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# Cyber-Physical Systems (CPS)

## IEEE Bombay Section and OPJU Panel

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# Talk - Outline

- The Big Picture
- The Driving Technologies
- The Challenges
- Some Solutions
- Conclusions and Future Directions

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# The Big Picture

# Smart Cities is a Solution for Urban Migration

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



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 - 3 Is

Instrumentation

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

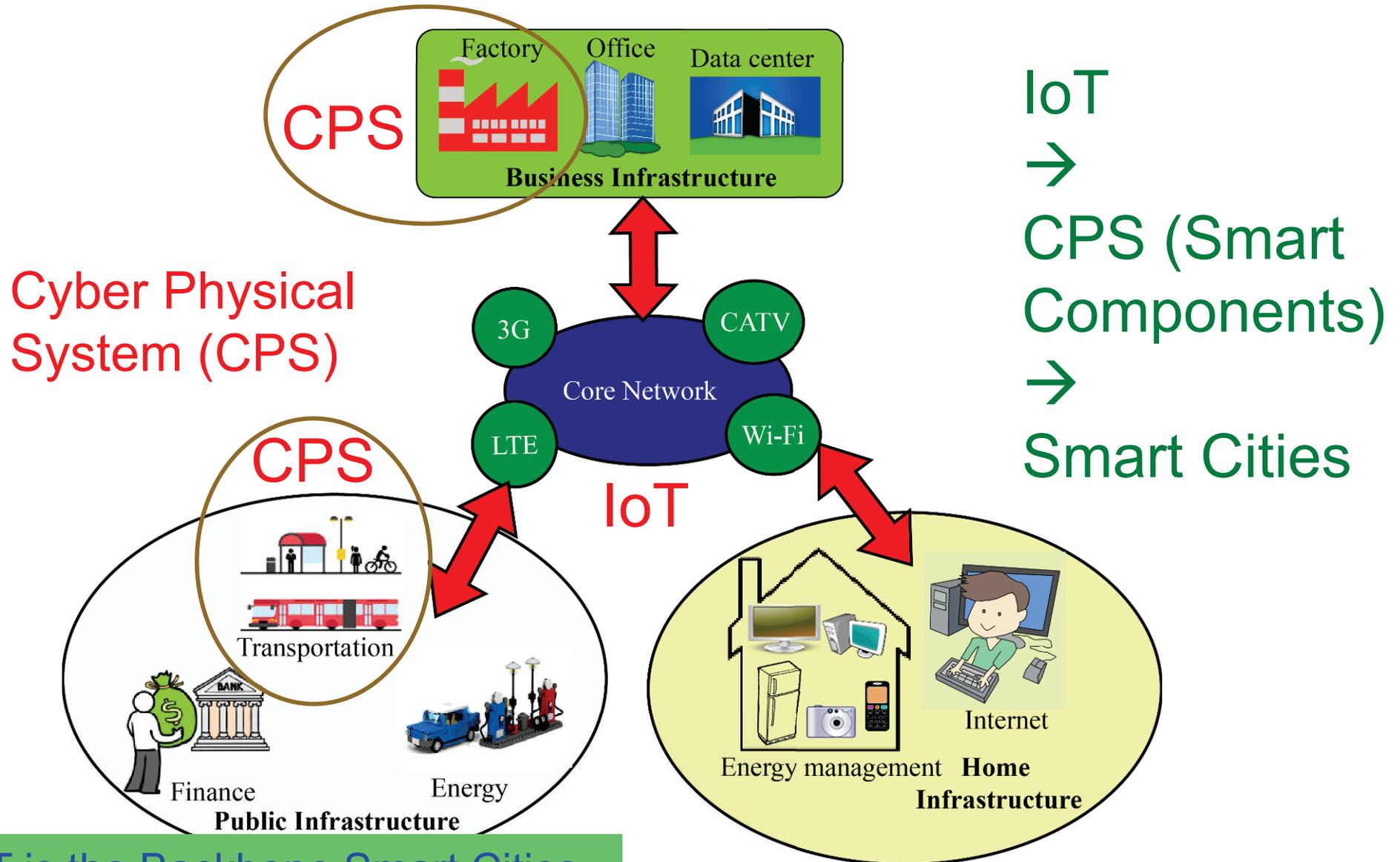
Smart Cities

Intelligence

Interconnection

Source: Mohanty ISC2 2019 Keynote

# IoT → CPS → Smart Cities

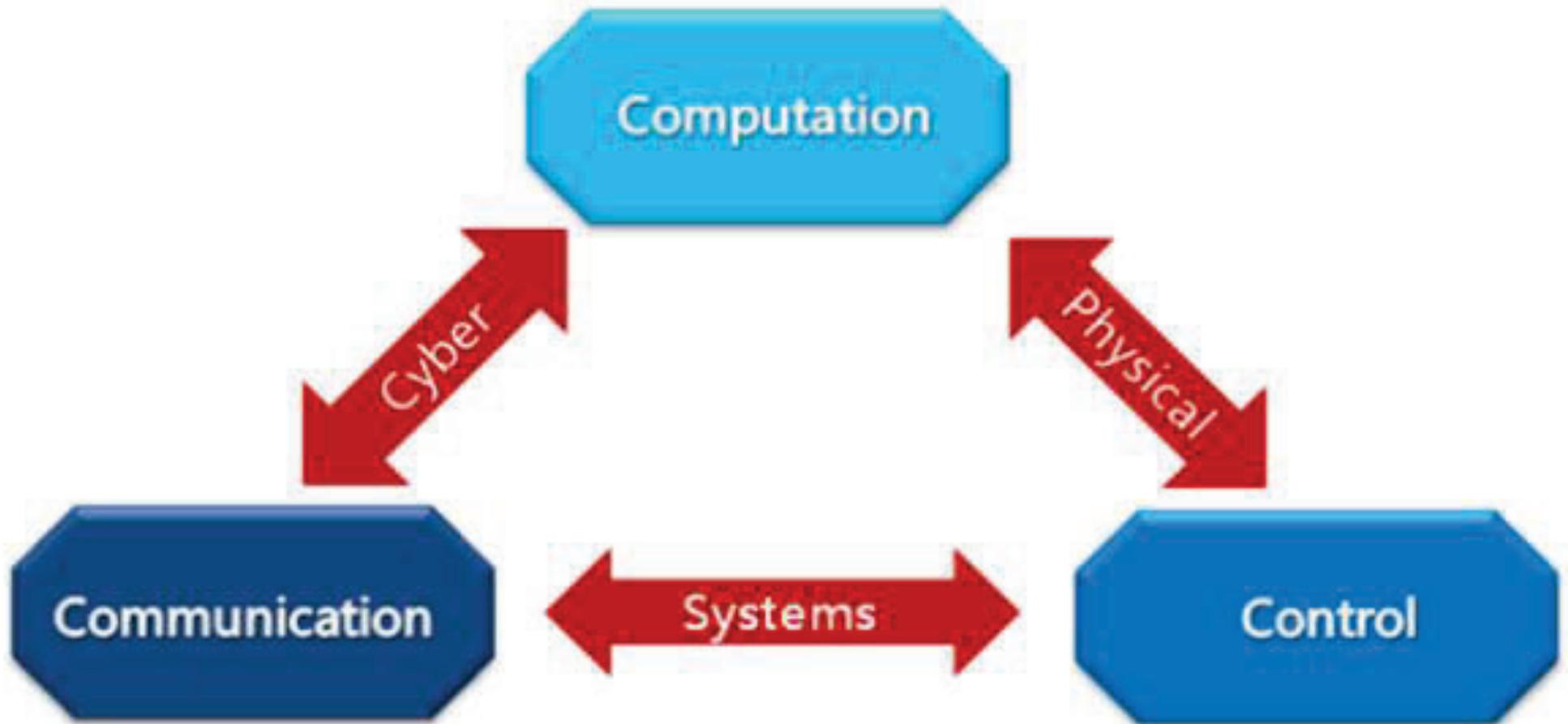


IoT is the Backbone Smart Cities.

Source: Mohanty CE Magazine July 2016



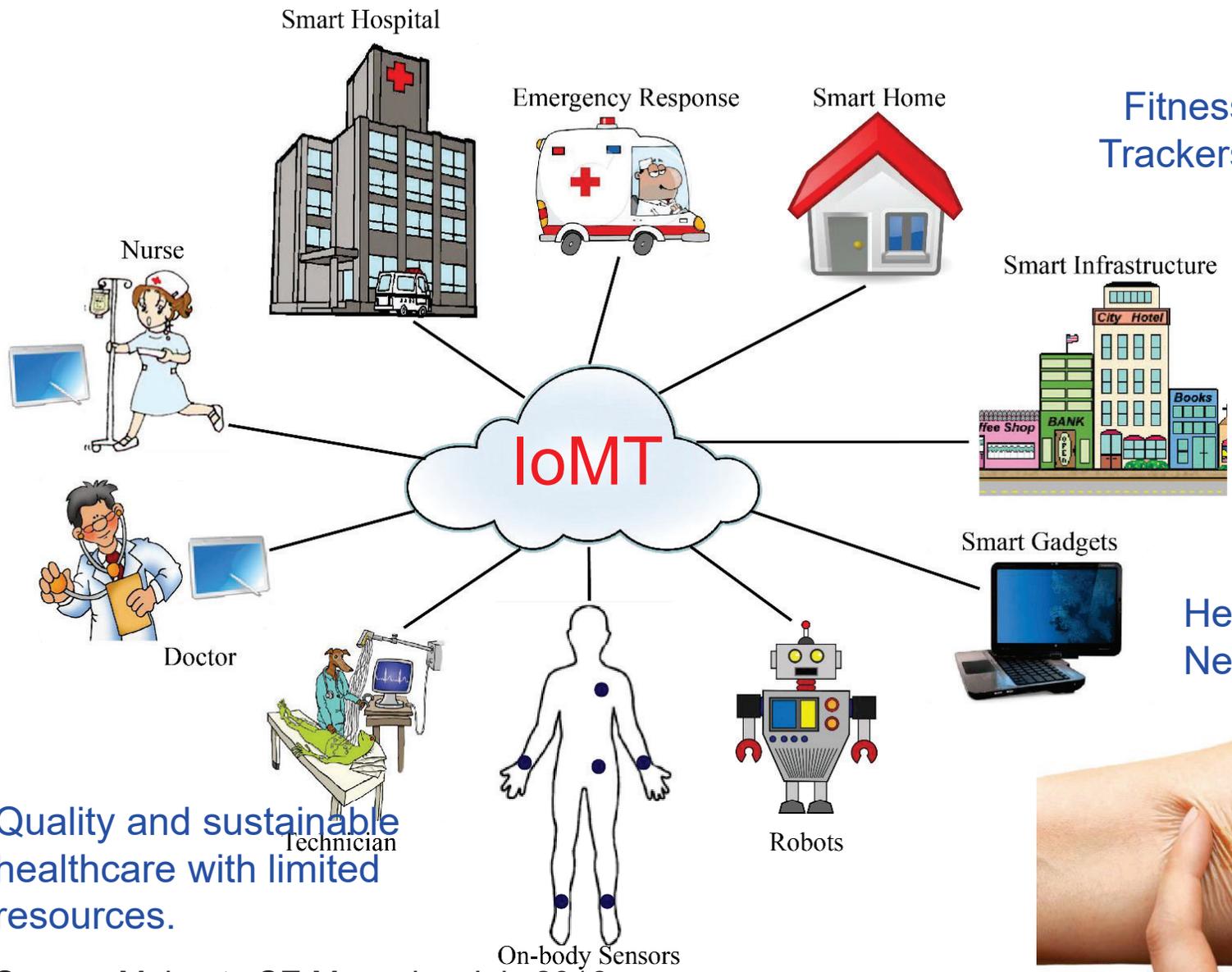
# Cyber-Physical Systems (CPS) - 3 Cs



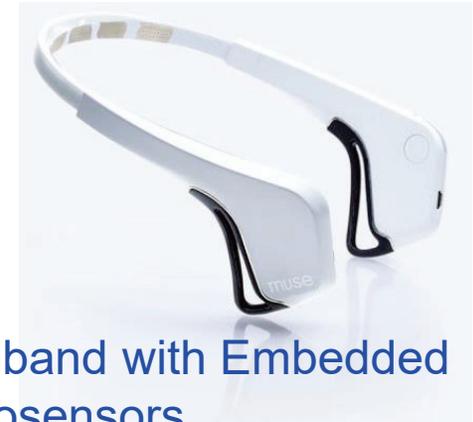
3 Cs of IoT - Connect, Compute, Communicate

Source: G. Jinghong, H. Ziwei, Z. Yan, Z. Tao, L. Yajie and Z. Fuxing, "An overview on cyber-physical systems of energy interconnection," in *Proc. IEEE International Conference on Smart Grid and Smart Cities (ICSGSC)*, 2017, pp. 15-21.

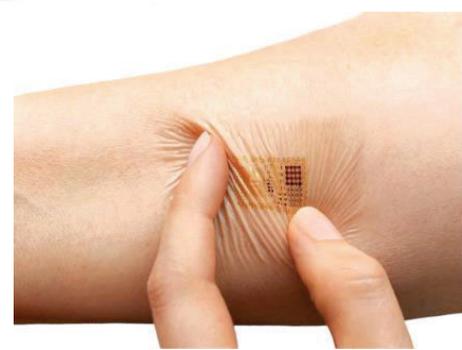
# Healthcare Cyber-Physical System (H-CPS)



Fitness Trackers



Headband with Embedded Neurosensors

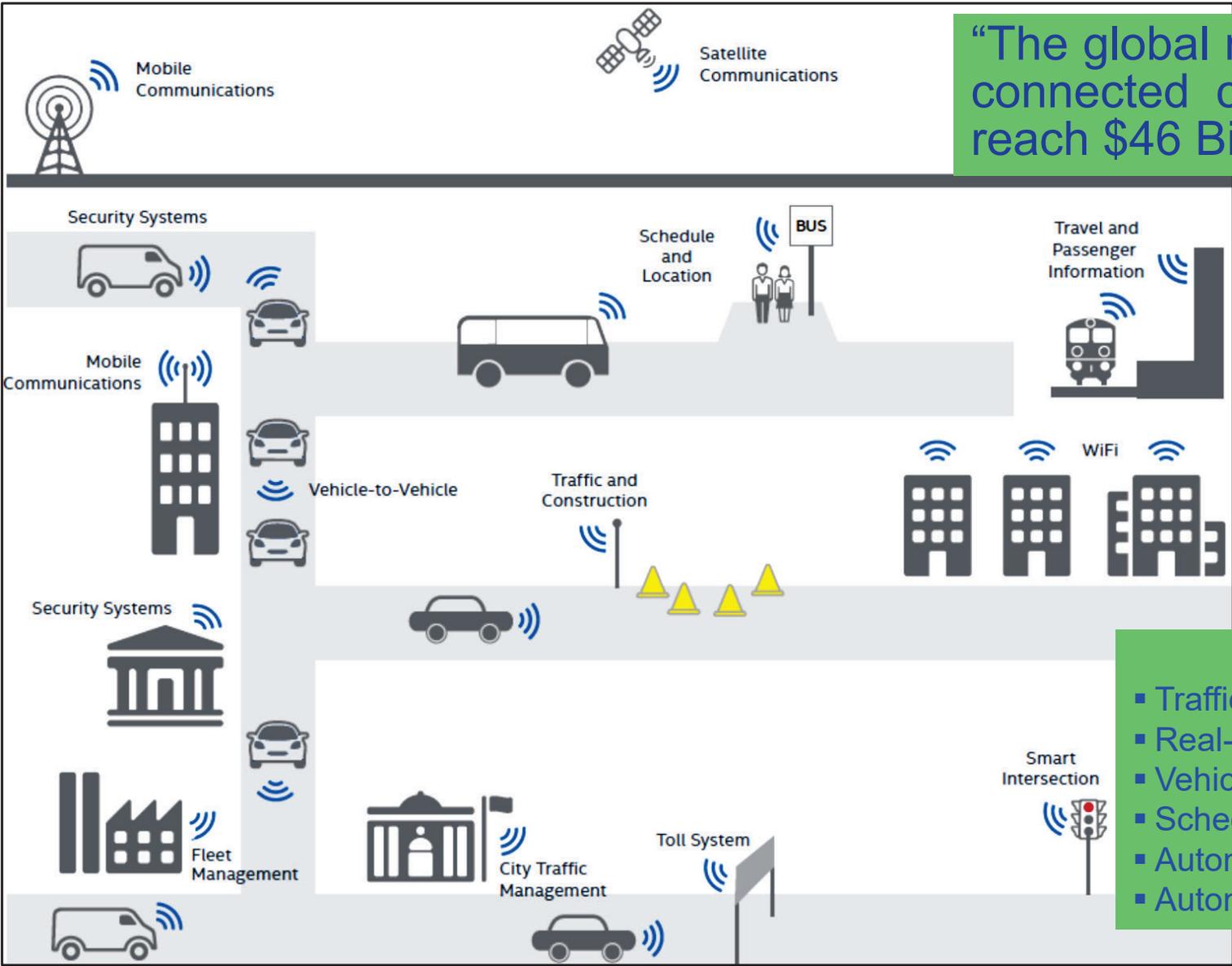


Embedded Skin Patches

Quality and sustainable healthcare with limited resources.

Source: Mohanty CE Magazine July 2016

# Transportation Cyber-Physical System (T-CPS)



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

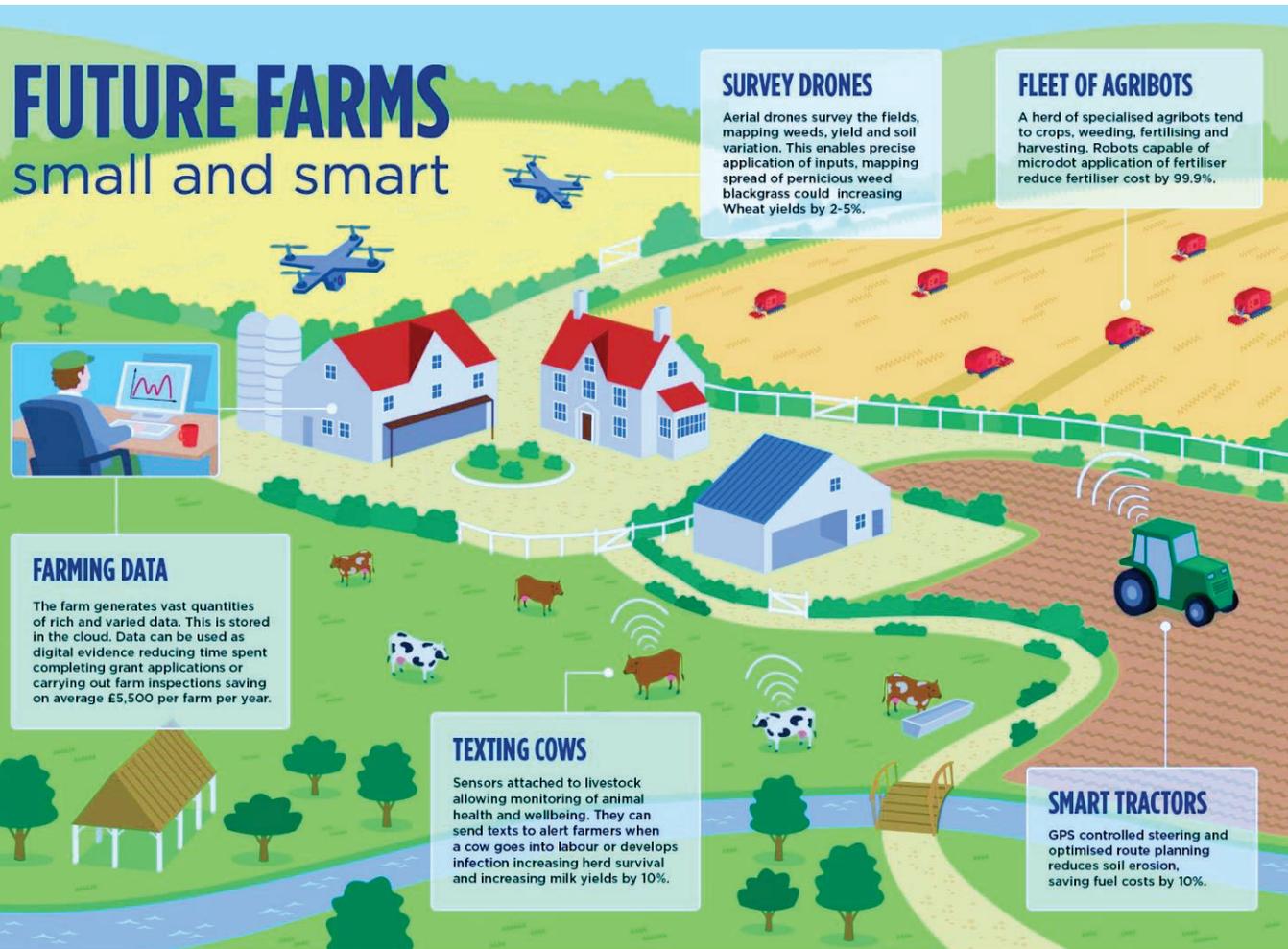
Source: Datta 2017, CE Magazine Oct 2017

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

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

# Agriculture Cyber-Physical System (A-CPS)

## FUTURE FARMS small and smart



## Climate-Smart Agriculture Objectives:

- Increasing agricultural productivity
- Resilience to climate change
- Reducing greenhouse gas

<http://www.fao.org>

## Automatic Irrigation System



Source: Maurya 2017, CE Magazine July 2017

Source: <http://www.nesta.org.uk/blog/precision-agriculture-almost-20-increase-income-possible-smart-farming>

**Smart Agriculture/Farming Market Worth \$18.21 Billion By 2025**

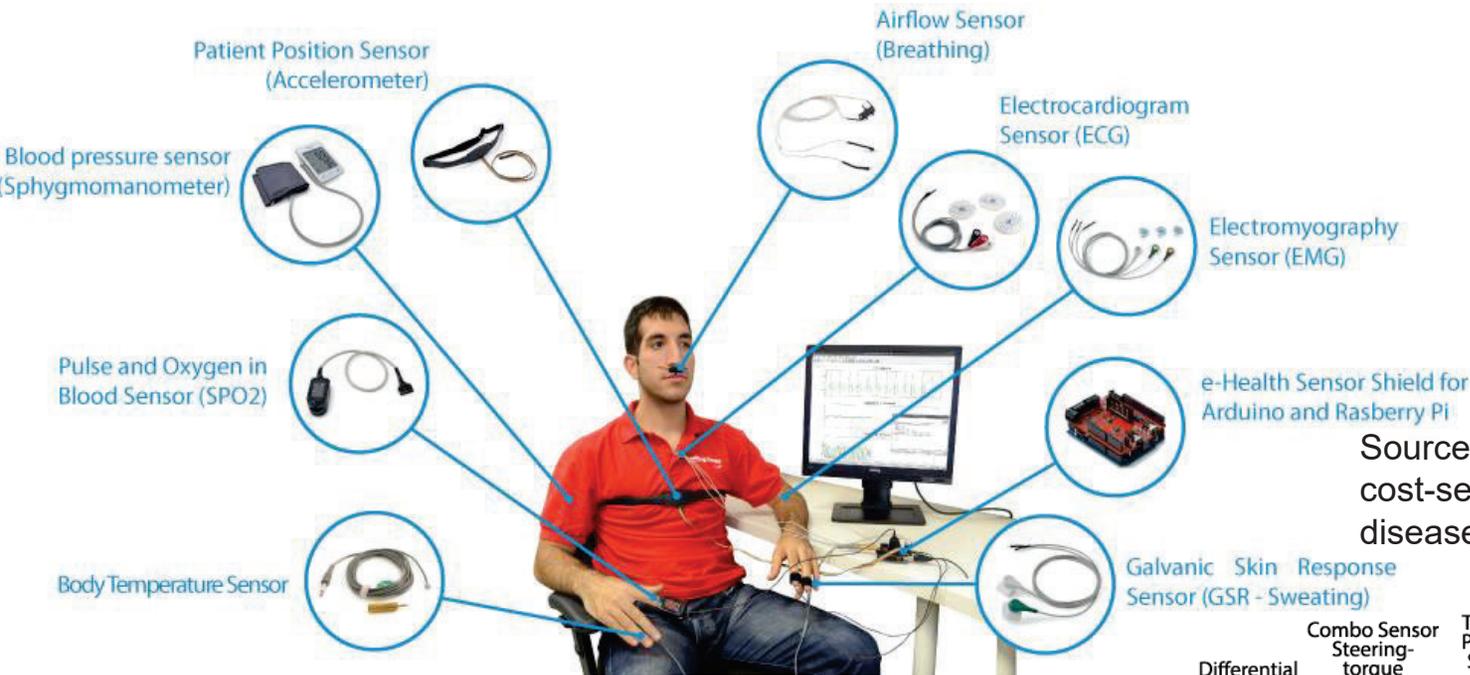
Sources: <http://www.grandviewresearch.com/press-release/global-smart-agriculture-farming-market>

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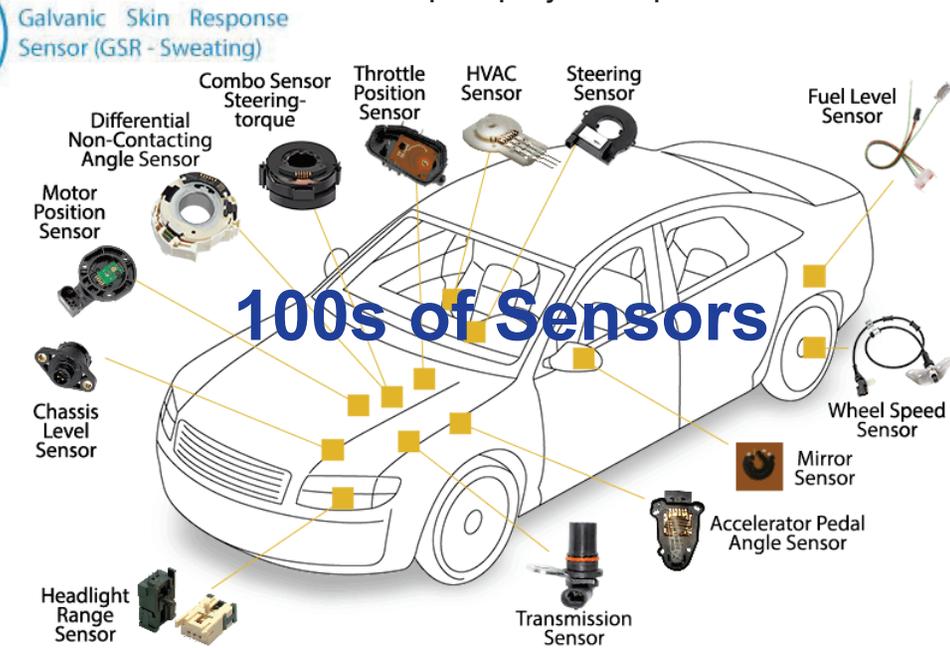
# Driving Technologies



# Sensor Technology – Variety of Them



Source: <http://www.libelium.com/e-health-low-cost-sensors-for-early-detection-of-childhood-disease-inspire-project-hope/>



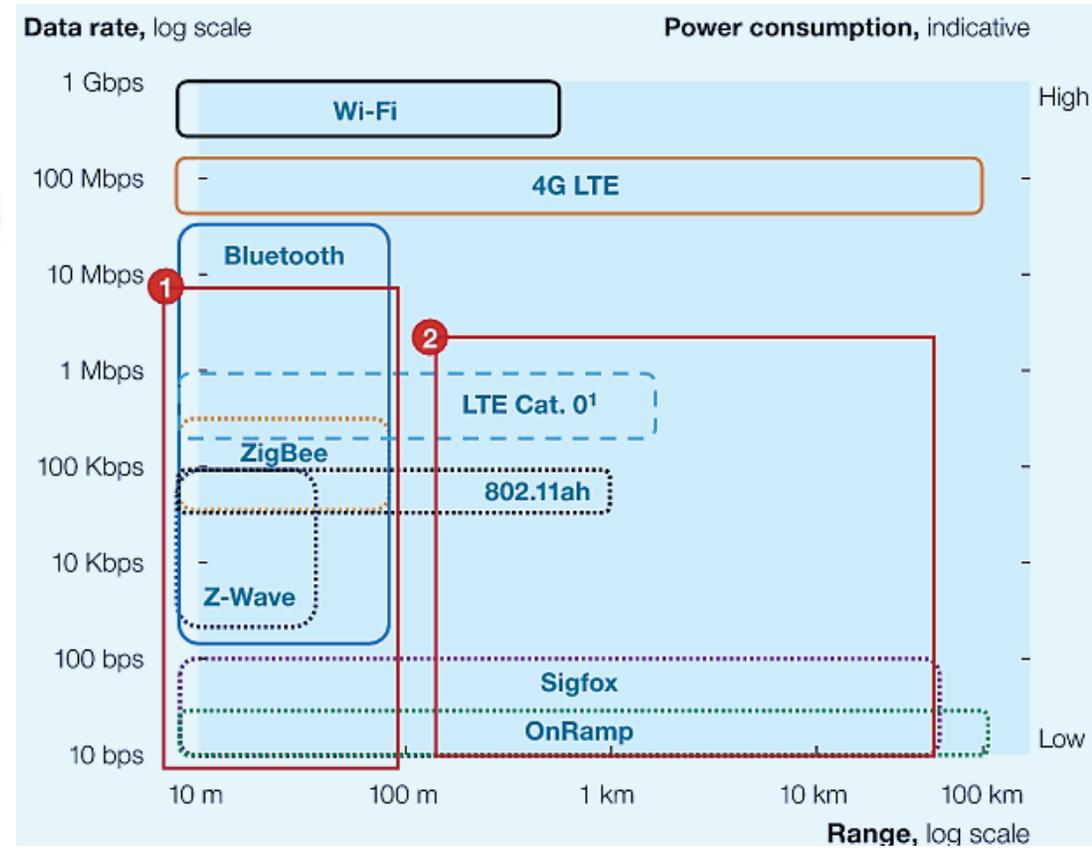
Thing ← Sensor + Device with its own IP address

Source: Mohanty ICCE 2019 Keynote

# IoT - Communications Technology

Selected IoT Communications Technology

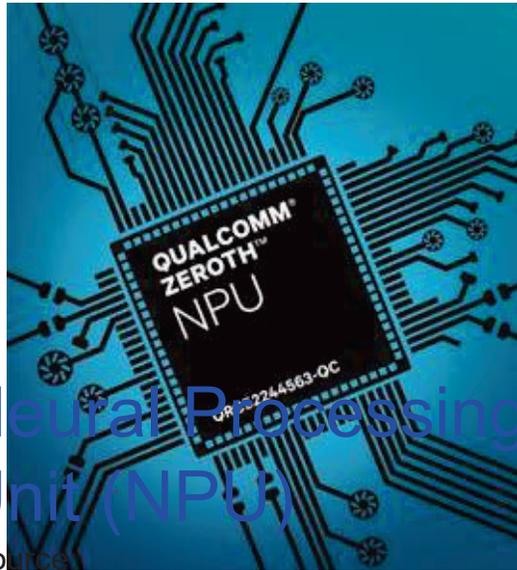
- Bluetooth Low-Energy (BLE) 
- Zigbee 
- Z-Wave 
- 6LoWPAN 
- Thread 
- WiFi 
- Cellular 
- NFC 
- Sigfox 
- Neul 
- LoRaWAN 



Source: <https://www.postscapes.com/internet-of-things-protocols/>

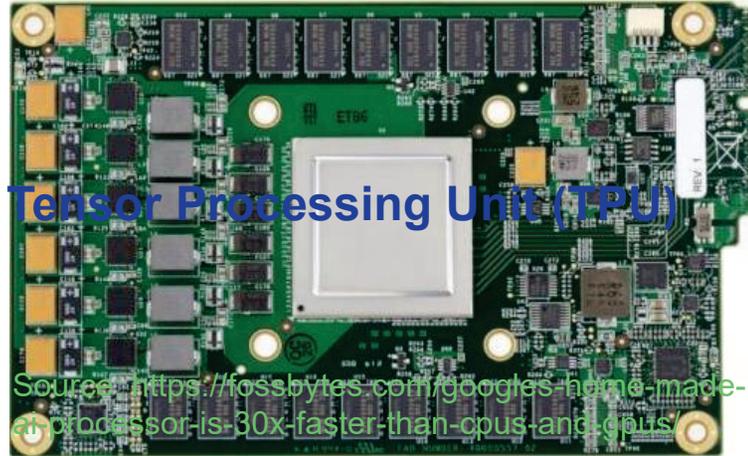
Source: <https://www.rs-online.com/designspark/eleven-internet-of-things-protocols-you-need-to-know-about>

# Computing Technology - Current and Emerging



Neural Processing Unit (NPU)

Source: <https://www.qualcomm.com/news/onq/2013/10/10/introducing-qualcomm-zeroth-processors-brain-inspired-computing>



Tensor Processing Unit (TPU)

Source: <https://fosbytes.com/googles-home-made-ai-processor-is-30x-faster-than-cpus-and-gpus/>



FPGA



320 trillion operations per second

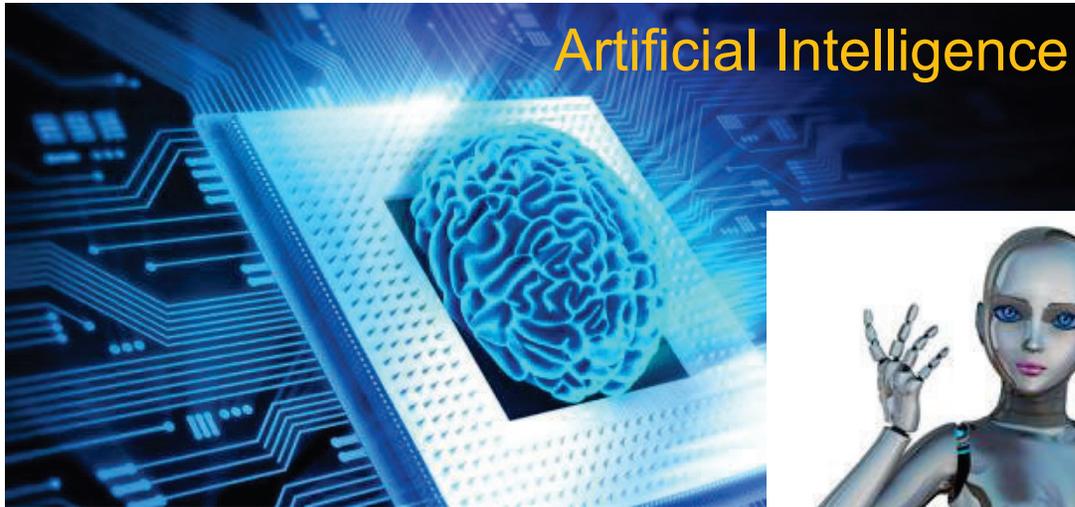
SoC based Design: 30 watts of power

Source: <https://www.engadget.com/2017/10/10/nvidia-introduces-a-computer-for-level-5-autonomous-cars/>

GPU

# Machine Learning Technology

## Artificial Intelligence



Source: <http://transmitter.ieee.org/impact-aimachine-learning-iot-various-industries/>



### IoT Use:

- Better decision
- Faster response



Source: <https://fossbytes.com/googles-home-made-ai-processor-is-30x-faster-than-cpus-and-gpus/>

A GUIDE TO THE CE INNERVERSE

# IEEE Consumer Electronics

MAGAZINE

VOL. 6, NO. 2, April 2017

Theory    Big data    Algorithms

Neural network    Deep learning

Model    Artificial intelligence    Data mining

IoT    Optimization    Hardware

## Going Deep

Pushing the Limits for Machine Learning, AI, and Computer Vision

April 2017

IEEE

# Blockchain Technology



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# UAV – Smart City Applications

## UAV Applications - 4 Categories

Data collection & surveying



Monitoring & Tracking



Temporary Infrastructure



Delivery of Goods



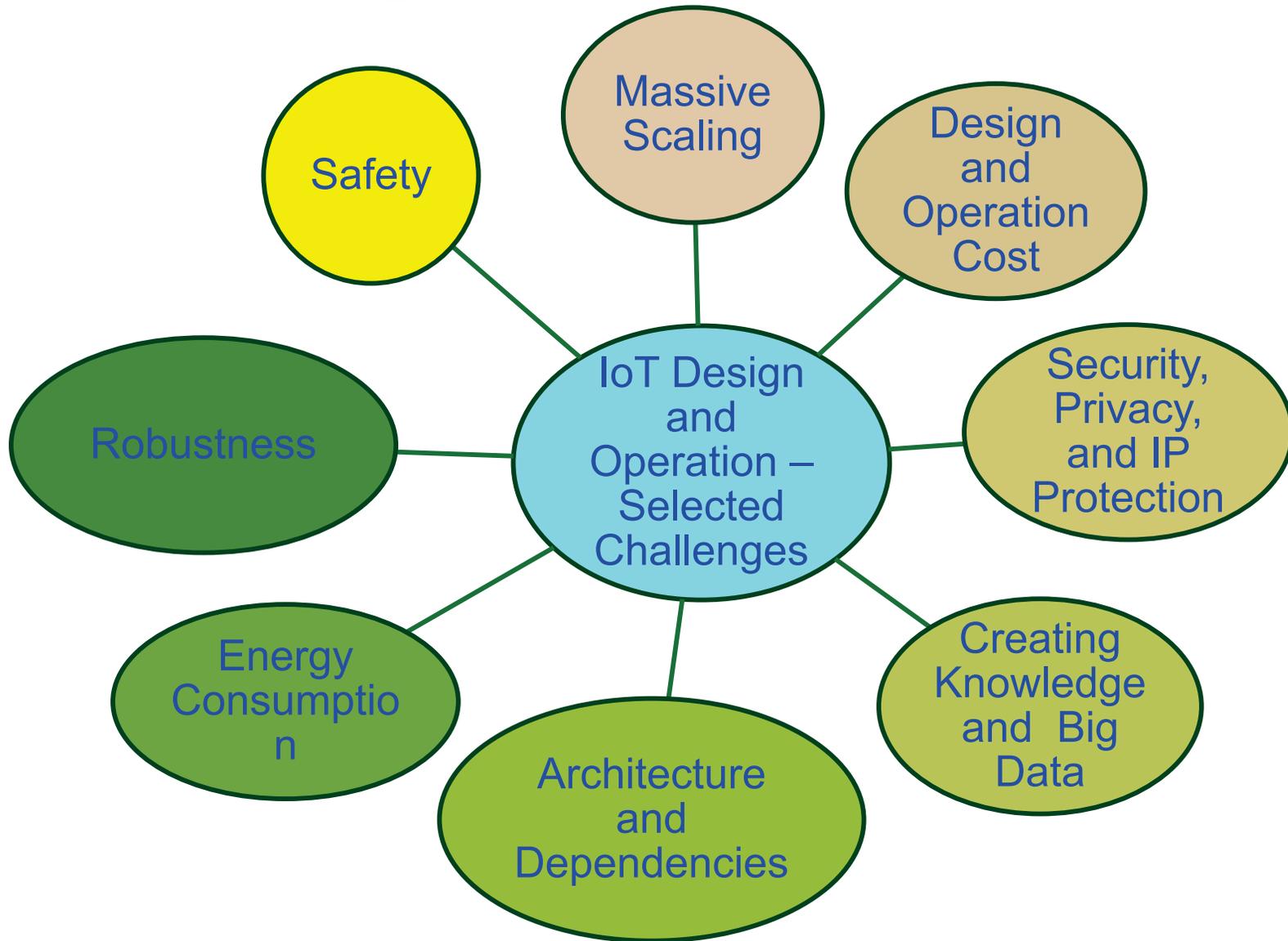
Source: Christos Kyrkou, Stelios Timotheou, Panayiotis Kolios, Theocharis Theocharides, and Christos Panayiotou, "Drones: Augmenting Our Quality of Life" IEEE Potentials Magazine, IEEE Potentials, vol. 38, no. 1, pp. 30-36, Jan.-Feb. 2019.

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# The Challenges



# Smart City – Selected Challenges



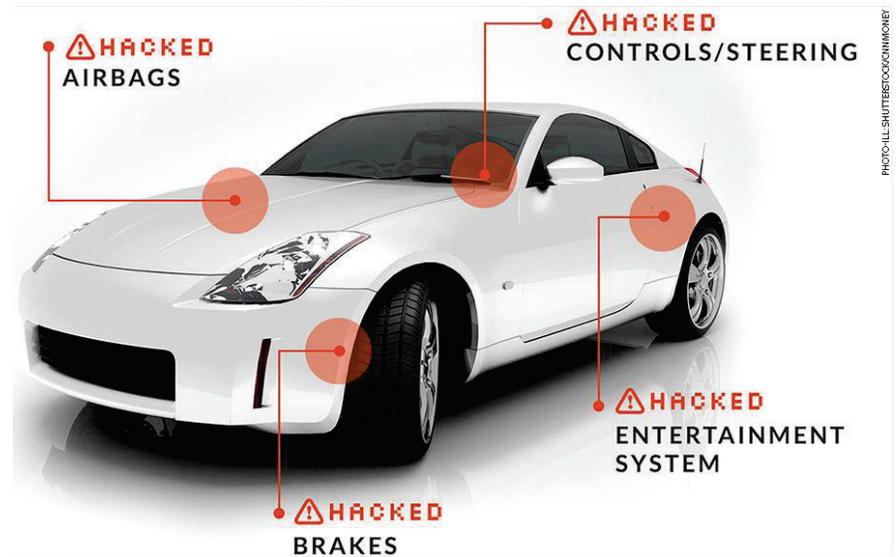
Source: Mohanty ICIT 2017 Keynote

# Security Challenge - System

## Power Grid Attack



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

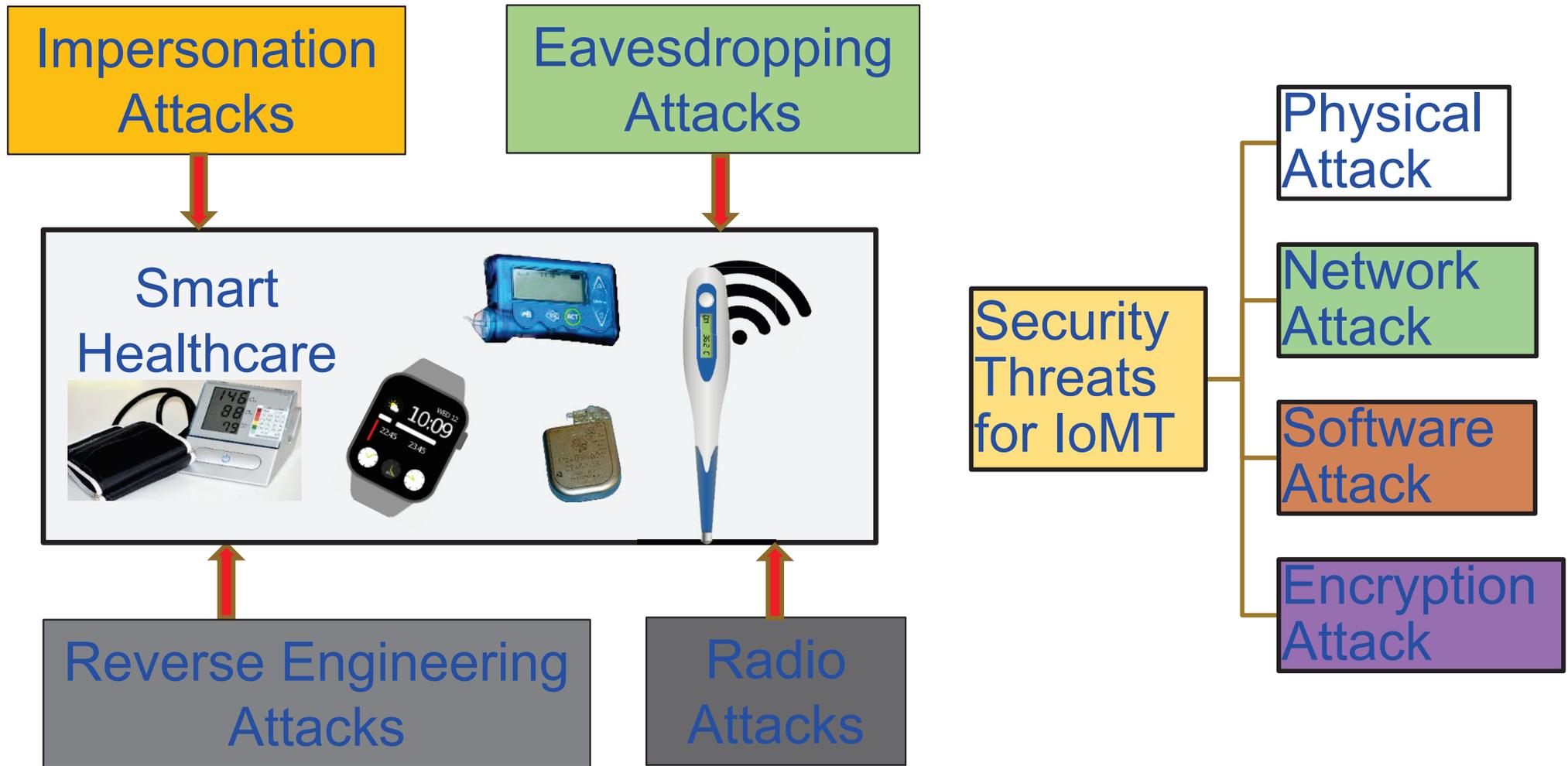


Source: <http://money.cnn.com/2014/06/01/technology/security/car-hack/>



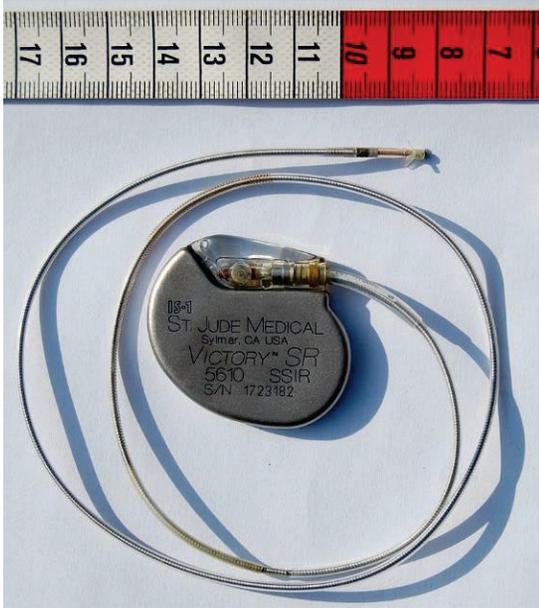
Source: <http://politicalblindspot.com/u-s-drone-hacked-and-hijacked-with-ease/>

# IoMT Security – Selected Attacks



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 Security Measures is Hard - Energy Constrained



Pacemaker  
Battery Life  
- 10 years

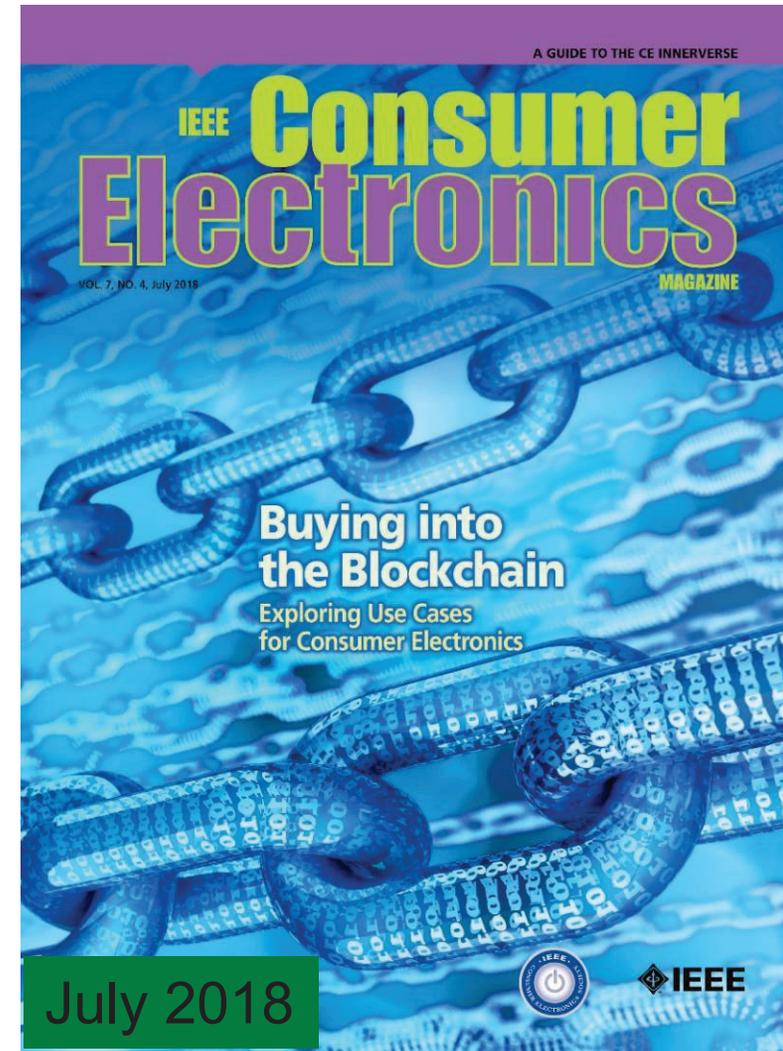
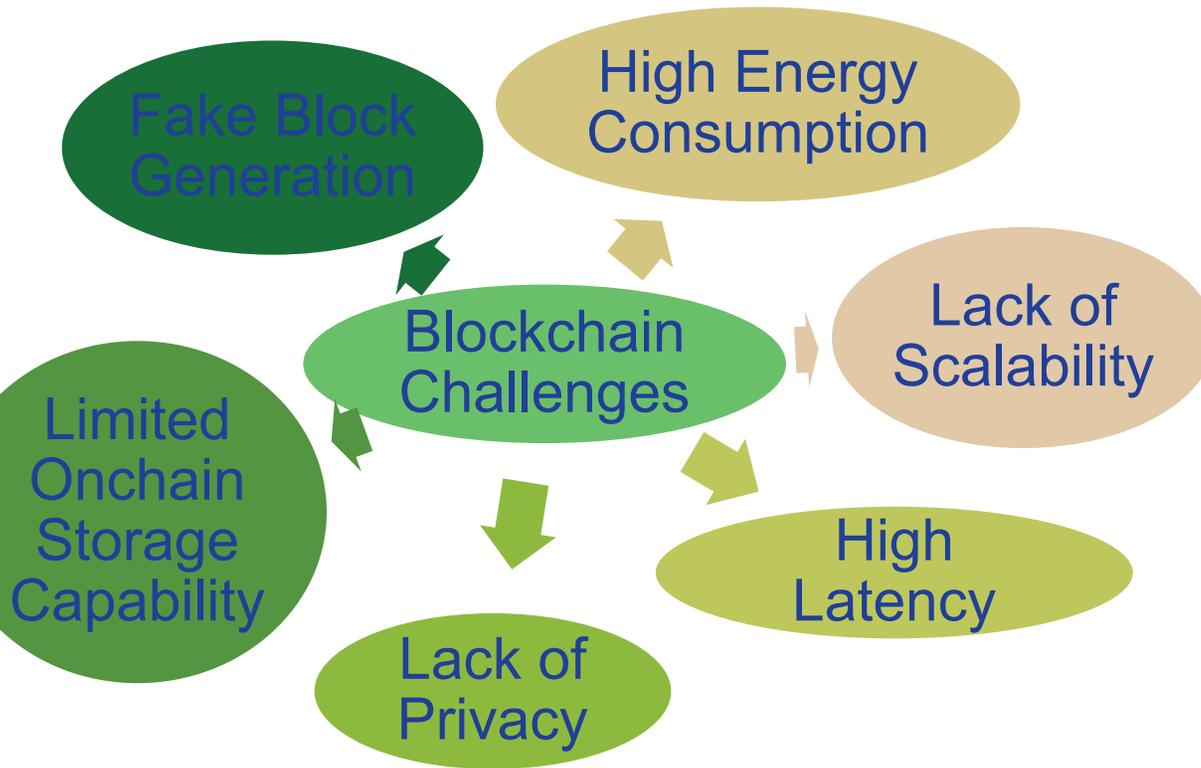


Neurostimulator  
Battery Life  
- 8 years

- 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

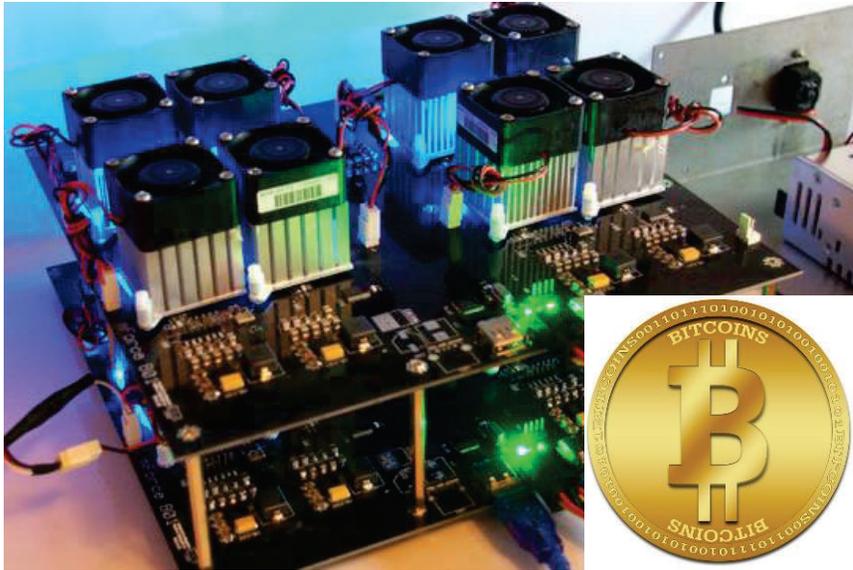
Source: Mohanty IEEE MetroCon 2019 Invited Talk

# Blockchain has Many Challenges

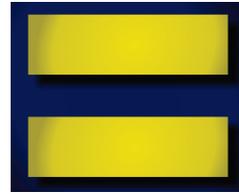


Source: D. Puthal, N. Malik, S. P. Mohanty, E. Kougianos, and G. Das, “Everything you Wanted to Know about the Blockchain”, *IEEE Consumer Electronics Magazine (CEM)*, Volume 7, Issue 4, July 2018, pp. 06--14.

# 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



80,000X

Energy consumption of a credit card processing



# AI Security - Attacks

Attacker's Capabilities



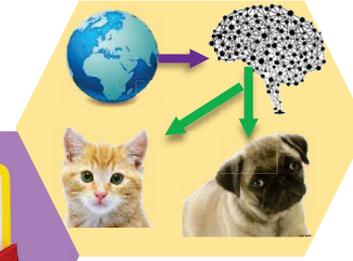
Get Data



Train Model



Deploy Model



Prepare Data



Model Testing



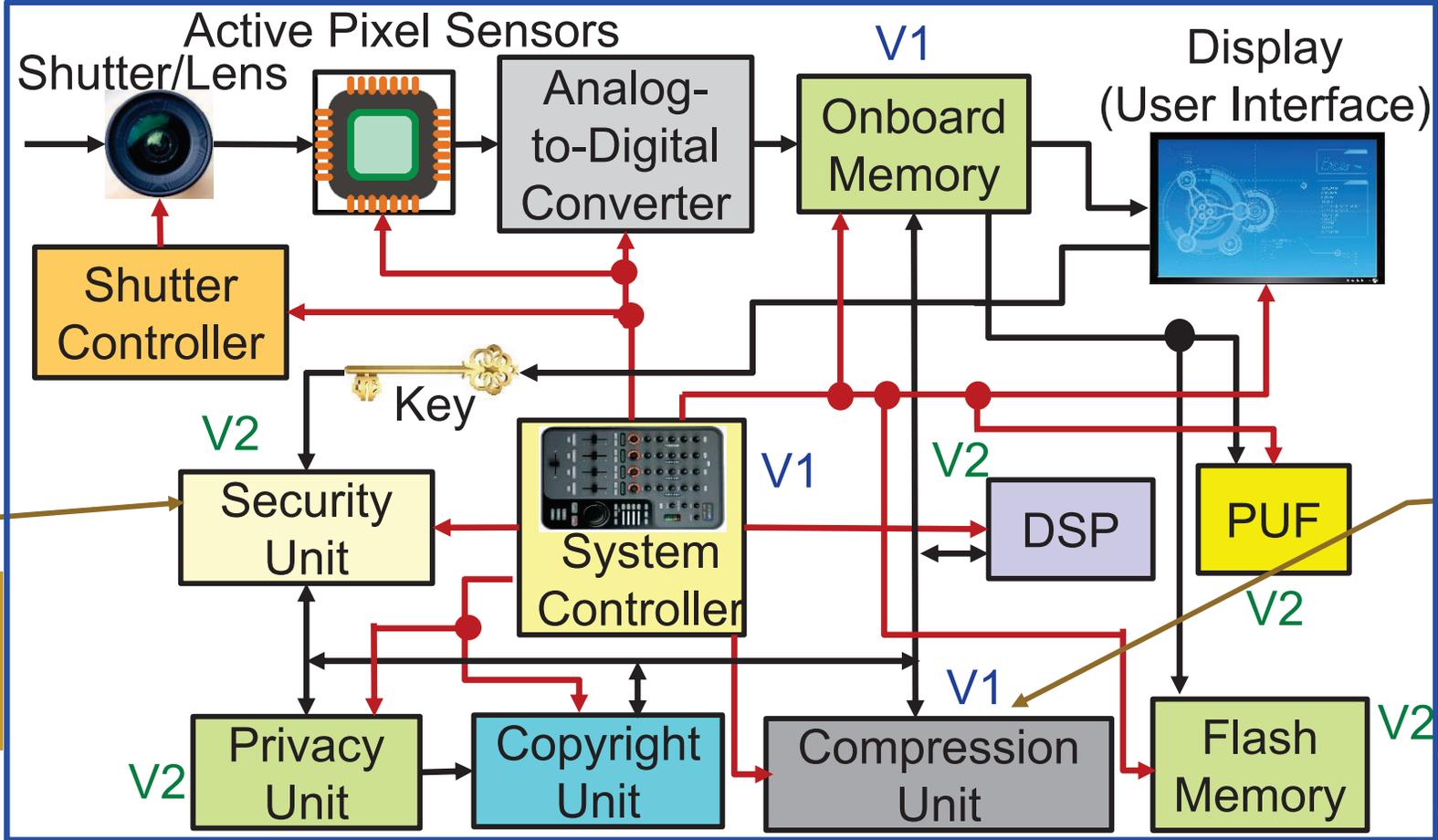
Attacker's Goals



Source: Sandip Kundu ISVLSI 2019 Keynote.



# Secure Digital Camera – My Invention



Light-Weight Cryptography (LWC)

Better Portable Graphics (BPG)

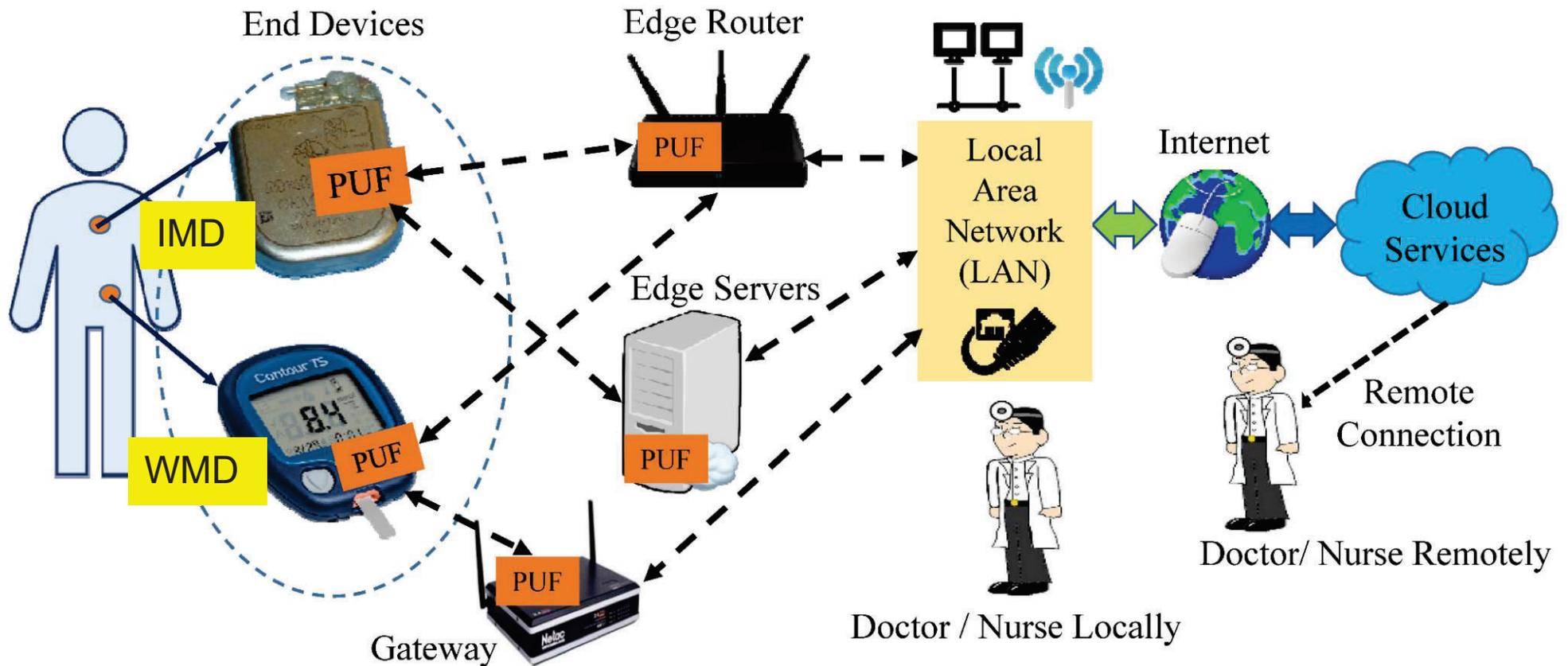
Include additional/alternative hardware/software components and uses DVFS like technology for energy and performance optimization.

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.

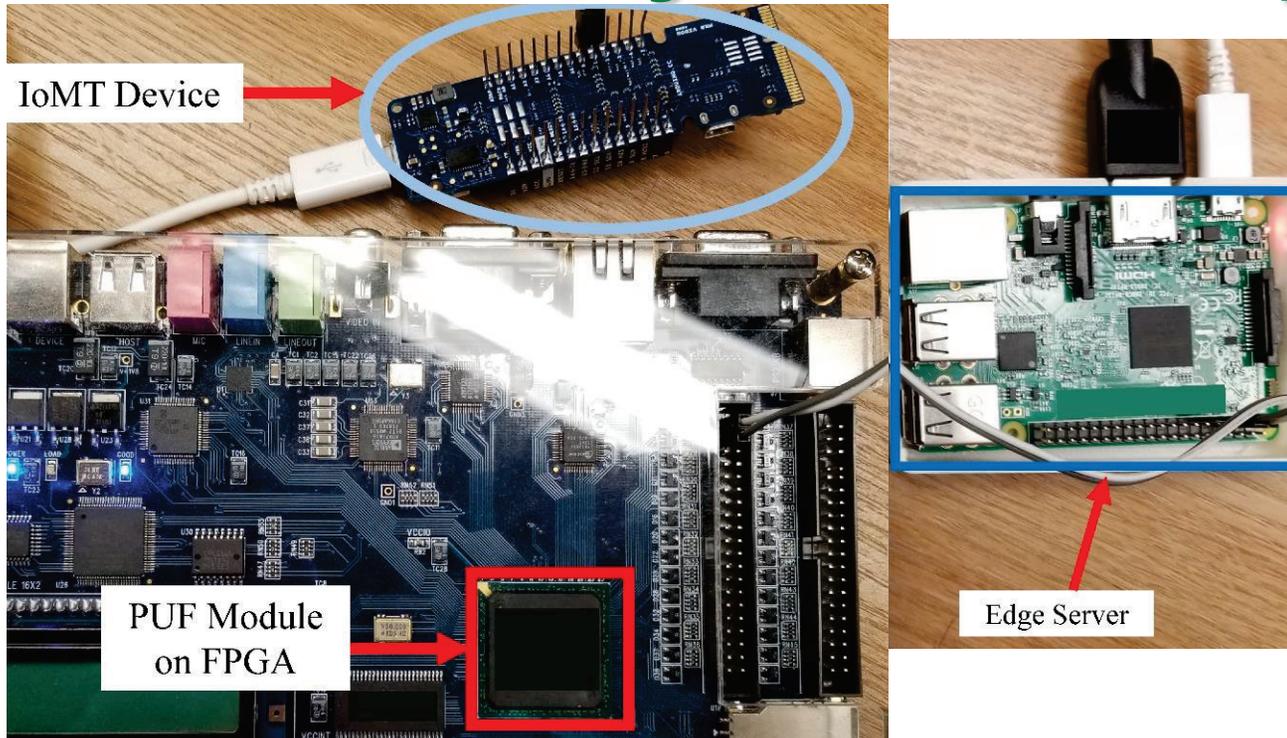


# Our Secure by Design Approach for Robust Security in Healthcare CPS



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.

# IoMT Security – Our Proposed PMsec

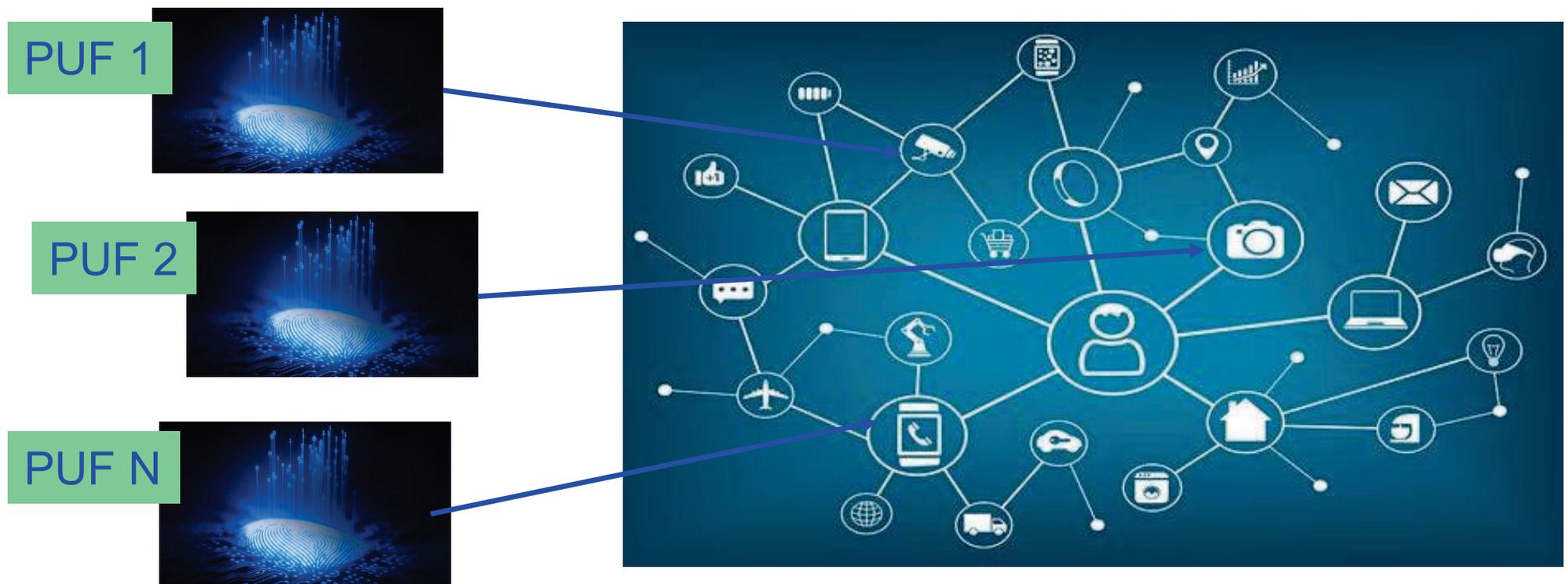


Average Power Overhead –  
~ 200  $\mu$ W

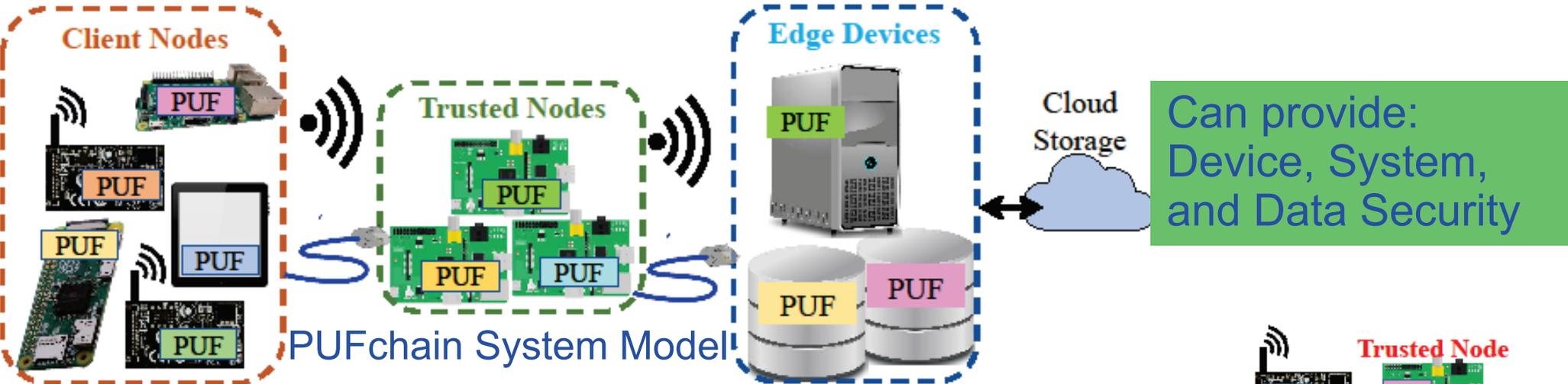
Proposed Approach Characteristics	Value (in a FPGA / Raspberry Pi platform)
Time to Generate the Key at Server	800 ms
Time to Generate the Key at IoMT Device	800 ms
Time to Authenticate the Device	1.2 sec - 1.5 sec

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 (TCE)*, Volume 65, Issue 3, August 2019, pp. 388--397.

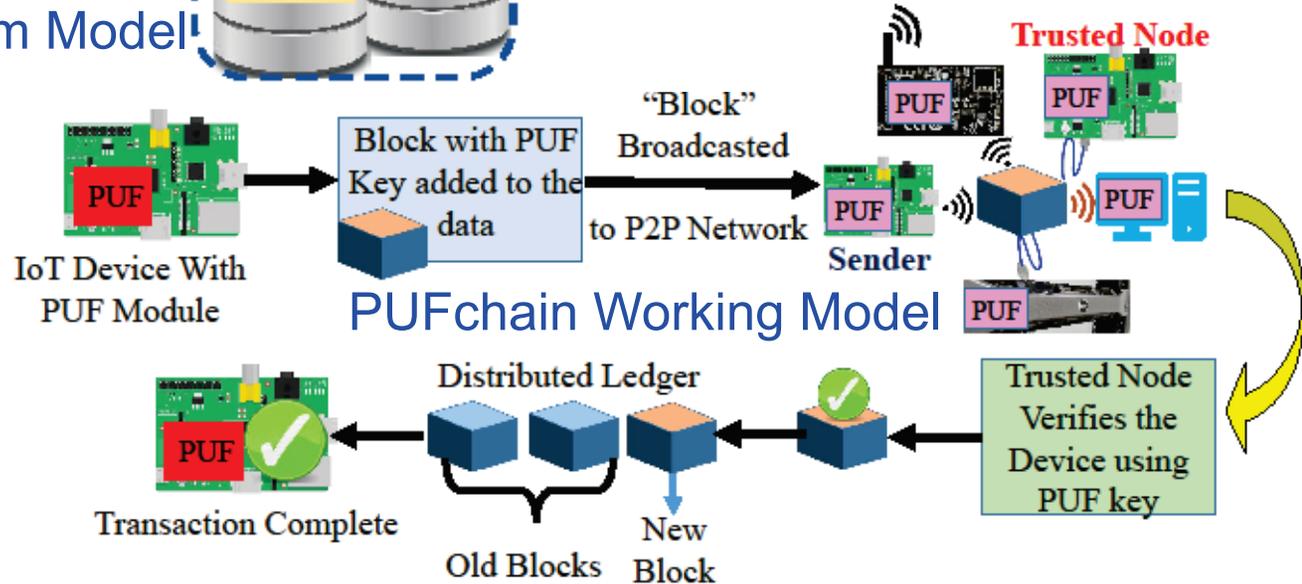
# We Proposed World's First Hardware-Integrated Blockchain (PUFchain) that is Scalable, Energy- Efficient, and Fast



# PUFchain: The Hardware-Assisted Scalable Blockchain

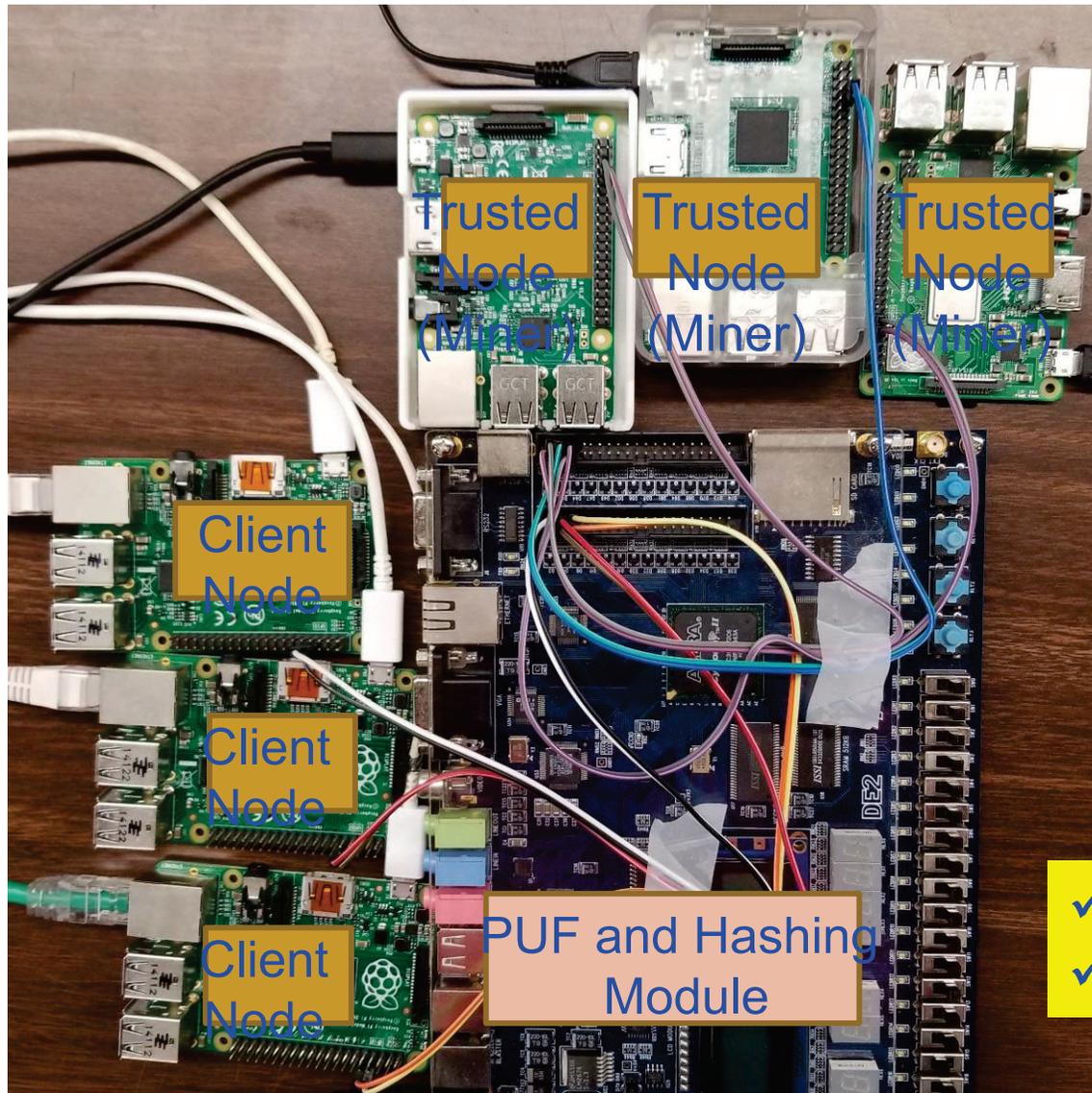


PUFChain 2 Modes:  
 (1) PUF Mode and  
 (2) PUFChain Mode



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. XX, No. YY, ZZ 2020, pp. Accepted.

# 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

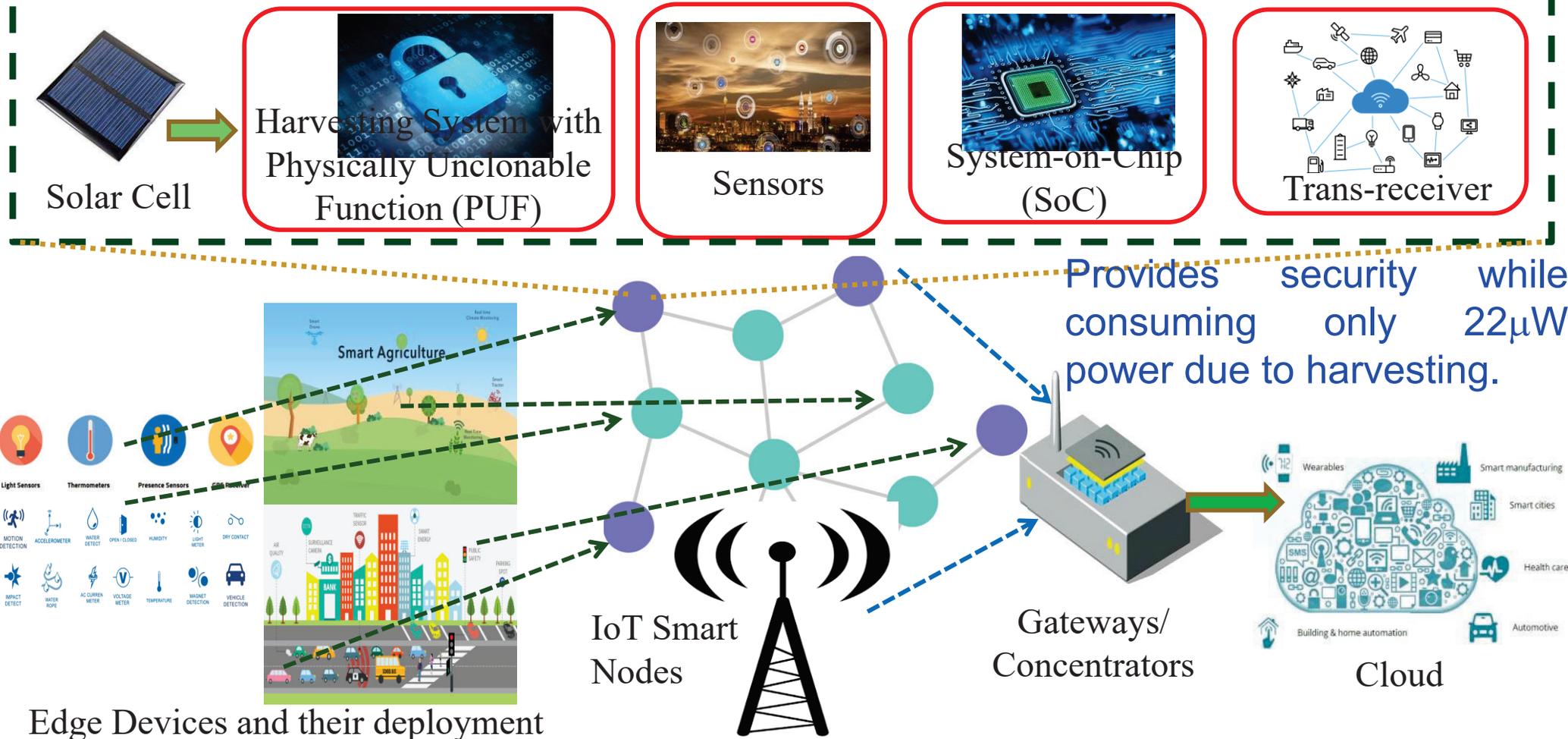
# Energy Consumption and Latency in Communications

- IoT with Cloud: Sensor big data goes to cloud for storage and analytics – Consumes significant energy in communications network
- Connected cars require latency of ms to communicate and avoid impending crash:
  - Faster connection
  - Low latency
  - Lower power
- **5G** for connected world: Enables all devices to be connected seamlessly.



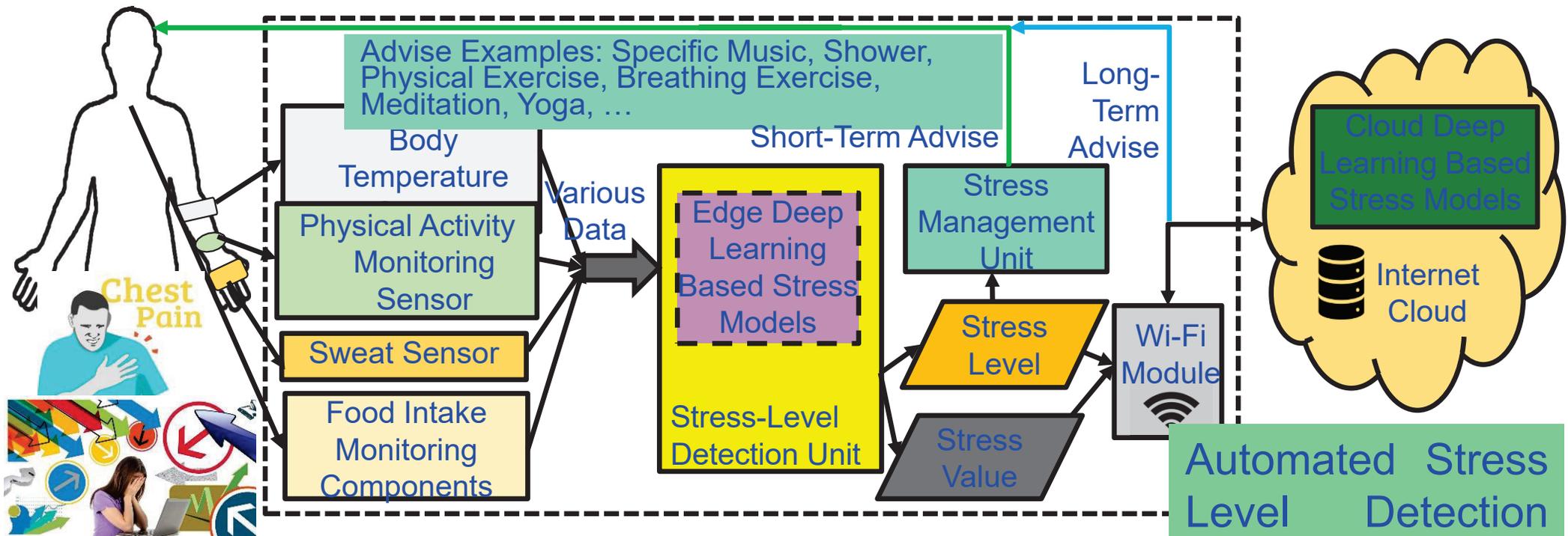
Source: <https://www.linkedin.com/pulse/key-technologies-connected-world-cloud-computing-ioe-balakrishnan>

# Eternal-Thing: Combines Security and Energy Harvesting at the Edge



Source: S. K. Ram, S. R. Sahoo, Baneer, 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. XX, No. YY, ZZ 2019, pp. Under Review.

# Smart Healthcare - Stress Monitoring & Control



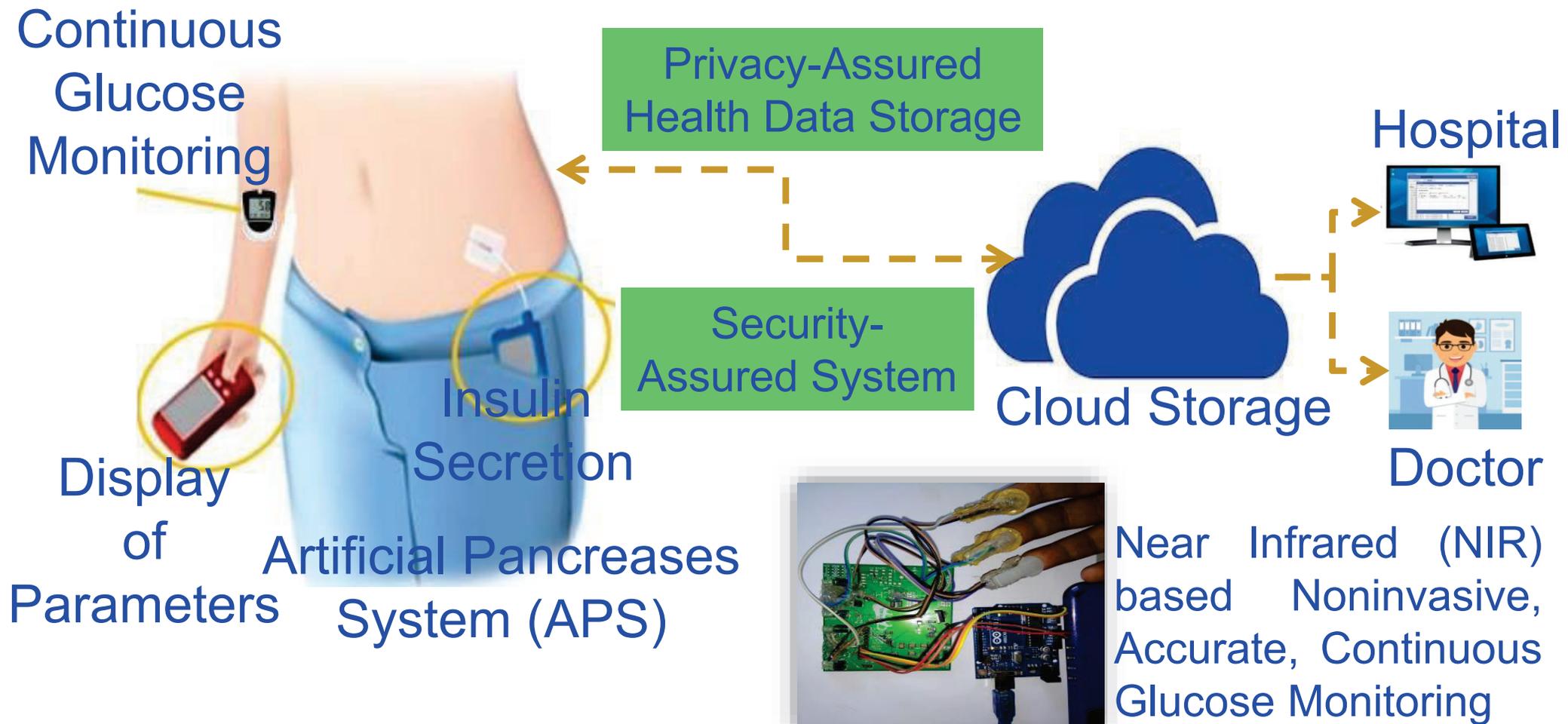
Sensor	Low Stress	Normal Stress	High Stress
Accelerometer (steps/min)	0-75	75-100	101-200
Humidity (RH%)	27-65	66-91	91-120
Temperature °F	98-100	90-97	80-90



Automated Stress Level Detection and Management

Source: L. Rachakonda, S. P. Mohanty, E. Kougianos, and P. Sundaravadivel, "Stress-Lysis: A DNN-Integrated Edge Device for Stress Level Detection in the IoMT", *IEEE Transactions on Consumer Electronics (TCE)*, Vol 65, No 4, Nov 2019, pp. 474--483.

# iGLU: Accurate Noninvasive Glucose Level Monitoring and Insulin Delivery



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.

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# Conclusions

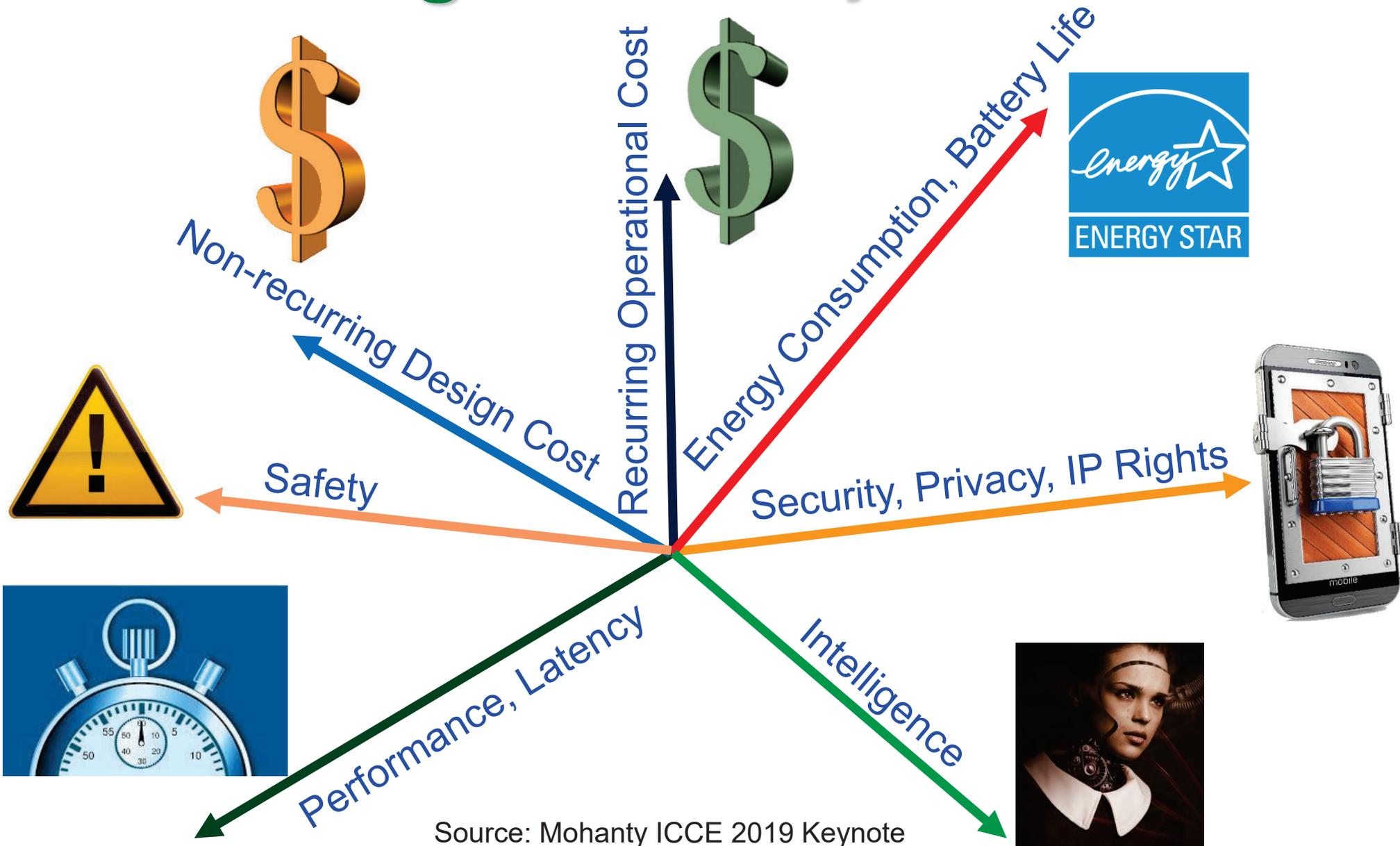


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# Conclusions

- Energy requirements and security vulnerability are important challenges in Cyber-Physical Systems (CPS).
- Various elements and components of CPS including Data, Devices, System Components, AI need security.
- Both software and hardware based attacks and solutions are possible.
- Security in H-CPS, E-CPS, and T-CPS, etc. can have serious consequences.
- Existing security 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) or Hardware-Assisted Security (HAS) advocate features at early design phases, no-retrofitting.

# CPS Design - Multi-Objective Tradeoffs



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/>

# Thank You !!!

Slides Available at: <http://www.smohanty.org>

Hardwares are the drivers of the civilization, even softwares need them.

