Column: Energy and Security

Collaborative Edge Computing for Smart Villages

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It is estimated that 55.7% of the world populations are in urban (cities) and rest of the people (i.e., 44.3%) are in rural areas (villages) [1][2]. Significant efforts are going on to make the urban area smart with projects like smart cities consisting of components, such as smart healthcare, smart agriculture, smart energy, and smart grid [3][4]. The Internet-of-Things (IoT) plays a vital role in sensing and processing the sensed data. Edge computing has become a key computational infrastructure for near real-time event detection, whereas cloud infrastructure deployed with the core-computing infrastructure and operated centrally [5].

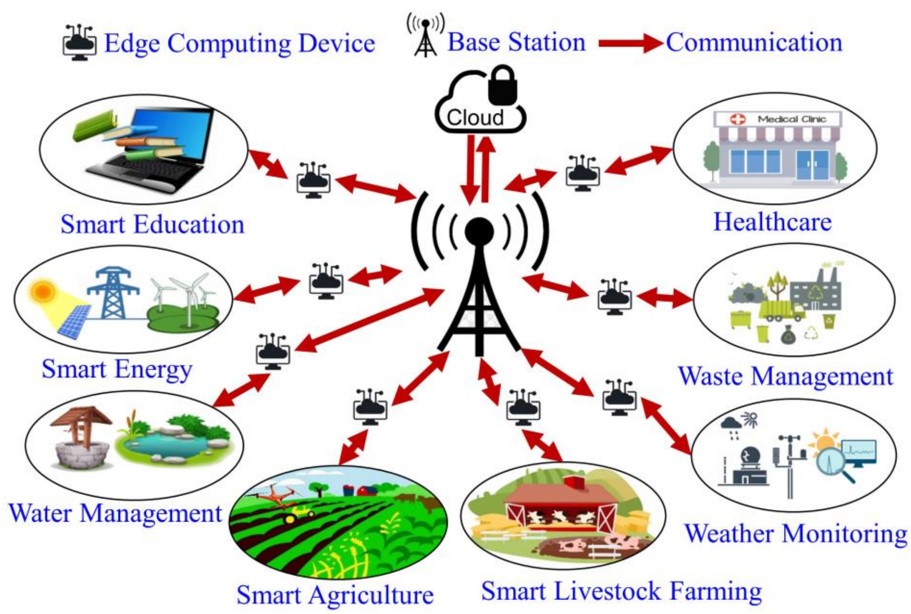

Figure 1: Cyber-Physical Systems (CPS) in Smart Villages.

Still, a significant part of the population is living in villages with minimal resources and technology. Different components and application domains of a smart village are as shown in Figure 1 [15]. Smart villages can address the need of village population while becoming a potential solution to the urban population migration. It is challenging to develop the villages as ‘smart villages’ with limited technological resources, i.e., computational infrastructure, communications, and devices used for sensing [6][7]. To solve these challenges, a new computing paradigm called "Collaborative Edge Computing (CEC)" can be effective in the deployment of technologies in smart villages. CEC can drive the collaboration and sharing of the resources in various smart components, such as smart farming, water management, and healthcare, to meet the demand of smart villages while ensuring low operational cost and sustainability.

COLLABORATIVE EDGE COMPUTING

While looking closely into the computing infrastructure, it can be observed that computations are done either in the core computing infrastructure (i.e., cloud computing) or source-end computations are in the network edges (i.e., edge computing). Cloud computing infrastructure follows the centralized working model, whereas edge computing (or fog computing) follows the distributed working model. In both of these computing infrastructures, they use their resources for the task processing, and in the case of unavailability of the resources, they performed load balancing. However, collaborative computing facilitated the resources to collaborate with the other available resource to meet the application's demands. CEC aims to manage and control heterogeneous network resources smartly to meet diversified user demands by collaborating distributed edges.

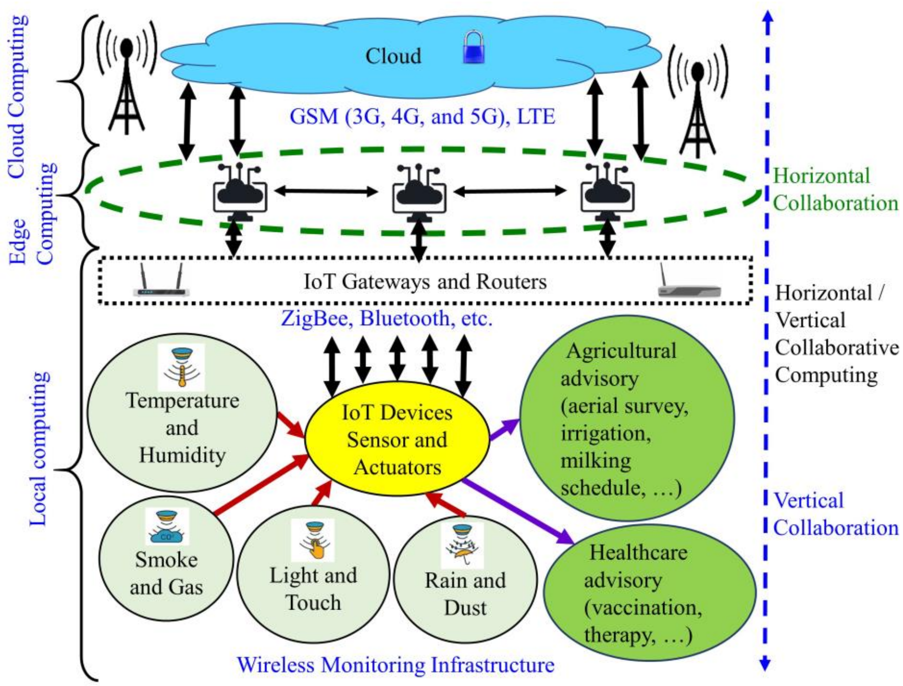

Figure 2: Collaborative edge computing paradigm of IoT.

The CEC's main aim is to facilitate collaborations among multiple edge devices (e.g. edge data centers or edge routers) to support data processing and storage. For example, edge devices of one smart village can work in collaboration with edge devices of another smart village during the time of higher computation demand [15]. Software-Defined Networks (SDN) is one of the key network concepts where it provides programmability to unite different edge computing resources collaborations to optimize edge computing resources [8]. We have conceptualized the CEC into two categories, i.e., (i) through horizontal collaboration; and (ii) through vertical collaboration [8]. Multitier computing architecture with collaborative computing features has been illustrated in Figure 2.

There are two ways of horizontal collaboration in CEC, i.e., Inter-domain and Intra-domain. CEC's "Inter-domain" collaboration facilitated edge devices to collaborate, whereas the "Intra-domain" collaboration of CEC facilitated collaboration between the different functionalities and services within an edge device. Similarly, vertical collaboration represents collaboration possibilities among various layers. In the three-layered IoT architecture (Refer Figure 2), the edge layer lies between the local computing (Infrastructure) and core computing (Cloud) layer. The vertical collaboration of the CEC facilitated collaboration with either local or cloud computing resources to meet the demand. Vertical collaboration improves the overall system QoS [9].

"SMART CITIES" versus "SMART VILLAGES"

The term "smart cities" is quite popular in the last few years, and the following definition clearly defines its features and properties [3]:

> "Connecting the physical infrastructure, the information technology infrastructure, the social infrastructure, and the business infrastructure to leverage the collective intelligence of the city."

In a city environment, we have easy access to the required resources, such as wire/wireless communication, computing infrastructure, and energy. Higher design and operational cost can be justified to an extend as population served is higher in number. However, these resources are not available easily in the villages to build a smart infrastructure. Therefore, the deployment of smart infrastructure in the villages is challenging. For example, Internet connectivity may not be available in villages. At the same time, higher design and operation cost may not be justifiable as the population of a village may be small. The technologies intended for the smart villages need to be cheaper and sustainable. Based on these thoughts, we define the term smart villages as follows [16]:

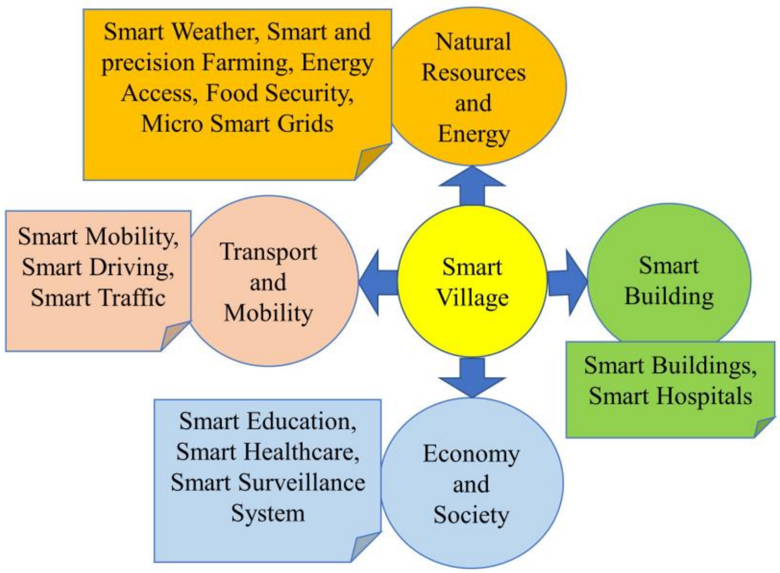

Figure 3: Services in Smart Villages.

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

We identified four key aspects that define a smart village: (i) Transport and Mobility; (ii) Natural Resources and Energy; (iii) Smart Building; and (iv) Economy and society. These critical aspects of smart villages has been shown in Figure 3.

EMERGING COMPONENTS FOR SMART VILLAGES

There are many technologies and processes involved to make the village smart [15]. Some key technologies are real-time monitoring of the event, data processing in the edge computing infrastructure, scalable data storage, and secure the system and data from potential threats (Refer Figure 4). We summarize these technologies in the context of a smart village.

Real-time Monitoring

The developments in technology enable us to track activities and collect data from devices placed remotely. IoT devices used in such locations detect activities, edge computing devices perform analysis on the data, and transfer those data to the cloud for further analysis and storage. These data in edge computing provides monitoring of the system in real-time. In IoT, real-time monitoring is effectively used in several smart village applications, such as water quality, security, and surveillance, agriculture, etc. Real-time monitoring of data helps to make quick decisions and emergency responses to deal with situations. It gives faster insights into the issues that need to be resolved. Lightweight machine learning models (TinyML) that can run on IoT-edge and IoT-end devices are important for smart villages [16].

Collaborative Edge Computing Elements			
Real-Time Monitoring	Edge Computing	Data Storage	Security against Cyber Threats

Figure 4. The components of the Smart Villages

Real-time monitoring can cause severe troubles if not monitored well. If there were any injection of spoof or fake data through the sensors, that would cause improper analyses, and the results would be disastrous. Faulty devices could cause undesired analysis of the data generated from the sensors. Such situations must be taken care of well.

Edge Computing

The emergence of IoT-Edge computing made a shift to this process by bringing computational processes closer to the origin of data (edges) [5]. Since the computations are done in the edges, the systems do not suffer latency, and real-time processing would work better for a smart village. It provides faster response and quick analysis in emergency scenarios. The possibility to run various algorithms in the edges is an added advantage that brings more instantaneous results. The rise in Edge computing was also prompted by the growth of IoT devices, which communicate a large amount of data to and from cloud services during its operations [10].

Data Storage

One of the major drawbacks of centralized (cloud) data storage is the central entity's involvement. A central entity manages data storage and indexing, which is vulnerable to potential cyber threats [11]. Blockchain brings sustainable decentralized data storage capabilities without the involvement of the central entity [12]. Also, cryptographically hashing involvement in decentralized data storage maintains data integrity without integrating further cryptography solutions. Secure data storage is also important because of the unattended edge devices deployment for smart villages.

Security against Cyber Threats

Security is a primary focus while building a system with the unattended deployment of devices, and the smart village is a prominent example of this. There are several possible cyber threats (i.e., both insider and outsider attackers) at the different layers of the system deployment (From Figure 2) [14]. Simultaneously, many security solutions exist for the device, data center, and communication layer security [14]. Still, many attacks are happening at every moment, and this demands a novel security solution with system requirements. One of the current ground-braking security solutions is to provide security based on user demands and device specifications (Software Defined Perimeter) [11], and the other one decentralizes the security solution by ignoring the involvement of a centralized controller (such as distributed ledger and Blockchain) [12][13]. Both of these solutions have a huge impact on the smart village deployment. Blockchain-enabled solution not only secures the system but also ensure the data storage integrity.

CONCLUSION

The term “collaborative edge computing” is new. Due to edge devices’ resource constraint features, collaborative computing is a key challenge to borrow computational resources to meet user demands. Edge Computing is a crucial technology for the deployment of smart villages. Therefore, collaborative edge computing is key for light-duty to heavy-duty applications in smart villages. This article defines the smart village concept and gives first-hand experiences on collaborative edge computing (CEC) and its use case for smart villages. TinyML can play an important role for smart homes and smart villages.

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