

Healthcare Cyber-Physical Systems (H-CPS)

Keynote – National Symposium on "Transforming Healthcare Through AI, Biotechnology, Digital Health & Smart Medical Technologies" (AIMED 2026)

<https://www.ganpatuniversity.ac.in/digitalhealthtech/digitalhealthtech-home>



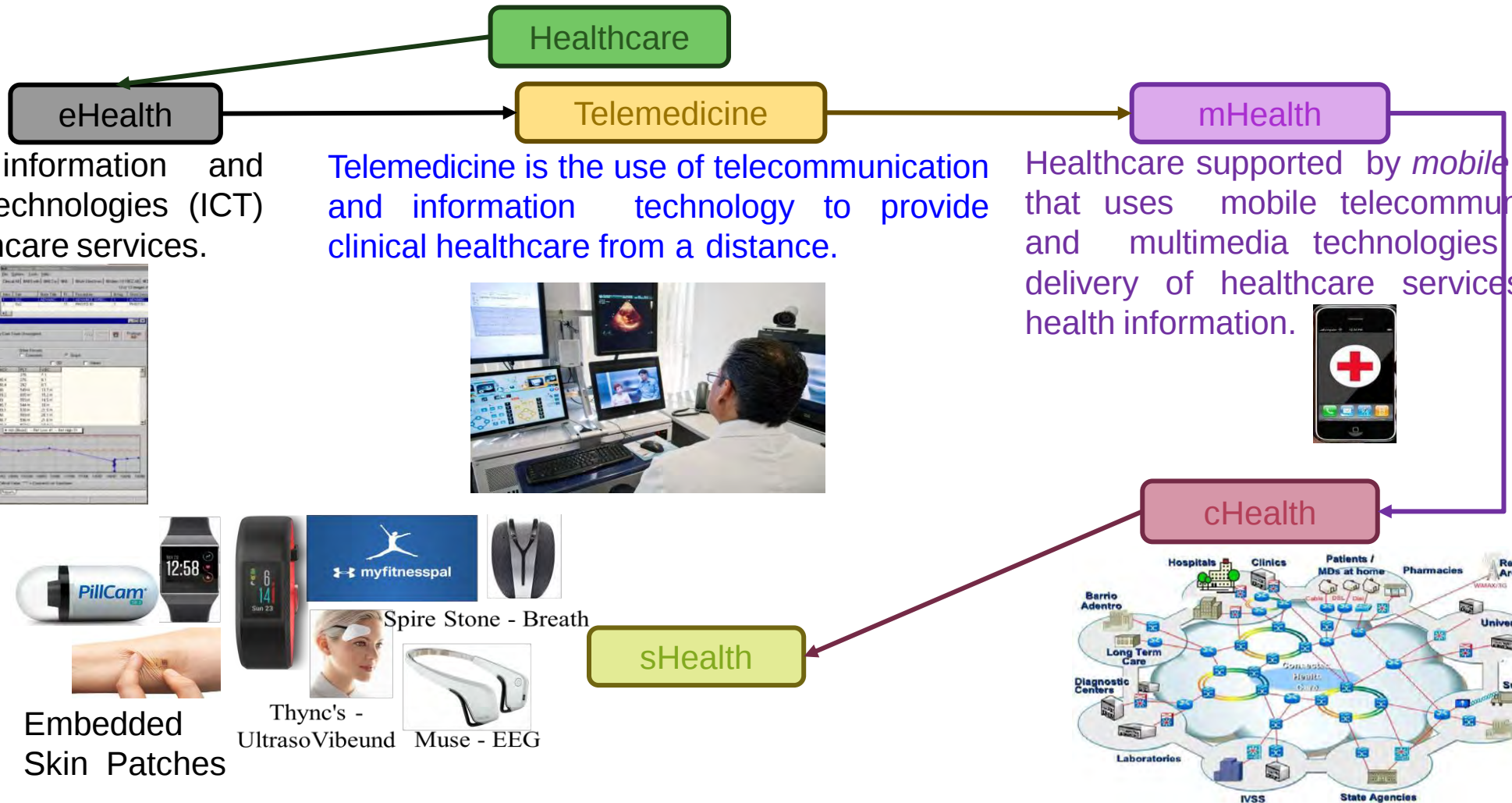
Ahmedabad, India, 7--8 Aug 2026

Homepage:
www.smohanty.org

Prof./Dr. Saraju Mohanty
University of North Texas, USA.

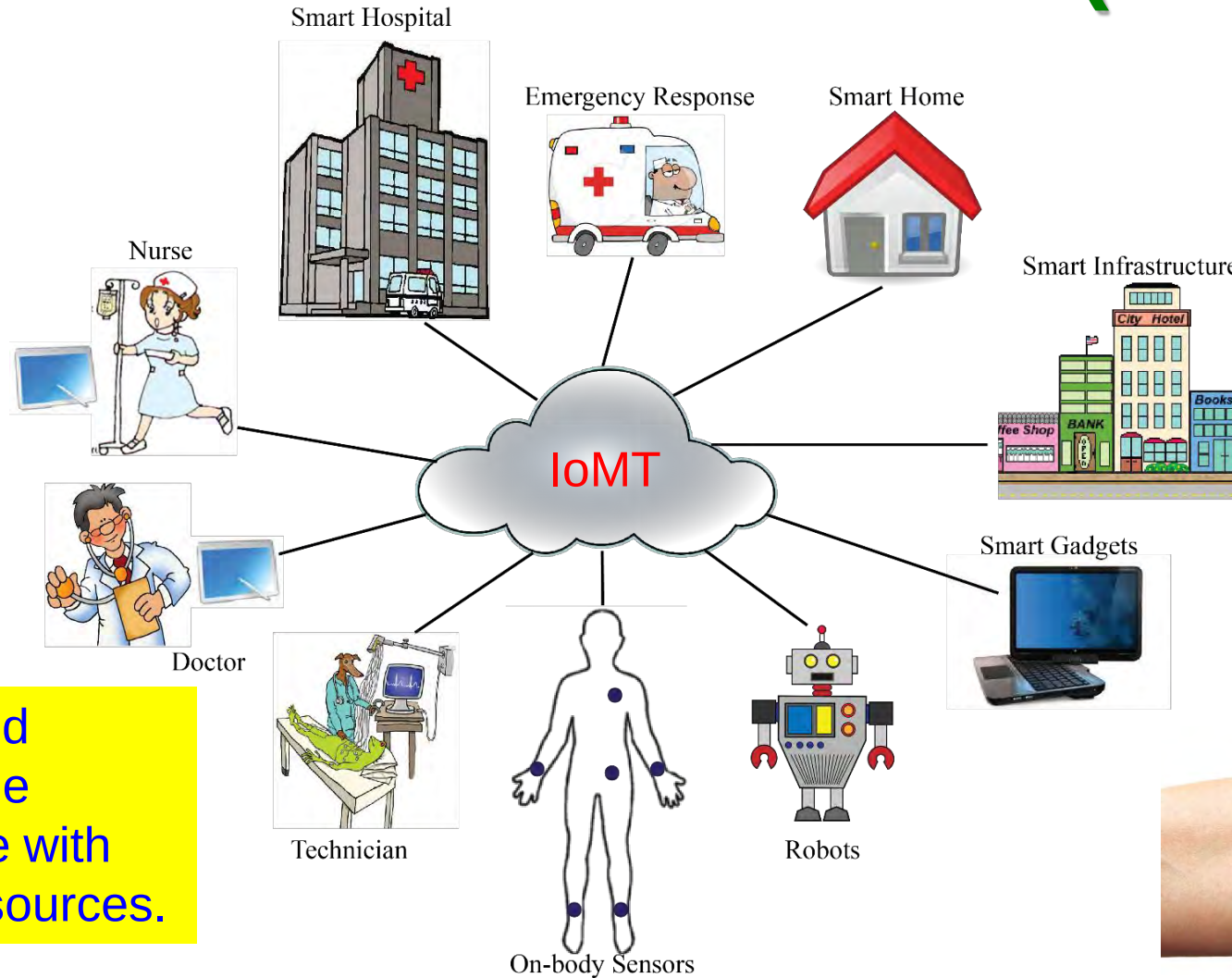


Healthcare → Smart Healthcare



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

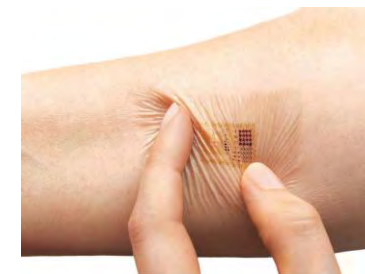
Smart Healthcare (sHealth)



Fitness Trackers



Headband with Embedded Neurosensors



Embedded Skin Patches

Quality and sustainable healthcare with limited resources.

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.

What is Smart Healthcare?

Smart Healthcare ←
Conventional Healthcare
+ Body sensors
+ Smart Technologies
+ Information & Communication Technology (ICT)
+ AI/ML

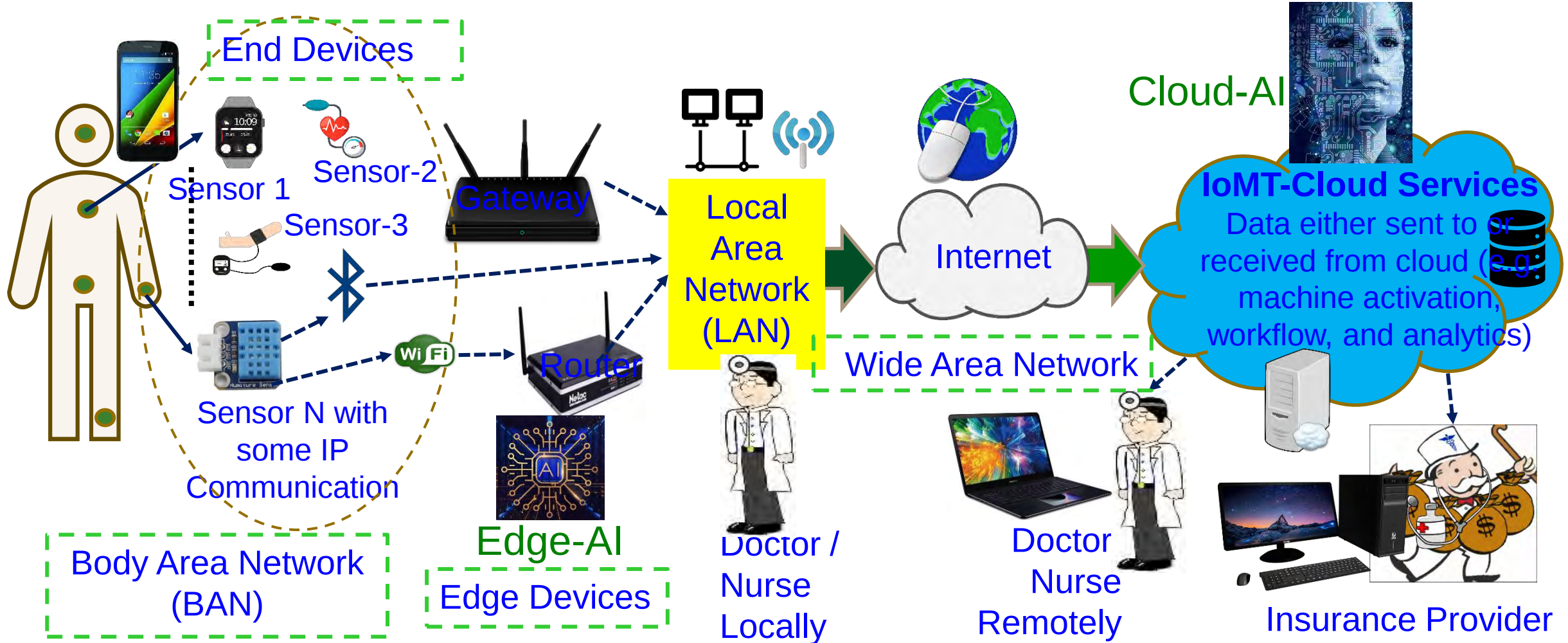
Internet of Medical Things (IoMT)

Internet of Health Things (IoHT)

Healthcare Cyber-Physical Systems (H-CPS)

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)*, Volume 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 – AI is Key

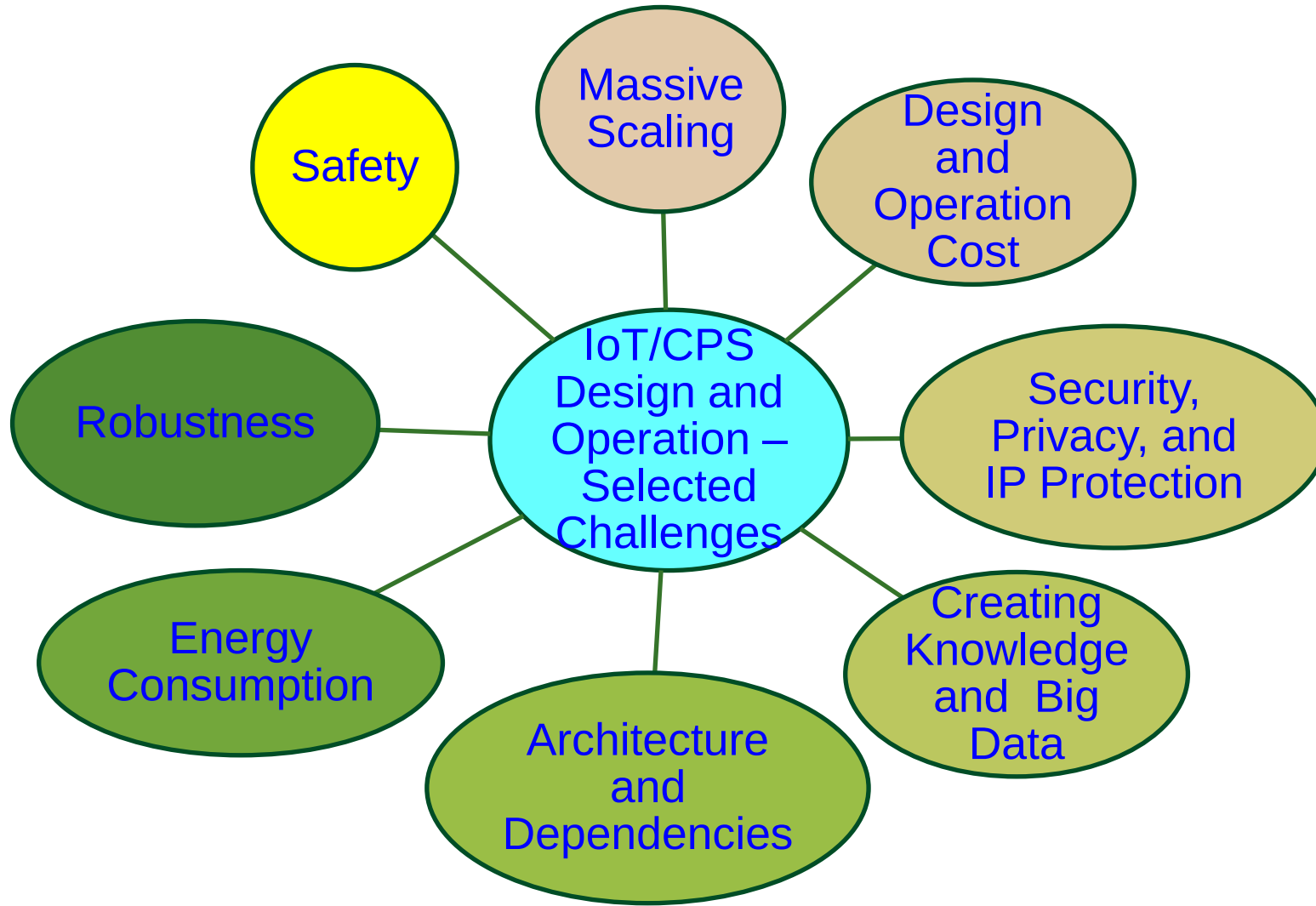


AI Role Includes:

- Automatic diagnosis
- Diet prediction
- Disease predication
- Automatic prescription
- Pandemic projection

Source: Robert Pearl, "Artificial Intelligence In Healthcare: Separating Reality From Hype", 13 Mar 2018, <https://www.forbes.com/sites/robertpearl/2018/03/13/artificial-intelligence-in-healthcare/?sh=598aa64d1d75>

CPS – Sustainability Challenges



Source: Mohanty ICIT 2017 Keynote

Challenges of Data in IoT/CPS are Multifold

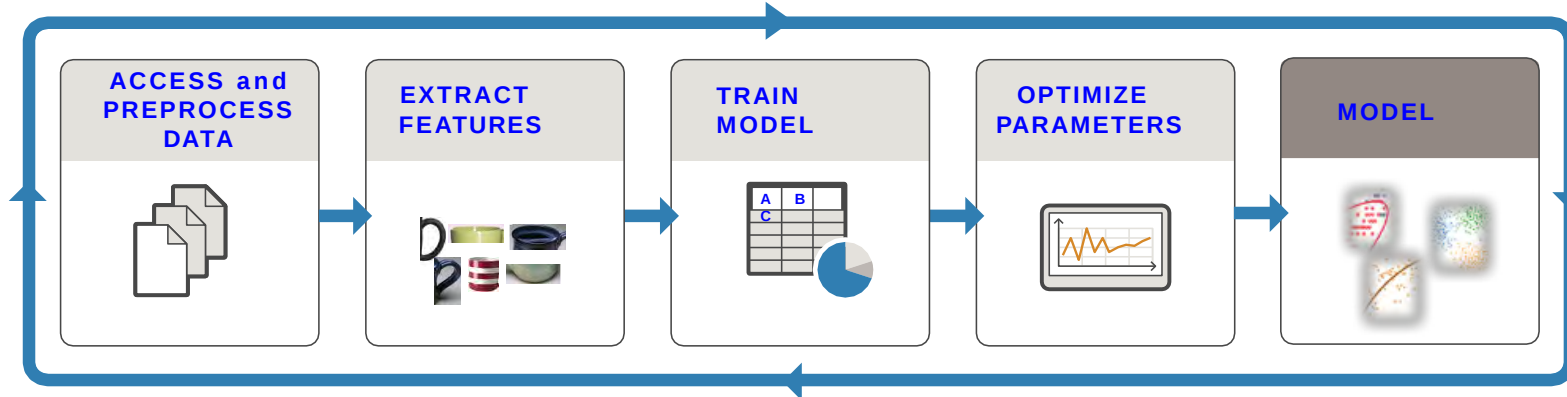


Deep Neural Network (DNN) - Resource and Energy Costs

TRAIN: Iterate until you achieve satisfactory performance.

Needs Significant:

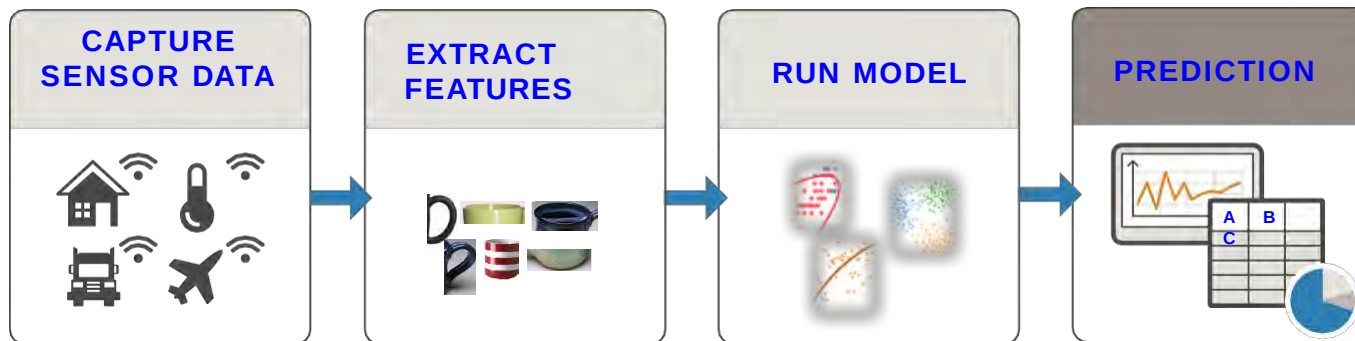
- Computational Resource
- Computation Energy



Limited Computational Capability
Limited Battery Life



PREDICT: Integrate trained models into applications.



Needs:

- Computational Resource
- Computation Energy



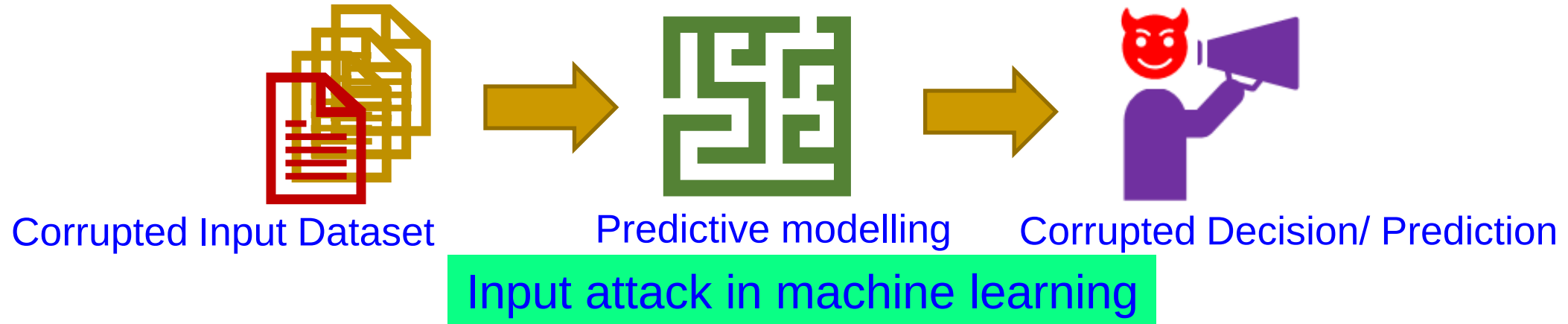
Source: <https://www.mathworks.com/campaigns/offers/mastering-machine-learning-with-matlab.html>

DNNs are not Always Smart



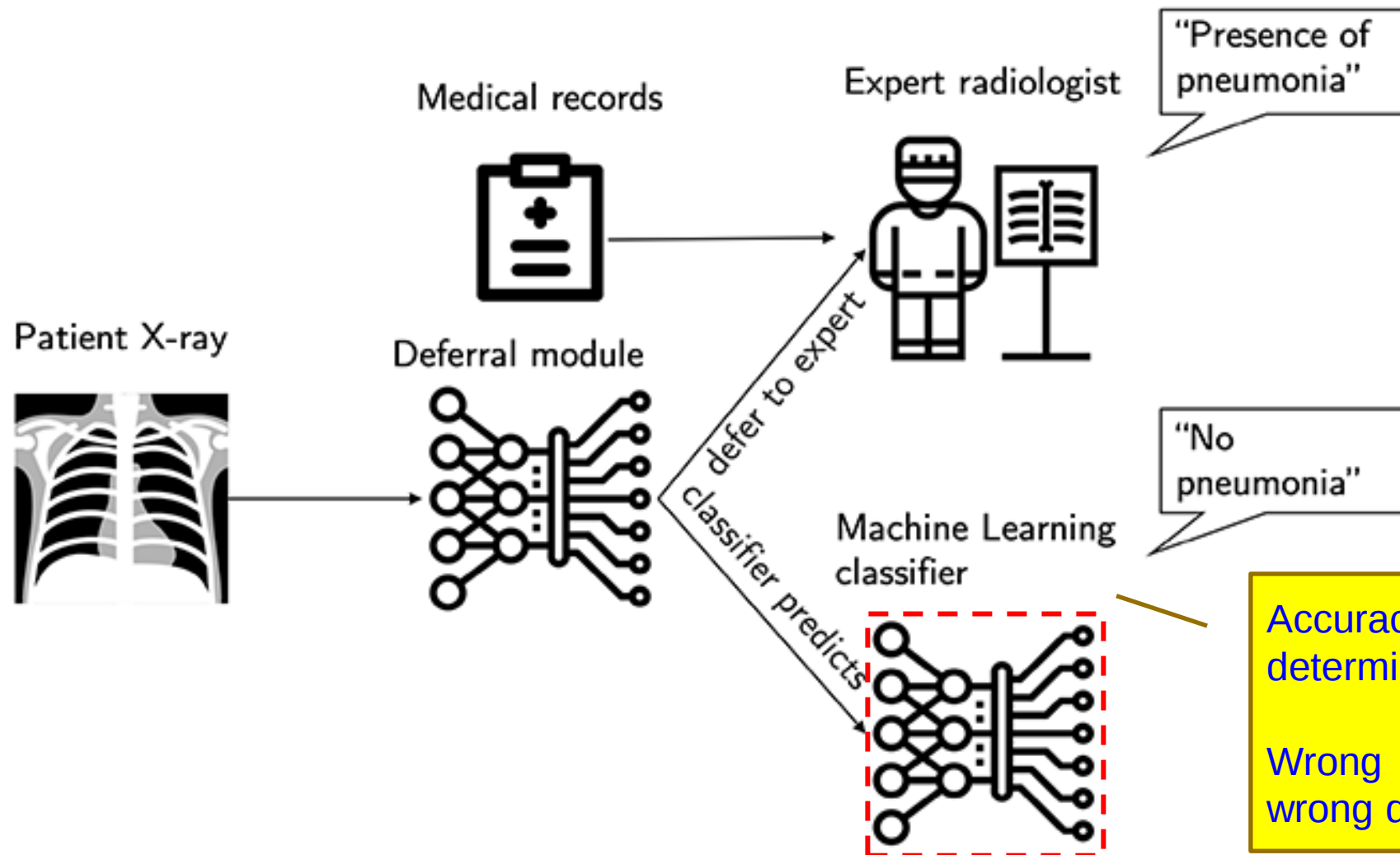
Machine learning: "I'm as intelligent as human beings".
Also machine learning:

AI/ML – Cybersecurity Issue



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



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

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

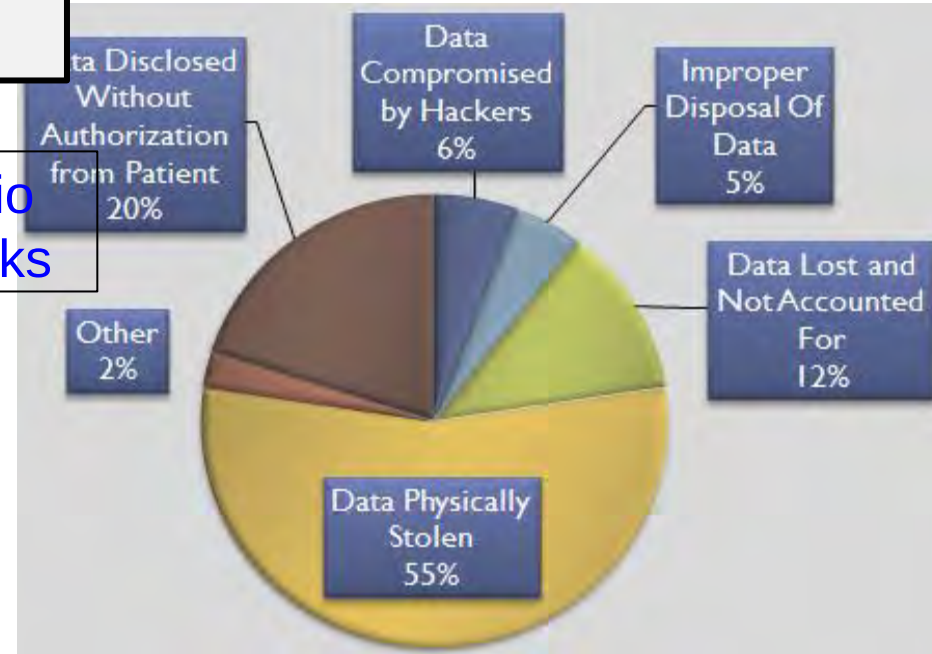
Radio Attacks



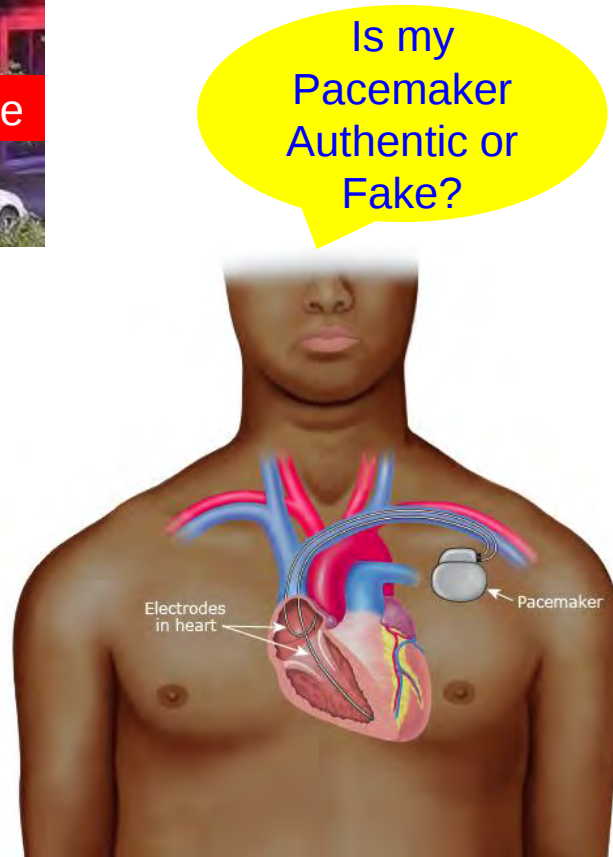
HIPAA

Health Insurance Portability and Accountability Act

HIPPA Privacy Violation by Types



Fake is Cheap – Why not Buy?



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
An implantable medical device



Authentic



Fake

A plug-in for car-engine computers

Counterfeits in Healthcare



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

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/>

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

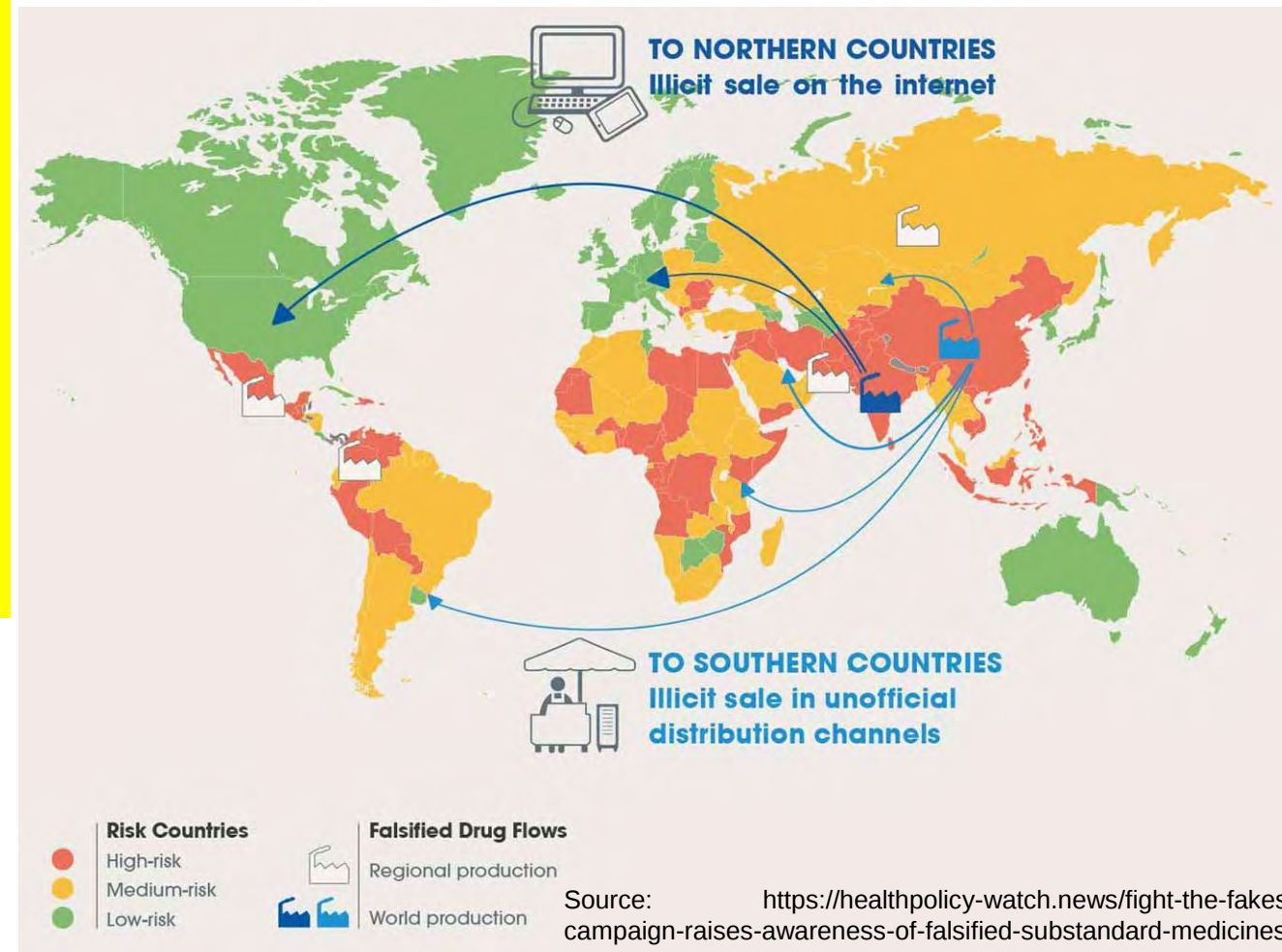
Fake Medicine - Serious Global Issue

- 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/>



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%

Reduced Fraud and Abuse

Blockchain
Immutability
Combats
prescription
fraud and
abuse

Enhanced Security and Privacy:

Provides
security and
integrity of
the medical
data

Efficiency and Accuracy

Accuracy
can be
improved to
reduce
medication
errors

Interoperability

Seamless
data
exchange
between
healthcare
providers

Addressing Opioid Crisis

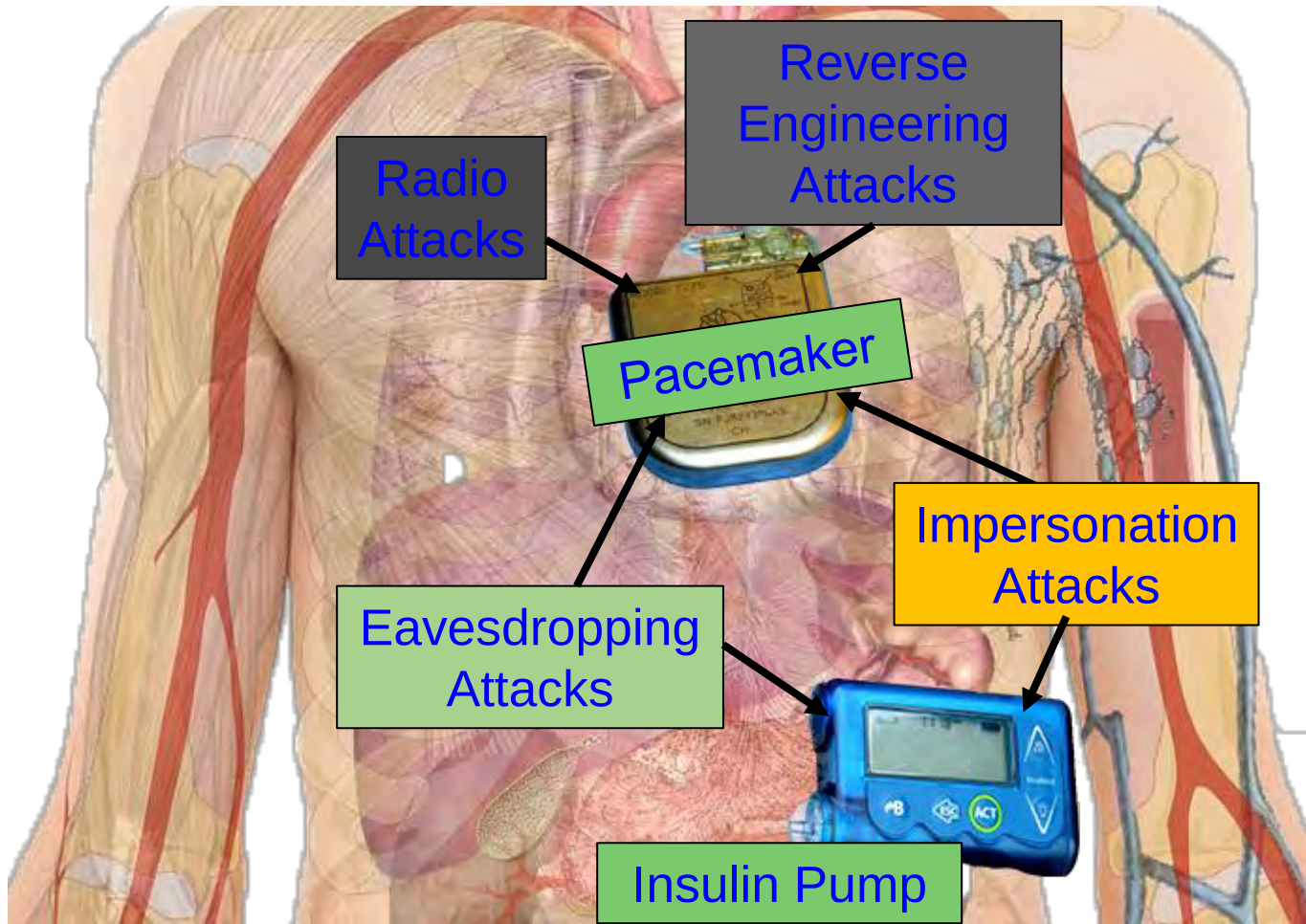
Prevents
misuse and
abuse of
opioids

- 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/>

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

CPS Design - Multiple Objectives for Sustainability



Source: Mohanty ICCE 2019 Keynote

Smart Cities
Vs
Smart Villages

Security by Design (SbD)

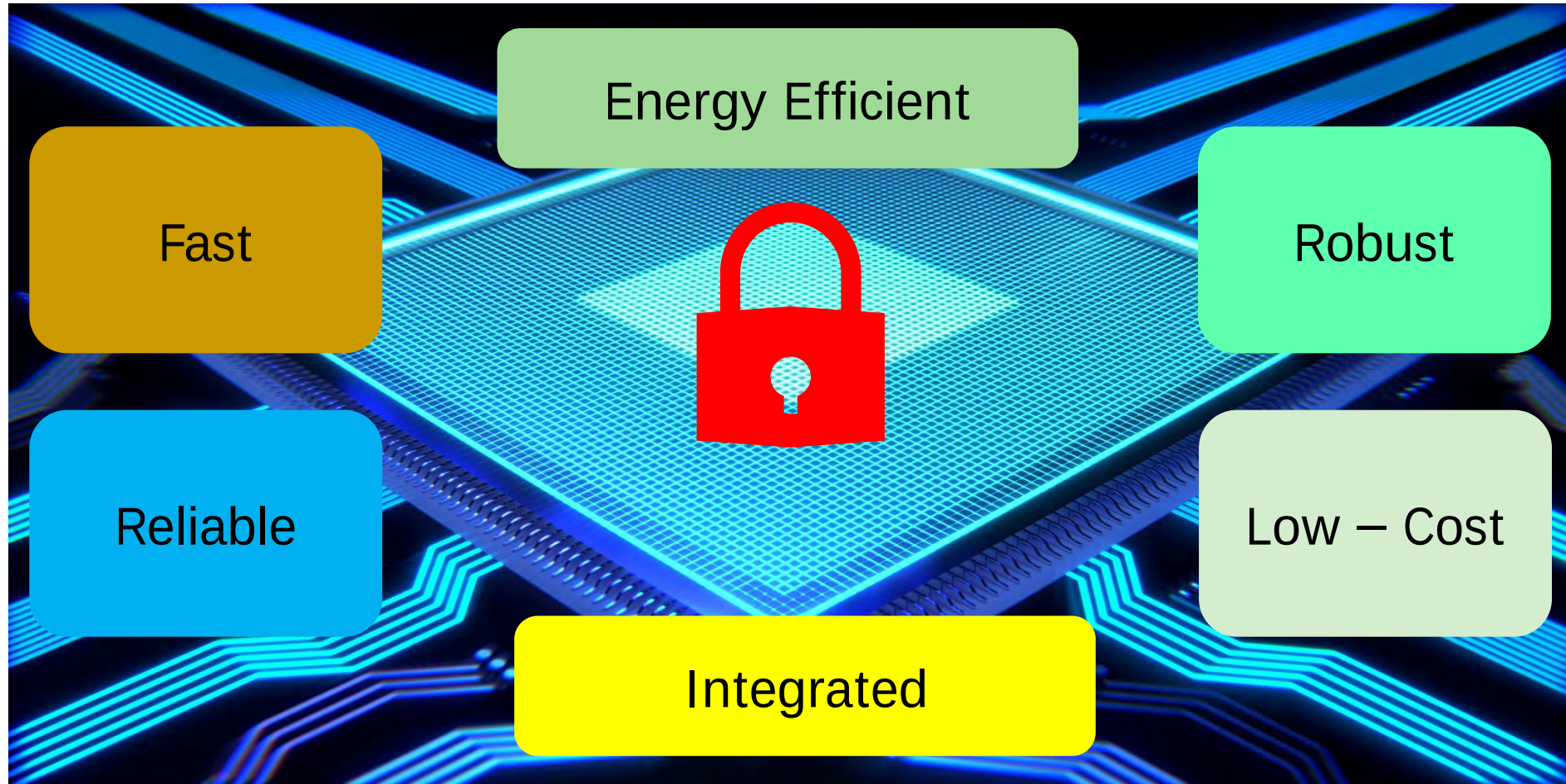
Embedding of security/privacy into the architecture (hardware+software) of various products, programs, or services.

Retrofitting: Difficult → Impossible!

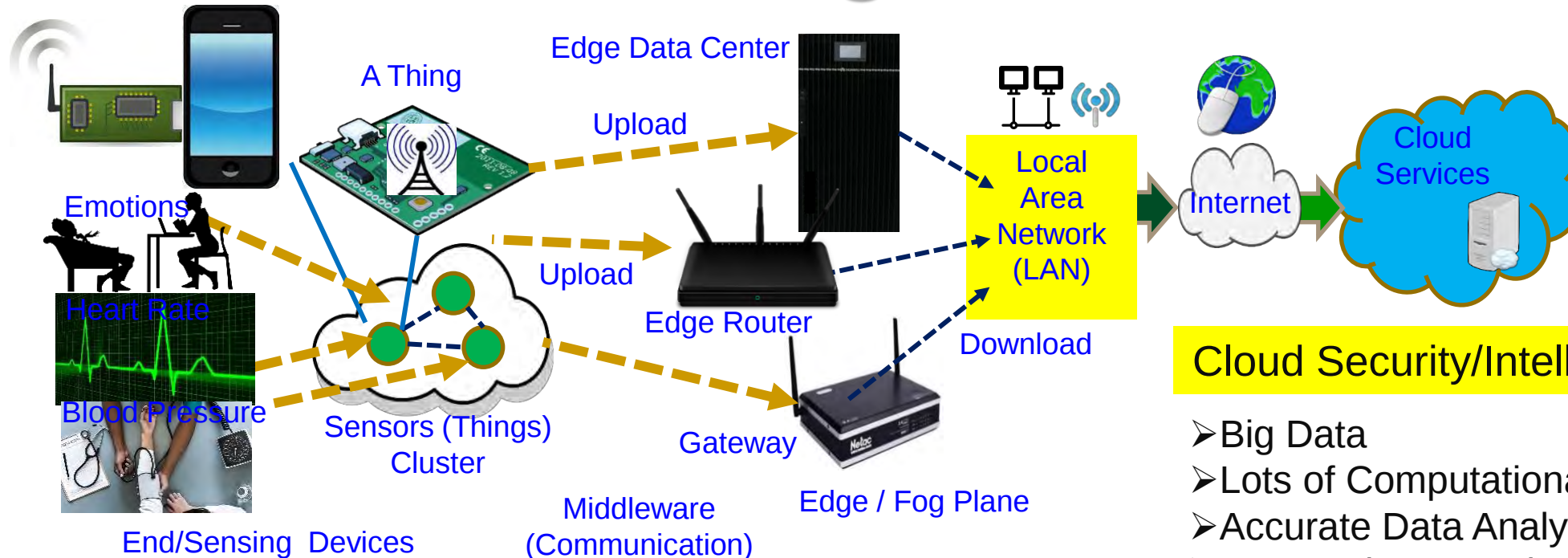


Source: <https://teachprivacy.com/tag/privacy-by-design/>

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



CPS – IoT-Edge Vs IoT-Cloud



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

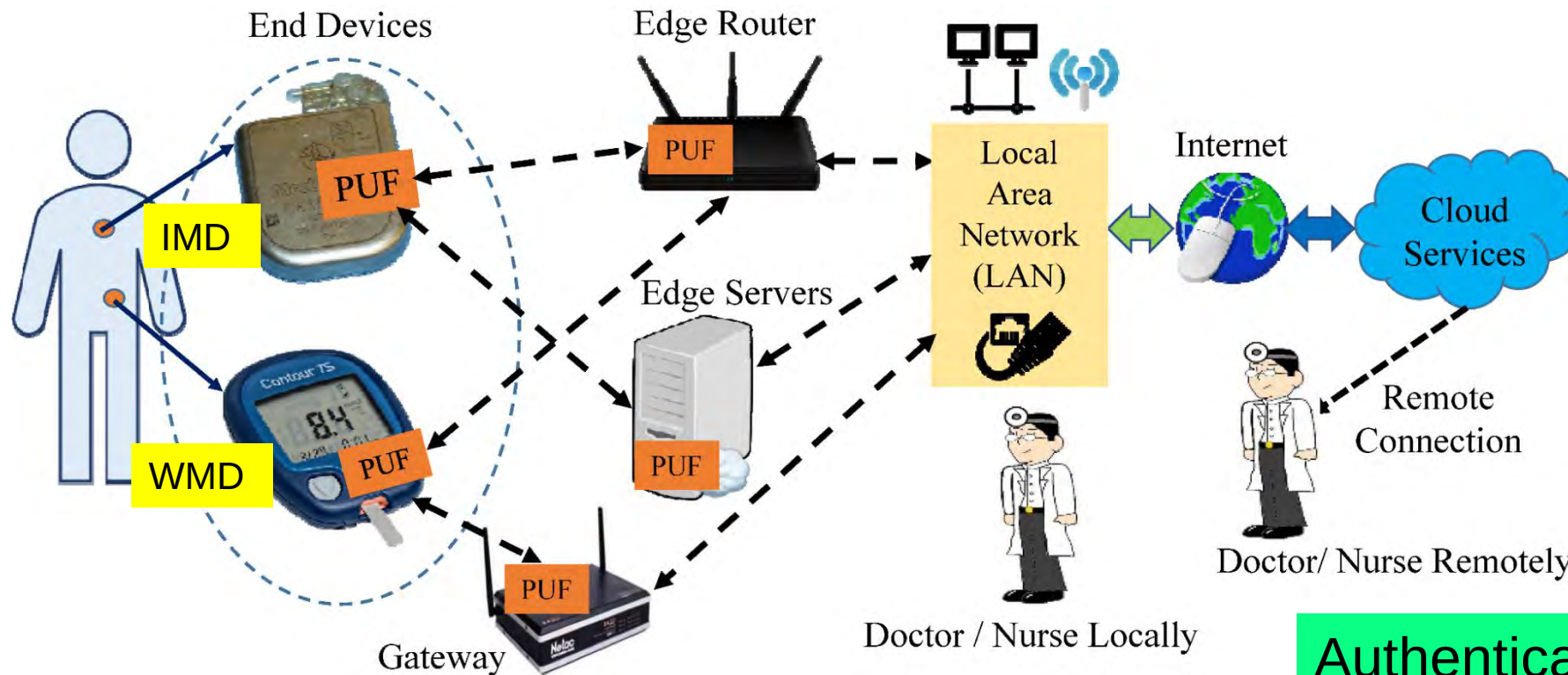
Cloud Security/Intelligence

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

Heavy-Duty ML is more suitable for smart cities

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

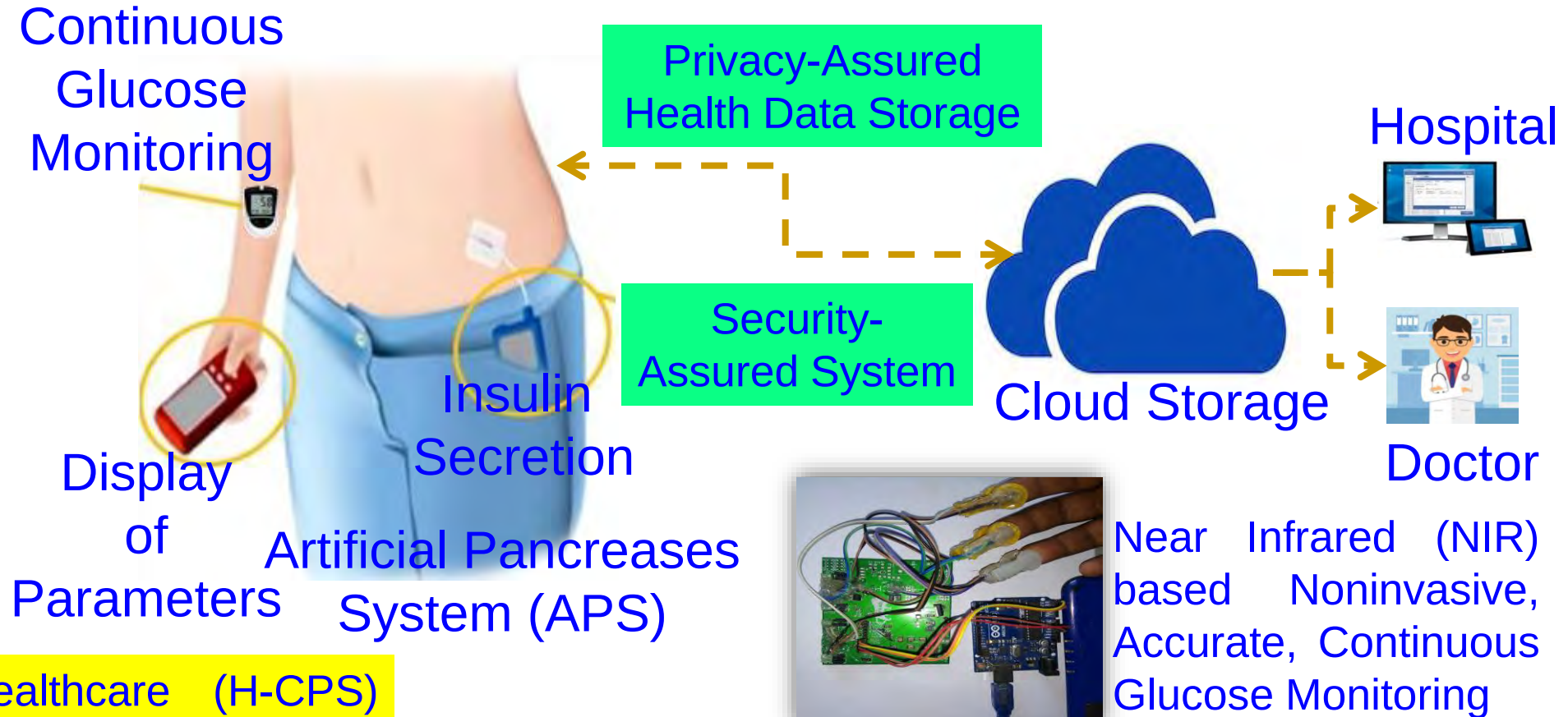
PMsec: Our Secure by Design Approach for Robust Security in Healthcare CPS



Authenticates Time - 1 sec
Power Consumption - 200 μ W

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.

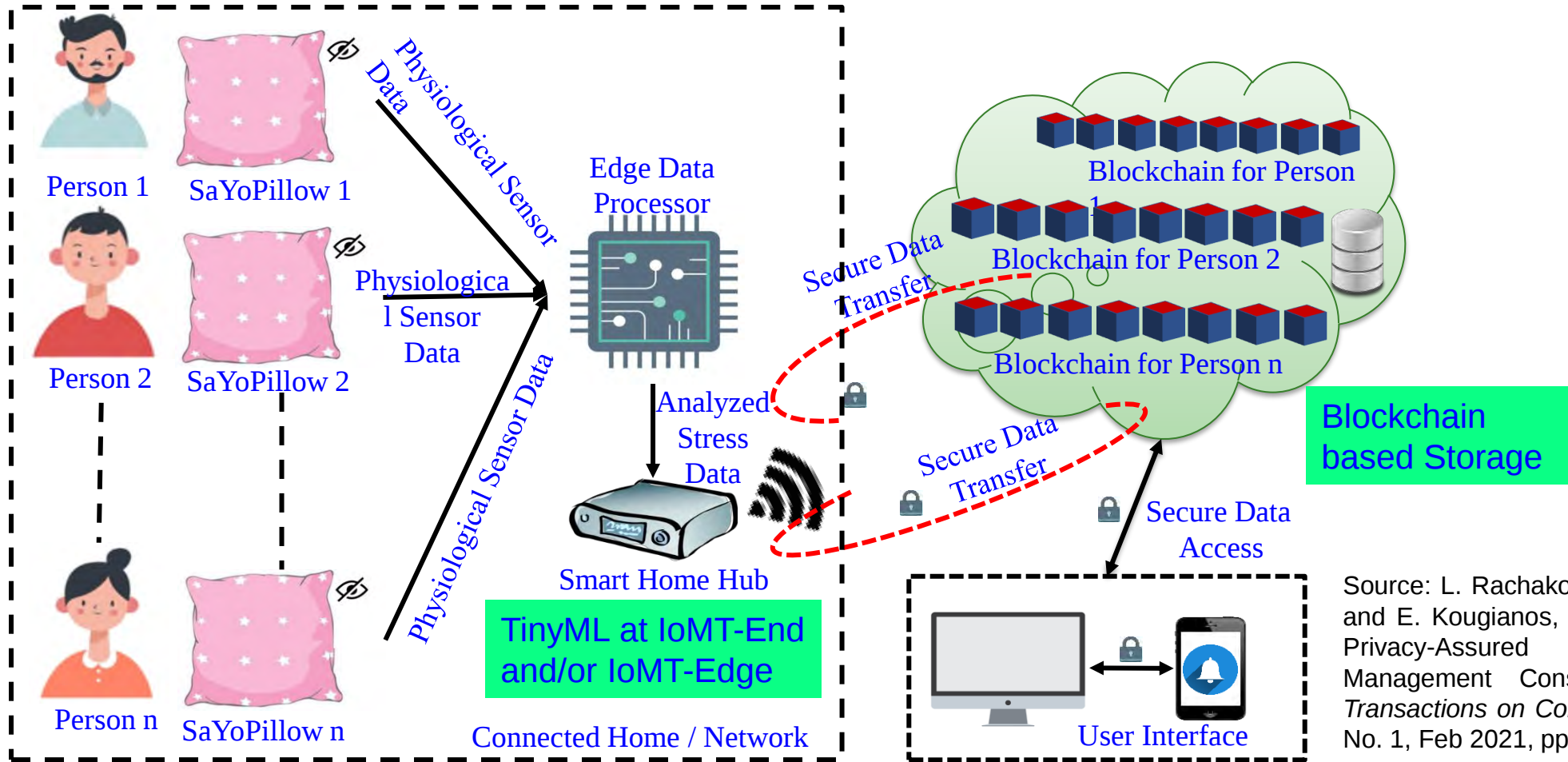
Secure-iGLU - Our Intelligent Non-Invasive Glucose Monitoring with Insulin Control Device



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

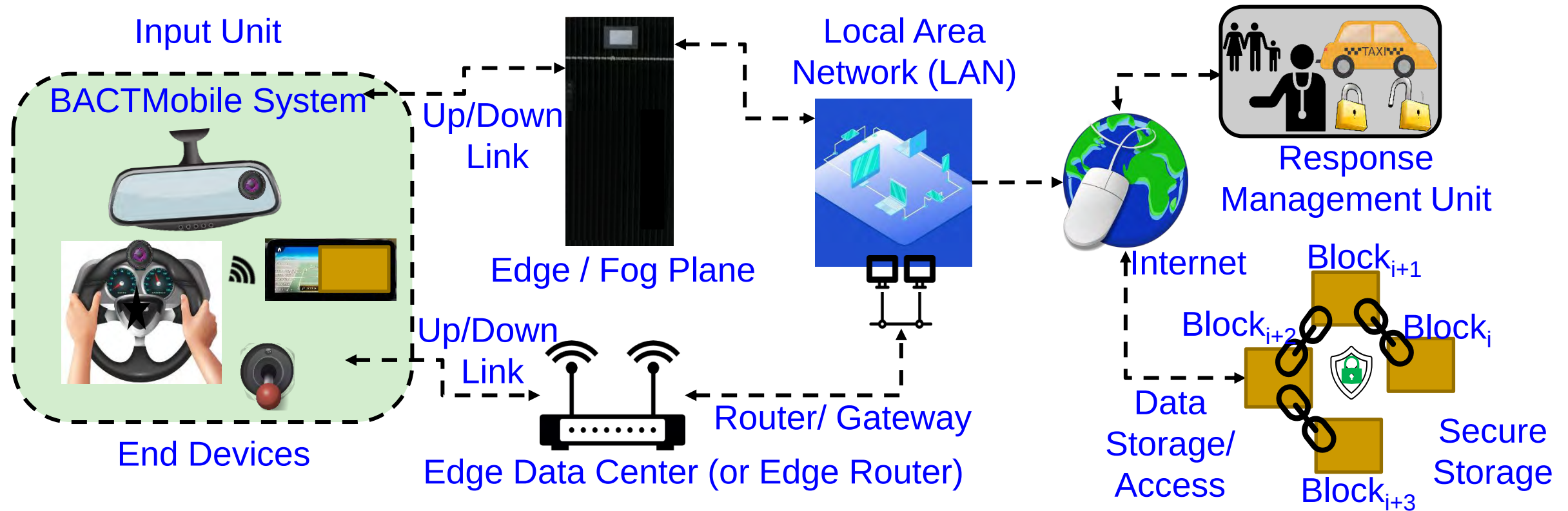
P. Jain, A. M. Joshi, and S. P. Mohanty, "iGLU: An Intelligent Device for Accurate Non-Invasive Blood Glucose-Level Monitoring in Smart Healthcare", *IEEE Consumer Electronics Magazine (MCE)*, Vol. 9, No. 1, January 2020, pp. 35–42.

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



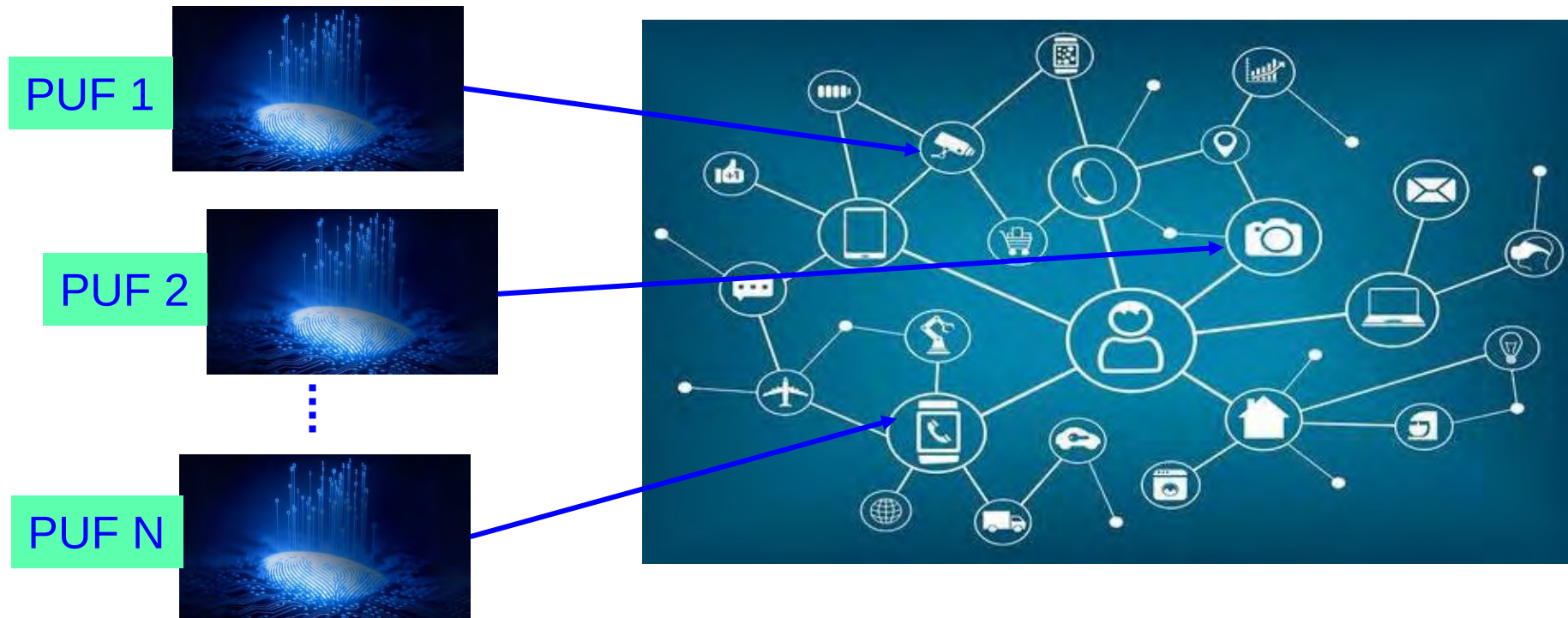
Source: L. Rachakonda, A. K. Bapatla, S. P. Mohanty, and E. Kougianos, "SaYoPillow: Blockchain-Integrated Privacy-Assured IoMT Framework for Stress Management Considering Sleeping Habit", *IEEE Transactions on Consumer Electronics (TCE)*, Vol. 67, No. 1, Feb 2021, pp. 20-29.

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



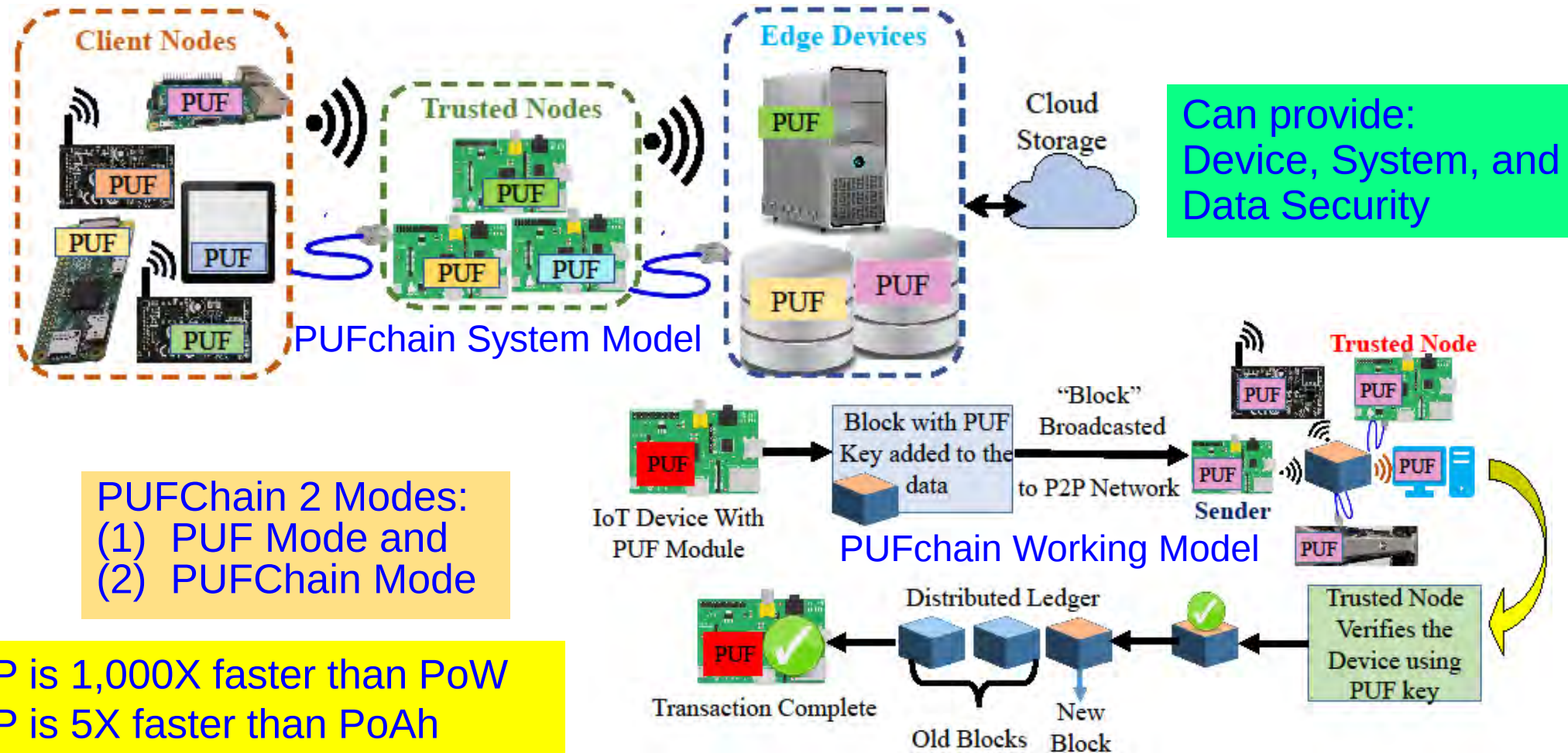
Source: L. Rachakonda, A. K. Bapatla, **S. P. Mohanty**, and E. Kougianos, "BACTmobile: A Smart Blood Alcohol Concentration Tracking Mechanism for Smart Vehicles in Healthcare CPS Framework", *Springer Nature Computer Science (SN-CS)*, Vol. 3, No. 3, May 2022, Article: 236, 24-pages, DOI: <https://doi.org/10.1007/s42979-022-01142-9>.

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



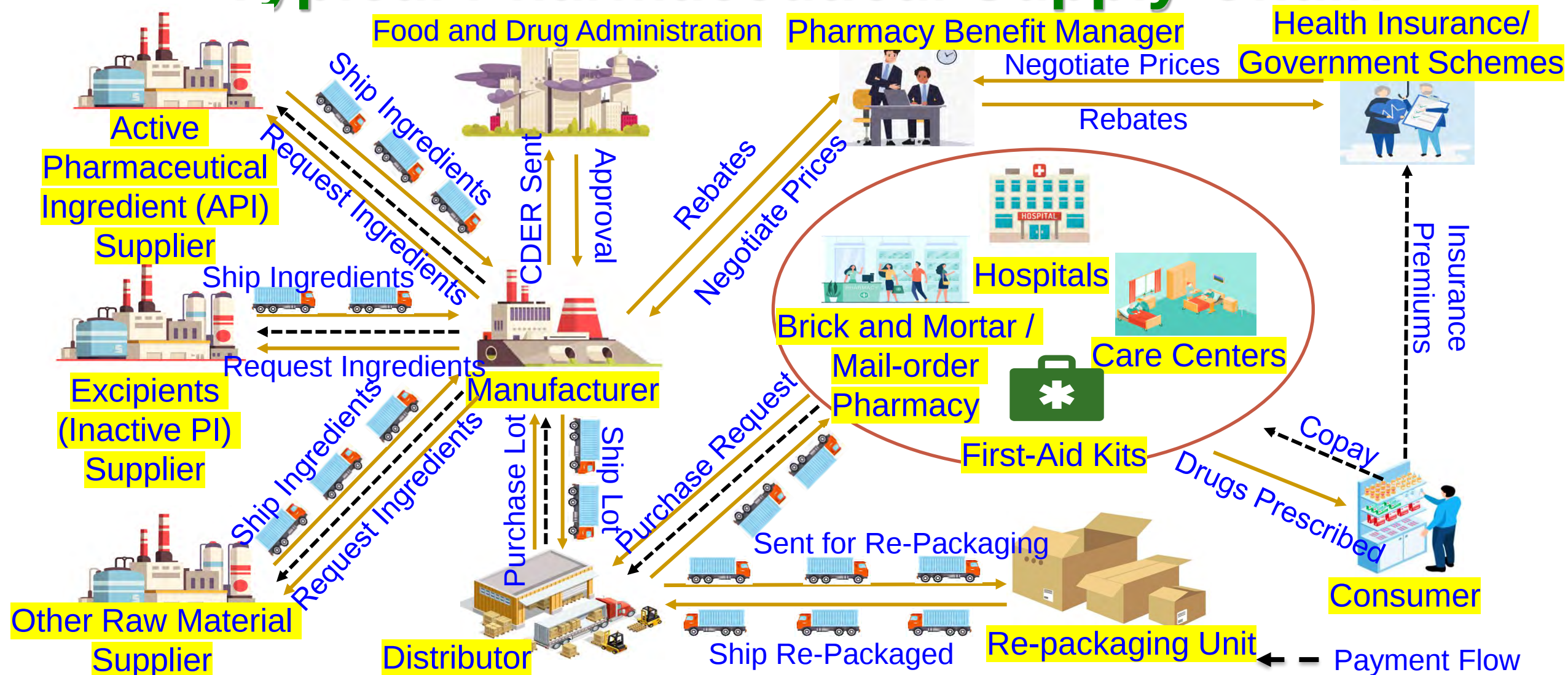
Source: S. P. Mohanty, V. P. Yanambaka, E. Kougianos, and D. Puthal, "PUFchain: Hardware-Assisted Blockchain for Sustainable Simultaneous Device and Data Security in Internet of Everything (IoE)", *IEEE Consumer Electronics Magazine (MCE)*, Vol. 9, No. 2, March 2020, pp. 8-16.

PUFchain: Our Hardware-Assisted Scalable Blockchain



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.

Typical Pharmaceutical Supply Chain



Source: Bapatla, A.K., et al.: PharmaChain: a blockchain to ensure counterfeit-free pharmaceutical supply chain. IET Netw. 1– 24 (2022). <https://doi.org/10.1049/ntw2.12041>

PharmaChain - Counterfeit Free Pharmaceutical

Enterprise Resource Planning

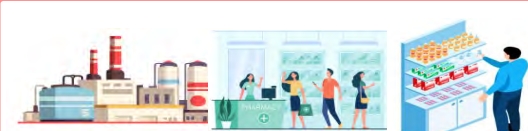
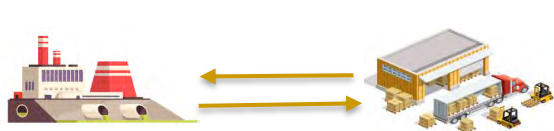
Transaction Ledger



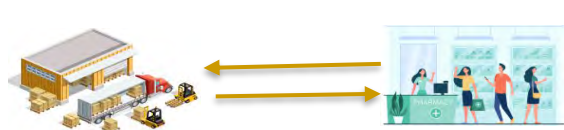
Blind Parties



Manufacturer places order and ingredients are supplied



Wholesaler places order from Manufacturer



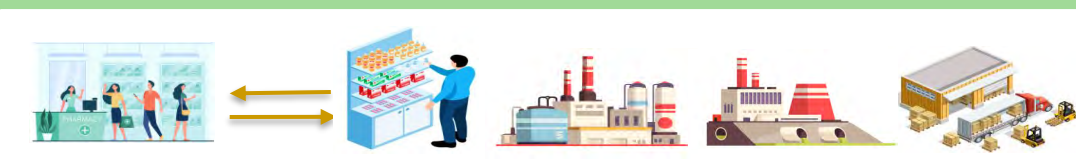
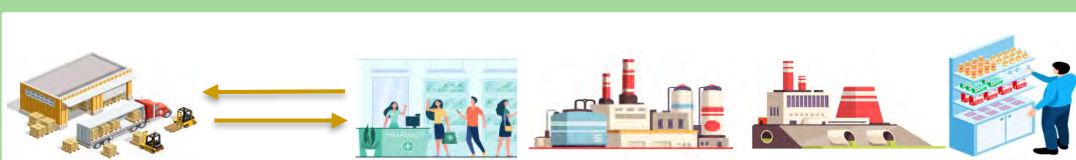
Transfer of drugs from wholesaler to pharmacy



Prescribed medicines are dispensed to the consumer

Blockchain System

Blockchain Ledger



Transparent Ledger

Ingredients

Manufacturer

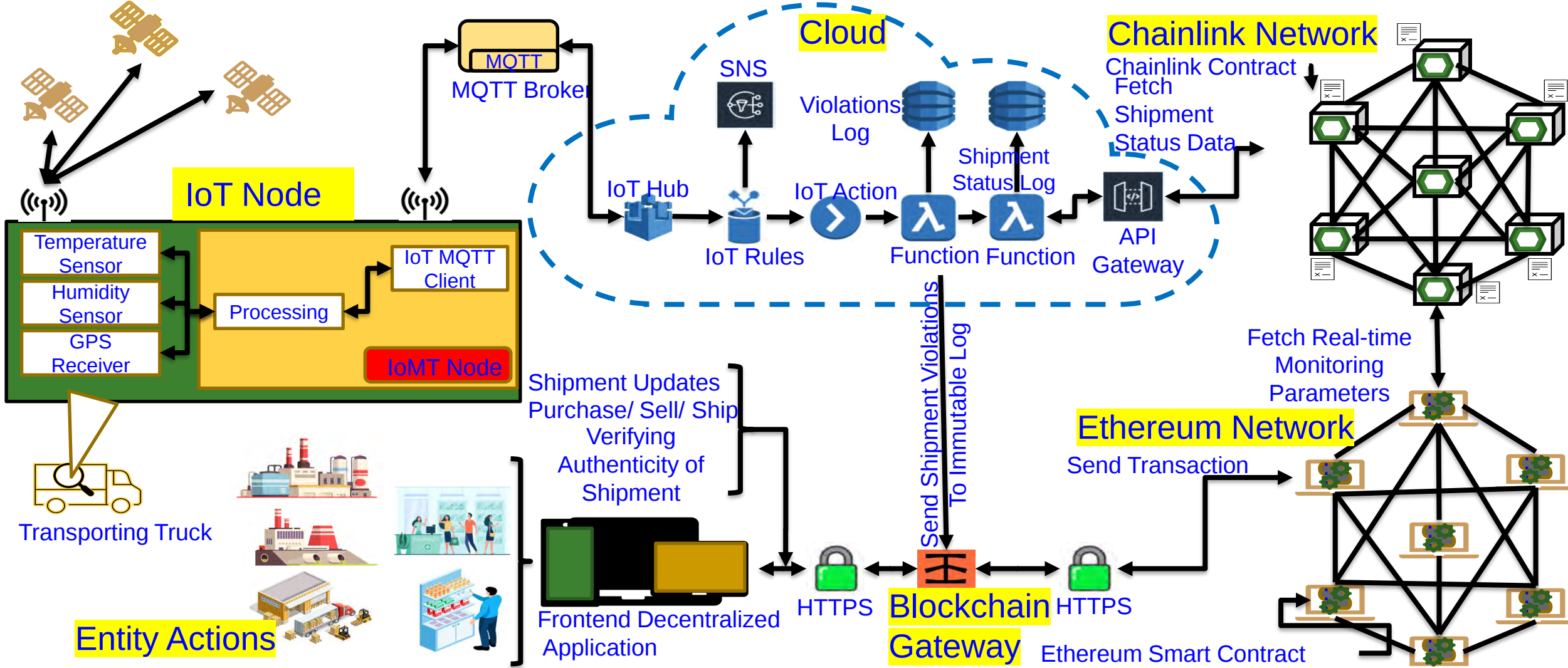
Wholesaler

Consumer

Pharmacy

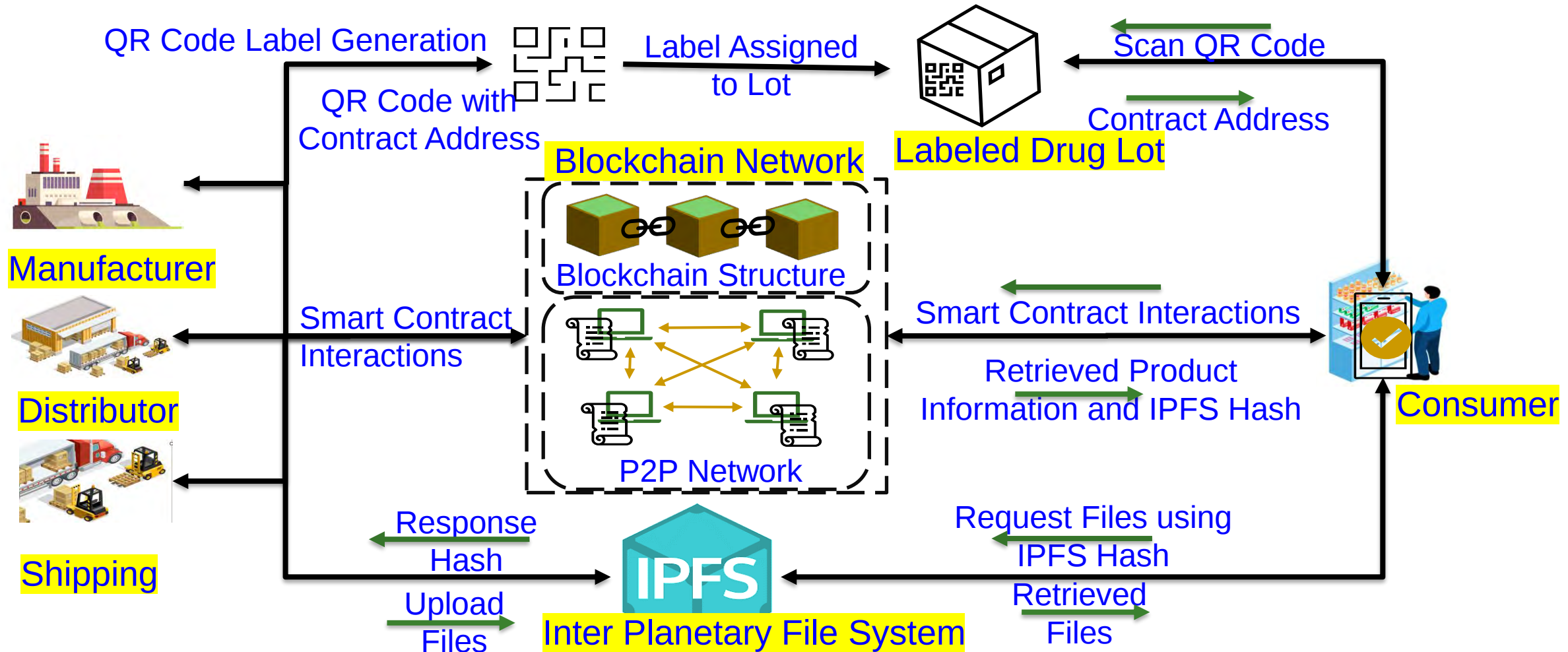
Source: A. K. Bapatla, **S. P. Mohanty**, E. Kougianos, D. Puthal, and A. Bapatla, "PharmaChain: A Blockchain to Ensure Counterfeit-Free Pharmaceutical Supply Chain", *IET Networks*, Vol. XX, No. YY, ZZ 2022, pp. Accepted on 24 June 2022, DOI: <https://doi.org/10.1049/ntw2.12041>. (Dataset for Research: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

PharmaChain 3.0 - Architectural Overview

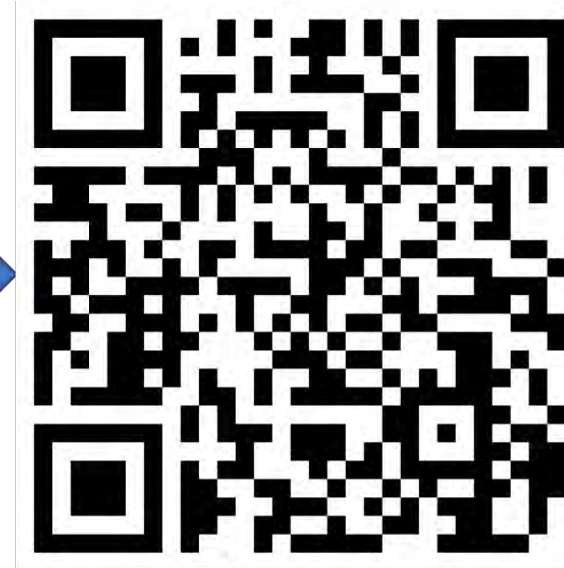


Source: A. K. Bapatla, **S. P. Mohanty**, and E. Kougianos, "PharmaChain 3.0: Efficient Tracking and Tracing of Drugs in Pharmaceutical Supply Chain using Blockchain Integrated Product Serialization Mechanism", *Springer Nature Computer Science (SN-CS)*, Vol. 5, No. 1, Jan 2024, Article: 149, 22-pages, DOI: <https://doi.org/10.1007/s42979-023-02510-9>.

PharmaChain 3.0 – The Key Idea

0x1EcbFd5Edb3747927033
Aa893416e4aD01DF0c6E

Lot Contract Address



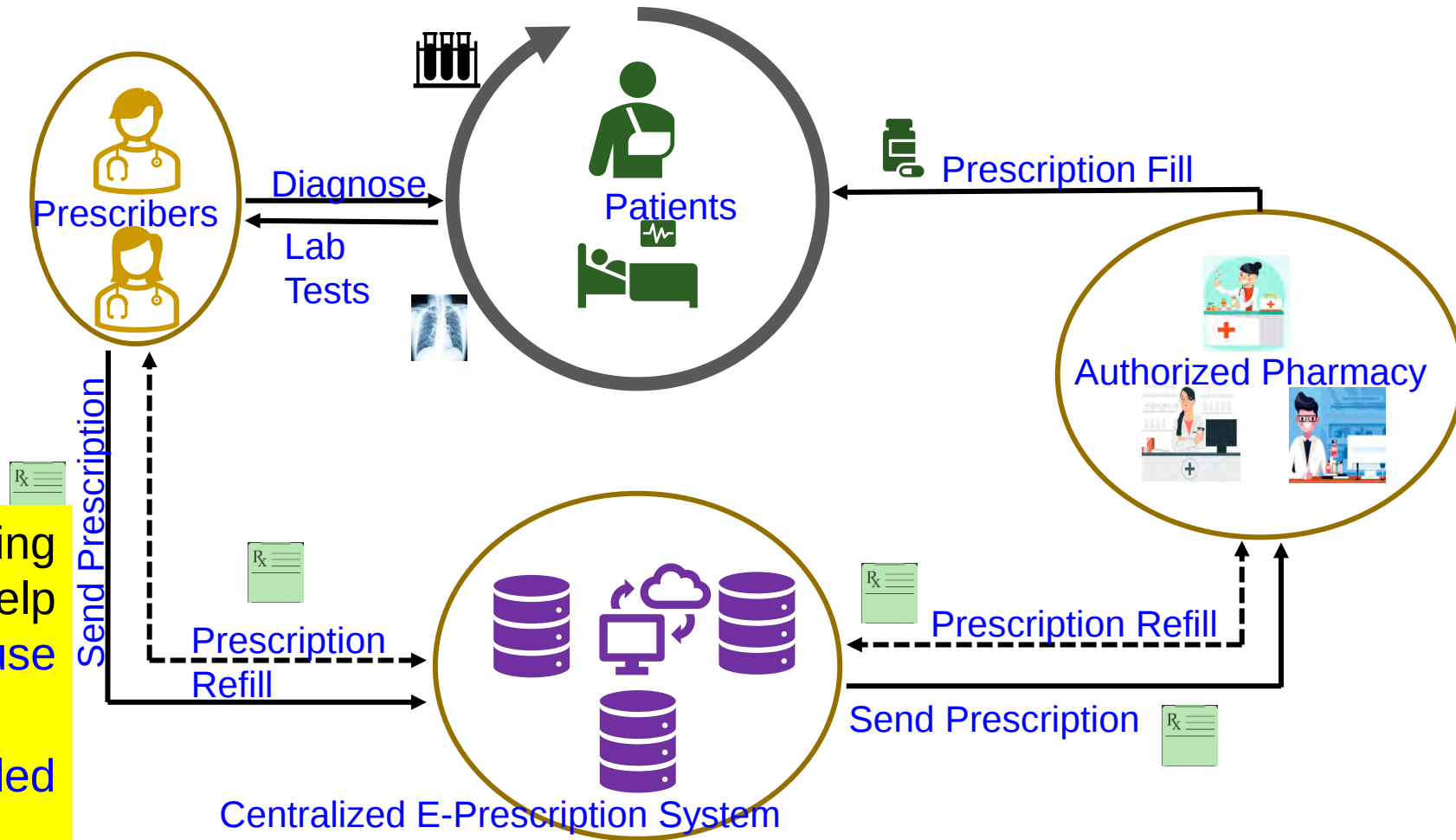
QR Code Generated for Lot Labelling

New Lot Contract Address Converted to QR Code for Labeling

Source: A. K. Bapatla, **S. P. Mohanty**, E. Kougianos, and D. Puthal, "PharmaChain 3.0: Blockchain Integrated Efficient QR Code Mechanism for Pharmaceutical Supply Chain", in *Proceedings of the OITS International Conference on Information Technology (OCIT)*, 2022, pp. Accepted.

E-Prescription System and Issues

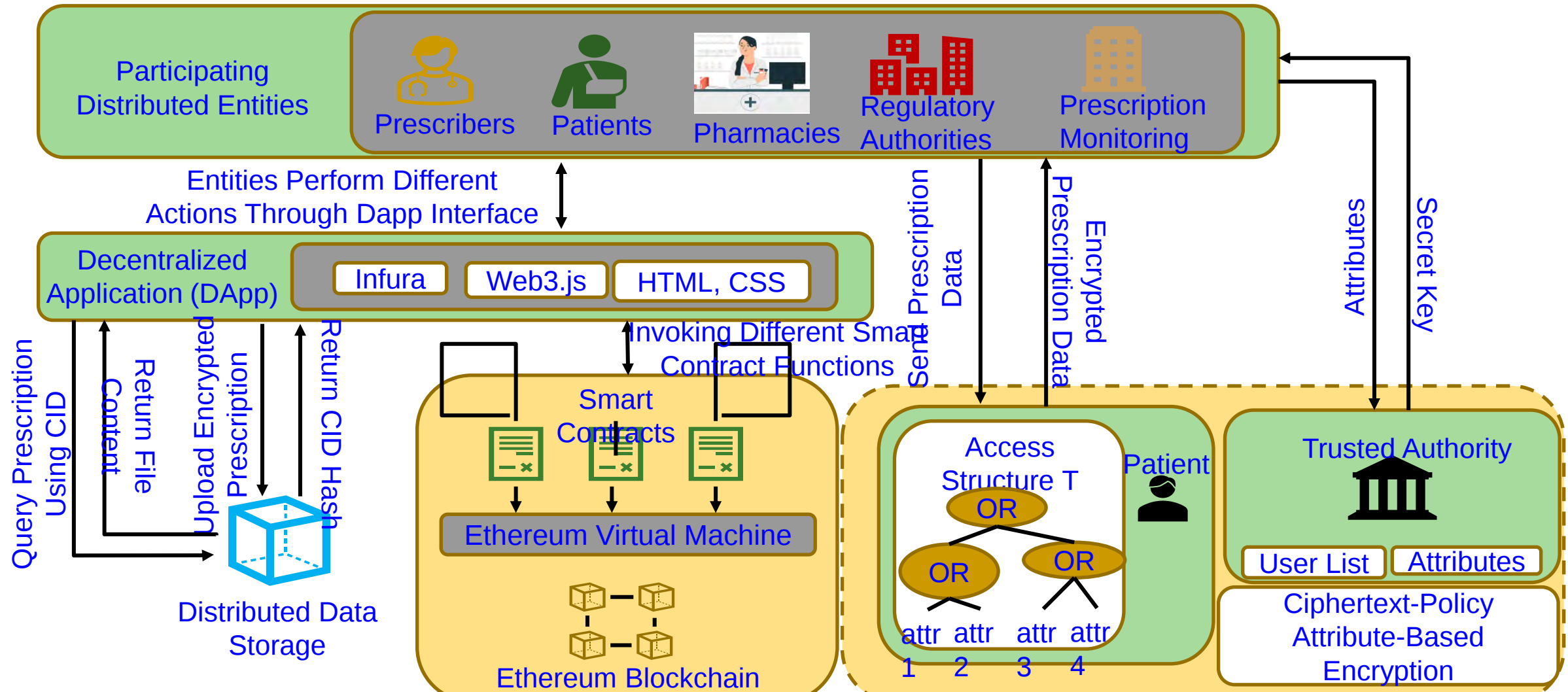
- Single Point of Failure (SPOF)
- Data Security
- Privacy Concerns
- Interoperability Concerns (PDMP)
- System availability Issues



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

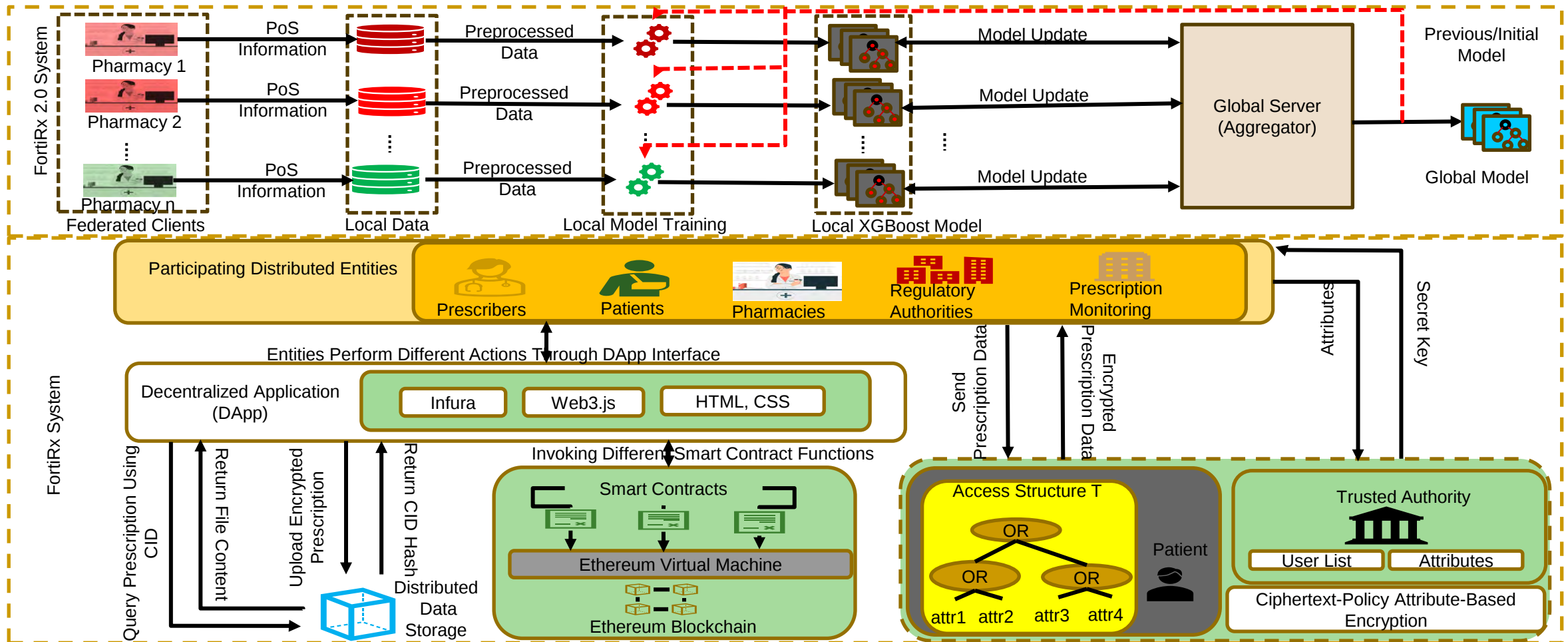
Source: A. K. Bapatla, **S. P. Mohanty**, and E. Kougianos, "FortiRx: Distributed Ledger Based Verifiable and Trustworthy Electronic Prescription Sharing", in *Proceedings of the IFIP International Internet of Things Conference (IFIP-IoT)*, 2023, pp. 283--301, DOI: https://doi.org/10.1007/978-3-031-45882-8_19.

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.

Our FortiRx 2.0: Architecture



Source: A. K. Bapatla, **S. P. Mohanty**, and E. Kougianos, "FortiRx 2.0: Smart Privacy-Preserved Demand Forecasting of Prescription Drugs in Healthcare-CPS", in *Proceedings of the OITS International Conference on Information Technology (OCIT)*, 2023, pp. 438--443, DOI: <https://doi.org/10.1109/OCIT59427.2023.10430944>.

FortiRx – A Comparative Perspective

Works	Blockchain Platform	Prescription Privacy	Data Management	Drug Demand Forecasting
Ionescu et al, SmartBlock4Health, 2022	Ethereum	Asymmetric Encryption	On-chain	×
VigilRx, 2022	Ethereum	Role-Based Access Control	On-Chain	×
FortiRx, 2023	Ethereum	Role-Based Access Control and CP-ABE	On-chain and off-chain	×
FortiRx 2.0	Ethereum	Role-Based Access Control and CP-ABE	On-chain and off-chain	✓

Source: A. K. Bapatla, **S. P. Mohanty**, and E. Kougianos, “[FortiRx 2.0: Smart Privacy-Preserved Demand Forecasting of Prescription Drugs in Healthcare-CPS](https://doi.org/10.1109/OCIT59427.2023.10430944)”, in *Proceedings of the OITS International Conference on Information Technology (OCIT)*, 2023, pp. 438--443, DOI: <https://doi.org/10.1109/OCIT59427.2023.10430944>.

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 has advantages but also has limitations in terms of cybersecurity; thus challenging to build sustainable healthcare.
- Cybersecurity in smart healthcare is a serious challenge as device as well as data security and privacy are important.
- Medical device security is a difficult problem due to resource and battery constraints; thus challenge for sustainable H-CPS.
- 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 research due to energy and computational overheads associated with it.
- SbD research for IoMT/H-CPS is needed.
- Trustworthy Pharmaceutical Supply Chain needs research.