AI-Based Communication-as-a-Service for Network Management in Society 5.0

Timam Ghosh, Rituparna Saha, Arijit Roy, *Member, IEEE*, Sudip Misra, *Senior Member, IEEE*, and Narendra Singh Raghuwanshi

***Abstract*—This paper explores the concept of AI-based Communication-as-a-Service (ACUTE) to reduce transmission delay and energy consumption, while transmitting data from end-devices to the cloud in the context of Society 5.0. Society 5.0 revolutionizes connected living with the help of a unified system that provides fully automated and end-to-end services, while addressing the demands of all the citizens or users in a society. On the other hand, 6G is one of the promising communication platforms that offers the communication requirements of Society 5.0 by provisioning dense network deployment and fast data delivery. Building Society 5.0 founded on the 6G architecture enables serialized data transmission in the connected living fabric by allowing a user to connect with an access point and transmit data over a single path. Without concurrent and intelligent data transmission, the communication framework of Society 5.0 increases network delay and overall energy consumption and affects the Quality-of-Service (QoS). To address these issues, we propose a solution founded on the concept of Communication-as-a-Service (CaaS), which offers an architecture to facilitate intelligent access point virtualization for enabling concurrency in data transmission across individual users in a 6G-enabled Society 5.0. In ACUTE, a virtual module (VM) employed at each edge device performs concurrent data transmissions by associating with a virtual access point (VAP), which is a set of access points optimally selected using Fuzzy C-Means. Thereafter, the VM forms a virtual path (VP), which maps to a set of paths between physical access points and VAPs. ACUTE distributes the data through the VAP and associated VP and randomizes data sequence for transmission across VP. Experimental results show that ACUTE outperforms the state-of-the-art while reducing the network delay by 27%, energy consumption by 95%, packet loss by 95%, and service cost by 26%.**

***Index Terms*—Society 5.0, 6G, Connected Living, Edge Intelligence, Artificial Intelligence, Communication-as-a-Service, Network Management.**

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I. Introduction

THE DEVELOPMENT of Society 5.0 is founded on building intelligent systems that unify the concepts of AI [1], IoT [2], [3], [4], and robotics to automate end-to-end smart services, while promoting sustainable development and user services [5], [6]. These systems encompass cross-sectional knowledge sharing, in-network data analysis [7], and close-integration among the physical, cyber, and social world to empower connected living [5], [8]. This paper focuses on promoting intelligent architectures to manage network services and increase data transmission efficiency by reducing network delay and energy consumption and the expenditure for such transmission in Society 5.0. In this regard, Society 5.0 covenants to involve edge intelligence and dense network deployment to provide global connectivity to each user and efficient in-network data analysis [7]. These requirements of Society 5.0 are the key enablers of 6G [9], [10], [11]. In contrast to contemporary telecommunication technologies such as 4G and 5G [12], [13], [14], 6G [15], [16] can help meet these requirements using the densely deployed access point network, reduced end-to-end latency and energy consumption, higher data rate, reliable connectivity, and edge intelligence.

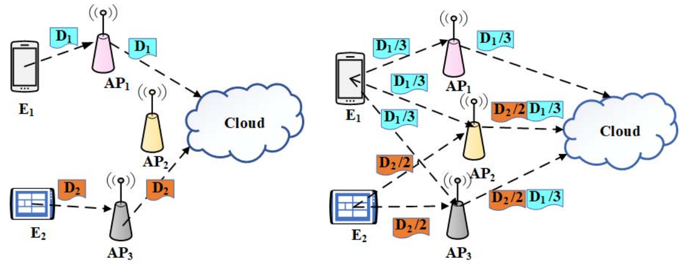
A. Motivation

This paper ideates 6G-enabled Society 5.0 that spans a densely deployed multi-hop network of access points. These access points belong to different owners, who may charge the users differently for relaying data towards the desired destination device. On the other hand, 6G-enabled Society 5.0 inherits the features of 6G, where an edge device connects to a single access point during data transmission. The communication framework of Society 5.0 permits *serialized* data transmission by allowing a end-user or edge device to transmit data over an access point associated with the user, thereby creating a communication path. By involving a densely deployed network, a 6G-enabled society with *serialized* data transmission *under-utilizes* network resources such as the abundance of access points. Thus, the communication framework of such a society reports increased transmission delay and energy consumption, reduction in transmission efficiency, and the quality of connected living due to such resource *under-utilization*. These lacunae in a 6G-enabled Society 5.0 foster the need to introduce concurrent data transmission.

A 6G-enabled Society 5.0 may efficiently manage network services by introducing concurrency in data transmission and increases resource utilization by transmitting data from an edge device to the cloud over multiple access points and communication paths. However, provisioning such concurrent data transmission in the existing 6G-enabled society may introduce some additional issues: (a) In the existing society, such application of concurrent data transmission remains unexplored. Moreover, the communication framework of such a society fails to provide a specific architecture to incorporate concurrent data transmission. (b) On the other hand, the access points deployed in 6G-enabled Society 5.0 belong to different users, who may charge *service cost* differently to the end-users during data transmission. Thus, while employing concurrent data transmission in 6G-enabled Society 5.0, a user requires to select an optimal set of access points and reduce the transmission delay and energy consumption and the expenditure for data transmission charged by the owners of these access points. Additionally, the selection of a cost-effective set of access points needs to be performed intelligently to reduce the load on the users. (c) Finally, in concurrent data transmission, data need to be divided into multiple segments and transferred from a user to the cloud over multiple access points associated directly with the user. While incorporating concurrent data transmission, the communication framework of Society 5.0 needs to apply a suitable data sequencing mechanism to ensure data integrity at the receiver end. Therefore, we need to conceptualize an architecture for 6G-enabled Society 5.0 that provides intelligent and cost-effective access point selection and data sequencing during concurrent data transmission.

This paper considers the CaaS for the communication frameworks for 6G-enabled Society 5.0 to reduce the load on the users for managing communication resources such as access points, gateways, and transmission channels. The concept of CaaS is a well-explored topic in various domain such as vehicular ad-hoc network [17], e-commerce [18], and contemporary cloud computing [19]. Among the exiting CaaS solutions, Garai *et al.* [17] proposed a CaaS solution for cloud that (a) enables autonomous communication between remote vehicle and road-side units, (b) guarantees QoS in terms of delay, throughput and packet loss rate, and (c) addresses the resource limitation in the vehicular network. Manvi and Shyam [19] discusses that the contemporary cloud frames works provides CaaS solution by automating the monitoring of networks with increasing size. However, it is conjectured that theses existing CaaS solutions lacks the communication framework to meet the requirement of intelligent and cost-effective access point selection and data sequencing during concurrent data transmission in 6G-enabled Society 5.0.

Example Scenario: We discuss two examples in Fig. 1 to explicate the lacuna in 6G-enabled Society 5.0. Fig. 1(a) depicts a serialized data transmission scheme, using which two edge devices E_1 and E_2 connect with two separate access points AP_1 and AP_2 and transmit data of size D_1 and D_2 to the cloud, respectively. In this scenario, we consider δ_1 and $\mathcal{E}_1$ as the overall transmission delay and energy consumption, respectively, for transmitting data of size D_1 from E_1 to the cloud. Typically, the transmission delay and energy consumption for these edge devices are directly proportional to the



(a) Single access point-based communication system

(b) Multi-access point-based communication system

Fig. 1. Motivating scenarios

size of the data. Therefore, if E_1 connects with AP_1 and AP_2 and distribute the data over these access points by employing concurrent data transmission, E_1 can reduce δ_1 and $\mathcal{E}_1$. The same can be conjectured for E_2. To elucidate this concurrent data transmission, we discuss a scenario in Fig. 1(b), similar to Fig. 1(a), additionally having access point AP_3. In Fig. 1(b), E_1 connects with AP_1, AP_2, and AP_3 and distribute data of size D_1/3 among each of these access points. Therefore, E_1 reduces δ_1 and $\mathcal{E}_1$ thrice over the scenario shown in Fig. 1(a). Moreover, Fig. 1(b) depicts higher utilization of network resources such as access points than Fig. 1(a). On the other hand, we consider that AP_1, AP_2, and AP_3 belong to different users charging the users with different service cost. Therefore, such concurrent data transmission, shown in Fig. 1(b), need to involve intelligent architectures to select access points cost-effectively.

B. Contribution

This paper proposes ACUTE – a distributed architecture for managing network services in 6G-enabled Society 5.0, anchored on the communication framework of existing CaaS solutions. ACUTE integrates the concepts of concurrent data transmission, increased network resource utilization, and intelligent access point selection, using AI. The main *contributions* of ACUTE are as follows:

1) Concurrent Data Transmission and Intelligent Resource Utilization: ACUTE virtualizes the access points to overcome the issues of increased transmission delay and energy consumption in 6G-enabled Society 5.0 due to serialized data transmission and resource under-utilization. It virtualizes access points by employing a VM in each edge. The VM forms a VAP by connecting with multiple neighbouring access points. It forms a VP by selecting the shortest communication path to the desired device, such as cloud, from each of these selected access points. During data transmission, the VM distributes the data among each access point in VAP. Concurrently, it transmits data over each path in VP. Using VM, VP, and VAP, ACUTE incorporates concurrent data transmission and increases resource utilization.

2) Cost-Effective and Intelligent Load Balancing in Concurrent Data Transmission: To enable ACUTE, we design a cost-effective VAP and VP selection algorithm using fuzzy c-means (FCM) clustering approach. With the help of this selection algorithm, ACUTE distribute the data and service cost, charged for data transmission, among a set of access points for each edge device. This paper considers a uniform distribution of data among the edge devices in VAP. In ACUTE, the VM in each edge device intelligently forms a VAP by selecting a *good* set of access points from neighbouring access points. We define a good set of access points for a user as the set of neighbouring access points with the properties – nearer to the user, has maximum residual energy, minimum workload, and service cost. For selecting a good set of access points, we use the FCM [20] clustering approach. For the same selection, we inspect parameters such as the distance from an access point, residual energy, and workload of an access point, and service cost. Moreover, it forms VP by selecting the shortest communication path to cloud from each access point in VAP based on the remaining residual energy, service cost, data rate, and the distance at a certain time.

3) Data Sequencing During Concurrent Data Transmission: In ACUTE, we introduce a framing structure and data sequencing scheme to secure the concurrent data transmission and maintain the data integrity at the receiver end. In ACUTE, a VM in each edge device divides the data in a set of fixed seized frames and rearranges these frames in a matrix consisting of column vectors. Further, inspired by the concept of frequency hopping, the VM randomly selects a column vector and transmits it a path in VP. This transmission is concurrent for all the column vectors. Moreover, VM embeds the 2D indices of a frame in the matrix in the same frame body using the bit stuffing approach. Therefore, the receiver can efficiently construct the original data from the received frames, which are randomly transmitted over the paths in VP.

II. Related Works

In this section, we discuss existing research works regarding 6G-enabled Society 5.0. According to Fukuyama *et al.* [7] and Ghosh *et al.* [6], Society 5.0 is envisioned to ensure sustainable global development by collaborating between information and corresponding knowledge sharing. Utilizing the concept of digitization and AI, Society 5.0 aims to exploit the knowledge between *people and things* and between *real and cyber* to facilitate connected living. Besides, it promises to resolve the various environmental and societal challenges such as the depletion of natural resources, aging society, and natural disasters. Additionally, Shiroishi *et al.* [5] unravel the challenges of sustainable development goal (SDG) in Society 5.0 by balancing the economic advancements with societal issues. Gladden [8] identify the main goal of society 5.0 as to provide high-quality service for the survival involving a healthier, enjoyable, and prosperous life. Ghosh *et al.* [6] proposed CASE — an attribute learning scheme that autonomously learns the attributes from users' activity information and preserves users' privacy using ciphertext-policy attribute-based encryption for Society 5.0. The proposed architecture of CASE allows a user to associate with a single access point and transmits data over a single communication path. However, most of the existing researches, e.g., Bryndin [21] and Federation [22], gives an overview of Society 5.0.

Contemporary researches on sixth-generation communication suggest that it has become the backbone of digital transformation in the current society. The research works, e.g., Giordani *et al.* [23], Tariq *et al.* [15], and Yang *et al.* [24], identifies several potential use cases of 6G. Additionally, Shafin *et al.* [16] identify future research directions along with top five challenges and a possible road map to realize the AI-enabled cellular networks for Beyond 5G. On the other hand, ML tools resolve various challenges regarding the 6G network. In this context, Nawaz *et al.* [25] surveyed the existing literature on machine learning, quantum computing, and quantum machine learning (QML). The authors explored challenges for applying these concepts in beyond 5G networks. To address these challenges, they proposed a QML-based framework for 6G communications. On the other hand, Mao *et al.* [26] explored the issues of low processing time and high energy consumption due to fixed high-level security protections in 6G IoT networks with dynamic security requirements. The authors proposed an AI-based adaptive security specification scheme for 6G IoT networks to reduce the processing time and energy consumption. For this scheme, they considered a 6G IoT network that allows the edge devices to connect with cellular networks using terahertz and millimetre wave (mmWave) frequency band. Sim *et al.* [27] discussed the issue of increased latency for initial beam establishment in 5G mmWave networks due to exhaustive search-based beam sweeping prescribed in 5G New Radio standard. The authors proposed a deep learning-based beam selection method to reduce the latency for initial beam establishment, which is compatible with the 5G New Radio standard. Rappaport *et al.* [28] proposed various challenges and opportunities for wireless communication and sensing above 100 GHz. Li *et al.* [29] made a comprehensive survey on UAV communication towards 5G/B5G network. These contemporary researches (e.g., [6], [25], [25], [25], [29]) on state-of-the-art communication systems suggest an architecture where a single user is allowed to associate with a single access point and to transmits data over single communication path. Such association between users and access points results in *serialized data transmission*.

Synthesis: From the literature, we conclude that, Considering the densely deployed network, the *serialized data transmission* found in these existing research works may results in poor utilization of network resource and higher delay and energy consumption for data transmission. The implementation of this extensive innovation, demands ubiquitous, reliable wireless connectivity. Thus, in this paper, we propose a 6G-enabled Society 5.0 – ACUTE to improve the wireless communication network.

III. ACUTE: The Proposed Architecture

This section explores the different aspects of ACUTE to reform connected living and efficiently manage network services in Society 5.0. For enabling ACUTE, We consider a system for Society 5.0 that comprises of three layers: (a) edge layer, (b) network layer, and (c) application layer, as depicted in Fig. 2. The edge layer consists of a set of edge devices,

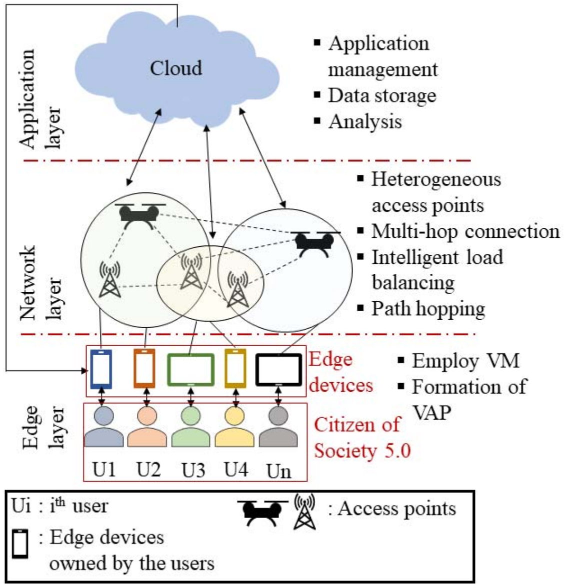


Fig. 2. Layered architecture of ACUTE.

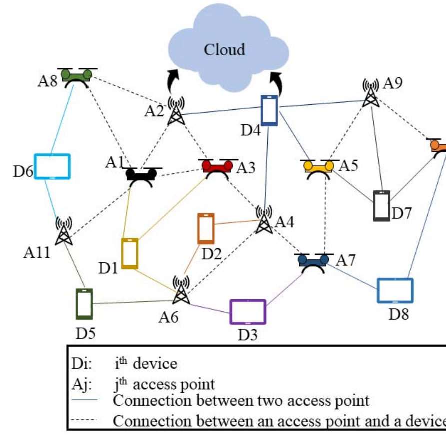


Fig. 3. Network model for ACUTE.

such as smart phones, tablet, and laptops, which are heterogeneous in nature and associated with users. These edge devices are also associated with access points in the network layer. These access points produce multi-hop connections among themselves. The application layer includes the cloud, which manages the applications in the 6G-enabled society 5.0. In our considered system, an edge device collects data from sensors and transmits these data to the cloud over access point-based multi-hop connections.

Assumptions: Before elaborating ACUTE, we assume that the considered society includes a dense deployment of enormous access points. Such deployment ensures that any device in the system has a set of access points within its coverage. Furthermore, enabling 6G allows this society to include access point of heterogeneous in nature. On the other hand, these access points belong to different owners, where different telecommunication industries own traditional access points and the individuals owns small cell access points. Therefore, while utilizing the network resources, end-users are differently charged by the owners.

A. System Model

In ACUTE, the considered society is represented as graph $\mathcal{G} = (\mathcal{V}, \mathcal{L})$ depicted in Fig. 3, where $\mathcal{V}$ and $\mathcal{L}$ denote the set of devices and the set of links among the devices, respectively and $\mathcal{V} = \{\mathcal{V}^e \cup \mathcal{V}^a \cup \mathcal{V}^c\}$. The $\mathcal{V}$ consists of a set of m edge device ($\mathcal{V}^e$), a set of n APs ($\mathcal{V}^a$), and a cloud server ($\mathcal{V}^c$), where $n \ll m$. At each edge device, ACUTE employs a VM – a software module, which performs intelligent tasks such as VAP formation, load balancing across VAP, VP formation, and synchronous data transmission. Additionally, ACUTE provides ACUTE by introducing the virtualization access point. In ACUTE, multiple users are able to use a common set of access points. However, the VM installed in each of the edge devices associated with these users are provided with an abstract view of having assigned a dedicated access point to them. An edge device $v_i \in \mathcal{V}^e$ communicates with the cloud in a 6G-enabled Society 5.0 environment using three steps, which are as follows:

1) Virtual Access Point Formation: Initially, in ACUTE, $v_i \in \mathcal{V}^e$ connects the VM, which is employed at v_i. This VM forms a VAP ($\mathcal{V}_i^{a''}$) using a set of neighboring access points ($\mathcal{V}_i^{ap}$) and a clustering approach. In Section III, we assume that the considered society includes densely deployed access points, which ensures has multiple access points within the coverage of each edge. Therefore, during data transmission, the VM at each edge device can form VAP using multiple neighbouring access points. The properties of VAP are as follow,

Proposition 1:

(a) A VAP produces a mapping function ($f : \mathcal{V}^e \rightarrow \mathcal{V}^a$) between a edge node and a set of access points, where $\forall v_i \in \mathcal{V}^e, f_1(v_i) = f_2(v_i)$ or $f_1(v_i) \neq f_2(v_i)$. If, at any moment, $f_1(v_i) = f_2(v_i)$, we can conjecture that v_i is associated with only one access point, otherwise v_i is associated with multiple access point within its coverage area.

(b) $\forall i, \mathcal{V}_i^{a''} \subset \mathcal{V}^a$, but not $\mathcal{V}_i^{a''} \subseteq \mathcal{V}^a$, which state that an edge device can not connect to all access point to form a VAP.

(c) $\exists (i, b)$ where $i \neq b$, $\mathcal{V}_i^{a''} \cap \mathcal{V}_b^{a''} \neq \phi$. This property states that two virtual access points $\mathcal{V}_i^{a''}$ and $\mathcal{V}_b^{a''}$ may share a set of access points if any two edge devices $v_i \in \mathcal{V}^e$ and $v_b \in \mathcal{V}^e$ are in close prolixity.

To form a cost-efficient VAP, ACUTE enables VM to select a set of good access points ($\mathcal{V}_i^{ap'}$) among all the available neighboring access points ($\mathcal{V}_i^{ap}$). While forming VAP, VM evaluates the validity of an access point $a_j \in \mathcal{V}^{ap}$ to be in a set of good access points ($\mathcal{V}_i^{ap'}$) using decision parameters: – (a) distance ($d_{i,j}$) from the edge device (v_i) to access point (a_j), (b) workload (w_j) in terms of the number of existing association with other edge devices, (c) service cost (c_j) charged by the access point for data transmission, and (d) residual energy (e_j) of the access points.

While forming VAP, an edge device v_i collects these parameters from neighboring access points and performs a clustering

Algorithm 1: Virtual Access Point Formation

Inputs : $\mathcal{V}^a$, $v_i \in \mathcal{V}^e$
Outputs: $\mathcal{V}_i^{a''}$
v_i selects $\mathcal{V}_i^{ap} \in \mathcal{V}^a$ within its coverage ;
v_i collects $d_{i,j}$, w_j, c_j, and e_j, $\forall a_j \in \mathcal{V}_i^{ap}$;
$\{\mathcal{V}_i^{ap'}, \mathcal{V}_i^{ap} - \mathcal{V}_i^{ap'}\} \leftarrow \mathcal{M}(\mathcal{V}_i^{ap})$;
$\mathcal{V}_i^{a''} \leftarrow \mathcal{V}_i^{ap'}$;
return $\mathcal{V}_i^{a''}$;

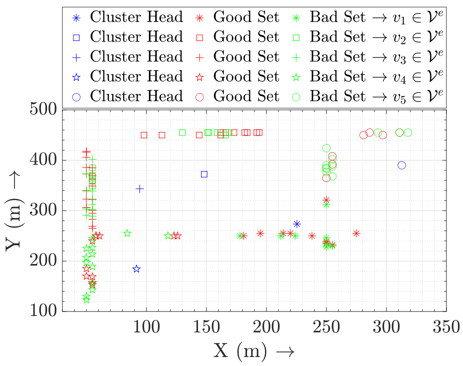


Fig. 4. Simulation results for cluster formation in ACUTE considering parameters (a) area: 500 × 500 m^2, (b) existing edge devices: 1000, (c) newly deployed edge devices: 5, and (d) Access points: 500. The considered ranges for remaining parameters are depicted in Table III.

model $\mathcal{M}(\cdot)$ to select $\mathcal{V}_i^{ap'}$. We consider that $\mathcal{M}(\cdot)$ includes the functionality of FCM clustering algorithm as it performs better [20] than other clustering approach such as K-means clustering approach. Moreover, we train this clustering model $\mathcal{M}(\cdot)$ in a resource-intensive device using historical data before deploying ACUTE. We use the pre-trained $(\mathcal{M})(.)$ for VAP formation during the deployment of ACUTE to reduce the overhead for the training process in the edge devices.

Algorithm 1 discusses the different steps of virtual access point formation. Fig. 4 depicts the simulation result of VAP formation algorithm considering 500 access points. In this figure, 1000 edge devices are currently associated with these access points, and 5 edge devices are newly deployed in the scenario which needs to be associated with the access points. The algorithm, initially, selects a certain number of neighbouring access points among 500 access points for each newly deployed edge device. The number of selected neighbouring access points for each newly deployed edge device is documented in Table I. Thereafter, the algorithm divides the set of neighbouring access points of the 5 edge devices into two clusters: good and bad. After selection, the VM within v_i forms the VAP consisting of a good set of access points. The cardinality of formed VAP for each newly deployed edge device is depicted in Table I.

The algorithm for VAP formation mainly focuses on segregating the good set of access points from the neighboring access points ($\mathcal{V}_i^{ap} \in \mathcal{V}^a$) within the coverage area of an edge device. This segregation process mainly predicts the good set of access points using the FCM-based clustering

TABLE I
CARDINALITY OF NEIGHBORING NODE SET AND VAP FOR EACH EDGE DEVICES IN FIG. 4

v_i	1	2	3	4	5
$\mathcal{V}^{ap}$	19	23	31	26	19
$\mathcal{V}^{a''}$	11	14	19	13	8

approach which involves a time complexity of $O(|\mathcal{V}_i^{ap}|)$. On the other hand, before forming the VAP, the edge devices collects the value of decsion parameters from each of access points within the within the coverage area of an edge device, which also involves a time complexity of $O(|\mathcal{V}_i^{ap}|)$. Therefore, the time complexity of VAP formation is evaluated as $O(|\mathcal{V}_i^{ap}|)$.

2) Virtual Path Selection: In 6G-enabled Society 5.0, after VAP formation, the VM in the edge device finds the path between the edge and the destination nodes such as the cloud. The VM can establish communication with the cloud through multiple communication paths from each access point in VAP and form VP. In the system, we define $\mathcal{L}_{i,j}^k$ as the path between v_i and v_j edge devices over a_k access points, where $a_k \in \mathcal{V}_i^{ap''}$. The VM in the edge device v_i is connected to $\mathcal{V}_i^{ap''}$, and thereby, the VM forms VP ($\mathcal{L}'_{i,j}$), which is a set of paths through all access points in $\mathcal{V}_i^{ap''}$. The properties of virtual path $\mathcal{L}'_{i,j}$ is as follows,

Proposition 2:
(a) $\mathcal{L}'_{i,j} = \mathcal{L}_{i,j}^k$, where $v_i, v_j \in \mathcal{V}^e$ and $a_k \in \mathcal{V}_i^{ap''}$.
(b) $|\mathcal{L}'_{i,j}| \geq 1$
(c) If $\mathcal{L}_{i,j}^k, \mathcal{L}_{i,j}^l \in \mathcal{L}'_{i,j}$, $\mathcal{L}_{i,j}^k \cap \mathcal{L}_{i,j}^l = \phi$ or $\mathcal{L}_{i,j}^k \cap \mathcal{L}_{i,j}^l \neq \phi$, which state that two paths in $\mathcal{L}'_{i,j}$ may or may not have common link.

ACUTE uses the Dijkstra algorithm to find the shortest path between two nodes based on the associated link weight values. ACUTE assigns the weight value to each link ($l_{ij} \in \mathcal{L}$), by computing a utility value ($\mathcal{U}_{ij}$) based on the residual energy ($e_j(t)$), the service cost (c_j) of the destination access points of the link, the data rate ($r_{ij}(t)$) and the distance (d_{ij}) of the link at time *t*. We determine the utility function as follows,

$$\mathcal{U}_{ij} = \frac{\mathcal{P}_{ij} e_j(t) c_j}{d_{ij} r_{ij}(t)}, \tag{1}$$

where $\mathcal{P}_{ij} = \frac{d_i^{comm} r_{ij}^{max}}{e_j^{max} c^{max}}$, such that $\mathcal{P}_{ij}$ is a positive constant value used to normalize the parameters, for communication range of v_i is d_i^{comm}, maximum data rate of l_{ij} is r_{ij}^{max}, maximum residual energy of v_j is e_j^{max}, and maximum cost charged by v_j is c^{max}. However, $\forall l_{ij} \in \mathcal{L}$, $\mathcal{U}_{ij}$ needs to be greater than 0 in order to assign the weight value while evaluating the shortest path using Dijkstra algorithm.

Theorem 1: The minimum value of $\mathcal{U}_{ij}$ is 0.

Proof: We analyze the theorem using the theory of contradiction, and we state that $\mathcal{U}_{ij} < 0$ is true. Thereby, as discussed previously that $\mathcal{P}_{ij} \geq 0$, any of $e_j(t)$, c_j, $\mathcal{R}_{ij}(t)$, and d_{ij} is less than 0. However, these parameters represent the physical condition of link and devices, which cannot be negative. Therefore, $\mathcal{U}_{ij} \geq 0$ is true. ■

The VP formation algorithm mainly uses the Dijkstra algorithm to find the sortest path between each access point associated with an edge device and the cloud. A generic Dijkstra algorithm [30] involves a time complexity of $O(V + E * \log V)$ where V and E denotes the number of nodes and links present in the network. In ACUTE, the time complexity of VP formation involves the complexity of $O(|\mathcal{V}_i^{ap}|^2 + |\mathcal{V}_i^{ap}| * |\mathcal{L}^{\mathcal{V}^{ap},C}| * \log|\mathcal{V}_i^{ap}|)$, where $|\mathcal{V}_i^{ap}|$ denotes the set of access points associated with an edge device and $\mathcal{L}^{\mathcal{V}^{ap'},C}$ denotes the liks exists between $|\mathcal{V}_i^{ap}|$ and a cloud. Furthermore, the VAP and VP formation process in ACUTE is visualized as a distributed approach to ommit the possibility of single node failure during these formation.

3) Data Transmission: We already defined the mechanism for VAP ($\mathcal{V}_i^{a''}$) and VP ($\mathcal{L}'_{i,j}$) formation in Section III-A1 and III-A2. Let us assume that the edge device v_i wants to transmit data of size $\mathcal{D}_i$ to the cloud. In ACUTE, the VM in v_i distributes $\mathcal{D}_i$ over multiple paths in VP. To transmit over multiple path, the VM in v_i divides the data into a set of fixed-size frames and rearrange them as matrix $\mathcal{F}^i_{m\times n}$, where $n = |\mathcal{V}_i^{a''}|$ and $m \times n = \mathcal{D}_i$. The matrix $\mathcal{F}^i_{m\times n}$ consists column vectors $[\mathcal{F}^i_a], \forall a = 1 to |\mathcal{V}_i^{a''}|$, where $\mathcal{F}^i_a$ data will be transmitted by the $\mathcal{V}_{ia}^{a''}$ access point over $\mathcal{L}^a_{i,j}$ path. Therefore, using this matrix, VM can specify the frames vector $\mathcal{F}^i_a$ that is going to be transmitted using access point $\mathcal{V}_{ia}^{a''}$. On the other hand, the cloud receives the frames concurrent, which may elevate an issue of ordering the frames while reconstructing the data in the cloud. To provide proper ordering of frames during the reconstruction of data in cloud, the VM in v_i needs to embed the indices (cd) of the frame $\mathcal{F}^i_{cd}$ in the content of the frame. In serialized data transmission, the existing transmission framework suggest on using bit-stuffing to embed the frame ordering in the frame content itself. Inspired by the existing framework, ACUTE enable the VM in v_i to embed the indices of frame $\mathcal{F}^i_{cd}$ in the frame content using bit-stuffing. Embedding the frame indices in the frame itself before data transmission allow the VM in v_i to transmit a frame vector $\mathcal{F}^i_a$ over any path in VAP without maintaining the sequence of frame transmission. Therefore, ACUTE introduces path hopping, where the VM in v_i randomly selects a $\mathcal{F}^i_a$ from $\mathcal{F}^i_{m\times n}$ and a path from VAP and assign the selected frames vector to the selected path for transmission. Using path hopping, the specificity of the frame vector, such as ordering of the frame vector, transmitted though a path can not be determined, which preserved the data privacy.

IV. Theoretical Models and Analysis

In this Section, we theoretically analyze the performance of ACUTE in comparison with the *serialized data transmission* observed in traditional architectures [6], [31]. As mentioned in Section I-A, the traditional architecture allows the edge device to connect with a single access point and transmit data over a single path.

TABLE II
Transition Table

Inputs	State	
	t	***(t+1)***
$r > Pr_1$	$C_g(t)$	$C_g(t+1)$
$r < Pr_1$	$C_g(t)$	$C_b(t+1)$
$r > (1 - Pr_2)$	$C_b(t)$	$C_g(t+1)$
$r < (1 - Pr_2)$	$C_b(t)$	$C_b(t+1)$

A. Network Model

The traditional approach [6], [31] follows a network where an edge device (v_i) transmits data of size $\mathcal{D}_i$ to the cloud using an AP v_j and a single communication path. In traditional approach, the association between an edge node $v_i \in \mathcal{V}^e$ and access point $v_j \in \mathcal{V}^a$ at a time instance t is represented with a binary variable $x_{ij}(t)$ as:

$$x_{ij}(t) = \begin{cases} 1, & \text{Association exists between } v_i \text{ and } v_j, \\ 0, & \text{Otherwise.} \end{cases} \tag{2}$$

Proposition 3: The function f defines the association between $\mathcal{V}^e$ and $\mathcal{V}^a$, defined as $f : \mathcal{V}^e \longrightarrow \mathcal{V}^a$. The properties of f are as follows.

(a) For traditional communication system, f follows one-to-one mapping.
(b) For traditional communication system, $\sum_{j=1}^{n} x_{i,j}(t) = 1, 0, \forall v_i \in \mathcal{V}^e$ and $v_j \in \mathcal{V}^a$.
(c) For ACUTE, $0 < \sum_{j=1}^{n} x_{i,j}(t) < |\mathcal{V}_i^{a''}|, \forall v_i \in \mathcal{V}^e$ and $v_j \in \mathcal{V}^a$.

We described the property of association between the devices in the network model in Property (3). In traditional approach, an edge device transmits data to the cloud via a single access point and a single path. However, in ACUTE, an edge device transmits data concurrently via multiple access points and multiple paths. Therefore, at a time, the average size of data transmitted from each edge device in ACUTE differs from that in the traditional approach.

Lemma 1: If $\forall v_i \in \mathcal{V}^e$, if $\mathcal{D}_i^t$ and $\mathcal{D}_i^g$ denotes the average size of tranmistting data at a time for traditional architecture and ACUTE, respectively, then $\mathcal{D}_i^t$ is greater than $\mathcal{D}_i^g$.

Proof: Let us assume that, $\forall v_i \in \mathcal{V}^e$, the v_i transmits the data size of d_i to the cloud. We prove the Lemma (1) using the theory of contradiction, considering $\mathcal{D}_i^t \leq \mathcal{D}_i^g$.

(a) For traditional communication system, the v_i transmits the data of d_i size through a single access point over a single path, Therefore, $\mathcal{D}_i^t = \mathcal{D}_i$.
(b) For ACUTE, the v_i transmits the data of $\mathcal{D}_i$ size through $\mathcal{V}_i^{a''}$ over $|\mathcal{V}_i^{a''}|$ communication paths simultaneously. Therefore, $\mathcal{D}_i^g = \frac{\mathcal{D}_i}{|\mathcal{V}_i^{a''}|}$.

Using the theory of contradiction, we can report that $\mathcal{D}_i^t \leq \mathcal{D}_i^g$. Therefore, we evaluate that $\mathcal{D}_i \leq \frac{\mathcal{D}_i}{|\mathcal{V}_i^{a''}|}$ or $|\mathcal{V}_i^{a''}| \leq 1$, which is not possible according to the Property 1. Therefore, $\mathcal{D}_i^t > \mathcal{D}_i^g$ is true. ■

B. Delay Model

We consider the delay model used in [32] to evaluate the delay for both the traditional approach and ACUTE. According to the model, the calculation of average delay are divided into – (a) processing delay, (b) transmission delay, (c) propagation delay, and (d) queuing delay. In 6G-enabled Society 5.0, we consider that the data processing is mainly performed in cloud with adequet resources, and therefore, the processing delay and queuing delay at cloud is negligible. We evaluate the transmission delay following the log distance path loss model, which considers the log-normal shadowing for urban scenario. Typically, the log distance path loss model is evaluated as $PL_{[dB]} = 140.7 + 36.7 \times log_{10} d_{[km]} + \mathcal{N}(0, 8)$, where d denotes the distance between two devices in kilometer, $\mathcal{N}(0, 8)$ is Gaussian distribution with 0 mean and 8 standard deviation. Using the log distance path loss model, we generate the maximum data rate between v_i and v_j, which is formulated as $r_{ij} = B \times log_2(1 + \frac{Tx_{[dB]} - PL_{[dB]}}{NP_{[dB]}})$, where $Tx_{[dB]}$ denotes the channel transmission power, B denotes the channel bandwidth, and $NP_{[dB]}$ denotes the noise power, respectively. The transmission delay for the i^{th} edge device is evaluated as $\delta_i^T = \frac{z_i}{r_{i,j}}$ and propagation delay from the j^{th} access point to cloud is computed as $\delta_i^P = \frac{Z_i \times d_{[m]}}{c}$, where z_i denotes datasize, $d_{[m]}$ denotes distance from access point to cloud in meter and c denotes speed of light. Thus, in traditional communication system the total delay to transmit data from an edge node to cloud is formulated as:

$$\delta_i^{TRAD} = \frac{\mathcal{D}_i^t}{r_{i,j}} + \frac{\mathcal{D}_i^t \times d_{[m]}}{c} \tag{3}$$

However, for ACUTE, the total delay is formulated as:

$$\delta_i^{ACUTE} = \frac{1}{|\mathcal{V}_i^{ap'}|} \sum_{j=1}^{|\mathcal{V}_i^{a''}|} \left(\frac{\mathcal{D}_i^g}{r_{i,j}} + \frac{\mathcal{D}_i^g \times d_{[m]}}{c} \right) \tag{4}$$

where here q denotes the total number of connected access points.

Theorem 2: $\forall v_i \in \mathcal{V}^e$, the total delay in ACUTE (δ_i^{ACUTE}) is less than that in the traditional approach (δ_i^{TRAD}).

Proof: We solve the Theorem 2 using the theory of contradiction. We state that, $\forall v_i \in \mathcal{V}^e, \delta_i^{ACUTE} > \delta_i^{TRAD}$. Therefore, we state that $\frac{1}{|\mathcal{V}_i^{ap'}|} \sum_{j=1}^{|\mathcal{V}_i^{ap'}|} (\frac{\mathcal{D}_i^g}{r_{i,j}} + \frac{\mathcal{D}_i^g \times d_{[m]}}{c}) > \frac{\mathcal{D}_i^t}{r_{i,j}} + \frac{\mathcal{D}_i^t \times d_{[m]}}{c}$. Now, let us consider that $b = \frac{1}{r_{i,j}} + \frac{1 \times d_{[m]}}{c}$ is constant $\forall v_i \in \mathcal{V}^a$. Therefore, we can evaluate that $\frac{b}{|\mathcal{V}_i^{ap'}|} \sum_{j=1}^{|\mathcal{V}_i^{ap'}|} \mathcal{D}_i^g > \mathcal{D}_i^t b$ or $\sum_{j=1}^{|\mathcal{V}_i^{ap'}|} \mathcal{D}_i^g > |\mathcal{V}_i^{ap'}| \mathcal{D}_i^t b$. In other words, we can say that $(d_1^g + d_2^g + \cdots + d_{|\mathcal{V}_i^{ap'}|}^g) > |\mathcal{V}_i^{ap'}| \mathcal{D}_i^t$, which state that $\mathcal{D}_i^g > \mathcal{D}_i^t$. It is not possible by Lemma 1. Therefore, the theorem is true. ■

C. Energy Consumption Model

We adopt the energy model of Heinzelman *et al.* [33] to calculate the transmission energy consumption of the i^{th} edge node transmitting data of size $\mathcal{D}_i$, to the j^{th} access point at time instant *t*, which is formulated as follows:

$$\mathcal{E}_i(t) = \mathcal{E}_i^{elec} z_i + \mathcal{E}_i^{amp} z_i \varphi_{i,j}^2, \quad \forall i \in \mathcal{V}^e, j \in \mathcal{AP}, \tag{5}$$

where $\mathcal{E}_i^{elec}$ and $\mathcal{E}_i^{amp}$ denote the transmission and amplification energies of the i^{th} edge node, respectively. Moreover, $z_i = |d_i|$ represents the data size and $\varphi_{i,j}$ represents the distance of the edge node to the cloud server. However, for the multi access point-based communication system the transmission energy consumption is formulated as follows:

$$\mathcal{E}_i^{ACUTE}(t) = \sum_{j=1}^{q} \left(\mathcal{E}_i^{elec} z_j + \mathcal{E}_i^{amp} z_j \varphi_{i,j}^2 \right), \quad \forall i \in \mathcal{V}^e. \tag{6}$$

D. Packet Loss Model

We also evaluate a packet loss model to generate the average packet loss rate for each edge node. This model is designed following the Markov model-based packetloss evaluation discussed by Jelassi and Rubino [34]. When an edge node $v_i \in \mathcal{V}^e$ with data of size $\mathcal{D}_i$ communicate with an access point through a path, the successful transmission of a packet $k \in \mathcal{D}_i$ depends on the path condition. We assume that at the t^{th} time instance for the k^{th} packet transmission from an the i^{th} edge node, there are two types of path conditions — good path condition denoted as $C_g(t)$ and bad path condition denoted as $C_b(t)$. The path conditional depends on the packet loss in the path. The packet loss of a path is inversely proportional to the number of successfully tranmitted packets. Therefore, if packet loss in the path is high, the path is in bad condition; otherwise in good condition. Moreover, the transmission status of the k^{th} packet is denoted as follows:

$$S_{i,k}(t) = \begin{cases} 1, & \text{successful, if path condition} = C_g(t), \\ 0, & \text{unsuccessful, if path condition} = C_b(t) \end{cases} \tag{7}$$

where the $S_{i,k}(t) = 1$ denotes the successful transmission of the packet for path condition $C_g(t)$ and $S_{i,k}(t) = 0$ denotes the opposite condition of the path. We consider the maximum allowable packet size denoted as P is uniform for all wireless paths. Thus, the total number of transmitted packets for each edge node i is formulated as follows:

$$\mathcal{P}_i^{sen} = \frac{d_i}{P}, \quad \forall i \in \mathcal{V}^e \tag{8}$$

and the total number of successfully receiving packet is evaluated as follows:

$$\mathcal{P}_i^{rec} = \sum_{k=1}^{\mathcal{P}_i^{sen}} S_{i,k}(t), \quad \forall i \in \mathcal{V}^e, k \in d_i \tag{9}$$

Therefore, total number of packet loss for the i^{th} edge node is calculated as follows:

$$\mathcal{P}_i^{loss} = \mathcal{P}_i^{sen} - \mathcal{P}_i^{rec} \tag{10}$$

We also assume that the next state path condition $C(t+1)$ can be predicted from the current state path condition $C(t)$, where for first packet transmission, we assume that the $S_{i,k}$ value is always 1. We follows Markov model-based path condition prediction for modelling packet loss in this paper. We consider two types of probability values, Pr_1 denotes the probability of path condition transition from good to bad, i.e., $C_g(t) \rightarrow C_b(t+1)$ and Pr_2 denotes the probability of path condition transition from bad to good, i.e., $C_b(t) \rightarrow C_g(t+1)$. Thus, a path in good condition $C_g(t)$, may continue to be in good condition $C_g(t+1)$ or transits into into good condition $C_b(t+1)$ and vice versa. For simulation, we consider a random value r to determine the next path condition. For a path with $C_g(t)$, when $r > Pr_1$, the path remains in the same state, otherwise transits into $C_b(t)$. Again. for a path with $C_b(t)$, when $r > (1 - Pr_2)$, the path transits into $C_g(t)$, otherwise remain in the same state.

E. Pricing Model

Similar to the traditional system mentioned in Section IV-A, in ACUTE, each access point is shared by multiple users. In traditional system, we consider all access points are owned by a same owner, and on the other hand in proposed system, access points are owned by different access point owners. For both traditional architecture [6], [31] and ACUTE, we assume that each access point $j \in \mathcal{AP}$ charges a price $\mathcal{R}_j$ unit/MB from a range [$\mathcal{R}^{min}$, $\mathcal{R}^{max}$] unit/MB. Therefore, in traditional system the service cost to an user associated with the i^{th} edge node with d_i data is formulated as follows:

$$Cost_i^{Trad}(t) = d_i \mathcal{R}_j x_{i,j}(t), \quad \forall i \in \mathcal{V}^e \tag{11}$$

On the other hand, for the proposed system the service cost is evaluated as follows,

$$Cost_i^{ACUTE}(t) = \frac{1}{q} \sum_{j=1}^{n} \big(d_i' \mathcal{R}_j x_{i,j}(t) \big), \quad \forall i \in \mathcal{V}^e, \tag{12}$$

where q denotes the number of access points connected with the i^{th} edge node at time t.

Theorem 3: At a time instance t for edge node $i \in \mathcal{V}^e$, i.e., $Cost_i^{Trad}(t) > Cost^{ACUTE}i(t), \quad \forall i \in \mathcal{V}^e$.

Proof: We prove this theorem by contradiction, i.e., $Cost_i^{Trad}(t) \leq Cost_i^{ACUTE}(t), \forall i \in \mathcal{V}^e$ is not true. Let we assume that $Cost_i^{Trad}(t) \leq Cost_i^{ACUTE}(t), \forall i \in \mathcal{V}^e$ is true. Based on the assumption, we can compute that,

$$d_i \mathcal{R}_j x_{i,j}(t) \leq \frac{1}{q} \sum_{j=1}^{n} \Big(d_{i,j}' \mathcal{R}_j x_{i,j}(t) \Big) \tag{13}$$

By simplifying Equation (13), we get

$$q d_i \mathcal{R}_j \leq \sum_{j=1}^{q} \Big(d_{i,j}' \mathcal{R}_j \Big) \quad \text{[For only the selected APs]}. \tag{14}$$

As we discussed already that in the proposed system, d_i is fragmented over q number of selected access points, so $d_i >> d_{i,j}'$, which contradicts the assumption. Therefore, it proves that $Cost_i^{Trad}(t) > Cost_i^{ACUTE}(t), \forall v_i \in \mathcal{V}^e$ is true. ■

TABLE III
SIMULATION PARAMETERS

Simulation Parameters	**Values**
Simulation Area	$1,000 \times 1,000$ m^2
Number of edge devices	1000, 2000, 3000
Number of APs	500, 1000, 1500
Number of clouds	1
Data size	0.2, 0.4, 0.6, 0.8, 1, 1.2 GB
Communication range for an edge device	100 m [32]
Communication range for an AP	350 m [32]
Transmission power	2.2 W [32]
Noise	−100 dB [32]
Bandwidth	1 Gbps [15]
Confidence interval	95%
Price charged by APs	[100, 500] unit/MB
Pr_1	0.02777 [34]
Pr_2	0.25 [34]

V. PERFORMANCE EVALUATION

A. Experimental Setup

We simulate the proposed system with 1,000, 2,000, and 3,000 edge devices, 500, 1,000, and 1,500 access points, and 1 cloud server. These devices are placed randomly over 1,000 × 1,000 m^2 area. Such huge deployment of these devices in a small area simulates the dense device deployment required in ACUTE. Each of the edge devices in this deployment sends data having 0.2, 0.4, 0.6, 0.8, 1, and 1.2 size to the cloud server, which helps in replicating the huge data transmission envisaged in ACUTE. Furthermore, these edge devices transmit the data with 2.2 W transmission power [32] over the channel having −100 dB [32] noise and 1 Gbps [15] bandwidth to imitate the actual IoT edge devices. Such channel changes from good state to bad state with (Pr_1) probability 0.02777 [34] and vice-versa with (Pr_2) probability 0.25 [34], which replicates the channel condition in real deployment. The owners of the deployed access points charge the associated edge devices a random price in the range of [100, 500] unit/MB. The communication range of these edge device and the access points are 100 and 350 m [32], respectively. In Table III, we tabulated these parameters used in the experiments. We design the experiment based on the network model mentioned in Section III-A and compare with the traditional approach [6], [31], mentioned in Section IV. In the simulation, we initialize the aforementioned number of edge devices, access points, and cloud server with random positions. The simulation follows the association property as Property 3. In the simulation, the cloud server is associated with a single access point. These access points forms a multi-hop connection to establish communication between end-users and cloud server. In the proposed architecture, an edge device can communicate with multiple access points at a time. However, the same edge device in the traditional architecture connect to only a single access point.

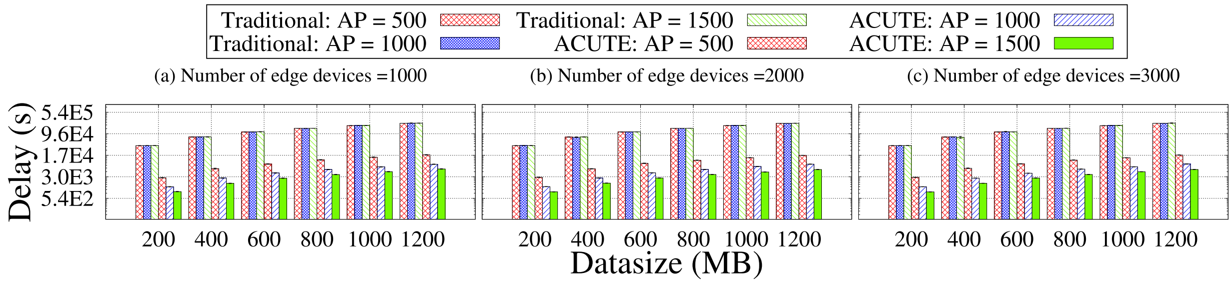


Fig. 5. Average delay.

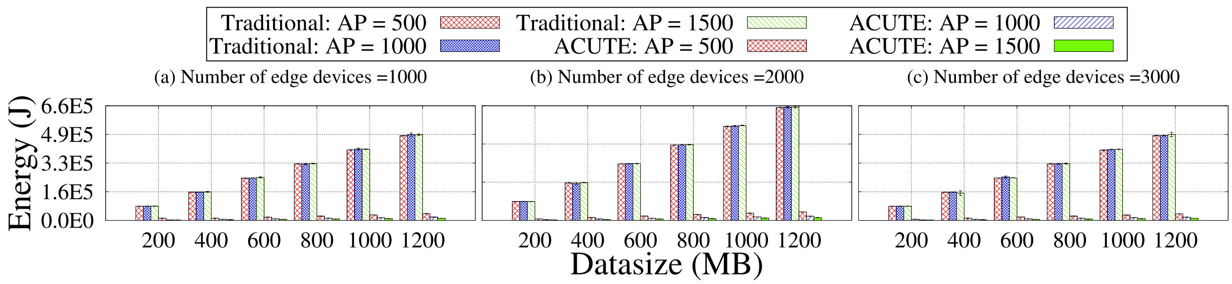


Fig. 6. Average energy consumption.

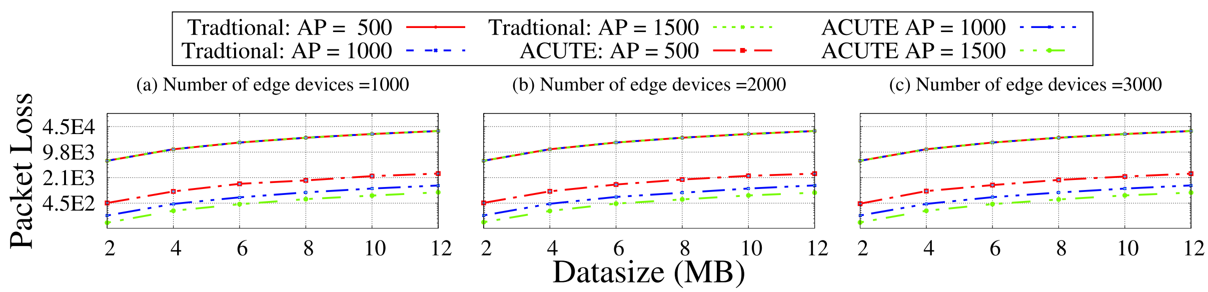


Fig. 7. Average packet loss.

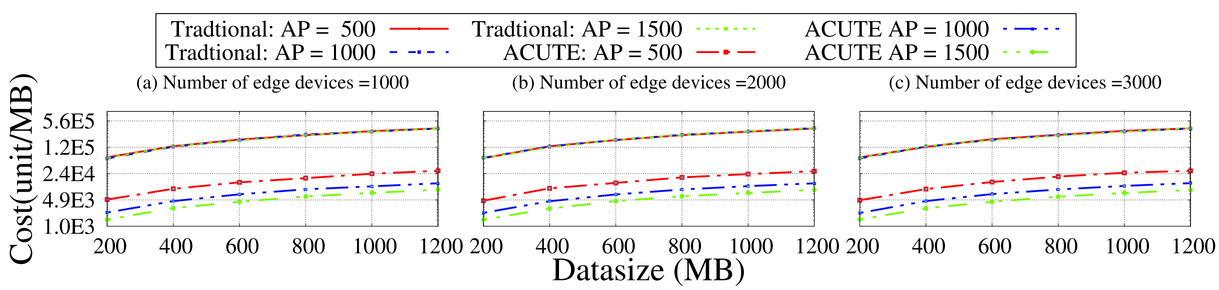


Fig. 8. Average cost charged by AP.

B. Performance Metrics

We evaluate the performance of ACUTE against the benchmark scheme based on the parameters such as average network delay, average energy consumption, average packet loss, service cost, and hop count. The evaluated results are depicted in the Fig. 5, 6, 7, 8, and 9 respectively. Therein, we evaluate average network delay, average energy consumption, average packet loss, and service cost with varying edge node, access points, and data size. On the other hand, we evaluate average hop count with varying edge nodes and access points as the evaluation average hop count does not depends on the data size. We report the impact of varying edge nodes and access points in ACUTE based on the evaluation of average network delay, average energy consumption, average packet loss, service cost, and hop count. However, we experiment the network throughput and the impact of varying data size base on the evaluation of average network delay, average energy consumption, average packet loss, and service cost. We evaluate the data transmission delay based on the evaluation of average network delay of the system to examine the impact of

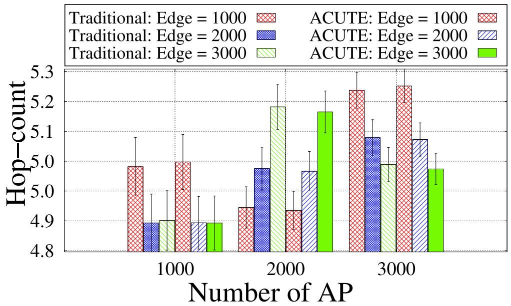


Fig. 9. Average hop-count.

ACUTE in 6G-enabled Society *5.0*. Further, we examine the network congestion and the network reliability based on the evaluation of average packet loss. The scalability of ACUTE can be evaluated based on the evaluation of the impact of varying edge nodes, access points, and datasize. lastly, we evaluate the network life time based on the evaluation of average energy consumption.

C. Results and Discussions

In this section, we discuss the simulation results in comparison with the benchmark scheme [6], [31].

1) Average Network Delay: We analyze the average network delay of the proposed system, and compare it with the benchmark scheme. We observe the evaluated results in Fig. 5a, 5b, and 5c with varying edge nodes, access points and data size. In these results, we observe overall 27% reduction in network delay. In this proposed architecture, the edge devices divide the data into a set of frame vectors and concurrently transmits the data over multiple access points. These access points further transmit the data to the cloud independently. Therefore, in the proposed architecture, bulk data is transmitted concurrently and such a transmission reduces the network delay in comparison to the benchmark architecture, which supports the results.

2) Average Energy Consumption: We analyze the average energy consumption of the proposed system, and compare it with the benchmark scheme. We observe the evaluated results in Fig. 6a, 6b, and 6c with varying edge nodes, access points and data size. In these results, we observe overall 95% reduction in energy consumption comparing the traditional approach. In the proposed architecture, edge device distribute the data among multiple edge devices, which consequently distribute in the network for transmitting the data to the cloud server. As data transmission depends on the size of the transmitted data, the energy consumption for each devices reduces in comparison to the benchmark architecture for transmitting or propagating the data. Thus, the results are justified.

3) Average Packet Loss: We analyze the average packet loss of the proposed system, and compare it with the benchmark scheme. We observe the evaluated results in Fig. 7a, 7b, and 7c with varying edge nodes, access points and data size. In these results, we observe overall 95% reduction in packet loss. According to the packet loss model discussed in Section IV-D, the packet loss for data transmission depends upon packet loss rate, which is determined as the maximum amount of packet is lost per transmission. Moreover, this packet loss rate depends on the size of the data which is being transmitted. To computation overhead for analyzing the packet loss, we consider that both proposed and traditional architectures transmit data of sizes 2-12 MB, with an interval of 2 MB. As mentioned in Section IV, each edge device in traditional architecture is associated with an access point and communicates with the cloud using a single communication path. Therefore, as per the packet loss model mentioned in Section IV-D, both the traditional architecture shows similar packet loss and a similar linear increase in packet loss over varying edge nodes, access points, and transmission data sizes. Consequently, the packet loss observations for the traditional architecture generates a set of overlapping lines in Fig. 7a, 7b, and 7c. However, in the proposed architecture, the edge device distributes the data among multiple access points, and thereby, the data size per access point is reduced. Therefore, the average packet loss is also reduced in comparison to the benchmark architecture. The results are justified.

4) Average Service Cost: We analyze the average cost for service of the proposed system, and compare it with the benchmark scheme. We observe the evaluated results in Fig. 8a, 8b, and 8c with varying edge nodes, access points and data size. In these results, we observe overall 26% reduction in costs for the service. In the proposed architecture, as mentioned, an edge device can get service from multiple access points parallelly. Therefore, in comparison to the benchmark architecture, the proposed architecture reduces average service cost, which can be observed in these figures. On the other hand, we observe a set of overlapping lines in Fig. 8a, 8b, and 8c that depict the service cost observation for the traditional architecture. According to the service cost model discussed in Section IV-E, the service cost for each of the edge devices directly depends on the transmitting data size. As mentioned in Section IV, each edge device in traditional architecture is associated with an access point and communicates with the cloud using a single communication path. Therefore, the traditional architecture results in a negligible variation in service costs for varying number of edge devices, APs and varying data size.

5) Average Hop Count: We analyze the average hop count of the proposed system, and compare it with the benchmark scheme. We observe the evaluated results in Fig. 9 with varying edge node and access points. In these results, we observe overall 0.2% reduction in average hop count. In the results, reduction average hop cont with varying access points is negligible, which states that the proposed architecture is as stable as the bench march architecture in terms of average hop count.

6) Impact of Varying Edge Nodes: We observe the impact of varying edge nodes in Fig. 5, 6, 7, 8, and 9. Therein, we observe that the architecture results linear increase in average delay, energy consumption, packet lost and service cost over varying edge nodes. However, in the case of average hop count, the architecture is affect by the varying edge nodes.

7) Impact of Varying Access Points: We observe the impact of varying access points in Fig. 5, 6, 7, 8, and 9. Therein, we observe that the architecture results linear decrease in average delay, energy consumption, packet lost and service cost over varying access points. However, the architecture reports negligible reduction with varying access points.

8) Impact of Varying Data Size: We observe the impact of varying size in Fig. 5, 6, 7, 8, and 9. Therein, we observe that the architecture results linear increase in average delay, energy consumption, packet lost and service cost over varying access points.

9) Impact on Network Throughput: The network throughput of any system inversly depends on the average delay, energy consumption, packet loss and hop count. In Sections V-C1, V-C2 and V-C3, we observe that the proposed architecture reports substantial reduction average delay, energy consumption and packet loss in comparison with the benchmark scheme. Furthermore, we observe in Section V-C5 that the proposed system shows negligible change in average hop count in comparison with the same. Therefore, we can conclude that the propose scheme increases the network through put in comparison with the benchmark scheme.

10) Impact on Network Lifetime: The network lifetime depends upon the energy consumption rate of each devices in any system. If these devices consume energy in order to perform the system's tasks, the network lifetime will decrease. In the proposed architecture, we can observe a substantial reduction in energy consumption by each devices in comparison with the benchmark scheme. Thereby, the proposed architecture increases the network lifetime in comparison with the benchmark scheme.

11) Impact on Network Congestion: The network congestion depends upon the packet loss in any system. If the average packet loss in the system decreases, the congestion in the system in the system also decreases. In the proposed architecture, we con observe a substantial reduction in average packet loss in the systems. Thus, we can conclude that that the proposed architecture reduces network congestion.

VI. Conclusion

This paper introduced the concept of concurrent data transmission for individual users to reduce data transmission delay and efficiently manage network services in 6G-enabled Society 5.0. Society 5.0 aims for a unified system which promises to provide complete, automated, end-to-end services and addresses the demands of connected living. To address the demands of individual users, Society 5.0 envisions a system having edge intelligence, dense network deployment, and fast data delivery — one of the core requirements provided by 6G. Using 6G, this system aims to facilitate the user with serialized data transmission by connecting an access point and transmitting data over a single communication path. To alleviate these problems, we proposed ACUTE — a concept of virtualizing communication for Society 5.0 that introduces parallelization during data transmission across individual users using virtual access points (VAPs) and virtual paths (VPs). In ACUTE, a VM employed at each edge device performs synchronous data transmission through: (a) connecting to a VAP – a set of optimally selected access points and VP – a set of subsequent paths from each of these access points, (b) load balancing across VAP and associated VP, and (c) introducing path hopping – a variant of frequency hopping.

In this manuscript, we consider the presence of stationary edge devices for ACUTE. Therefore, the association between access points and edge devices is also static. However, Society 5.0 envisions providing real-time and seamless services to both static and mobile users [35]. In this context, the static association between the access points and the edge devices in ACUTE may increase the data transmission latency and energy consumption in the presence of mobile users. We plan to extend this work by introducing a novel VP and VAP selection mechanism in the presence of mobile users. On the other hand, ACUTE enables an edge device to associate with multiple APs simultaneously, and distribute the transmitting data among these APs. These APs owned by an individual owner, who can monitor and tamper with the data. Additionally, these APs may exhibit malicious behaviors [36], which causes reduced efficiency of data transmission and compromise data privacy. We also plan to address the issues of the presence of malicious APs by designing a privacy-aware VAP selection scheme for ACUTE.

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