IoT Empowered Solutions for Smart Villages: Collaborative Edge Computing, Lightweight Blockchain, and Edge-AI Fit the Need

IEEE-iSES 2021 Panel Session

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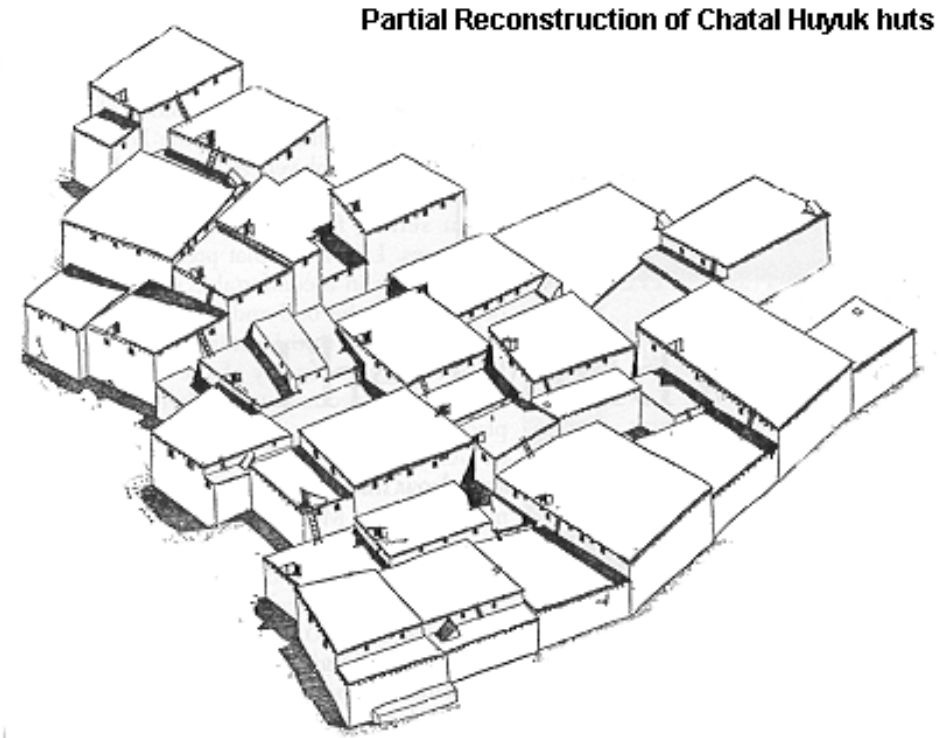
Cities and Villages - History



Based on a reconstruction by Orrin C. Shane III
Source: http://www1.biologie.uni-hamburg.de/b-online/library/darwin/prerm5.htm

"First true cities arose in Mesopotamia, and in the Indus and Nile valleys sometime around 3500 BCE."
-- LeGates and Stout 2016, The City Reader

After 10.000 BC humans settled down in villages. One of the best preserved is the Neolithic village at Chatal Huyuk in Anatolia (now modern Turkey). The partial reconstruction of the village gives an idea of buildings.

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 (MCE)*, 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. XX, No. YY, ZZ 2021, DOI: 10.1109/MCE.2020.3023293.

Smart Cities Vs Smart Villages

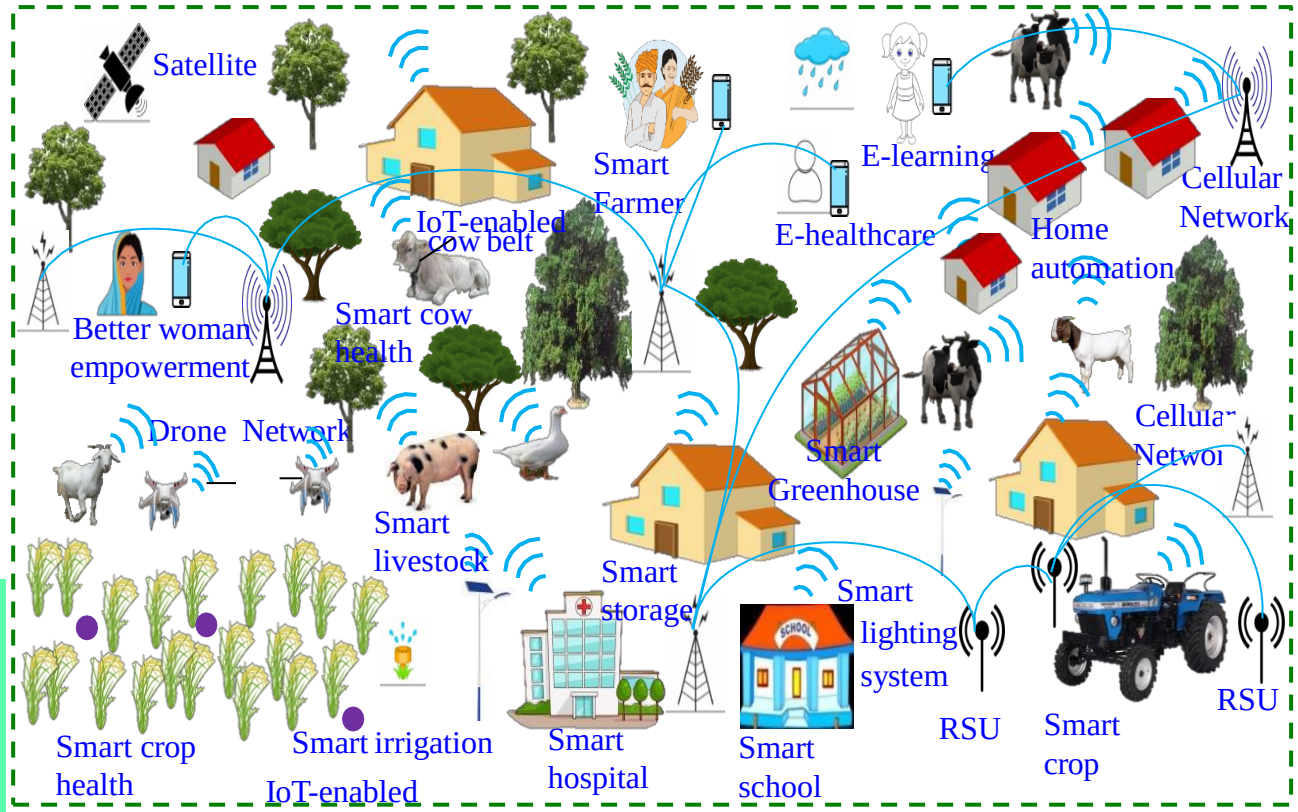
Source: http://edwingarcia.info/2014/04/26/principal/

Smart Cities

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

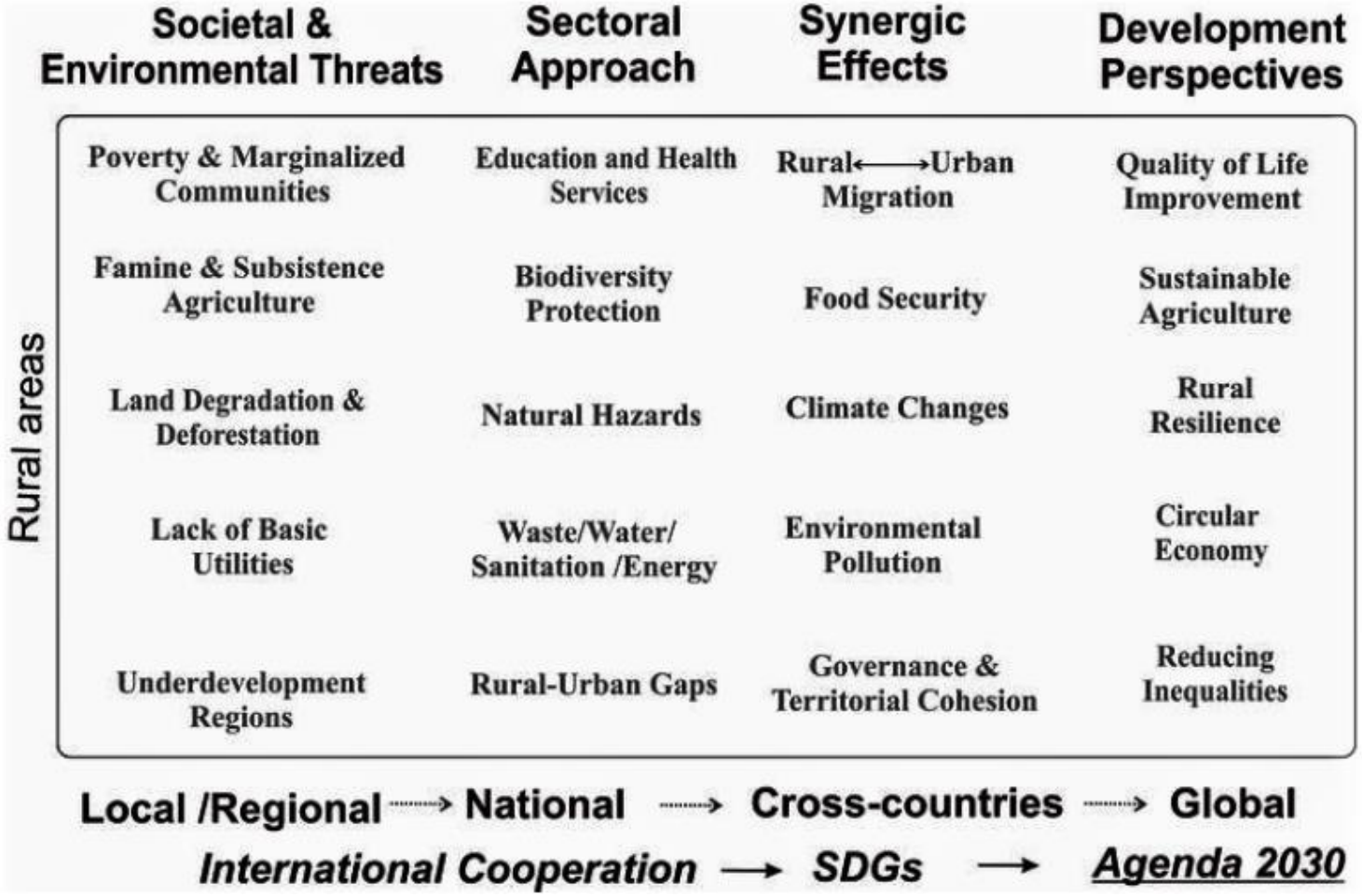
Smart Villages

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



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.

Population Urban Migration is not a Problem for Smart Villages – Why to Bother?

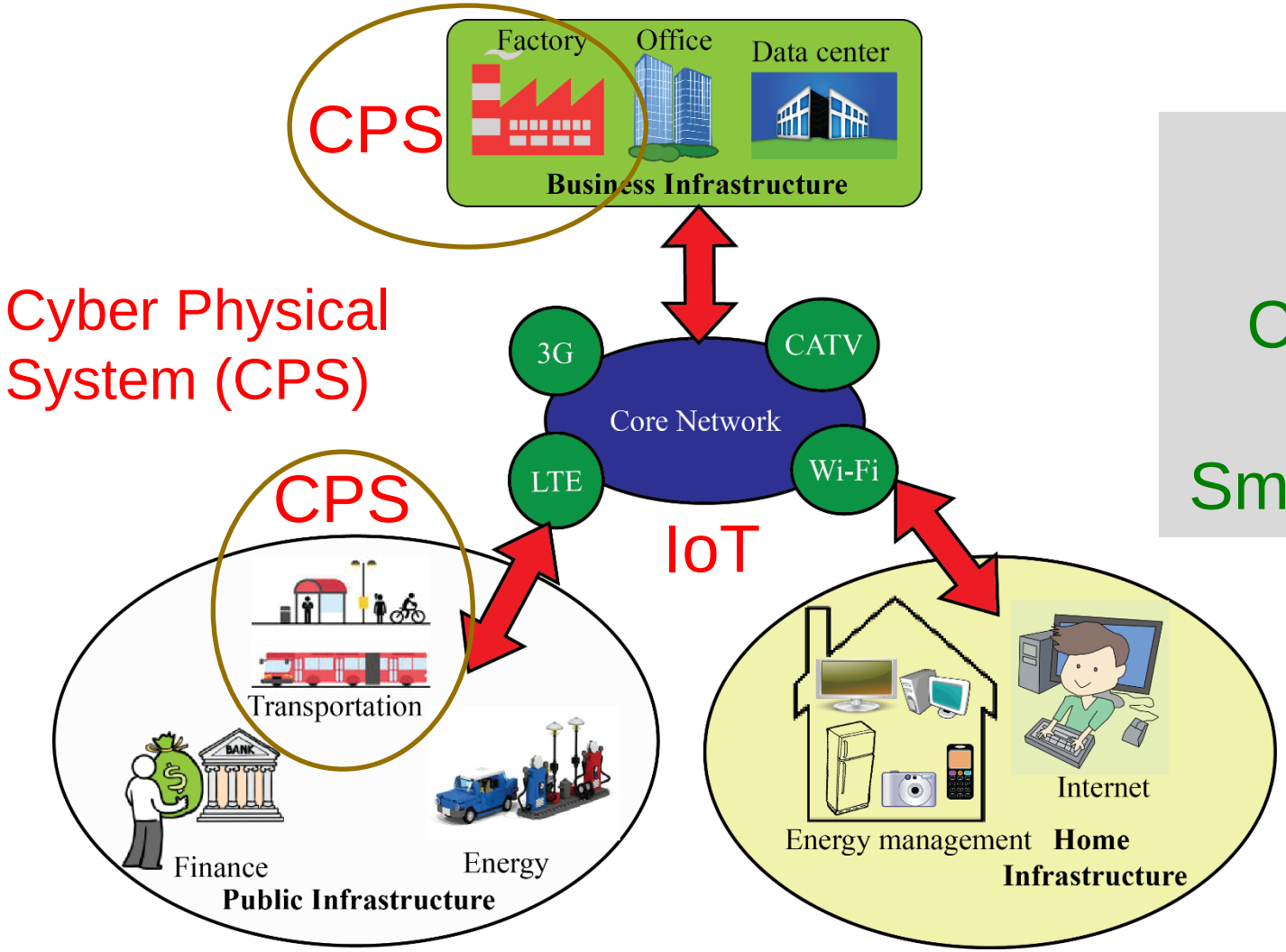


- Efficient usage of limited resources
- Sustainability at low-cost
- Reverse urban migration of population

Source: M. Adamowicz and M. Zwolińska-Ligaj, "The “Smart Village” as a Way to Achieve Sustainable Development in Rural Areas of Poland", Sustainability, Vol. 12, No. 16, 2020, DOI: 10.3390/su12166503.

Smart Villages – Global Impact

IoT → CPS → Smart Cities or Smart Villages



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

IoT is the backbone

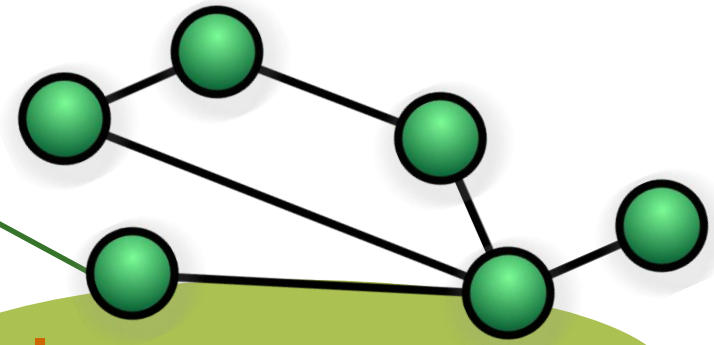
Source: S. P. Mohanty, U. Choppali, and E. Kougianos, "Everything You wanted to Know about Smart Cities", *IEEE Consumer Electronics Magazine*, Vol. 5, No. 3, July 2016, pp. 60--70.

Smart Cities or Smart Villages - 3 Is

Instrumentation

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

Smart Cities



Intelligence

Interconnection

Source: Mohanty IEEE Smart Cities Conference 2019 Keynote Address (Security and Energy Trade-Offs in Smart City Cyber-Physical Systems)

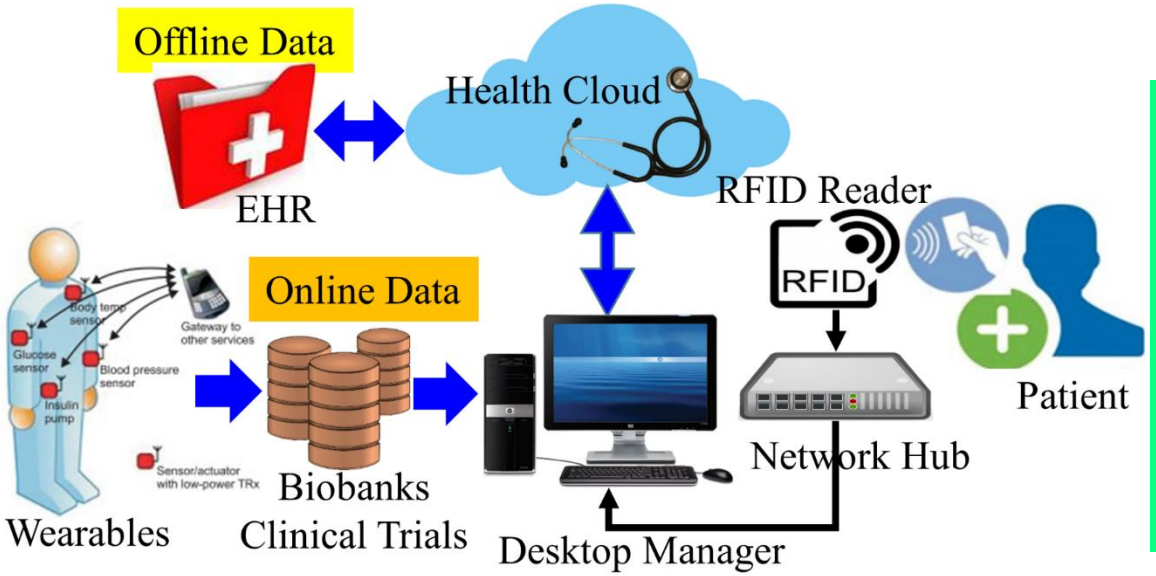
Frost and Sullivan predicts smart city development worldwide will create business opportunities worth US$2.46 trillion by 2025.

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.

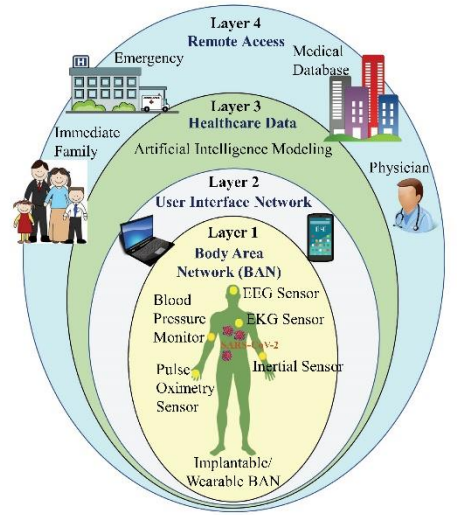
Healthcare Cyber-Physical System (H-CPS)



Internet-of-Medical-Things (IoMT)

OR

Internet-of-Health-Things (IoHT)



Healthcare Cyber-Physical System (H-CPS)

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

Requires:

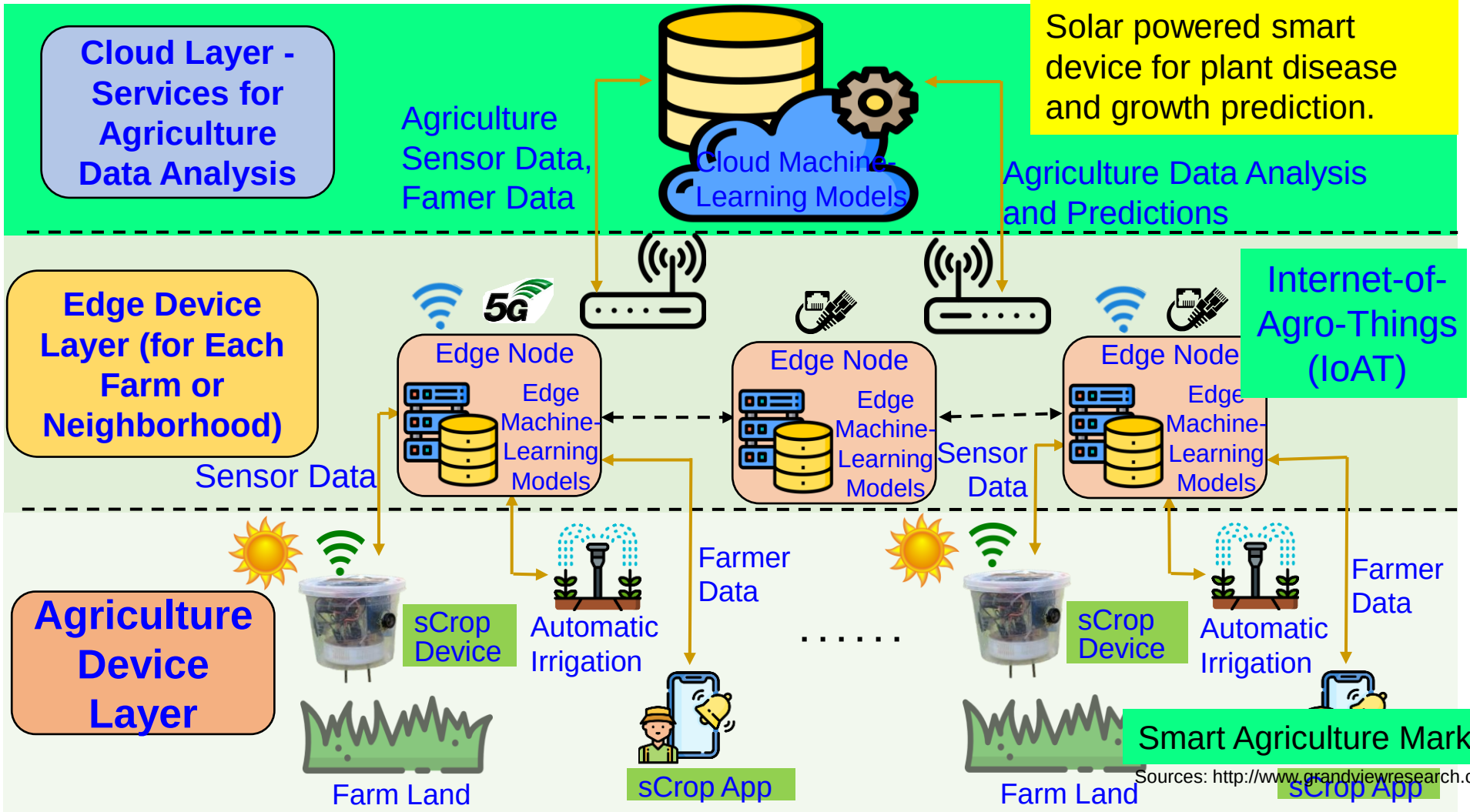
- Data and Device Security
- Data Privacy

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

IEEE CTSoc CONSUMER TECHNOLOGY SOCIETY
http://ctsoc.ieee.org

IEEE

Agriculture Cyber-Physical System (A-CPS)



Smart Agriculture Market Worth $18.21 Billion By 2025.

Sources: http://www.grandviewresearch.com/press-release/global-smart-agriculture-farming-market

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. XX, No. YY, ZZ 2020, pp. Accepted on 14 Oct 2020, DOI: 10.1109/JSEN.2020.3032438.

IoT/CPS Design – Multiple Objectives

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

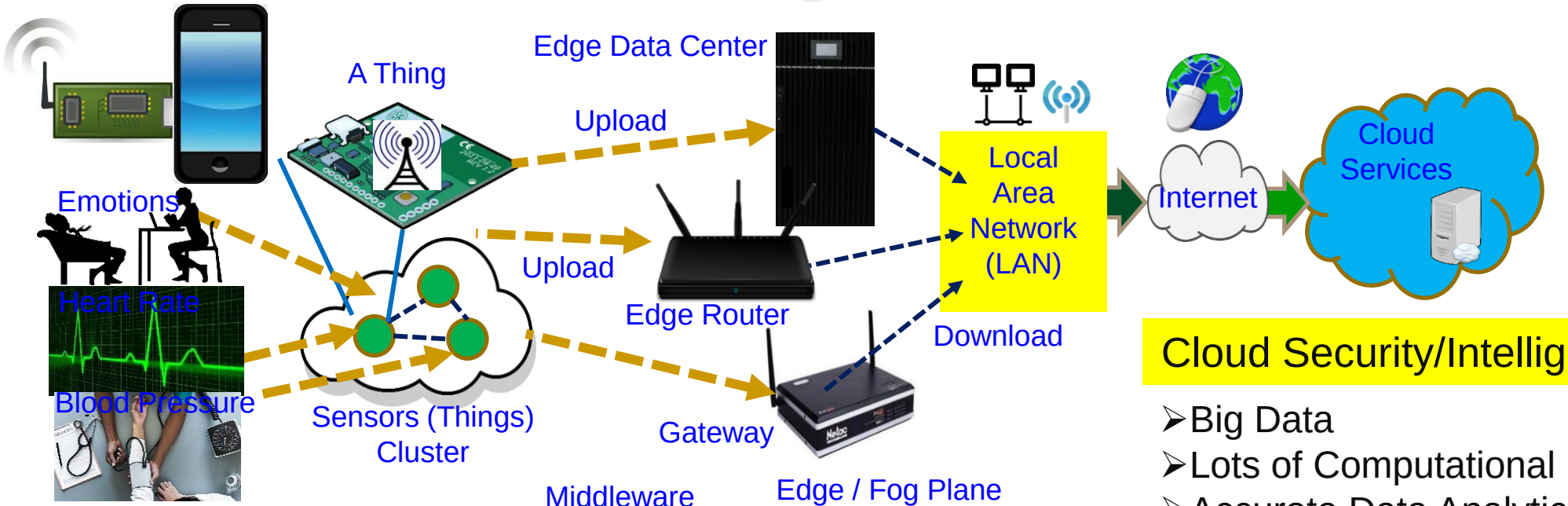
Security by Design (SbD) and/or Privacy by Design (PbD)

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/

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

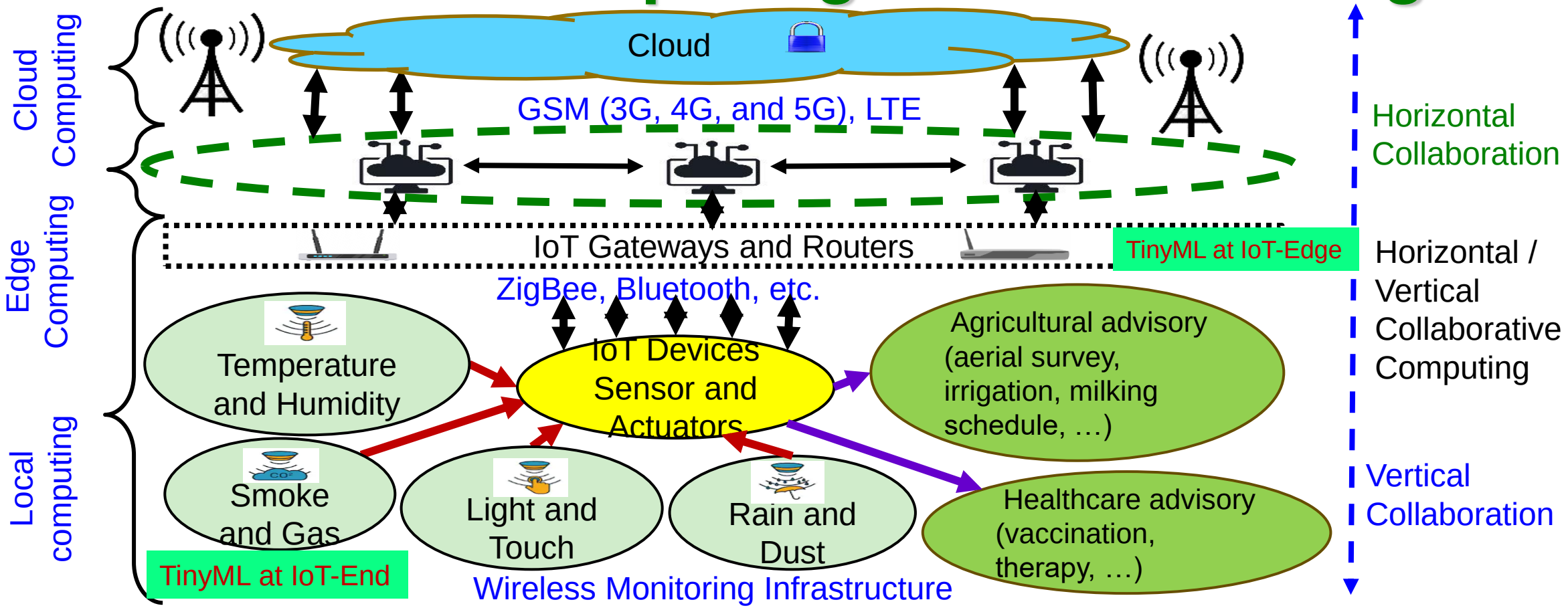
Cloud Security/Intelligence

- 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.

Collaborative Edge Computing is Cost Effective Sustainable Computing for Smart Villages

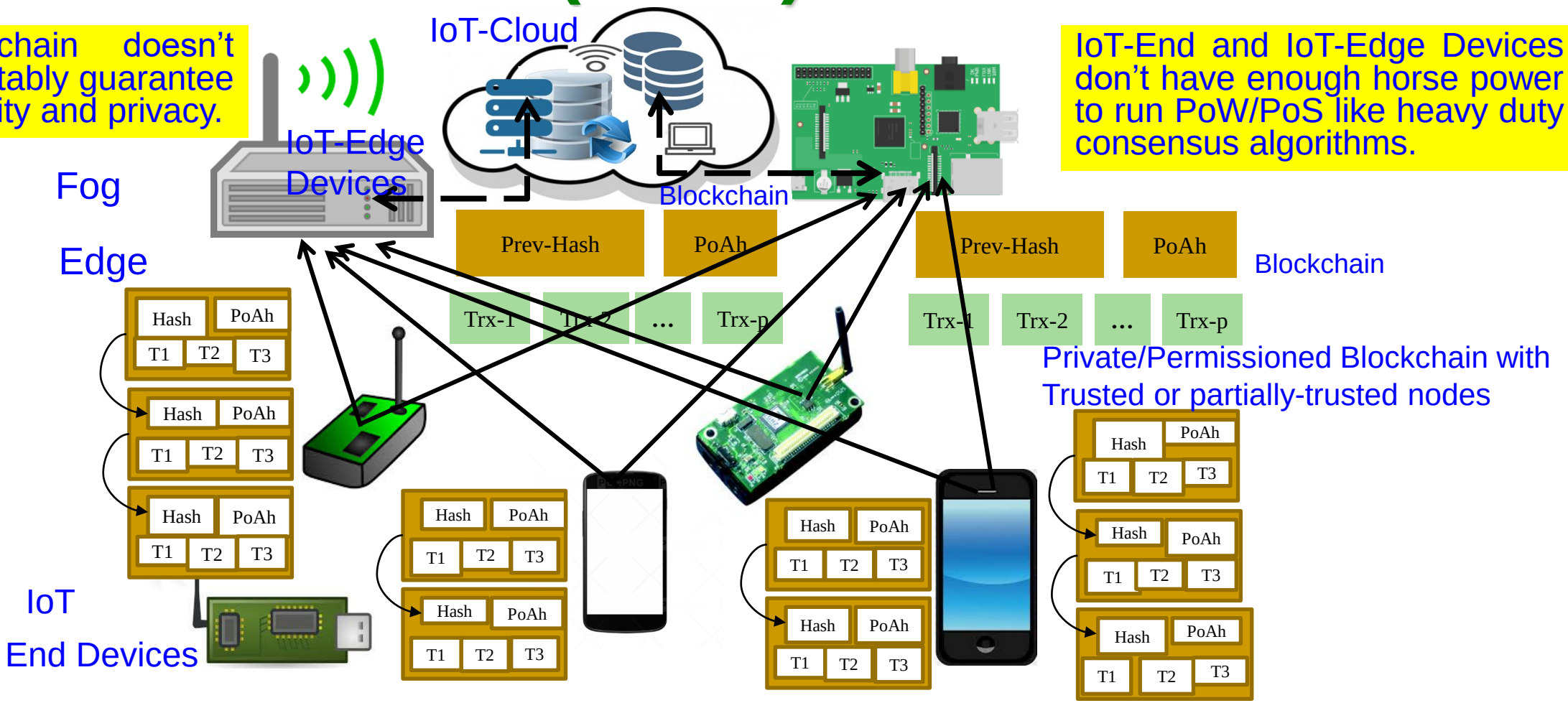


Source: D. Puthal, S. P. Mohanty, S. Wilson and U. Choppali, "Collaborative Edge Computing for Smart Villages", *IEEE Consumer Electronics Magazine (MCE)*, Vol. 10, No. 03, May 2021, pp. 68-71.

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

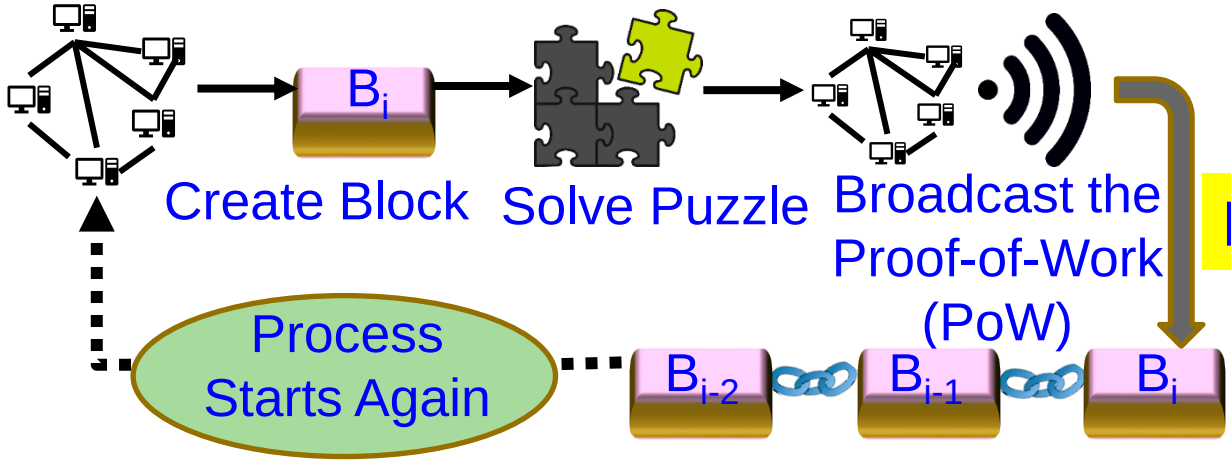
Blockchain doesn't inheritably guarantee security and privacy.

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



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.

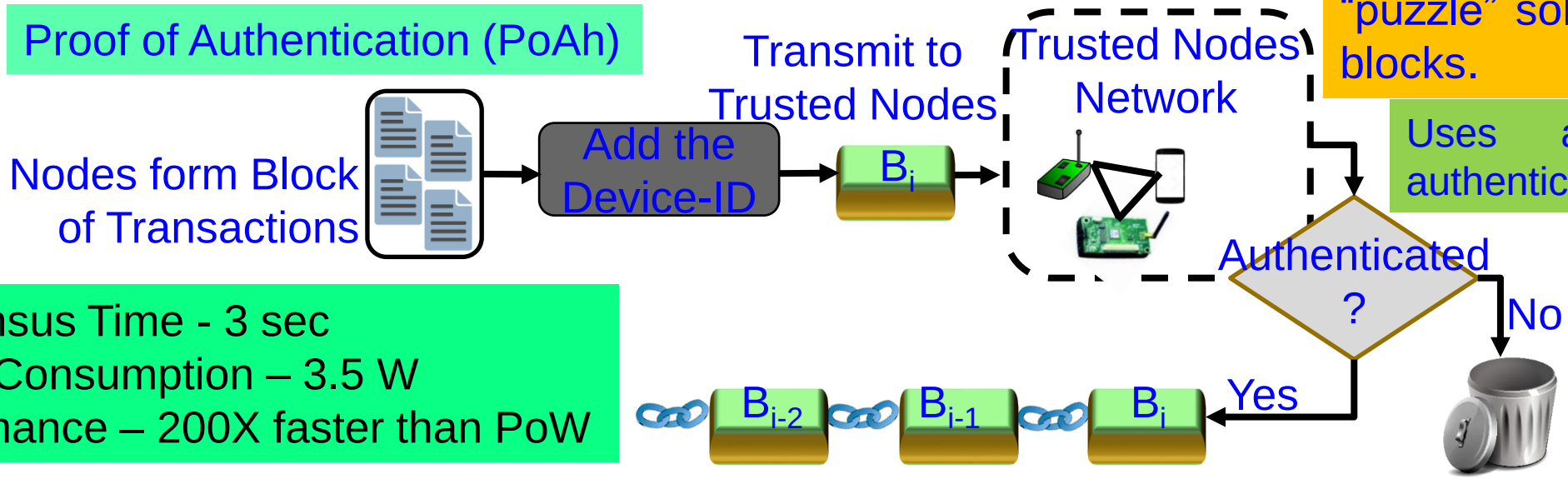
Our Proof-of-Authentication (PoAh)



Proof-of-Work (PoW)

Eliminates cryptographic "puzzle" solving to validate blocks.

Proof of Authentication (PoAh)



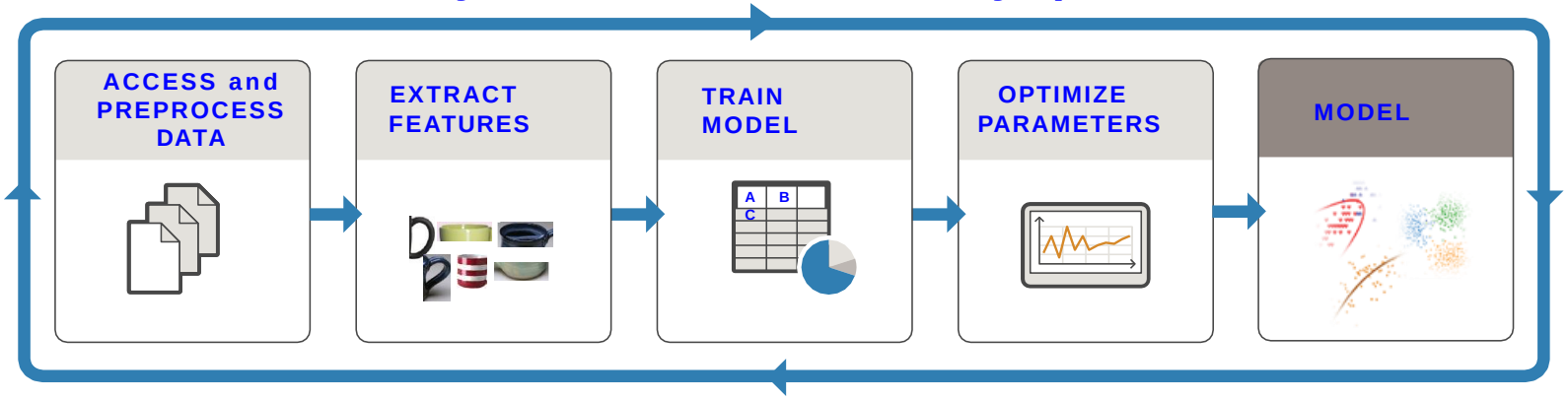
Uses a cryptographic authentication mechanism.

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

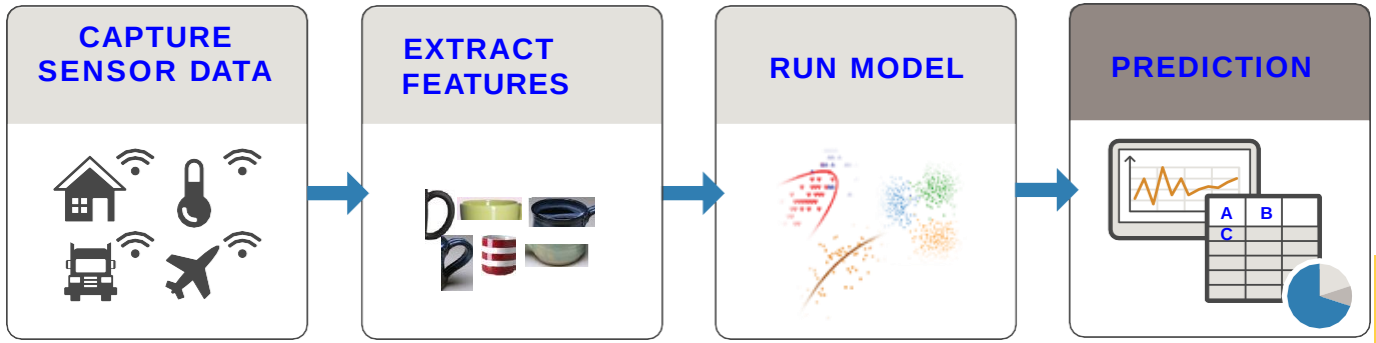
Source: D. Puthal and S. P. Mohanty, "Proof of Authentication: IoT-Friendly Blockchains", *IEEE Potentials Magazine*, Vol. 38, No. 1, January 2019, pp. 26--29.

TinyML - Key for 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?

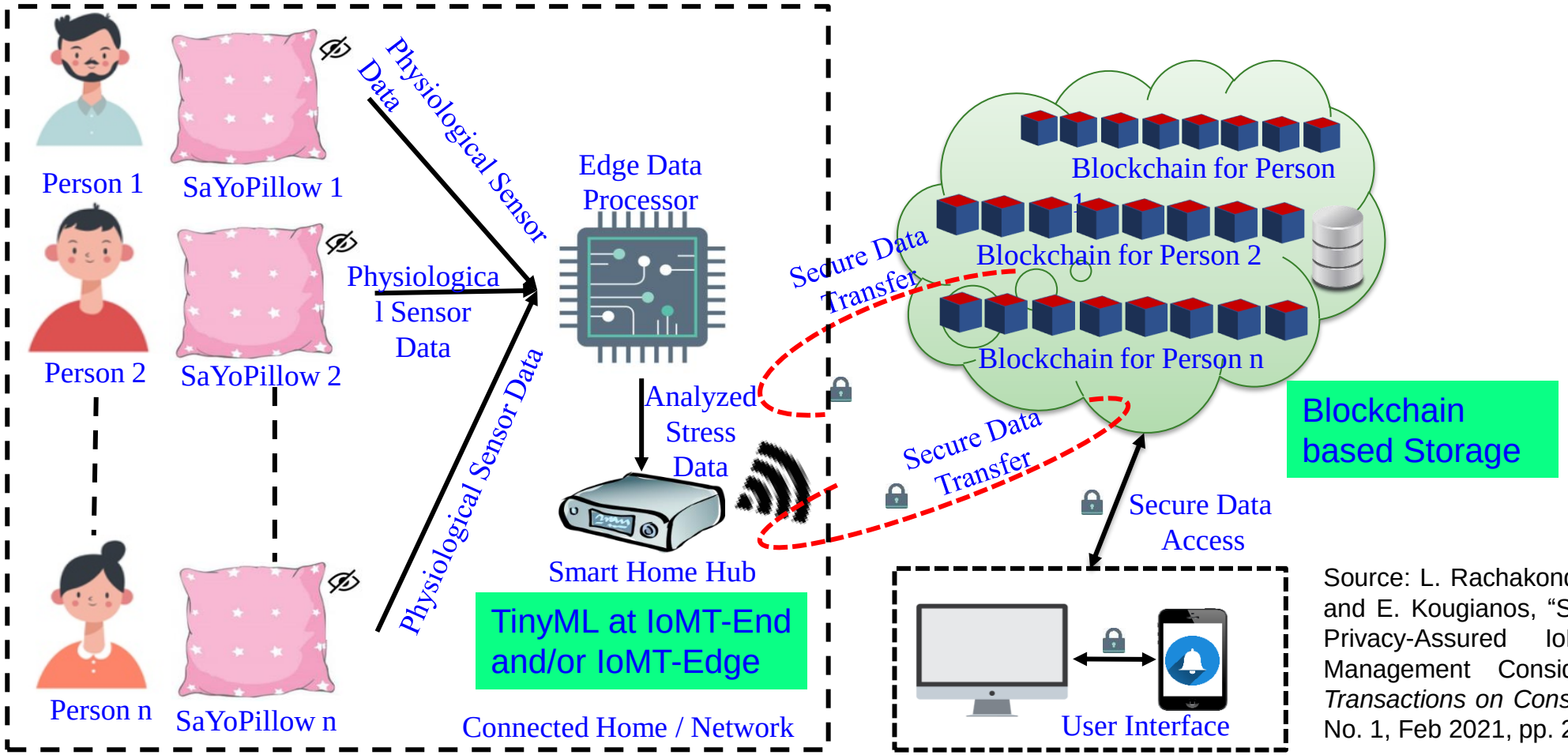
Source: www-cnx--software-com.cdn.ampproject.org.html

Needs:

- Computational Resource
- Computation Energy

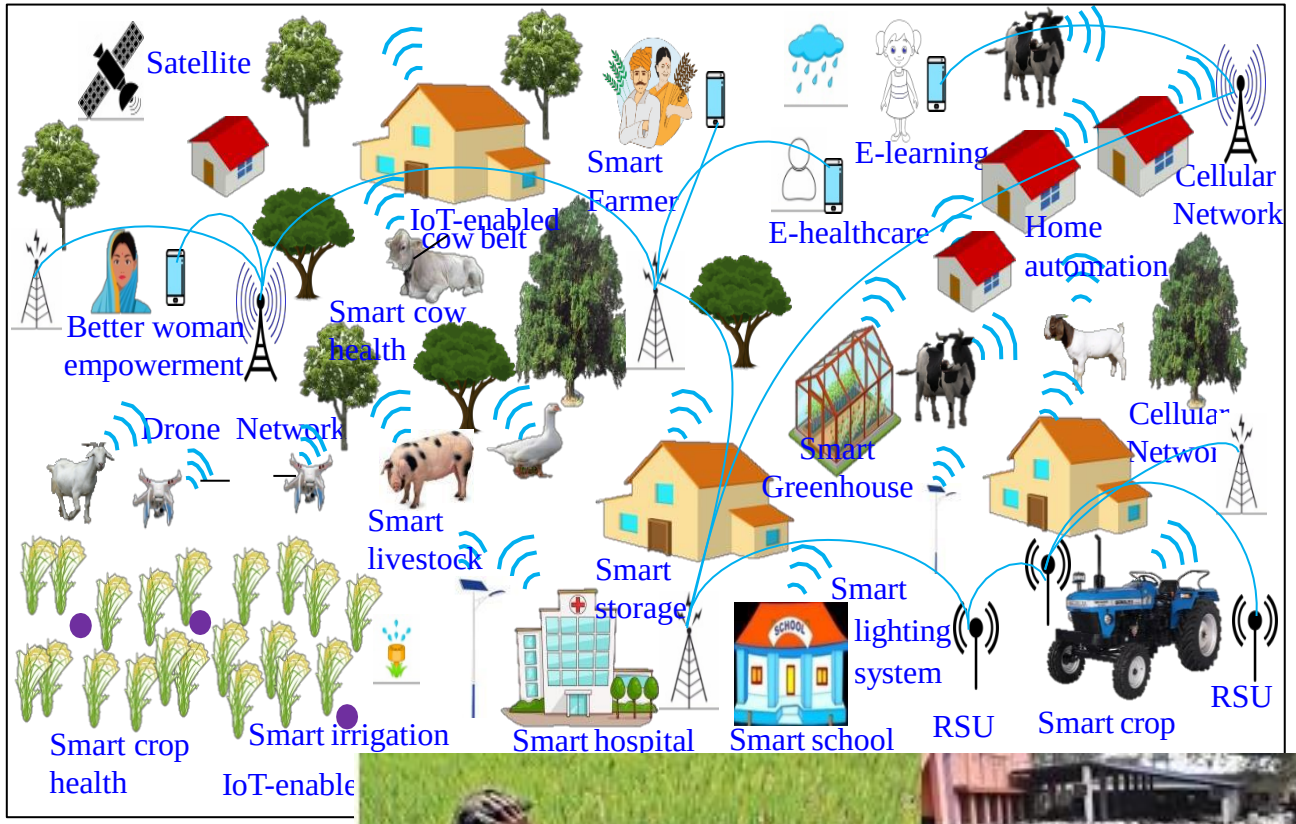
Solution: TinyML

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.

Villages – May not have Electricity, Connectivity…



- How to be connected?
- How to run AI?

Source; P. Chanak and I. Banerjee, "Internet of Things-enabled Smart Villages: Recent Advances and Challenges," *IEEE Consumer Electronics Magazine*, vol. 10, no. 3, pp. 12-18, May 2021.

Can Any Smartness/Intelligence/IoT Solve?

Source: https://www.wilsoncenter.org/article/building-slum-free-mumbai