Smart Village: An IoT Based Digital Transformation

Amit Degada
University of Kentucky
Lexington, KY, USA
amit.degada@uky.edu

Himanshu Thapliyal
University of Kentucky
Lexington, KY, USA
hthapliyal@ieee.org

Saraju P. Mohanty
University of North Texas
Denton, TX, USA
smohanty@ieee.org

Abstract—Almost 46% of the world's population resides in a rural landscape. Smart villages, alongside smart cities, are in need of time for future economic growth, improved agriculture, better health, and education. The smart village is a concept that improves the traditional rural aspects with the help of digital transformation. The smart village is built up using heterogeneous digital technologies pillared around the Internet-of-Thing (IoT). There exist many opportunities in research to design a low-cost, secure, and efficient technical ecosystem. This article identifies the key application areas, where the IoT can be applied in the smart village. The article also presents a comparative study of communication technology options.

Index Terms—Internet-of-Thing, smart village, smart cities, communication technologies, LoRaWAN, NB-IoT, sensors

I. WHY SMART VILLAGES ARE NEEDED?

Approximately 60 Million people and 97% of the landmass in the US is classified as rural [1]. The three most populated countries China, India, and Indonesia have a considerable amount of population are living in villages. Some countries, e.g., Nepal, Cambodia, Chad, Uganda, Malawi, Rwanda, St. Lucia, and Solomon Island, etc. have more than three fourth of the population lives in rural areas. It is well-understood that the nature of the problem in villages is beyond the quality of life and requires utmost attention [2]. Therefore, the general assembly of the United Nations (UN) has adopted seventeen Sustainable Development Goals (SDG) towards the holistic development of every aspect of an individual's life [3].

On the other hand, the technological advancement in communication and computing technologies have transformed health, education, food, energy access, and the way we interact with our surroundings on a large scale. In recent years, the research community has focused on the development of the sustainable settlements of the communities, e.g., smart cities. The development of the smart villages, parallel to the smart cities, are the need of the time to bring both at the same level to sustain equilibrium in holistic development.

To envisage the smart village (Figure 1), the Internet-of-Thing (IoT) is a key technology player. The IoT provides interactive platforms for exchange of the information, and control the actions between the smart devices. Smart things are embedded with smart sensor-computing platforms and information exchanges across the communication protocols. The IoT is a proven solution with improved efficiency and reduction in time, as well as cost. This article aims to bridge the gap between the existing challenges in smart villages, and potential digital solutions through IoT technology. Wireless
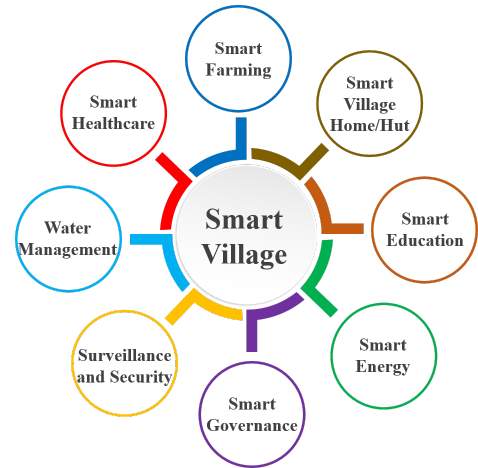

Fig. 1: Smart Village.

networking creates the skeleton for everything to communicate. The wireless technology in rural environments should be low power, large range, and have less bandwidth. The article presents a comparison between two competing technology, Long Range Wide Area Network (LoRaWAN) and Narrow Band-IoT (NB-IoT), enabling the designer to chose that can provide optimal performance in the smart village vertical.

II. SMART VILLAGE DESIGN CYCLE

The setting up of the idea of smart communities is not recent. There are plenty of successful smart cities, and villages have already been established at many places across the globe. The smart village design uses smart technology to build viable services to alleviate the hardship of the village community, sustain the social ecosystem, and contribute towards economical growth. The smart village design problem is highly dispersed and often involves many non-hierarchical structures. Further, the resource in the villages are often shared, and a holistic approach is needed for sustainability. The four primary steps to design a smart village, as shown in Figure 2 are identification and mapping, decision making, prototype development, and evaluation and scale-up.

The first step is to identify the current problem, evaluate the challenges, and map it to a cost-effective smart digital solution for long-term inclusive growth. The second important step is to decide the relevant, appropriate and adaptable digital solutions to mobilize the resource and sustainable growth. The success of the smart village depends upon energy-efficient, low-cost power solutions, connected digital solutions, and

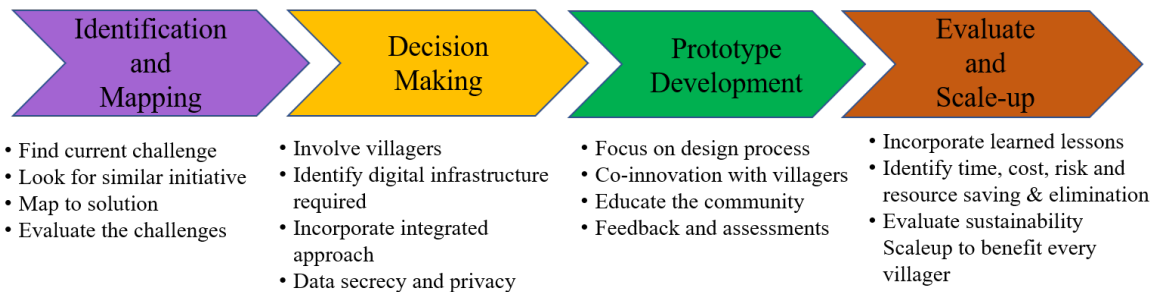| Identification and Mapping	Decision Making	Prototype Development	Evaluate and Scale-up
• Find current challenge • Look for similar initiative • Map to solution • Evaluate the challenges	• Involve villagers • Identify digital infrastructure required • Incorporate integrated approach • Data secrecy and privacy	• Focus on design process • Co-innovation with villagers • Educate the community • Feedback and assessments	• Incorporate learned lessons • Identify time, cost, risk and resource saving & elimination • Evaluate sustainability Scaleup to benefit every villager

Fig. 2: Smart village design cycle.

uninterrupted connectivity. The key deciding factors of digital technology are coverage, data rate, power, and cost. The trust in user data privacy and secrecy are important for the success of the smart village. To ensure it, the design should specify how the data will be collected, used, stored, and shared. The third step is to deploy a scalable prototype. The prototype implementation helps to evaluate the deployed technology, study possible vulnerabilities, and explore another technological opportunity for better reach, revenue generation, and cost-effective solutions. The final step will replicate the prototype for the entire pool of villagers. This is often an iterative process to look for identifying the time, cost risk, and resource-saving or elimination.

III. IoT as backbone of the smart village

The problem of designing the smart village can be complex and it should be addressed at multiple levels. The IoT application domain includes smart homes/huts, smart farming and dairy, smart cattle tracking, smart healthcare, smart water, and waste management, smart energy management, smart transportation, and smart governance, etc. We classify village-life aspects (Figure 3) into three categories: Agriculture, Social, home, and utilities. Table I summarizes the important issues being addressed in the literature so far.
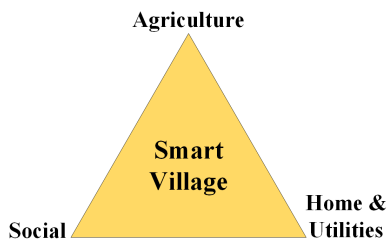

Fig. 3: Smart village key aspects.

Farming is perhaps the oldest industry, which requires the ability of the farmer to foresee the changes in surrounding nature, analyze the conditions and execute the required set of actions to increase the quality and quantity of the crops and livestock. IoT-based smart farming is seen as a prospect to revolutionize in many aspects. The IoT sensors collect weather information, soil moisture conditions, the health of crops and cattle. The ability to automate data analysis (using machine learning, big data) helps to better control the production cycle,

growth, and meet a higher standard. The researchers in [11], proposed an online semantic framework that enables real-time data analytic, detects important events, automate decision making and works seamlessly among different sensors, process, applications, and operations. Similarly, IoT sensors can be used to track the location, monitor the health, and create a log of animal performance [12].

In Europe and the US, villages have a large elder population. A significant portion of the village population is living below poverty. The people in the village are often deprived of good medical support and care at a low cost. IoT-based smart healthcare is a potential solution to provide evidence-based primary medical care. Chronic diseases (e.g. high blood pressure, high cholesterol, and diabetes) often cause heart and kidney disease, diabetes, blindness, and amputation. The authors in [13] reviewed several machine learning and emerging optimization algorithms for Alzheimer, dementia, tuberculosis, diabetes mellitus, and cardiovascular disease. They could be applicable for the smart village healthcare system.

The village usually adopts the traditional methods to collects the waste, thereby, lacks to create a healthy community. The waste produced in the village depends upon the agriculture season and varies widely depending upon the community. The IoT empowered solutions to help to identify the capacity of the trash cans, reduce overflows, determine the optimal route for garbage collection, and analysis of waste generation [14], [15]. Smart energy management is meant to generate green electricity (e.g. Solar, windmill), monitor its usage, and control its wastage. The IoT sensors, controllers, solar panels, energy storage, and smart energy grids are key parameters for efficient and optimized usage. The IoT sensors placed at solar panels and windmills can sense the weather, and optimize electricity generation. Further, the smart energy system also manages the smart street light and electric vehicle charging. The extra energy generated from green energy sources (e.g. solar panels, windmills, etc.) can also sell extra energy to urban areas [16], [17]. The researchers in [18] have proposed a big data analytics model based on four key aspects, viz. management at power generation side, renewable energy, and its microgrid management, collaborative operations, and demand-side management.

Other than limited employment, and revenue generation opportunity, the social aspects (e.g. education, safety, governance, etc.) is a common reason for village community migrations. The IoT-empowered education can track the attendance (using RFID, ZigBee), monitor the progress in quizzes (using

TABLE I: The smart village goal

Village-life aspects	Towards smart village	Issue being addressed
Agriculture	• Smart farming • Smart irrigation • Smart live-stock tracking • Smart dairy • Smart agriculture waste management	• Climate monitoring and forecasting • Irrigation and fertilizer management system • Crop health monitoring and predictive analysis • Monitor the health and performance of individual animal and collective analysis as herd • On-time forecasting and meeting the need of agriculture product • Reducing the agriculture waste and recycle management [4], [5]
Social	• Education • Surveillance and security • Governance • Infotainment	• Interactive learning experience, connected classrooms and libraries • Understand the learning style, attitude and adapt the methodology for individual student [6] • The real-time surveillance provide greater visibility, reach for prevention of crime, and critical asset loss • Improve the governance efficiency, tracking the village wide services, safety of villagers, and enable sustainable growth [7]
Home & Utilities	• Smart village home/hut • Smart healthcare • Smart Energy • Water and waste management	• Gas, smoke-fire detection, camera surveillance and better energy management • Catering the need of the elderly people, e.g health, stress and fall detection. Monitor the chronic illness, e.g. high blood pressure, high cholesterol, diabetes, and rehabbing [8] • Security by design in energy harvesting consumer IoT devices [9] • Efficient and cost-effective distribution of the clean water, check pH, oxygen, turbidity in water, hydrocarbons, metal and chemical contains in the soil [10]

cloud computing), smart libraries (with sensors), interactive learning experience, and resource-saving. Additionally, virtual reality-based smart education can be useful for vocational skill enhancement, healthcare training, and disaster management training, etc [19], [20]. The smart education concept successfully made the school dropout to 0 with the introduction of smart education practices at model "smart village" Punsari, India [21].

IV. BUILDING TOWARDS DATA DRIVEN ECOSYSTEM

The digital world is driven by the collection of data efficiently, communication, and take intelligent decisions in a decentralized platform. The data-driven platform requires trusted information exchange between every "thing" in a secure, and efficient way. The foundation of the smart village depends upon choosing the right sensor, computing platform, energy supply mechanism, communication networking, and efficient information processing. The section provides an outline to build an IoT-based data-driven ecosystem for smart villages.

A. IoT enabled digital transformation

Fig. 4: Digital transformation towards smart village.

The IoT is an integration of sensors, actuators, and small computing units to automate a system via the internet. The digital transformation of a village is built up (as shown in Figure 4), primarily around IoT enabling blocks and value addition technology. The technologies that directly contribute are listed as follow:

- IoT Enabling blocks: The IoT is essentially machine-to-machine (M2M) communication protocols and interfaces. It includes the sensors, microcontrollers, energy harvesting mechanism, positioning technology (e.g. GPS), Radio Frequency Identification (RFID), Bluetooth low energy (BLE), Zig-Bee, Z-wave, Low Power Wide Area Networks (LPWANs), and Near-Field Communication (NFC).
- Value addition technology: These technologies add the values, aid decision making, and enhance the security in overall service. The list includes cloud computing, Big data analytics, machine learning, artificial intelligence, virtual reality, and blockchain. Further, the usage of drones and robotics can also fall into this category.

B. Wireless communication for wide-area network

The smart village deployment is often complex and suffers low connectivity. Thereby, no single communication technology can serve all the building blocks. The connectivity technology should support a wide area range, low power dissipation, support connectivity in all different climates, and can be set up quickly. The examples of wireless communication explored in literature are RFID, Bluetooth low power, Wi-Fi, NFC, LPWAN, and cellular technologies. Each smart village vertical has a unique set of requirements in terms of cost, range, power consumption, network management, and security. Table II maps the smart village verticals to preferred IoT communication technology. Further, Figure 5 shows the comparison of different wireless technology in terms of distance, data rate, power consumption, and cost.

TABLE II: Mapping of smart village verticals to IoT communication technology.

Smart Village verticals	RFID	ZigBee	Z-Wave	Bluetooth BLE	Wi-Fi Wi-Fi Halow	LPWAN	Cellular
Climate monitoring in smart Farming	–	–	–	–	–	✓	–
Irrigation	–	–	–	–	–	✓	–
Livestock monitoring	✓	–	–	–	–	✓	–
Dairy	✓	✓	–	–	–	✓	–
Health-care	–	–	–	✓	✓	–	✓
Energy harvesting and management	–	–	–	–	–	✓	–
Smart lighting	–	–	–	–	–	✓	–
Smart village home/hut	–	✓	✓	✓	✓	–	✓
Surveillance	–	✓	–	–	✓	–	–
Asset monitoring and tracking	✓	–	–	–	–	✓	✓
Water and waste management	✓	–	–	✓	✓	✓	–
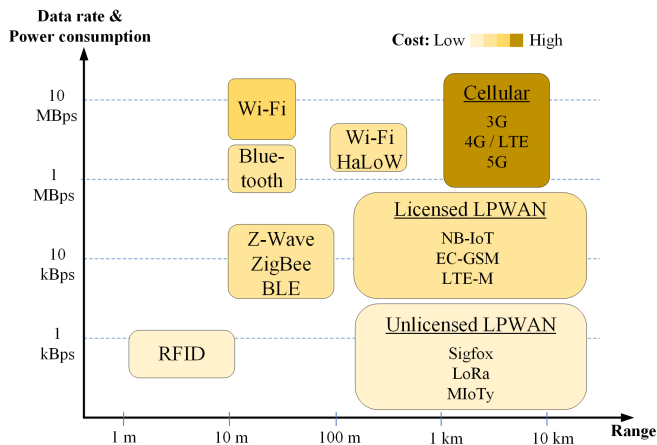
Fig. 5: Wireless communication technologies in IoT [22] [23].

Fig. 6: LoRaWAN and NB-IoT Comparison [24].

The majority of the smart village verticals do not require high speed and large bandwidth. Low Power Wide Area Network (LPWAN) technology emerged as the preferred wireless technology for M2M communication, offering cost-effective and energy-efficient solutions. The LPWAN uses an intermittent data packet size of 10 to 1000 bytes at a data rate ranging from 3 kbps to 375 kbps. Additionally, the LPWAN supports a large number of devices compared to other IoT communication technology. The first important choice that a designer needs to make is to use either unlicensed or licensed LPWAN. The unlicensed LPWAN uses the free license spectrum which could bring the cost down. However, there is the possibility that other organizations could use the same spectrum. It could result in interference from the different networks operating on the same spectrum. On the other hand, the licensed LPWAN supports a cellular communication network (e.g. 2G, 3G, 4G, and 5G). The licensed LPWAN facilitates instant seamless connectivity, the 'roaming' among networks, and operates on an exclusive spectrum allocated to a particular mobile operator. Further, it results in better secure, and reliable connections.
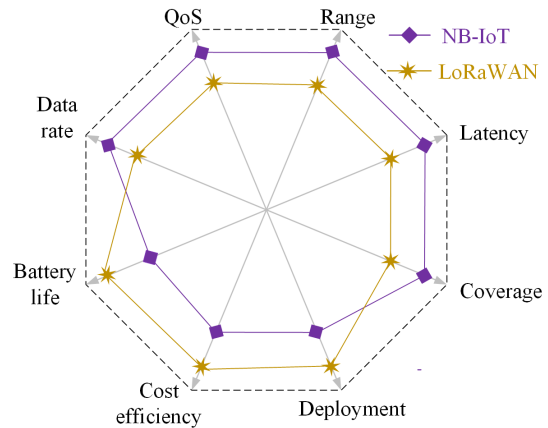
The licensed LPWAN are based on cellular transmission, e.g. Narrow Band-IoT (NB-IoT), Long Term Evaluation-Machine type communication (LTE-M), Extended Coverage-GSM (EC-GSM). The unlicensed LPWAN uses spread-spectrum technology in Long Range WAN (LoRaWAN), telegram splitting in MIoTy, and ultra-narrowband in SigFox schemes. It is often to fall into the trap to believe that LoRa and LoRaWAN is interchangeable. The LoRa is a modulation technique based on Chirp Spread Spectrum (CSS), while LoRAWAN is a WAN protocol defined up to the application layer, and permitting the connection of several devices. Among licensed and unlicensed LPWAN: NB-IoT, and LoRaWAN are more suitable in smart village applications due to their bandwidth, data-rate, battery requirement, and mobility. Figure 6 shows the comparison of LoRaWAN and NB-IoT. The

selection of the technology depends upon IoT factors, i.e. range, cost, coverage, battery life, latency, and Quality of Service (QoS). LoRaWAN and NB-IoT have the respective advantage compared to different IoT factors. LoRaWAN is better in terms of coverage, deployment, cost efficiency, and battery life. However, NB-IoT is advantageous for range, data-rate, latency, and QoS.

TABLE III: Comparison of LoRaWAN and NB-IoT [24].

Technical Parameter	LoRaWAN	NB-IoT
Bandwidth	125 kHZ	180 kHZ
Coverage	157 dB	164 dB
Security	AES 128 bit	3GPP (128 - 256 bits)
Battery life	15+ years	10+ years
Peak Current	32 mA	12-130 mA
Sleep Current	1 μA	5 μA
Latency	latency insensitive	< 10 S
Uplink MCL	165 dB	145-169 dB
Downlink MCL	165 dB	151 dB
Range	< 15 KM	< 35 KM
Spectrum cost	Free	> 500 USD million/MHz
Network and deployment cost	100-1000 USD per gateway	15K USD per base station

There are several factors needed to be considered to select the best communication technology. Table III lists the comparison of NB-IoT and LoRa in terms of bandwidth, coverage, battery life, security, scalability, spectrum cost, and deployment cost, etc. However, there is no clear winner, and each technology has the potential to meet a specific smart village vertical. The superior choice depends upon the life cycles, coverage area, networking options, ability to access the device.

V. CONCLUSION

The smart village concept addresses many life verticals of rural life, involves multiple stakeholders, and should be self-sustaining. Agriculture, education, health, energy, water, and waste management, governance are the critical village life verticals to achieve sustainable development. The IoT is a digital transformation platform that can serve as the backbone to develop the digital data-driven ecosystem. The digital transformation requires IoT communication technology that can serve a large area, work on limited power, less setup time, and operates across different climates. The LoRaWAN and NB-IoT are seen as closely competitive options, and there is no clear winner. The comparison between LoRaWAN and NB-IoT presented in this article can provide help to smart village designers select the optimal communication technology.

REFERENCES

[1] D. Murfet, "New census data show differences between urban and rural populations, release numbercb16-210," https://therisingsea.org/notes/FoundationsForCategoryTheory.pdf, Last Accessed: 5-5-2021.

[2] S. Patnaik, S. Sen, and M. S. Mahmoud, *Smart Village Technology: Concepts and Developments.* Springer Nature, 2020, vol. 17.

[3] "Envision2030: 17 goals to transform the world for persons with disabilities." United Nations Department of Economic and Social Affairs Disability, https://therisingsea.org/notes/FoundationsForCategoryTheory.pdf, Last Accessed: 5-5-2021.

[4] A. A. Gnanaraj and J. G. Jayanthi, "An application framework for iots enabled smart agriculture waste recycle management system," in *2017 World Congress on Computing and Communication Technologies (WCCCT)*, 2017, pp. 1–5.

[5] R. C. Loehr, "13 - management," in *Agricultural Waste Management*, R. C. Loehr, Ed. Academic Press, 1974, pp. 453–499.

[6] P. Pruet, C. S. Ang, D. Farzin, and N. Chaiwut, "Exploring the internet of "educational things"(ioet) in rural underprivileged areas," in *2015 12th International Conference on Electrical Engineering/Electronics, Computer, Telecommunications and Information Technology (ECTI-CON)*. IEEE, 2015, pp. 1–5.

[7] P. B. Anand and J. Navío-Marco, "Governance and economics of smart cities: opportunities and challenges," *Telecommunications Policy*, vol. 42, no. 10, pp. 795–799, 2018.

[8] H. Thapliyal, R. K. Nath, and S. P. Mohanty, "Smart home environment for mild cognitive impairment population: Solutions to improve care and quality of life," *IEEE Consumer Electronics Magazine*, vol. 7, no. 1, pp. 68–76, 2017.

[9] S. K. Ram, B. B. Das, K. Mahapatra, S. P. Mohanty, and U. Choppali, "Energy perspectives in iot driven smart villages and smart cities," *IEEE Consumer Electronics Magazine*, vol. 10, no. 3, pp. 19–28, 2021.

[10] M. V. Ramesh, K. V. Nibi, A. Kurup, R. Mohan, A. Aiswarya, A. Arsha, and P. R. Sarang, "Water quality monitoring and waste management using iot," in *2017 IEEE Global Humanitarian Technology Conference (GHTC)*, 2017, pp. 1–7.

[11] A. Kamilaris, F. Gao, F. X. Prenafeta-Boldu, and M. I. Ali, "Agri-iot: A semantic framework for internet of things-enabled smart farming applications," in *2016 IEEE 3rd World Forum on Internet of Things (WF-IoT)*. IEEE, 2016, pp. 442–447.

[12] 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*, 2020.

[13] K. T. Chui, W. Alhalabi, S. S. H. Pang, P. O. d. Pablos, R. W. Liu, and M. Zhao, "Disease diagnosis in smart healthcare: Innovation, technologies and applications," *Sustainability*, vol. 9, no. 12, p. 2309, 2017.

[14] N. M. Yusof, A. Z. Jidin, and M. I. Rahim, "Smart garbage monitoring system for waste management," in *MATEC Web of Conferences*, vol. 97. EDP Sciences, 2017, p. 01098.

[15] S. Mahajan, A. Kokane, A. Shewale, M. Shinde, and S. Ingale, "Smart waste management system using iot," *International Journal of Advanced Engineering Research and Science*, vol. 4, no. 4, p. 237122, 2017.

[16] A. S. Spanias, "Solar energy management as an internet of things (iot) application," in *2017 8th International Conference on Information, Intelligence, Systems & Applications (IISA)*. IEEE, 2017, pp. 1–4.

[17] G. Prinsloo, R. Dobson, and A. Mammoli, "Synthesis of an intelligent rural village microgrid control strategy based on smartgrid multi-agent modelling and transactive energy management principles," *Energy*, vol. 147, pp. 263–278, 2018.

[18] K. Zhou, C. Fu, and S. Yang, "Big data driven smart energy management: From big data to big insights," *Renewable and Sustainable Energy Reviews*, vol. 56, pp. 215–225, 2016.

[19] M. Abdel-Basset, G. Manogaran, M. Mohamed, and E. Rushdy, "Internet of things in smart education environment: Supportive framework in the decision-making process," *Concurrency and Computation: Practice and Experience*, vol. 31, no. 10, p. e4515, 2019.

[20] Z.-T. Zhu, M.-H. Yu, and P. Riezebos, "A research framework of smart education," *Smart learning environments*, vol. 3, no. 1, pp. 1–17, 2016.

[21] A. Singh and M. Patel, "Achieving inclusive devlopment through smart village." Pandit Deendayal Petroleum University, Gandhinagar, 2019.

[22] P. Chanak and I. Banerjee, "Internet-of-things-enabled smartvillages: An overview," *IEEE Consumer Electronics Magazine*, vol. 10, no. 3, pp. 12–18, May 2021.

[23] A. Behr, "Best uses of wireless iot communication technology." Industry Today, https://industrytoday.com/best-uses-of-wireless-iot-communication-technology/, Last Accessed: 5-5-2021.

[24] R. S. Sinha, Y. Wei, and S.-H. Hwang, "A survey on lpwa technology: Lora and nb-iot," *ICT Express*, vol. 3, no. 1, pp. 14–21, 2017.