Everything You Wanted to Know about the Internet of Things (IoT)

Oriental University, Indore

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

Talk - Outline

- Motivations for IoT
- Selected Components of IoT
- Selected Applications of IoT
- Driving Technologies of IoT
- Challenges and Research in IoT
- IoT Design Flow
- Tools and Solutions for IoT
- Related Buzzwords of IoT
- Conclusions and Future Directions

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

Human Migration Problem

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

Source: https://humanitycollege.org

Smart Cities - A Solution

- Smart Cities: For effective management of limited resource to serve largest possible population to improve:
  - Livability
  - Workability
  - Sustainability

July 2016

"Cities around the world could spend as much as $41 trillion on smart tech over the next 20 years."

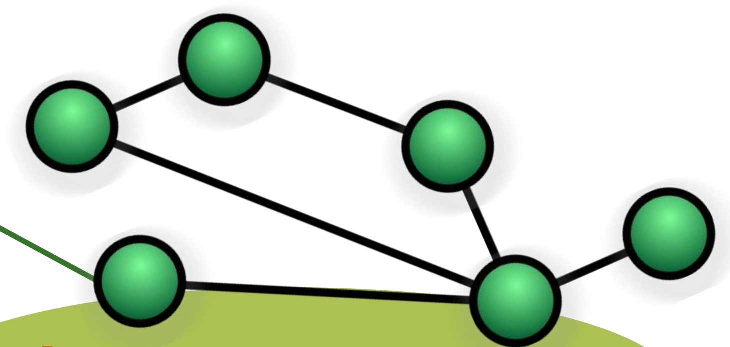
Source: http://www.cnbc.com/2016/10/25/spending-on-smart-cities-around-the-world-could-reach-41-trillion.html

Smart Cities - 3 Is

Instrumentation

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

Smart Cities

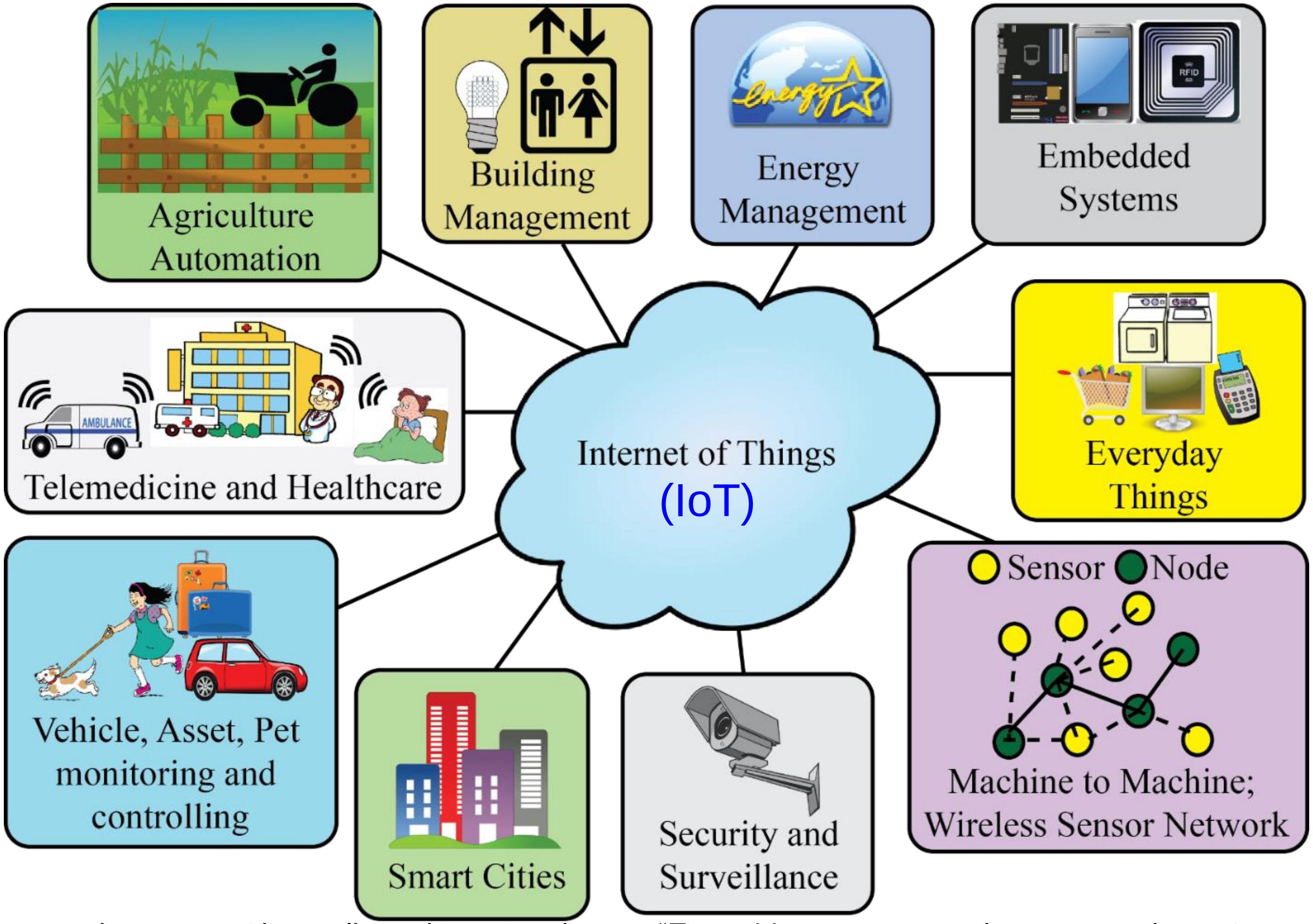


Intelligence

Interconnection

Source: Mohanty EuroSimE 2016 Keynote Presentation

IoT is the Backbone Smart Cities



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.

Internet of Things (IoT) - History

Source: http://events.linuxfoundation.org/sites/events/files/slides/Design%20-%20End-to-End%20%20IoT%20Solution%20-%20Shivakumar%20Mathapathi.pdf

IoT Components

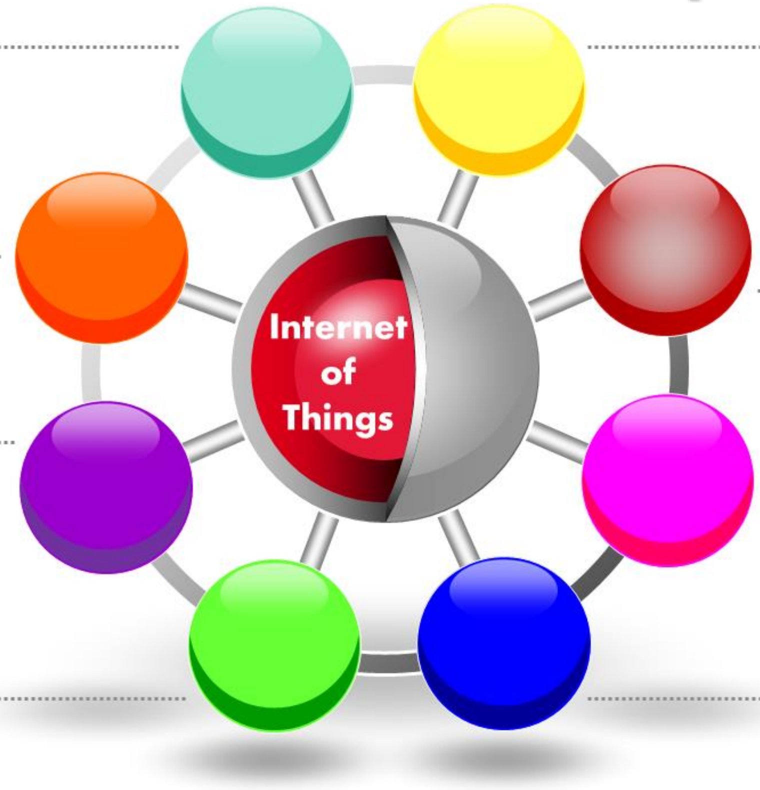
IoT – Definition - IoT European Research Cluster (IERC)

A ***dynamic global network infrastructure***

with ***self configuring capabilities***

based on ***standard and interoperable communication protocols***

where ***physical and virtual "things"***



have ***identities, physical attributes, and virtual personalities***

and

use ***intelligent interfaces***,

and are ***seamlessly integrated***

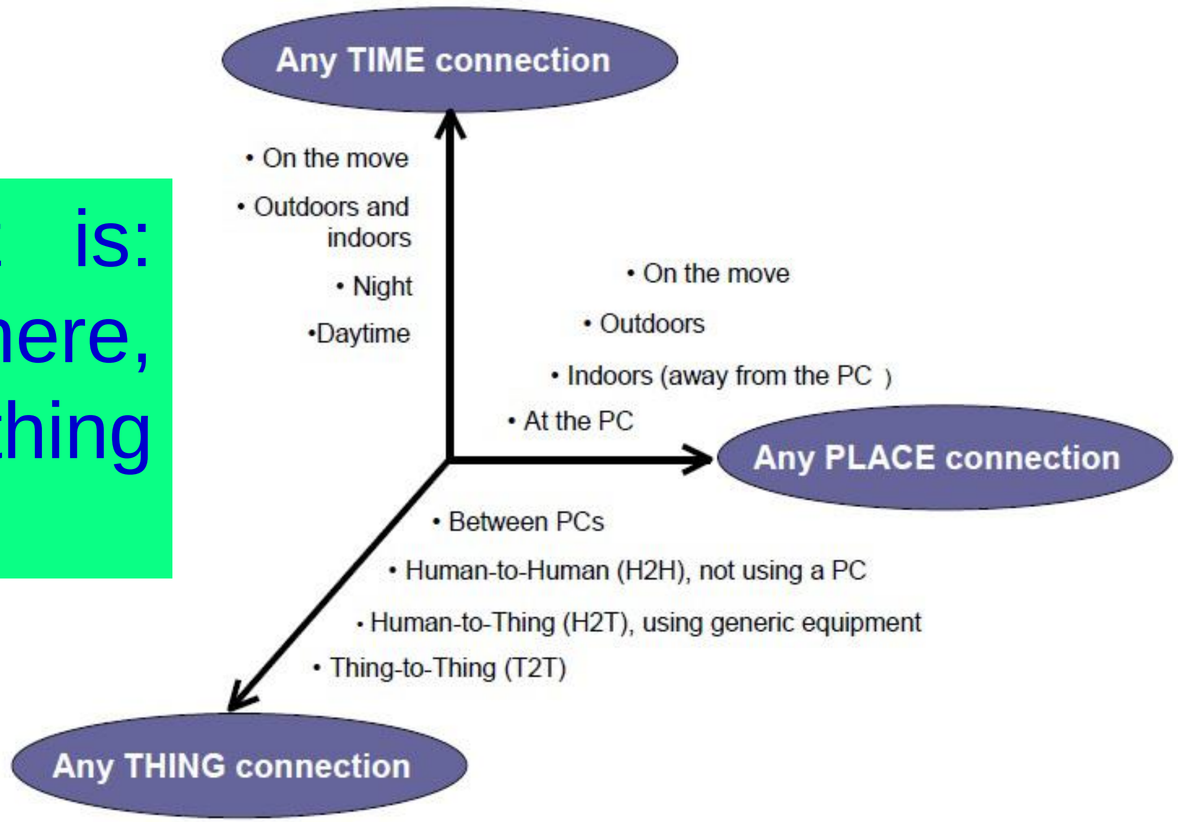
into ***the information network.***

Source: http://iot.ieee.org/images/files/pdf/IEEE_IoT_Towards_Definition_Internet_of_Things_Revision1_27MAY15.pdf

IEEE also provides a formal, comprehensive definition of IoT.

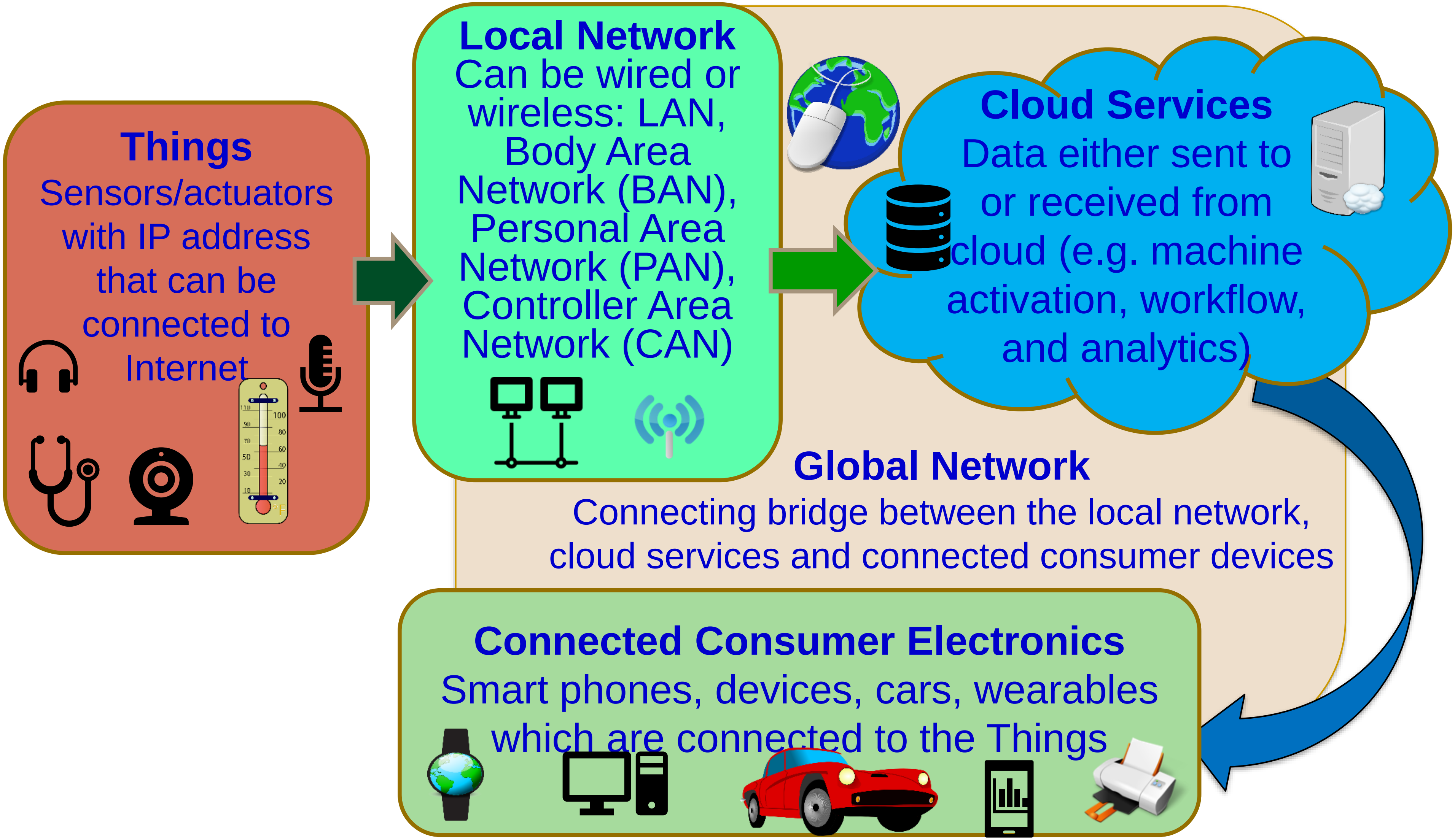
IoT – Definition - International Telecommunication Union (ITU)

A network that is: “Available anywhere, anytime, by anything and anyone.”

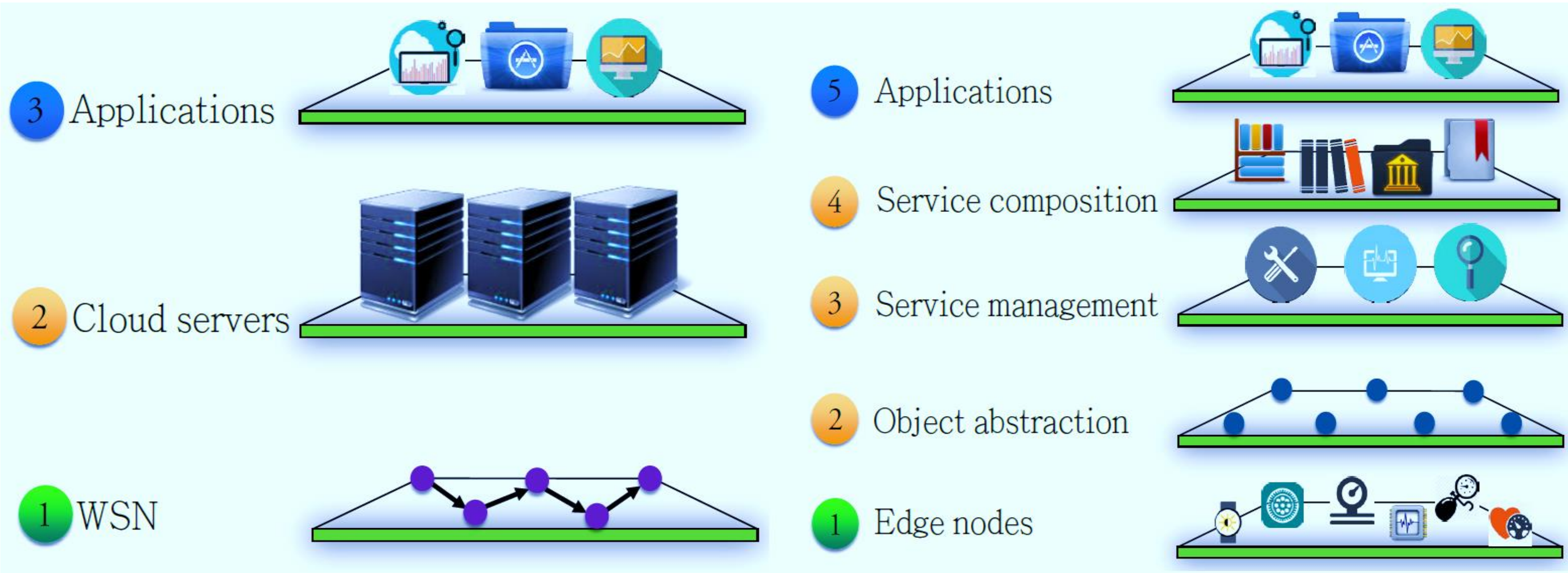


Source: http://iot.ieee.org/images/files/pdf/IEEE_IoT_Towards_Definition_Internet_of_Things_Revision1_27MAY15.pdf

Internet of Things (IoT) – Concept



IoT Architecture - 3 & 5 Level Model

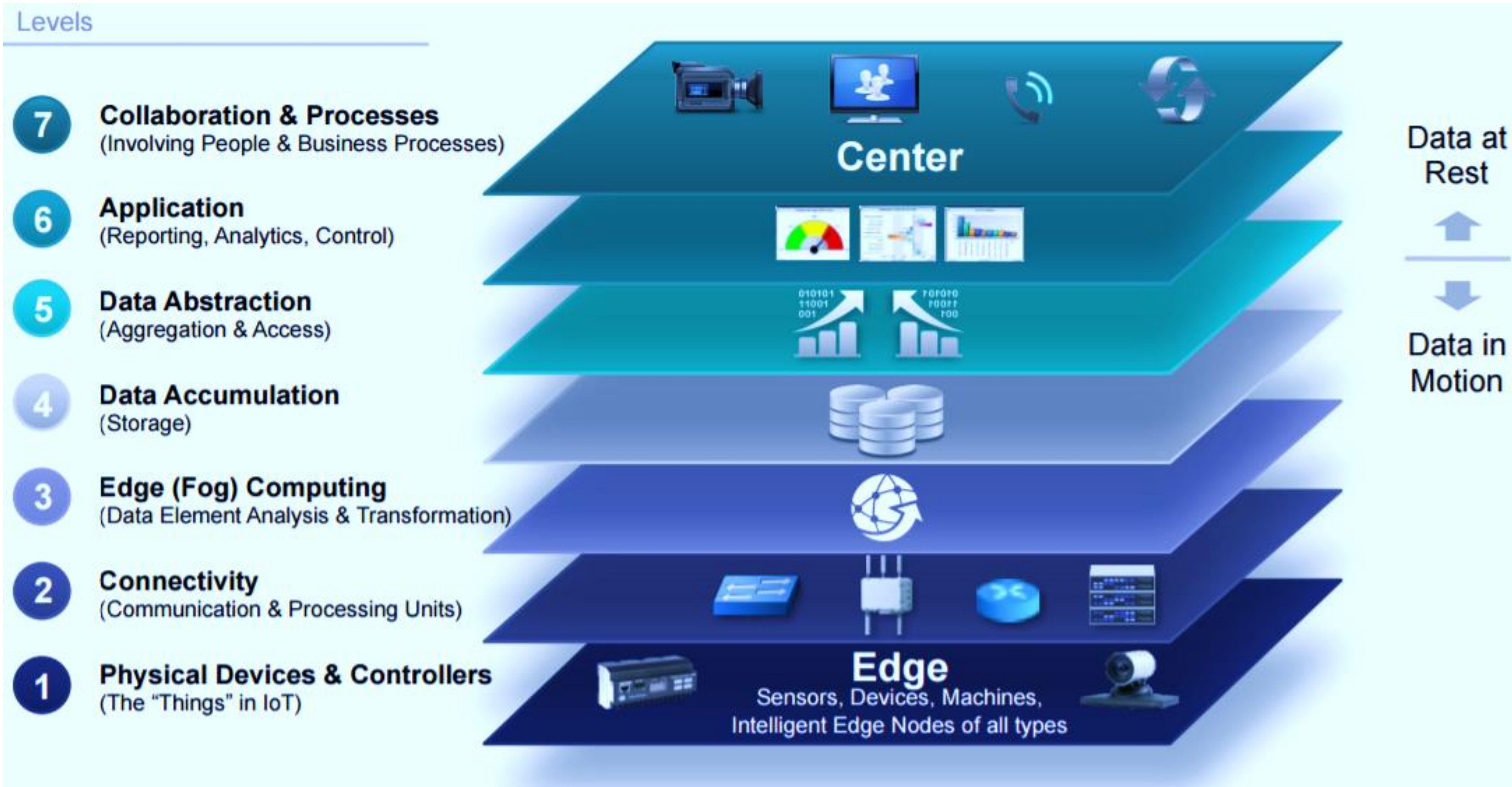


Three Level Model

Five Level Model

Source: Nia 2017, IEEE TETC 2017

IoT Architecture - 7 Level Model

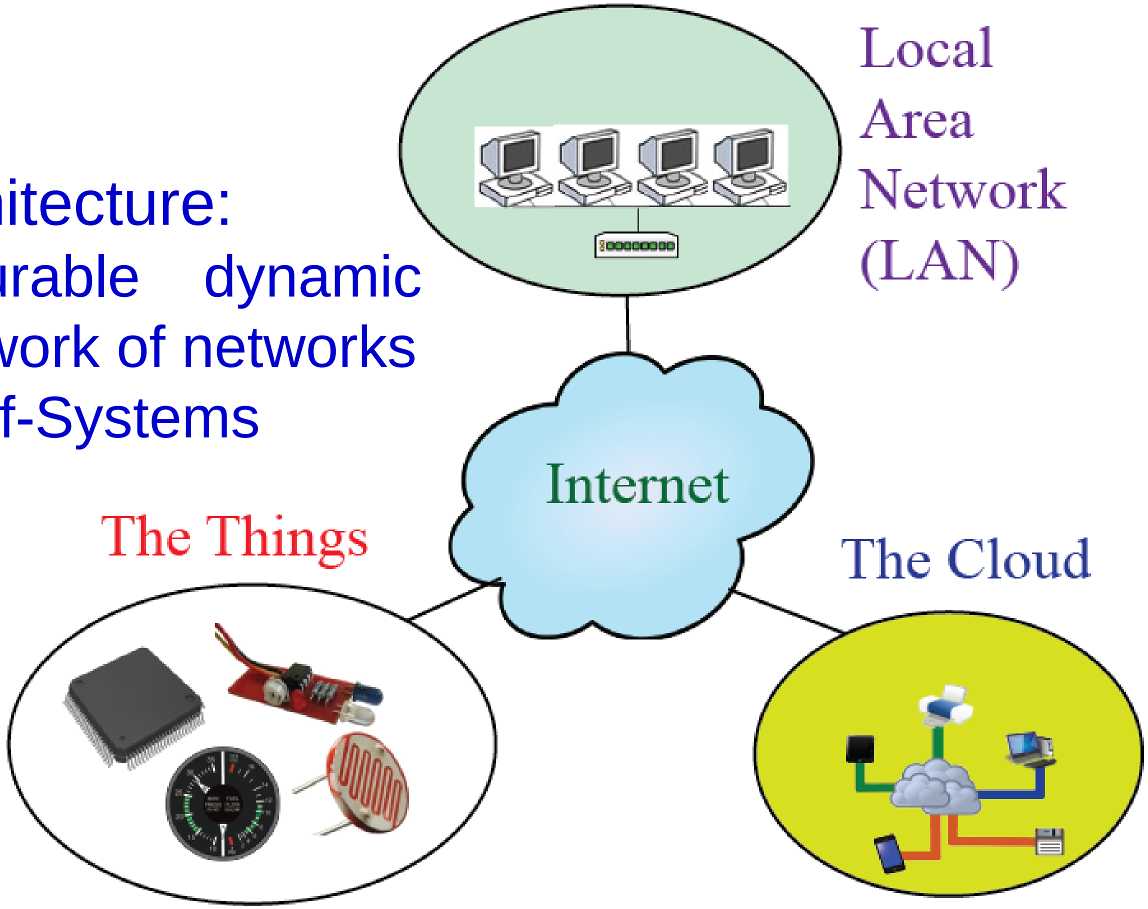


Source: http://cdn.iotwf.com/resources/71/IoT_Reference_Model_White_Paper_June_4_2014.pdf

IoT - Architecture

Overall architecture:

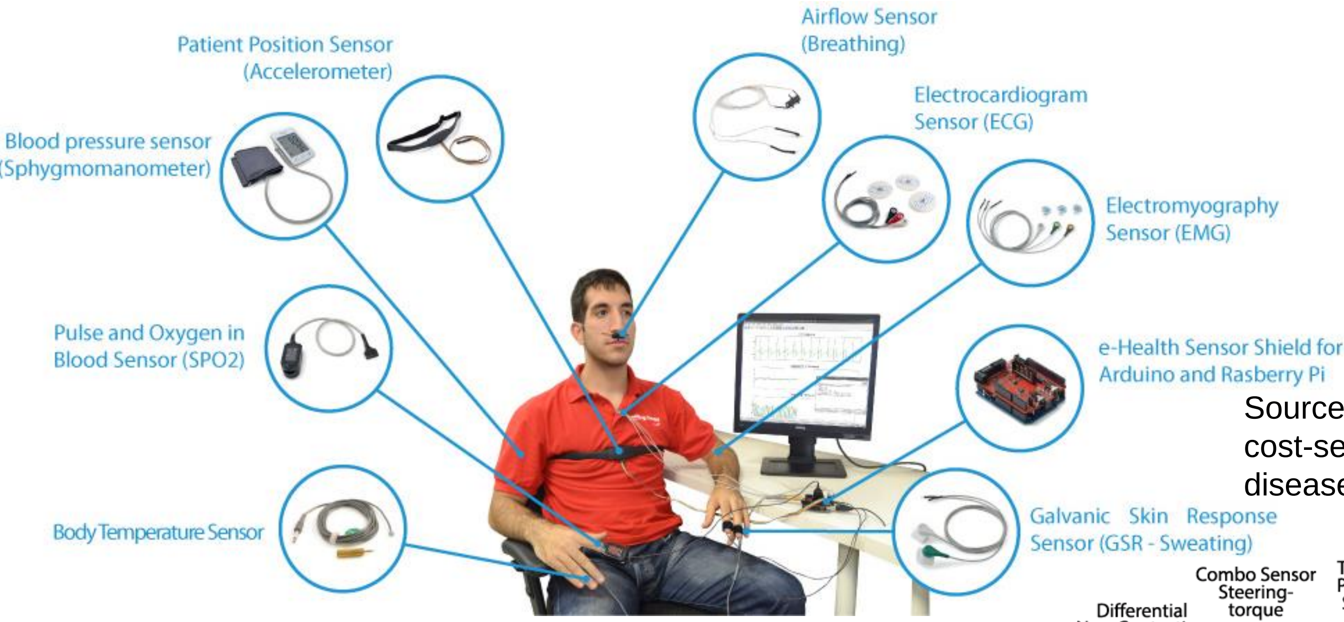
- ❖ A configurable dynamic global network of networks
- ❖ Systems-of-Systems



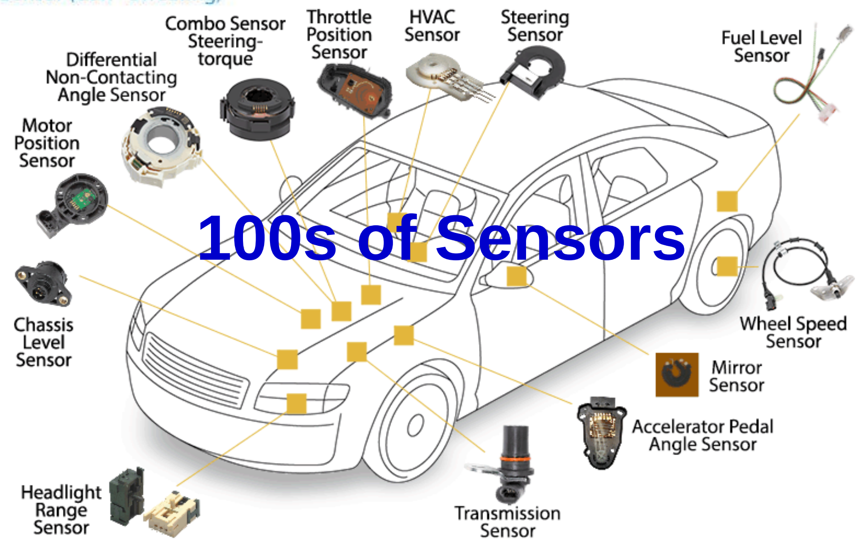
Four Main Components of IoT.

Source: Mohanty 2016, EuroSimE 2016 Keynote Presentation

Sensor Technology – Variety of Them



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

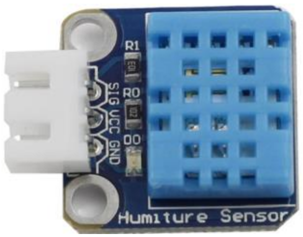


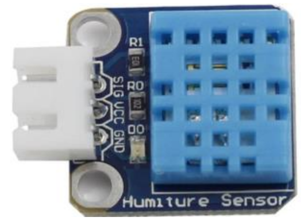
Thing ← Sensor
+ Device with its own IP address

Source: Mohanty ICCE 2019 Keynote

IoT – Things

Sensor





Thing

Sensors + Device with its own IP address → Things

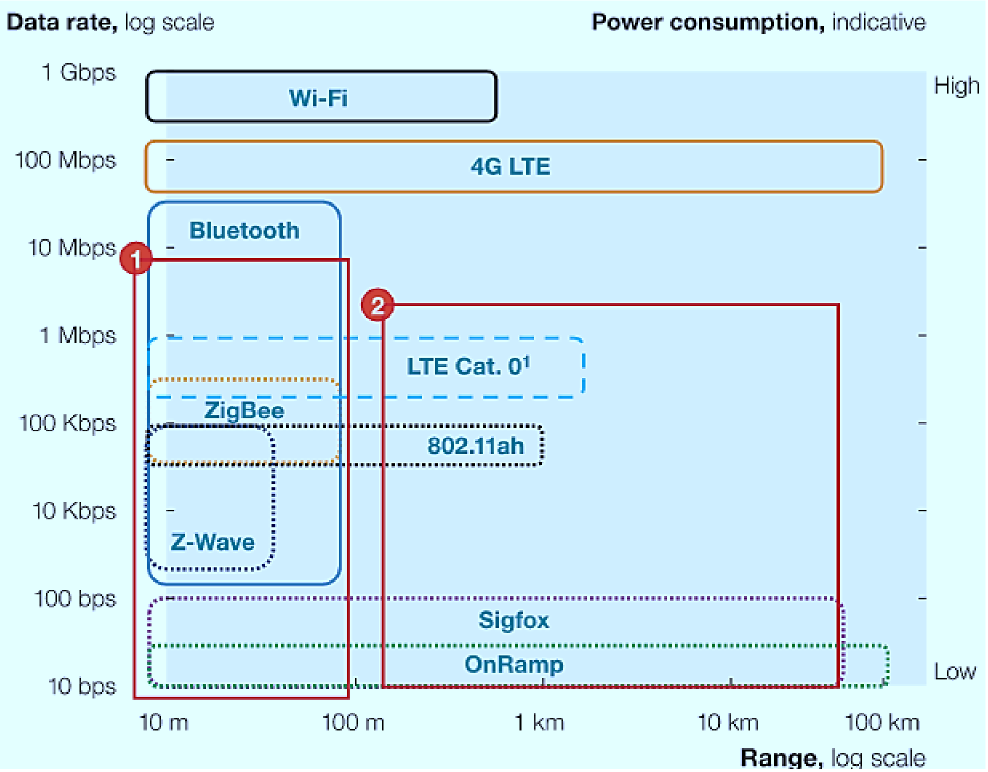
IP Address for Internet Connection

The "Things" refer to any physical object with a device that has its own IP address and can connect and send/receive data via network.

IoT - Communications

Selected IoT Communications Technology

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

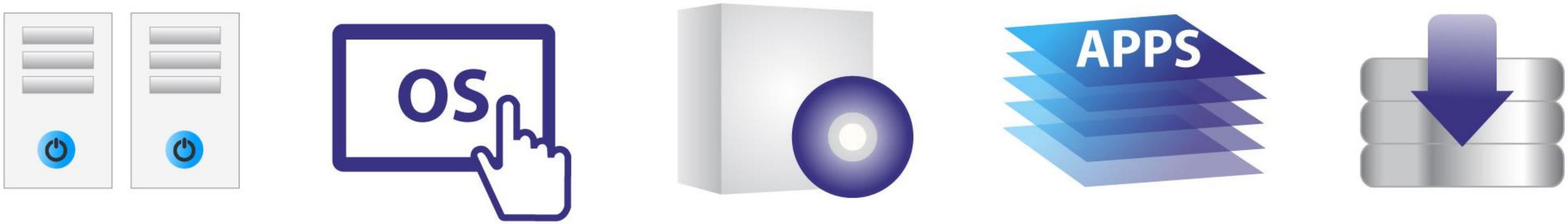


Source: https://www.postscapes.com/internet-of-things-protocols/

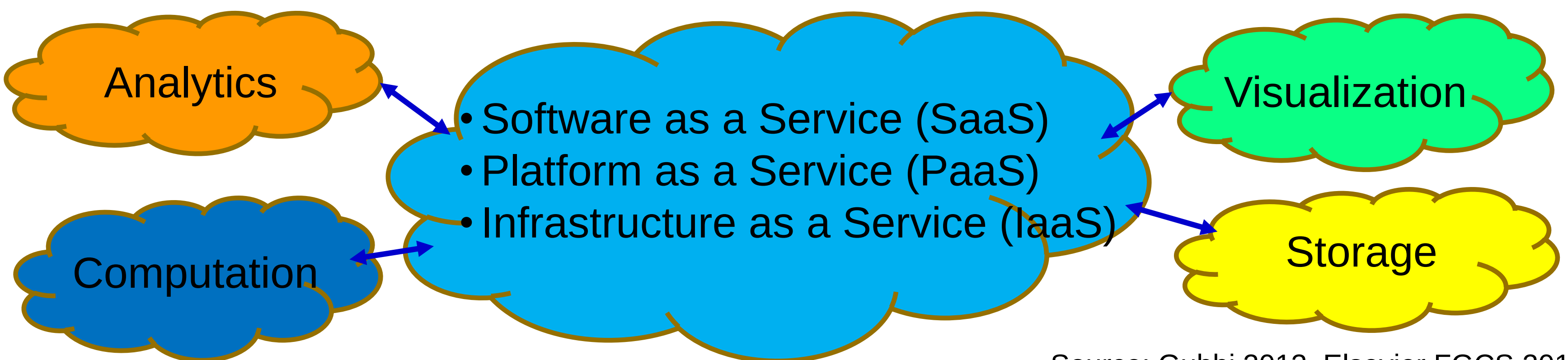
Source: https://www.rs-online.com/designspark/eleven-internet-of-things-iot-protocols-you-need-to-know-about

IoT - Cloud

Servers | Virtual Desktop | Software Platform | Applications | Storage / Data



Source: https://www.livewireindia.com/cloud_computing_training.php



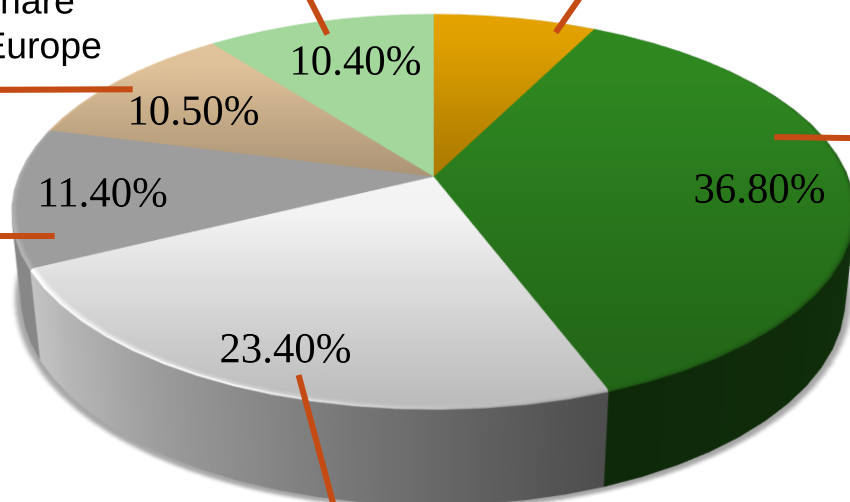
Source: Gubbi 2013, Elsevier FGCS 2013

IoT - Applications

Smart City Market Segments – by 2025

5 Smart Healthcare
Market Value: $348.5Billion
CAGR: 8.8% (2012-2025)
North America to dominate Smart Healthcare market with more than 50% share by 2025 followed by Europe

6 Smart Building
Market Value: $248.65Billion
CAGR: 4.1% (2012-2025)
China and India are fastest growing markets followed by Japan and Korea



4 Smart Transportation
Market Value: $351.13Billion
CAGR: 19.6% (2012-2025)
Market growth in Latin America, Middle East, Africa, CIS + Eastern Europe

1 Smart Governance and Smart Security
Market Value: $1230.26 Billion
CAGR: 11.6% (2012-2025)
More Projects coming up in North America, Middle East and European regions

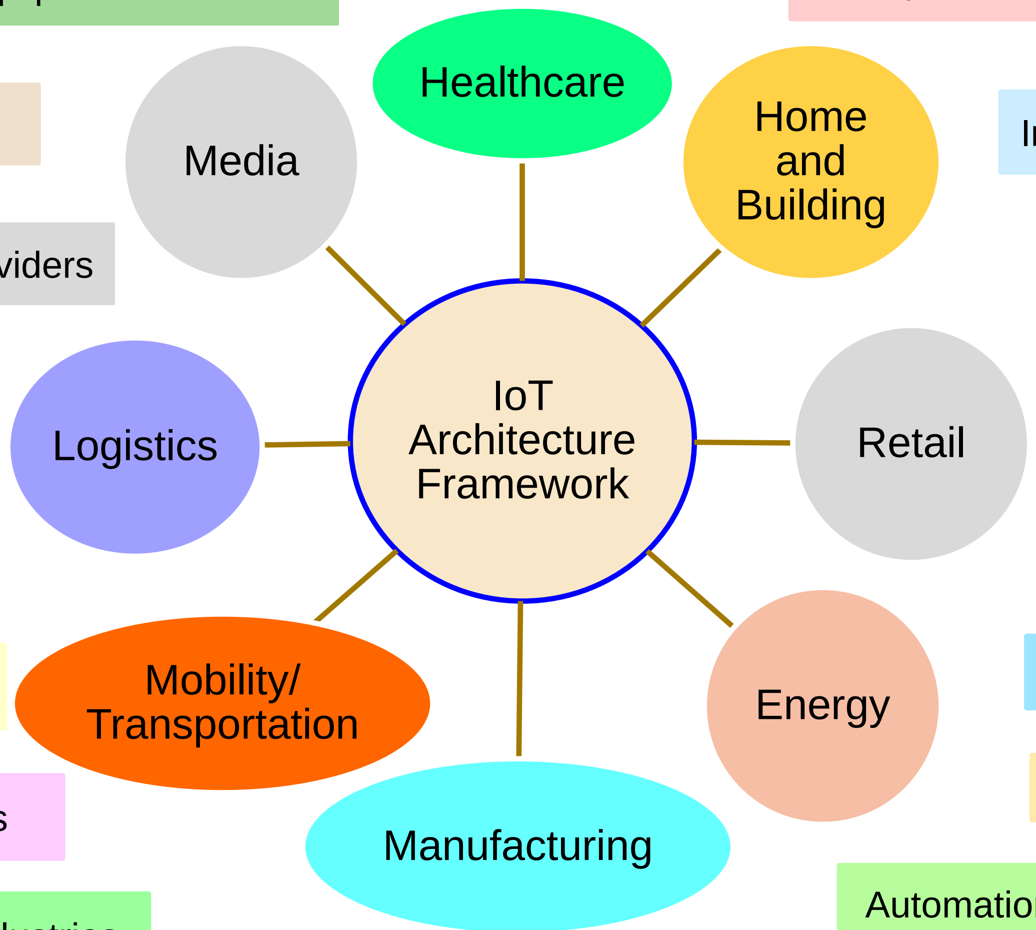
3 Smart Infrastructure
Market Value: $381.53 Billion
CAGR: 12.0% (2012-2025)
Highest growth in North America and Asia

2 Smart Energy
Market Value: $781.66 Billion
CAGR: 28.7% (2012-2025)
Highest growth in North America

Source: Frost & Sullivan analysis.

Source: https://www.slideshare.net/IoTTunisia/farouk-kamoun-smart-cities-innovative-applications-iot-tunisia-2016

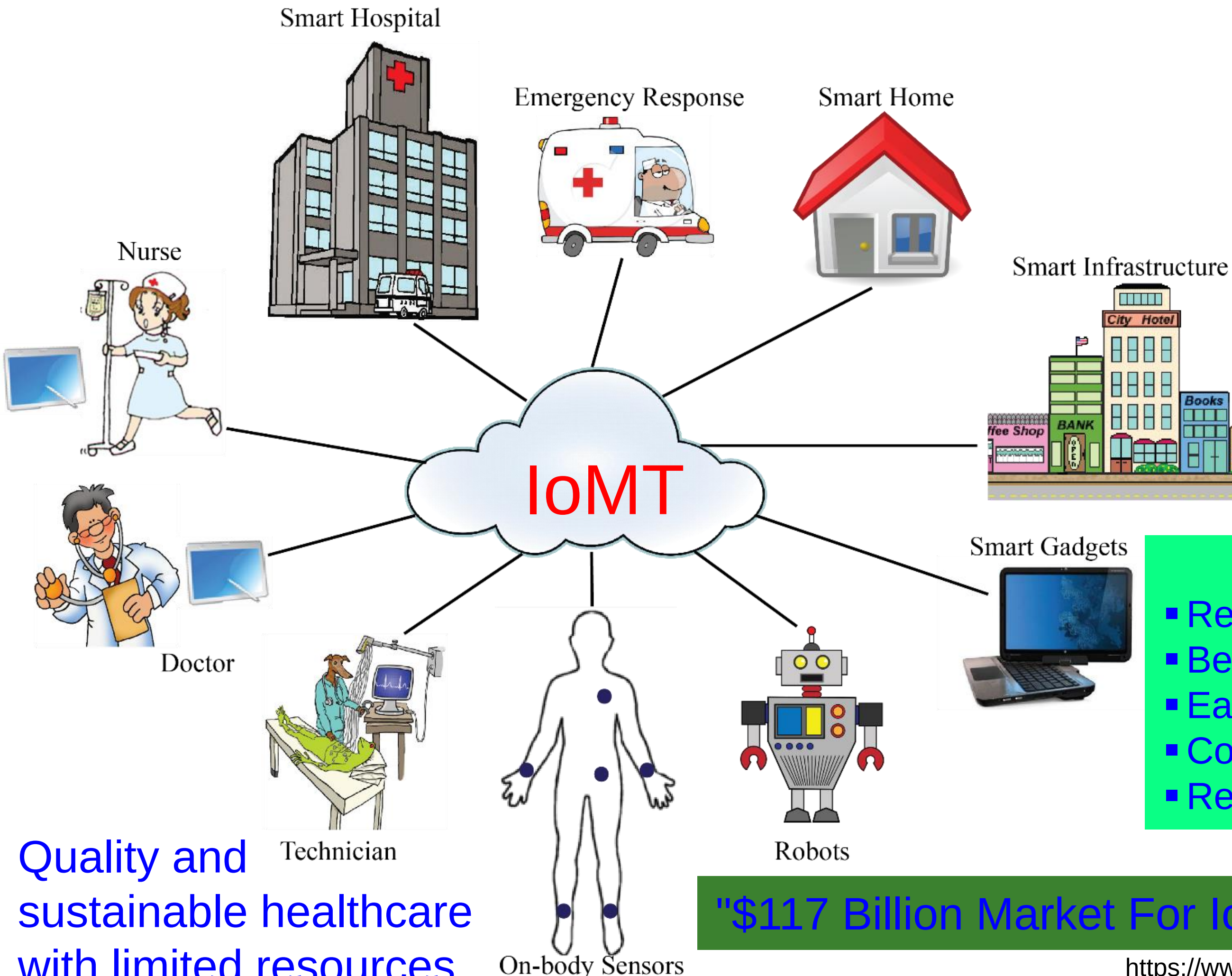
IoT - Markets and Stakeholders



- Consumer Equipment Providers
- Consumers
- ICT Infrastructure Providers
- Regulators
- Logistics Companies
- Public Transportation Companies
- City Authorities
- Manufacturing Industries
- Hospitals and Doctors
- Insurance Companies
- Appliances Providers
- Facility Management
- Retail Stores
- Application developers
- Utilities
- Automation equipment providers

Source: http://iot.ieee.org/images/files/pdf/IEEE_IoT_Towards_Definition_Internet_of_Things_Revision1_27MAY15.pdf

IoT in Smart Healthcare



Fitness Trackers

IoT Role Includes:

- Real-time monitoring
- Better emergency response
- Easy access of patient data
- Connectivity among stake holders
- Remote access to healthcare

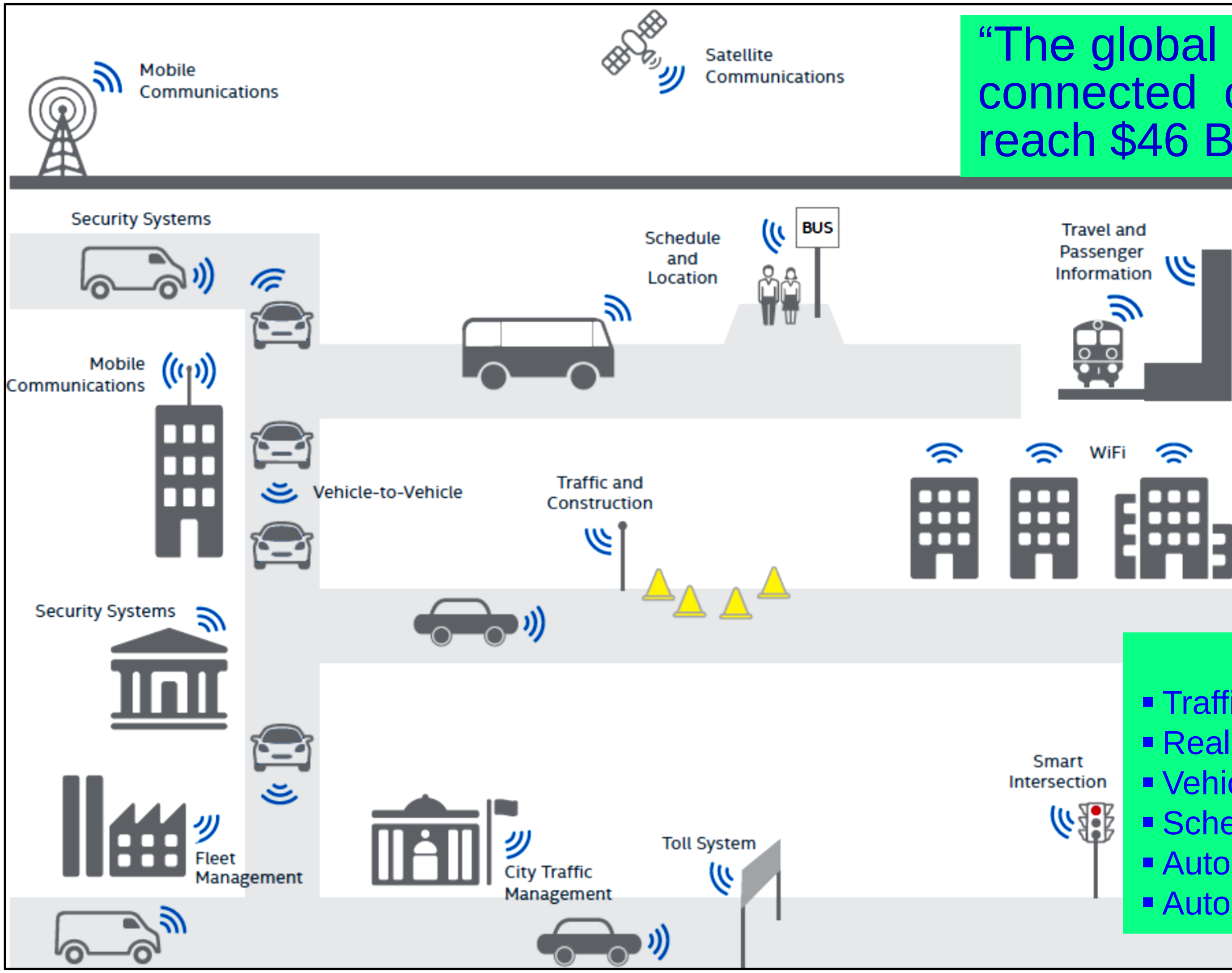
Quality and sustainable healthcare with limited resources, anywhere, anytime.

"$117 Billion Market For IoT in Healthcare By 2020."

https://www.forbes.com/sites/tjmccue/2015/04/22/117-billion-market-for-internet-of-things-in-healthcare-by-2020/

Source: Mohanty 2016, CE Magazine July 2016

IoT in Smart Transportation



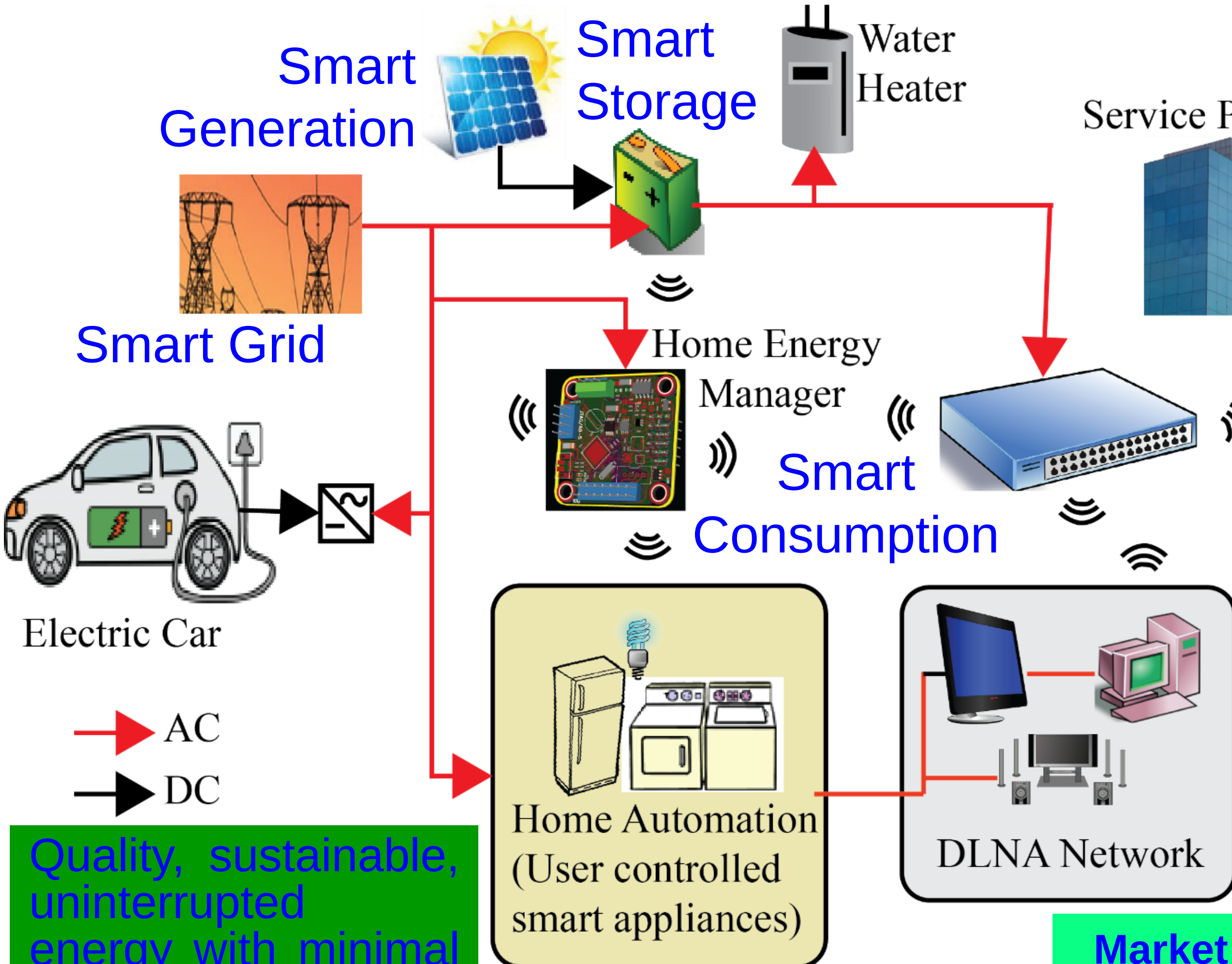
"The global market of IoT based connected cars is expected to reach $46 Billion by 2020."

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

IoT in Smart Energy



Internet of Energy

IoT Role Includes:
- 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

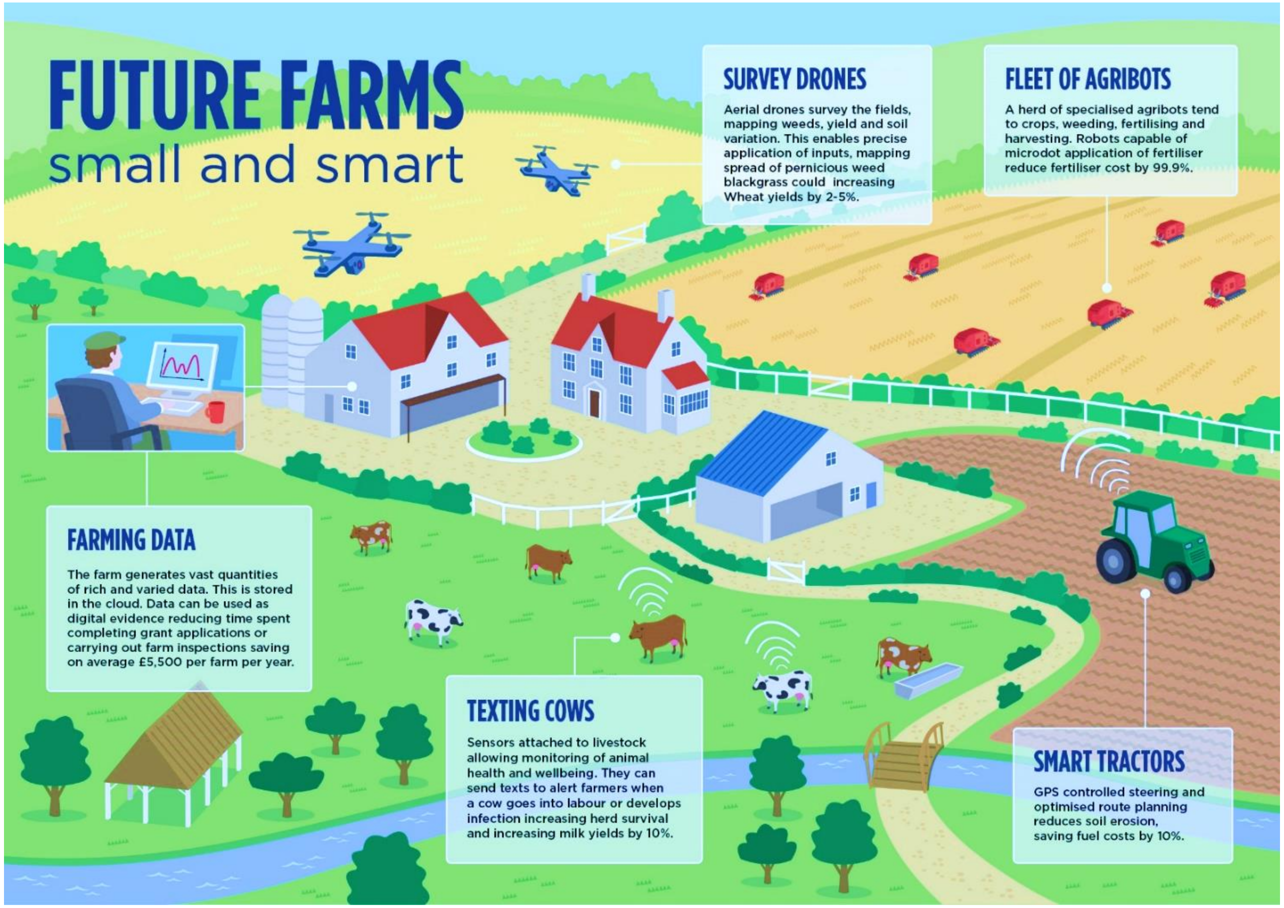
Quality, sustainable, uninterrupted energy with minimal carbon footprint.

Market Value by 2025: $781.66 Billion

Source: Frost & Sullivan

Source: Mohanty 2016, CE Magazine July 2016

IoT in 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

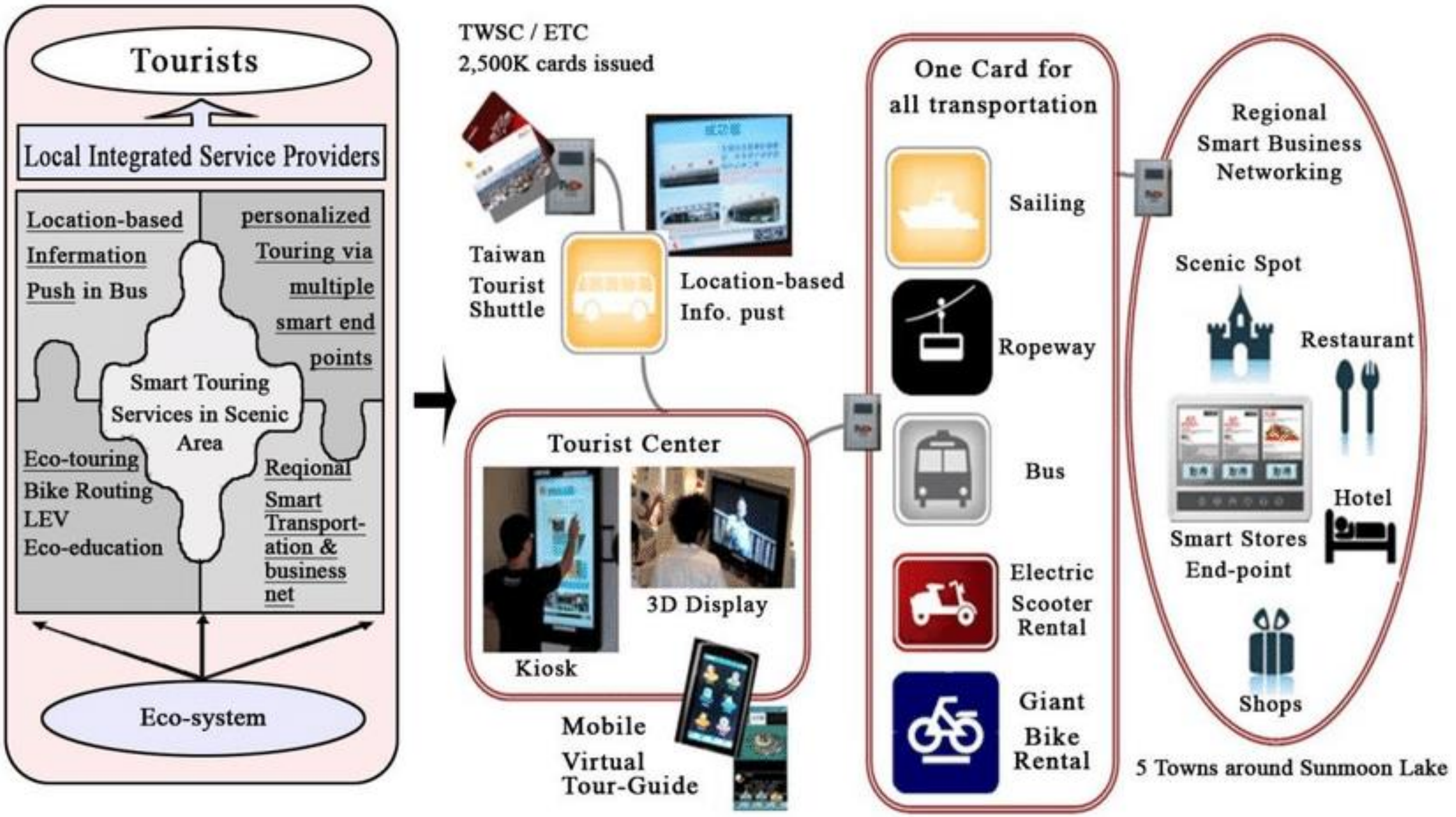
Automatic Irrigation System

Source: Maurya 2017, CE Magazine July 2017

Smart Agriculture/Farming Market Worth $18.21 Billion By 2025

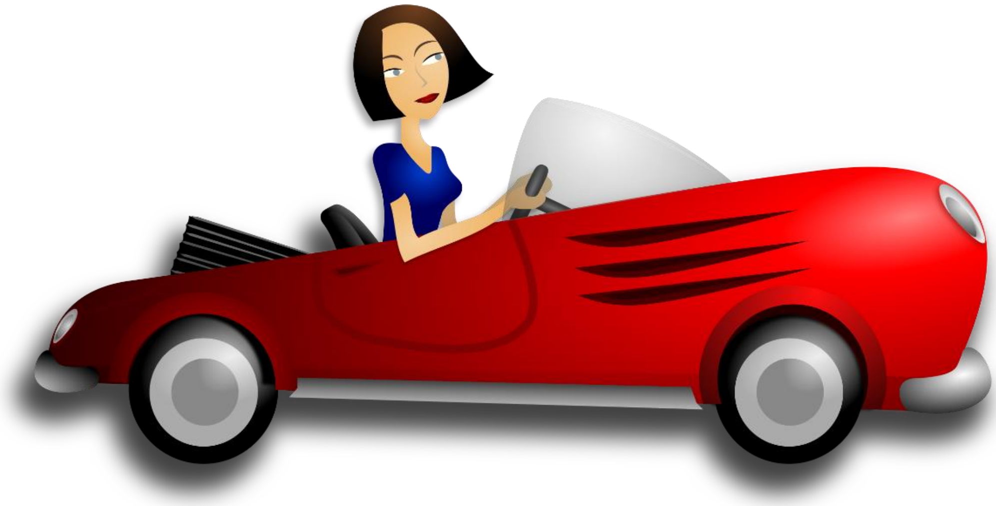
Sources: http://www.grandviewresearch.com/press-release/global-smart-agriculture-farming-market

Smart Tourism

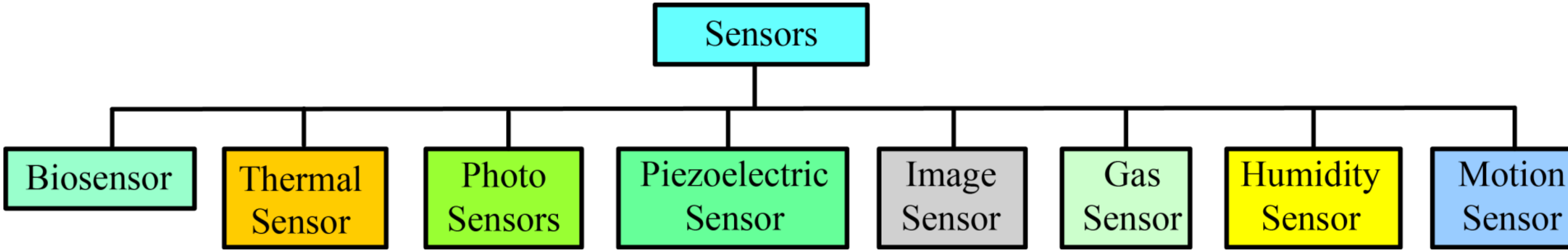


Source: Chih-Kung Lee: https://www.researchgate.net/figure/Concept-of-In-Joy-Life-smart-tourism-8_fig4_269666526

Driving Technologies of IoT



Cheap and Compact Sensor Technology



Source: Mohanty 2015, McGraw-Hill 2015


Gas Sensor

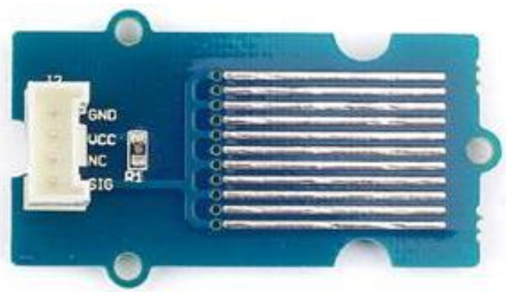

Temperature Sensor


Air Quality Sensor


Humidity and Temperature Sensor


Light Sensor

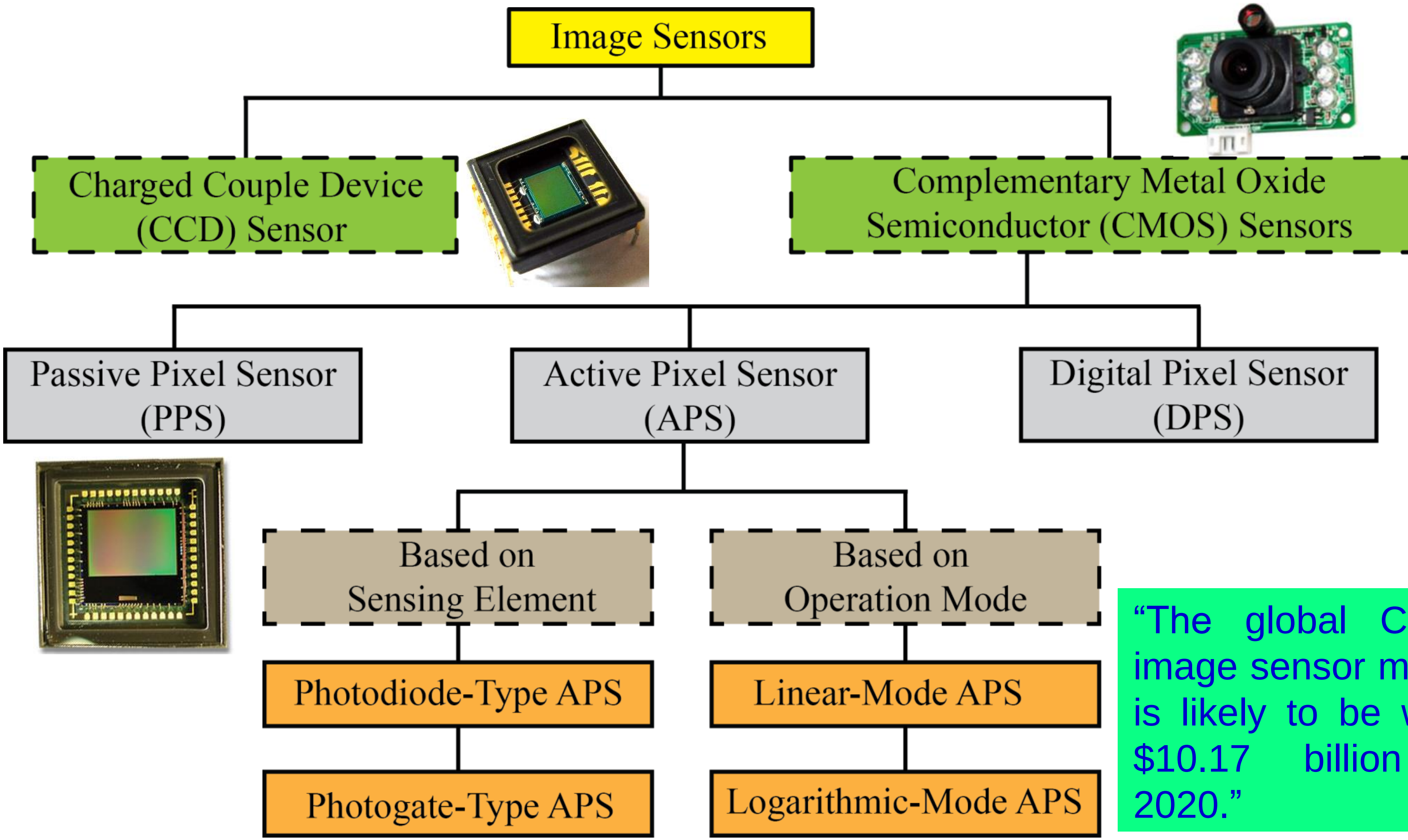

Barometer Sensor


Water Sensor


Dust Sensor

Source: http://wiki.seeed.cc/Sensor/

Better Imaging Sensor Technology



"The global CMOS image sensor market is likely to be worth $10.17 billion by 2020."

Source: Mohanty 2015, McGraw-Hill 2015

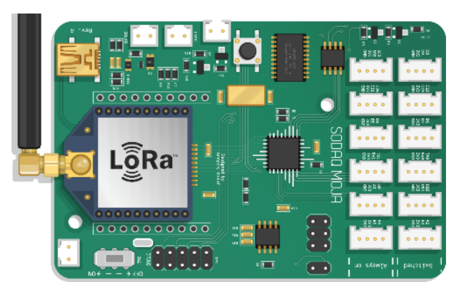
Source: http://www.grandviewresearch.com/press-release/global-cmos-image-sensors-market

Communications – Energy, Data Rate, and Range Tradeoffs

- LoRa: Long Range, low-powered, low-bandwidth, IoT communications as compared to 5G or Bluetooth.
- SigFox: SigFox utilizes an ultra-narrowband wide-reaching signal that can pass through solid objects.

Technology	Protocol	Maximum Data Rate	Coverage Range
ZigBee	ZigBee Pro	250 kbps	1 mile
WLAN	802.11x	2-600 Mbps	0.06 mile
Cellular	5G	1 Gbps	Short - Medium
LoRa	LoRa	50 kbps	3-12 miles
SigFox	SigFox	1 kbps	6-30 miles

Source: Mohanty iSES Keynote 2018



Visible Light for High-Bandwidth Wireless Communications

- ❑ LEDs can switch their light intensity at a rate that is imperceptible to human eye.
- ❑ Property can be used for the value added services based on Visible Light Communication (VLC).

High Data Density

Short Range

Source: VLCS-2014

Source: Ribeiro 2017, CE Magazine October 2017

October 2017

Variety of Computer Memory

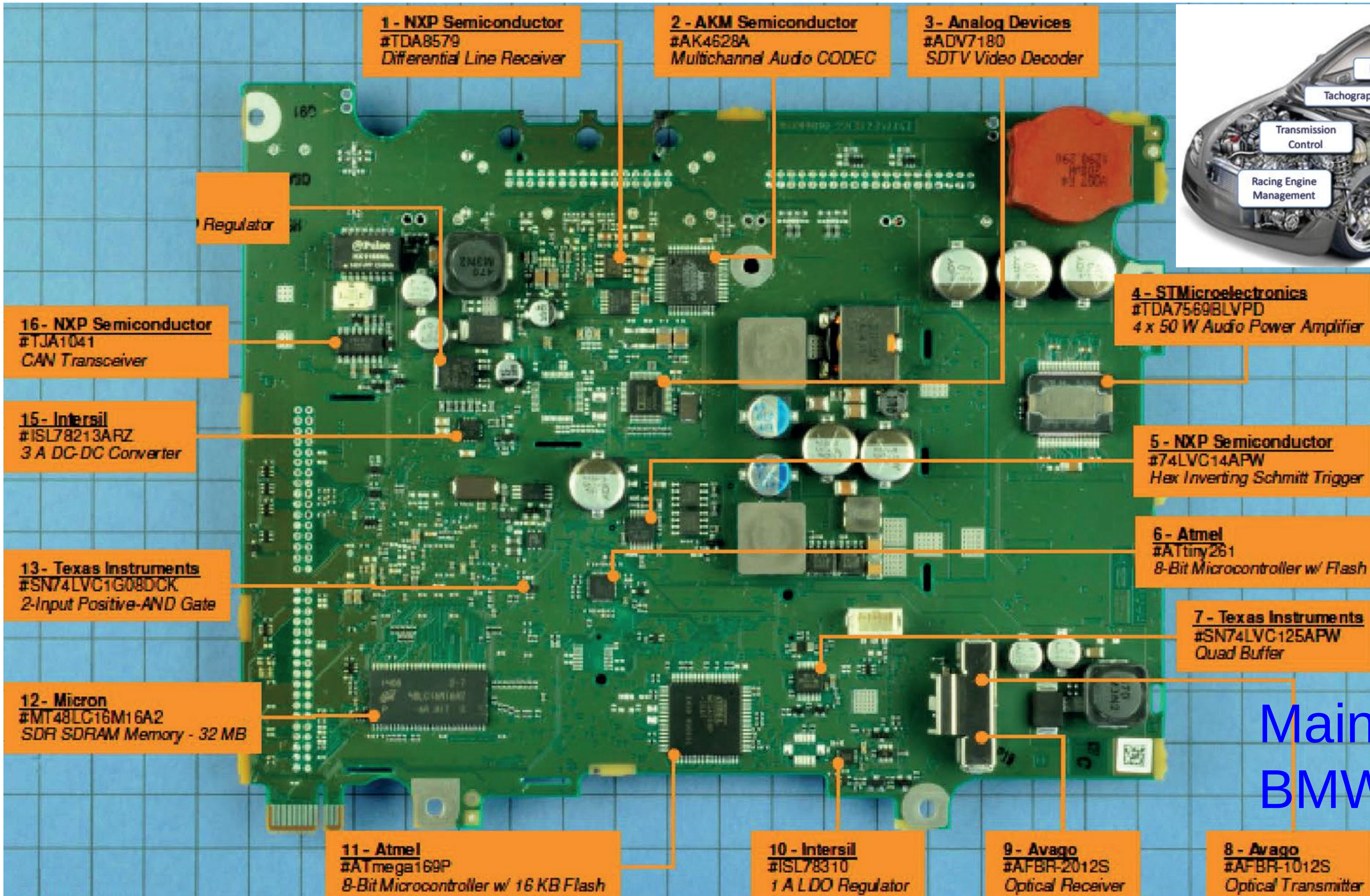
- **Computer Memory**
  - **Based on Storage Capability**
    - **Volatile**
      - Static RAM (SRAM)
      - Dynamic RAM (DRAM)
      - Twin Transistor RAM (TTRAM)
      - Zero-Capacitor RAM (ZRAM)
      - Thyristor RAM (TRAM)
    - **Nonvolatile**
      - Read-Only Memory (e.g. Programmable ROM (PROM), Erasable PROM (EPROM), Electrically Erasable PROM (EEPROM)
      - Magnetic Storage Hard Disk Drive (HDD)
      - Non-Volatile RAM (NVRAM) (e.g Flash Memory)
      - Resistive RAM (RRAM or ReRAM)
      - Magnetic or Magnetoresistive RAM (MRAM)
      - Phase-Change RAM (PRAM, PCRAM)
      - Conductive Metal Oxide (CMOX) Memory
  - **Based on Access**
    - Random-Access Memory (RAM)
    - Serial Access Memory (e.g. Shift Registers, Queues)
    - Content Addressable Memory (CAM)

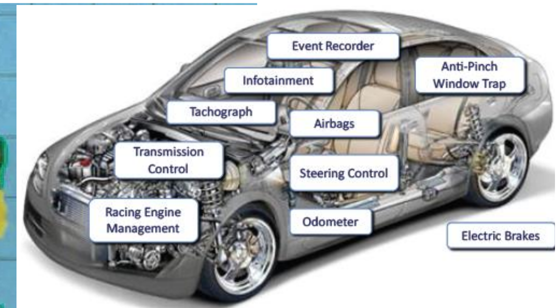
Source: Mohanty 2015, McGraw-Hill 2015

The flash memory market is expected to be worth $37.6 worldwide by 2020.

Source: https://www.statista.com/statistics/553556/worldwide-flash-memory-market-size/

Memory Technology – Car Example



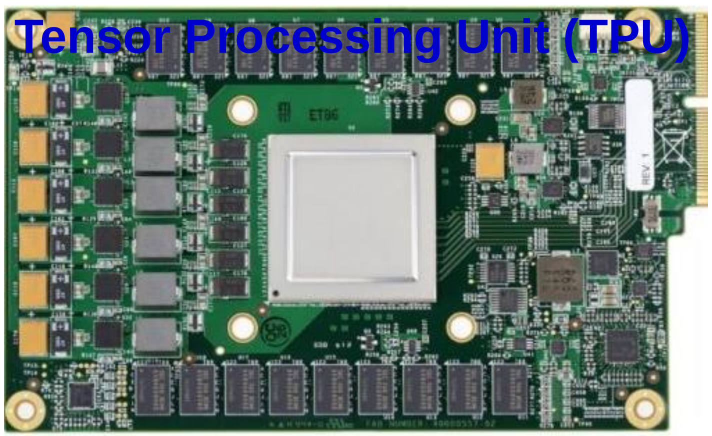


Main Board of BMW HBB125.

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

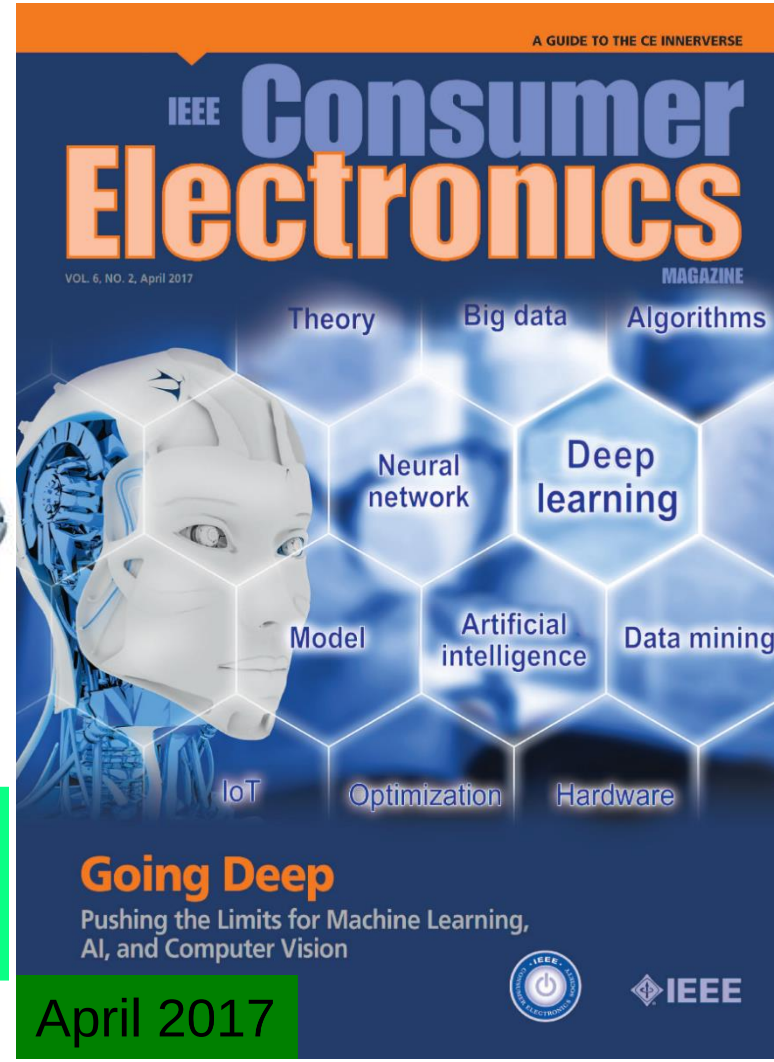
Machine Learning Technology

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



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

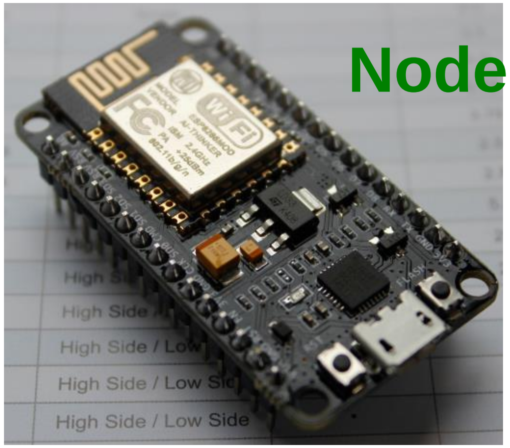
IoT Use:
- Better decision
- Faster response

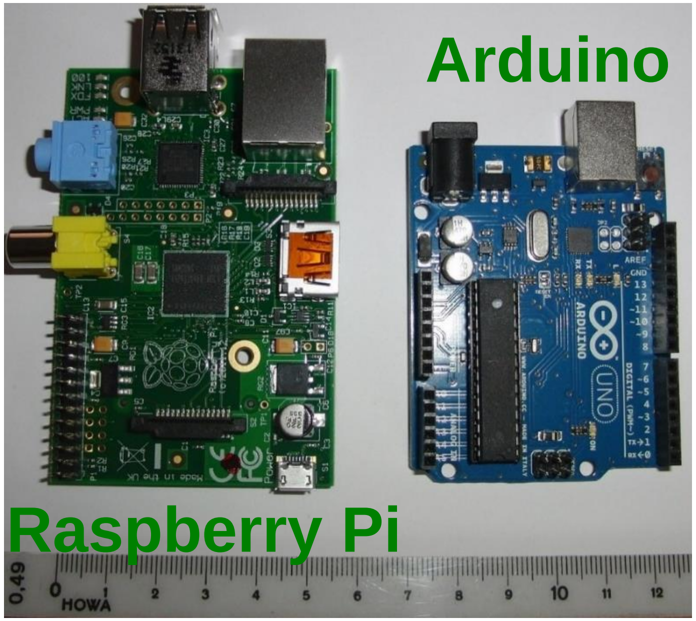


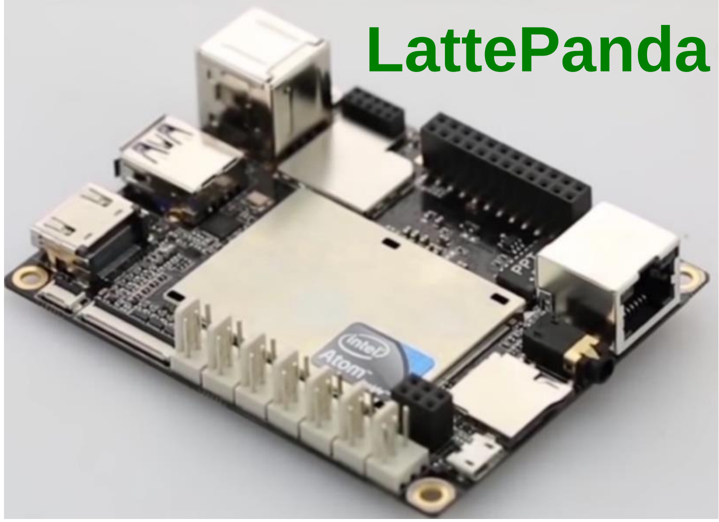
April 2017

Computing Technology - IoT Platform

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

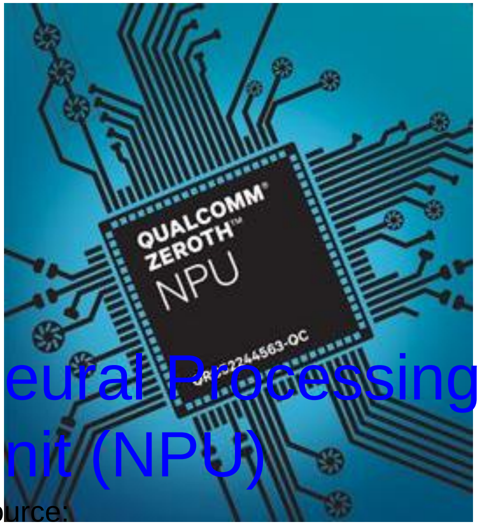






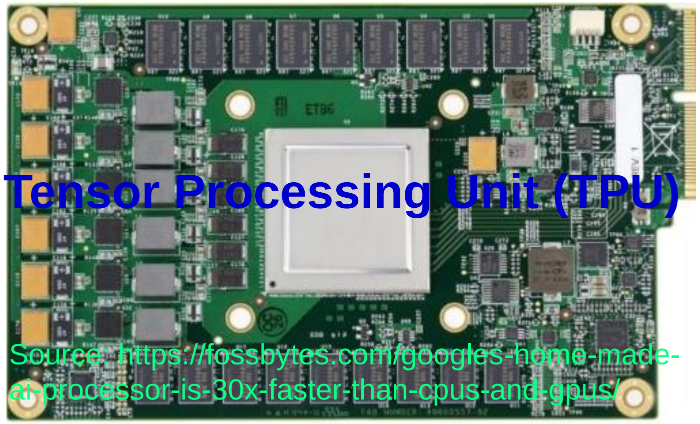
Source: http://www.lattepanda.com

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

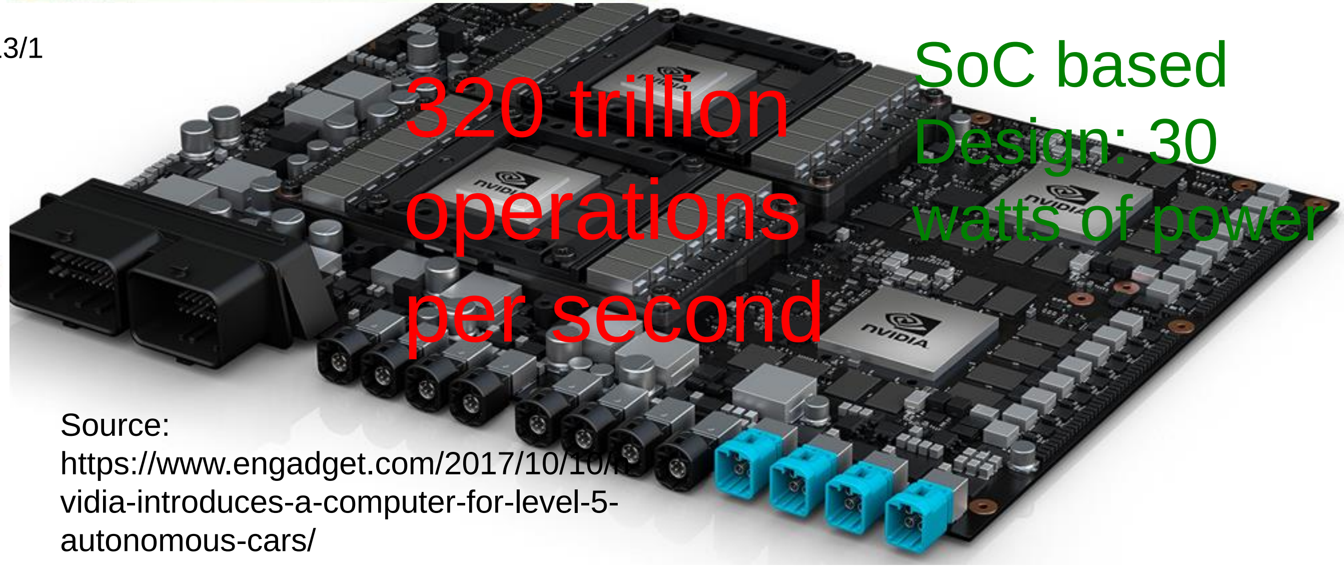


Tensor Processing Unit (TPU)

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/

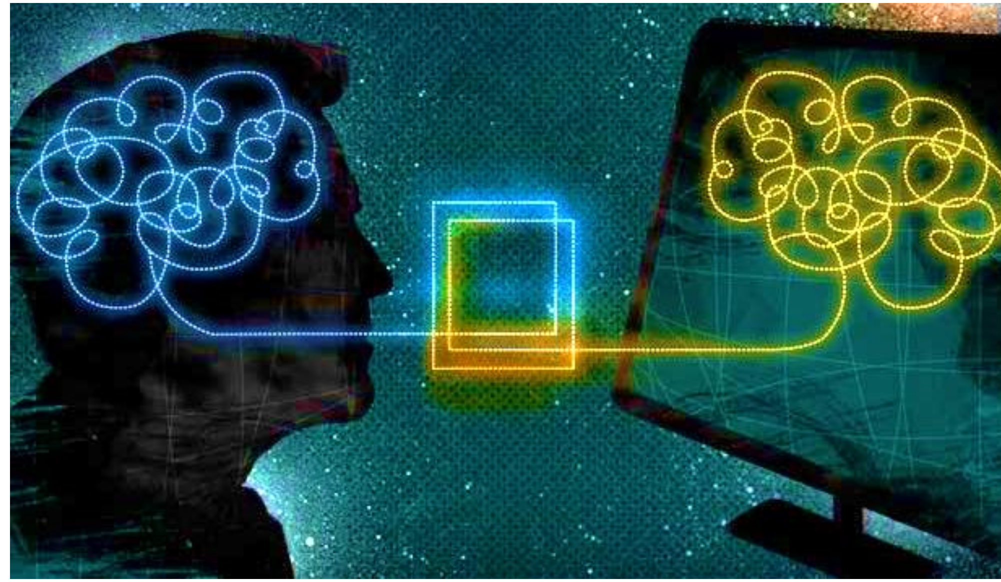
ML Hardware – Cloud and Edge

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

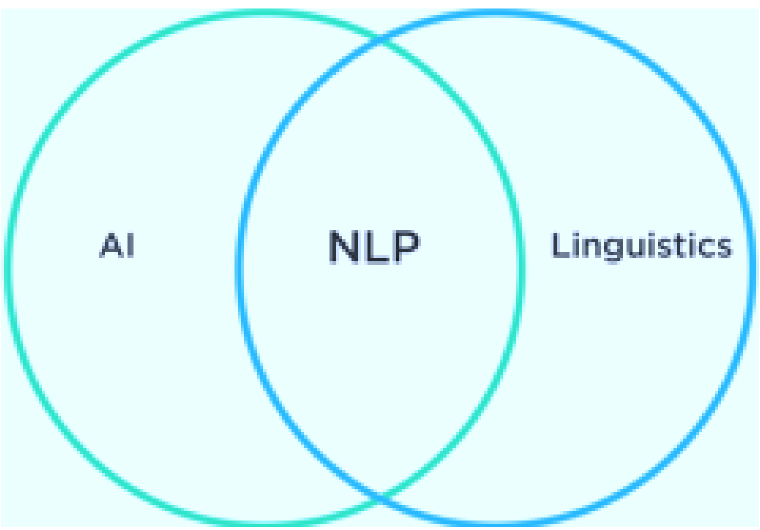
Source: Presutto 2018: https://www.academia.edu/37781087/Current_Artificial_Intelligence_Trends_Hardware_and_Software_Accelerators_2018_

Natural Language Processing (NLP)

- NLP is the computer method to analyze, understand, and derive meaning from human language.
- Enables user to address computers as if they are communicating with a person.



Source: https://www.linkedin.com/pulse/natural-language-processing-2016-global-market-forecasts-rane



Source: http://blog.algorithmia.com/introduction-natural-language-processing-nlp/

Selected NLP Applications

- Machine Translation
- Information Retrieval
- Text Categorization
- Big Data

Cognitive Computing

The Tabulating Era (1900s – 1940s) | The Programming Era (1950s– present) | The Cognitive Era (2011 –)

Cognitive Computing: Not just "right" or "wrong" anymore but "probably".

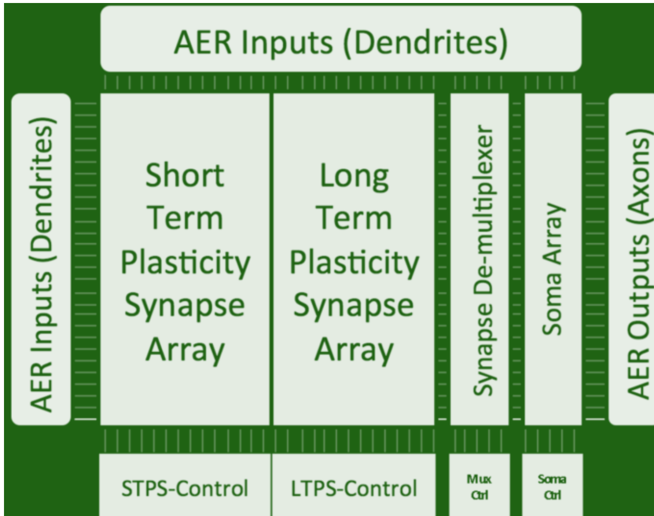
- Systems that learn at scale, reason with purpose and interact with humans naturally.
- Learn and reason from their interactions with humans and from their experiences with their environment; not programmed.

Usage:

- AI applications
- Expert systems
- Natural language processing
- Robotics
- Virtual reality

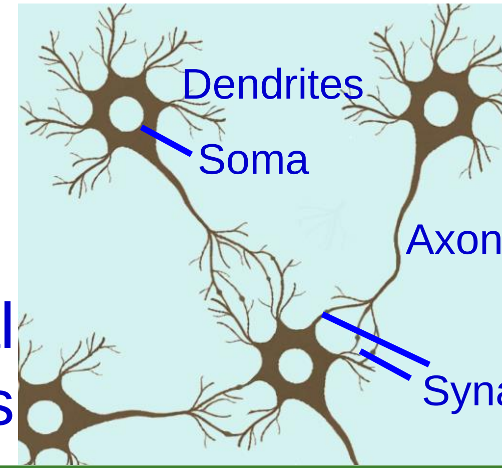
Source: http://www.research.ibm.com/software/IBMResearch/multimedia/Computing_Cognition_WhitePaper.pdf

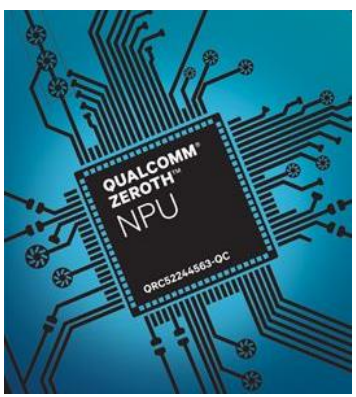
Neuromorphic Computing or Brain-Inspired Computing



Neuromorphic Architecture

Neuronal Circuits





Processing Powers MIT Technical Review

Types of Chips	Functions	Applications
Traditional Chips (von Neumann Architecture)	Reliably make precision calculations	Any numerical problem, Complex problems require more amount of energy
Neuromorphic Chips	Detect and Predict Patterns in complex data using minimal energy	Applications with significant visual/ auditory data requiring a system to adjust its behavior as it interacts with the world

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

Neuromorphic Computing or Brain-Inspired Computing

Application 1: Integrate into assistive glasses for visually impaired people for navigating through complex environments, even without the need for a WiFi connection.

Application 2: Neuromorphic-based, solar-powered “sensor leaves” equipped with sensors for sight, smell or sound can help to monitor natural disasters.

Source: https://blogs.scientificamerican.com/observations/brain-inspired-computing-reaches-a-new-milestone/

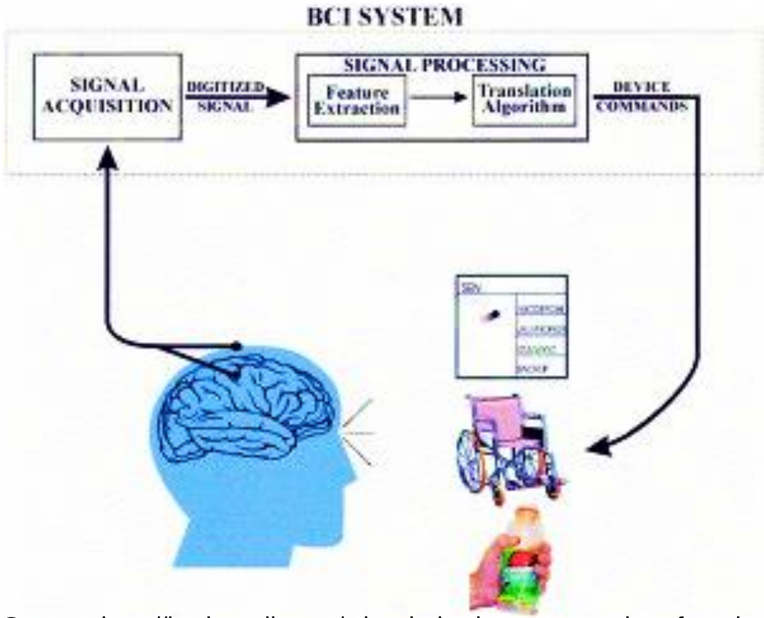
Brain Computer Interface (BCI)

"Currently, people interact with their devices by thumb-typing on their phones. A high-bandwidth interface to the brain would help achieve a symbiosis between human and machine intelligence and could make humans more useful in an AI-driven world."

-- Neuralink - neurotechnology company - Elon Musk.

Sources: http://brainpedia.org/elon-musk-wants-merge-human-brain-ai-launches-neuralink/

BCI - Applications



Source: http://brainpedia.org/what-is-brain-computer-interface-bci/

BCI Allows paralysis patients move a wheelchair

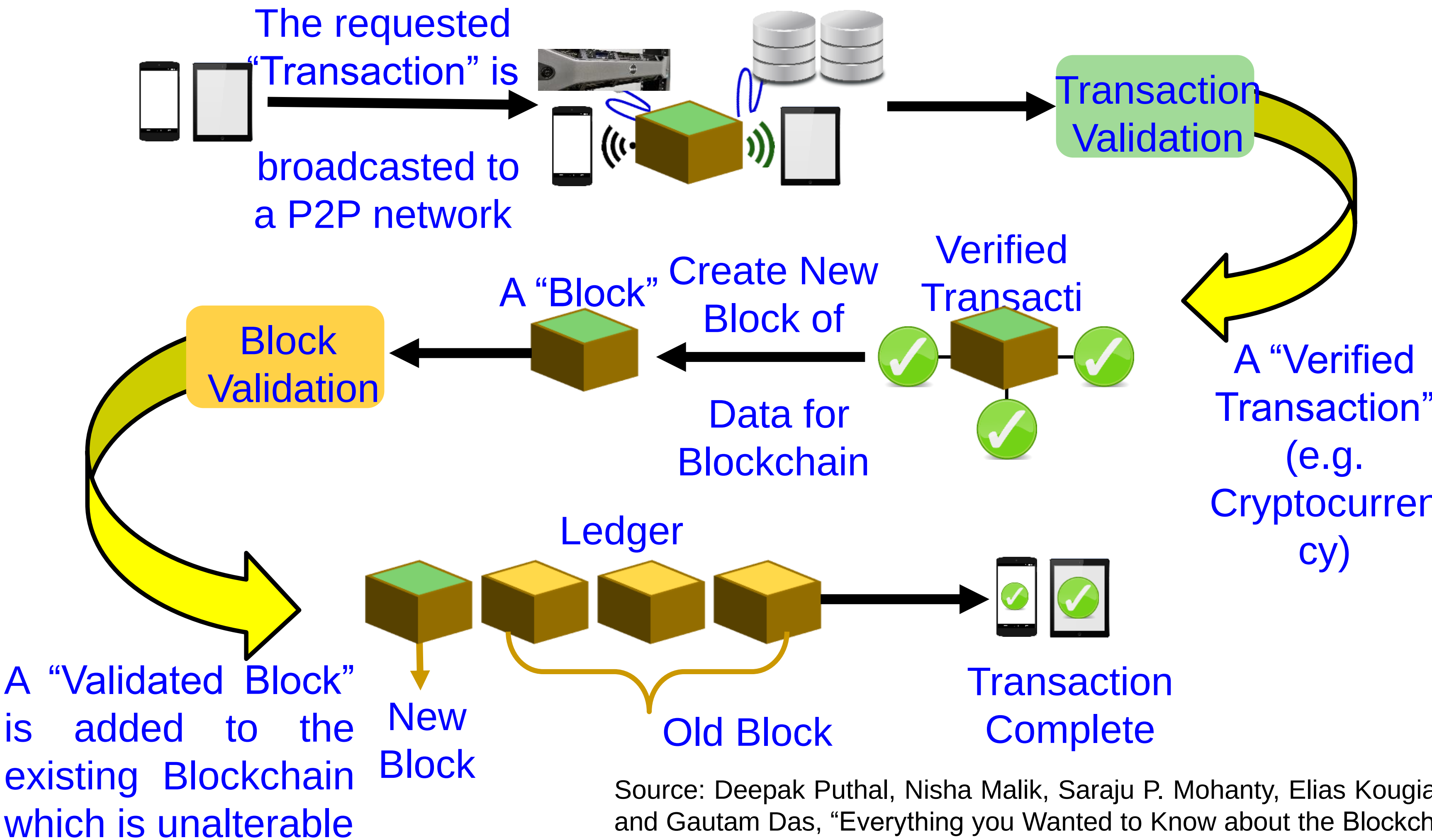
Source: http://brainpedia.org/brain-computer-interface-allows-paralysis-als-patients-type-much-faster/

BCI Allows paralysis patients to Type

- BCI Types
  - Based on Location
    - Non-invasive
    - Semi-invasive
    - Invasive
  - Based on Signal
    - EEG
    - MEG
    - fNIR
    - fMRI

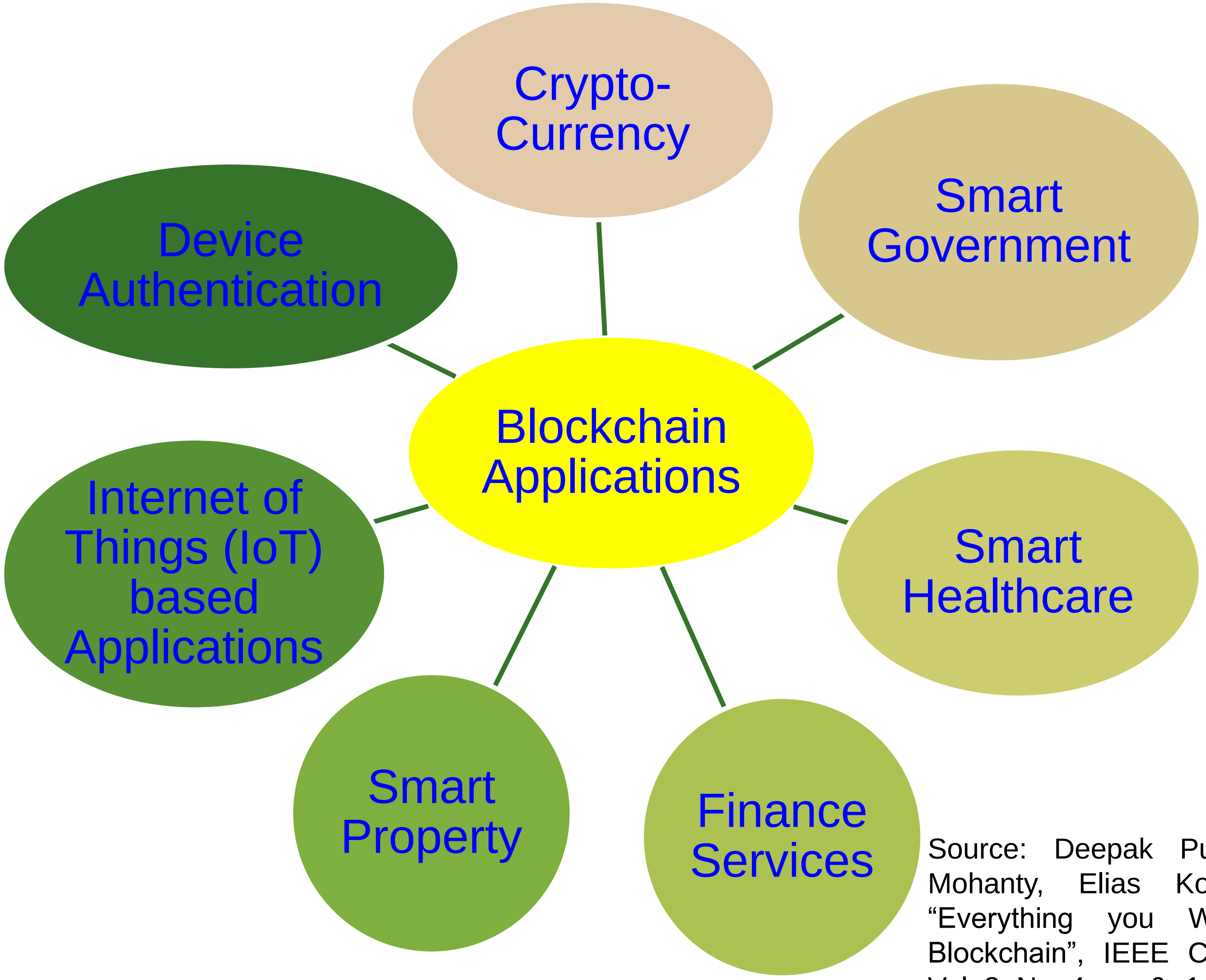
Blockchain Technology

Blockchain - Working Model



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.

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.

Data Compression in Smart Cities

- Data Compression Techniques based on Data Types
  - Video Data
    - MPEG-4, H.264
    - H.265 (High Efficiency Video Coding, HEVC)
  - Image Data
    - JPEG, PNG
    - Better Portable Graphics (BPG)
  - Audio Data
    - Advanced Audio Coding (AAC)
    - MP3, Dolby AC-4
  - Documents
    - ZIP, rar, 7z
    - ISO Image
  - Medical Images
    - JPEG 2000, JPEG-LS
  - Sensor Data
    - Compressed Sensing, Derivatives of Lempel-Ziv-Welch (LZW)

Efficient Media Compression – Better Portable Graphics (BPG)

- **BPG compression instead of JPEG?**
- Attributes that differentiate BPG from JPEG and make it an excellent choice include:
  - Meeting modern display requirements: high quality and lower size.
  - BPG compression is based on the High Efficiency Video Coding (HEVC), which is considered a major advance in compression techniques.
  - Supported by most web browsers with a small Javascript decoder.

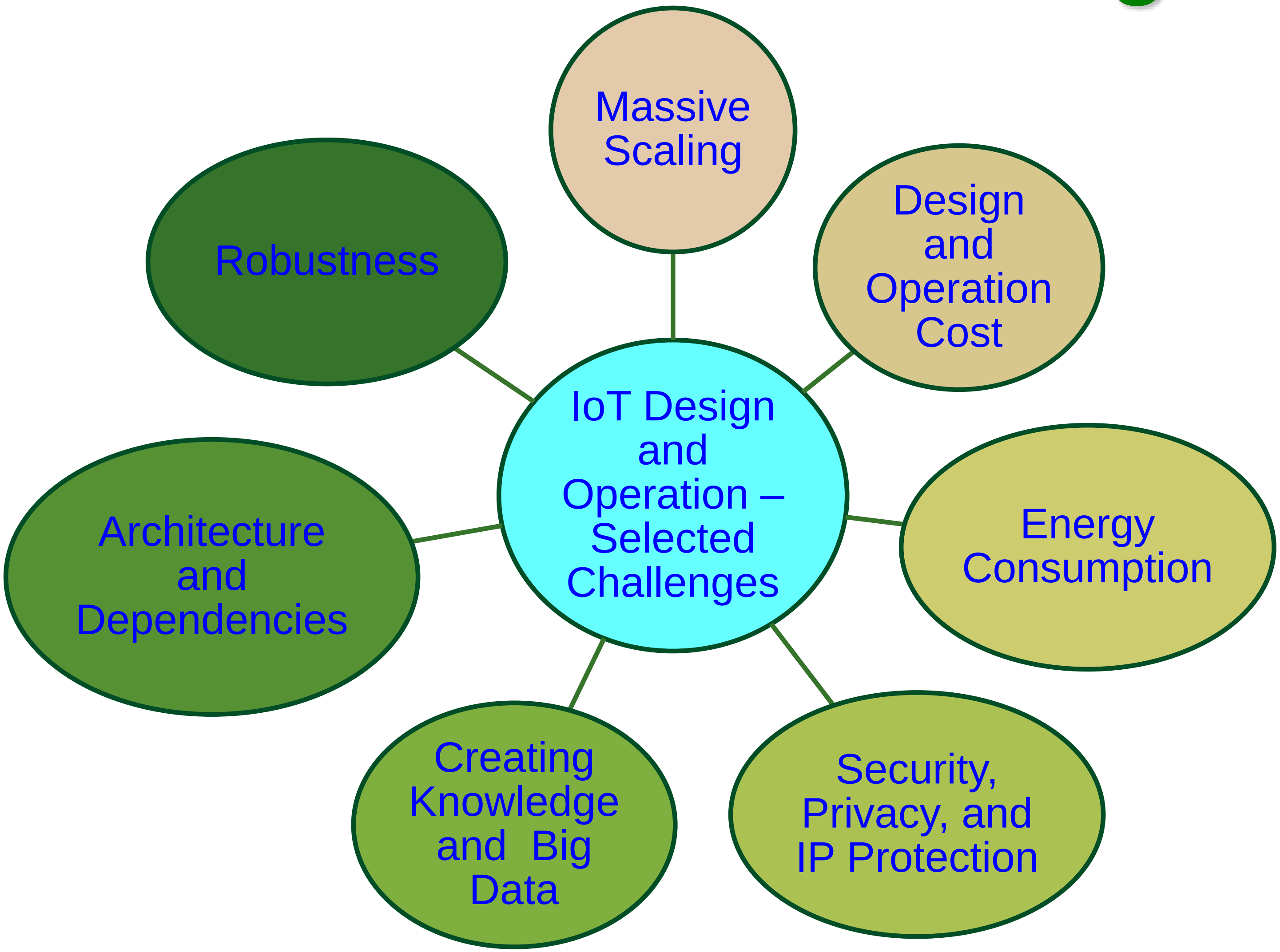
JPEG Compression

BPG Compression

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.

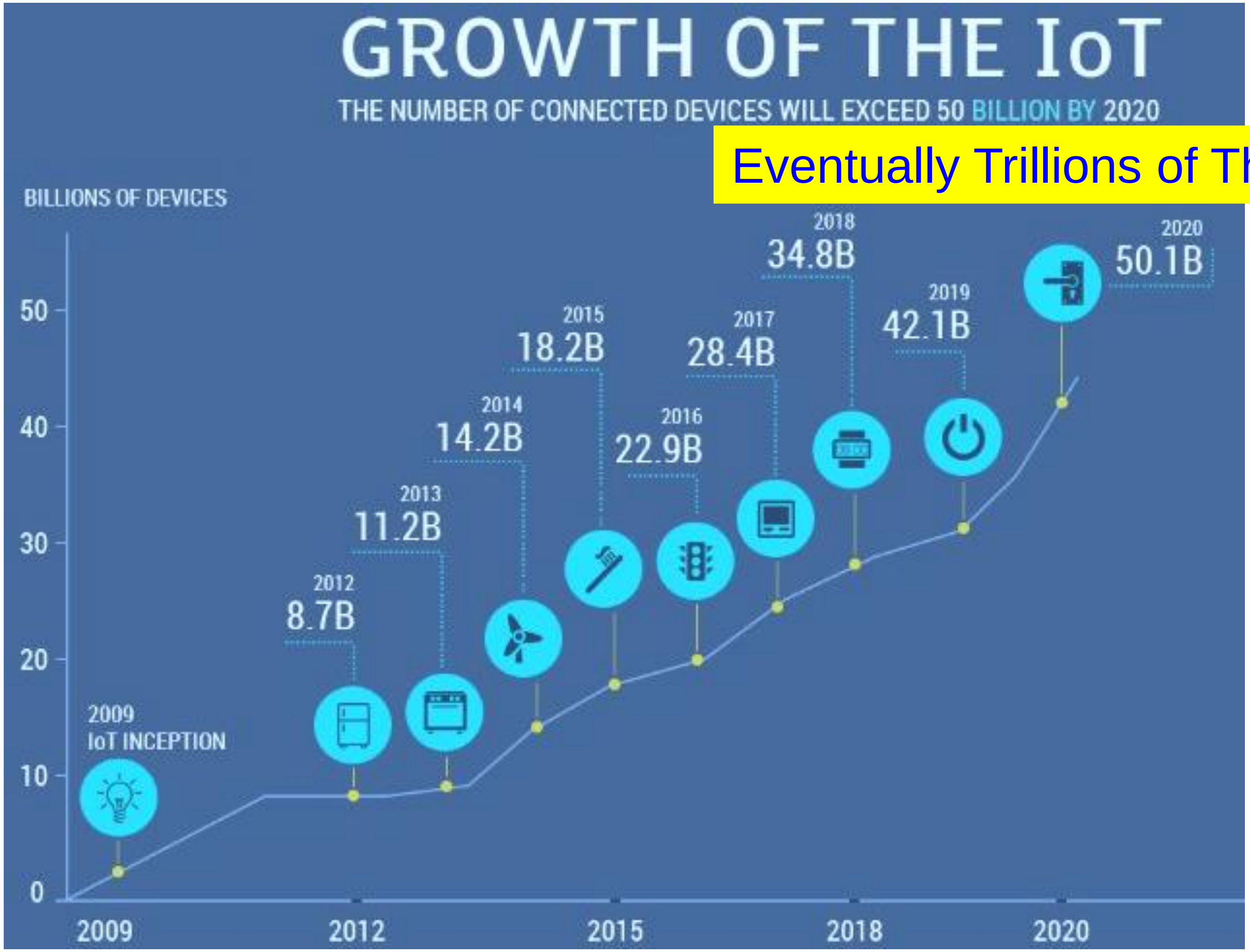
Challenges and Research

IoT – Selected Challenges



Source: Mohanty ICIT 2017 Keynote

Massive Scaling



Eventually Trillions of Things

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

High Design and Operation Cost

- The design cost is a one-time cost.
- Design cost needs to be small to make a IoT realization possible.
- The operations cost is that required to maintain the IoT.
- A small operations cost will make it easier to operate in the long run with minimal burden on the budget of application in which IoT is deployed.

Source: http://www.industrialisation-produits-electroniques.fr

"Cities around the world could spend as much as $41 trillion on smart tech over the next 20 years."

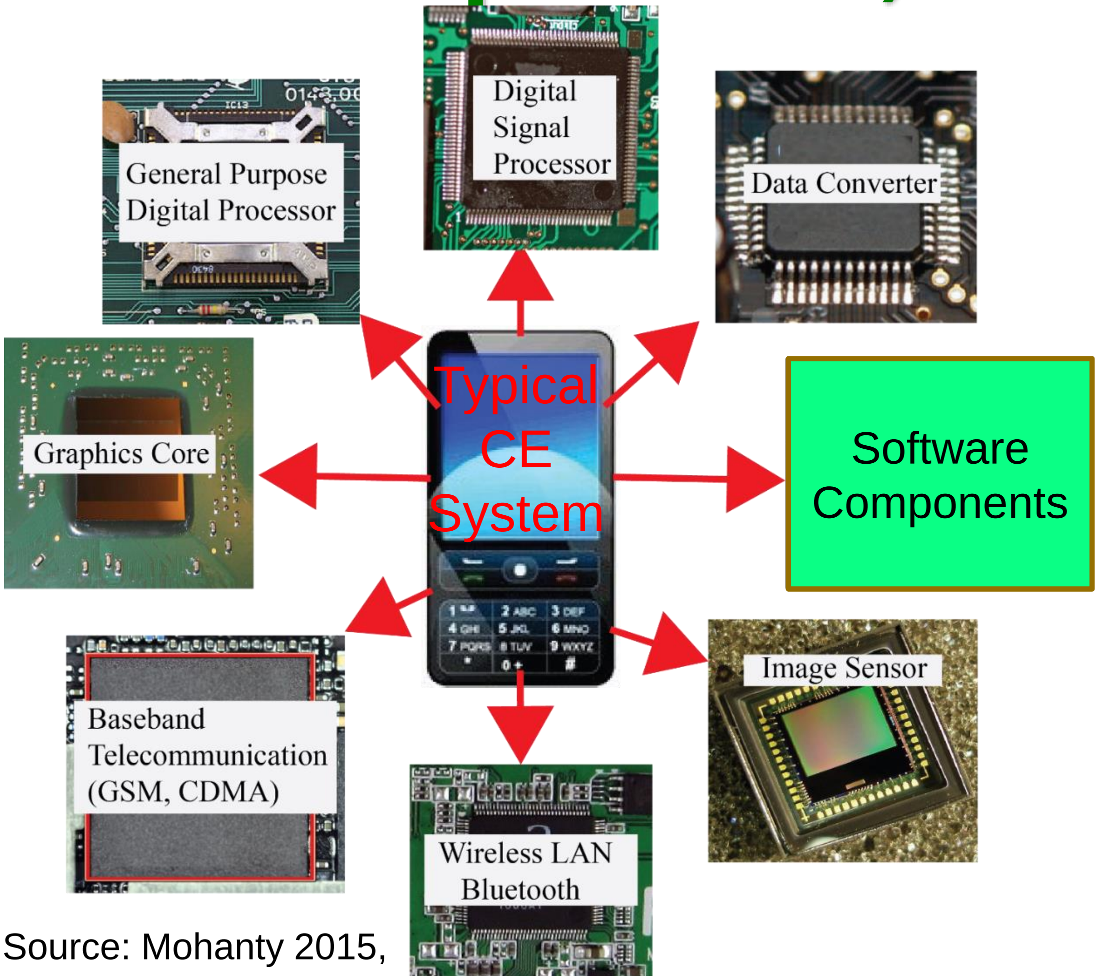
Source: http://www.cnbc.com/2016/10/25/spending-on-smart-cities-around-the-world-could-reach-41-trillion.html

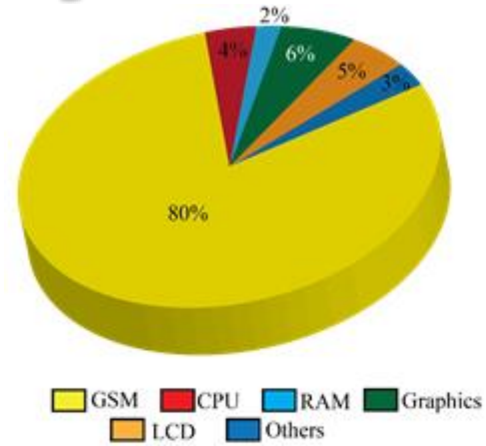
Communication Latency and Energy Consumption

- Connected cars require latency of ms to communicate and avoid impending crash.
  - Faster connection
  - Low latency
  - Lower power
- 5G for connected world: This enables all devices to be connected seamlessly.
- How about 5G, WiFi working together more effectively?

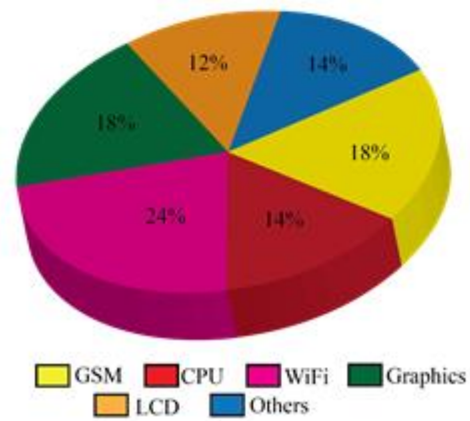
Source: https://www.linkedin.com/pulse/key-technologies-connected-world-cloud-computing-ioe-balakrishnan

Energy Consumption of Sensors, Components, and Systems





During GSM Communications



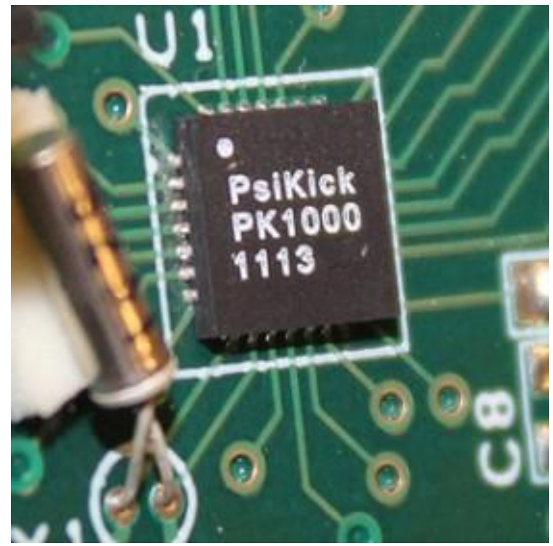
During WiFi Communications

Source: Mohanty 2015, McGraw-Hill 2015

Battery-Less IoT

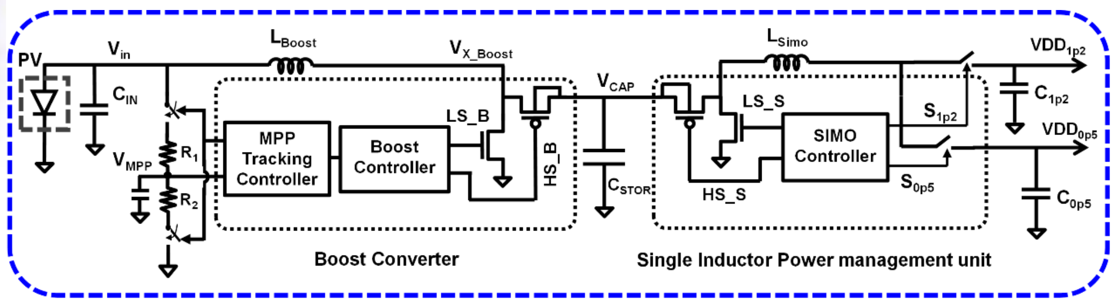
Battery less operations can lead to reduction of size and weight of the edge devices.

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/

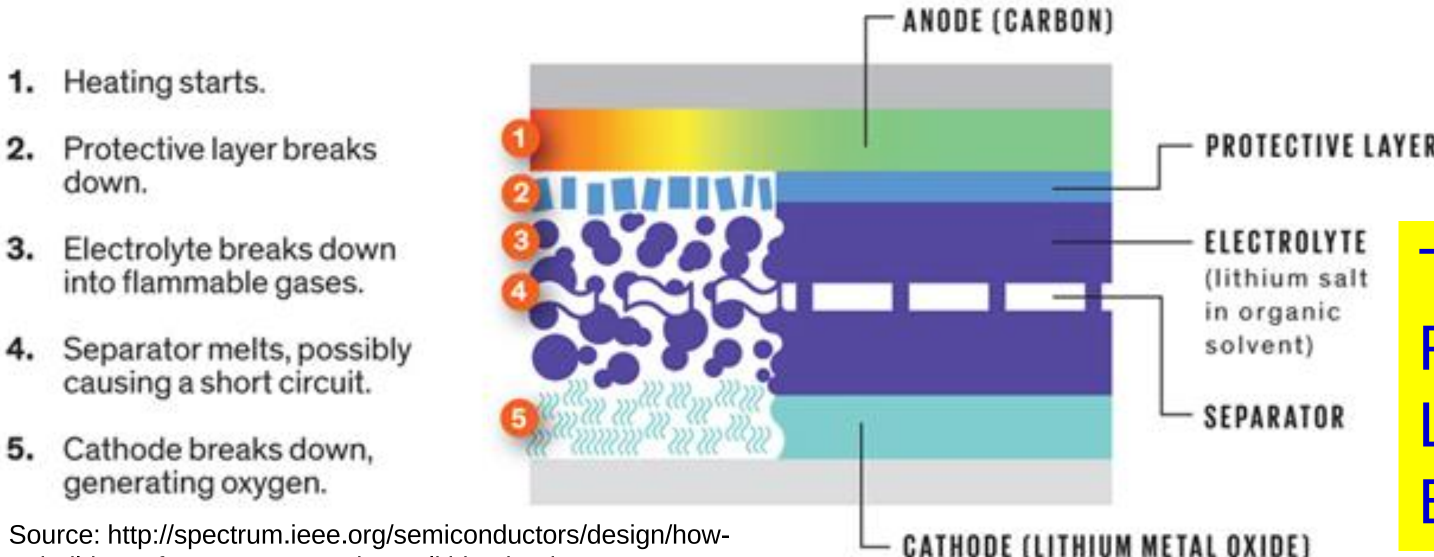


Energy Harvesting and Power Management

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

Safety of Electronics

Smartphone Battery



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

Thermal Runaway in a Lithium-Ion Battery

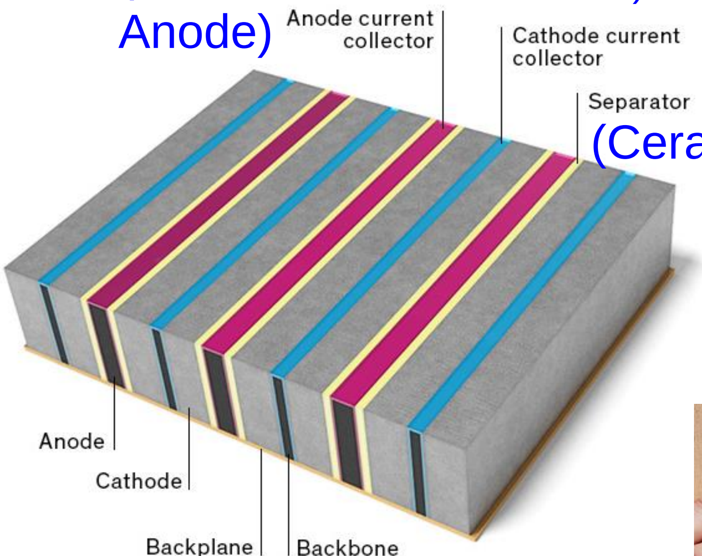
Source: Mohanty ZINC 2018 Keynote

Energy Storage - High Capacity and Safer Needed

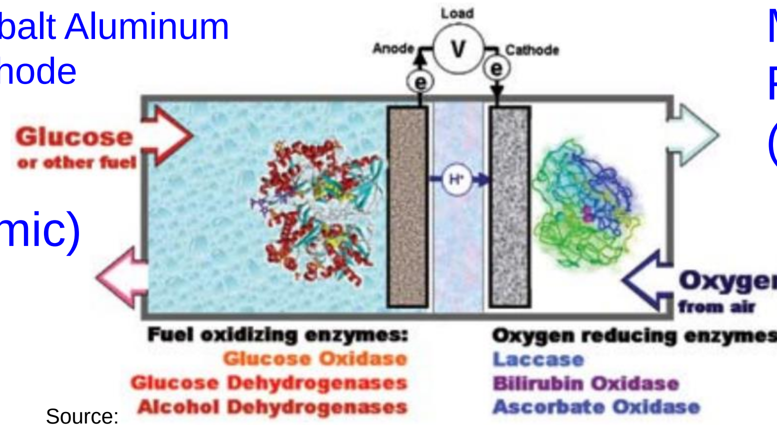
(Silicon Anode)

(Lithium Nickel Cobalt Aluminum Oxide - NCA) Cathode

(Ceramic)



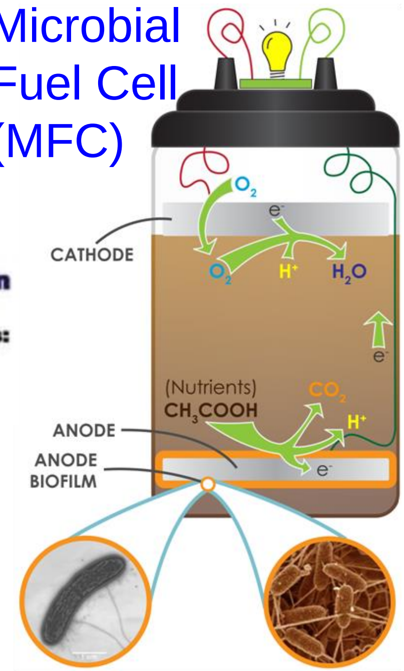
Source: http://spectrum.ieee.org/semiconductors/design/how-to-build-a-safer-more-energydense-lithiumion-battery

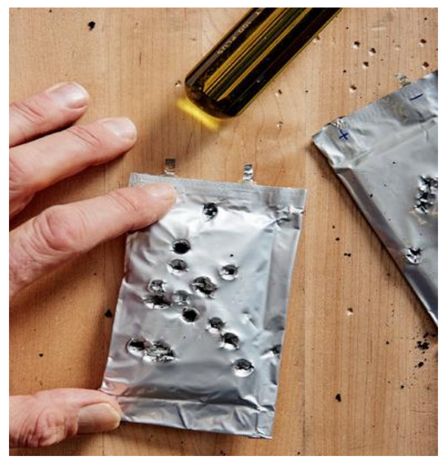


Source: https://www.electrochem.org/dl/interface/sum/sum07/su07_p28_31.pdf

Enzymatic Biofuel Cell

Microbial Fuel Cell (MFC)

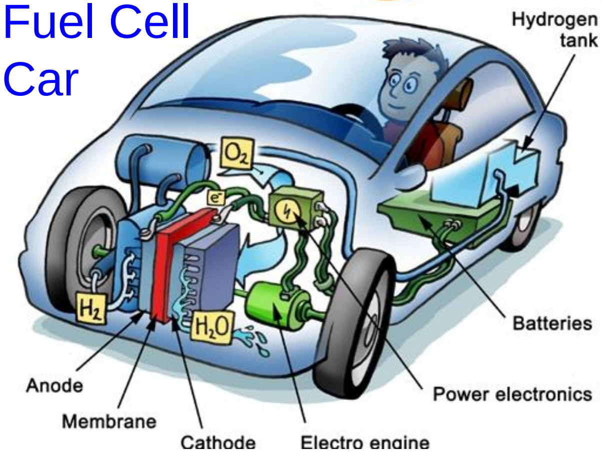




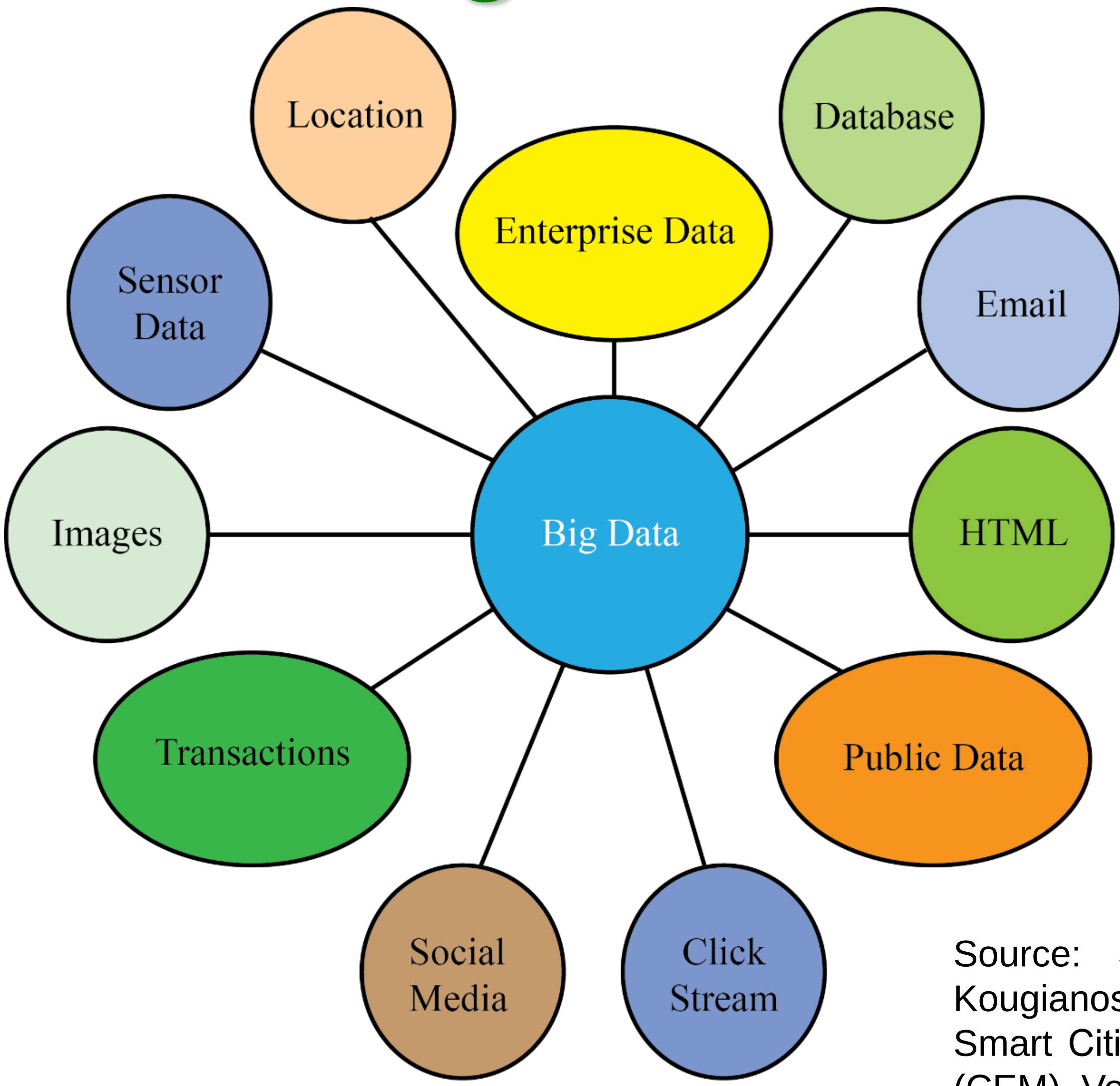
Solid Polymer Lithium Metal Battery

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

Fuel Cell Car



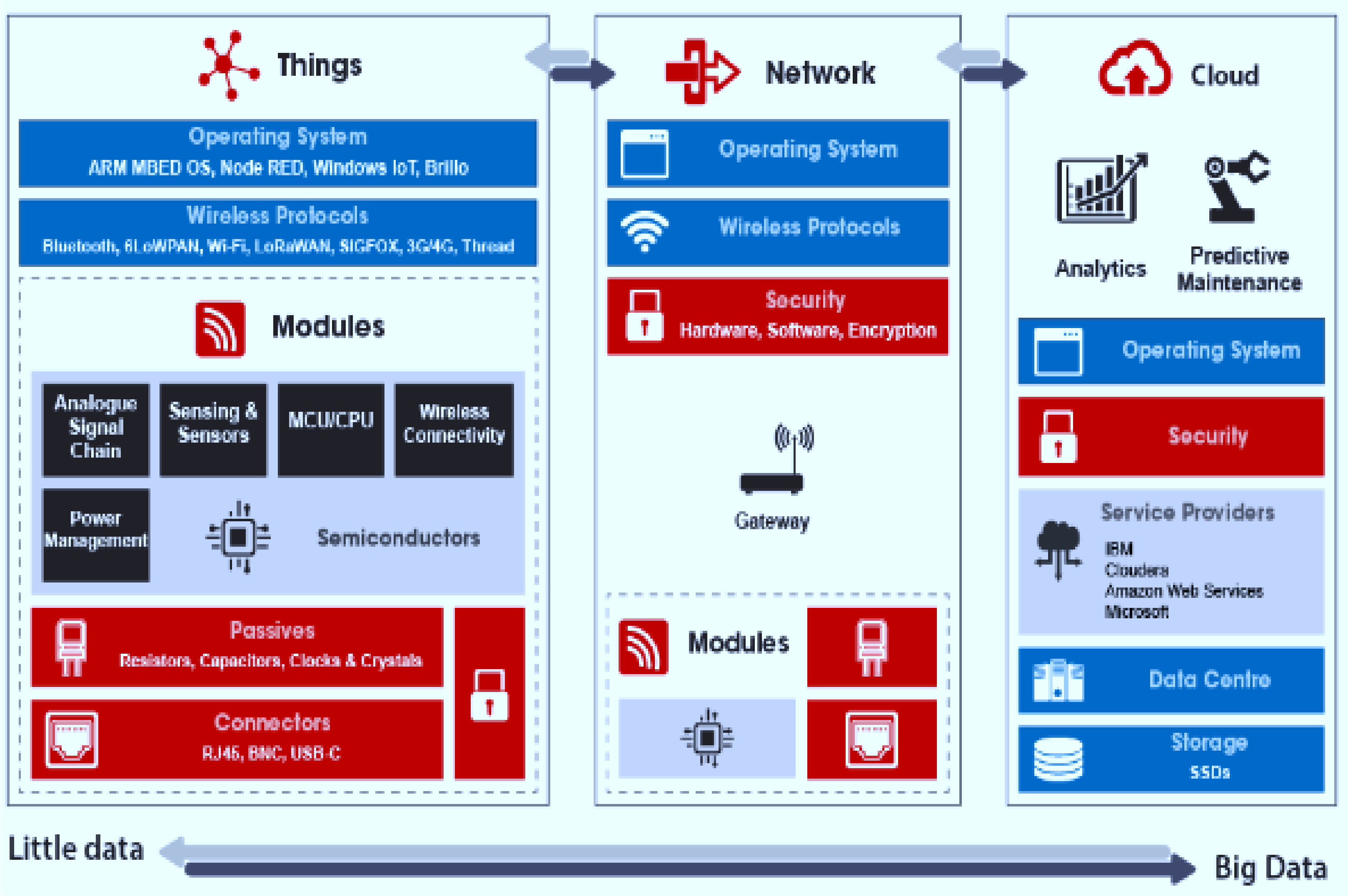
Bigdata in Smart Cities



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.

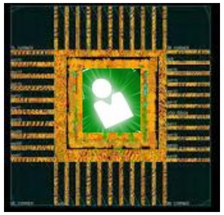
Bigdata in IoT and Smart Cities



Source: M. Elbeheiry, "Internet of Things (IoT) Architecture", Article, March 12, 2017.

Security, Privacy, and IP Rights

Hardware Trojan

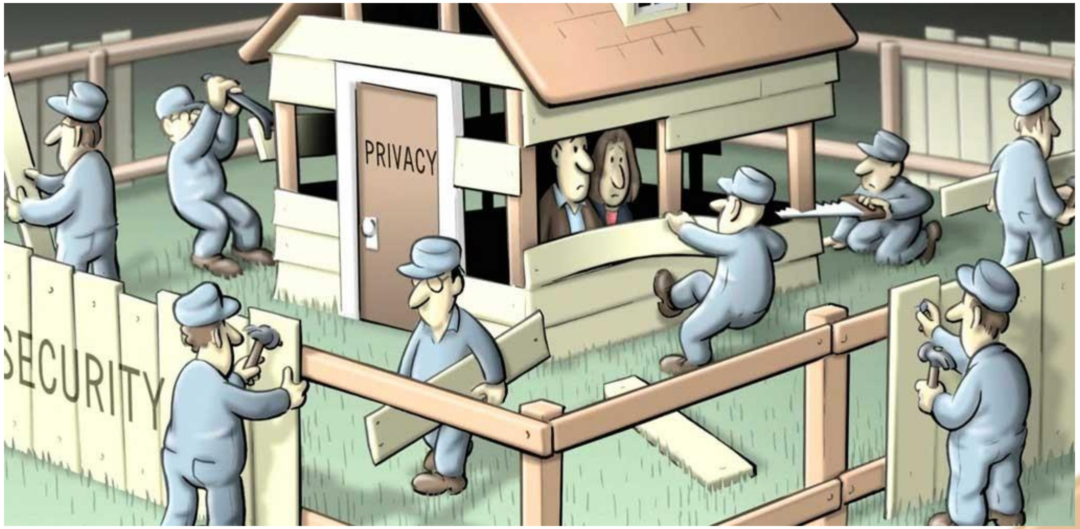


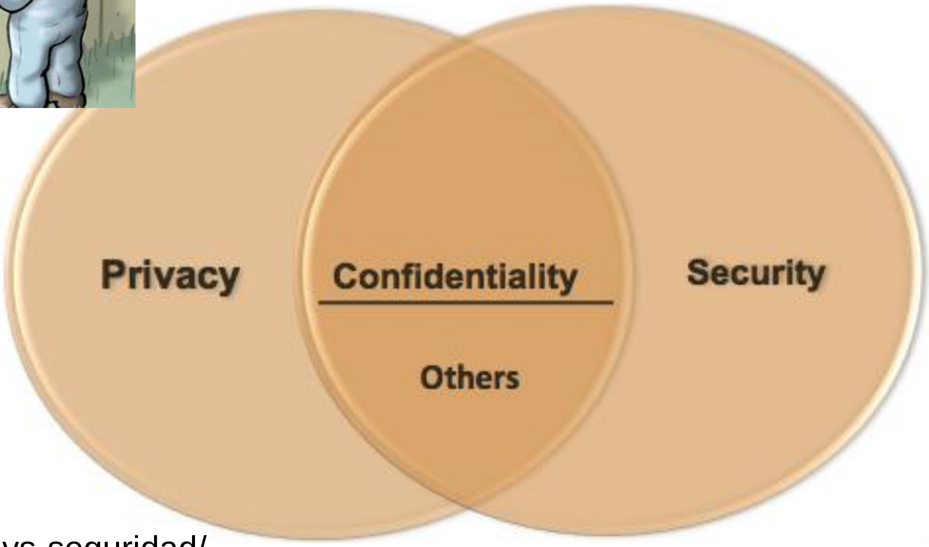
Counterfeit Hardware

July 2017

Source: Mohanty ICIT 2017 Keynote

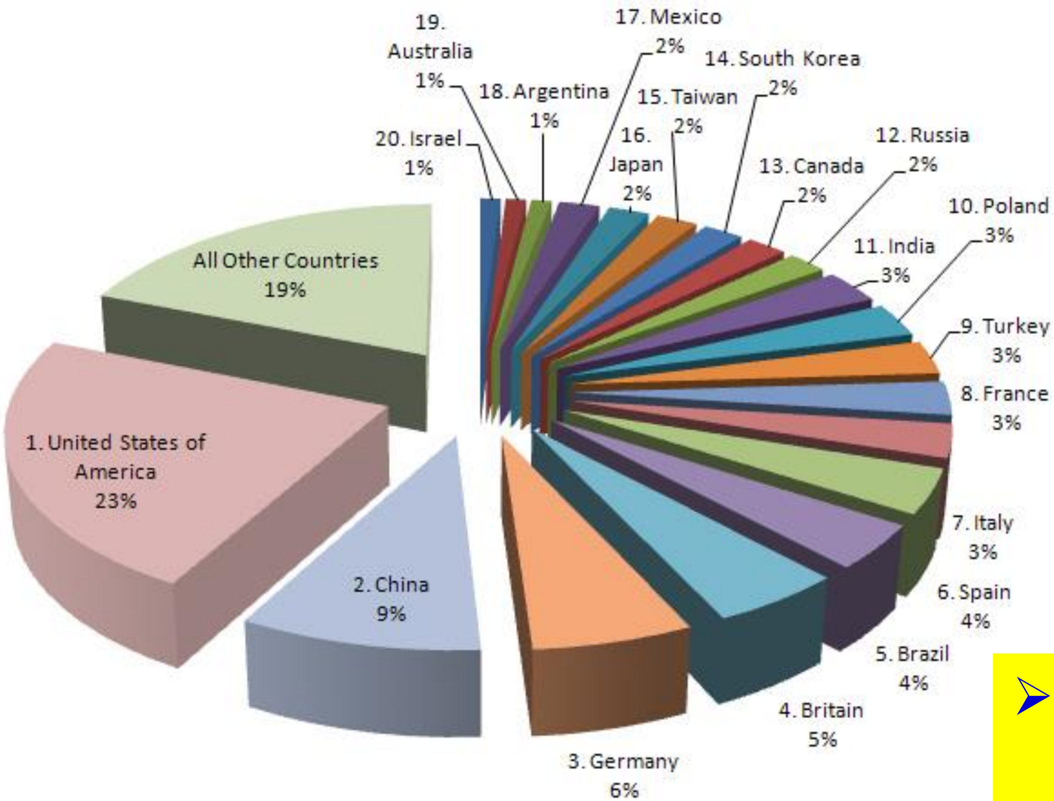
Security, Privacy, IP Rights





Source: https://blogs.deusto.es/master-informatica/privacidad-vs-seguridad/

Security - Information, System



Cybercrime: Top 20 Countries

Source: https://www.enigmasoftware.com/top-20-countries-the-most-cybercrime/

- Cybercrime damage costs to hit $6 trillion annually by 2021
- Cybersecurity spending to exceed $1 trillion from 2017 to 2021

Source: http://www.csoonline.com/article/3153707/security/top-5-cybersecurity-facts-figures-and-statistics-for-2017.html

Security – Information …

Online Banking

Credit Card Theft


Hacked: Linkedin, Tumbler, & Myspace

Linked in
tumblr.
myspace

Who did it: A hacker going by the name Peace.

What was done: 500 million passwords were stolen.

Details: Peace had the following for sale on a Dark Web Store:

- 167 million Linkedin passwords
- 360 million Myspace passwords
- 68 million Tumbler passwords
- 100 million VK.com passwords
- 71 million Twitter passwords

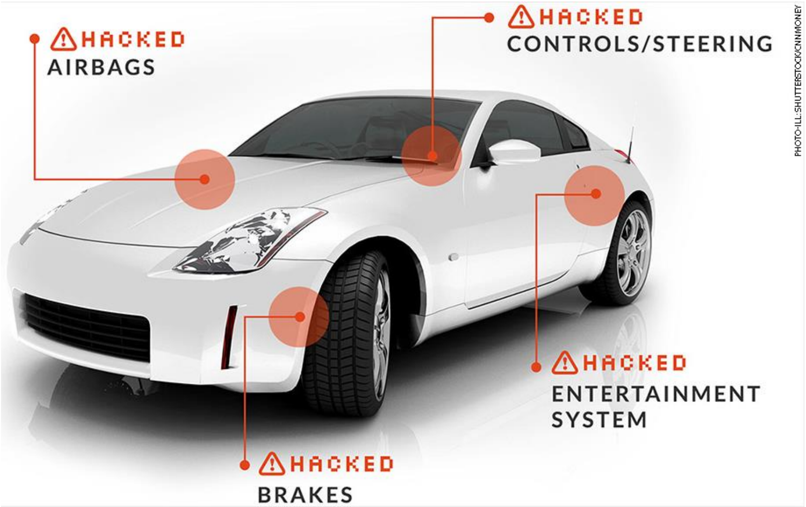
Personal Information

Credit Card/Unauthorized Shopping

Security - Systems …

Power Grid Attack

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

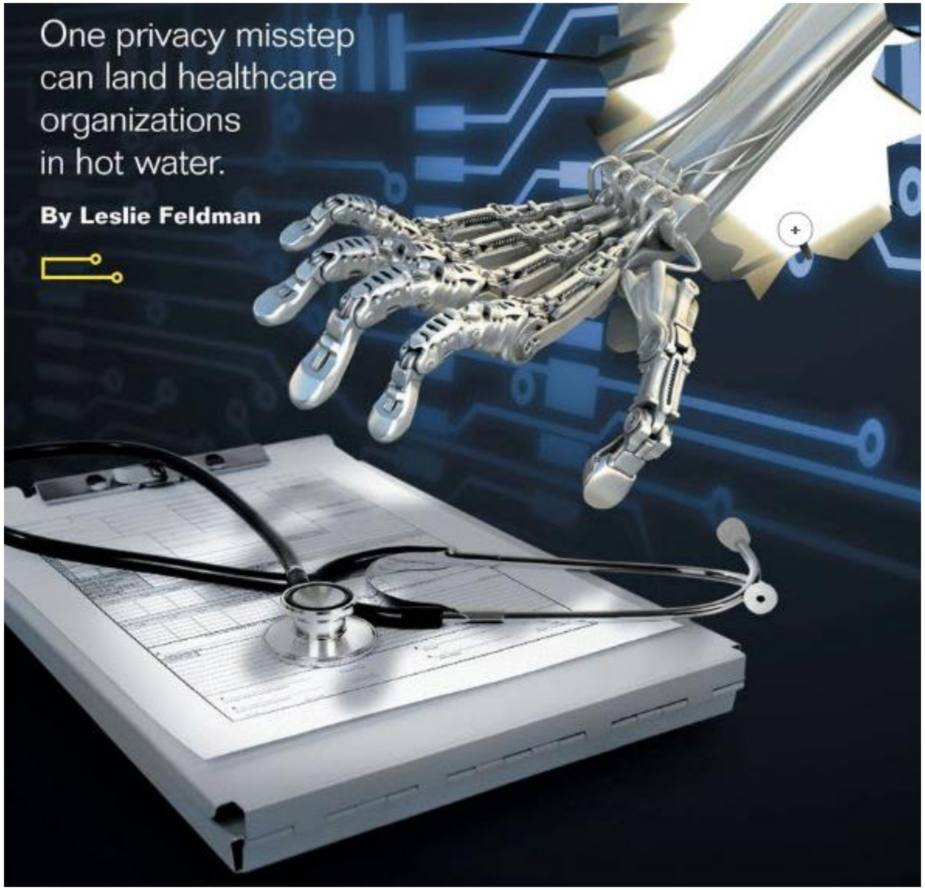


Source: http://money.cnn.com/2014/06/01/technology/security/car-hack/

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

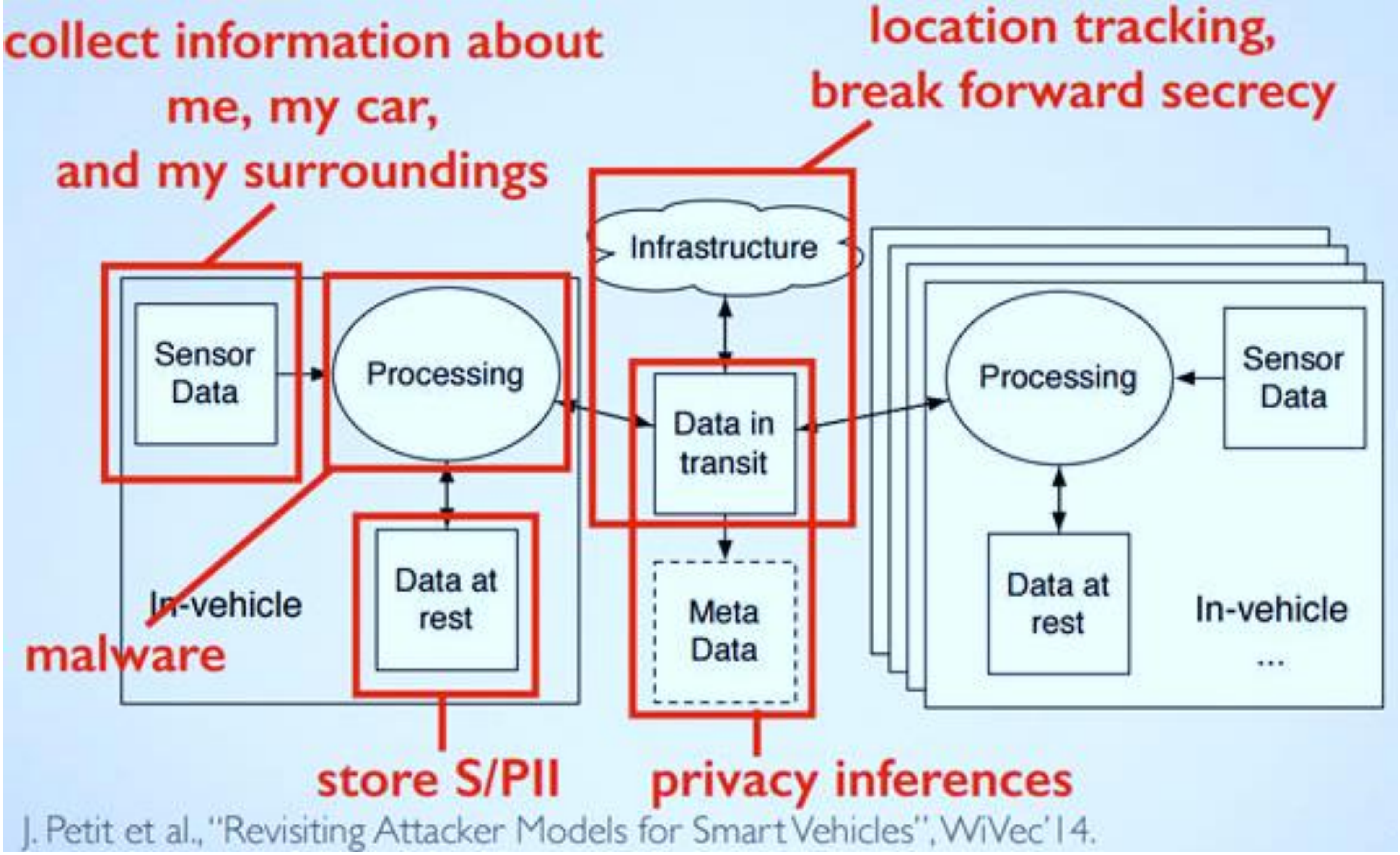
Information Privacy

Source: http://ciphercloud.com/three-ways-pursue-cloud-data-privacy-medical-records/



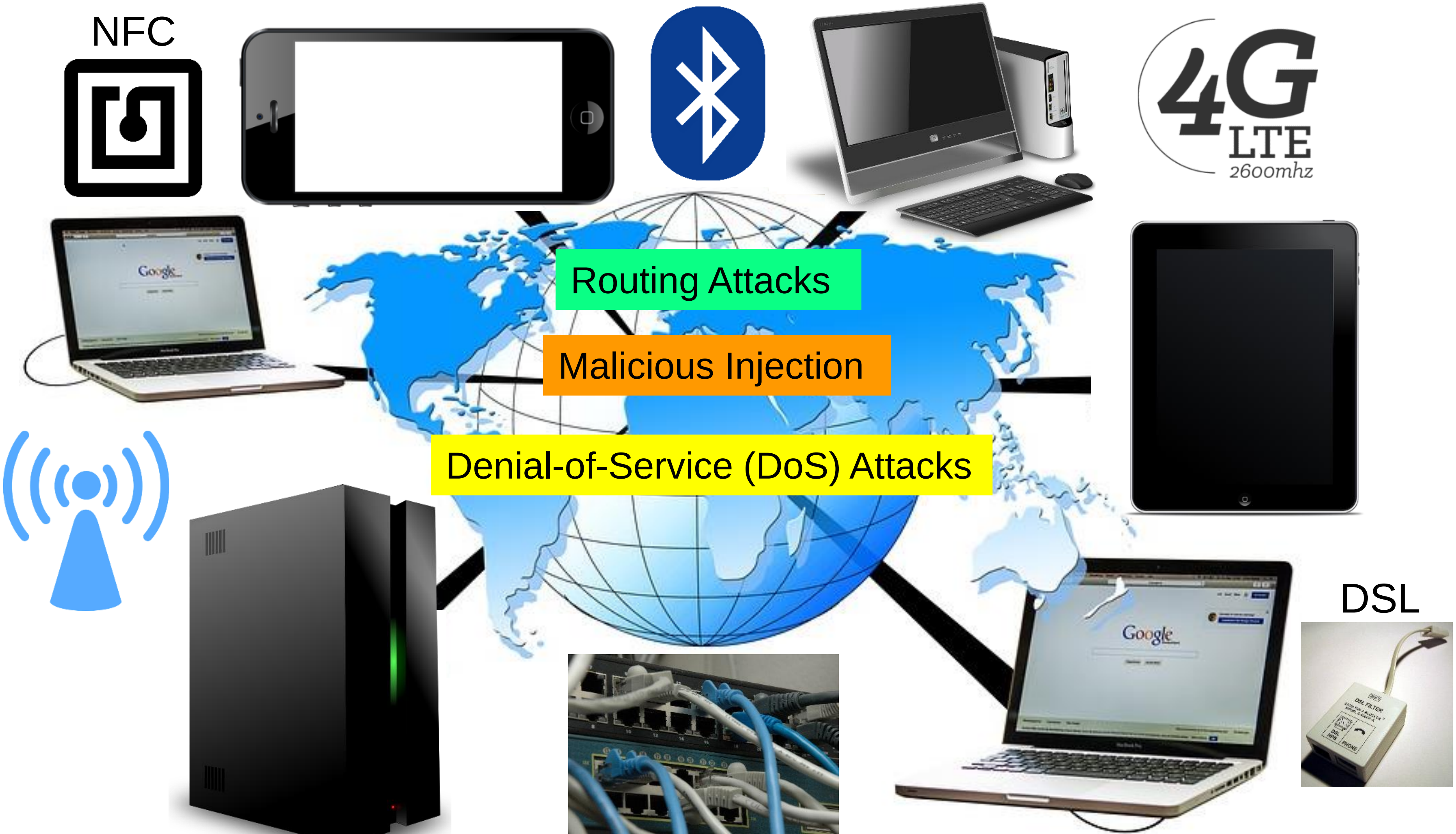
Source: http://blog.veriphyr.com/2012/06/electronic-medical-records-security-and.html

Privacy Challenge – System, Smart Car



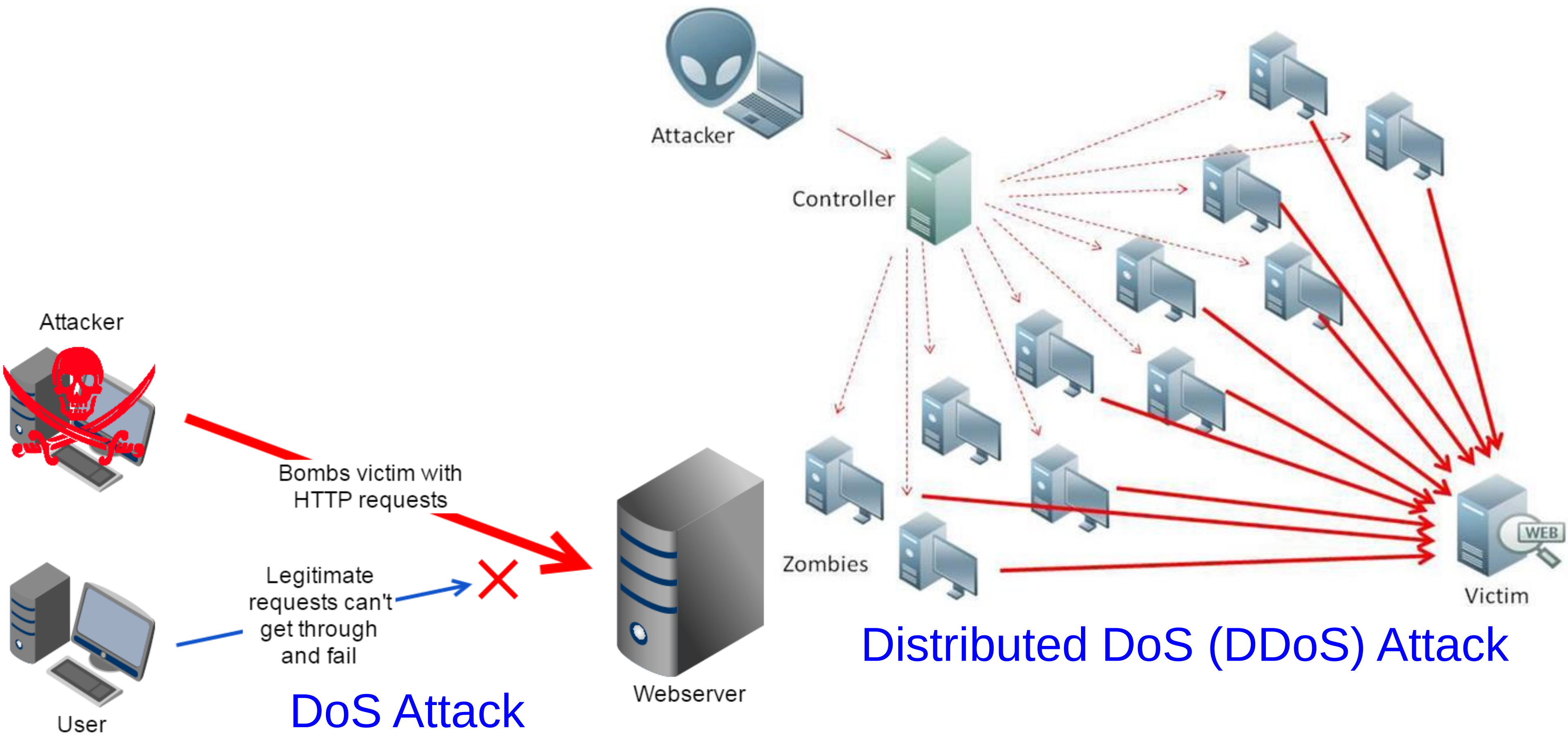
Source: http://www.computerworld.com/article/3005436/cybercrime-hacking/black-hat-europe-it-s-easy-and-costs-only-60-to-hack-self-driving-car-sensors.html

Security in Communications Technology



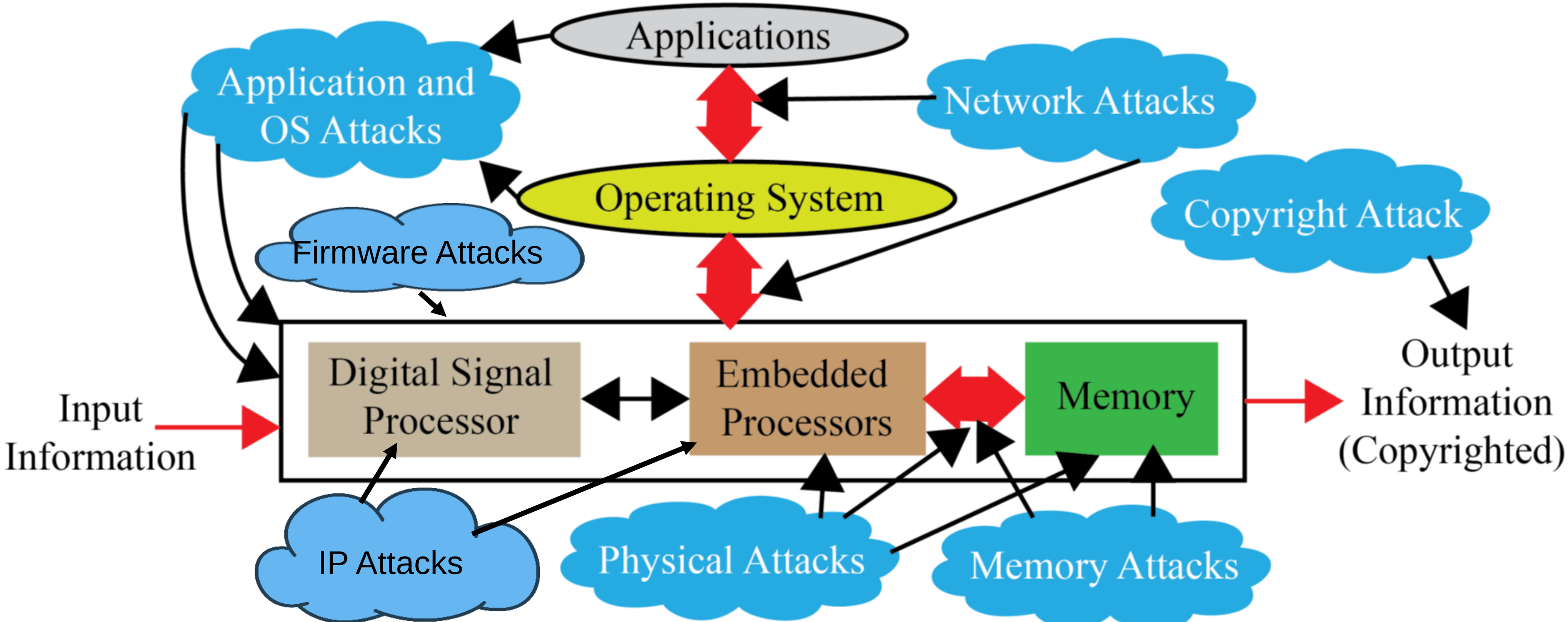
Source: Mohanty ICIT 2017 Keynote

Denial-of-Service (DoS) Attacks



Source: https://bogner.sh/2015/05/analysing-a-denial-of-service-attack-tool/

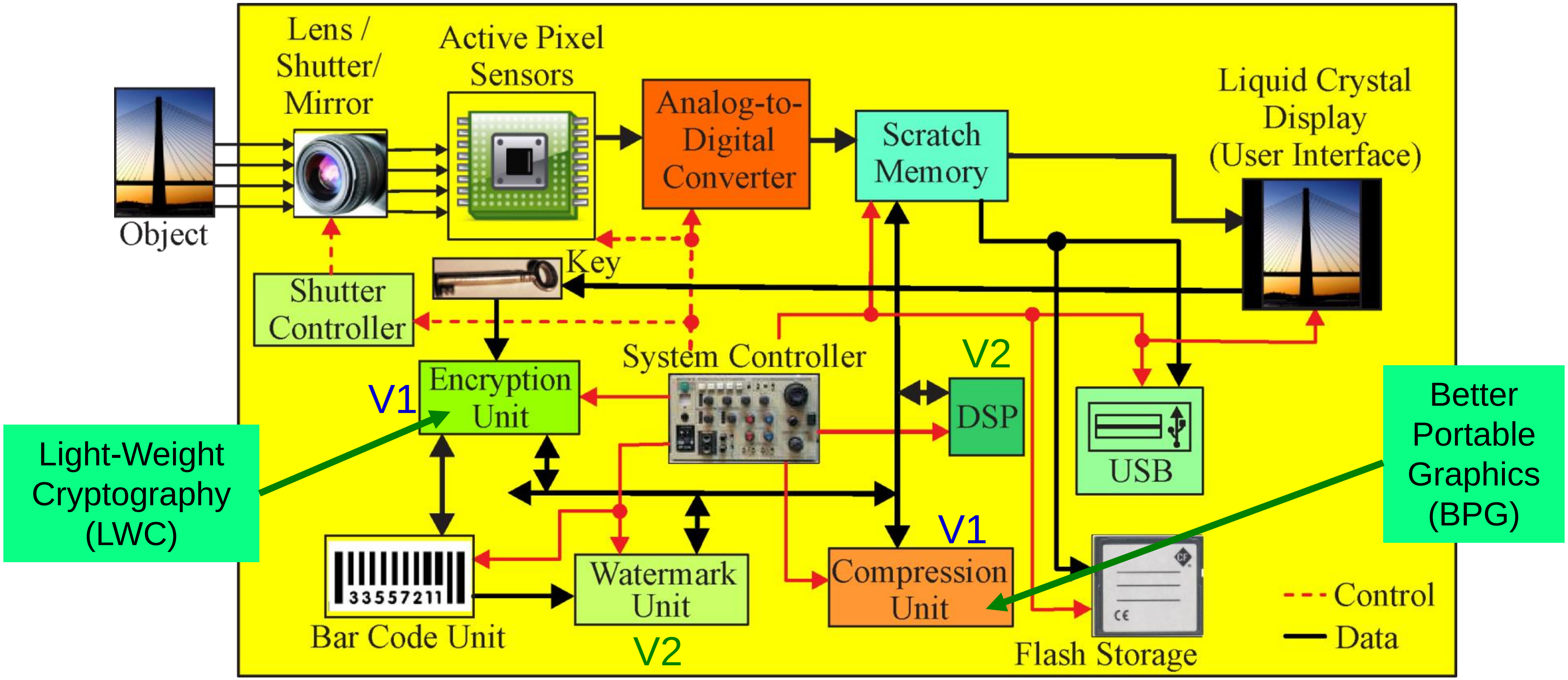
Selected Attacks on a CE System – Security, Privacy, IP Rights



Diverse forms of Attacks, following are not the same: System Security, Information Security, Information Privacy, System Trustworthiness, Hardware IP protection, Information Copyright Protection.

Source: Mohanty ZINC 2018 Keynote

ESR-Smart – End-Device Optimization



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

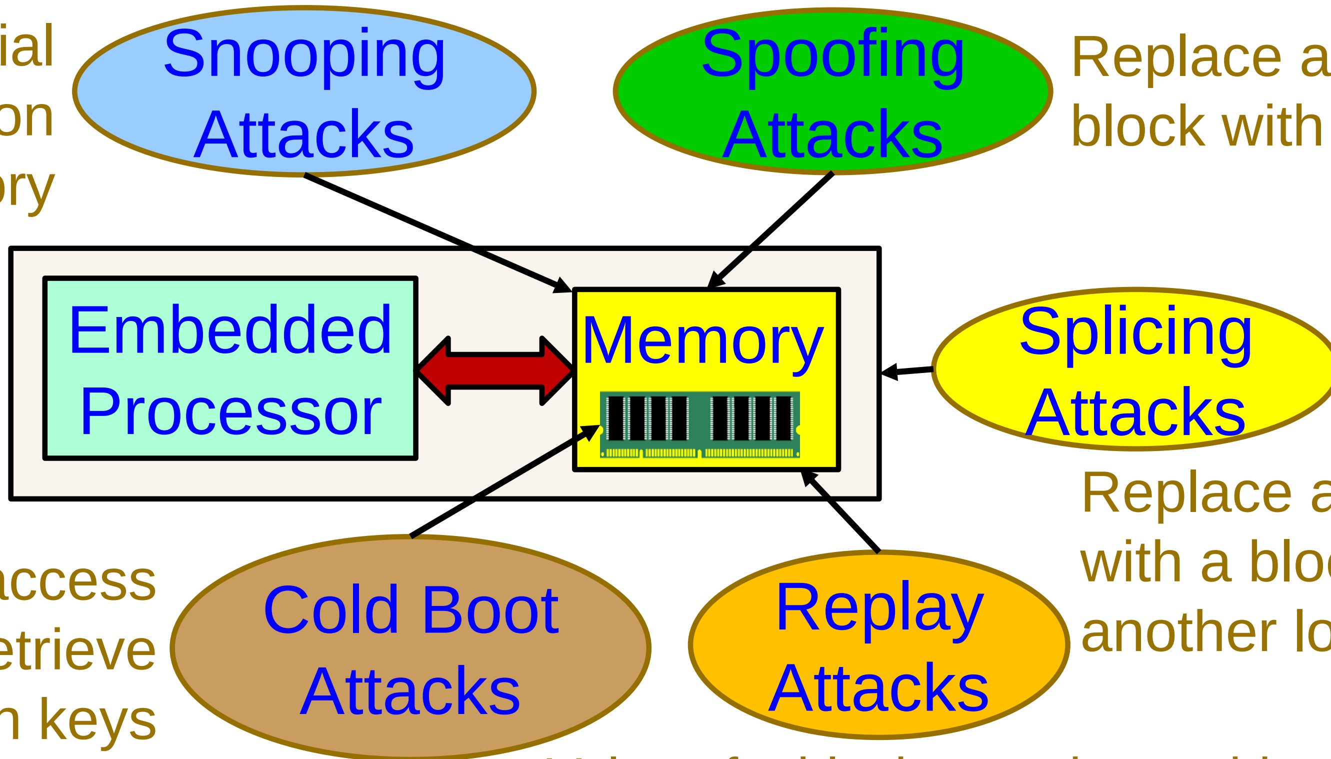
Source: S. P. Mohanty, "A Secure Digital Camera Architecture for Integrated Real-Time Digital Rights Management", Elsevier Journal of Systems Architecture (JSA), Volume 55, Issues 10-12, October-December 2009, pp. 468-480.

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

Memory Attacks

Read confidential information in memory

Replace a block with fake



Replace a block with a block from another location

Physical access memory to retrieve encryption keys

Value of a block at a given address at one time is written at exactly the same address at a different times; Hardest attack.

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.

Nonvolatile Memory Security and Protection

Source: http://datalocker.com

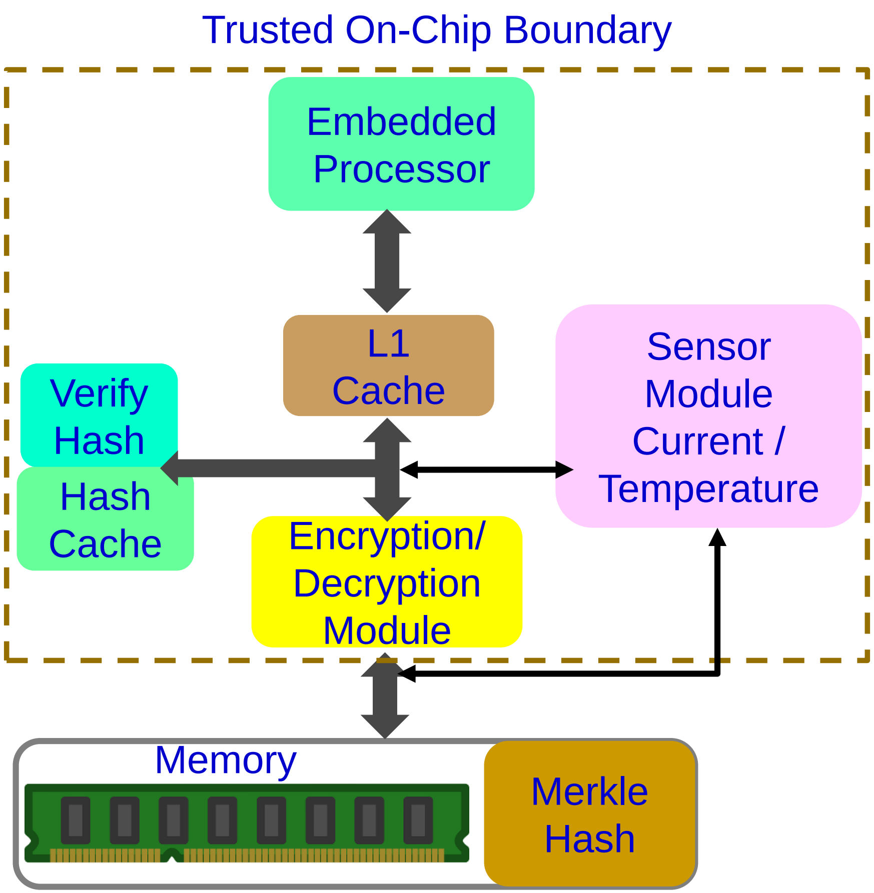
Nonvolatile / Harddrive Storage

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

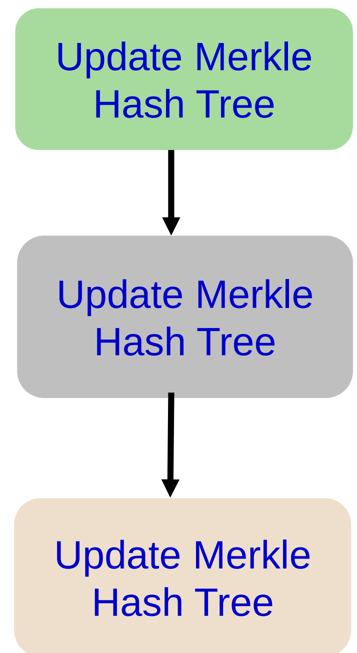
Software-based encryption to secure systems and partitions of hard drive.

Some performance penalty due to increase in latency!

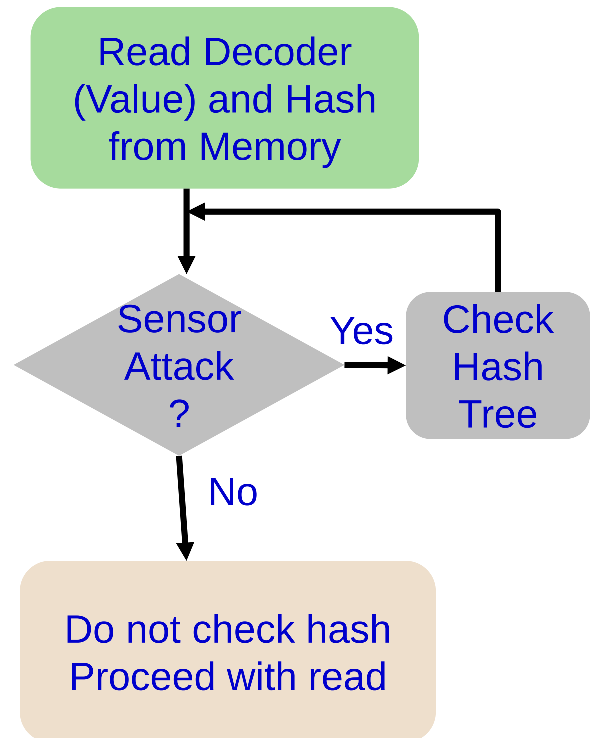
Embedded Memory Security and Protection



On-Chip/On-Board Memory Protection



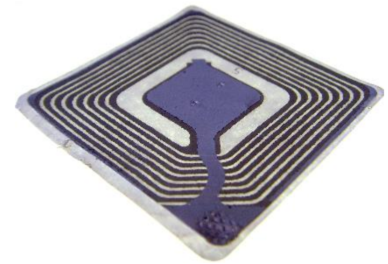
Write Operation



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.

RFID Security - Attacks



- Selected RFID Attacks
  - Physical RFID Threats
    - Disabling Tags
    - Tag Modification
    - Cloning Tags
    - Reverse Engineering and Physical Exploration
  - RFID Channel Threats
    - Eavesdropping
    - Snooping
    - Skimming
    - Replay Attack
    - Relay Attacks
    - Electromagnetic Interference
  - System Threats
    - Counterfeiting and Spoofing Attacks
    - Tracing and Tracking
    - Password Decoding
    - Denial of Service (DoS) Attacks

Numerous Applications

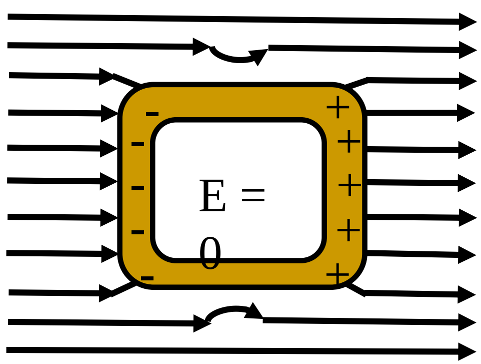
Source: Khattab 2017: Springer 2017 RFID Security

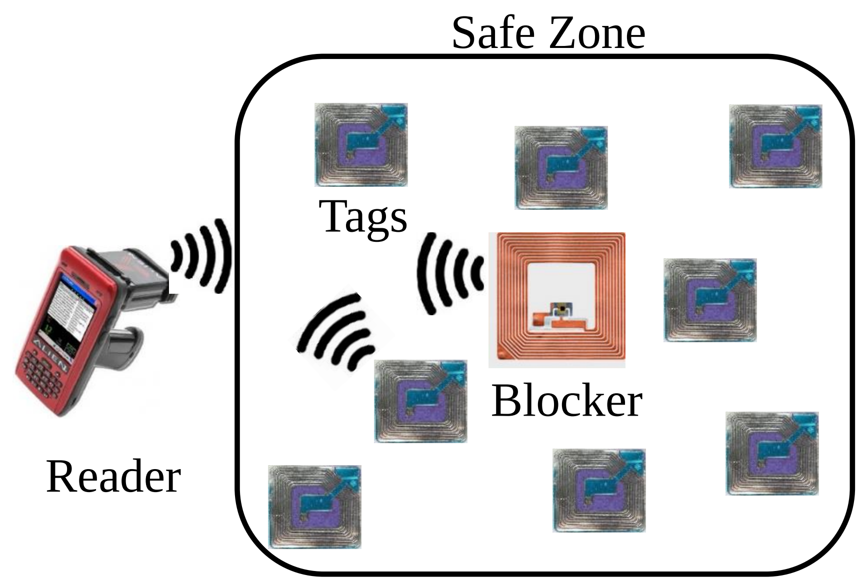
RFID Security - Solutions

Selected RFID Security Methods

- Killing Tags
- Sleeping Tags
- Faraday Cage
- Blocker Tags
- Tag Relabeling
- Minimalist Cryptography
- Proxy Privacy Devices

Faraday Cage





Blocker Tags

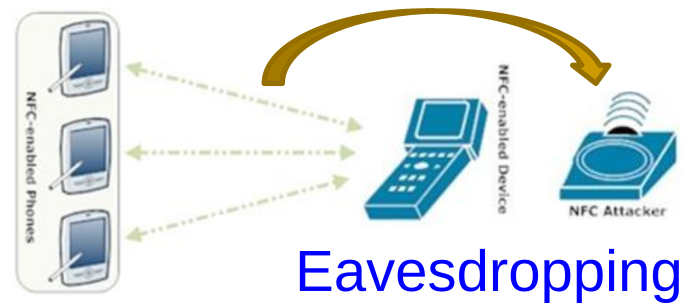
Source: Khattab 2017, Springer 2017 RFID Security

NFC Security - Attacks

Selected NFC Attacks

- Eavesdropping
- Data Modification
- Relay Attacks
- Data Corruption
- Spoofing
- Interception Attacks
- Theft

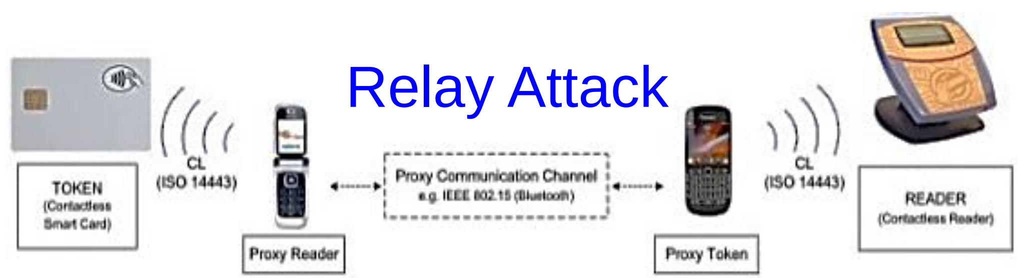
Source: http://www.idigitaltimes.com/new-android-nfc-attack-could-steal-money-credit-cards-anytime-your-phone-near-445497



Eavesdropping

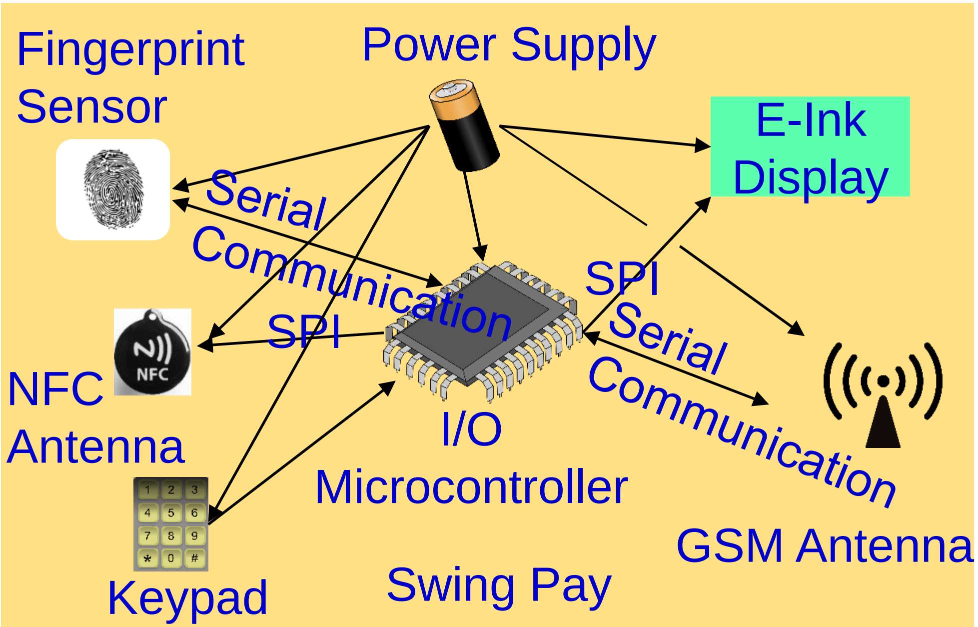
Source: http://resources.infosecinstitute.com/near-field-communication-nfc-technology-vulnerabilities-and-principal-attack-schema/

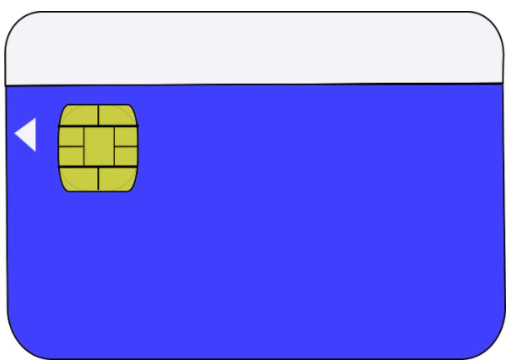
Relay Attack

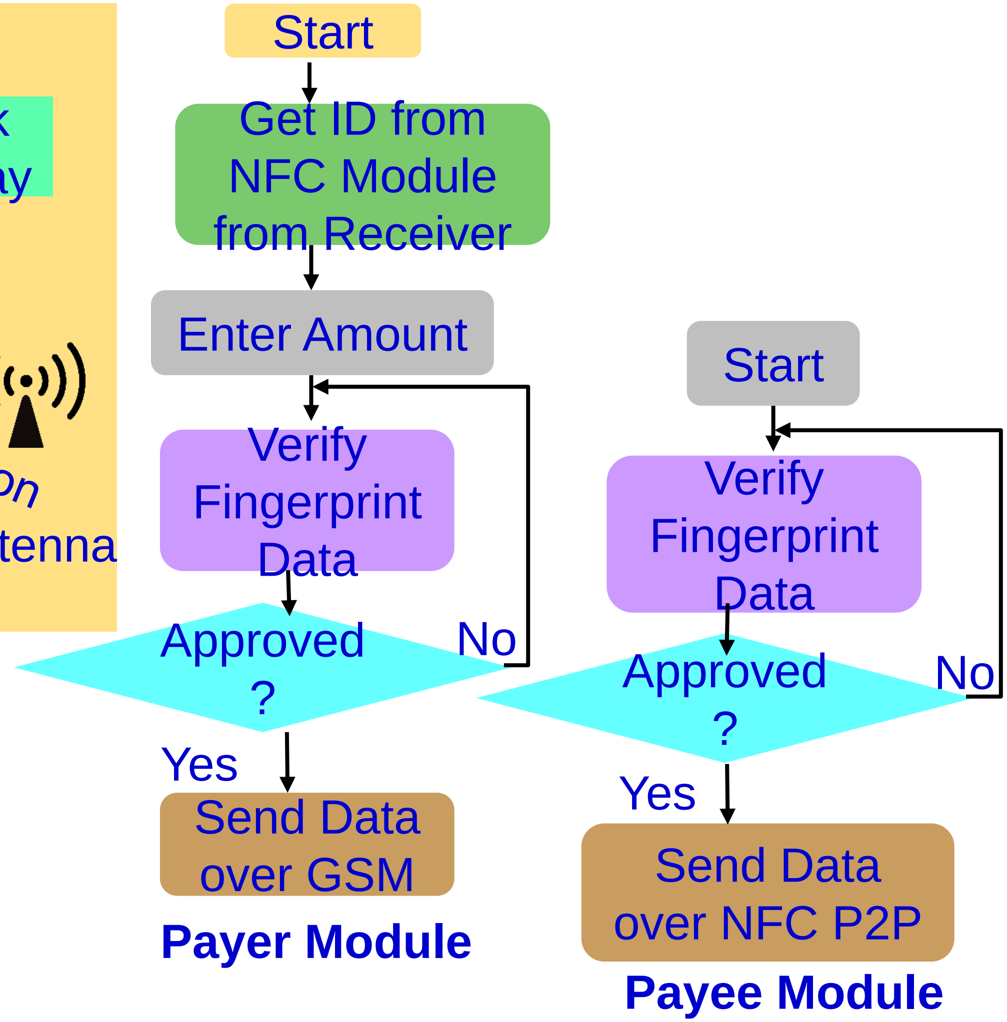


Source: https://www.slideshare.net/cgvwzq/on-relaying-nfc-payment-transactions-using-android-devices

NFC Security - Solution





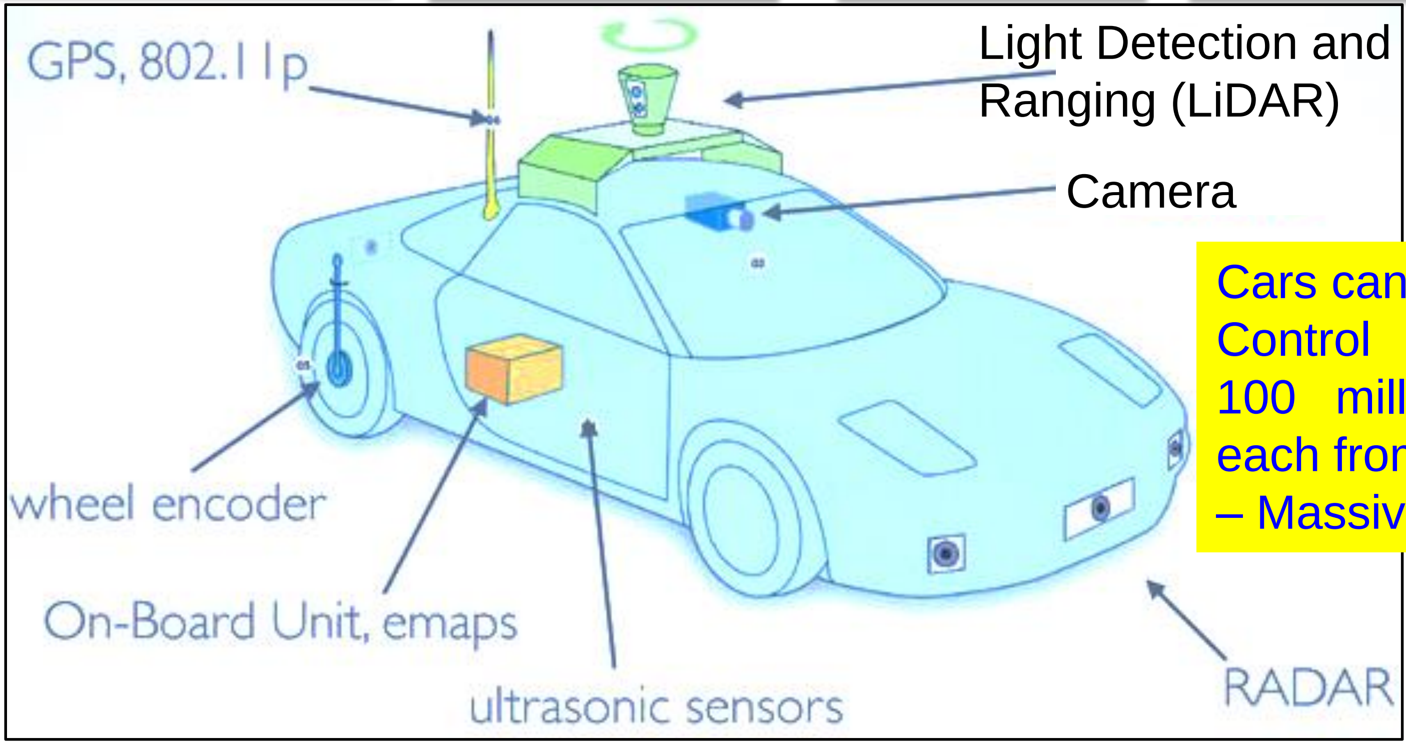


Source: Mohanty 2017, CE Magazine Jan 2017

Autonomous Car – Security Venerability

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.

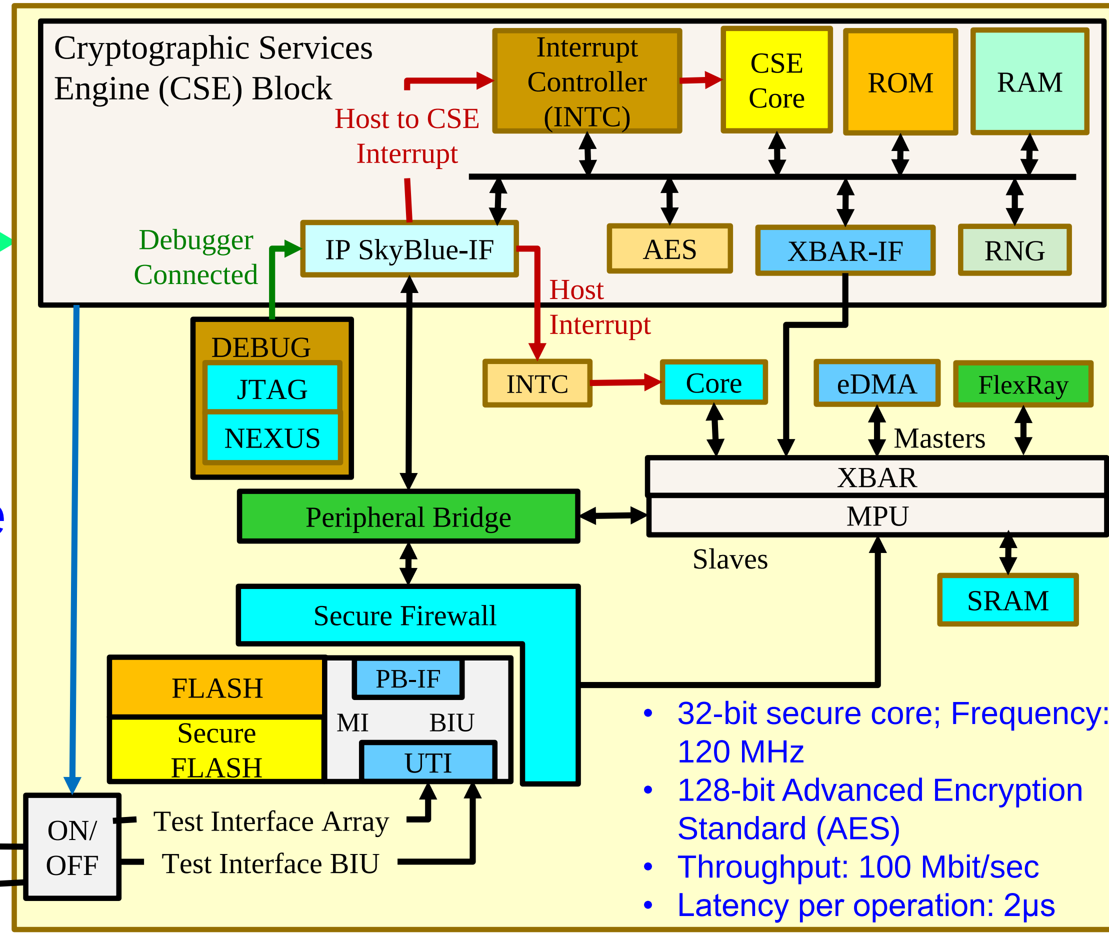
Source: http://www.computerworld.com/article/3005436/cybercrime-hacking/black-hat-europe-it-s-easy-and-costs-only-60-to-hack-self-driving-car-sensors.html

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

Source: Petit 2015: IEEE-TITS Apr 2015

Autonomous Car Security – Cryptographic Hardware

Cryptographic Services Engine (CSE) Block



- 32-bit secure core; Frequency: 120 MHz
- 128-bit Advanced Encryption Standard (AES)
- Throughput: 100 Mbit/sec
- Latency per operation: 2μs

Qorivva MPC564xB/C Family from NXP/Freescale

Microcontroller Unit (MCU)

Source: http://www.nxp.com/assets/documents/data/en/supporting-information/DWF13_AMF_AUT_T0112_Detroit.pdf

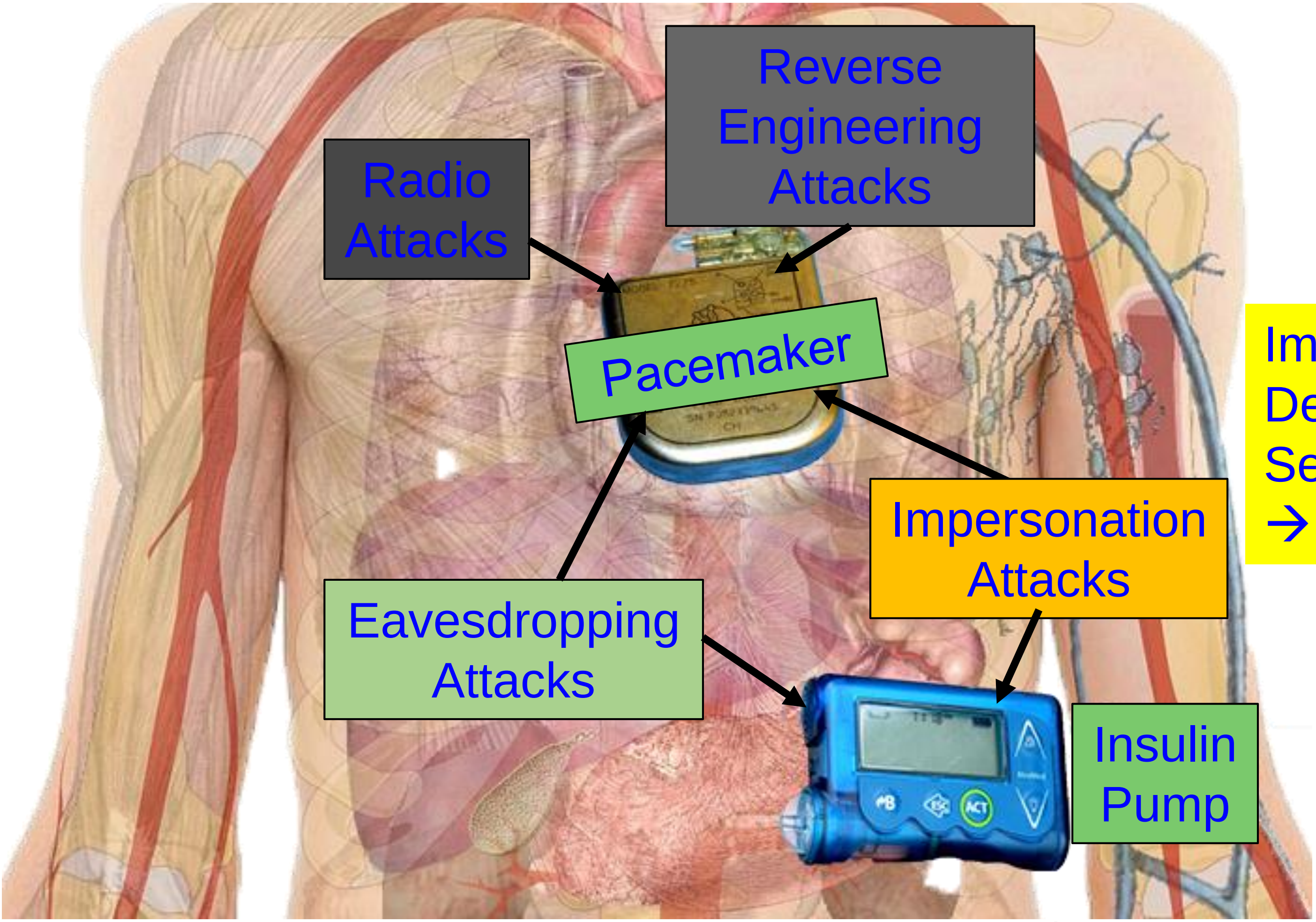
Smart Healthcare - Security and Privacy Issue

Source: Mohanty iSES 2018 Keynote

Selected Smart Healthcare Security/Privacy Challenges

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

Security Measures in Smart Devices – Smart Healthcare



Implantable Medical Devices (IMDs) Security
→ Energy Constraints

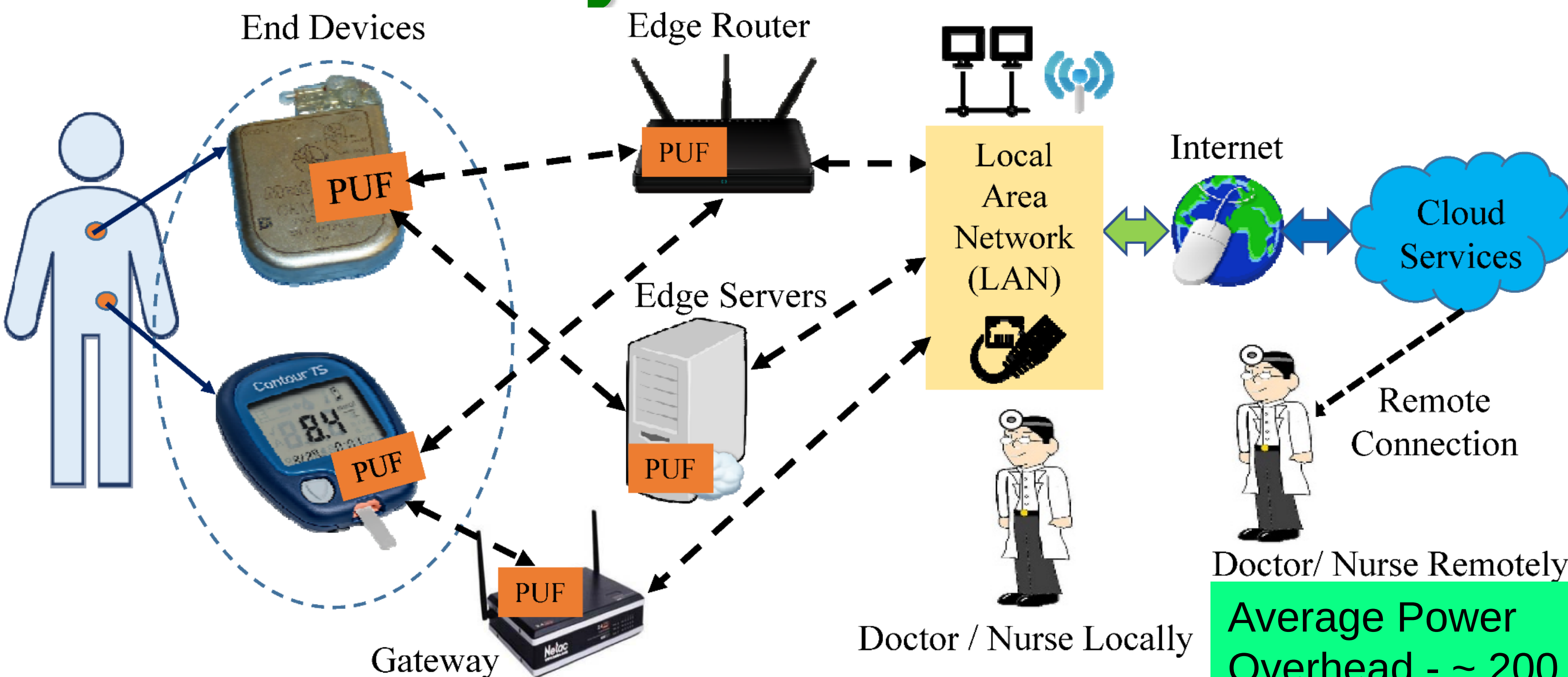
Source: Mohanty 2019, IEEE TCE Under Preparation

Implanted 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.

IoMT Security - PUF based Device Authentication

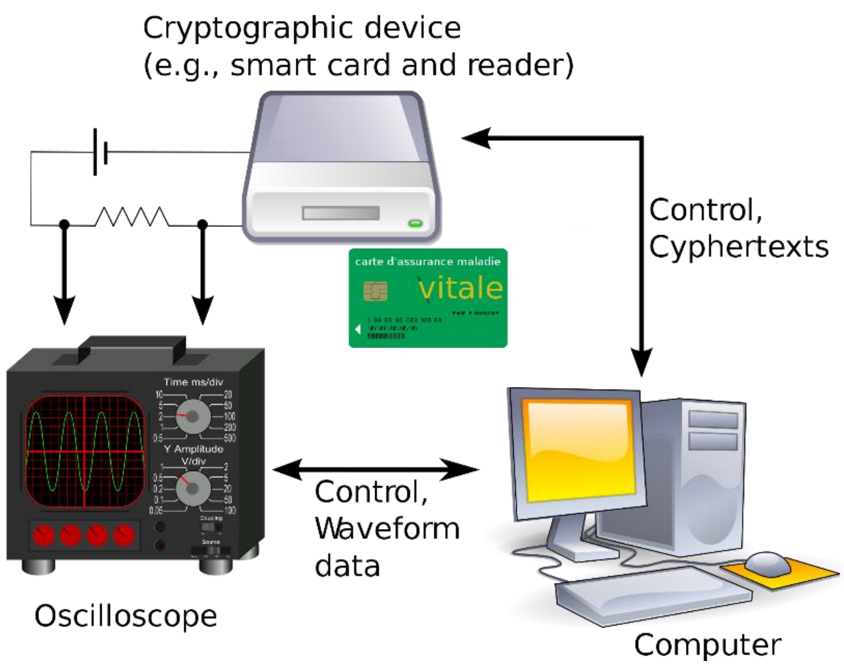


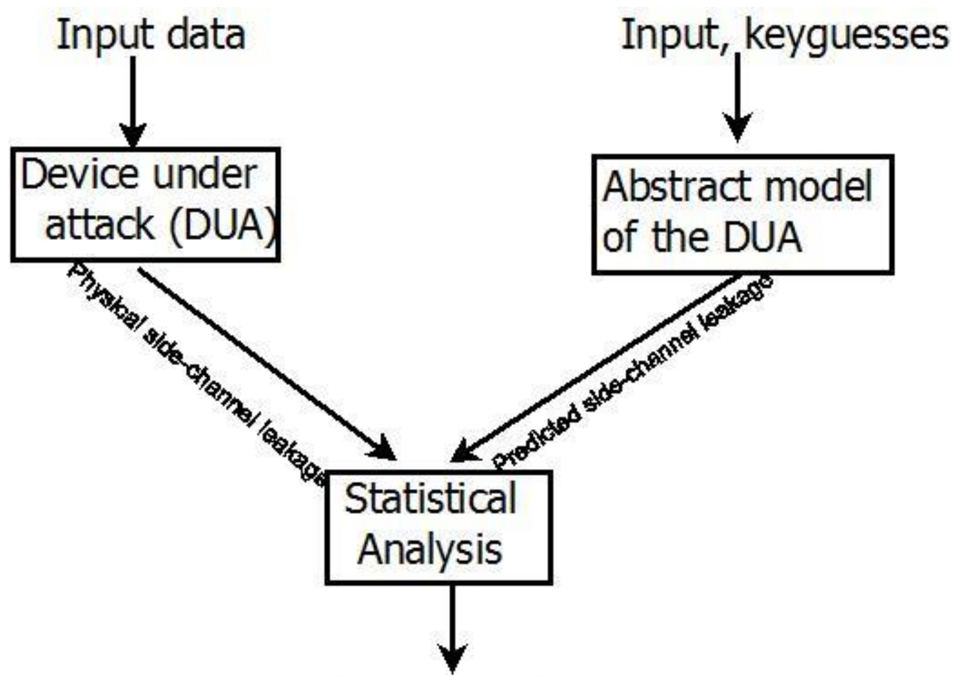
Average Power Overhead - ~ 200 μW

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: Mohanty 2019, IEEE TCE Under Review

Side Channel Attacks – Differential and Correlation Power Analysis (DPA/CDA)

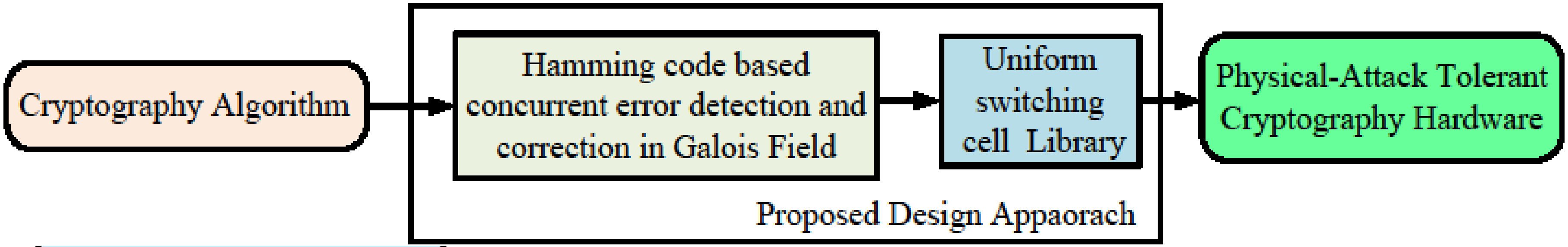


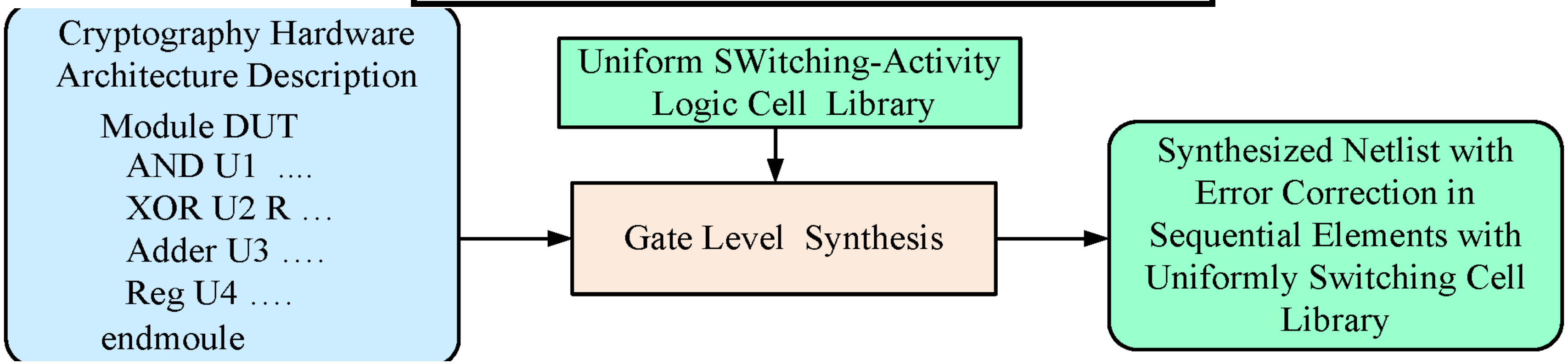


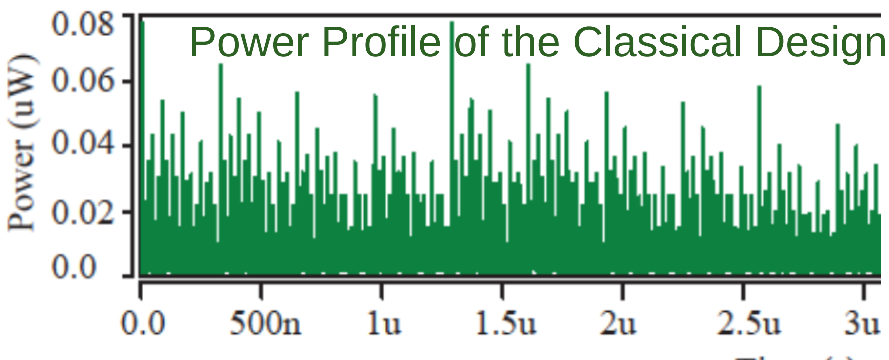
Decision on key guess

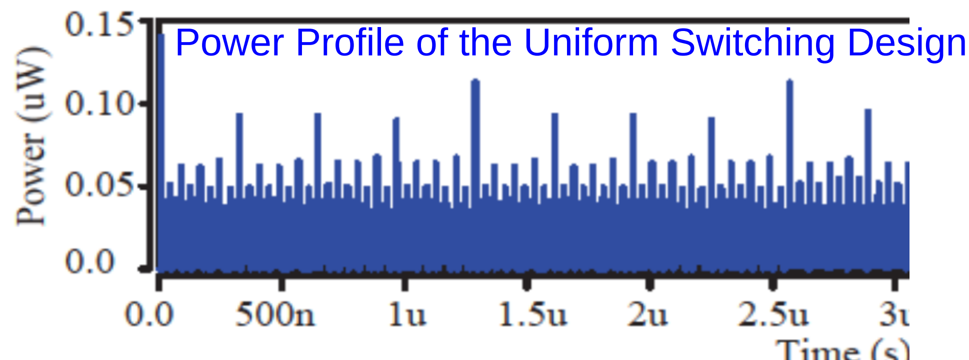
Source: Mohanty ICIT 2017 Keynote

DPA Resilience Hardware: Design



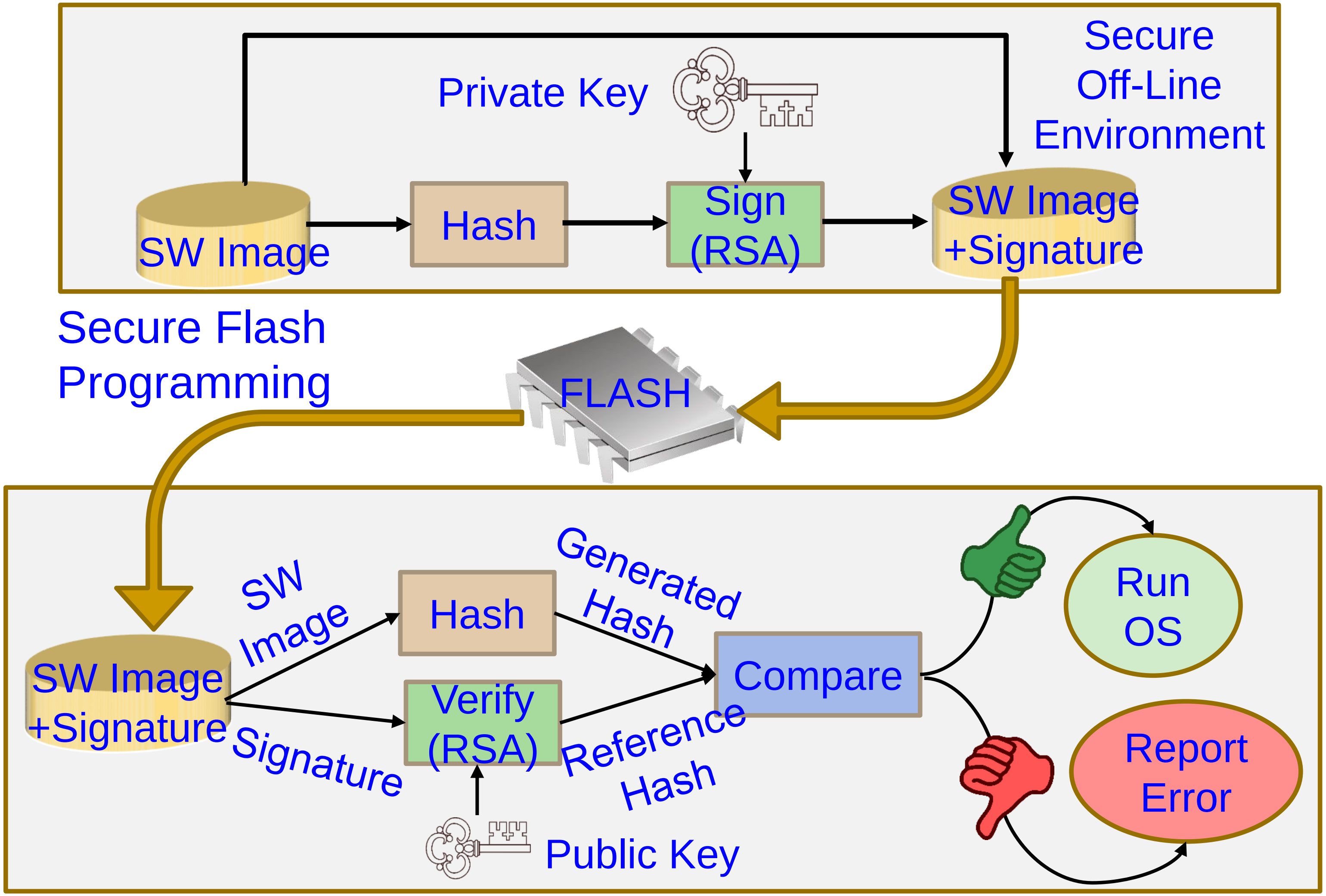






Source: J. Mathew, S. P. Mohanty, S. Banerjee, D. K. Pradhan, and A. M. Jabir, "Attack Tolerant Cryptographic Hardware Design by Combining Galois Field Error Correction and Uniform Switching Activity", Elsevier Computers and Electrical Engineering, Vol. 39, No. 4, May 2013, pp. 1077--1087.

Firmware Security



Source: https://www.nxp.com/docs/en/white-paper/AUTOSECURITYWP.pdf

Multimedia Piracy – Movie/Video

High

Studio

Cinema

On-line

Video on Demand

DVD/Blu-ray

Pay-TV Broadcasting

Free-to-Air Broadcasting

Low

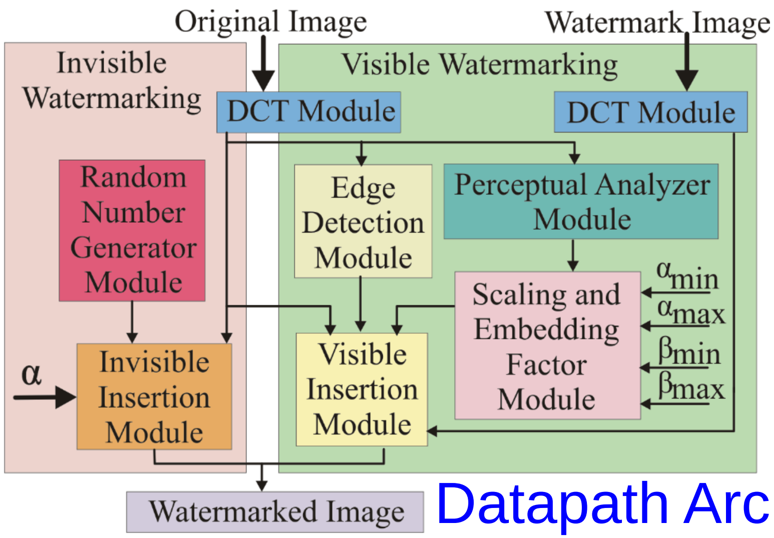
Piracy Threat Level

Blu-ray Disc™

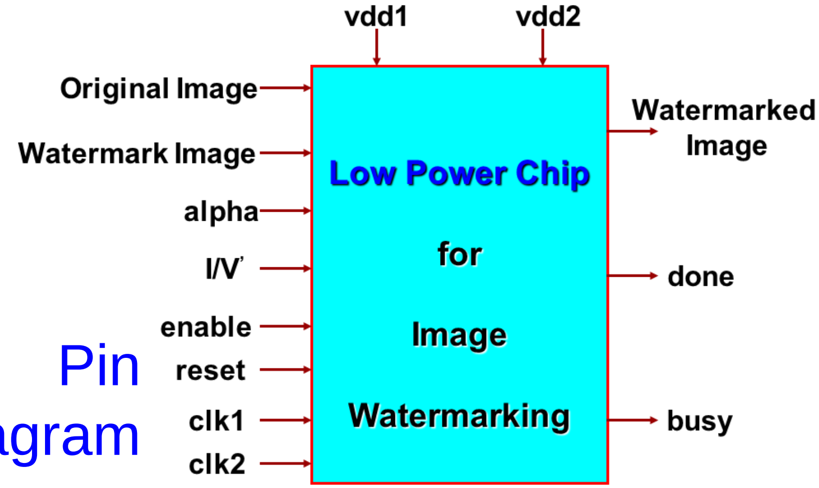
"Film piracy cost the US economy $20.5 billion annually."

Source: http://www.ipi.org/ipi_issues/detail/illegal-streaming-is-dominating-online-piracy

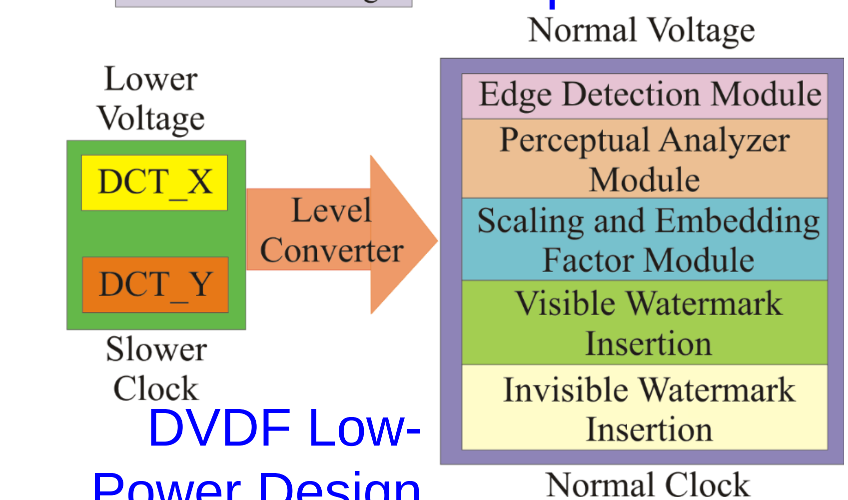
Copyright Protection Hardware



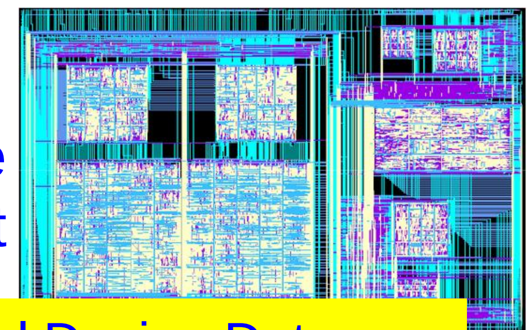
Datapath Architecture



Pin Diagram



DVDF Low-Power Design



Hardware Layout

Physical Design Data

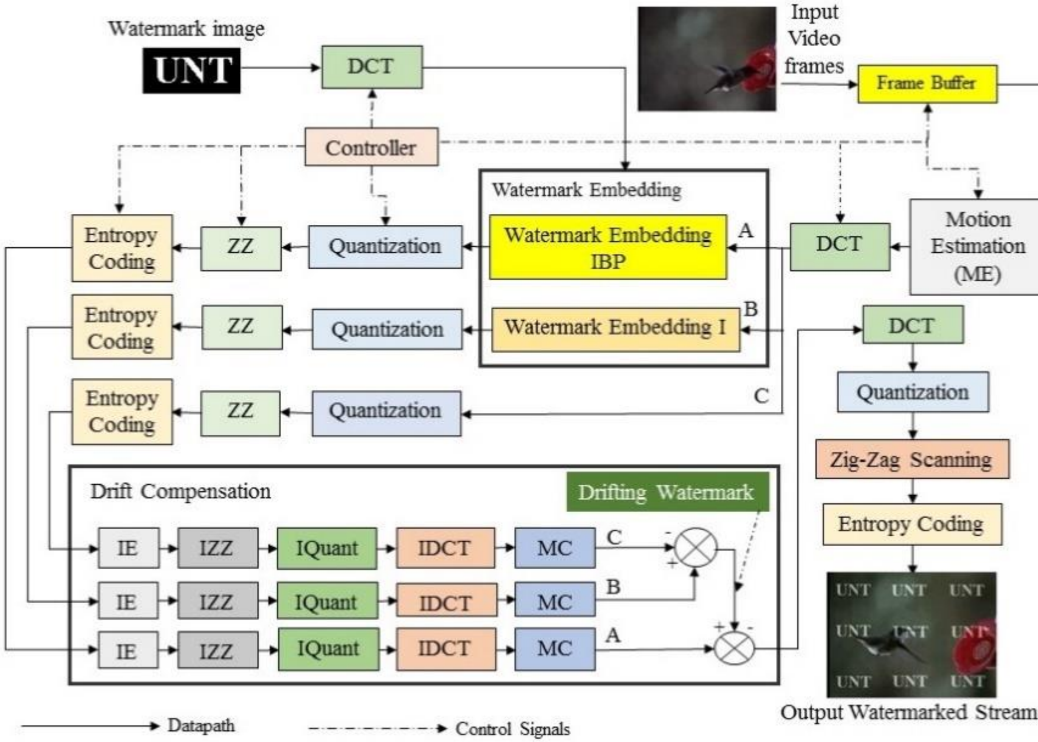
Total Area : 16.2 sq mm

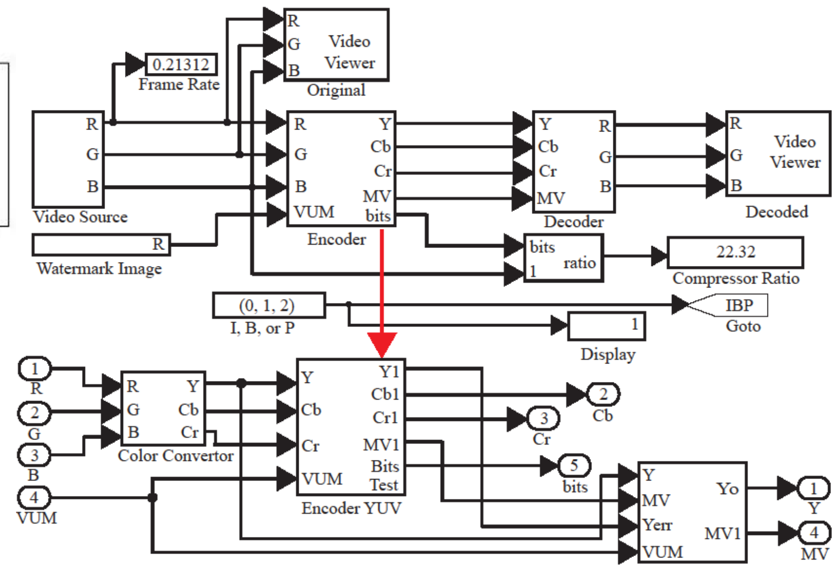
No. of Transistors: 1.4 million

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.

Copyright Protection Hardware – MPEG-4 Video Watermarking





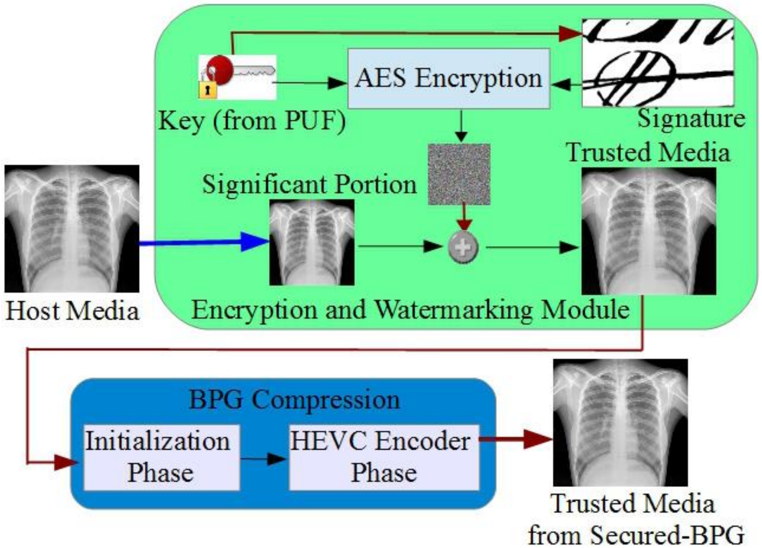
Video Watermarking Architecture: Simulink Model

Video Watermarking Architecture Datapath

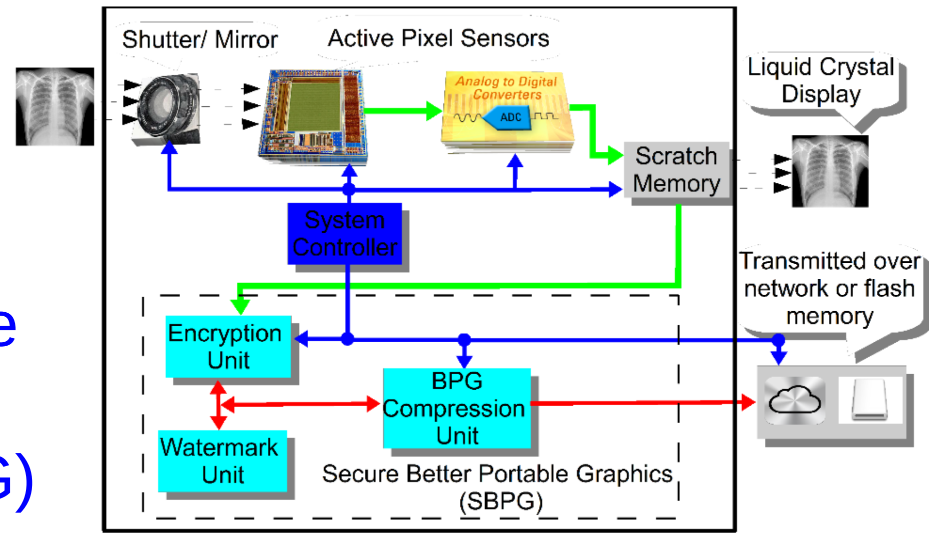
FPGA Prototyping
Throughput: 44 frames/sec
Logic Elements in Prototyping : 28322

Source: S. P. Mohanty and E. Kougianos, "Real-Time Perceptual Watermarking Architectures for Video Broadcasting", Elsevier Journal of Systems and Software (JSS), Vol. 84, No. 5, May 2011, pp. 724--738.

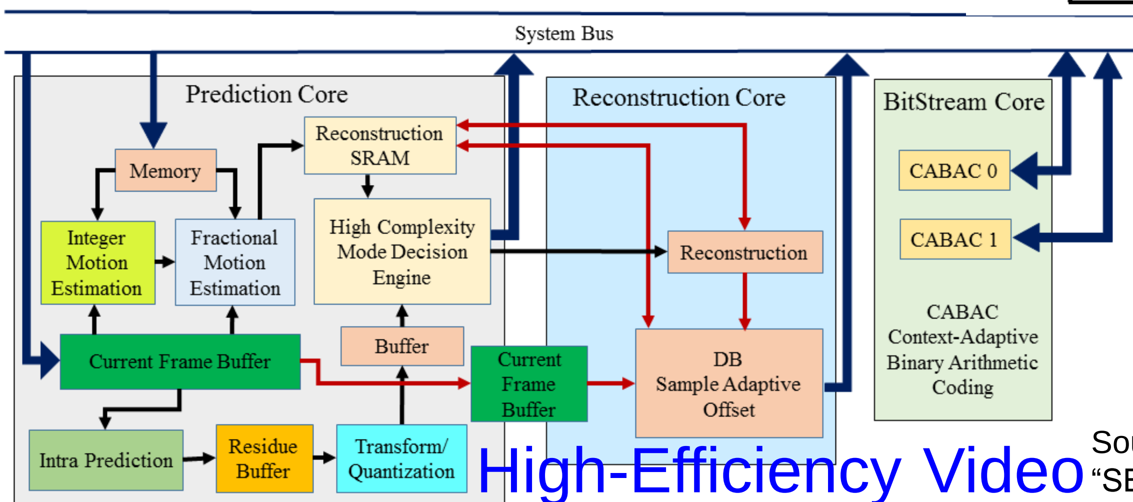
Secure Better Portable Graphics (SBPG)



Secure BPG (SBPG)



Secure Digital Camera (SDC) with SBPG

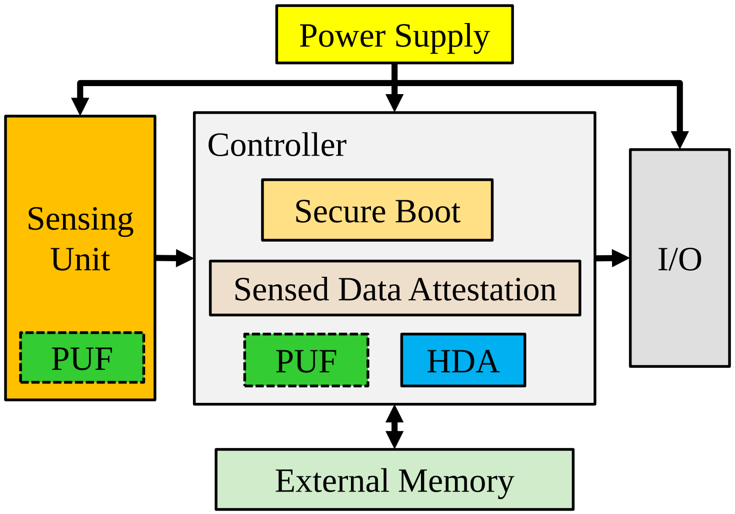


High-Efficiency Video Coding Architecture

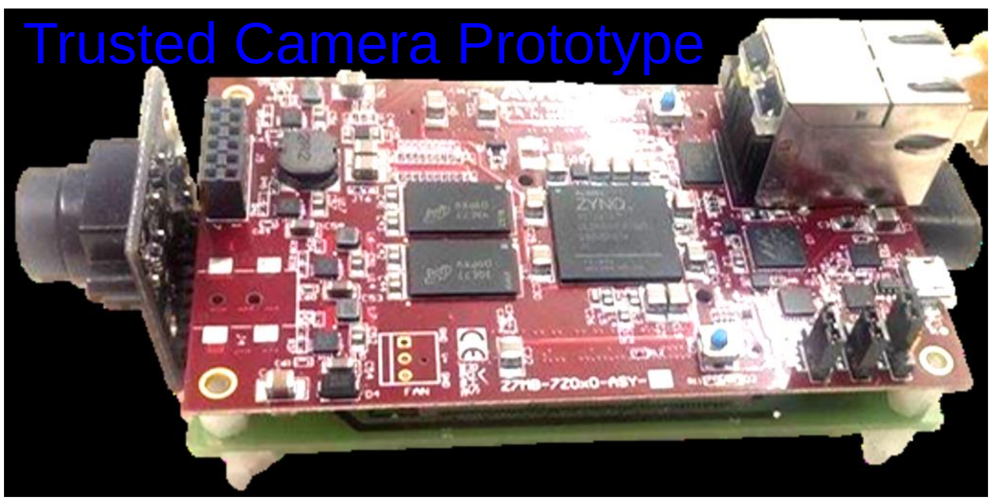
Simulink Prototyping
Throughput: 44 frames/sec
Power Dissipation: 8 nW

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.

PUF-based Trusted Sensor



PUF-based Trusted Sensor



Source: https://pervasive.aau.at/BR/pubs/2016/Haider_IOTPTS2016.pdf

PUF-based Secure Key Generation and Storage module provides key:

- Sensed data attestation to ensure integrity and authenticity.
- Secure boot of sensor controller to ensure integrity of the platform at booting.
  - ❖ On board SRAM of Xilinx Zynq7010 SoC cannot be used as a PUF.
  - ❖ A total 1344 number of 3-stage Ring Oscillators were implemented using the Hard Macro utility of Xilinx ISE.

Process Speed: 15 fps

Key Length: 128 bit

Hardware Reverse Engineering

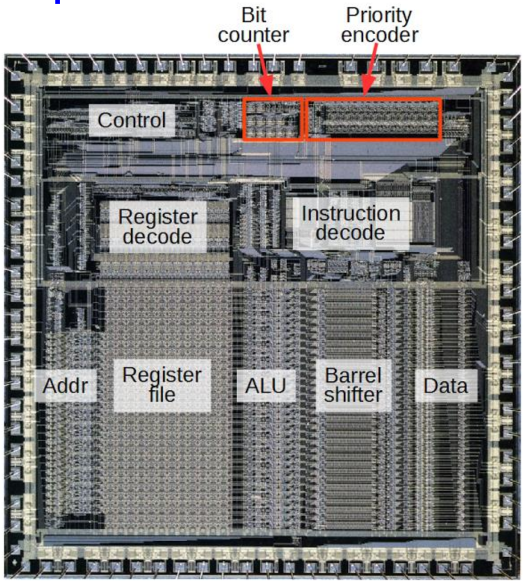
Source: http://legacy.lincolninteractive.org/html/CES%20Introduction%20to%20Engineering/Unit%203/u3l7.html

CE System disassembly
Subsystem identification, modification

Source: https://www.slideshare.net/SOURCEConference/slicing-into-apple-iphone-reverse-engineering

Source: http://grandideastudio.com/wp-content/uploads/current_state_of_hh_slides.pdf

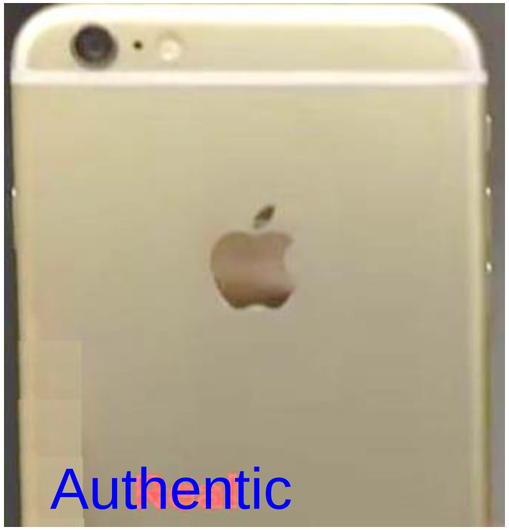
Chip-Level Modification



Source: http://pic-microcontroller.com/counting-bits-hardware-reverse-engineering-silicon-arm1-processor/

Cloned/Fake Electronics Hardware – Example - 1

Source: https://petapixel.com/2015/08/14/i-bought-a-fake-nikon-dslr-my-experience-with-gray-market-imports/

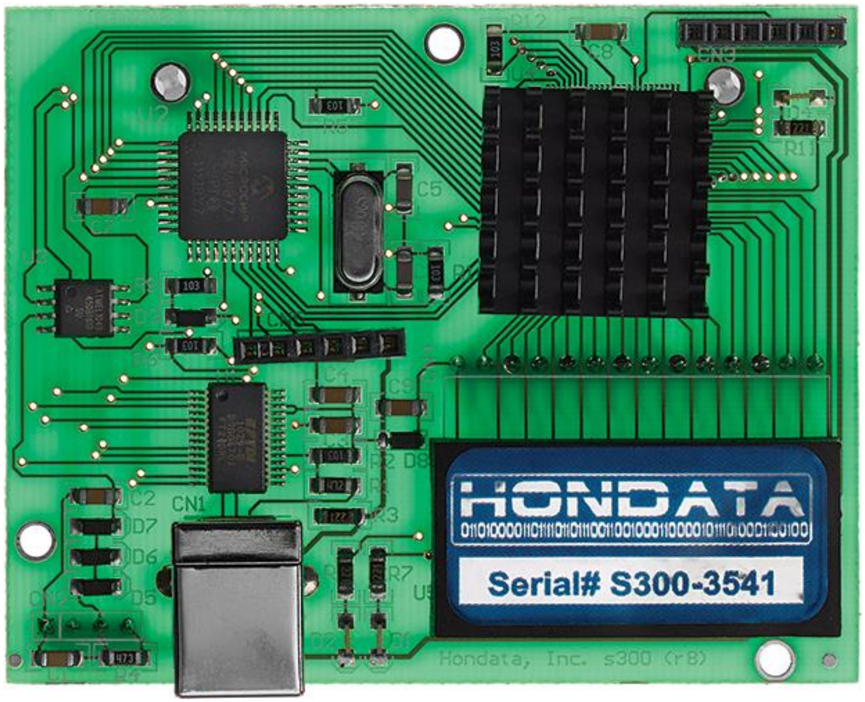


Source: http://www.manoramaonline.com/

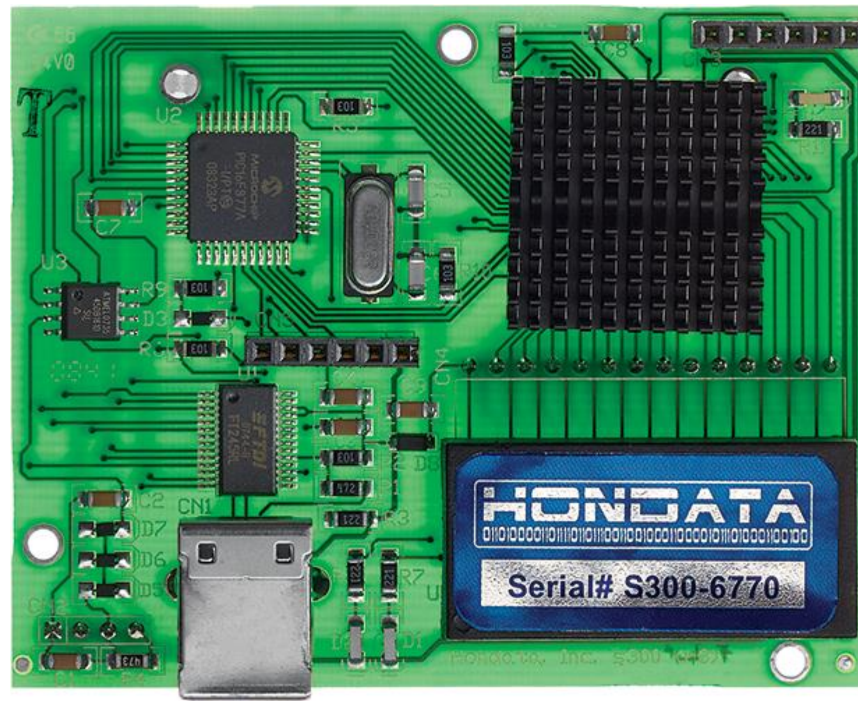
Source: http://www.cbs.cc/fake-capacity-usb-drives/

Typical Consumer Electronics

Cloned/Fake Electronics Hardware – Example - 2



Fake



Authentic

A plug-in for car-engine computers.

Source: http://spectrum.ieee.org/computing/hardware/invasion-of-the-hardware-snatchers-cloned-electronics-pollute-the-market

Cloned/Fake Electronics Hardware – Example - 3

Fake

Authentic

A typical rechargeable battery in a typical CE

Source: https://www.premiumbeat.com/blog/how-to-spot-counterfeit-camera-gear/

Cloned/Fake Electronics Hardware - What is the Problem? It is cheaper!

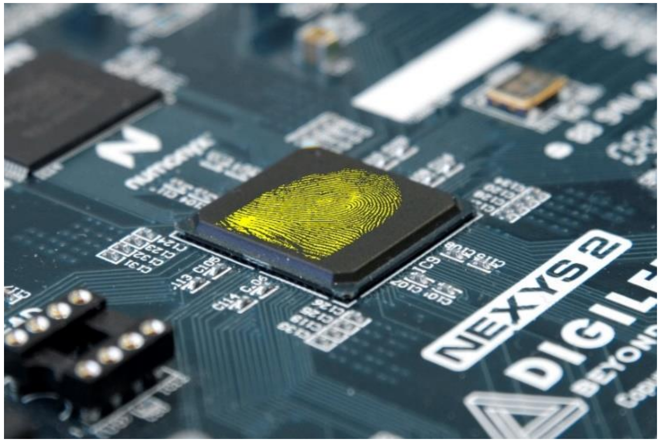
- Installing cloned hardware into networks can open door to hackers: man-in-the-middle attacks or secretly alter a secure communication path between two systems to bypass security mechanisms.
- Cloned hardware may lack the security modules intended to protect IoT devices, and so it opens up the user to cyberattack.
- If a hacker embeds a malicious hardware in a drone then he could shut it down or retarget it when it reached preset GPS coordinates.

Source: https://www.scientificamerican.com/article/electronic-chip-counterfeit-china/

Source: http://spectrum.ieee.org/computing/hardware/invasion-of-the-hardware-snatchers-cloned-electronics-pollute-the-market

Protecting Hardware using PUF

- A countermeasure against electronics cloning is a physical unclonable function (PUF).
- It can potentially protect chips, PCBs, and even high-level products like routers.
- PUFs give each chip a unique “fingerprint.”



Source: https://phys.org/news/2011-02-fingerprint-chips-counterfeit-proof.html

An on-chip measuring circuit (e.g. a ring oscillator) can generate a characteristic clock signal which allows the chip’s precise material properties to be determined. Special electronic circuits then read these measurement data and generate the component-specific key from the data.

Source: http://spectrum.ieee.org/computing/hardware/invasion-of-the-hardware-snatchers-cloned-electronics-pollute-the-market

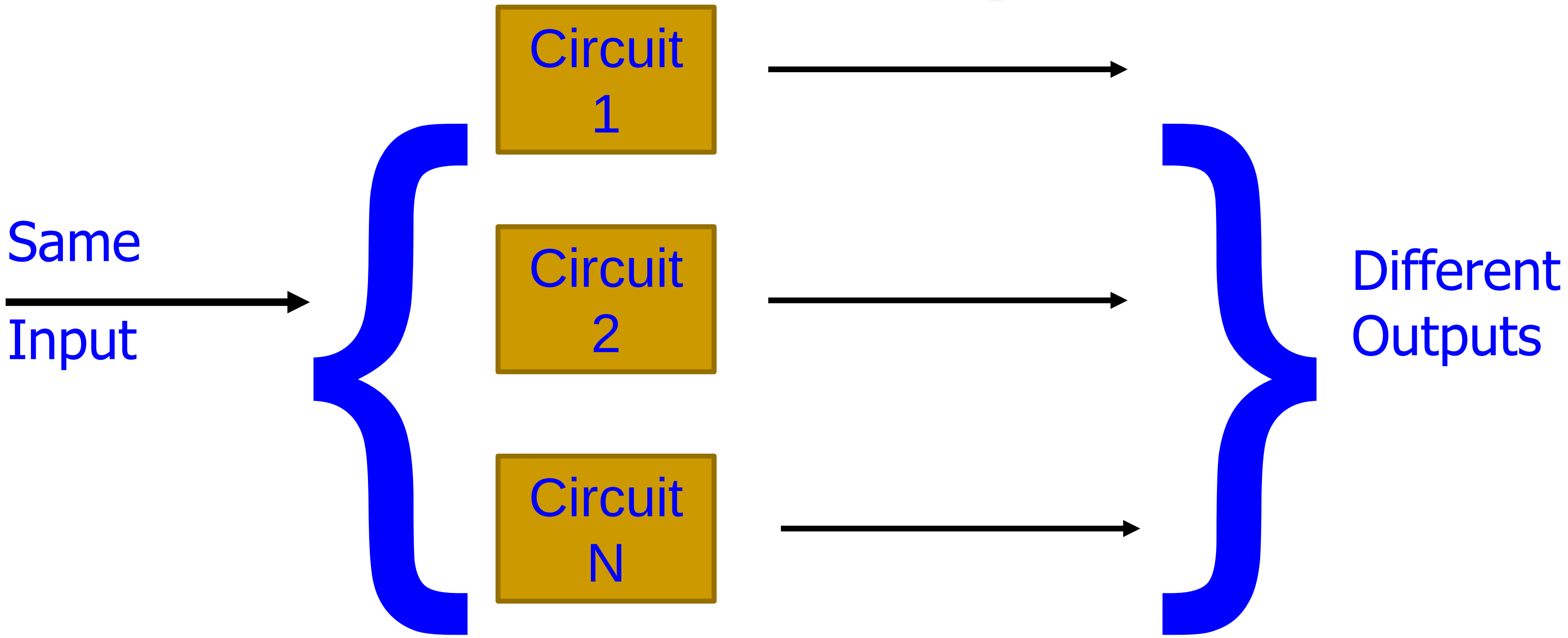
Physical Unclonable Function (PUF)

- Physical Unclonable Functions are simple primitives for security.
- PUFs are easy to build and impossible to duplicate (Theoretically).
- Input and Output are called Challenge Response Pair (CRP).

Source: V. P. Yanambaka, S. P. Mohanty, and E. Kougianos, “Making Use of Manufacturing Process Variations: A Dopingless Transistor Based-PUF for Hardware-Assisted Security”, IEEE Transactions on Semiconductor Manufacturing (TSM), Volume 31, Issue 2, May 2018, pp. 285--294.

Only an authentic hardware can produce a correct Response for a Challenge.

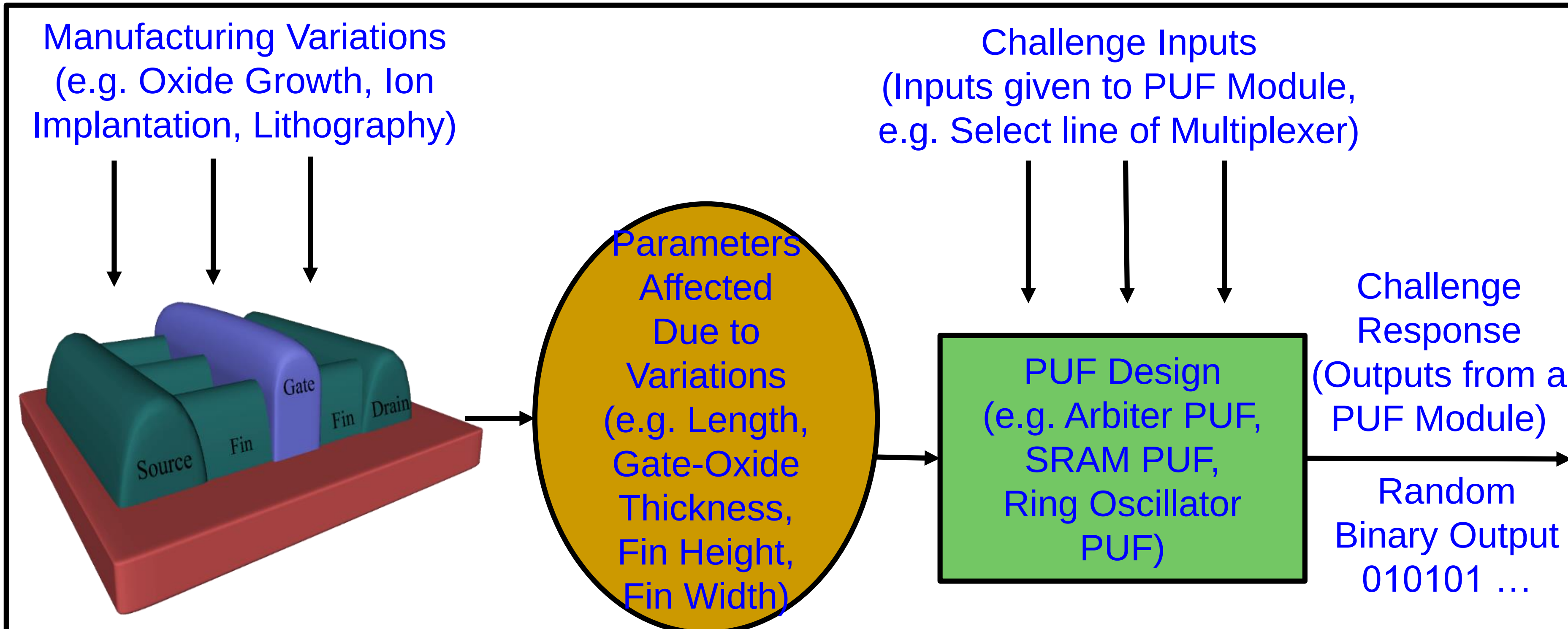
PUF - Principle



- With the same input to different copies of the same circuit, different outputs are obtained, each unique to each circuit.

Source: V. P. Yanambaka, S. P. Mohanty, and E. Kougianos, “Making Use of Manufacturing Process Variations: A Dopingless Transistor Based-PUF for Hardware-Assisted Security”, IEEE Transactions on Semiconductor Manufacturing (TSM), Volume 31, Issue 2, May 2018, pp. 285--294.

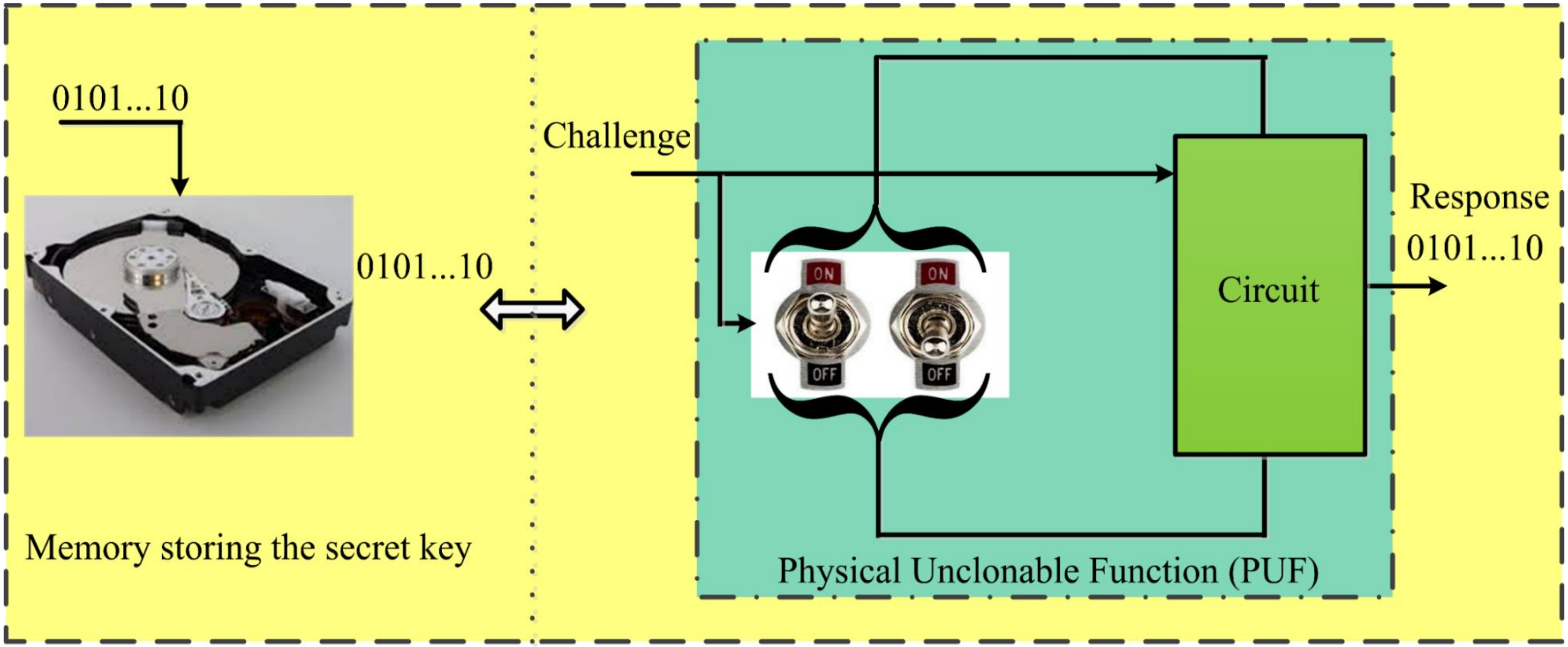
Physical Unclonable Function (PUF) - Principle



Silicon manufacturing process variations are turned into a feature rather than a problem.

Source: V. P. Yanambaka, S. P. Mohanty, and E. Kougianos, "Making Use of Semiconductor Manufacturing Process Variations: FinFET-based Physical Unclonable Functions for Efficient Security Integration in the IoT", Springer Analog Integrated Circuits and Signal Processing Journal, Volume 93, Issue 3, December 2017, pp. 429--441.

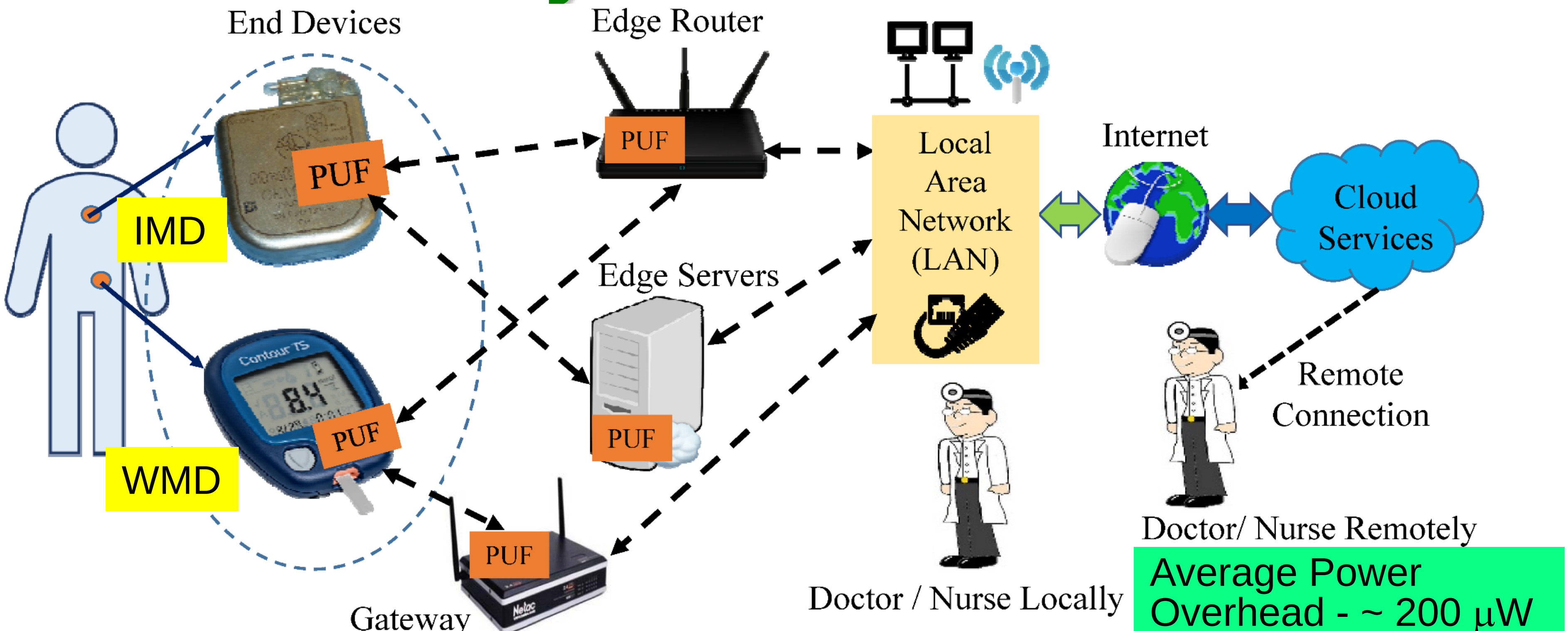
Security Primitives - PUF



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.

IoMT Security - PUF based Device Authentication



Average Power Overhead - ~ 200 μW

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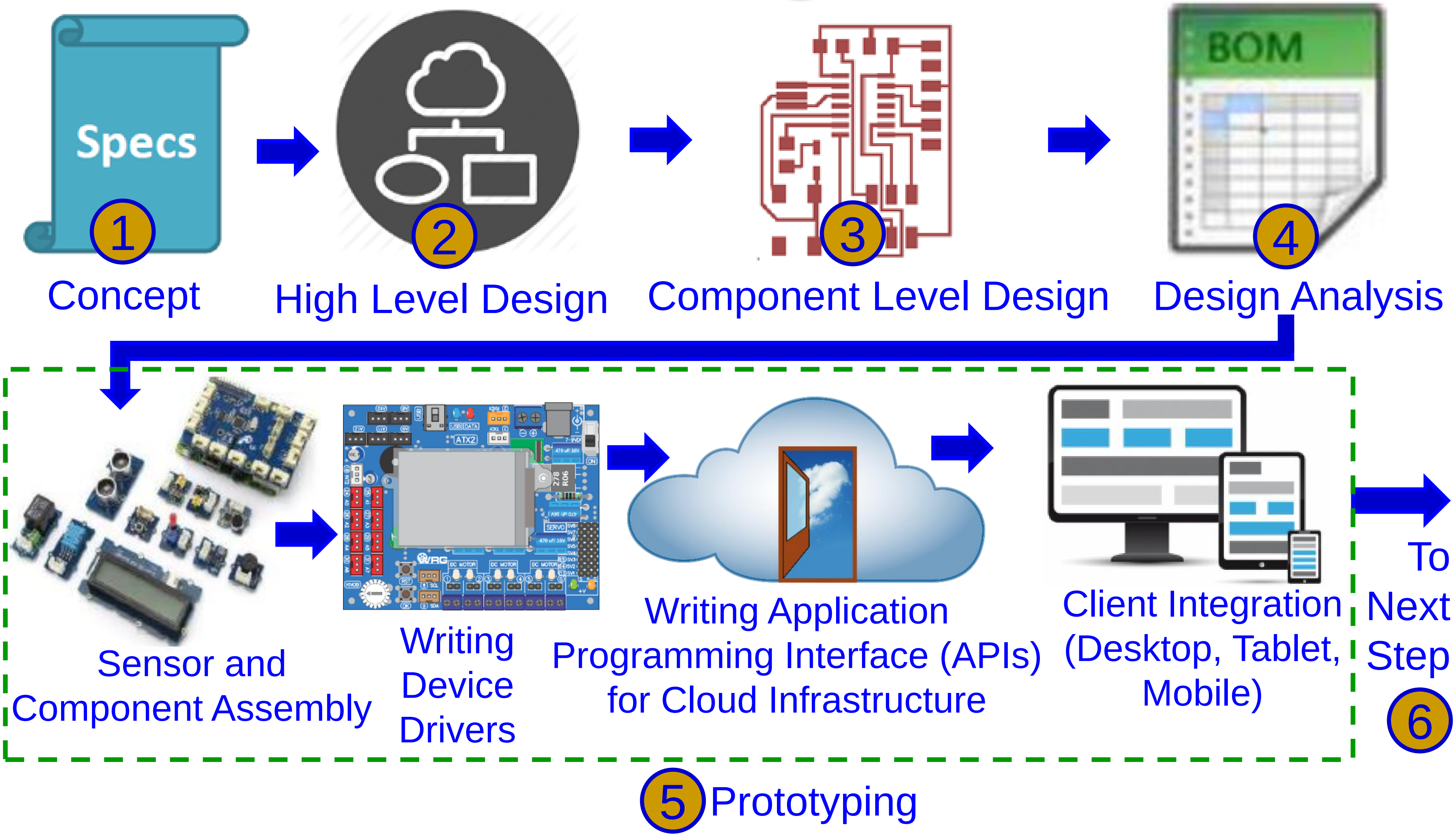
Time to Generate the Key at IoMT Device	800 ms
Time to Authenticate the Device	1.2 sec - 1.5 sec

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.

IoT Design Flow

IoT – Design Flow



Source: http://events.linuxfoundation.org/sites/events/files/slides/Design%20-%20End-to-End%20%20IoT%20Solution%20-%20Shivakumar%20Mathapathi.pdf

IoT – Design Flow

6 Field Testing

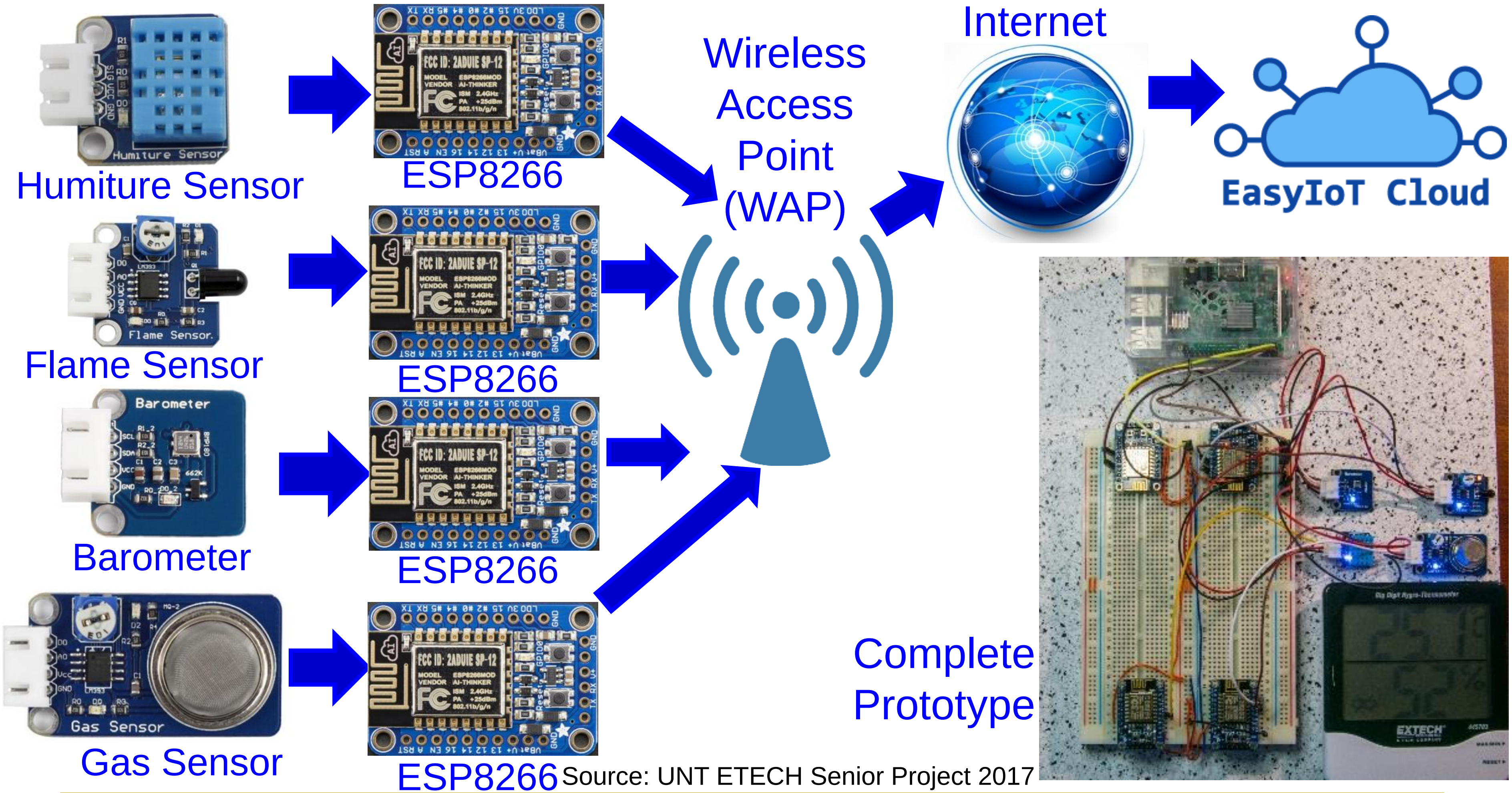
7 Release of Beta Version

8 Production

9 Release and Documentation

Source: http://events.linuxfoundation.org/sites/events/files/slides/Design%20-%20End-to-End%20%20IoT%20Solution%20-%20Shivakumar%20Mathapathi.pdf

IoT Design – Case Study – Indoor Air Quality Monitoring



Source: UNT ETECH Senior Project 2017

Hardware for IoT

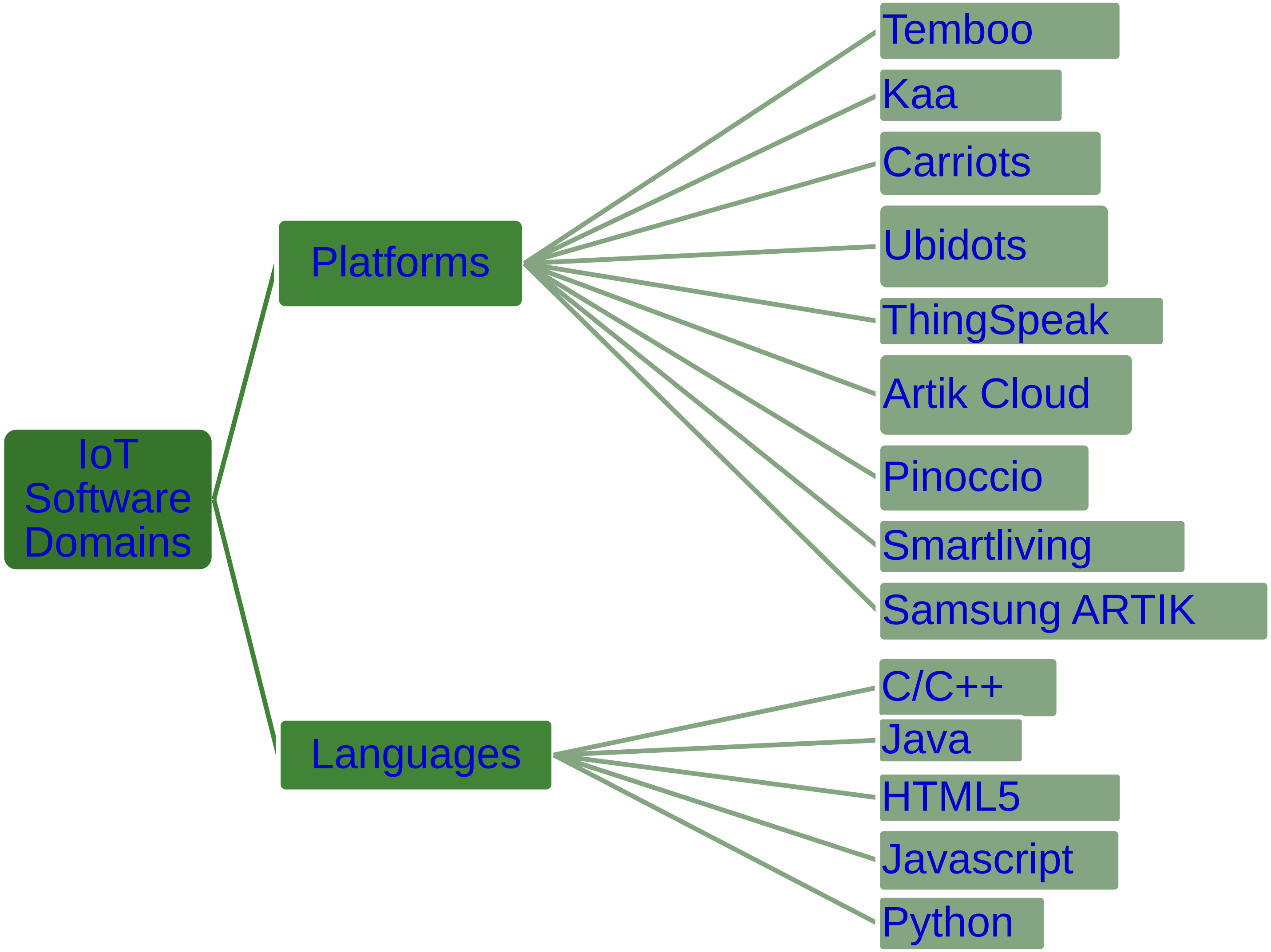
IoT Hardware Domains

- Embedded Systems and Boards (e.g. Arduino Yun, Raspberry Pi, BeagleBone, Samsung ARTIK)
- Wearable Devices and Gadgets (e.g. Samsung Gear 2, FitBit Flex, FLORA, iWallet)

Features	Processor/Microcontroller	Graphics Processing Unit	Clock Speed	Size	Memory	RAM	Supply Voltage	Listed Price
SparkFun Blynk Board	Tensilica L106 32-b	No	26 MHz	51 mm x 42 mm	4 MB	128 KB	5 V via micro-USB/ Li-Po connector and charging circuit	US$29.95
Arduino Yun	ATmega32u4 and Atheros AR9331 (for Linux)	No	16 MHz and 400 MHz	73 mm x 53 mm	32 KB and 16 MB + micro-SD	64 MB DDR2	5 V via micro-USB	US$58
Raspberry Pi 3	Broadcom BCM2837 and ARM Cortex-A53 64-b Quad Core	VideoCore IV @ 300/400 MHz	1.2 GHz	85 mm x 56 mm	Micro-SD	1 GB LPDDR2	5 V via micro-USB	US$35
cloudBit	Freescale i.MX233 (ARM926EJ-S core)	No	454 MHz	55 mm x 19 mm	Micro-SD slot with 4-GB micro-SD	64 MB	5 V via micro-USB	US$59.95
Photon	STM32F205 120Mhz ARM Cortex M3	No	120 MHz	36.5 mm x 20.3 mm	1 MB	128 KB	5 V via micro-USB	US$19
BeagleBone Black	AM335x ARM Cortex-A8	PowerVR SGX530	1 GHz	86 mm x 56 mm	4 GB 8-b eMMC, micro-SD	512 MB DDR3	5 V via mini-USB	US$49
Pinoccio	ATmega256RFR2	No	16 MHz	70 mm x 25 mm	256 KB	32 KB	5 V via micro-USB/ Li-Po connector and charging circuit	US$109
UDOO	Freescale i.MX 6 ARM Cortex-A9 and Atmel SAM3X8E ARM Cortex-M3	Vivante GC 2000 for 3-D + GC 355 for 2-D (vector graphics) + GC 320 for 2-D	1 GHz	110 mm x 85 mm	Micro-SD	1 GB DDR3	12 V	US$135
Samsung Artik 10	ARM A15x4 and A7x4	Mali-T628 MP6 core	1.3 GHz and 1.0 GHz	39 mm x 29 mm	16 GB	2 GB LPDDR3	3.4–5 V	US$100

Source: Singh 2017, CE Magazine, April 2017

Software for IoT



Source: Singh 2017, CE Magazine, April 2017

IoT - Design & Simulation Challenges

- Traditional controllers and processors do not meet IoT requirements, such as multiple sensor, communication protocol, and security requirements.
- Existing tools are not enough to meet challenges such as time-to-market, complexity, cost of IoT.
- Can a framework be developed for simulation, verification, and optimization:
  - of individual (multidiscipline) "Things"
  - of IoT Components
  - of IoT Architecture

IoT Simulators

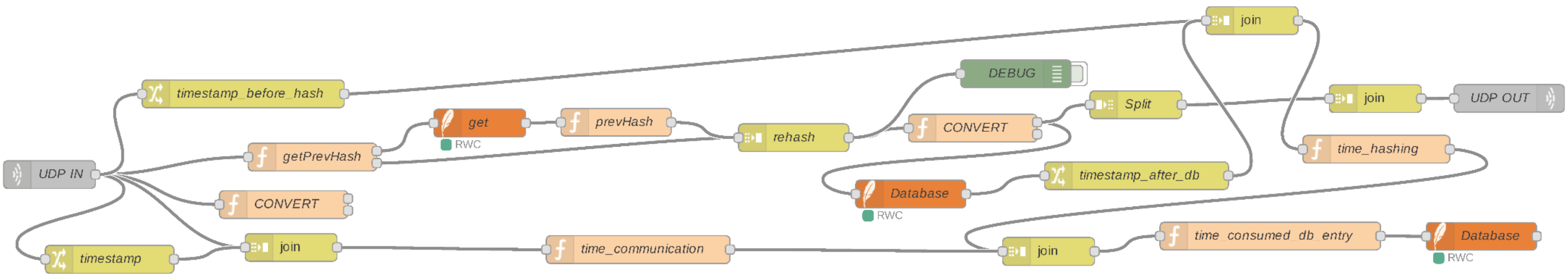
Selected IoT Simulators

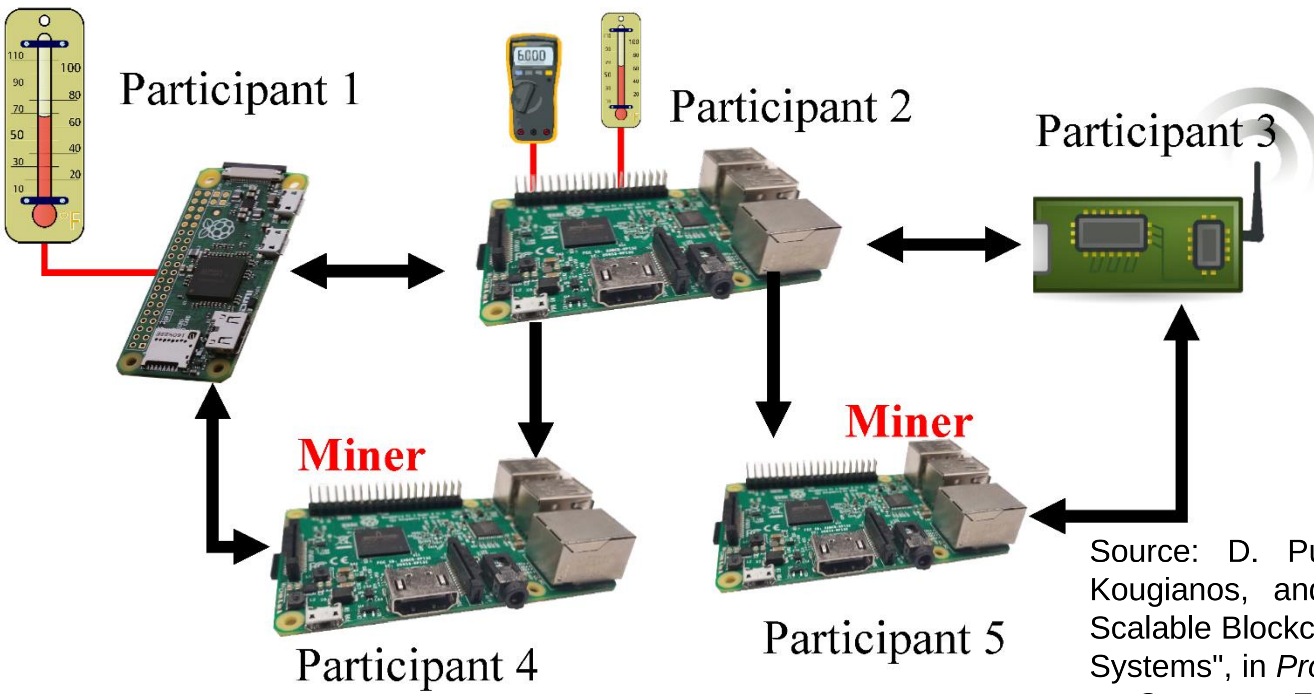
- Bevywise IoT Simulator
- CupCarbon
- IoTIFY
- Meshify
- Node-RED
- NetSim
- SimpleIoTSimulator

IoT Simulators - Node-RED

- **About**:
  - Node-RED is a flow-based IoT Simulator.
  - It is a programming tool for wiring together hardware devices, APIs and online services in new ways.
  - The light-weight runtime is built on Node.js, taking full advantage of its event-driven, non-blocking model.
- **Editor**:
  - Browser-based editor.
  - The flows created in Node-RED are stored using JSON which can be easily imported and exported for sharing with others.
- **Advantages**:
  - Available for smaller computing devices such as Raspberry Pi.
  - It takes moments to create cloud applications that combine services from across the platform.

IoT Simulators - Node-RED - Example





Simulation: Proof-of-Authentication (PoAh) based IoT Friendly Blockchain

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. of 37th IEEE International Conference on Consumer Electronics (ICCE)*, 2019.

IoT Simulators - SimpleIoTSimulator

- About:
  - SimpleIoTSimulator is an IoT Sensor/device simulator that quickly creates test environments made up of thousands of sensors and gateways, all on just one computer.

IoT Simulators - Meshify

- About:
  - Meshify offers industrial IoT solutions. It helps to monitor, analyze, control, & track your devices.
  - It was founded in 2011 with the goal of making IoT more accessible.
- Services:
  - Hardware Selection & Implementation
  - UI/UX Design & development
  - Seasoned Integrations Team
  - End-to-end Architecture design
  - Professional Project Management

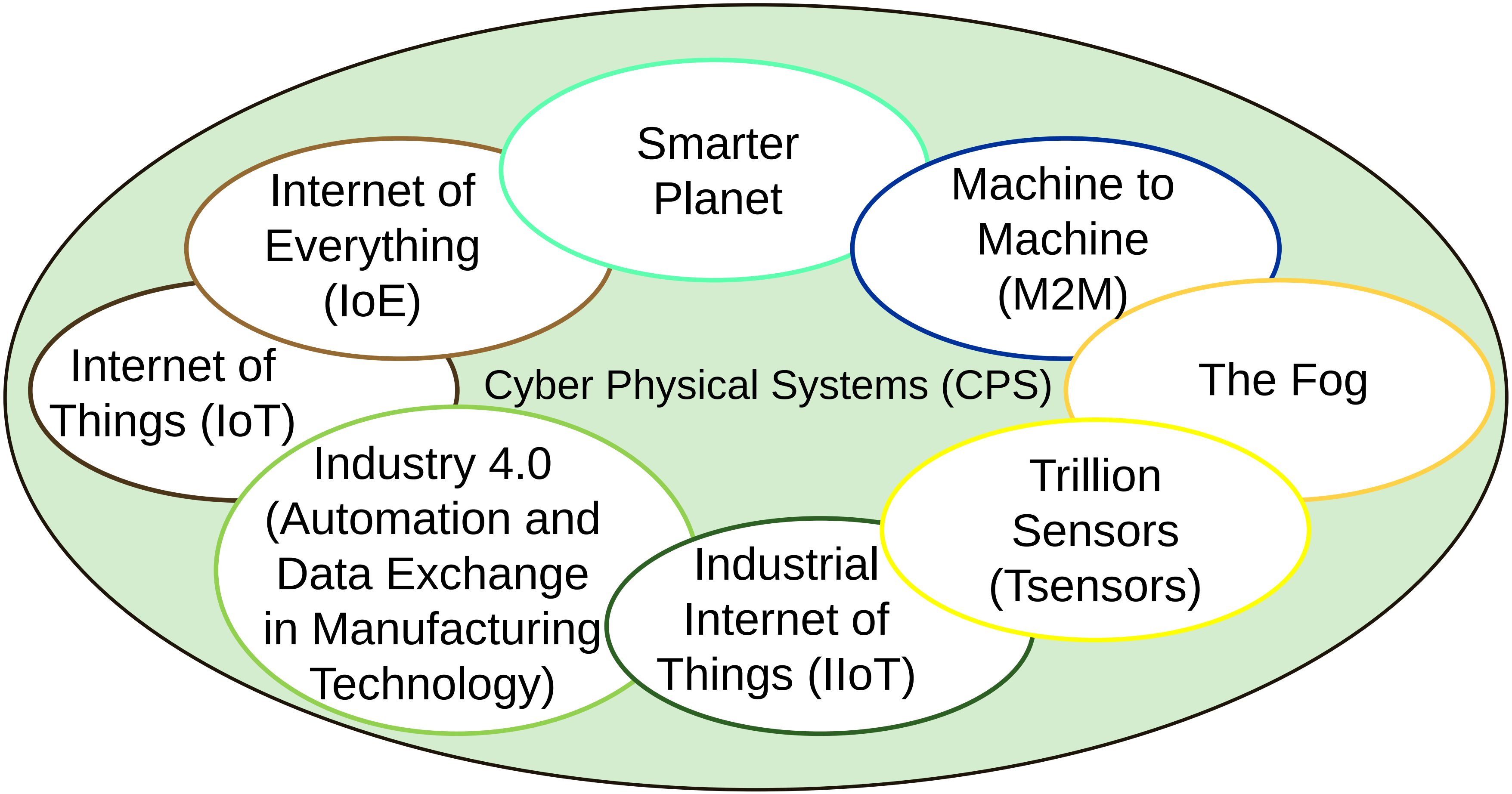
IoT Simulators – Observations

- IoT does not have a one-size-fits-all solution.
- IoT solutions often require pulling together different device APIs and online services in new and interesting ways.
- It is a multi-disciplinary domain and everyone cannot master everything.
- Tools that make it easier for developers at all levels, are always in demand.

Related Buzzwords

Smart Electronic Systems Laboratory (SESL)

Some related Buzzwords



Source: Sangiovanni-Vincentelli 2016, ISC2 2016

IoT Vs Sensor Networks

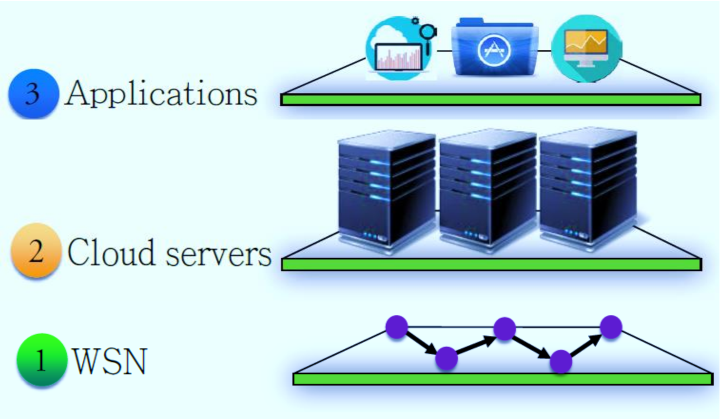
Wireless Sensor Networks (WSN)

- WSN is like the eyes and ears of the IoT.
- Anetwork of small wireless electronic nodes which consists of different sensors.
- The purpose is to collect data from the environment.

IoT adds value to data!

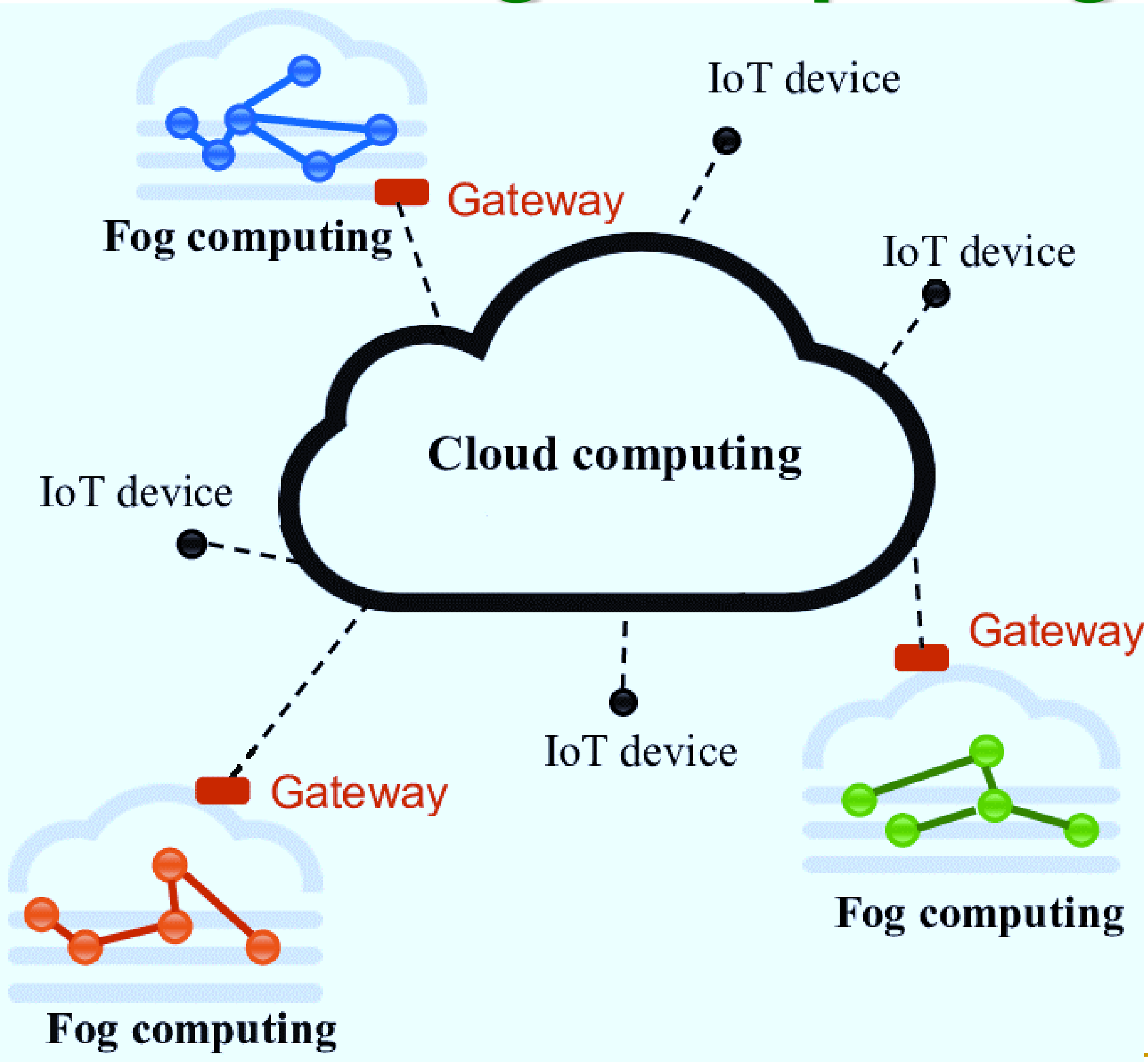
IoT

- IoT in a broad sense is like a brain.
- Store both real world data and can also be used to monitor the real world parameters and give meaningful interpretation.



Source: Nia 2017, IEEE TETC 2017

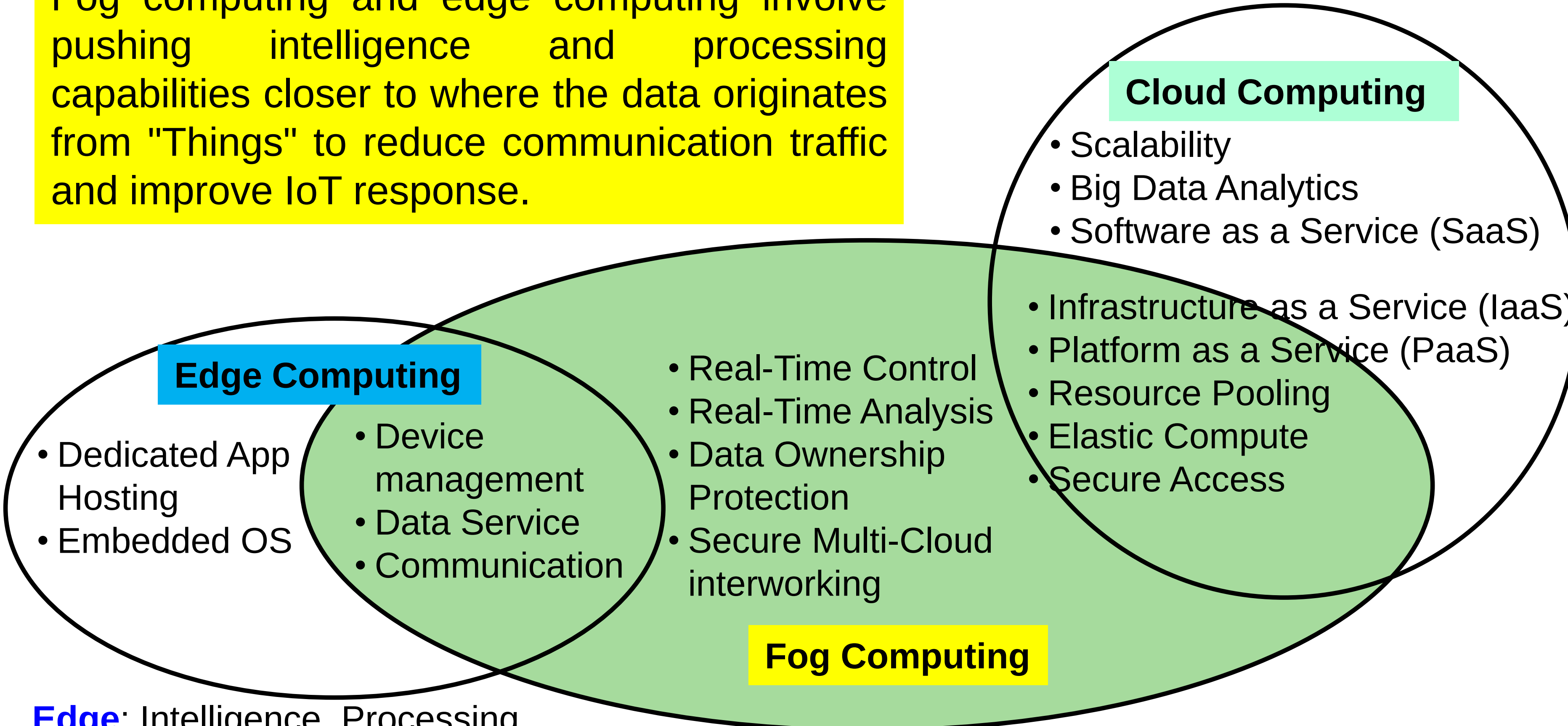
IoT Vs Fog Computing



Source: https://www.researchgate.net/figure/311918306_fig1_Fig-1-High-level-architecture-of-Fog-and-Cloud-computing

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.



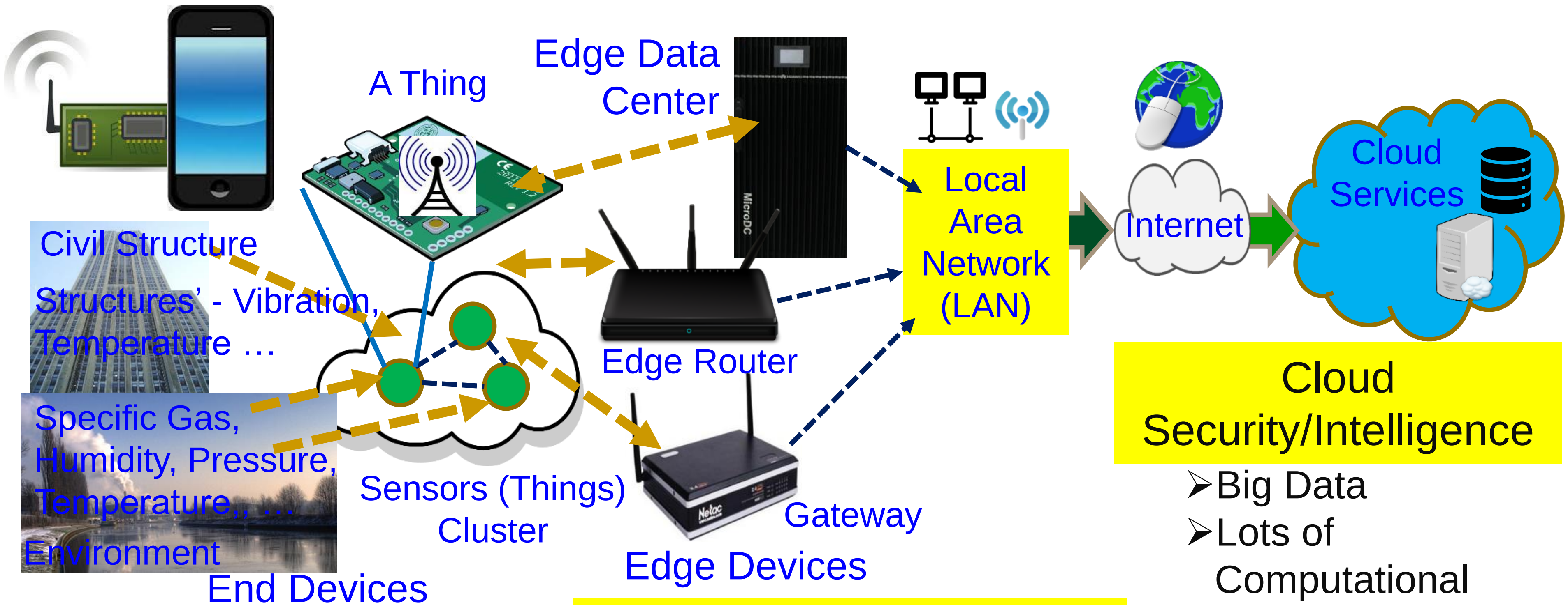
Edge: Intelligence, Processing, and Communication - Devices like Programmable Automation Controllers (PACs)

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 …



End Security/Intelligence

- Minimal Data
- Minimal Computational Resource
- Least Accurate Data Analytics
- Very Rapid Response

Edge Security/Intelligence

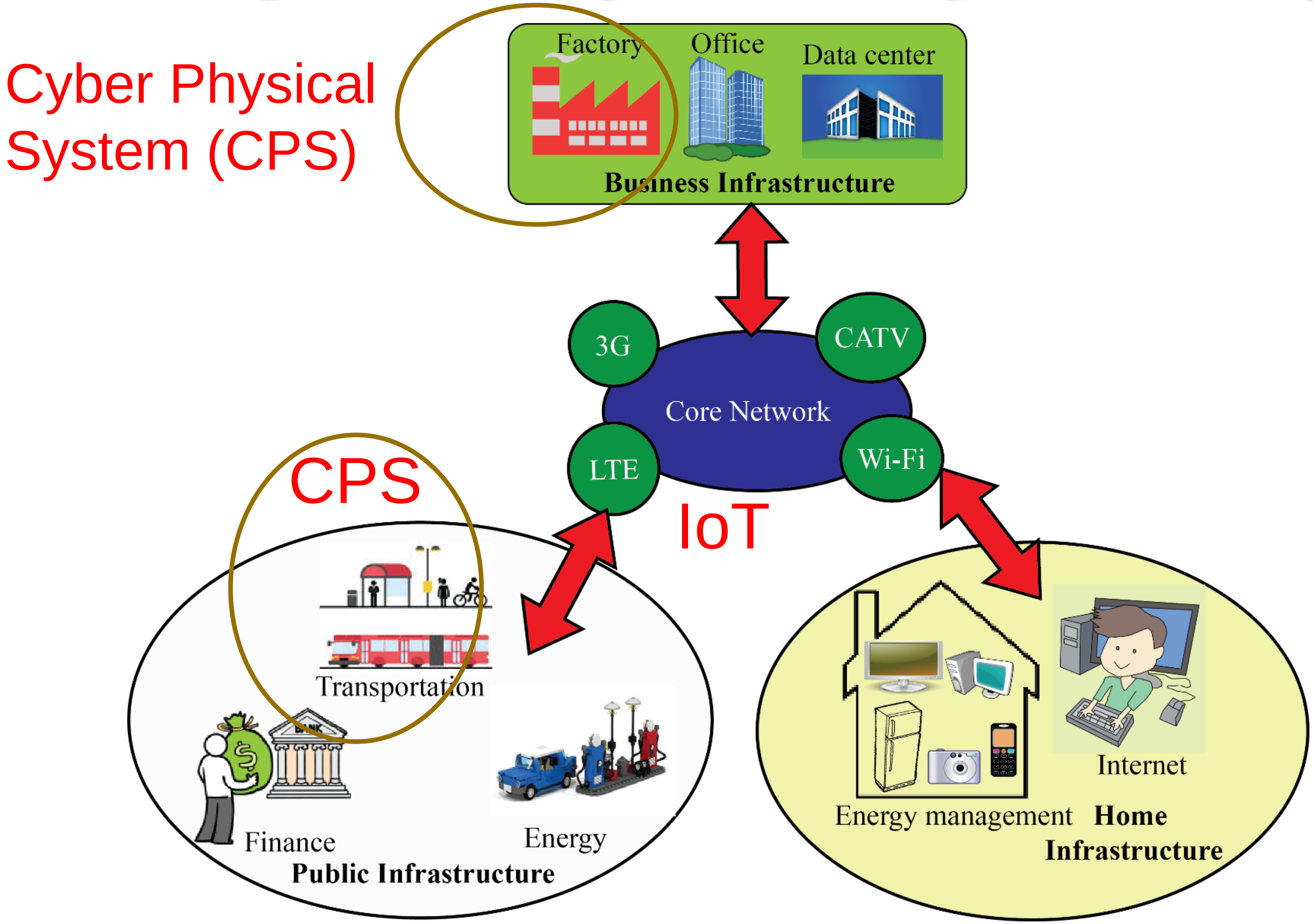
- Less Data
- Less Computational Resource
- Less Accurate Data Analytics
- Rapid Response

Cloud Security/Intelligence

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

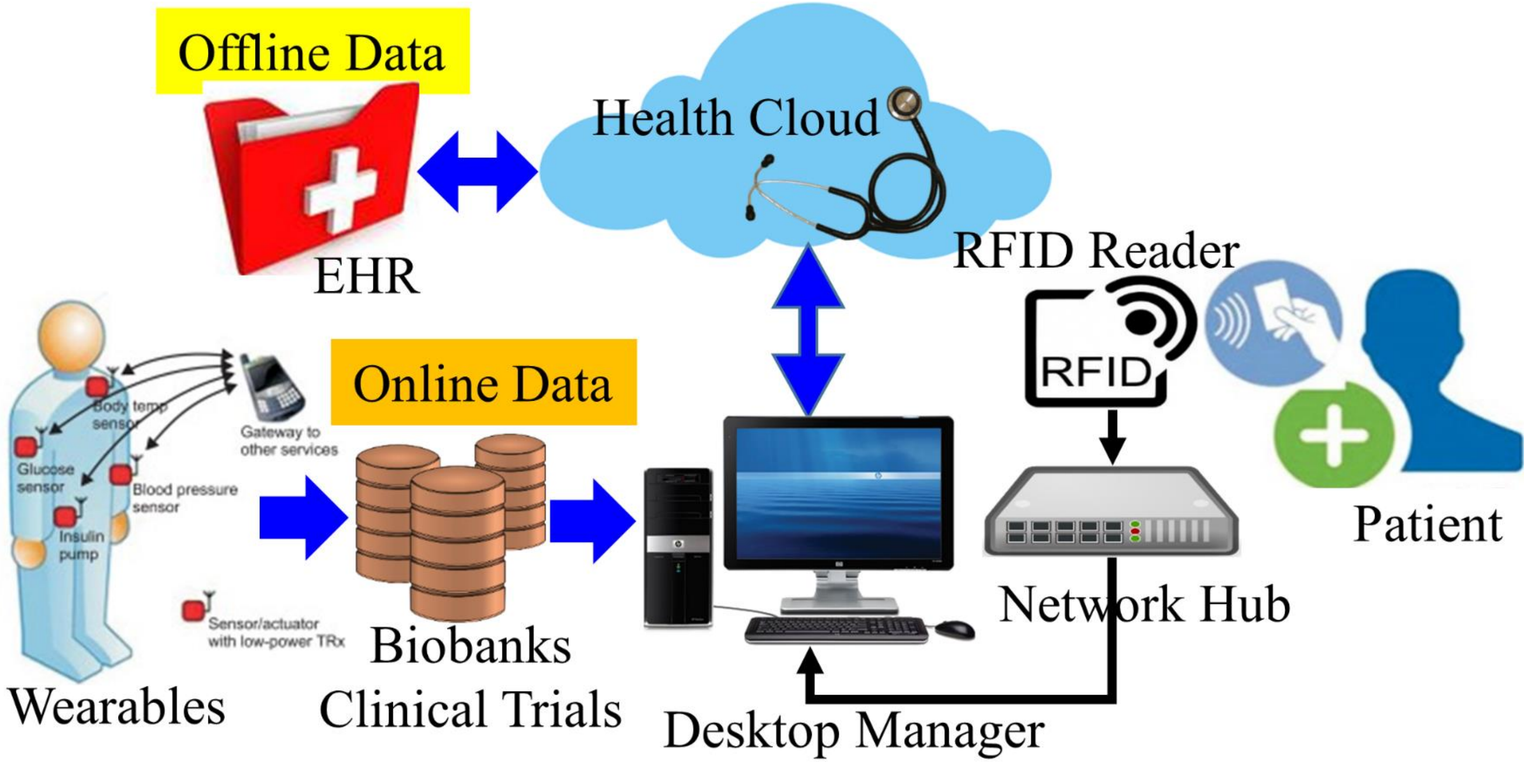
Source: Mohanty iSES Keynote 2018 and ICCE 2019 Panel

IoT Vs Cyber Physical Systems (CPS)



Source: Mohanty 2016, CE Magazine July 2016

Internet of Medical Things (IoMT)



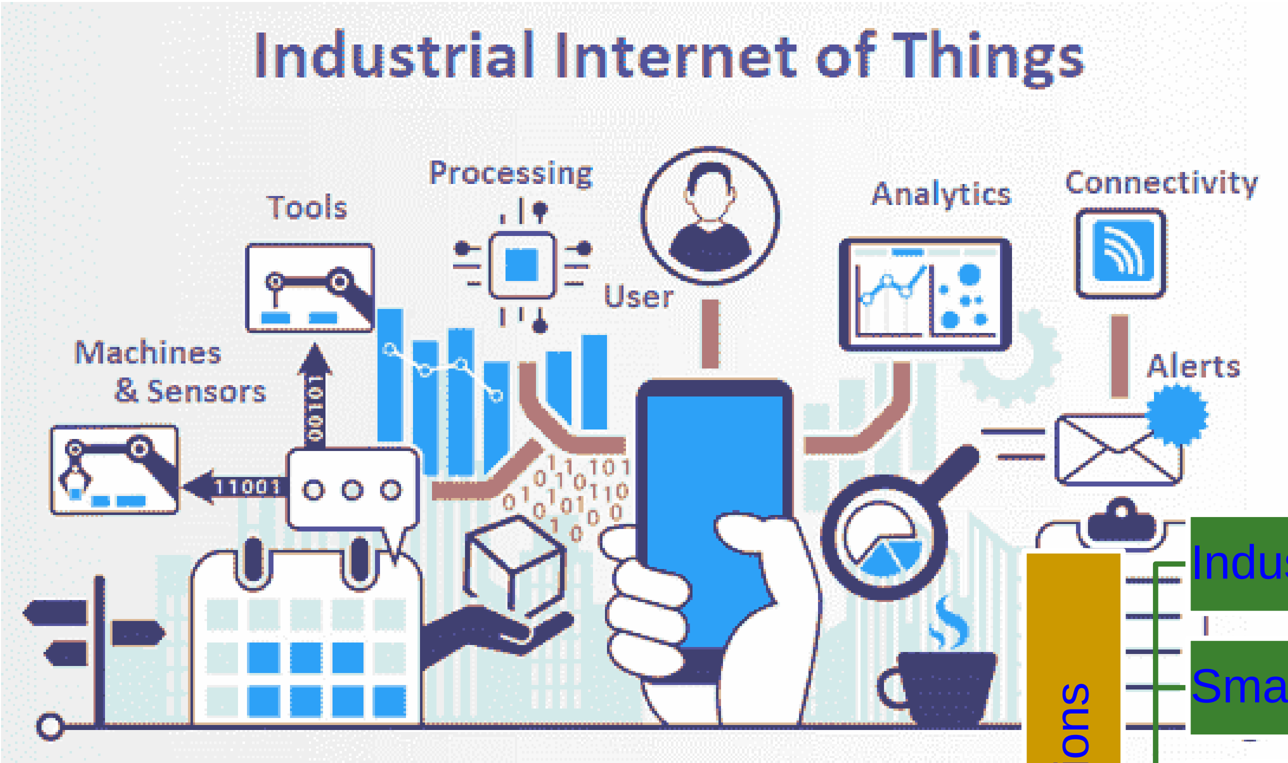
Internet of Health Things (IoHT)

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

Industrial Internet of Things (IIoT)



Source: https://www.rfpage.com/applications-of-industrial-internet-of-things/

Applications

- Industrial Automation
- Smart Robotics
- Predictive Maintenance
- Integration of Tools / Wearables
- Smart Logistics

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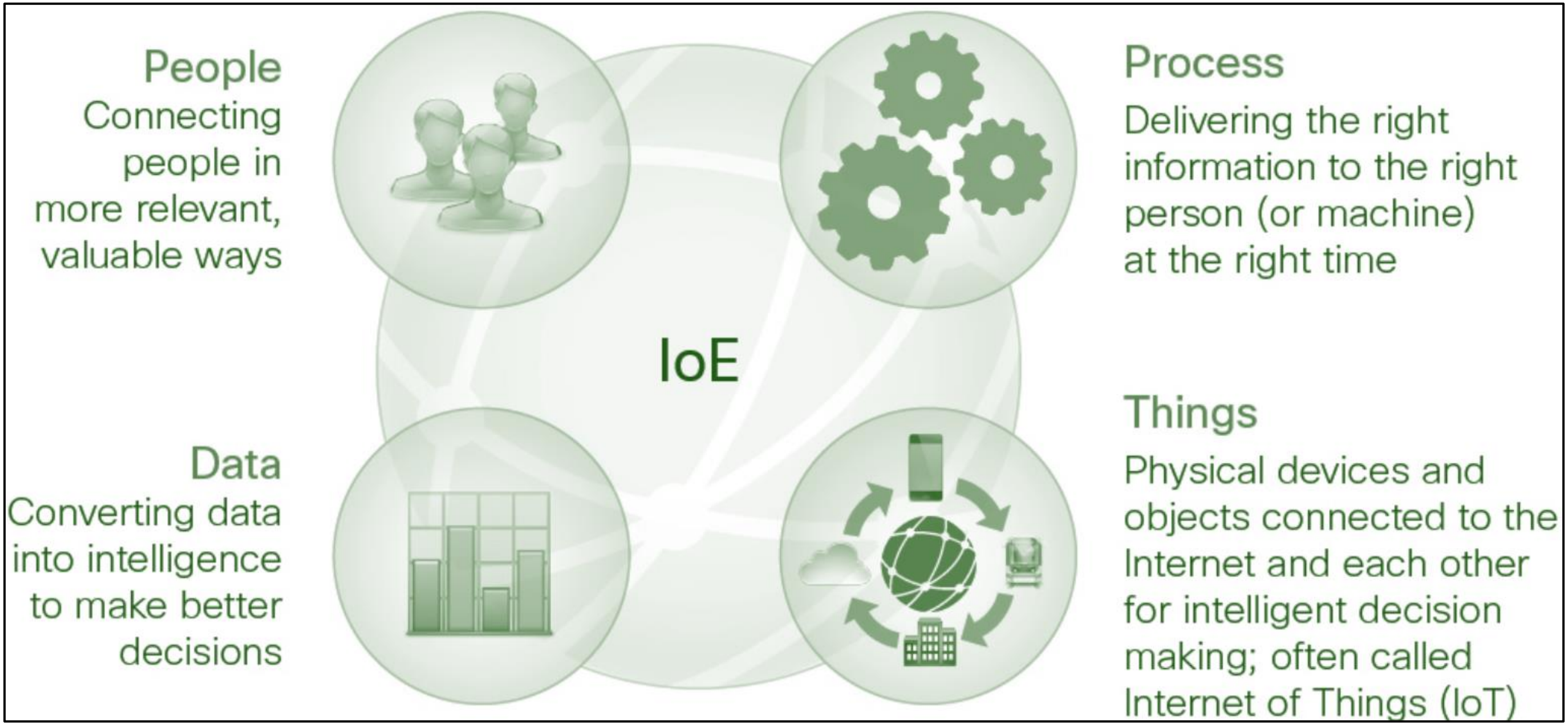
UNT

Internet of Every Things (IoE)



Source: http://iot.ieee.org/images/files/pdf/IEEE_IoT_Towards_Definition_Internet_of_Things_Revision1_27MAY15.pdf

Conclusions

Conclusions

- IoT has following components: Things, LAN, Cloud, Internet.
- IoT is backbone of smart cities.
- Scalability, Cost, Energy-consumption, Security are some important challenges of IoT.
- Security, Privacy, and Ownership Rights are critical for trustworthy IoT design.
- Physical Unclonable Functions (PUF) emerging as a good security solution.
- Coordination among the various researchers and design engineers is a challenge as IoT is multidisciplinary.

Future Directions

- Energy-Efficient “Thing” design is needed.
- Security and Privacy of Information need more research.
- Security of the CE systems (e.g. UAV, Smart Cars) needs research.
- Safer and efficient battery need research.
- IoT automatic design tool needs research.
- Some IoT simulators exist, but more needed for efficient, accurate, scalable, multi-discipline simulations.

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

Thank You !!!

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