# Towards Sustainable Smart Healthcare

**Keynote – 3rd International Conference on Communication, Control and Intelligent Systems (CCIS 2024).**

**Mathura, India**
**07 Dec 2024**

**Homepage:**
www.smohanty.org

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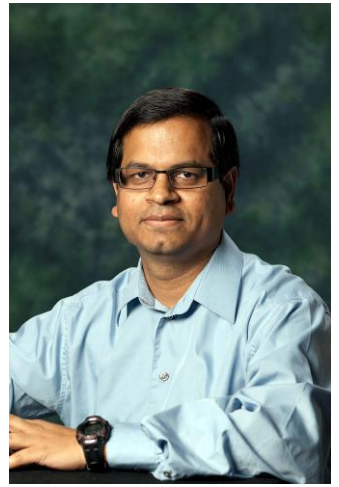


# Outline

- Smart Healthcare – Broad Introduction
- Smart Healthcare – Challenges Against Sustainability
- Selected Cybersecurity Solutions for IoT/CPS
- Drawbacks of Existing Cybersecurity Solutions of IoMT/H-CPS
- Security by Design (SbD) Principle
- Security by Design (SbD) Example Solutions
- Trustworthy Pharmaceutical Supply Chain
- Trustworthy Medical Prescription
- Conclusion

# Smart Healthcare – Broad Introduction

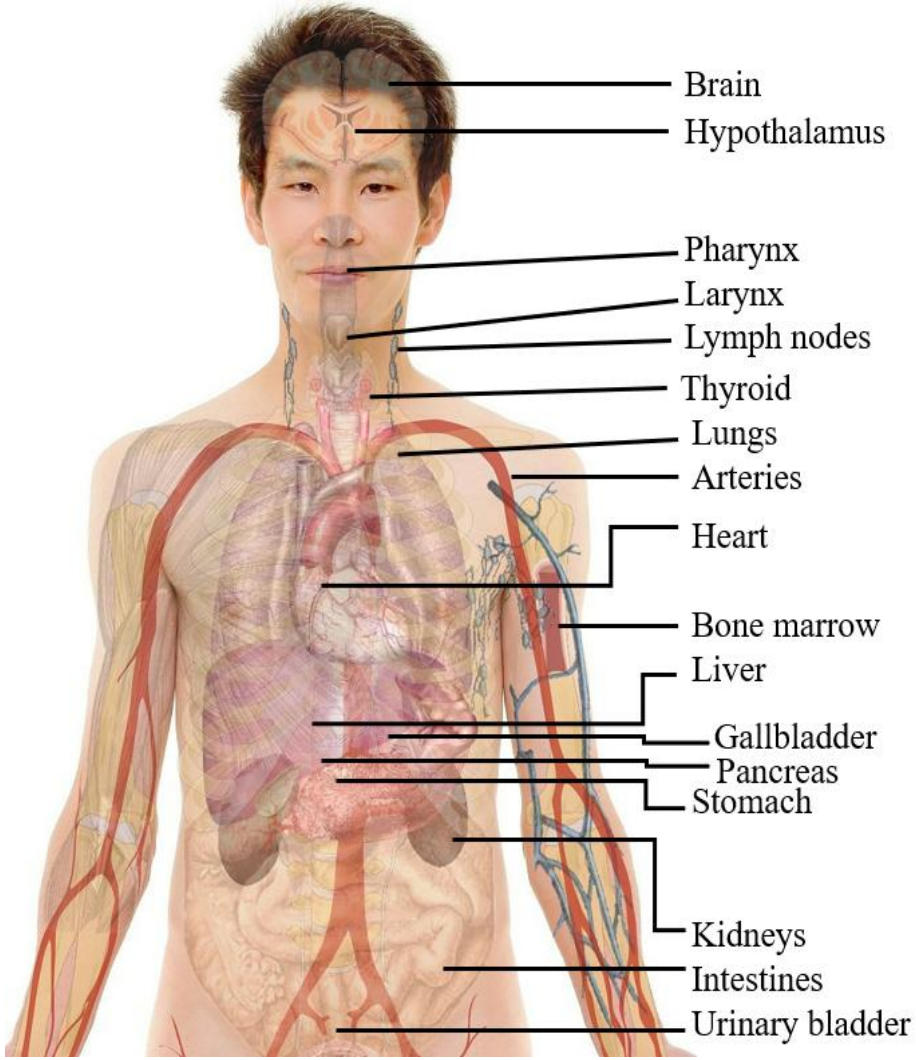
# Human Body and Health

## Human Body

- From an engineering perspective - Human body can be defined as a combination of multi-disciplinary subsystems (electrical, mechanical, chemical …).

## Health

- Human health is a state of complete physical, mental and social well-being.



# Healthcare → Smart Healthcare

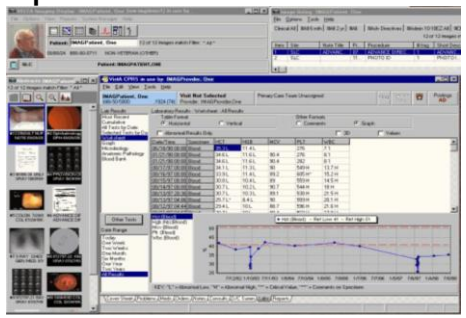
Healthcare

eHealth

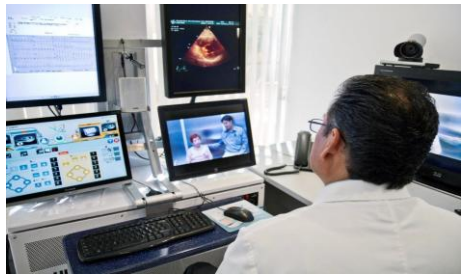
Telemedicine

mHealth

The use of information and communication technologies (ICT) to improve healthcare services.

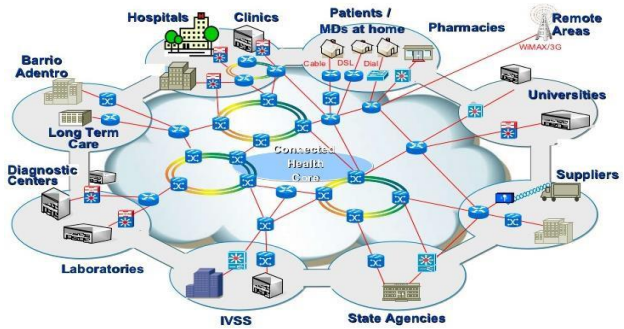


Telemedicine is the use of telecommunication and information technology to provide clinical healthcare from a distance.



Healthcare supported by *mobile devices* that uses mobile telecommunications and multimedia technologies for the delivery of healthcare services and health information.

cHealth




sHealth


Spire Stone - Breath

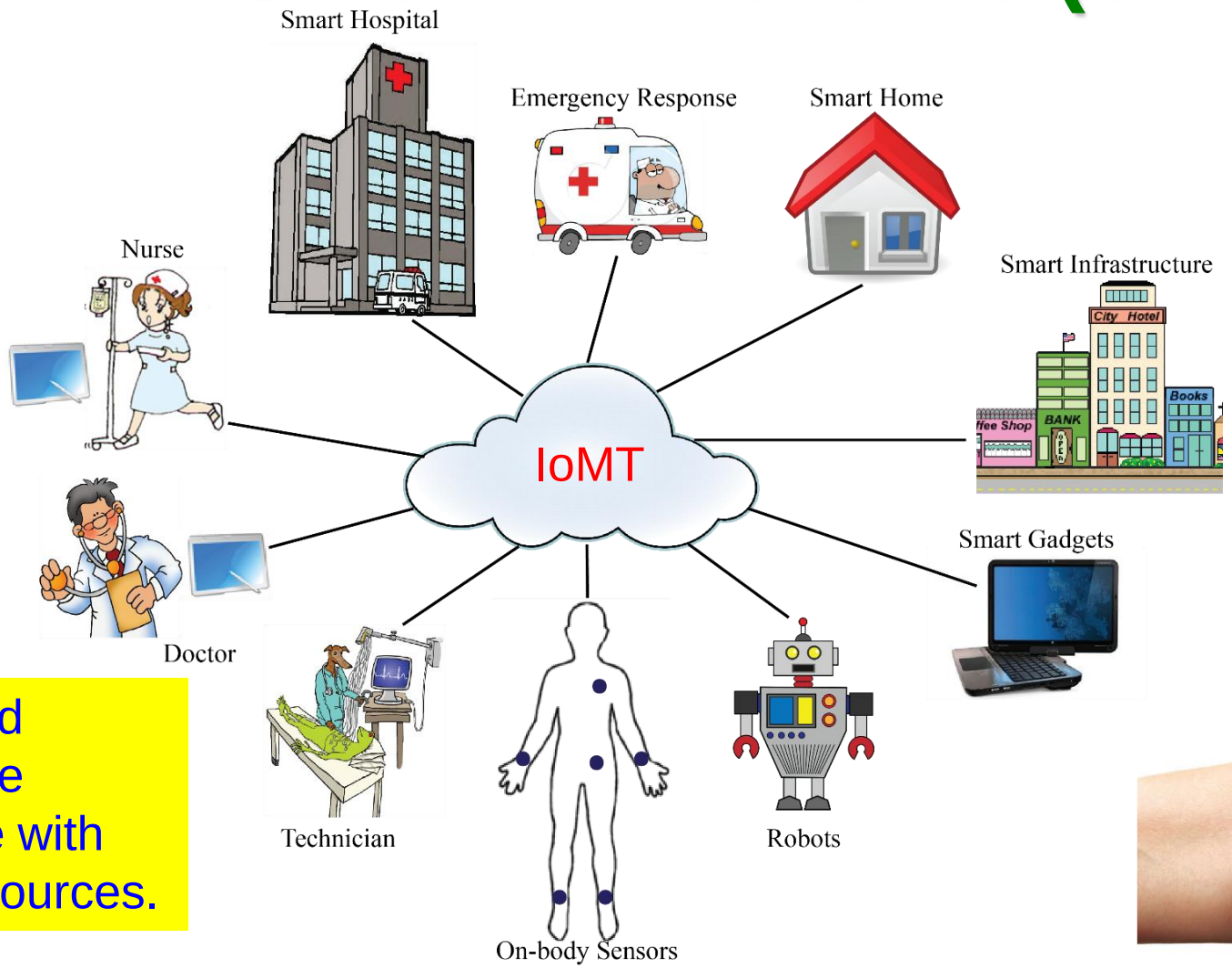
Embedded Skin Patches

Thync's - UltrasoVibeund

Muse - EEG

Source: **S. P. Mohanty**, "Smart Healthcare: From Healthcare to Smart Healthcare", ICCE 2020 Panel, Jan 2020.

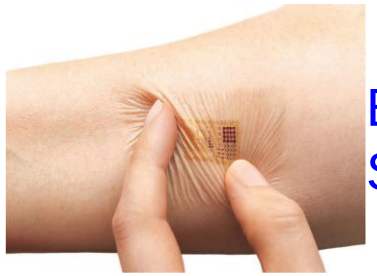
# Smart Healthcare (sHealth)




Fitness Trackers

Headband with Embedded Neurosensors

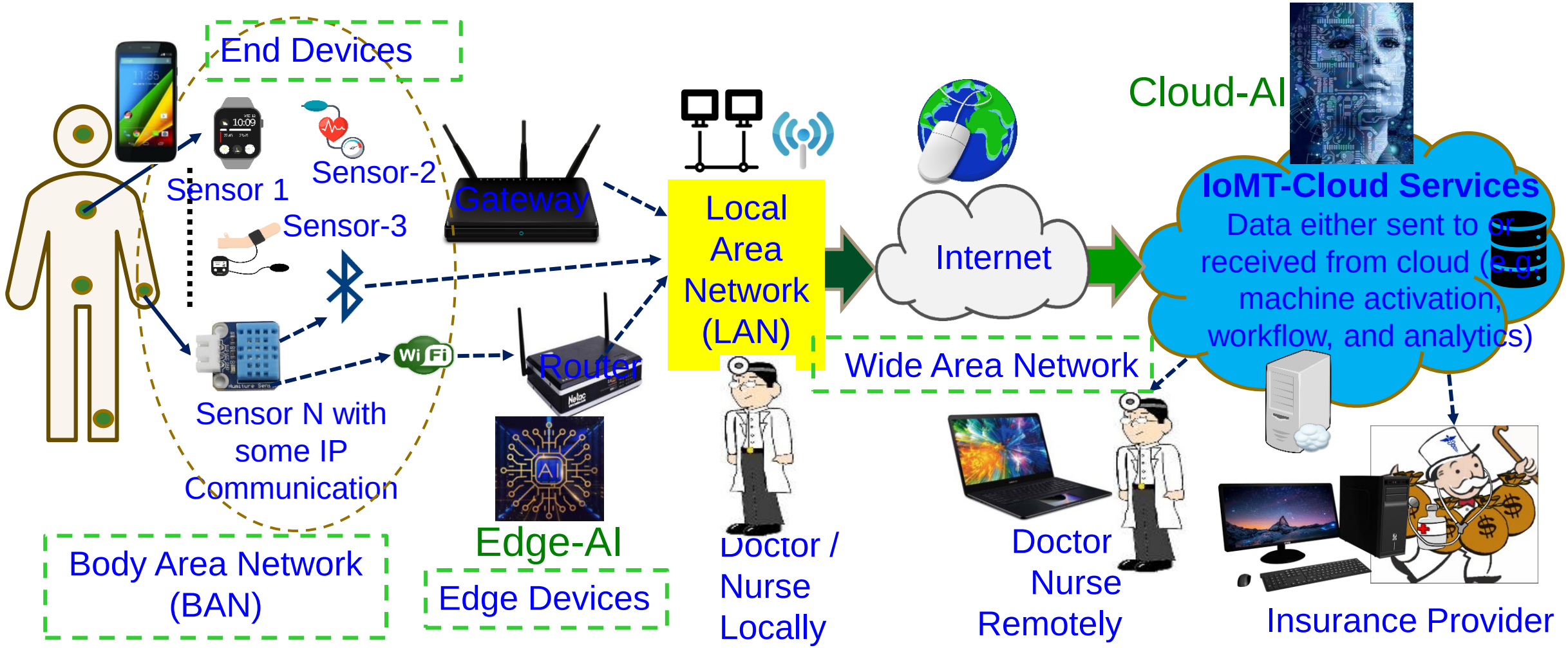
Quality and sustainable healthcare with limited resources.



Embedded Skin Patches

Source: P. Sundaravadivel, E. Kougianos, S. P. Mohanty, and M. Ganapathiraju, "Everything You Wanted to Know about Smart Health Care", *IEEE Consumer Electronics Magazine (MCE)*, Vol. 7, Issue 1, January 2018, pp. 18-28.

# Smart Healthcare – Healthcare CPS

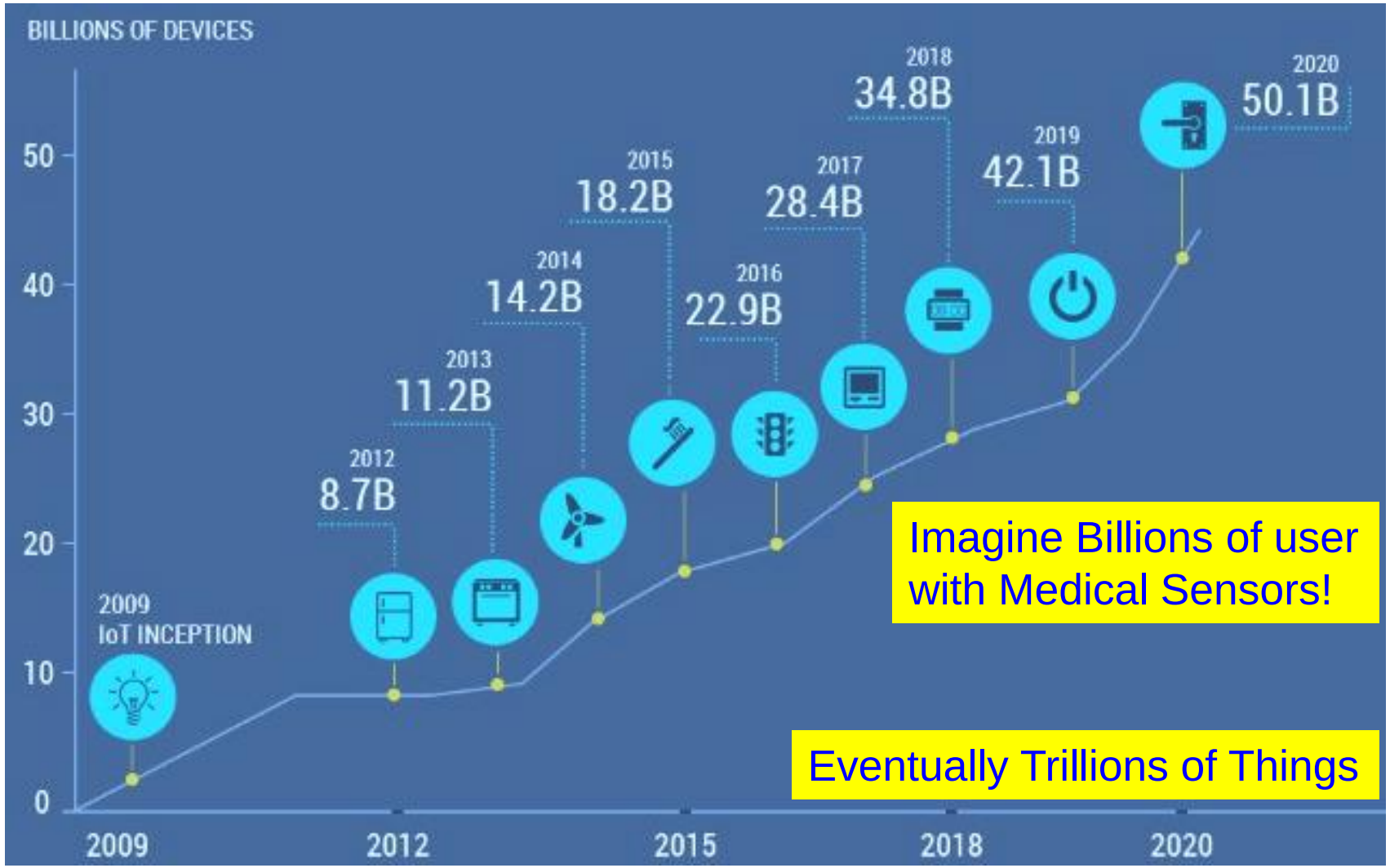



Frost and Sullivan predicts smart healthcare market value to reach US$348.5 billion by 2025.

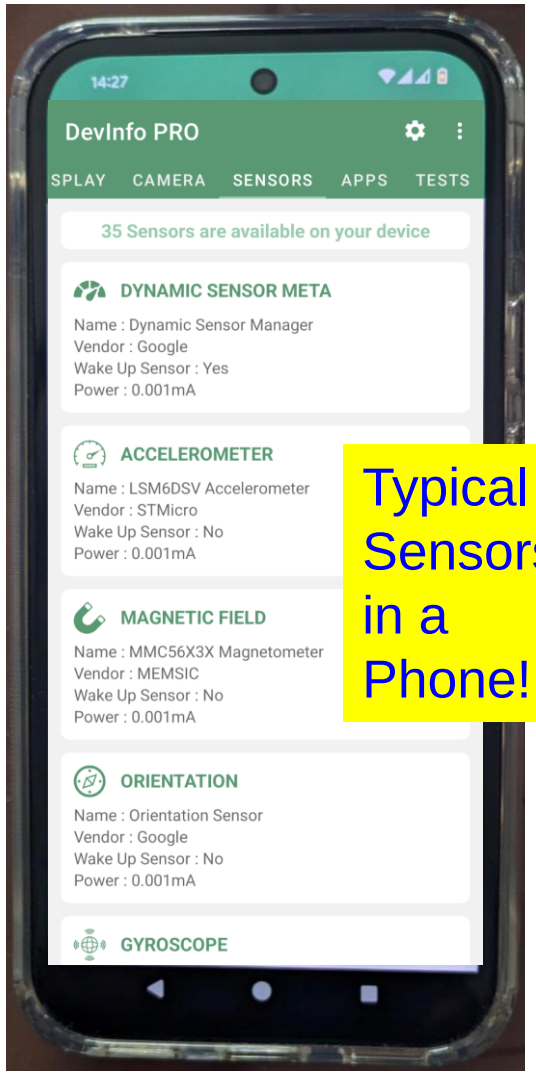
Source: S. P. Mohanty, Secure IoT by Design, Keynote, 4th IFIP International Internet of Things Conference (IFIP-IoT), 2021, Amsterdam, Netherlands, 5th November 2021.

# Smart Healthcare – Challenges Against Sustainability

# Massive Growth of Sensors/Things




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




Typical Sensors in a Phone!

# Challenges of Data in IoT/CPS are Multifold



Data Curation

Data Cost

Data Storage

Lots of Data

Data Ownership

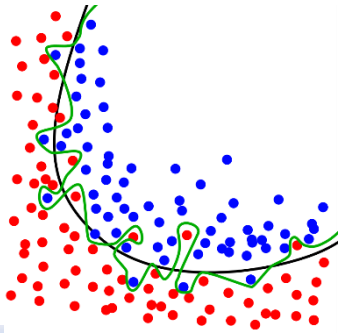
Data Modeling

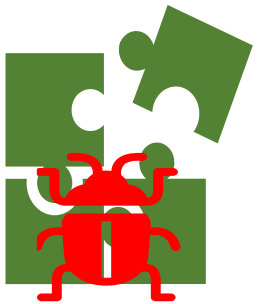
Data Quality

# AI/ML Modeling Challenges

Machine Learning Issues

- High Energy Requirements
- High Computational Resource Requirements
- Large Amount of Data Requirements
- Underfitting and Overfitting Issue
- Class Imbalance Issue
- Fake Data Issue
- Attack on Training Process

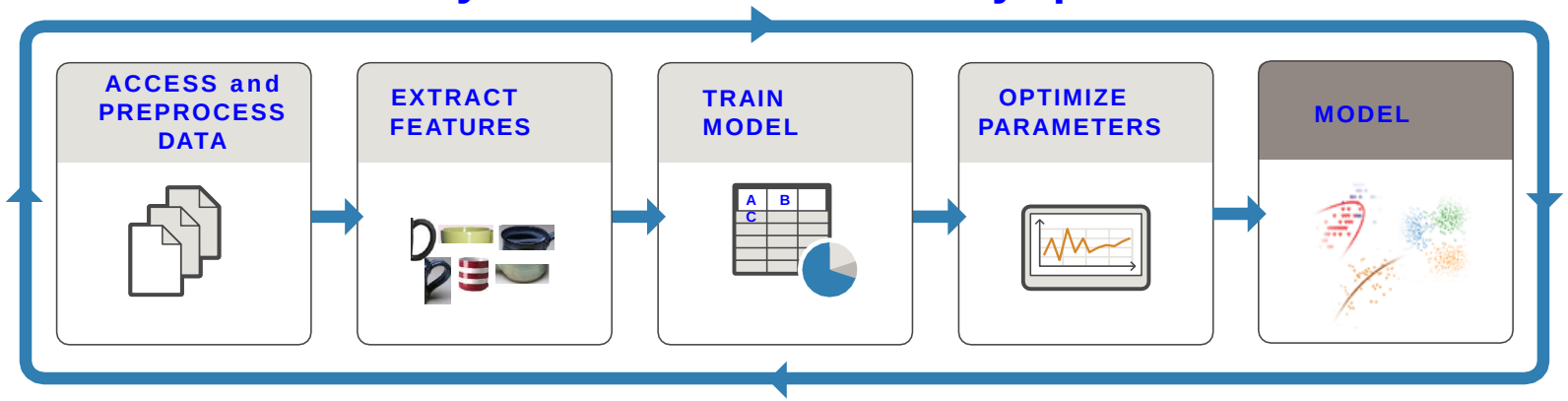





Source: Mohanty ISCT Keynote 2019

# Deep Neural Network (DNN) - Resource and Energy Costs

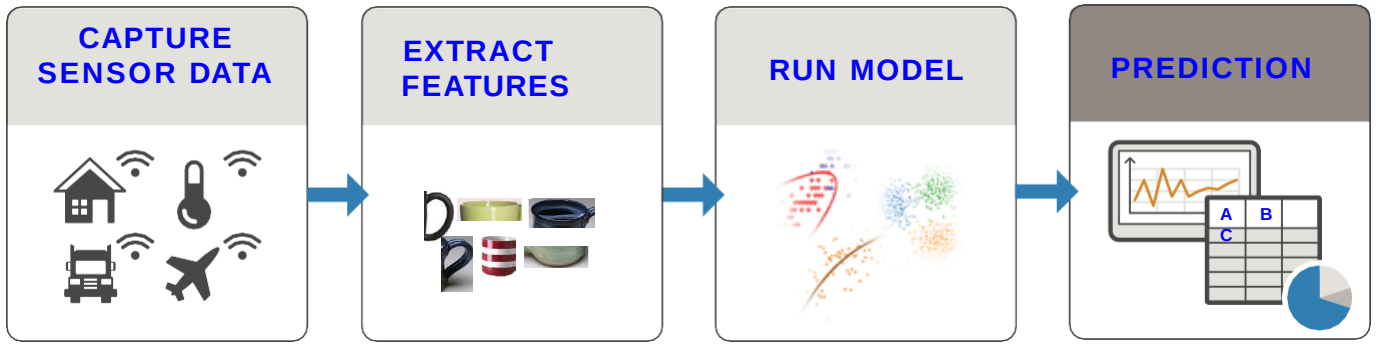
**TRAIN: Iterate until you achieve satisfactory performance.**




Needs Significant:

- Computational Resource
- Computation Energy

**PREDICT: Integrate trained models into applications.**



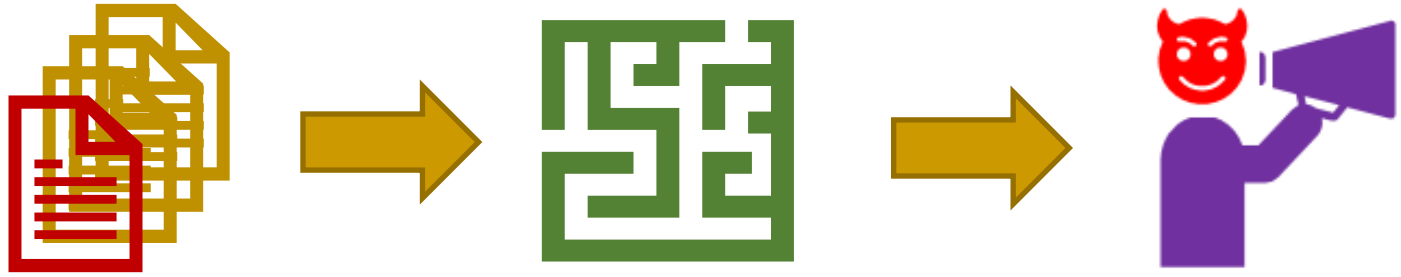

Source: https://www.mathworks.com/campaigns/offers/mastering-machine-learning-with-matlab.html

Limited Computational Capability
Limited Battery Life

Needs:

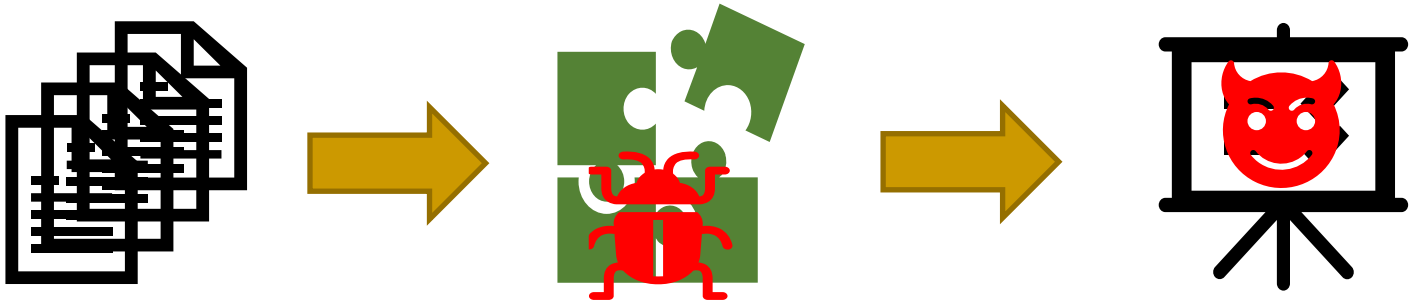
- Computational Resource
- Computation Energy

# AI/ML – Cybersecurity Issue



Corrupted Input Dataset → Predictive modelling → Corrupted Decision/ Prediction

Input attack in machine learning

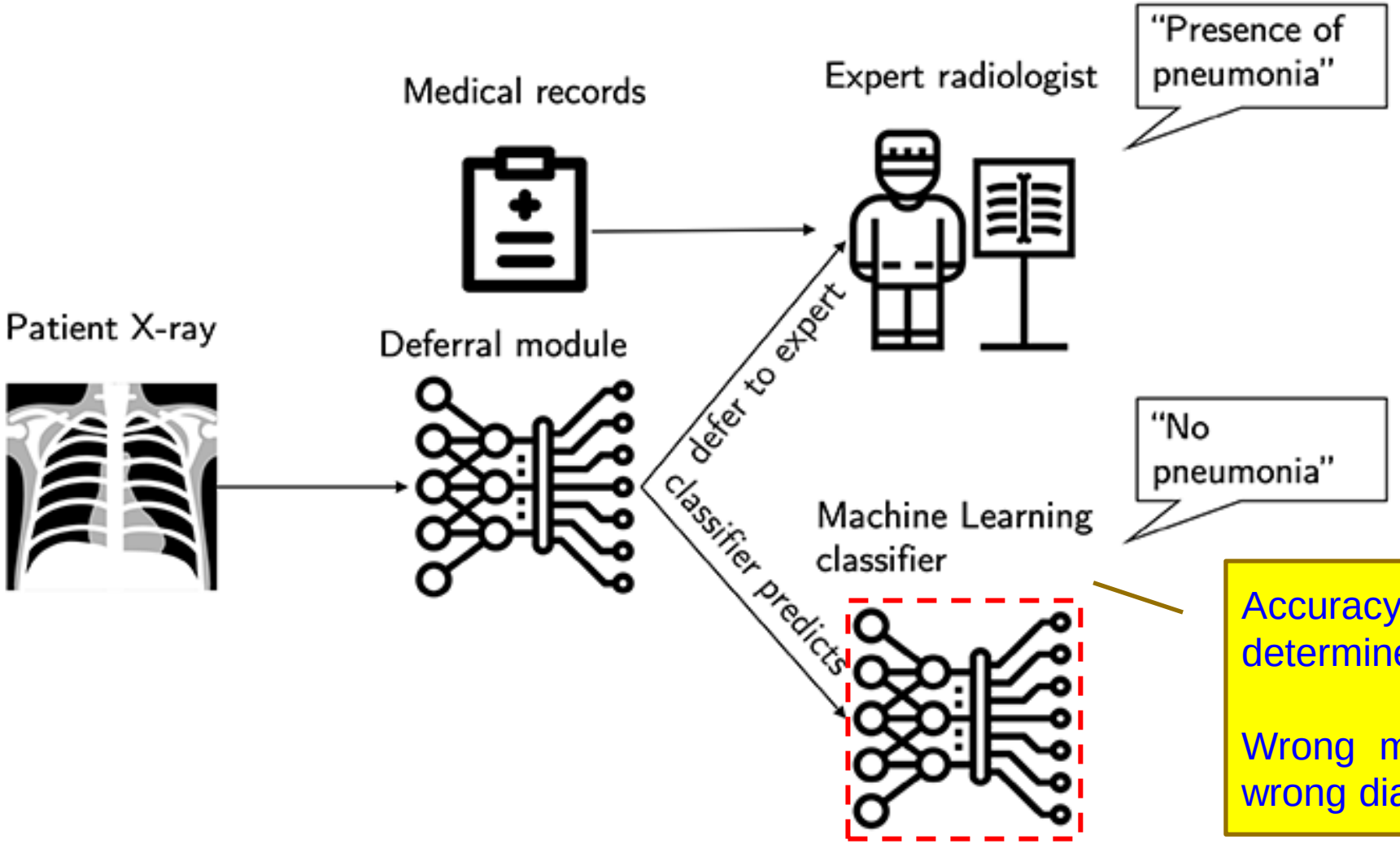


Input Dataset → Attacked training Process → Corrupt Classifications

Poisoning attack in training process

Source: D. Puthal, and **S. P. Mohanty**, "Cybersecurity Issues in AI", *IEEE Consumer Electronics Magazine (MCE)*, Vol. 10, No. 4, July 2021, pp. 33--35.

# Wrong ML Model → Wrong Diagnosis




Accuracy is important determine pneumonia

Wrong model can lead to wrong diagnosis altogether

Source: https://www.healthcareitnews.com/news/new-ai-diagnostic-tool-knows-when-defer-human-mit-researchers-say

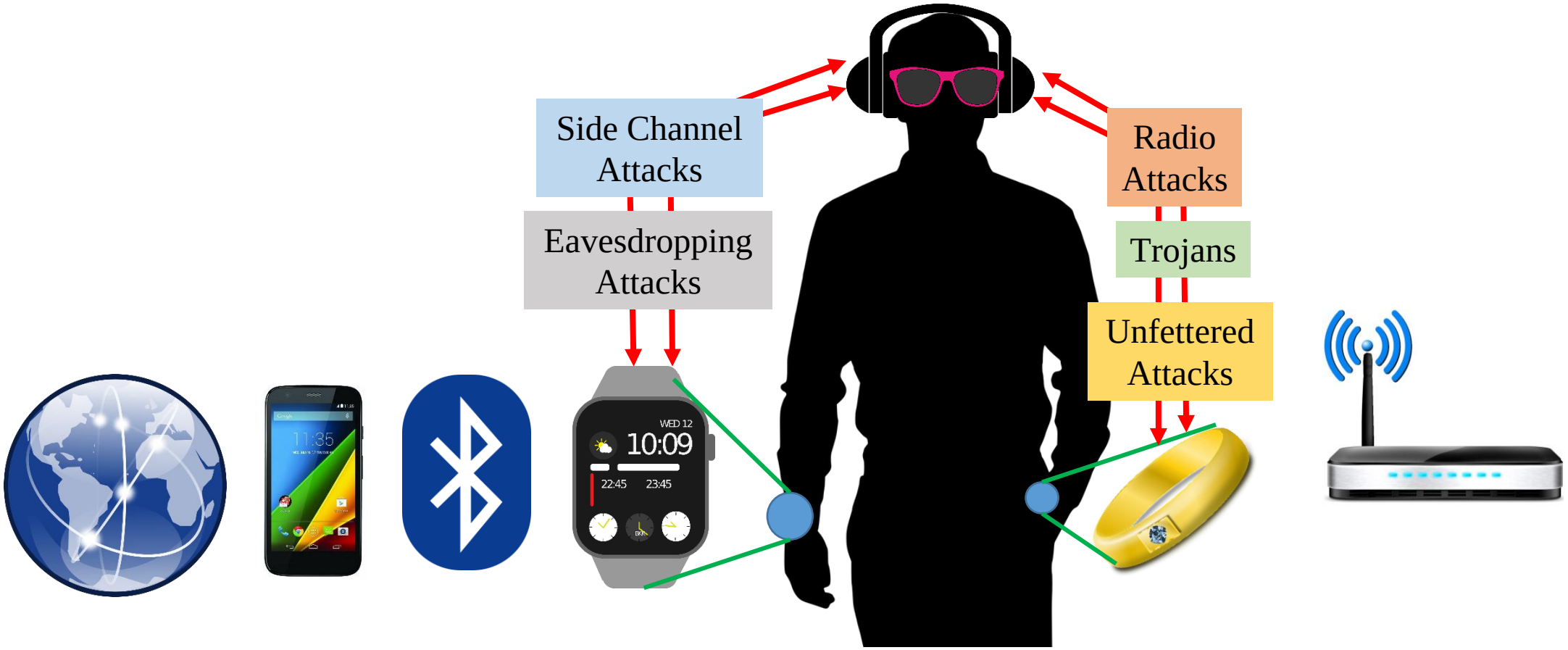
# Smart Healthcare - Security Challenges

**Selected Smart Healthcare Security/Privacy Challenges**

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

Source: P. Sundaravadivel, E. Kougianos, S. P. Mohanty, and M. Ganapathiraju, “Everything You Wanted to Know about Smart Health Care”, *IEEE Consumer Electronics Magazine (CEM)*, Volume 7, Issue 1, January 2018, pp. 18-28.

# Attacks on Wearable Devices

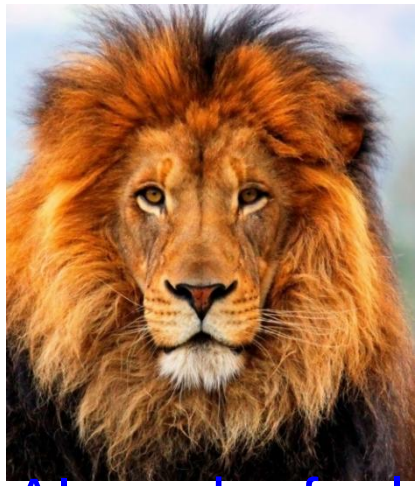


# Implantable Medical Devices - Attacks


- 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.

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



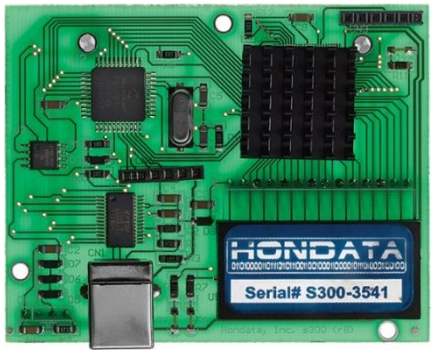
AI can be fooled by fake data

AI can create fake data (Deepfake)



Authentic Fake

An implantable medical device

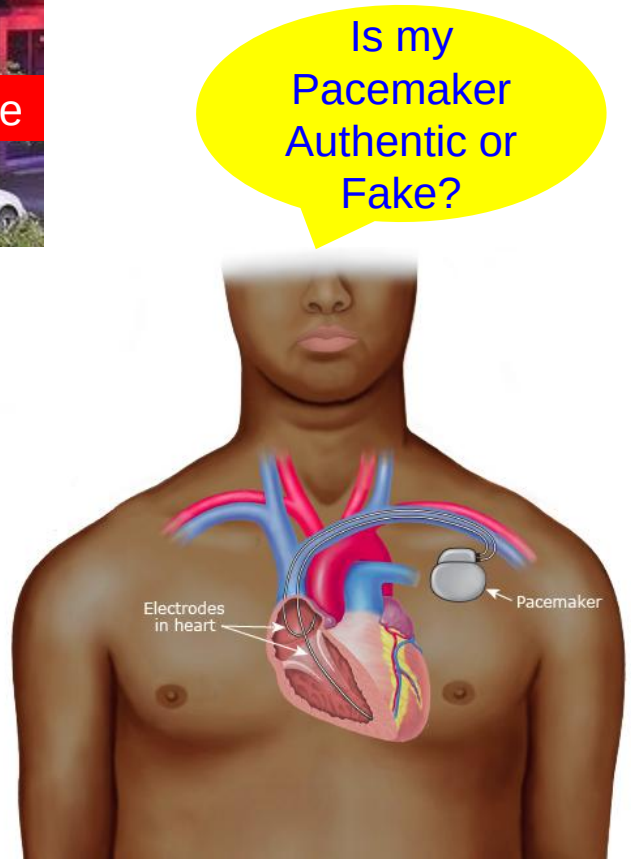

Authentic Fake

A plug-in for car-engine computers

# Fake is Cheap – Why not Buy?

Source: https://www.quora.com

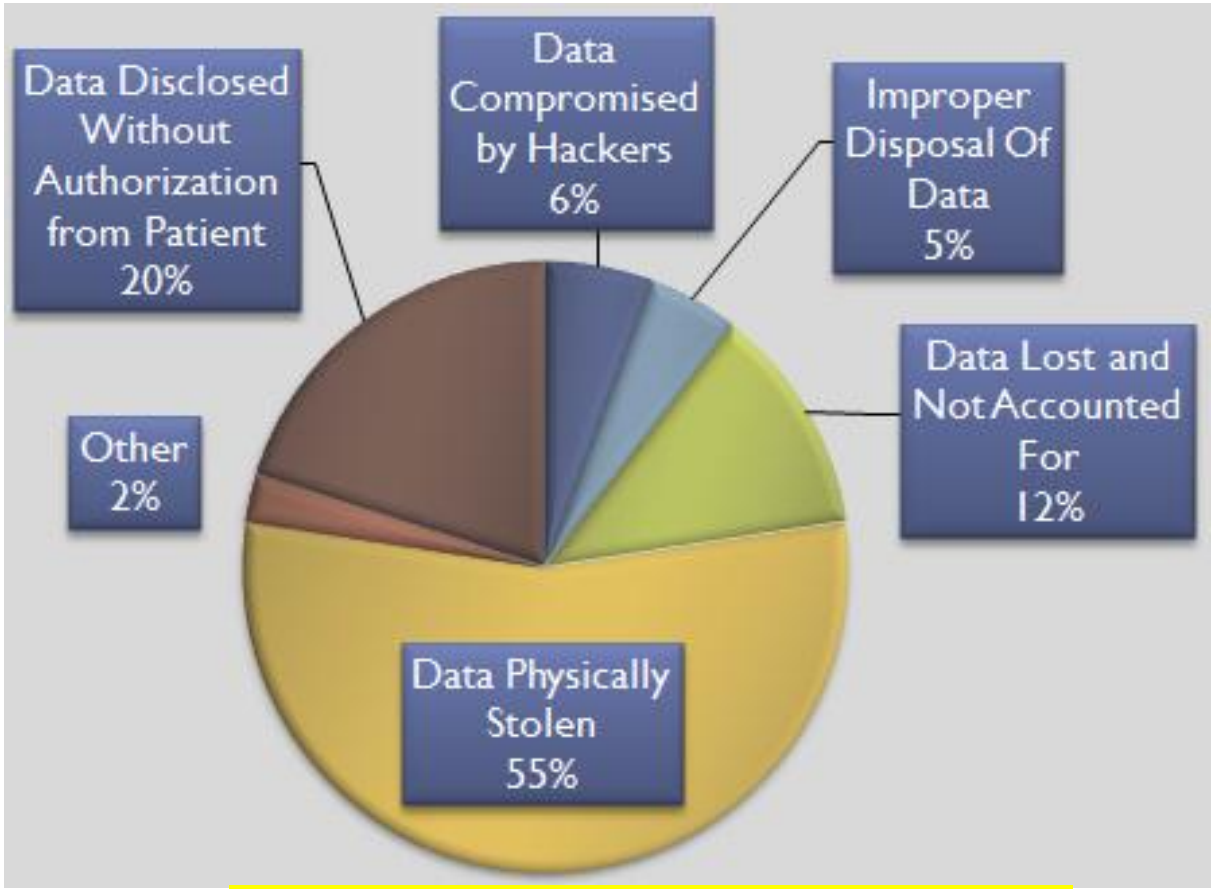
Source: https://nypost.com/




Source: https://apro.ipsf.org/

# Health Insurance Portability and Accountability Act (HIPPA)

HIPAA
Health Insurance Portability and Accountability Act

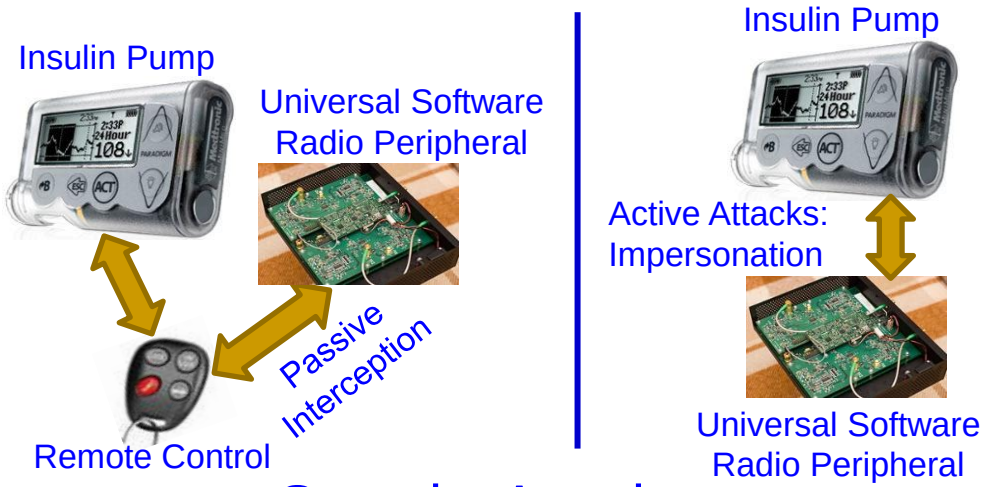



HIPPA Privacy Violation by Types

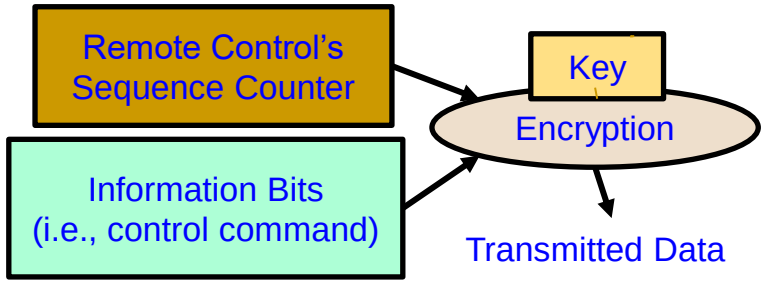
# Cybrsecurity Solution for IoT/CPS

# Smart Healthcare Cybersecurity

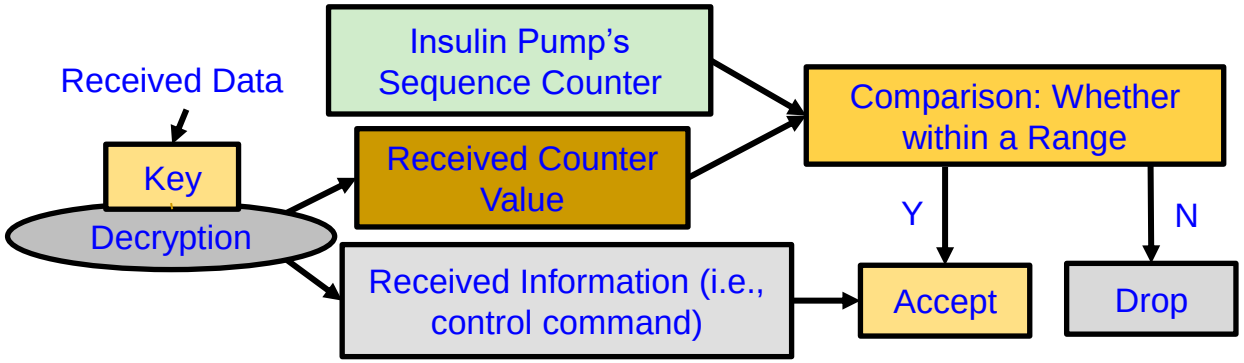

Insulin Delivery System




Security Attacks



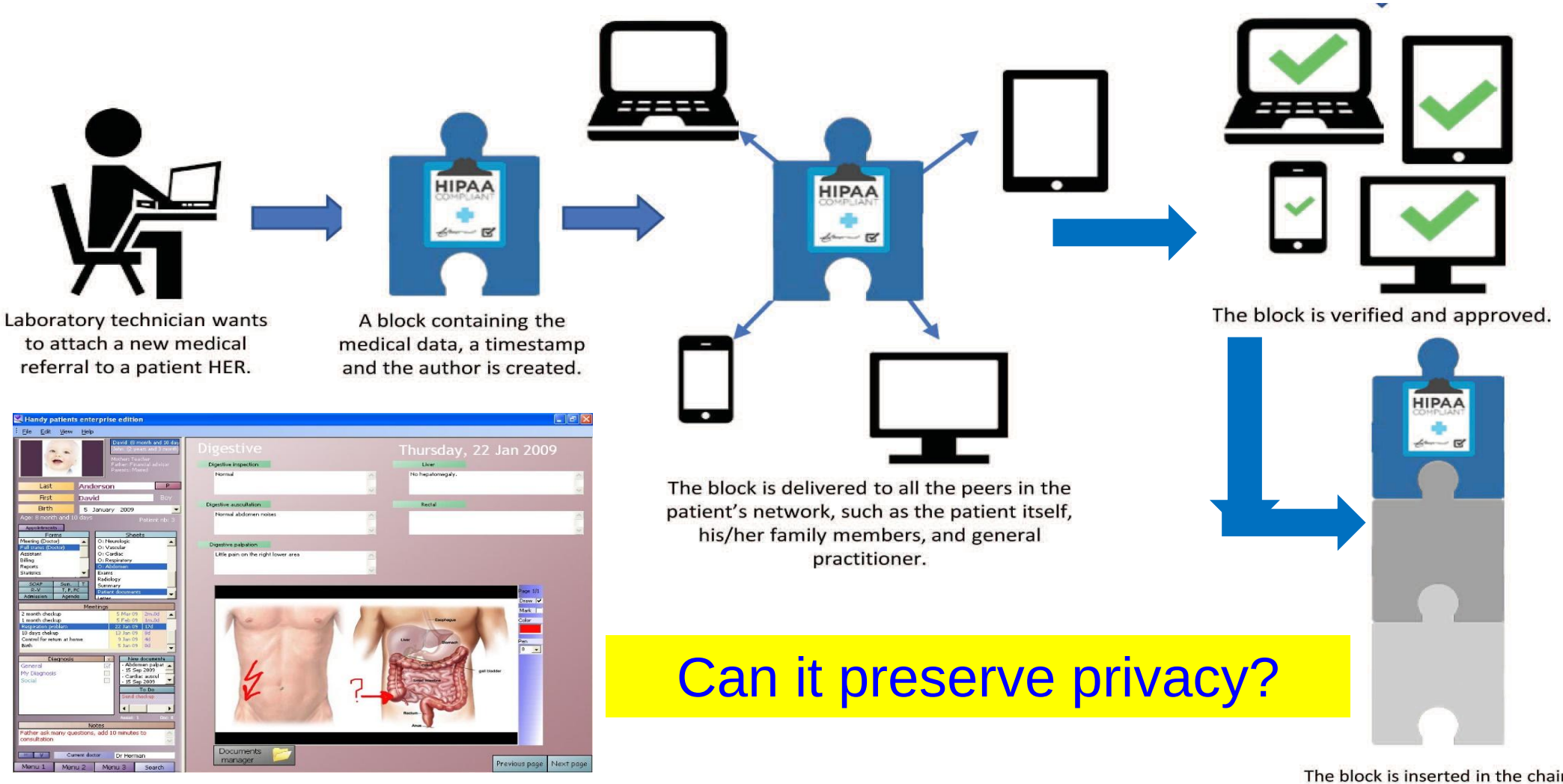

Rolling Code Encoder in Remote Control




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.

# 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!

How Cloud storage changes this scenario?

# Drawbacks of Existing Cybersecurity Solutions

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

## IT Cybersecurity

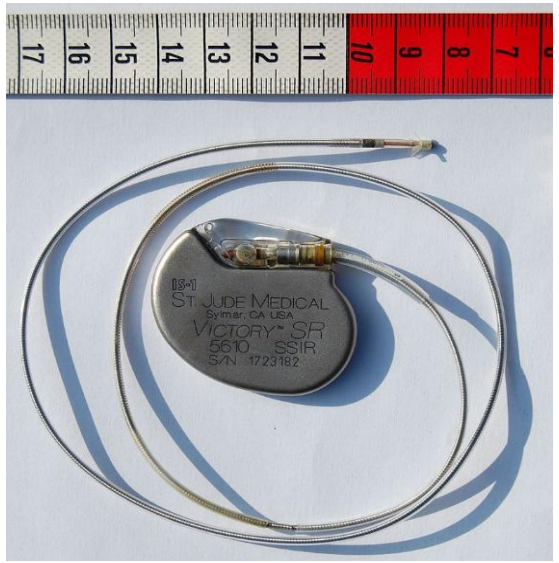
- IT infrastructure may be well protected rooms
- Limited variety of IT network devices
- Millions of IT devices
- Significant computational power to run heavy-duty security solutions
- IT security breach can be costly

## 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

Incorporation of Cybersecurity of Electronic Systems, IoT, CPS, needs Energy, and hence affects Performance.

# H-CPS Cybersecurity Measures is Hard - Energy Constrained




Pacemaker
Battery Life
- 10 years


Neurostimulator
Battery Life
- 8 years

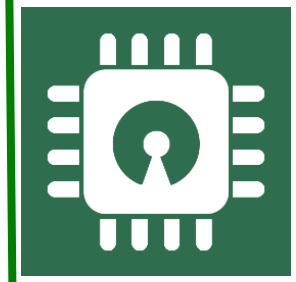
- Implantable Medical Devices (IMDs) have integrated battery to provide energy to all their functions → Limited Battery Life depending on functions
- Higher battery/energy usage → Lower IMD lifetime
- Battery/IMD replacement → Needs surgical risky procedures

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.

# 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

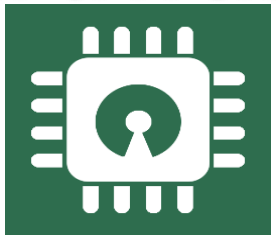
Source: Mohanty ICCE Panel 2018

# 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

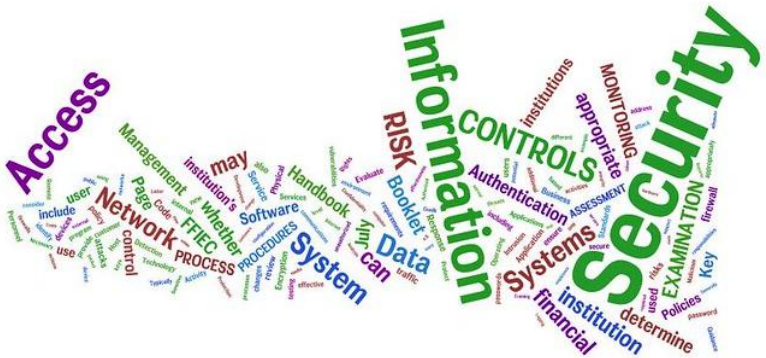
## Hardware Based

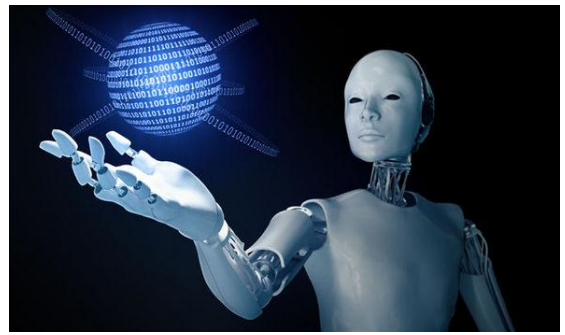


- High-Speed operation
- Energy-Efficient operation
- Low-cost using ASIC and FPGA
- Tasks of encryption easy compared to software – bit permutation
- Easy integration in CE systems
- Possible security at source-end like sensors, better suitable for IoT
- Susceptible to side-channel attacks
- Can’t stop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

Source: Mohanty ICCE Panel 2018

# Security-by-Design (SbD) – The Principle

# CPS Design - Multiple Objectives for Sustainability

Non-recurring Design Cost

Recurring Operational Cost

Energy Consumption, Battery Life


Ethics, Safety

Security, Privacy, IP Rights

Smart Cities
Vs
Smart Villages

Performance, Latency

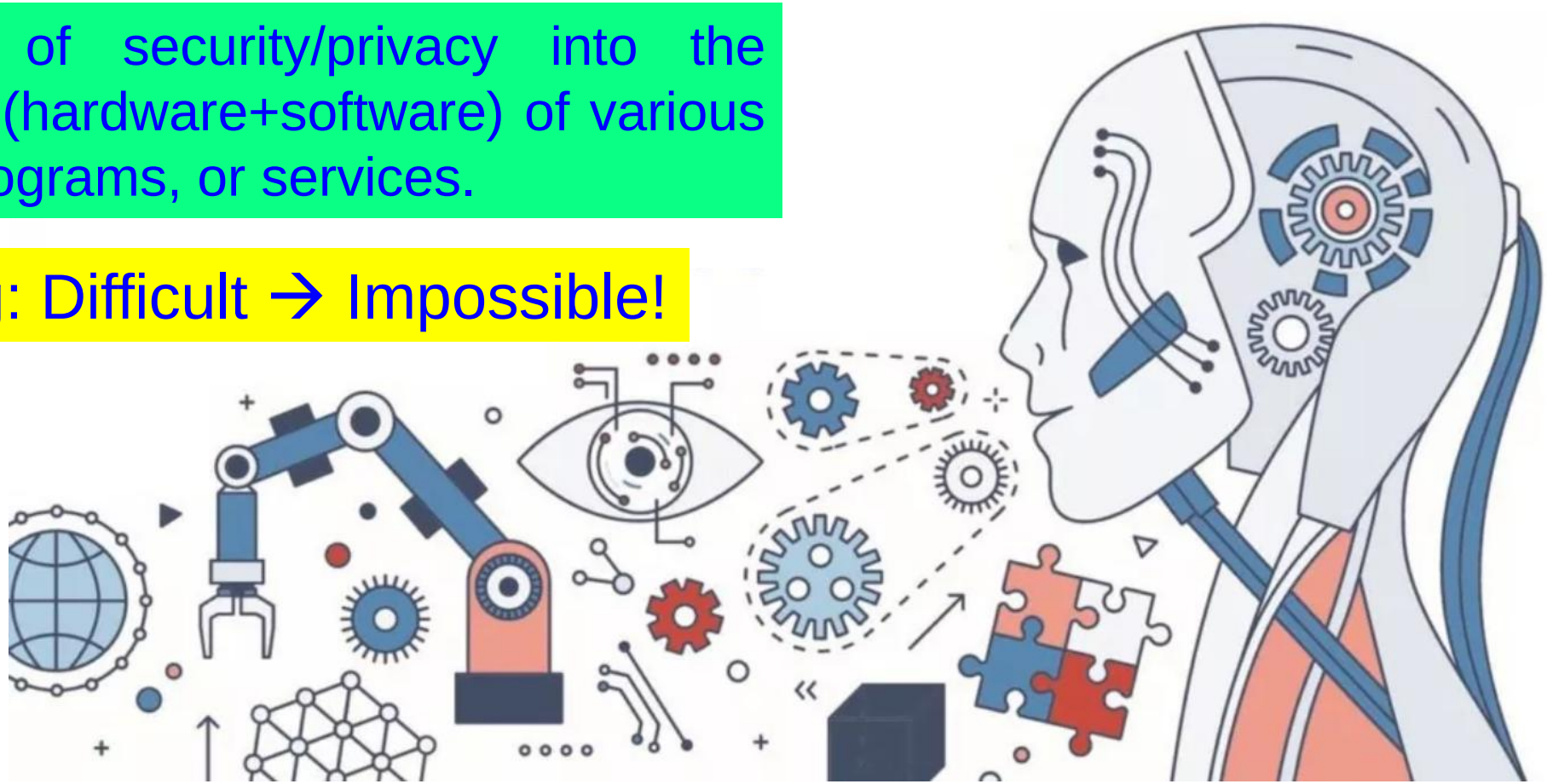
Intelligence

Source: Mohanty ICCE 2019 Keynote

# Security by Design (SbD)

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/

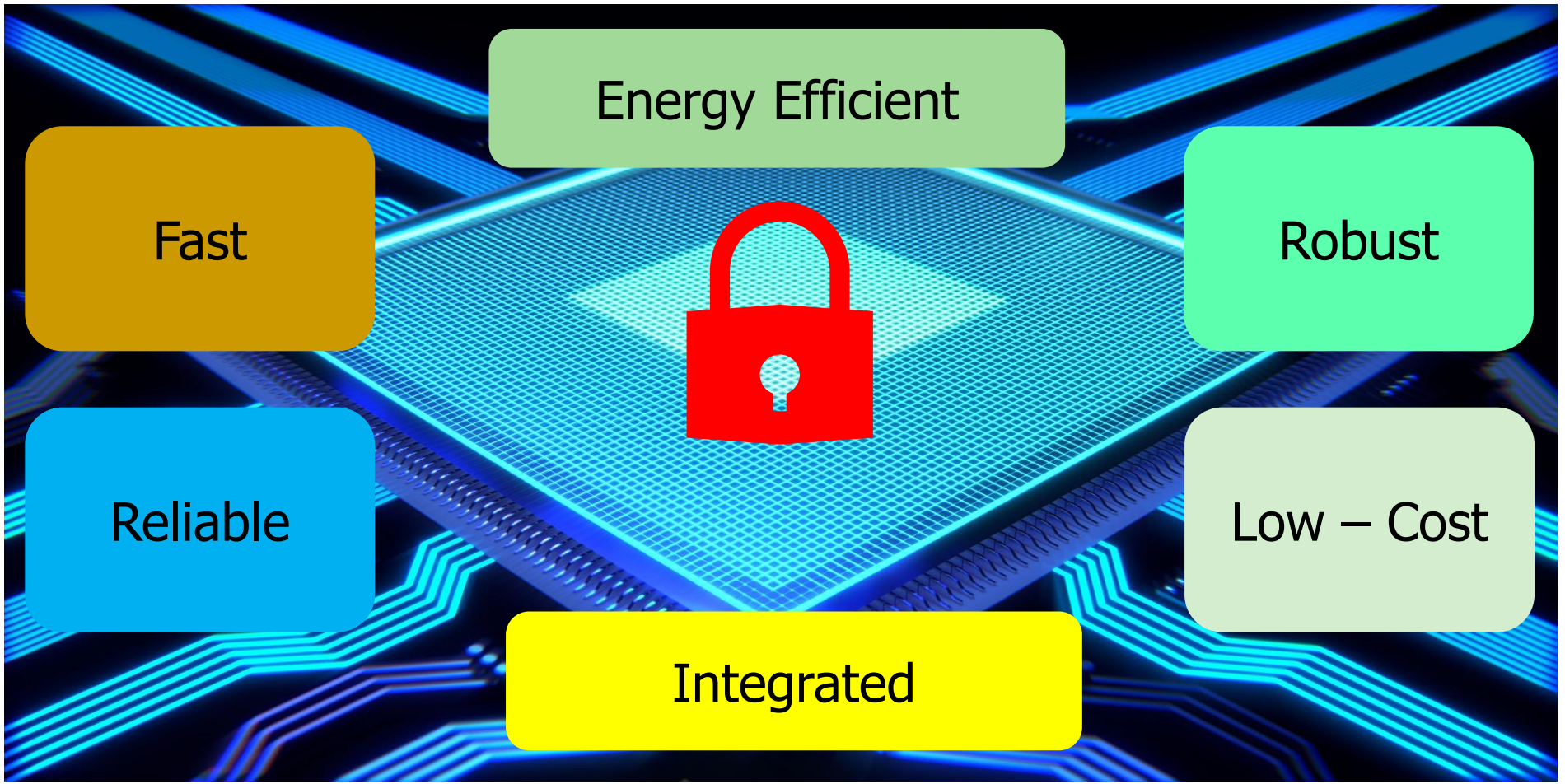
# Security by Design (SbD)

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

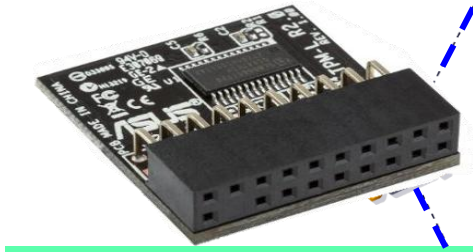
Source: https://iapp.org/media/pdf/resource_center/Privacy%20by%20Design%20-%207%20Foundational%20Principles.pdf

# Security-by-Design (SbD) or Hardware Assisted Security (HAS) - Advantages

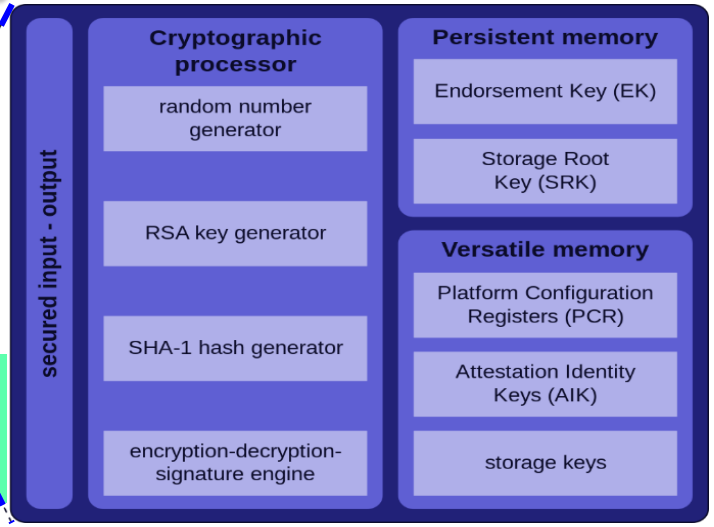


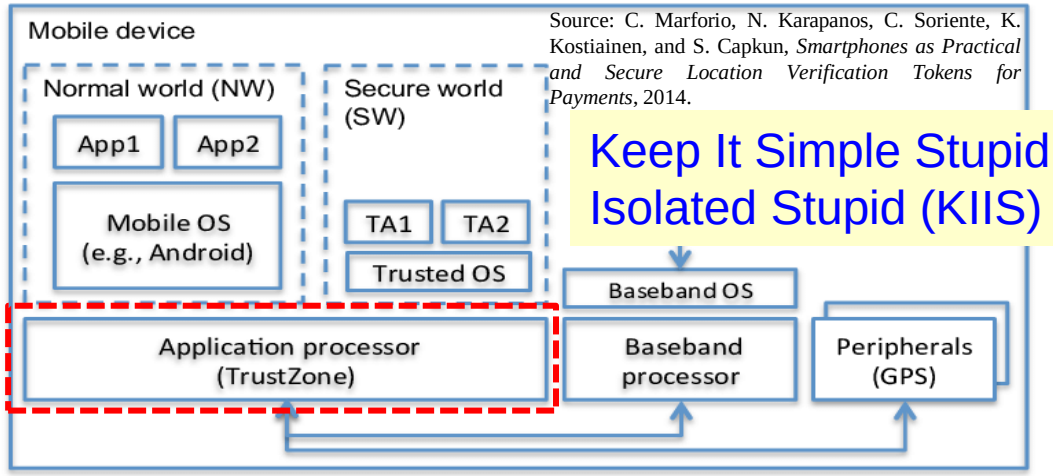
# Hardware Cybersecurity Primitives – HSM, TrustZone, TPM, and PUF

Hardware Security Module (HSM)



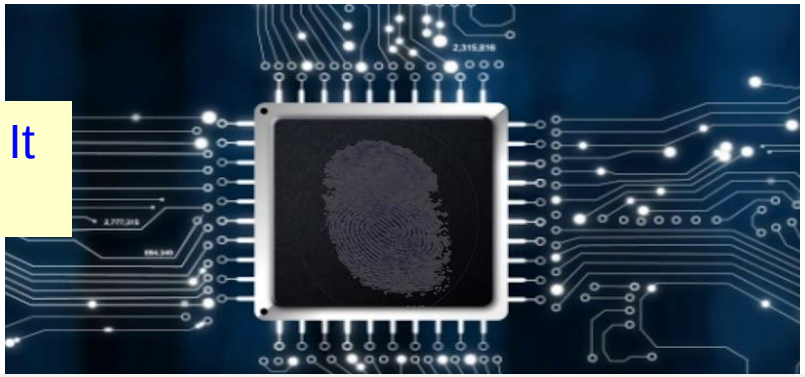
Trusted Platform Module (TPM)




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)

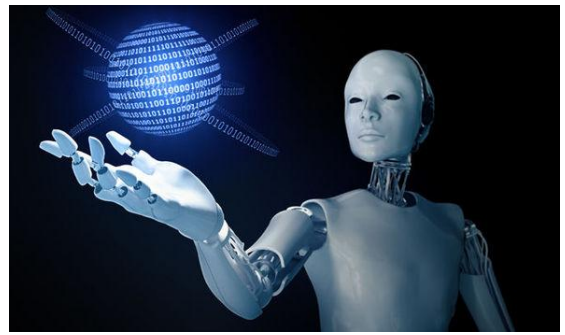


Physical Unclonable Functions (PUF)

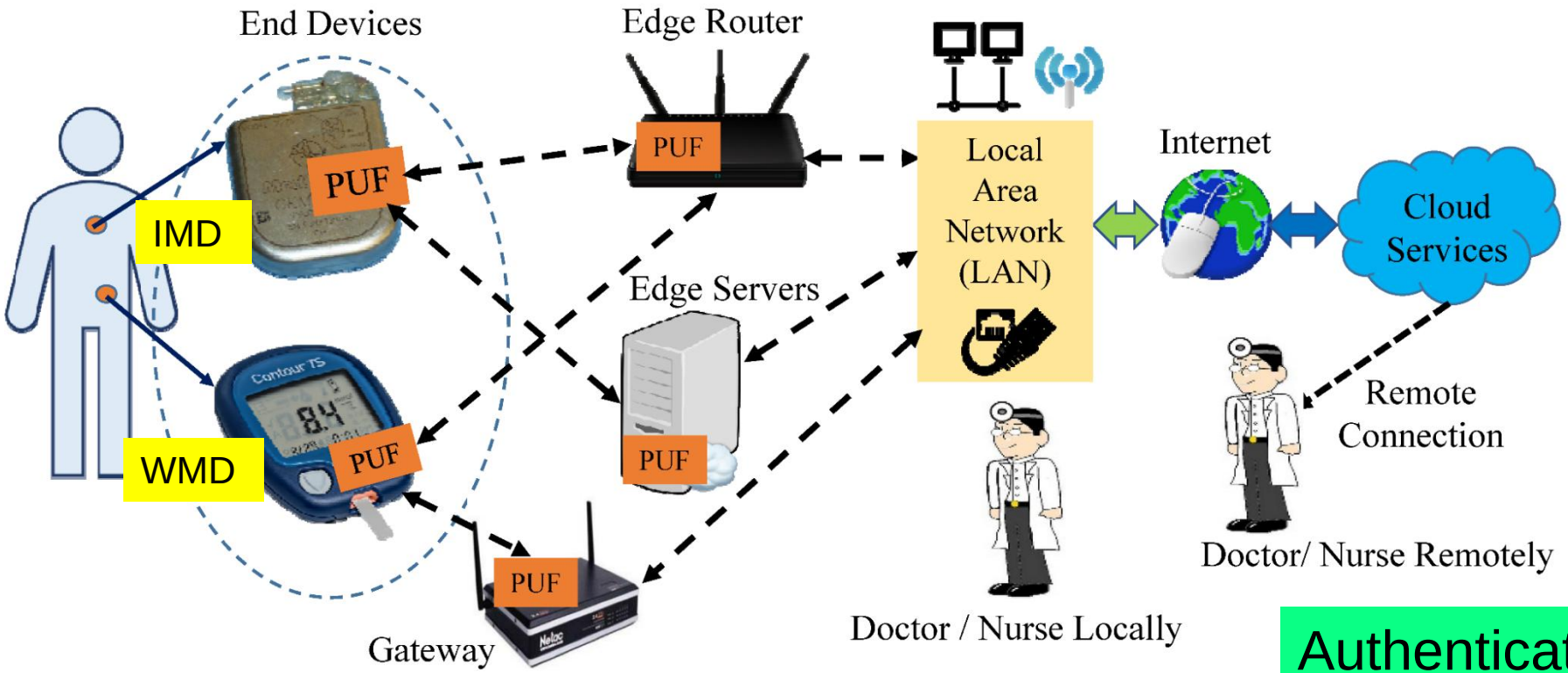
Source: Electric Power Research Institute (EPRI)

# Security-by-Design (SbD) – Specific Examples





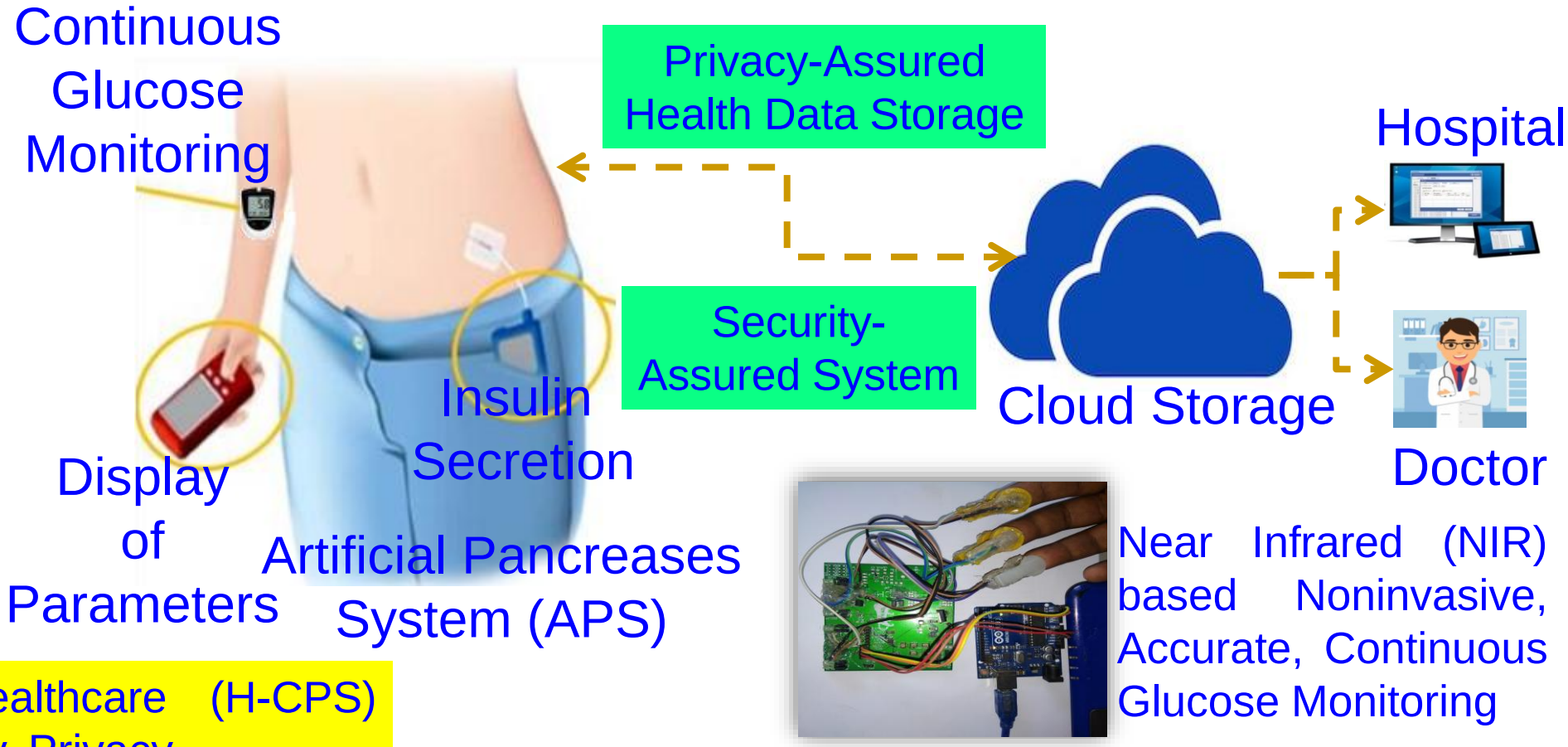
# PMsec: Our Secure by Design Approach for Robust Security in Healthcare CPS




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.

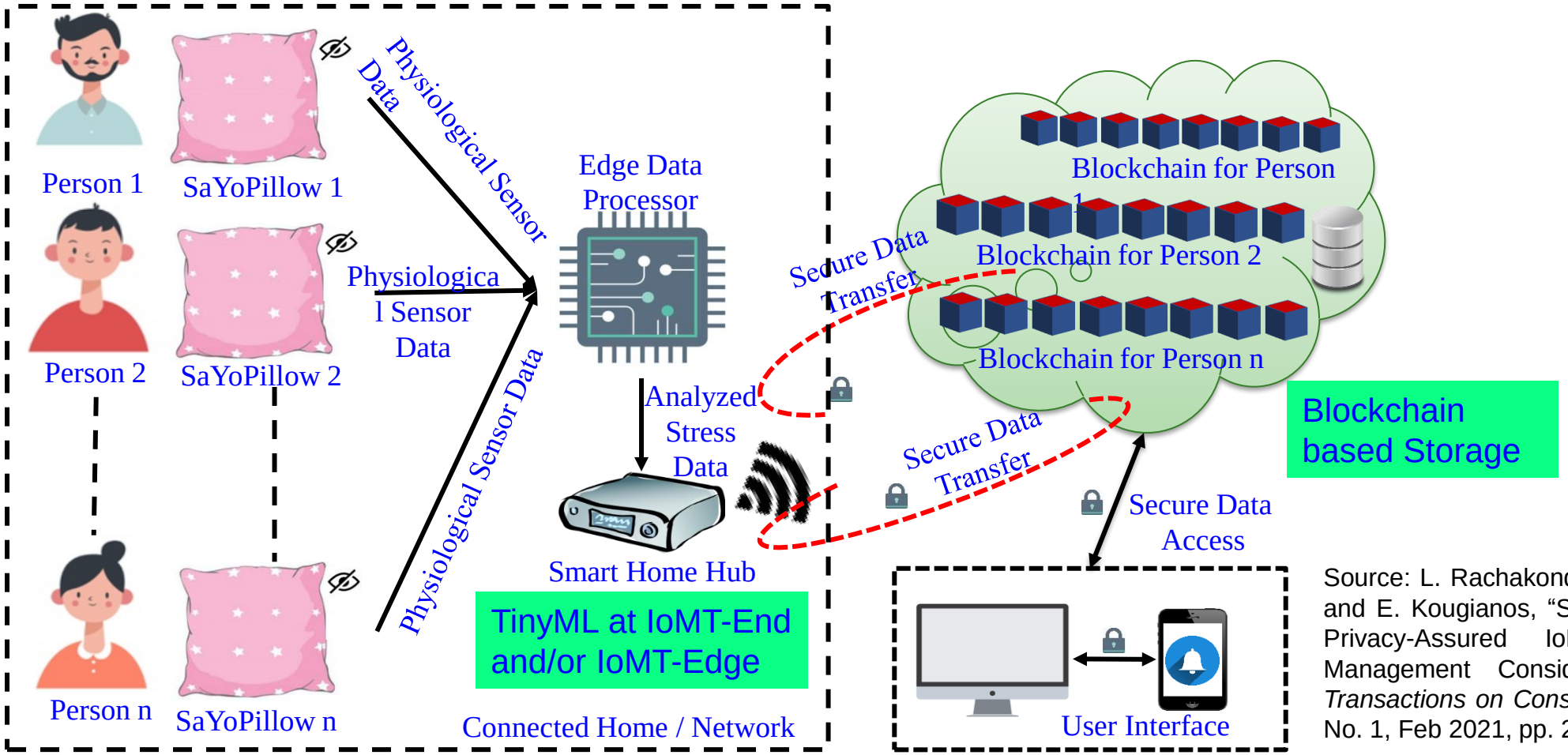
# Secure-iGLU - Our Intelligent Non-Invasive Glucose Monitoring with Insulin Control Device




Smart Healthcare (H-CPS)
→ Security, Privacy, …

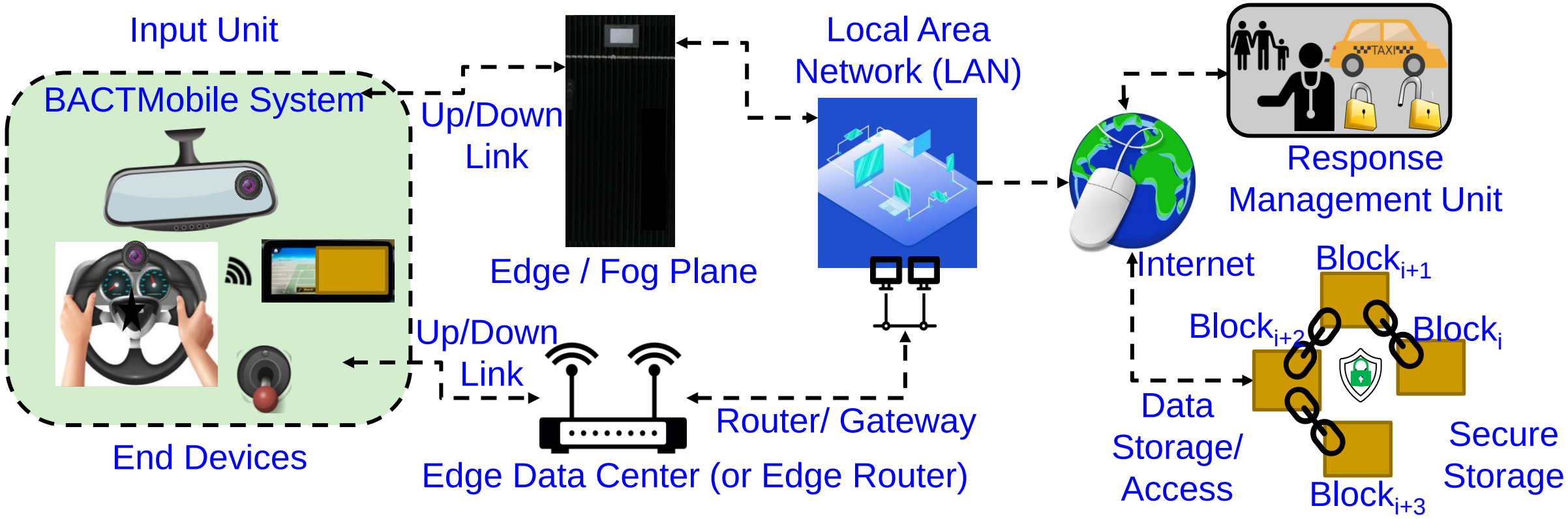
P. Jain, A. M. Joshi, and S. P. Mohanty, "iGLU: An Intelligent Device for Accurate Non-Invasive Blood Glucose-Level Monitoring in Smart Healthcare", *IEEE Consumer Electronics Magazine (MCE),* Vol. 9, No. 1, January 2020, pp. 35–42.

# 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.

# Our Smart Blood Alcohol Concentration Tracking Mechanism in Healthcare CPS - BACTmobile

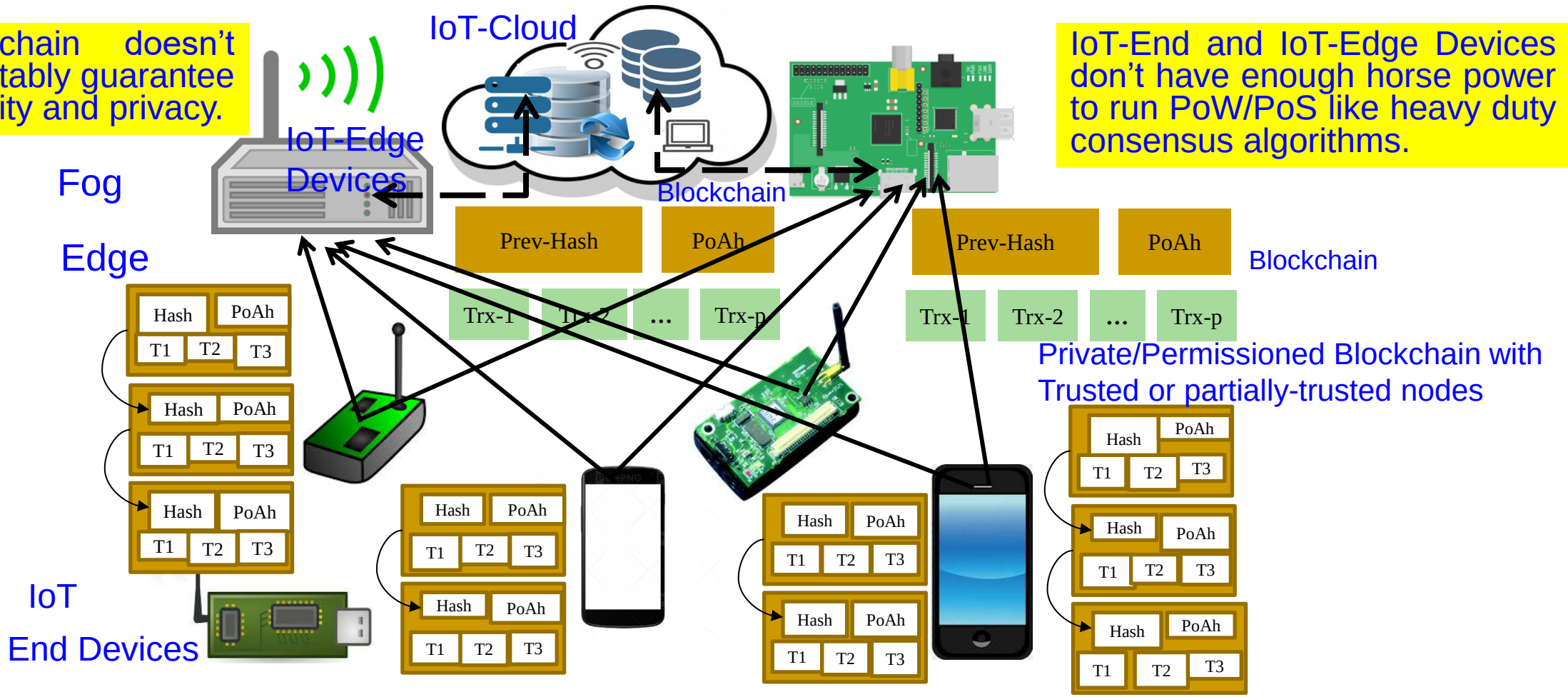



Source: L. Rachakonda, A. K. Bapatla, **S. P. Mohanty**, and E. Kougianos, "BACTmobile: A Smart Blood Alcohol Concentration Tracking Mechanism for Smart Vehicles in Healthcare CPS Framework", *Springer Nature Computer Science (SN-CS)*, Vol. 3, No. 3, May 2022, Article: 236, 24-pages, DOI: https://doi.org/10.1007/s42979-022-01142-9.

# IoT-Friendly Blockchain – Our EasyChain

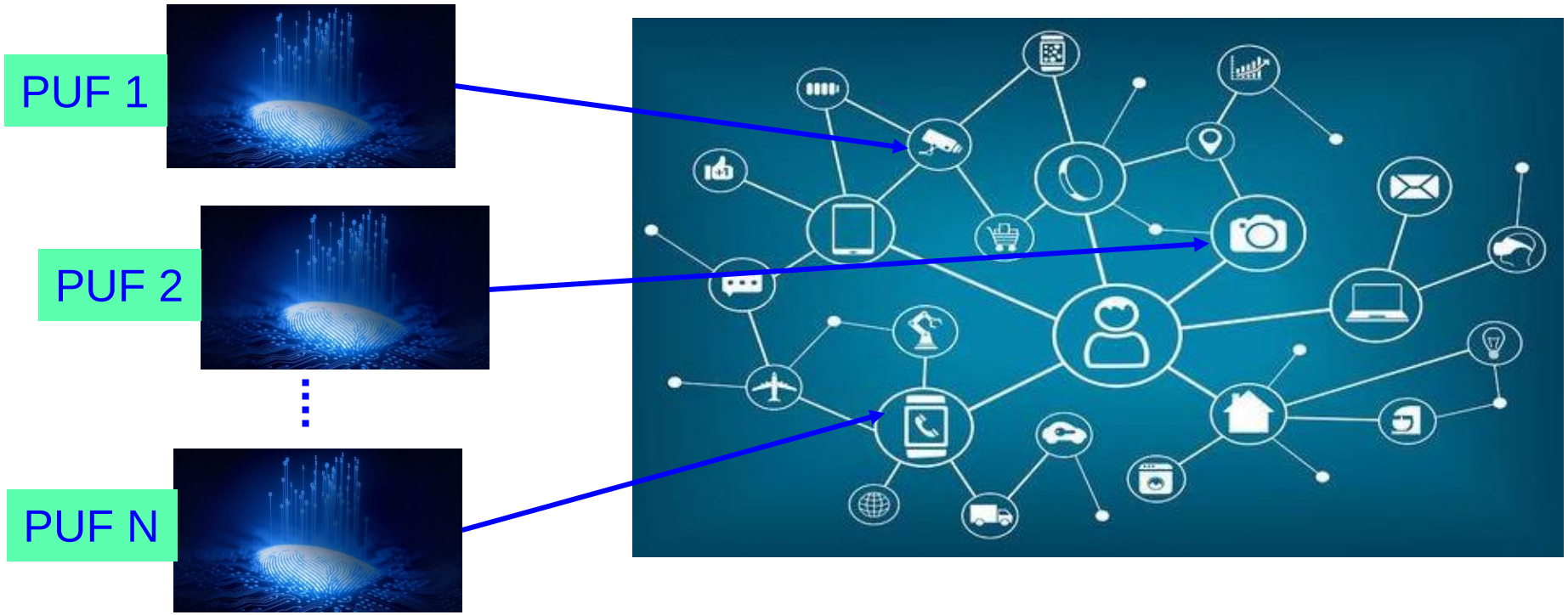
Blockchain doesn't inheritably guarantee security and privacy.

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



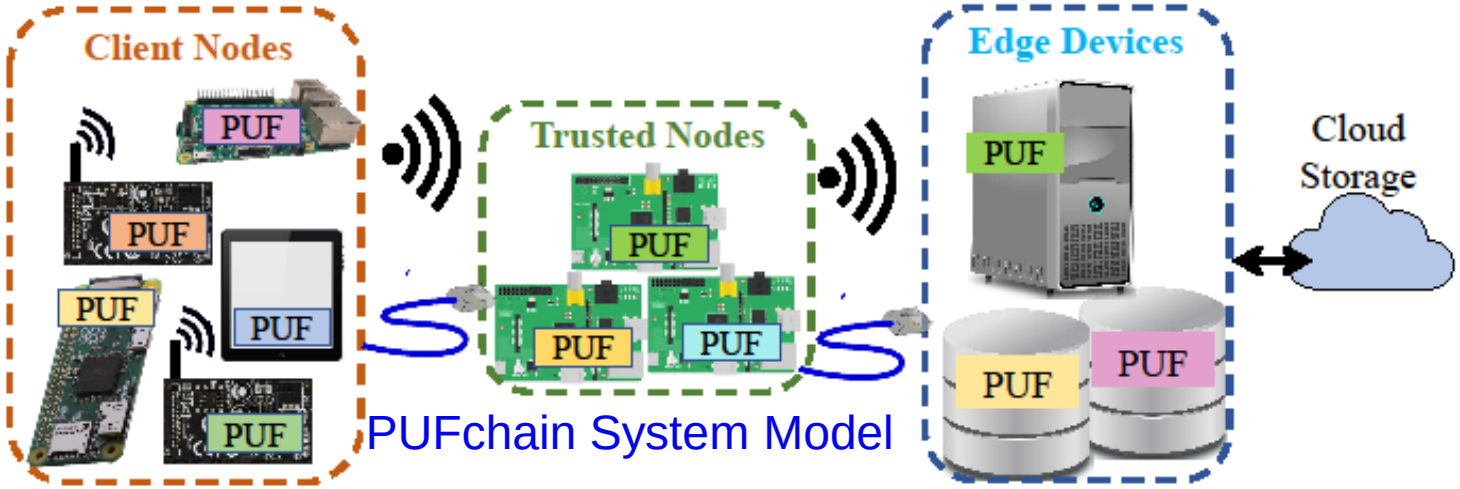

Source: D. Puthal and S. P. Mohanty, "Proof of Authentication: IoT-Friendly Blockchains", *IEEE Potentials Magazine*, Vol. 38, No. 1, January 2019, pp. 26--29.

# 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

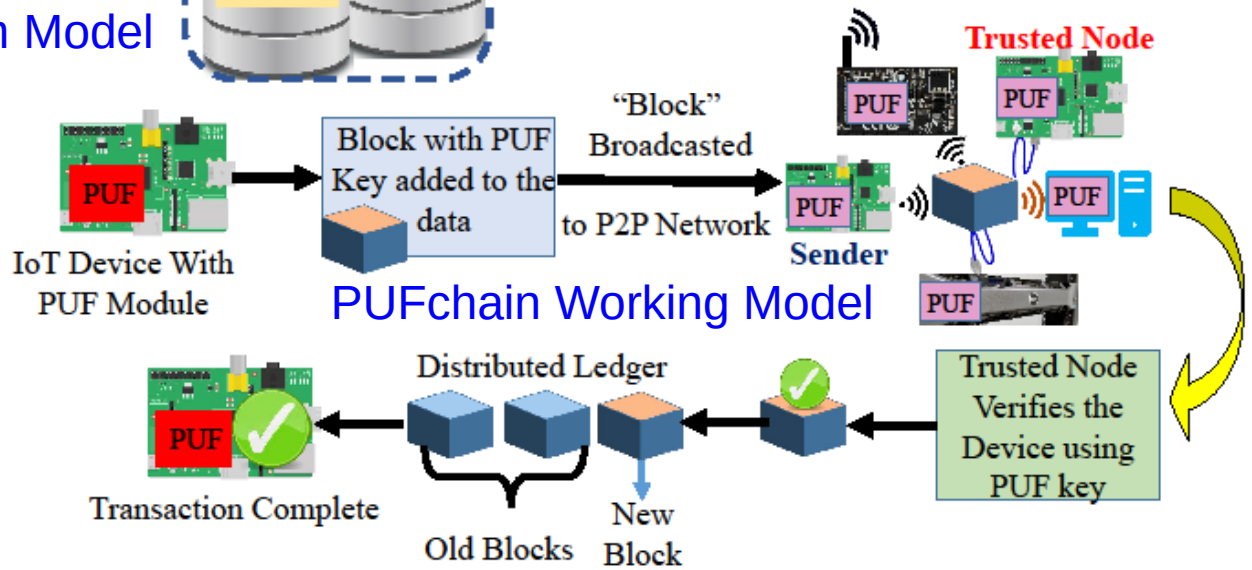



PUFchain System Model

Can provide:
Device, System, and Data Security

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

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




PUFchain Working Model

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.

# Smart Healthcare – Trustworthy Pharmaceutical Supply Chain

# Counterfeits in Healthcare


Source: GA-FDD (Government Analyst –Food and Drug Department) issues warning over "fake" drug on local market, https://www.inewsguyana.com/ga-fdd-issues-warning-over-fake-drug-on-local-market/

The original product:

- sold in a white box with blue borders
- contains sixty (60) 500mg tablets
- divided on four (4) silver blister packs, each containing fifteen (15) tablets

The fake product:

- sold in a white box with no border
- contains sixty (60) 500mg tablets
- divided on six (6) silver with blue blister packs, each containing ten (10) tablets

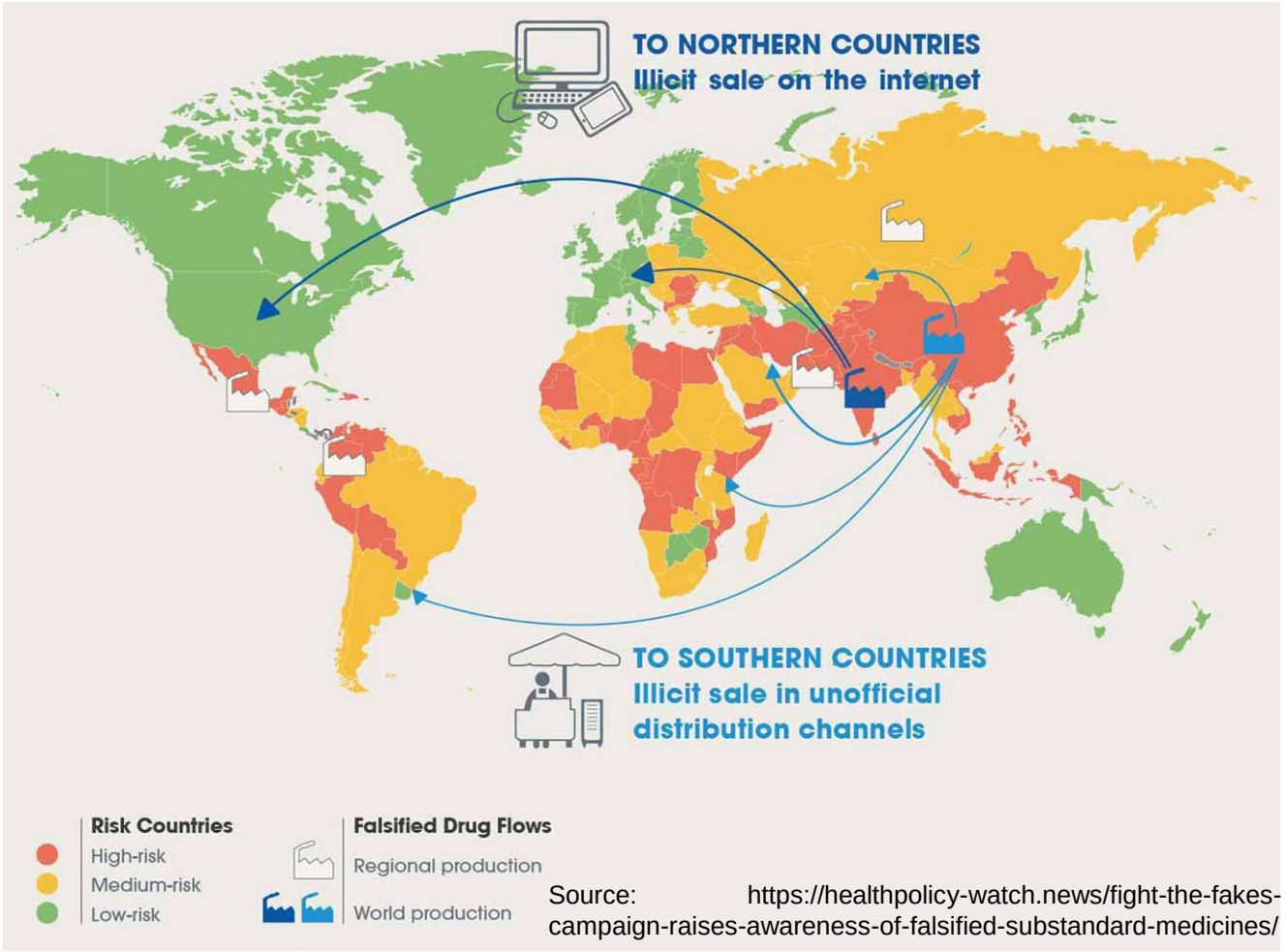
Daflon 500 is used to treat gravitational (stasis) dermatitis and dermatofibrosclerosis

# Fake Medicine - Serious Global Issue

- It is estimated that close to $83 billion worth of counterfeit drugs are sold annually.
- One in 10 medical products circulating in developing countries are substandard or fake.
- In Africa: Counterfeit antimalarial drugs results in more than 120,000 deaths each year.
- USA has a closed drug distribution system intended to prevent counterfeits from entering U.S. markets, but it isn't foolproof due to many reason including illegal online pharmacy.

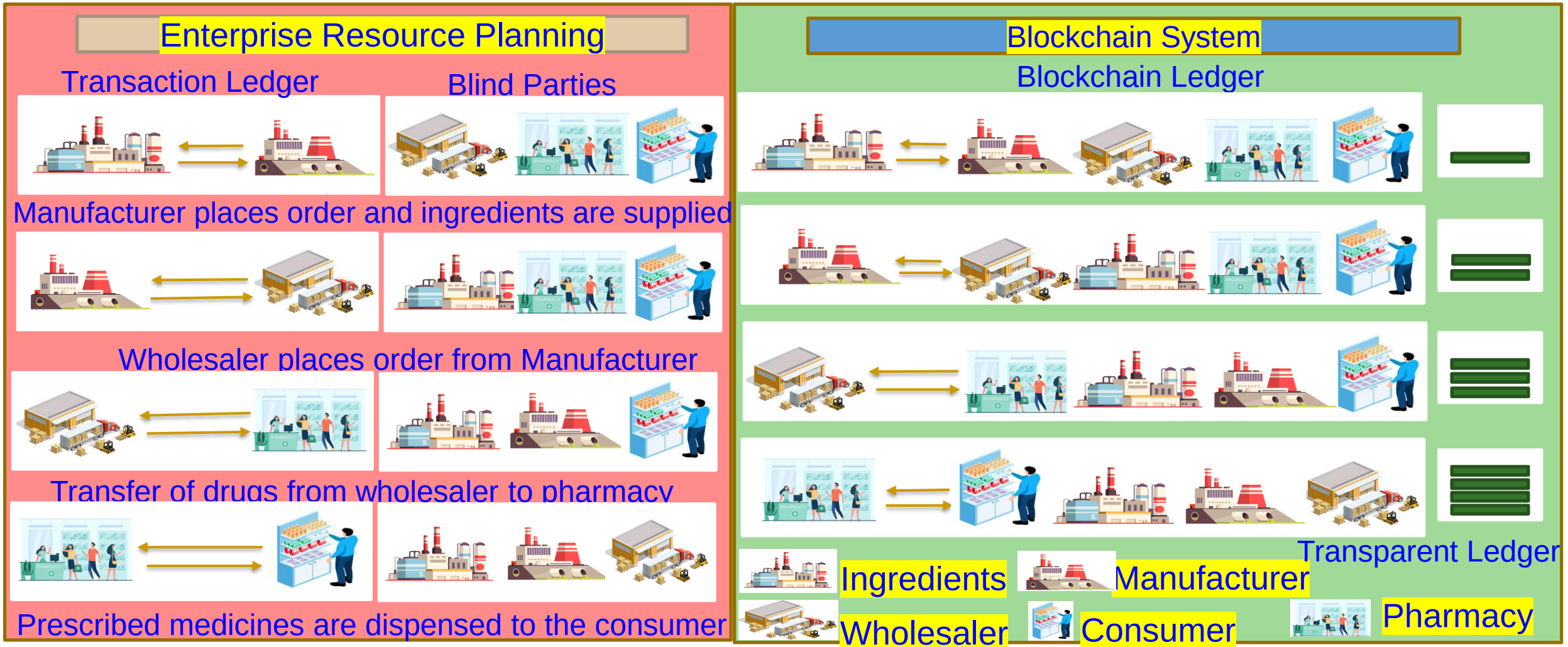
Source: https://fraud.org/fakerx/fake-drugs-and-their-risks/counterfeit-drugs-are-a-global-problem/


Source: https://allaboutpharmacovigilance.org/be-aware-of-counterfeit-medicine/



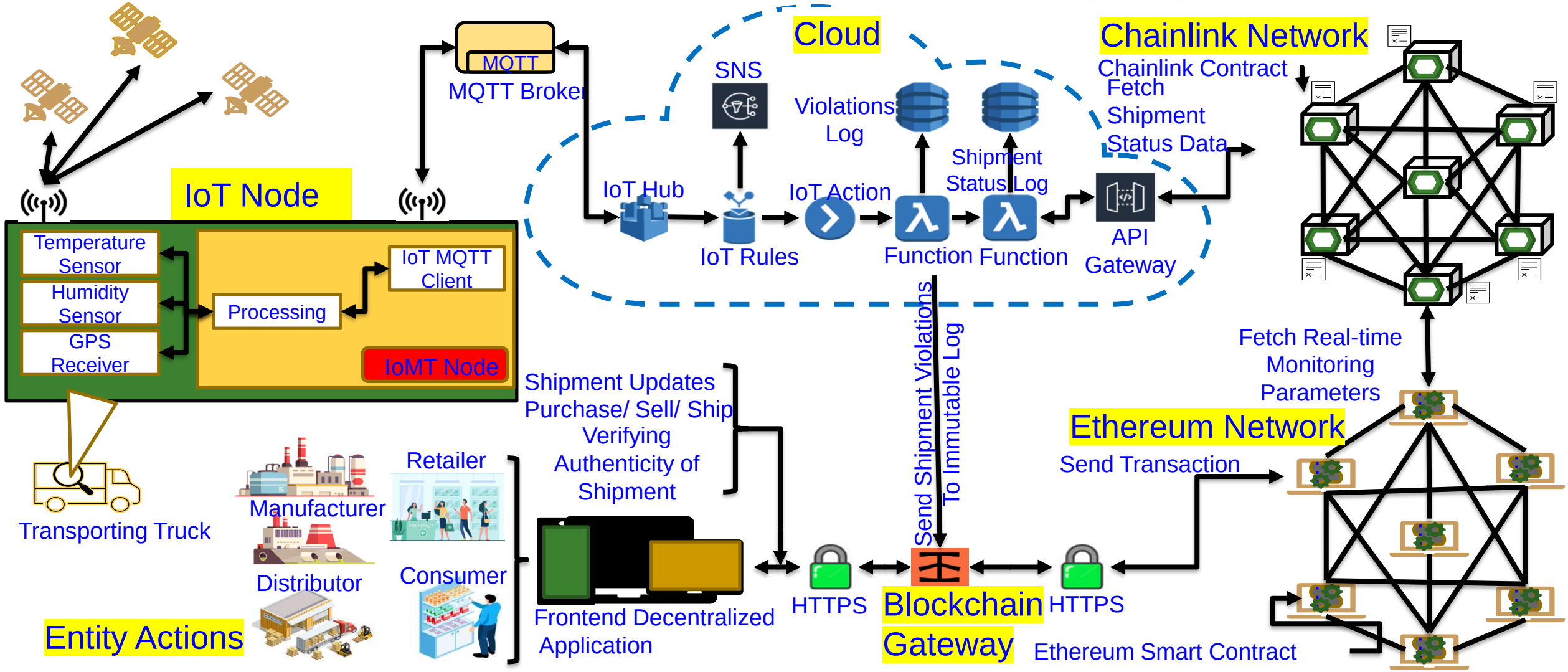

Source: https://healthpolicy-watch.news/fight-the-fakes-campaign-raises-awareness-of-falsified-substandard-medicines/

# PharmaChain - Counterfeit Free Pharmaceutical




Source: A. K. Bapatla, **S. P. Mohanty**, E. Kougianos, D. Puthal, and A. Bapatla, "PharmaChain: A Blockchain to Ensure Counterfeit-Free Pharmaceutical Supply Chain", *IET Networks*, Vol. XX, No. YY, ZZ 2022, pp. Accepted on 24 June 2022, DOI: https://doi.org/10.1049/ntw2.12041. (Dataset for Research: GitHub)

# Our PharmaChain: Architectural Overview

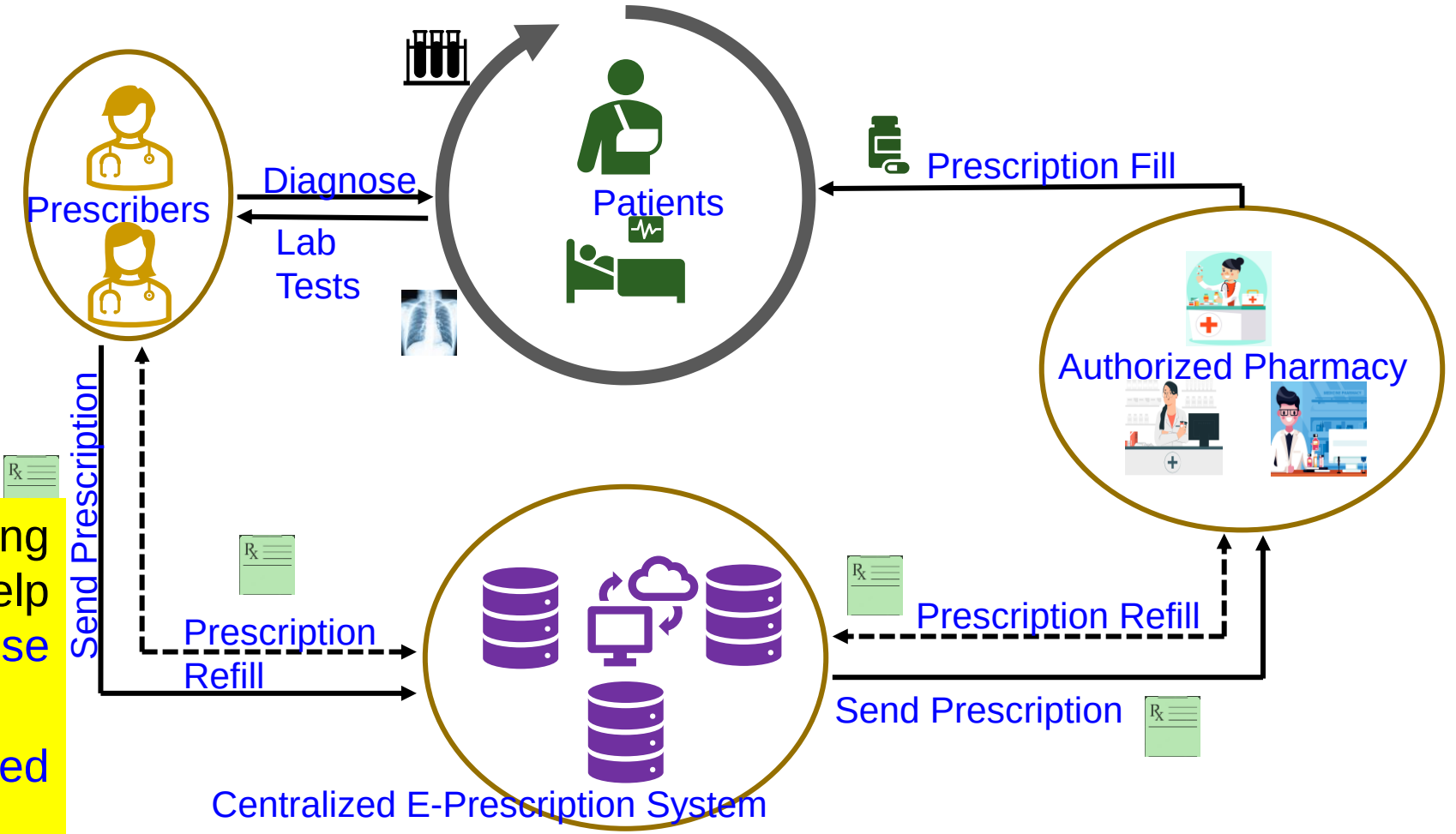



Source: A. K. Bapatla, **S. P. Mohanty**, E. Kougianos, D. Puthal, and A. Bapatla, "PharmaChain: A Blockchain to Ensure Counterfeit-Free Pharmaceutical Supply Chain", *IET Networks*, Vol. 12, No. 2, March 2023, pp. 53--76, DOI: https://doi.org/10.1049/ntw2.12041. (Dataset for Research: GitHub)

# Smart Healthcare – Trustworthy Medical Prescription

# E-Prescription System and Issues

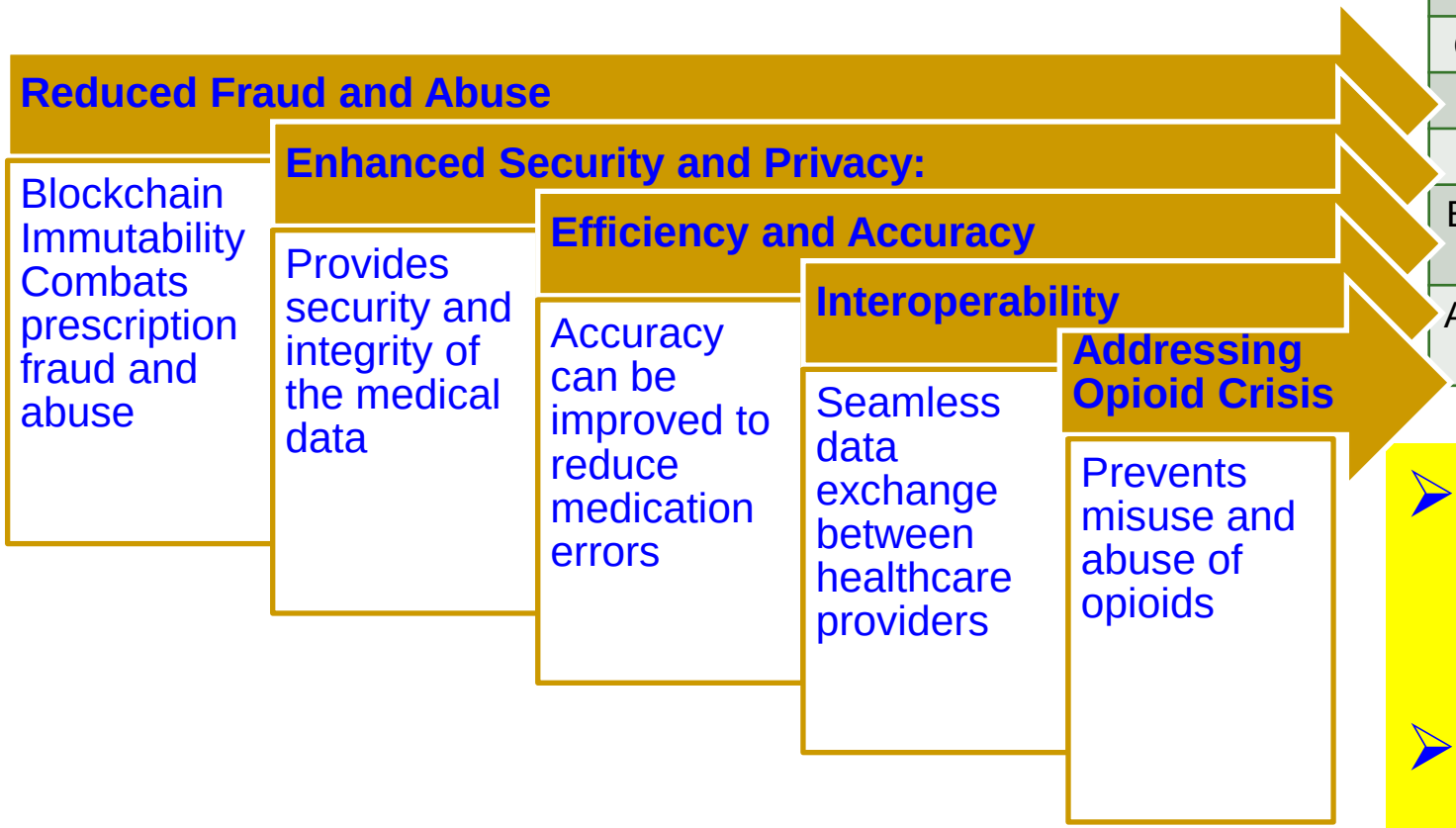
- Single Point of Failure (SPOF)
- Data Security
- Privacy Concerns
- Interoperability Concerns (PDMP)
- System availability Issues




- Prescription Drug Monitoring Programs(PDMP) help mitigate prescription misuse and diversion
- Oversight of controlled substance prescriptions

Source: A. K. Bapatla, **S. P. Mohanty**, and E. Kougianos, "FortiRx: Distributed Ledger Based Verifiable and Trustworthy Electronic Prescription Sharing", in *Proceedings of the IFIP International Internet of Things Conference (IFIP-IoT)*, 2023, pp. 283--301, DOI: https://doi.org/10.1007/978-3-031-45882-8_19.

# E-Prescription is the Need of the Hour

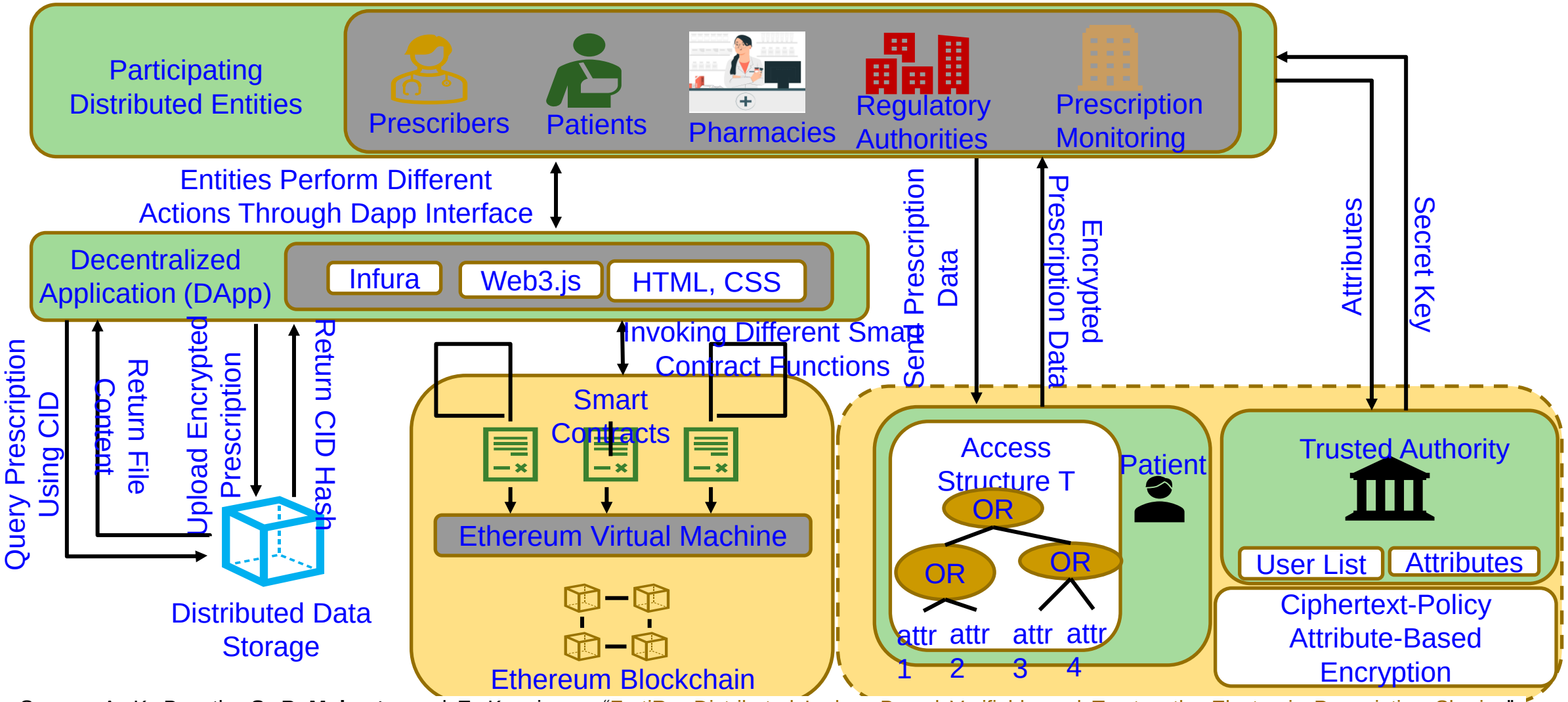



| Prescription Drug Type | Annual Abusers | % Among Rx Abusers | % Among Americans |
|---|---|---|---|
| Painkillers | 9.7 million | 59.5% | 3.43% |
| Opioids Alone | 9.3 million | 57.1% | 3.29% |
| Sedatives | 5.9 million | 36.2% | 2.08% |
| Stimulants | 4.9 million | 30.1% | 1.73% |
| Benzodiazepine Alone | 4.8 million | 29.4% | 1.70% |
| All Prescription Drugs | 16.3 million | 100% | 5.76% |

- 16M – 6% of Americans over the age of 12 abuse prescriptions in a year.
- 2M – 12% of prescription drug abusers are addicted.

Statistics Source: https://drugabusestatistics.org/prescription-drug-abuse-statistics/

# Our FortiRx: Architecture Overview




Source: A. K. Bapatla, **S. P. Mohanty**, and E. Kougianos, "FortiRx: Distributed Ledger Based Verifiable and Trustworthy Electronic Prescription Sharing", in *Proceedings of the IFIP International Internet of Things Conference (IFIP-IoT)*, 2023, pp. 283--301, DOI: https://doi.org/10.1007/978-3-031-45882-8_19.

# Conclusion and Future Research

# Conclusion

- Healthcare has been evolving to Healthcare-CPS (H-CPS).
- Internet of Medical Things (IoMT) is key for smart healthcare.
- Smart healthcare can reduce cost of healthcare and give more personalized experience to the individual.
- IoMT/H-CPS has advantages but also has limitations in terms of cybersecurity; thus challenging to build sustainable healthcare.
- Medical device security is a difficult problem due to resource and battery constraints; thus challenge for sustainable H-CPS.
- Robust pharmaceutical supply chain is important for counterfeit-free medical supplies.
- Trustworthy e-prescription is key in H-CPS to ensure safe medication.
- Security-by-Design is critical for IoMT/H-CPS.

# Future Research

- TinyML for smart healthcare that can run at user-end (edge/sensor) needs research.
- H-CPS requires robust data, devices, along with cybersecurity and privacy assurance to be sustainable and hence needs research.
- Security of IWMDs needs to have extremely minimal energy overhead to be useful and hence needs research.
- Integration of blockchain for smart healthcare need more research due to energy, computational overheads, and lack of scalability, associated with it.
- Robust Pharmaceutical Supply Chain needs research.
- Trustworthy Insurance Processing in H-CPS needs research.
- SbD research for IoMT/H-CPS application is needed.