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IoT in smart villages: challenges and prospects

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ABSTRACT

Smart villages, which use the Internet of Things (IoT), offer a viable solution to the issues that rural communities confront around the world. This study provides a complete overview of the role of IoT technology in transforming rural communities into long-term, technologically advanced centers. It investigates the fundamental elements of smart villages, such as renewable energy, digital connection, agriculture, healthcare, and community interaction. It also addresses the benefits, constraints, and prospects of using IoT in smart village programs. This study provides insights into the potential benefits and best practices for using IoT solutions in rural development.

INTRODUCTION

The Internet of Things (IoT) generally refers to an extensive network of interconnected applications, smart devices, and computing technologies using the existing communications infrastructure and services to share data and execute predefined operations without the need for human intervention (Mohamed *et al*., 2021; Al-Fuqaha *et al*., 2015). The Internet of Things represents a new revolution in the internet, connecting various things (such as sensors, devices, and mobile phones) to the internet. This connectivity aims to make these objects smart by embedding intelligence within them, thus, enabling the things to communicate with each other and with the people thereby facilitating ubiquitous monitoring (Javaid *et al*., 2018).

The Internet of Things (IoT) has become widely adopted by many companies in a range of industries, including weather, healthcare, and agriculture (Atzori *et al*., 2010). The smart grid is an example of IoT. Ullah *et al*. (2020) proposed using a network of sensors and intelligent devices to raise customer awareness of electricity usage, hence improving energy use efficiency. The smart health monitoring system demonstrated by Abdulmalek *et al*. (2022) is another example that is relevant to the current generation. Today's athletes assess their physical condition and exertion levels throughout training with a variety of health monitoring equipment. These gadgets can be linked to a network, allowing the athlete's trainers or other medical professionals to access the data and offer suggestions on how to modify their training plans.

Figure 1 illustrates the various components that work together to enable connectivity and functionality in an IoT network. Typically, IoT devices consist of several layers, each serving a specific purpose in the device's operation. The first is the Perception Layer which uses sensors and actuators to collect data from the device's environment and interact with it. Sensors gather information such as temperature, humidity, light, motion, or other physical parameters, while actuators enable the device to perform actions based on received data. The second is the Network Layer which facilitates communication between IoT devices and other components of the IoT ecosystem. It includes protocols and technologies for wireless or wired connectivity, such as Wi-Fi, Bluetooth, Zigbee, or cellular networks. The third is the Data Processing Layer which manages and processes the vast amounts of data generated by IoT devices, utilizing cloud-based or edge computing platforms for efficient data analysis. It includes components like cloud services that handle data aggregation, and filtering such as AWS IoT, Azure IoT Hub, or Google Cloud IoT Core. The fourth is UI/UX Layer that provides intuitive interfaces and seamless interactions for users to monitor, manage, and control IoT devices and applications. These applications may include monitoring systems, predictive maintenance solutions, smart home automation, or healthcare management platforms.

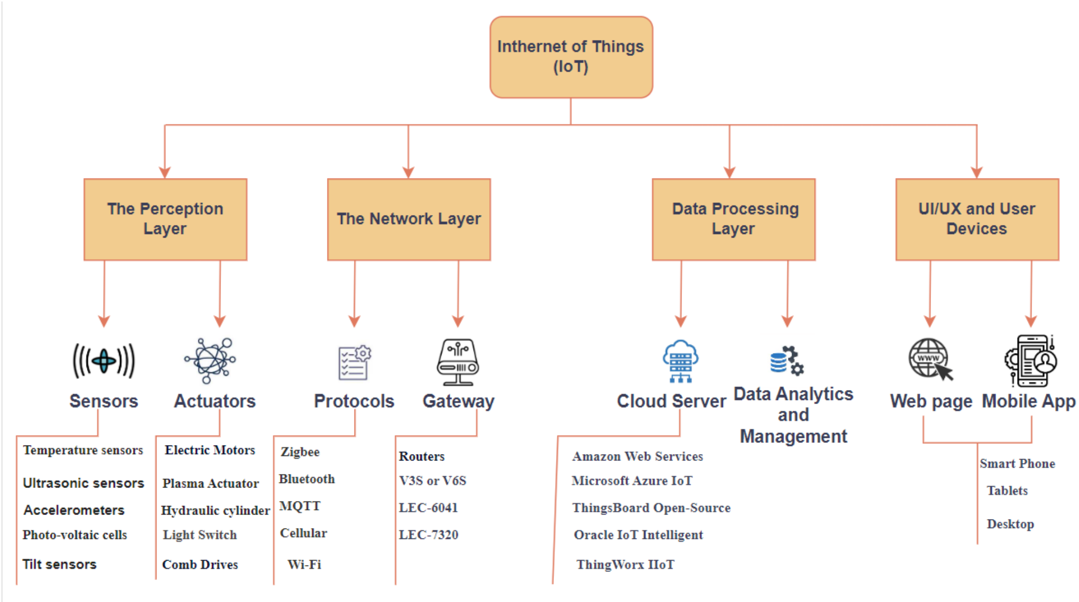

Figure 1: Components, layers and communication technologies in a typical IoT network.

Overview of Smart Villages

The smart village is a novel idea that aims to reduce the digital divide in rural areas. It aims to provide people in rural regions with greater opportunities, more appealing prospects, and enhanced access to services (Butun *et al*., 2019). It accomplishes this by using information and communication technologies (ICT) to mobilize human, social, and geographically anchored capital to support social cohesion and economic development. Smart villages provide a variety of ICT-enabled services, a cutting-edge governance structure, and technology infrastructure while building on traditional rural forms and assets (Khodadadi *et al*., 2017; Sempreboni and Viganò, 2018; Majumdar, 2020). In addition to helping rural communities become better stewards of their natural resources, these tools can enable them to create art, education, and cultural heritage for global consumption. Technological solutions serve as tools to enhance livelihoods and empower rural communities to shape their future, rather than being goals in themselves (Sempreboni and Viganò, 2018). The Uttarakhand, a state located in India, which is located in the middle Himalayas, serves as an example of a smart village initiative (Sati, 2021). Many small hamlets in the area were abandoned due to significant migration out of the region. The goal of a smart village project has been to enhance the lives of those who have stayed behind while also attempting to draw migrants back to their home communities (Cambra-Fierro and Pérez, 2022; Kalinowski *et al*., 2022; Kabuya *et al*., 2024). A combination of internet and telecommunication connectivity, media and IT preservation of traditional culture, and improved access to government services were identified as important efforts towards addressing self-sufficiency and migration in rural communities.

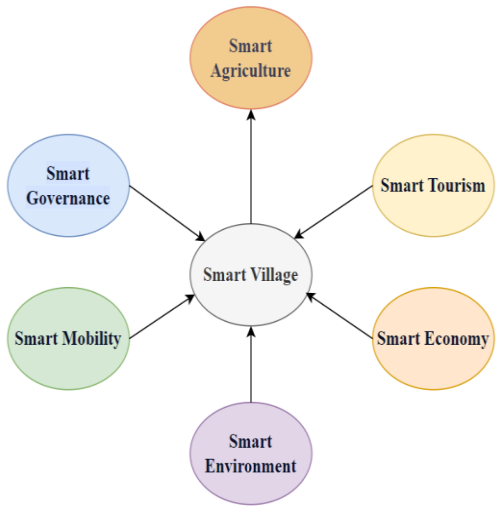

Figure 2: Major Components of a Smart Village

Figure 2 shows the key features of smart villages which encompasses various crucial facets for sustainable rural development, including digital connectivity to facilitate access to information and services, renewable energy sources to ensure energy security and environmental conservation, and e-governance systems for efficient administration and citizen engagement. Agrotech solutions play a pivotal role in enhancing agricultural productivity and food security while community development initiatives foster social cohesion and empowerment (Abhijeet *et al*., 2023; Popkova *et al*., 2022). Environmental sustainability is prioritized through eco-friendly practices and resource management strategies. Additionally, infrastructure innovation is essential for improving the accessibility and quality of essential services. These interconnected components form the foundation of smart villages, driving inclusive growth and resilience in rural communities.

Overall, smart villages aim to bridge the urban-rural divide, enhance the quality of life, and create opportunities for economic growth and sustainable development in rural communities.

Importance of IoT in Smart Villages

The creation of smart villages is greatly aided by the Internet of Things (IoT) which enables multiple sectors to be automated, make data-driven decisions, and connect seamlessly. The following sums up the significance of IoT in smart villages:

A. Remote Monitoring and Management: Several facets of village life, including infrastructure, agriculture, and environmental conditions, can be remotely monitored by IoT sensors and devices. Real-time monitoring and management are made possible by IoT which enhances decision-making and facilitates more effective resource allocation.
B. Precision Agriculture: Through precision agriculture approaches, farmers may maximize crop yields, minimize environmental impact, and optimize resource use with the use of IoT-enabled agricultural devices like weather stations, automated irrigation systems, and soil moisture sensors.
C. Infrastructure Management: Smart village waste management facilities, energy grids, and water supply systems are just a few examples of vital infrastructure that IoT devices can monitor and control. This guarantees prompt maintenance, effective

operation, and enhanced resident service delivery.

D. Healthcare and Telemedicine: In smart villages, IoT-based healthcare systems facilitate early disease detection, prompt intervention, and remote monitoring of patient health data. IoT-powered telemedicine services remove geographical constraints by facilitating access to medical specialists and specialized consultations.

E. Smart Energy Management: IoT devices make it easier to integrate renewable energy, energy-efficient appliances, and smart grid technology into smart communities. This enables optimal energy generation, delivery, and consumption, resulting in cost savings and a lower carbon footprint.

F. Community Safety and Security: The safety and security of smart villages are improved by IoT-enabled surveillance systems, intelligent lighting, and emergency response systems. Ensuring the safety and well-being of residents, these systems require real-time monitoring, early detection of security risks, and quick reaction to emergencies.

Applications of IoT in Smart Villages

There are many ways in which IoT can be used in smart villages, such as monitoring and managing resources like water and electricity, improving healthcare through remote monitoring and telemedicine, and enhancing agriculture through precision farming and real-time crop monitoring.

Smart Agriculture

To improve several areas of agricultural output, smart agriculture also referred to as precision agriculture or digital farming involves integrating technology and data-driven methodologies (Kabuya *et al*., 2024). The objectives of this strategy are to increase farming operations' profitability, sustainability, productivity, and efficiency.

Sensing and Internet of Things (IoT) devices play a major role in smart agriculture, gathering data in real-time on crop health, temperature, humidity, and soil moisture (Karunathilake *et al*., 2023). These devices are placed all over the farm to give farmers information on pest infestations, crop growth, and water usage. Advanced analytics techniques are then used to analyze the data gathered from sensors and IoT devices to produce insights that farmers can act upon (Degada *et al*., 2021). The farmers can use these data to assist them make well-informed decisions about insect control, fertilizer use, crop management, and irrigation timing. Using cloud-based systems and smartphone applications, farmers may also remotely manage and keep an eye on their crops.

This increases operational flexibility and efficiency by enabling workers to access real-time data, receive alerts about possible problems, and operate farm equipment from any location (Chowdhury *et al*., 2023; Degada *et al*., 2021). Figure 3 shows a simple design for smart agriculture requiring deploying sensors throughout the farm to monitor environmental conditions like temperature and soil moisture. Data collected by these sensors are transmitted wirelessly to a central processing unit where they are analyzed to provide insights and recommendations to farmers. This data-driven approach enables farmers to make informed decisions about crop management, automate irrigation and other processes, and remotely monitor and control their farms. Over time, the system integrates feedback and refines its algorithms, leading to improved productivity, resource conservation, and sustainability in farming practices.

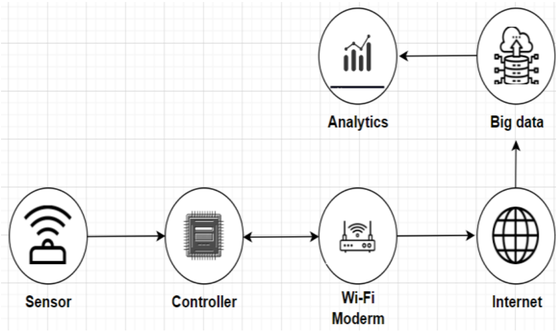

Fig 3: A typical scheme for the implementation of smart agriculture showing information flow from the sensors and controllers to the applications

Smart Energy Management

The activities of regulating, maintaining, and actively controlling energy consumption in the environment of the energy consumer are typically included in smart energy management. The energy controller uses feedback on the energy impact of a particular change to influence future decisions in smart energy management, which is a real-time process. A gadget or pertinent software intended to control a certain kind of energy consumption system is called an energy controller. This approach is more focused on minimizing energy use where it won't negatively impact the user than it is on significant energy conservation or automatic behaviour adaption.

Energy management has become a more important topic for both public and private sector enterprises due to rising energy costs, new environmental issues, and increased legislative interest in the field (Mischos *et al*., 2022). New approaches to managing and regulating energy usage are thus actively pursued and created (Dahunsi *et al.*, 2021). Even with the challenges associated with initial adoption and the possible discomfort and/or inconvenience to the users whose energy consumption is being monitored, smarter approaches are an appealing choice in an uncertain economic climate since they have the potential to save costs and energy.

Smart Healthcare

One technology that is propelling the adoption of smart healthcare is the Internet of Things (IoT) (Zaman *et al*., 2021). IoT will benefit smart healthcare in some ways. IoT has the power to improve healthcare delivery and raise people's standard of living in general (Talpur, 2013). The cost and amount of time required to care for a patient will go down when an IoT smart healthcare system is used, and it can also improve the effectiveness and efficiency of patient care. Recent years have seen an acceleration of technical breakthroughs, which has changed several industries (Turcu and Turcu, 2019).

The health industry is one of the sectors using this new technology. Healthcare is one of the most developed and expanding systems. Remote patient monitoring is used in smart healthcare (Ciocca *et al*., 2022). The distance between the patient and the healthcare professional is irrelevant when the most recent technology is used. This is achieved by employing medical sensors to track the patient's vital signs and then sending the collected data to healthcare professionals located elsewhere (Babalola *et al*., 2022). Because it might lessen the need for the patient to see and confer with the healthcare professional, this technology is tremendously helpful in lowering healthcare costs (Roy *et al*., 2023). The ability to diagnose and treat patients earlier is one of the main benefits of IoT in smart healthcare (Ganskaia and Abaimov, 2022).

IoT can make it possible to monitor patients remotely, which can enhance the quality of diagnosis by allowing experts to evaluate the data remotely. Additionally, this may lessen the necessity for some prophylactic visits, saving both the patient's and the clinician's time. Using the Internet of Things to monitor asthmatic patients is a great example of remote monitoring (Ciocca *et al*., 2022; Behar *et al*., 2020). There are wearable sensors that can identify the onset of an asthma attack, which can help with early intervention and the avoidance of more serious episodes (Lakshman *et al*., 2023; Babalola *et al*., 2022). Change of steps advances in the early detection and treatment of serious illnesses can contribute to the achievement of the intended therapeutic results, enhancing the patient's quality of life and frequently lowering long-term healthcare expenses. It can lessen the requirement for recurrent outpatient sessions and emergency hospital admissions in the event of asthma.

Smart Transportation

The future of intelligent transportation may be shaped by the implementation of contemporary IoT technologies in several ways. By detecting the present needs for transportation and informing travellers in advance about the available facilities, it can improve the reliability of transportation (Hu *et al*., 2021). Since everything is automated, no manual involvement is necessary. Knowing the kind of cars and traffic density can be aided by IoT devices such as RFID. Situated in a specific order as smart tiles, they transmit data to a wireless device that analyzes the circumstance and sends the information to the traveller (Chegeni *et al*., 2021). For instance, a bus arriving at a bus stop or early notice of a traffic bottleneck gives travellers other options to go where they're going at that particular moment. The environment can be greatly enhanced by better transportation and its management. Many nations that experience severe traffic conditions are also those that still rely on antiquated methods for managing transportation and making decisions. Because of the vast amounts of real-time data that it can gather, IoT can offer analytical answers and forecasts for the current traffic conditions (Thakur and Malekian, 2019).

Smart traffic signals, for instance, can operate dynamically and maintain a smooth traffic flow, preventing traffic congestion (Oki and Ubochi, 2021; Wu, 2022; Samson *et al*., 2022). Reducing vehicle fuel use and travel time would have a positive impact on the environment by lowering carbon dioxide emissions. Public health, traffic safety, and travel satisfaction are just a few of the areas that smart transportation may improve, but the environment stands to gain the most. Finally, and maybe most significantly, IoT can completely rethink how the disabled can travel (Elgazzar *et al*., 2022). It would be feasible to determine the precise transportation services required at a given time and location with the use of sophisticated sensing devices and automatic data transmitters concerning specific transport facilities to a central system (Ahmed *et al*., 2023). In addition to saving the disabled time and discomfort, this would also make them feel equally represented in the transit system.

Challenges and Considerations in Implementing IoT in Smart Villages

Implementing IoT in smart villages presents unique challenges and considerations. These are discussed in the following sections.

Limited Connectivity and Infrastructure

Compared to metropolitan areas, internet connectivity is less reliable in rural locations. There could be inconsistent and low connection speeds and bandwidth (Rahiem, 2020). In comparison to urban areas, the cost of dependable high-speed internet access in rural locations could be too high. The internet's perceived high cost and limited availability could prevent it from ever being a profitable venture. This is because many ICT services are always-on or on-demand, which contributes to their benefits. Access to the internet and ICT services may be hampered by rural areas' inconsistent internet service (Yaacoub and Alouini, 2020).

The problem of inconsistent connections is an obstacle that impacts both Internet service providers (ISPs) and users. Customers can believe that the service does not live up to their expectations and that they would have to wait too long for too little benefit. Users may choose not to use the internet or search for another provider if they are unhappy with the service. Low customer retention and high service dissatisfaction will result in low payback on investment for the ISP(Yaacoub and Alouini, 2020; Chaoub *et al*., 2021). Additionally, this will make it more difficult for customers to convert to internet protocol and get all of their communications services from a single supplier. Government broadband initiatives may encourage additional ISPs to focus on improving or expanding network infrastructure to rural areas, which might boost access but also increase competition and exacerbate the problem of low customer retention and high parity with alternative providers.

Small rural areas will unavoidably experience a typical case of market failure as a result of this, as they will never have access to connections that sufficient consumers will find valuable enough to utilize in the absence of a suitable dedicated network provider. The digital divide will essentially increase as a result of many tiny rural areas being lost to the customary global ICT leapfrog practice of adopting the internet and ICT services and applications that depend on it before adopting previous generations of technology. This gap will exist not just between rural and urban areas and between geographically isolated locations, but also between rural communities and, in the end, individual homes (Martínez-Domínguez and Mora-Rivera, 2020). Should the internet fail to achieve an ideal critical mass of users, it could raise the marginal cost of adoption in rural areas and lead to a stop to new ICT service development and innovation as they won't be seen as feasible enough to be implemented. As a market with low demand intention, this limits rural areas' ability to profit from numerous ICT service costs and reach reduction benefits.

Some people's lack of internet access can be attributed to a variety of factors, including acquired behaviours, user competence, training demands, inconsistent connectivity, user payback on investment threshold, and sustainability (Renukappa *et al.*, 2022; Cvar *et al*., 2020). In the context of smart village IoT, persuading people to use the internet will be a significant challenge. Adoption may be low because people are unaware of the benefits of the internet (Komorowski *et al*., 2020). Even people who are aware of the possible benefits may decide against using the internet because of concerns. As a result, they will not want to pay for internet services.

Likely, older people won't accept new technology or changes. The abundance of information on the internet may not be fully accessible to those with low computing skills. This could result in adoption failure because of online irritation.

Bandwidth is also a major concern under connectivity, bandwidth is the capacity or speed of data transmission over a network between IoT devices and other components, such as servers, gateways, or cloud platforms. It represents the amount of data that can be transferred within a given period, typically measured in bits per second (bps), kilobits per second (kbps), megabits per second (Mbps), or gigabits per second (Gbps). Rural areas often have limited internet connectivity and lower bandwidth availability compared to urban areas. This can result in slow or inconsistent data transmission, leading to buffering or freezing of video streams.

Data Security and Privacy

The capacity to shield data—whether it is in motion or at rest—from tampering or illegal access at any point in its existence is known as data security. Ensuring the CIA (confidentiality, integrity, and availability) of data is the process at hand (Chanal and Kakkasageri, 2020). Data is transferred between devices or to a central server for processing and storing when IoT devices are networked and communicating to automate smart solutions. There is a significant chance that an attacker will intercept data during this transfer. The attacker has two options: either he may listen in and gather information to use for his benefit, or he can alter the information as it's being transmitted, which could alter the system's next course of action (Kavitha *et al.*, 2021). However, the data gathered may contain sensitive information. For example, in a medical setting, the patient's health record. Unless the data is securely preserved via an encrypted file system, storing it on an IoT device itself carries some danger. Because the patient may suffer if the data is exploited or falls into the wrong hands. The scenarios thus demonstrate that there are significant security risks associated with both data in transit and data at rest (Alvarez and Leguizamón-Páez, 2021). Using secure protocols for data transfer, such as HTTPS, and maintaining a safe system with frequent security audits to find and address flaws are two ways to guarantee data security. Putting in place procedures to prevent data loss and performing routine data backups are other precautions.

Ensuring data security and privacy are crucial elements impeding the rapid spread of IoT across multiple industries. When IoT is used in a smart village, these variables become more intricate. When IoT is implemented in a smart village, information gathered from several nodes and sensors is utilized to automate and offer intelligent solutions in a range of scenarios, including disaster relief, smart farming, smart irrigation, and healthcare, to mention a few (Aljuhani *et al*., 2022). Future scenarios are anticipated and prepared for by using the conclusions drawn from the data gathered in the aforementioned scenarios. As a result, the data endures and is essential for planning and decision-making. Regretfully, though, this data is a prime target for spies and hackers who abuse it for a variety of purposes, such as economic espionage, influencing policy, or undermining the infrastructure of the village. Because of the wide-ranging and irrevocable effects of data leaks, it is crucial to protect the security and privacy of the information.

Cost and Affordability

An IoT system's implementation costs in a smart village are strongly correlated with consumer affordability. The majority of our interviews and participants strongly indicated that affordability is the most significant obstacle to the development of smart village technology, as this has been identified (Antony *et al*., 2020). The cost of a technology is commonly considered to be its affordability, and this is undoubtedly an important consideration. When comparing smart village technologies to their traditional counterparts, analysts frequently find that the former is more expensive than the latter (Nižetić *et al*., 2020). While numerous comparisons exist between technology A, typically representing smart village innovations and conventional low-tech alternatives like technology B, several examples illustrate this trend. These include assessing the cost of grain grinding services at a solar-powered mill versus diesel-powered mechanized grinding and comparing the cost of electric lighting from photovoltaic panels with incandescent bulbs.

The social and economic circumstances in which individuals would purchase technology, as well as the diversity of possible customers, are often overlooked in favour of this relative cost focus (Szentesi *et al*., 2021; Mudholkar *et al*., 2021). Imagine, for example, that a solar water pump is being provided to a small-scale farmer to replace his or her manual pump. Because it is more powerful and takes up less of the farmer's time, the solar pump is more cost-effective when compared to the motorized and manual pump in terms of maintenance and running costs. A farmer with little disposable income would only purchase a solar pump if there was an outside funding source available, as the initial cost of the pump would still make it more expensive than a motorized pump powered by subsidized grid electricity.

Skill and Knowledge Gap

The skill gap is a major issue in smart villages and one that potentially has an impact on the village's overall development. This issue arises from rural residents' lack of readiness and perhaps ignorance of the technologies available to them. According to Thai research (Amornkitvikai *et al*., 2022), the primary obstacle to IoT adoption in rural areas is a lack of awareness and comprehension of the technology itself, making it difficult to apply in the current environment. In addition, there is a lack of technological expertise among the local population, business community, and government, and there are no forecasts on the labour market needs of rural areas in the future. Ultimately, this disparity would be detrimental to village growth over time because the technology industry still offers a plethora of high-paying job opportunities. High-tech professions are often performed in cities, but if a rural resident has the necessary knowledge and abilities, they may be able to work remotely from their village (Szentesi *et al*., 2021).

Education and training on the Internet of Things and related sectors are necessary to engage rural residents in the establishment of smart villages. The community should be aware of the Internet of Things (IoT), its advantages for their way of life, and how to put it into practice so that they may create IoT systems as well as use them. The needs of the IoT labour market, both now and in the future, should be known before beginning the education and training process, allowing locals to modify their skill sets to take full advantage of the opportunity. Because technology workers make a lot of money relative to other professions, locals may be encouraged to learn about technology.

Prospects and Recommendations for IoT in Smart Villages

Potential Benefits and Opportunities

Cost savings can be realized in infrastructure maintenance by using smart monitoring systems. These systems can detect and address issues, such as leaks in pipes, prolonging the need for costly replacement. Additionally, smart systems can optimize street lighting by illuminating lights only when needed, resulting in energy savings.

Lastly, implementing preventive measures can lower insurance premiums, providing environmental benefits and saving money.

Understanding the benefits of IoT in smart villages can guide future development and support. IoT offers economic and social opportunities, such as creating new revenue streams and cost savings. For example, smart health systems can detect problems early, reducing treatment costs and improving quality of life. This could be offered with subsidized costs for low-income individuals.

Policy and Regulatory Framework

Policymakers should recognize the endless potential of IoT for development. They should be open to new ideas and involve communities and local businesses in the project design and IoT selection process. The policy should encourage involvement from government agencies, the private sector, and NGOs and promote public-private partnerships for sustainable village development.

IoT offers the potential to address challenges in smart villages. Government commitment to use IoT for development is important. Pilot projects in critical areas like agriculture can demonstrate their effectiveness.

Capacity Building and Awareness Programs

The IoT will involve multi-disciplinary systems, and to implement these, a new breed of engineers will be required with skills that cross the traditional boundaries of information technology, communications technology, and control. The industry will need to define these new skill requirements and develop curricula and materials for teaching those skills. The industry will also need conversion programs that take engineers from one of the traditional areas into the new area of IoT. This spans education from the informal, such as raising awareness with decision-makers or encouraging children to take up technology and engineering, to formal education at universities or vocational training.

Capacity building and awareness programmes are vital components for participating in and exploiting the benefits of IoT. Currently, capacity building and awareness programmes about IoT technologies and benefits are close to zero. When it comes to capacity building, the IoT industry will need to look into areas such as system design and architecture, new user interfaces, deployment, and system maintenance. The industry must get away from the idea that IoT is just another technology and that deployment can be learned on the job, as with previous technologies. IoT represents a holistic system that may touch many aspects of an organization and the systems it deploys into. Change management is also a key area. IoT may bring about changes to the way systems are developed and maintained. It may change user habits through new user interfaces. It may change the way an organization does business, or it may bring about legislative changes through the data that it collects.

CONCLUSIONS

In conclusion, this review has shed light on the challenges and prospects of implementing the Internet of Things (IoT) in smart villages. Despite the numerous benefits it offers, such as enhanced infrastructure, efficient resource management, and improved quality of life, several challenges remain, including connectivity issues, limited technical expertise, and concerns regarding data privacy and security. However, with advancements in technology and increased awareness, there is immense potential for IoT to revolutionize rural development and create sustainable and resilient smart villages. To fully realize this potential, collaboration among stakeholders, investment in infrastructure, and tailored solutions to address local needs are essential. Moving forward, concerted efforts towards addressing these challenges and harnessing the opportunities presented by IoT can pave the way for inclusive and equitable development in rural areas, ultimately leading to empowered and thriving smart villages.

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