Consumer Technologies for Smart Cities to Smart Villages

ICCE 2021 Tutorial Session

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The Drivers

Population Trend – Urban Migration

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

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

Source: http://www.urbangateway.org

Issues Challenging City Sustainability

Pollution

Water Crisis

Energy Crisis

Traffic

Smart City Technology - As a Solution

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

At Different Levels:
- Smart Village
- Smart State
- Smart Country

- Year 2050: 70% of world population will be urban

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

Smart Cities Vs Smart Villages

City - An inhabited place of greater size, population, or importance than a town or village

-- Merriam-Webster

Smart City: A city "connecting the physical infrastructure, the information-technology infrastructure, the social infrastructure, and the business infrastructure to leverage the collective intelligence of the city".

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

Smart Village: A village that uses information and communication technologies (ICT) for advancing economic and social development to make villages sustainable.

Source: S. K. Ram, B. B. Das, K. K. Mahapatra, S. P. Mohanty, and U. Choppali, "Energy Perspectives in IoT Driven Smart Villages and Smart Cities", *IEEE Consumer Electronics Magazine (MCE)*, Vol. XX, No. YY, ZZ 2021, DOI: 10.1109/MCE.2020.3023293.

Smart Cities Vs Smart Villages

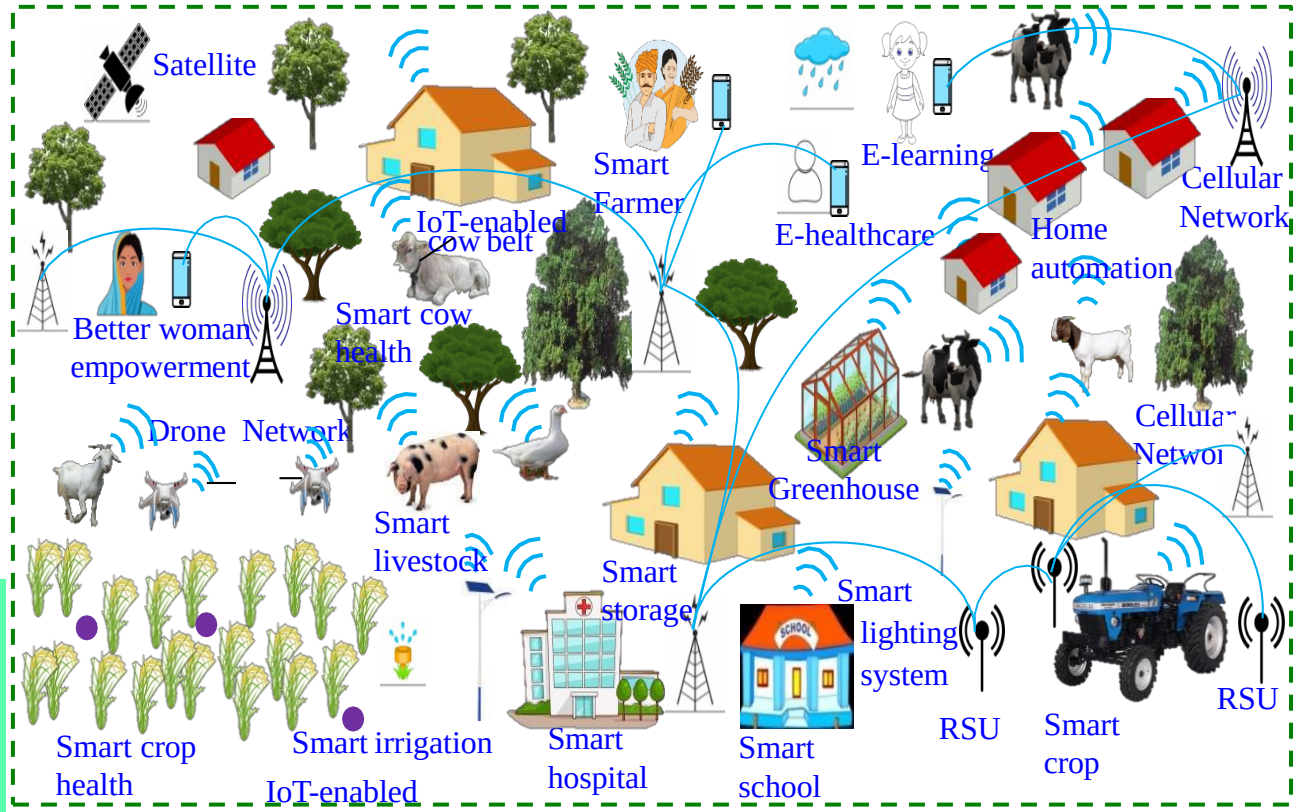
Source: http://edwingarcia.info/2014/04/26/principal/

Smart Cities

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

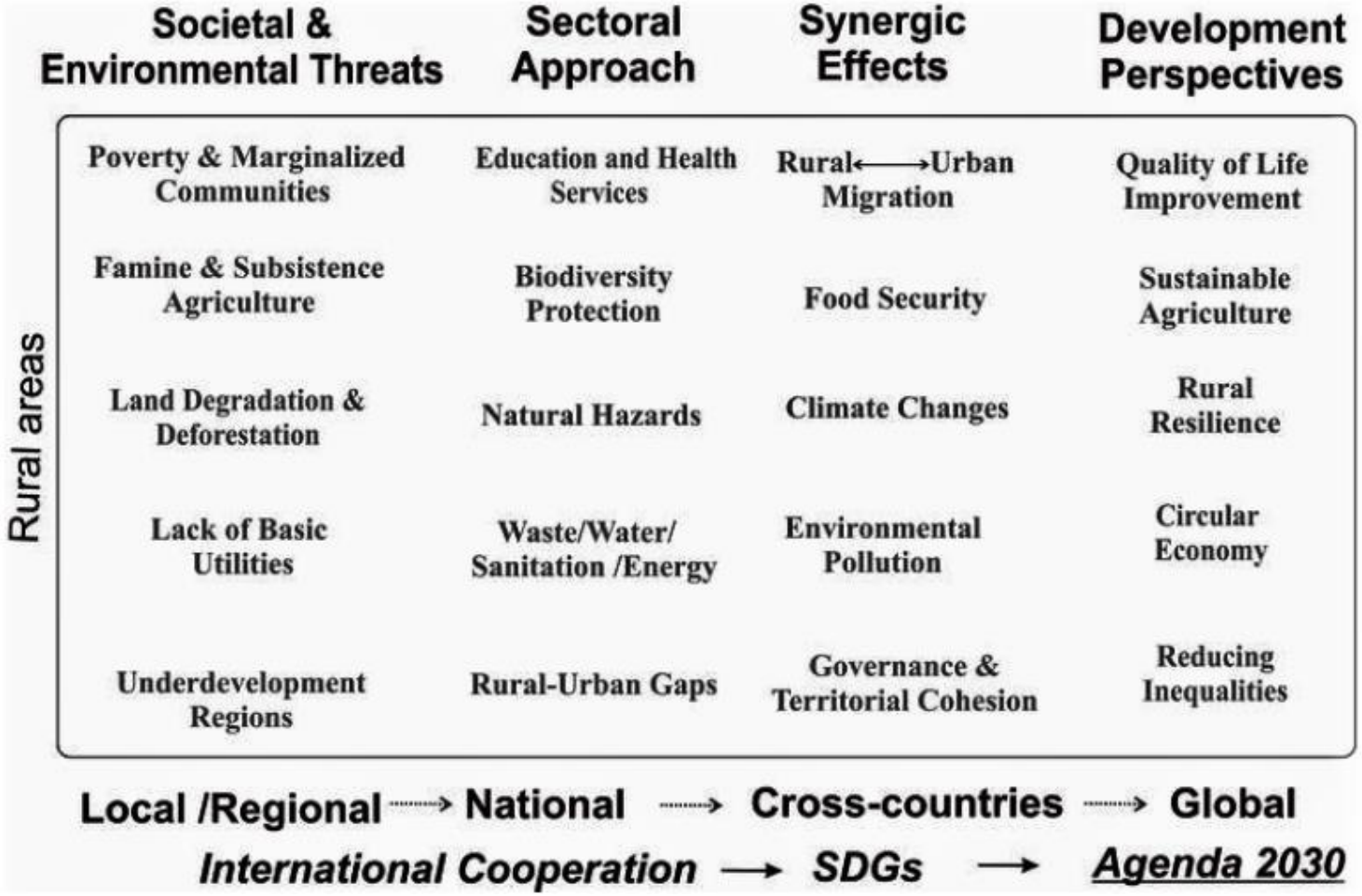
Smart Villages

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



Source; P. Chanak and I. Banerjee, "Internet of Things-enabled Smart Villages: Recent Advances and Challenges," *IEEE Consumer Electronics Magazine*, DOI: 10.1109/MCE.2020.3013244.

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



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

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

Smart Villages – Global Impact

Cities - History

City - An inhabited place of greater size, population, or importance than a town or village

-- Merriam-Webster

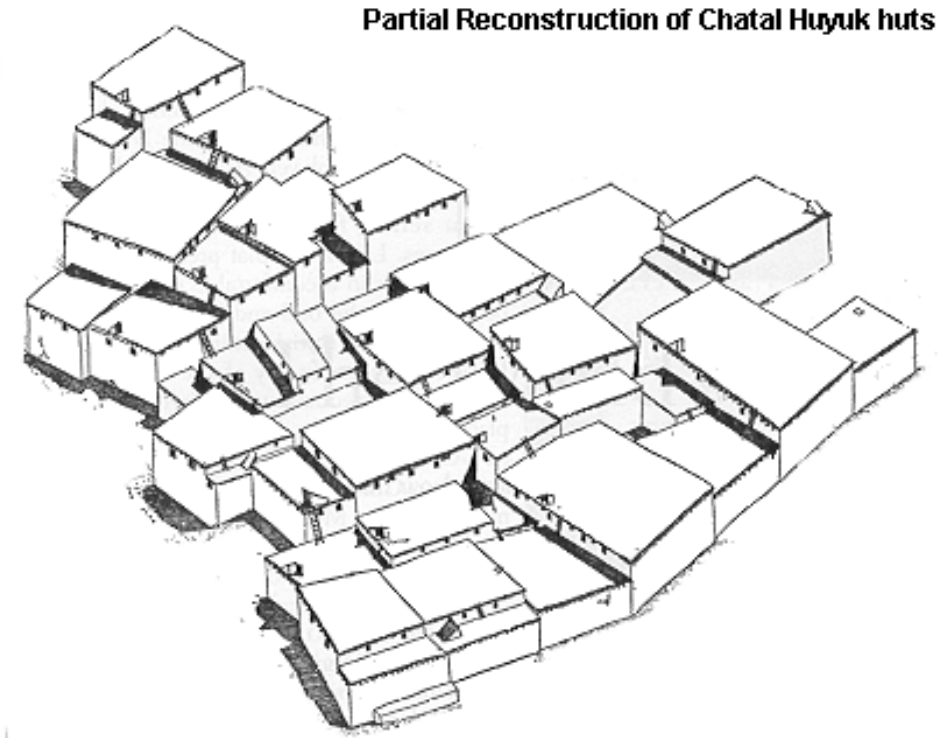
"First true cities arose in Mesopotamia, and in the Indus and Nile valleys sometime around 3500 BCE."

-- LeGates and Stout 2016, The City Reader

Hippodamus of Miletus, 498-408 BC, the first Greek city planner, considered as "the Father of European Urban Planning".

-- Edward Glaeser - 2011, Triumph of the City

Cities and Villages - History



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

"First true cities arose in Mesopotamia, and in the Indus and Nile valleys sometime around 3500 BCE."

-- LeGates and Stout 2016, The City Reader

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

The Components

Smart Cities

Smart Cities ←

Regular Cities

+ Information and Communication Technology (ICT)

+ Smart Components

+ Smart Technologies

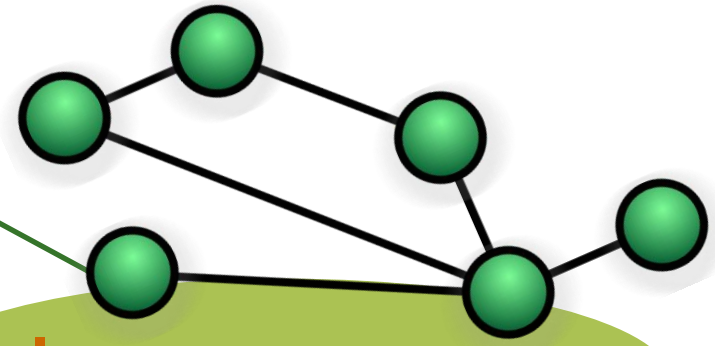
Source: S. P. Mohanty, U. Choppali, and E. Kougianos, “Everything You wanted to Know about Smart Cities”, IEEE Consumer Electronics Magazine (CEM), Volume 5, Issue 3, July 2016, pp. 60--70.

Smart Cities - 3 Is

Instrumentation

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

Smart Cities

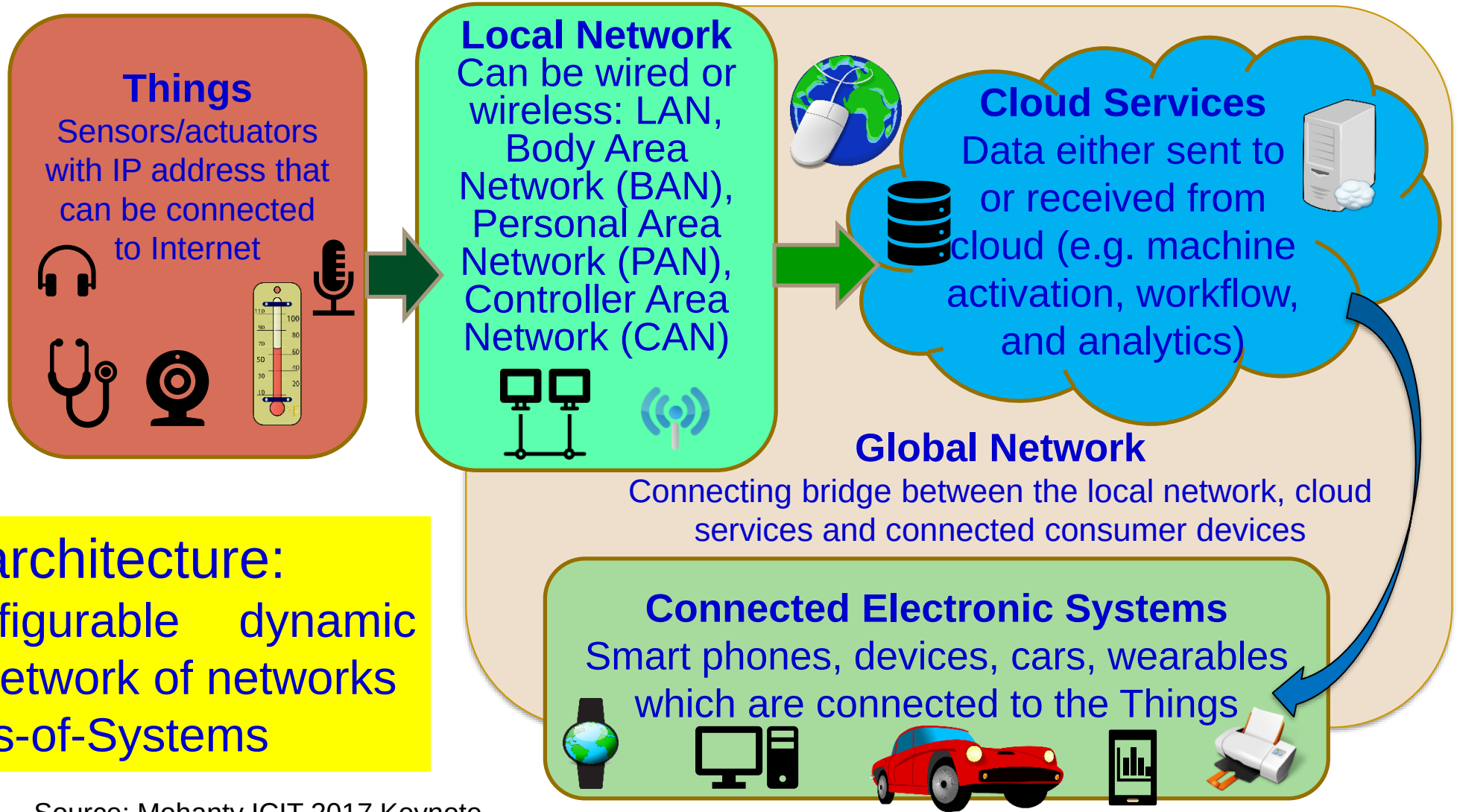


Intelligence

Interconnection

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

Internet of Things (IoT) – Concept

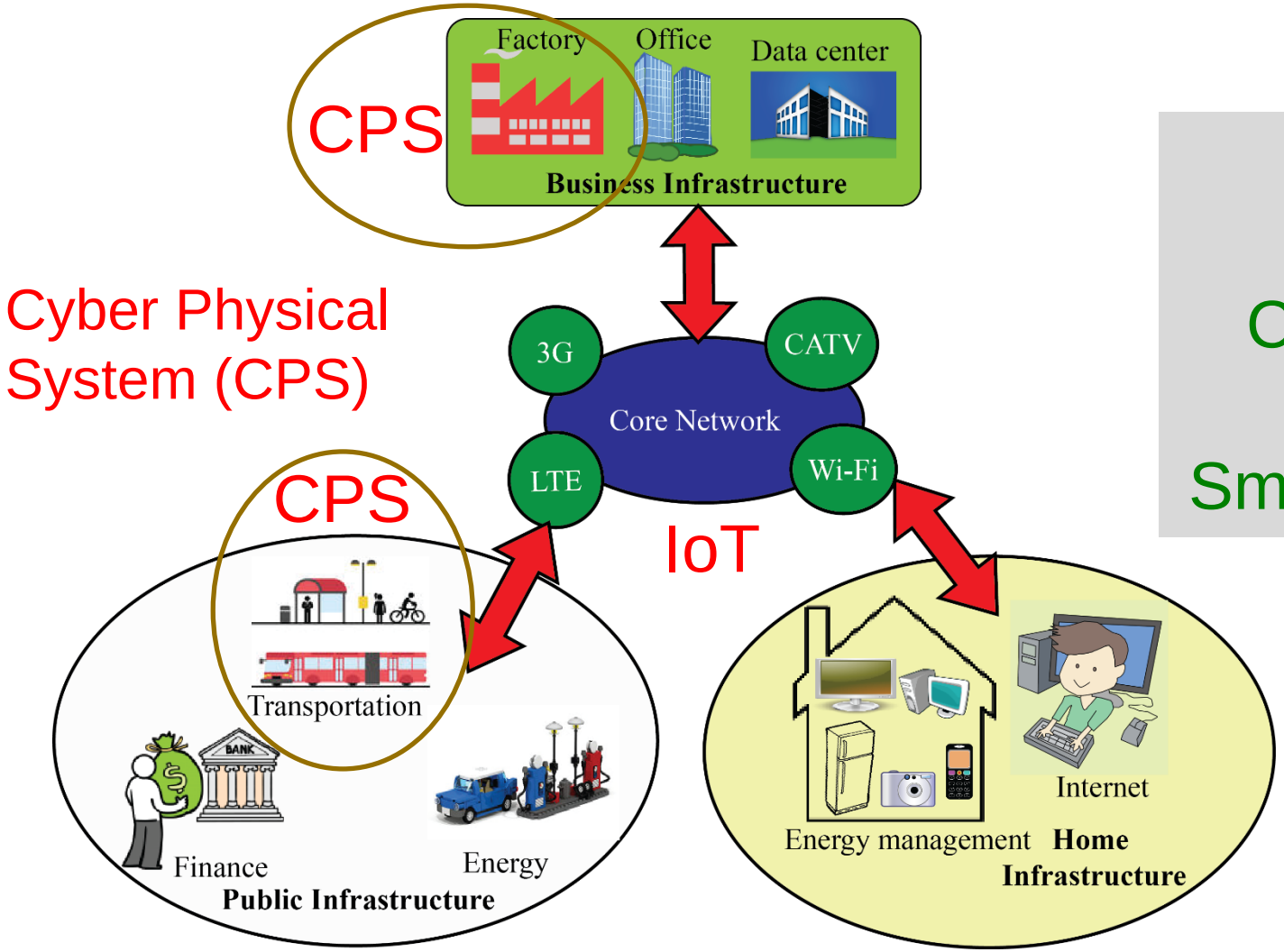


Overall architecture:

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

Source: Mohanty ICIT 2017 Keynote

IoT → CPS → Smart Cities or Smart Villages

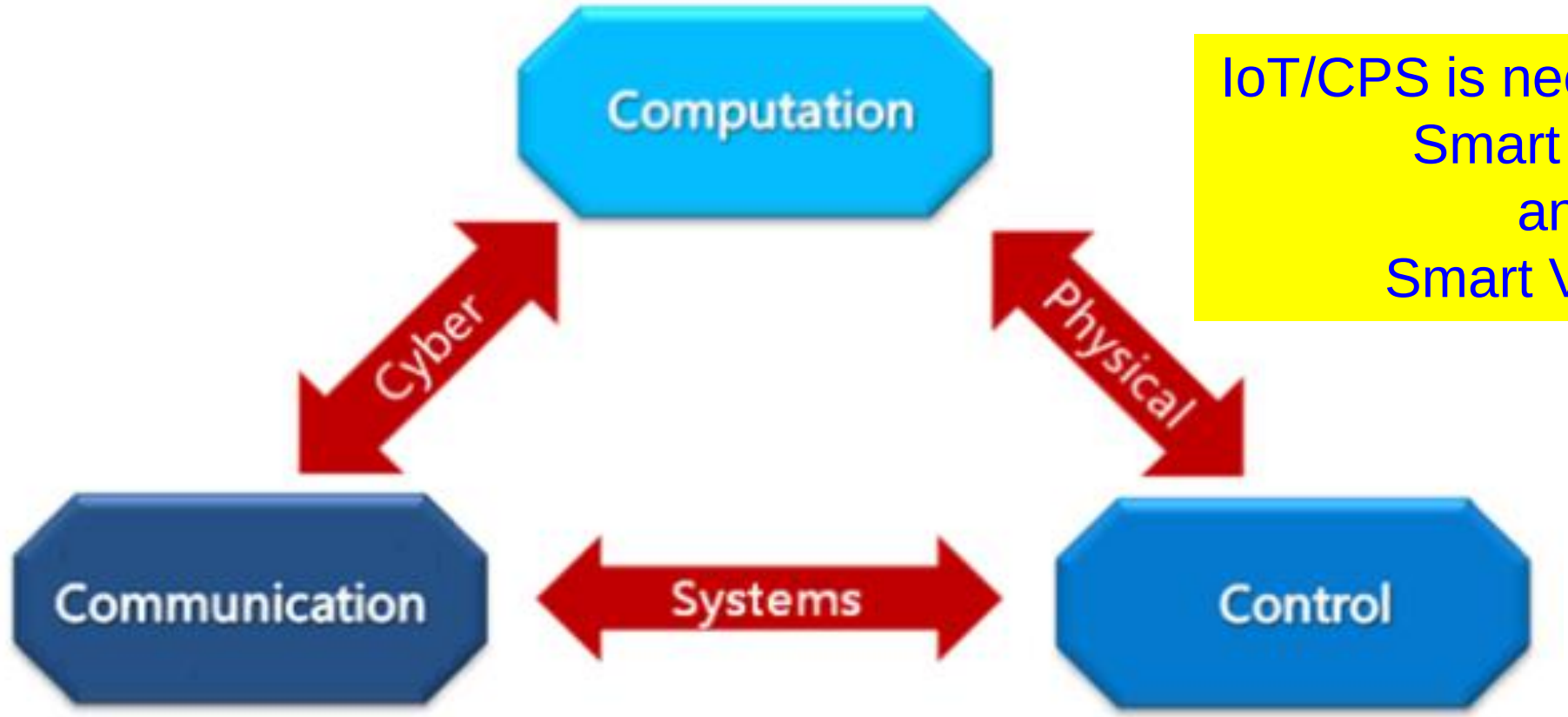


IoT
→
CPS (Smart Components)
→
Smart Cities or Smart Villages

IoT is the backbone

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

Cyber-Physical Systems (CPS) - 3 Cs



IoT/CPS is needed for both:
Smart Cities
and
Smart Villages

3 Cs of IoT - Connect, Compute, Communicate

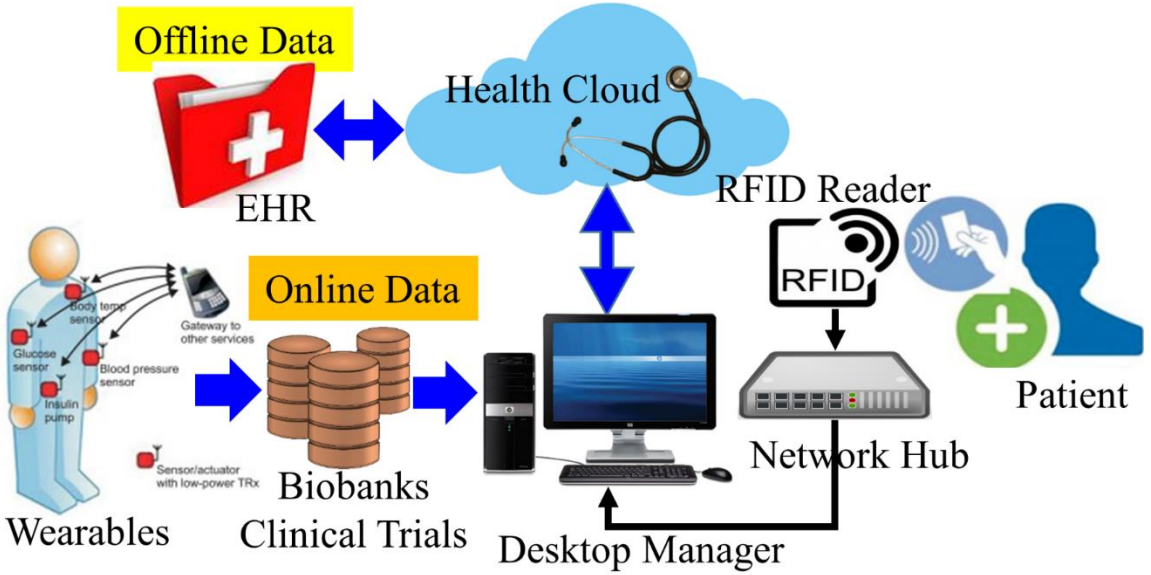
Source: G. Jinghong, H. Ziwei, Z. Yan, Z. Tao, L. Yajie and Z. Fuxing, "An overview on cyber-physical systems of energy interconnection," in *Proc. IEEE International Conference on Smart Grid and Smart Cities (ICSGSC)*, 2017, pp. 15-21.

Healthcare Cyber-Physical System (H-CPS)

Internet-of-Medical-Things (IoMT)

OR

Internet-of-Health-Things (IoHT)



Requires:

- Data and Device Security
- Data Privacy

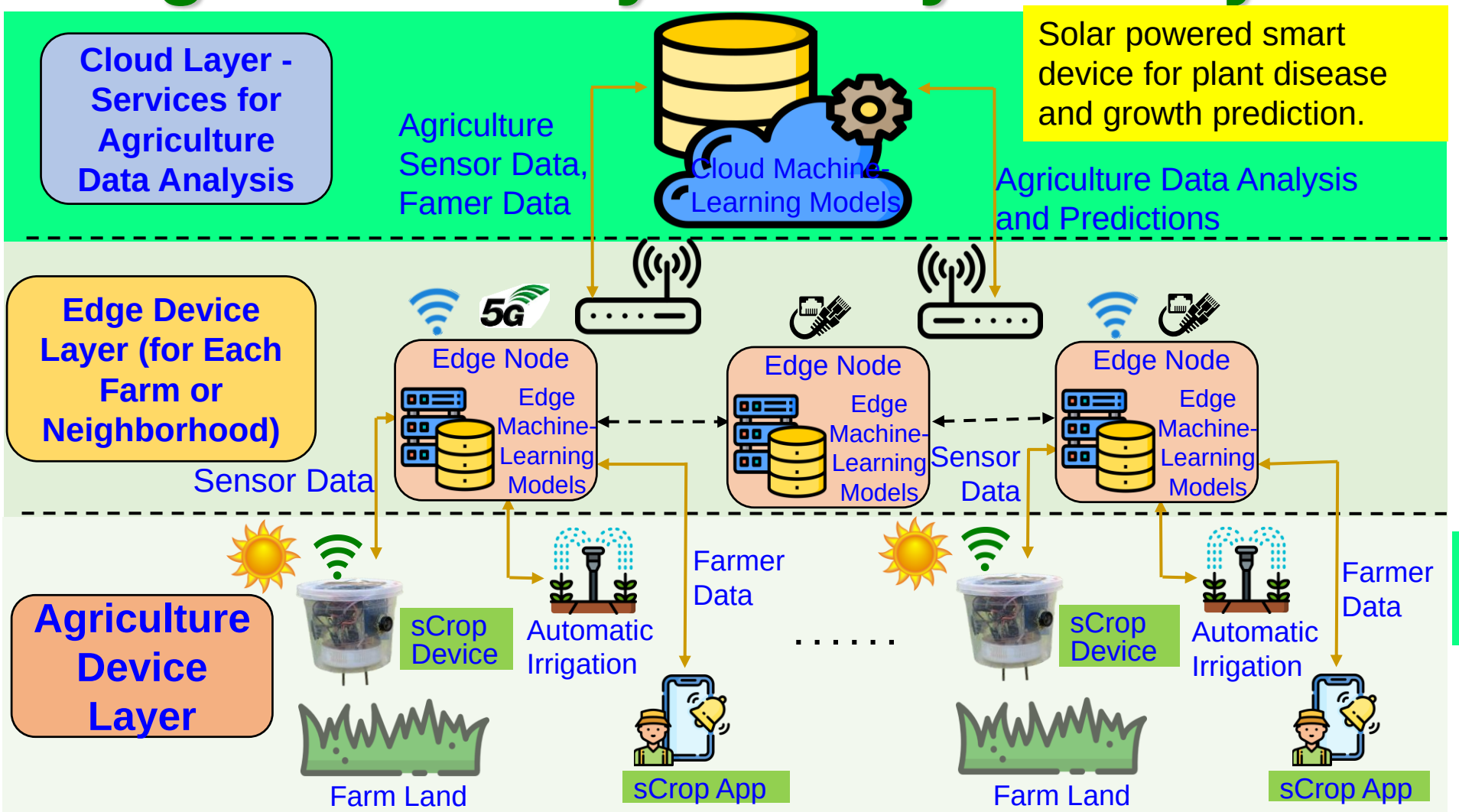
H-CPS ← Biosensors + Medical Devices + Wearable Medical Devices (WMDs) + Implantable Medical Devices (IMDs) + Internet + Healthcare database + AI/ML + Applications that connected through Internet.

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

IEEE

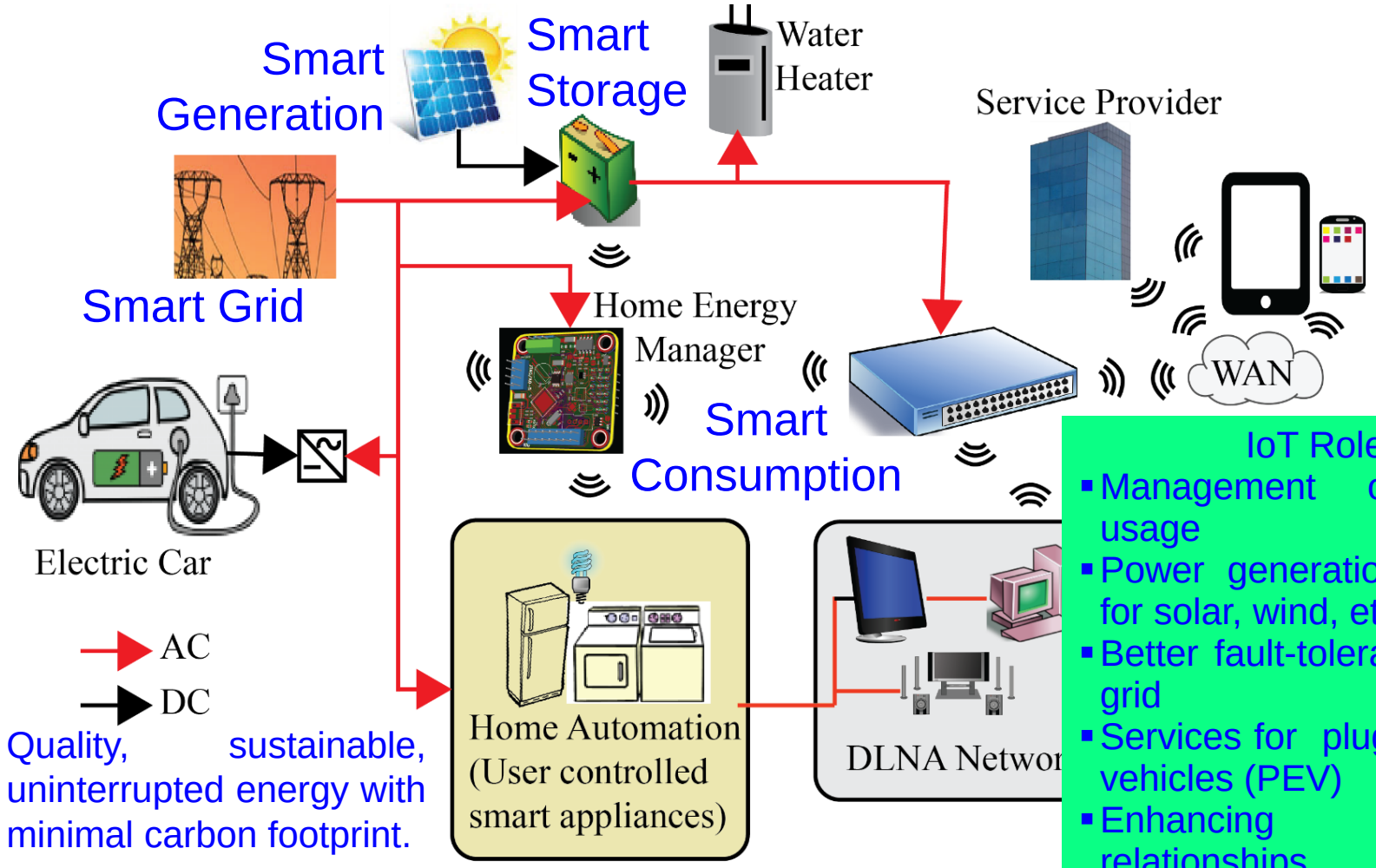
Frost and Sullivan predicts smart healthcare market value to reach US$348.5 billion by 2025.

Agriculture Cyber-Physical System (A-CPS)



Source: V. Udutalapally, S. P. Mohanty, V. Pallagani, and V. Khandelwal, "sCrop: A Novel Device for Sustainable Automatic Disease Prediction, Crop Selection, and Irrigation in Internet-of-Agro-Things for Smart Agriculture", *IEEE Sensors Journal*, Vol. XX, No. YY, ZZ 2020, pp. Accepted on 14 Oct 2020, DOI: 10.1109/JSEN.2020.3032438.

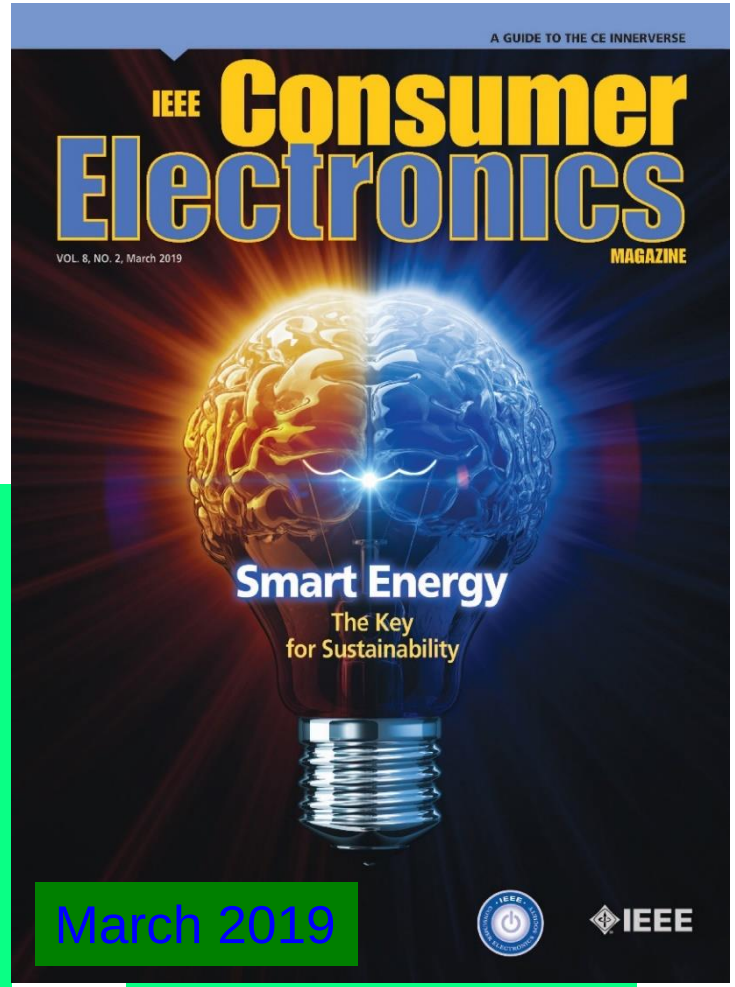
Energy Cyber-Physical System (E-CPS)



Quality, sustainable, uninterrupted energy with minimal carbon footprint.

IoT Role:

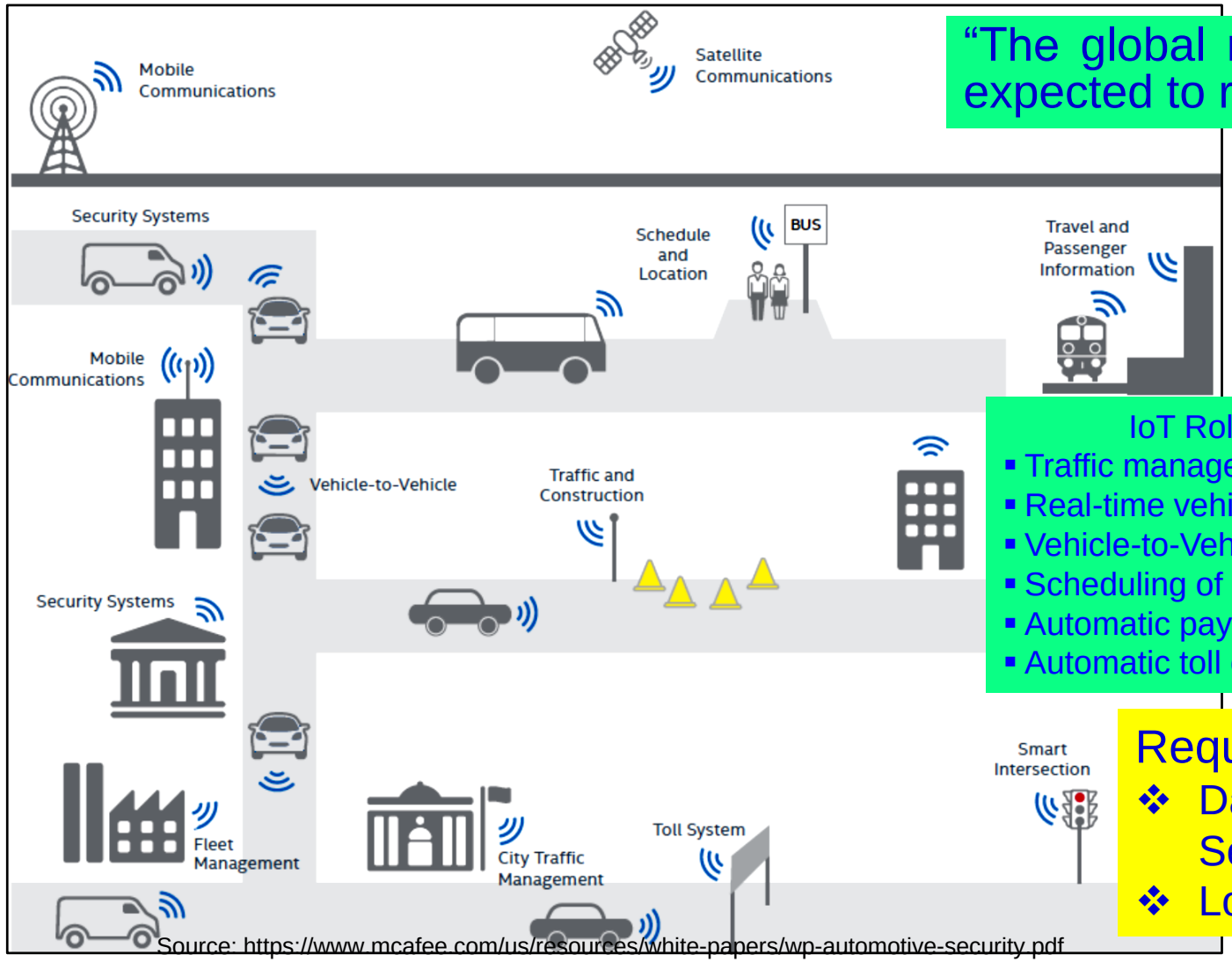
- Management of energy usage
- Power generation dispatch for solar, wind, etc.
- Better fault-tolerance of the grid
- Services for plug-in electric vehicles (PEV)
- Enhancing consumer relationships



Internet of Energy

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

Transportation Cyber-Physical System (T-CPS)



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

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

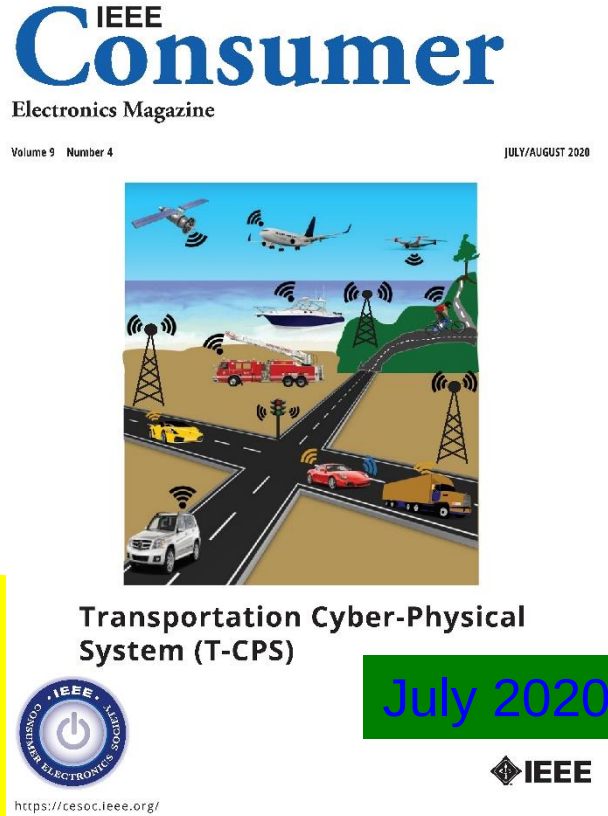
Source: Datta 2017, CE Magazine Oct 2017

IoT Role Includes:

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

Requires:

- Data and Device Security
- Location Privacy



July 2020

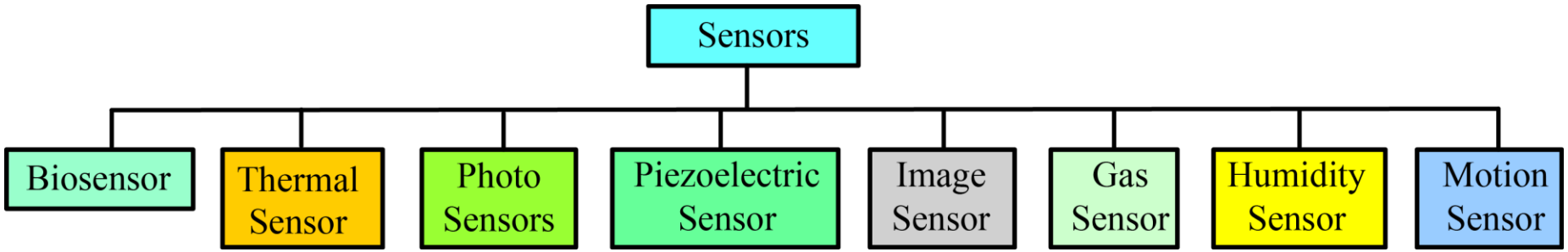
Services in Smart Cities and Smart Village

In Smart Cities	In Smart Village	Communication Type	Energy Source	Feasibility
Waste Management	Waste Management	WiFi, Sigfox, Neul, LoRaWAN	Battery Powered and Energy Harvesting	Feasible but smart containers adds in cost
Air Quality Monitoring	Smart Weather and Irrigation	BLE, ZigBee, 6LoWPAN, WiFi, Cellular, Sigfox, LoRaWAN	Solar Panels, Battery Power and Energy Harvesting	Feasible
Smart Surveillance	NA	BLE, WiFi, ZigBee, Cellular, Sigfox, LoRaWAN	Battery Power and Energy Harvesting	Feasible but additional sensors needed
Smart Energy	Smart Energy	ZigBee, Z-Wave, 6LoWPAN, Sigfox, LoRaWAN	PowerGrid, Solar Power, Wind Power, Energy Harvesting	Feasible
Smart Lighting	Smart Lighting	WiFi, ZigBee, Z-Wave, Sigfox, LoRaWAN	Power Grid, Solar Power, Energy Harvesting	Feasible
Smart Healthcare	Smart Healthcare	BLE, Bluetooth, WiFi, Cellular, Sigfox	Power Grid, Battery Power, and Energy Harvesting	Feasible
Smart Education	Smart Education	LR-WPAN, WiFi and Ethernet	Power Grid, Battery Power, and Energy Harvesting	Feasible
Smart Parking	NA	Z-Wave, WiFi, Cellular, Sigfox, LoRaWAN	Power Grid, Solar Power, Energy Harvesting	Feasible
Structural Health Monitoring	NA	BLE, WiFi, ZigBee, 6LoW-PAN, Sigfox	Power Grid, Solar Power, Battery Power, Energy Harvesting	Energy harvesting can be useful for power specs
Noise Monitoring	NA	6LoWPAN, WiFi, Cellular	Battery Power, Energy Harvesting, and Energy Scavenging	Sound pattern identification is a bottleneck
NA	Smart Farming	BLE, Bluetooth, WiFi, 6LoW-PAN, Sigfox, LoRaWAN	Power Grid, Battery Power and Energy Harvesting	Feasible
NA	Smart Diary	Bluetooth, WiFi, ZigBee, 6LoWPAN, LoRaWAN	Power Grid, Battery Power and Energy Harvesting	Feasible

Source: S. K. Ram, B. B. Das, K. K. Mahapatra, S. P. Mohanty, and U. Choppali, "Energy Perspectives in IoT Driven Smart Villages and Smart Cities", *IEEE Consumer Electronics Magazine (MCE)*, Vol. XX, No. YY, ZZ 2021, pp. Accepted on 08 Sep 2020, DOI: 10.1109/MCE.2020.3023293.

The Technologies

Cheap and Compact Sensor Technology



Source: S. P. Mohanty, Nanoelectronic Mixed-Signal System Design, McGraw-Hill, 2015, ISBN-13: 978-0071825719.

Gas Sensor

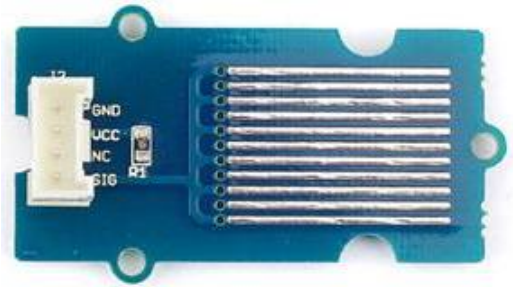
Temperature Sensor

Air Quality Sensor

Humidity and Temperature Sensor

Light Sensor

Barometer Sensor



Water Sensor

Dust Sensor

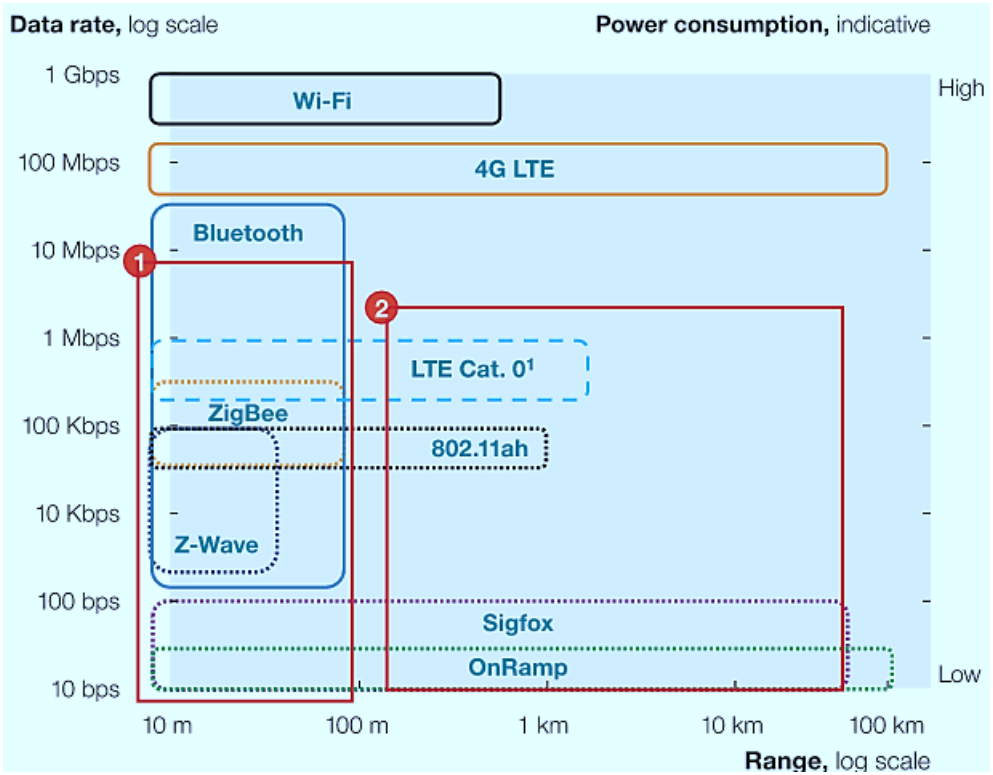
Source: http://wiki.seeed.cc/Sensor/

IoT - Communications Technology

Selected IoT Communications Technology

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

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



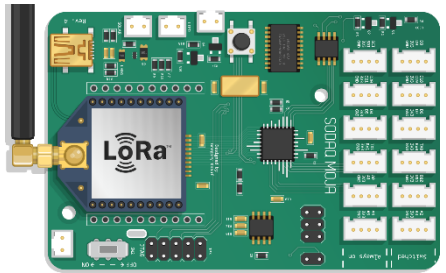
Source: https://www.postscapes.com/internet-of-things-protocols/

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.

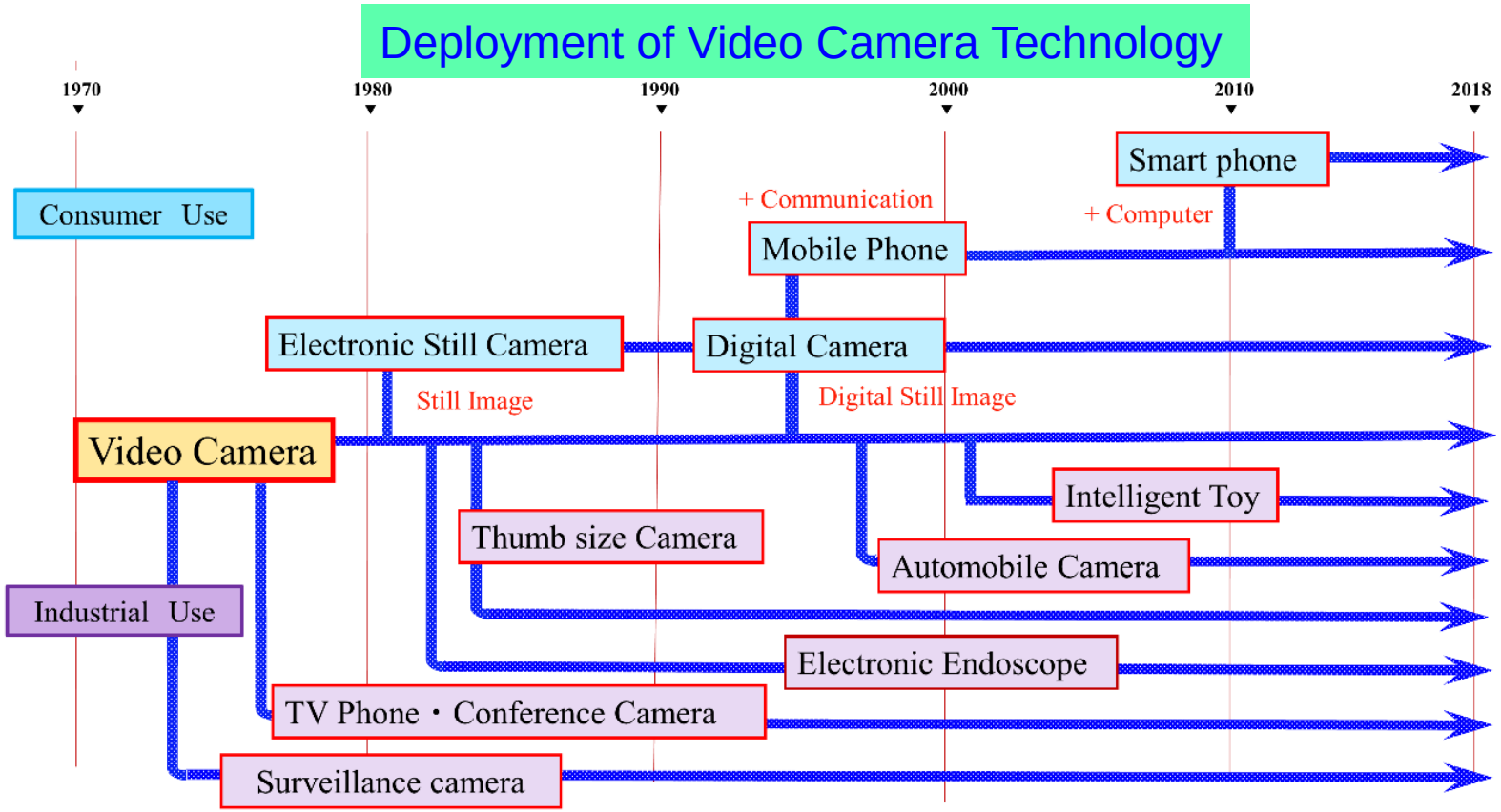
Technology	Protocol	Maximum Data Rate	Coverage Range
ZigBee	ZigBee Pro	250 kbps	1 mile
WLAN	802.11x	2-600 Mbps	0.06 mile
Cellular	5G	1 Gbps	Short - Medium
LoRa	LoRa	50 kbps	3-12 miles
SigFox	SigFox	1 kbps	6-30 miles

Source: Mohanty iSES Keynote 2018



Effective for smart villages where Internet may not be available for villages.

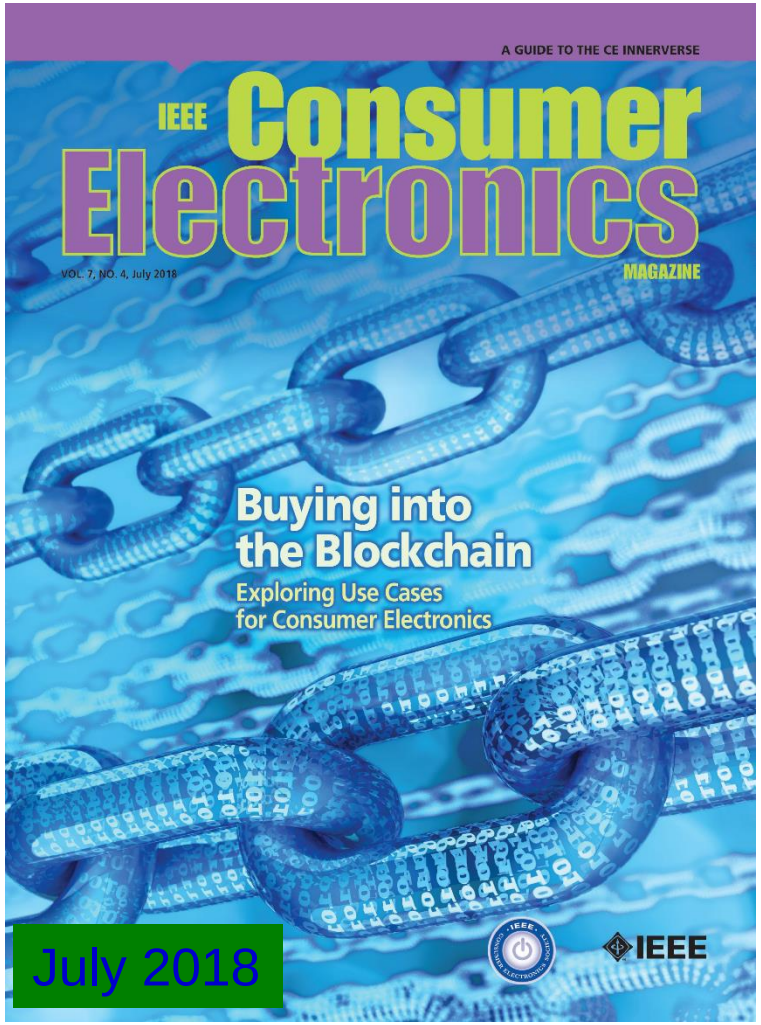
Cameras are Everywhere



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

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

Blockchain Technology



Unmanned Ariel Vehicle (UAV)

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

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

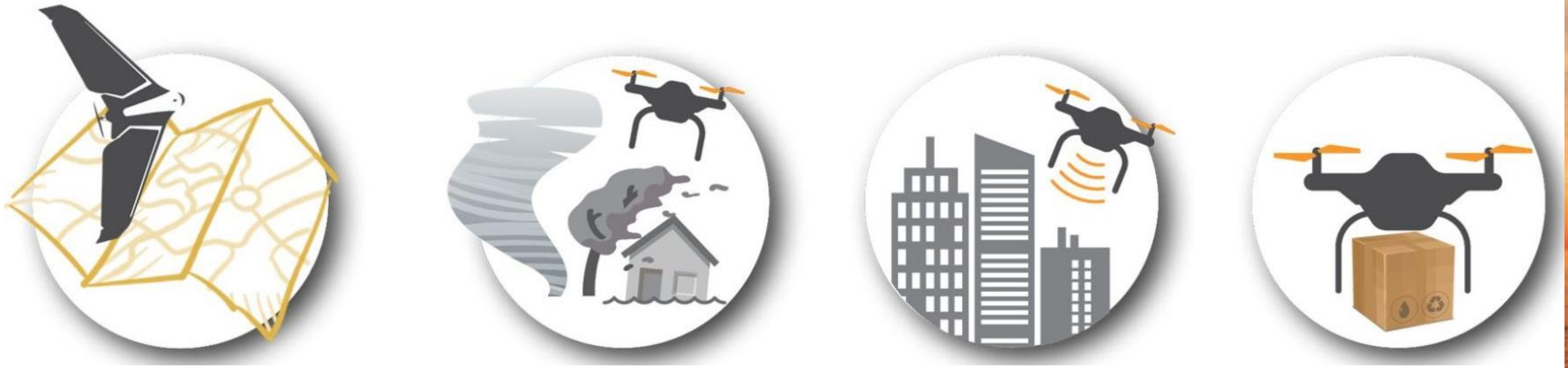
UAV Applications - 4 Categories

Data collection & surveying

Monitoring & Tracking

Temporary Infrastructure

Delivery of Goods



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

Virtual and Augmented Reality Technology

Virtual Reality

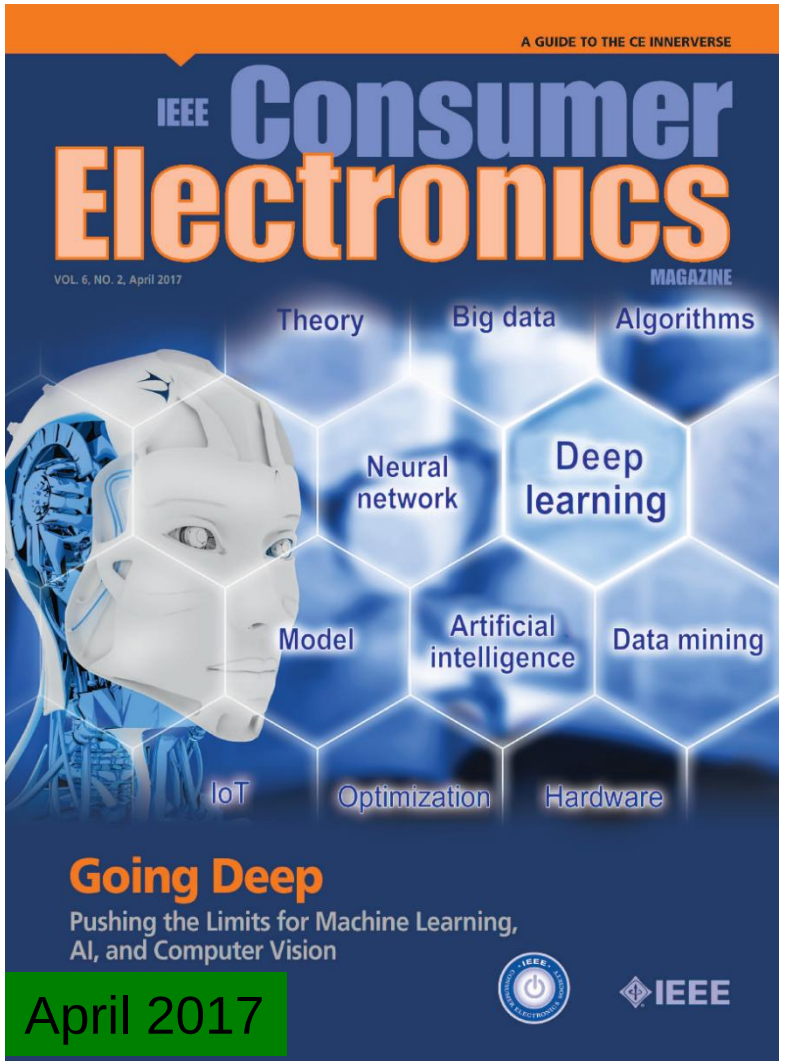
Smart City Use:
- Healthcare - Therapy, Surgery
- Tourism - Recreate History
- Entertainment - Movies

Augmented Reality

Source: http://www.prweb.com/releases/2011/5/prweb8462670.htm

Artificial Intelligence Technology

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



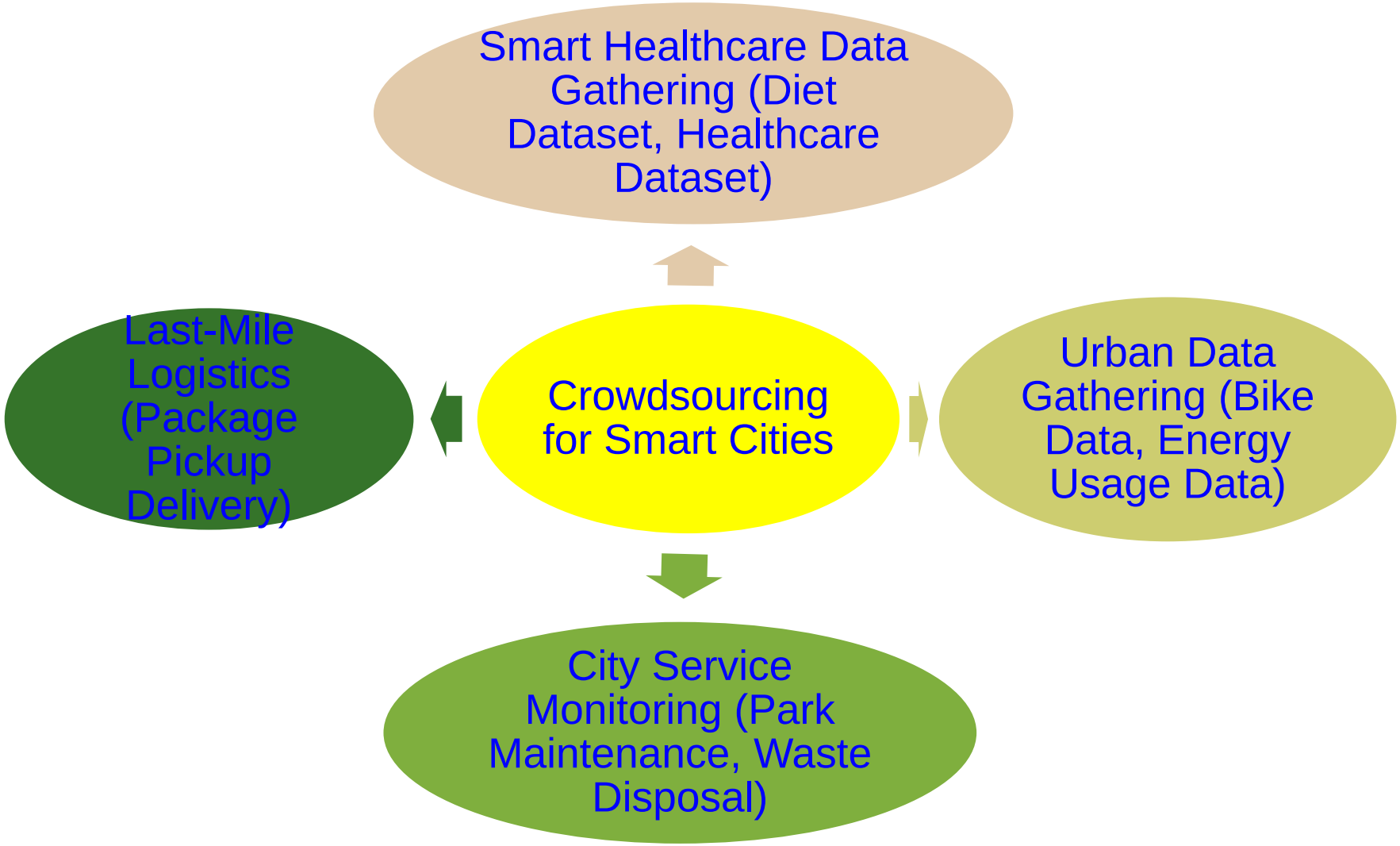
Tensor Processing Unit (TPU)

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

Smart City Use:

- Better analytics
- Better decision
- Faster response

Crowdsourcing for Smart Cities



Design Optimization

IoT/CPS Design – Multiple Objectives

Non-recurring Design Cost

Recurring Operational Cost

Energy Consumption, Battery Life

Ethics, Safety

Security, Privacy, IP Rights

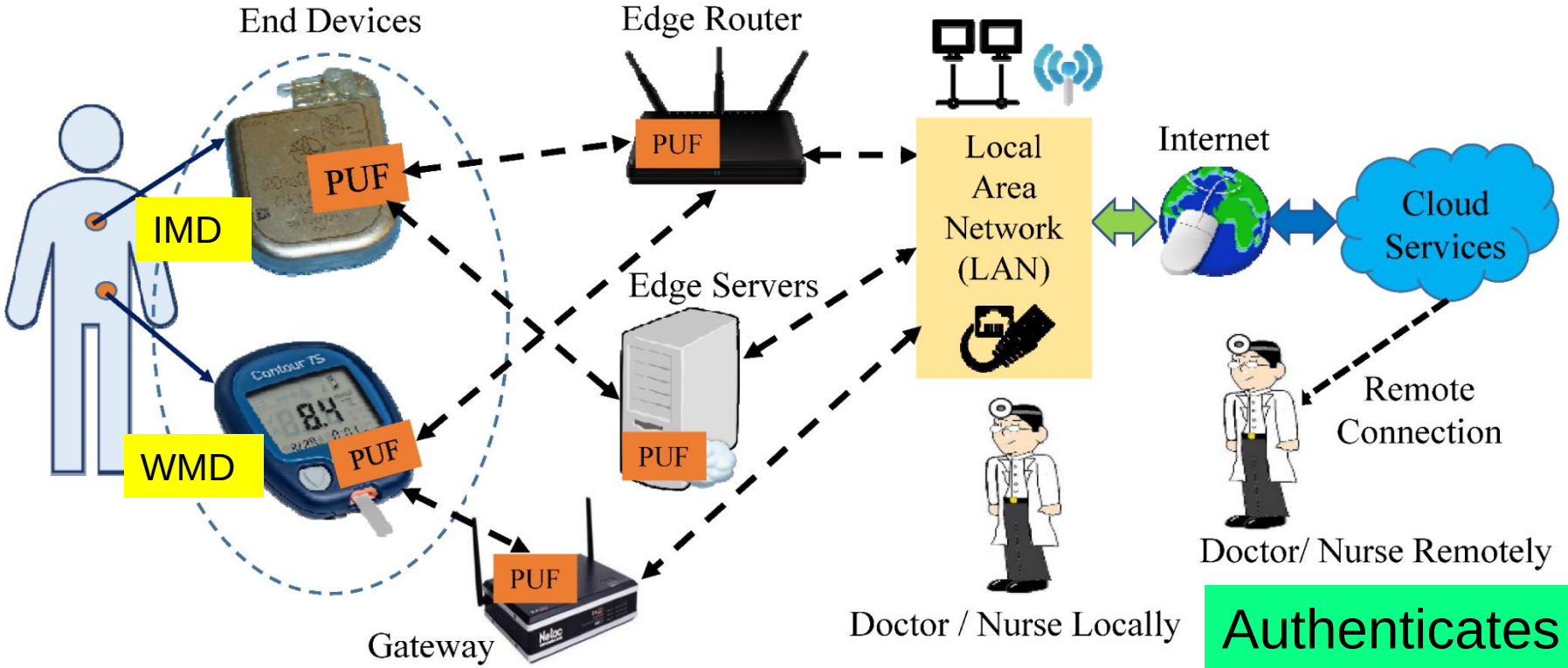
Smart Cities
Vs
Smart Villages

Performance, Latency

Intelligence

Source: Mohanty ICCE 2019 Keynote

PMsec: Our Secure by Design Approach for Robust Security in Healthcare CPS

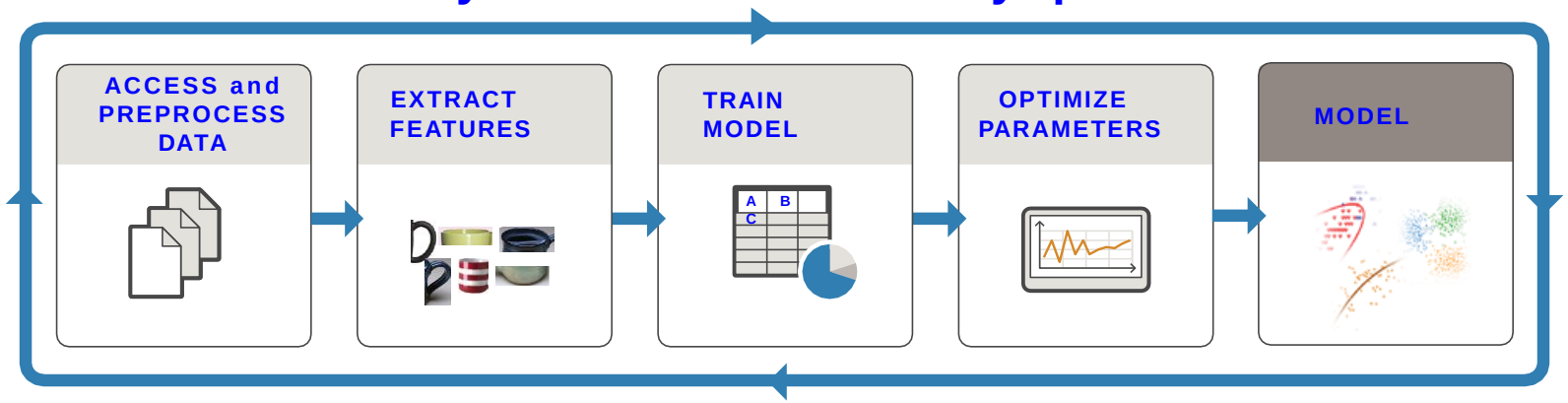


Authenticates Time - 1 sec
Power Consumption - 200 μW

Source: V. P. Yanambaka, S. P. Mohanty, E. Kougianos, and D. Puthal, "PMsec: Physical Unclonable Function-Based Robust and Lightweight Authentication in the Internet of Medical Things", *IEEE Transactions on Consumer Electronics (TCE)*, Volume 65, Issue 3, August 2019, pp. 388--397.

TinyML - Key for Smart Cities and Smart Villages

TRAIN: Iterate until you achieve satisfactory performance.

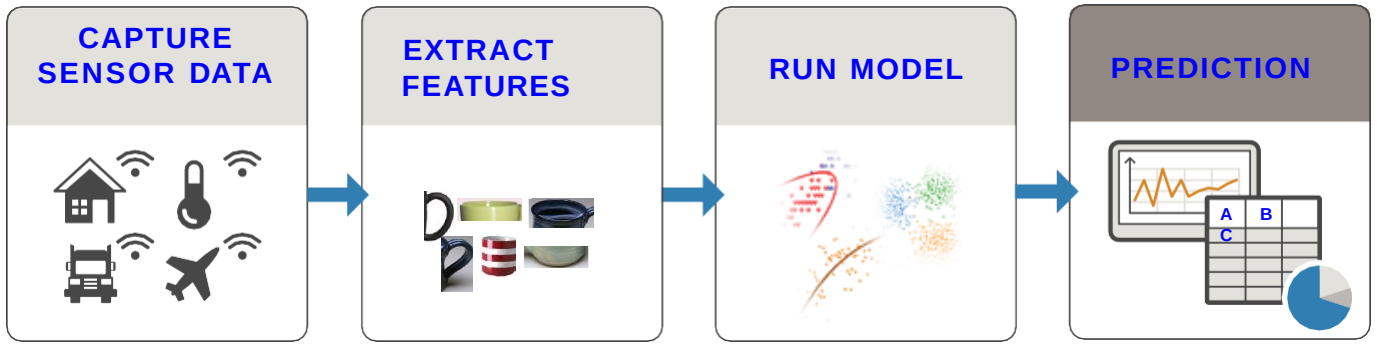


Needs Significant:

- Computational Resource
- Computation Energy

Solution: Reduce Training Time and/or Computational Resource

PREDICT: Integrate trained models into applications.



Needs:

- Computational Resource
- Computation Energy

Solution: TinyML

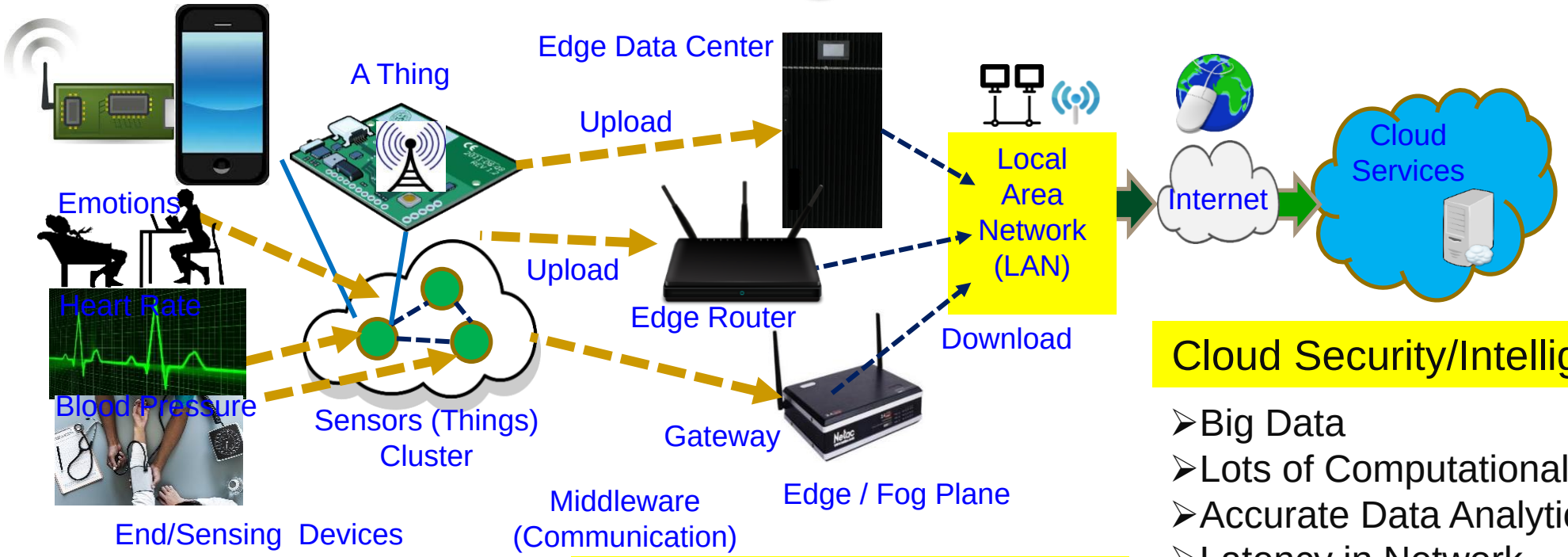
Source: https://www.mathworks.com/campaigns/offers/mastering-machine-learning-with-matlab.html

Where to Store and Process Data for ML Modeling, and where to Execute ML models?

Sensor, Edge, Fog, Cloud?

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

CPS – IoT-Edge Vs IoT-Cloud



End Security/Intelligence

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

Edge Security/Intelligence

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

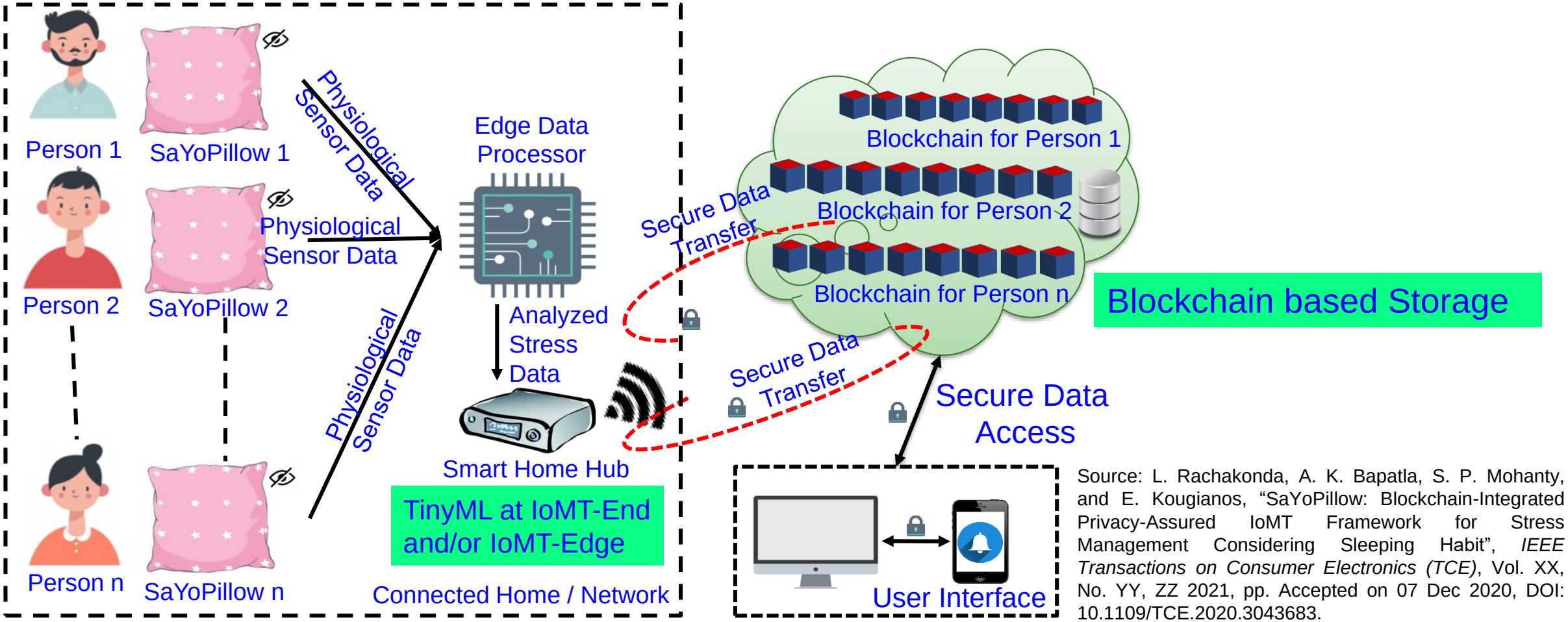
Cloud Security/Intelligence

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

TinyML at End and/or Edge is key for smart villages.

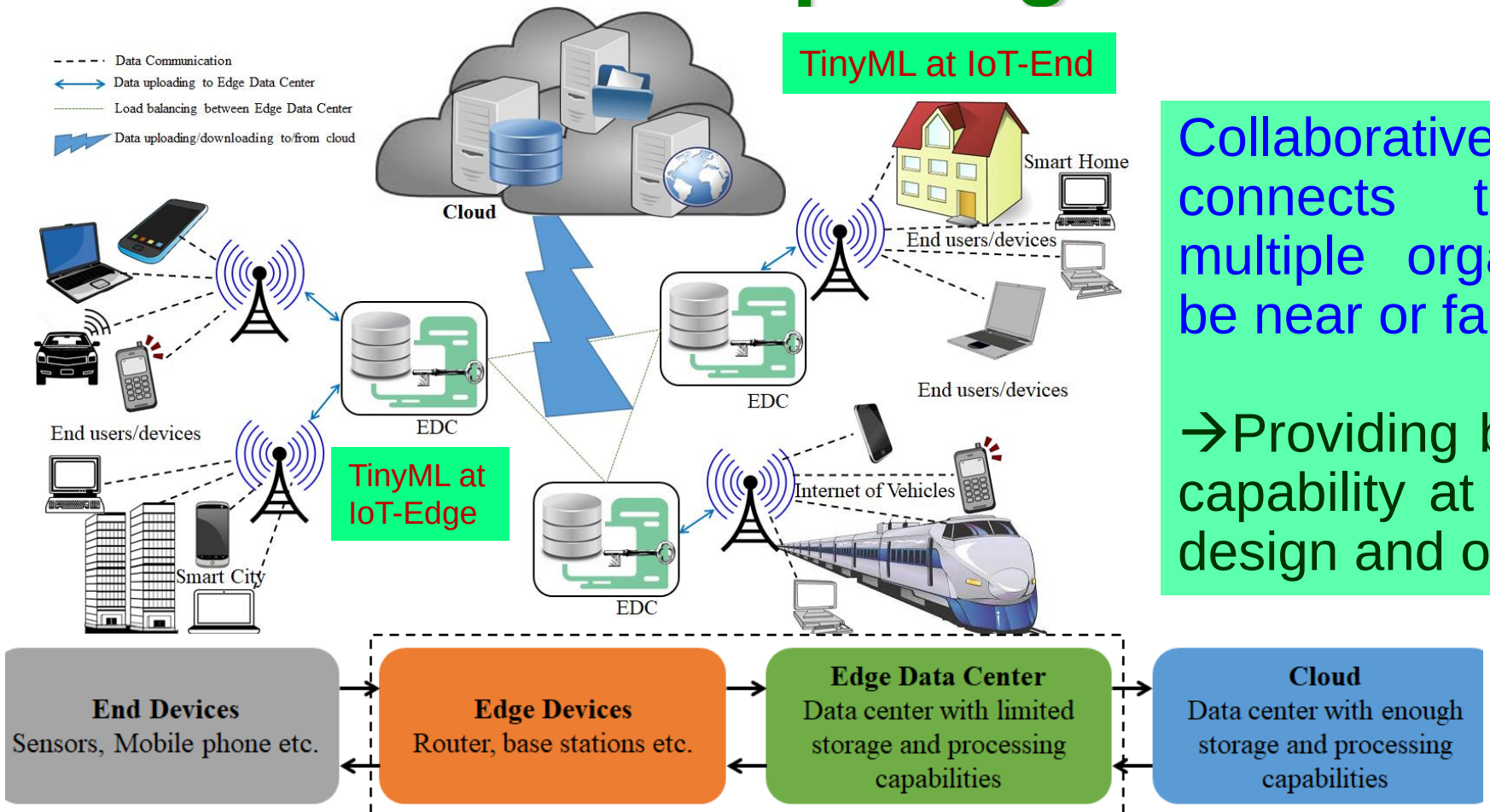
Heavy-Duty ML is more suitable for smart cities

Our Smart-Yoga Pillow (SaYoPillow) with TinyML and Blockchain based Security



Source: L. Rachakonda, A. K. Bapatla, S. P. Mohanty, and E. Kougianos, "SaYoPillow: Blockchain-Integrated Privacy-Assured IoMT Framework for Stress Management Considering Sleeping Habit", *IEEE Transactions on Consumer Electronics (TCE)*, Vol. XX, No. YY, ZZ 2021, pp. Accepted on 07 Dec 2020, DOI: 10.1109/TCE.2020.3043683.

Collaborative Edge Computing is Cost Effective Sustainable Computing for Smart Villages



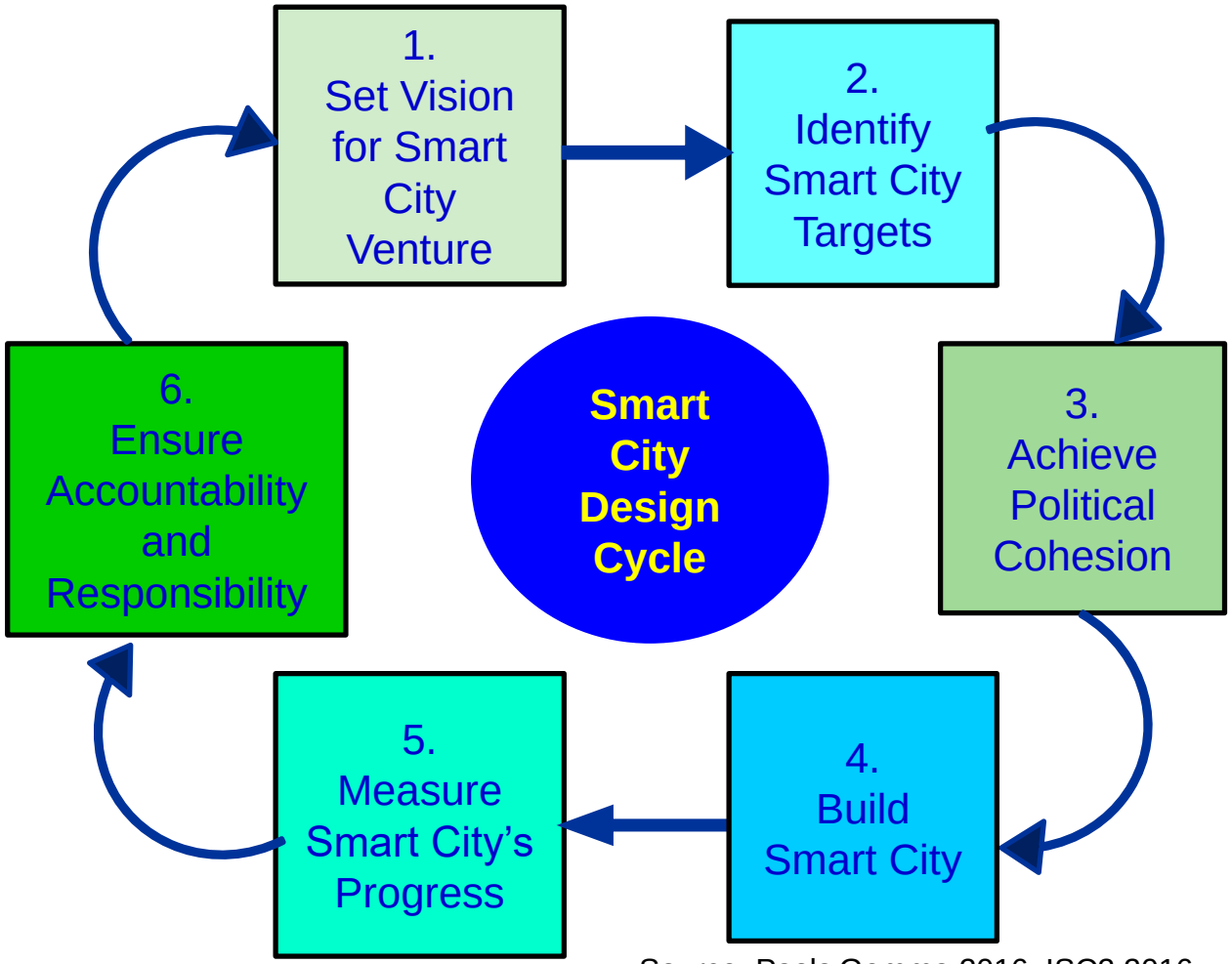
Collaborative edge computing connects the IoT-edges of multiple organizations that can be near or far from each other

→Providing bigger computational capability at the edge with lower design and operation cost.

Source: D. Puthal, M. S. Obaidat, P. Nanda, M. Prasad, S. P. Mohanty, and A. Y. Zomaya, "Secure and Sustainable Load Balancing of Edge Data Centers in Fog Computing", *IEEE Communications Mag*, Vol. 56, No 5, May 2018, pp. 60--65.

Design and Operation

Smart Cities - Design Cycle

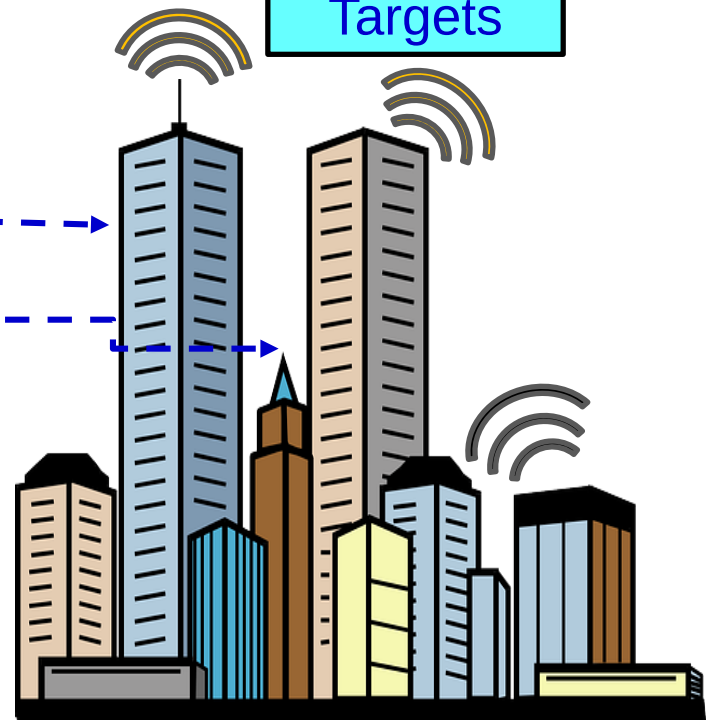


Source: Paolo Gemma 2016, ISC2 2016

Smart City Design – Vision and Target

1.
Set Vision for Smart City Venture

2.
Identify Smart City Targets



Source: Paolo Gemma 2016, ISC2 2016

Smart City Design - Stakeholders

Source: Paolo Gemma 2016, ISC2 2016

Smart City Design - Sustainable Developmental Goals

5. Measure City's Progress

Dimensions of Key Performance Indicators (KPIs)

Environment	Society and Culture	Economy
• Air quality • Water • Noise • Biodiversity • Energy • Environmental quality	• Education • Health • Safety • Housing • Culture • Social inclusion	• Innovation • Employment • Trade • Productivity • Physical infrastructure • ICT infrastructure and Access/Usage • Public Sector

Source: Paolo Gemma 2016, ISC2 2016

Smart City Design – Building Trust

6. Ensure Accountability and Responsibility

Citizen-Centric

Data-Driven Decision

Cost Effective

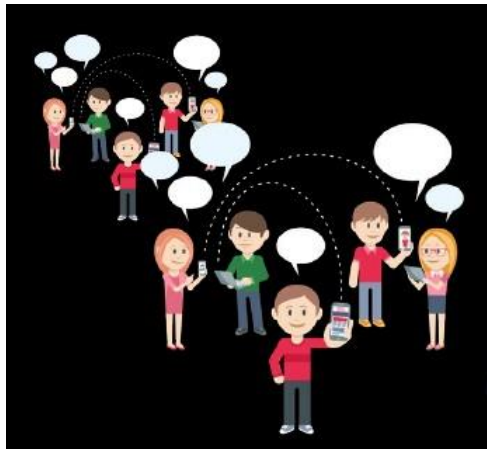
Smart Tools

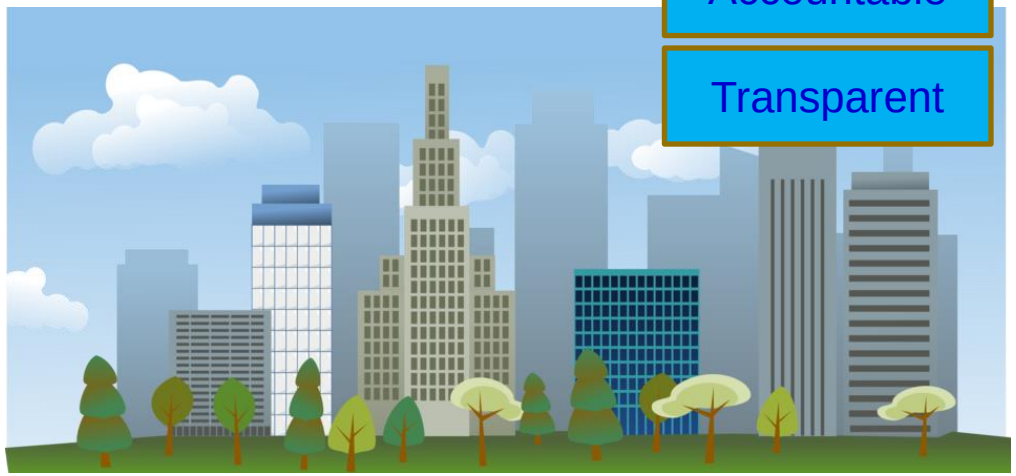
Collaborative

Responsive

Accountable

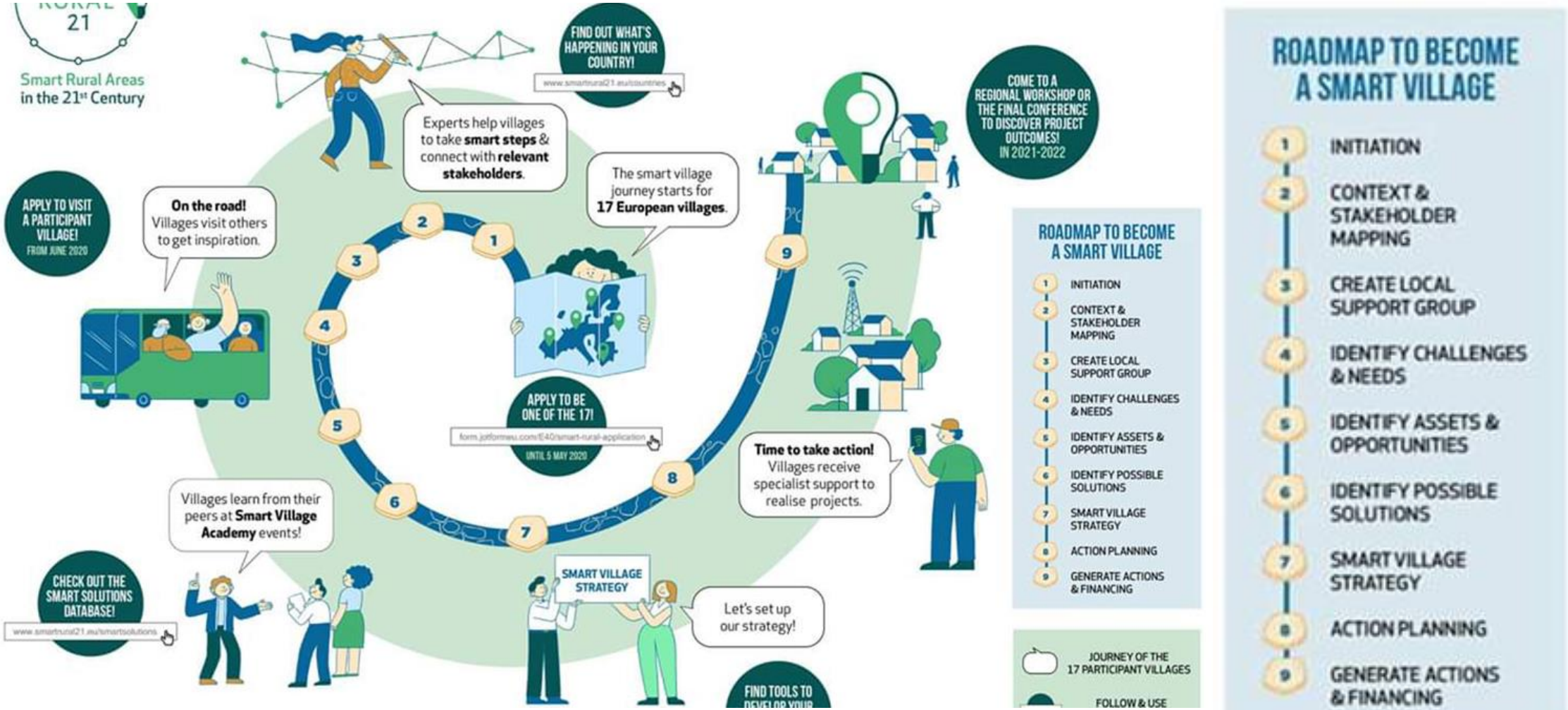
Transparent





Source: Paolo Gemma 2016, ISC2 2016

Smart Villages - Design Cycle



ROADMAP TO BECOME A SMART VILLAGE
1 INITIATION
2 CONTEXT & STAKEHOLDER MAPPING
3 CREATE LOCAL SUPPORT GROUP
4 IDENTIFY CHALLENGES & NEEDS
5 IDENTIFY ASSETS & OPPORTUNITIES
6 IDENTIFY POSSIBLE SOLUTIONS
7 SMART VILLAGE STRATEGY
8 ACTION PLANNING
9 GENERATE ACTIONS & FINANCING

Source: https://worldarchitecture.org/article-links/egphe/the-regeneration-of-abandoned-italy-through-smart-villages.html

Smart City - How Many Facilities?

- Number of city facilities required is a function of city population.
- Calculated as follows:

$$N_f = N_p\ People\left(\frac{R_p}{Year}\right)\left(\frac{1\ Year}{D\ Days}\right)\left(\frac{1\ Hour}{N_c\ People}\right)\left(\frac{1\ Day}{H\ Hours}\right)$$

where N_f is the number of facilities, N_p is the city population in millions, R_p is the rate per person use in year/week, D is days per year, N_c is the customers per hours, and H is the hours per day.

- For example: How many dental offices might there be for a city population of one million? One Solution:

$$N_f = 10^6\ People\ \left(\frac{1}{Year}\right)\left(\frac{1\ Year}{300\ Days}\right)\left(\frac{1\ Hour}{5\ People}\right)\left(\frac{1\ Day}{8\ Hours}\right)$$

$$= \left(\frac{10^6}{1.2 \times 10^4}\right) \simeq 100$$

Source: Adam 2012, X and the city : modeling aspects of urban life

Conclusions

- Smart cities and smart villages are not technological trends, rather are necessities.
- Consumer Technologies are building blocks of smart cities as well as smart villages.
- Smart cities technology and smart villages are ongoing R & D.
- Multi-Front research on smart cities and smart villages from academia and industries are in full swing.
- Smart cities still need significant maturity for effective design and operation.
- R & D seems to be in right direction.

Future Research

- Energy-efficiency at various levels of smart city: sensor, edge, communications, cloud
- System and Data Security methods
- System and Data Privacy methods
- Big data processing at: Edge, Cloud
- ML training time and resource requirement reduction
- Cybersecurity, Energy, and Intelligence Tradeoffs in IoT/CPS for sustainable smart cities and smart villages