Energy and Security Trade-Offs in Smart City Components

IIT Kanpur - Prof. M. Ramamoorty Distinguished Lecture

05 Aug 2019

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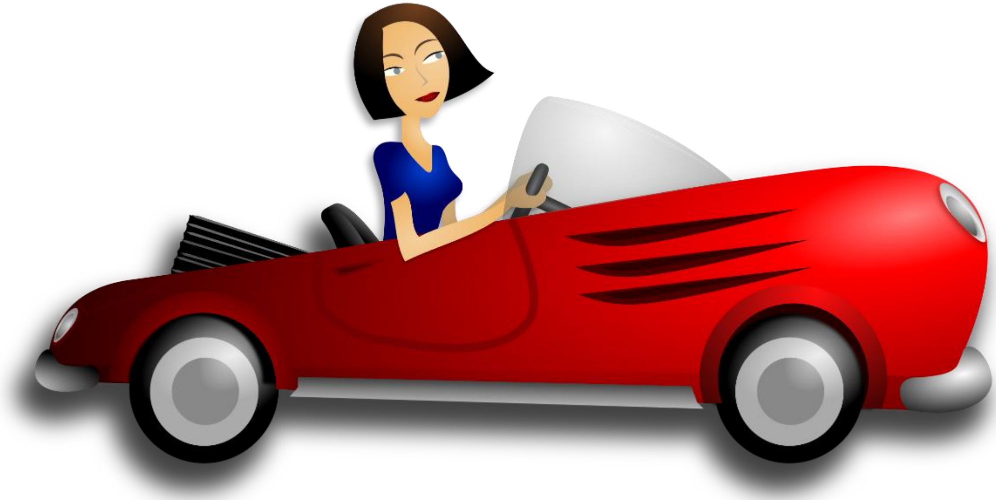
More Info: http://www.smohanty.org

Talk - Outline

- Smarty City Drivers
- Smarty City Components and Technologies
- Challenges on Smarty Cities Design
- Security, Privacy, IP Rights solutions
- Energy consumption solutions
- Design Trade-offs in Smart City Components
- Conclusions and Future Directions

Smart City Drivers



Population Trend – Urban Migration

"India is to be found not in its few cities, but in its 700,000 villages."
- Mahatma Gandhi

- 2025: 60% of world population will be urban
- 2050: 70% of world population will be urban

Source: http://www.urbangateway.org

Issues Challenging Sustainability

➢ Pollution

➢ Water crisis

➢ Energy crisis

➢ Traffic

The Problem

- Uncontrolled growth of urban population
- Limited natural and man-made resources

Source: https://humanitycollege.org

The Solution – Smart Cities

- 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

Other Drivers …

- Managing vital services
  - Waste management
  - Traffic management
  - Healthcare
  - Crime prevention
- Making the city competitive
  - Investment
  - Tourism
- Technology push
  - IoT, CPS, Sensor, Wireless

Source: Sangiovanni-Vincentelli 2016, ISC2 2016

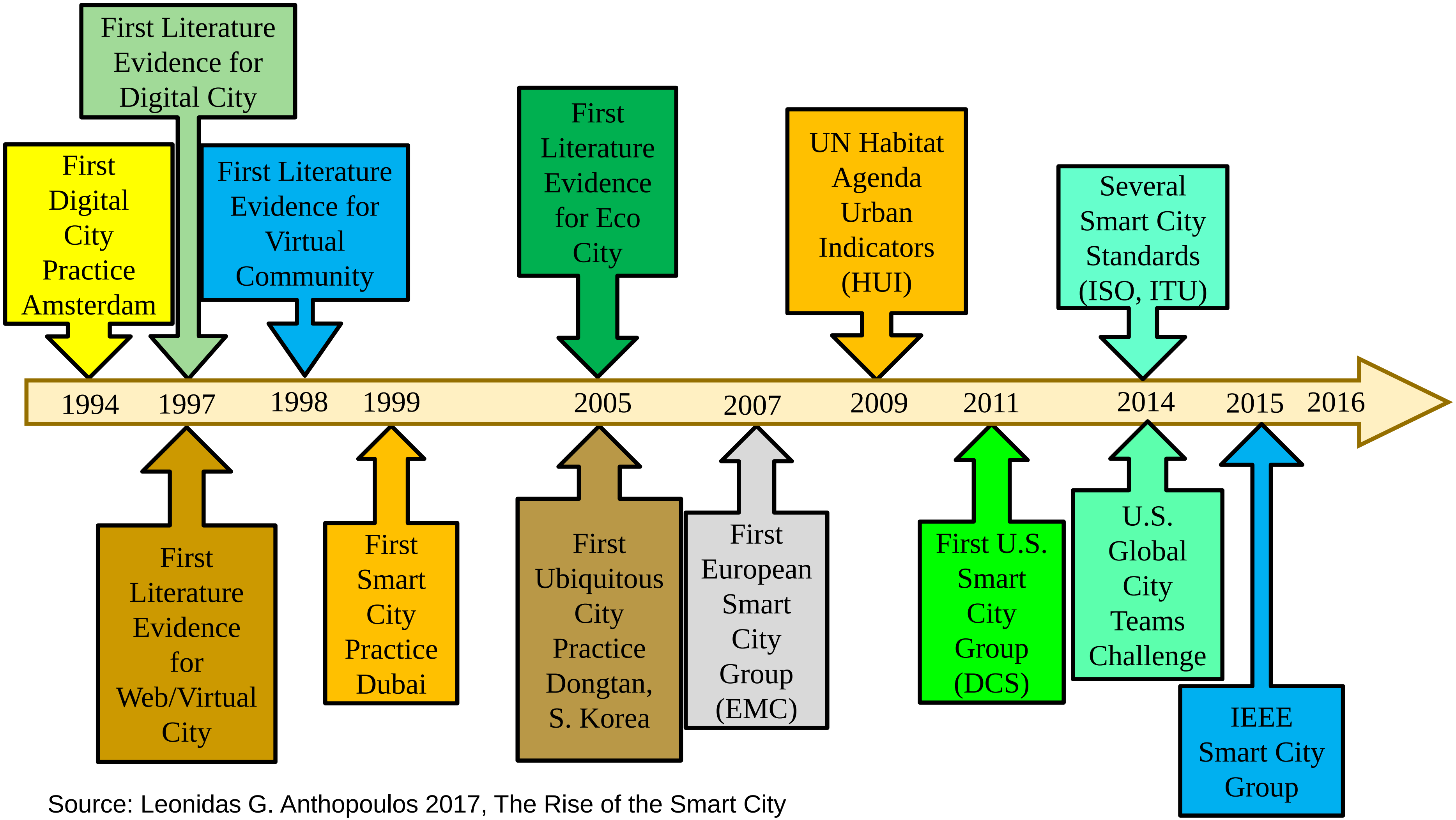
Smart Cities - Formal Definition

- Definition - 1: 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”.

- Definition - 2: “A smart sustainable city is an innovative city that uses information and communication technologies (ICTs) and other means to improve quality of life, efficiency of urban operations and services, and competitiveness, while ensuring that it meets the needs of present and future generations with respect to economic, social and environmental aspects”.

Source: S. P. Mohanty, U. Choppali, and E. Kougianos, “Everything You wanted to Know about Smart Cities”, IEEE Consumer Electronics Magazine (CEM), Volume 5, Issue 3, July 2016, pp. 60--70.

Smart Cities - History

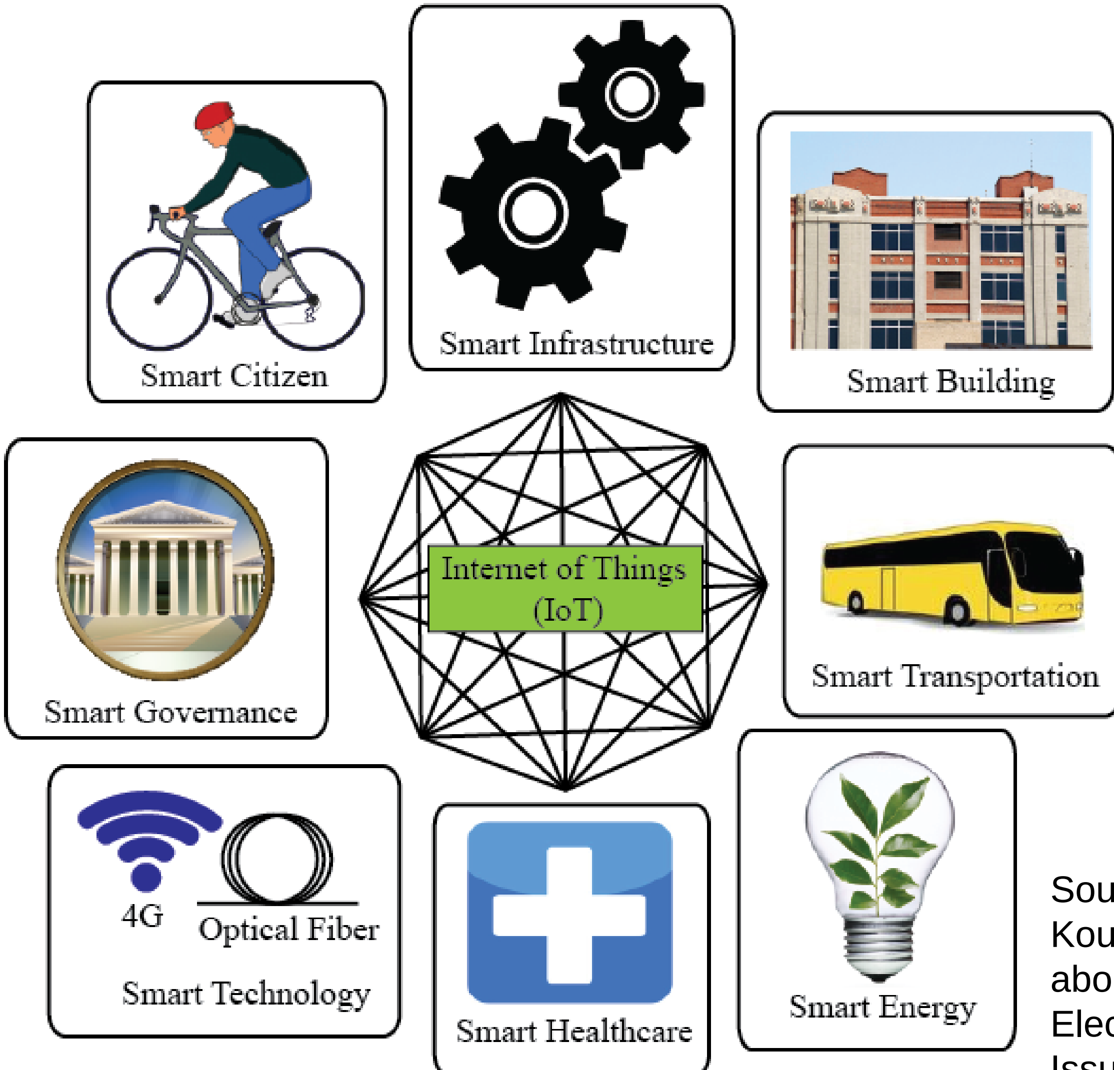


Source: Leonidas G. Anthopoulos 2017, The Rise of the Smart City

Smart City Components

Smart Electronic Systems Laboratory (SESL)

Smart Cities - Components



A smart city can have one or more of the smart components.

Source: S. P. Mohanty, U. Choppali, and E. Kougianos, "Everything You wanted to Know about Smart Cities", IEEE Consumer Electronics Magazine (CEM), Volume 5, Issue 3, July 2016, pp. 60--70.

Smart Healthcare

Healthy Living
- Fitness Tracking
- Disease Prevention
- Food monitoring

Home Care
- Mobile health
- Telemedicine
- Self-management
- Assisted Living

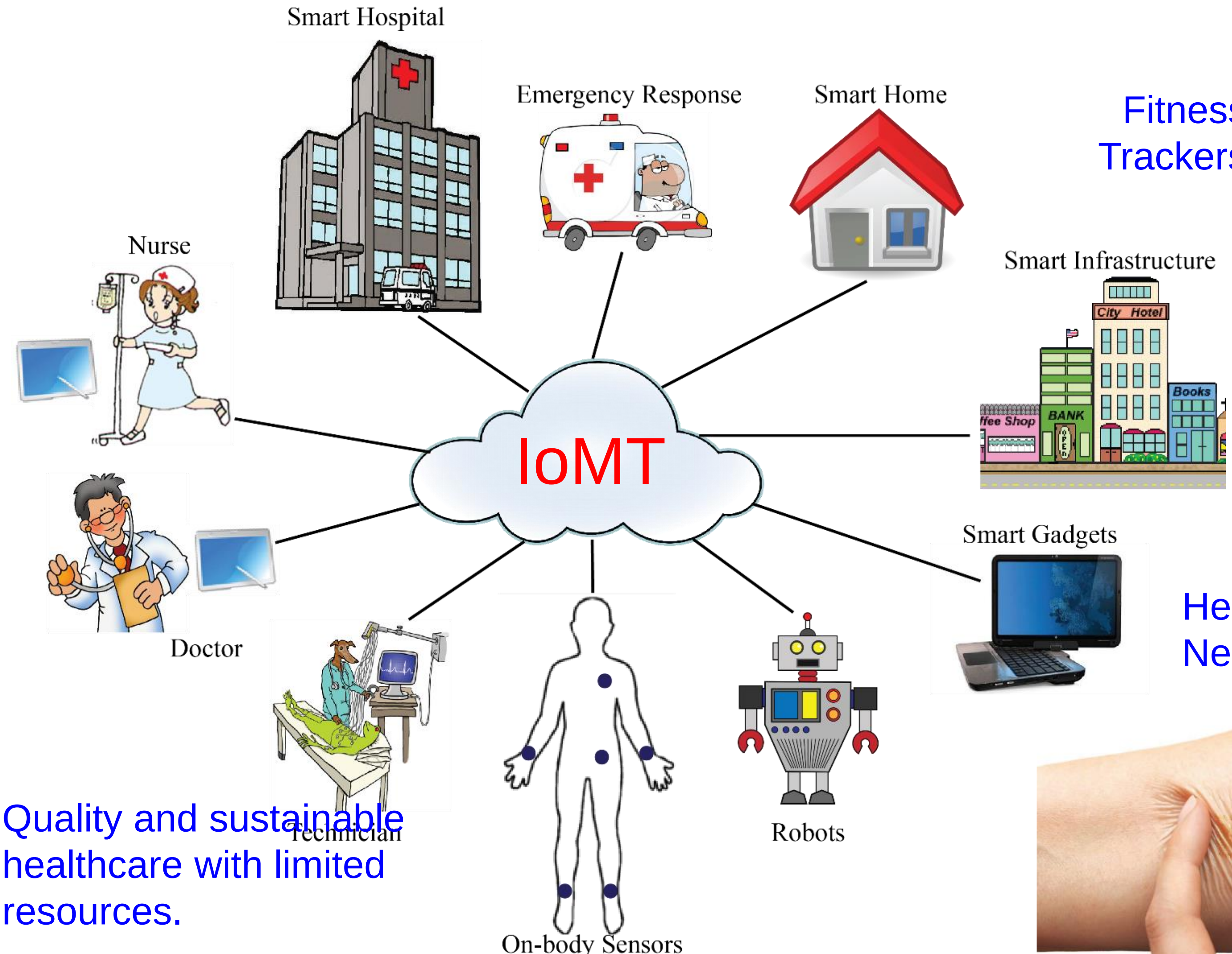
Acute care
- Hospital
- Specialty clinic
- Nursing Home
- Community Hospital

Frost and Sullivan predict smart health-care market value to reach US$348.5 billion by 2025.

January 2018

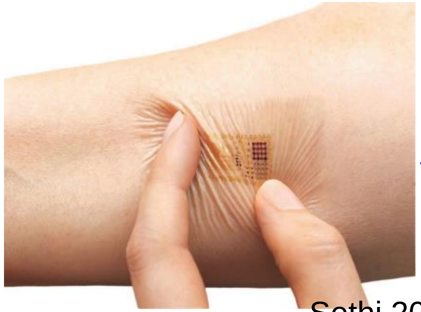
Source: P. Sundaravadivel, E. Kougianos, S. P. Mohanty, and M. Ganapathiraju, “Everything You Wanted to Know about Smart Health Care”, IEEE Consumer Electronics Magazine (CEM), Volume 7, Issue 1, January 2018, pp. 18-28.

Smart Healthcare



Fitness Trackers

Headband with Embedded Neurosensors



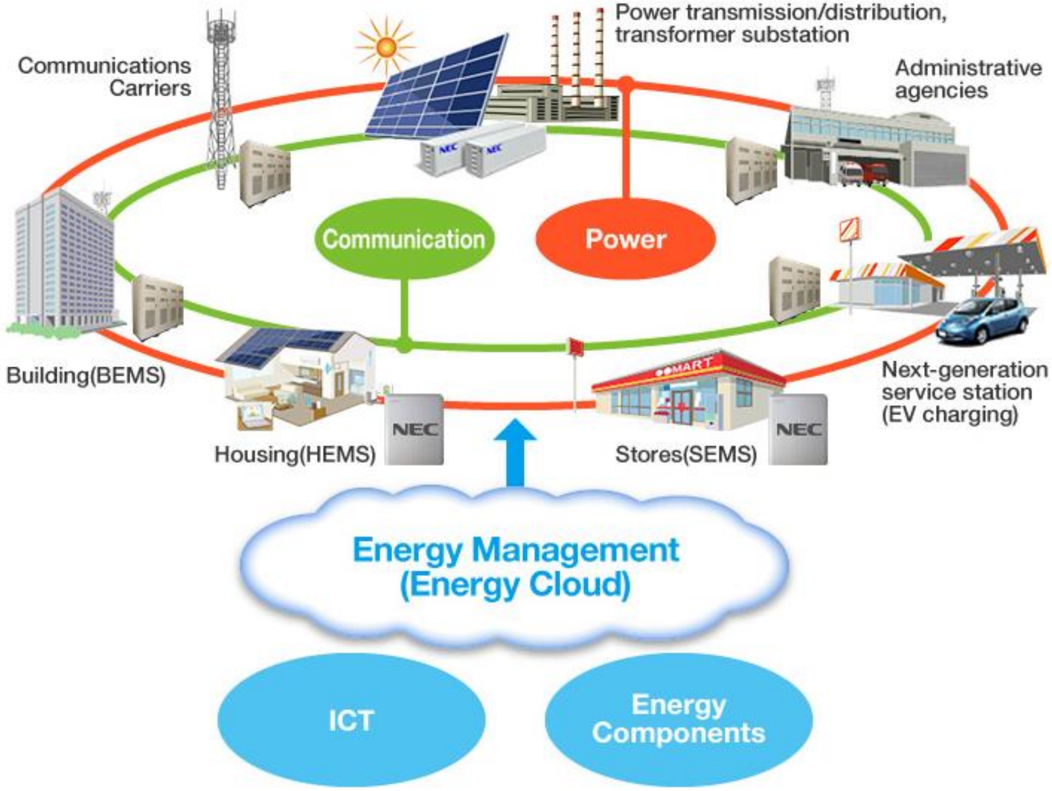
Embedded Skin Patches

Quality and sustainable healthcare with limited resources.

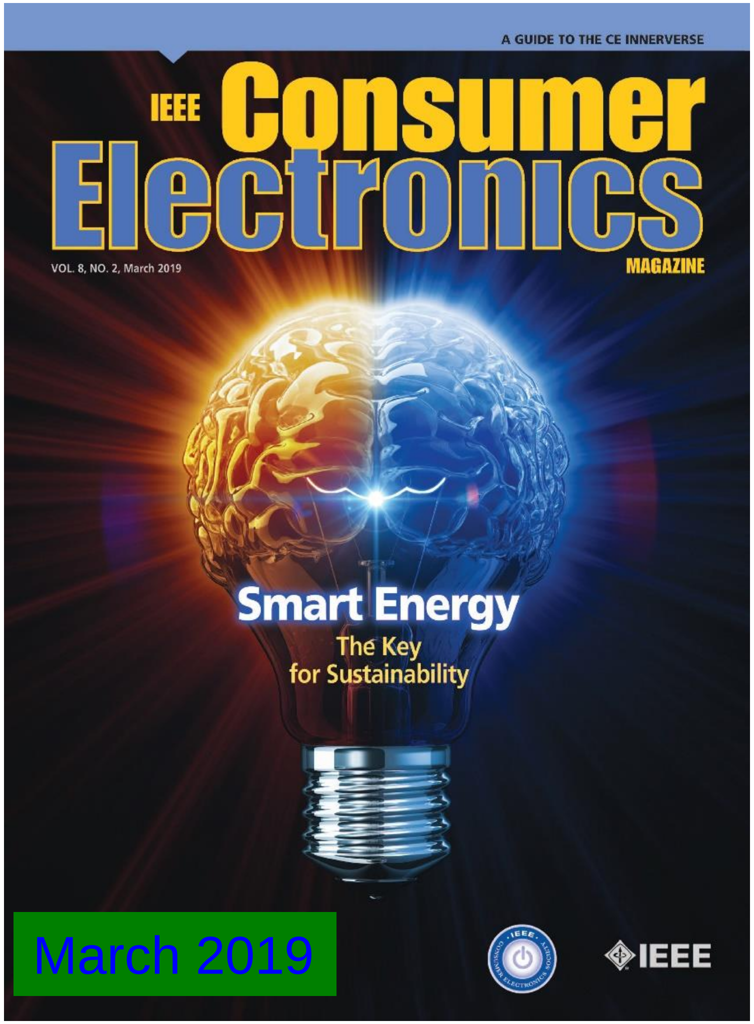
Source: Mohanty 2016, CE Magazine July 2016

Sethi 2017: JECE 2017

Smart Energy

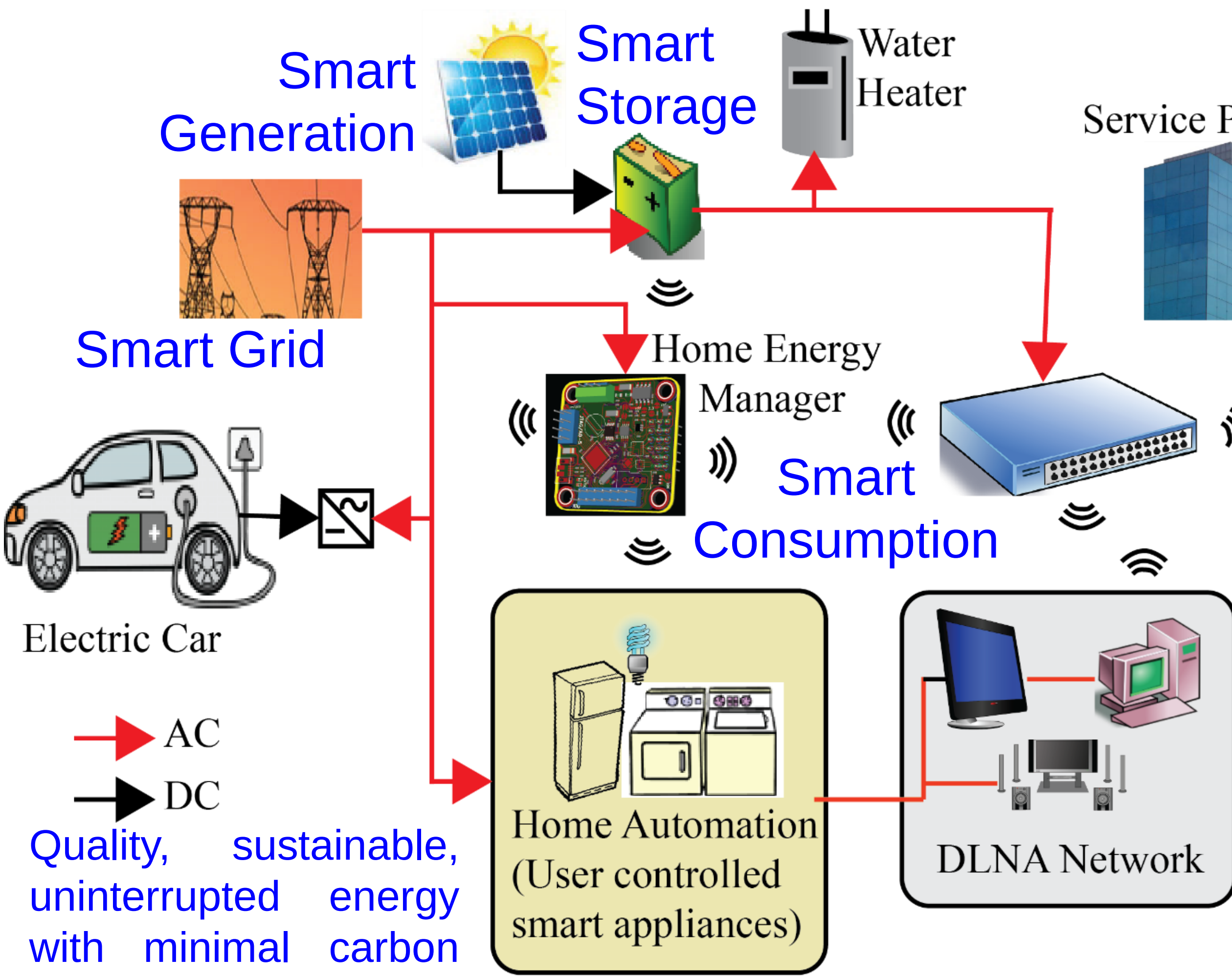


Source: https://www.nec.com/en/global/solutions/energy/index.html



March 2019

Smart Energy



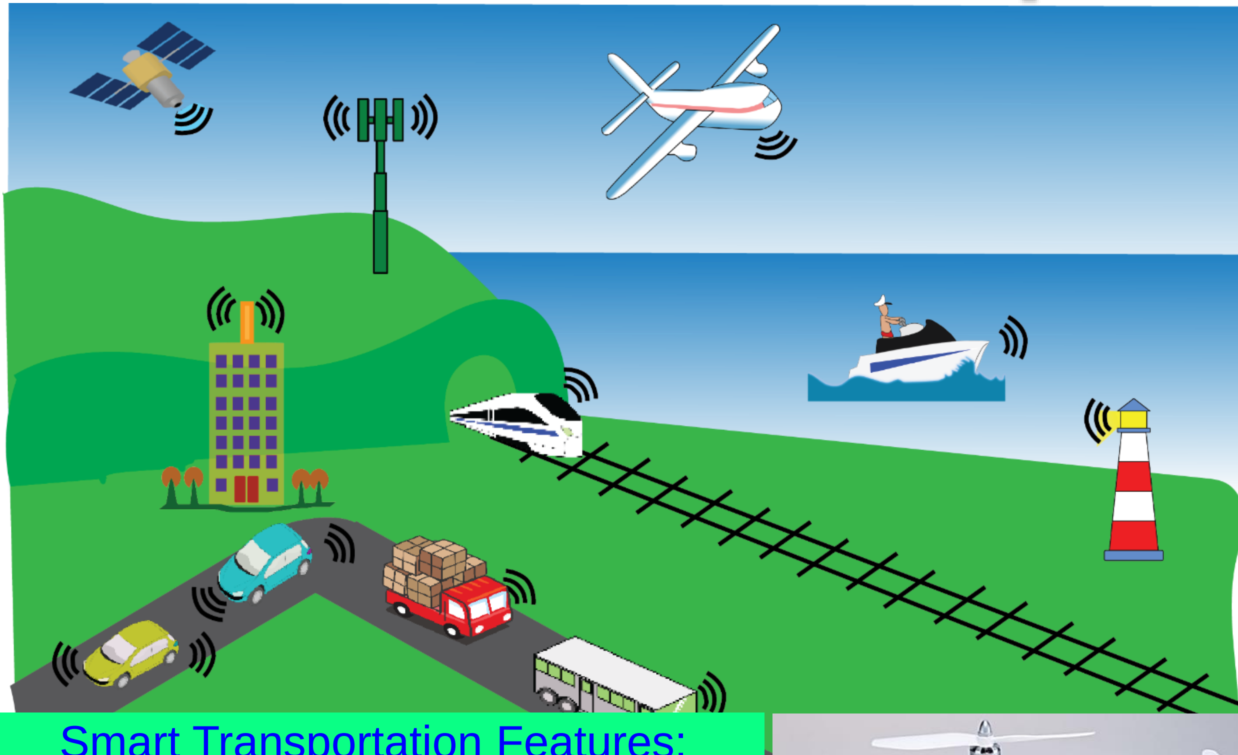
Quality, sustainable, uninterrupted energy with minimal carbon footprint.

Source: Mohanty 2016, CE Magazine July 2016

Internet of Energy

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

Smart Transportation



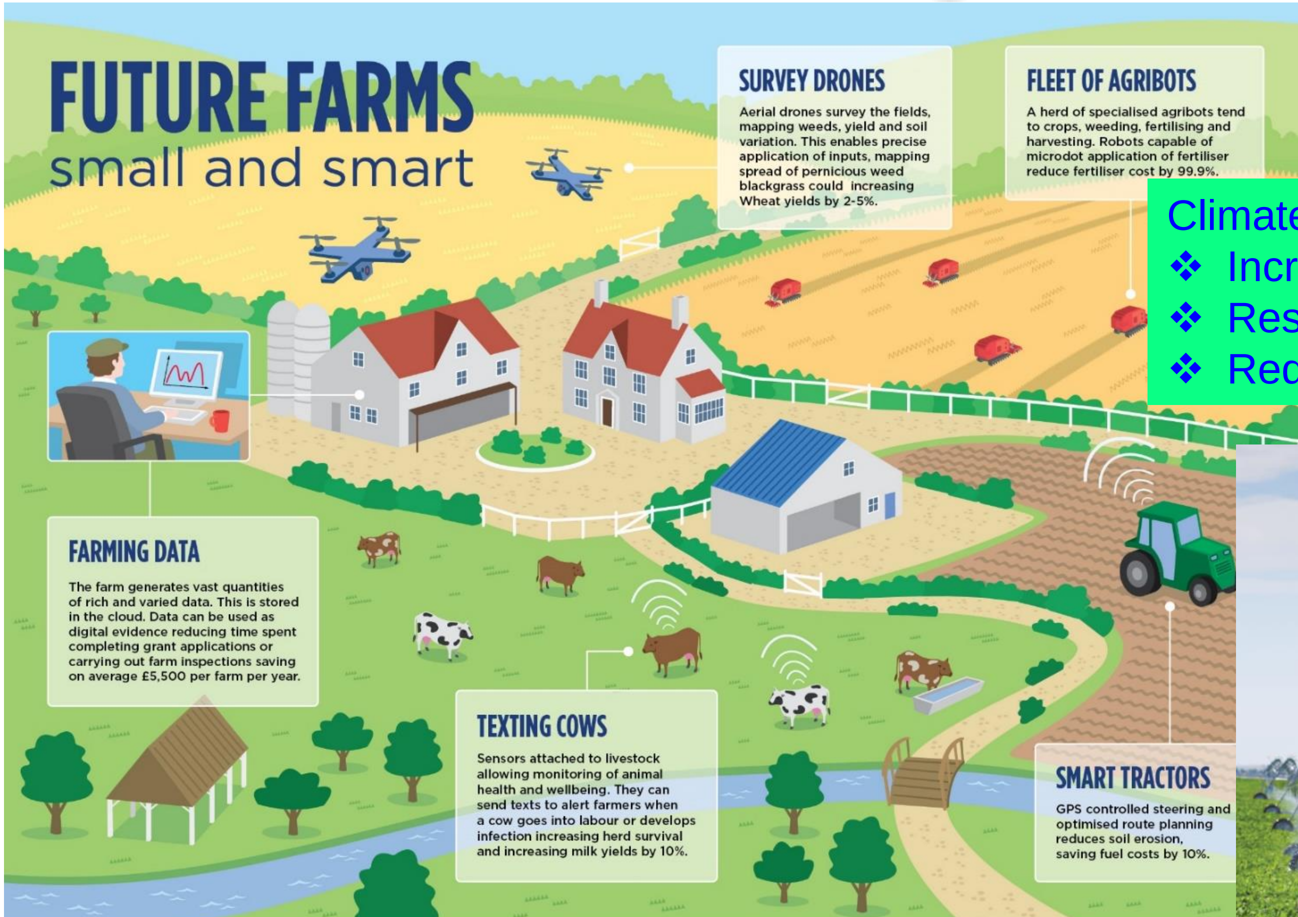
Smart Transportation Features:

- Autonomous driving
- Effective traffic management
- Real-time vehicle tracking
- Vehicle safety – Automatic brake
- Vehicle-to-Vehicle communication
- Better scheduling of train, aircraft
- Easy payment system

"The smart transportation system allows passengers to easily select different transportation options for lowest cost, shortest distance, or fastest route."

Source: Mohanty 2016, CE Magazine July 2016

Smart Agriculture



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

Climate-Smart Agriculture Objectives:

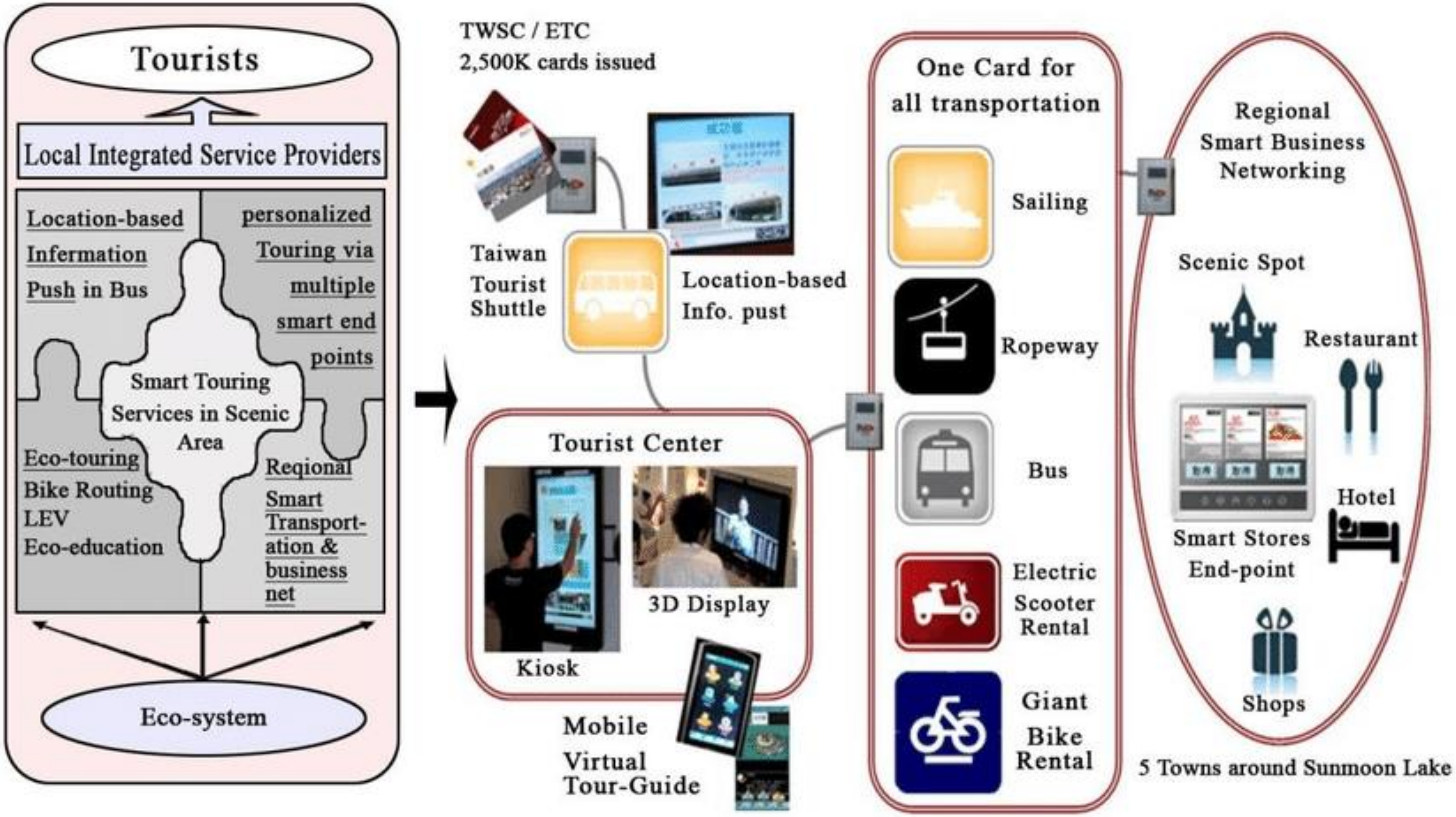
- ❖ Increasing agricultural productivity
- ❖ Resilience to climate change
- ❖ Reducing greenhouse gas

http://www.fao.org

Automatic Irrigation System

Source: Maurya 2017: CE Magazine July 2017

Smart Tourism



Source: Chih-Kung Lee: https://www.researchgate.net/figure/Concept-of-In-Joy-Life-smart-tourism-8_fig4_269666526

Smart City Technologies

Smart Cities

Smart Cities ←

Regular Cities

+ Information and Communication Technology (ICT)

+ Smart Components

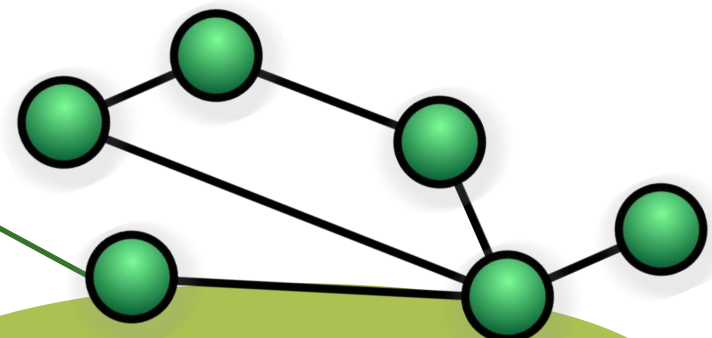
+ Smart Technologies

Source: S. P. Mohanty, U. Choppali, and E. Kougianos, "Everything You wanted to Know about Smart Cities", IEEE Consumer Electronics Magazine (CEM), Volume 5, Issue 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 EuroSimE 2016 Keynote Presentation

Internet of Things (IoT) – Concept

Things
Sensors/actuators with IP address that can be connected to Internet

Local Network
Can be wired or wireless: LAN, Body Area Network (BAN), Personal Area Network (PAN), Controller Area Network (CAN)

Cloud Services
Data either sent to or received from cloud (e.g. machine activation, workflow, and analytics)

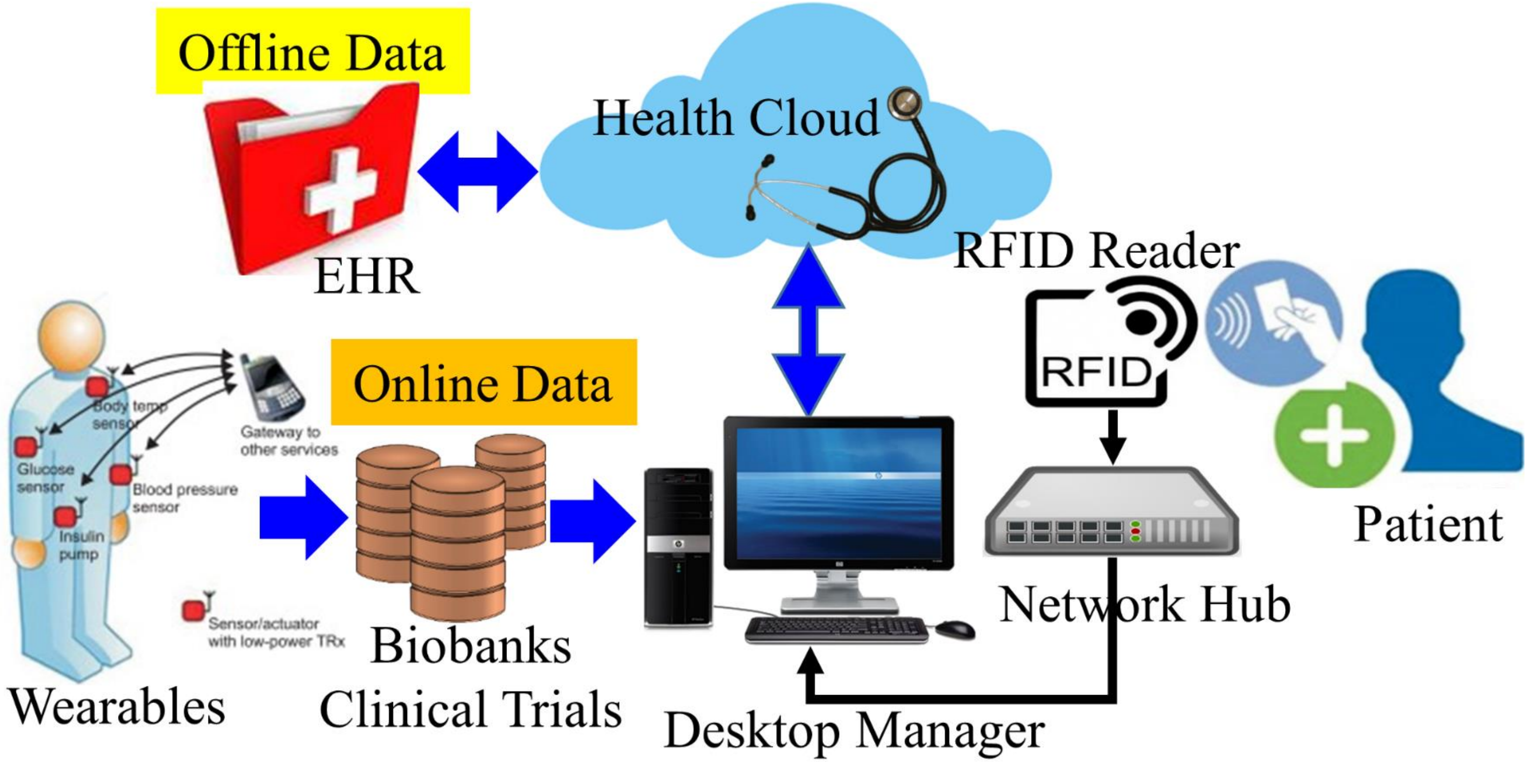
Global Network
Connecting bridge between the local network, cloud services and connected consumer devices

Connected Consumer Electronics
Smart phones, devices, cars, wearables which are connected to the Things

Overall architecture:
- ❖ A configurable dynamic global network of networks
- ❖ Systems-of-Systems

Source: Mohanty ICIT 2017 Keynote

Internet of Medical Things (IoMT)



Internet of Health Things (IoHT)

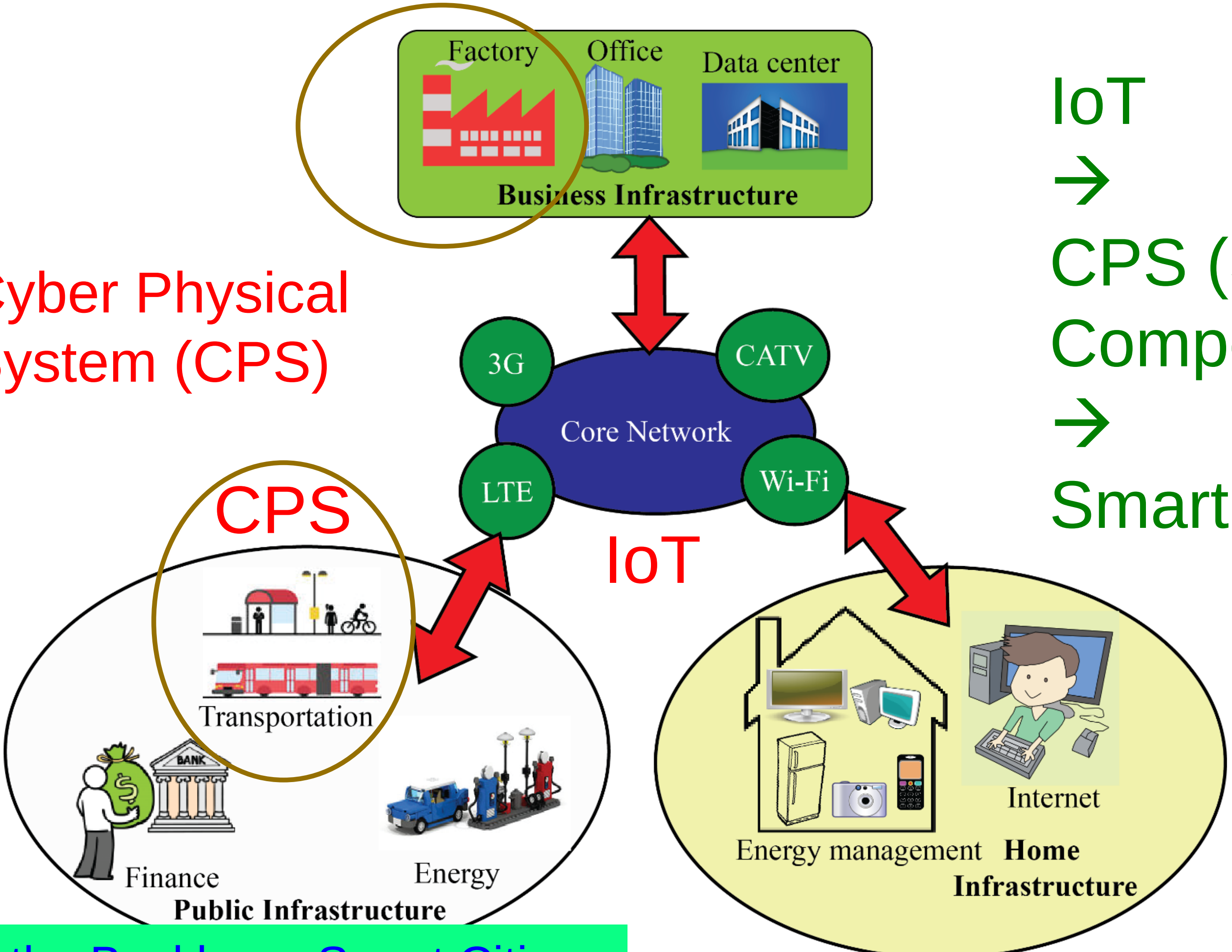
IoMT is a collection of medical devices and applications that connect to healthcare IT systems through Internet.

Source: http://www.icemiller.com/ice-on-fire-insights/publications/the-internet-of-health-things-privacy-and-security/

Source: http://internetofthingsagenda.techtarget.com/definition/IoMT-Internet-of-Medical-Things

IoT → CPS → Smart Cities

Cyber Physical System (CPS)

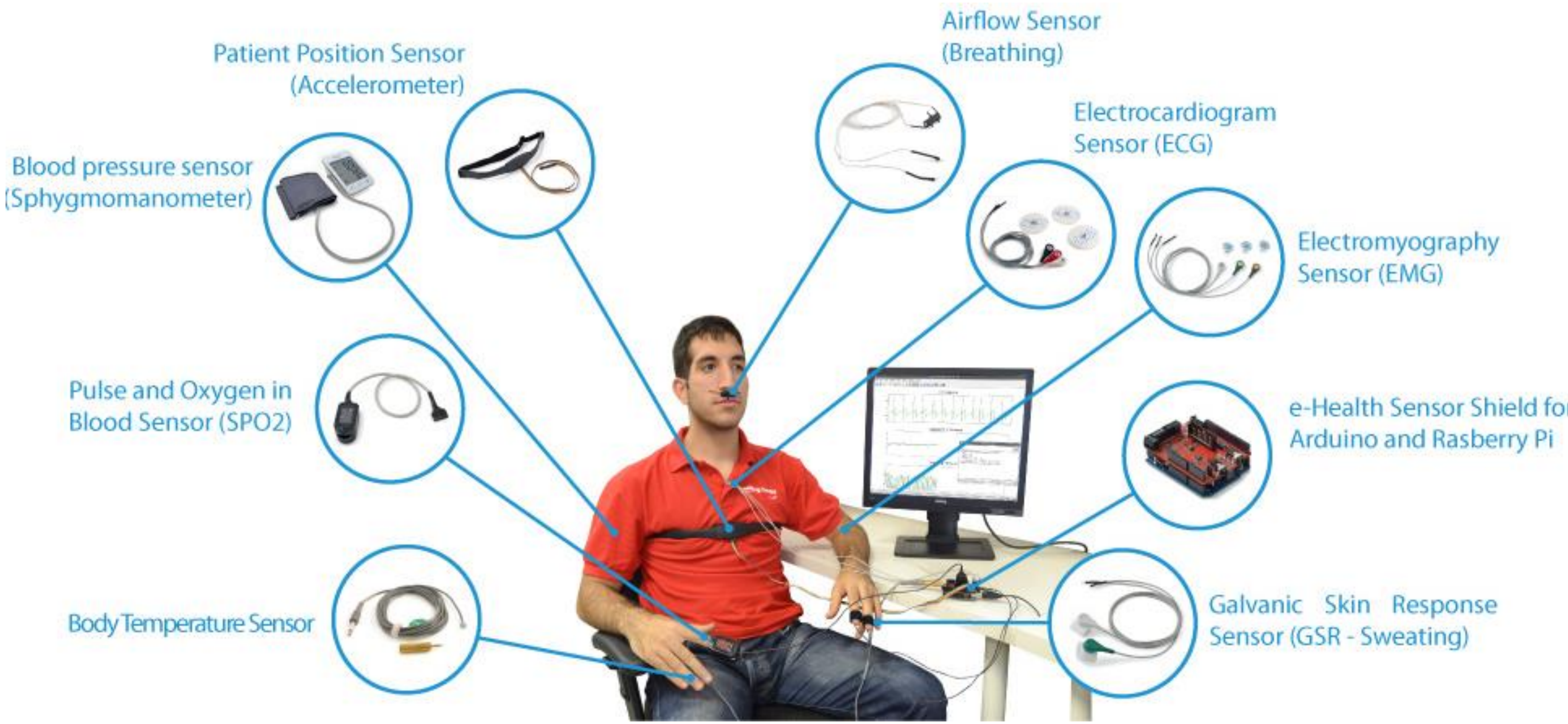


IoT
→
CPS (Smart Components)
→
Smart Cities

IoT is the Backbone Smart Cities.

Source: Mohanty 2016, CE Magazine July 2016

Sensor Technology - Healthcare

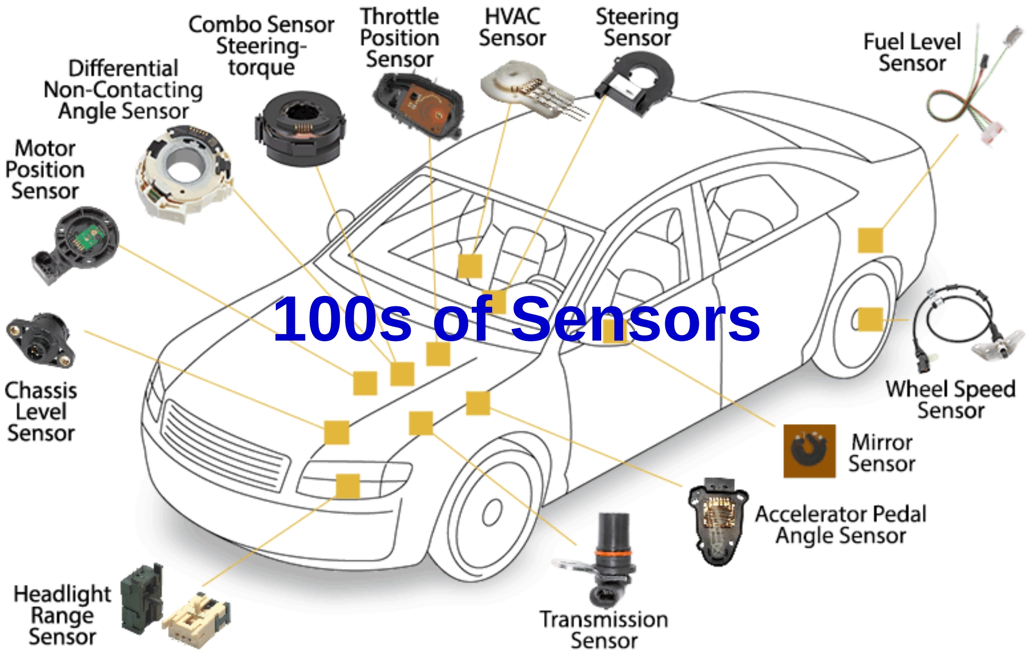


Thing ← Sensor
+ Device with its own IP address

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

Sensor Technology – Automobiles

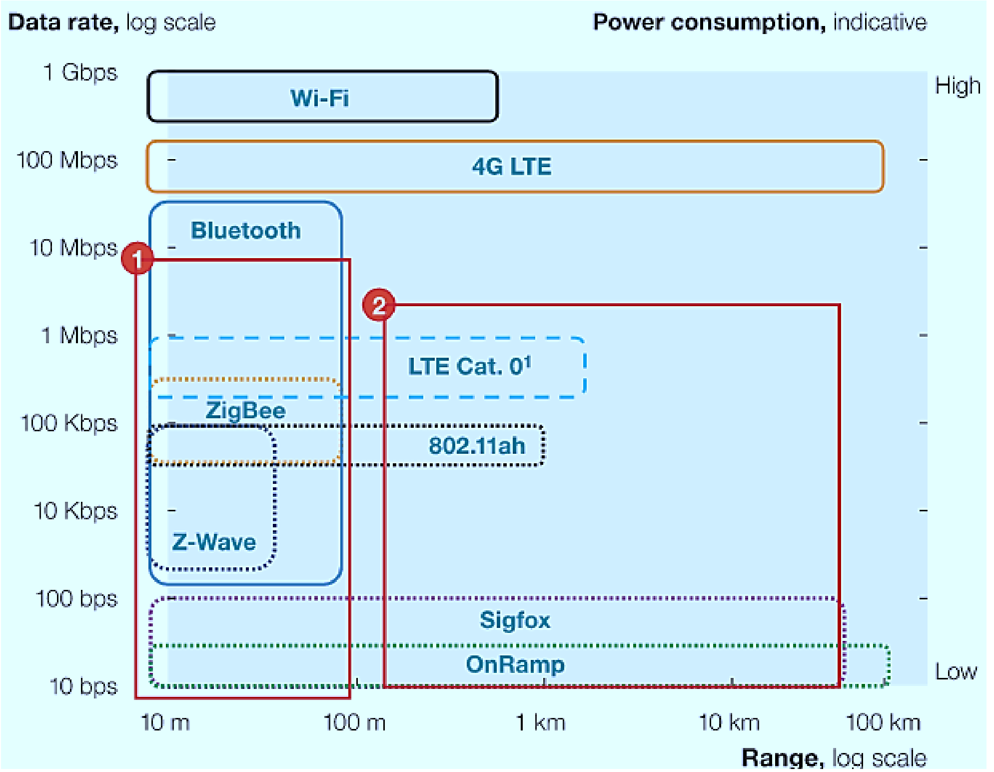
September 2018



100s of Sensors

IoT - Communications Technology

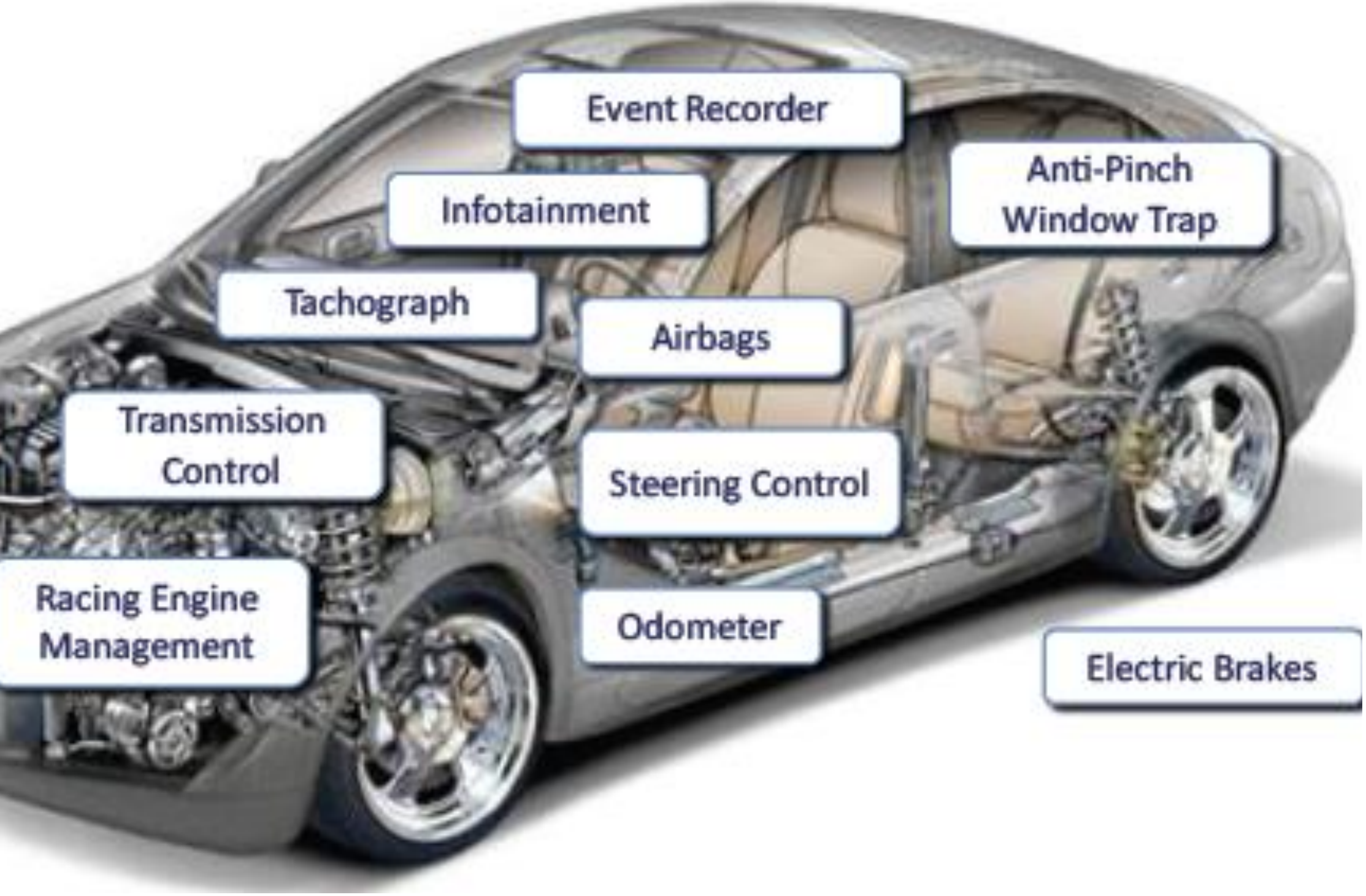
Selected IoT Communications Technology
- Bluetooth Low-Energy (BLE)
- Zigbee
- Z-Wave
- 6LowPAN
- Thread
- WiFi
- Cellular
- NFC
- Sigfox
- Neul
- LoRaWAN



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

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

Memory Technology – Car Example



Source: T. Coughlin, "The Memory of Cars [The Art of Storage]," in IEEE Consumer Electronics Magazine, vol. 5, no. 4, pp. 121-125, Oct. 2016.

Unmanned Ariel Vehicle (UAV)

Unmanned Arial Vehicles or Remotely Piloted Vehicles is an aircraft without a human pilot on board.

- Unmanned Aerial Vehicle
- Drone - remotely piloted
- Controlled autonomously

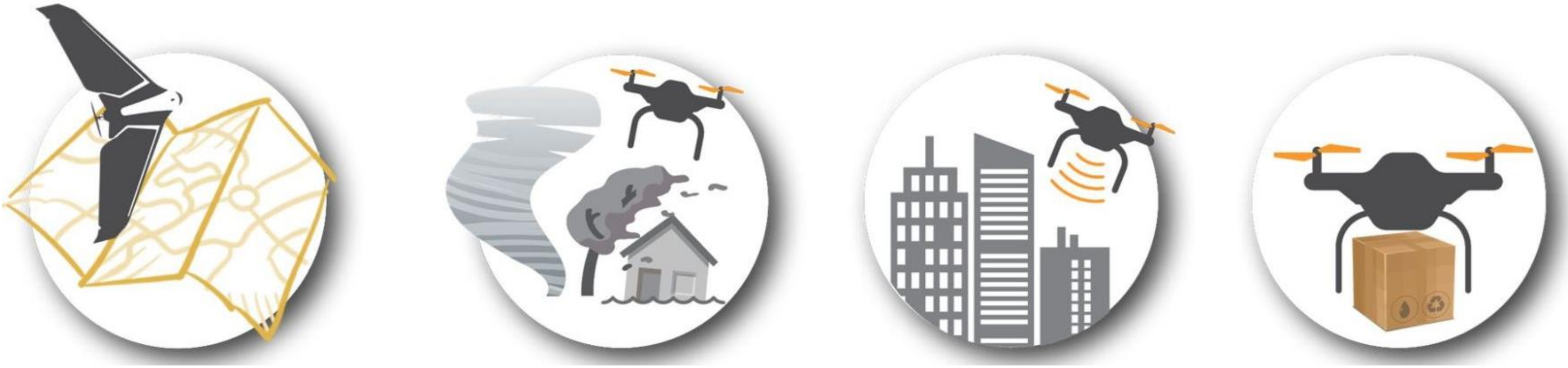
First used in Austria for military purposes during 1849.

May 2019

UAV – Smart City Applications

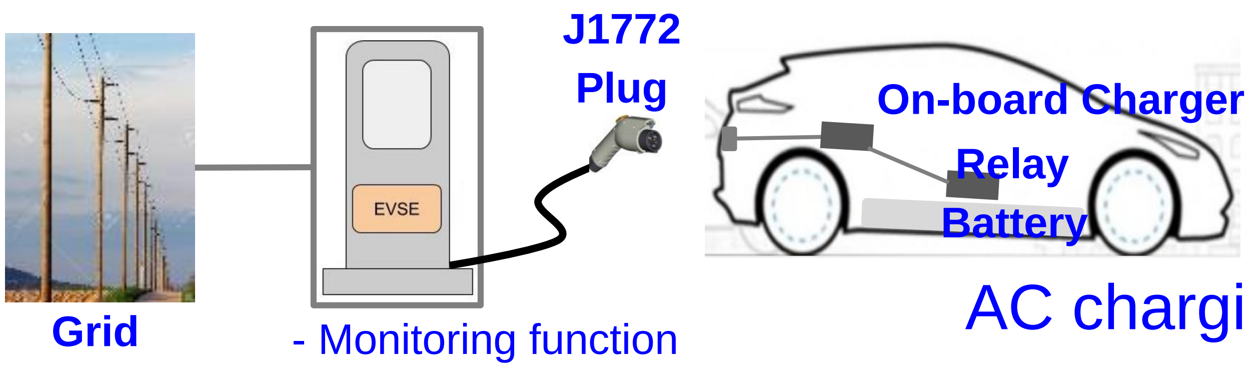
UAV Applications - 4 Categories

Data collection & surveying | Monitoring & Tracking | Temporary Infrastructure | Delivery of Goods



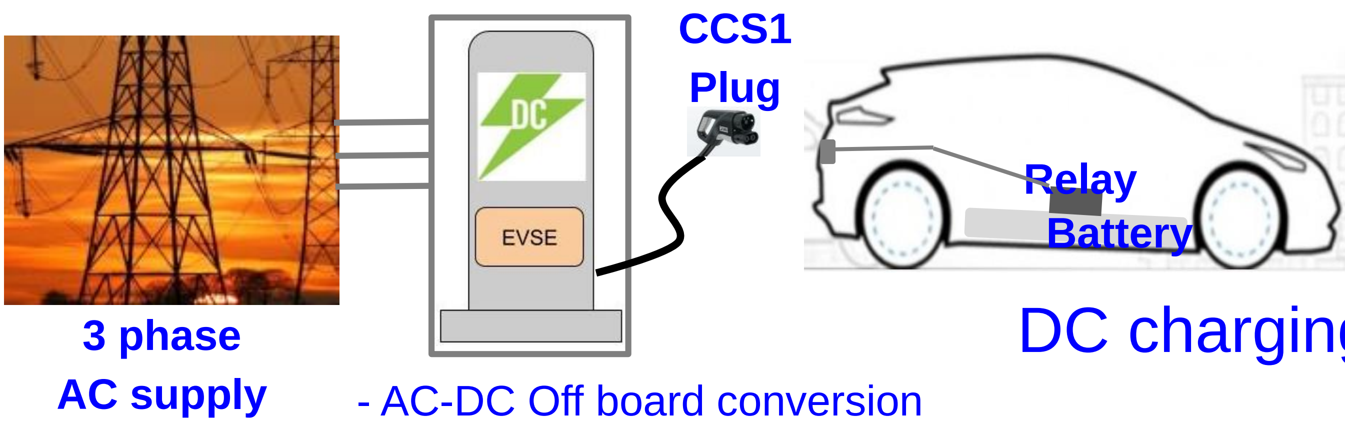
Source: Christos Kyrkou, Stelios Timotheou, Panayiotis Kolios, Theocharis Theocharides, and Christos Panayiotou, "Drones: Augmenting Our Quality of Life" IEEE Potentials Magazine, IEEE Potentials, vol. 38, no. 1, pp. 30-36, Jan.-Feb. 2019.

EV Charging Technology



AC charging station

- Monitoring function
- Communication and safety



DC charging station

- AC-DC Off board conversion
- Monitoring Power flow
- EV to grid communication
- Safety monitoring

Electric Vehicle Supply Equipment (EVSE)

Source: S. K. Rastogi, A. Sankar, K. Manglik, S. K. Mishra, and S. P. Mohanty, "Toward the Vision of All-Electric Vehicles in a Decade", IEEE Consumer Electronics Magazine (CEM), Volume 8, Issue 2, March 2019, pp. 103--107.

Artificial Intelligence Technology

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

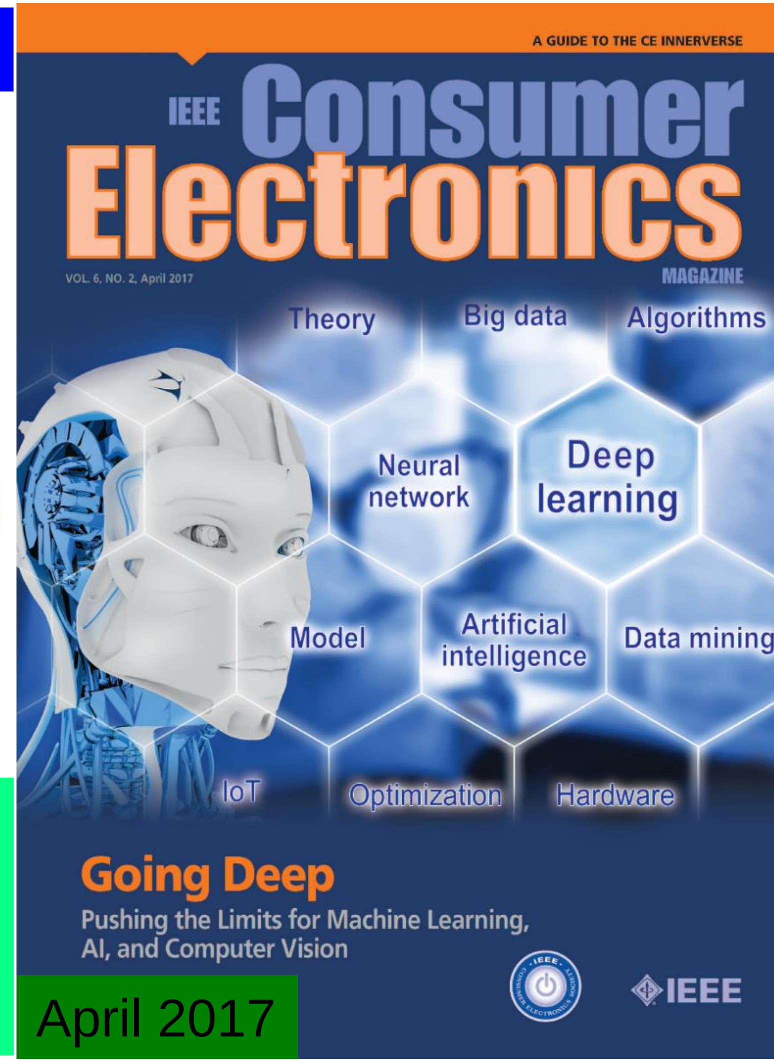
Machine Learning

Deep Learning

Tensor Processing Unit (TPU)

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

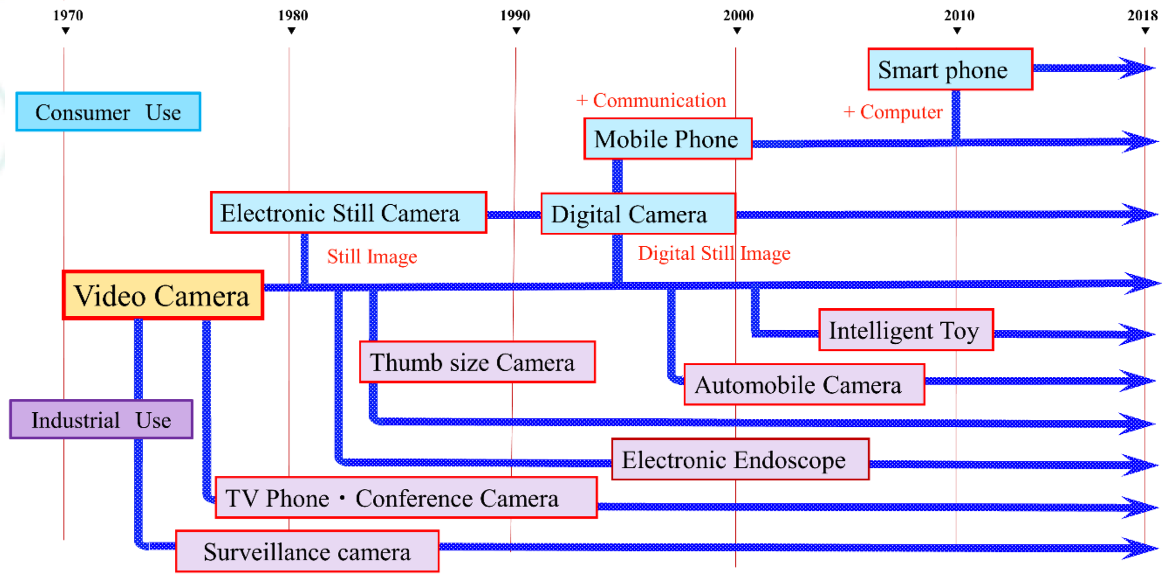
Smart City Use:
- Better analytics
- Better decision
- Faster response



April 2017

Cameras are Everywhere

July 2019



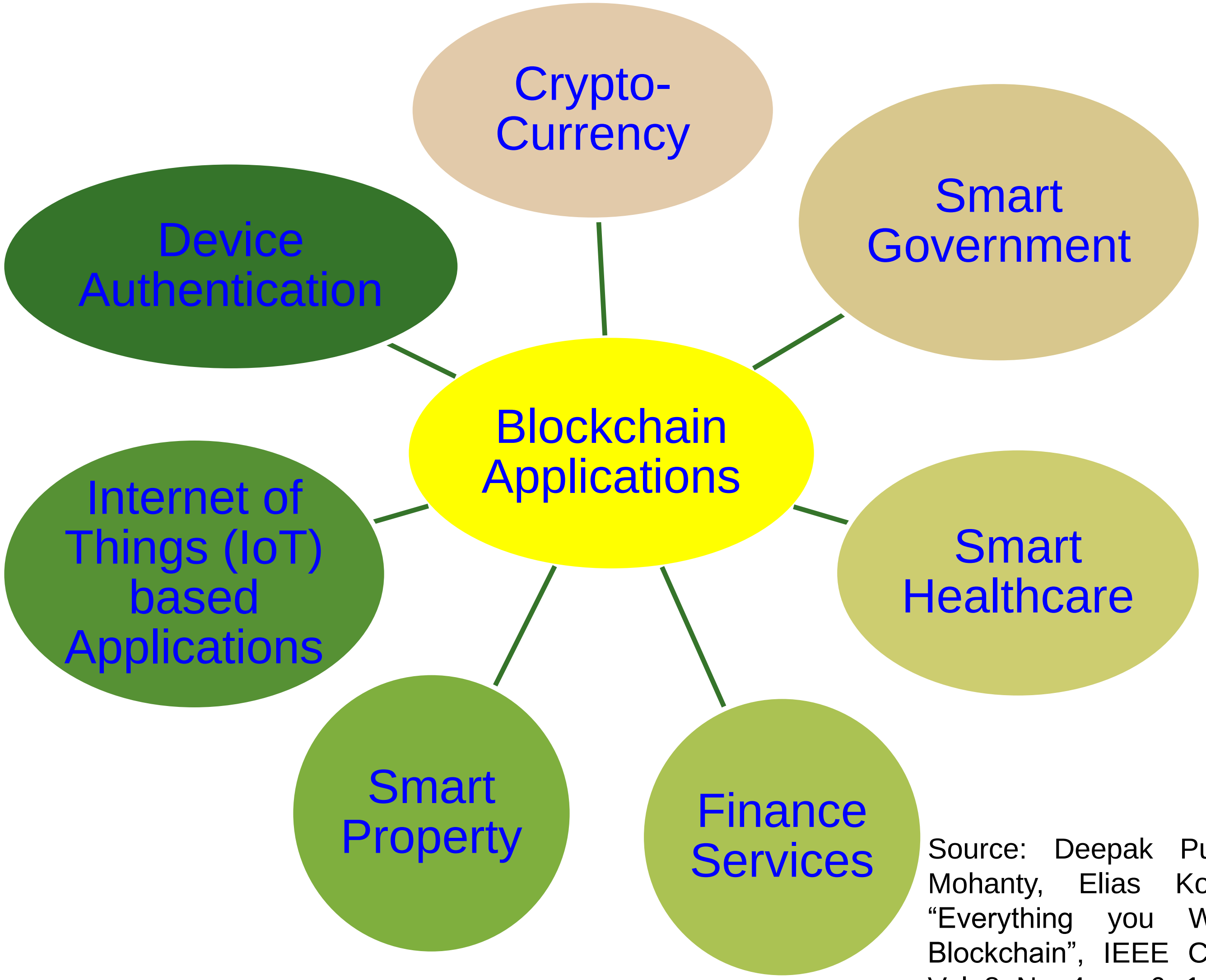
Y. Takemura, "The Development of Video-Camera Technologies: Many Innovations Behind Video Cameras Are Used for Digital Cameras and Smartphones," IEEE Consumer Electronics Magazine, vol. 8, no. 4, pp. 10-16, July 2019.

CMOS image sensors → Cameras of any size, part of any device, and placed at any location.

In 1986: 1.3 megapixels CCD sensor Kodak camera was $13,000.

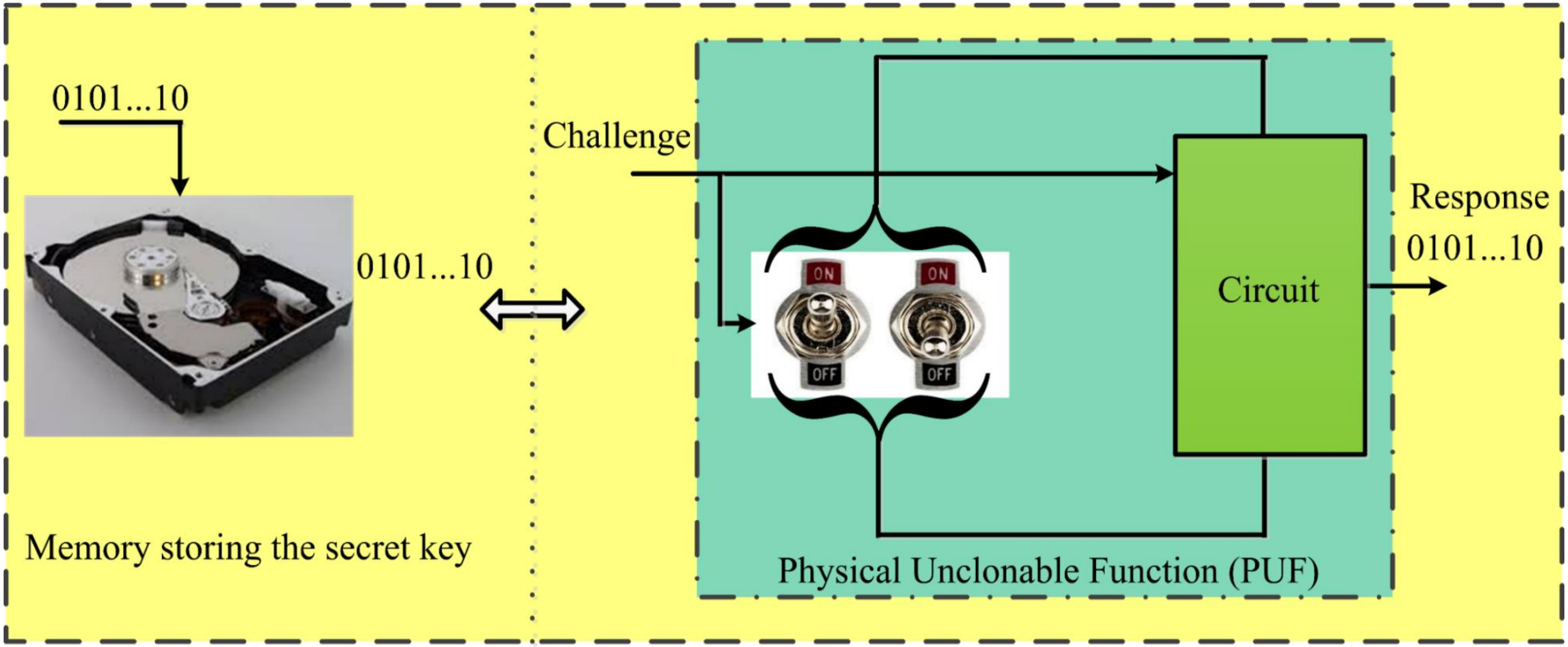
Blockchain Technology

Blockchain Applications



Source: Deepak Puthal, Nisha Malik, Saraju P. Mohanty, Elias Kougianos, and Gautam Das, “Everything you Wanted to Know about the Blockchain”, IEEE Consumer Electronics Magazine, Vol. 8, No. 4, pp. 6--14, 2018.

Security Primitives - PUF



PUFs don't store keys in digital memory, rather derive a key based on the physical characteristics of the hardware; thus secure.

Source: S. Joshi, S. P. Mohanty, and E. Kougianos, "Everything You Wanted to Know about PUFs", *IEEE Potentials Magazine*, Volume 36, Issue 6, November-December 2017, pp. 38--46.

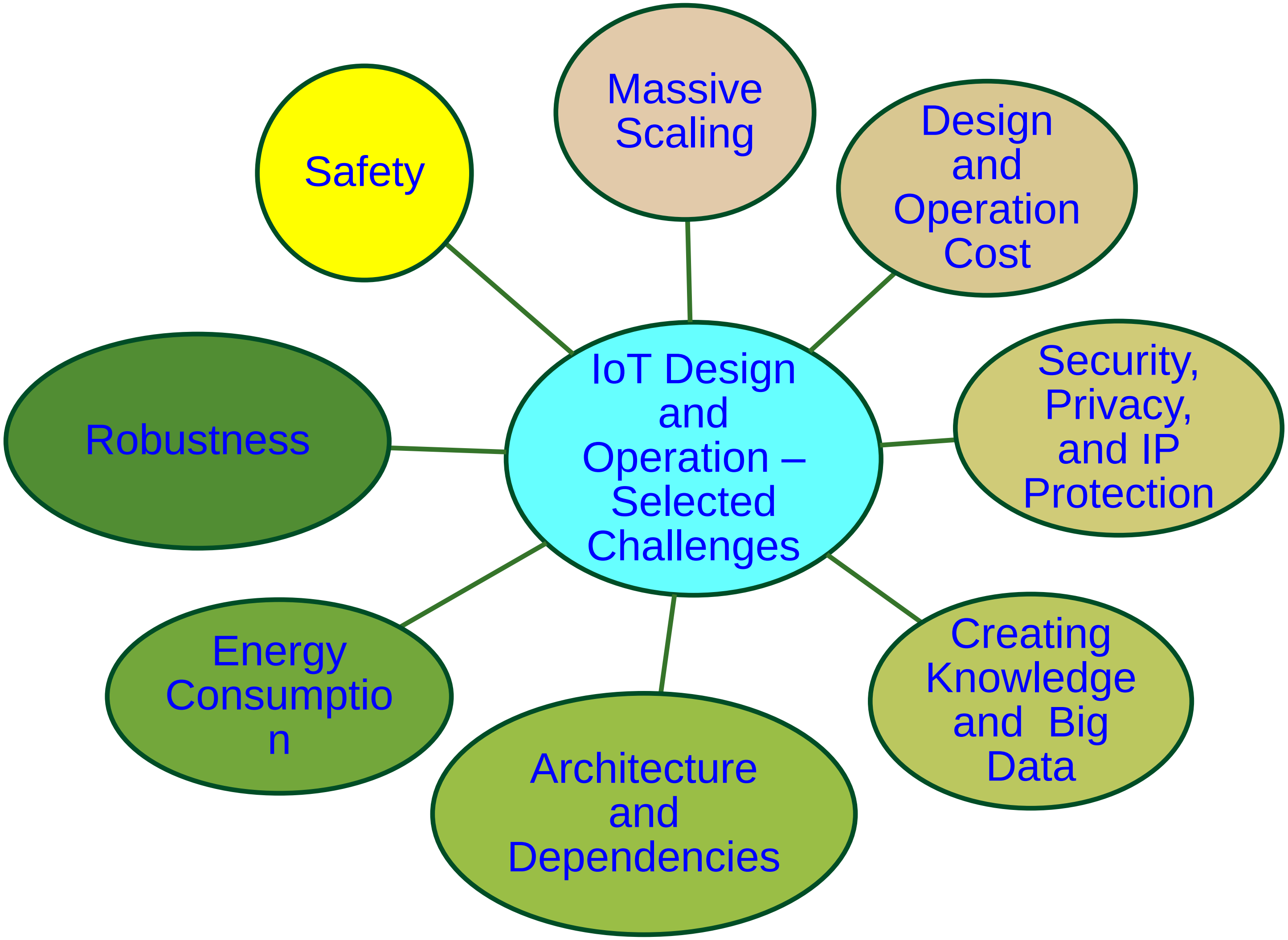
Physical Unclonable Functions (PUFs) - Applications

- Random Number Generator
- Device Authentication
- Secret Key Generation
- Software Licensing
- Memory Protection

Source: S. Joshi, S. P. Mohanty, and E. Kougianos, “Everything You Wanted to Know about PUFs”, IEEE Potentials Magazine, Volume 36, Issue 6, Nov-Dec 2017, pp. 38--46.

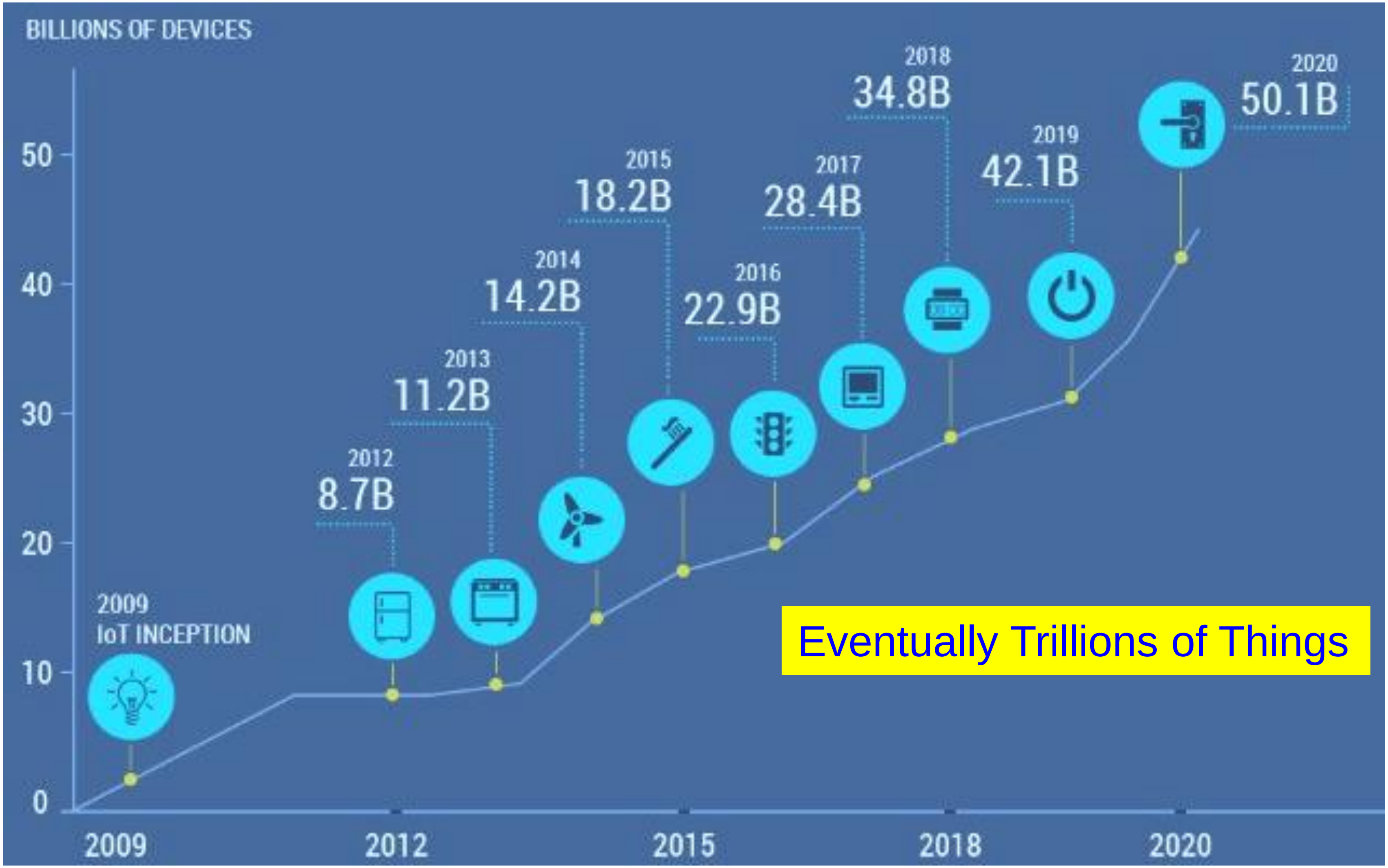
Challenges in Smart City Component and Technology Design

IoT – Selected Challenges



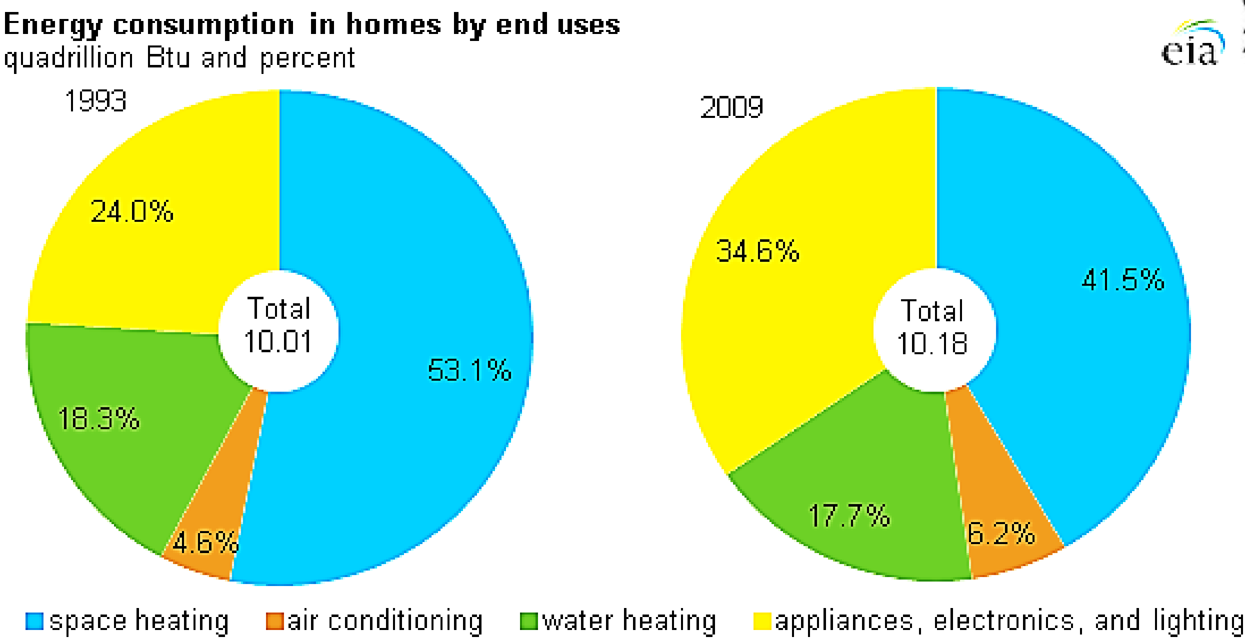
Source: Mohanty ICIT 2017 Keynote

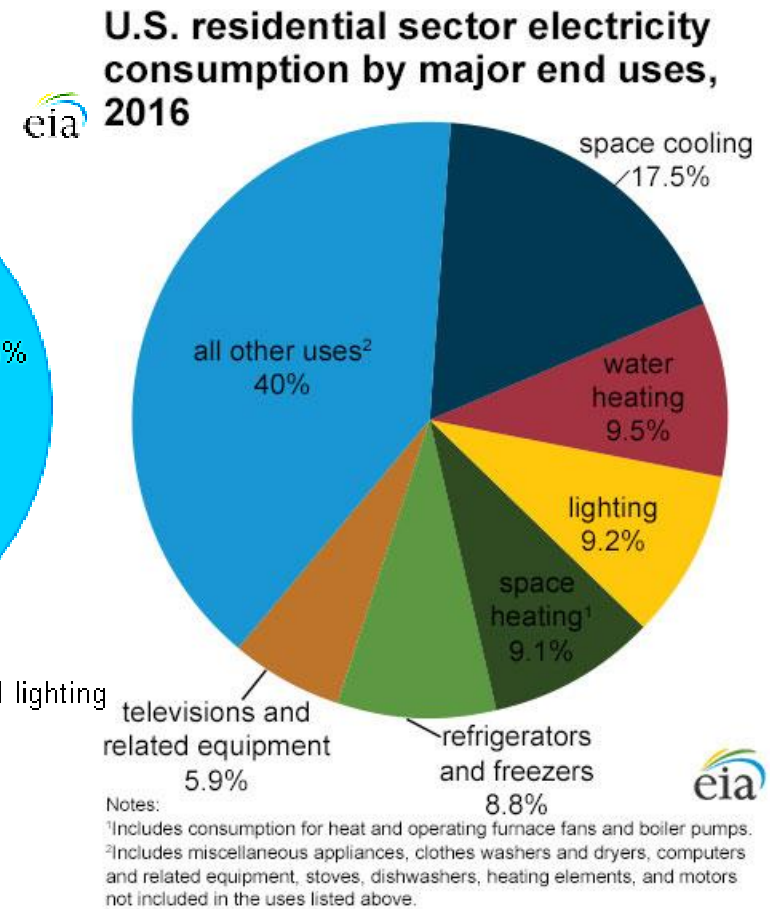
Massive Growth of Sensors/Things



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

Consumer Electronics Demand More and More Energy



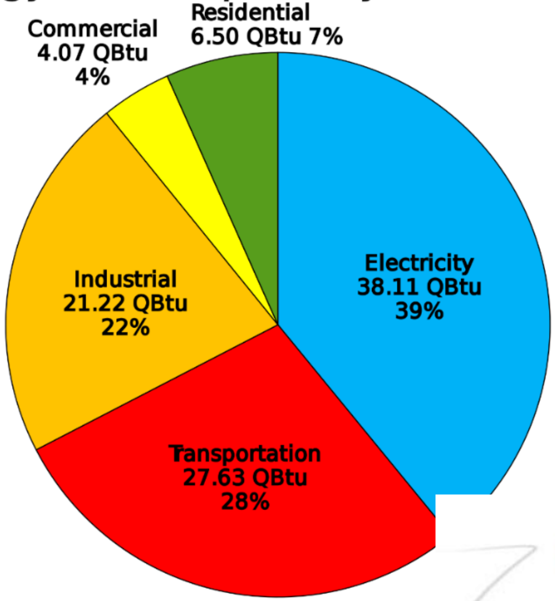


Quadrillion BTU (or quad): 1 quad = 10^{15} BTU = 1.055 Exa Joule (EJ).

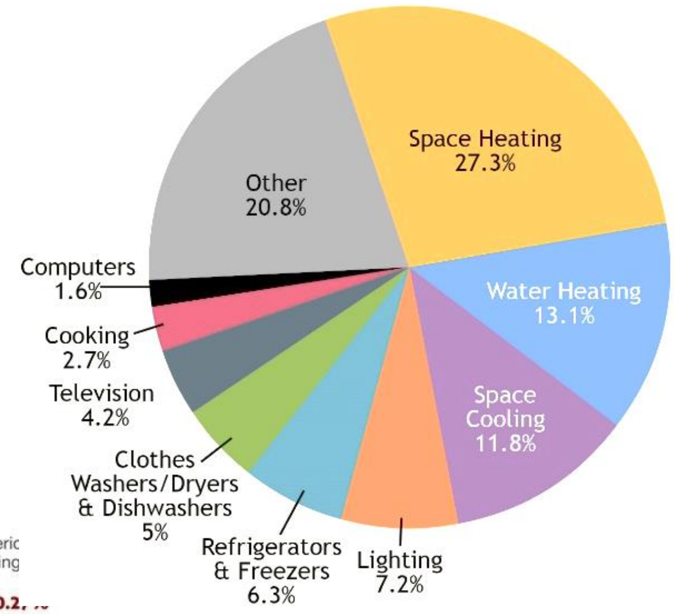
Source: U.S. Energy Information Administration.

Energy Consumption

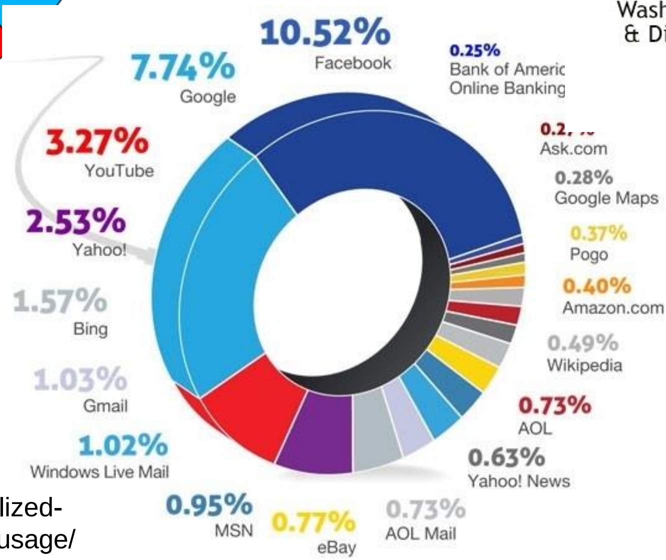
Energy Consumption by Sector (2015)



Energy Usage in the U.S. Residential Sector in 2015



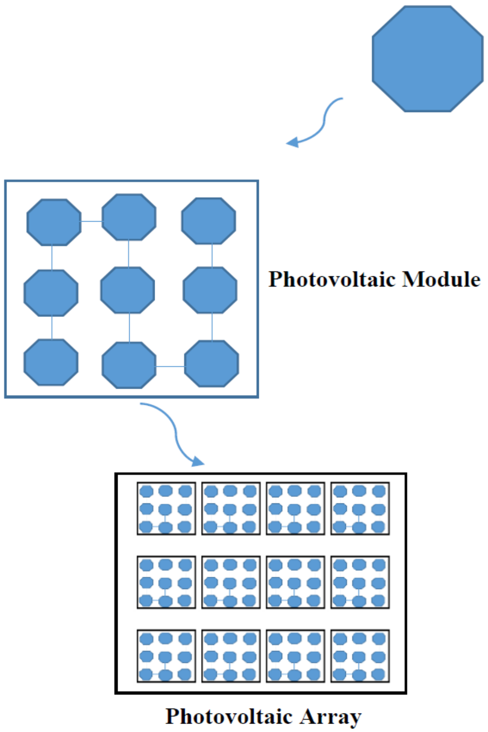
Data Center Power Usage



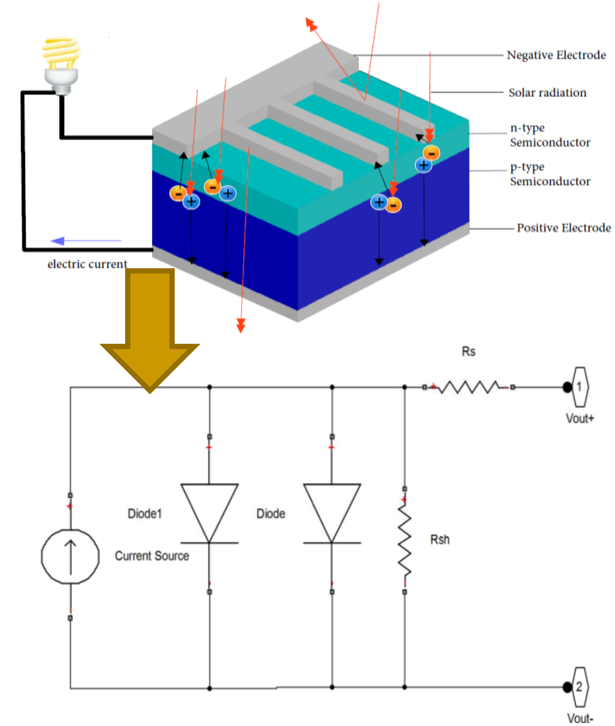
Individual Level: Imagine how often we charge our portable CE!

Source: https://www.engadget.com/2011/04/26/visualized-ring-around-the-world-of-data-center-power-usage/

Energy Conversion Efficiency



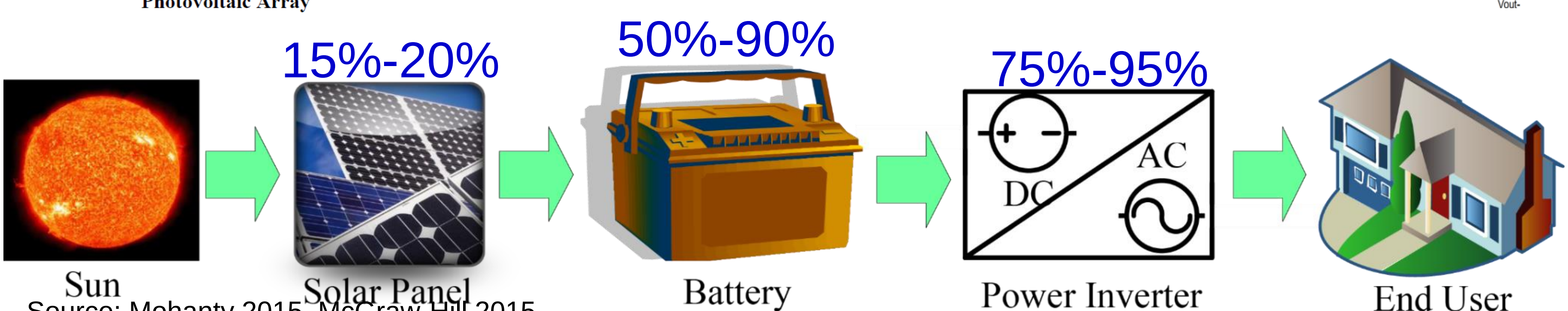
Small solar cells in CE systems to big solar panels in smart grids.



Solar Cell Efficiency:

Research stage: 46%

Commercial: 18%



Source: Mohanty 2015, McGraw-Hill 2015

Energy Storage Efficiency and Safety

One 787 Battery: 12 Cells / 32 V DC

Source: http://www.newairplane.com

- Boeing 787's across the globe were grounded.

Smartphone Battery

Security, Privacy, and IP Rights

Hardware Trojan

Counterfeit Hardware

July 2017

Source: Mohanty ICIT 2017 Keynote

CE Systems – Diverse Security/ Privacy/ Ownership Requirements

Medical Devices

RFID Chip

Pace maker

Insulin Pump

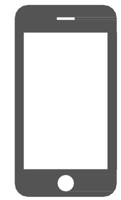
Heart Rate Monitor

Home Devices

Smart Coffee Maker

Smart Thermostat

Personal Devices



Smart Phones/ Tablets

Wearable Devices

Smart Clothing

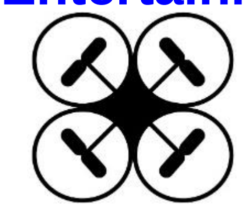
Smart watch

Business Devices

Smart Payment Systems

ATM/Banking Systems

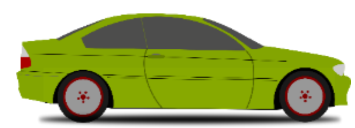
Entertainment Devices



Drones /UAVs

Video Games

Transportation Devices



Smart Vehicles/ Autonomous Vehicles

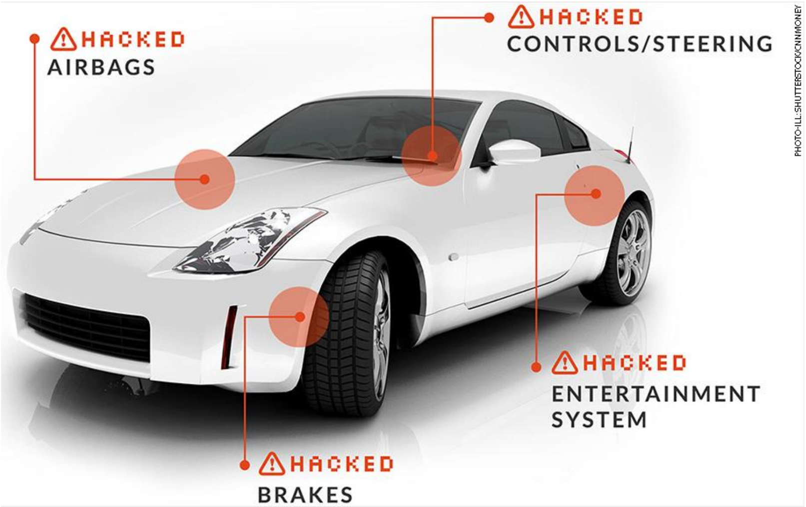
Smart Traffic Controllers

Source: D. A. Hahn, A. Munir, and S. P. Mohanty, “Security and Privacy Issues in Contemporary Consumer Electronics”, IEEE Consumer Electronics Magazine (CEM), Volume 8, Issue 1, January 2019, pp. 95--99.

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/

Smart Healthcare - Security 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

Source: Mohanty iSES 2018 Keynote

Implantable Medical Devices - Attacks

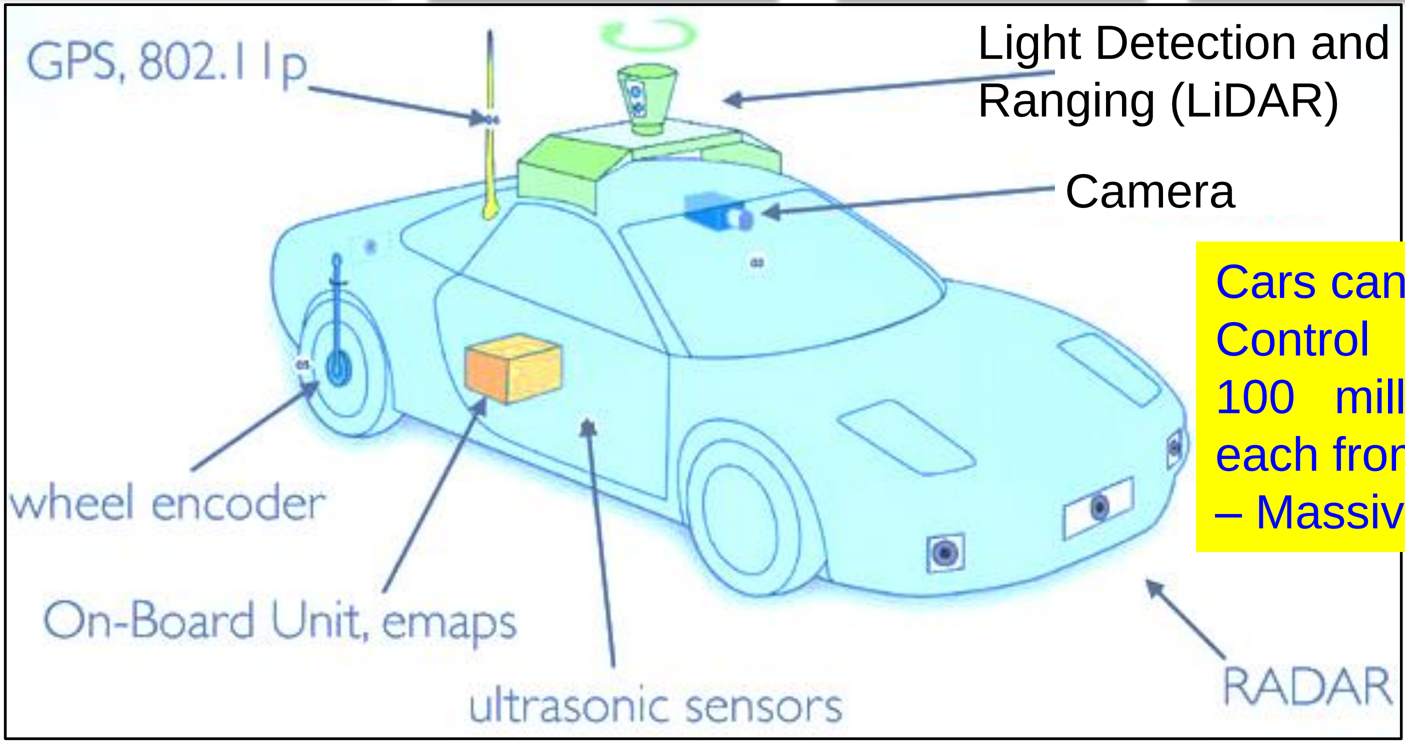
- The vulnerabilities affect implantable cardiac devices and the external equipment used to communicate with them.
- The devices emit RF signals that can be detected up to several meters from the body.
- A malicious individual nearby could conceivably hack into the signal to jam it, alter it, or snoop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

CE System Security – Smart Car

Selected Attacks on Autonomous Cars

- Replay
- Relay
- Jamming
- Spoofing
- Tracking



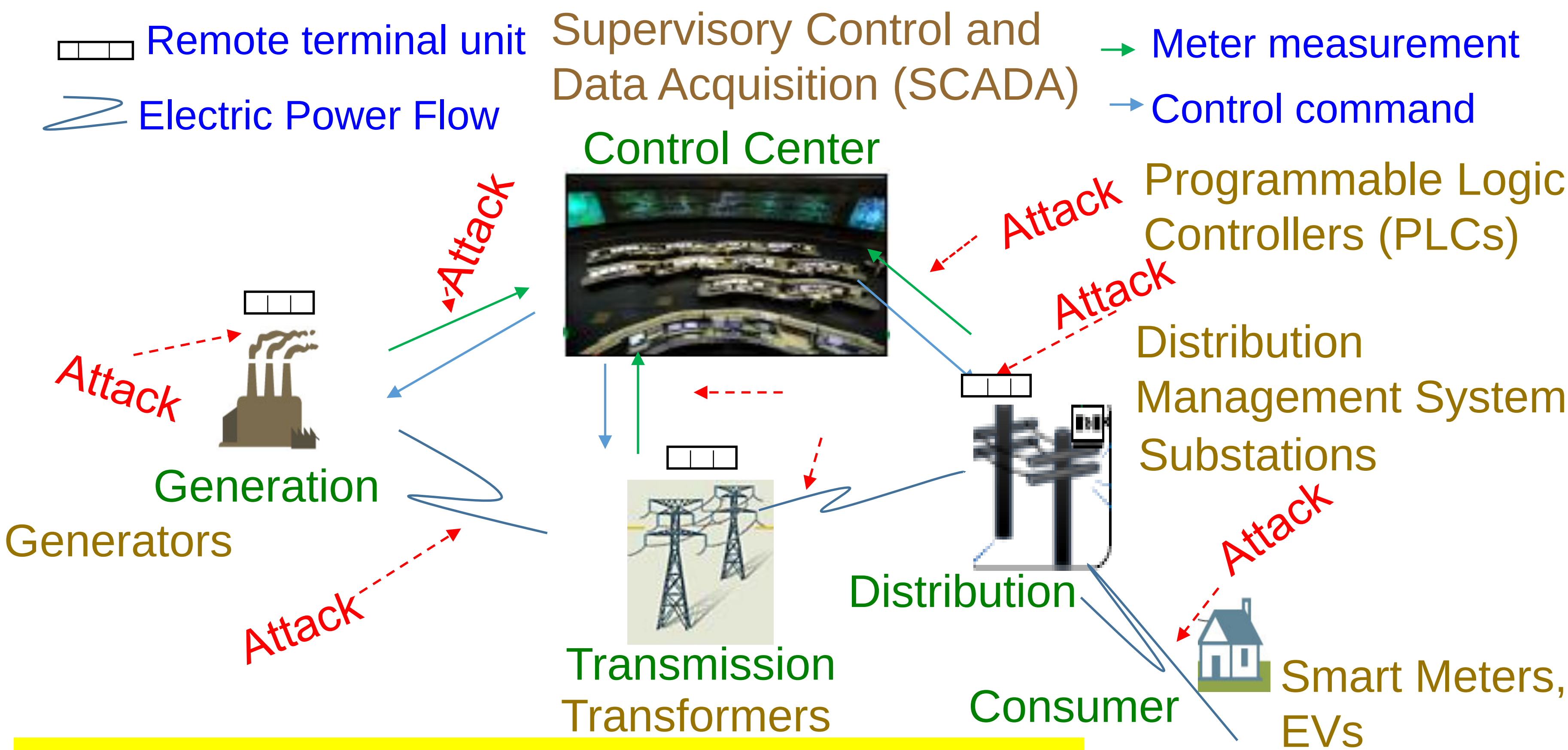
Cars can have 100 Electronic Control Units (ECUs) and 100 million lines of code, each from different vendors – Massive security issues.

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

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

Source: Petit 2015: IEEE-TITS Apr 2015

Smart Grid - Vulnerability



ICT components of smart grid is cyber vulnerable.

Source: (1) 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, March 2019.
(2)https://www.enisa.europa.eu/topics/critical-information-infrastructures-and-services/smart-grids/smart-grids-and-smart-metering/ENISA_Annex%20II%20-%20Security%20Aspects%20of%20Smart%20Grid.pdf

Smart Grid - Attacks

Vulnerabilities

Threats

- **Security group knowledge**
  - Management deficiencies of network access rules
  - Inaccurate critical assests documentation
- **Information leakage**
  - Unencrypted services in IT systems
  - 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 attack

Impacts

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

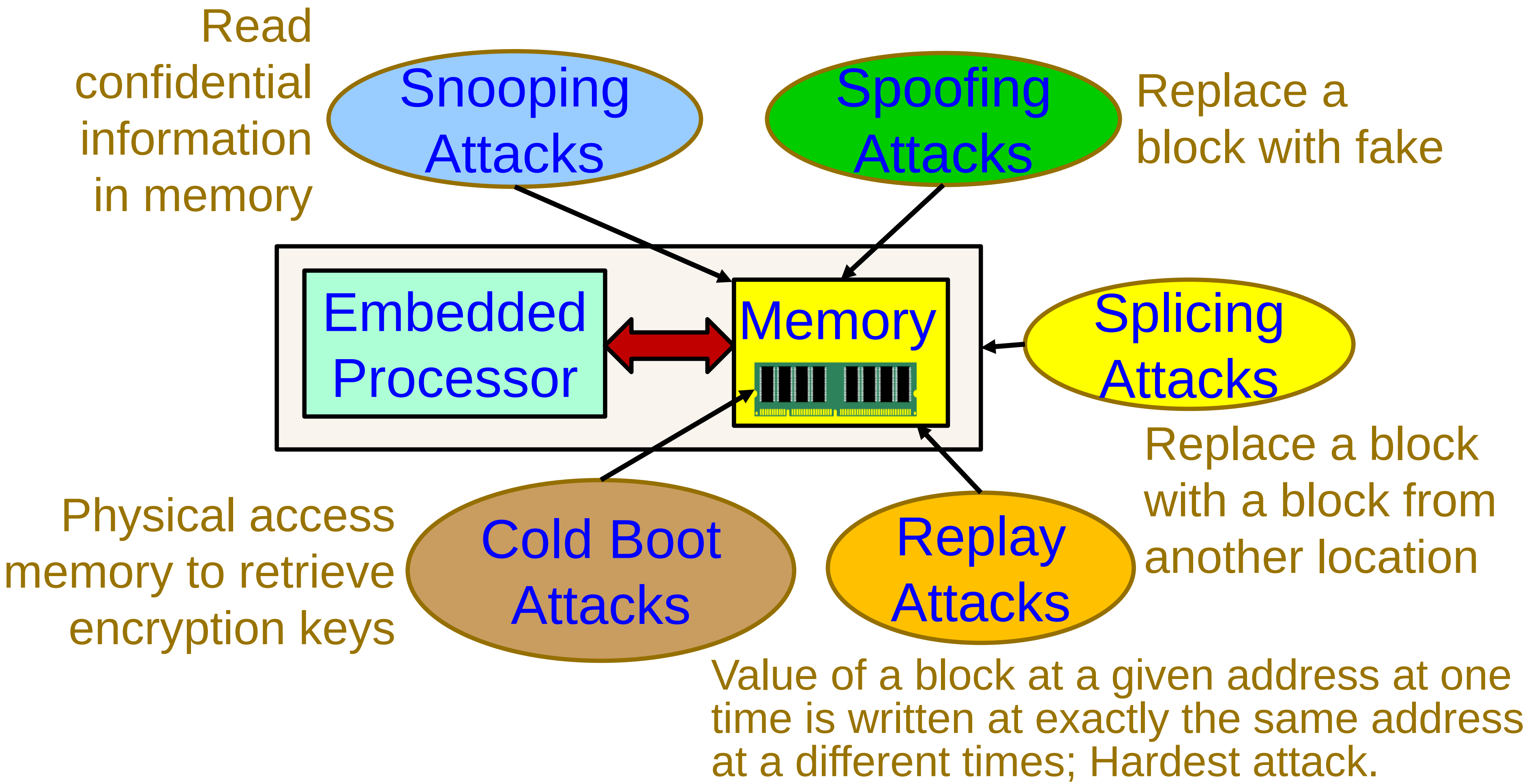
Source: R. K. Kaur, L. K. Singh and B. Pandey, "Security Analysis of Smart Grids: Successes and Challenges," IEEE Consumer Electronics Magazine, vol. 8, no. 2, pp. 10-15, March 2019.

Electromagnetic Pulse (EMP) Attack

- An electromagnetic pulse (EMP) is the electric wave produced by nuclear blasts which can knocking out electronics and the electrical grid as far as 1,000 miles away.
- The disruption could cause catastrophic damage and loss of life if power is not restored or backed up quickly.

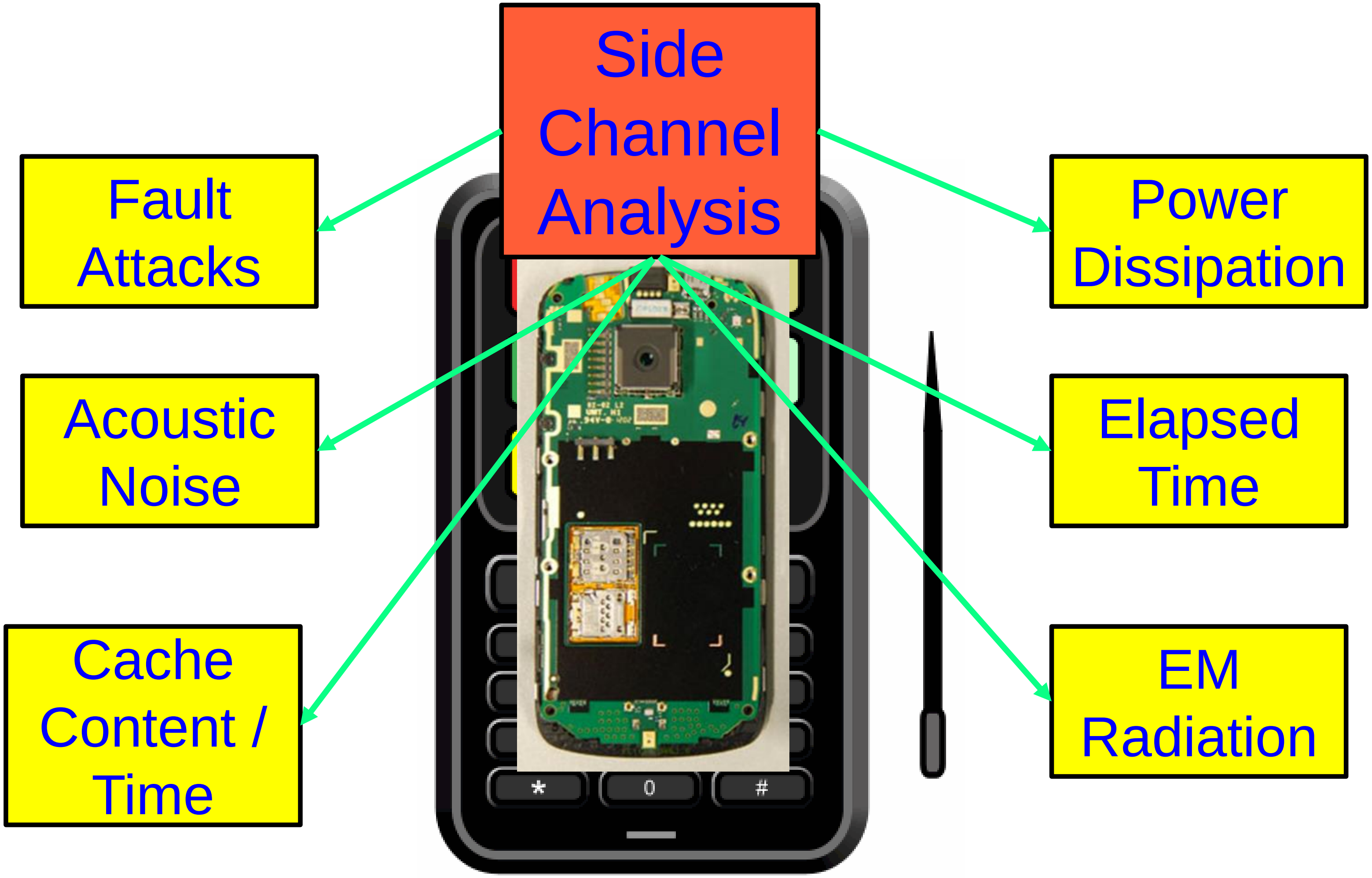
Source: http://bwcentral.org/2016/06/an-electromagnetic-pulse-emp-nuclear-attack-may-end-modern-life-in-america-overnight/

Memory Attacks



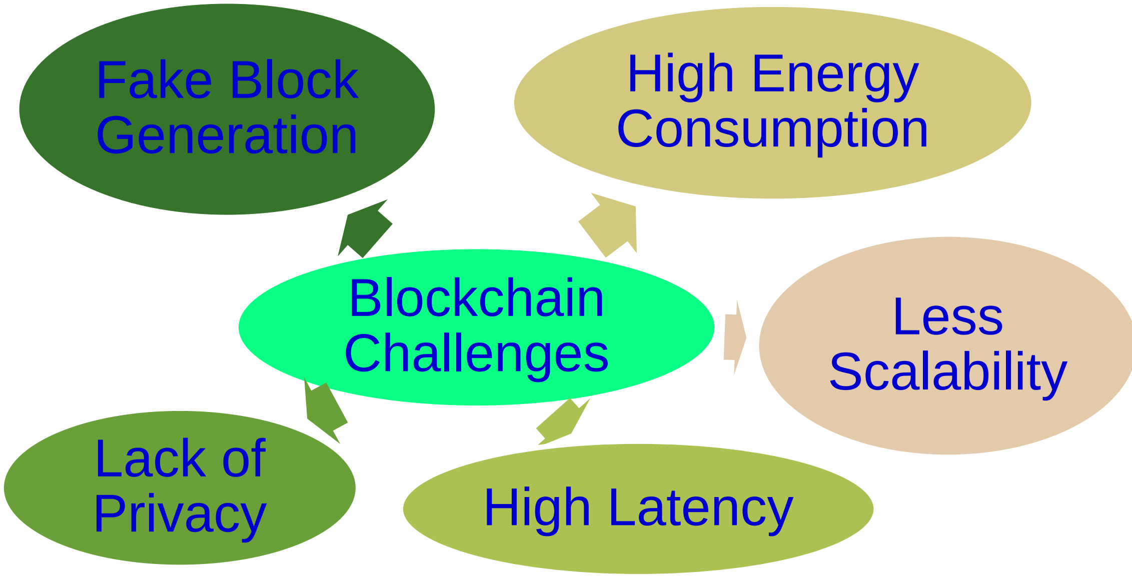
Source: S. Nimgaonkar, M. Gomathisankaran, and S. P. Mohanty, "TSV: A Novel Energy Efficient Memory Integrity Verification Scheme for Embedded Systems", Elsevier Journal of Systems Architecture, Vol. 59, No. 7, Aug 2013, pp. 400-411.

Side Channel Analysis Attacks



Source: Parameswaran Keynote iNIS-2017

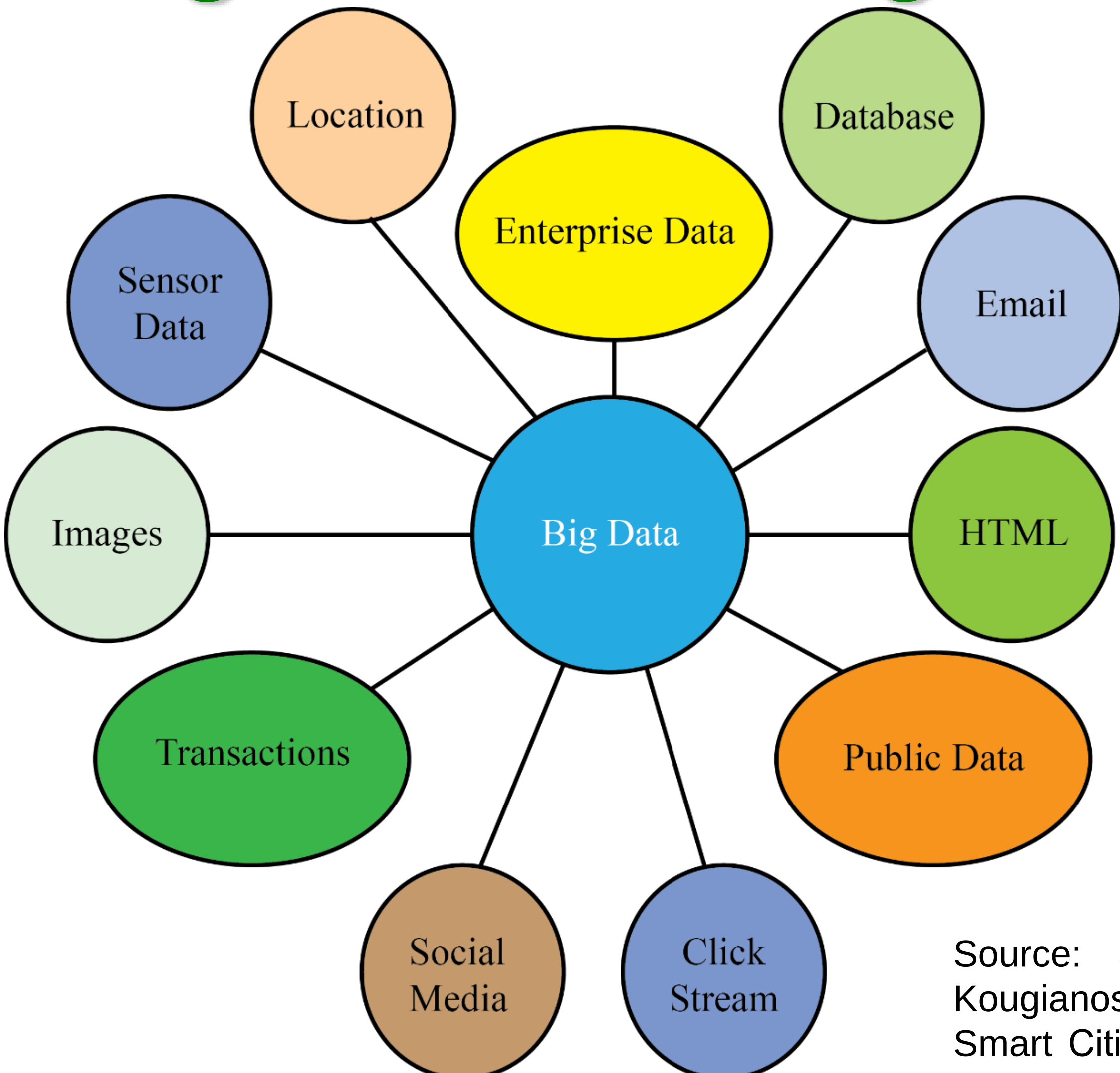
Blockchain - Challenges



- Energy for mining of 1 bitcoin → 2 years consumption of a US household.
- Energy consumption for each bitcoin transaction → 80,000X of energy consumption of a credit card processing.

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.

Bigdata Challenge in Smart Cities

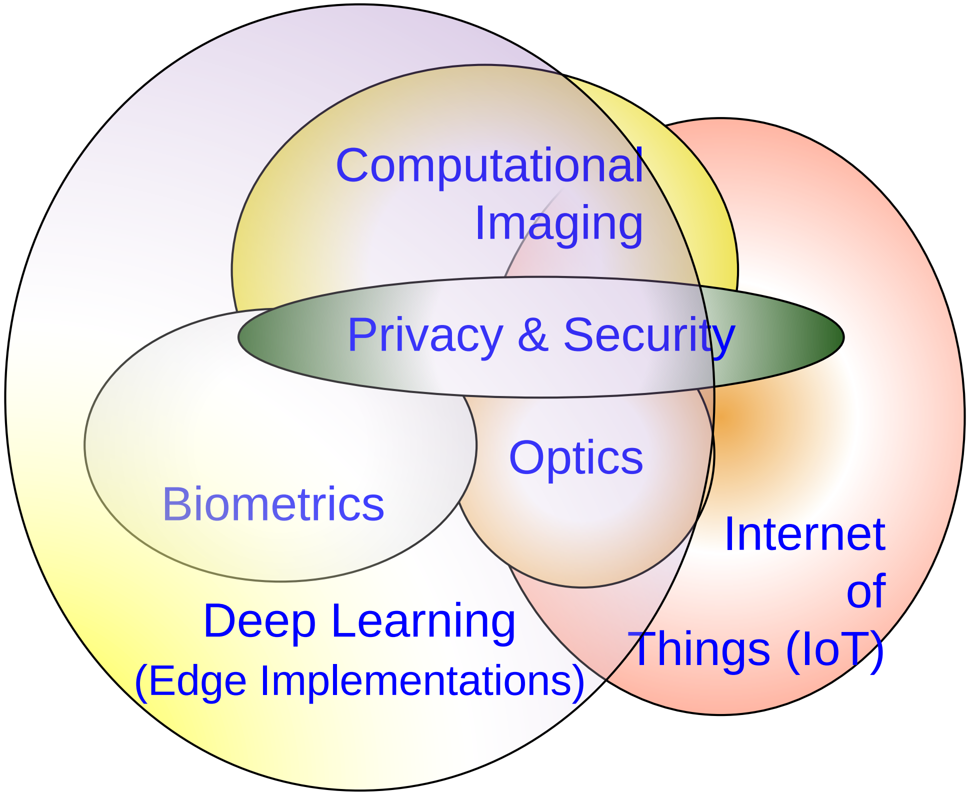


Sensors, social networks, web pages, image and video applications, and mobile devices generate more than 2.5 quintillion bytes data per day.

Source: S. P. Mohanty, U. Choppali, and E. Kougianos, "Everything You wanted to Know about Smart Cities", IEEE Consumer Electronics Magazine (CEM), Volume 5, Issue 3, July 2016, pp. 60--70.

Bigdata → Intelligence – Deep Learning is the Key

- "DL at the Edge" overlaps all of these research areas.
- New Foundation Technologies, enhance data curation, improved AI, and Networks accuracy.

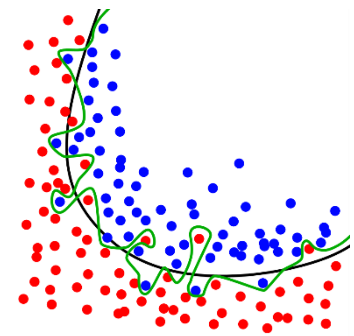


Source: Corcoran Keynote 2018

ML Modeling Issues

Machine Learning Issues

- High Energy Requirements
- High Computational Resource Requirements
- Large Amount of Data Requirements
- Underfitting/Overfitting Issue
- Class Imbalance Issue
- Fake Data Issue

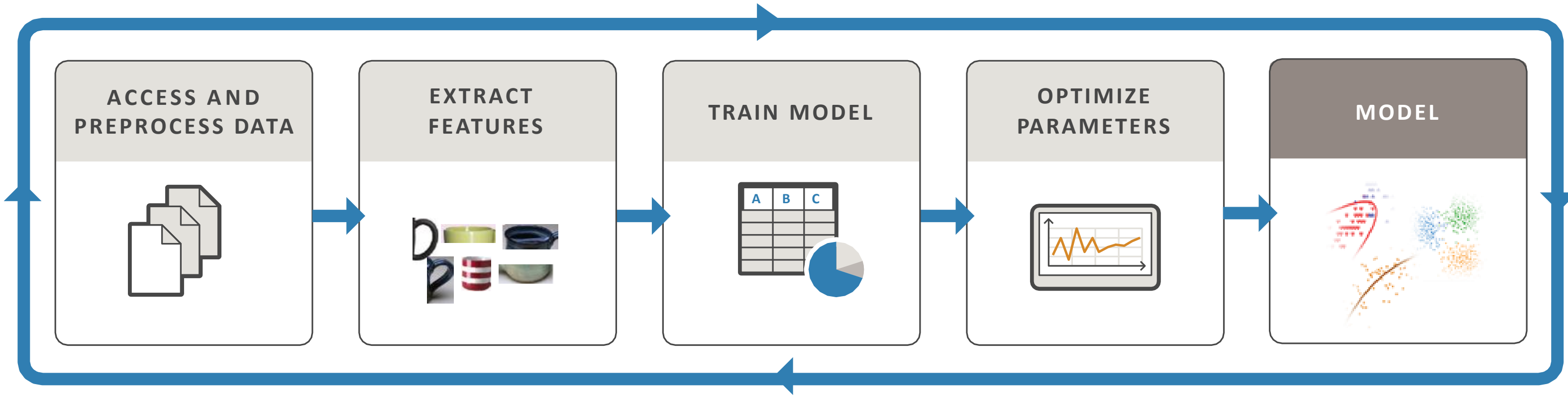


Source: Mohanty ISCT Keynote 2019

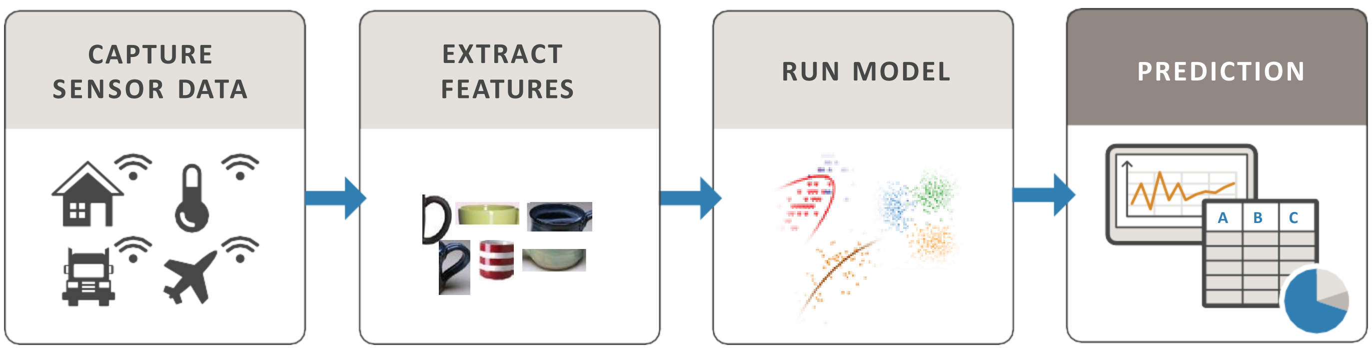
Deep Neural Network (DNN) - Resource and Energy Costs

TRAIN: Iterate until you achieve satisfactory performance.

Needs Significant:
- ➢ Resource
- ➢ Energy



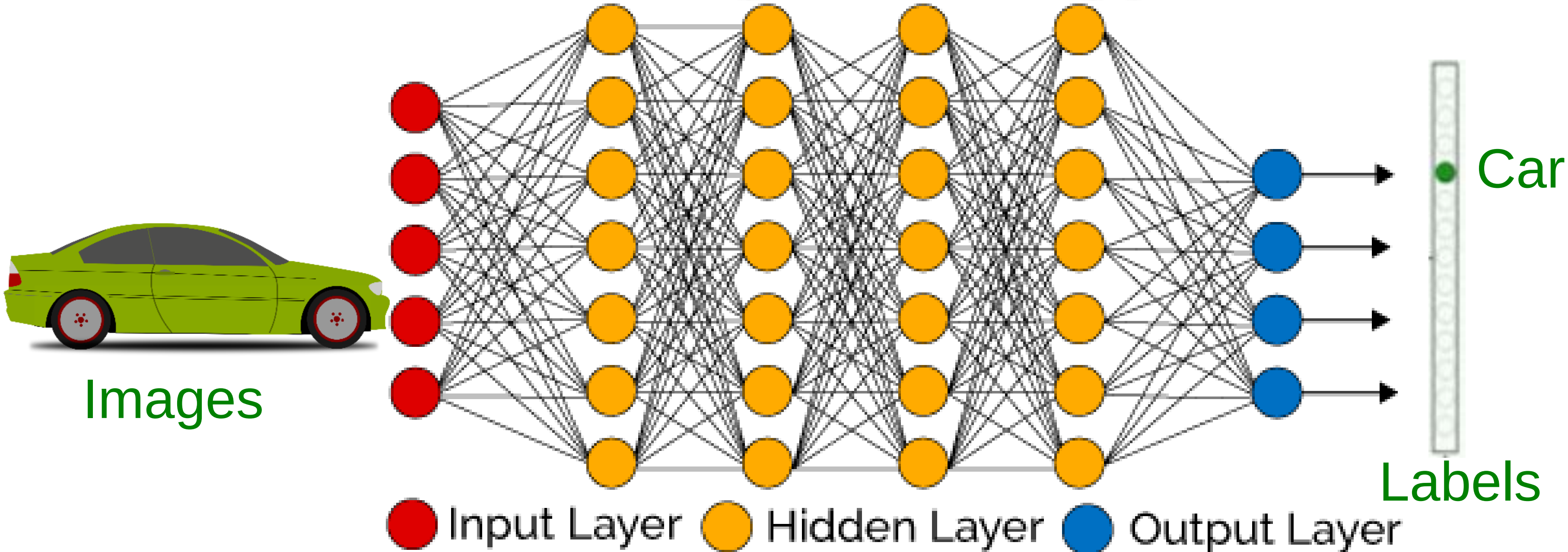
PREDICT: Integrate trained models into applications.



Needs:
- ➢ Resource
- ➢ Energy

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

DNN Training - Energy Issue

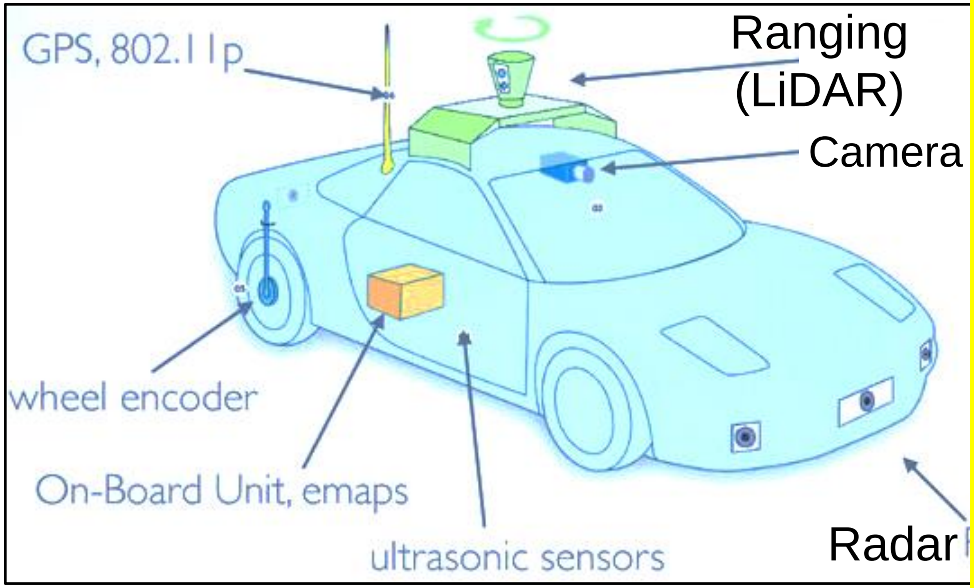


- DNN considers many training parameters, such as the size, the learning rate, and initial weights.
- High computational resource and time: For sweeping through the parameter space for optimal parameters.
- DNN needs: Multicore processors and batch processing.
- DNN training happens mostly in cloud not at edge or fog.

Source: Mohanty iSES 2018 Keynote

Autonomous/Driverless/Self-Driving Car

Smart Car



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

Level 0
- Complete Driver Control

Level 1
- Most functions by driver, some functions automated.

Level 2
- At least one driver-assistance system is automated.

Level 3
- Complete shift of critical safety systems to vehicle; Driver can intervene

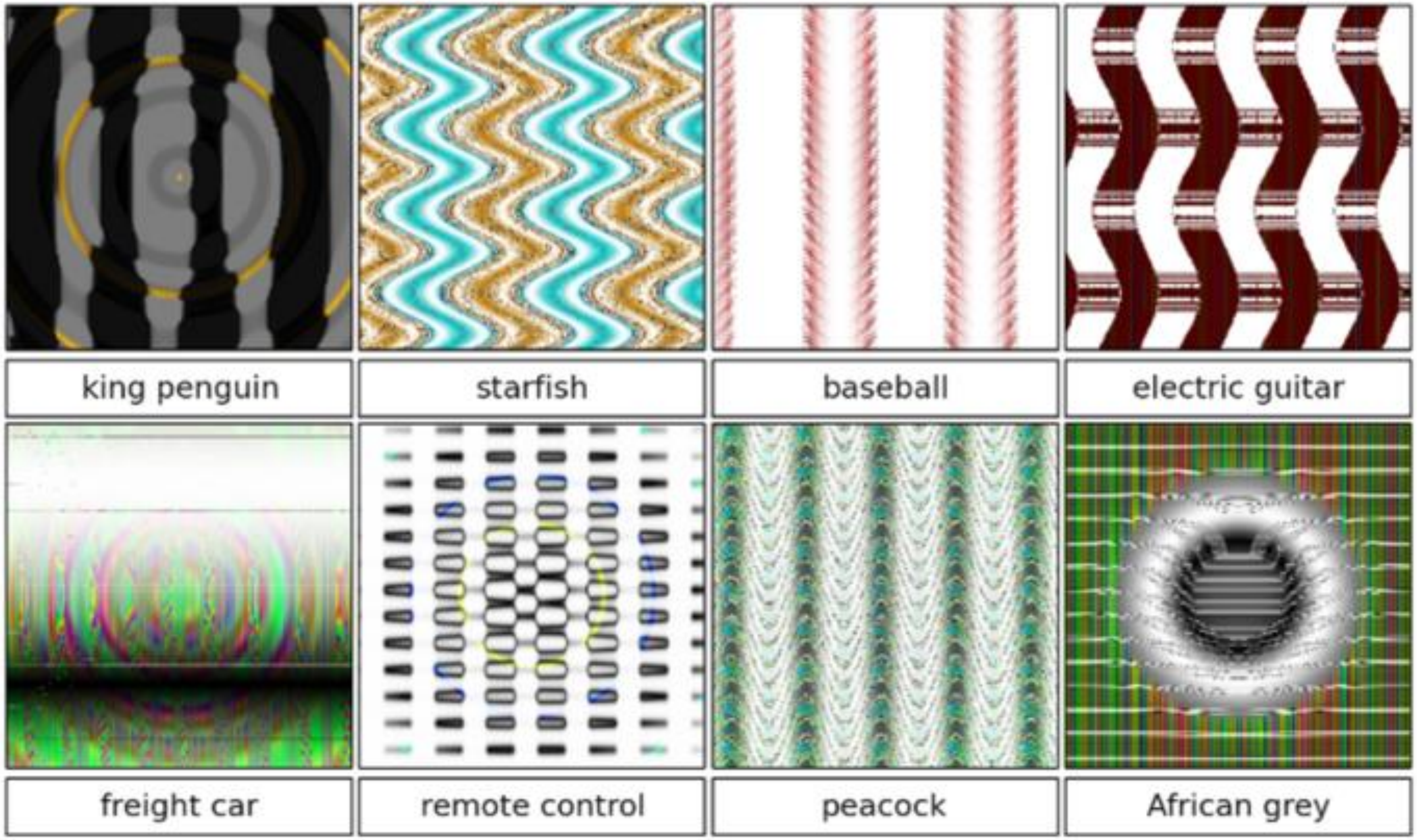
Level 4
- Perform All Safety-Critical Functions
- Limited to Operational Domain

Level 5
- All Safety-Critical Functions in All Environments and Scenarios

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

Datta 2017: CE Magazine Oct 2017

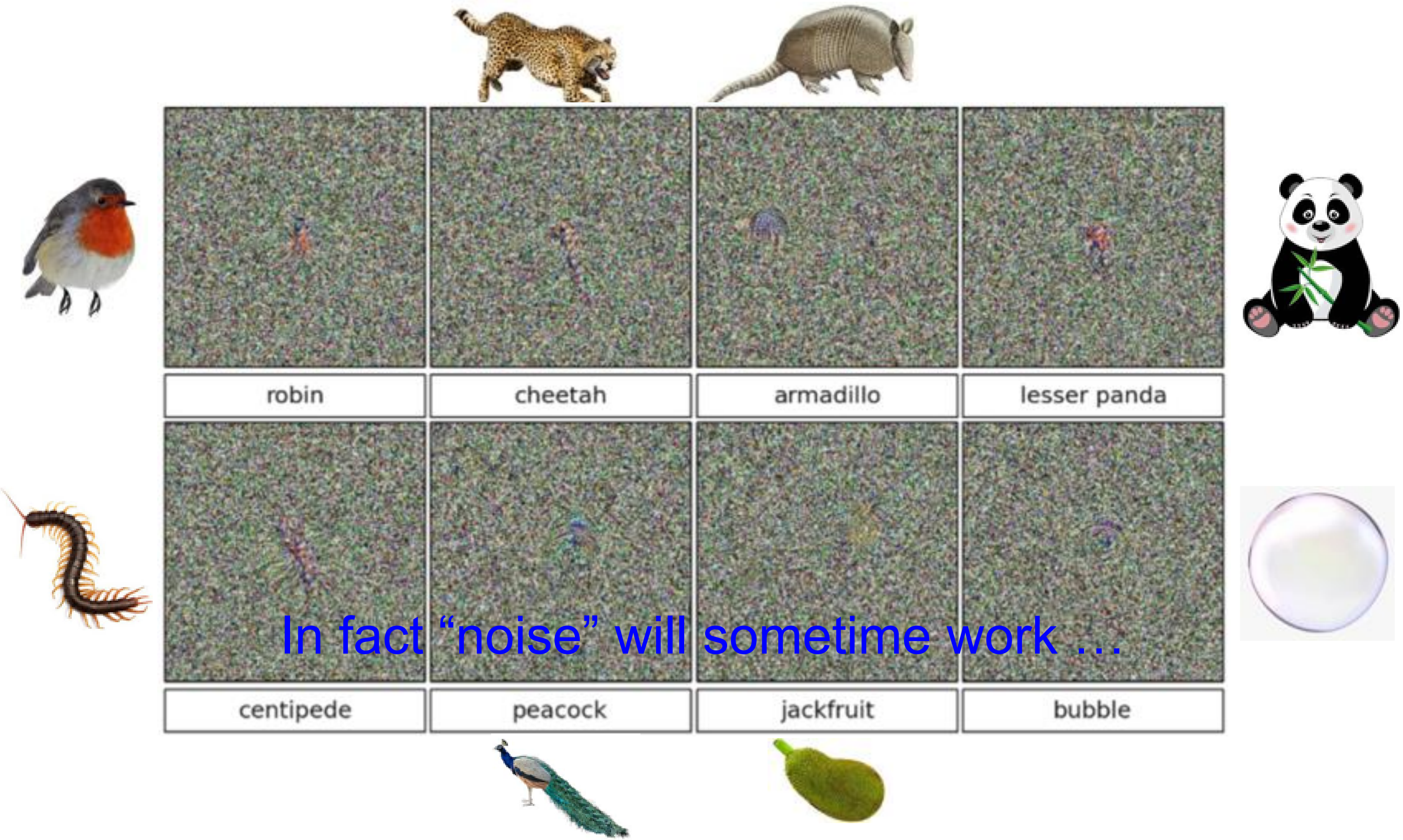
DNNs are not Always Smart



DNNs can be fooled by certain “learned” (Adversarial) patterns …

Source: A. Nguyen, J. Yosinski and J. Clune, "Deep neural networks are easily fooled: High confidence predictions for unrecognizable images," in Proc. IEEE Conference on Computer Vision and Pattern Recognition (CVPR), 2015, pp. 427-436.

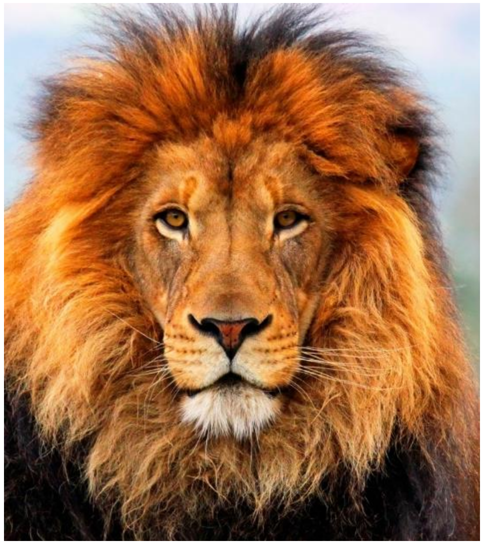
DNNs are not Always Smart



Source: A. Nguyen, J. Yosinski and J. Clune, "Deep neural networks are easily fooled: High confidence predictions for unrecognizable images," in Proc. IEEE Conference on Computer Vision and Pattern Recognition (CVPR), 2015, pp. 427-436.

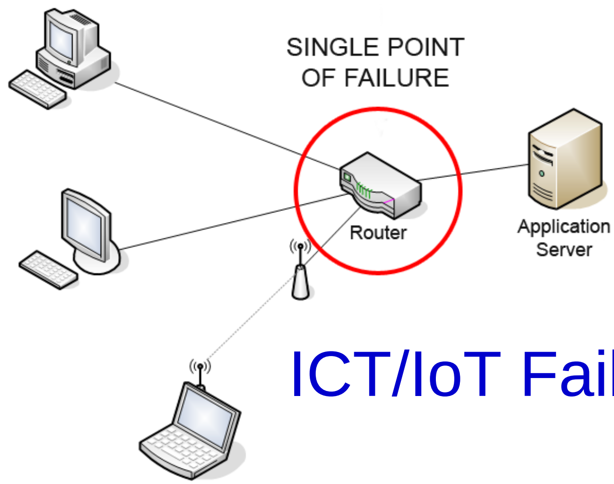
DNNs are not Always Smart

- Why not use Fake Data?
- "Fake Data" has some interesting advantages:
  - Avoids *privacy issues* and side-steps *new regulations* (e.g. General Data Protection Regulation or GDPR)
  - Significant cost reductions in data acquisition and annotation for big datasets



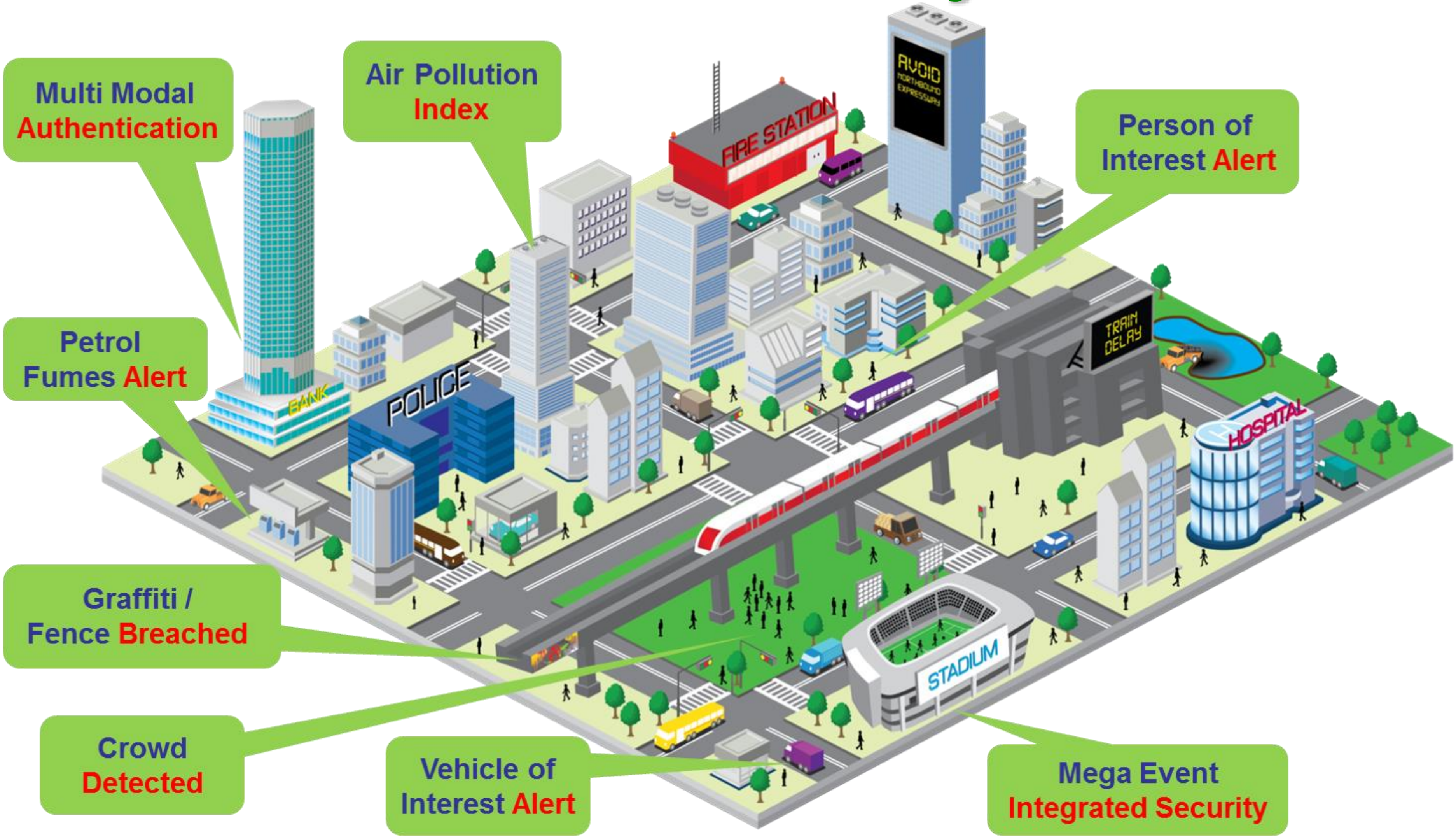
Source: Corcoran Keynote 2018

Failure Tolerance and Resilience



ICT/IoT Failure

Public Safety



Source: http://www.nec.com/en/global/solutions/safety/Inter-Agency/index.html

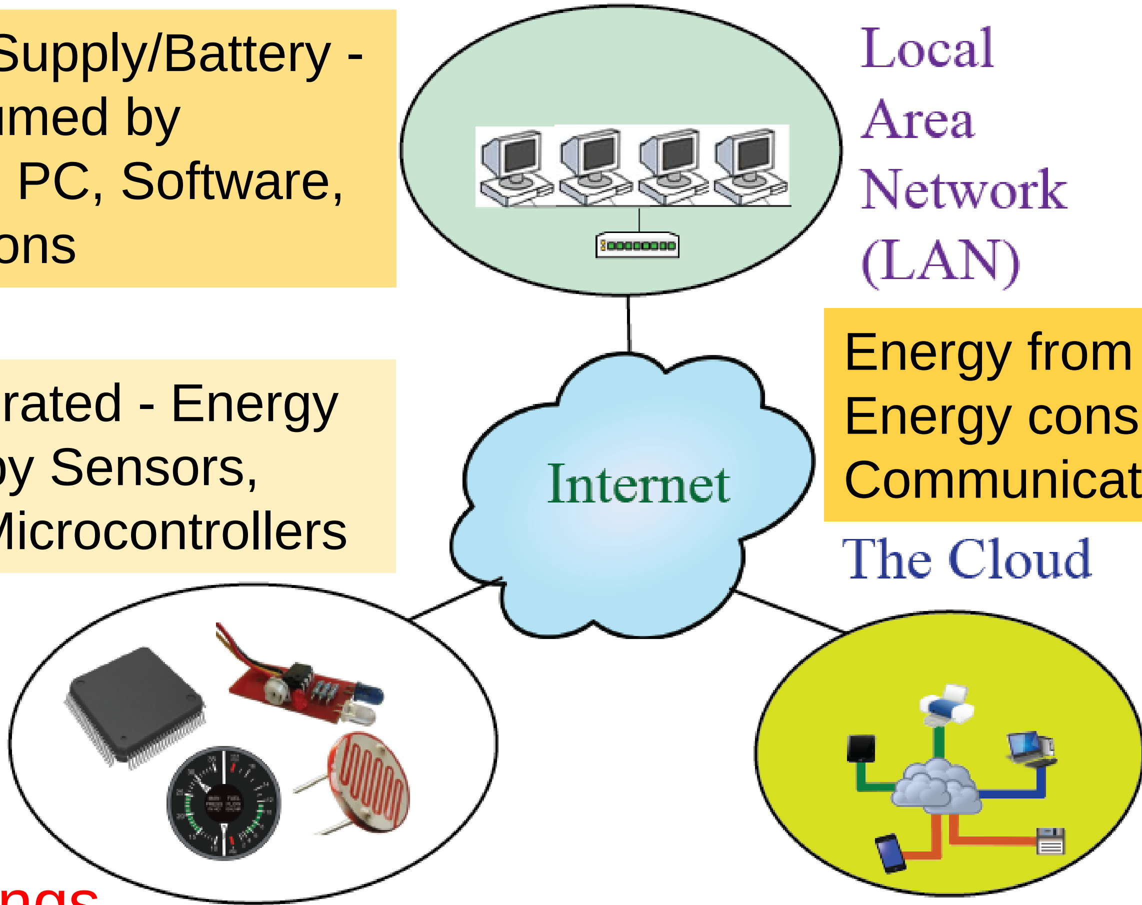
Energy Smart

energy
ENERGY STAR

Energy Consumption Challenge in IoT

Energy from Supply/Battery - Energy consumed by Workstations, PC, Software, Communications

Battery Operated - Energy consumed by Sensors, Actuators, Microcontrollers



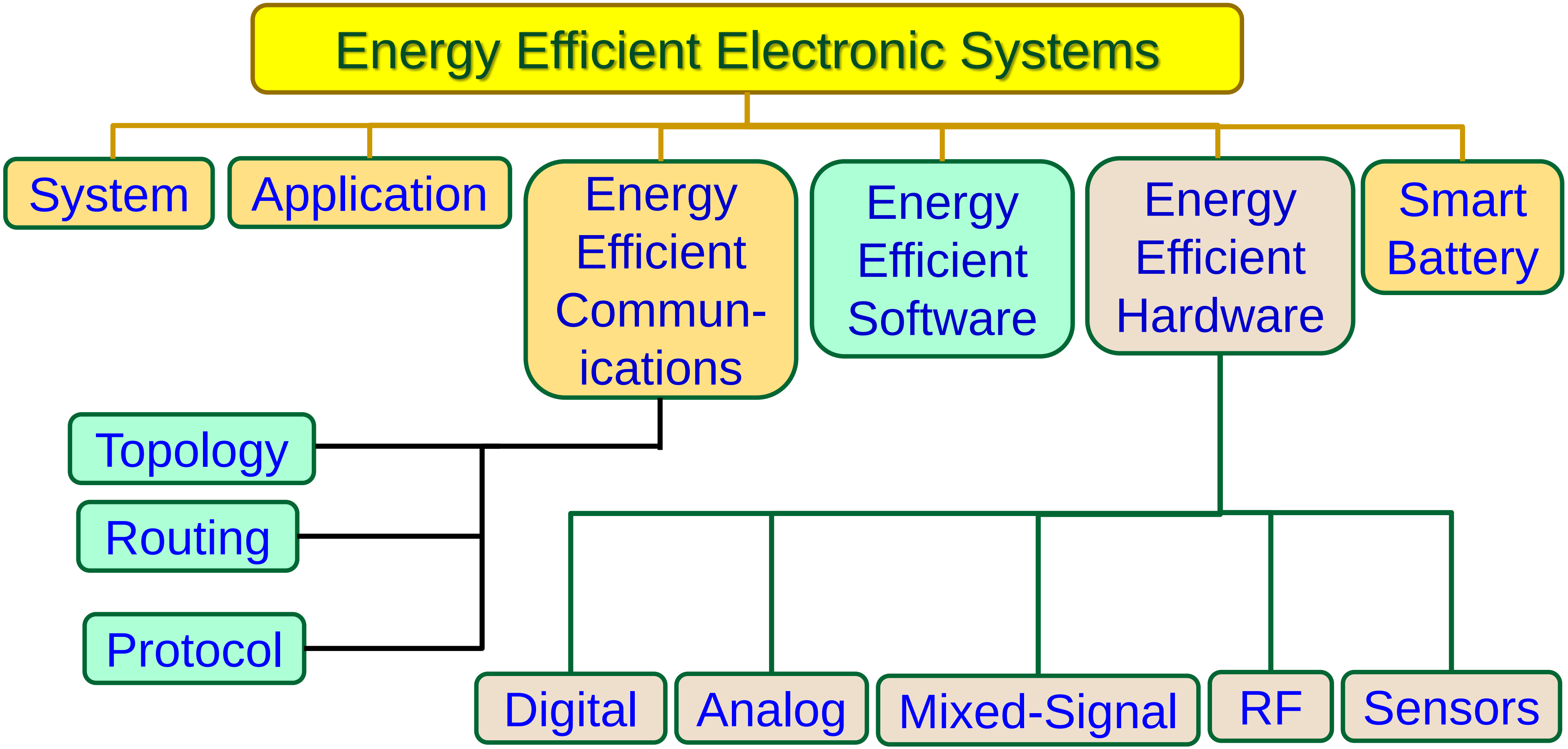
Energy from Supply/Battery - Energy consumed by Communications

Energy from Supply - Energy consumed in Server, Storage, Software, Communications

Four Main Components of IoT.

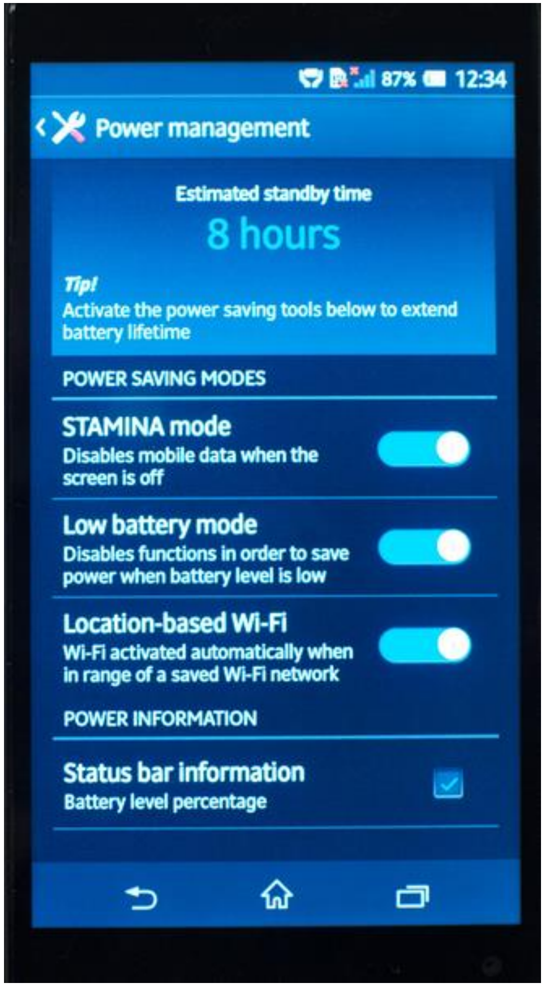
Source: Mohanty iSES 2018 Keynote

Energy Efficient Electronics: Possible Solution Fronts



Source: Mohanty ZINC 2018 Keynote

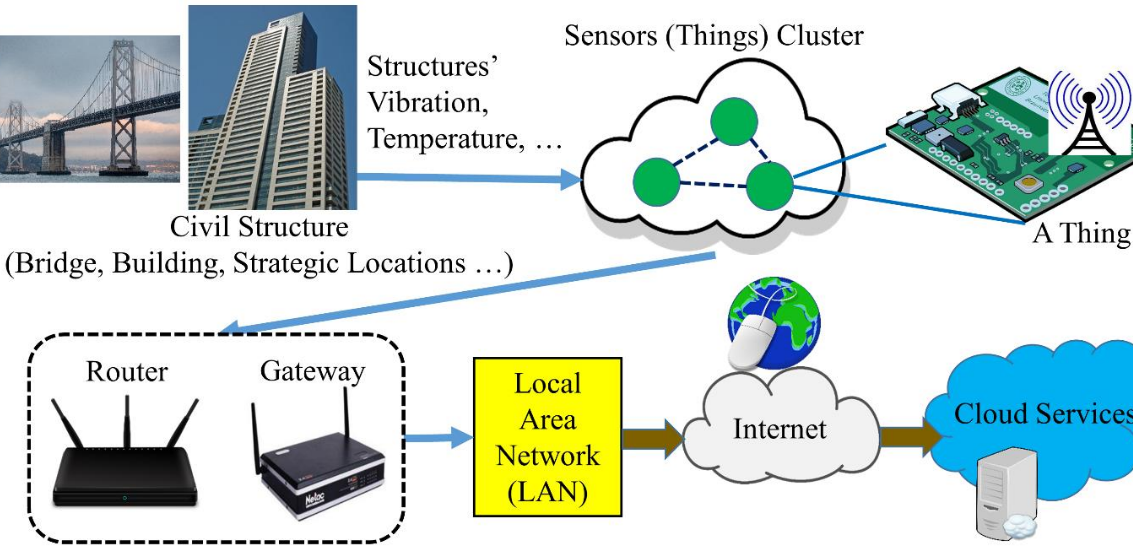
Smart Energy – Smart Consumption

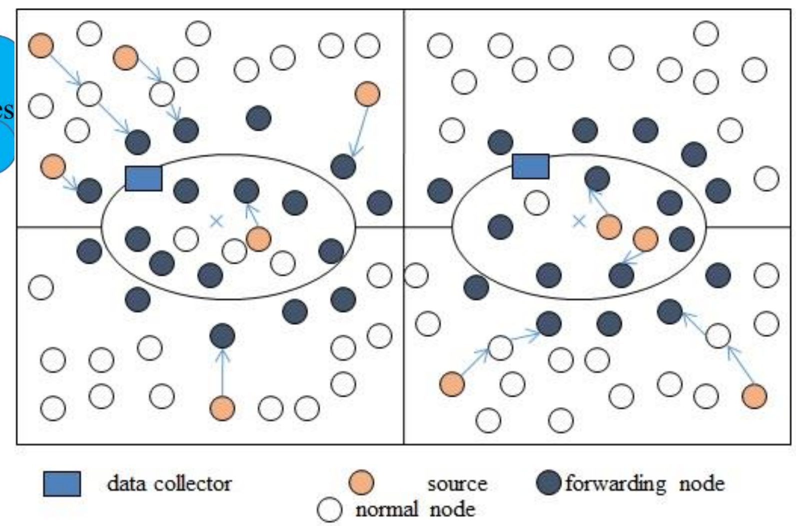


Battery Saver

Smart Home

Sustainable IoT - Low-Power Sensors and Efficient Routing

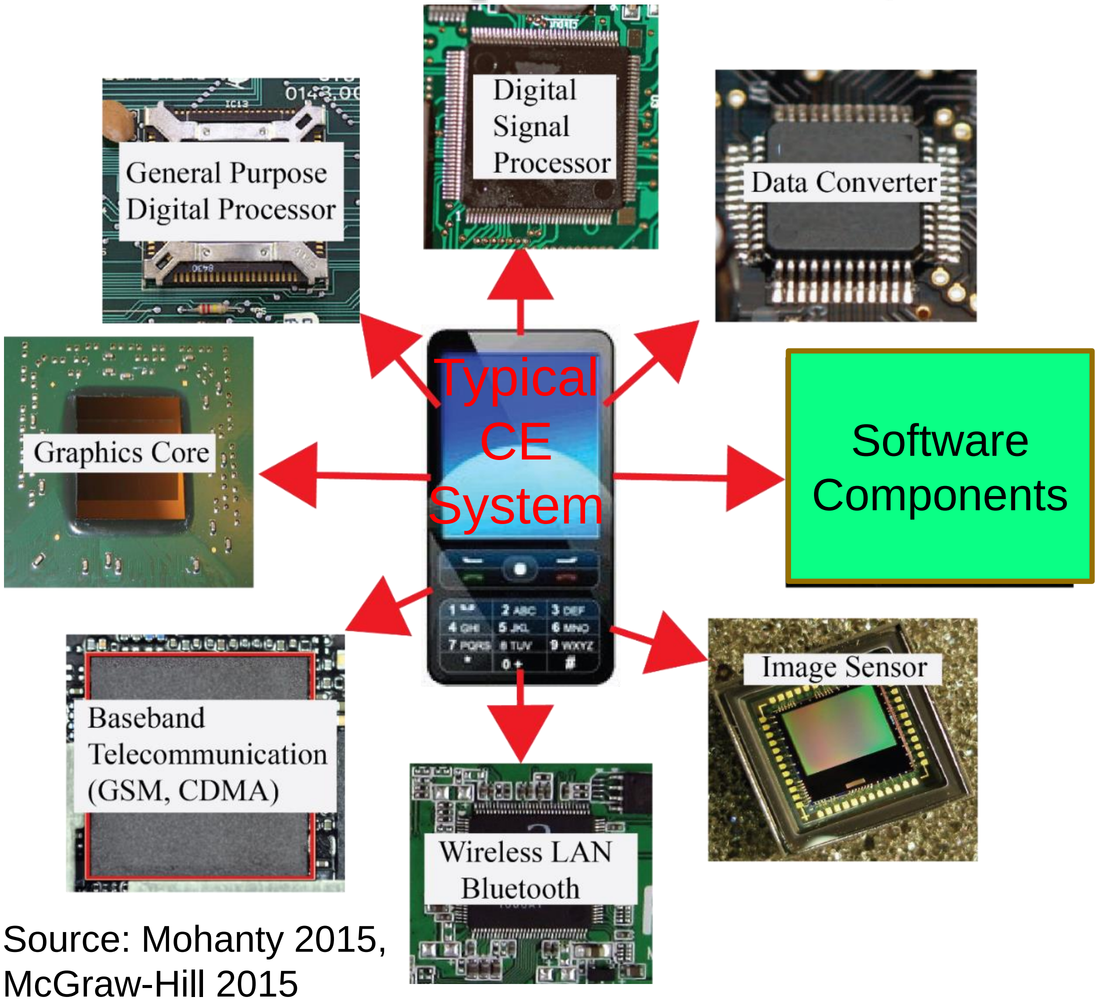




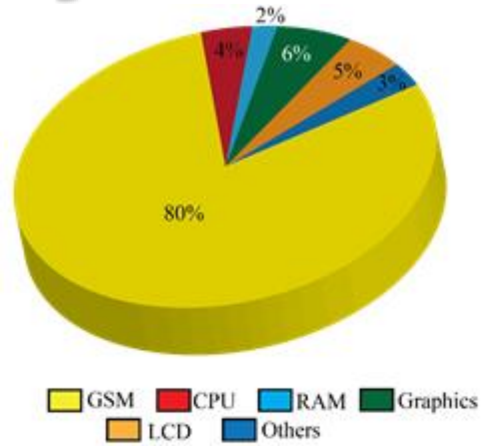
- IoT - sensors near the data collector drain energy faster than other nodes.
- Solution Idea - Mobile sink in which the network is balanced with node energy consumption.
- Solution Need: New data routing to forward data towards base station using mobile data collector, in which two data collectors follow a predefined path.

Source: S. S. Roy, D. Puthal, S. Sharma, S. P. Mohanty, and A. Y. Zomaya, "Building a Sustainable Internet of Things", *IEEE Consumer Electronics Magazine (CEM)*, Volume 7, Issue 2, March 2018, pp. 42--49.

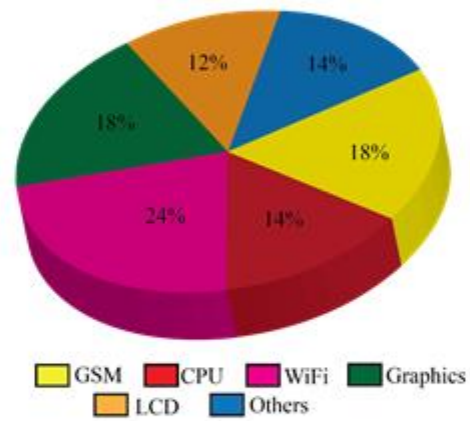
Energy Consumption of Sensors, Components, and Systems



Source: Mohanty 2015, McGraw-Hill 2015

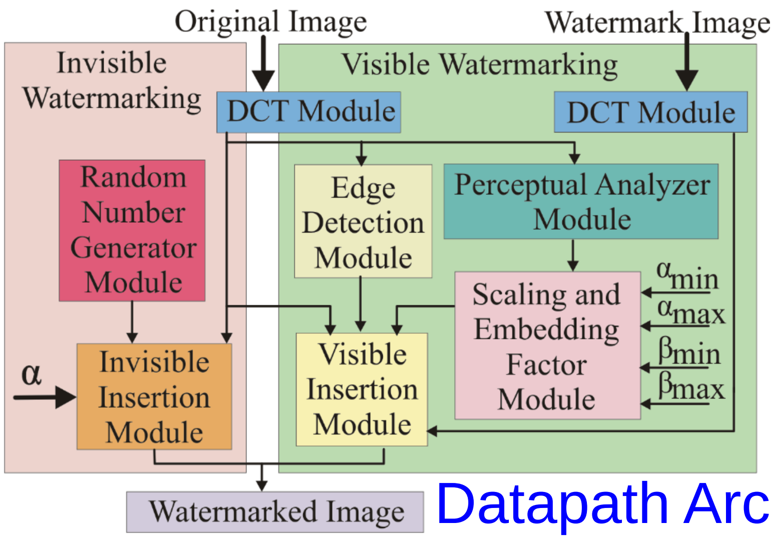


During GSM Communications

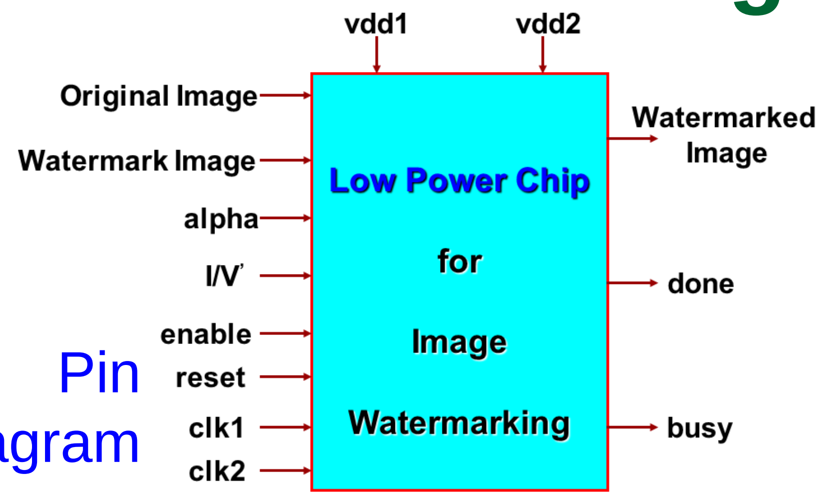


During WiFi Communications

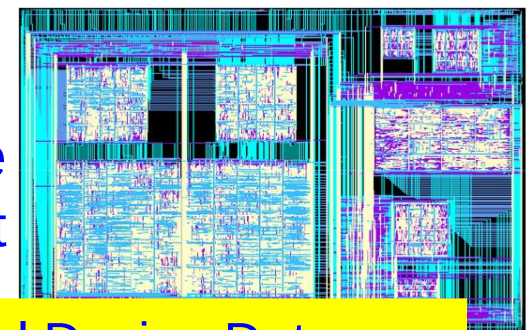
Energy-Efficient Hardware - Dual-Voltage



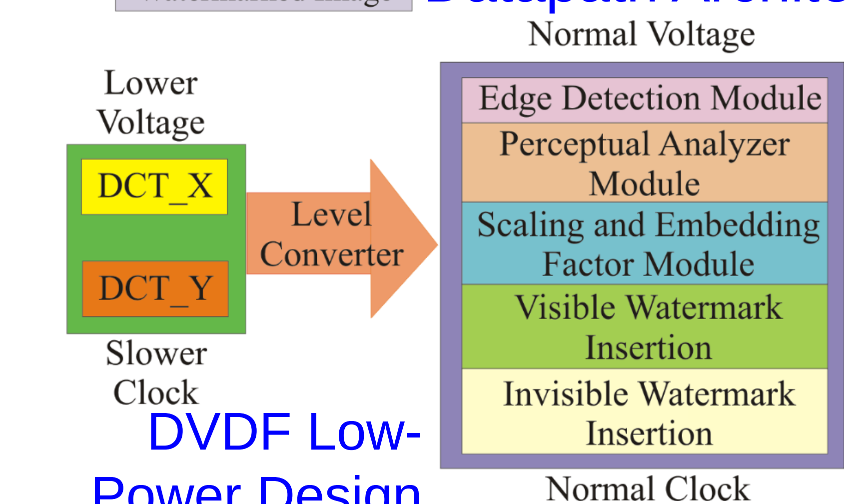
Datapath Architecture



Pin Diagram



Hardware Layout



DVDF Low-Power Design

Physical Design Data

Total Area : 16.2 sq mm

No. of Transistors: 1.4 million

Power Consumption: 0.3 mW

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.

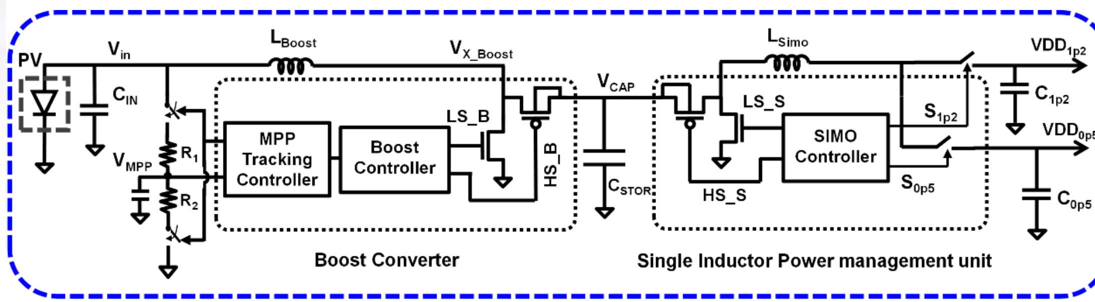
Battery-Less IoT

Battery less operations can lead to reduction of size and weight of the edge devices.

Source: http://newscenter.ti.com/2015-02-25-TI-makes-battery-less-IoT-connectivity-possible-with-the-industrys-first-multi-standard-wireless-microcontroller-platform

Batter-Less SoC

Source: https://www.technologyreview.com/s/529206/a-batteryless-sensor-chip-for-the-internet-of-things/



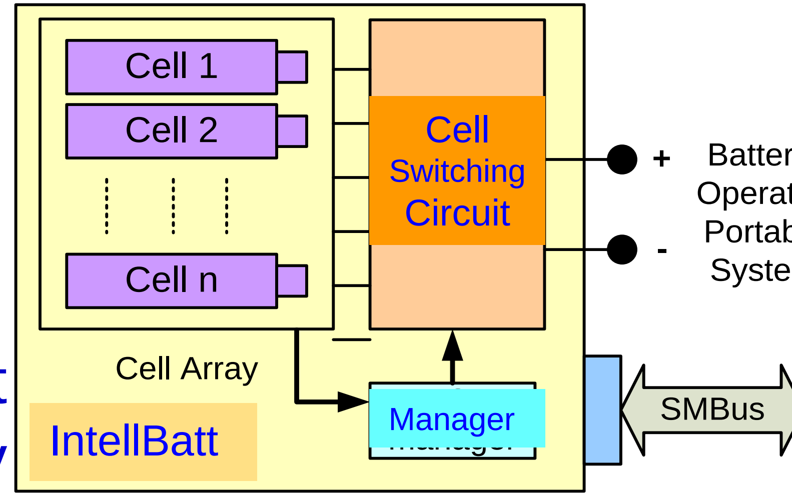
Energy Harvesting and Power Management

Source: http://rlpvlsi.ece.virginia.edu/node/368

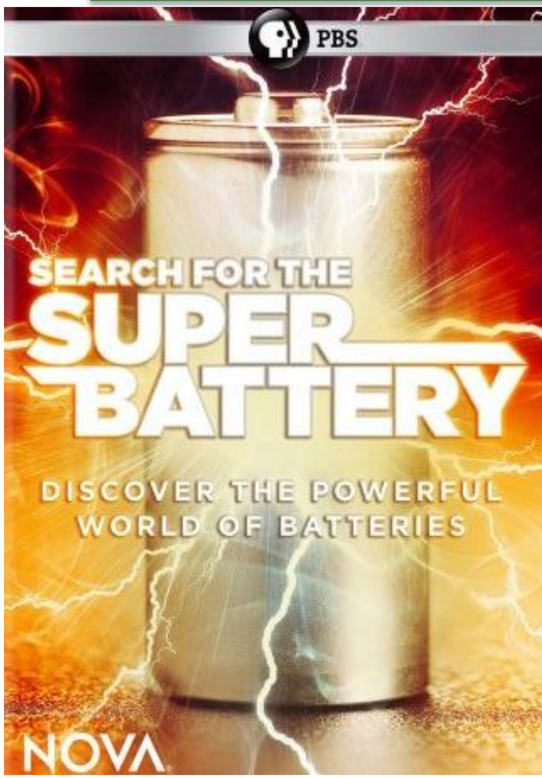
Energy Storage - High Capacity and Efficiency Needed

Battery	Conversion Efficiency
Li-ion	80% - 90%
Lead-Acid	50% - 92%
NiMH	66%

Intelligent Battery



Mohanty 2010: IEEE Computer, March 2010
Mohanty 2018: ICCE 2018



Lithium Polymer Battery

Supercapacitor

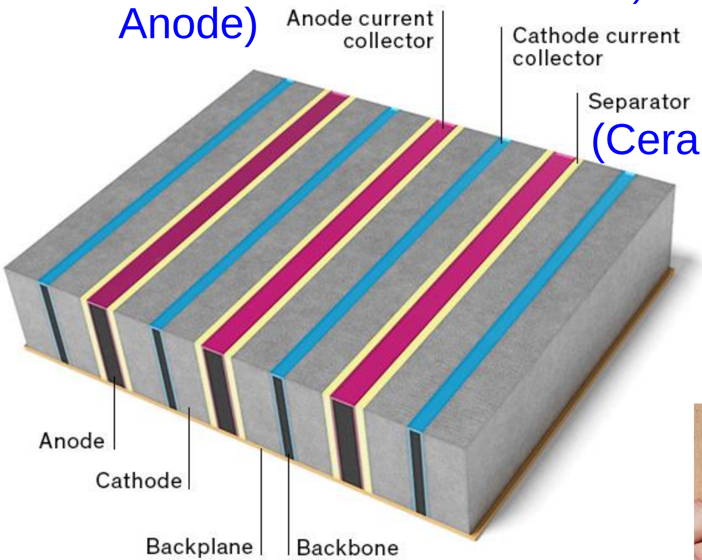
Source: Mohanty MAMI 2017 Keynote

Energy Storage - High Capacity and Safer Needed

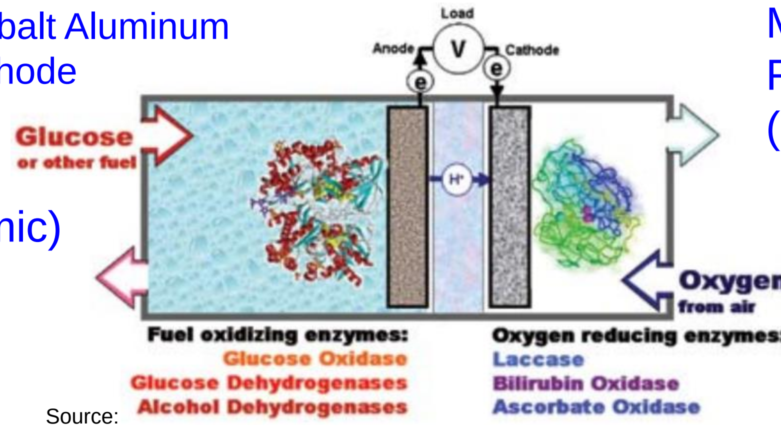
(Silicon Anode)

(Lithium Nickel Cobalt Aluminum Oxide - NCA) Cathode

(Ceramic)

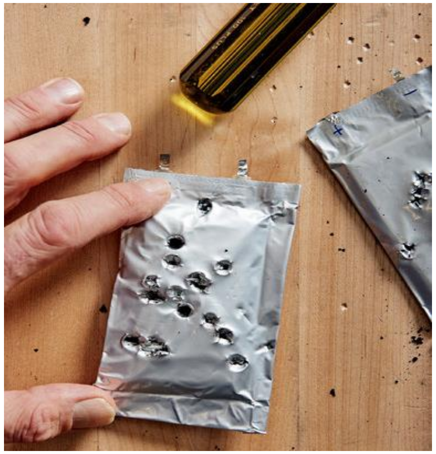


Source: http://spectrum.ieee.org/semiconductors/design/how-to-build-a-safer-more-energydense-lithiumion-battery



Source: https://www.electrochem.org/dl/interface/sum/sum07/su07_p28_31.pdf

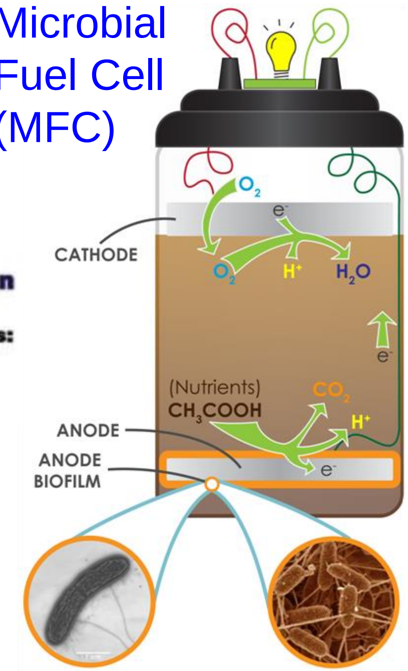
Enzymatic Biofuel Cell



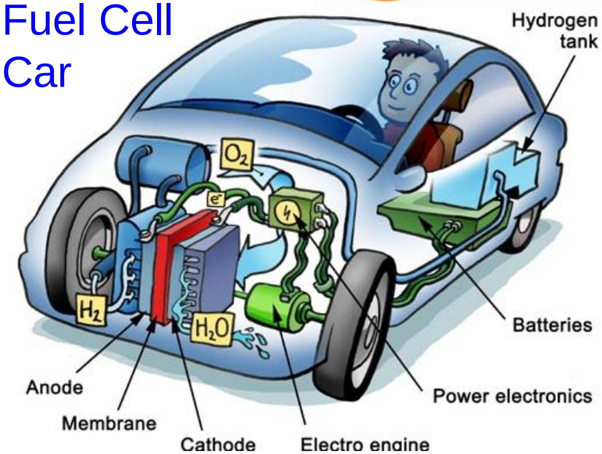
Solid Polymer Lithium Metal Battery

Source: https://www.nytimes.com/2016/12/11/technology/designing-a-safer-battery-for-smartphones-that-wont-catch-fire.html

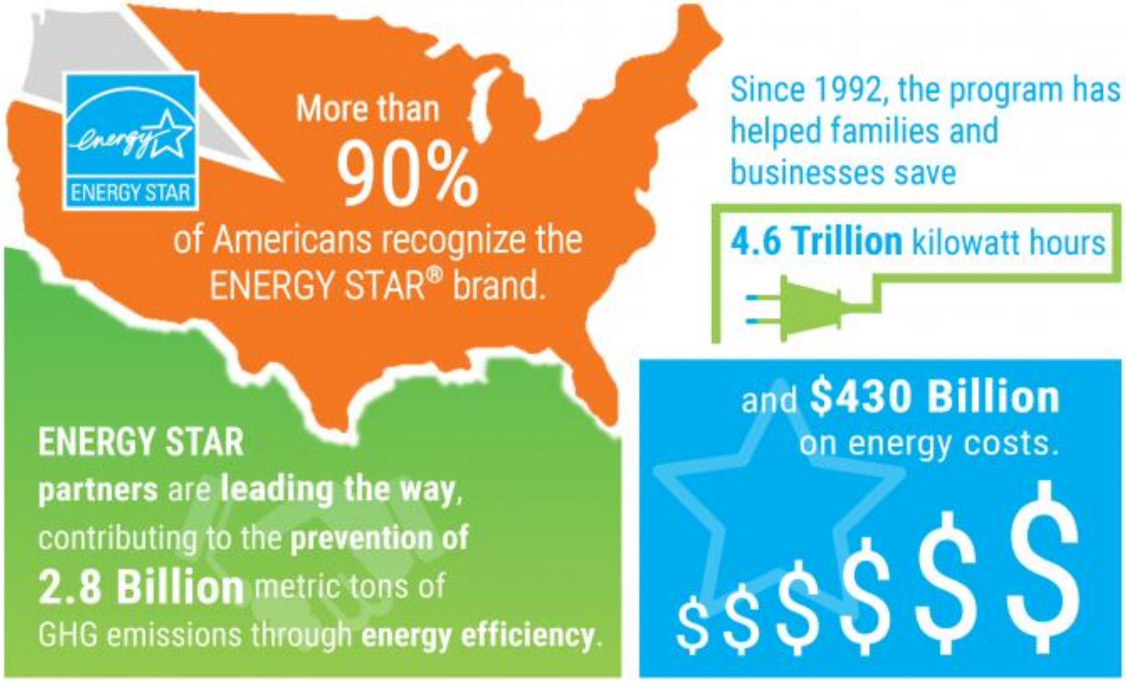
Microbial Fuel Cell (MFC)



Fuel Cell Car



Energy Star Ratings



Source: https://www.energystar.gov/about/2017_energy_star_award_winners

CODE FOR A SUSTAINABLE BUILT ENVIRONMENT
BREEAM
BRE GLOBAL

Source: https://www.breeam.com/

Source: https://new.usgbc.org/leed

Security Smart

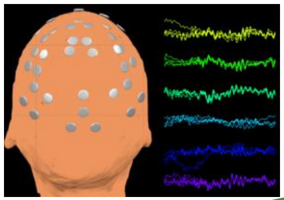
CE Security – Selected Solutions

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

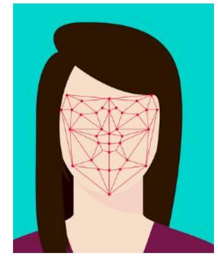
Source: D. A. Hahn, A. Munir, and S. P. Mohanty, “Security and Privacy Issues in Contemporary Consumer Electronics”, IEEE Consumer Electronics Magazine (CEM), Volume 8, Issue 1, January 2019, pp. 95--99.

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



Finger Vein

Facial Recognition



Fingerprint

Electroencephalography (EEG)

Security Methods (Authentication)

Personal Identification Number (PIN)

Electrocardiography (ECG)

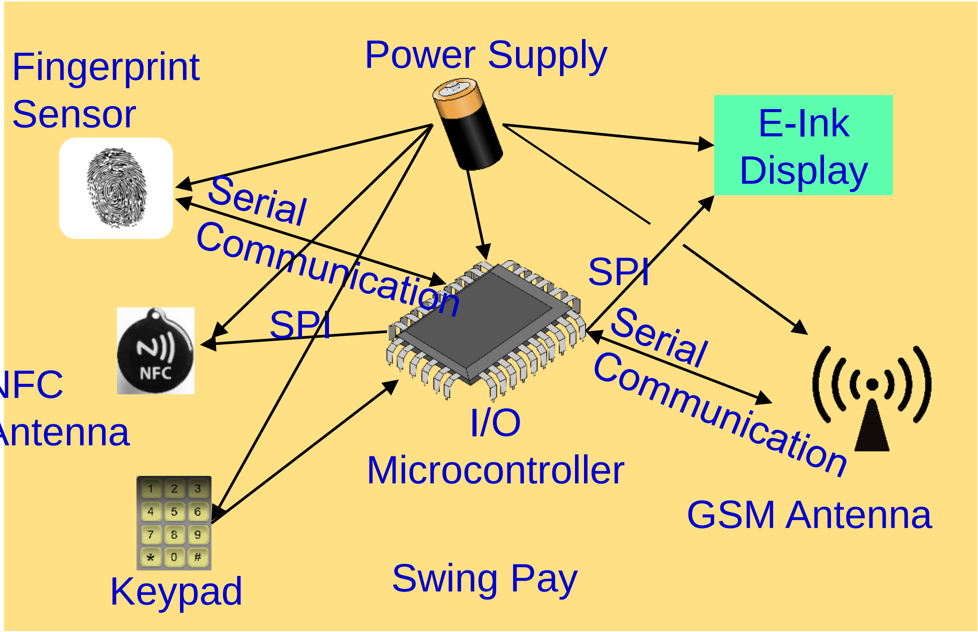
Password

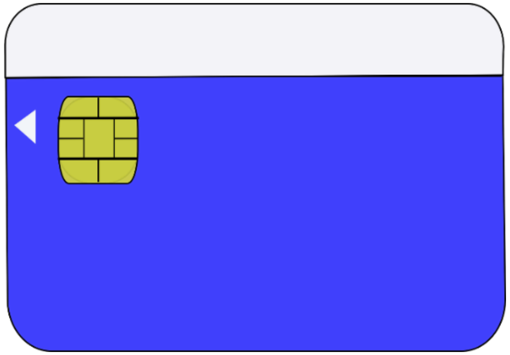
Online Signature

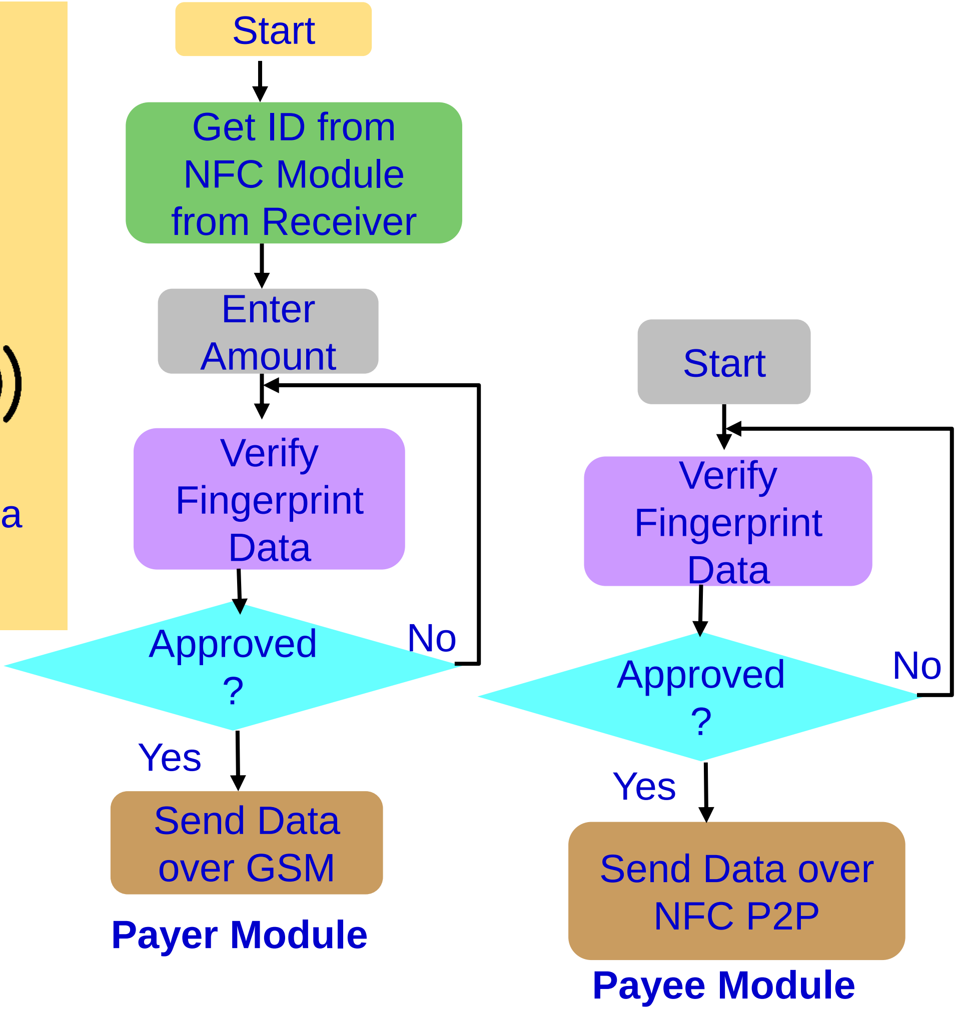
Touch-Screen Pattern

Source: Mohanty ISCT 2019 Keynote

NFC Security - Solution

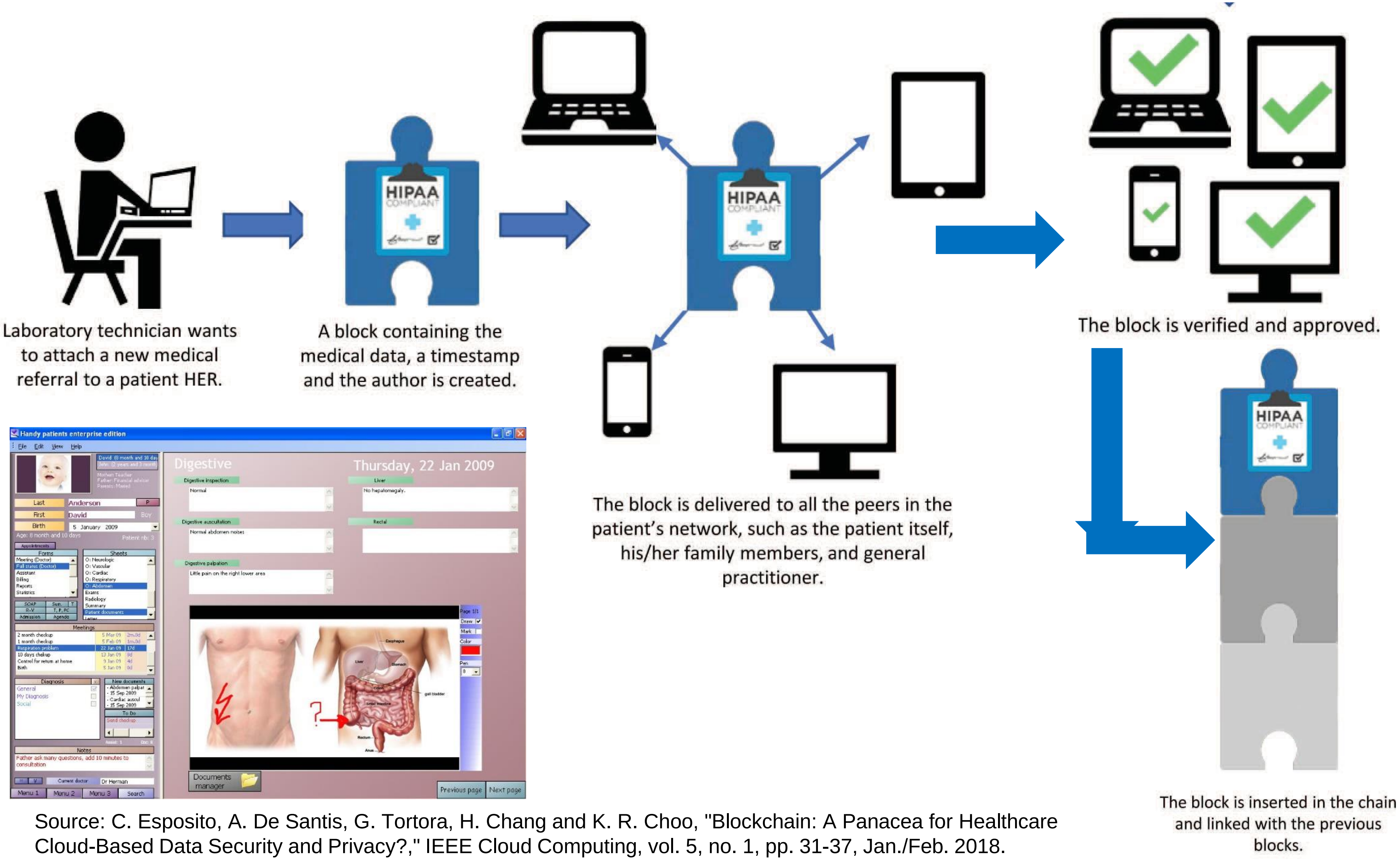






Source: Mohanty 2017, CE Magazine Jan 2017

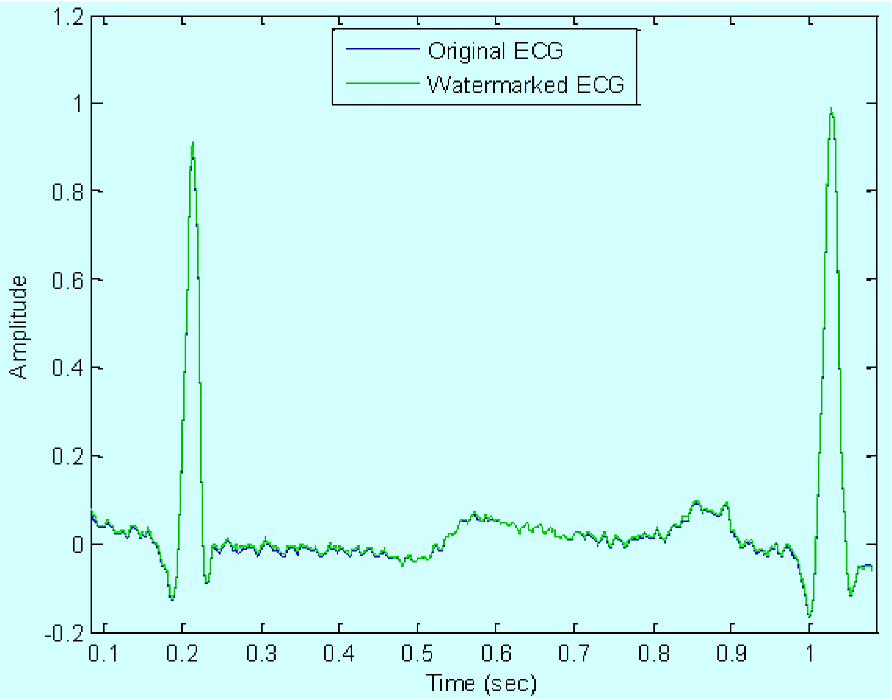
Blockchain in Smart Healthcare



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.

Smart Healthcare Security – Medical Signal Authentication

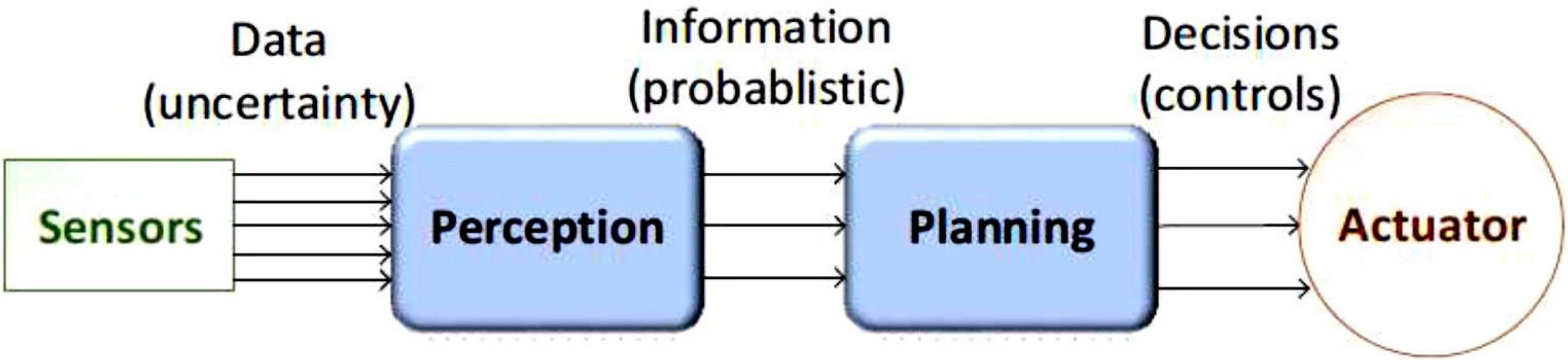
- Physiological signals like the electrocardiogram (EKG) are obtained from patients, transmitted to the cloud, and can also stored in a cloud repository.
- With increasing adoption of electronic medical records and cloud-based software-as-service (SaaS), advanced security measures are necessary.
- Protection from unauthorized access to Protected Health Information (PHI) also protects from identity theft schemes.
- From an economic stand-point, it is important to safeguard the healthcare and insurance system from fraudulent claims.



Source: Tseng 2014, Tseng Sensors Feb 2014

Smart Car – Decision Chain

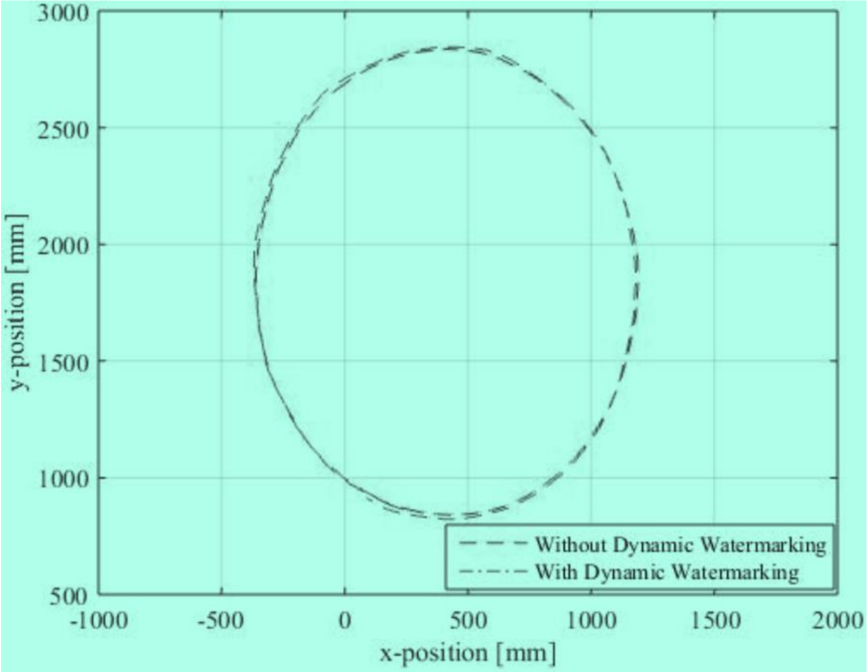
- Designing an AV requires decision chains.
- Human driven vehicles are controlled directly by a human.
- AV actuators controlled by algorithms.
- Decision chain involves sensor data, perception, planning and actuation.
- Perception transforms sensory data to useful information.
- Planning involves decision making.



Source: Plathottam 2018, COMSNETS 2018

Autonomous Car Security – 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

Nonvolatile Memory Security and Protection

Source: http://datalocker.com

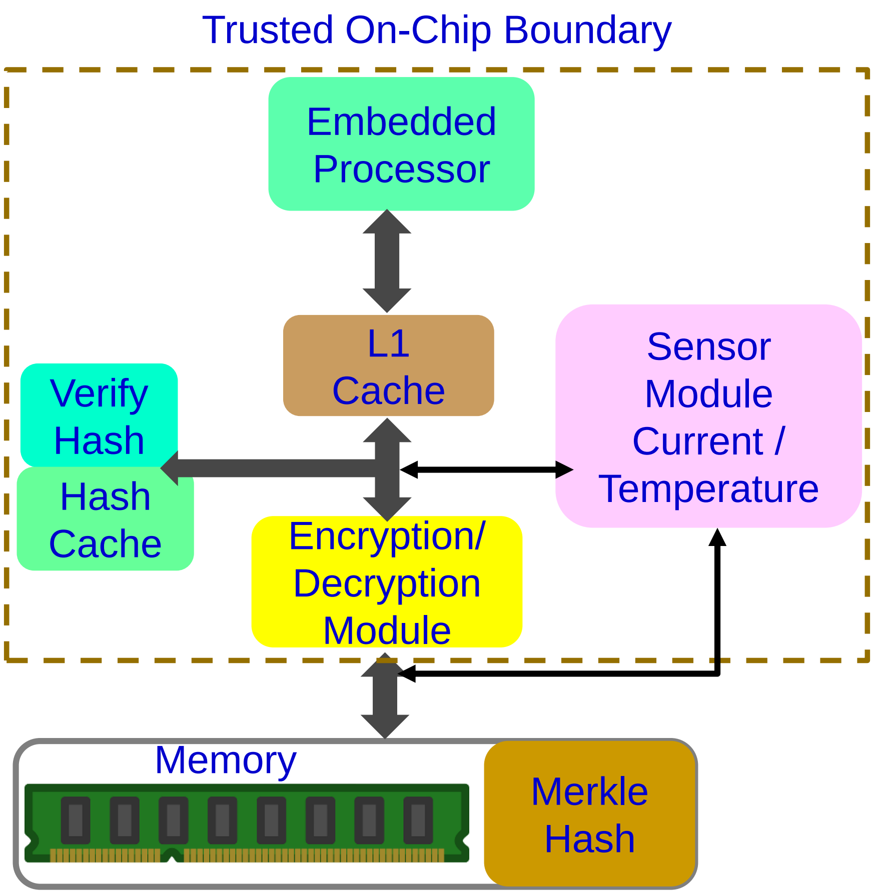
Nonvolatile / Harddrive Storage

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

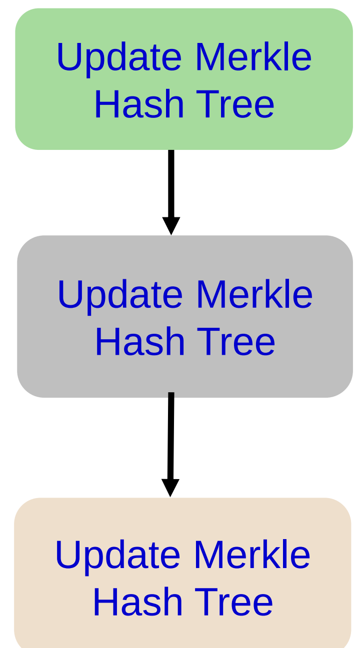
Software-based encryption to secure systems and partitions of hard drive.

Some performance penalty due to increase in latency!

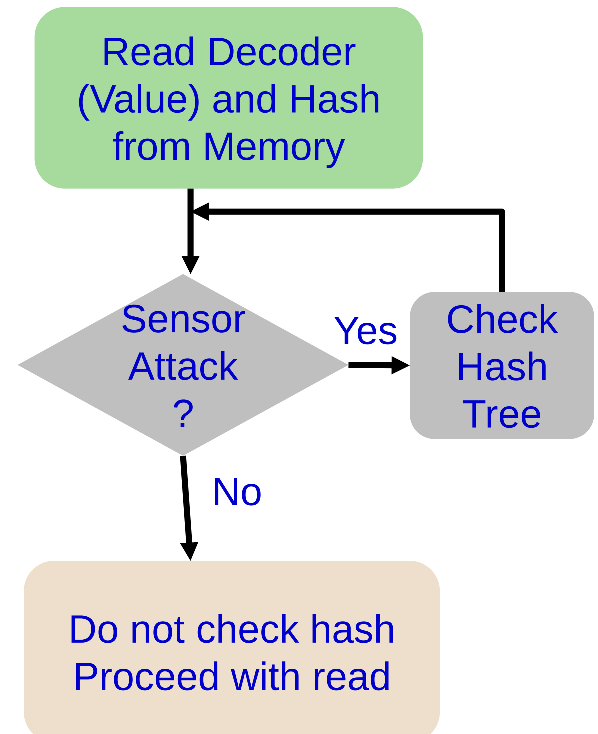
Embedded Memory Security and Protection



On-Chip/On-Board Memory Protection



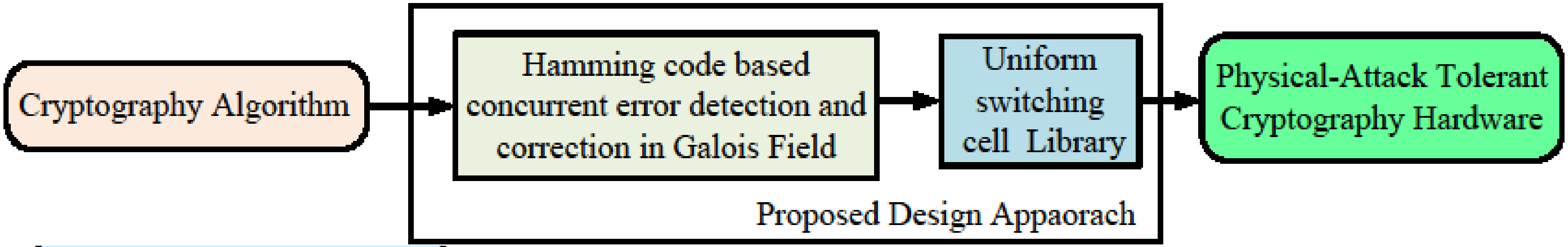
Write Operation

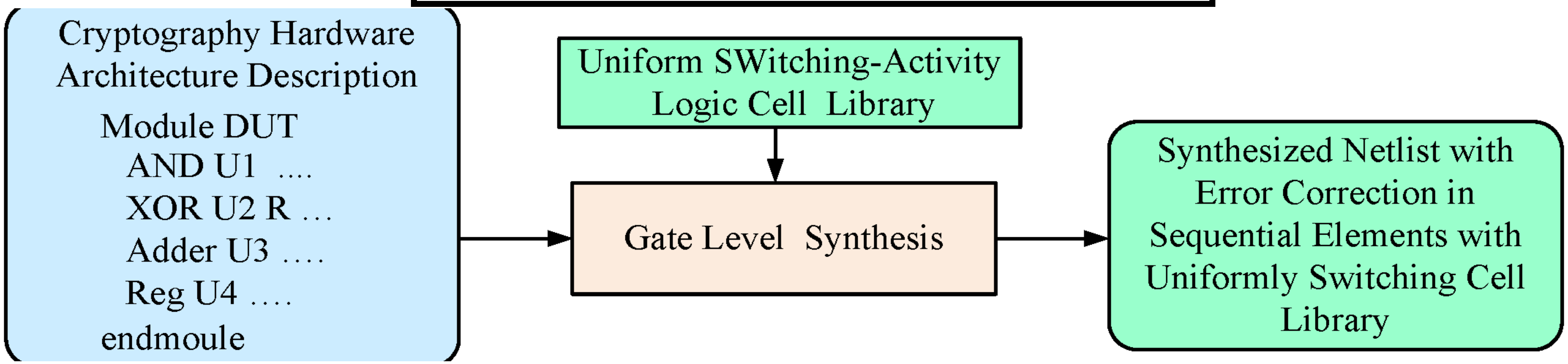


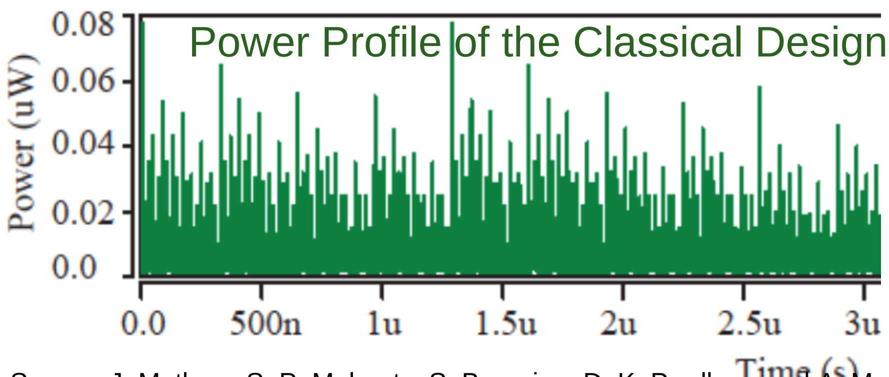
Read Operation

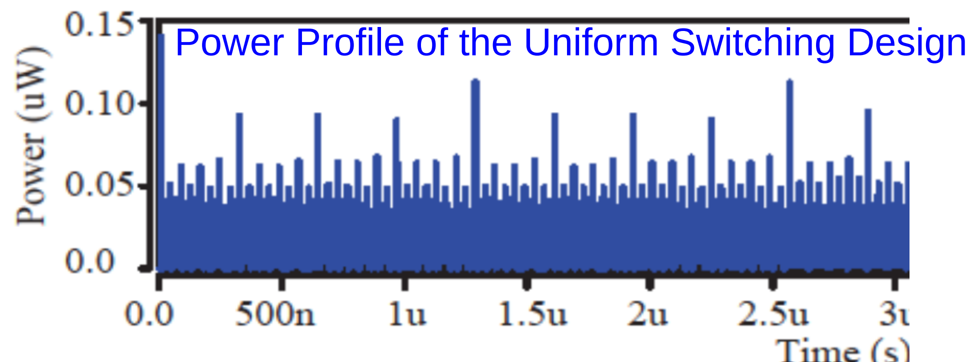
Source: S. Nimgaonkar, M. Gomathisankaran, and S. P. Mohanty, “MEM-DnP: A Novel Energy Efficient Approach for Memory Integrity Detection and Protection in Embedded Systems”, Springer Circuits, Systems, and Signal Processing Journal (CSSP), Volume 32, Issue 6, December 2013, pp. 2581--2604.

DPA Resilience Hardware Design





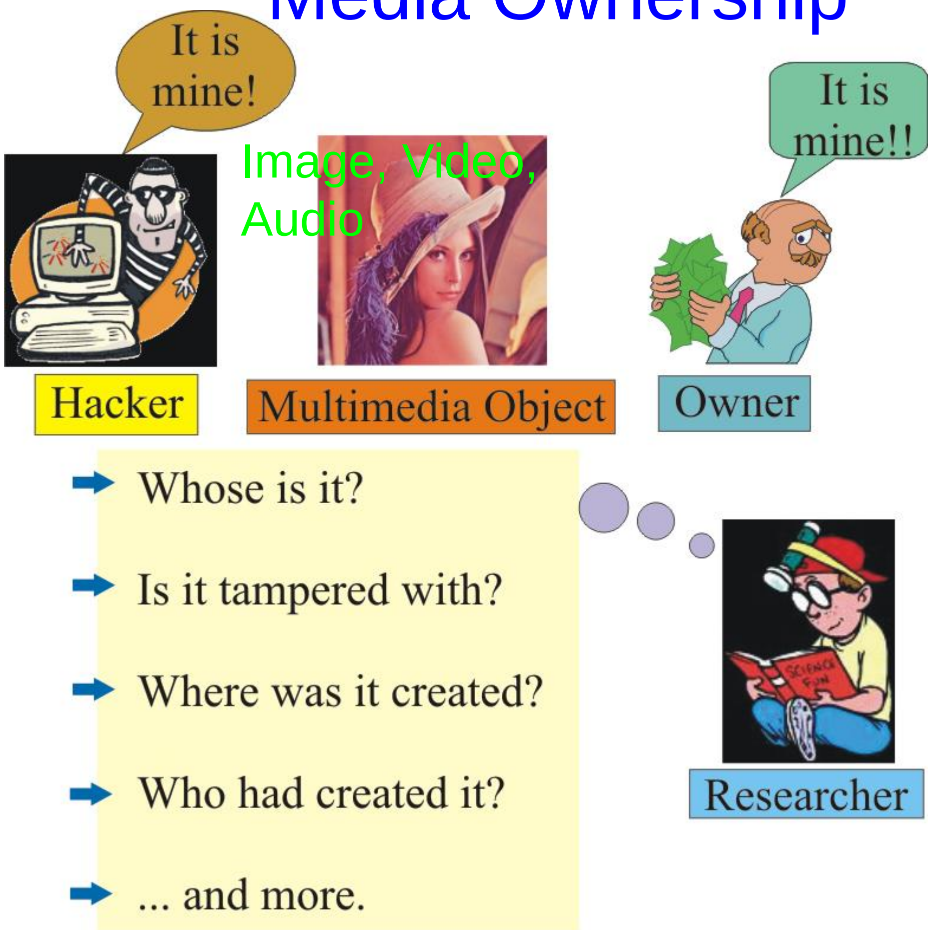




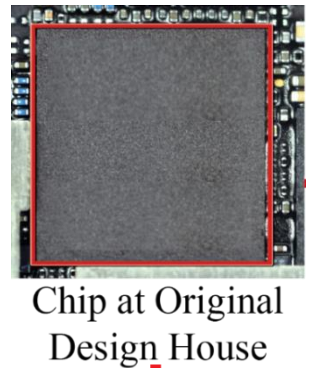
Source: J. Mathew, S. P. Mohanty, S. Banerjee, D. K. Pradhan, and A. M. Jabir, "Attack Tolerant Cryptographic Hardware Design by Combining Galois Field Error Correction and Uniform Switching Activity", Elsevier Computers and Electrical Engineering, Vol. 39, No. 4, May 2013, pp. 1077--1087.

Copyright, Intellectual Property (IP), Or Ownership Protection

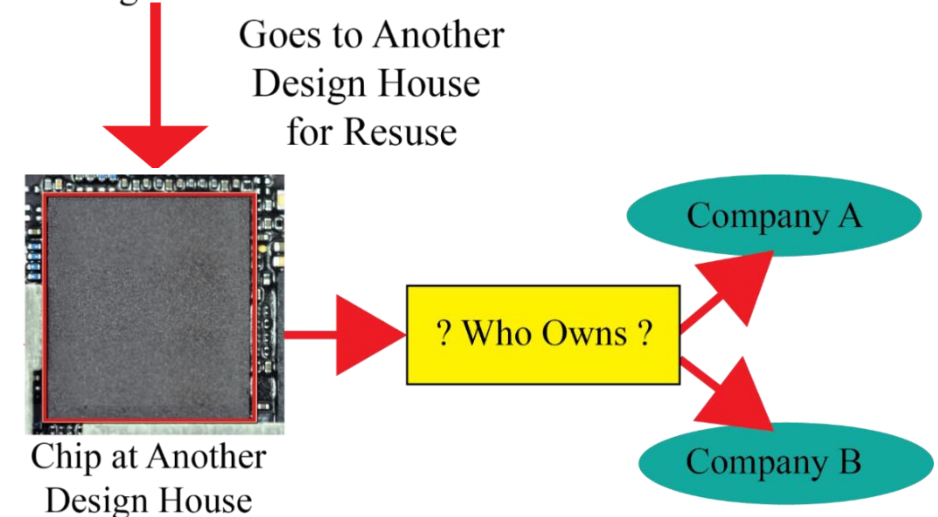
Media Ownership



Hardware Ownership

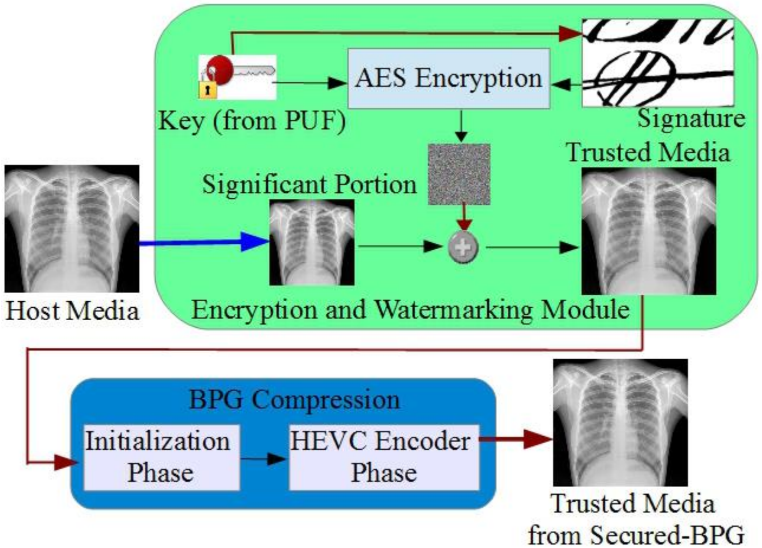


IP cores or reusable cores are used as a cost effective SoC solution but sharing poses a security and ownership issues.

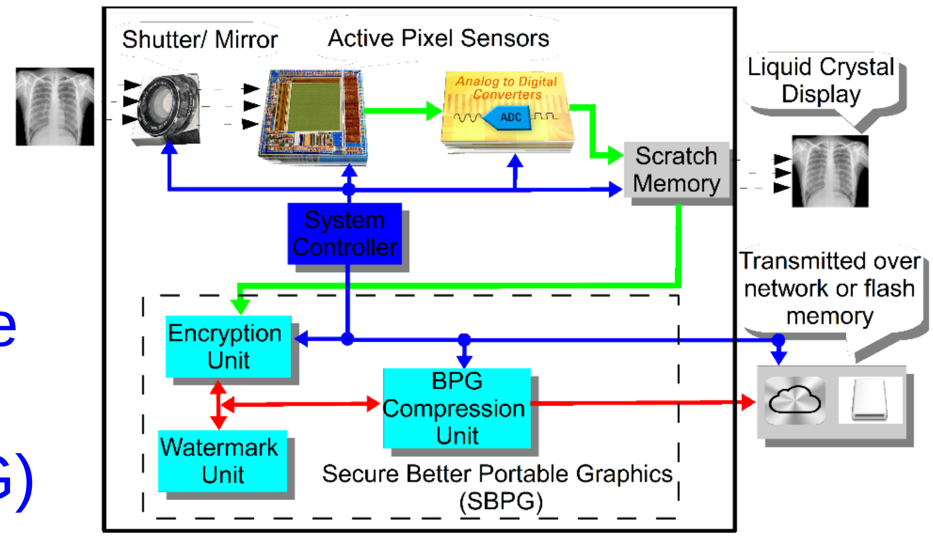


Source: Mohanty ZINC 2018 Keynote

Secure Better Portable Graphics (SBPG)

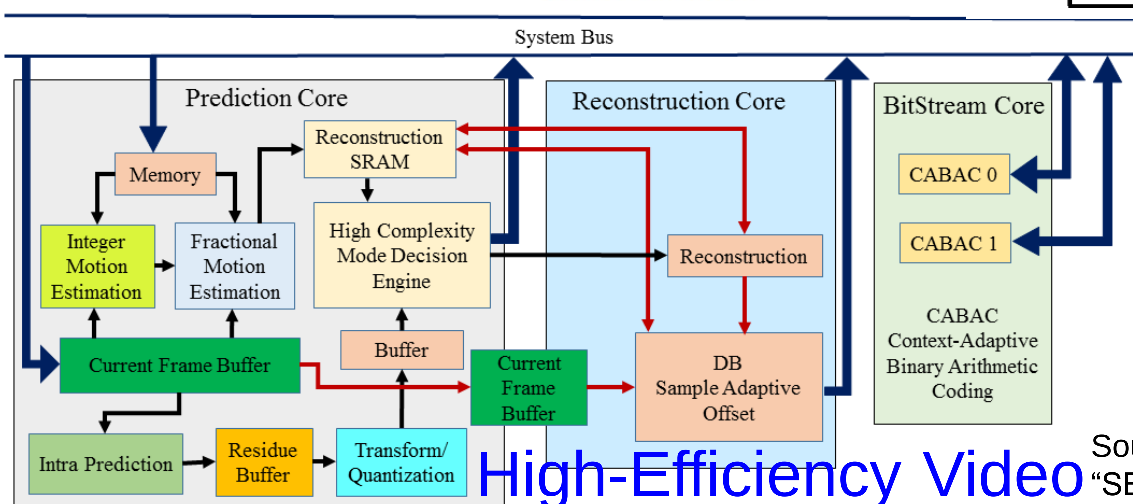


Secure BPG (SBPG)



Secure Digital Camera (SDC) with SBPG

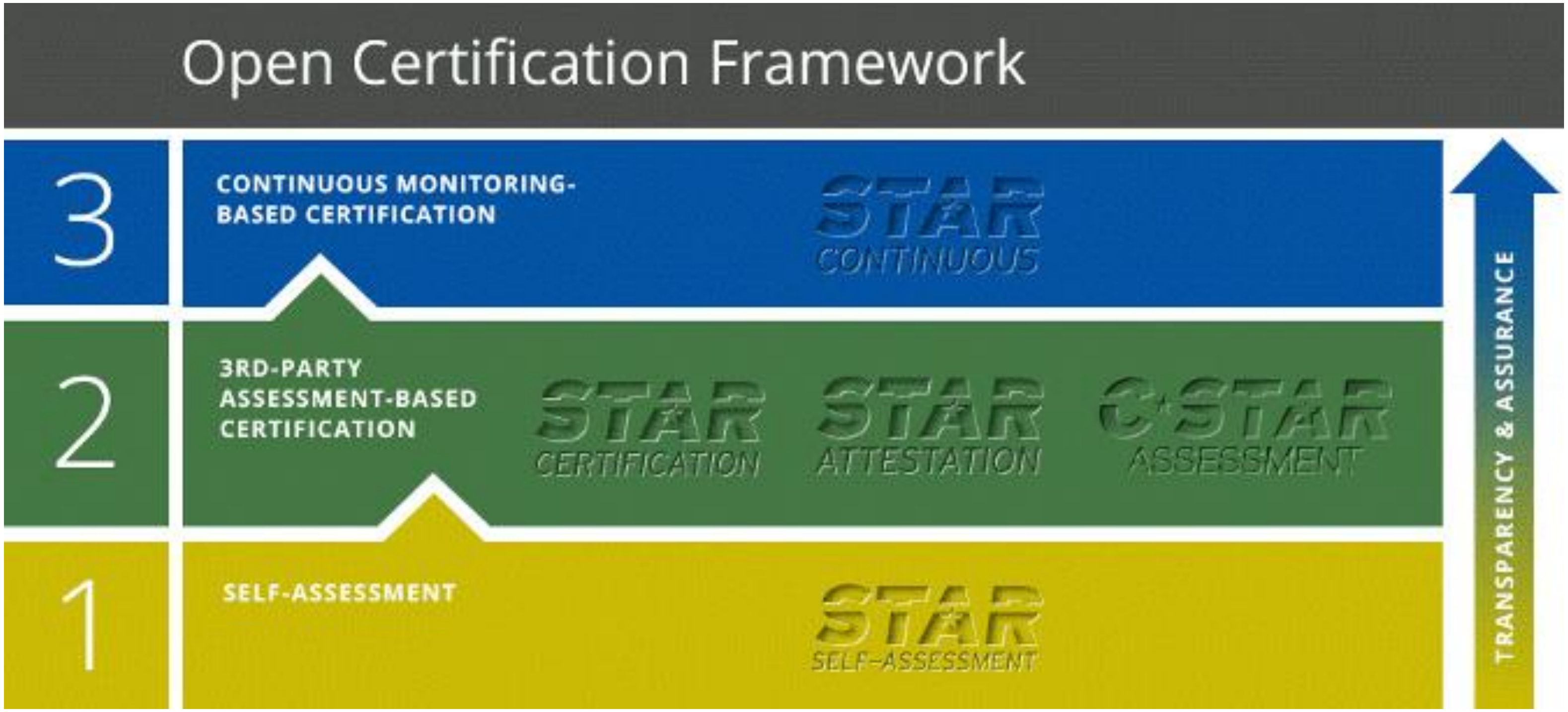
Simulink Prototyping
Throughput: 44 frames/sec
Power Dissipation: 8 nW



High-Efficiency Video Coding Architecture

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.

Security Star Ratings



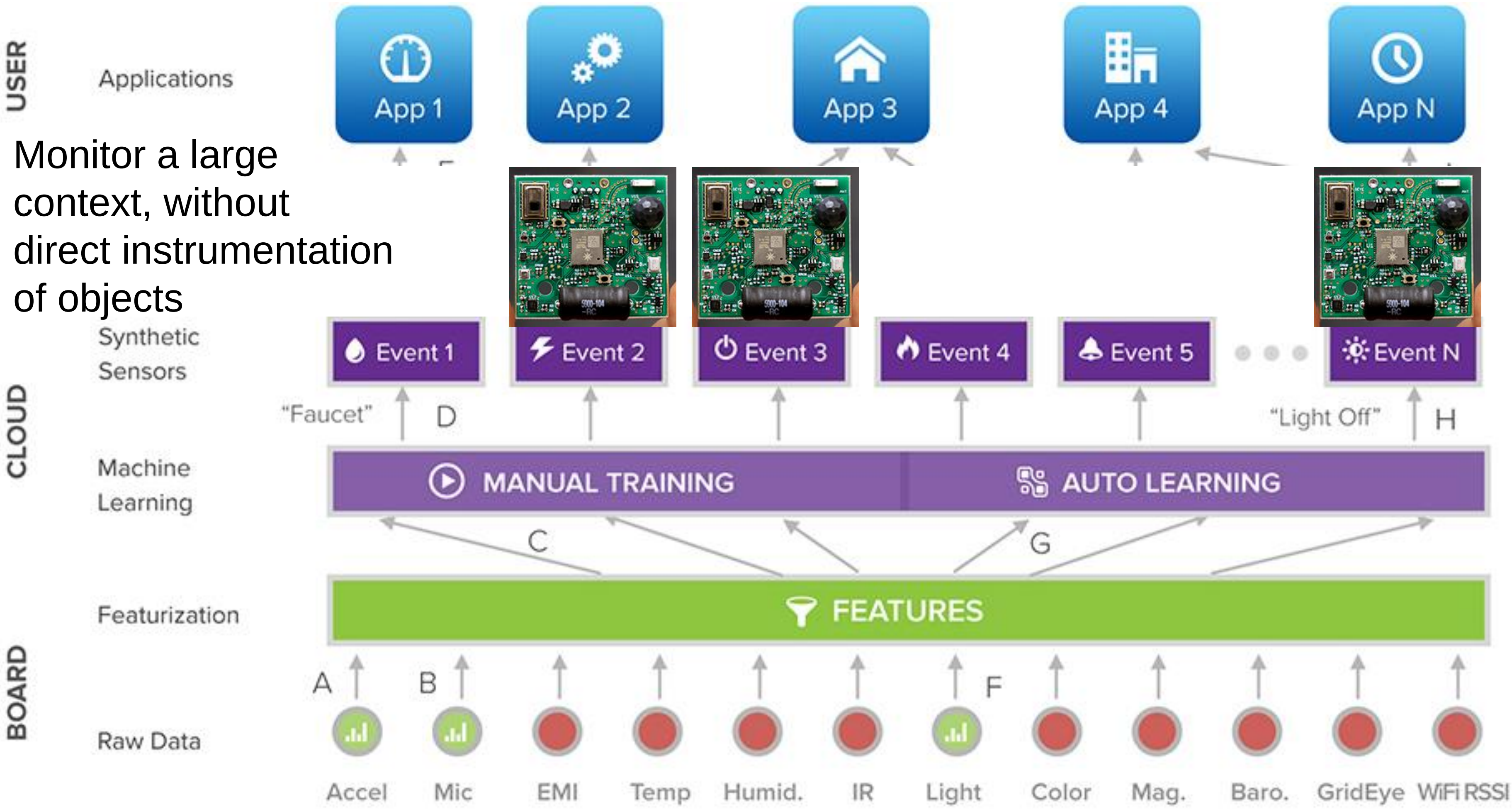
Source: https://cloudsecurityalliance.org/star/#_overview

Cloud Security Alliance (CSA) Security, Trust & Assurance Registry (STAR)

Response Smart

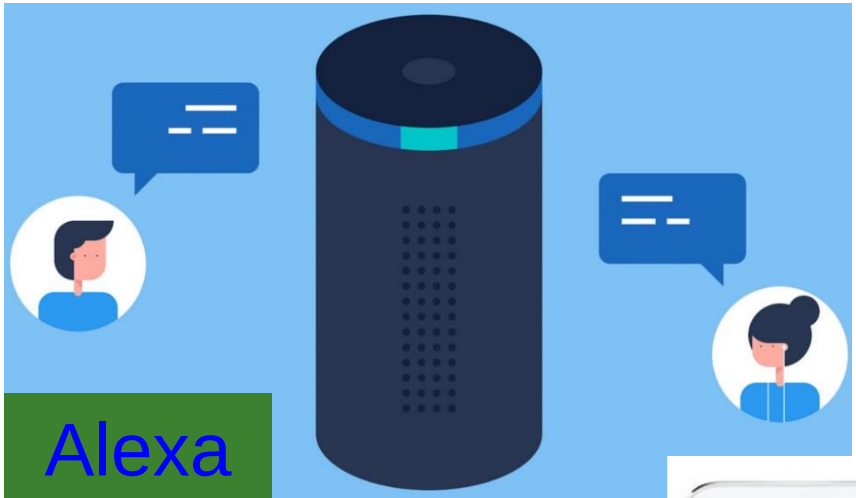
Smart Sensors - General-Purpose/ Synthetic Sensors

Monitor a large context, without direct instrumentation of objects



Source: Laput 2017, http://www.gierad.com/projects/supersensor/

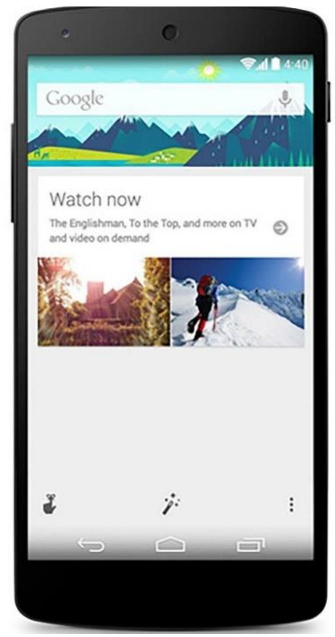
Systems – End Devices



Alexa

Apple Siri

Google Now

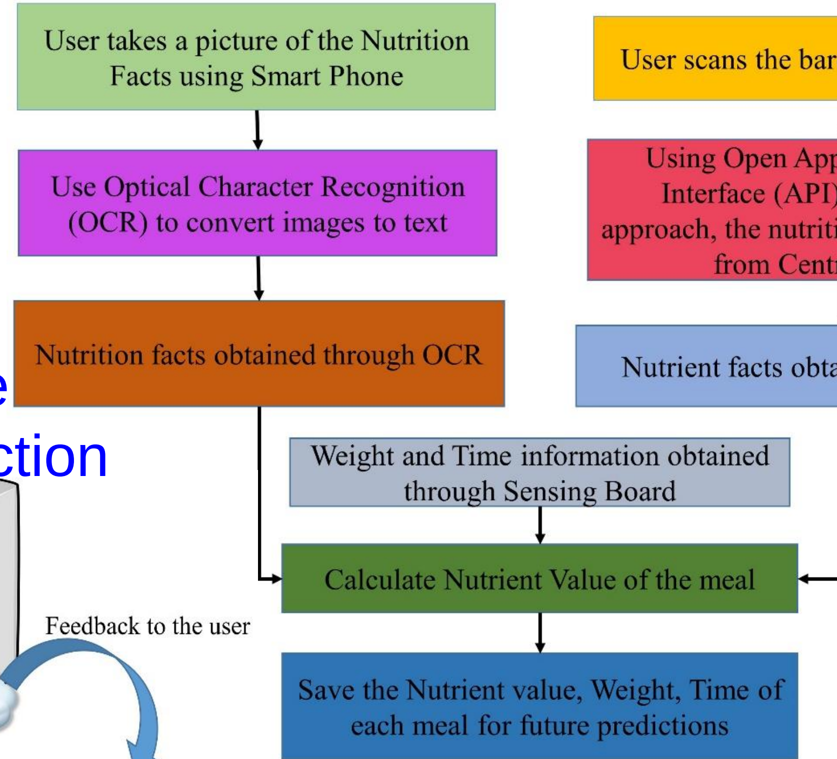


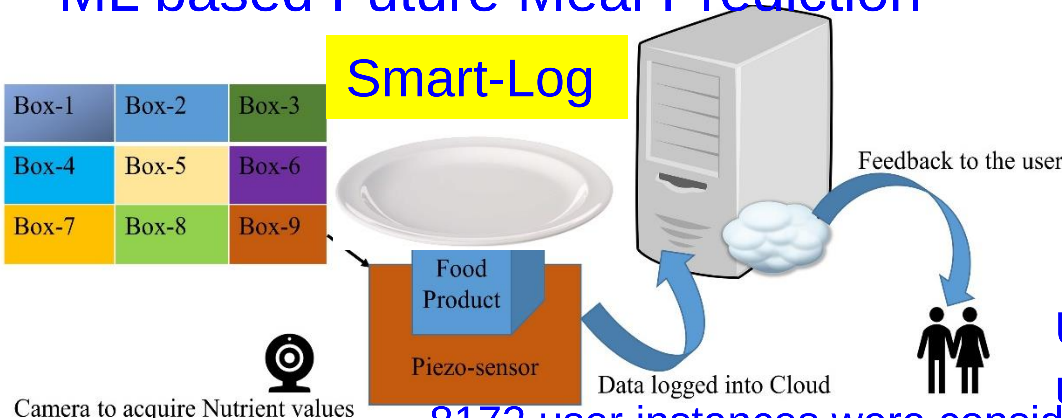
Windows Cortana

Smart Healthcare – Diet Monitoring

Automated Food intake Monitoring and Diet Prediction System

- Smart plate
- Data acquisition using mobile
- ML based Future Meal Prediction





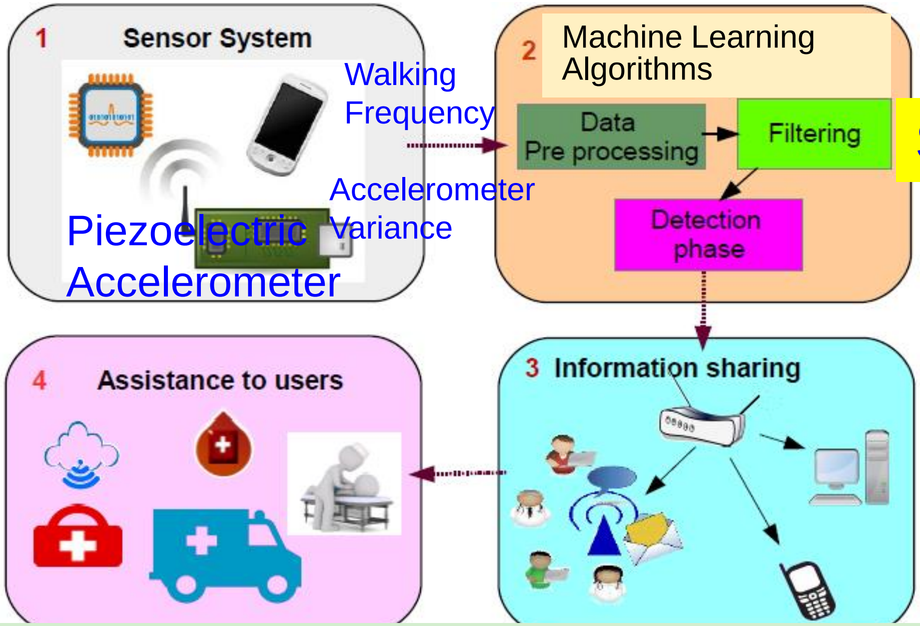
USDA National Nutrient Database used for nutrient values of 8791 items.

8172 user instances were considered

Research Works	Food Recognition Method	Efficiency (%)
This Work	Mapping nutrition facts to a database	98.4

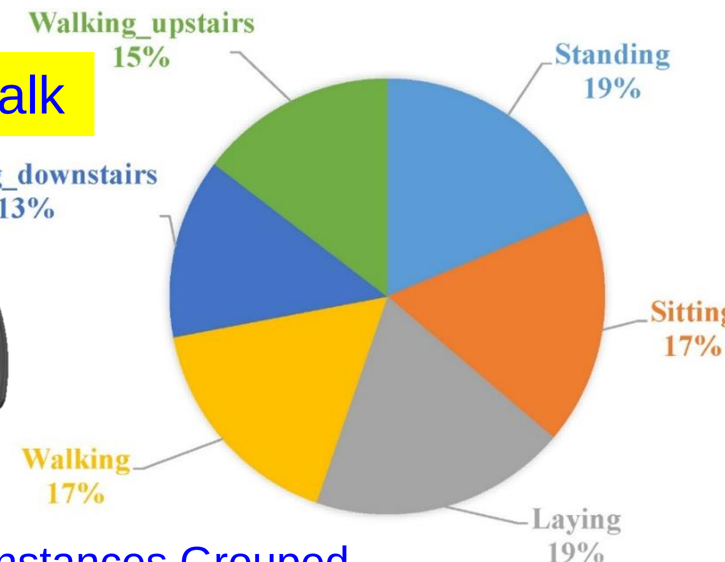
Source: P. Sundaravadivel, K. Kesavan, L. Kesavan, S. P. Mohanty, and E. Kougianos, "Smart-Log: A Deep-Learning based Automated Nutrition Monitoring System in the IoT", IEEE Trans. on Consumer Electronics, Vol 64, No 3, Aug 2018, pp. 390-398.

Smart Healthcare - Activity Monitoring



Automated Physiological Monitoring System

Smart-Walk

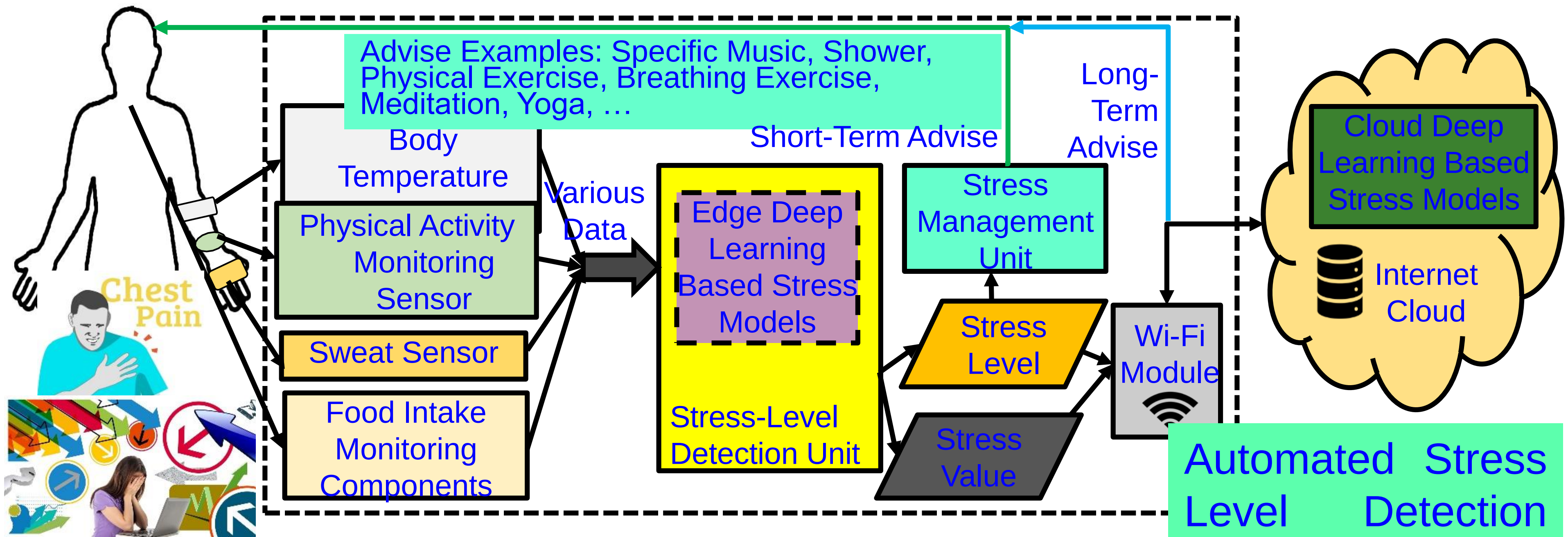


10291 Instances Grouped Under 6 Activities - Kaggle

Research Works	Method (WEKA)	Features considered	Activities	Accuracy (%)
This Work	Adaptive algorithm based on feature extraction	Step detection and Step length estimation	Walking, sitting, standing, etc.	97.9

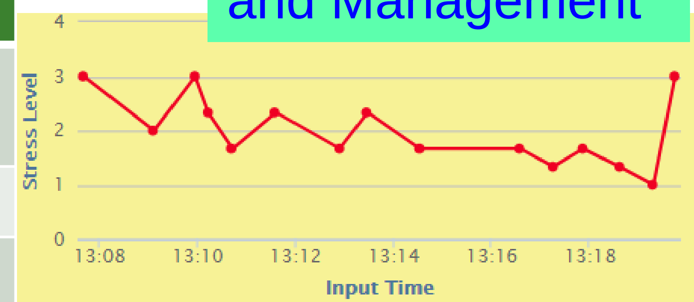
P. Sundaravadivel, S. P. Mohanty, E. Kougianos, V. P. Yanambaka, and M. K. Ganapathiraju, “Smart-Walk: An Intelligent Physiological Monitoring System for Smart Families”, in Proc. 36th IEEE International Conf. Consumer Electronics (ICCE), 2018.

Smart Healthcare - Stress Monitoring & Control



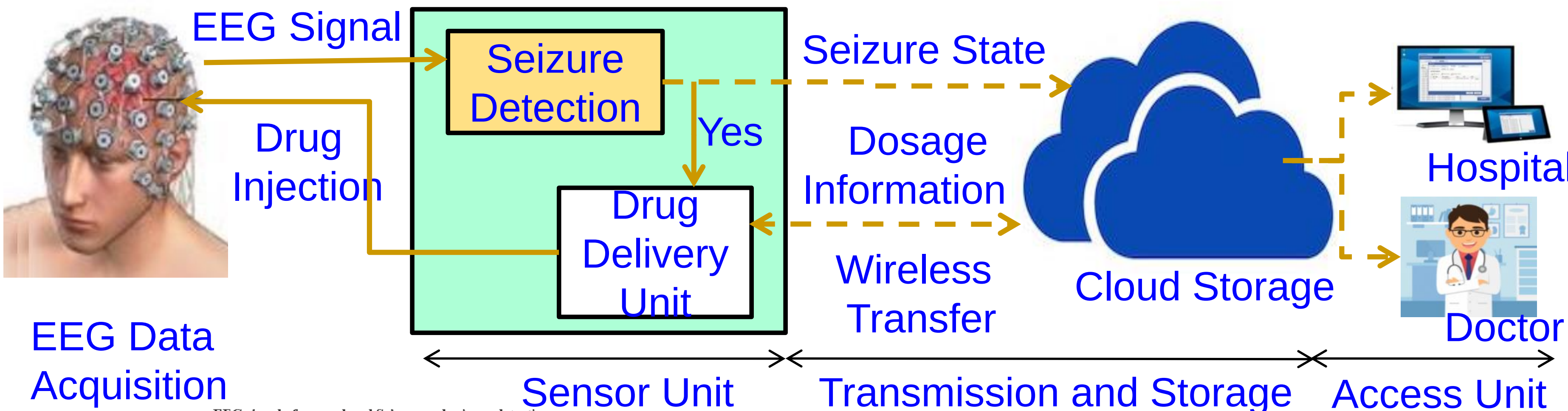
Automated Stress Level Detection and Management

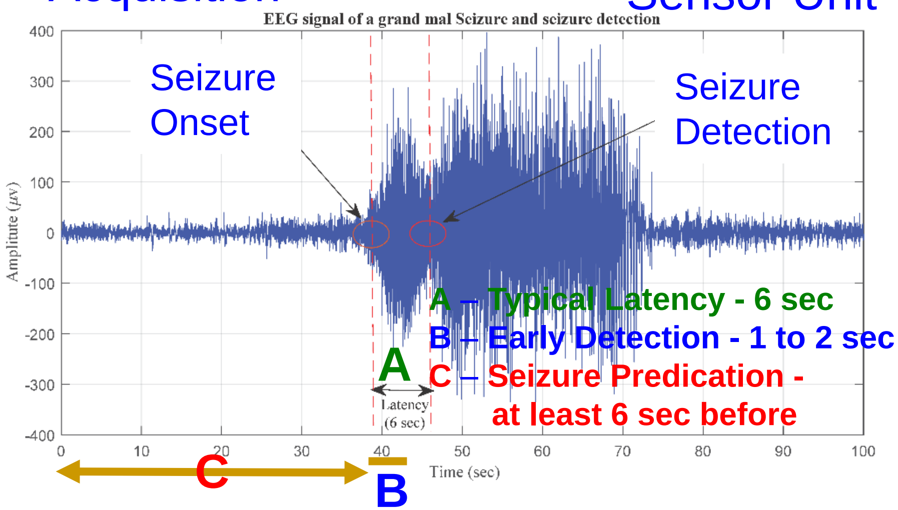
Sensor	Low Stress	Normal Stress	High Stress
Accelerometer (steps/min)	0-75	75-100	101-200
Humidity (RH%)	27-65	66-91	91-120
Temperature ℉	98-100	90-97	80-90



Source: L. Rachakonda, P. Sundaravadivel, S. P. Mohanty, E. Kougianos, and M. Ganapathiraju, “A Smart Sensor in the IoMT for Stress Level Detection”, in Proc. 4th IEEE International Symposium on Smart Electronic Systems (iSES), 2018, pp. 141--145.

Smart Healthcare - Seizure Detection & Control





Automated Epileptic Seizure Detection and Control System

Cloud Vs Edge	Latency	Accuracy
Cloud-IoT based Detection	2.5 sec	98.65%
Edge-IoT based Detection	1.4 sec	98.65%

Source: M. A. Sayeed, S. P. Mohanty, E. Kougianos, and H. Zaveri, “Neuro-Detect: A Machine Learning Based Fast and Accurate Seizure Detection System in the IoMT”, *IEEE Transactions on Consumer Electronics (TCE)*, Volume XX, Issue YY, ZZ 2019, pp. Accepted on 16 May 2019, DOI: 10.1109/TCE.2019.2917895 .

Energy, Security, and Response Smart (ESR-Smart)

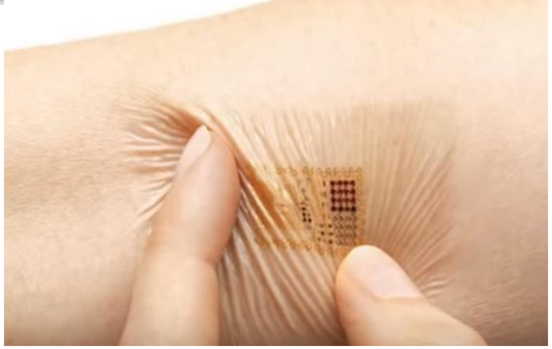
Wearable Medical Devices (WMDs)

Fitness Trackers

Headband with Embedded Neurosensors

Source: https://www.empatica.com/embrace2/

Smart watch to detect seizure



Embedded Skin Patch

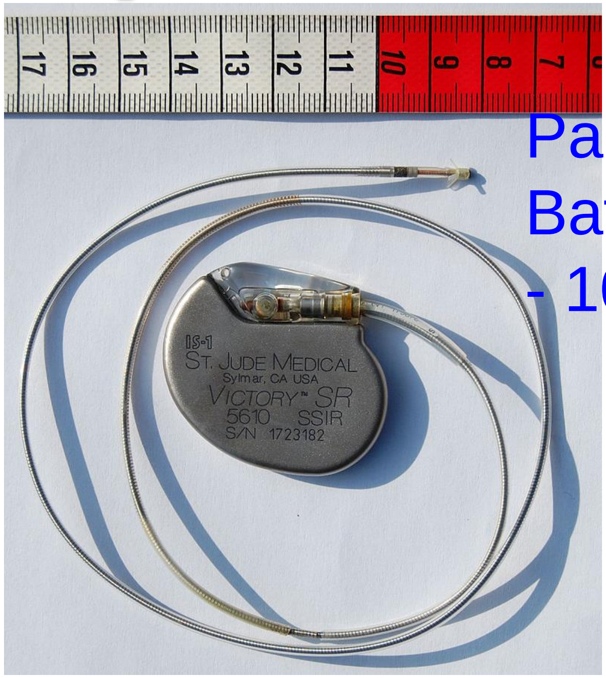
Source: http://www.sciencetimes.com/articles/8087/20160107/ces-loreals-smart-skin-patch-reveals-long-exposed-sun.htm

Insulin Pump

Source: https://www.webmd.com

Wearable Medical Devices (WMDs)
→ Battery Constrained

Implantable Medical Devices (IMDs)



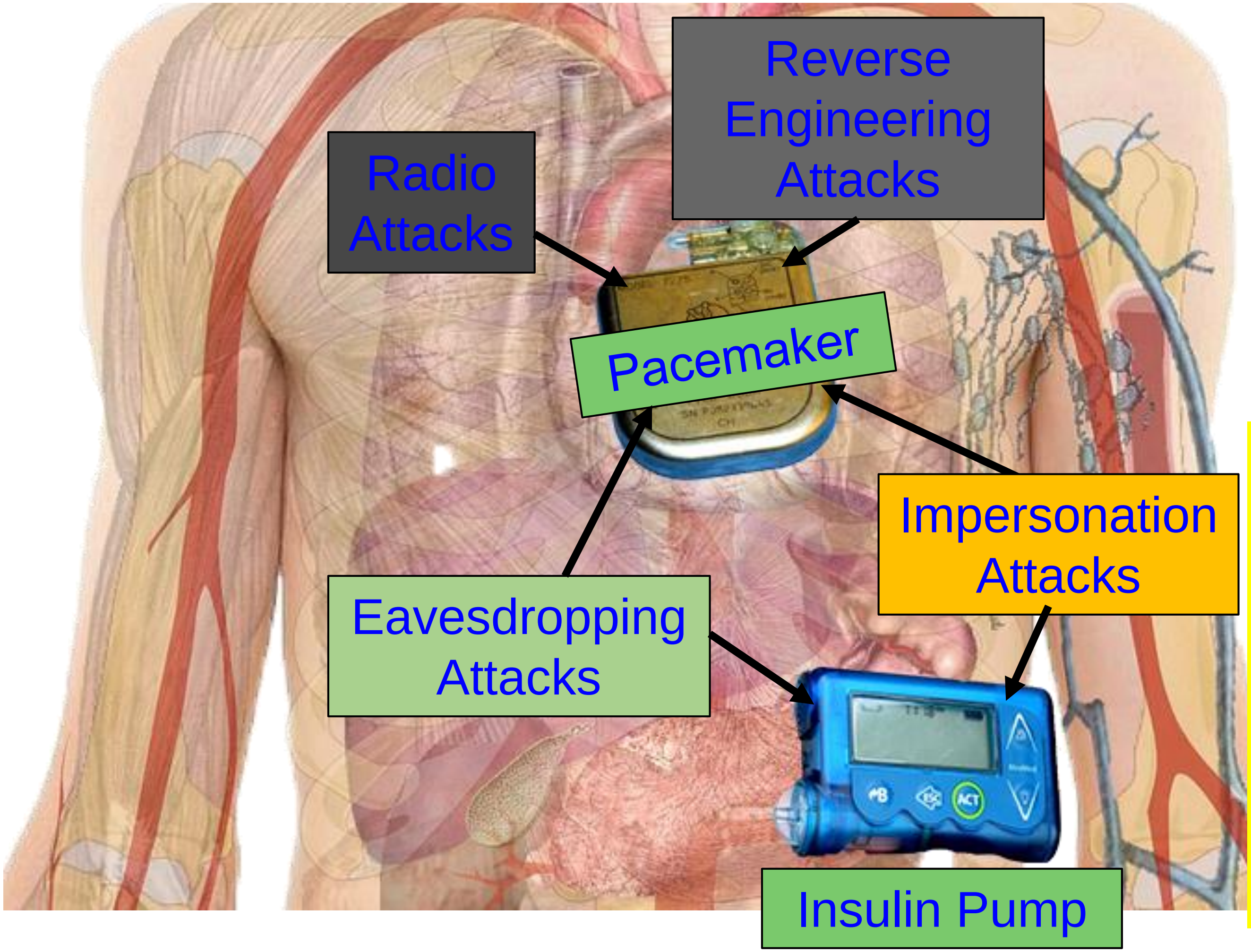
Pacemaker
Battery Life
- 10 years

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: Carmen Camara, PedroPeris-Lopeza, and Juan 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.

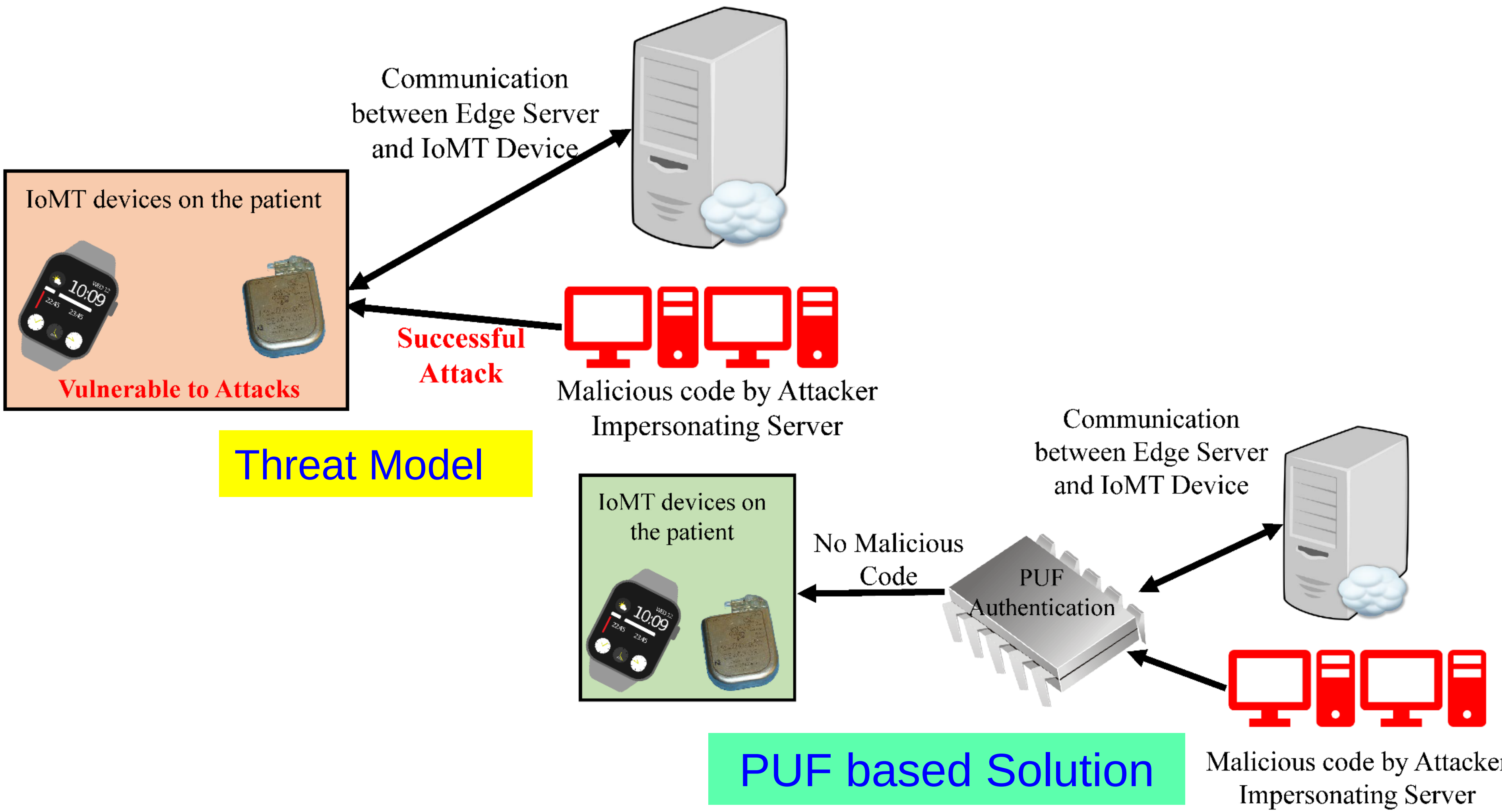
Security Measures in Smart Devices – Smart Healthcare



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

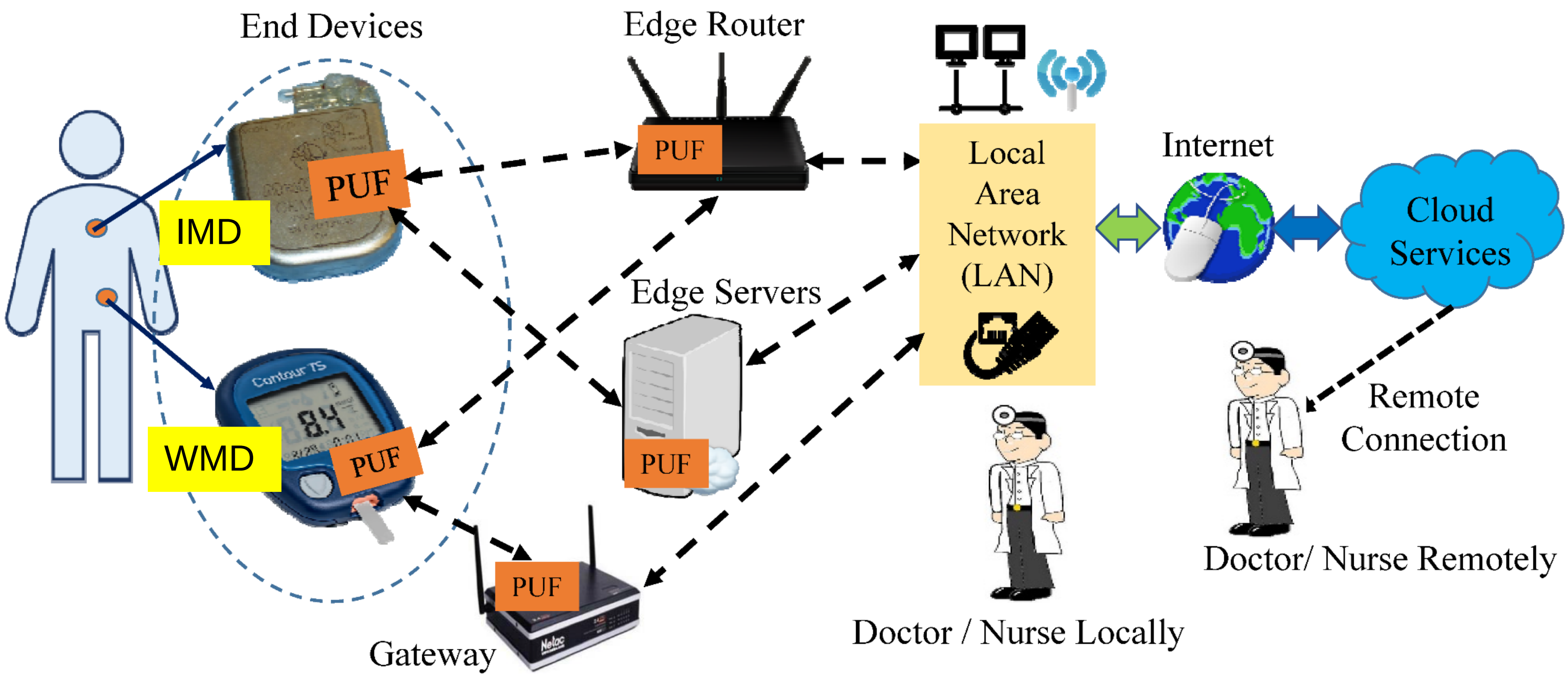
Implantable and Wearable Medical Devices (IWMDs) -- Battery Characteristics:
- → Longer life
- → Safer
- → Smaller size
- → Smaller weight

IoMT Security - PUF based Device Authentication



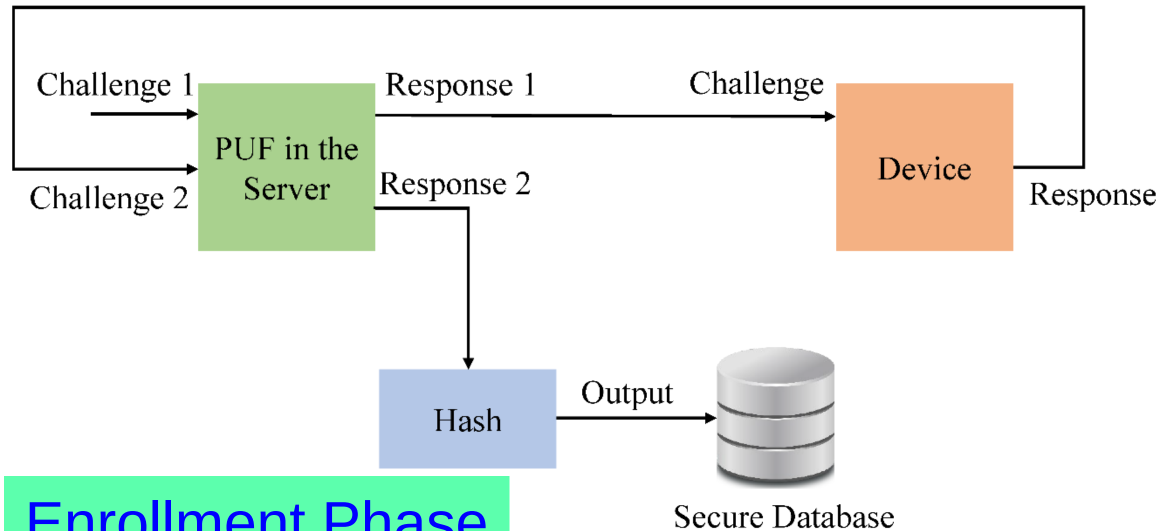
Source: V. P. Yanambaka, S. P. Mohanty, E. Kougianos, and D. Puthal, “PMsec: Physical Unclonable Function-Based Robust and Lightweight Authentication in the Internet of Medical Things”, IEEE Transactions on Consumer Electronics (TCE), Volume XX, Issue YY, ZZ 2019, DOI: 10.1109/TCE.2019.2926192.

IoMT Security - PUF based Device Authentication



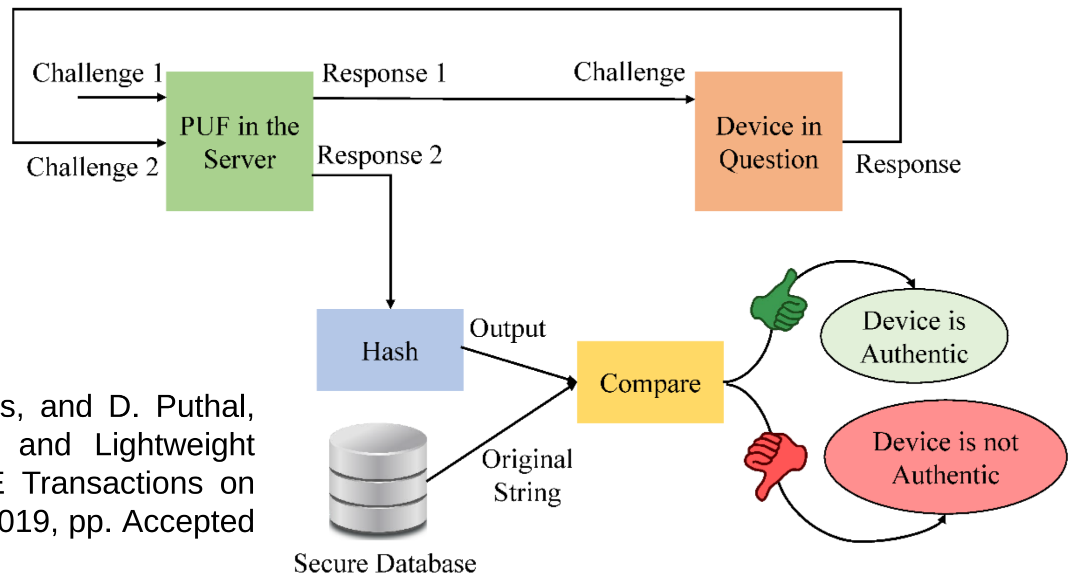
Source: V. P. Yanambaka, S. P. Mohanty, E. Kougianos, and D. Puthal, “PMsec: Physical Unclonable Function-Based Robust and Lightweight Authentication in the Internet of Medical Things”, IEEE Transactions on Consumer Electronics (TCE), Volume XX, Issue YY, ZZ 2019, pp. Accepted on 28 June 2019, DOI: 10.1109/TCE.2019.2926192.

IoMT Security - PUF based Device Authentication



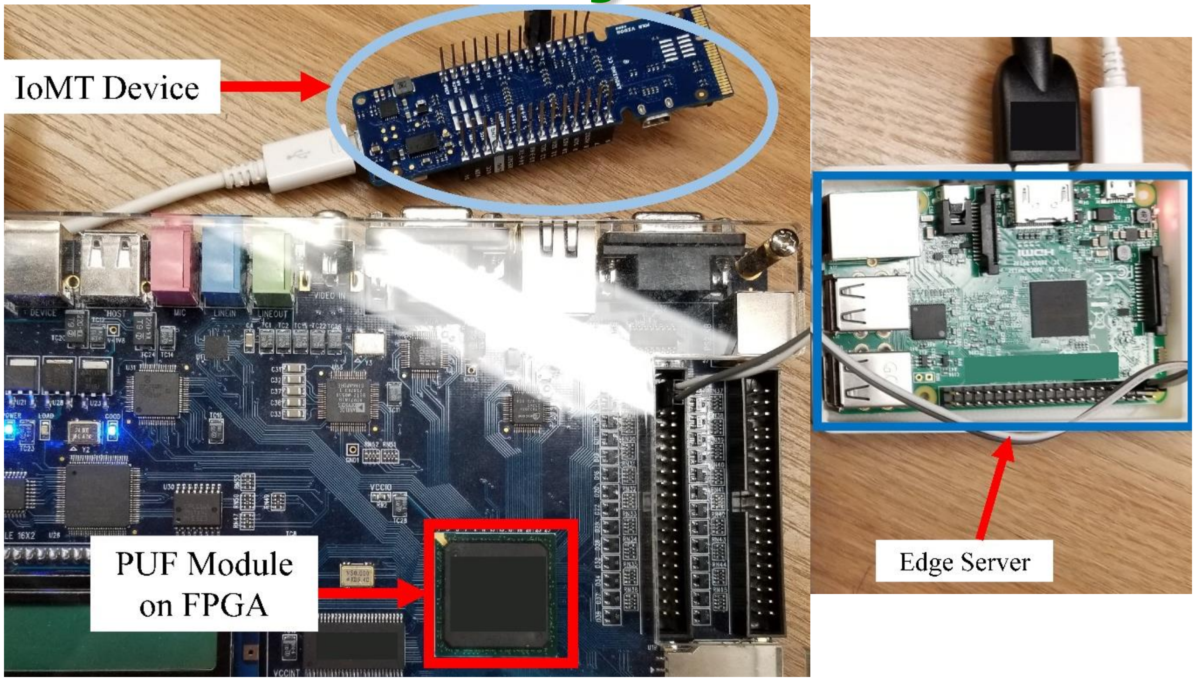
Enrollment Phase

Authentication Phase



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 XX, Issue YY, ZZ 2019, pp. Accepted on 28 June 2019, DOI: 10.1109/TCE.2019.2926192.

IoMT Security - PUF based Device Authentication

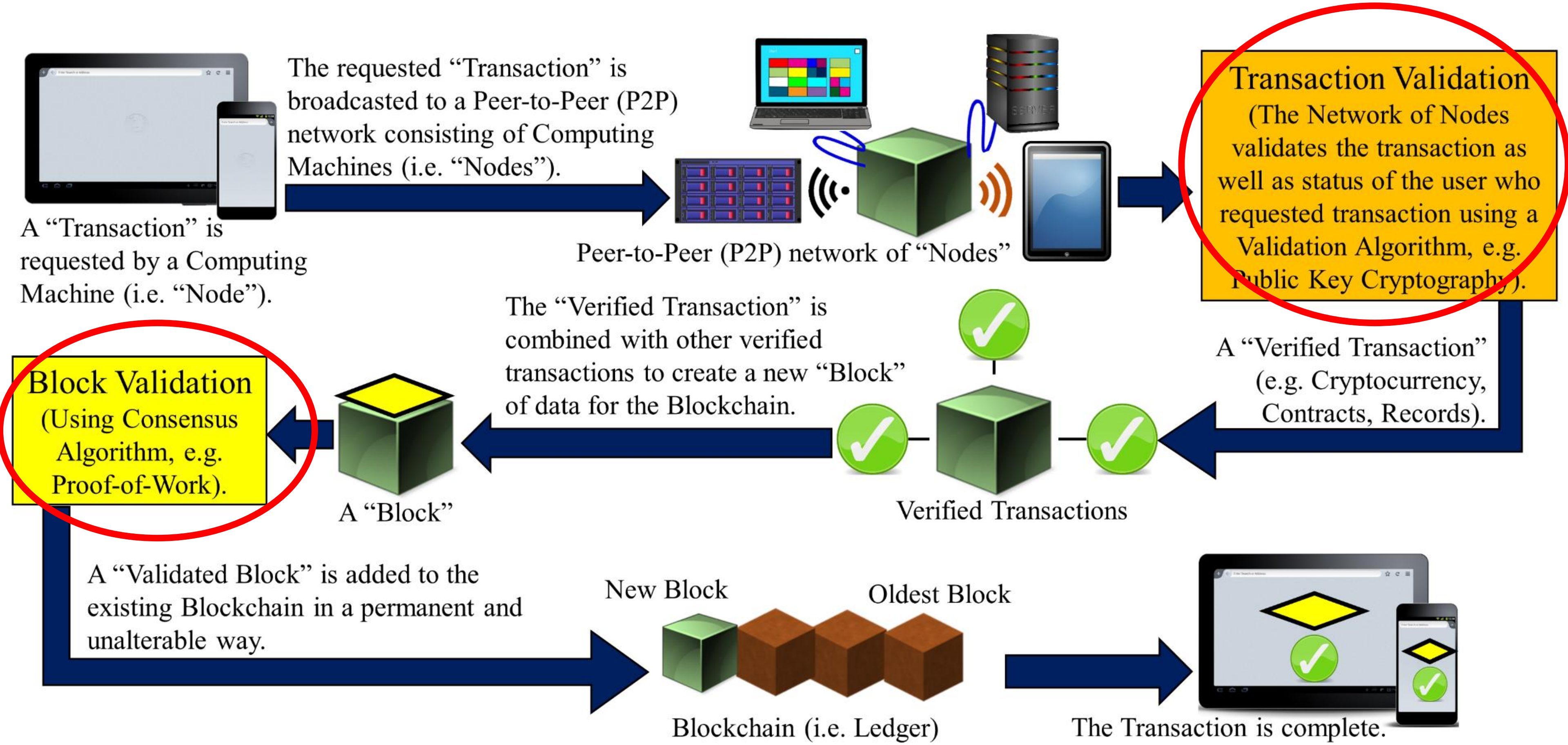


Average Power Overhead – ~ 200 μW

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

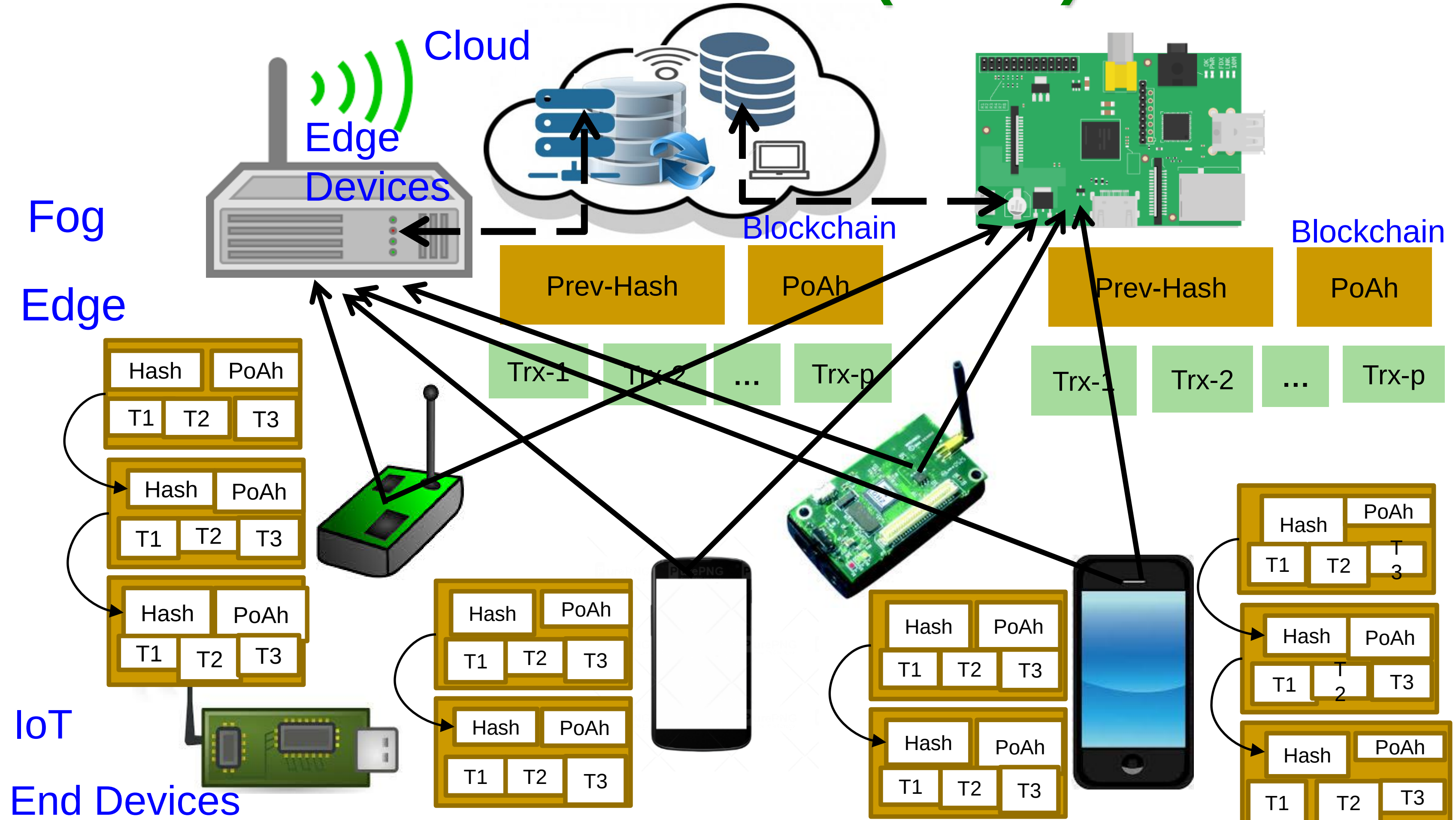
Source: V. P. Yanambaka, S. P. Mohanty, E. Kougianos, and D. Puthal, "PMsec: Physical Unclonable Function-Based Robust and Lightweight Authentication in the Internet of Medical Things", IEEE Transactions on Consumer Electronics (TCE), Volume XX, Issue YY, ZZ 2019, pp. Accepted on 28 June 2019, DOI: 10.1109/TCE.2019.2926192.

Blockchain Technology



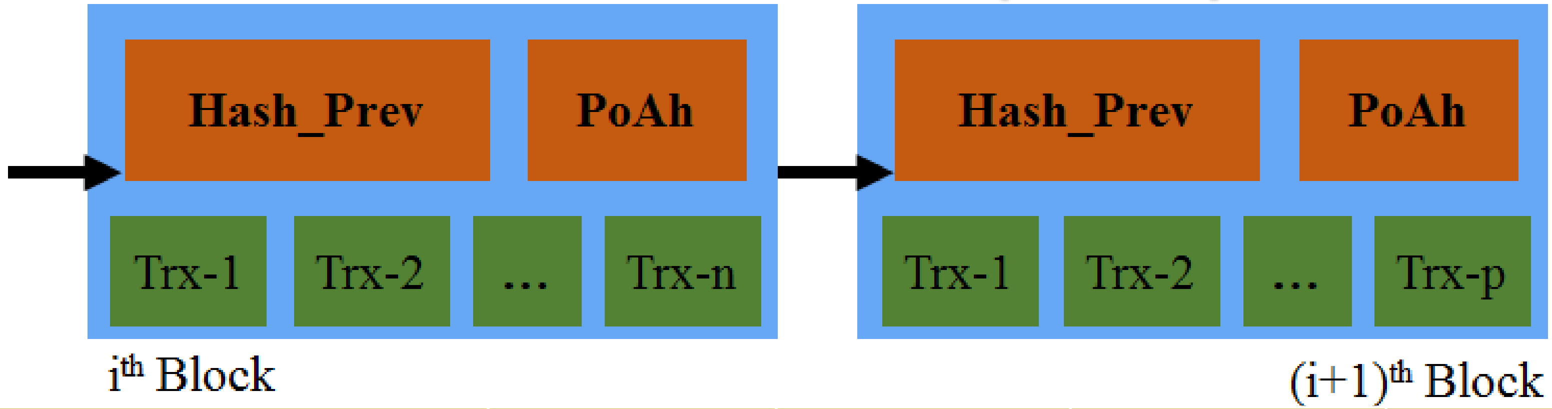
Source: D. Puthal, N. Malik, S. P. Mohanty, E. Kougianos, and G. Das, "Everything you Wanted to Know about the Blockchain", *IEEE Consumer Electronics Magazine (CEM)*, Volume 7, Issue 4, July 2018, pp. 06--14.

IoT Friendly Blockchain - Proof-of-Authentication (PoAh)



Source: D. Puthal and S. P. Mohanty, "Proof of Authentication: IoT-Friendly Blockchains", *IEEE Potentials Magazine*, Volume 38, Issue 1, January 2019, pp. 26--29.

IoT Friendly Blockchain - Proof-of-Authentication (PoAh)



	Proof-of-Work (PoW)	Proof-of-Stake (PoS)	Proof-of-Activity (PoA)	Proof-of-Authentication (PoAh)
Energy consumption	High	High	High	Low
Computation requirements	High	High	High	Low
Latency	High	High	High	Low
Search space	High	Low	NA	NA

PoW - 10 min in cloud	**PoAh - 3 sec in Rasperry Pi**	**PoAh - 200X faster than PoW**

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.

Smart Car Security - 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 security issues.

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

Mitigating Advanced Threats
Analytics in the Car and in the Cloud

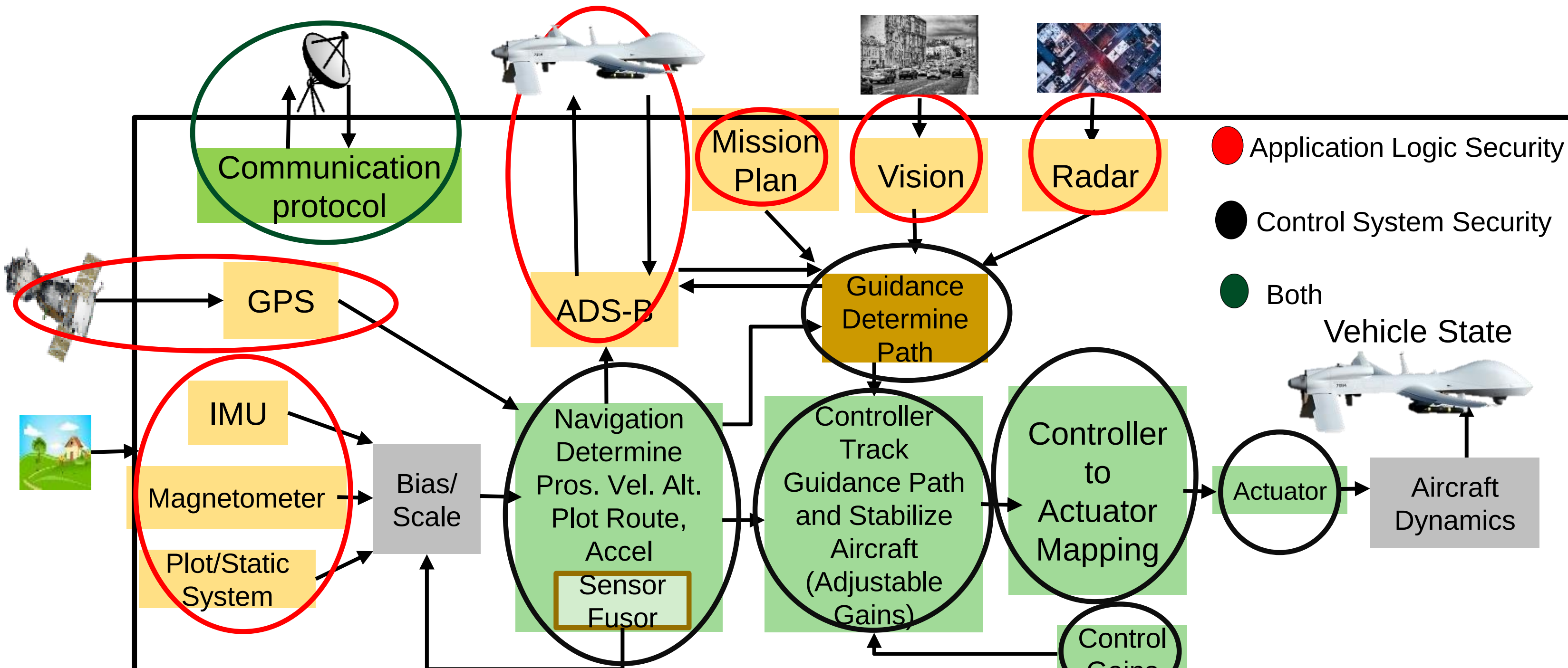
- Connected cars require latency of ms to communicate and avoid impending crash:
  - Faster connection
  - Low latency
  - Energy efficiency

Security Mechanism Affects:
- Latency
- Mileage
- Battery Life

Car Security – Latency Constraints

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

UAV Security - Energy & Latency Constrained

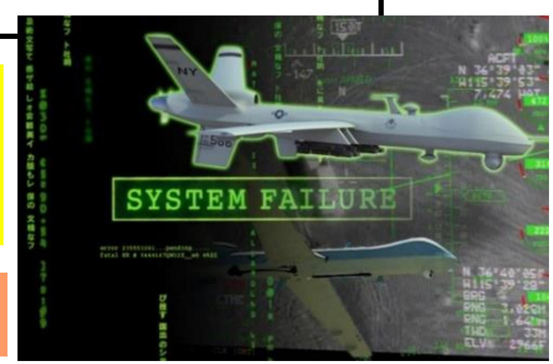


Source: http://www.secmation.com/control-design/

Security Mechanisms Affect:

Battery Life | Latency | Weight | Aerodynamics

UAV Security – Energy and Latency Constraints



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

Attacks - Software Vs Hardware

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
  - CE system tampering/jailbreaking
  - Eavesdropping for protected memory
  - Side channel attack
  - CE hardware counterfeiting

Source: Mohanty ICCE Panel 2018

Security - Software Vs Hardware

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

Maintaining of Security of Consumer Electronics, CE Systems, IoT, CPS, etc. needs Energy and affects performance.

Hardware Assisted Security

- 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: Security/Protection provided by the hardware: for information being processed by a CE system, for hardware itself, and/or for the CE system.

Hardware Assisted Security

- Hardware-Assisted Security: Security provided by hardware for:
  (1) information being processed,
  (2) hardware itself,
  (3) overall system
- Additional hardware components used for security.
- Hardware design modification is performed.
- System design modification is performed.

Privacy by Design (PbD)

Security/Secure by Design (SbD)

RF Hardware Security

Digital Hardware Security – Side Channel

Hardware Trojan Protection

Information Security, Privacy, Protection

IR Hardware Security

Memory Protection

Digital Core IP Protection

Source: Mohanty ICCE 2018 Panel

Trustworthy CE System

- A selective attributes of CE system to be trustworthy:
  - It must maintain integrity of information it is processing.
  - It must conceal any information about the computation performed through any side channels such as power analysis or timing analysis.
  - It must perform only the functionality it is designed for, nothing more and nothing less.
  - It must not malfunction during operations in critical applications.
  - It must be transparent only to its owner in terms of design details and states.
  - It must be designed using components from trusted vendors.
  - It must be built/fabricated using trusted fabs.

Where and How to Compute?

October 2016

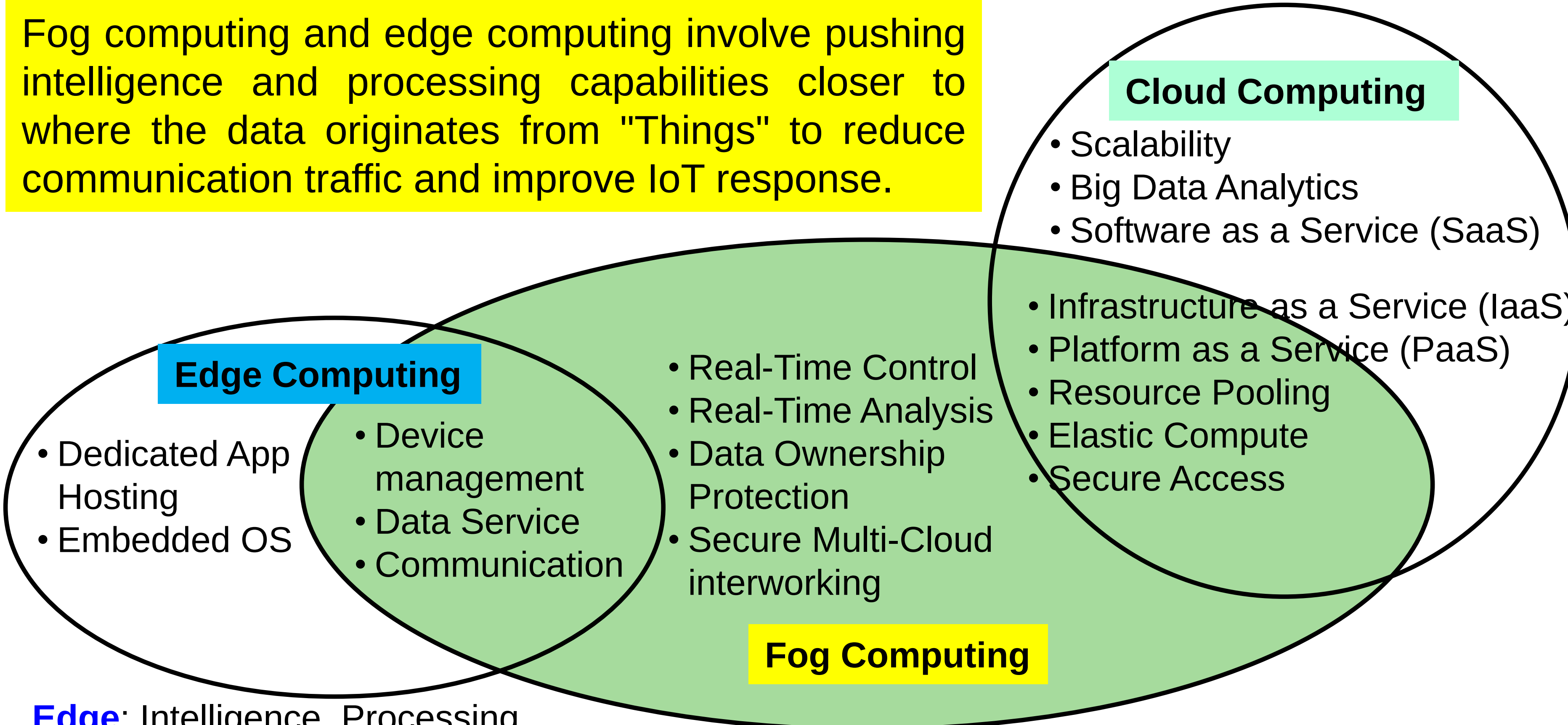
Sensor, Edge, Fog, Cloud?

July 2018

ASIC, FGPA, SoC, FP-SoC, GPU, Neuromorphic, Quantum?

Fog Vs Edge Vs Cloud Computing

Fog computing and edge computing involve pushing intelligence and processing capabilities closer to where the data originates from "Things" to reduce communication traffic and improve IoT response.



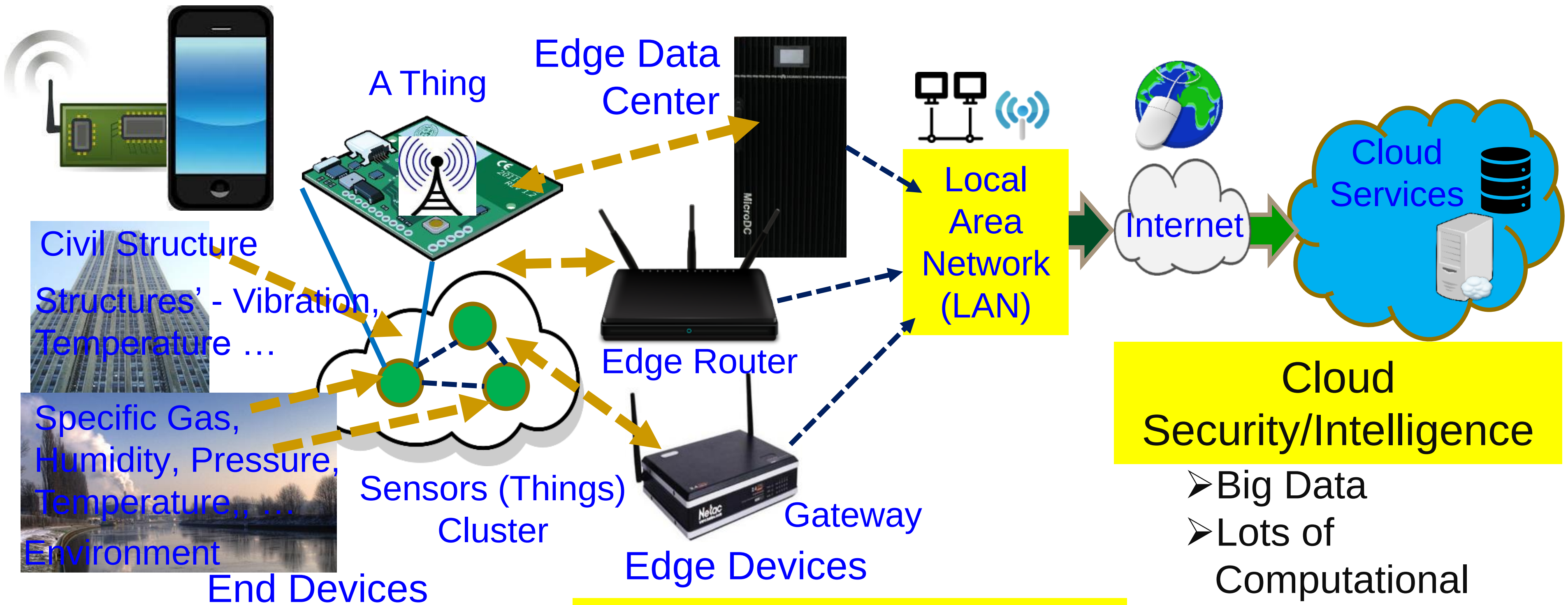
Edge: Intelligence, Processing, and Communication - Devices like Programmable Automation Controllers (PACs)

Fog: Intelligence - LAN, Processing - fog node or IoT gateway.

Source: https://www.automationworld.com/fog-computing-vs-edge-computing-whats-difference

Source: https://www.nebbiolo.tech/wp-content/uploads/whitepaper-fog-vs-edge.pdf

End, Edge Vs Cloud Security, Intelligence …



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

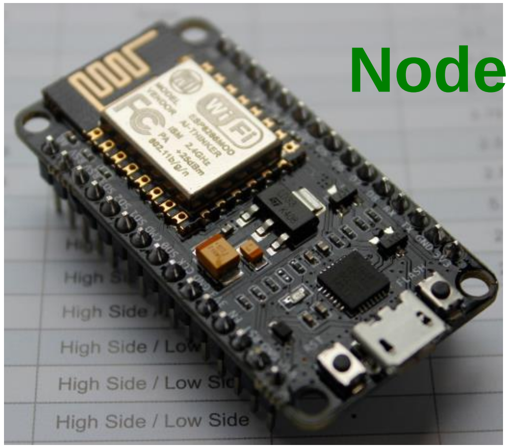
Edge Security/Intelligence

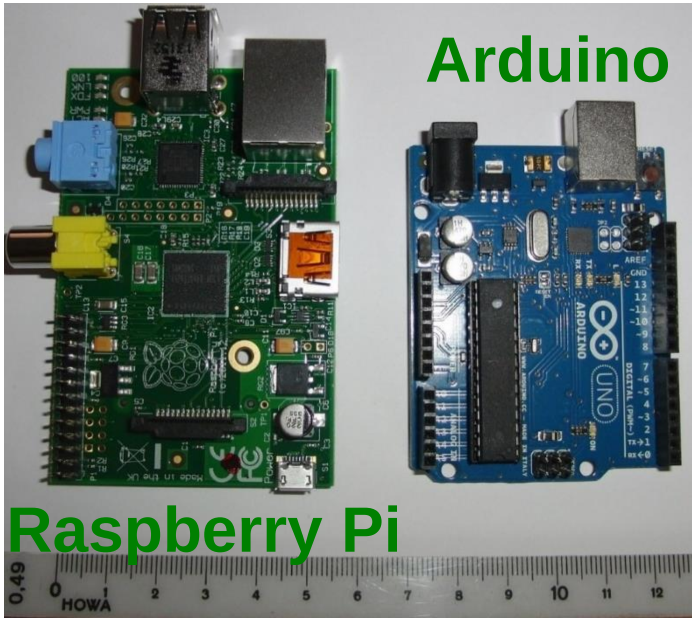
- Less Data
- Less Computational Resource
- Less Accurate Data Analytics
- Rapid Response

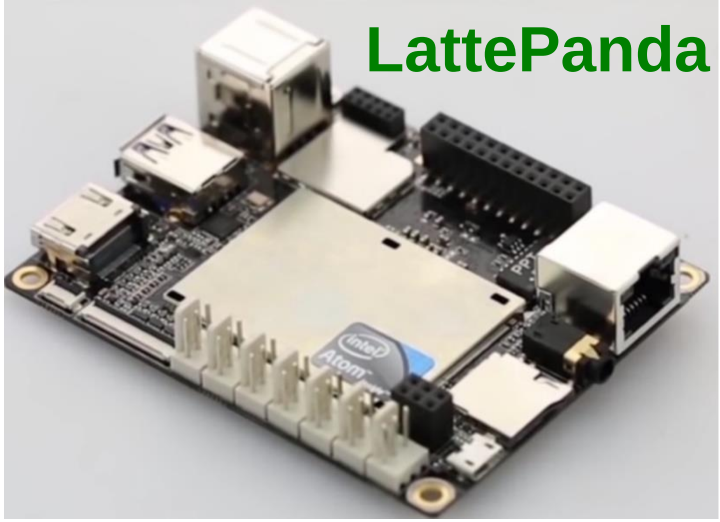
Source: Mohanty iSES Keynote 2018 and ICCE 2019 Panel

Computing Technology - IoT Platform

Source: https://www.sparkfun.com/products/13678

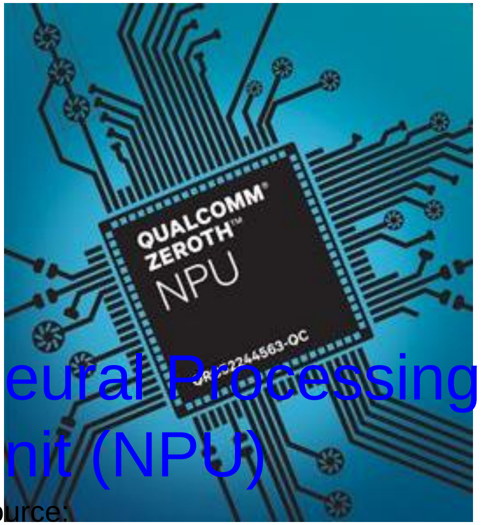






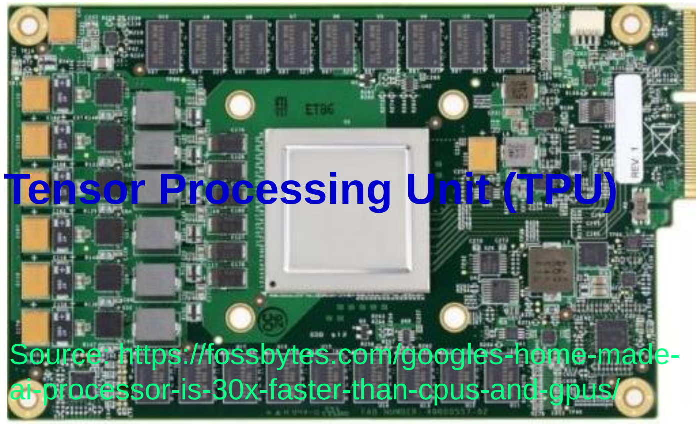
Source: http://www.lattepanda.com

Computing Technology - Current and Emerging



Neural Processing Unit (NPU)

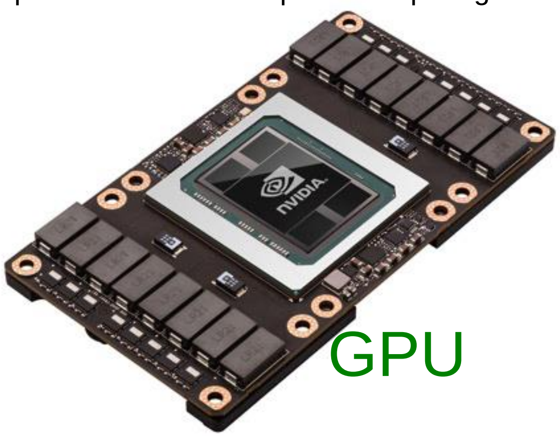
Source: https://www.qualcomm.com/news/onq/2013/10/10/introducing-qualcomm-zeroth-processors-brain-inspired-computing



Tensor Processing Unit (TPU)

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

FPGA



GPU

320 trillion operations per second

SoC based Design: 30 watts of power

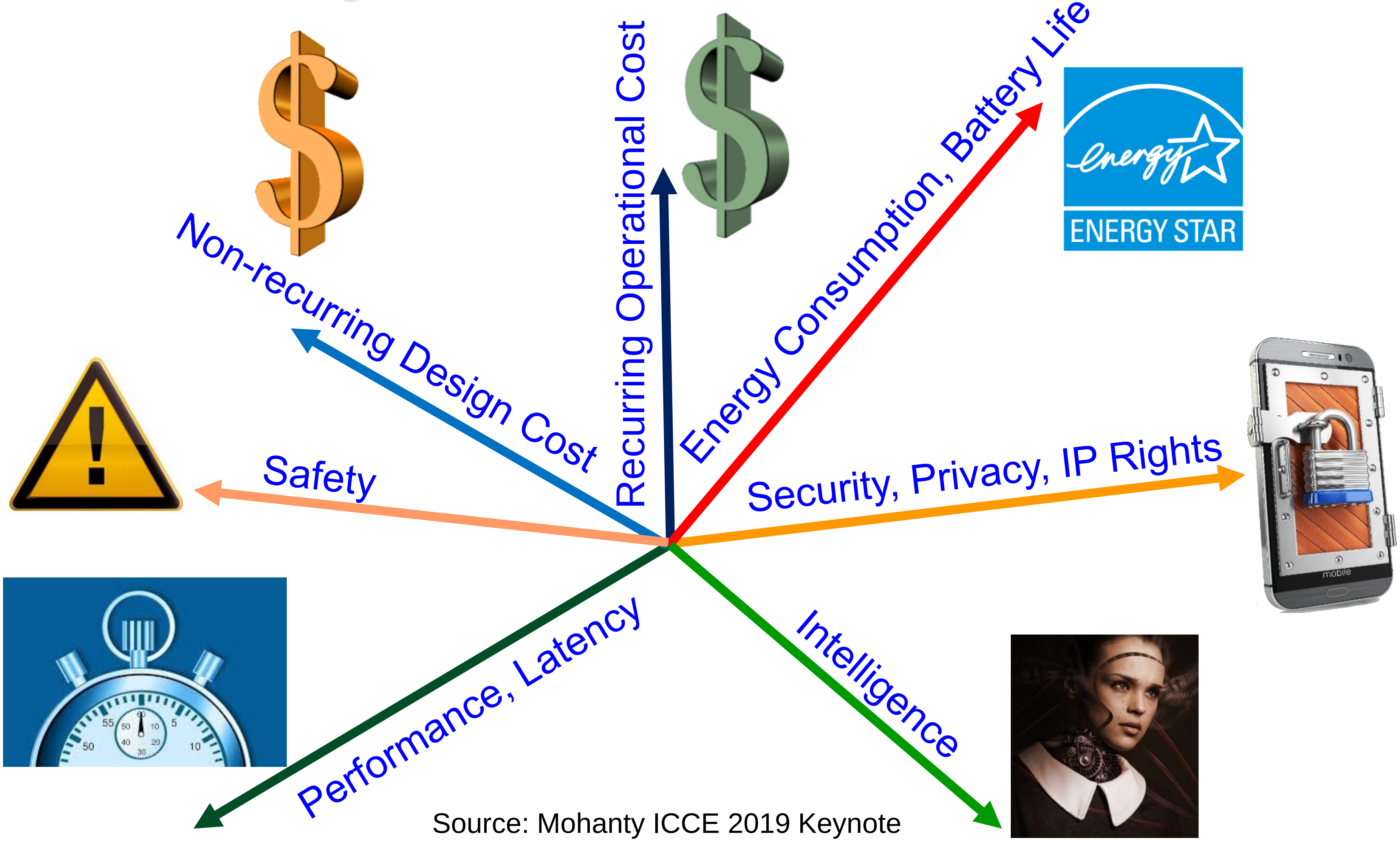
Source: https://www.engadget.com/2017/10/10/nvidia-introduces-a-computer-for-level-5-autonomous-cars/

ML Hardware – Cloud and Edge

Product	Cloud or Edge	Chip Type
Nvidia - DGX series	Cloud	GPU
Nvidia - Drive	Edge	GPU
Arm - ML Processor	Edge	CPU
NXP - i.MX processor	Edge	CPU
Xilinx - Zinq	Edge	Hybrid CPU/FPGA
Xilinx - Virtex	Cloud	FPGA
Google - TPU	Cloud	ASIC
Tesla - AI Chip	Edge	Unknown
Intel - Nervana	Cloud	CPU
Intel - Loihi	Cloud	Neuromorphic
Amazon - Echo (custom AI chip)	Edge	Unknown
Apple - A11 processor	Edge	CPU
Nokia - Reefshark	Edge	CPU
Huawei - Kirin 970	Edge	CPU
AMD - Radeon Instinct MI25	Cloud	GPU
IBM - TrueNorth	Cloud	Neuromorphic
IBM - Power9	Cloud	CPU
Alibaba - Ali-NPU	Cloud	Unknown
Qualcomm AI Engine	Edge	CPU
Mediatek - APU	Edge	CPU

Source: Presutto 2018: https://www.academia.edu/37781087/Current_Artificial_Intelligence_Trends_Hardware_and_Software_Accelerators_2018_

CE/IoT System - Multi-Objective Tradeoffs



Source: Mohanty ICCE 2019 Keynote

ESR-Smart Electronics

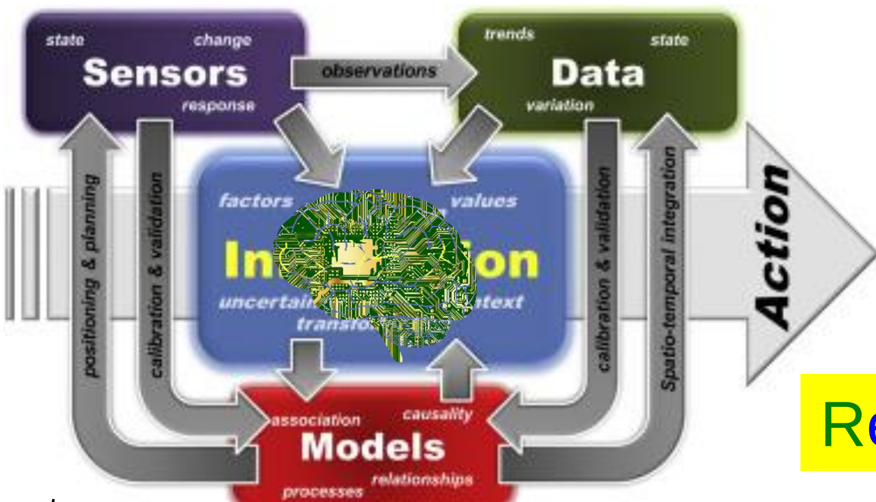
Energy Smart

Source: https://mashable.com/2012/10/05/energy-efficient-smartphone/

Security of systems and data.

Security Smart

Energy consumption is minimal and adaptive for longer battery life and lower energy bills.



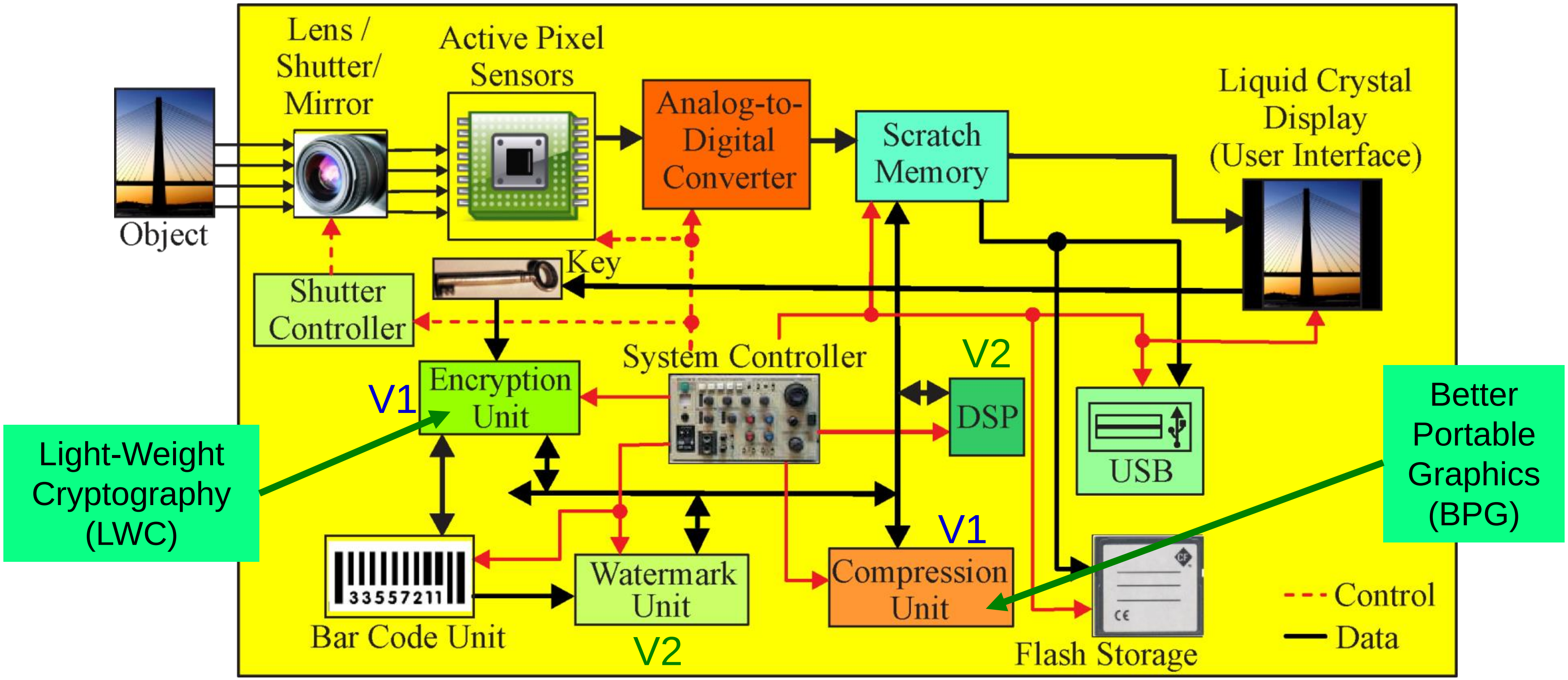
Accurate sensing, analytics, and fast actuation.

Response Smart

Source: Mohanty iSES 2018 Keynote

Source: Reis, et al. Elsevier EMS Dec 2015

ESR-Smart – End-Device Optimization



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.

Source: Mohanty 2006, TCAS-II May 2006; Mohanty 2009, JSA Oct 2009; Mohanty 2016, Access 2016

Conclusions

Conclusions

- Privacy, security, and ownership rights are important problems in CE systems.
- Energy dissipation and performance are also key challenges.
- Hardware-Assisted Security: Security provided by hardware for: (1) information being processed, (2) hardware itself, (3) overall system.
- It is low-cost and low-overhead solution as compared to software only based.
- Many hardware based solutions exist for media copyright and information security.
- Many hardware design solutions exist for IP protection and security of the CE systems that use such hardware.
- NFC and RFID security are important for IoT and CE security.
- Privacy and security in smart healthcare need research.

Future Directions

- Energy-Efficient CE/IoT is needed.
- Security, Privacy, IP Protection of Information and System need more research.
- Security of the CE systems (e.g. smart healthcare device, UAV, Smart Cars) needs research.
- Safer and efficient battery need research.
- Important aspect of smart CE design: trade-offs among energy, response latency, and security
- Sustainable Smart City: needs sustainable IoT