Everything you Wanted to Know about Internet of Things (IoT)

IEEE Distinguished Lecture

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IEEE

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

Human Migration Problem

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

Source: https://humanitycollege.org

70% of world population will be urban by 2050.

Urgent Push for Smart Cities

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

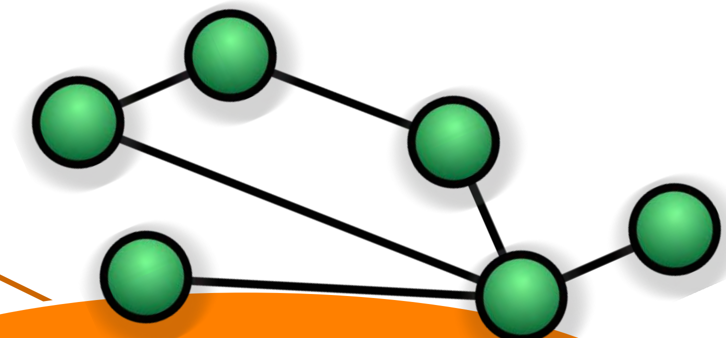
July 2016

Smart Cities: 3 Is

Instrumentation

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

Smart Cities

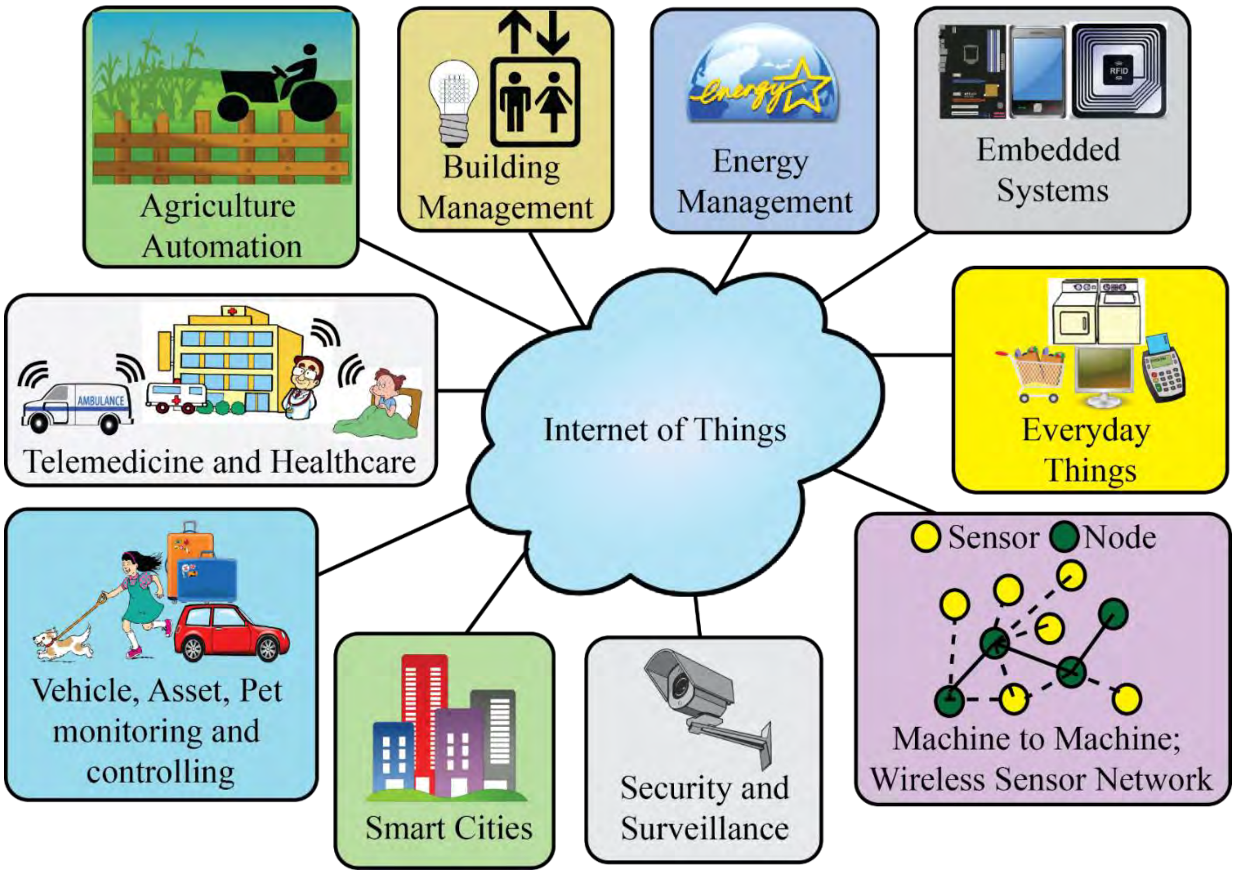


Intelligence

Interconnection

Source: Mohanty 2016, EuroSimE 2016 Keynote Presentation

IoT is the Backbone Smart Cities



Source: Mohanty 2016, CE Magazine July 2016

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

Components

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

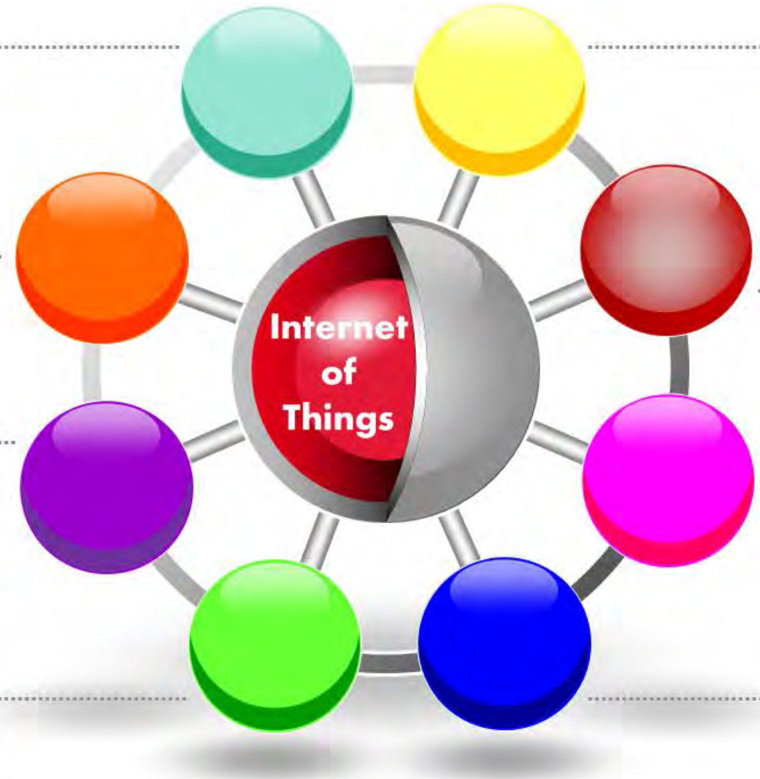
IoT – Definition - IoT European Research Cluster (IERC)

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***

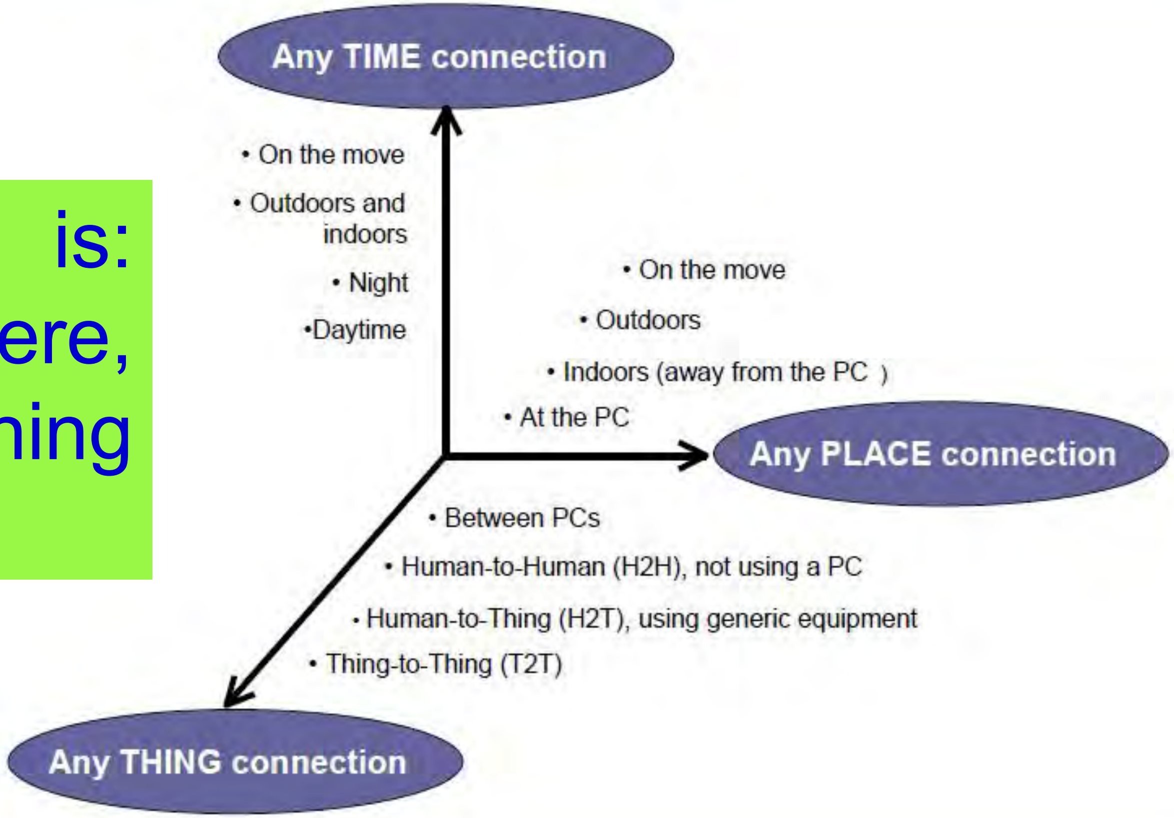
into ***the information network.***

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)

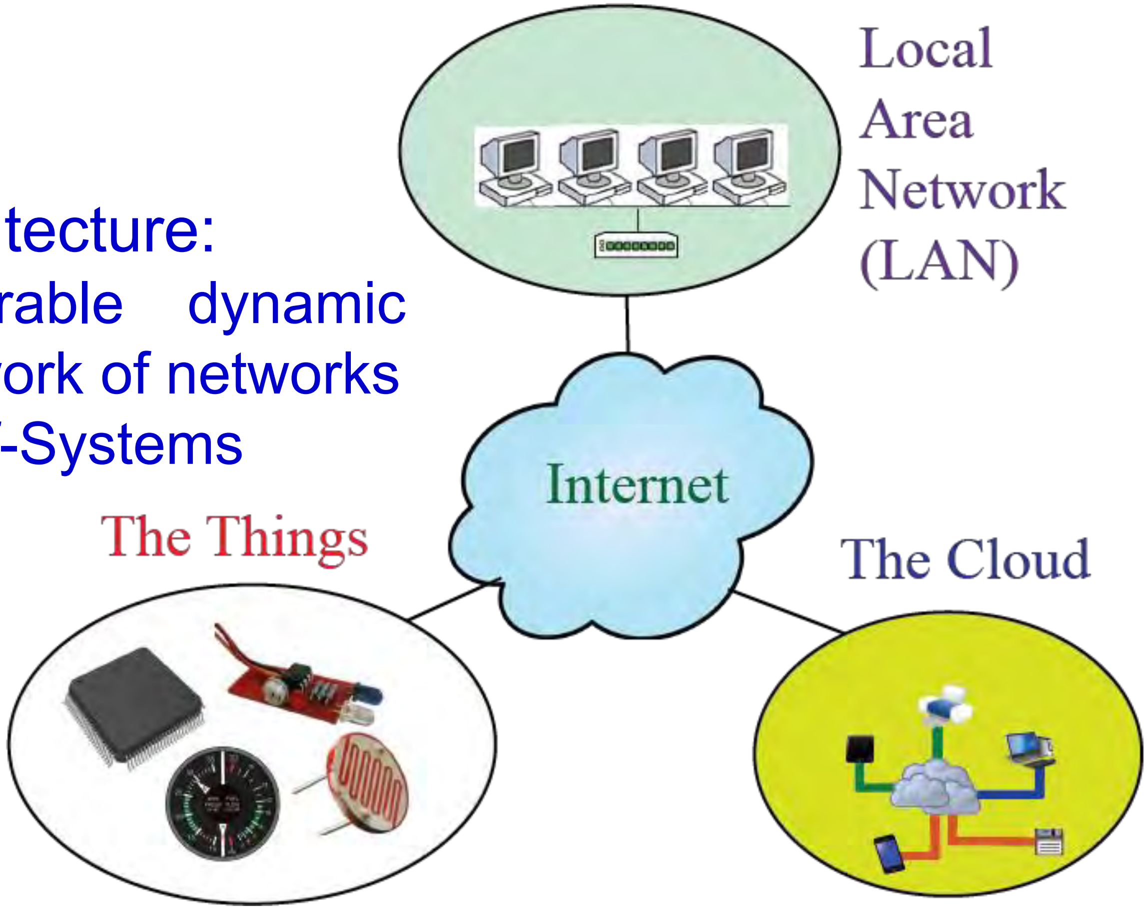
A network that is: "Available anywhere, anytime, by anything and anyone."



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

IoT: Architecture

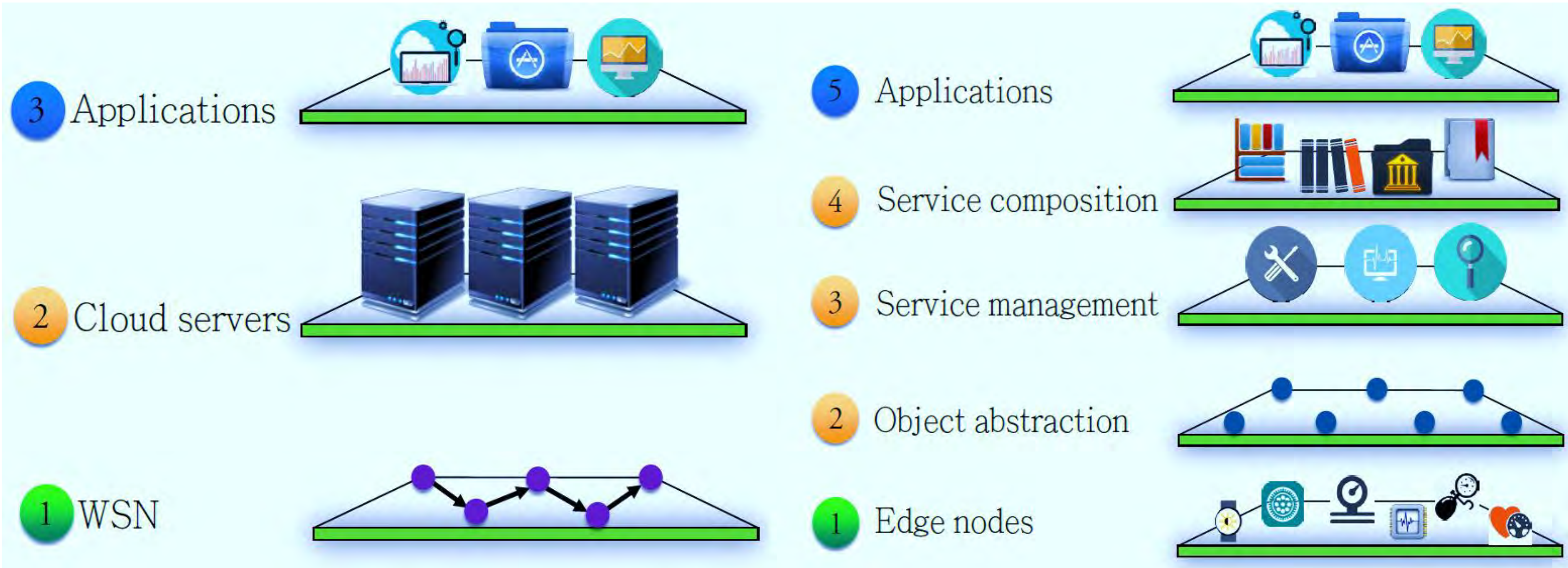
Overall architecture:
- ❖ A configurable dynamic global network of networks
- ❖ Systems-of-Systems



Four Main Components of IoT.

Source: Mohanty 2016, EuroSimE 2016 Keynote Presentation

IoT Architecture - 3 and 5 Level Model

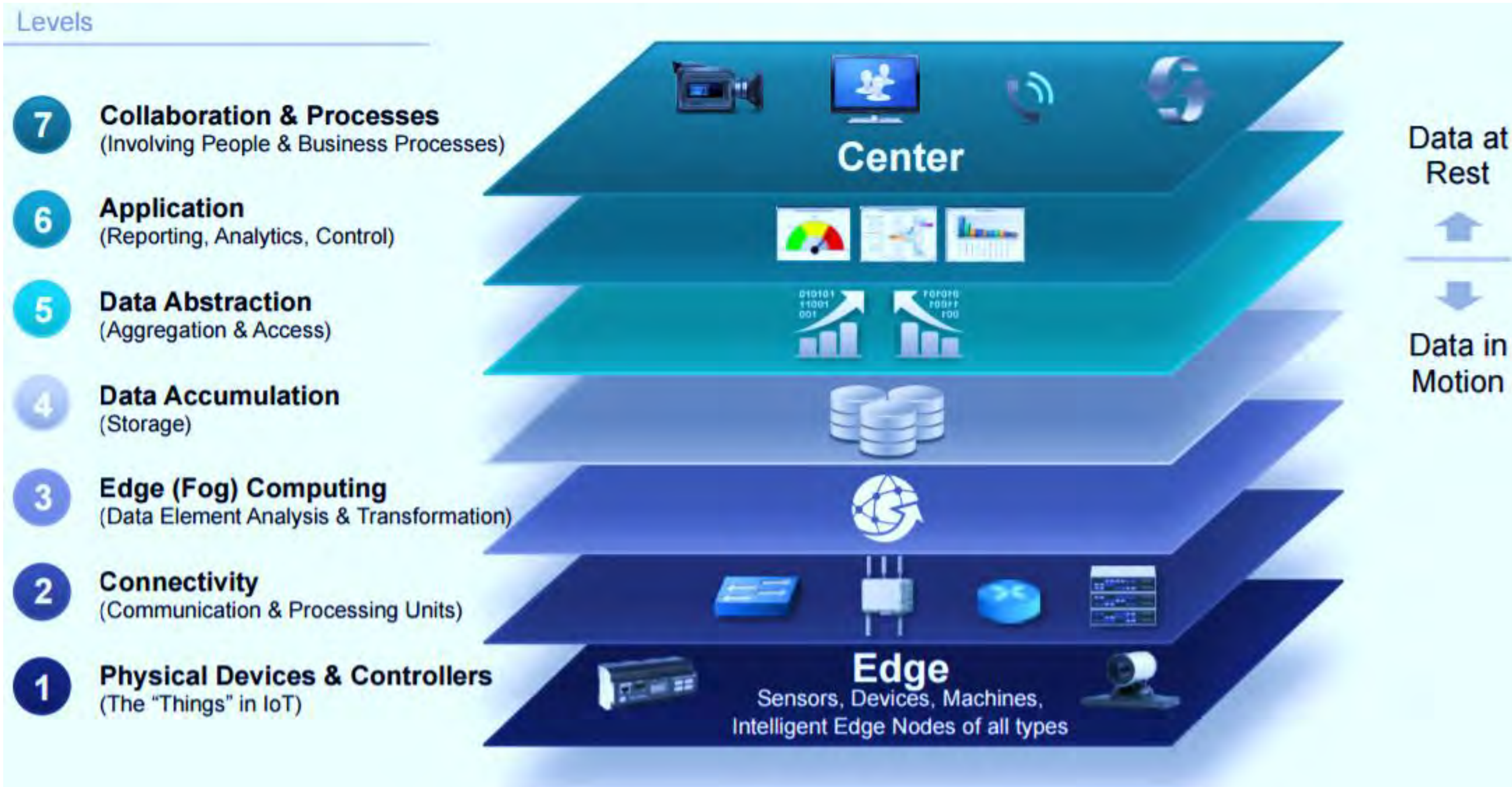


Three Level Model

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: The Things

- EveryTHING is connected
- EveryTHING emits signals
- EveryTHING communicates

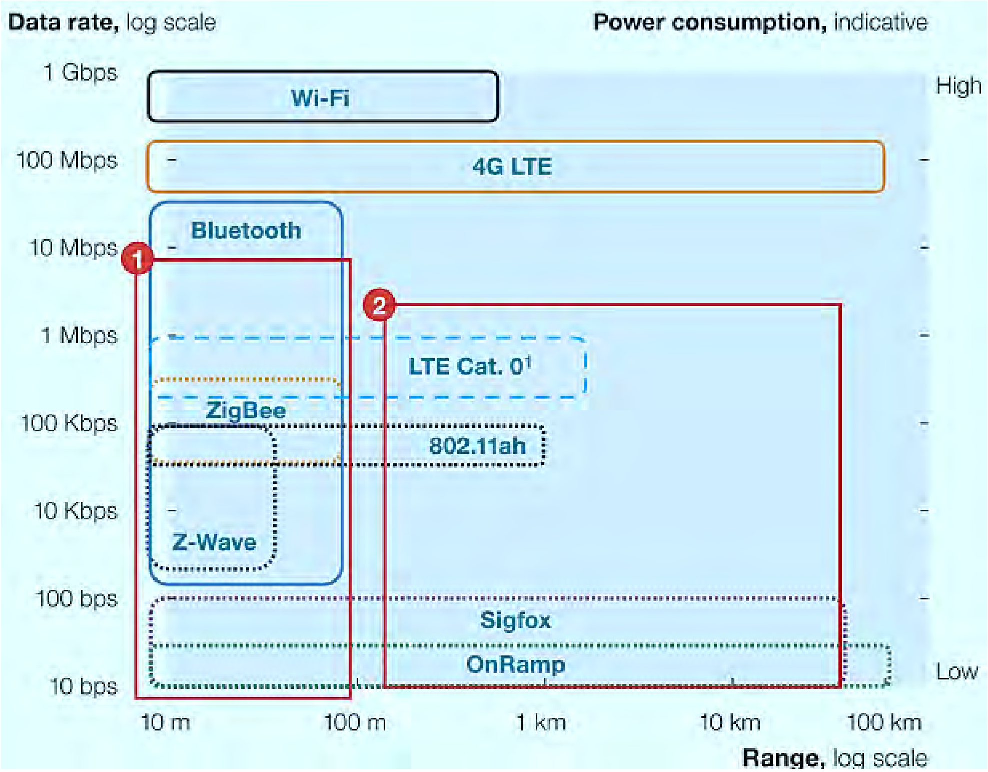
Thing ← Sensor
+ Device with its own IP address

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

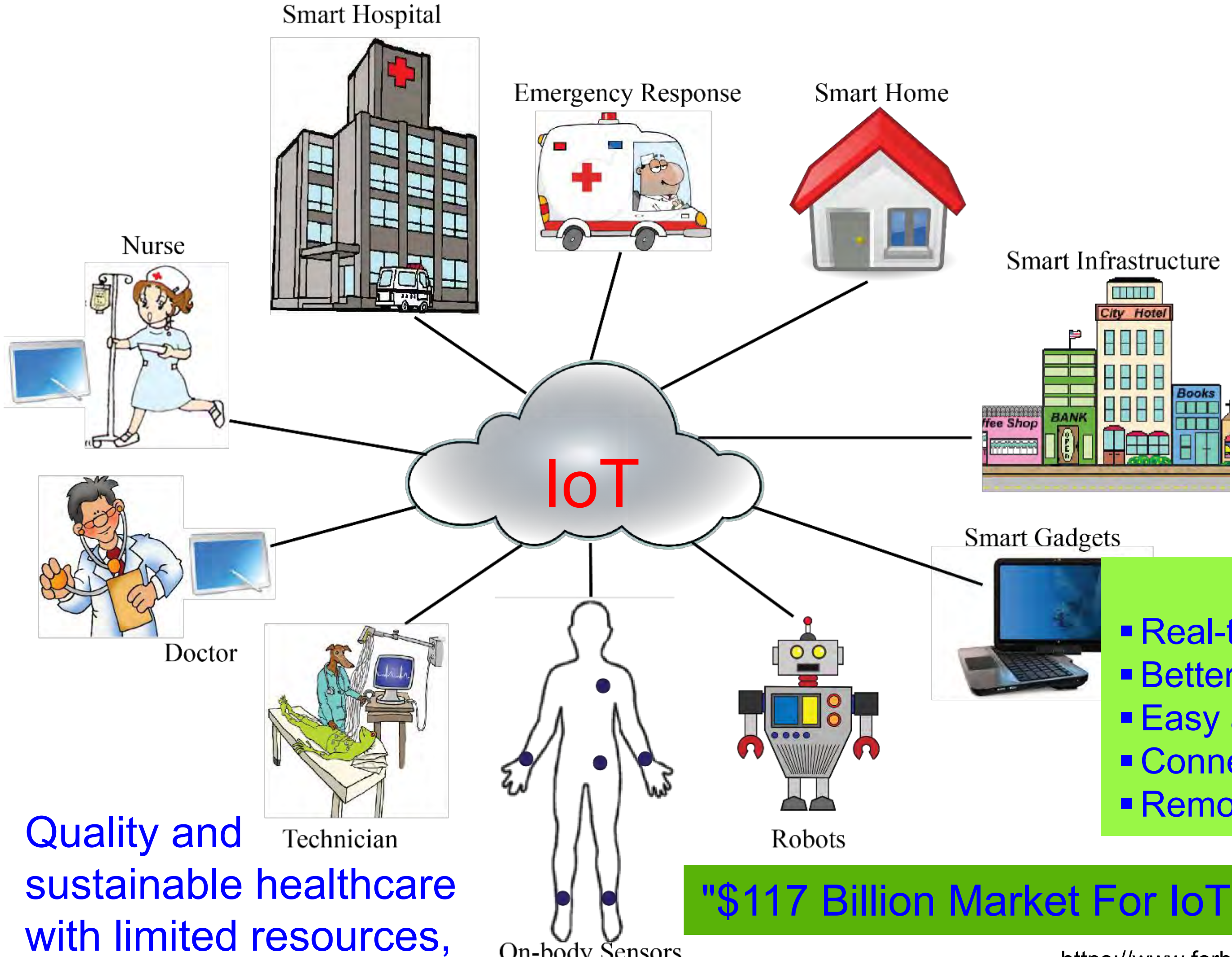


Source: https://www.postscapes.com/internet-of-things-protocols/

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

IoT - Applications

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

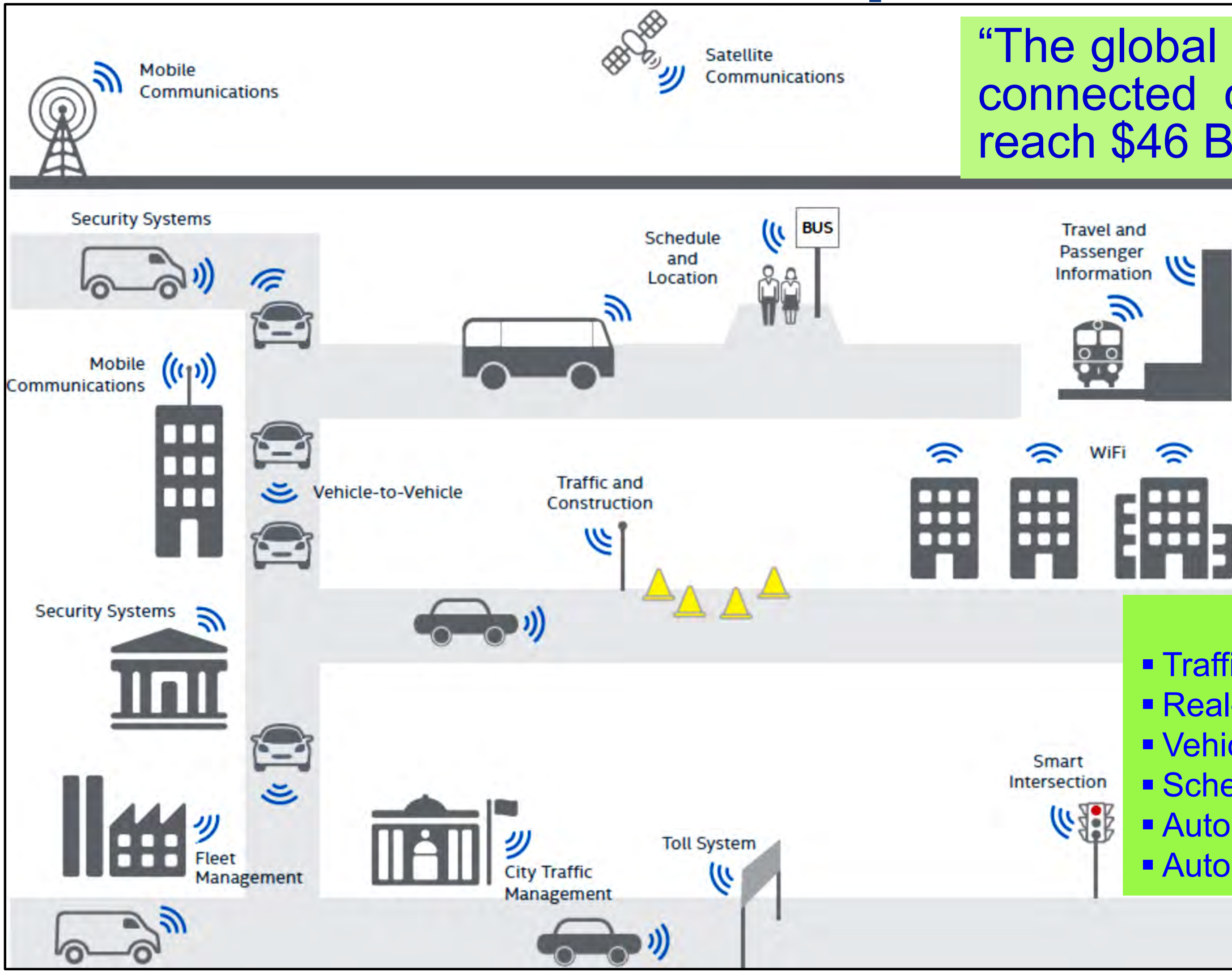
"$117 Billion Market For IoT in Healthcare By 2020."

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

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

Source: Mohanty 2016, CE Magazine July 2016

IoT in Smart Transportation



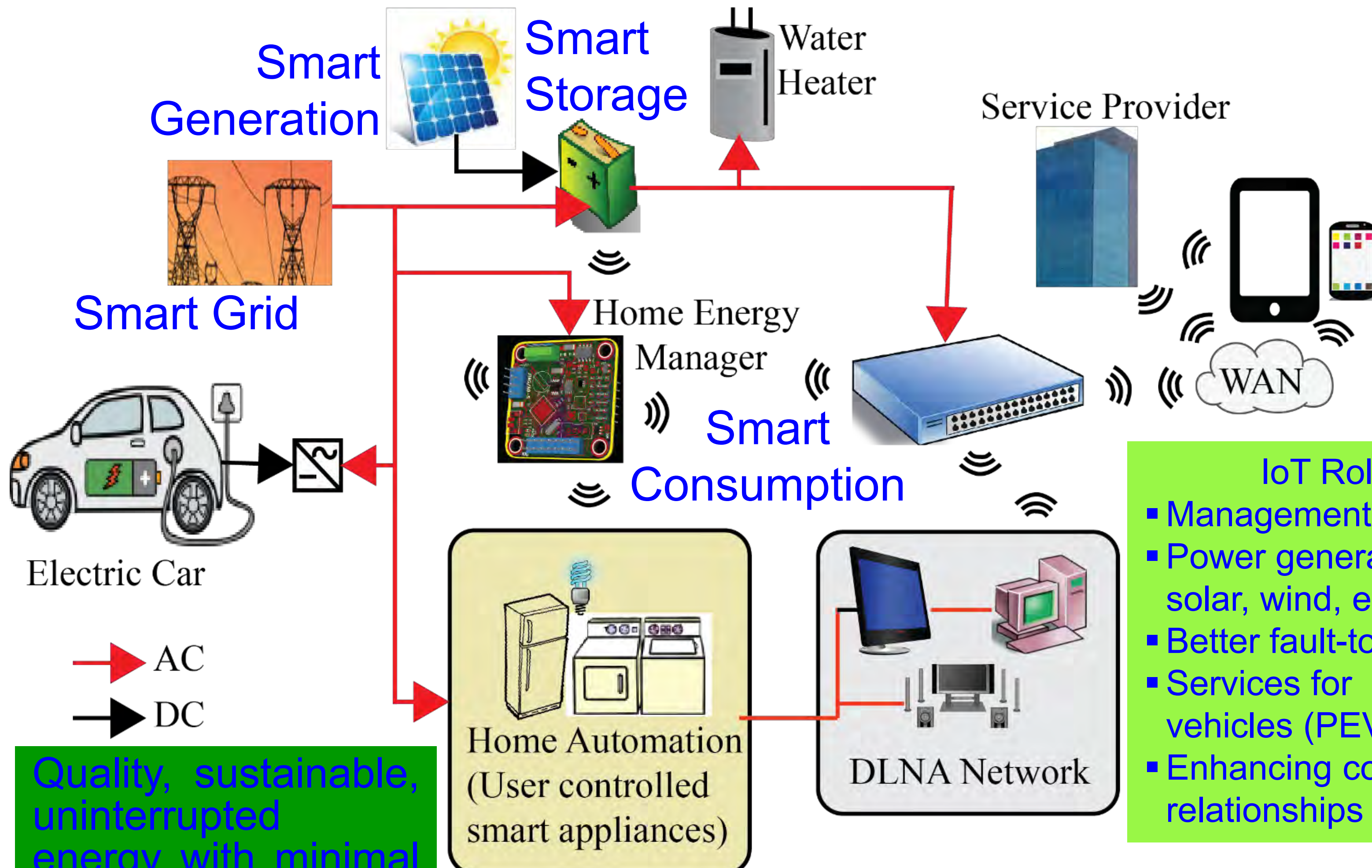
"The global market of IoT based connected cars is expected to reach $46 Billion by 2020."

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



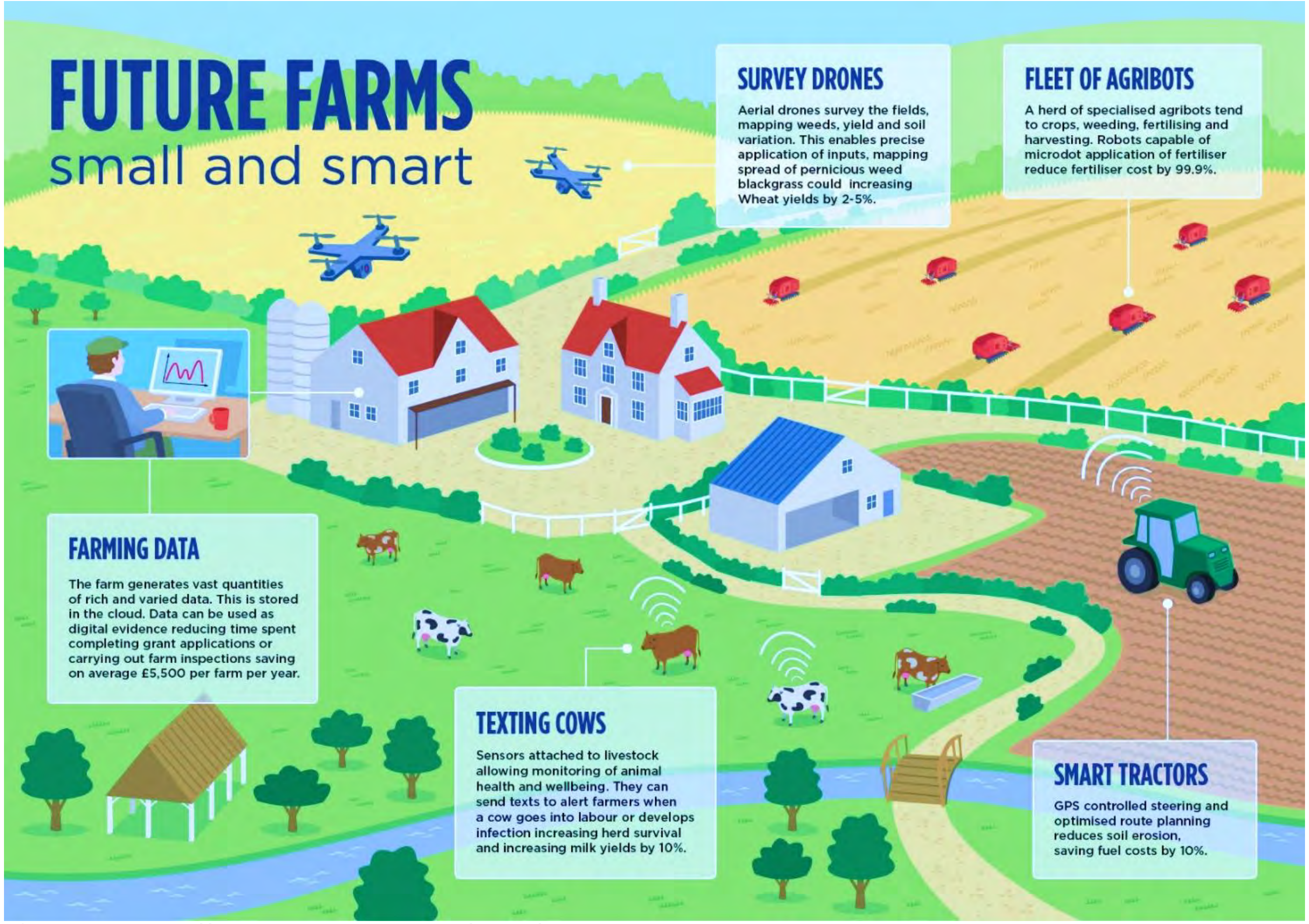
IoT Role Includes:
- Management of energy usage
- Power generation dispatch for solar, wind, etc.
- Better fault-tolerance of the grid
- Services for plug-in electric vehicles (PEV)
- Enhancing consumer relationships

Quality, sustainable, uninterrupted energy with minimal carbon footprint.

Internet of Energy

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

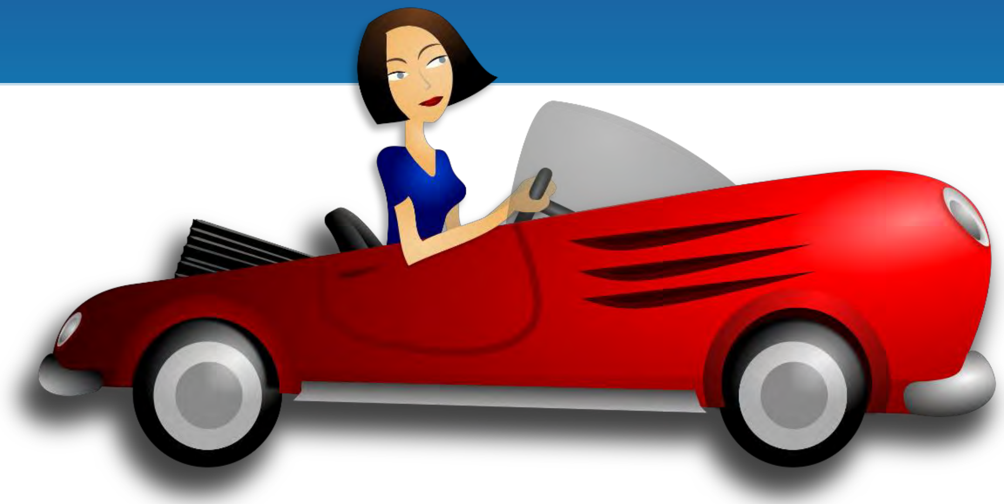
Climate-Smart Agriculture Objectives:
- Increasing agricultural productivity
- Resilience to climate change
- Reducing greenhouse gas

http://www.fao.org

Automatic Irrigation System

Source: Maurya 2017, CE Magazine July 2017

Driving Technologies



Cheap and Compact Sensor Technology

Sensors
- Biosensor
- Thermal Sensor
- Photo Sensors
- Piezoelectric Sensor
- Image Sensor
- Gas Sensor
- Humidity Sensor
- Motion Sensor

Source: Mohanty 2015, McGraw-Hill 2015

Gas Sensor

Temperature Sensor

Air Quality Sensor

Humidity and Temperature Sensor

Light Sensor

Barometer Sensor

Water Sensor

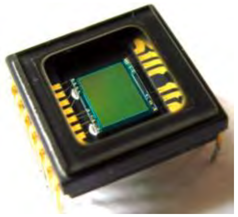
Dust Sensor

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

Imaging Sensor Technology

Image Sensors

Charged Couple Device (CCD) Sensor

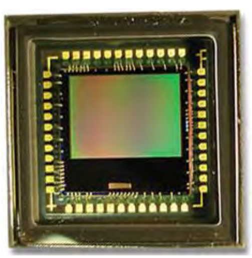


Complementary Metal Oxide Semiconductor (CMOS) Sensors

Passive Pixel Sensor (PPS)

Active Pixel Sensor (APS)

Digital Pixel Sensor (DPS)



Based on Sensing Element

Photodiode-Type APS

Photogate-Type APS

Based on Operation Mode

Linear-Mode APS

Logarithmic-Mode APS

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

Source: Mohanty 2015, McGraw-Hill 2015

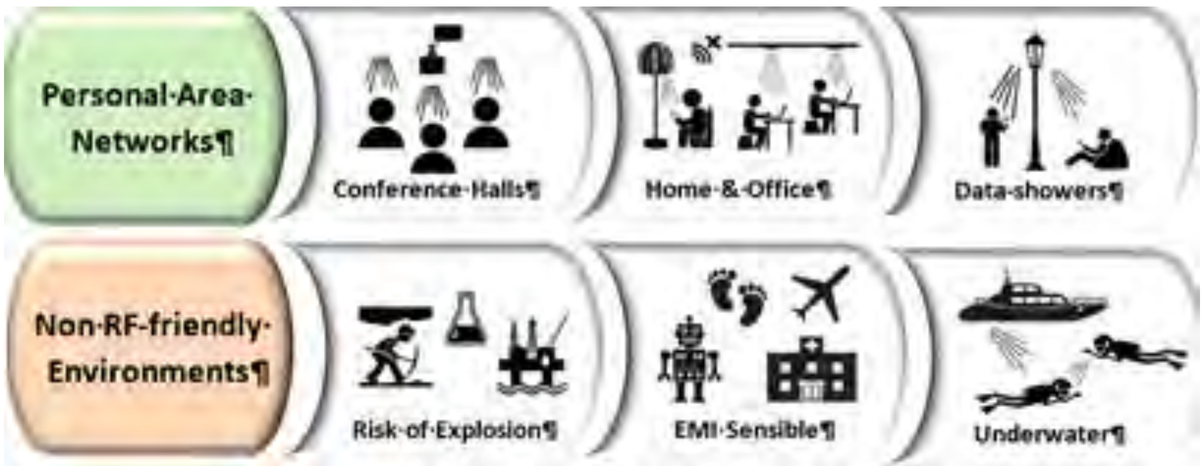
Source: http://www.grandviewresearch.com/press-release/global-cmos-image-sensors-market

Visible Light Communications (VLC)

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

Characteristic	LiFi	WiFi
Bandwidth	Huge	Limited
Requires Line of Sight	Yes	No
EMI + Hazard Concerns	Low	High
Susceptibility to Eavesdropping	Low	High
Range	Short	Medium
Data Density	High	Limited

Source: VLCS-2014



Source: Ribeiro 2017, CE Magazine October 2017

Media Compression - Better Portable Graphics (BPG)

- **Why 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: Mohanty 2016, IEEE Access 2016

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)

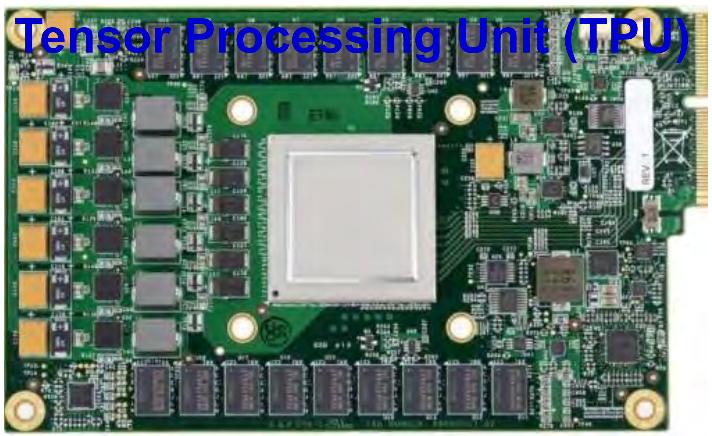
Source: Mohanty 2015, McGraw-Hill 2015

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/

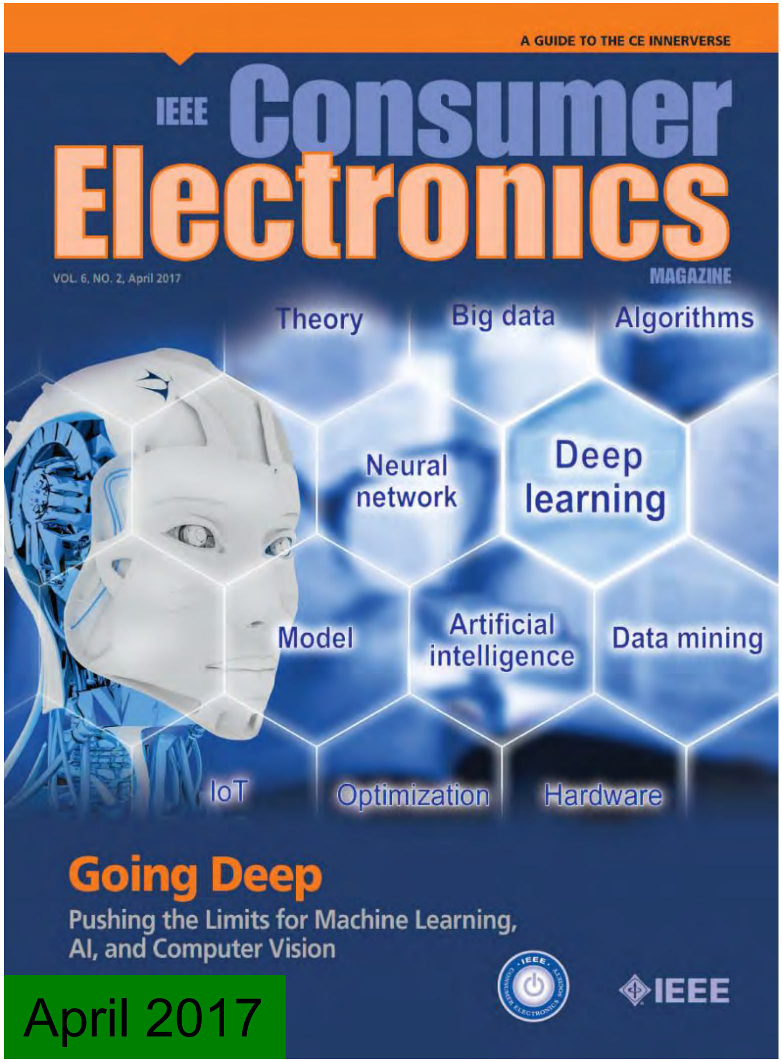
Machine Learning Technology

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/

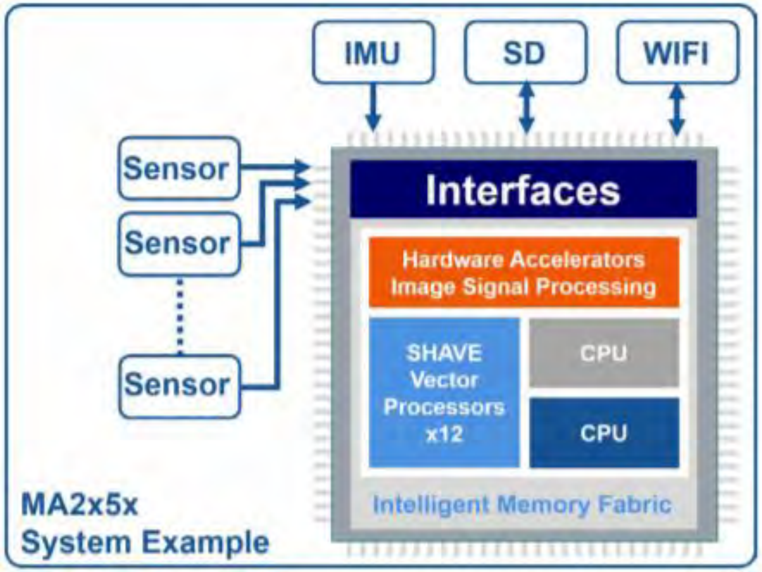
IoT Use:
- Better decision
- Faster response



April 2017

Vision Processing Unit

- High-Performance Machine Vision Processing
- Deep Neural Network-based Classification
- Pose Estimation
- 3D Depth Estimation
- Visual Inertial Odometry (Navigation)
- Gesture/Eye Tracking and Recognition



Vision Processing Unit (VPU)

Source: https://www.movidius.com/solutions/vision-processing-unit

- Video Processing Unit → Video encoding and decoding
- Graphics Processing Unit (GPU) → Rasterization and Texture Mapping
- Vision Processing Unit (VPU) → Machine vision algorithms (e.g. Convolutional Neural Network (CNN)

Natural User Interface (NUI)

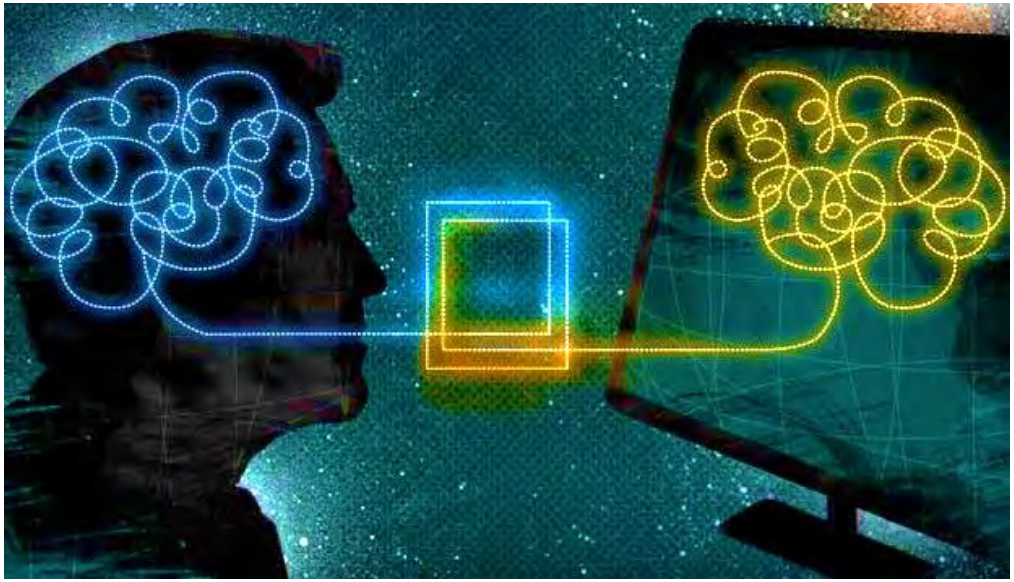
NUI : User interfaces where the interaction is direct and consistent with our “natural” behavior.


Microsoft Kinect

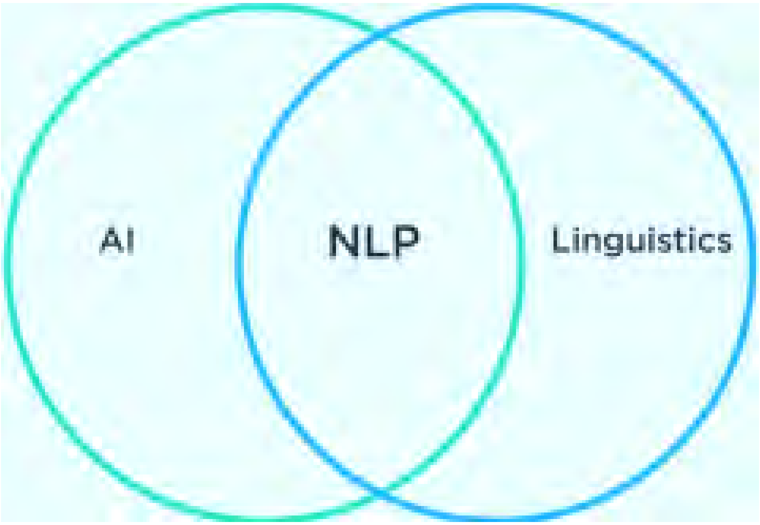
Source: https://www.interaction-design.org/literature/article/natural-user-interfaces-what-are-they-and-how-do-you-design-user-interfaces-that-feel-natural

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


Source: IBM

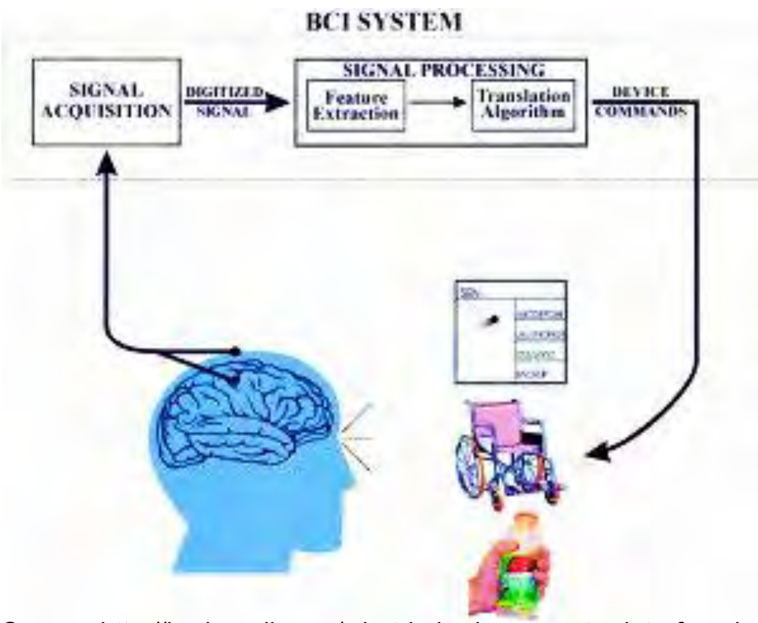
Application 1: Integrate into assistive glasses for visually impaired people for navigating through complex environments, even without the need for a WiFi connection.


Source: IBM

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)



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

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

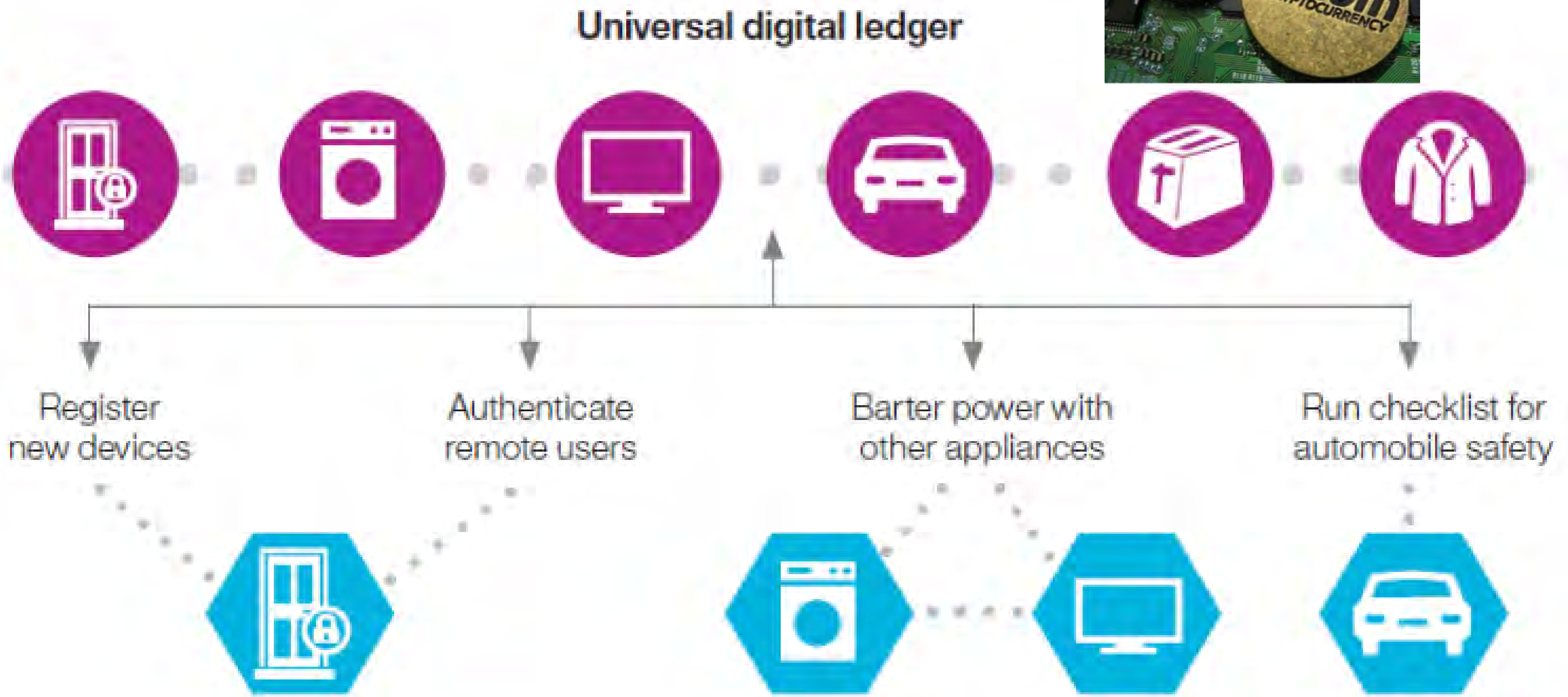
Brain-Computer Interface Allows paralysis patients to Type Faster

"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/

The Blockchain



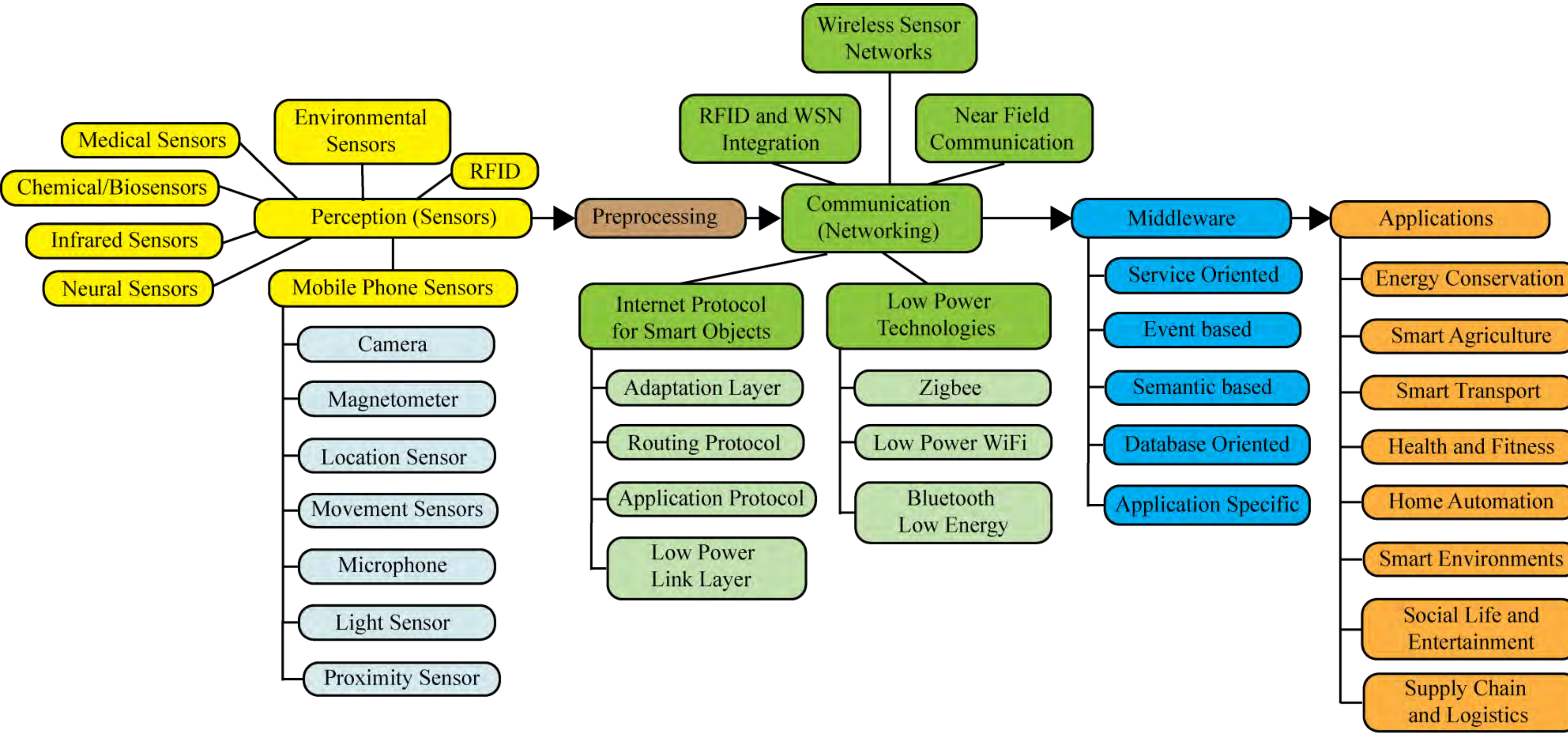
- Think of it as cloud based peer to peer ledger.
- A Blockchain is a cloud based database shared by every participant in a system.
- The Blockchain contains the complete transaction or other record keeping.

Source: https://www.linkedin.com/pulse/securing-internet-things-iot-blockchain-ahmed-banafa

Stay Tuned to: Mohanty 2018, CE Magazine March 2018

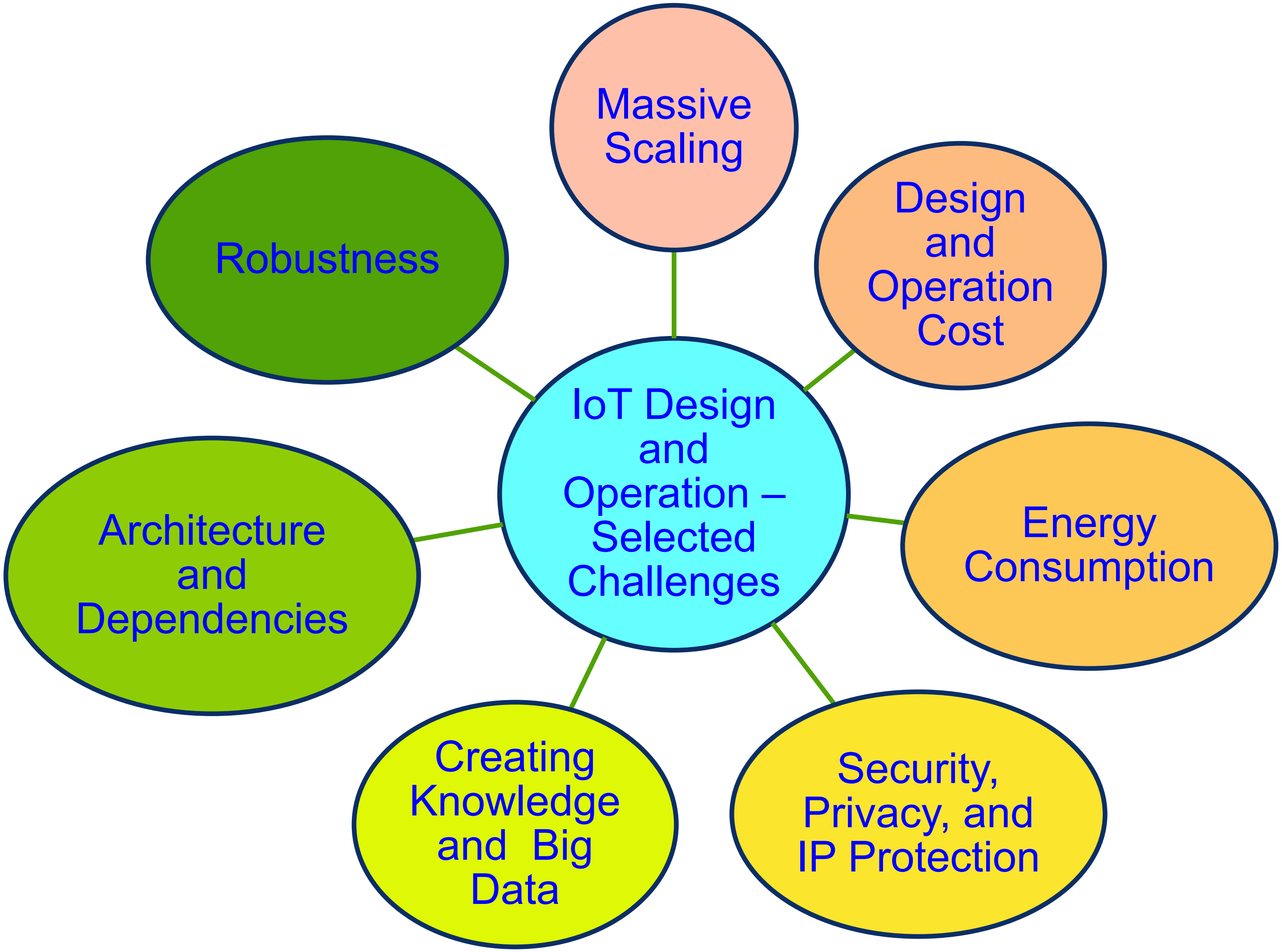
Challenges and Research

IoT – Multidiscipline Research



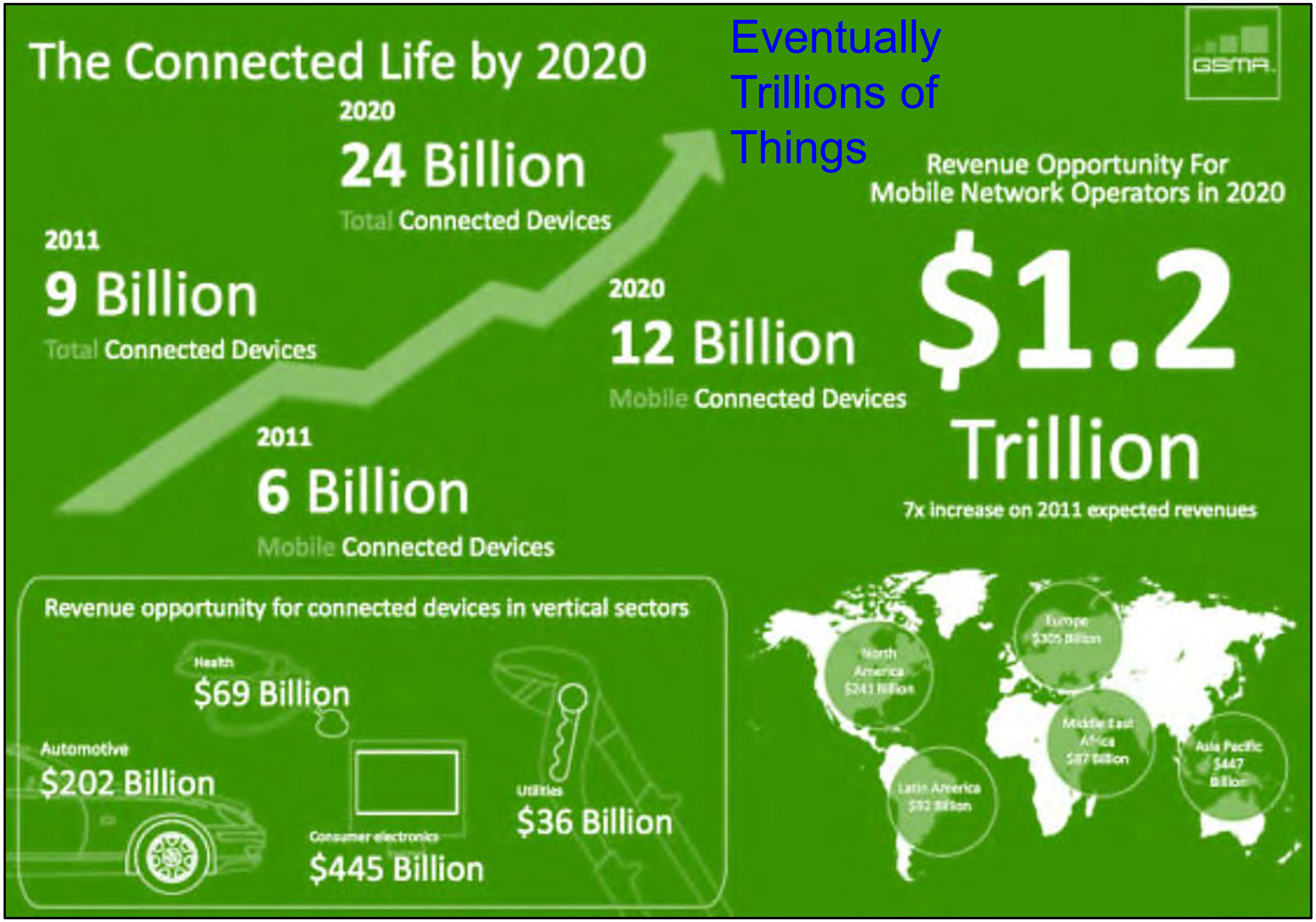
Source: Sethi 2017, JECE 2017

IoT – Selected Challenges



Source: Mohanty 2016, EuroSimE 2016 Keynote Presentation

Massive Scaling



Eventually Trillions of Things

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

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.

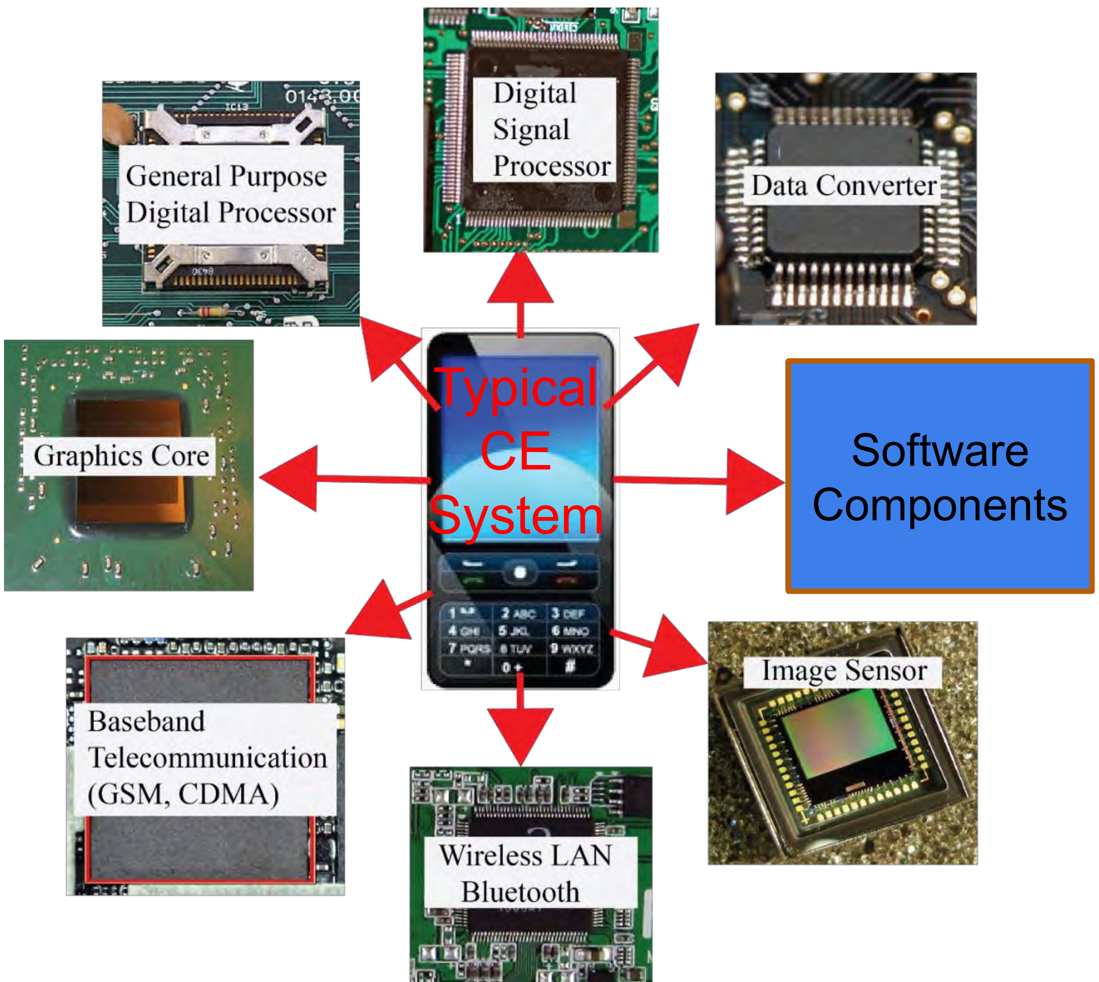
Source: http://www.industrialisation-produits-electroniques.fr

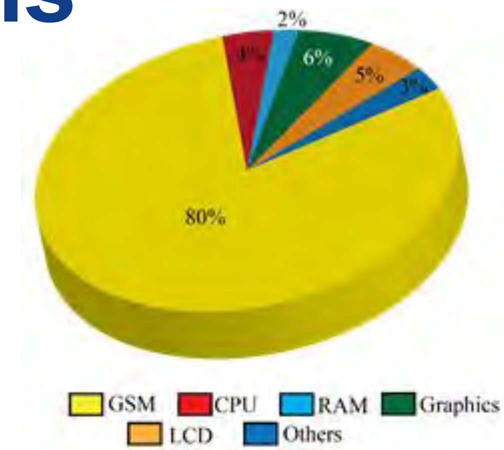
Communication Latency and Energy Consumption

- 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?

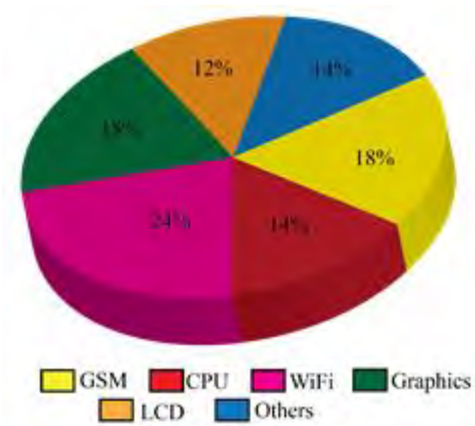
Source: https://www.linkedin.com/pulse/key-technologies-connected-world-cloud-computing-ioe-balakrishnan

Energy Consumption of Sensors, Components, and Systems





During GSM Communications



During WiFi Communications

Source: Mohanty 2015, McGraw-Hill 2015

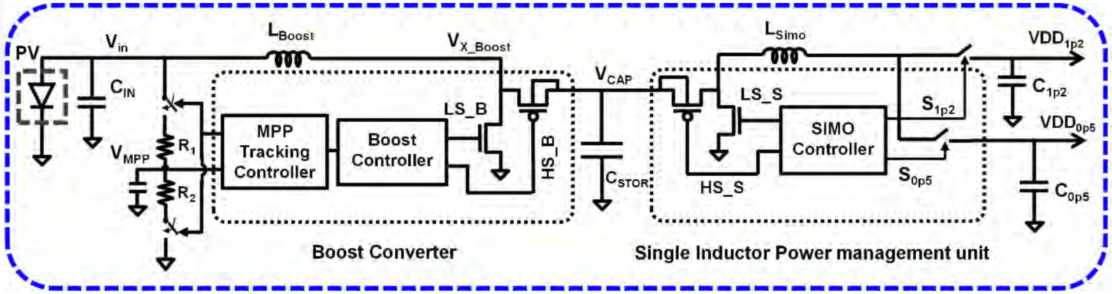
Battery-Less IoT

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/

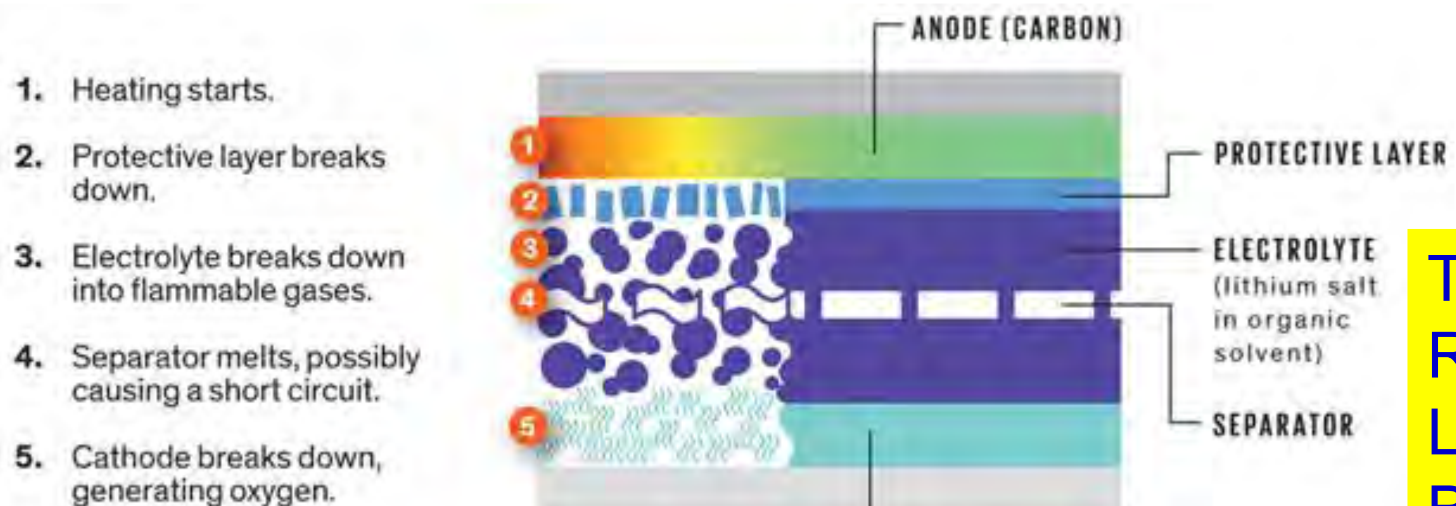


Energy Harvesting and Power Management

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

Safety of Electronics

Smartphone Battery



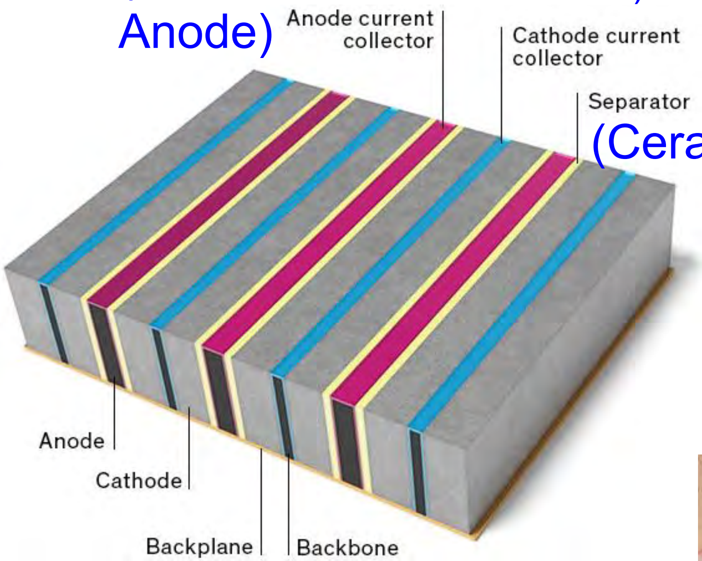
Source: http://spectrum.ieee.org/semiconductors/design/how-to-build-a-safer-more-energydense-lithiumion-battery

Thermal Runaway in a Lithium-Ion Battery

Energy Storage - High Capacity and Safer Needed

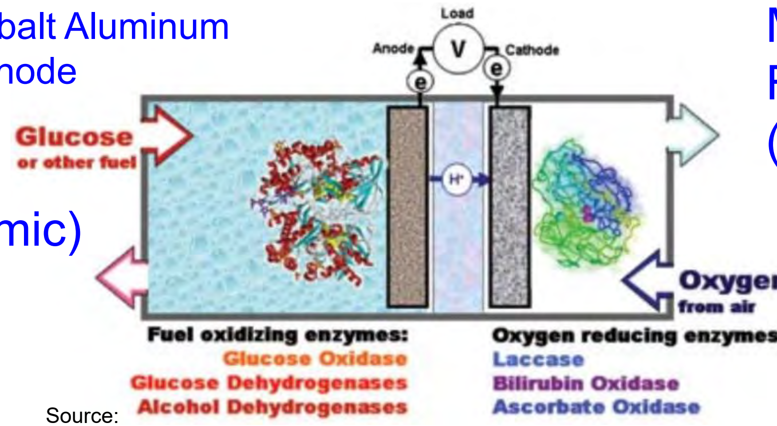
(Silicon Anode)

(Lithium Nickel Cobalt Aluminum Oxide - NCA) Cathode



(Ceramic)

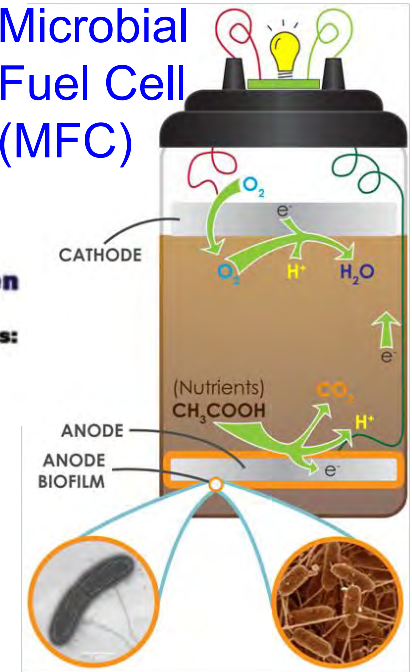
Source: http://spectrum.ieee.org/semiconductors/design/how-to-build-a-safer-more-energydense-lithiumion-battery

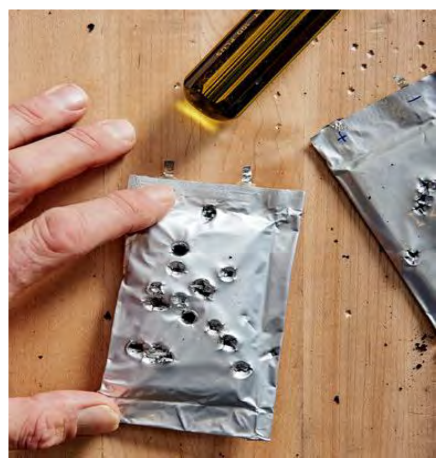


Source: https://www.electrochem.org/dl/interface/sum/sum07/su07_p28_31.pdf

Enzymatic Biofuel Cell

Microbial Fuel Cell (MFC)

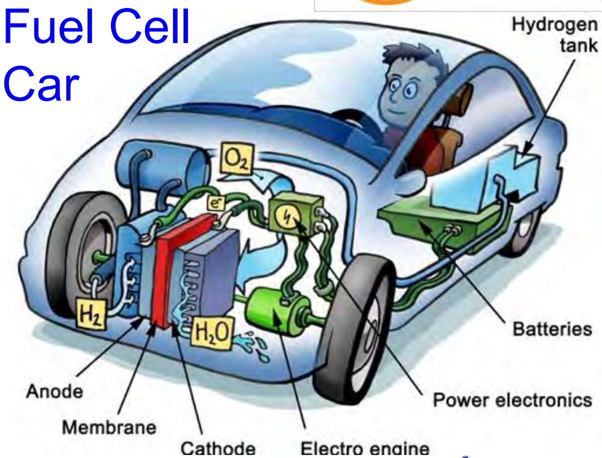




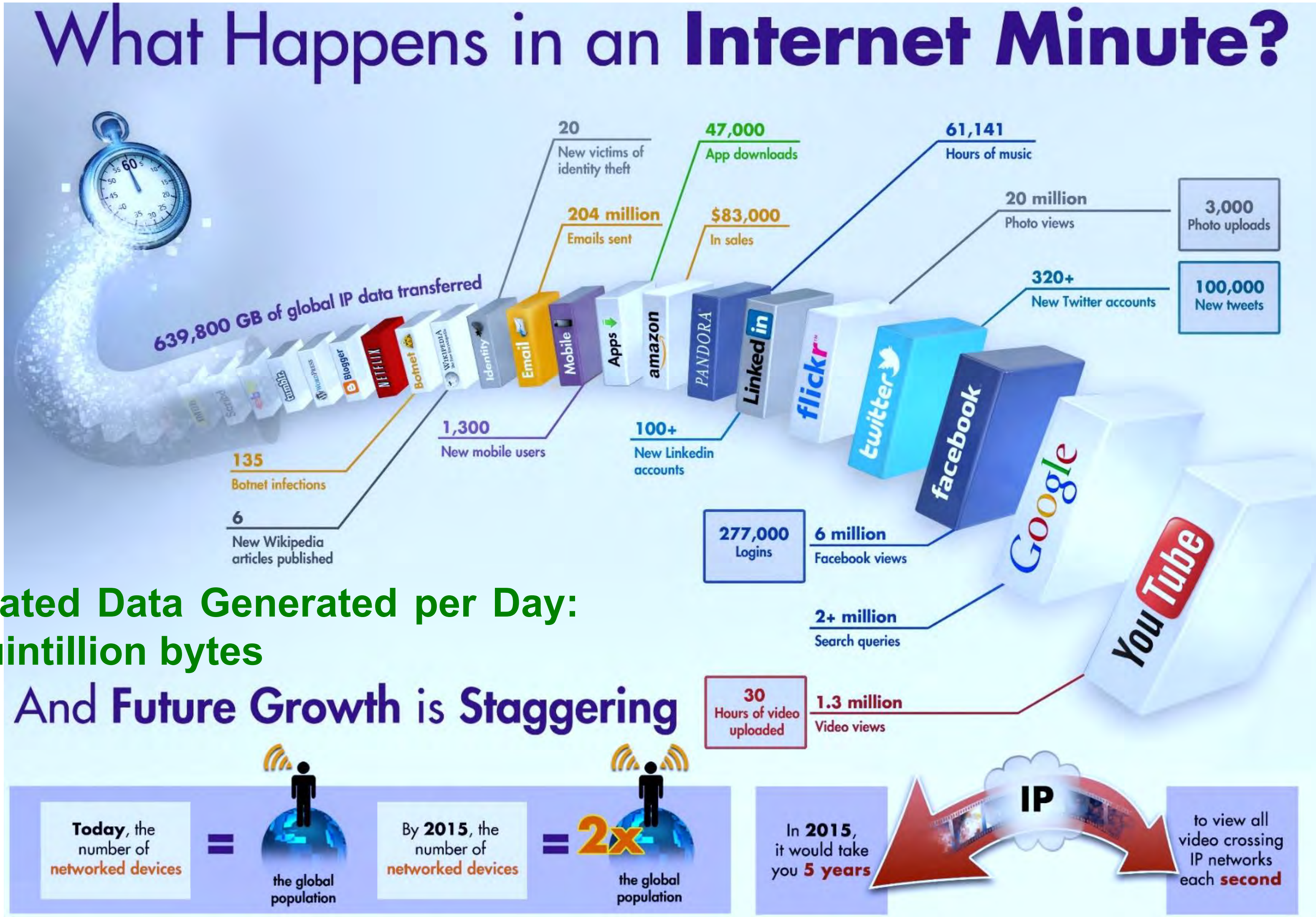
Solid Polymer Lithium Metal Battery

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

Fuel Cell Car

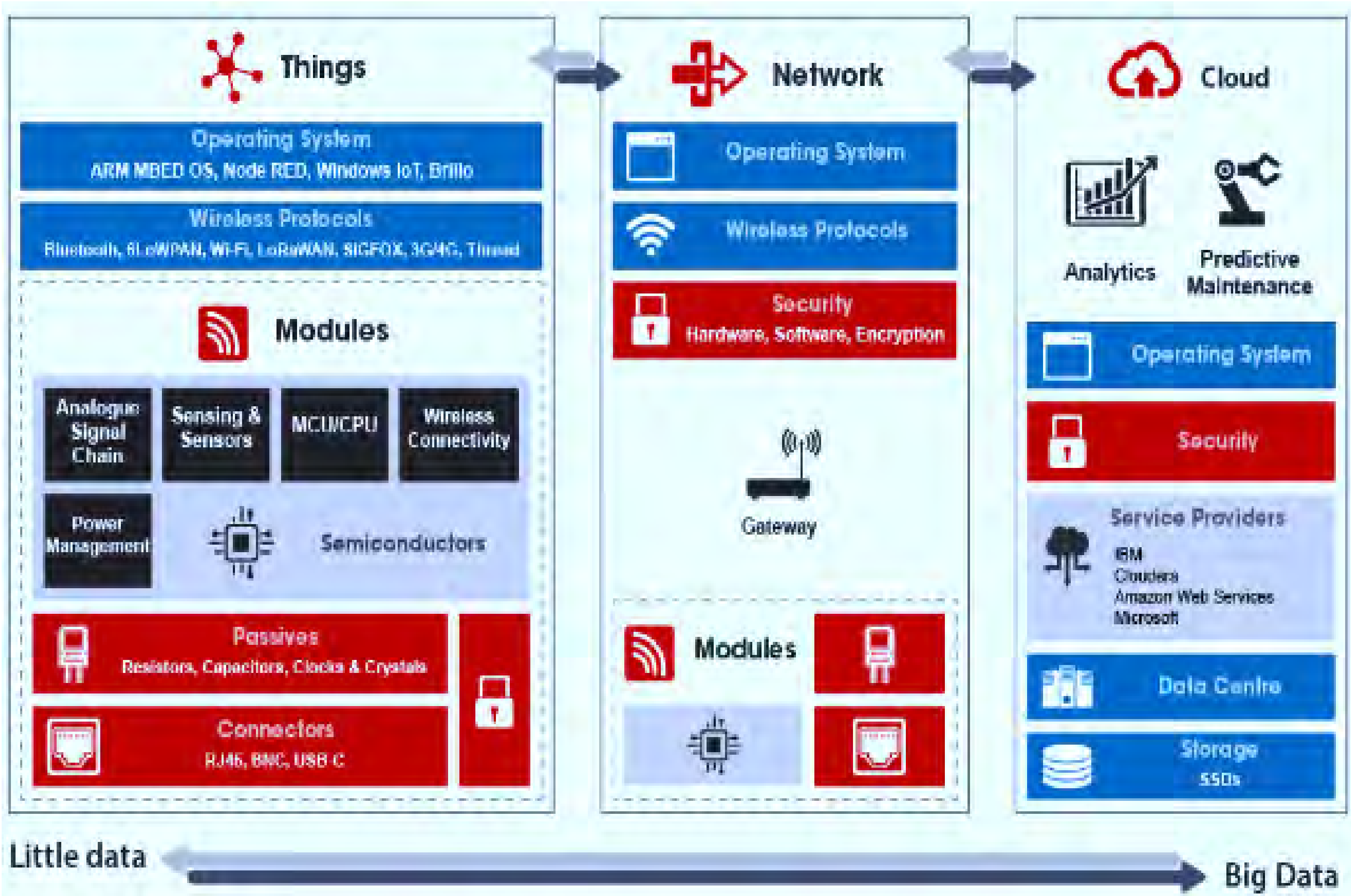


Huge Amount of Data



Estimated Data Generated per Day: 2.5 quintillion bytes

Bigdata in IoT and Smart Cities



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

IoT Security - Attacks and Countermeasures

Edge nodes	Computing nodes
	RFID tags
Communication	
Edge computing	

Threat	Against
Hardware Trojans	All
Side-channel attacks	C,AU,NR,P
Denial of Service (DoS)	A,AC,AU,NR,P
Physical attacks	All
Node replication attacks	All
Camouflage	All
Corrupted node	All
Tracking	P, NR
Inventorying	P, NR
Tag cloning	All
Counterfeiting	All
Eavesdropping	C,NR,P
Injecting fraudulent packets	P,I,AU,TW,NR
Routing attacks	C,I,AC,NR,P
Unauthorized conversation	All
Malicious injection	All
Integrity attacks against learning	C,I
Non-standard frameworks and inadequate testing	All
Insufficient/Inessential logging	C,AC,NR,P

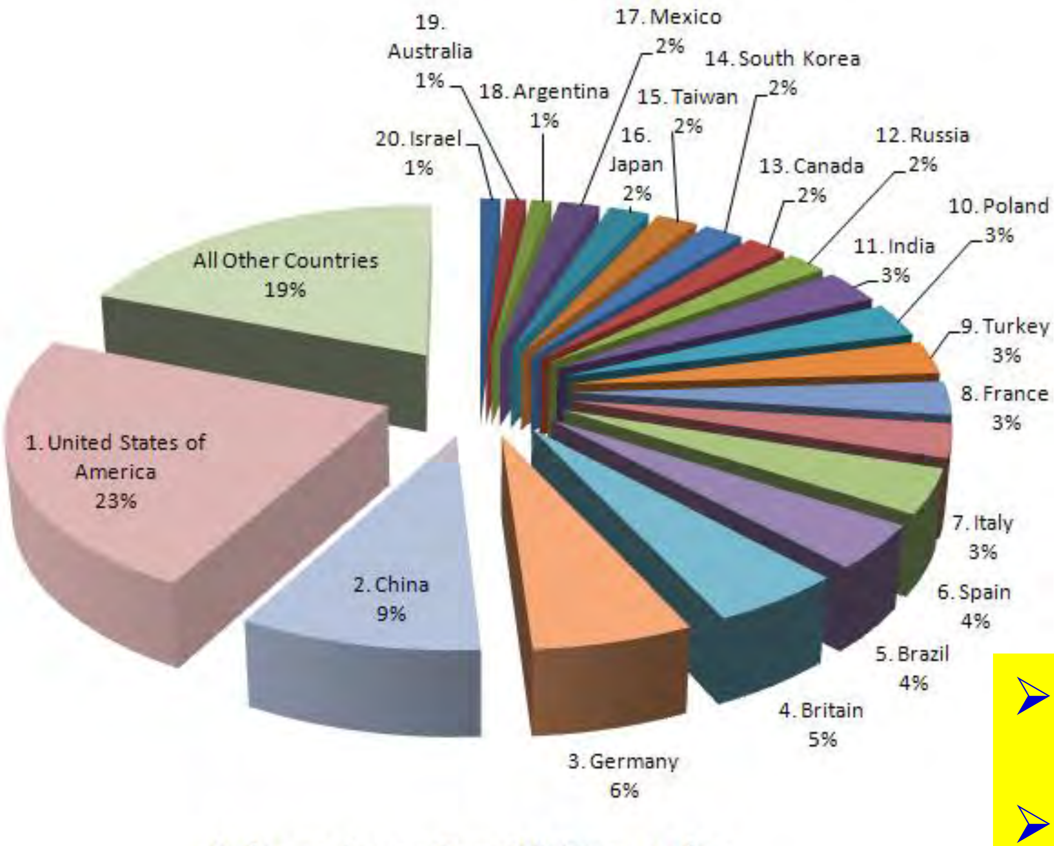
Countermeasures
Side-channel signal analysis
Trojan activation methods
Intrusion Detection Systems (IDSs)
Securing firmware update
Circuit/design modification
Kill/sleep command
Isolation
Blocking
Anonymous tag
Distance estimation
Personal firewall
Cryptographic schemes
Reliable routing
De-patterning and Decentralization
Role-based authorization
Information Flooding
Pre-testing
Outlier detection

C- Confidentiality, I – Integrity, A - Availability, AC – Accountability, AU – Auditability, TW – Trustworthiness, NR - Non-repudiation, P - Privacy

Source: Nia 2017,IEEE TETC 2017

Security, Privacy, and Copyright

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

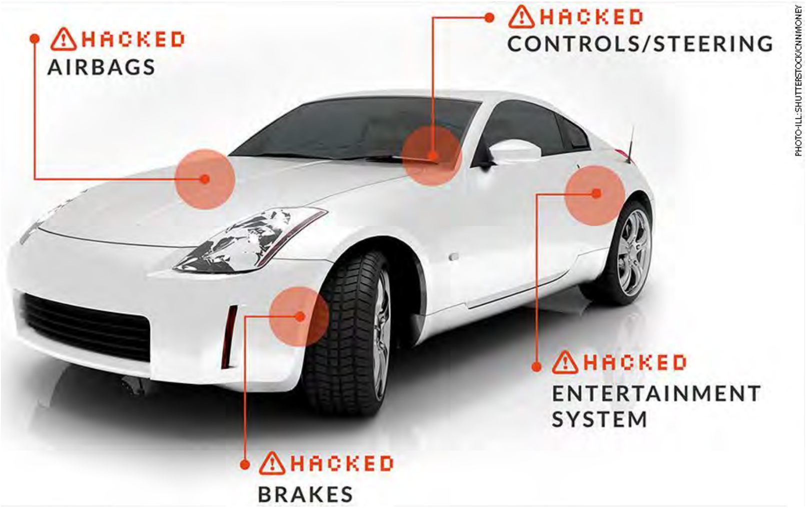
Security in Communications Technology

Routing Attacks

Denial-of-Service (DoS) Attacks

Malicious Injection

Security - Systems …



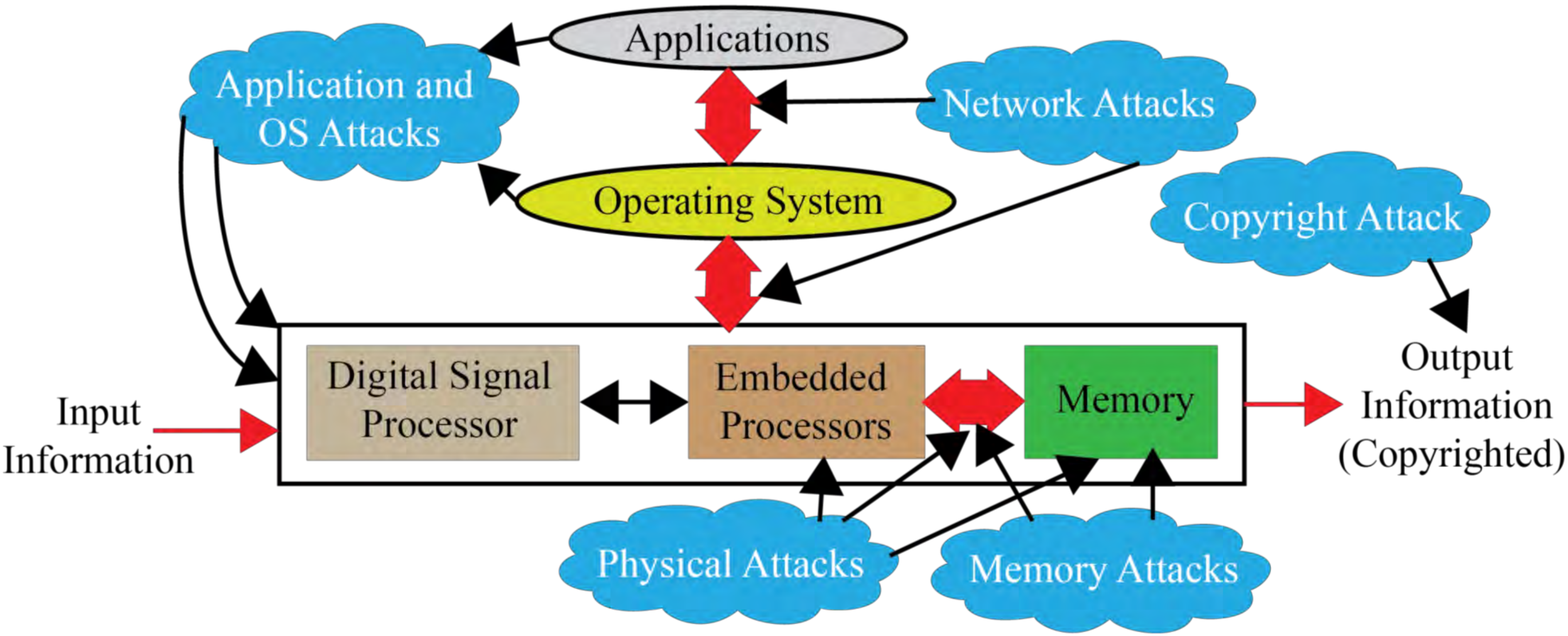
Source: http://money.cnn.com/2014/06/01/technology/security/car-hack/

Power Grid Attack

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

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

Different Attacks on a Typical CE System

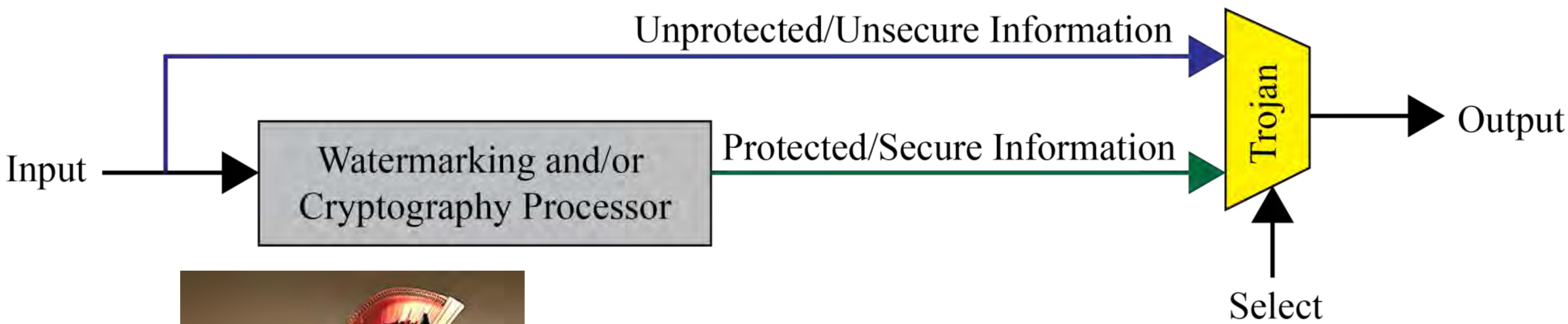


Source: Mohanty 2015, McGraw-Hill 2015

Malicious Design Modifications Issue

Information may bypass giving a non-watermarked or non-encrypted output.

Hardware Trojans

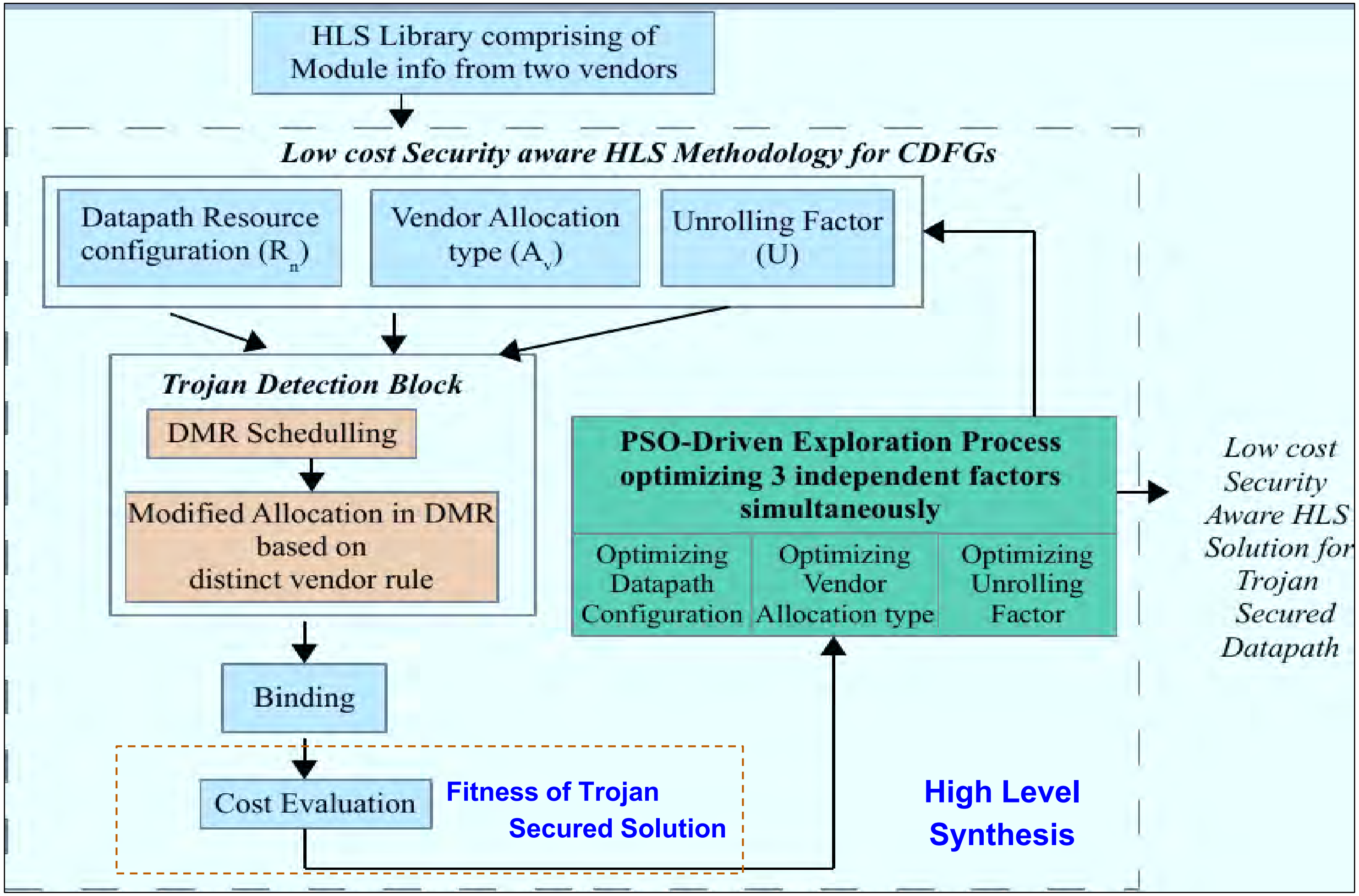


Source: Mohanty 2015, McGraw-Hill 2015

Chip fails to work during critical needs.

Source: Mitra 2015, IEEE Spectrum Jan 2015

Trojans Secure Digital Hardware Synthesis



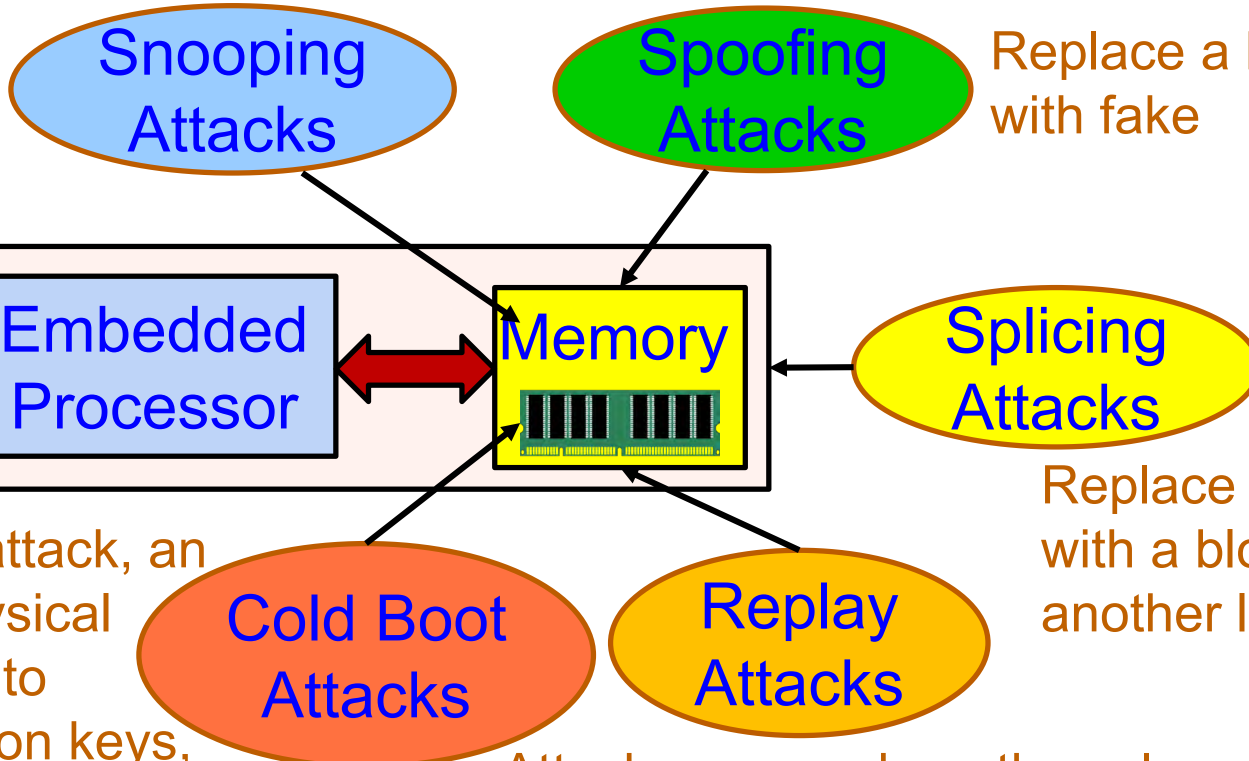
Design-For-Security (DFS) flow against Trojan resulting into functional change

Source: Sengupta and Mohanty 2017, TCAD April 2017

Memory Attacks

Read confidential information in memory

Replace a block with fake



Replace a block with a block from another location

A side channel attack, an attacker has physical access memory to retrieve encryption keys, has to be in seconds-to-minute of power OFF

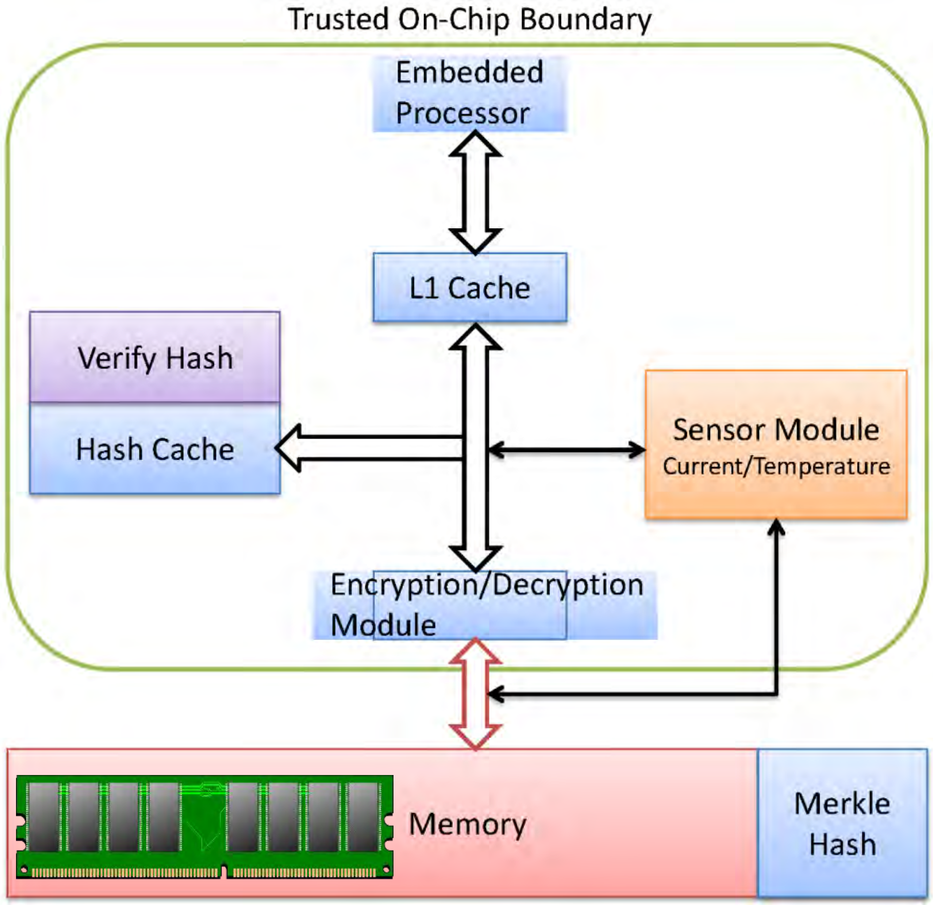
Attacker remembers the value of a block at a given address at one time, and writes that value at exactly the same address at a different times; Hardest attack.

Source: Mohanty 2013, Springer CSSP Dec 2013

Memory Security and Protection

Nonvolatile Storage

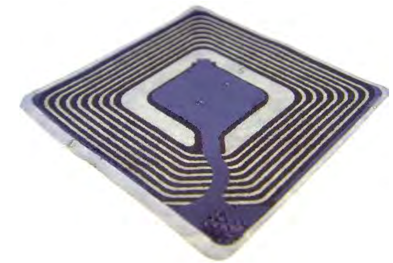
Source: http://datalocker.com



On-Chip/On-Board Memory Protection

Source: Mohanty 2013, Springer CSSP Dec 2013

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

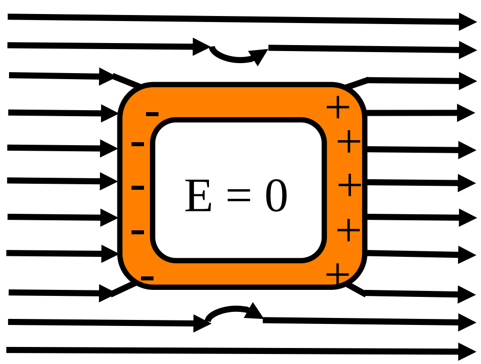
Source: Khattab 2017: Springer 2017 RFID Security

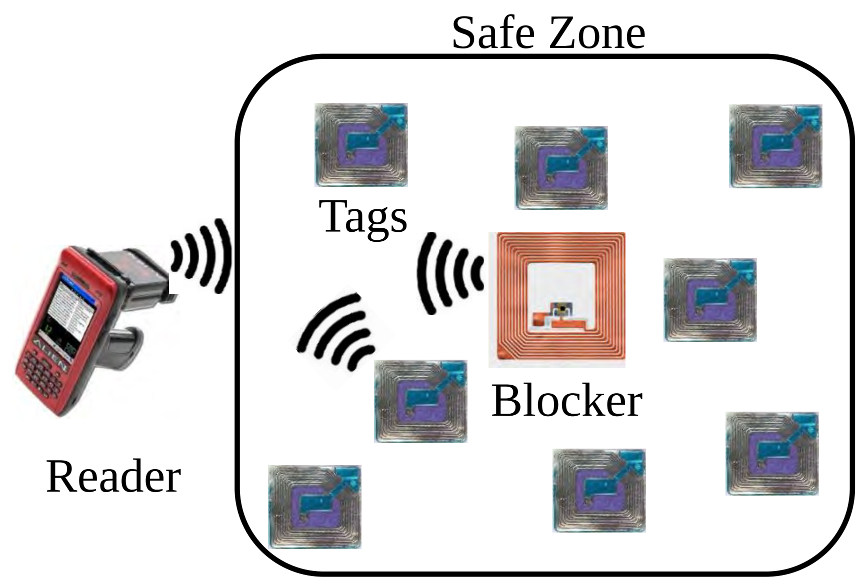
RFID Security - Solutions

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

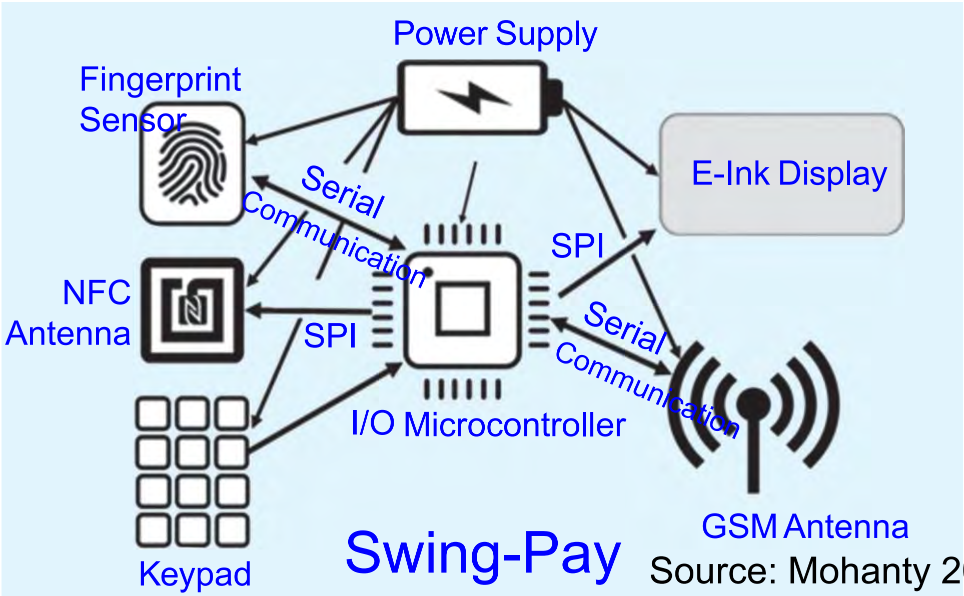
Eavesdropping

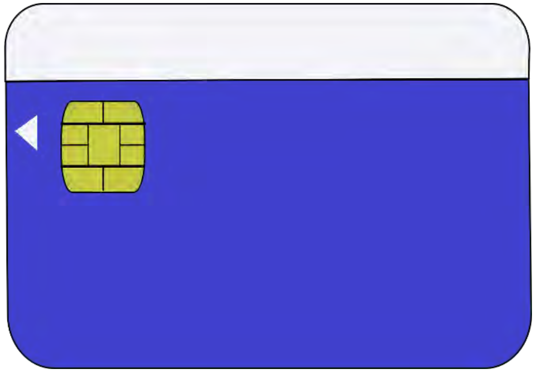
Source: http://resources.infosecinstitute.com/near-field-communication-nfc-technology-vulnerabilities-and-principal-attack-schema/

Relay Attack

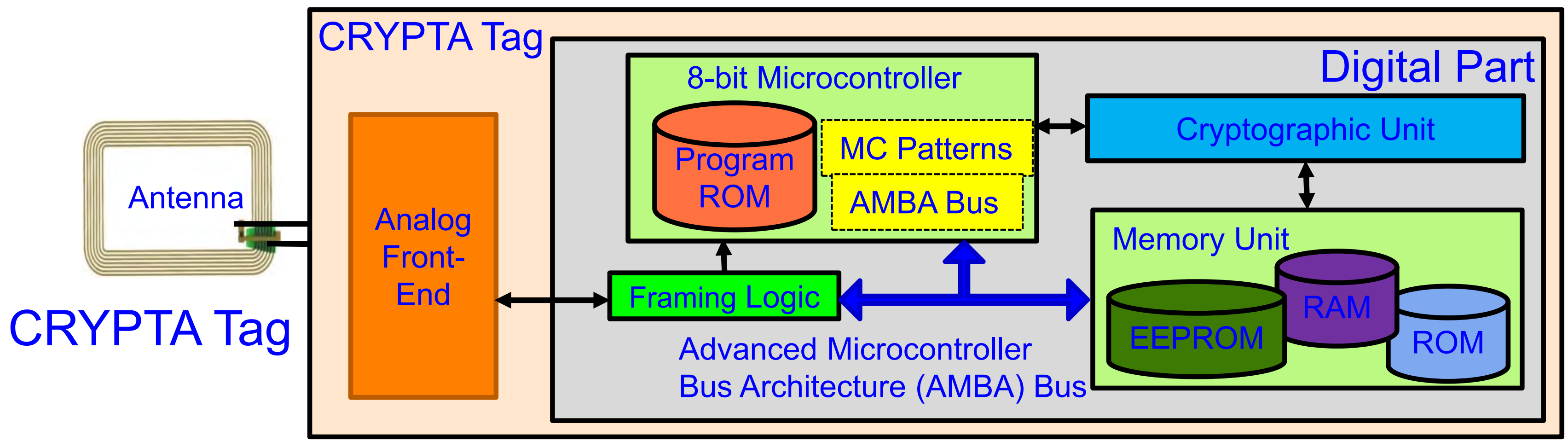
Source: https://www.slideshare.net/cgvwzq/on-relaying-nfc-payment-transactions-using-android-devices

NFC Security - Solutions





Source: Mohanty 2017, CE Magazine Jan 2017

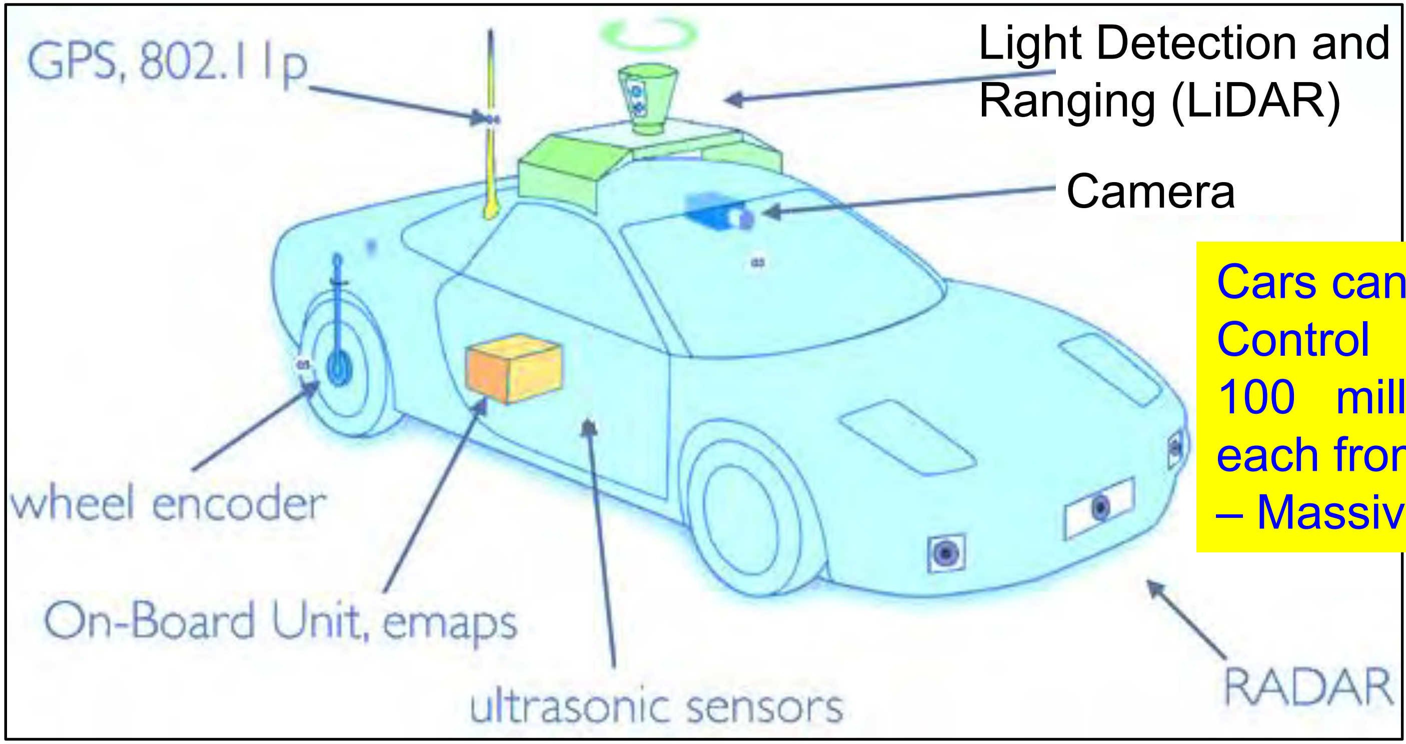


Source: Plos 2013, TVLSI Nov 2013

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

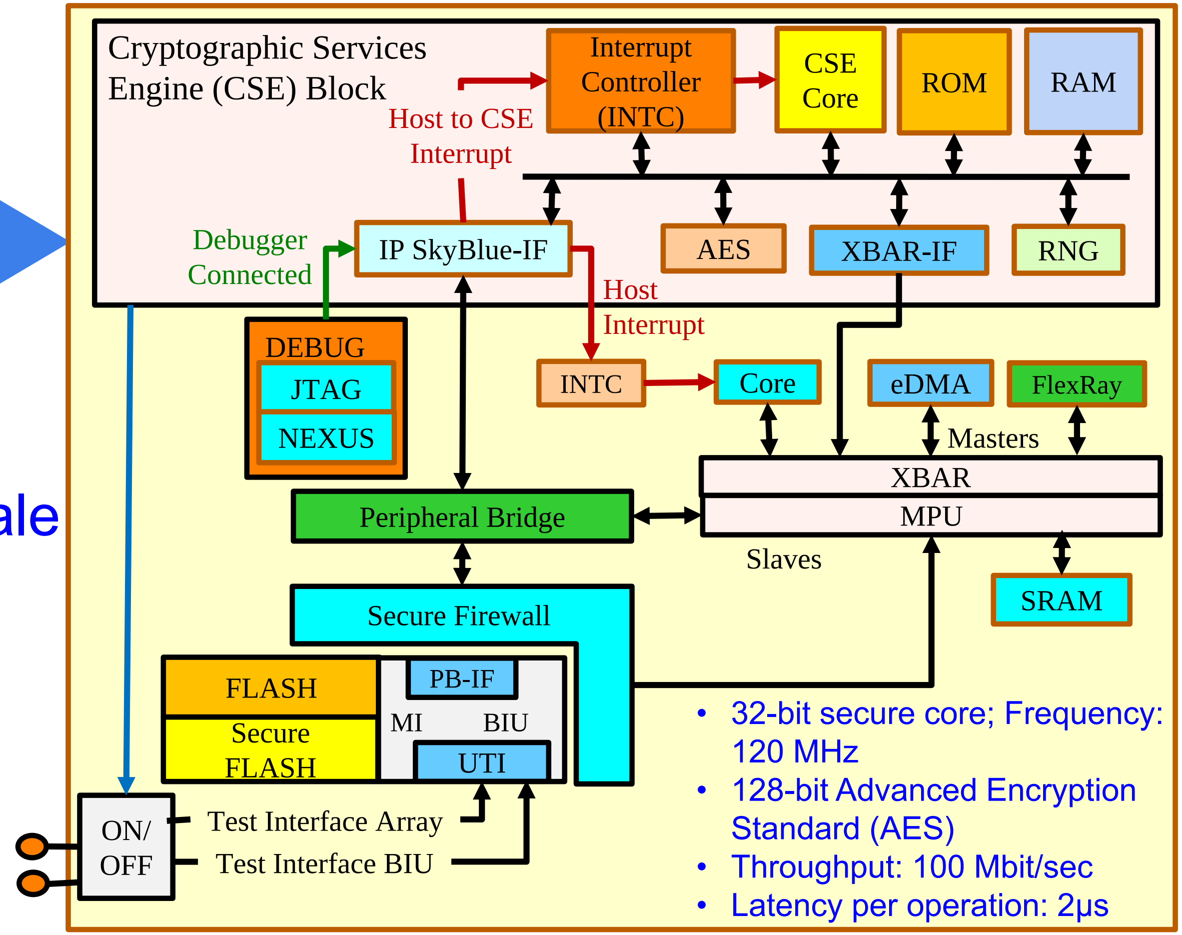
Source: https://www.mcafee.com/us/resources/white-papers/wp-automotive-security.pdf

Source: Petit 2015: IEEE-TITS Apr 2015

Autonomous Car Security – Cryptographic Hardware

Cryptographic Services Engine (CSE) Block

Qorivva MPC564xB/C Family from NXP/Freescale



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

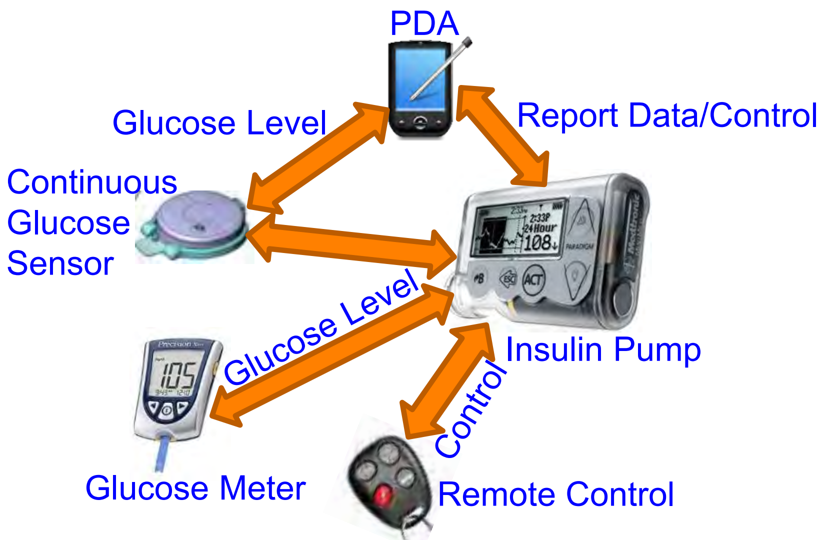
Source: http://www.nxp.com/assets/documents/data/en/supporting-information/DWF13_AMF_AUT_T0112_Detroit.pdf

Smart Healthcare - Security and Privacy Issue

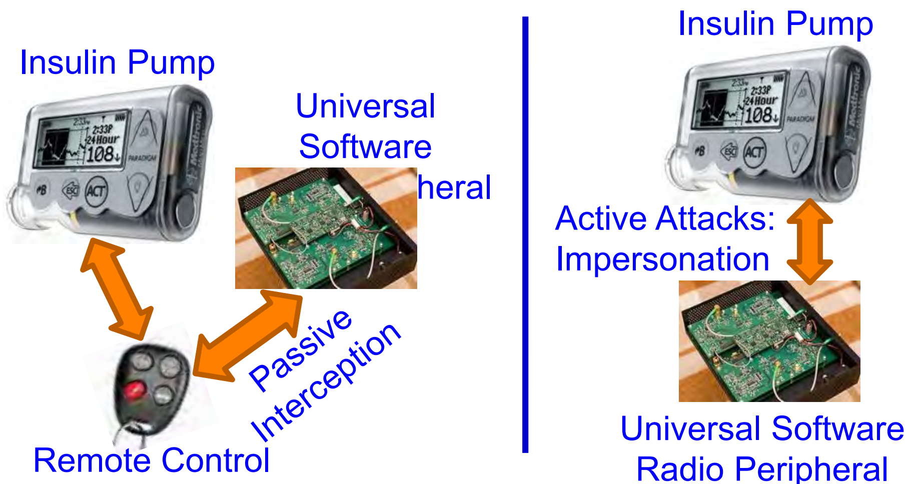
Selected Smart Healthcare Security/Privacy Challenges

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

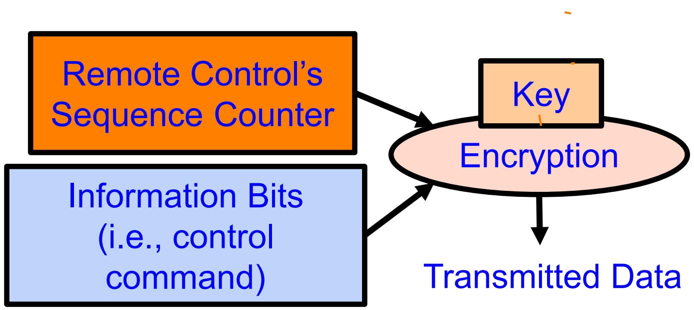
Smart Healthcare Security



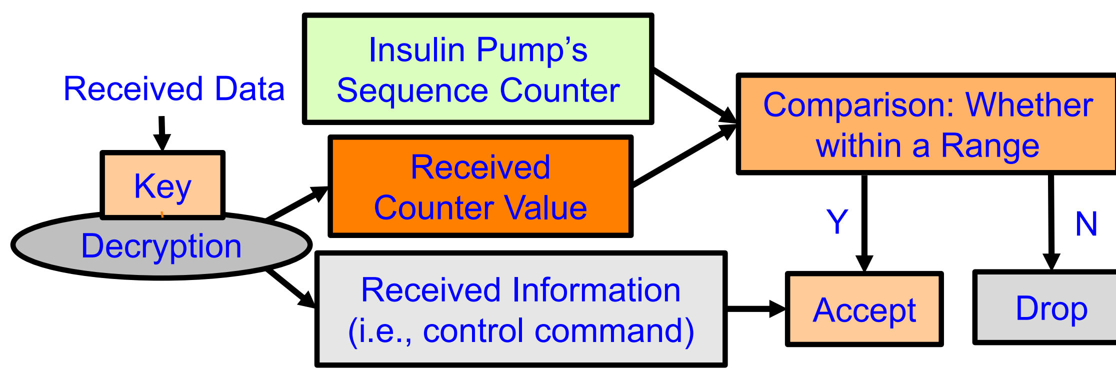
Insulin Delivery System



Security Attacks



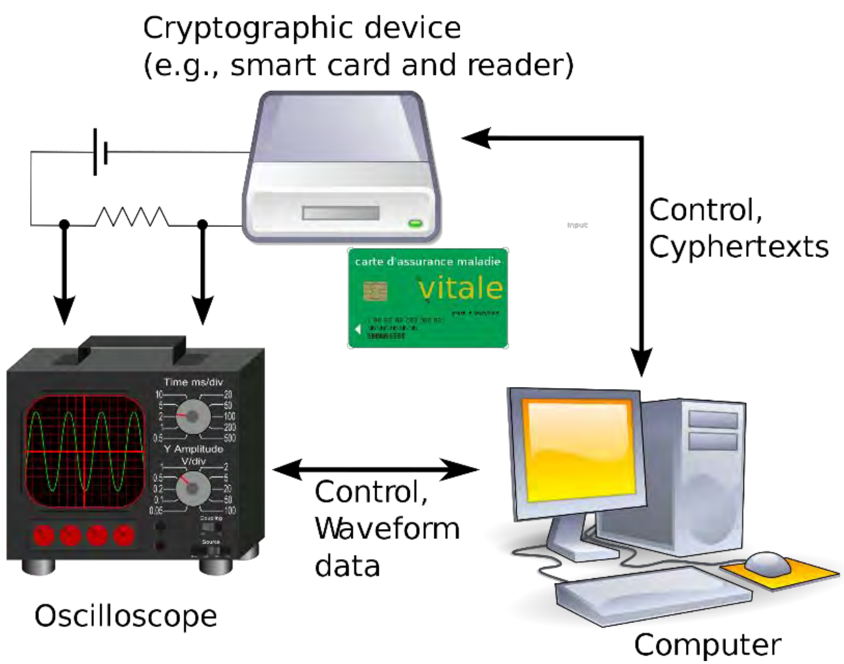
Rolling Code Encoder in Remote Control

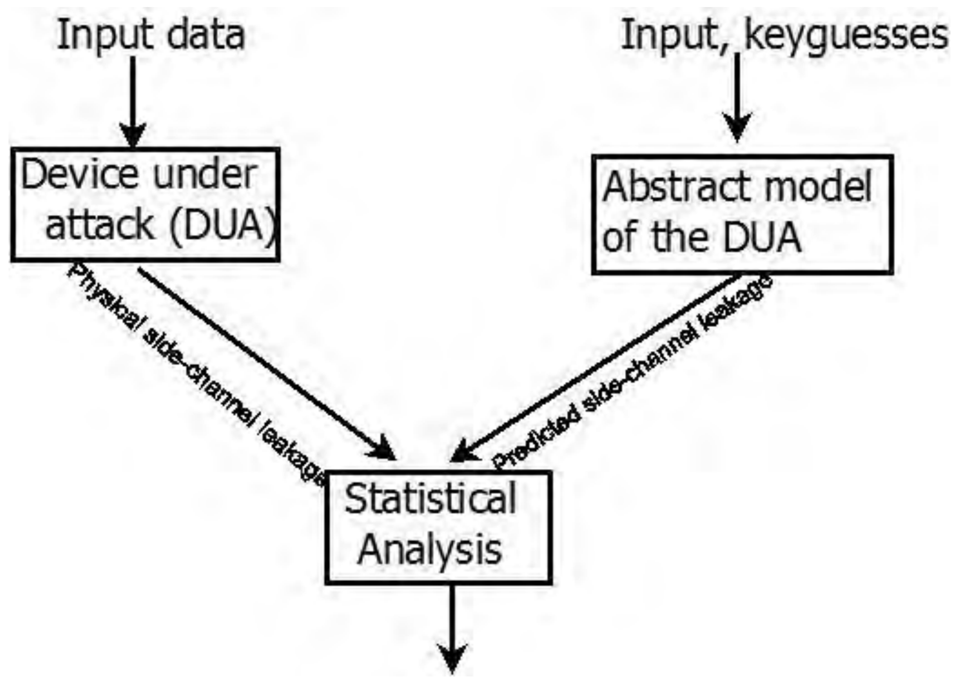


Rolling Code Decoder in Insulin Pump

Source: Li 2011, e-Health 2011

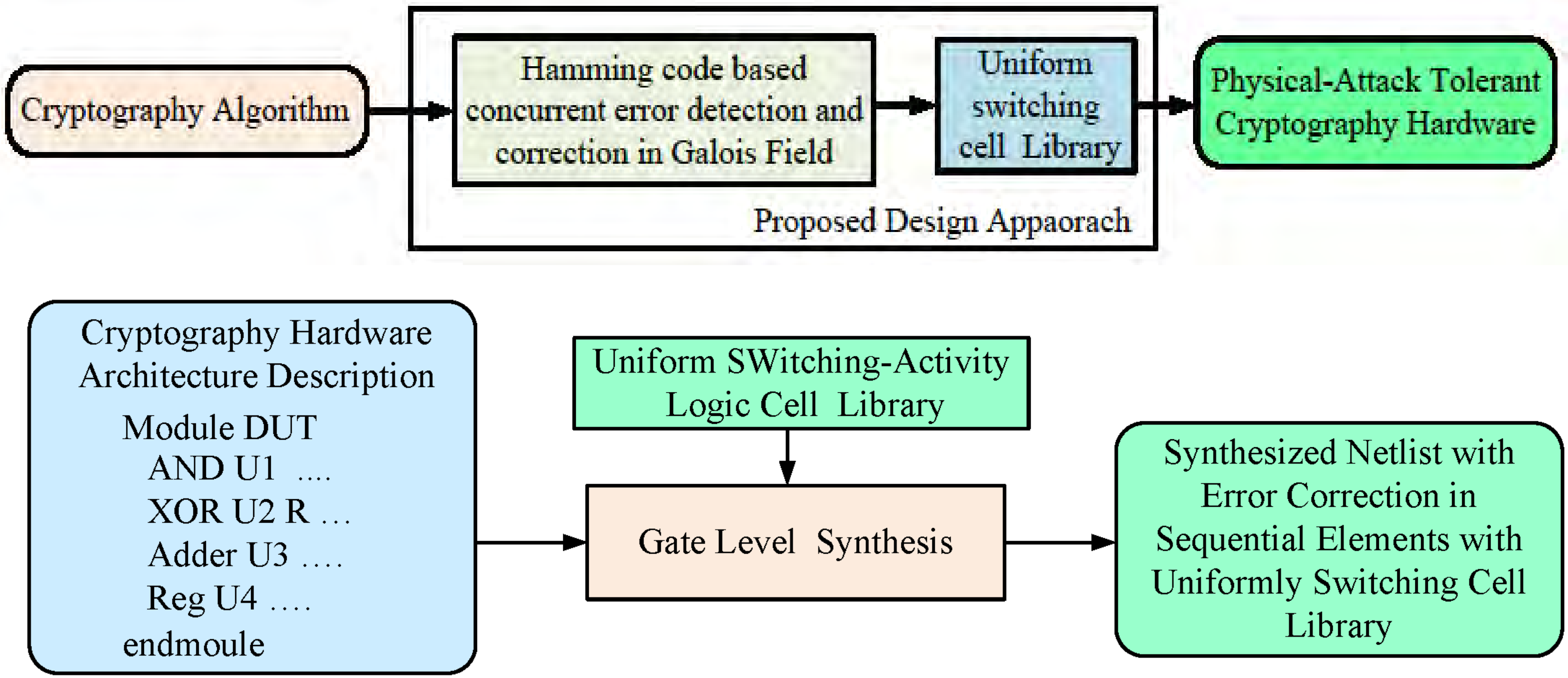
Side Channel Attacks – Differential and Correlation Power Analysis (DPA/CDA)





Decision on key guess

DPA Resilience Hardware - Synthesis Flow



Source: Mohanty 2013, Elsevier CEE 2013

Multimedia Piracy – Movie/Video

High

Studio

Cinema

On-line

Video on Demand

Piracy Threat Level

DVD/Blu-ray

Pay-TV Broadcasting

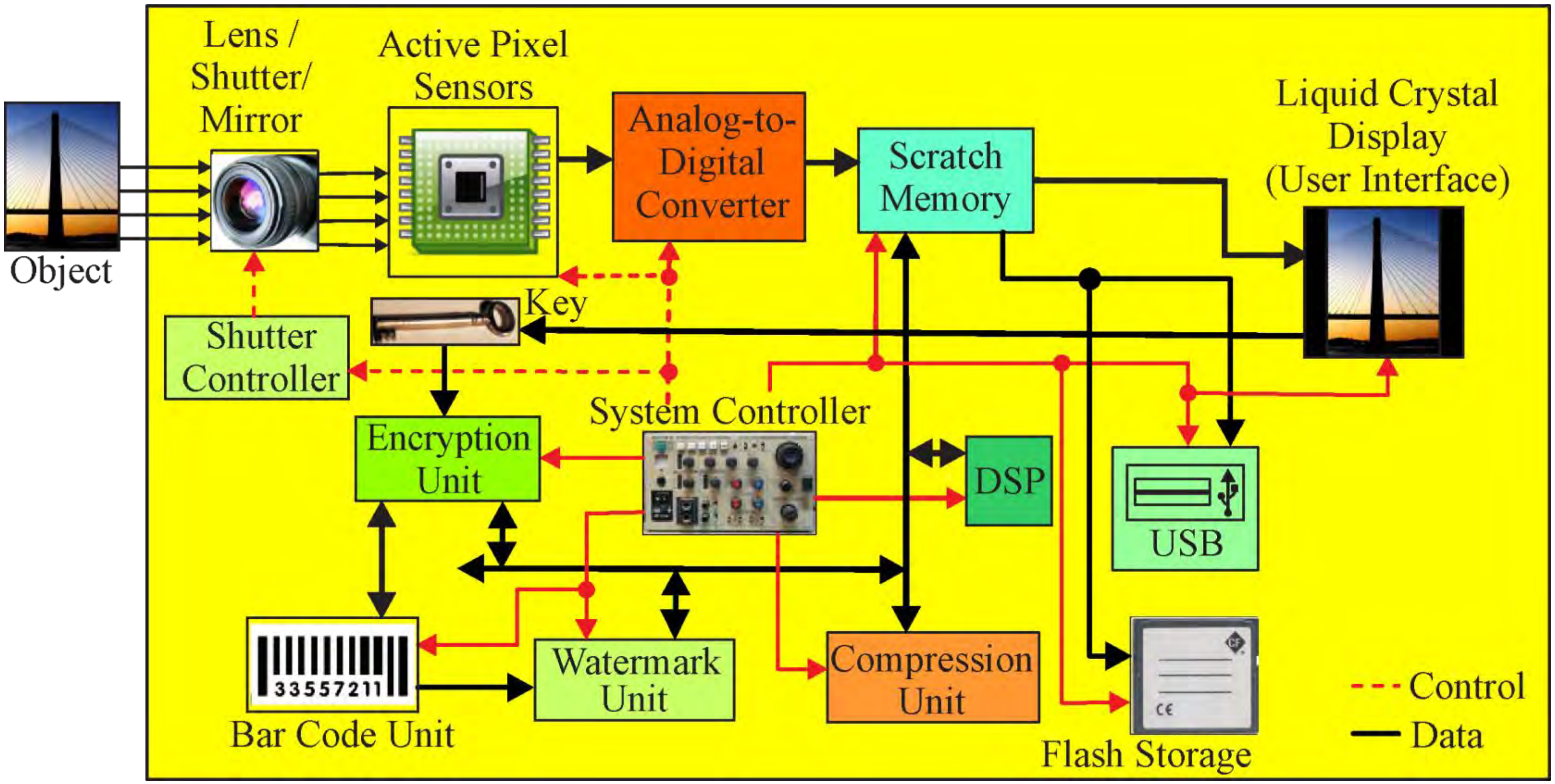
Free-to-Air Broadcasting

Low

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

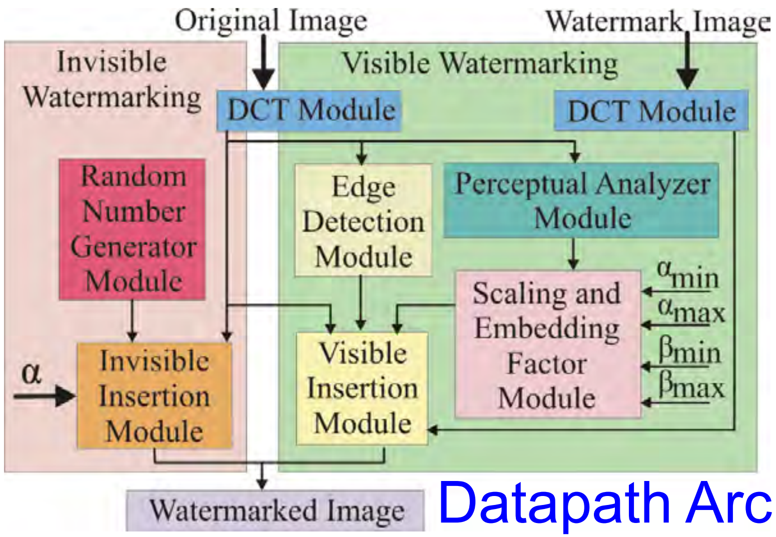
Source: http://www.ipi.org/ipi_issues/detail/illegal-streaming-is-dominating-online-piracy

A DRM Hardware Integrated CE System – Secure Digital Camera (SDC) Example

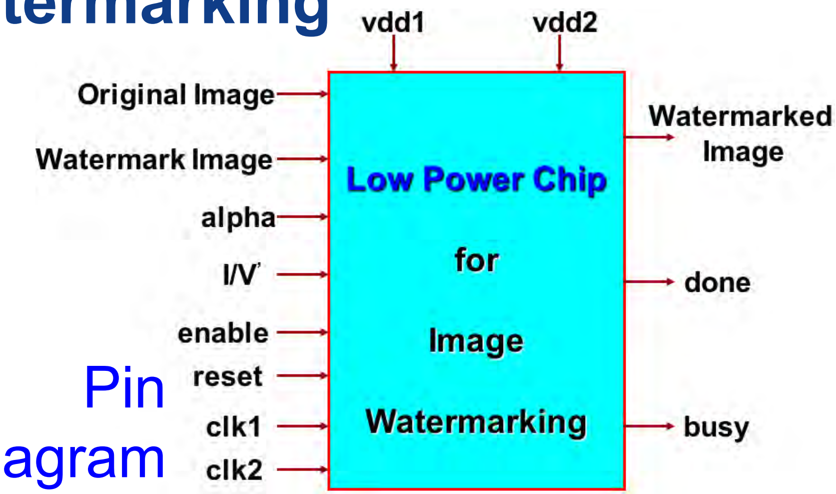


Source: Mohanty 2017, CE Magazine July 2017; Mohanty 2009, JSA Oct 2009

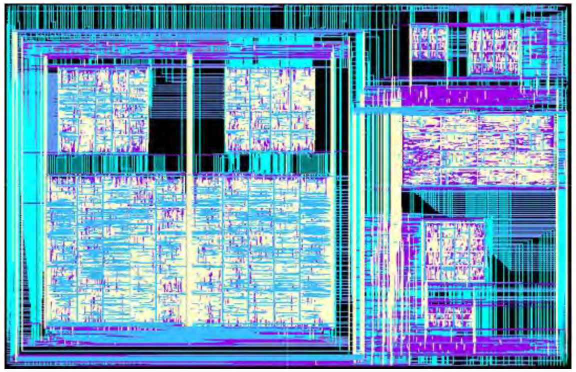
Copyright Protection Hardwares – DCT Domain Watermarking



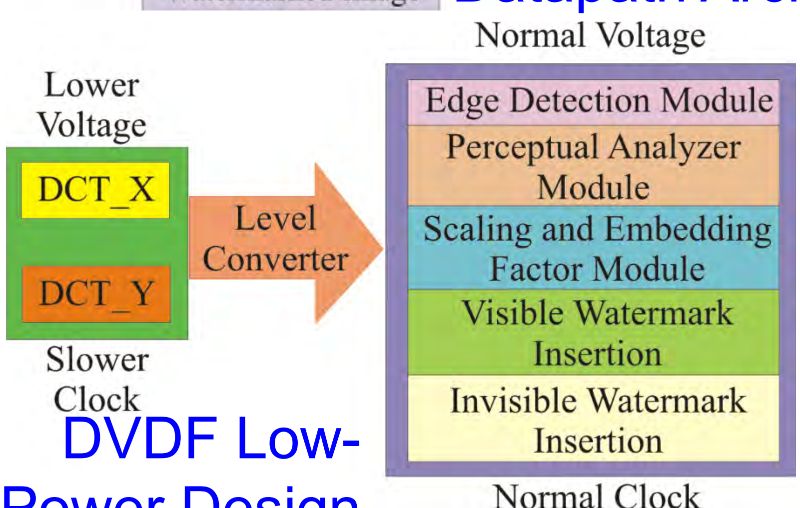
Datapath Architecture



Pin Diagram



Hardware Layout

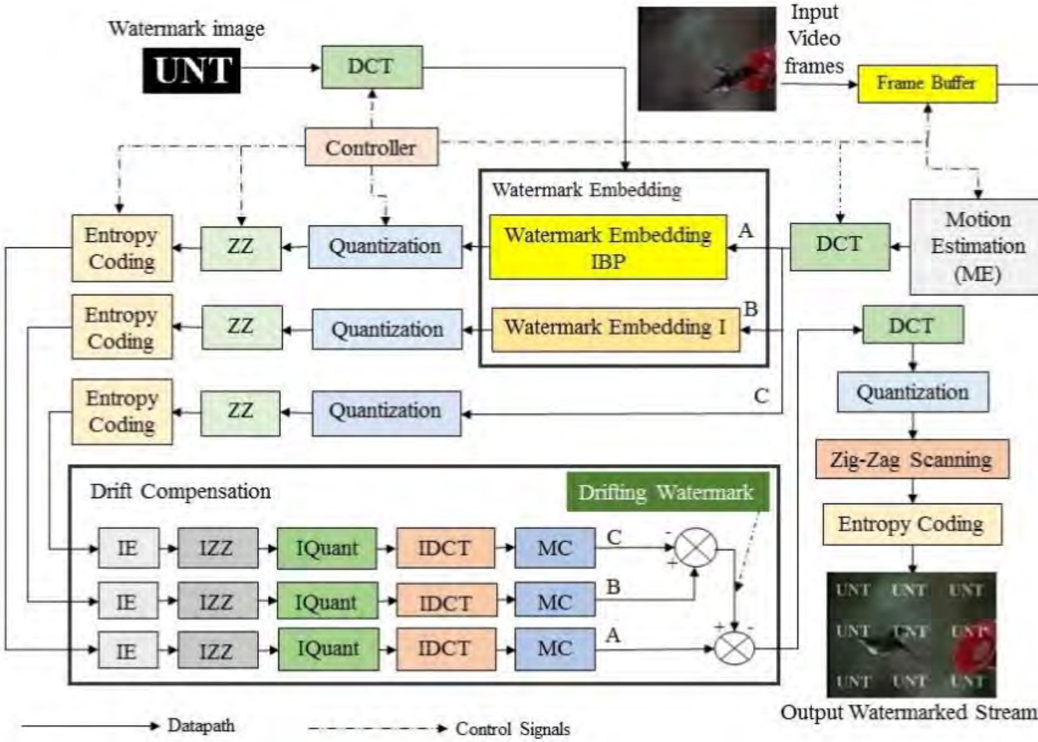


DVDF Low-Power Design

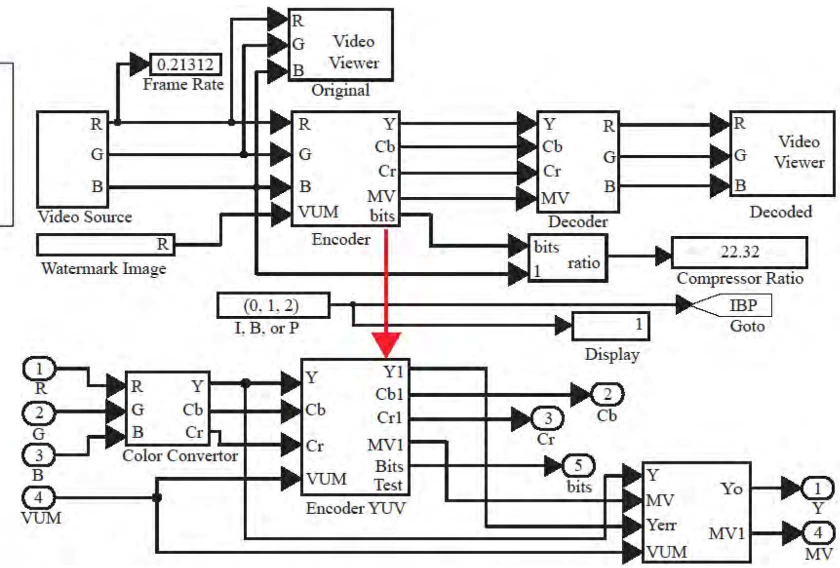
Physical Design Data
Total Area : 16.2 sq mm
No. of Transistors: 1.4 million
Power Consumption: 0.3 mW

Source: Mohanty 2006, TCASII May 2006

Copyright Protection Hardware –
MPEG-4 Video Watermarking



Video Watermarking Architecture Datapath



Video Watermarking Architecture: Simulink Model

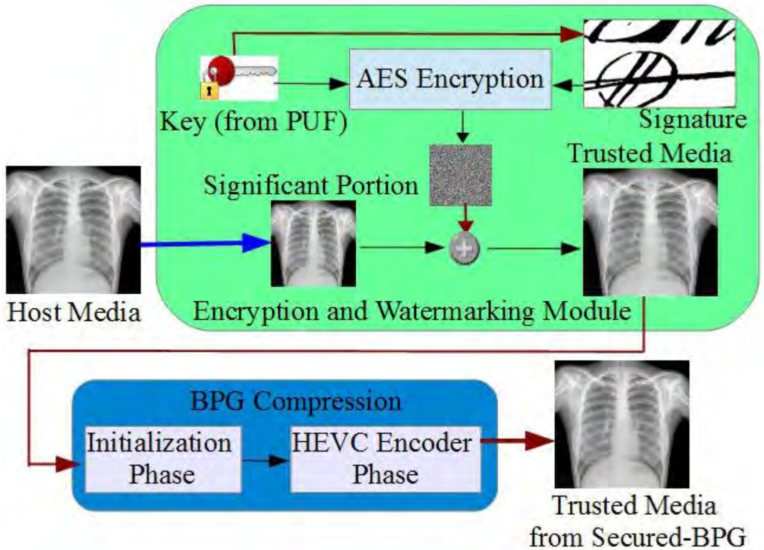
FPGA Prototyping

Throughput: 44 frames/sec

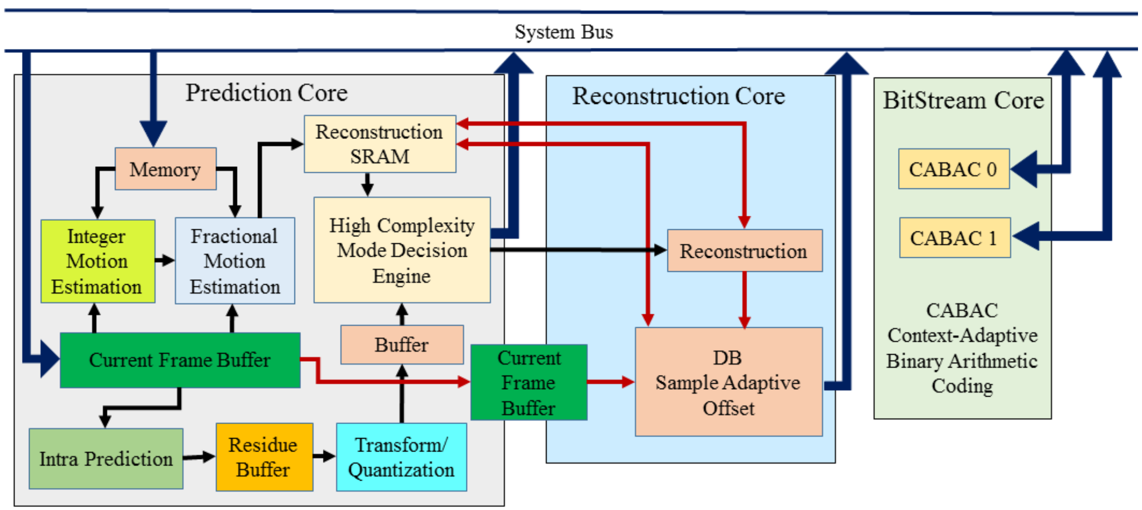
Logic Elements in FPGA Prototyping : 28322

Source: Mohanty 2011, JSS May 2011

DRM Hardware - Secure Better Portable Graphics (SBPG)



Idea of Secure BPG (SBPG)

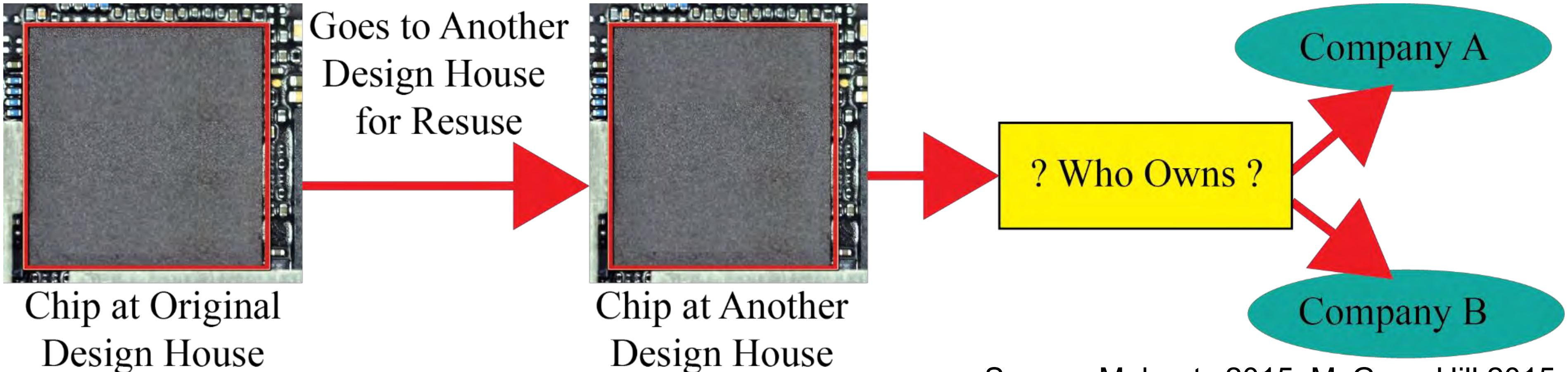


High-Efficiency Video Coding Architecture

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

Source: Mohanty 2016, ISVLSI 2016 and EuroSimE 2016

Hardware IP Right Infringement



Source: Mohanty 2015, McGraw-Hill 2015

Hardware IPR Infringement

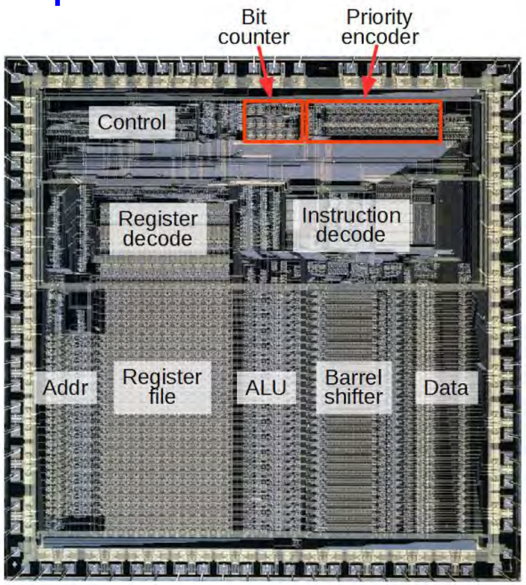
- False Ownership Claim
- Sub-licensing
- Piracy (Reverse Engineering)

Hardware Reverse Engineering

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

CE System disassembly
Subsystem identification, modification

Chip-Level Modification



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

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

Counterfeit Hardware

2014 Analog Hardware Market (Total Shipment Revenue US $)

Wireless Market
$18.9 billion (34.8%)

Consumer Electronics
$9.0 billion (16.6%)

Industrial Electronics
$8.9 billion (16.5%)

Automotive
$8.5 billion (15.7%)

Data Processing
$6.0 billion (11%)

Wired Communications
$2.9 billion (5.4%)

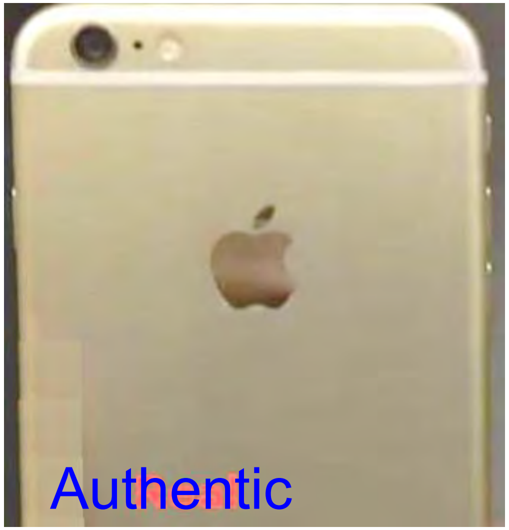
Source: https://www.slideshare.net/rorykingihs/ihs-electronics-conference-rory-king-october

Top counterfeits could have impact of $300B on the semiconductor market.

Source: https://www.slideshare.net/rorykingihs/ihs-electronics-conference-rory-king-october

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/

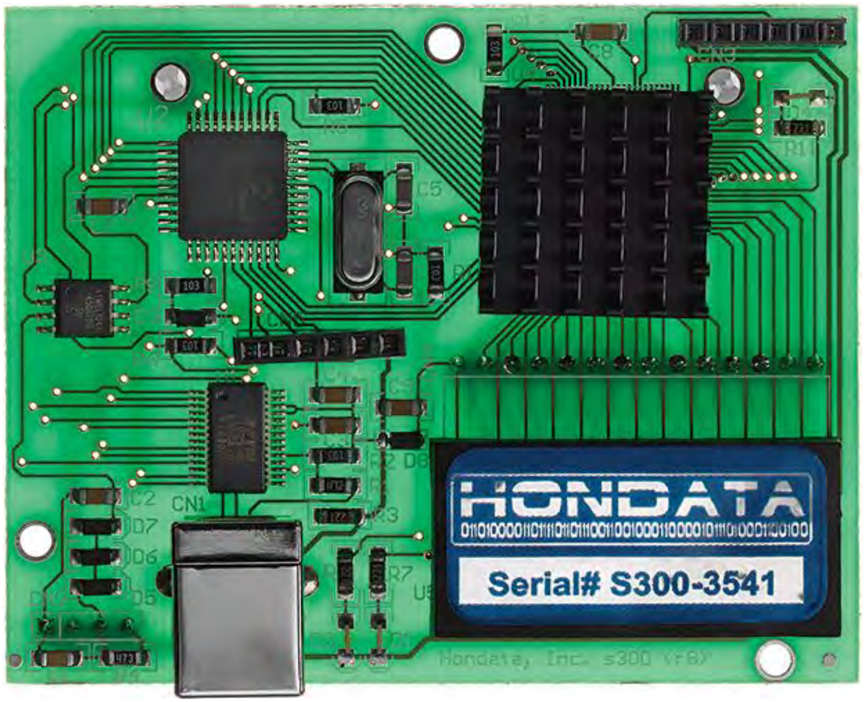


Source: http://www.manoramaonline.com/

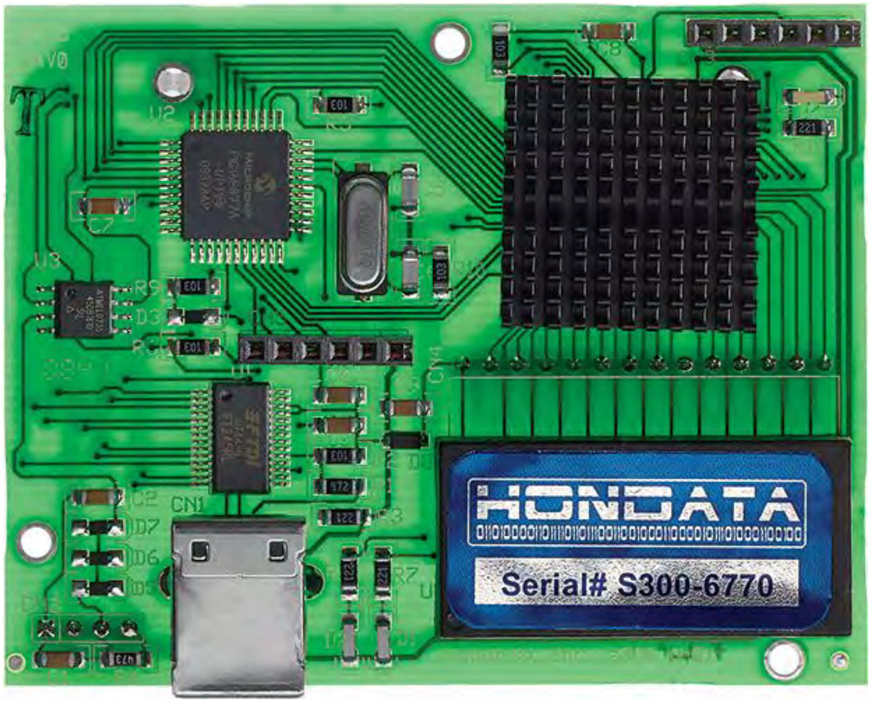
Source: http://www.cbs.cc/fake-capacity-usb-drives/

Typical Consumer Electronics

Cloned/Fake Electronics Hardware – Example - 2



Fake

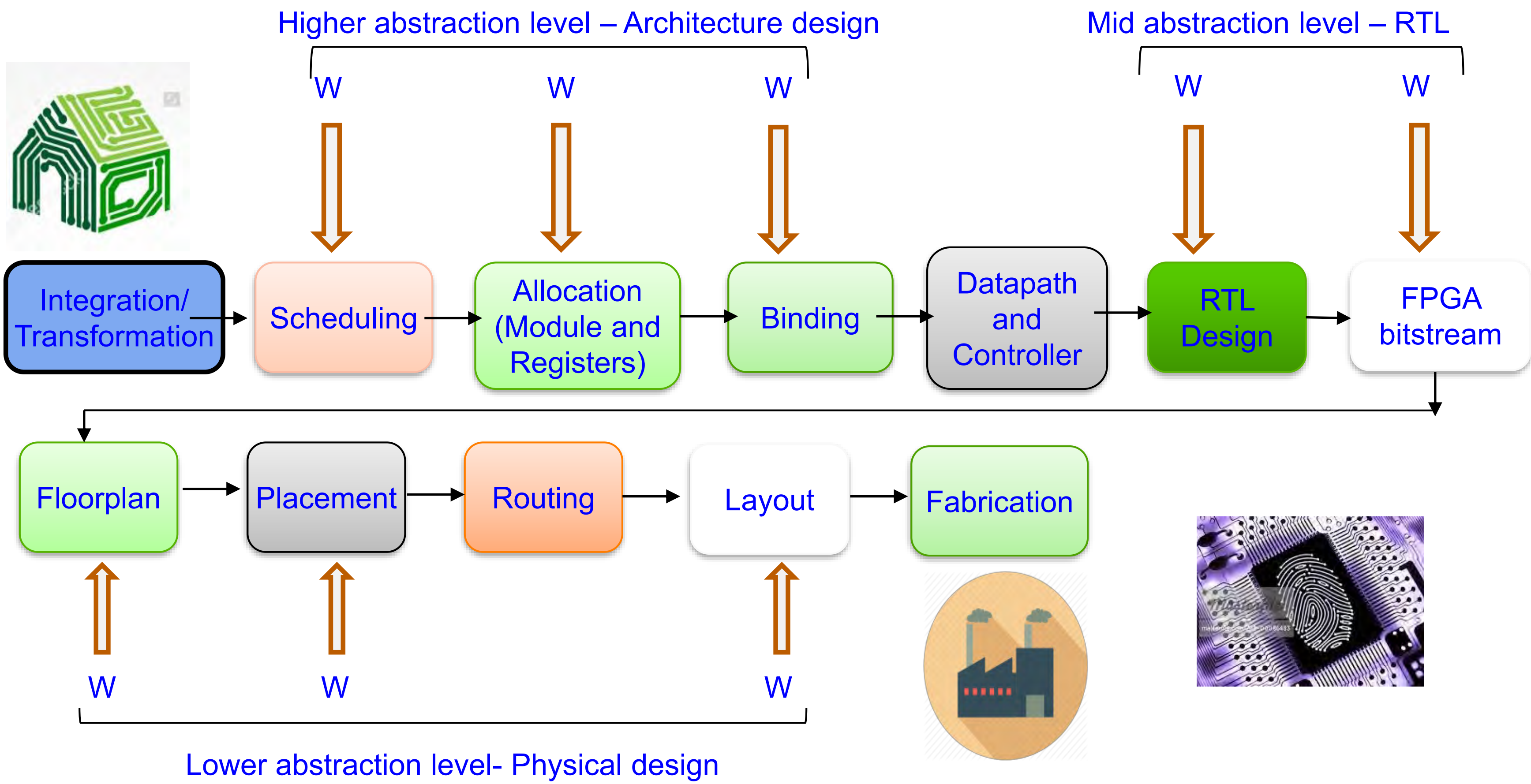


Authentic

A plug-in for car-engine computers.

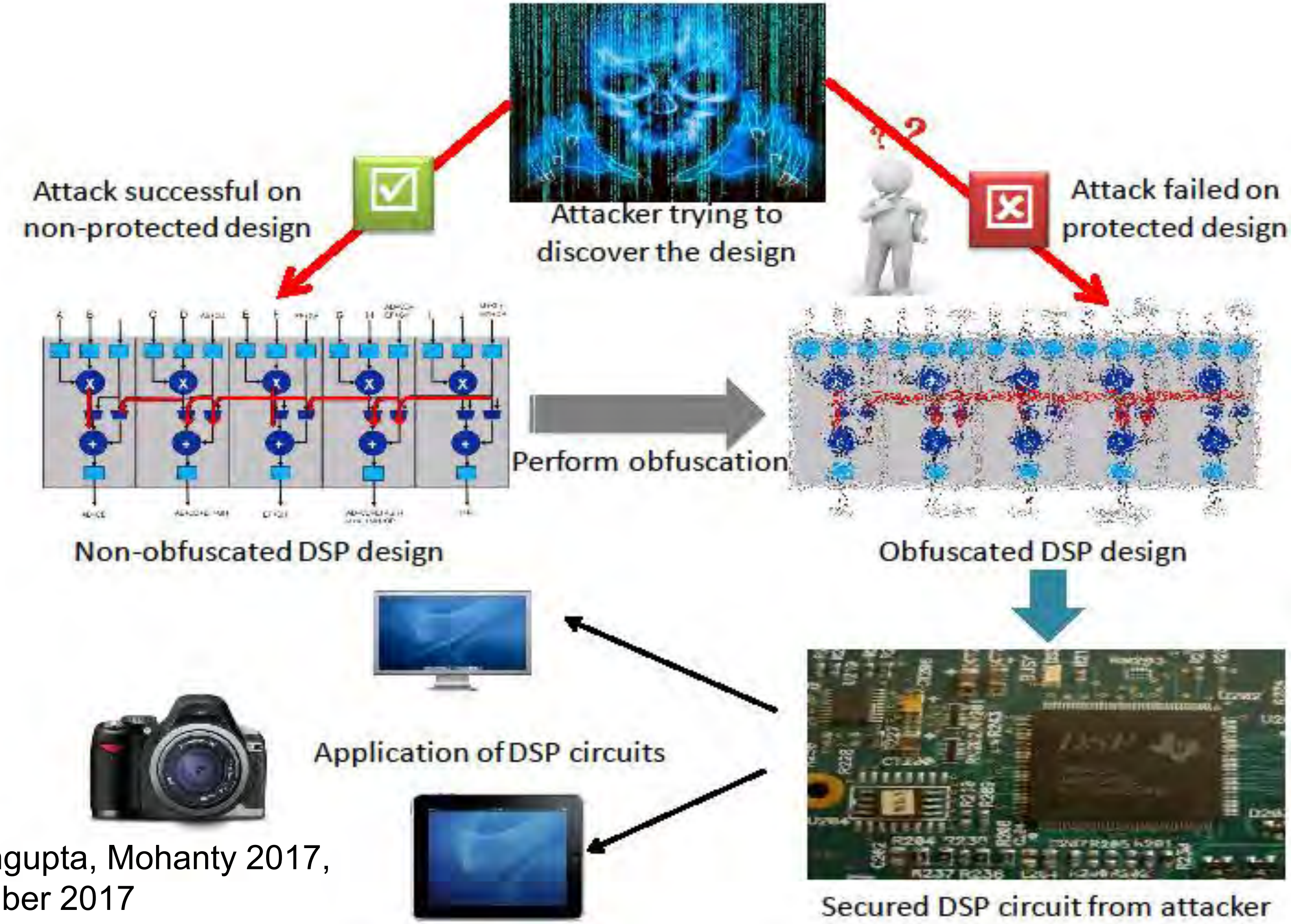
Source: http://spectrum.ieee.org/computing/hardware/invasion-of-the-hardware-snatchers-cloned-electronics-pollute-the-market

Digital Hardware - Watermark



Source: Mohanty 2017: CE Magazine October 2017

Digital Hardware – Obfuscation



Source: Sengupta, Mohanty 2017, TCE November 2017

Obfuscation – Intentional modification of the description or the structure of electronic hardware to conceal its functionality for making reverse-engineering difficult.

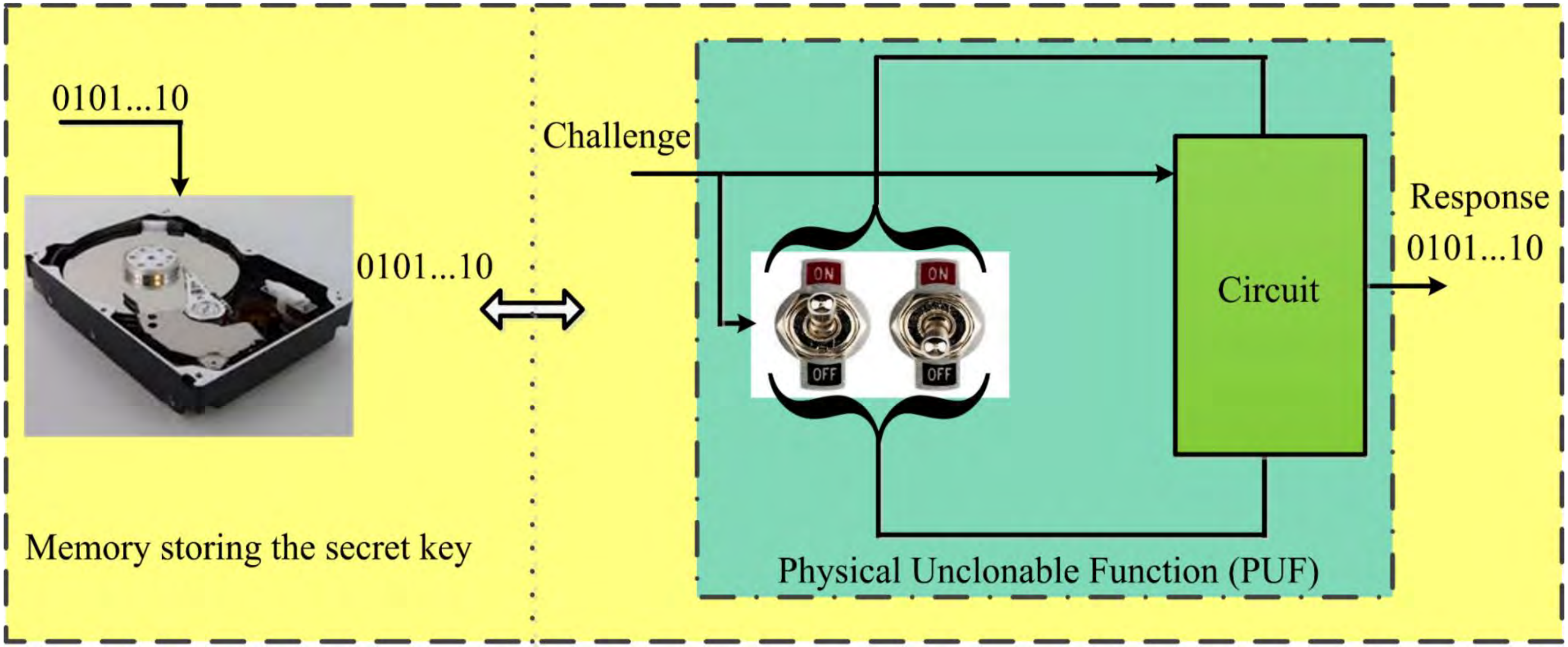
Physical Unclonable Function (PUF)

- 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).

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

Source: Mohanty 2017, Springer ALOG Dec 2017

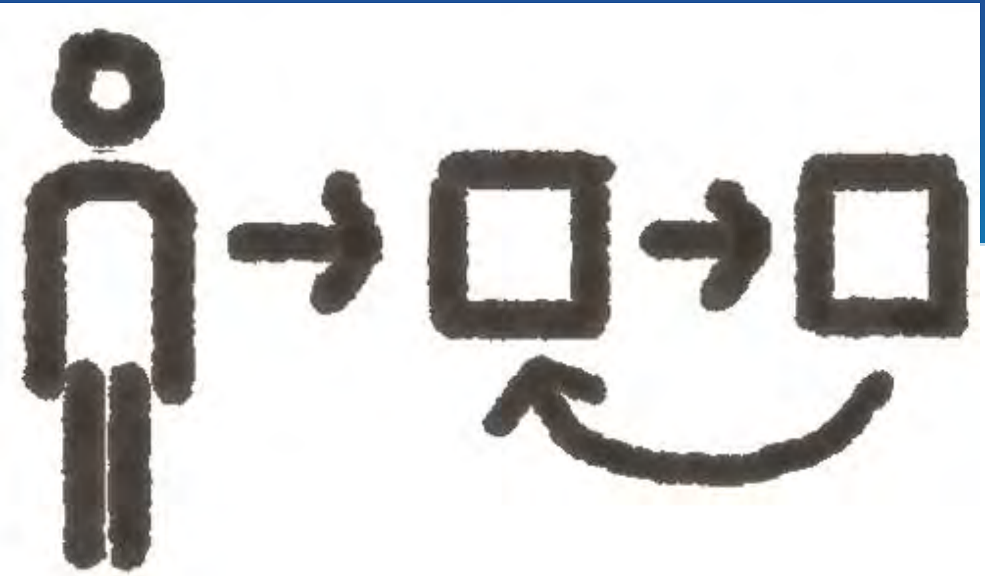
PUF - Principle



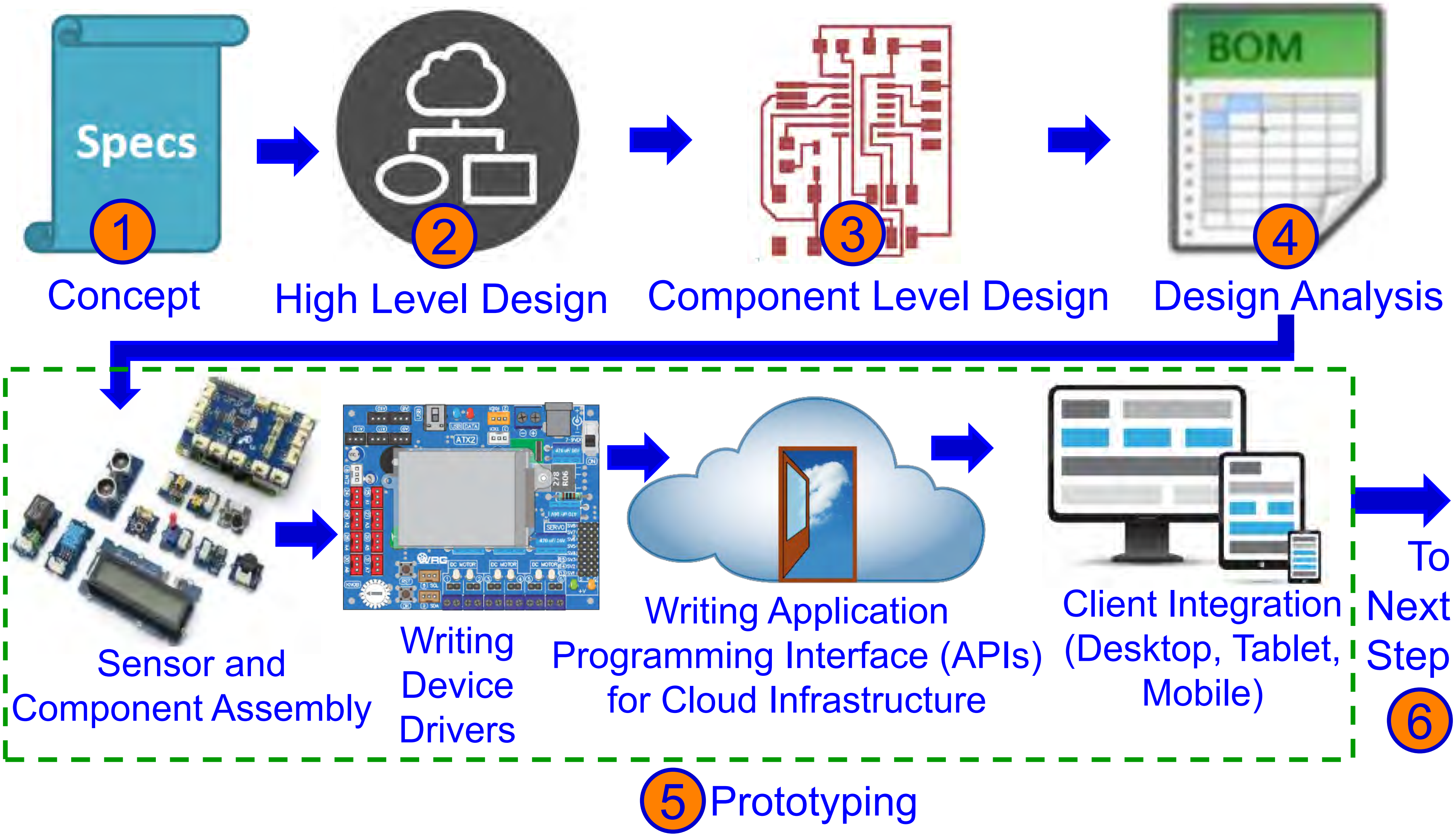
PUFs don't store keys in digital memory, rather derive a key based on the physical characteristics of the hardware; thus secure.

Source: Mohanty 2017, IEEE Potentials Nov-Dec 2017

Design Flow



IoT – Design Flow



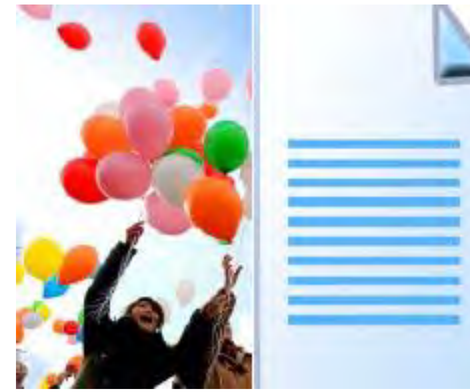
Source: http://events.linuxfoundation.org/sites/events/files/slides/Design%20-%20End-to-End%20%20IoT%20Solution%20-%20Shivakumar%20Mathapathi.pdf

IoT – Design Flow

6 Field Testing

7 Release of Beta Version

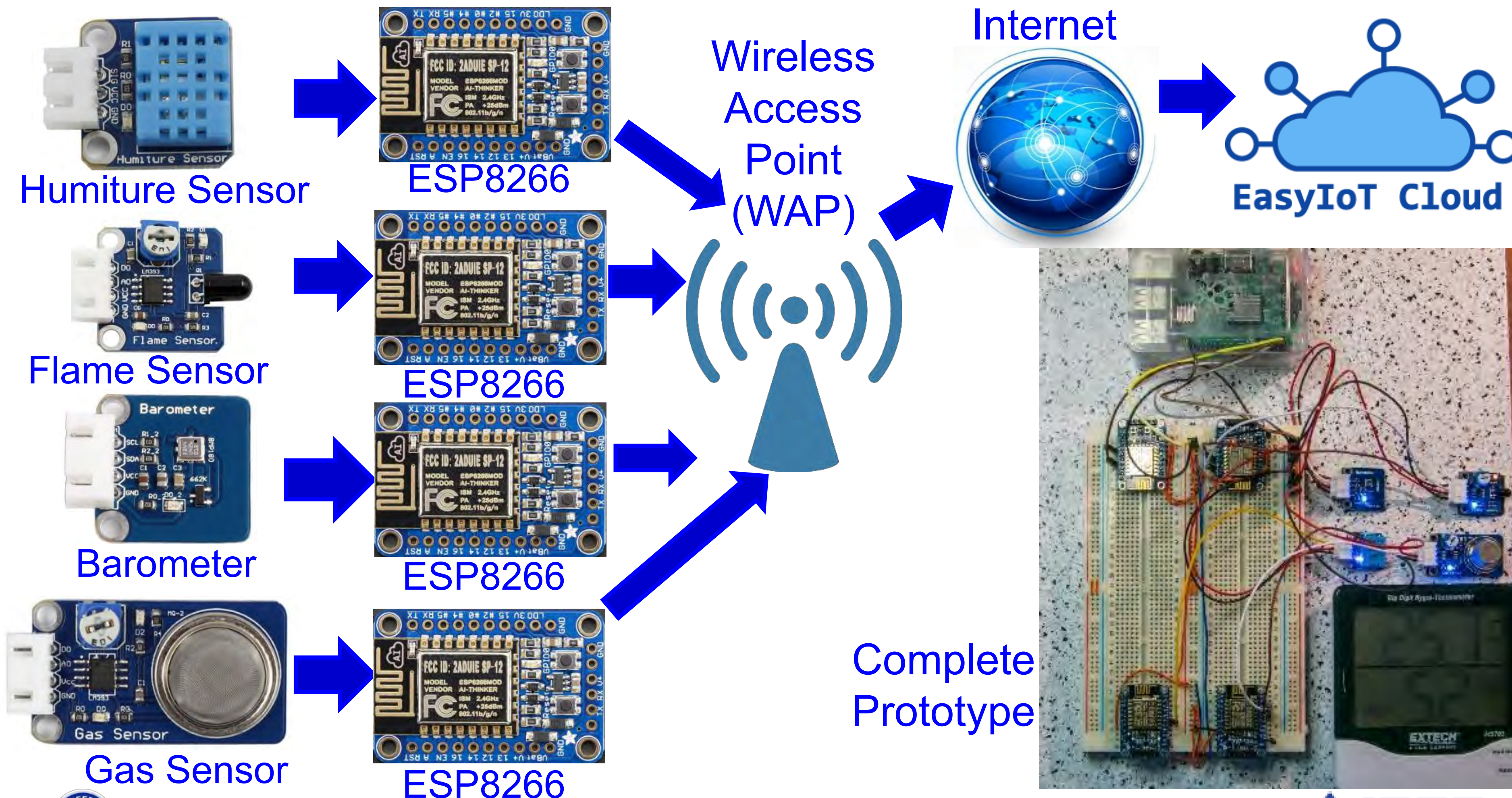
8 Production



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



Complete Prototype

Source: UNT ETECH Senior Project 2017

Hardware for IoT

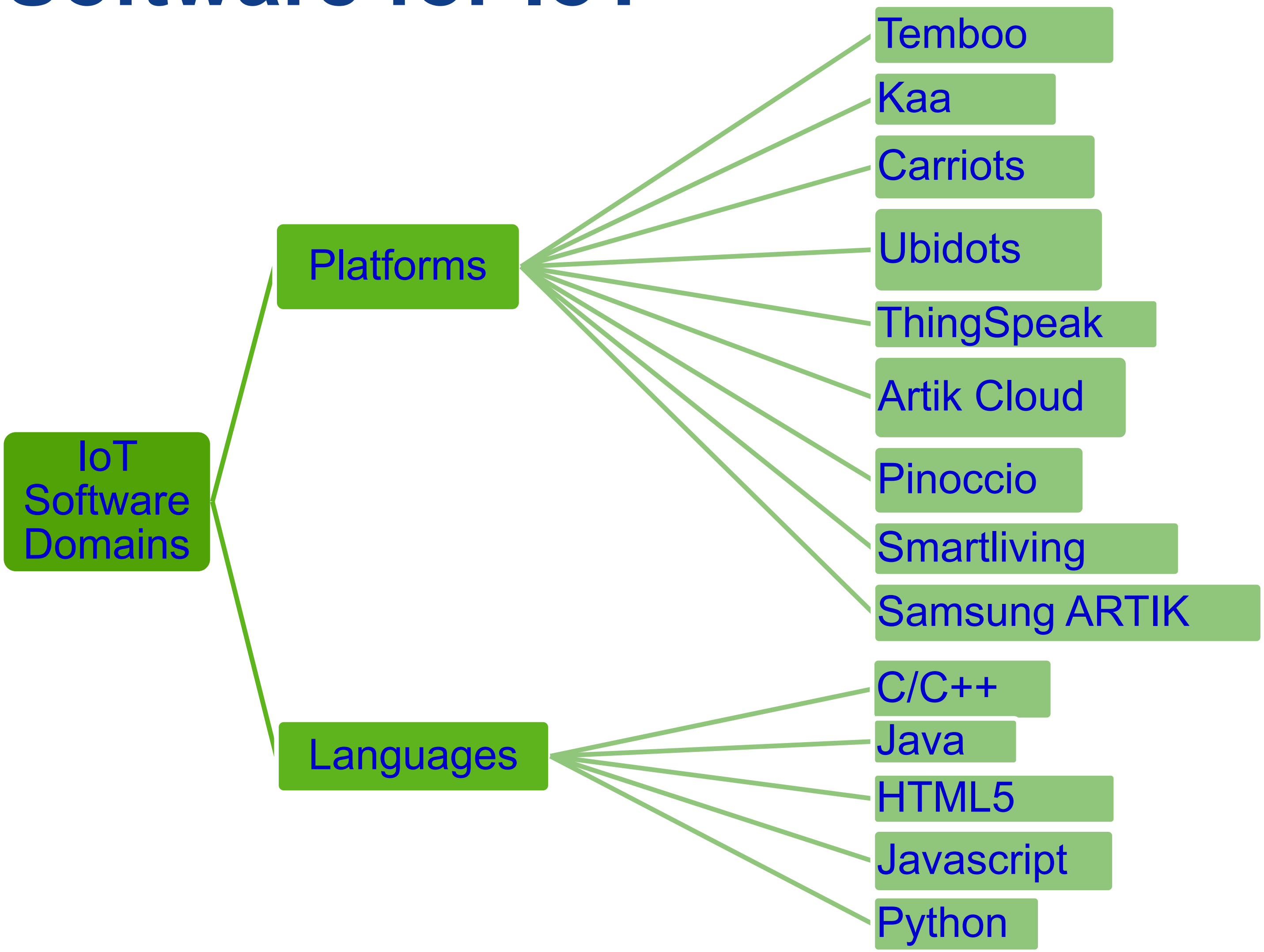
IoT Hardware Domains

- 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

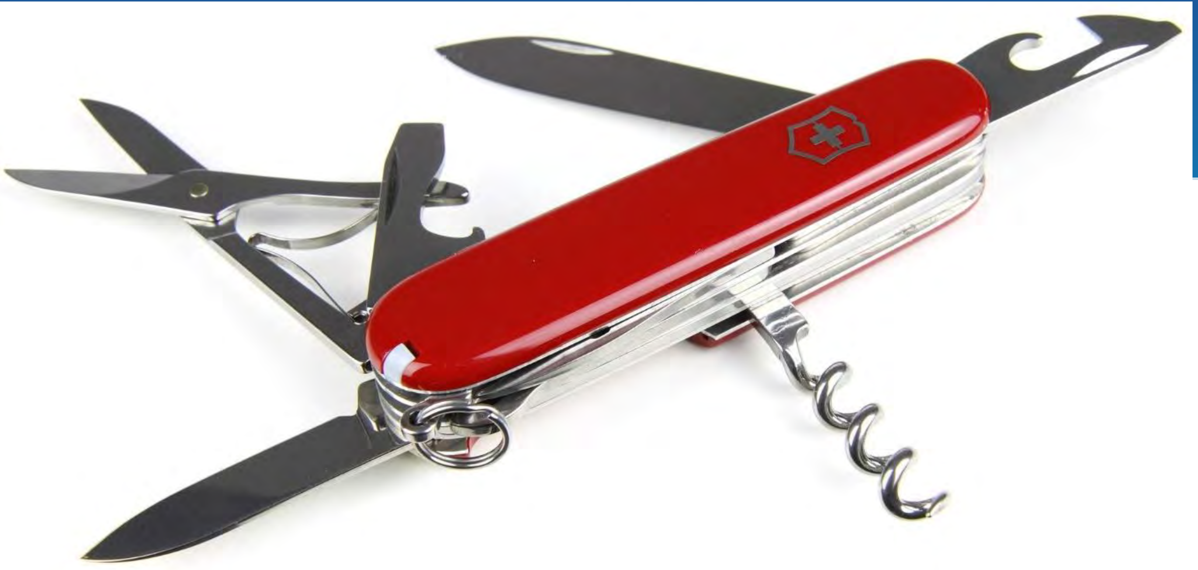
Source: Singh 2017, CE Magazine, April 2017

Software for IoT



Source: Singh 2017, CE Magazine, April 2017

Tools and Solutions



IoT: Design and 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 Simulator - CUPCARBON

About

– CUPCARBON is a smart city and Internet of Things Wireless sensor network simulator (SCI-WSN)

Source: http://www.cupcarbon.com/

Objective

– Design, Visualize, Debug
– Validate distributed algorithms
– Create environmental scenarios

Environments

➢ Design of mobility scenarios and the generation of natural events such as fires and gas as well as the simulation of mobiles such as vehicles and flying objects (e.g. UAVs, insects, etc.).

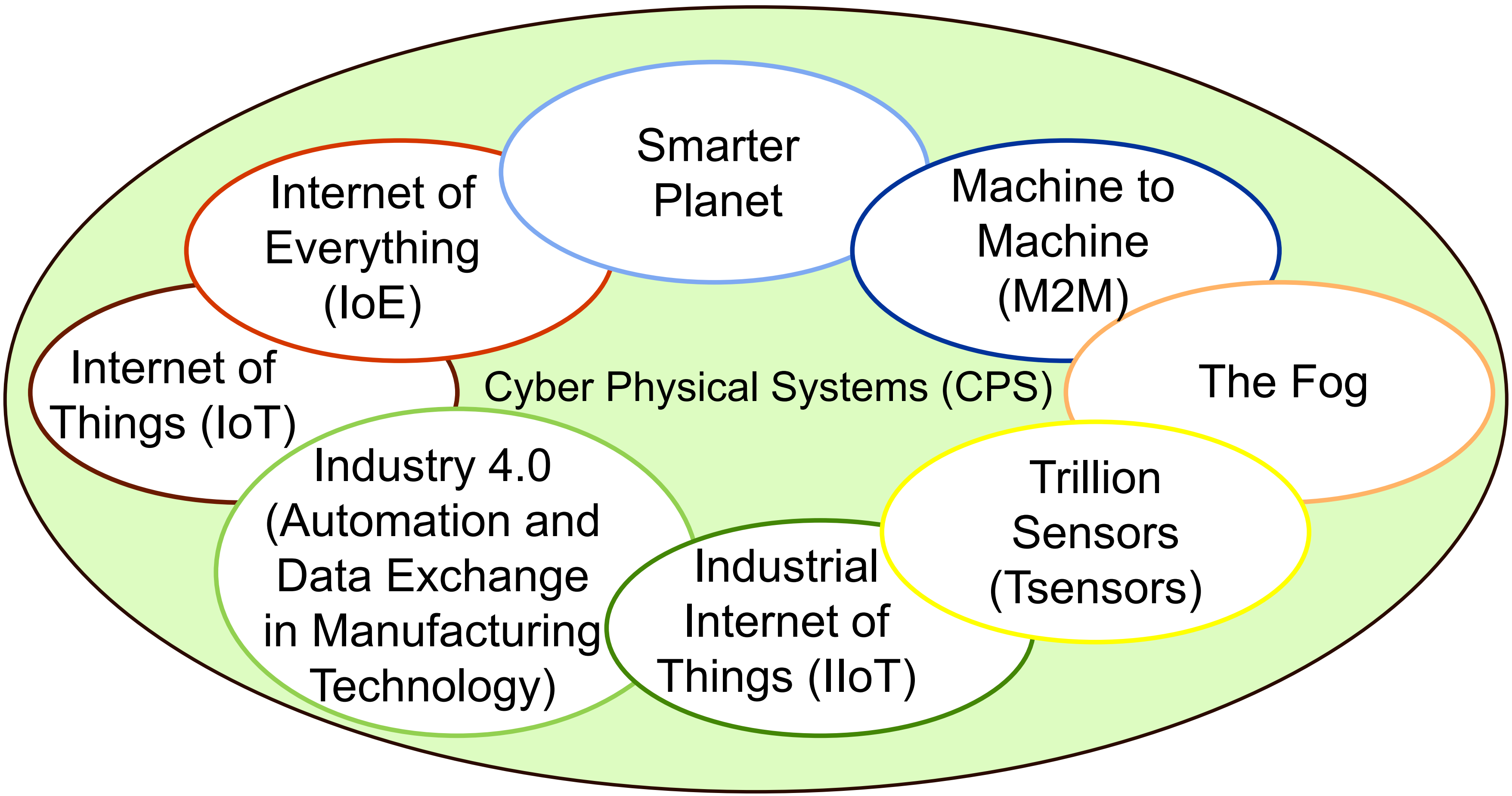
➢ A discrete event simulation of WSNs which takes into account the scenario designed on the basis of the first environment.

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.

Related Buzzwords

Some related Buzzwords



Source: Sangiovanni-Vincentelli 2016, ISC2 2016

IoT Vs Sensor Networks

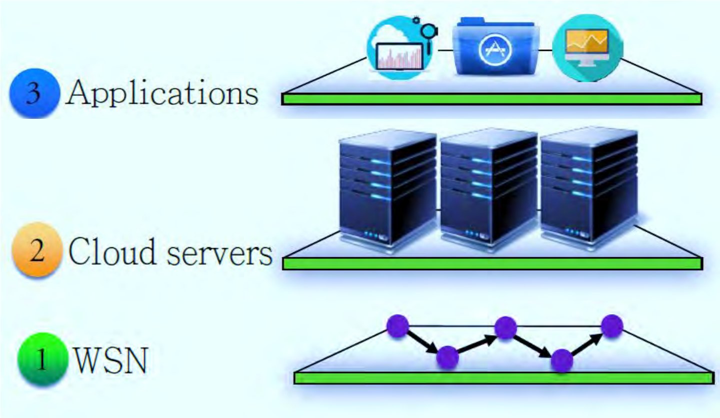
Wireless Sensor Networks (WSN)

- 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

- 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.

IoT adds value to data!



Source: Nia 2017, IEEE TETC 2017

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.

Cloud Computing

- Scalability
- Big Data Analytics
- Software as a Service (SaaS)
- Infrastructure as a Service (IaaS)
- Platform as a Service (PaaS)
- Resource Pooling
- Elastic Compute
- Secure Access

Edge Computing

- Dedicated App Hosting
- Embedded OS
- Device management
- Data Service
- Communication

- Real-Time Control
- Real-Time Analysis
- Data Ownership Protection
- Secure Multi-Cloud interworking

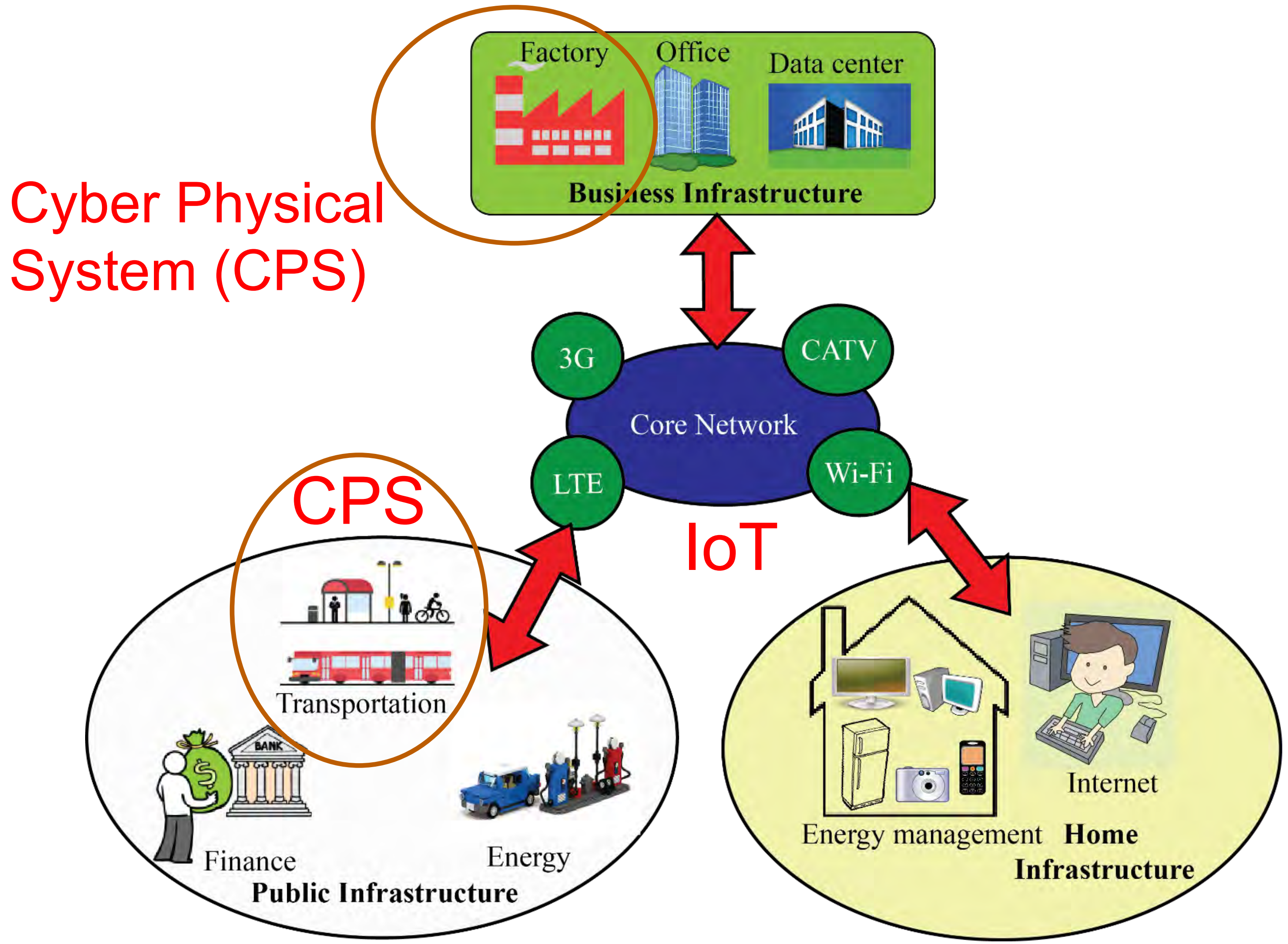
Fog Computing

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

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

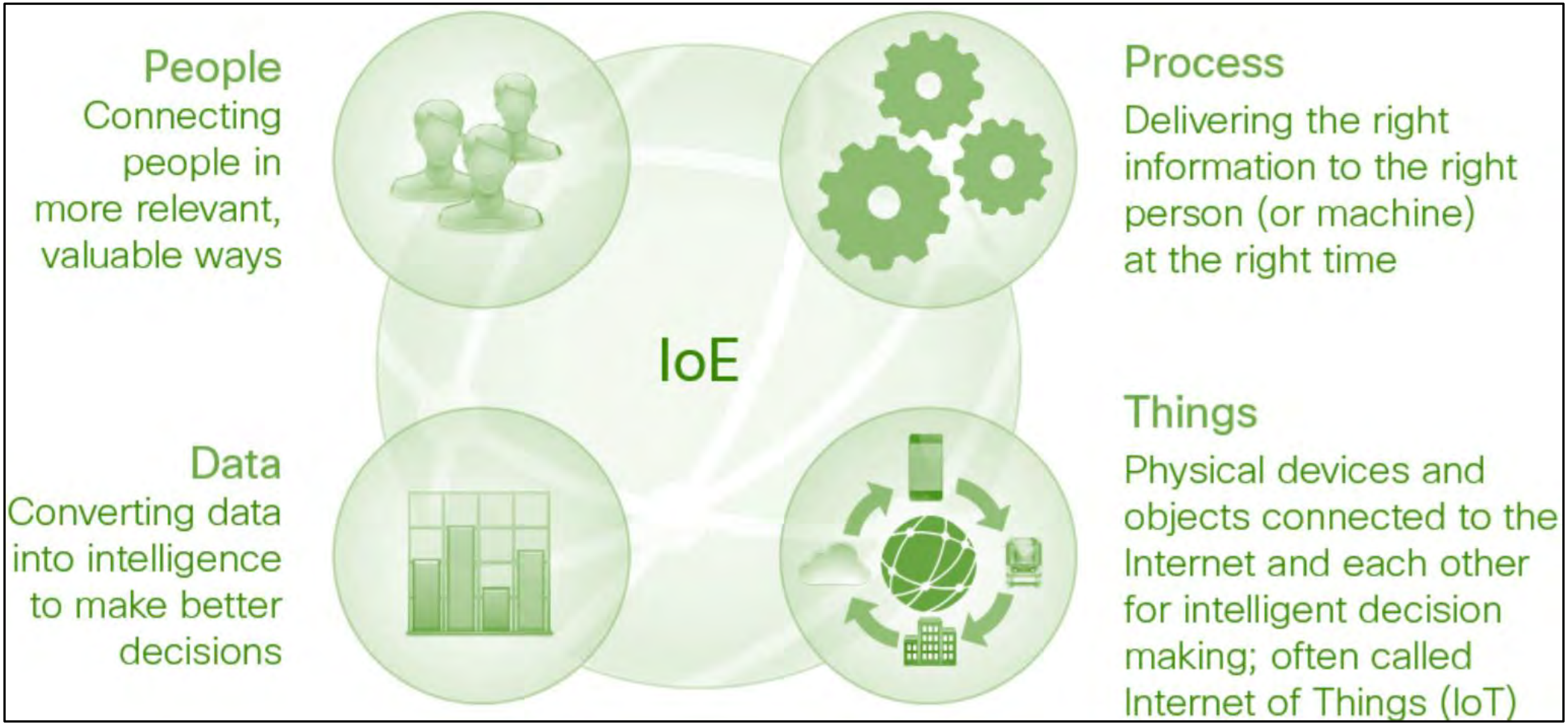
Source: https://www.nebbiolo.tech/wp-content/uploads/whitepaper-fog-vs-edge.pdf
Source: https://www.automationworld.com/fog-computing-vs-edge-computing-whats-difference

IoT Vs Cyber Physical Systems (CPS)



Source: Mohanty 2016, CE Magazine July 2016

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