Energy Perspectives in IoT Driven Smart Villages and Smart Cities

Saswat K. Ram, Banee B. Das, and Kamalakanta Mahapatra
National Insitute of Technology Rourkela

Saraju P. Mohanty
University of North Texas

Uma Choppali
Dallas College - Eastfield Campus

***Abstract*—The Internet-of-Things (IoT) consists of a large number of different and heterogeneous devices under one umbrella. Building a typical architecture for the devices used in IoT is a challenge due to the involvement of a vast number of devices, layers, protocols, middleware, and software. The sensors in IoT have to monitor the activities regularly, making the end node devices energy hungry. Traditional fixed batteries get drained out in limited time, requiring continuous replacement, thereby increasing the budget. This article focuses on consumer technologies in the perspective of IoT computing targeted for smart villages and smart cities. The article discusses security-by-design (SbD) concepts in the energy harvester technologies for sustainable and secured IoT with uninterrupted energy resource smart villages and smart cities.**

I. Introduction

The key features, such as instrumentation, intelligence and interconnection (3Is) of smart cities are provided by the Internet-of-Things (IoT) [1], [2]. While smart cities concept has been practiced for the last decade, the new concepts of smart villages on a smaller scale as well as smart states and smart countries on a bigger scale are evolving for the same reason, i.e. better utilization of man-made and natural limited resources. IoT integrated with physical systems make the cyber-physical systems (CPS) which are essentially individual smart components like smart agriculture (agriculture CPS), smart healthcare (healthcare CPS), and smart transportation (transportation CPS). A combination of

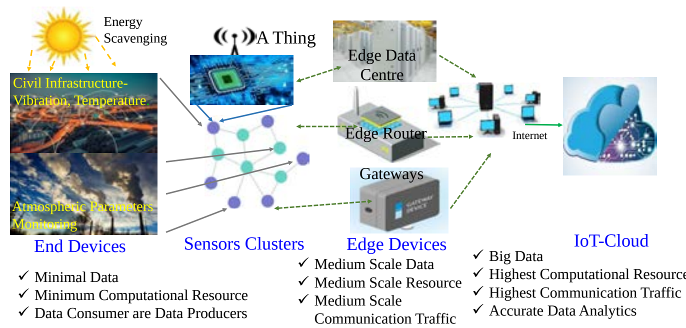


Fig. 1: Overview of IoT Computing - A Critical Need for Smart Villages and Smart Cities [3].

these CPS of different sizes and varieties are ingredients of the system-of-systems like smart villages, smart cities, or smart countries.

The IoT paradigm that leads to CPS (see Figure 1) is crucial in improving efficiency of various physical components [3]. The efficient use of public resources and enhanced quality of services to the citizens driven by IoT/CPS reduces the operational cost in specific components of smart villages and smart cities [2]. There are many elements including sensors, communication protocols, machine learning models, and embedded devices which build an IoT node (i.e. a Thing) [4]. To provide a continuous power supply to the sensors is a challenge, and can be addressed by low power designs [3]. The use of batteries for energy supply leads to increase in budget as well as limits its usage/life time. The natural resources can be used for energy harvesting to mitigate this problem.

II. Smart Cities and Smart Villages - Broad Perspectives

A. Smart Cities

The smart cities around the globe are making strong progress as it is expected that 70% of the world population will live in the city by 2050. It relates the key industries with the service sectors as smart governance, smart utility, smart mobility, smart buildings, and smart environment [5]–[7]. The physical, social, and business infrastructures can have enhanced performances by using IoT and AI driven data analytics smart cities. The challenges of smart cities include design and operation cost, energy requirements, big data analytic, security and privacy issues, and disaster resilience [1].

B. Smart Villages

Smart village concept that combines renewable energy and community-based education can have impact on estimated 940 million population worldwide [8]. The smart villages exhibit certain characteristics which may have some commonalities with smart cities, but also some distinctly different (see Figure 2) [9]. Various technologies, such as information and communication technology (ICT), geography information system (GIS), IoT-cloud, IoT-edge, and remote sensing can be effectively utilized in building a smart village.

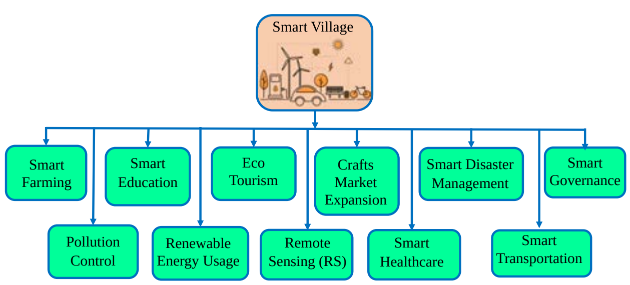


Fig. 2: Essential Requirements in a Smart Village.

A variety of consume technologies including sensors, actuators, cameras, drones, robots, medical devices, and agro-devices, can be involved in automating decision-making in the smart village components such as smart energy, smart agriculture and smart healthcare. Solar panels can be installed in the roofs for renewable energy [9]. A smart and robust mobility system can be enhanced by using smart transportation and logistics infrastructure to link the rural and urban areas. Smart classrooms can be built for effective use of leaning materials and sharing of knowledge with experts. The smart healthcare can be used to reach remote places, and citizens in villages can benefit from it. Waste materials can be used to generate energy in the form of gas, fuel, fertilizers, and it helps in generation of revenue. Water harvesting can fulfill the demands for drinking water as well as for agriculture. The crafts are mainly part of villages and have a high demand in urban areas; more training and production can be targeted for its marketing [10]. The smart villages can be a reality using numerous sensors in IoT and their energy requirement is a crucial parameter for sustainability.

C. Challenges for Sustainable IoT

There are many challenges alongwith opportunities that arise in building sustainable smart villages and smart cities.

1) Selected Challenges:

High Energy Requirement: High energy requirement is a challenge that any smart city and smart village needs to handle. The energy requirements of the cities is as much as 70% of worlds total requirements and it will be worse with the population migration to cities [1], [11]. Various components of the smart cities including the bigdata computational resource consume significant amount of energy. The continuous monitoring and transmission of data to the control room need an uninterrupted power supply [12]. To cater to the power requirement using fixed energy resource like battery is a limitation [13]; thus, natural energy scavenging and harvesting techniques should be investigated.

Security and Privacy: The privacy and security is the most crucial aspect in a smart cities scenario [14], [15]. The refurbished hardware are nowadays becoming a threat to consumer electronics products. It needs to secure designs with privacy intact.

2) Tradeoffs through Optimization:

Energy and Cost: Computational resources as well data transmission networks need a lot of energy. The edge node can be made self-sustainable by scavenging natural energy to power the edge nodes [15], [16] instead of using fixed batteries.

By adopting optimized methods at each layer of computation, the cost factor can be minimized.
Latency and Bandwidth: The operation latency is not only due to the computation, but the network path also contributes to it specifically when processing is performed at the IoT-cloud. The computations can be performed near the user to reduce the communication latency, which is the essence of edge/fog computing [17], [18]. Higher bandwidth allocation at the edge and pre-processing of data can reduce traffic to the IoT-cloud.

D. Collaborative IoT-Edge Computing for Smart Services and Components

IoT-edge or fog computing is decentralized IoT-computing as compared to IoT-cloud computing which is centralized [17], [19]. Collaborative edge computing connects the IoT-edges of multiple organizations that can be near or far from each other, thus providing bigger computational capability at the edge [20], [21]. Collaborative edge computing can effective for a variety of smart services and components in both smart cities and smart villages (see Figure 3).

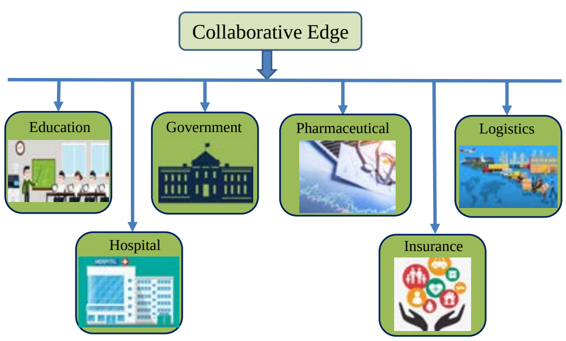


Fig. 3: Collaborative Edge can have significant applications in both smart villages and smart cities.

1) Smart Energy: Priorities can be set for emergency activities if energy storage and consumption are known in advance [22]. The photovoltaic panels can be installed in infrastructures to meet the energy demands in the cities [12], [16], [23]. The street lighting plays a significant contribution to the energy consumption of the whole city. Various parameters including, time of the day, weather condition, and human/object presence can be monitored for efficient lighting use under "smart street lighting" [24]. The smart poles (new solar cell enabled electric poles) with failure detection mechanisms can be installed within the city to cater to these issues.

2) Waste Management and Air Quality: Waste management is an essential aspect in smart cities that involves the cost and storage of garbage in landfills. The use of an intelligent waste collector, which ultimately manages the load of the container, and directs the collector vehicle route to save cost and speed up the recycling process [2]. The use of renewable energies can reduce the pollution level in cities and improve air quality.

3) Smart Transportation: IoT sensors can be placed in cities to find an appropriate place to facilitate transportation [25], [26], which may ensure less carbon emission from vehicles and less traffic. Near field communications (NFC) can be used to identify slots for parking and occupancy. The proper linking of the transport system as road, air, water, and rail transport with each other boosts economy [27]. Protected paths for cycling and walking can be made for citizens. All electric vehicles with charging capability and battery capacity suitable for a range of vehicles needed for smart villages and smart cities can be effective to reduce dependence on fossil fuel as well as corresponding air pollution (See Figure 4) [28].

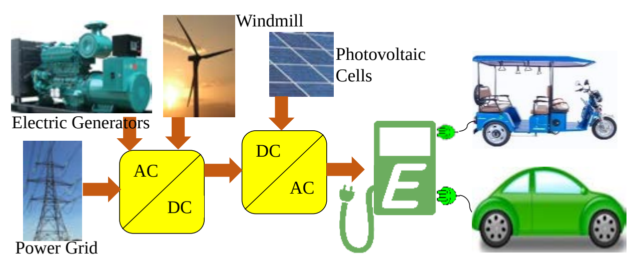


Fig. 4: Mix-energy source charging of electric vehicles [28].

4) Smart Healthcare: The use of IoT in healthcare called as the internet of medical things (IoMT) helps a large number of patients to be diagnosed, and queue from hospitals can be reduced [29], [30]. The smart healthcare is built healthcare Cyber-Physical System (H-CPS) by using IoMT, AI models and electronic health records (EHR).

5) Smart Home: Various appliances in smart homes are energy hungry and smart consumption is key to keep the energy cost low [1]. The connection of a wireless module to existing equipment will not make it smart. There must be intelligent decision on various aspects of home including air-conditioning temperature, appliance usage duration and lighting, for smart consumption and even harvesting of energy. In this regard, processing at the edge is beneficial [4].

6) Noise Monitoring and Traffic Congestion: Sound detection sensors with cameras can be placed in cities to identify the noisemaker in the cities. GPS enabled vehicles database ensures the citizens to get the easiest route [6].

7) Structural Health of Buildings: Proper maintenance and monitoring of the conditions of the buildings is possible in smart cities by using IoT sensors placed in the buildings for monitoring parameters, which provides a robust database of the environmental conditions for analysis and actions [6], [31].

E. Smart Villages versus Smart Cities

Table I depicts the practical requirements and features involved in harmonizing services in a smart villages and smart cities.

III. Energy Management in IoT for Smart Villages and Smart Cities

The global energy harvesting (EH) market will grow to US$4.4 billion by 2021 (see Figure 5a and Figure 5b) [32], [33]. Consumer electronics cover the maximum share of the global EH market. Industrial and wireless sensor networks (WSNs) experience the fastest growth amongst energy harvesting sectors. To be ubiquitous and self-sustainable, IoT needs sensor technology, which exhibits some properties as maintenance free, scalable, supports Mobility, low cost, long lifetime, flexible, environment friendly, and sustainable. Energy harvesting or scavenging aims to transduce ambient energy into electrical energy targeting sensors, and self-powered hardware towards battery-less IoT. The reclaiming of energy can be termed as energy scavenging while generating energy is called as energy harvesting.

A. Energy Scavenging

Energy scavenging is mostly hunting of sources that can be reused further (see Figure 6a). It is reclaimed from natural sources and from the unused portion of the energy that is dumped [34], [35]. It happens on a small scale. It reduces some percentage of the burden of the main system in terms of activity and cost. It is done for a specific purpose to achieve sustainability. Energy scavenging is ideal for the sensors placed in proximity to the machinery as industrial equipment, household appliances, and vehicles.

B. Energy Harvesting

Energy harvesting is a complete process, and full of activities to use, and storing the energy scavenged from natural resources (see Figure 6b). It happens on a large scale. It is done for particular or multiple purposes of fulfilling the power demands. Energy harvesting technologies are the basics in enabling the realization of zero power in wireless sensors, and implementing the IoT and man-to-machine (M2M) communication [36]. Table II presents the energy sources available for powering IoT and Table III has the power density information of various sources.

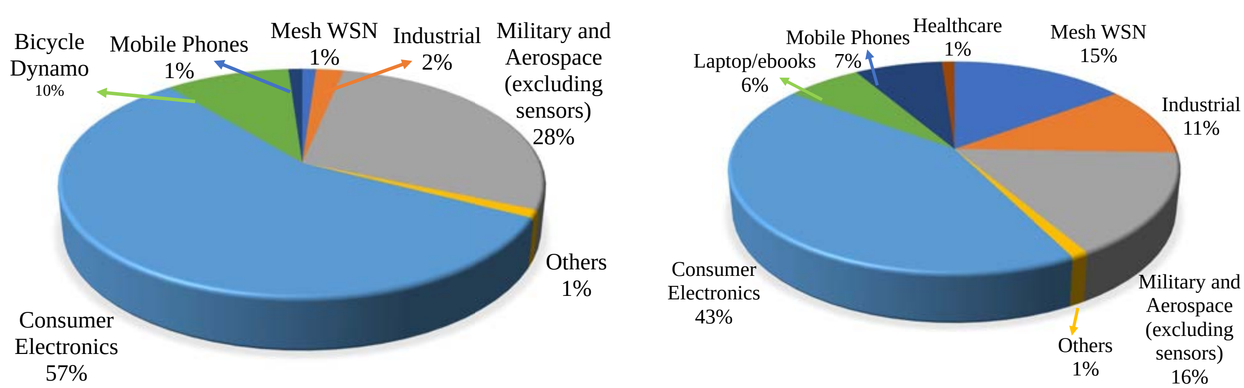
C. Energy Harvesting from Natural Resources

The energy is a limited resource of paramount importance to make a device active for an infinite period in a smart village and city. Energy harvesting from natural resources like solar, wind, piezoelectric, and thermoelectric [12] can be effectively used for powering IoT. The energy harvesting mainly deals with energy generation (source), conversion (using a transducer), storage (for use at a later time), and distribution (delivering it efficiently to the required component) [15], [39].

The energy/power requirement in a sensor based environment is increasing. It will increase further if the computation to be performed at the sensors using IoT-end devices. Fixed batteries are not a permanent solution to fulfill the energy demand of the power-hungry sensors. The power requirement and cost restrictions lead researchers to scavenge energy from natural resources. The energy can be used directly or stored in batteries/supercapacitors for blackout periods.

TABLE I: Service Specifications in a Smart Village and Smart City.

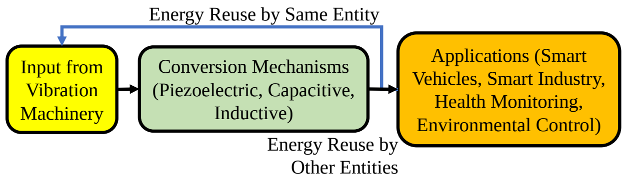
Services in Smart City	Services in Smart Village	Communication Type	Energy Source	Feasibility
Waste Management	Waste Management	WiFi, Sigfox, Neul, LoRaWAN	Battery Powered and Energy Harvesting	Feasible but smart garbage containers adds in cost
Air Quality Monitoring	Smart Weather and Irrigation	BLE, ZigBee, 6LoWPAN, WiFi, Cellular, Sigfox, LoRaWAN	Solar Panels, Battery Power and Energy Harvesting	Feasible
Smart Surveillance	Smart Surveillance	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	Power Grid, Solar Power, Wind Power, Energy Harvesting, and Energy Scavenging	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, 6LoWPAN, Sigfox	Power Grid, Solar Power, Battery Power, Energy Harvesting, Energy Scavenging	Easy integration and energy harvesting can be beneficial to fulfill power requirement
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, 6LoWPAN, 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



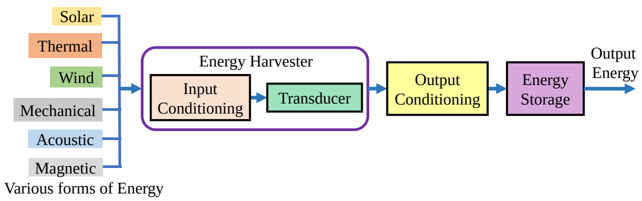
(a) Energy Harvesting Market 2011 [32].

(b) Energy Harvesting Market 2017 [33].

Fig. 5: Energy Harvesting Market Scenario.



(a) Energy Scavenging from Vibration Machinery for Sustainability in Smart City



(b) Energy Harvesting for Sustainability in Smart Villages

Fig. 6: Energy Scavenging versus Energy Harvesting.

TABLE II: Energy harvesting from nature sources to provide self-powered nodes.

Energy Type	Energy Source
Mechanical Energy	Vibrations or Deformations
Thermal Energy	Points at different temperatures
Solar or Light Energy	Sun or artificial light can be harvested with photo diodes
Acoustic Energy	Energy Harvested with MEMS
Electromagnetic Energy	Energy harvested with antennas

D. Energy Storage: Battery versus Supercapacitor

Batteries can store more energy in a given weight and volume and have better energy density. Supercapacitors can charge very quickly and have improved power density, thus, saving more energy. Supercapacitors are the preferred element for high energy storage applications that requires high-voltage and high-current drive. They are suited for a broad range of applications such as IoT, consumer products, white goods, office automation, long term battery backup and energy harvesting. Table IV presents a comparative perspective of the performances of energy storage elements in IoT.

TABLE III: Different energy harvester with power densities [37], [38].

Energy Harvester	**Power Densities (Indoor Conditions)**	**Power Densities (Outdoor Conditions)**
Solar Panel	$100\mu W/cm^2$	$10mW/cm^2$
Wind Turbine Generator	$35\mu W/cm^2$	$3.5mW/cm^2$
Thermal electric Generator	$100\mu W/cm^2$	$3.5mW/cm^2$
Electromagnetic Generator	$4\mu W/cm^3$	$800\mu W/cm^3$

TABLE IV: Battery versus Supercapacitor [13], [40].

Features	**Li-ion Batteries**	**Supercapacitors**
Voltage of a Cell (V)	3.6	2.7-3.3
ESR (mW)	500	40-300
Charging Time	Hours	Few Seconds
Power Density (W/kg)	1500	3000-40000
Efficiency (%)	75-90	98
Life (years)	5-10	10-18
Bio Compatibility	No Harsh Chemicals	Harsh Chemicals
Risk of Explosion	Yes	No
Energy Harvesting	Less Preferred	Widely Preferred
Ageing	More Affected	Less Affected

IV. Security-by-Design (SbD) is Key for Sustainable IoT in Smart Cities

A. Security-by-Design (SbD)

Security is an equally critical concern as the energy in IoT or CPS. Security aspects include identifying and authentication of hardware, preventing invasive or semi-invasive attacks, and detecting refurbished (counterfeited) hardware from the obsolete information. The energy requirement of the sensors in IoT is continuous, which leads to harvesting energy from natural resources to fulfill the demand. A new design paradigm called Security-by-Design (SbD) or Secure-by-Design (SbD) has been envisioned that handles security at the early stages of design phases while taking care of energy aspects so that retrofitting to provide security is not needed [41]. SbD ensures device, system and data security in various components IoT and CPS (See Figure 7).

B. Our Eternal-Thing: Secure Energy-Harvesting for Sustainable IoT

We introduced an unique hardware component called "Eternal-Thing" for sustainable IoT using the

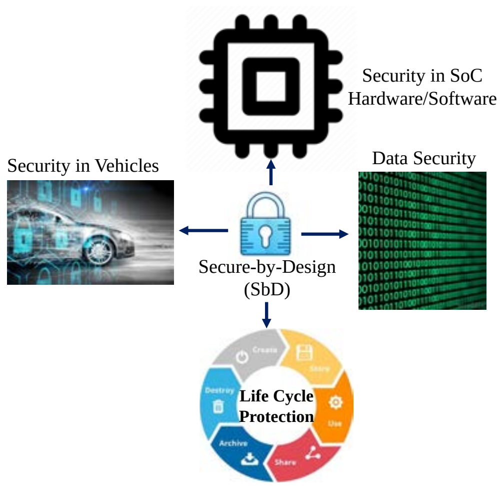


Fig. 7: Security-by-Design or Secure-by-Design (SbD) in CPS to integrated security during design phase while avoiding retrofitting [41].

principle of SbD [15]. It is a fact that the attacks on the energy harvesting hardware by an adversary can lead to damage to the sensors and denial of services. The hardware security is an important criterion, as the EHS chip after fabrication has to deploy in different locations. Eternal-Thing can have the physical unclonable functions (PUF) to provide secutity which are designed by re-utilizing available oscillators of EHS (see Figure 8) [15]. Eternal-Thing can also have other mechanisms such as hardware Trojan resilience built in for its security. Thus, the Eternal-Thing has capability to power itself from the solar energy while providing security continuously as long as possible for a sustainable IoT or CPS of smart villages and smart cities [3].

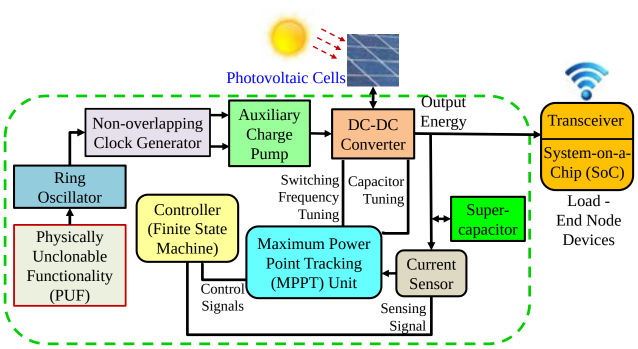


Fig. 8: Our Vision of Eternal-Thing - Secure Energy-Harvesting for Sustainable IoT [15].

C. *Eternal-Thing 1.0 - Security with PUF*

An instance of Eternal-Thing, Eternal-Thing 1.0 deploys PUF as security primitive that generates the keys from the inherent nanoelectronic manufacturing process variations [15] (see Figure 9). The key from the RO-PUF is used to trigger the RO of EHS, once it is powered ON. The PUFs can be designed from the existing modules of EHS, which indicates that the area overhead due to additional PUF module can be lowered. The PUFs are designed to generate a 128-bit secret key, which is used to trigger different modules of Eternal-Thing. In a specific implementation of Eternal-Thing 1.0, for the solar input is in the range of 1-1.55 V and maximum power point (MPP) at 1.22 V, the output voltage is in the range of 3-3.55 V. The metal insulator metal (MIM) capacitors are used in designing the converter. The load for the EHS is designated with a 200 kΩ resistor and a 33 mF supercapacitor. The Eternal-Thing 1.0 has power specifications within the ultra-low-power realm.

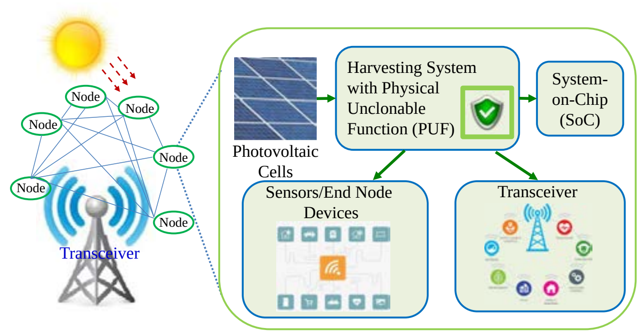


Fig. 9: Eternal-Thing 1.0 - EHS Security with PUF in an IoT Smart Node [15].

D. *Eternal-Thing 2.0 - Hardware Trojan Resilience*

Our research on Eternal-Thing is on going to integrate more security features right during the early design phases as per SbD principle. The reliability can be explored in terms of intentional aging of circuits and use a specific Trojan to affect the EHS module. These reliability issues and their appropriate mitigation techniques are essential. Although different Trojan attacks are possible, the EHS architecture is more sensitive to A2 based Trojan due to the presence of counter in the design. A2 is a specific analog hardware Trojan that uses capacitors, which charges from the nearby values in wires as they transition between digital logic values [42]. It will affect the EHS performance drastically. Proper mitigation techniques should be adopted that uses aging tolerant and Trojan detection circuits to cater to various Trojans like intentional increase in temperature and A2, for designing Trojan resilient IoT (see Figure 10).

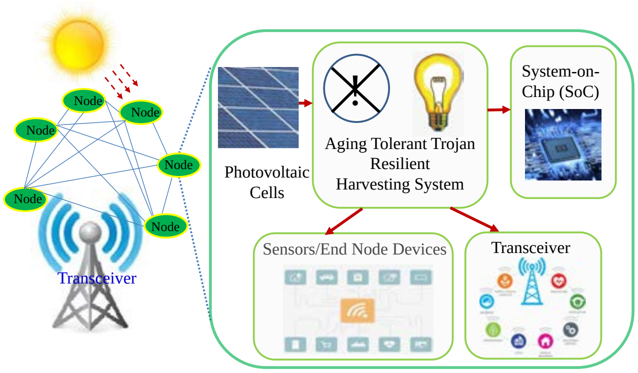


Fig. 10: Eternal-Thing 2.0 - EHS with Trojan Resilience Design in an IoT Smart Node.

V. Conclusions and Future Directions

IoT has a vast application in smart villages and smart cities. The usage of new consumer technologies for the betterment of society put a lot of burden on the IoT-cloud and communications network. The complete computing at the IoT-cloud makes the decision, and its implementation more complicated and time-consuming. The IoT-edge/fog computing reduces the computational complexities at the IoT-cloud and reduces energy and latency in communication networks. The edge computing involves many sensors for gathering information, and have to be ON for a more extended period. The natural energy harvesting is an effective way to mitigate the energy-related issues in IoT for sustainability rather than using fixed batteries. A state of art energy harvesting system alongwith builtin security mechanisms is critical to power several sensors in the smart village and smart city for sustainable IoT. Thus secure-by-design (SbD) and/or privacy-by-design (PbD) mechanisms can be deployed for sustainable IoT for smart villages and smart cities.

In the future, SbD/PbD principles will be deployed for overall design optimization of IoT and CPS, not just at the IoT-end and IoT-edge. Novel concepts will be investigated to bring consumer electronics gadgets that will be secure by design to fill the gap in the functioning of things from edge to cloud. Cost factor of the design and operation of the sustainable IoT for its applications in smart villages is an added constraint for the design flow.

Acknowledgments

This research work is supported by Special Manpower Development Program for Chips to System Design (SMDP-C2SD), the Meity, Government of India.

References

[1] S. P. Mohanty, U. Choppali, and E. Kougianos, “Everything You wanted to Know about Smart Cities: The Internet of Things is the backbone,” *IEEE Consumer Electronics Magazine*, vol. 5, no. 3, pp. 60–70, July 2016.

[2] A. Zanella, N. Bui, A. Castellani, L. Vangelista, and M. Zorzi, “Internet of things for smart cities,” *IEEE Internet of Things journal*, vol. 1, no. 1, pp. 22–32, 2014.

[3] S. S. Roy, D. Puthal, S. Sharma, S. P. Mohanty, and A. Y. Zomaya, “Building a sustainable Internet of Things: Energy-efficient routing using low-power sensors will meet the need,” *IEEE Consumer Electronics Magazine*, vol. 7, no. 2, pp. 42–49, Mar 2018.

[4] M. O. Farooq, I. Wheelock, and D. Pesch, “IoT-Connect: An interoperability framework for smart home communication protocols,” *IEEE Consumer Electronics Magazine*, vol. 9, no. 1, pp. 22–29, Jan 2020.

[5] J. Beneicke, A. A. Juan, F. Xhafa, D. Lopez-Lopez, and A. Freixes, “Empowering citizens’ cognition and decision making in smart sustainable cities,” *IEEE Consumer Electronics Magazine*, vol. 9, no. 1, pp. 102–108, Jan 2020.

[6] P. Barsocchi, P. Cassara, F. Mavilia, and D. Pellegrini, “Sensing a city’s state of health: Structural monitoring system by Internet-of-Things wireless sensing devices,” *IEEE Consumer Electronics Magazine*, vol. 7, no. 2, pp. 22–31, 2018.

[7] L. Huang, S. Bi, L. P. Qian, and Z. Xia, “Adaptive scheduling in energy harvesting sensor networks for green cities,” *IEEE Transactions on Industrial Informatics*, vol. 14, no. 4, pp. 1575–1584, 2017.

[8] IEEEE, “IEEE smart village,” 2020, last accessed on 22 Aug 2020. [Online]. Available: https://smartvillage.ieee.org/

[9] A. Umar, “Smart Collaborating Hubs and a Smart Global Village-An Alternative Perspective on Smart Cities,” in *Proc. IEEE Technology and Engineering Management Conference (TEMSCON)*, 2018, pp. 1–6.

[10] A. Davies, “IoT, Smart Technologies, Smart Policing: The Impact for Rural Communities,” in *Smart Village Technology*. Springer, 2020, pp. 25–37.

[11] US-DOE, "Understanding energy use in cities infographic," 2020, last accessed on 27 Aug 2020. [Online]. Available: https://www.energy.gov/eere/understanding-energy-use-cities-infographic

[12] A. Omairi, Z. H. Ismail, K. A. Danapalasingam, and M. Ibrahim, "Power harvesting in wireless sensor networks and its adaptation with maximum power point tracking: Current technology and future directions," *IEEE Internet of Things Journal*, vol. 4, no. 6, pp. 2104–2115, 2017.

[13] A. S. Sengupta, S. Satpathy, S. P. Mohanty, D. Baral, and B. K. Bhattacharyya, "Supercapacitors Outperform Conventional Batteries [Energy and Security]," *IEEE Consumer Electronics Magazine*, vol. 7, no. 5, pp. 50–53, 2018.

[14] D. A. Hahn, A. Munir, and S. P. Mohanty, "Security and Privacy Issues in Contemporary Consumer Electronics [Energy and Security]," *IEEE Consumer Electronics Magazine*, vol. 8, no. 1, pp. 95–99, 2018.

[15] S. K. Ram, S. R. Sahoo, B. B. Das, K. K. Mahapatra, and S. P. Mohanty, "Eternal-Thing: A Secure Aging-Aware Solar-Energy Harvester Thing for Sustainable IoT," *IEEE Transactions on Sustainable Computing (TSUSC)*, vol. XX, no. TSUSC.2020.2987616, p. Accepted on 08 Apr 2020, 2020. [Online]. Available: http://dx.doi.org/10.1109/TSUSC.2020.2987616

[16] S. K. Ram, B. B. Das, A. K. Swain, and K. K. Mahapatra, "Ultra-Low Power Solar Energy Harvester for IoT Edge Node Devices," in *Proc. IEEE International Symposium on Smart Electronic Systems (iSES)*, 2019, pp. 205–208.

[17] Z. Guan, Y. Zhang, G. Si, Z. Zhou, J. Wu, S. Mumtaz, and J. Rodriguez, "ECOSECURITY: Tackling challenges related to data exchange and security: An edge-computing-enabled secure and efficient data exchange architecture for the energy internet," *IEEE Consumer Electronics Magazine*, vol. 8, no. 2, pp. 61–65, Mar 2019.

[18] G. Zhang, W. Zhang, Y. Cao, D. Li, and L. Wang, "Energy-delay tradeoff for dynamic offloading in mobile-edge computing system with energy harvesting devices," *IEEE Transactions on Industrial Informatics*, vol. 14, no. 10, pp. 4642–4655, 2018.

[19] S. Saraswat, A. Gupta, H. P. Gupta, and T. Dutta, "An incremental learning based gesture recognition system for consumer devices using edge-fog computing," *IEEE Transactions on Consumer Electronics*, vol. 66, no. 1, pp. 51–60, Feb 2020.

[20] E. O'Dowd, "Collaborative edge computing supports health IT advancement," 2018, last accessed on 22 Aug 2020. [Online]. Available: https://hitinfrastructure.com/news/collaborative-edge-computing-supports-health-it-advancement

[21] J. Ren, G. Yu, Y. He, and G. Y. Li, "Collaborative cloud and edge computing for latency minimization," *IEEE Transactions on Vehicular Technology*, vol. 68, no. 5, pp. 5031–5044, May 2019.

[22] G. Rostirolla, R. da Rosa Righi, J. L. V. Barbosa, and C. A. da Costa, "ElCity: An elastic multilevel energy saving model for smart cities," *IEEE Transactions on Sustainable Computing*, vol. 3, no. 1, pp. 30–43, 2017.

[23] T. Ruan, Z. J. Chew, and M. Zhu, "Energy-aware approaches for energy harvesting powered wireless sensor nodes," *IEEE Sensors Journal*, vol. 17, no. 7, pp. 2165–2173, 2017.

[24] S. Chou, T. Wu, Z. Chen, R. Weng, C. Chang, Y. Lu, C. Chang, and W. Wu, "Early warning system for smart street lights," in *Proc. IEEE International Conference on Consumer Electronics - Taiwan (ICCE-TW)*, 2019, pp. 1–2.

[25] S. Goel, R. Kumar, A. Kumar, and R. Malhotra, "S^3A: Smart station search assistance for electric vehicle - a step toward smart city," *IEEE Consumer Electronics Magazine*, vol. 9, no. 4, pp. 27–33, July 2020.

[26] A. K. Tripathy, P. K. Tripathy, A. G. Mohapatra, N. K. Ray, and S. P. Mohanty, "WeDoShare: A Ridesharing Framework in Transportation Cyber-Physical System for Sustainable Mobility in Smart Cities," *IEEE Consumer Electronics Magazine*, vol. 9, no. 4, pp. 41–48, July 2020.

[27] D. Fooladivanda, A. D. Domínguez-García, and P. W. Sauer, "Utilization of Water Supply Networks for Harvesting Renewable Energy," *IEEE Transactions on Control of Network Systems*, vol. 6, no. 2, pp. 763–774, 2018.

[28] S. K. Rastogi, A. Sankar, K. Manglik, S. K. Mishra, and S. P. Mohanty, "Toward the vision of all-electric vehicles in a decade [energy and security]," *IEEE Consumer Electronics Magazine*, vol. 8, no. 2, pp. 103–107, Mar 2019.

[29] M. Aazam, S. Zeadally, and K. A. Harras, "Health Fog for Smart Healthcare," *IEEE Consum. Electron. Mag.*, vol. 9, no. 2, pp. 96–102, Mar 2020.

[30] S. Puranik and A. W. Morales, "Heart Rate Estimation of PPG Signals With Simultaneous Accelerometry Using Adaptive Neural Network Filtering," *IEEE Trans. Consum. Electron.*, vol. 66, no. 1, pp. 69–76, Jan 2020.

[31] S. Sharma, B. K. Panigrahi, and A. Verma, "A smarter method for self-sustainable buildings: Using multiagent systems as an effective alternative for managing energy operations," *IEEE Consumer Electronics Magazine*, vol. 7, no. 2, pp. 32–41, 2018.

[32] IDTechEx, "Energy harvesting and storage for electronic devices 20112021," 2011, last accessed on 27 Aug 2020. [Online]. Available: http://www.idtechex.com/research/reports/energy-harvesting-and-storage-for-electronic-devices2011-2021-000270.asp

[33] FMI, "Energy harvesting market: Global industry analysis and opportunity assessment 20142020," 2017, last accessed on 27 Aug 2020. [Online]. Available: https://www.futuremarketinsights.com/reports/global-energyharvesting-market

[34] M. M. Tentzeris, A. Georgiadis, and L. Roselli, "Energy harvesting and scavenging [scanning the issue]," *Proceedings of the IEEE*, vol. 102, no. 11, pp. 1644–1648, 2014.

[35] U. C. Chukwu and S. M. Mahajan, "Harvesting vibration energy from vehicle suspension system for mileage improvement," in *Proc. IEEE Power & Energy Society General Meeting*, 2018, pp. 1–8.

[36] D. Newell and M. Duffy, "Review of power conversion and energy management for low-power, low-voltage energy harvesting powered wireless sensors," *IEEE Transactions on Power Electronics*, vol. 34, no. 10, pp. 9794–9805, 2019.

[37] M. Prauzek, J. Konecny, M. Borova, K. Janosova, J. Hlavica, and P. Musilek, "Energy harvesting sources, storage

devices and system topologies for environmental wireless sensor networks: A review," *Sensors*, vol. 18, no. 8, p. 2446, 2018.

[38] S. Cao and J. Li, "A survey on ambient energy sources and harvesting methods for structural health monitoring applications," *Advances in Mechanical Engineering*, vol. 9, no. 4, p. 1687814017696210, 2017.

[39] S. K. Ram, S. Chourasia, B. B. Das, A. K. Swain, K. Mahapatra, and S. P. Mohanty, "A Solar Based Power Module for Battery-Less IoT Sensors Towards Sustainable Smart Cities," in *Proc. IEEE Computer Society Annual Symposium on VLSI (ISVLSI)*, 2020, pp. 458–463.

[40] P. Svasta, R. Negroiu, and A. Vasile, "Supercapacitors - an alternative electrical energy storage device," in *Proc. 5th International Symposium on Electrical and Electronics Engineering*, 2017, pp. 1–5.

[41] S. P. Mohanty, "Security and Privacy by Design is Key in the Internet of Everything (IoE) Era," *IEEE Consumer Electronics Magazine*, vol. 9, no. 2, pp. 4–5, Mar 2020.

[42] K. Yang, M. Hicks, Q. Dong, T. Austin, and D. Sylvester, "A2: Analog malicious hardware," in *Proc. IEEE Symposium on Security and Privacy*, 2016, pp. 18–37.

Saswat K. Ram is currently pursuing the Ph.D. degree in Electronics and communication engineering at NIT, Rourkela, India. Contact him at saswatram01@gmail.com.

Banee B. Das is currently pursuing the Ph.D. degree in computer science engineering in NIT, Rourkela, India. Contact her at banee.bandana@gmail.com.

Kamalakanta Mahapatra is a Professor in Electronics and Communication Engineering Department of National Institute of Technology (NIT), Rourkela. Contact him at kkm@nitrkl.ac.in.

Saraju P. Mohanty is a Professor at the Department of Computer Science and Engineering (CSE), University of North Texas (UNT), Denton, TX, USA. Contact him at saraju.mohanty@unt.edu.

Uma Choppali is a Physics Full-Time Faculty at the Dallas College - Eastfield Campus. Contact her at Email: uchoppali@dcccd.edu.