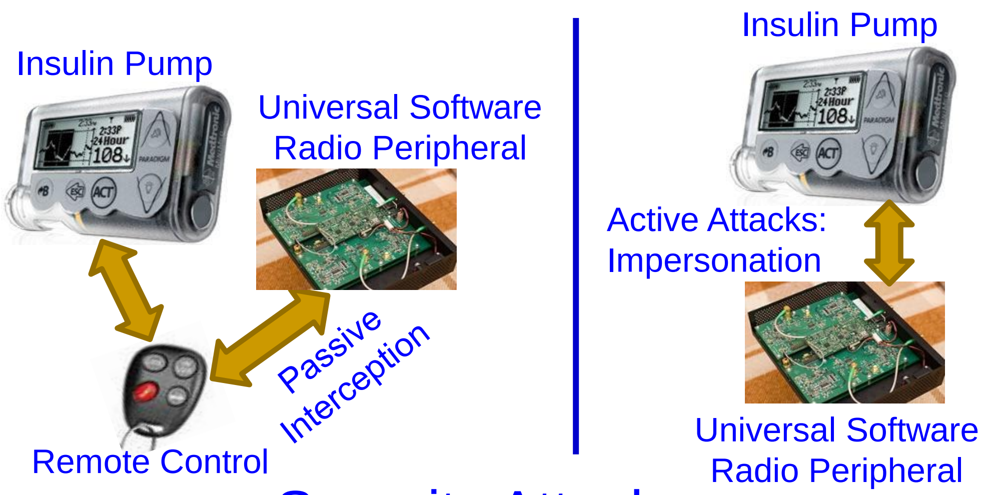
Memory integrity verification with 85% energy savings with minimal performance overhead.

Source: S. Nimgaonkar, M. Gomathisankaran, and S. P. Mohanty, “MEM-DnP: A Novel Energy Efficient Approach for Memory Integrity Detection and Protection in Embedded Systems”, *Springer Circuits, Systems, and Signal Processing Journal (CSSP)*, Volume 32, Issue 6, December 2013, pp. 2581--2604.

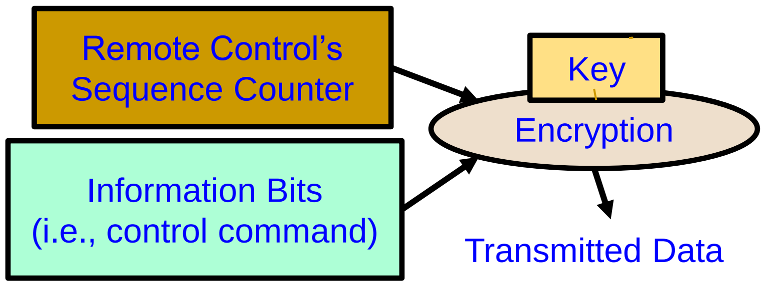
Smart Healthcare Cybersecurity



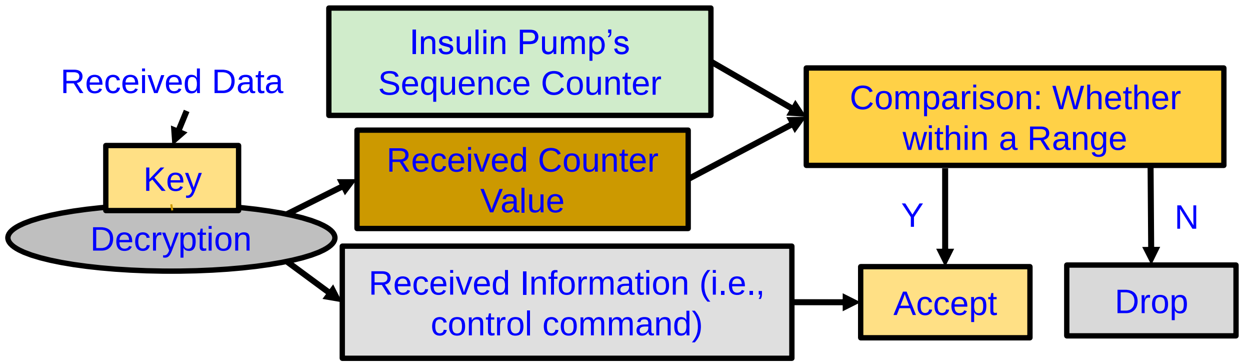
Insulin Delivery System



Security Attacks



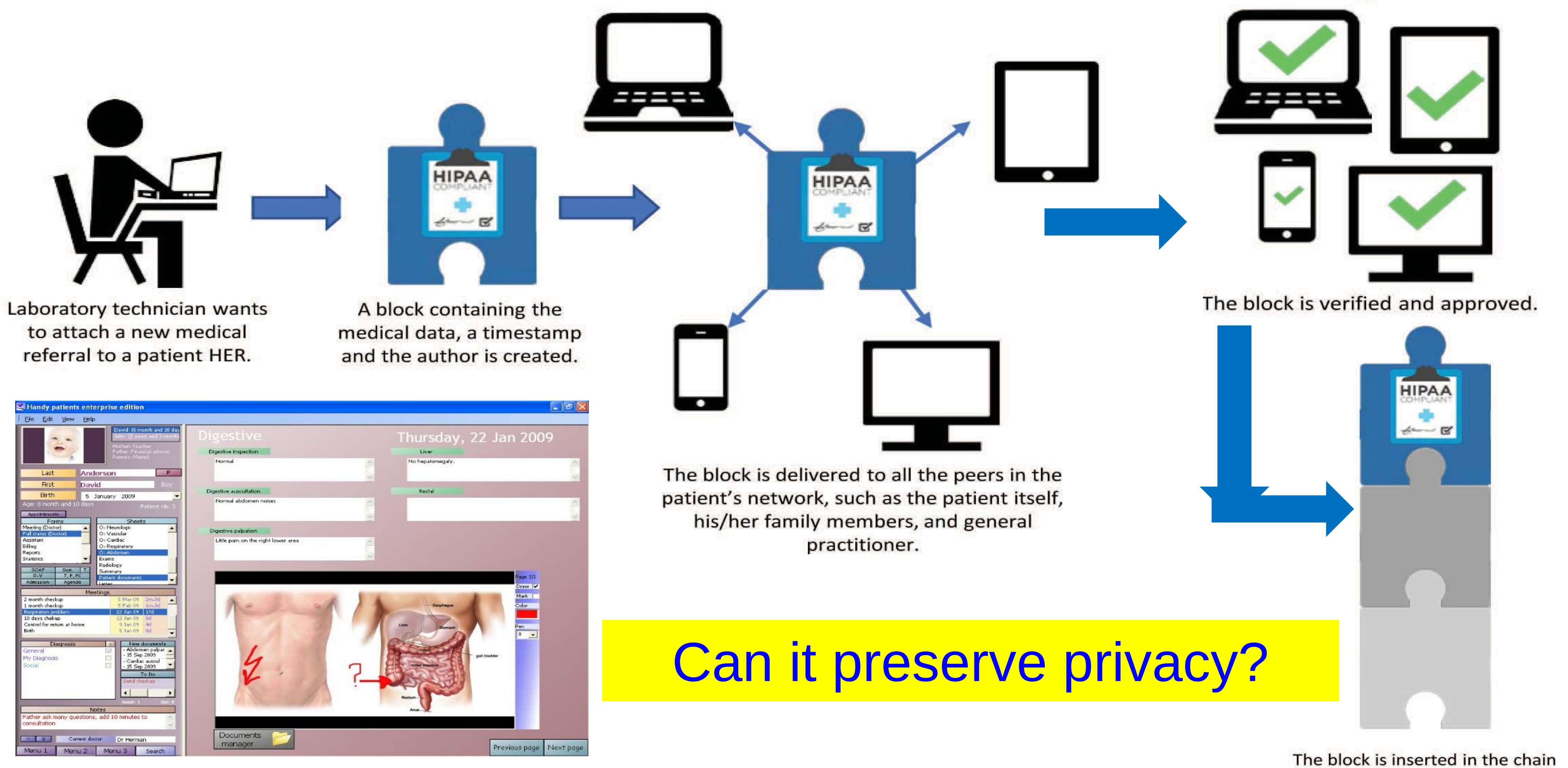
Rolling Code Encoder in Remote Control



Rolling Code Decoder in Insulin Pump

Source: Li and Jha 2011: HEALTH 2011

Blockchain in Smart Healthcare

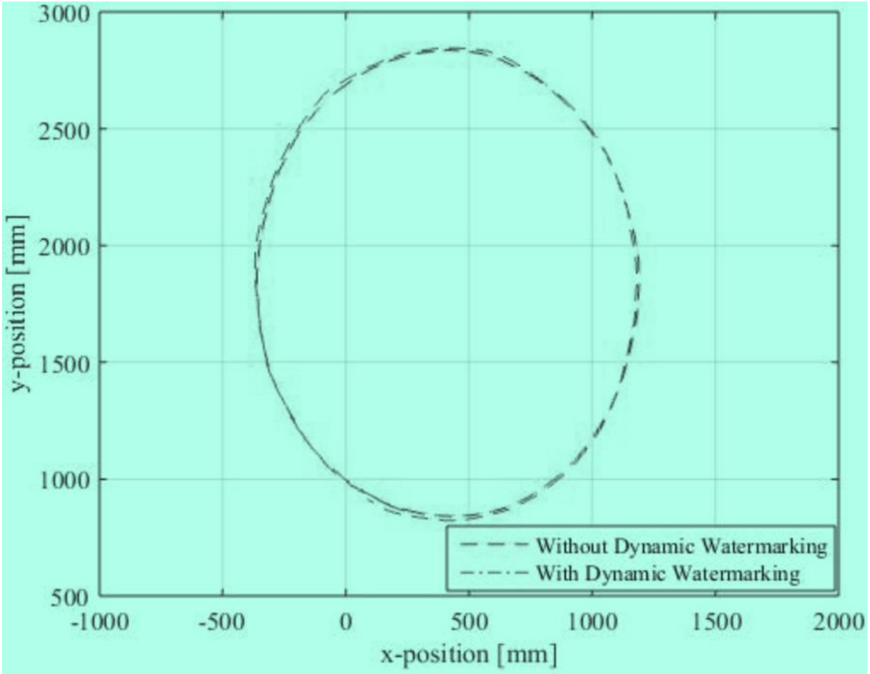


Can it preserve privacy?

Source: C. Esposito, A. De Santis, G. Tortora, H. Chang and K. R. Choo, "Blockchain: A Panacea for Healthcare Cloud-Based Data Security and Privacy?," *IEEE Cloud Computing*, vol. 5, no. 1, pp. 31-37, Jan./Feb. 2018.

Autonomous Car Cybersecurity – Collision Avoidance

- Attack: Feeding of malicious sensor measurements to the control and the collision avoidance module. Such an attack on a position sensor can result in collisions between the vehicles.
- Solutions: “**Dynamic Watermarking**” of signals to detect and stop such attacks on cyber-physical systems.
- Idea: Superimpose each actuator *i* a random signal $e_i[t]$ (watermark) on control policy-specified input.



Source: Ko 2016, CPS-Sec 2016

Drawbacks of Existing Cybersecurity Solutions

IoT/CPS Cybersecurity Solutions – Advantages and Disadvantages

Analysis of selected approaches to security and privacy issues in CE.			
Category	**Current Approaches**	**Advantages**	**Disadvantages**
Confidentiality	Symmetric key cryptography	Low computation overhead	Key distribution problem
	Asymmetric key cryptography	Good for key distribution	High computation overhead
Integrity	Message authentication codes	Verification of message contents	Additional computation overhead
Availability	Signature-based authentication	Avoids unnecessary signature computations	Requires additional infrastructure and rekeying scheme
Authentication	Physically unclonable functions (PUFs)	High speed	Additional implementation challenges
	Message authentication codes	Verification of sender	Computation overhead
Nonrepudiation	Digital signatures	Link message to sender	Difficult in pseudonymous systems
Identity privacy	Pseudonym	Disguise true identity	Vulnerable to pattern analysis
	Attribute-based credentials	Restrict access to information based on shared secrets	Require shared secrets with all desired services
Information privacy	Differential privacy	Limit privacy exposure of any single data record	True user-level privacy still chal-lenging
	Public-key cryptography	Integratable with hardware	Computationally intensive
Location privacy	Location cloaking	Personalized privacy	Requires additional infrastructure
Usage privacy	Differential privacy	Limit privacy exposure of any single data record	Recurrent/time-series data challenging to keep private

Source: D. A. Hahn, A. Munir, and S. P. Mohanty, “Security and Privacy Issues in Contemporary Consumer Electronics”, *IEEE Consumer Electronics Magazine*, Vol 8, No. 1, Jan 2019, pp. 95--99.

IT Cybersecurity Solutions Can't be Directly Extended to IoT/CPS Cybersecurity

IT Cybersecurity

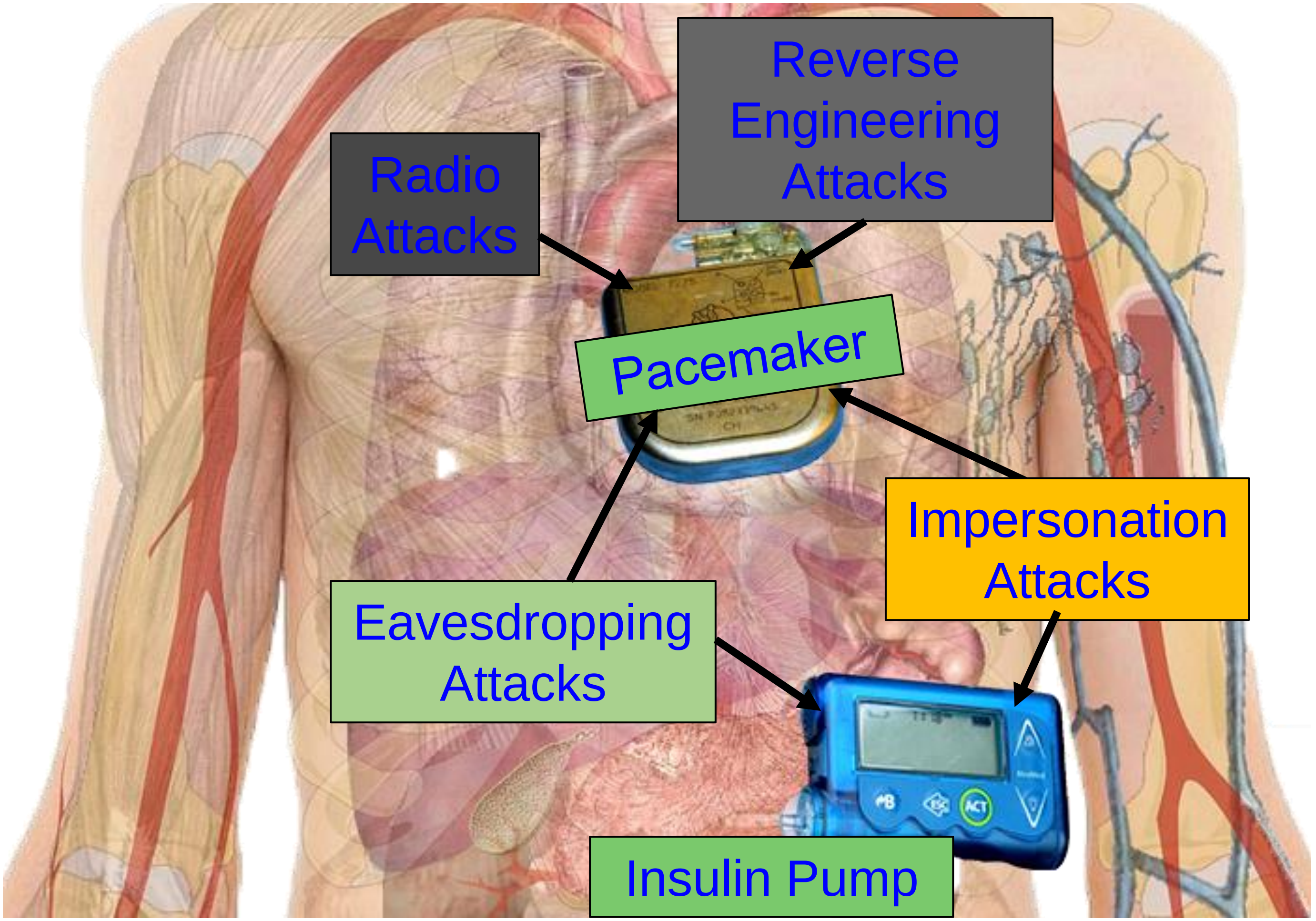
- IT infrastructure may be well protected rooms
- Limited variety of IT network devices
- Millions of IT devices
- Significant computational power to run heavy-duty security solutions
- IT security breach can be costly

IoT Cybersecurity

- IoT may be deployed in open hostile environments
- Significantly large variety of IoT devices
- Billions of IoT devices
- May not have computational power to run security solutions
- IoT security breach (e.g. in a IoMT device like pacemaker, insulin pump) can be life threatening

Maintaining of Cybersecurity of Electronic Systems, IoT, CPS, needs Energy, and affects performance.

Cybersecurity Measures in Healthcare Cyber-Physical Systems is Hard

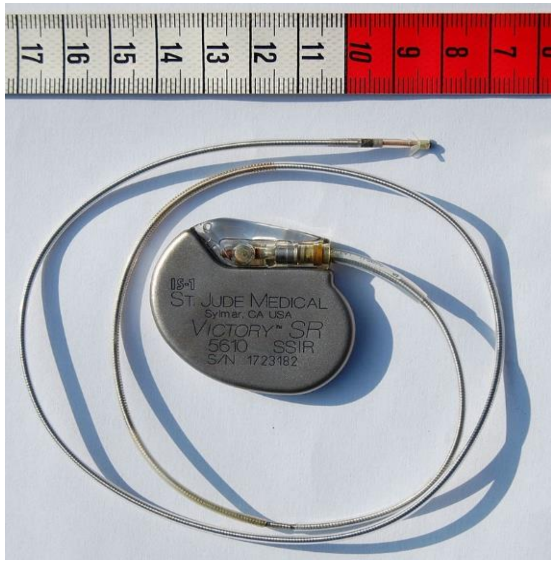


Collectively (WMD+IMD): Implantable and Wearable Medical Devices (IWMDs)

Implantable and Wearable Medical Devices (IWMDs):

→ Longer Battery life
→ Safer device
→ Smaller size
→ Smaller weight
→ Not much computational capability

H-CPS Cybersecurity Measures is Hard - Energy Constrained



Pacemaker
Battery Life
- 10 years

Neurostimulator
Battery Life
- 8 years

- Implantable Medical Devices (IMDs) have integrated battery to provide energy to all their functions → Limited Battery Life depending on functions
- Higher battery/energy usage → Lower IMD lifetime
- Battery/IMD replacement → Needs surgical risky procedures

Source: C. Camara, P. Peris-Lopeza, and J. E.Tapiadora, “Security and privacy issues in implantable medical devices: A comprehensive survey", *Elsevier Journal of Biomedical Informatics*, Volume 55, June 2015, Pages 272-289.

Smart Car Cybersecurity - Latency Constrained

Protecting Communications
Particularly any Modems for In-vehicle Infotainment (IVI) or in On-board Diagnostics (OBD-II)

Over The Air (OTA) Management
From the Cloud to Each Car

Cars can have 100 Electronic Control Units (ECUs) and 100 million lines of code, each from different vendors – Massive cybersecurity issues.

Protecting Each Module
Sensors, Actuators, and Anything with an Microcontroller Unit (MCU)

Mitigating Advanced Threats
Analytics in the Car and in the Cloud

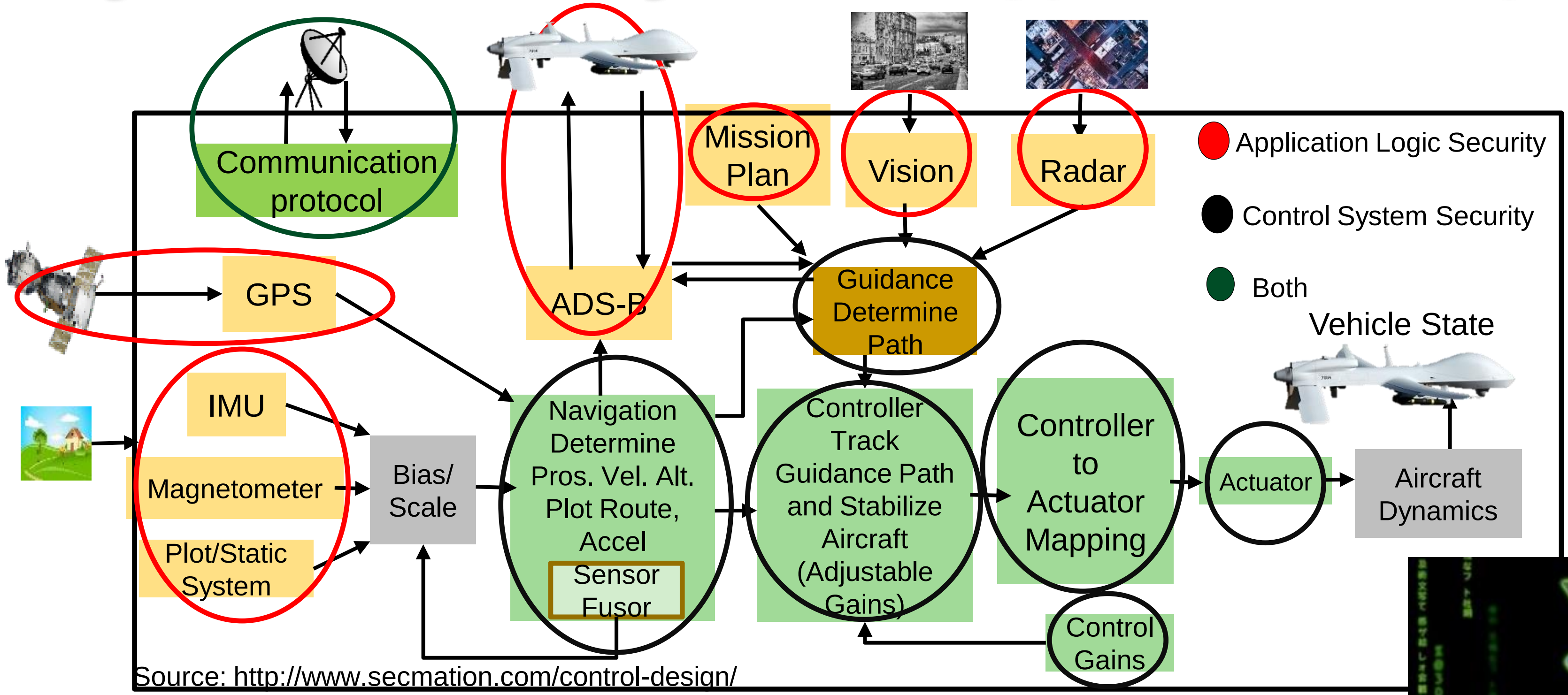
Source: http://www.symantec.com/content/en/us/enterprise/white_papers/public-building-security-into-cars-20150805.pdf

- Connected cars require latency of ms to communicate and avoid impending crash:
  - Faster connection
  - Low latency
  - Energy efficiency

Security Mechanism Affects:
- Latency
- Mileage
- Battery Life

Car Cybersecurity – Latency Constrained

UAV Cybersecurity - Energy & Latency Constrained



Source: http://www.secmation.com/control-design/

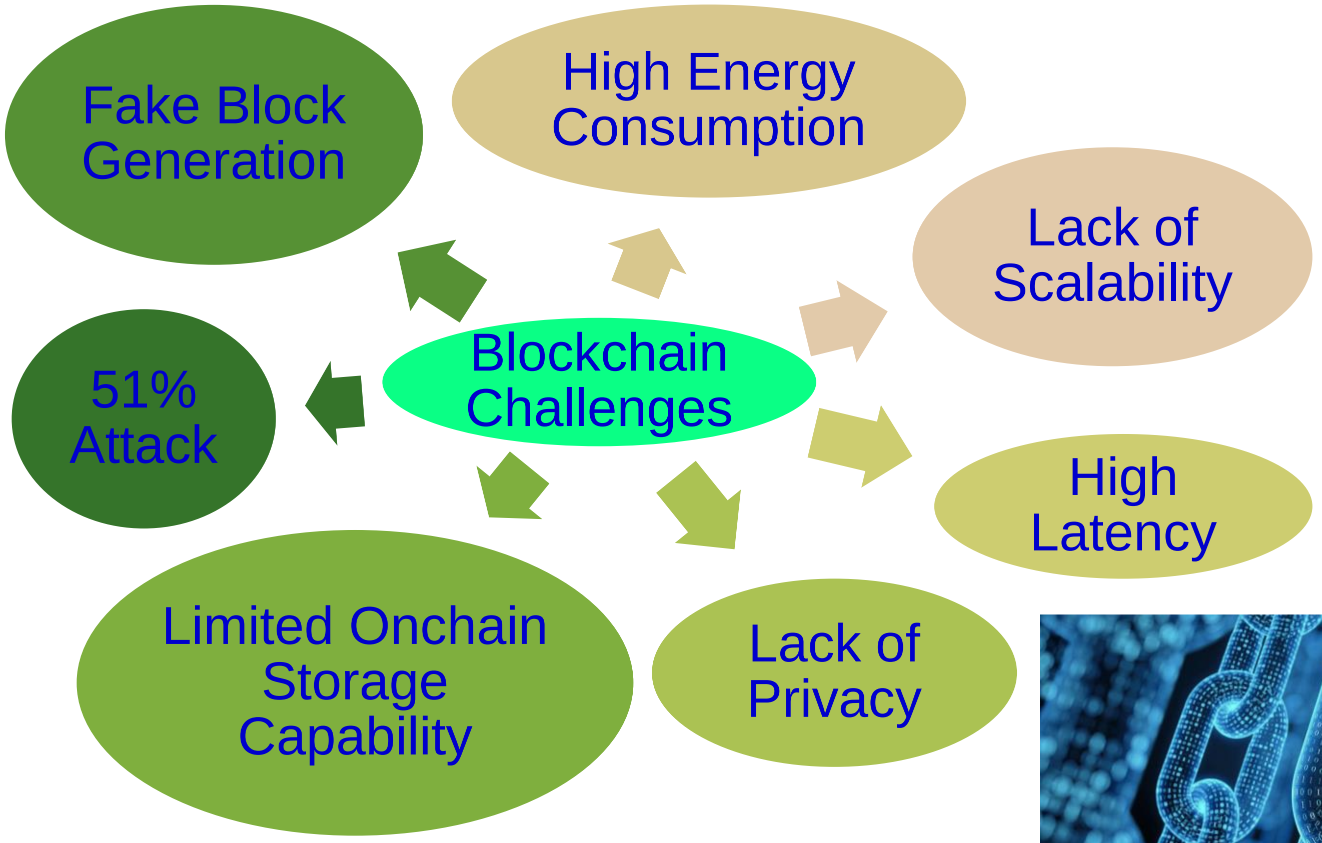
Source: http://politicalblindspot.com/u-s-drone-hacked-and-hijacked-with-ease/

Cybersecurity Mechanisms Affect:

Battery Life | Latency | Weight | Aerodynamics

UAV Security – Energy and Latency Constraints

Blockchain has Many Challenges



Source: https://www.etorox.com

Source: D. Puthal, N. Malik, S. P. Mohanty, E. Kougianos, and G. Das, “Everything you Wanted to Know about the Blockchain”, *IEEE Consumer Electronics Magazine*, Volume 7, Issue 4, July 2018, pp. 06--14.

Source: https://www.monash.edu/blockchain/news/how-do-we-know-blockchain-cant-be-hacked-or-manipulated-or-can-it

Blockchain Energy Need is Huge

Energy for mining of 1 bitcoin

=

Energy consumption 2 years of a US household

Energy consumption for each bitcoin transaction

=

80,000 X

Energy consumption of a credit card processing

Blockchain has Cybersecurity Challenges

Selected attacks on the blockchain and defences		
Attacks	Descriptions	Defence
Double spending	Many payments are made with a body of funds	Complexity of mining process
Record hacking	Blocks are modified, and fraudulent transactions are inserted	Distributed consensus
51% attack	A miner with more than half of the network's computational power dominates the verification process	Detection methods and design of incentives
Identity theft	An entity's private key is stolen	Reputation of the blockchain on identities
System hacking	The software systems that implement a blockchain are compromised	Advanced intrusion detection systems

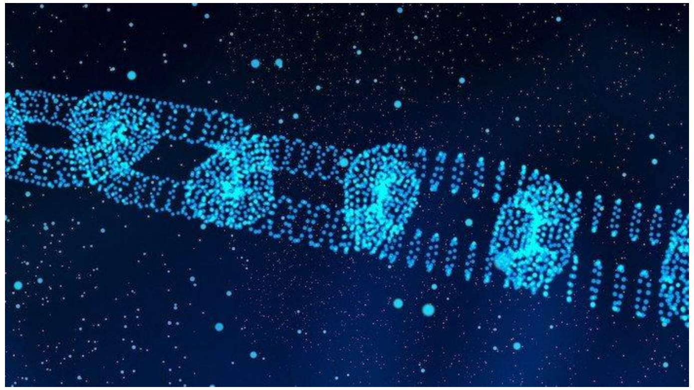
Source: N. Kolokotronis, K. Limniotis, S. Shiaeles, and R. Griffiths, "Secured by Blockchain: Safeguarding Internet of Things Devices," *IEEE Consumer Electronics Magazine*, vol. 8, no. 3, pp. 28–34, May 2019.

Blockchain has Serious Privacy Issue

	Bitcoin	Dash	Monero	Verge	PIVX	Zcash
Origin	-	Bitcoin	Bytecoin	Bitcoin	Dash	Bitcoin
Release	January 2009	January 2014	April 2014	October 2014	February 2016	October 2016
Consensus Algorithm	PoW	PoW	PoW	PoW	PoS	PoW
Hardware Mineable	Yes	Yes	Yes	Yes	No	Yes
Block Time	600 sec.	150 sec.	120 sec.	30 sec.	60 sec.	150 sec.
Rich List	Yes	Yes	No	Yes	Yes	No
Master Node	No	Yes	No	No	Yes	No
Sender Address Hidden	No	Yes	Yes	No	Yes	Yes
Receiver Address Hidden	No	Yes	Yes	No	Yes	Yes
Sent Amount Hidden	No	No	Yes	No	No	Yes
IP Addresses Hidden	No	No	No	Yes	No	No
Privacy	No	No	Yes	No	No	Yes
Untraceability	No	No	Yes	No	No	Yes
Fungibility	No	No	Yes	No	No	Yes

Source: J. Lee, "Rise of Anonymous Cryptocurrencies: Brief Introduction", *IEEE Consumer Electronics Magazine*, vol. 8, no. 5, pp. 20-25, September 2019.

When do You Need the Blockchain?



Information of the System that may need a blockchain?

Does system need permanent shared data storage? — No → Blockchain is not needed; Yes ↓

Blockchain provides historical consistent data storage

Are there multiple data contributors to system? — No → Blockchain is not needed; Yes ↓

Blockchain is used when multiple entities are giving data

Does the application modify data after storage? — No → Blockchain is not needed; Yes ↓

Blockchain does not allow data modification after storage

Is data privacy required? — No → Blockchain is not needed; Yes ↓

Blockchain does not provide data privacy, even if it is in an encrypted format

Does the system work in an untrusted environment? — No → Blockchain is not needed; Yes ↓

Blockchain is not required, if there are no trust issues in a system

Does the system need tamperproof data storage? — No → Blockchain is not needed; Yes ↓

Blockchain is not suitable solution if auditing in real-time

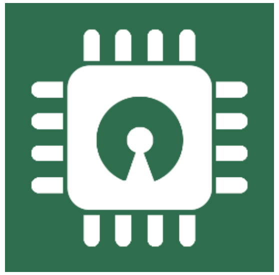
Your system needs the blockchain

Source: D. Puthal, S. P. Mohanty, E. Kougianos and G. Das, "When Do We Need the Blockchain?," *IEEE Consumer Electronics Magazine*, Vol 10, No. 2, Mar 2021, pp. 53--56.

Cybersecurity Attacks – Software Vs Hardware Based

Software Based

- Software attacks via communication channels
- Typically from remote
- More frequent
- Selected Software based:
  - Denial-of-Service (DoS)
  - Routing Attacks
  - Malicious Injection
  - Injection of fraudulent packets
  - Snooping attack of memory
  - Spoofing attack of memory and IP address
  - Password-based attacks



Hardware Based

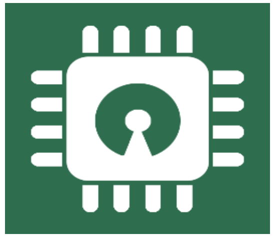
- Hardware or physical attacks
- Maybe local
- More difficult to prevent
- Selected Hardware based:
  - Hardware backdoors (e.g. Trojan)
  - Inducing faults
  - Electronic system tampering/ jailbreaking
  - Eavesdropping for protected memory
  - Side channel attack
  - Hardware counterfeiting

Source: Mohanty ICCE Panel 2018

Cybersecurity Solutions – Software Vs Hardware Based

Software Based

- Introduces latency in operation
- Flexible - Easy to use, upgrade and update
- Wider-Use - Use for all devices in an organization
- Higher recurring operational cost
- Tasks of encryption easy compared to hardware – substitution tables
- Needs general purpose processor
- Can’t stop hardware reverse engineering

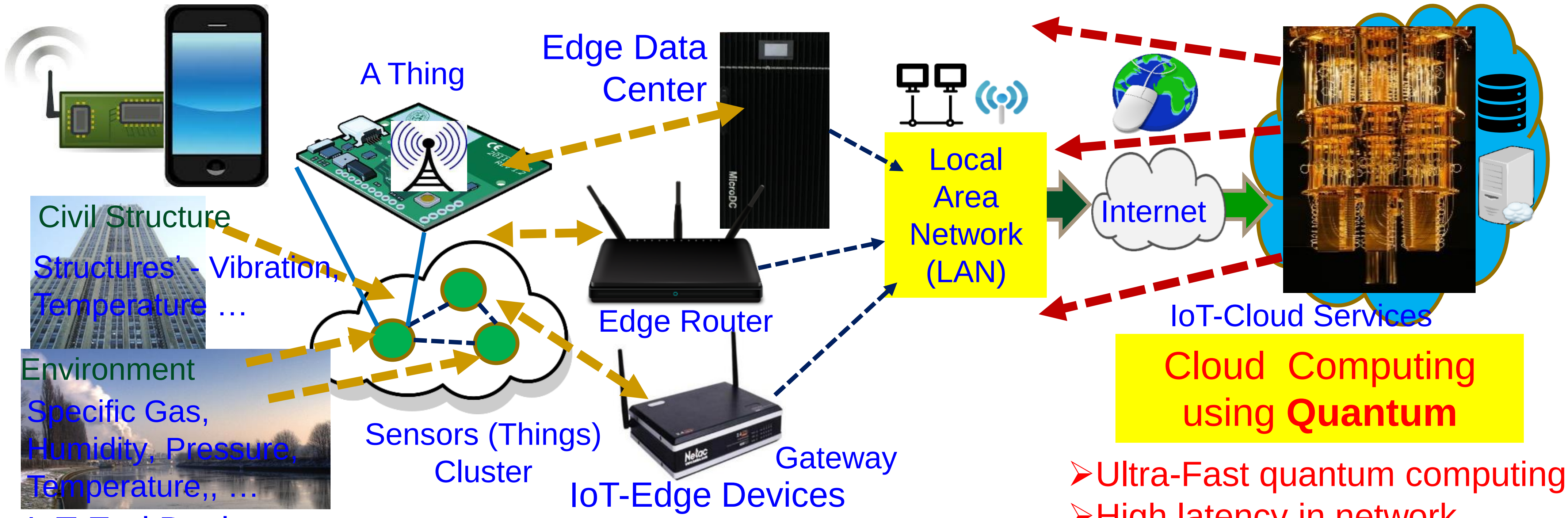


Hardware Based

- High-Speed operation
- Energy-Efficient operation
- Low-cost using ASIC and FPGA
- Tasks of encryption easy compared to software – bit permutation
- Easy integration in CE systems
- Possible security at source-end like sensors, better suitable for IoT
- Susceptible to side-channel attacks
- Can’t stop software reverse engineering

Source: Mohanty ICCE Panel 2018

Cybersecurity Nightmare ← Quantum Computing



In-Sensor/End-Device Computing

- Minimal computational resource
- Negligible latency in network
- Very lightweight security

Edge Computing

- Less computational resource
- Minimal latency in network
- Lightweight security

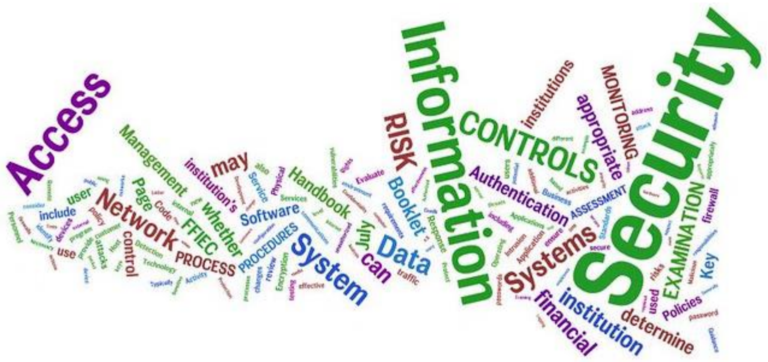
Cloud Computing using Quantum

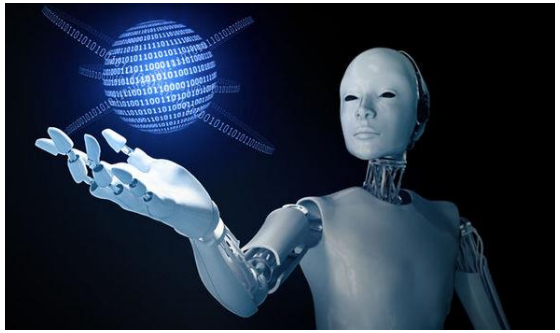
- Ultra-Fast quantum computing resources
- High latency in network
- Breaks every encryption in no time

A quantum computer could break a 2048-bit RSA encryption in 8 hours.

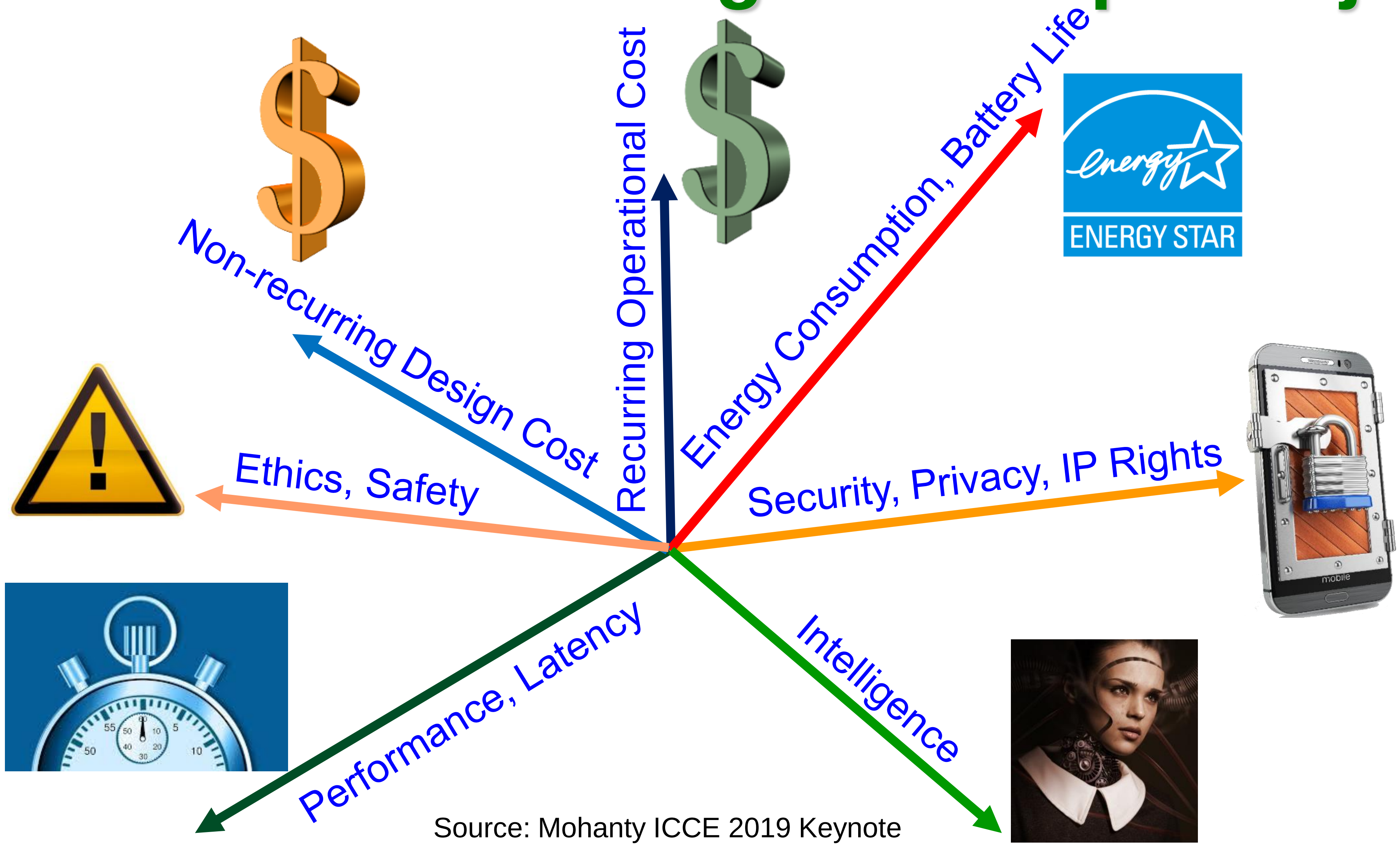
Smart Electronic Systems Laboratory (SESL) UNT

Security-by-Design (SbD) – The Principle





IoT/CPS Design – Multiple Objectives



Source: Mohanty ICCE 2019 Keynote

Smart Cities
Vs
Smart Villages

Privacy by Design (PbD) → General Data Protection Regulation (GPDR)

1995
Privacy by Design (PbD)

- Treat privacy concerns as design requirements when developing technology, rather than trying to retrofit privacy controls after it is built

2018
General Data Protection Regulation (GDPR)

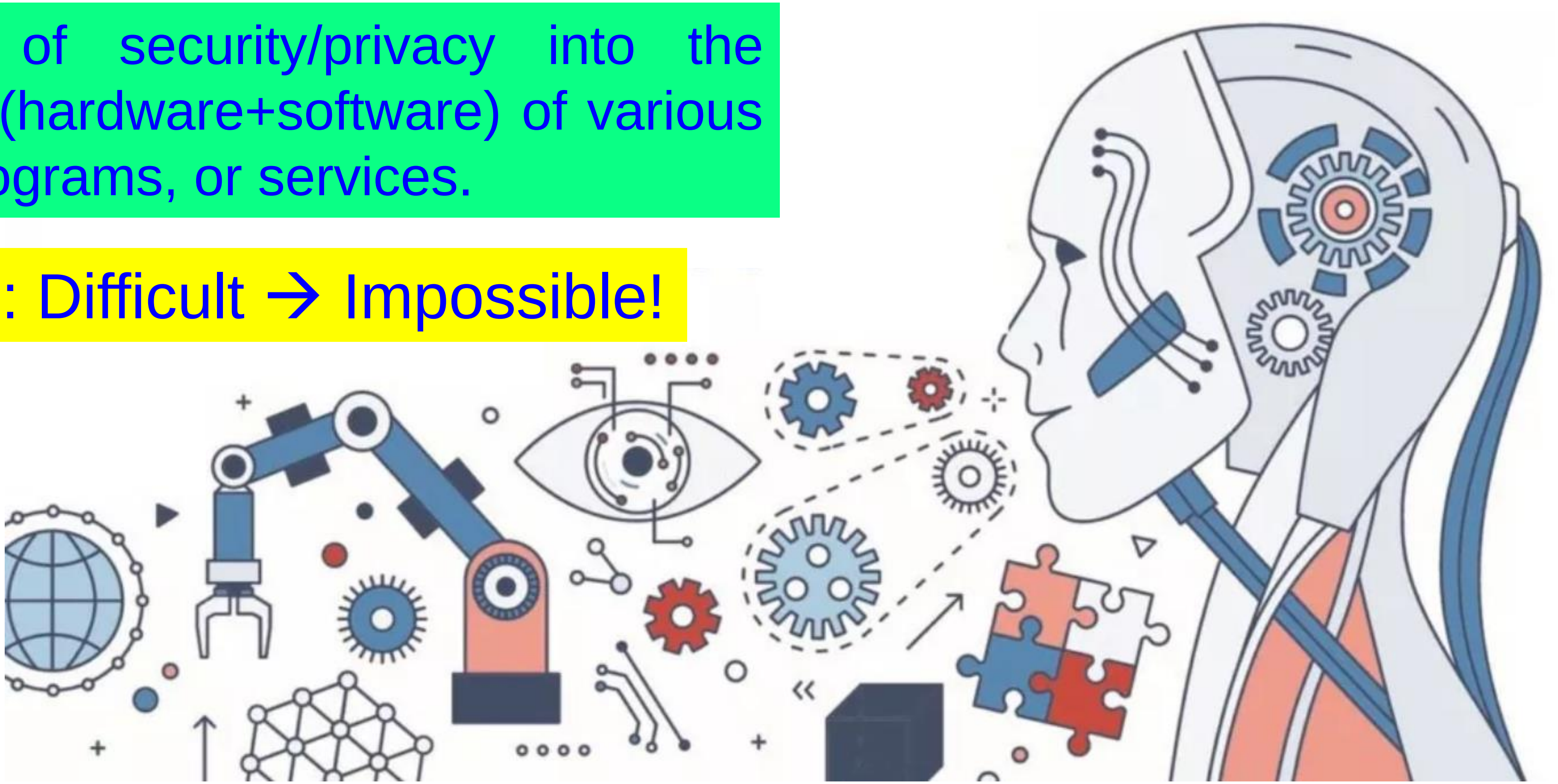
- GDPR makes Privacy by Design (PbD) a legal requirement

Security by Design
aka
Secure by Design (SbD)

Security by Design (SbD) and/or Privacy by Design (PbD)

Embedding of security/privacy into the architecture (hardware+software) of various products, programs, or services.

Retrofitting: Difficult → Impossible!



Source: https://teachprivacy.com/tag/privacy-by-design/

Security by Design (SbD) and/or Privacy by Design (PbD)

7 Fundamental Principles

- Proactive not Reactive
- Security/Privacy as the Default
- Security/Privacy Embedded into Design
- Full Functionality - Positive-Sum, not Zero-Sum
- End-to-End Security/Privacy - Lifecycle Protection
- Visibility and Transparency
- Respect for Users

Source: https://iapp.org/media/pdf/resource_center/Privacy%20by%20Design%20-%207%20Foundational%20Principles.pdf

Hardware-Assisted Security (HAS)

- Software based Security:
  - A general purposed processor is a deterministic machine that computes the next instruction based on the program counter.
  - Software based security approaches that rely on some form of encryption can't be full proof as breaking them is just matter of time.
  - It is projected that quantum computers that use different paradigms than the existing computers will make things worse.
- Hardware-Assisted Security (HAS): Security/Protection provided by the hardware: for information being processed by an electronic system, for hardware itself, and/or for the system.

Hardware-Assisted Security (HAS)

- Hardware-Assisted Security: Security provided by hardware for:
  (1) information being processed,
  (2) hardware itself,
  (3) overall system

Privacy by Design (PbD)

Security/Secure by Design (SbD)

- Additional hardware components used for cybersecurity.
- Hardware design modification is performed.
- System design modification is performed.

RF Hardware Security

Digital Hardware Security – Side Channel

Hardware Trojan Protection

Information Security, Privacy, Protection

Bluetooth Hardware Security

Memory Protection

Digital Core IP Protection

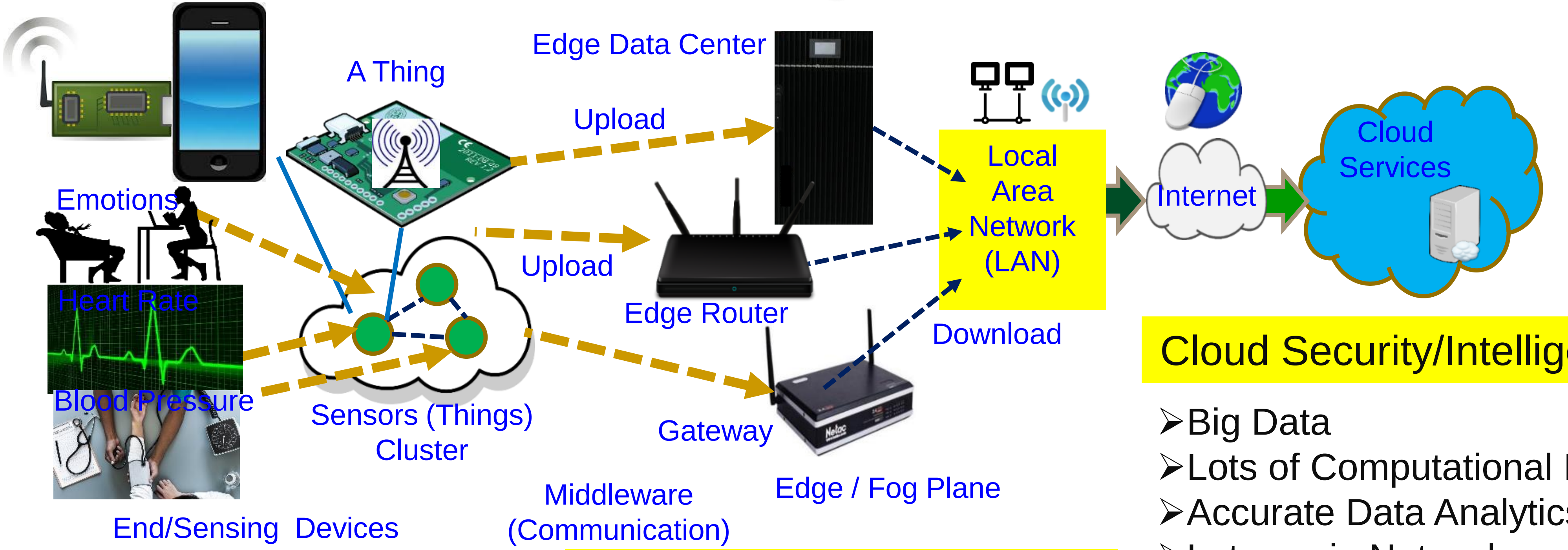
Source: Mohanty ICCE 2018 Panel

Source: E. Kougianos, S. P. Mohanty, and R. N. Mahapatra, "Hardware Assisted Watermarking for Multimedia", Special Issue on Circuits and Systems for Real-Time Security and Copyright Protection of Multimedia, Elsevier International Journal on Computers and Electrical Engineering, Vol 35, No. 2, Mar 2009, pp. 339-358..

Secure SoC Design: Alternatives

- Addition of security and AI features in SoC:
  - Algorithms
  - Protocols
  - Architectures
  - Accelerators / Engines – Cybersecurity and AI Instructions
- Consideration of security as a dimension in the design flow:
  - New design methodology
  - Design automation or computer aided design (CAD) tools for fast design space exploration.

CPS – IoT-Edge Vs IoT-Cloud



Cloud Security/Intelligence

- Big Data
- Lots of Computational Resource
- Accurate Data Analytics
- Latency in Network
- Energy Overhead in Communications

End Security/Intelligence

- Minimal Data
- Minimal Computational Resource
- Least Accurate Data Analytics
- Very Rapid Response

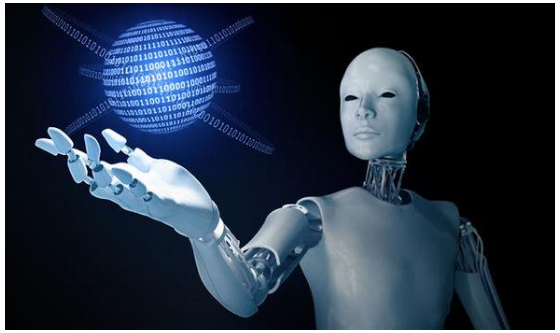
Edge Security/Intelligence

- Less Data
- Less Computational Resource
- Less Accurate Data Analytics
- Rapid Response

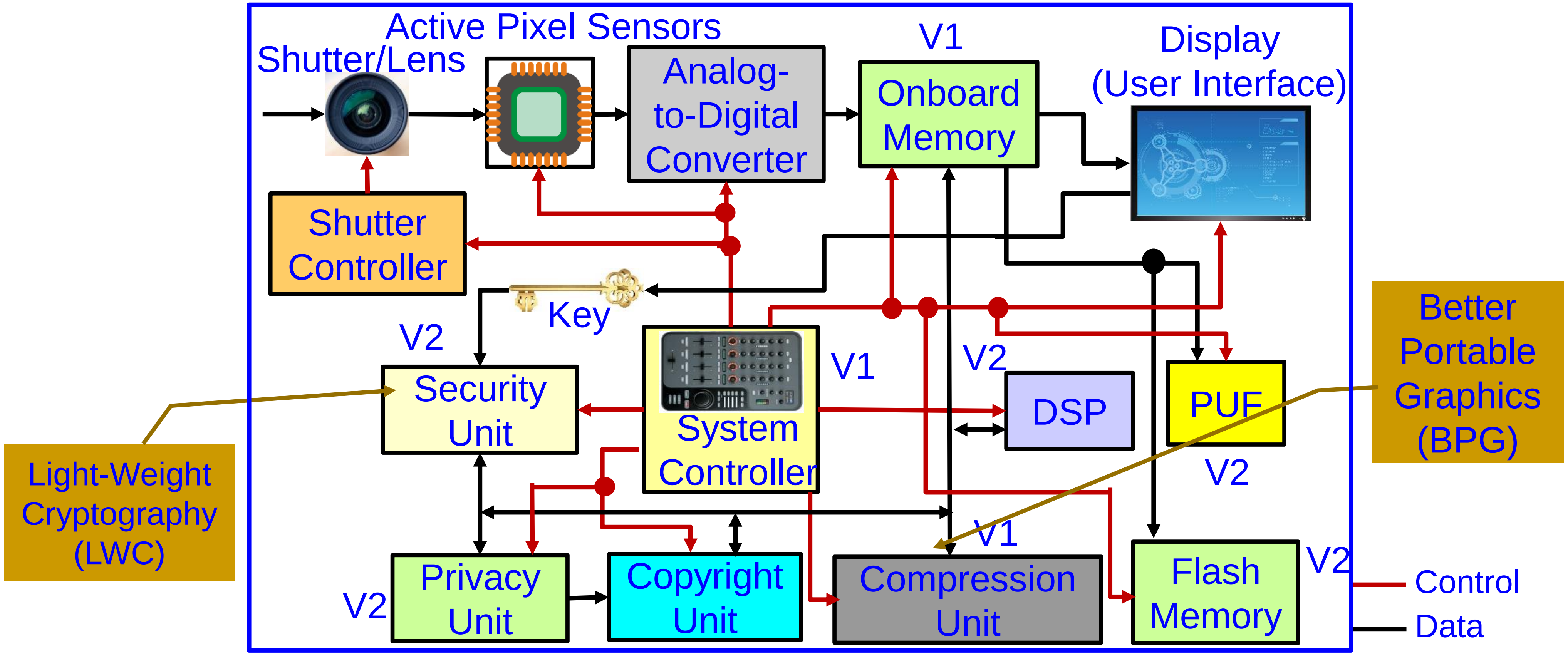
TinyML at End and/or Edge is key for smart villages.

Heavy-Duty ML is more suitable for smart cities

Security-by-Design (SbD) – Specific Examples



Secure Digital Camera (SDC) – My Invention



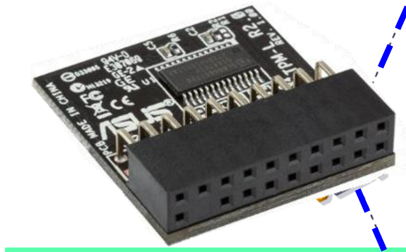
Include additional/alternative hardware/software components and uses DVFS like technology for energy and performance optimization.

Security and/or Privacy by Design (SbD and/or PbD)

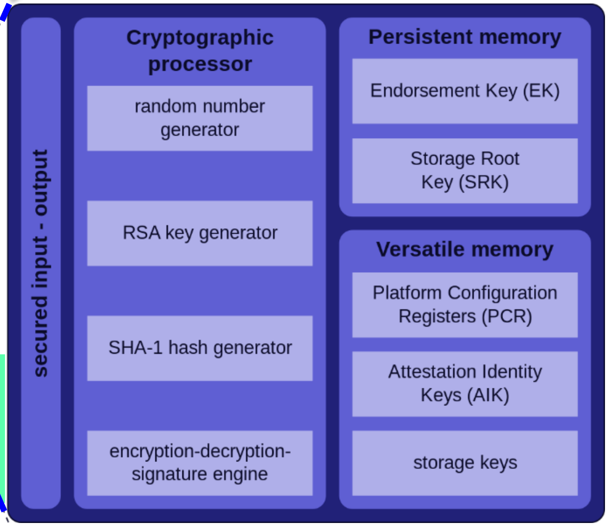
Source: S. P. Mohanty, "A Secure Digital Camera Architecture for Integrated Real-Time Digital Rights Management", *Elsevier Journal of Systems Architecture (JSA)*, Volume 55, Issues 10-12, October-December 2009, pp. 468-480.

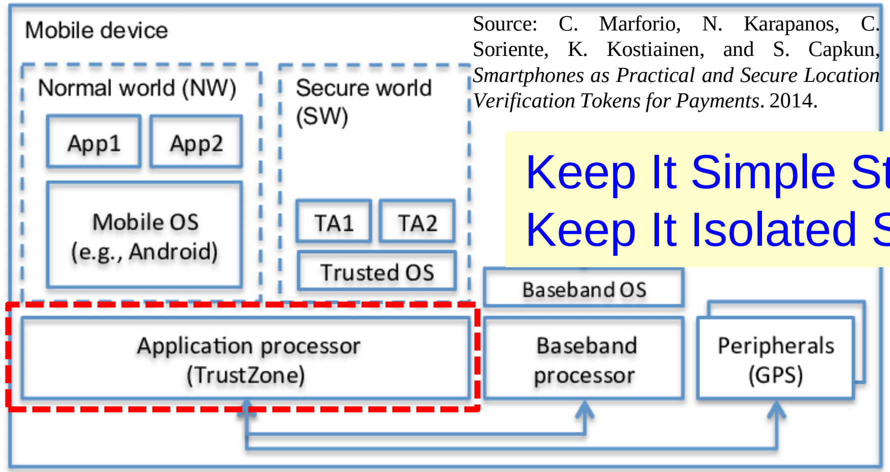
Hardware Cybersecurity Primitives – TPM, HSM, TrustZone, and PUF

Hardware Security Module (HSM)



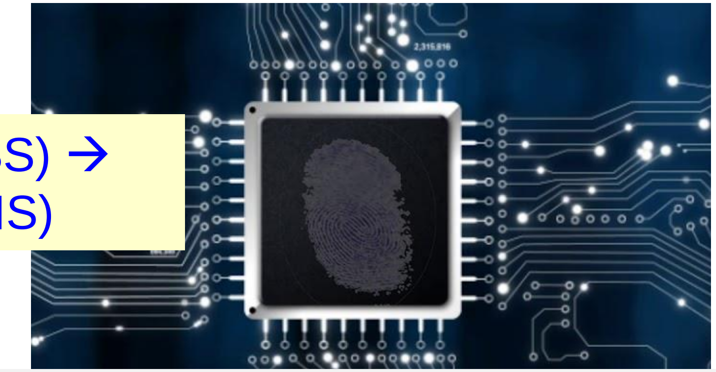
Trusted Platform Module (TPM)





Source: C. Marforio, N. Karapanos, C. Soriente, K. Kostiainen, and S. Capkun, *Smartphones as Practical and Secure Location Verification Tokens for Payments*. 2014.

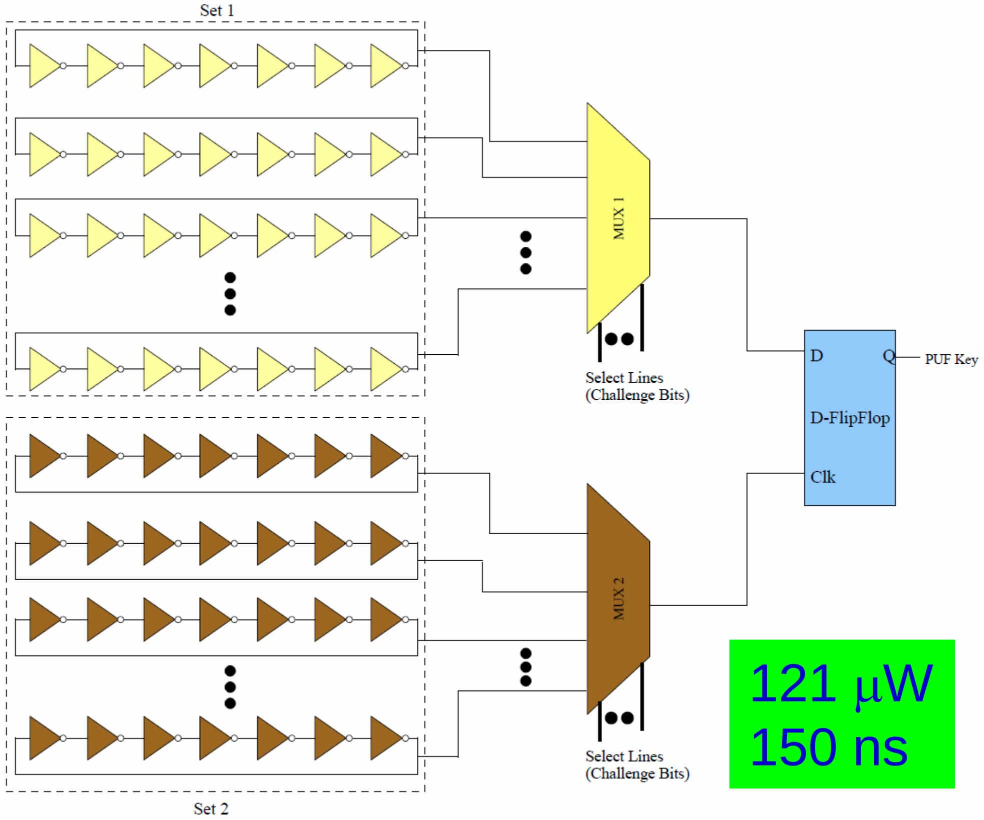
Keep It Simple Stupid (KISS) → Keep It Isolated Stupid (KIIS)



Physical Unclonable Functions (PUF)

Source: Electric Power Research Institute (EPRI)

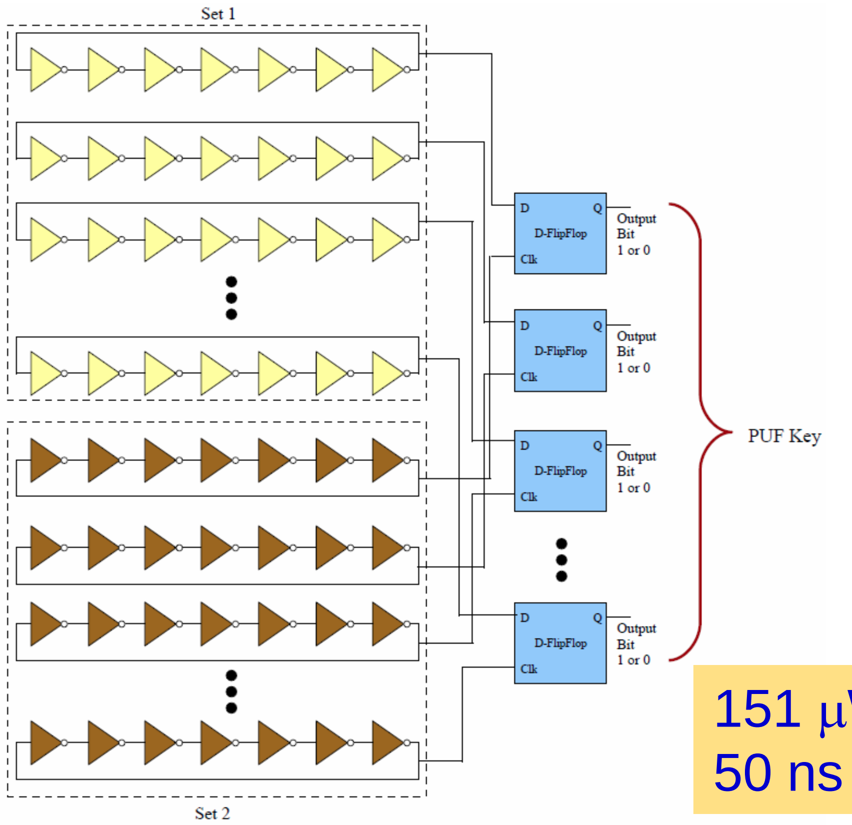
We Have Design a Variety of PUFs - DLFET Based



121 μW
150 ns

Power Optimized Hybrid Oscillator Arbiter PUF

Suitable for Healthcare CPS



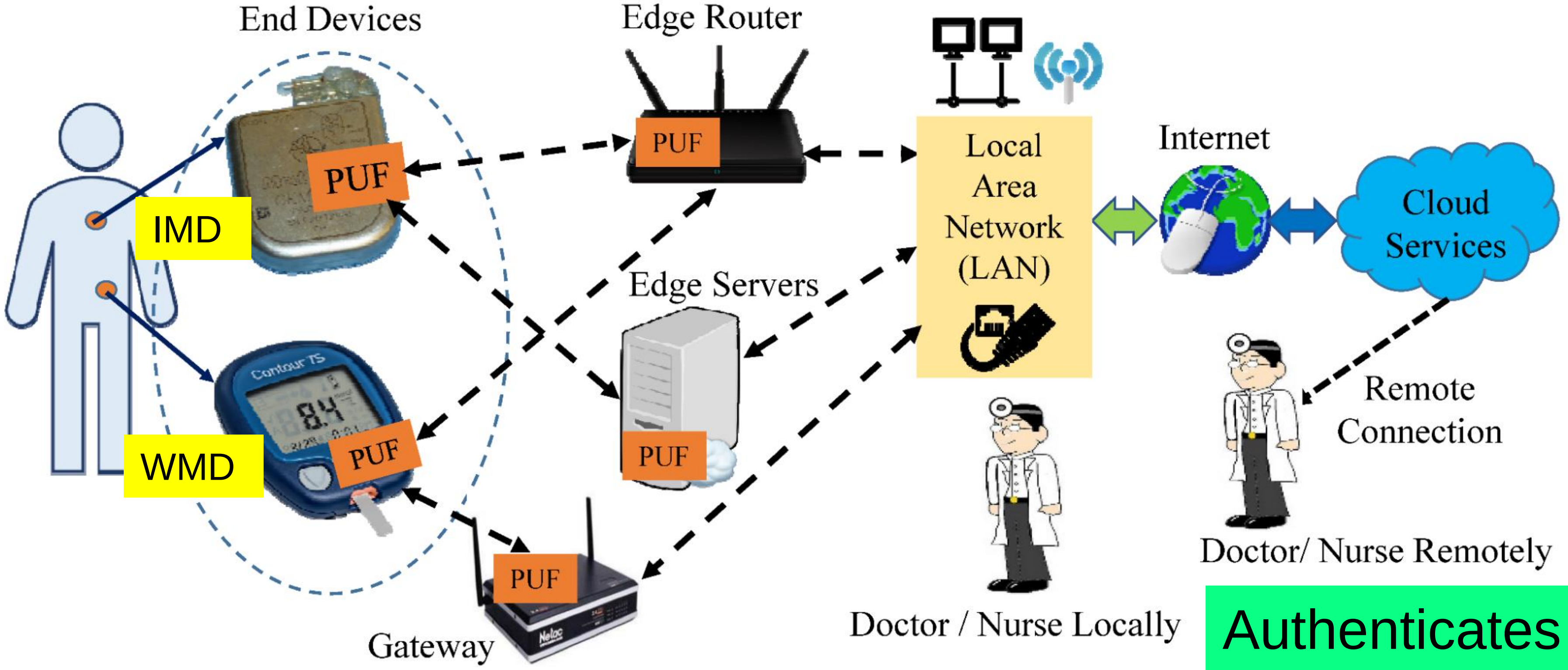
151 μW
50 ns

Speed Optimized Hybrid Oscillator Arbiter PUF

Suitable for Transportation and Energy CPS

Source: V. P. Yanambaka, S. P. Mohanty, and E. Kougianos, “Making Use of Manufacturing Process Variations: A Dopingless Transistor Based-PUF for Hardware-Assisted Security”, *IEEE Transactions on Semiconductor Manufacturing (TSM)*, Volume 31, Issue 2, May 2018, pp. 285--294.

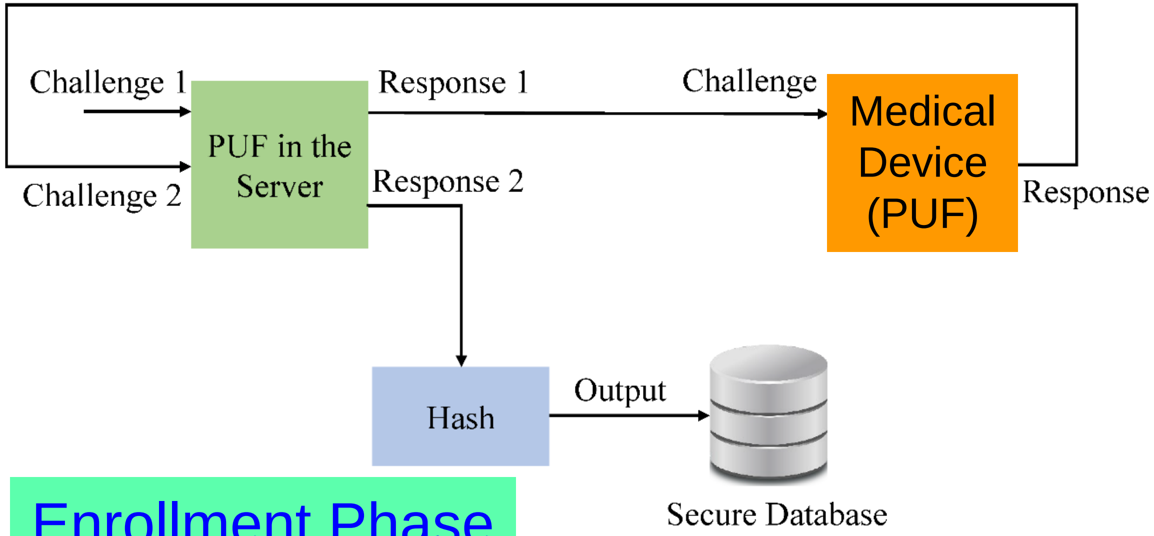
PMsec: Our Secure by Design Approach for Robust Security in Healthcare CPS



Authenticates Time - 1 sec
Power Consumption - 200 μW

Source: V. P. Yanambaka, S. P. Mohanty, E. Kougianos, and D. Puthal, “PMsec: Physical Unclonable Function-Based Robust and Lightweight Authentication in the Internet of Medical Things”, *IEEE Transactions on Consumer Electronics (TCE)*, Volume 65, Issue 3, August 2019, pp. 388--397.

H-CPS Cybersecurity – Our Proposed PMsec

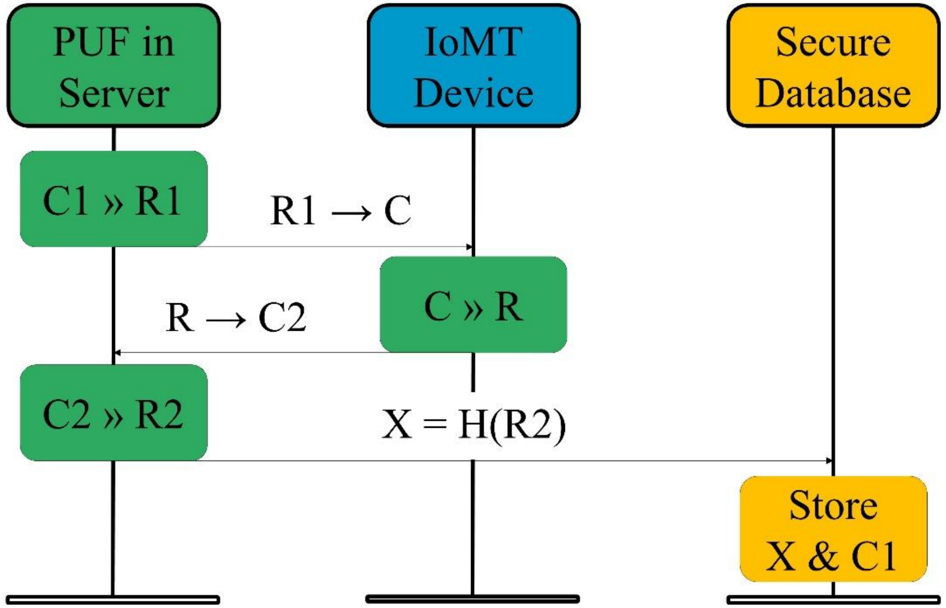


Enrollment Phase

At the Doctor

- When a new IoMT-Device comes for an User

Device Registration Procedure

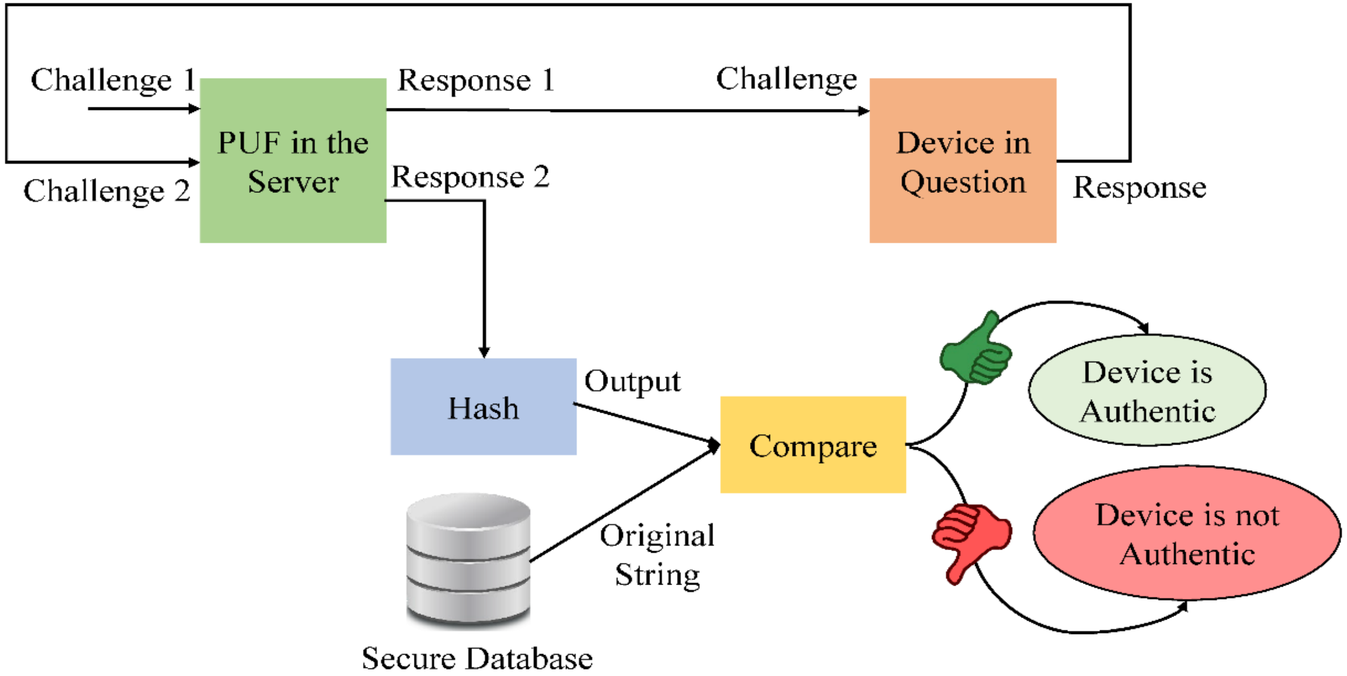


PUF Security Full Proof:

- Only server PUF Challenges are stored, not Responses
- Impossible to generate Responses without PUF

Source: V. P. Yanambaka, S. P. Mohanty, E. Kougianos, and D. Puthal, "PMsec: Physical Unclonable Function-Based Robust and Lightweight Authentication in the Internet of Medical Things", *IEEE Transactions on Consumer Electronics (TCE)*, Volume 65, Issue 3, August 2019, pp. 388--397.

H-CPS Cybersecurity – Our Proposed PMsec

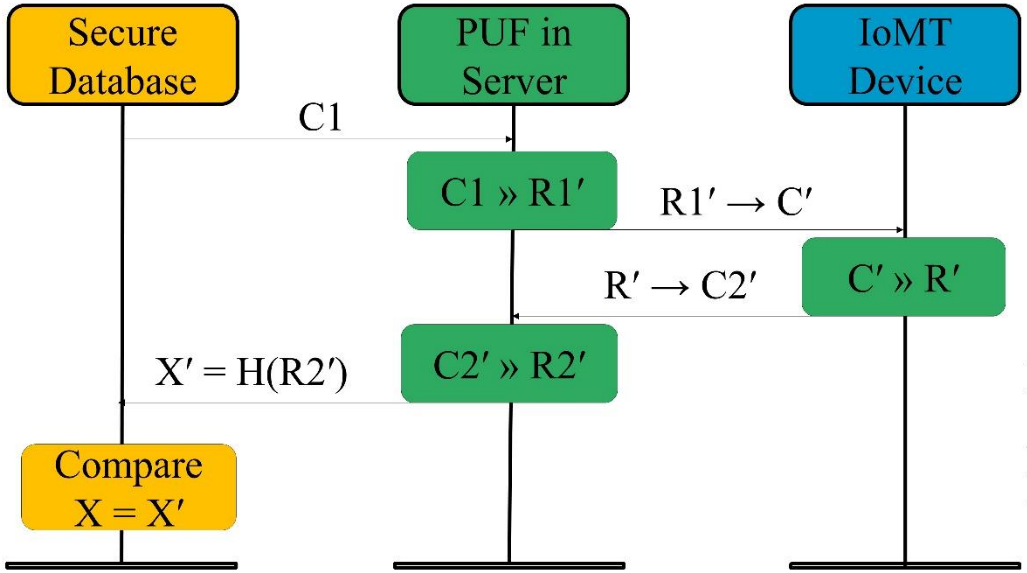


Authentication Phase

At the Doctor

- When doctor needs to access an existing IoMT-device

Device Authentication Procedure



Source: V. P. Yanambaka, S. P. Mohanty, E. Kougianos, and D. Puthal, "PMsec: Physical Unclonable Function-Based Robust and Lightweight Authentication in the Internet of Medical Things", *IEEE Transactions on Consumer Electronics (TCE)*, Volume 65, Issue 3, August 2019, pp. 388--397.

H-CPS Cybersecurity – Our PMsec in Action

Output from IoMT-Server during Enrollment

```
------------Enrollment Phase------------
Generating the Keys
Sending the keys to the Client
Receiving the Keys from the client
Saving the database
>>>
```

Output from the IoMT-Device

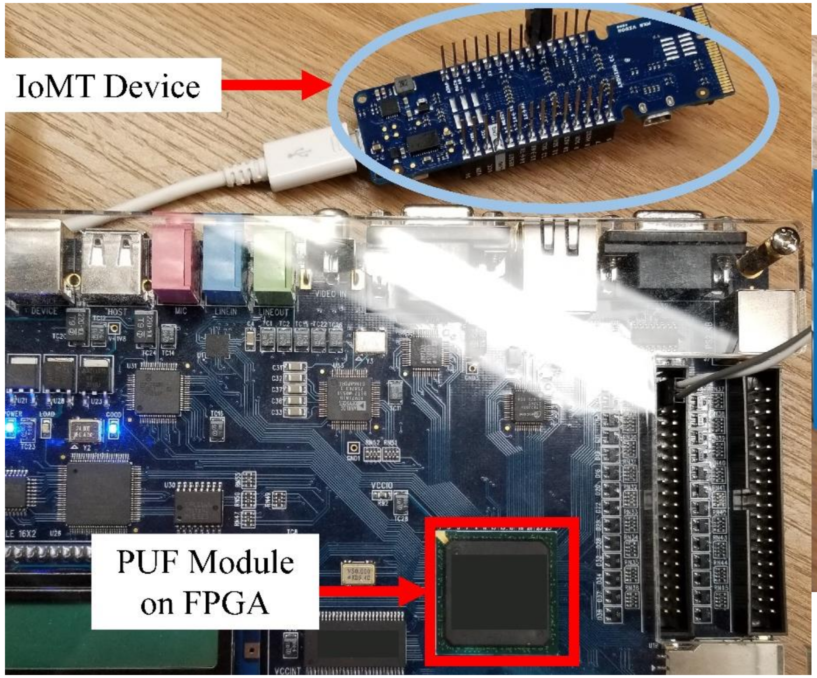
```
COM4
Send
Hello
Received Key from the Server
Generating PUF Key
PUF Key : 1011100001011100101111000101111000101101001101110010100101000011
Sending key for authentication
```

Output from IoMT-Server during Authentication

```
>>>
Hello
------------Authentication Phase------------
Input to the PUF at server : 01001101
Generating the PUF key
Sending the PUF key to the client
PUF Key from client is  1011100001011100101111000101111000101101001101110010100101000011
SHA256 of PUF Key is :  580cdc9339c940cdc60889c4d8a3bc1a3c1876750e88701cbd4f5223f6d23e76
Authentication Successful
>>>
```

Source: V. P. Yanambaka, S. P. Mohanty, E. Kougianos, and D. Puthal, "PMsec: Physical Unclonable Function-Based Robust and Lightweight Authentication in the Internet of Medical Things", *IEEE Transactions on Consumer Electronics (TCE)*, Volume 65, Issue 3, August 2019, pp. 388--397.

H-CPS Cybersecurity – Our Proposed PMsec



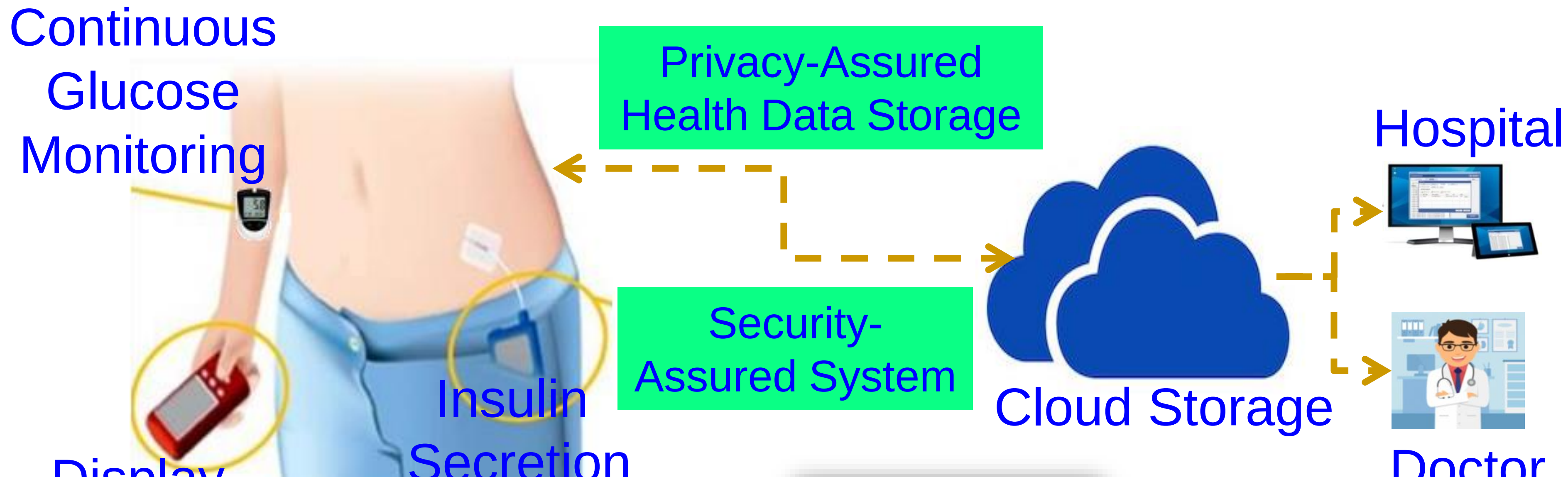
Average Power Overhead – 200 μW

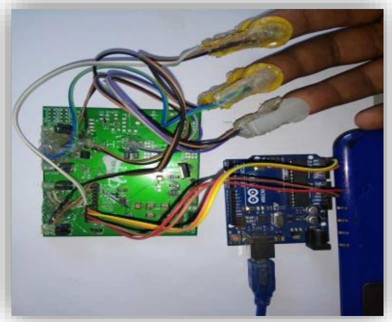
Ring Oscillator PUF – 64-bit, 128-bit, …

Proposed Approach Characteristics	Value (in a FPGA / Raspberry Pi platform)
Time to Generate the Key at Server	800 ms
Time to Generate the Key at IoMT Device	800 ms
Time to Authenticate the Device	1.2 sec - 1.5 sec

Source: V. P. Yanambaka, S. P. Mohanty, E. Kougianos, and D. Puthal, “PMsec: Physical Unclonable Function-Based Robust and Lightweight Authentication in the Internet of Medical Things”, *IEEE Transactions on Consumer Electronics*, Vol 65, No 3, Aug 2019, pp. 388--397.

iGLU: Accurate Glucose Level Monitoring and Secure Insulin Delivery

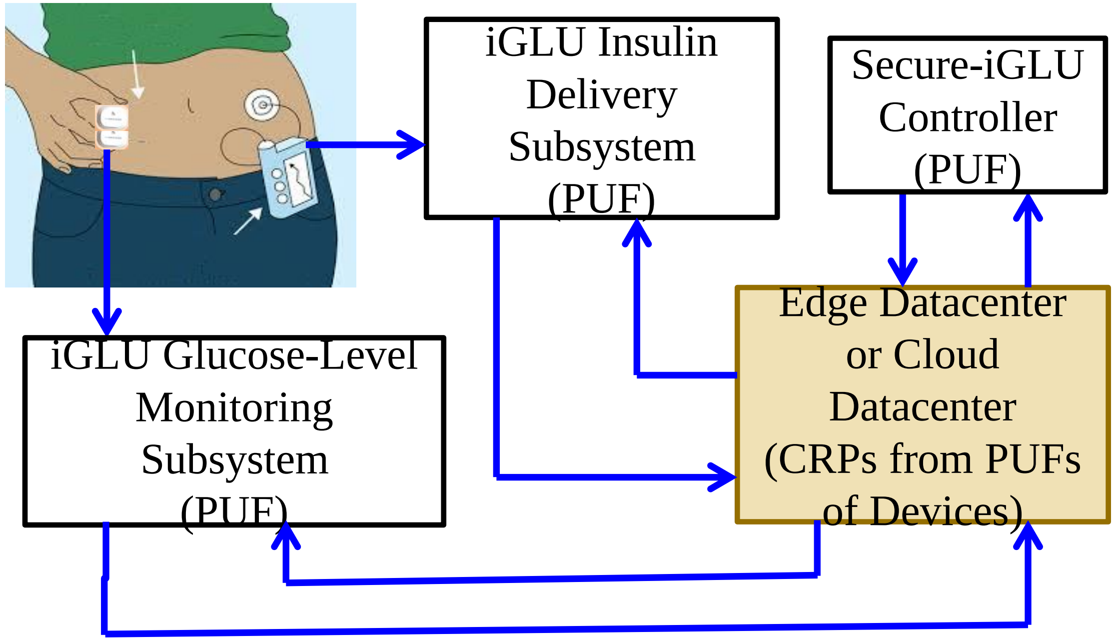


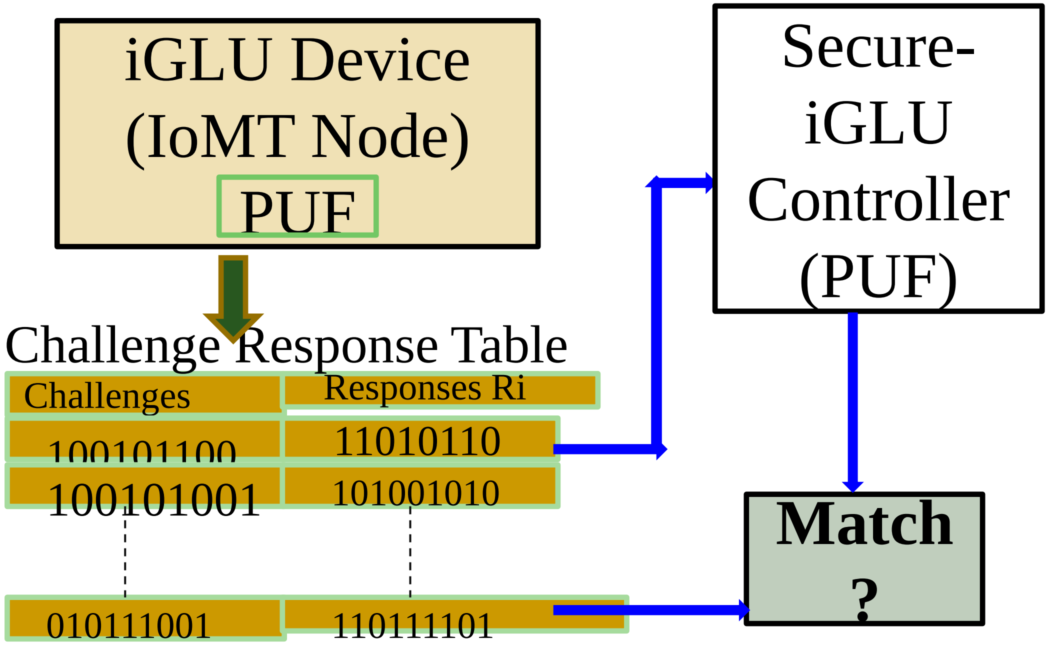


Near Infrared (NIR) based Noninvasive, Accurate, Continuous Glucose Monitoring

P. Jain, A. M. Joshi, and S. P. Mohanty, “iGLU: An Intelligent Device for Accurate Non-Invasive Blood Glucose-Level Monitoring in Smart Healthcare”, *IEEE Consumer Electronics Magazine (MCE),* Vol. 9, No. 1, January 2020, pp. 35–42.

Secure-iGLU: Accurate Glucose Level Monitoring and Secure Insulin Delivery

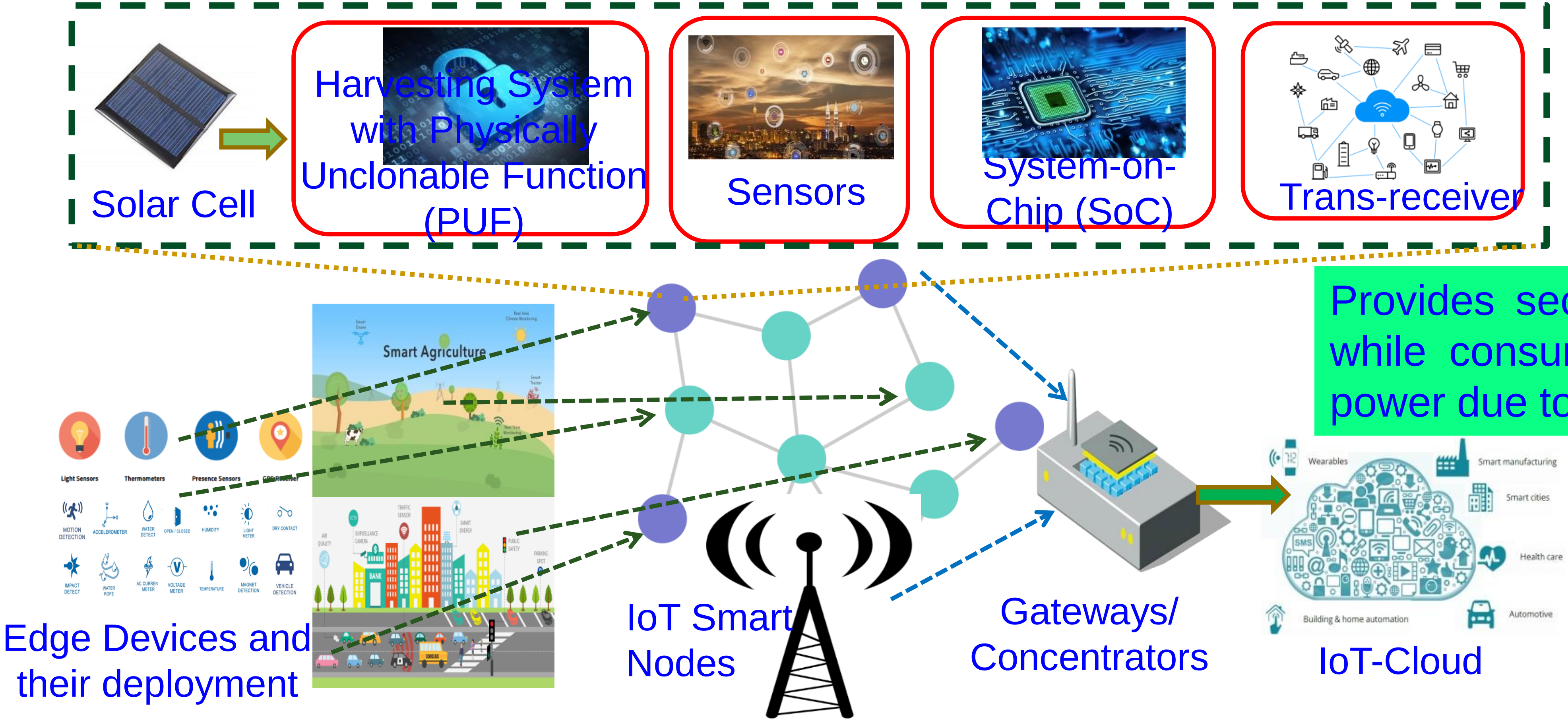




Arbiter PUF – 64-bit, 128-bit, 256 bit …

Source: A. M. Joshi, P. Jain, and S. P. Mohanty, "Secure-iGLU: A Secure Device for Noninvasive Glucose Measurement and Automatic Insulin Delivery in IoMT Framework", *Proceedings of the 19th IEEE Computer Society Annual Symposium on VLSI (ISVLSI)*, 2020, pp. 440-445.

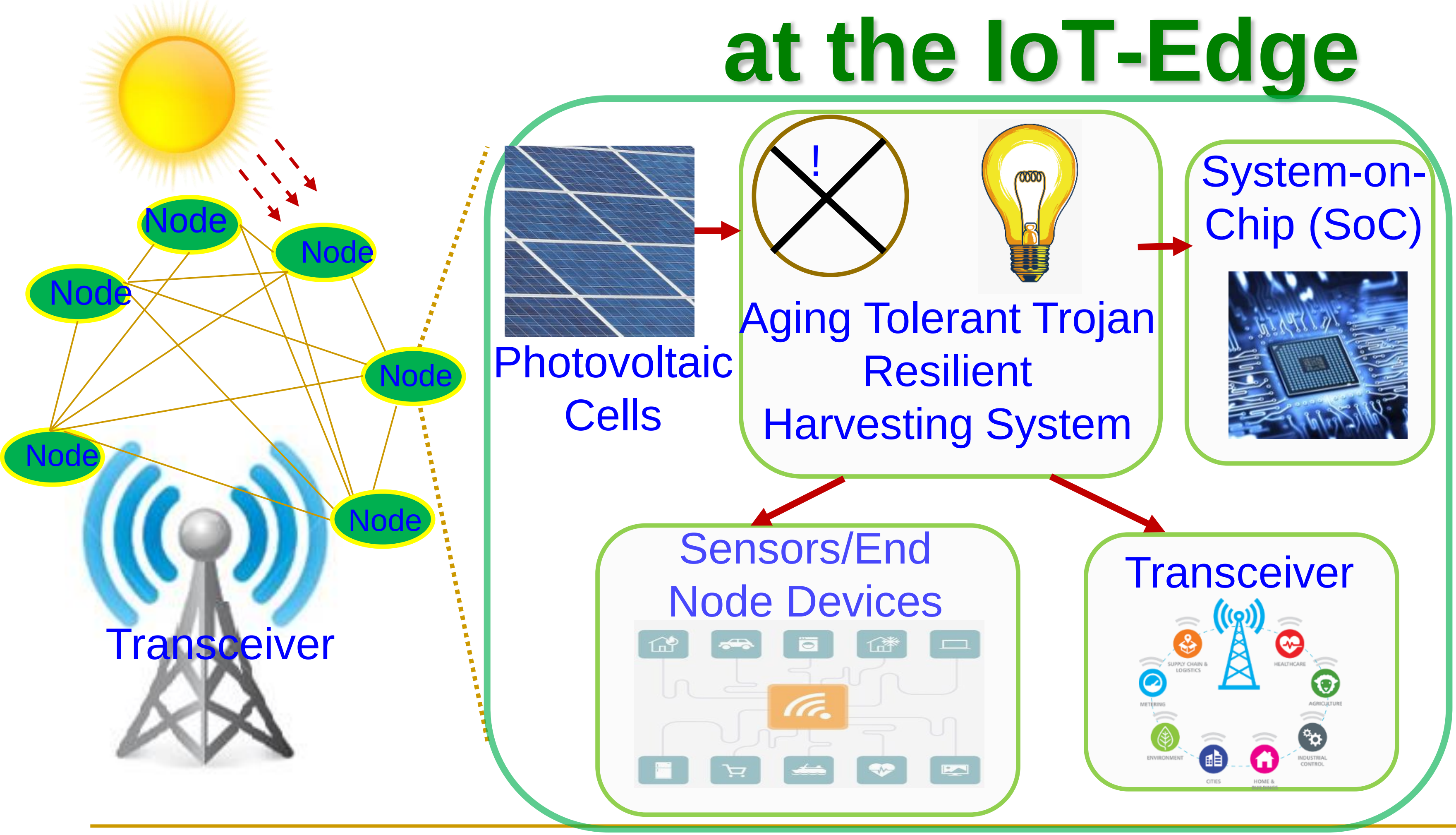
Our SbD: Eternal-Thing: Combines Security and Energy Harvesting at the IoT-Edge



Provides security using PUFs while consuming only 22 μW power due to harvesting.

Source: S. K. Ram, S. R. Sahoo, Banee, B.Das, K. K. Mahapatra, and S. P. Mohanty, “Eternal-Thing: A Secure Aging-Aware Solar-Energy Harvester Thing for Sustainable IoT”, *IEEE Transactions on Sustainable Computing*, Vol. 6, No. 2, April 2021, pp. 320--333.

Our SbD based Eternal-Thing 2.0: Combines Analog-Trojan Resilience and Energy Harvesting at the IoT-Edge



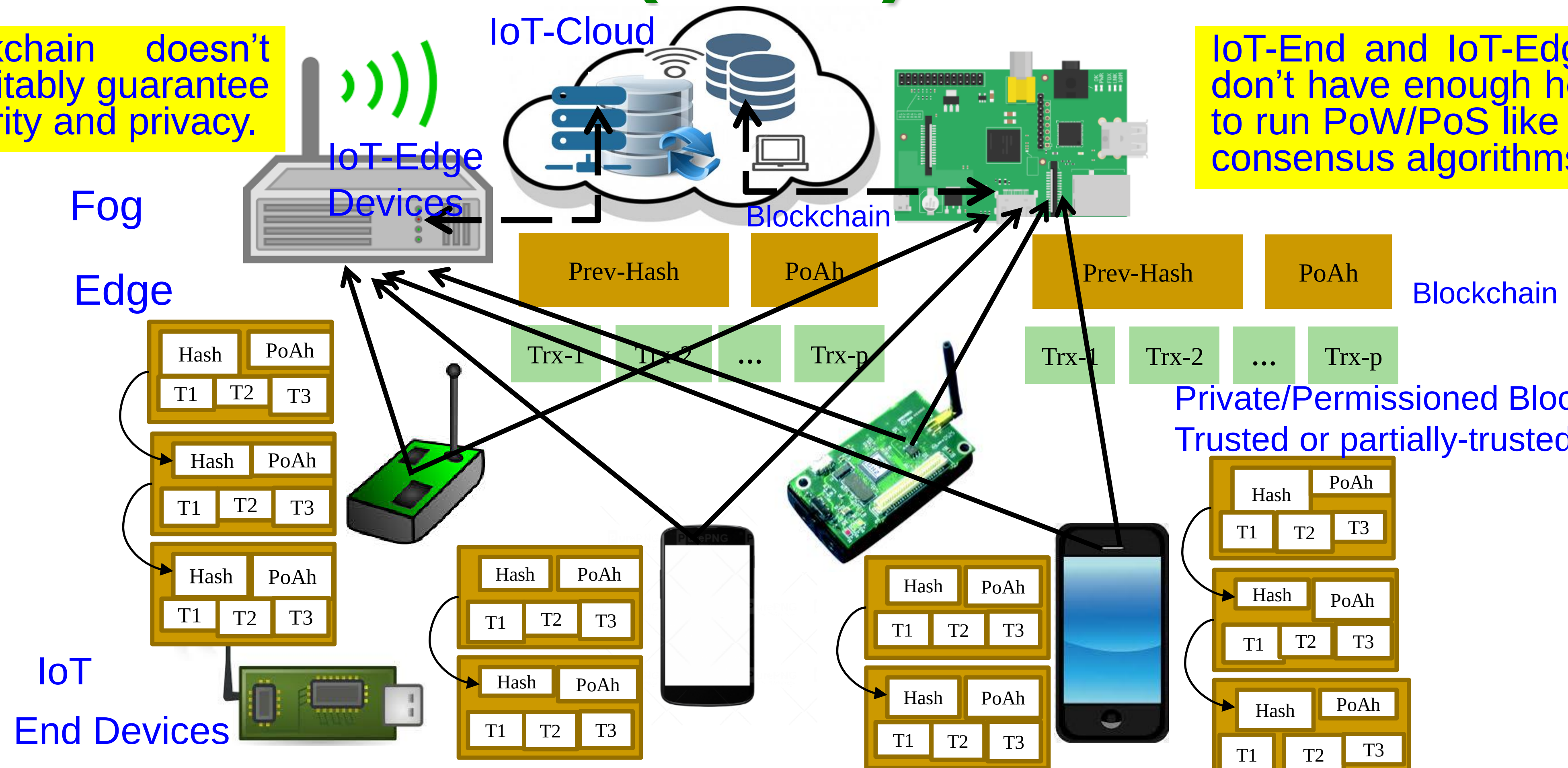
Provides security against analog-Trojan while consuming only 22 µW power due to harvesting.

Source: S. K. Ram, S. R. Sahoo, Banee, B.Das, K. K. Mahapatra, and S. P. Mohanty, “Eternal-Thing 2.0: Analog-Trojan Resilient Ripple-Less Solar Harvesting System for Sustainable IoT”, arXiv Computer Science, arXiv:2103.05615, March 2021, 24-pages.

IoT-Friendly Blockchain – Our Proof-of-Authentication (PoAh) based Blockchain

Blockchain doesn't inheritably guarantee security and privacy.

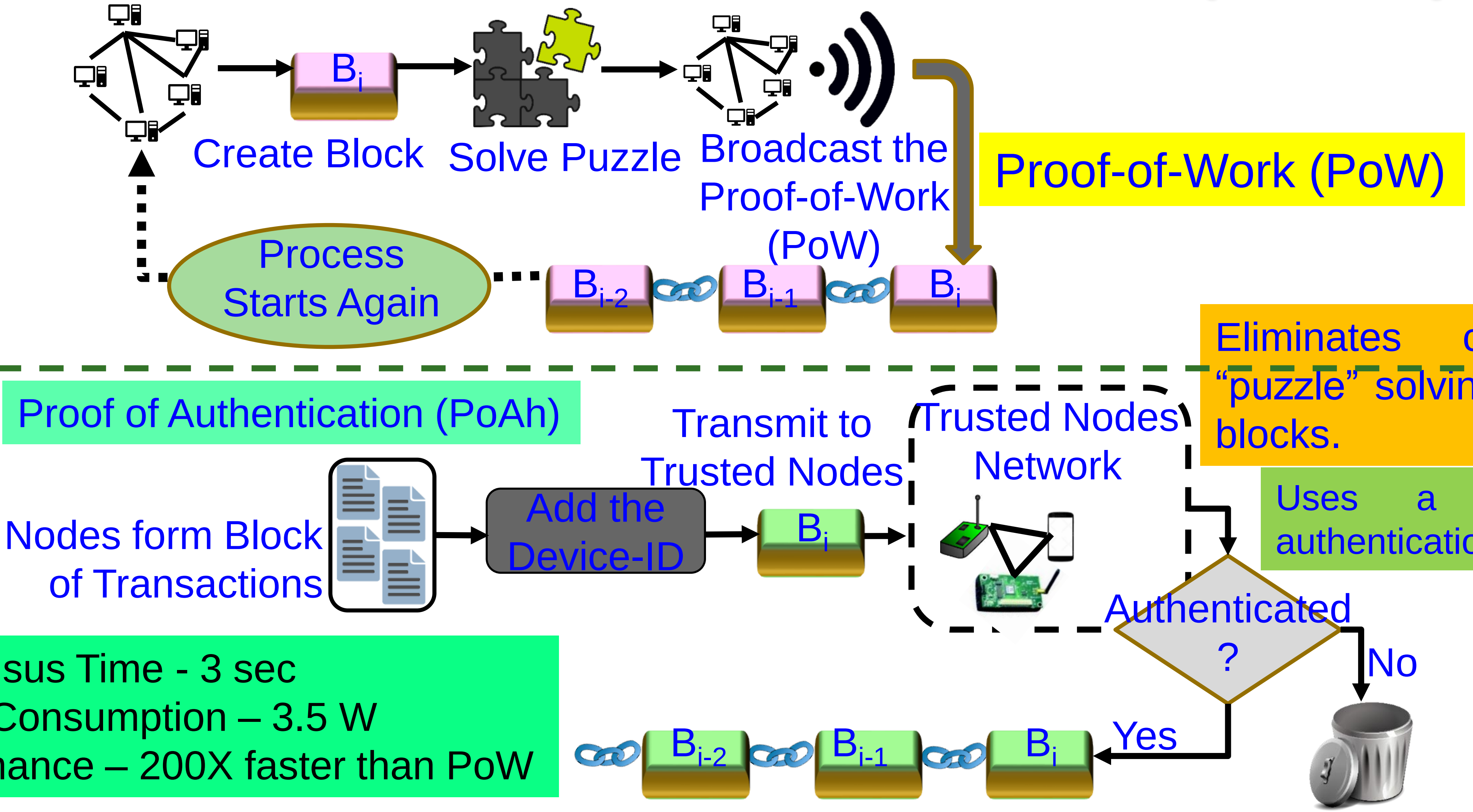
IoT-End and IoT-Edge Devices don't have enough horse power to run PoW/PoS like heavy duty consensus algorithms.



Private/Permissioned Blockchain with Trusted or partially-trusted nodes

Source: D. Puthal and S. P. Mohanty, "Proof of Authentication: IoT-Friendly Blockchains", *IEEE Potentials Magazine*, Vol. 38, No. 1, January 2019, pp. 26--29.

Our Proof-of-Authentication (PoAh)



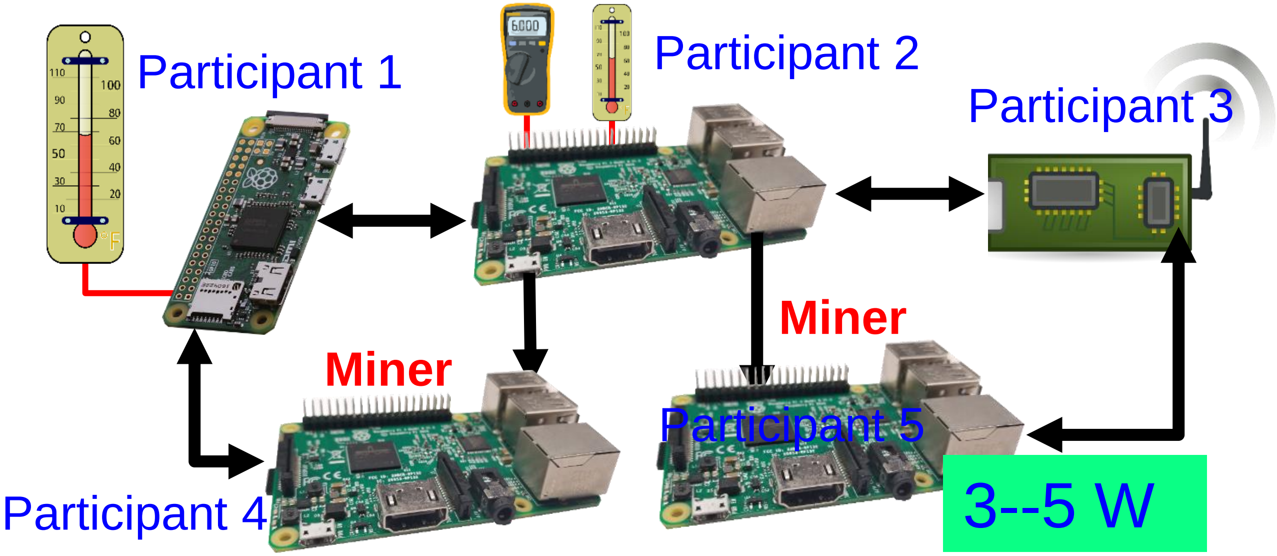
Eliminates cryptographic "puzzle" solving to validate blocks.

Uses a cryptographic authentication mechanism.

Consensus Time - 3 sec
Power Consumption – 3.5 W
Performance – 200X faster than PoW

Source: D. Puthal and S. P. Mohanty, "Proof of Authentication: IoT-Friendly Blockchains", *IEEE Potentials Magazine*, Vol. 38, No. 1, January 2019, pp. 26--29.

Our PoAh-Chain Runs in Resource Constrained Environment

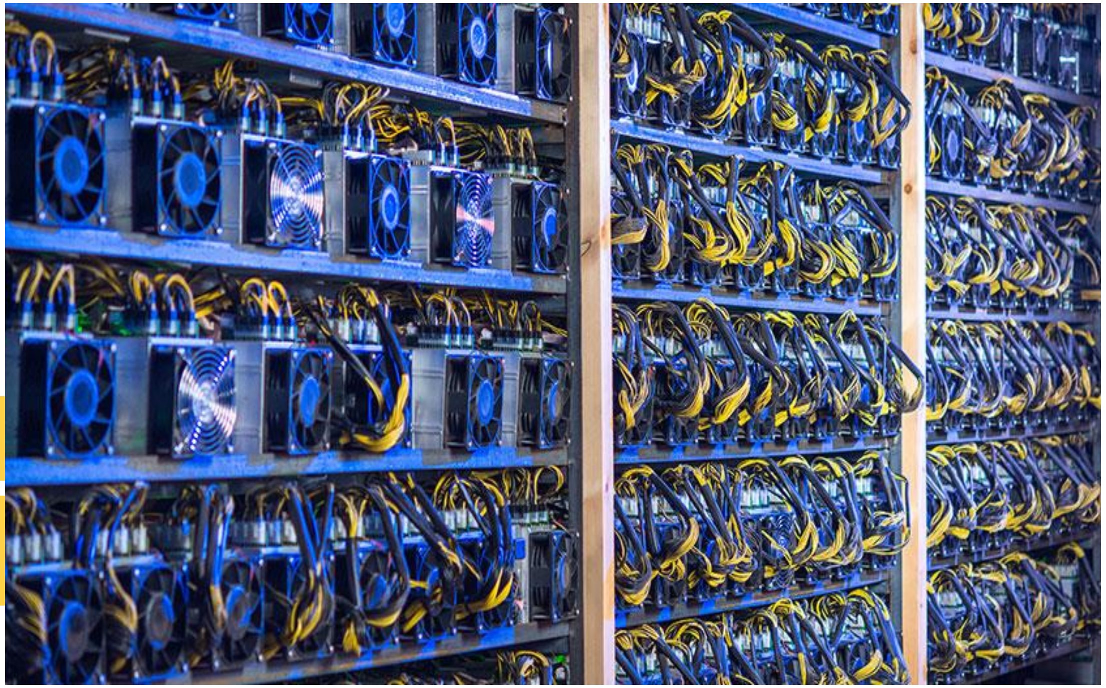


3--5 W

Our PoAh-Chain Runs even in IoT-end devices.

Blockchain using PoW Needs Significant Resource

500,0000 W

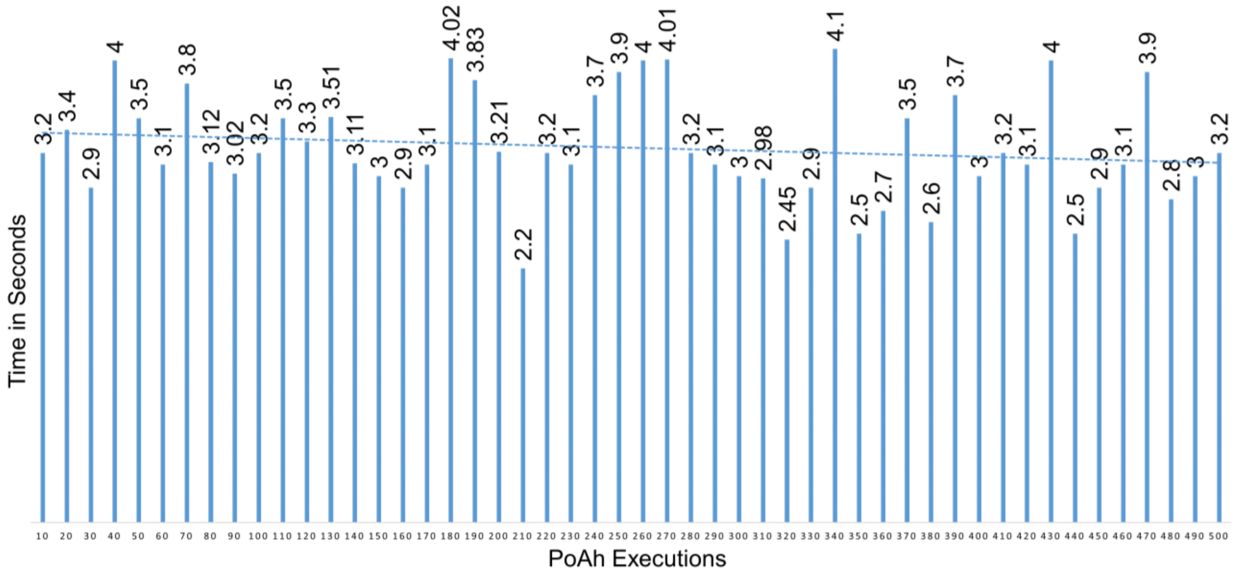


Source: D. Puthal, S. P. Mohanty, V. P. Yanambaka, and E. Kougianos, "PoAh: A Novel Consensus Algorithm for Fast Scalable Private Blockchain for Large-scale IoT Frameworks", *arXiv Computer Science*, arXiv:2001.07297, January 2020, 26-pages.

Source: https://www.iea.org/newsroom/news/2019/july/bitcoin-energy-use-mined-the-gap.html

Our PoAh is 200X Faster than PoW While Consuming a Very Minimal Energy

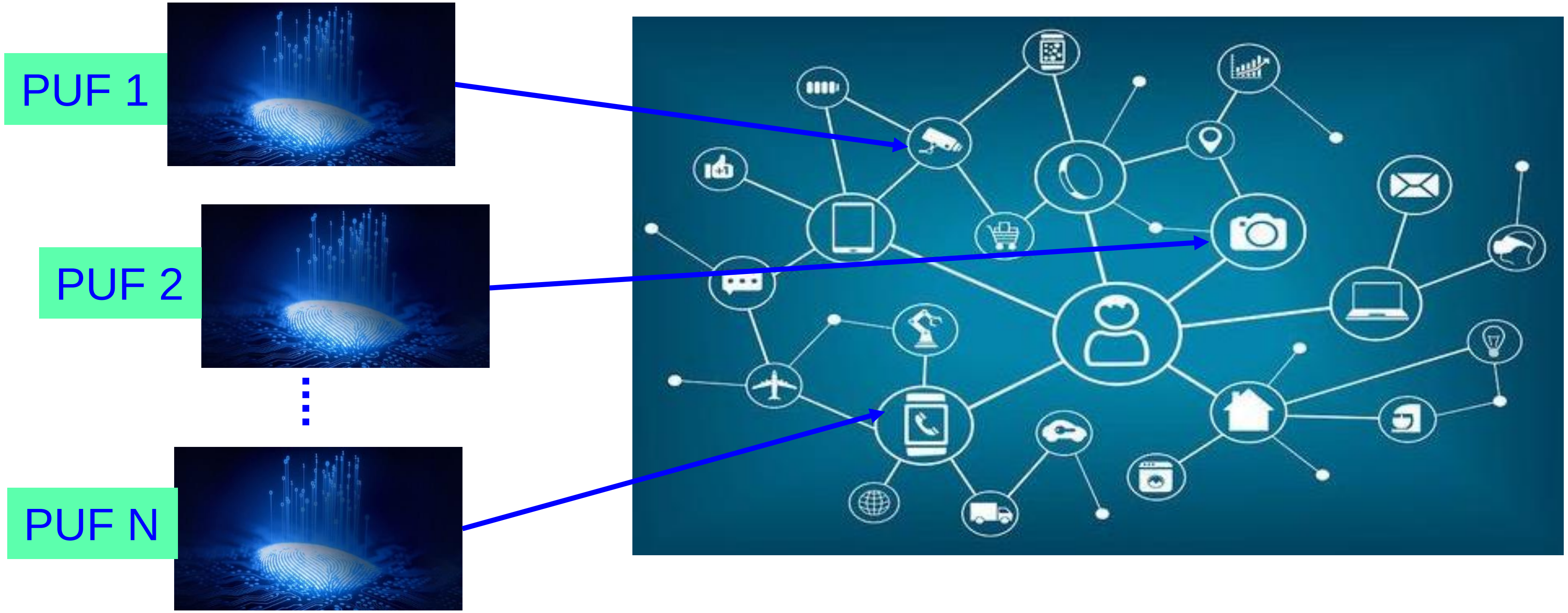
Consensus Algorithm	Blockchain Type	Prone To Attacks	Power Consumption	Time for Consensus
Proof-of-Work (PoW)	Public	Sybil, 51%	538 KWh	10 min
Proof-of-Stake (PoS)	Public	Sybil, DoS	5.5 KWh	
Proof-of-Authentication (PoAh)	Private	Not Known	3.5 W	3 sec



PoAh Execution for 100s of Nodes

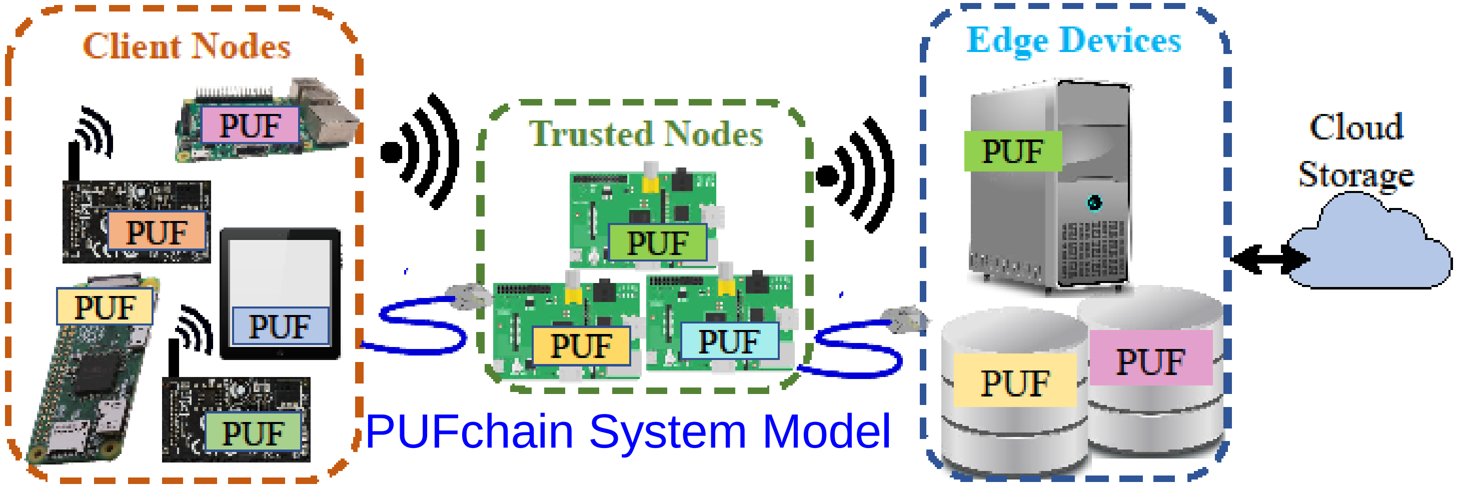
Source: D. Puthal, S. P. Mohanty, P. Nanda, E. Kougianos, and G. Das, "Proof-of-Authentication for Scalable Blockchain in Resource-Constrained Distributed Systems", in *Proc. 37th IEEE International Conference on Consumer Electronics (ICCE)*, 2019.

We Proposed World's First Hardware-Integrated Blockchain (PUFchain) that is Scalable, Energy-Efficient, and Fast



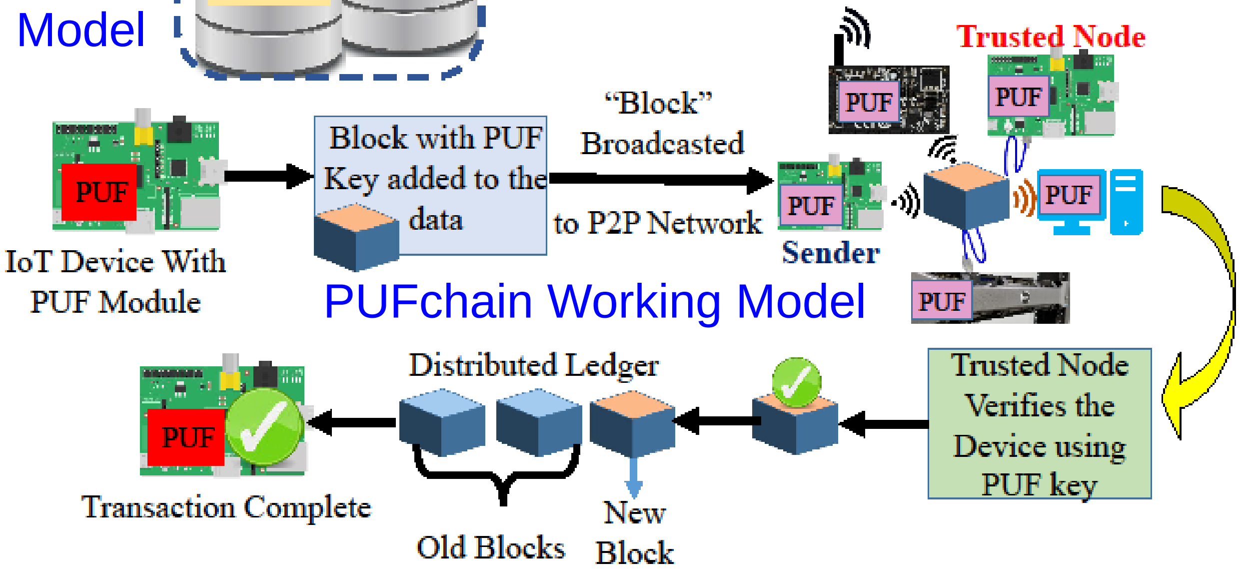
Source: S. P. Mohanty, V. P. Yanambaka, E. Kougianos, and D. Puthal, "PUFchain: Hardware-Assisted Blockchain for Sustainable Simultaneous Device and Data Security in Internet of Everything (IoE)", *IEEE Consumer Electronics Magazine (MCE)*, Vol. 9, No. 2, March 2020, pp. 8-16.

PUFchain: Our Hardware-Assisted Scalable Blockchain



PUFchain System Model

Can provide:
Device, System, and
Data Security



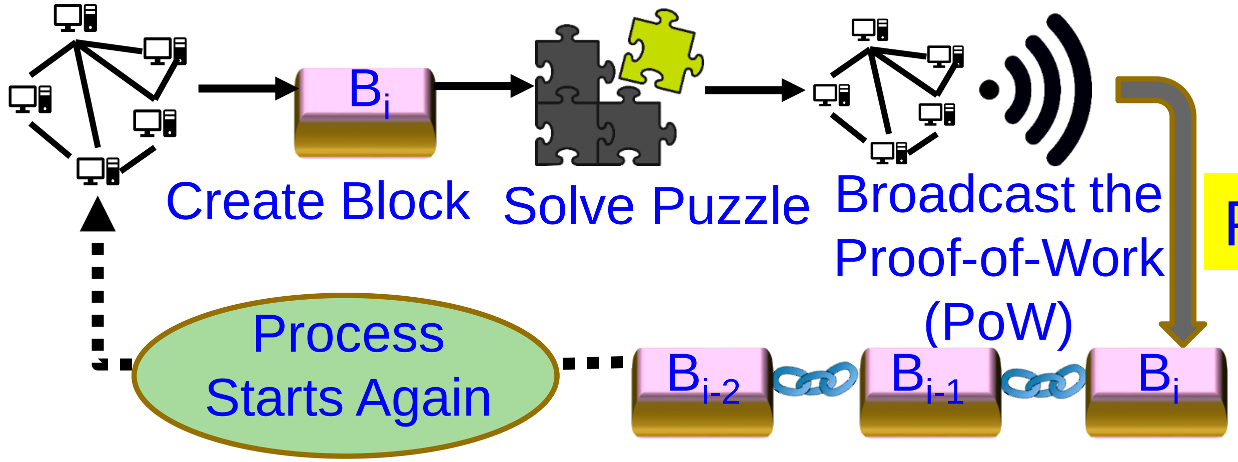
PUFchain Working Model

PUFChain 2 Modes:
(1) PUF Mode and
(2) PUFChain Mode

- ✓ PoP is 1,000X faster than PoW
- ✓ PoP is 5X faster than PoAh

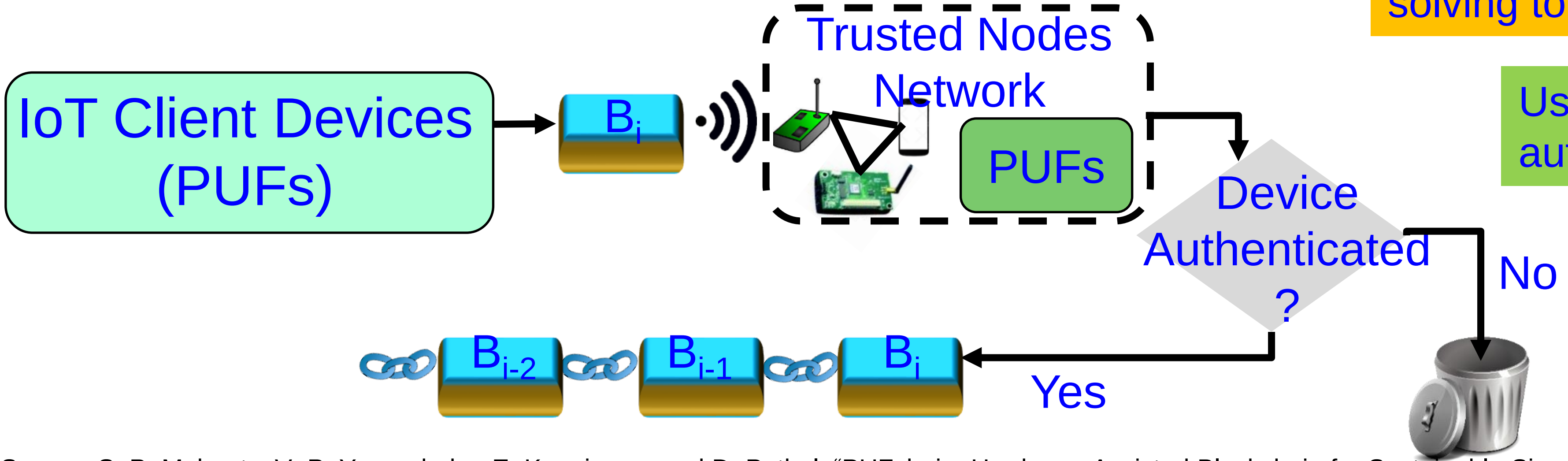
Source: S. P. Mohanty, V. P. Yanambaka, E. Kougianos, and D. Puthal, "PUFchain: Hardware-Assisted Blockchain for Sustainable Simultaneous Device and Data Security in Internet of Everything (IoE)", *IEEE Consumer Electronics Magazine (MCE)*, Vol. 9, No. 2, March 2020, pp. 8-16.

Our Proof-of-PUF-Enabled-Authentication (PoP)



Proof-of-Work (PoW)

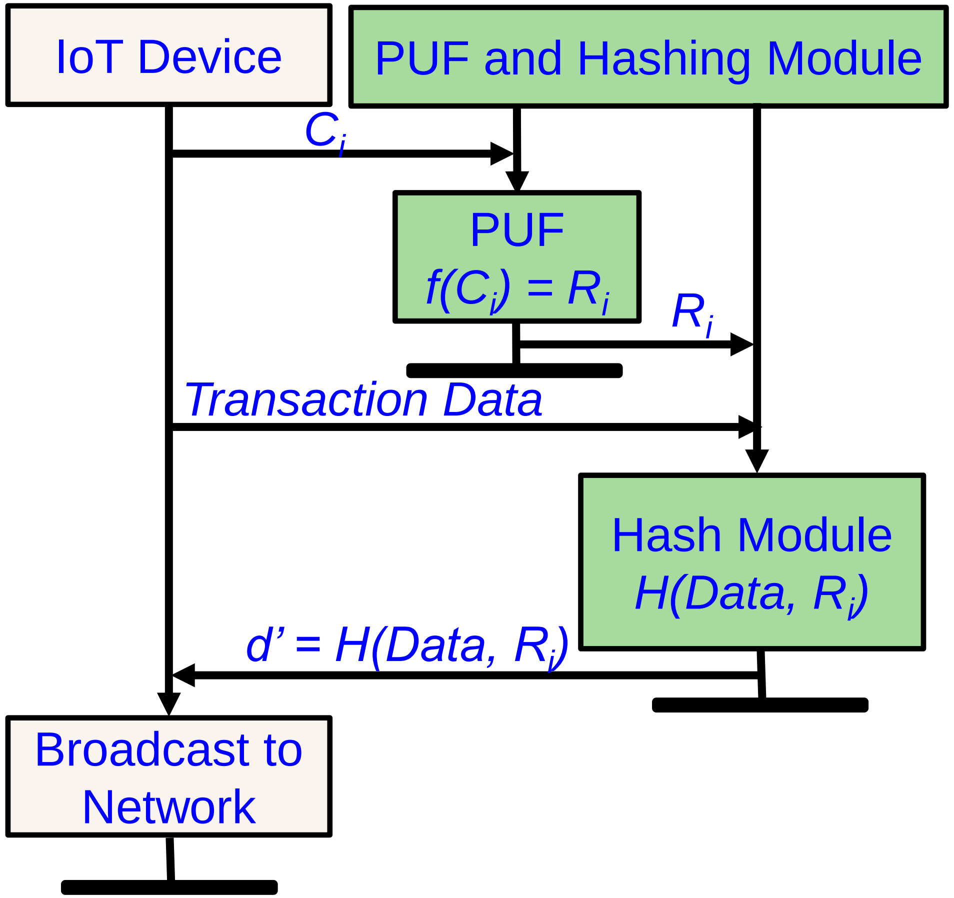
Eliminates cryptographic "puzzle" solving to validate blocks.



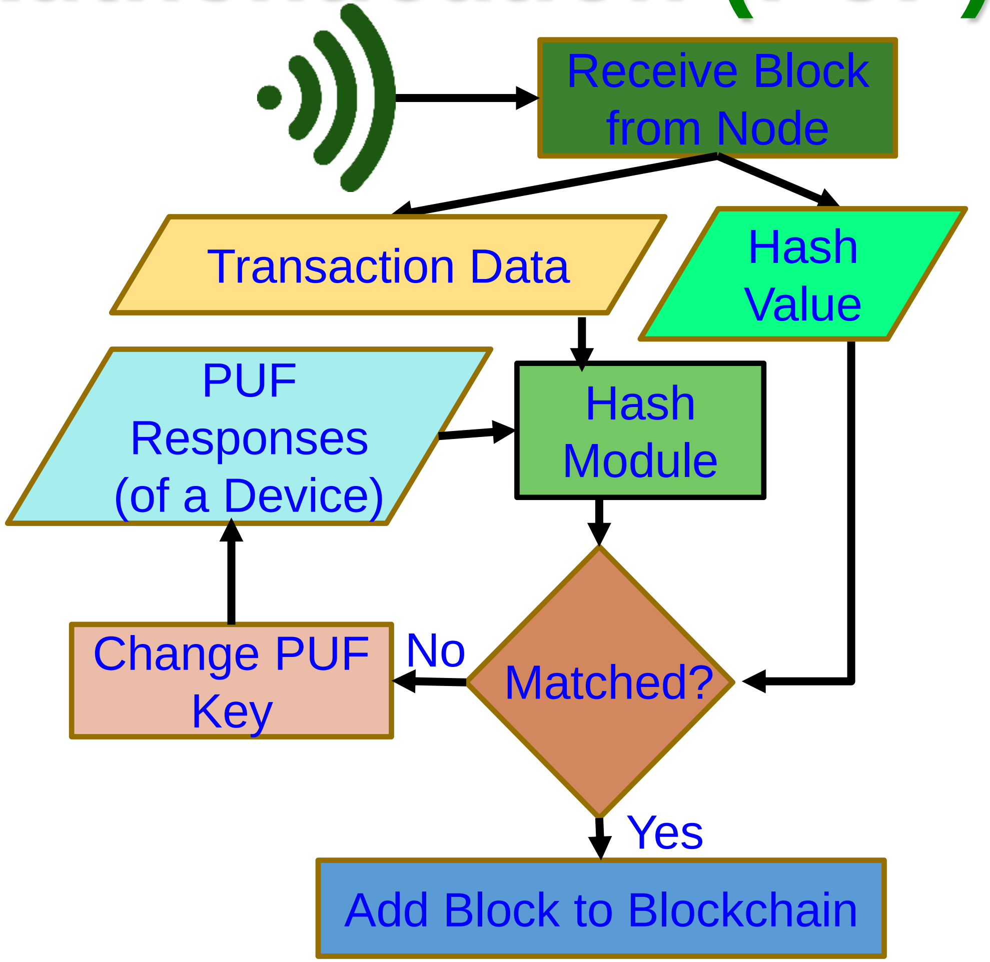
Uses a PUF-based authentication mechanism.

Source: S. P. Mohanty, V. P. Yanambaka, E. Kougianos, and D. Puthal, "PUFchain: Hardware-Assisted Blockchain for Sustainable Simultaneous Device and Data Security in Internet of Everything (IoE)", *IEEE Consumer Electronics Magazine (MCE)*, Vol. 9, No. 2, March 2020, pp. 8-16.

Proof-of-PUF-Enabled-Authentication (PoP)



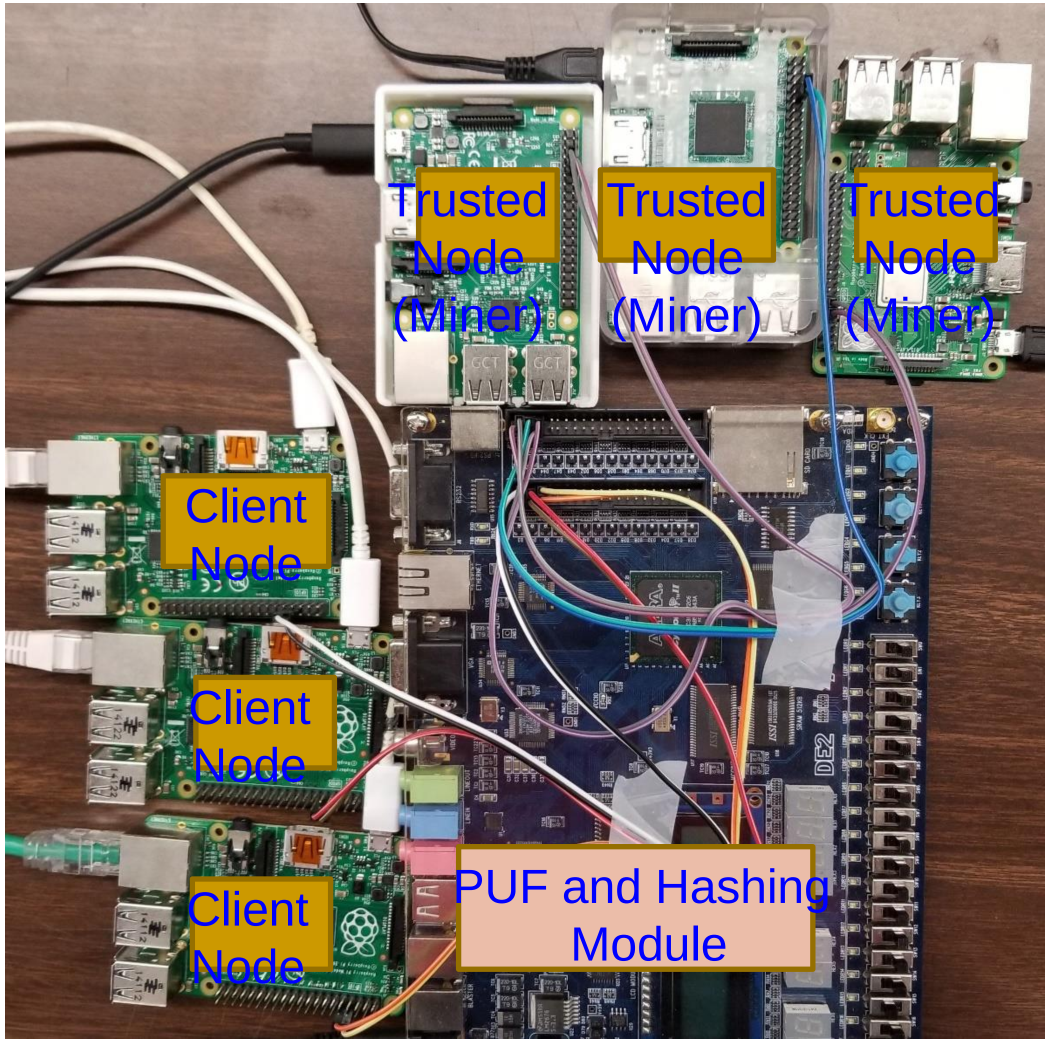
Steps for Transactions Initiation



Steps for Device Authentication

Source: S. P. Mohanty, V. P. Yanambaka, E. Kougianos, and D. Puthal, "PUFchain: Hardware-Assisted Blockchain for Sustainable Simultaneous Device and Data Security in Internet of Everything (IoE)", *IEEE Consumer Electronics Magazine (MCE)*, Vol. 9, No. 2, March 2020, pp. 8-16.

Our PoP is 1000X Faster than PoW

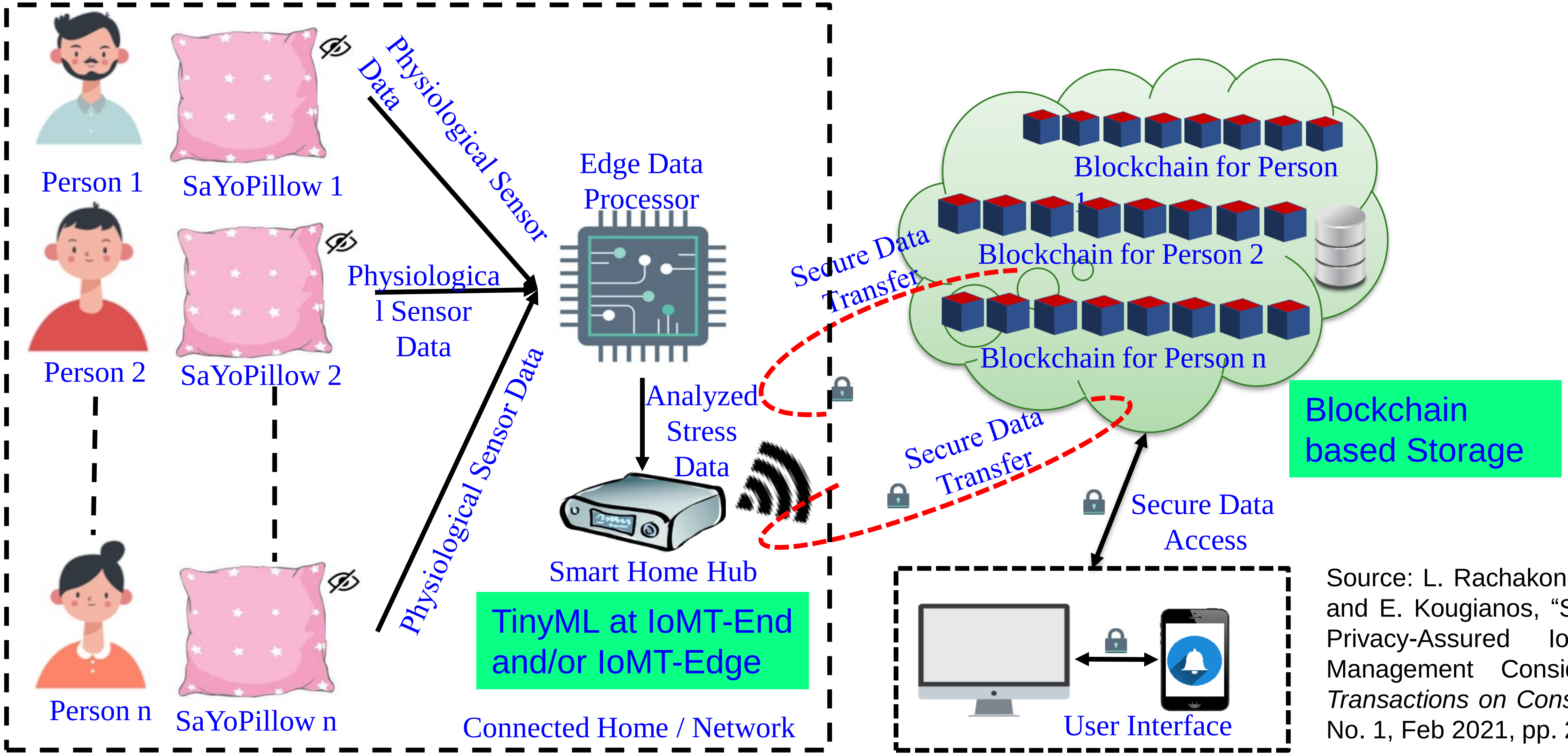


PoW - 10 min in cloud	PoAh – 950ms in Raspberry Pi	PoP - 192ms in Raspberry Pi
High Power	3 W Power	5 W Power

- ✓ PoP is 1,000X faster than PoW
- ✓ PoP is 5X faster than PoAh

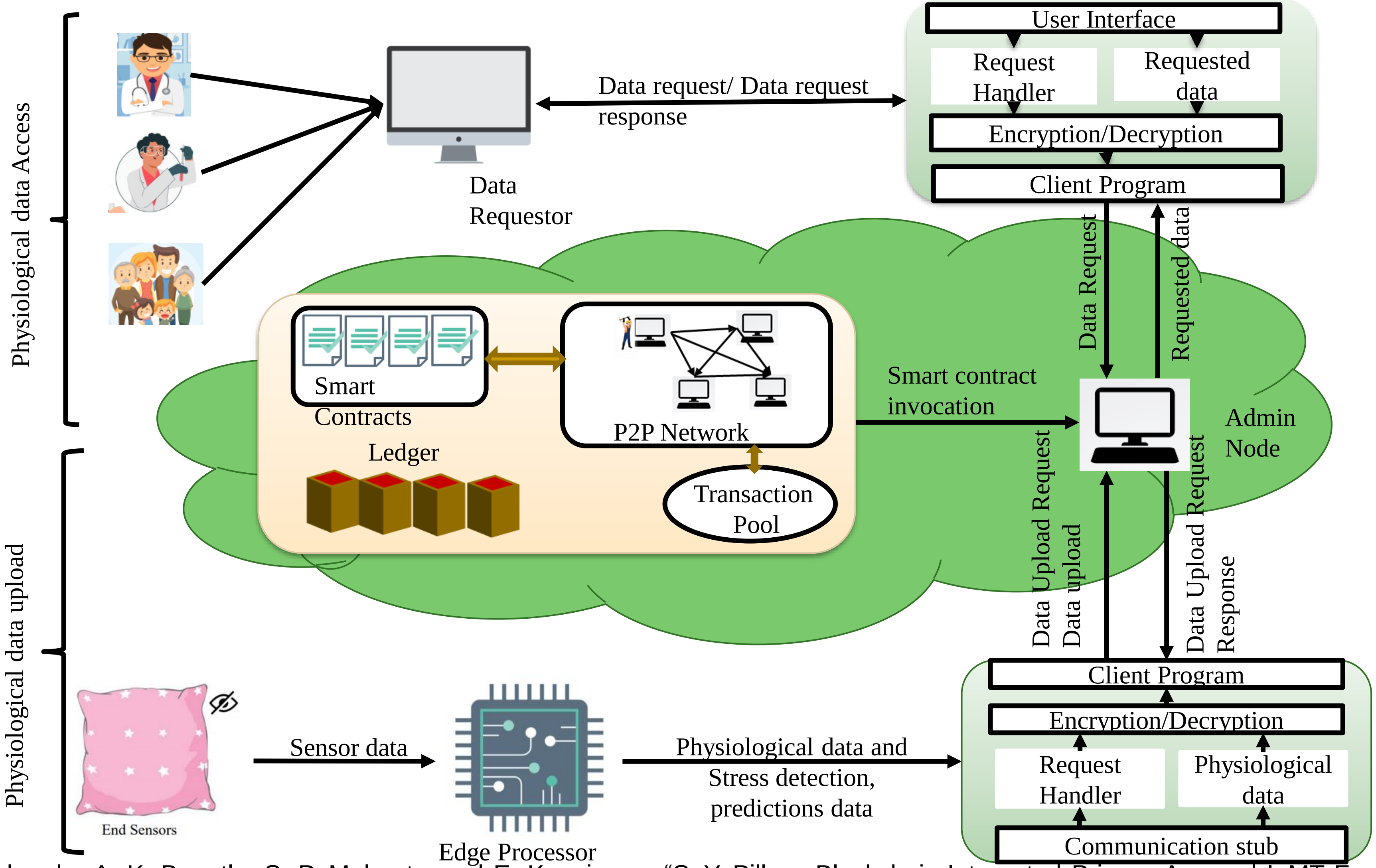
Source: S. P. Mohanty, V. P. Yanambaka, E. Kougianos, and D. Puthal, “PUFchain: Hardware-Assisted Blockchain for Sustainable Simultaneous Device and Data Security in Internet of Everything (IoE)”, *IEEE Consumer Electronics Magazine (MCE)*, Vol. 9, No. 2, March 2020, pp. 8-16.

Our Smart-Yoga Pillow (SaYoPillow) with TinyML and Blockchain based Security



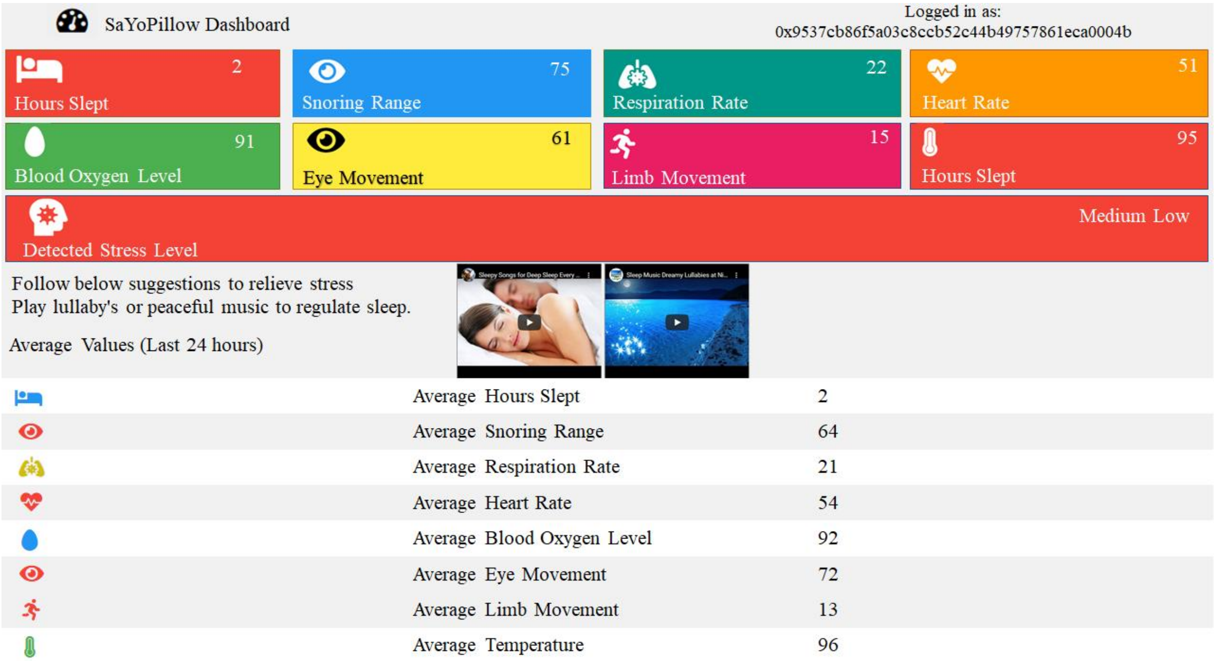
Source: L. Rachakonda, A. K. Bapatla, S. P. Mohanty, and E. Kougianos, "SaYoPillow: Blockchain-Integrated Privacy-Assured IoMT Framework for Stress Management Considering Sleeping Habit", *IEEE Transactions on Consumer Electronics (TCE)*, Vol. 67, No. 1, Feb 2021, pp. 20-29.

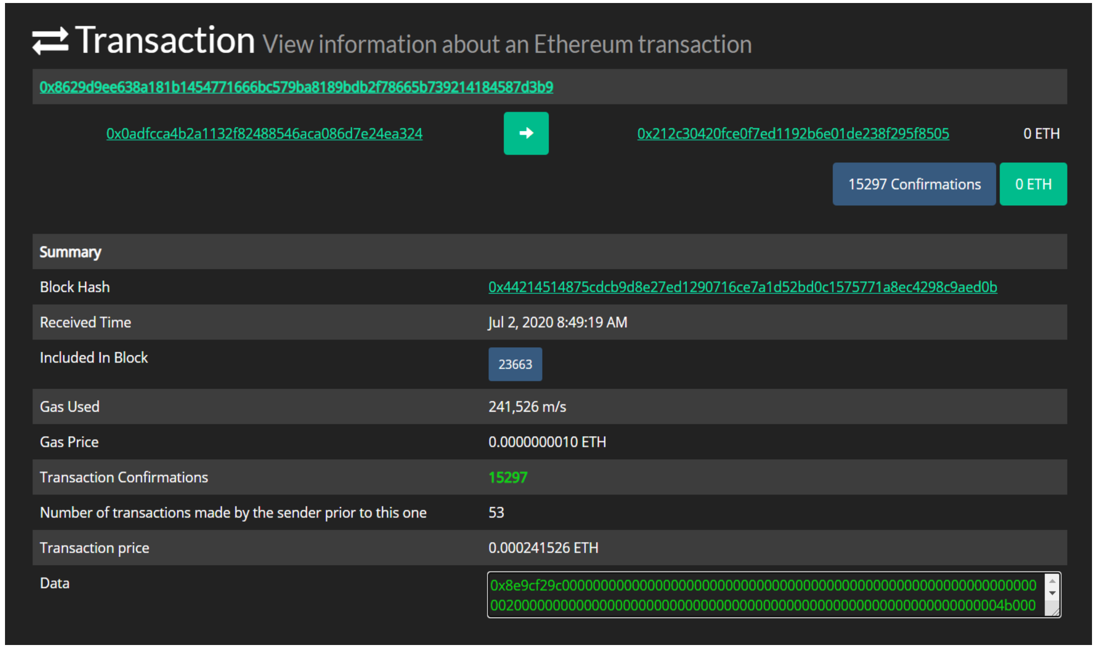
SaYoPillow: Blockchain Details

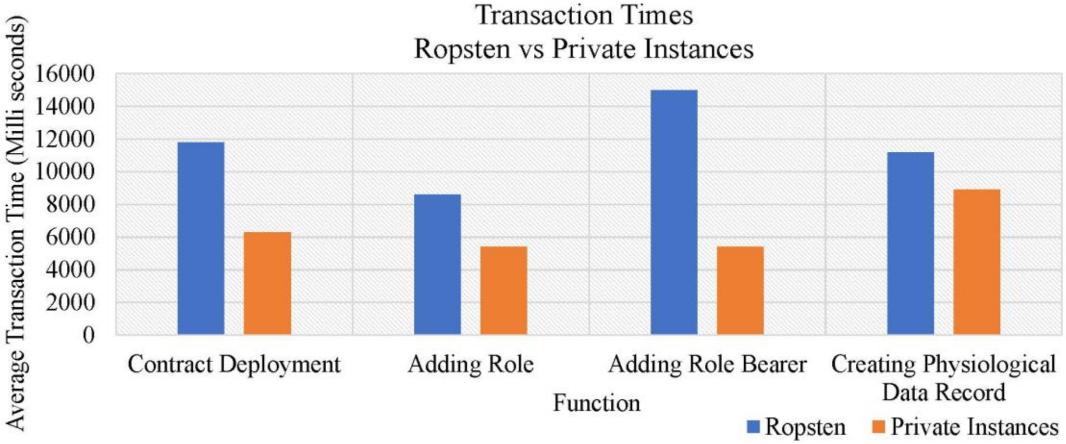


Source: L. Rachakonda, A. K. Bapatla, S. P. Mohanty, and E. Kougianos, "SaYoPillow: Blockchain-Integrated Privacy-Assured IoMT Framework for Stress Management Considering Sleeping Habit", *IEEE Transactions on Consumer Electronics (TCE)*, Vol. 67, No. 1, Feb 2021, pp. 20-29.

SaYoPillow: Blockchain Results



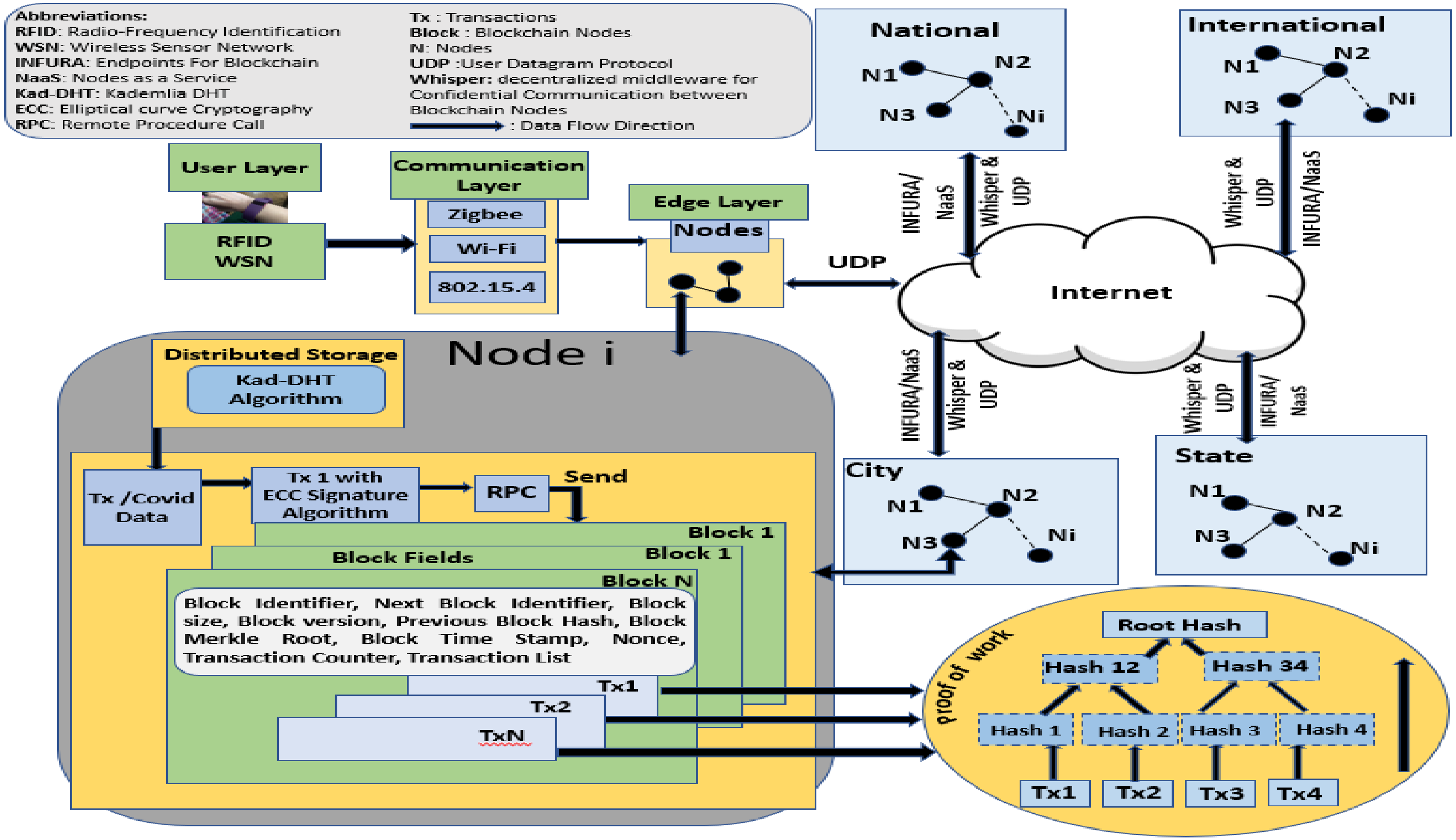




Transaction times of Private Ethereum in SaYoPillow is 2X faster in operations as compared to public ethereum test network Ropsten, as it is impacted by network congestion.

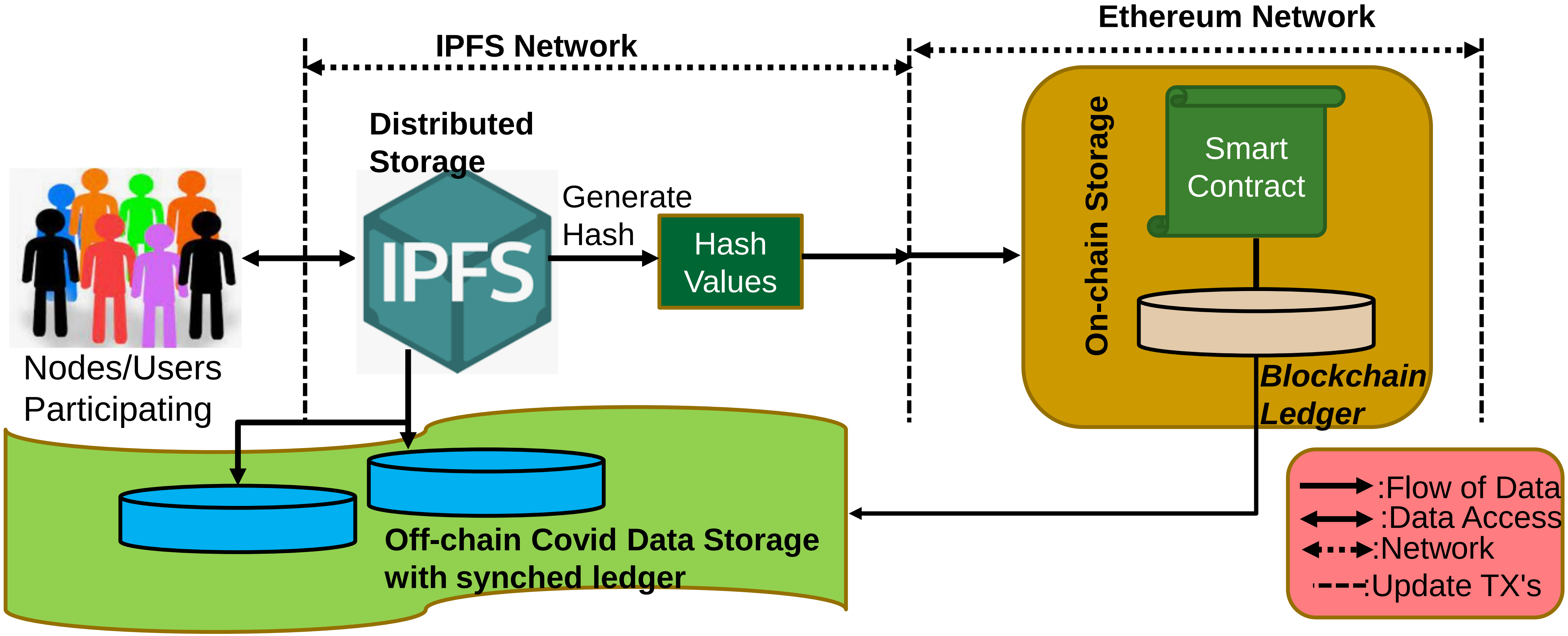
Source: L. Rachakonda, A. K. Bapatla, S. P. Mohanty, and E. Kougianos, "SaYoPillow: Blockchain-Integrated Privacy-Assured IoMT Framework for Stress Management Considering Sleeping Habits", *IEEE Transactions on Consumer Electronics (TCE)*, Vol. 67, No. 1, Feb 2021, pp. 20-29.

CoviChain: A Blockchain based Framework for Nonrepudiable Contact Tracing in H-CPS



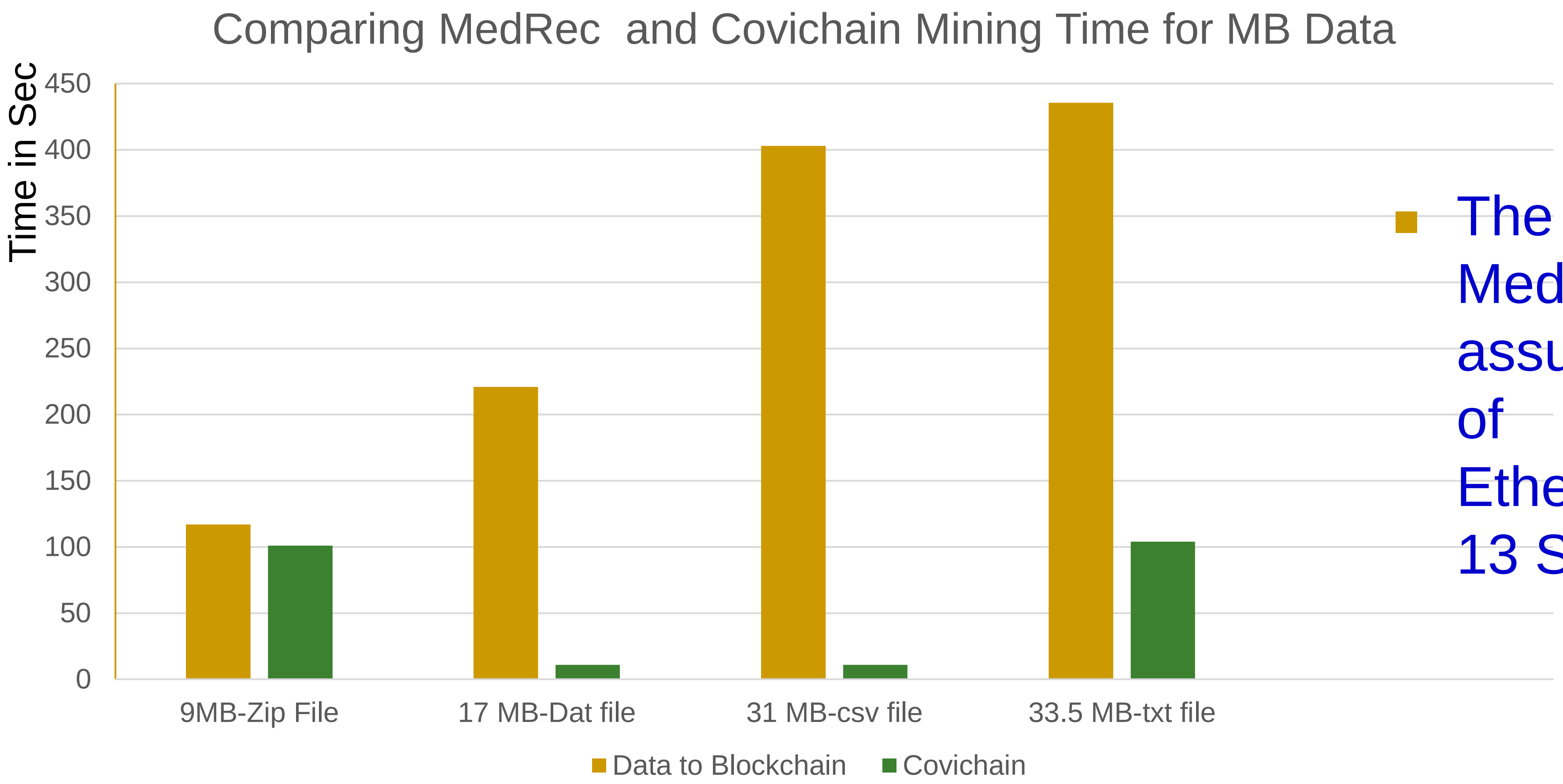
Source: S. L. T. Vangipuram, S. P. Mohanty, and E. Kougianos, “CoviChain: A Blockchain based Framework for Nonrepudiable Contact Tracing in Healthcare Cyber-Physical Systems during Pandemic Outbreaks”, *Springer Nature Computer Science (SN-CS)*, Vol. 2, No. 2, June 2021, Article: 346, 16-pages.

CoviChain: A Blockchain based Framework for Nonrepudiable Contact Tracing in H-CPS



Source: S. L. T. Vangipuram, S. P. Mohanty, and E. Kougianos, "CoviChain: A Blockchain based Framework for Nonrepudiable Contact Tracing in Healthcare Cyber-Physical Systems during Pandemic Outbreaks", *Springer Nature Computer Science (SN-CS)*, Vol. 2, No. 2, June 2021, Article: 346, 16-pages.

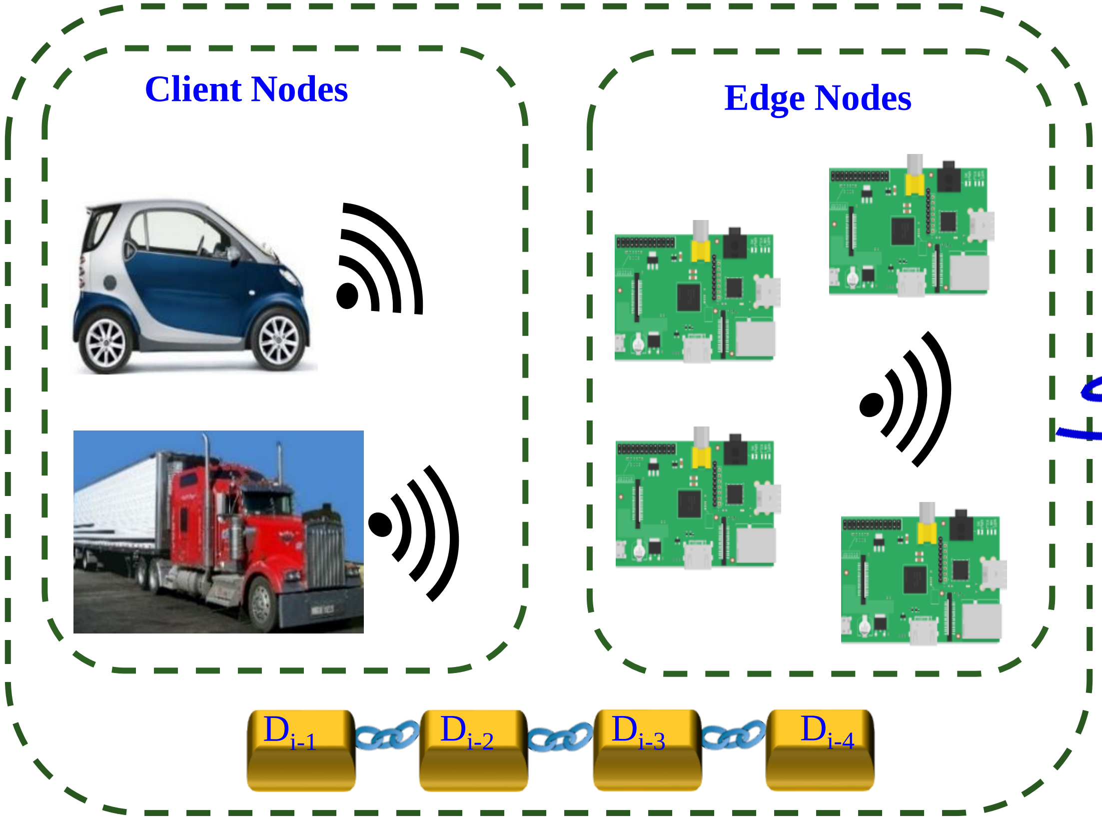
CoviChain: A Blockchain based Framework for Nonrepudiable Contact Tracing in H-CPS



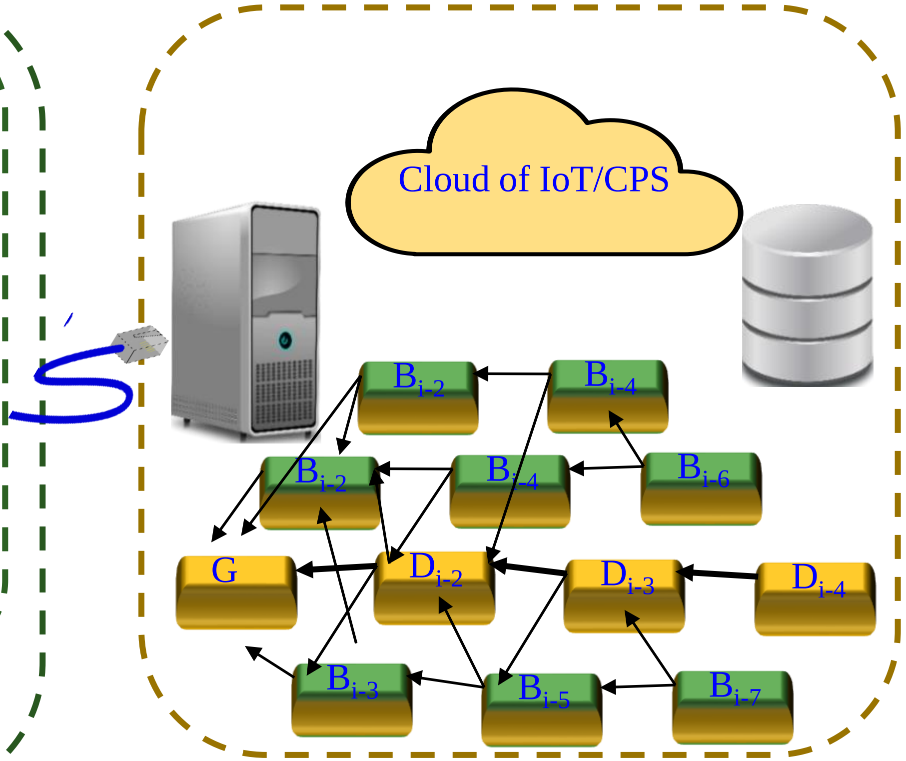
- The time for data in MedRec are calculated assuming the mining time of the conventional Ethereum blockchain to be 13 Seconds for 1MB Data.

Source: S. L. T. Vangipuram, S. P. Mohanty, and E. Kougianos, “CoviChain: A Blockchain based Framework for Nonrepudiable Contact Tracing in Healthcare Cyber-Physical Systems during Pandemic Outbreaks”, *Springer Nature Computer Science (SN-CS),* Vol. 2, No. 2, June 2021, Article: 346, 16-pages.

Our Multi-Chain Technology to Enhance Blockchain Scalability



(a) Nodes-Chain



(b) Multi-Blockchains

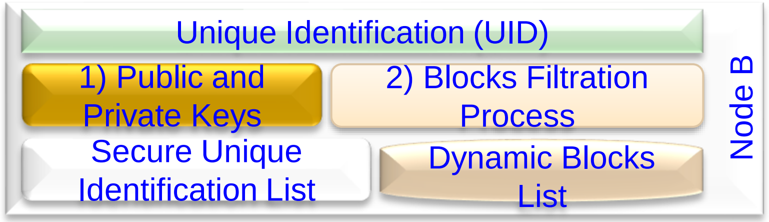
Source: A. J. Alkhodair, S. P. Mohanty, E. Kougianos, and D. Puthal, "McPoRA: A Multi-Chain Proof of Rapid Authentication for Post-Blockchain based Security in Large Scale Complex Cyber-Physical Systems", in *Proceedings of the 19th IEEE Computer Society Annual Symposium on VLSI (ISVLSI)*, 2020, pp. 446--451.

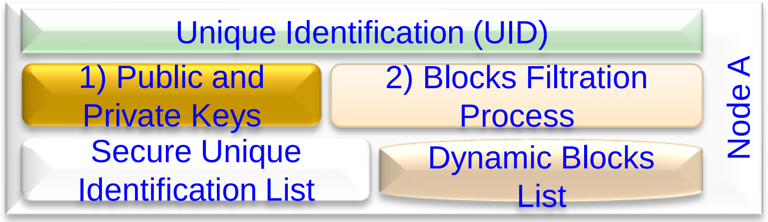
A Perspective of BC, Tangle Vs Our Multichain

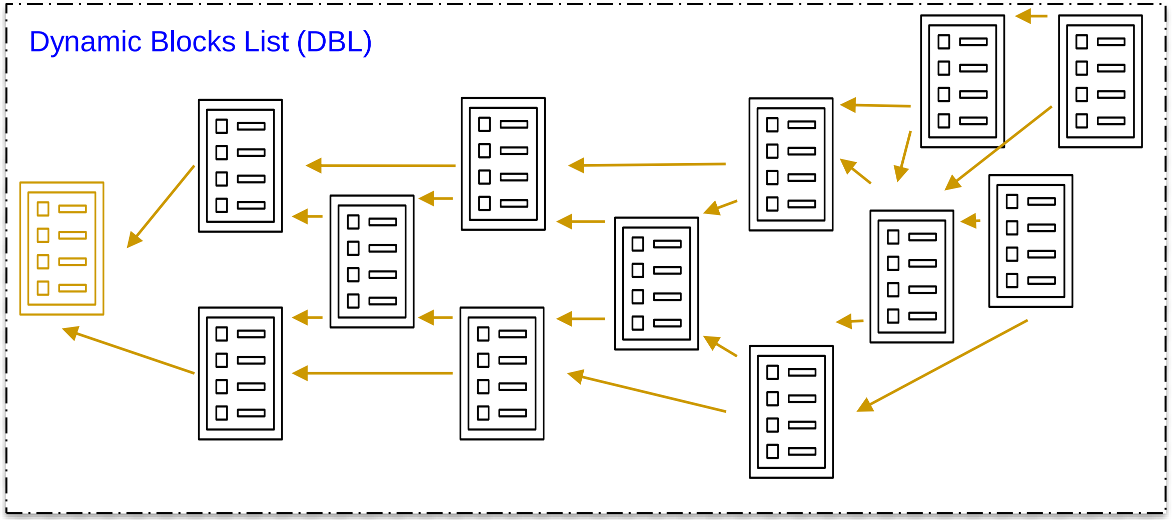
Features/Technology	Blockchain (Bitcoin)	Proof of Authentication	Tangle	HashGraph	McPoRA (current Paper)
Linked Lists	• One linked list of blocks. • Block of transactions.	• One linked list of blocks. • Block of transactions.	• DAG linked list. • One transaction.	• DAG linked List. • Container of transactions hash	• DAG linked List. • Block of transactions. • Reduced block.
Validation	Mining	Authentication	Mining	Virtual Voting (witness)	Authentication
Type of validation	Miners	Trusted Nodes	Transactions	Containers	All Nodes
Ledger Requirement	Full ledger required	Full ledger required	Portion based on longest and shortest paths.	Full ledger required	Portion based on authenticators' number
Cryptography	Digital Signatures	Digital Signatures	Quantum key signature	Digital Signatures	Digital Signatures
Hash function	SHA 256	SHA 256	KECCAK-384	SHA 384	SCRYPT
Consensus	Proof of Work	Cryptographic Authentication	Proof of Work	aBFT	Predefined UID
Numeric System	Binary	Binary	Trinity	Binary	Binary
Involved Algorithms	HashCash	No	• Selection Algorithm • HashCash	No	BFP
Decentralization	Partially	Partially	Fully	Fully	Fully
Appending Requirements	Longest chain	One chain	Selection Algorithm	Full Randomness	Filtration Process
Energy Requirements	High	Low	High	Medium	Low
Node Requirements	High Resources Node	Limited Resources Node	High Resources Node	High Resources Node	Limited Resources Node
Design Purpose	Cryptocurrency	IoT applications	IoT/Cryptocurrency	Cryptocurrency	IoT/CPS applications

Source: A. J. Alkhodair, S. P. Mohanty, E. Kougianos, and D. Puthal, "McPoRA: A Multi-Chain Proof of Rapid Authentication for Post-Blockchain based Security in Large Scale Complex Cyber-Physical Systems", in *Proceedings of the 19th IEEE Computer Society Annual Symposium on VLSI (ISVLSI)*, 2020, pp. 446--451.

McPoRA based MultiChain -- Components







Secure Unique Identification List (SUIL)

Secure IDs' file consists of all active Nodes joined the Private network.

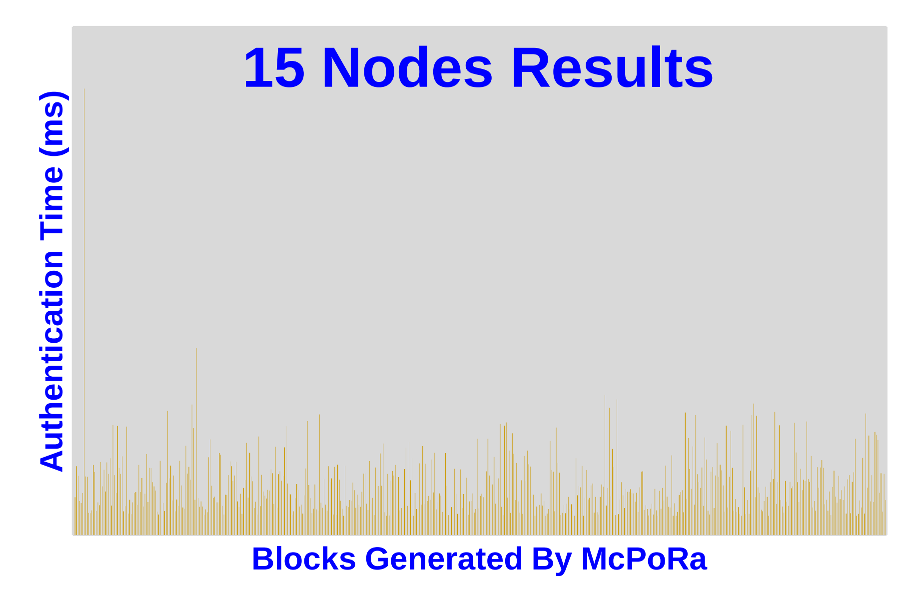
Hashed
Node A Unique Identification (UID)
Node B Unique Identification (UID)
Node C Unique Identification (UID)
Node D Unique Identification (UID)
Node E Unique Identification (UID)
Node F Unique Identification (UID)
Node G Unique Identification (UID)
Node H Unique Identification (UID)
Node I Unique Identification (UID)

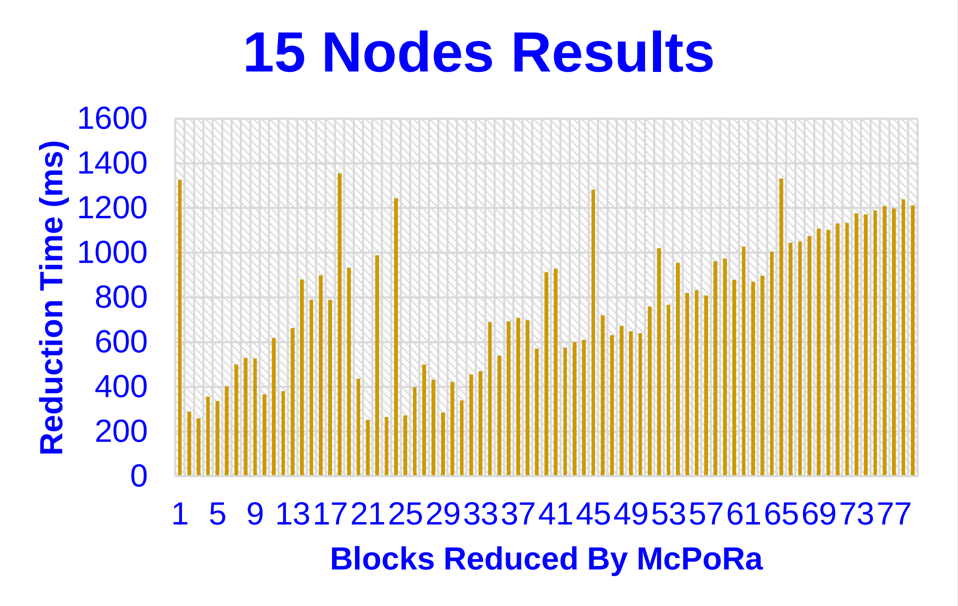
Consensus Time – 0.7 sec (Avg)
Power Consumption – 3.5 W
Performance – 4000X faster than PoW

Source: A. J. Alkhodair, S. P. Mohanty, E. Kougianos, and D. Puthal, "McPoRA: A Multi-Chain Proof of Rapid Authentication for Post-Blockchain based Security in Large Scale Complex Cyber-Physical Systems", in *Proceedings of the 19th IEEE Computer Society Annual Symposium on VLSI (ISVLSI)*, 2020, pp. 446—451.

McPoRA – Experimental Results

Time (ms)	Authentication (ms)	Reduction (ms)
Minimum	1.51	252.6
Maximum	35.14	1354.6
Average	3.97	772.53



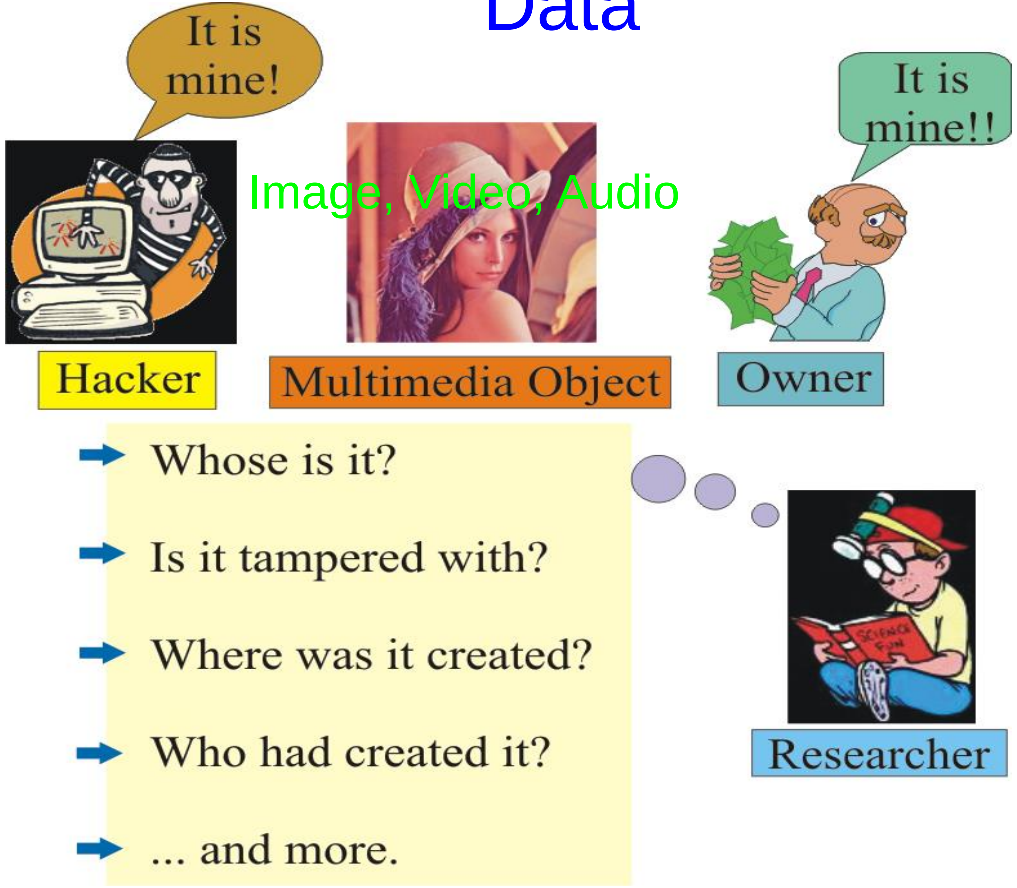


Source: A. J. Alkhodair, S. P. Mohanty, E. Kougianos, and D. Puthal, "McPoRA: A Multi-Chain Proof of Rapid Authentication for Post-Blockchain based Security in Large Scale Complex Cyber-Physical Systems", in *Proceedings of the 19th IEEE Computer Society Annual Symposium on VLSI (ISVLSI)*, 2020, pp. 446—451.

Data and System Authentication and Ownership Protection – My 20 Years of Experiences

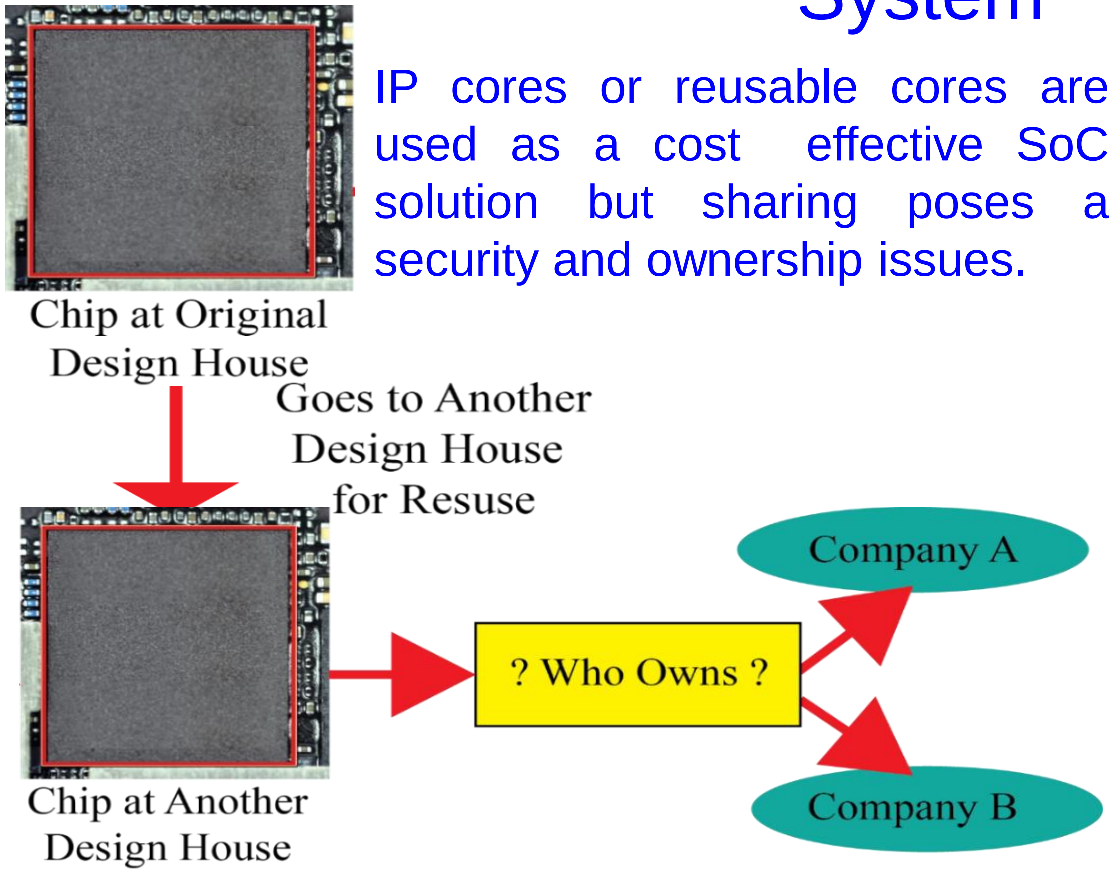
Data

Image, Video, Audio



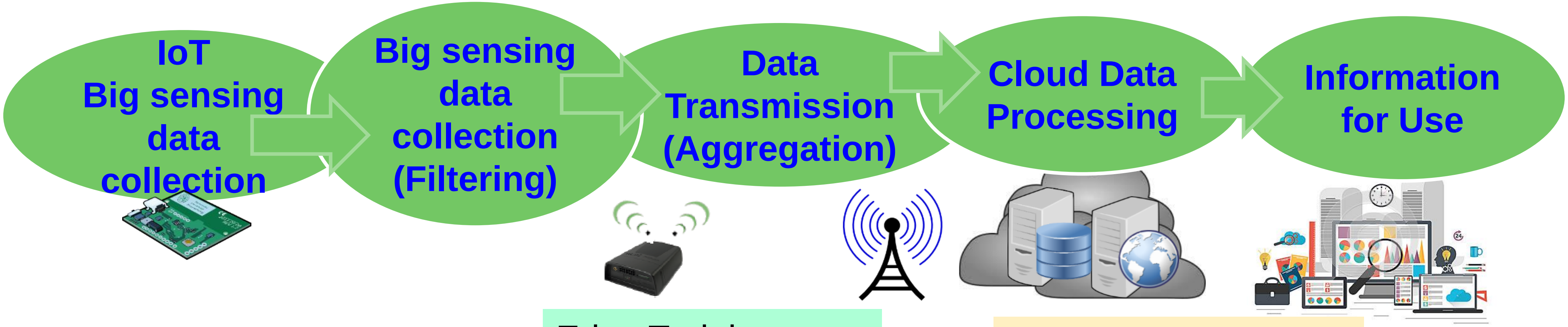
System

IP cores or reusable cores are used as a cost effective SoC solution but sharing poses a security and ownership issues.



Source: S. P. Mohanty, A. Sengupta, P. Guturu, and E. Kougianos, "Everything You Want to Know About Watermarking", *IEEE Consumer Electronics Magazine (CEM),* Volume 6, Issue 3, July 2017, pp. 83--91.

Data Quality Assurance in IoT/CPS



Edge Training:
- ➢ Data Signature
- ➢ Model Signature

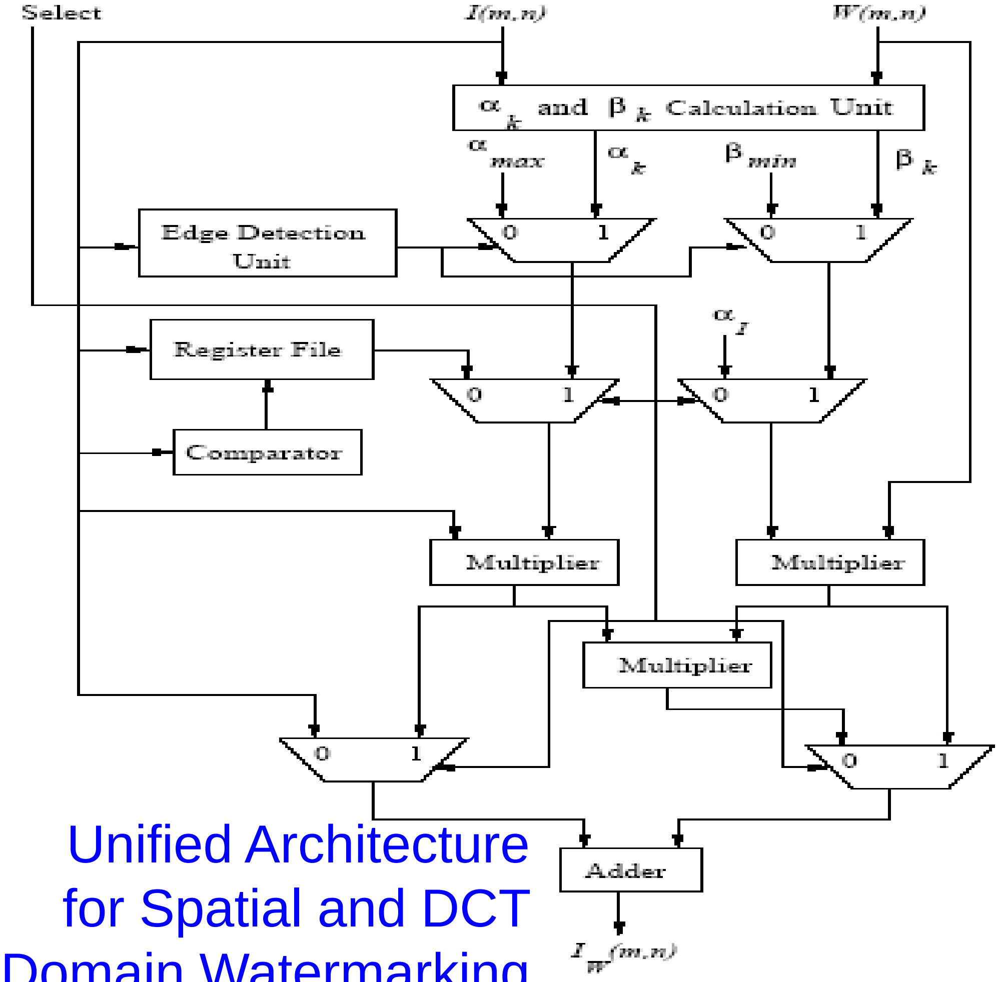
Cloud Training:
- ❖ Data Signature
- ❖ Model Signature

Fake Data Defense:
- Stop (Shield)
- Detect

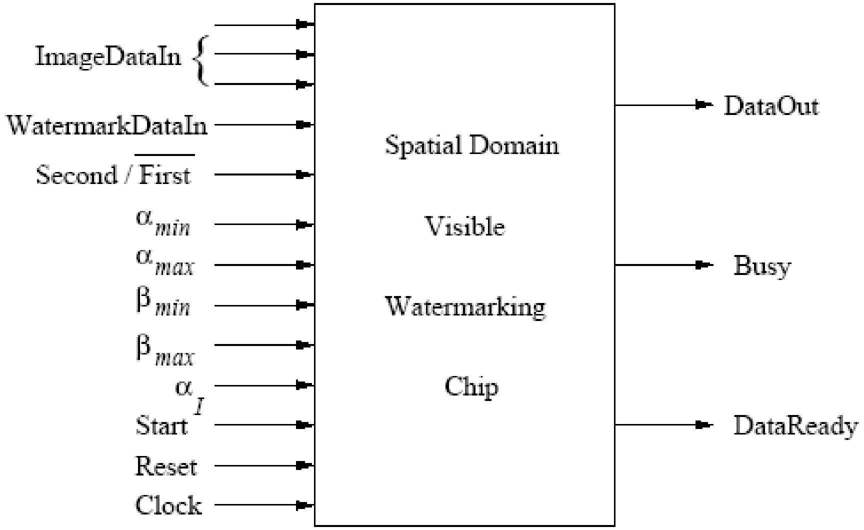
Secure data curation a solution for fake data?

Source: C. Yang, D. Puthal, S. P. Mohanty, and E. Kougianos, “Big-Sensing-Data Curation for the Cloud is Coming”, *IEEE Consumer Electronics Magazine (CEM)*, Volume 6, Issue 4, October 2017, pp. 48--56.

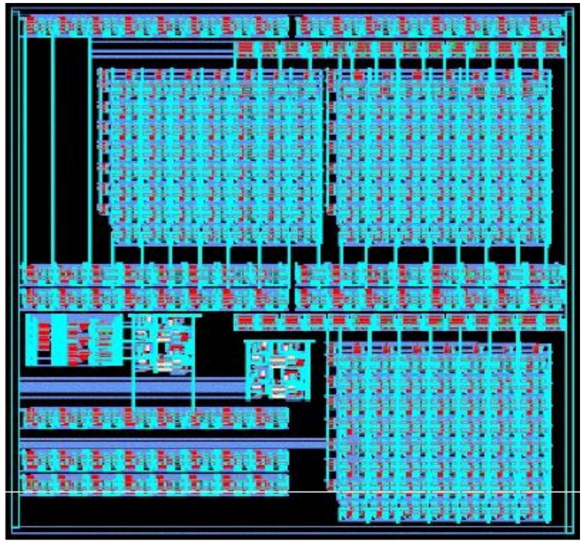
Our Design: First Ever Watermarking Chip for Source-End Visual Data Protection



Unified Architecture for Spatial and DCT Domain Watermarking



Pin Diagram



Chip Layout

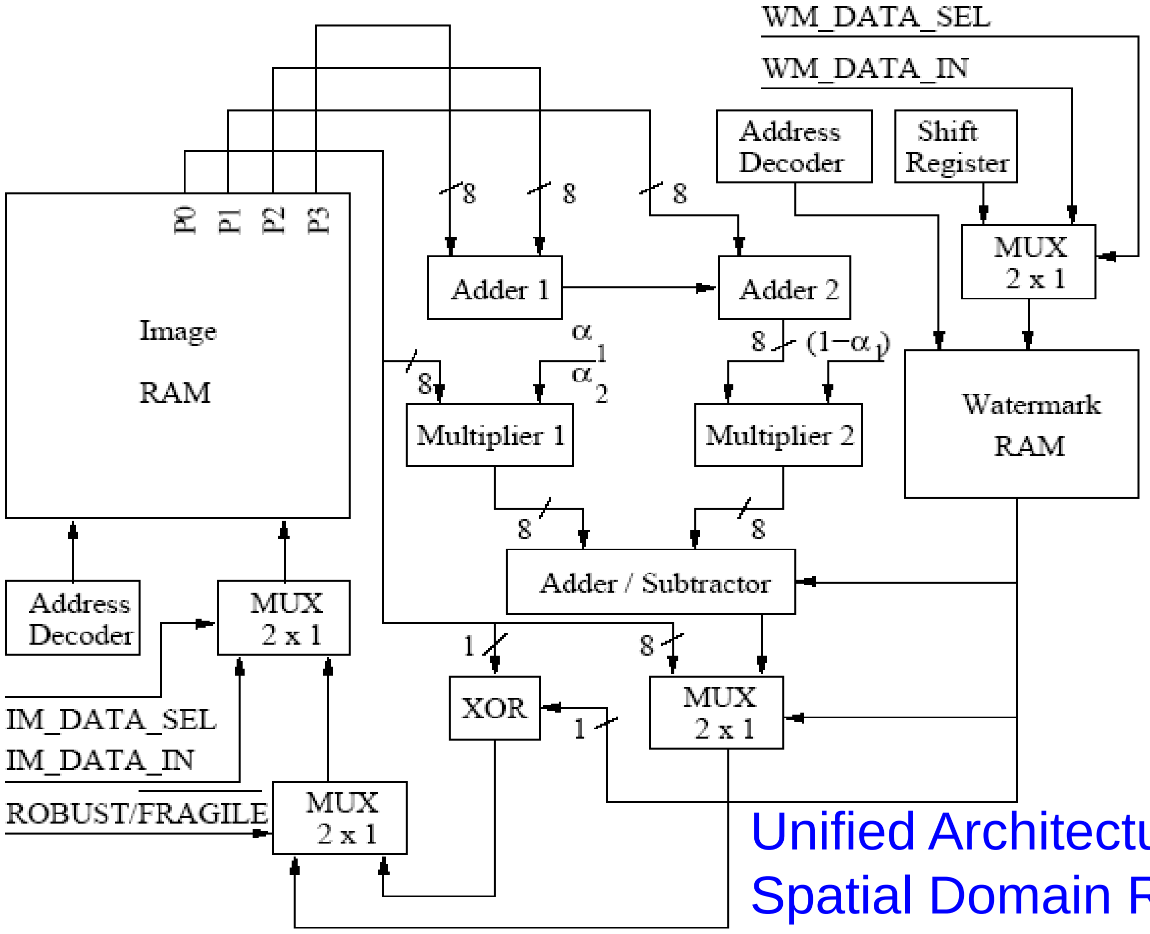
Chip Design Data

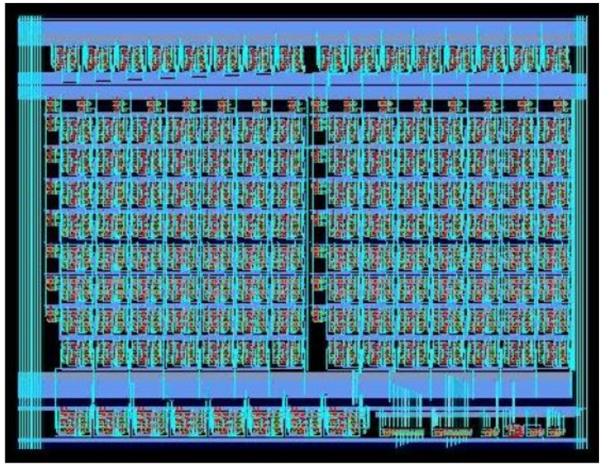
Total Area : 9.6 sq mm, No. of Gates: 28,469

Power Consumption: 6.9 mW, Operating Frequency: 292 MHz

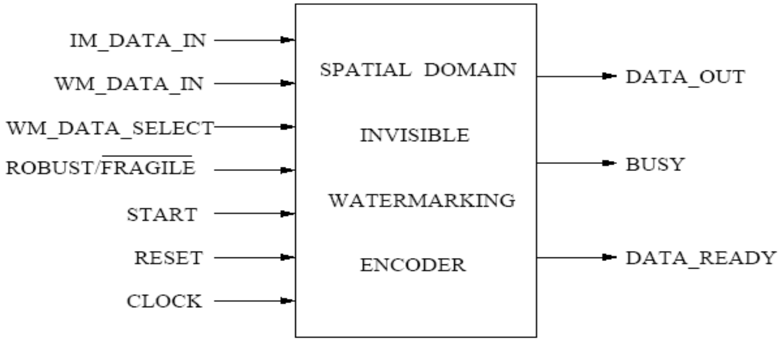
Source: **S. P. Mohanty**, N. Ranganathan, and R. K. Namballa, "A VLSI Architecture for Visible Watermarking in a Secure Still Digital Camera (S^2DC) Design", *IEEE Transactions on Very Large Scale Integration Systems (TVLSI)*, Vol. 13, No. 8, August 2005, pp. 1002-1012.

Our Design: First Ever Watermarking Chip for Source-End Visual Data Integrity





Chip Layout



Pin Diagram

Chip Design Data

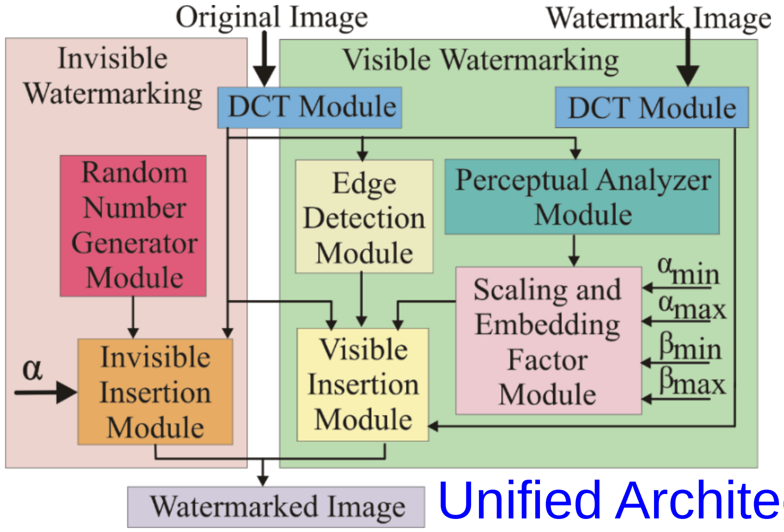
Total Area : 0.87 sq mm, No. of Gates: 4,820

Power Consumption: 2.0 mW, Frequency: 500 MHz

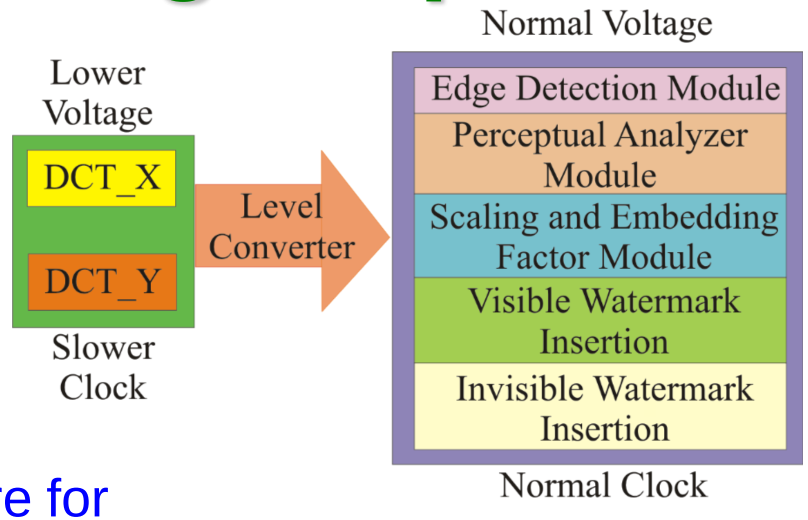
Unified Architecture for Spatial Domain Robust and Fragile Watermarking

Source: S. P. Mohanty, E. Kougianos, and N. Ranganathan, "VLSI Architecture and Chip for Combined Invisible Robust and Fragile Watermarking", *IET Computers & Digital Techniques (CDT)*, Sep 2007, Vol. 1, Issue 5, pp. 600-611.

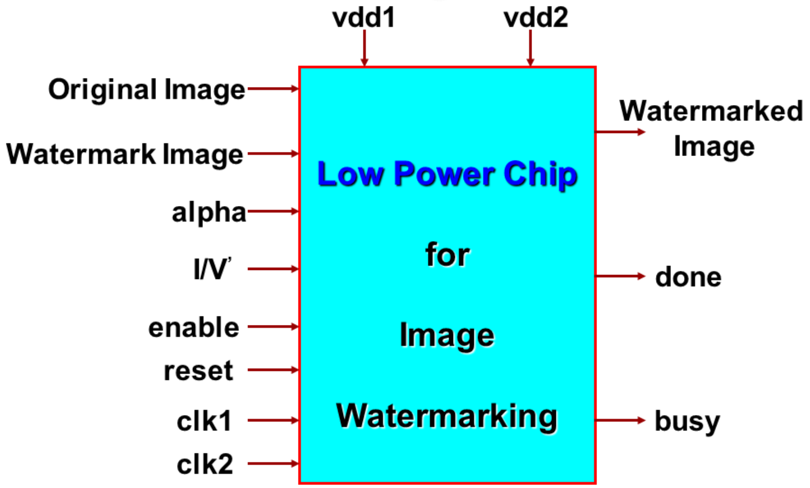
Our Design: First Ever Low-Power Watermarking Chip for Data Quality



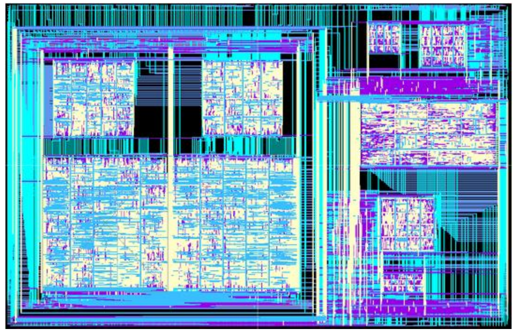
Unified Architecture for DCT Domain Watermarking



DVDF Low-Power Design



Pin Diagram



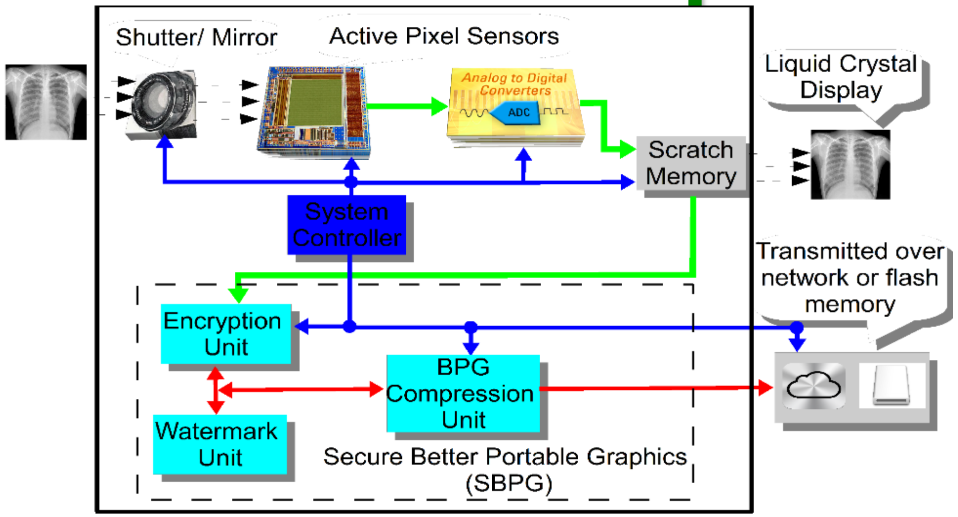
Chip Layout

Chip Design Data

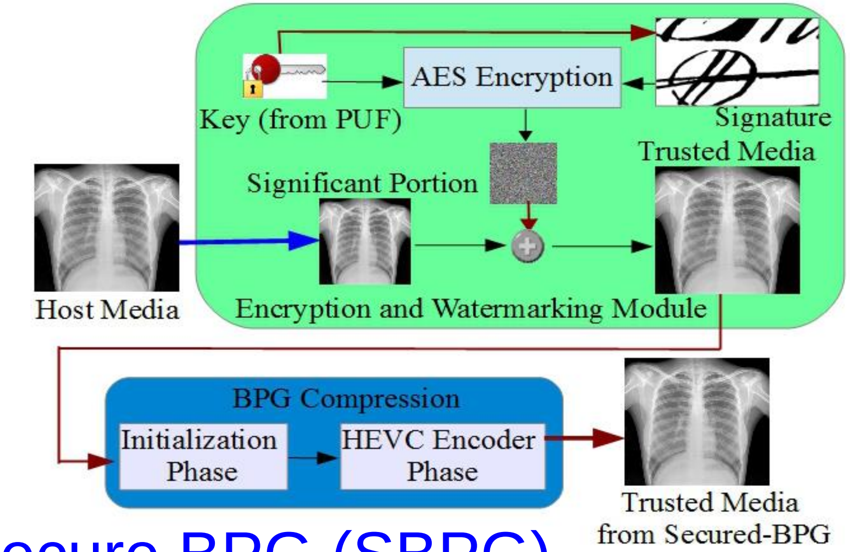
Total Area : 16.2 sq mm, No. of Transistors: 1.4 million
Power Consumption: 0.3 mW, Operating Frequency: 70 MHz and 250 MHz at 1.5 V and 2.5 V

Source: S. P. Mohanty, N. Ranganathan, and K. Balakrishnan, "A Dual Voltage-Frequency VLSI Chip for Image Watermarking in DCT Domain", *IEEE Transactions on Circuits and Systems II (TCAS-II)*, Vol. 53, No. 5, May 2006, pp. 394-398.

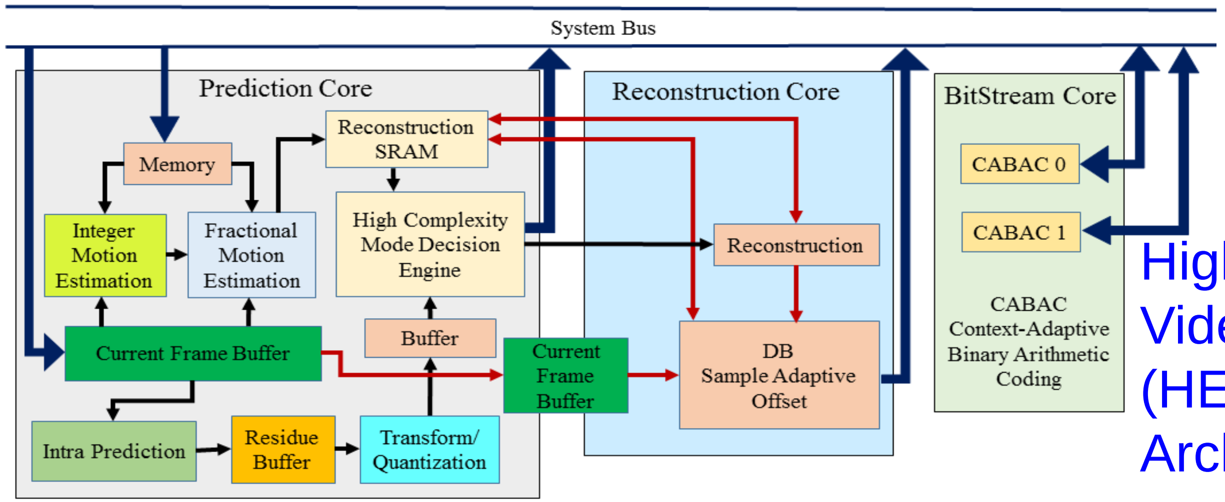
We Introduced First Ever Secure Better Portable Graphics (SBPG) Architecture



Secure Digital Camera (SDC) with SBPG



Secure BPG (SBPG)

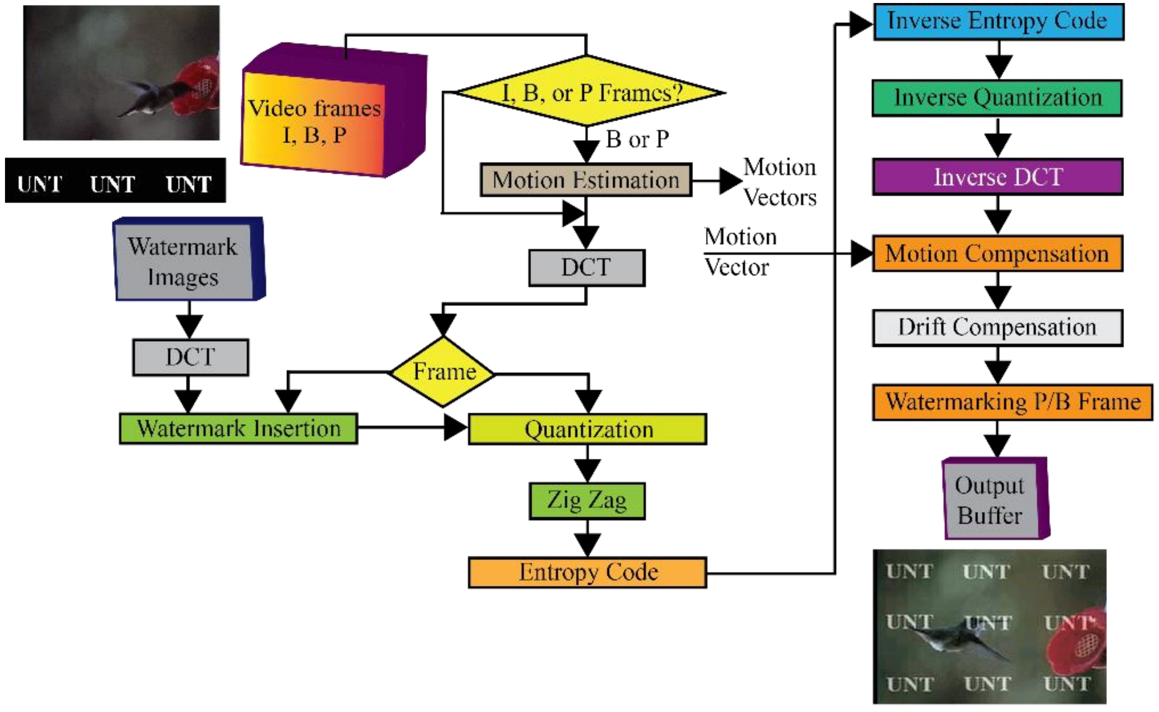


High-Efficiency Video Coding (HEVC) Architecture

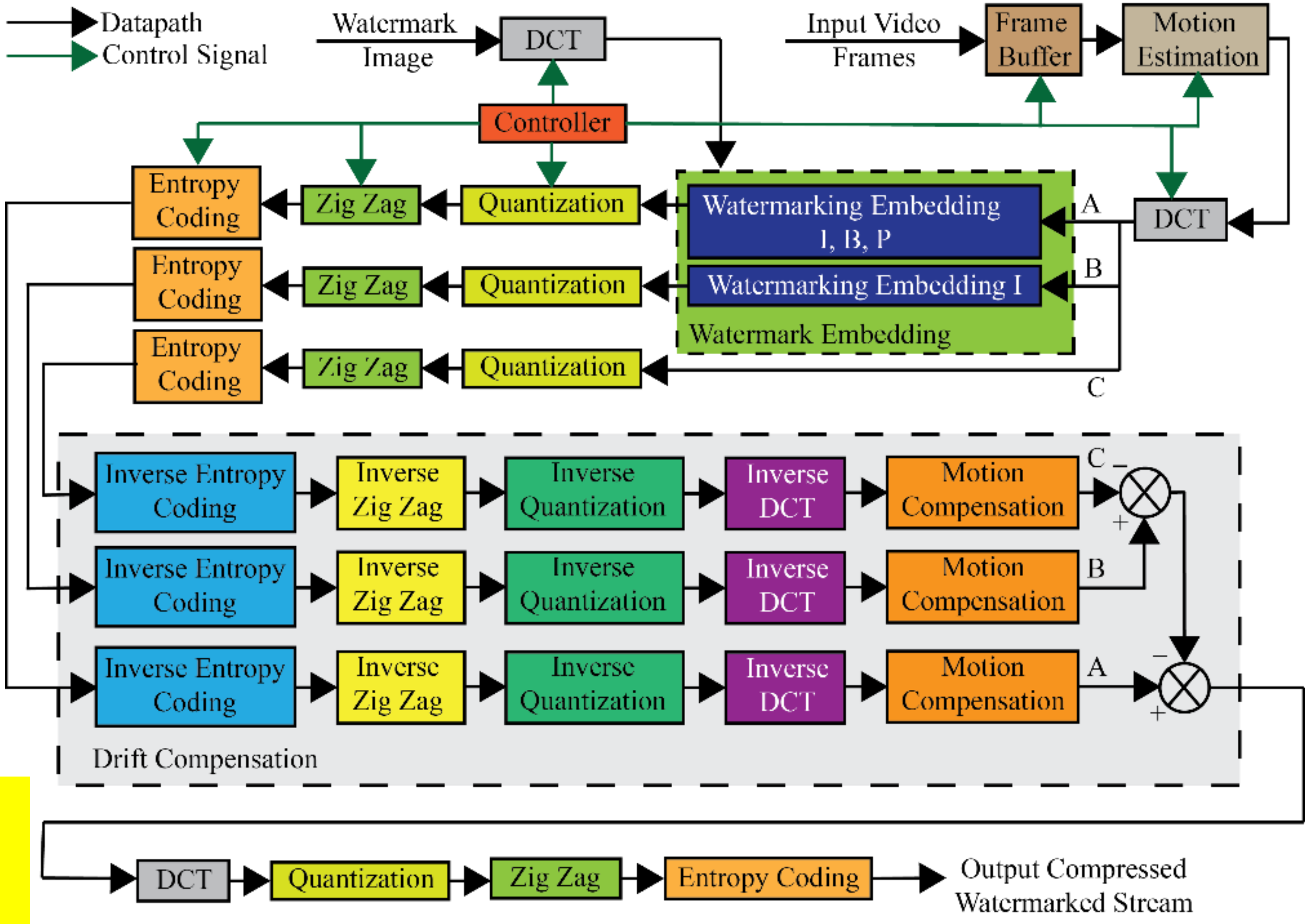
Simulink Prototyping
Throughput: 44 frames/sec
Power Dissipation: 8 nW

Source: S. P. Mohanty, E. Kougianos, and P. Guturu, "SBPG: Secure Better Portable Graphics for Trustworthy Media Communications in the IoT (Invited Paper)", *IEEE Access Journal*, Volume 6, 2018, pp. 5939--5953.

Our Hardware for Real-Time Video Watermarking



(a) Video Watermarking Algorithm as a Flow Chart

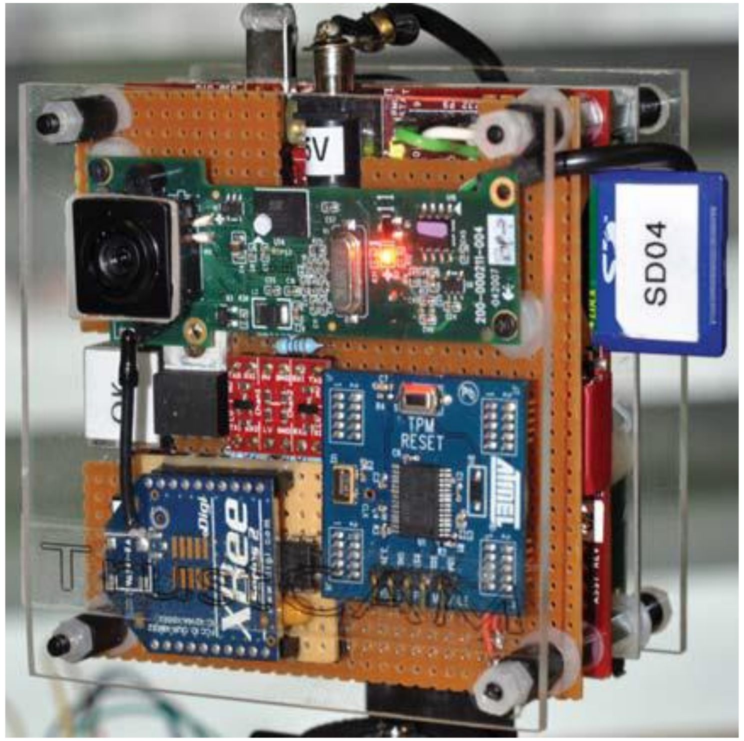


(b) Architecture of the Video Watermrking Algorithm

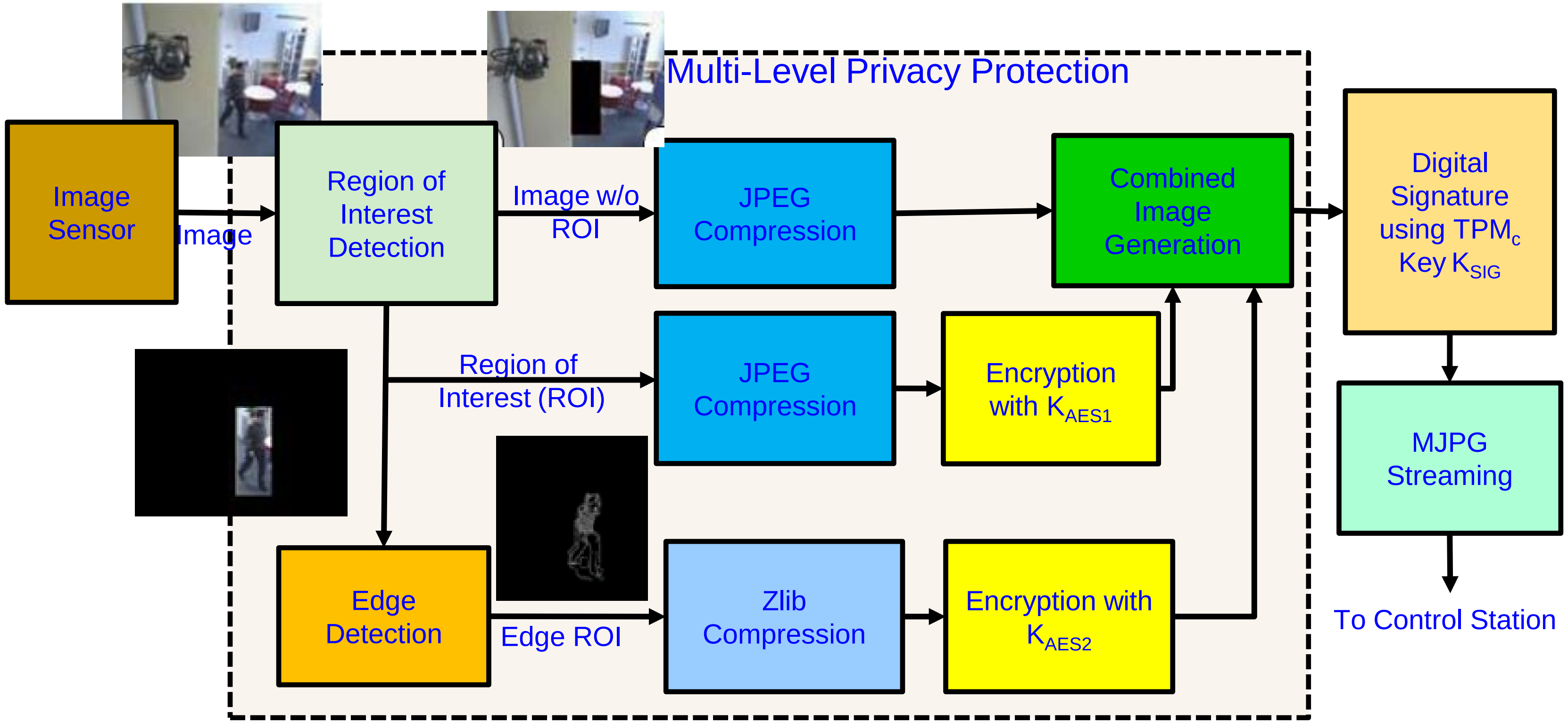
FPGA based Design Data
Resource: 28322 LE, 16532 Registers, 9 MUXes
Operating Frequency: 100 MHz
Throughput: 43 fps

Source: **S. P. Mohanty** and E. Kougianos, "Real-Time Perceptual Watermarking Architectures for Video Broadcasting", *Journal of Systems and Software*, Vol. 84, No. 5, May 2011, pp. 724--738.

My Watermarking Research Inspired - TrustCAM



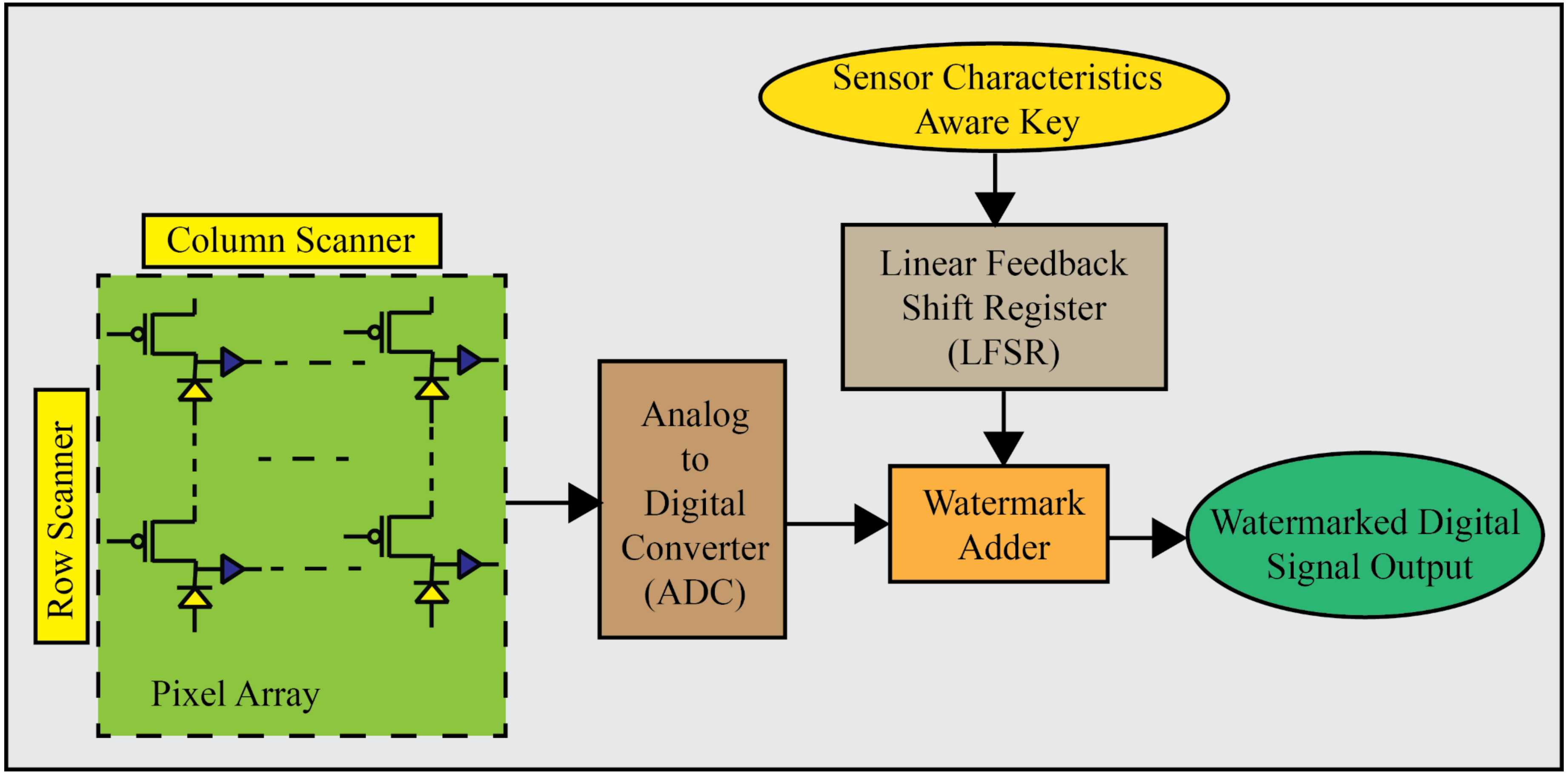
Source: https://pervasive.aau.at/BR/pubs/2010/Winkler_AVSS2010.pdf



For integrity protection, authenticity and confidentiality of image data.

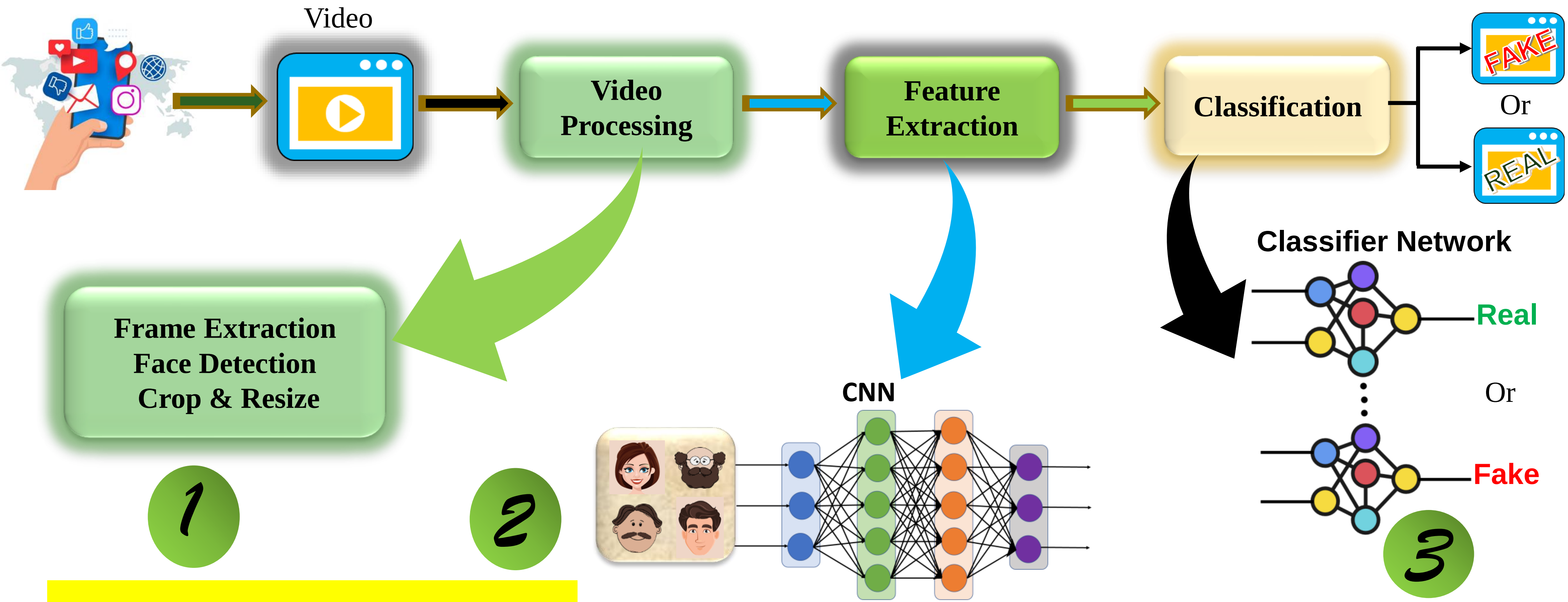
- Identifies sensitive image regions.
- Protects privacy sensitive image regions.
- A Trusted Platform Module (TPM) chip provides a set of security primitives.

My Watermarking Research Inspired – Secured Sensor



Source: G. R. Nelson, G. A. Jullien, O. Yadid-Pecht, "CMOS Image Sensor With Watermarking Capabilities", in *Proc. IEEE International Symposium on Circuits and Systems* (*ISCAS*), 2005, pp. 5326–5329.

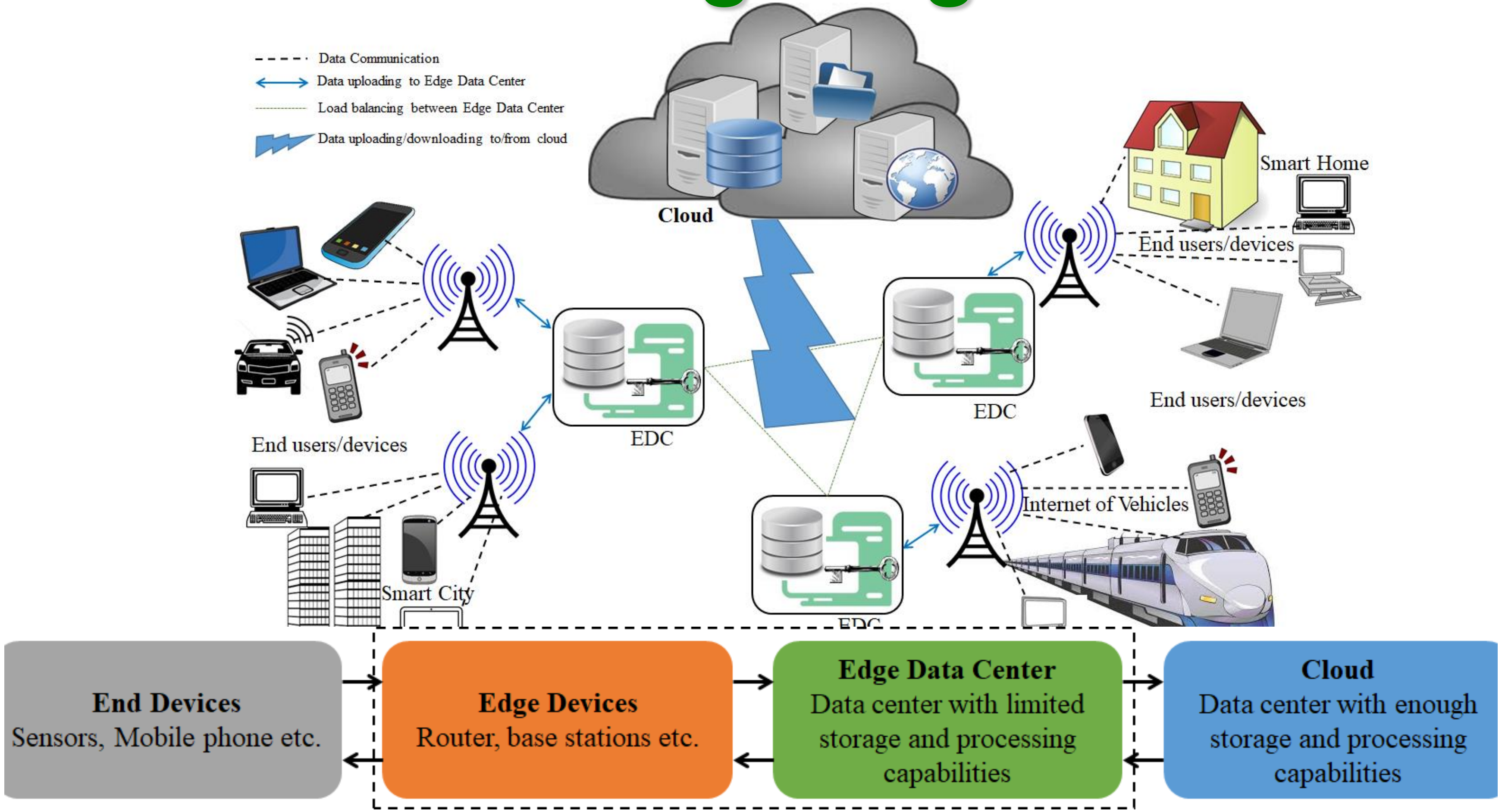
Our Deepfake Detection Method



Accuracy = 96%

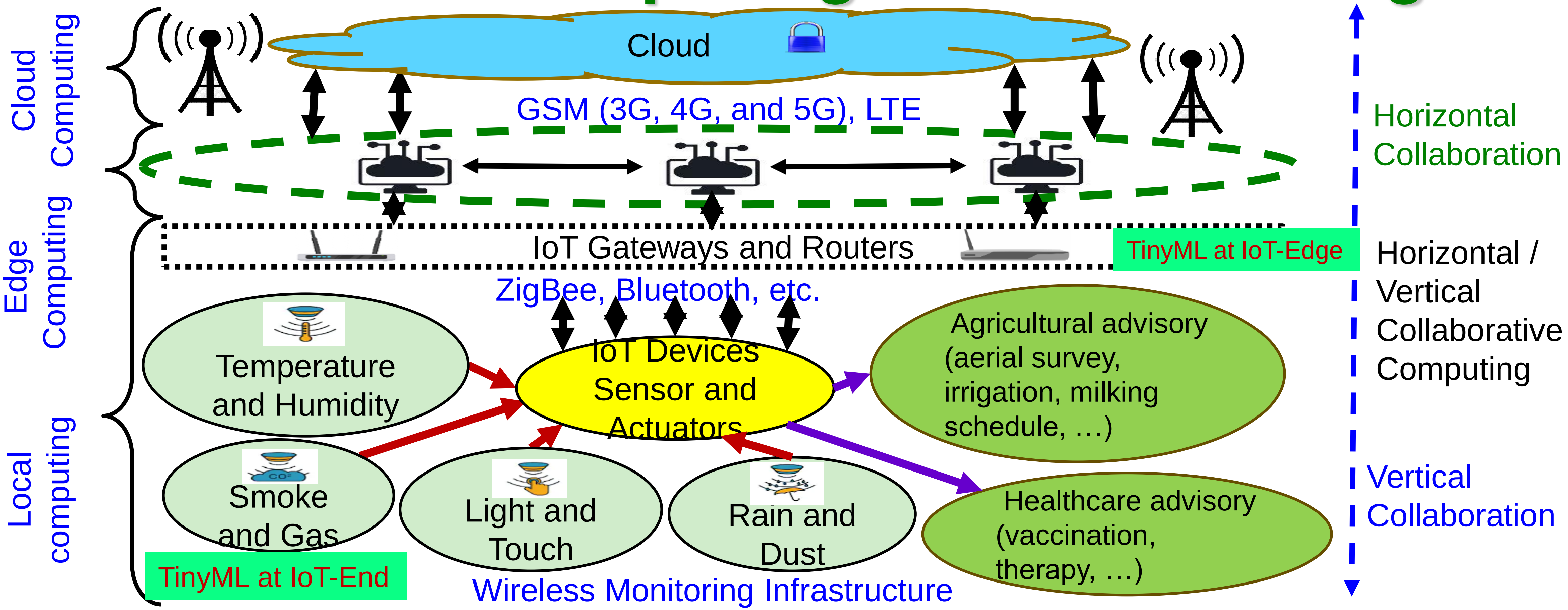
Source: A. Mitra, S. P. Mohanty, P. Corcoran, and E. Kougianos, “A Machine Learning based Approach for DeepFake Detection in Social Media through Key Video Frame Extraction”, *Springer Nature Computer Science (SN-CS)*, Vol. 2, No. 2, Feb 2021, Article: 99, 18-pages.

Data and Security Should be Distributed using Edge Datacenter



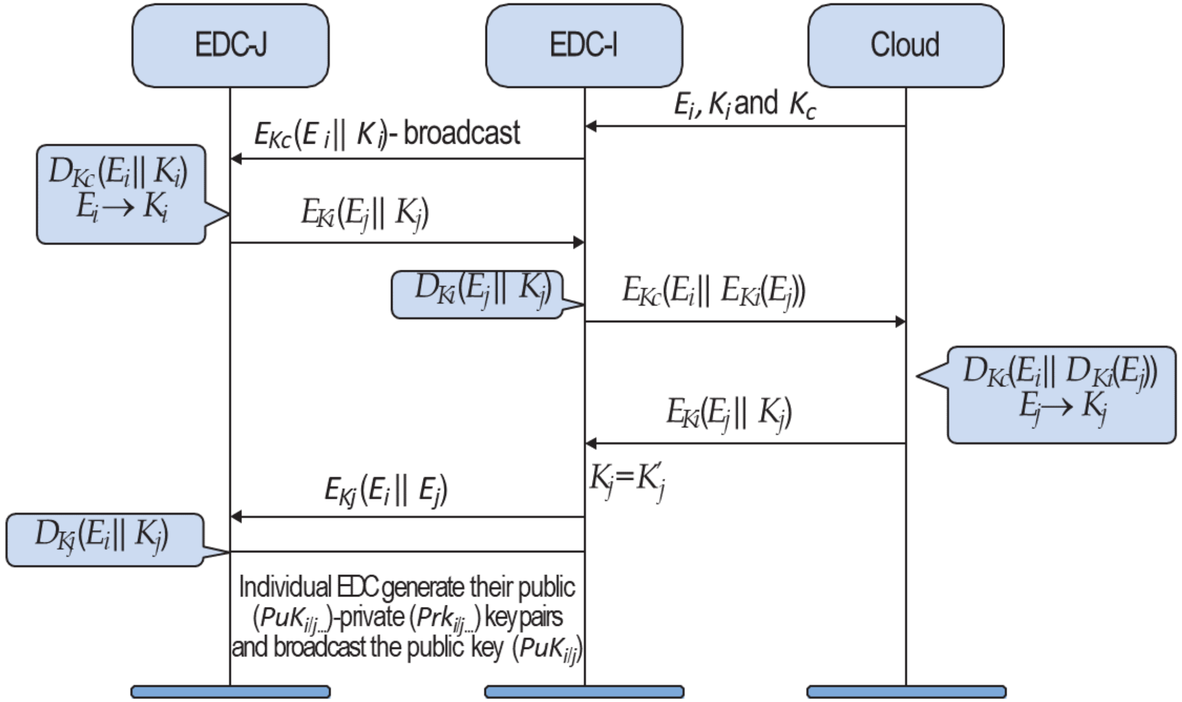
Source: D. Puthal, M. S. Obaidat, P. Nanda, M. Prasad, S. P. Mohanty, and A. Y. Zomaya, "Secure and Sustainable Load Balancing of Edge Data Centers in Fog Computing", *IEEE Communications Magazine*, Volume 56, Issue 5, May 2018, pp. 60--65.

Collaborative Edge Computing is Cost Effective Sustainable Computing for Smart Villages



Source: D. Puthal, S. P. Mohanty, S. Wilson and U. Choppali, "Collaborative Edge Computing for Smart Villages", *IEEE Consumer Electronics Magazine (MCE)*, Vol. 10, No. 03, May 2021, pp. 68-71.

Our Proposed Secure Edge Datacenter



Secure edge datacenter –
- Balances load among the EDCs
- Authenticates EDCs

Algorithm 1: Load Balancing Technique

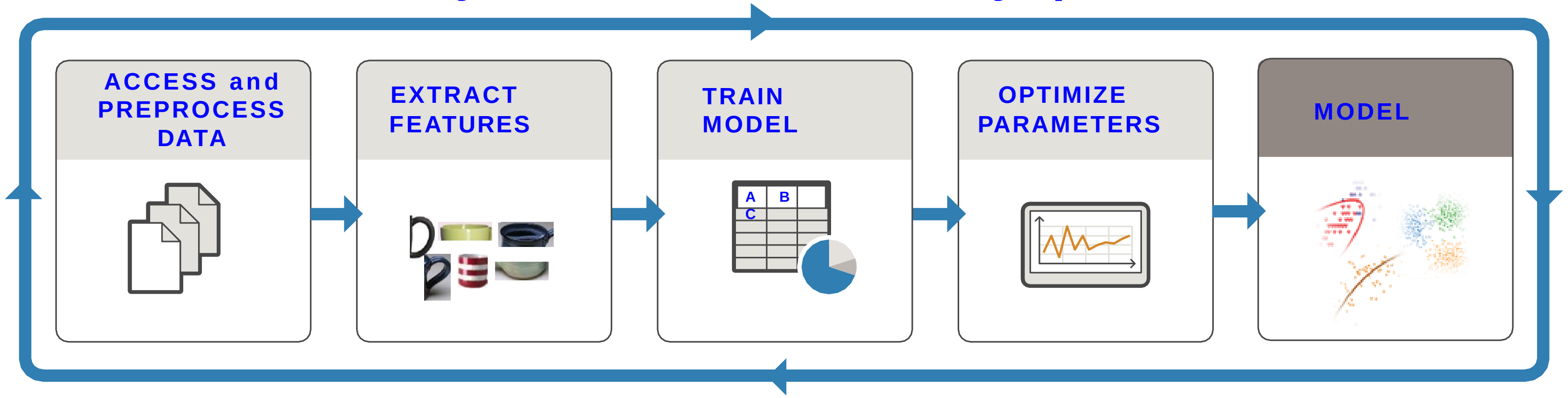
1. If (EDC-I is overloaded)
2. EDC-I broadcast (E_i, L_j)
3. EDC-J (neighbor EDC) verifies:
4. If (E_i is in database) & ($p \leq 0.6$&L_i<<(n-m))
5. Response $E_{Kpu_i}(E_j||K_j||p)$
6. EDC-I perform $D_{Kpr_i}(E_j||K_j||p)$
7. $k_j' \leftarrow E_j$
8. If $(k_j' = k_j)$
9. EDC-I select EDC-J for load balancing.

Response time of the destination EDC has reduced by 20-30% using the proposed allocation approach.

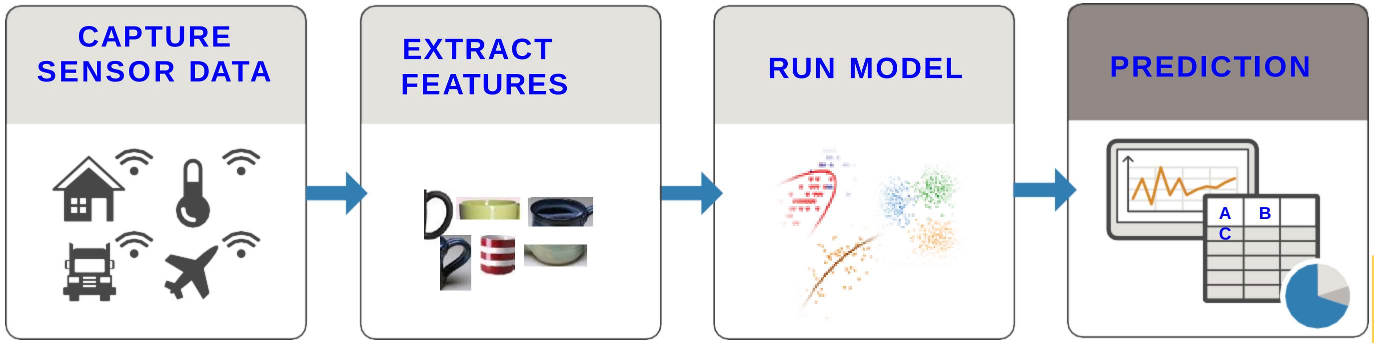
Source: D. Puthal, M. S. Obaidat, P. Nanda, M. Prasad, S. P. Mohanty, and A. Y. Zomaya, "Secure and Sustainable Load Balancing of Edge Data Centers in Fog Computing", *IEEE Communications Magazine*, Volume 56, Issue 5, May 2018, pp. 60--65.

TinyML - Key for Smart Cities and Smart Villages

TRAIN: Iterate until you achieve satisfactory performance.



PREDICT: Integrate trained models into applications.

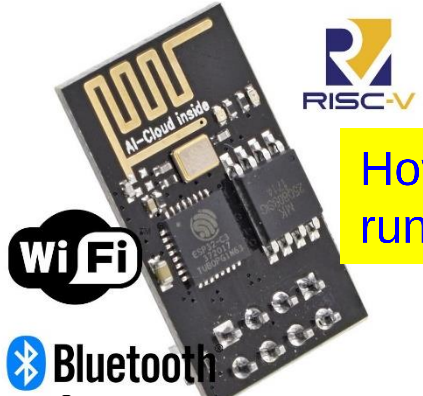


Source: https://www.mathworks.com/campaigns/offers/mastering-machine-learning-with-matlab.html

Needs Significant:

- Computational Resource
- Computation Energy

Solution: Reduce Training Time and/or Computational Resource



How complex AI models run in IoT-end devices?

Source: www-cnx--software-com.cdn.ampproject.org.html

Needs:

- Computational Resource
- Computation Energy

Solution: TinyML

Conclusions

Conclusions

- Cybersecurity and Privacy are important problems in IoT-driven Cyber-Physical Systems (CPS).
- Various elements and components of IoT/CPS including Data, Devices, System Components, AI need security.
- Both software and hardware-based attacks and solutions are possible for cybersecurity in IoT/CPS.
- Cybersecurity in IoT-based H-CPS, A-CPS, E-CPS, and T-CPS, etc. can have serious consequences.
- Existing cybersecurity solutions have serious overheads and may not even run in the end-devices (e.g. a medical device) of CPS/IoT.
- Security-by-Design (SbD) advocate features at early design phases, no-retrofitting.
- Hardware-Assisted Security (HAS): Security provided by hardware for: (1) information being processed, (2) hardware itself, (3) overall system.

Future Directions

- Privacy and/or Security by Design (PbD or SbD) needs research.
- Cybersecurity, Privacy, IP Protection of Information and System (in Cyber-Physical Systems or CPS) need more research.
- Cybersecurity of IoT-based systems (e.g. Smart Healthcare device/data, Smart Agriculture, Smart Grid, UAV, Smart Cars) needs research.
- Sustainable Smart City and Smart Villages: need sustainable IoT/CPS

Acknowledgement(s)

This material is based upon work supported by the National Science Foundation under Grant Nos. OAC-1924112 and HBCU-EiR-2101181. Any opinions, findings, and conclusions or recommendations expressed in this material are those of the author(s) and do not necessarily reflect the views of the National Science Foundation.