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A Novel Cloud Architecture for Internet of Space Things (IoST)

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ABSTRACT The Internet of Things (IoT) has influenced technology in numerous ways. What started as a network of physical devices communicating over the Internet grew tremendously sophisticated by incorporating billions of devices and defining specific IoT domains. IoT has found its subdomains in many fields such as medicine, healthcare, robotics, etc., and several domains are yet to incorporate IoT. One of the rapidly advancing technologies in space research. Space research has been growing tremendously over the last few decades, with studies ranging across exoplanet detection, colonization, space communication, and the possibility of life forms across other bodies. In this paper, we suggest a novel architecture of the Internet of Space Things (IoST) compatible with the cloud for the increasingly growing and futuristic field of space technology. The article proposes a detailed physical and logical architecture considering the public network, cloud provider, enterprise network, ground station, and interspace communication. The study will benefit researchers and scientists working in IoT, space technologies, colonization, robot-assisted surgery, space farming, etc.

INDEX TERMS Internet of Things (IoT), Internet of Space Things (IoST), space technology, interspace communication, satellite network.

I. INTRODUCTION

The visions of machines communicating with one another have been there since the early 1980s, but the Internet of Things (IoT) came to light only in the early 2000s. The earliest example of IoT from the early 1980s is a Coca-Cola machine from Carnegie Mellon University, connected to the refrigerated appliance. Over the last few decades, as technology advanced and devices increased, there has been exuberant growth in IoT technologies. Simply stated, IoT incorporates any device equipped with an on/off switch connected to the Internet. It includes almost everything ranging from cellphones to maintaining the engines of an airplane. The computing power has increased significantly over the last fifteen years, asserting the existence of Moore's Law [1]. Applications like real-time analytics have found much more sophisticated platforms and moved towards cloud and edge computing.

Additionally, with the introduction of 5G, improvised mobile connectivity supports applications like augmented and virtual reality [2]. The existing information technology devices will be connected to the IoT, thus leading to the growth of the IoT market. The IoT incorporates billions of physical devices connected worldwide through the internet, simultaneously collecting and sharing data. The ubiquity of wireless networks and ultra-efficient computer chips make it possible to convert small and big devices into a part of the IoT. As these different objects are connected across the globe, they are issued digital intelligence by introducing sensors to them. Hence, these devices communicate in real-time without human intervention. These devices rely on the Internet Protocol (IP) for communication, as it can identify computers all over the world and ensure communication between them. The devices are expected to self-report in time, with increased efficiency.

From the previous discussion, it is clear that the network provides a key role in transmitting the message from one place to another digitally, but by default, the private network is heterogeneous and it is functionally dependent on protocols and network architecture. Hence for integrating different applications using this architecture is difficult. IoT provides a uniform and standardized platform to interconnect all the

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devices in a single platform using the internet. Previous works [3] on space communication have been developed from several unrelated perspectives of the various initiatives to provide communication services for each new journey as it progresses. For example, communication for Earth observation missions like human shuttle and ISS missions was developed independently of other missions. NASA implemented an administration and data Satellite System called Tracking and Data Relay Satellite System (TDRSS) as a Space Network for Common Use by NASA Human Missions and Earth Observation missions. The cost of using the TDRSS (Tracking and Data Relay Satellite System) was considered too high for most Earth observer's missions. Hence these missions used old and modified old ground stations to record their data. Communication for Mars and deep space missions was also developed independently of the others and sharing the use of the Deep Space Network (DSN).

Thus, communication was re-handled from a service perspective. Although the interface and protocols used for various missions were regulated, the standards could not support autonomous networks and data management. The campaigns have recently gathered the necessary capabilities for future missions. However, the named business solutions for future communications are still service-based. The solutions are specific to each company's missions. They are not integrated into a complete NASA communication infrastructure solution, where the nodes in space can communicate with each other and consumers on Earth over the internet. Although not as it succeeded as initially expected, the Commercial Iridium satellite communications constellation proved that communication and networking between spacecraft were possible.

In 2019, by Akyildiz *et al.* [4], a new Internet of Things/CubeSats (IoST) concept was explained. At IoST, CubeSats play the role of network infrastructure that provides scalable connectivity across the globe and acts as passive and active sensors of the physical world. More importantly, the closed-loop integration of CubeSat sensing and CubeSat communication leads to a new cyber-physical system with innovative applications spanning land, air, and space. It may also be noted that while IoST is entirely different from previous IoST systems, we expect to receive additional connections from LEOs, MEOs, and GEOs as needed. In 2018 Ai *et al.* [39] explains that the latency can be decreased by adding cloud and edge technology in IoT network.

The proposed system explained an architecture compatible with the cloud. Using this cloud-integrated architecture, several features of IoT can be incorporated into an IoST platform. Connectivity is one of the essential features, which allows seamless communication among the interrelated components that may form the IoST ecosystems. Furthermore, cross-platform technologies and services can work together to establish an active engagement among the IoST components. Scalability is yet another essential feature. Hence, IoST can integrate various cross-domain models and ensure a proper trade-off between infrastructure and operational costs. This study also proposes an overall architecture for the IoST communication, along with the cloud connectivity. As a result, a considerable amount of information can be managed, which also happens to be the critical contribution of the study.

The rest of the paper has been organized as follows. Section II Related works. Section III, Application scenarios. Section IV, Explain the System architecture design, Section V discusses the Infrastructure layer. Section VI presents the design of the Control and Management Layer. Section VII, System procedure, and Section VIII discusses the Conclusion and Future Work.

II. RELATED WORKS

Necessity being the mother of invention has led to technological advancement in several fields, which the Internet of Things promises to transform [6]. Integrating devices in medicine assists medical professionals in monitoring patients inside and outside the hospital environment. Computers can evaluate patient data for adjusting treatments and improving patient outcomes [7]. Recently, urban planning has witnessed the emergence of IoT owing to transformation. Sensors with IP addresses can be placed in a busy street, and city officials can notify drivers about impending delays and accidents. Smart trash cans can also alert individuals when they become full, leading to optimized waste collection [8]. Smart devices can also contribute immensely to businesses if used strategically.

For example, a service that tracks data concerning energy usage and inventory levels can reduce overall costs. Connectivity can also assist companies in understanding customers' behavior, hence leading to the creation of tailored product recommendations. Connectivity could increase the overall size of the sale, and the product in the customers' home, once connected to the Internet, could also provide updates regarding service schedules and schedule appointments.

Thus, the Internet of Things is not only concerned with devices connected all over the world but can also be specific to various fields depending on utilities. Some of the areas that have witnessed specific Internet of Things within their domain are Industrial IoT [9], Internet of Agricultural Things (IoAT) [10], Internet of Healthcare Things (IoHT) [11], [12], Internet of Medical Things (IoMT) [13]–[17], Internet of Nano Things (IoNT) [18], Internet of Robotics Things (IoRT) [19], [20], Internet of Drone Things (IoDT) [21], Internet of Underwater Things (IoUT) [22], blockchain and IoT [23], Social IoT [24], Green IoT [25]–[27], etc. Some of the recent areas that highlight the necessity of IoT are Next-Generation IoT [28], [29], Satellite IoT [30], Internet of nano things [31], Internet of underwater things [32], [33]. As more and more devices connect to the Internet and new problems are identified, more such domains may be introduced in the future.

Space technology is one of the fastest-growing and rapidly explored fields [4], [5], [34]. There is no limit to curiosity, and humans, being curious creatures, have started explorations beyond Earth by introducing several technologies. More and more space expeditions are being launched, and there are a variety of objects surrounding Earth in space. While several satellites and the International Space Station are responsible for monitoring situations in and around Earth, other objects are being launched into deep space for gathering data [35]. The National Aeronautics and Space Administration (NASA) collaborates with Nokia to build a cellular network on the Moon. The Curiosity rover relays information from Mars to Earth regarding the soil, atmosphere, climate, etc. [36]. As colonization is being proposed as a prospect and several planets seem like potential candidates, it is necessary to dedicate an IoT platform for communication beyond Earth.

Based on the current work, many IoT research works have been defined specific to domains and tasks. This paper proposes a novel architecture of the Internet of Space Things (IoST). This IoT platform synchronizes and supervises communication between objects in space and stores every information integrated into the cloud. While the universe is massive and expanding at an alarming rate, the IoST may be built and extended as needed. The suggested platform may be created for interconnecting the devices in the earth to neighboring planets Venus and Mars and further beyond the asteroid belt. Much of the solar system is yet to be explored, and the proposed platform could help relay information between potentially habitable bodies that are distant. For example, Enceladus, an active moon, hides oceans of salty water beneath its surface (Barge and Rodriguez, 2021).

In this work, several other factors like atmosphere, climate, amount of sunlight received, soil toxicology, etc. that determine whether life is possible and if human colonization is feasible. This critical information must be received timely, reliably, and efficiently. Moreover, space data may be full of noise. Therefore, we can implement concepts like dissing and machine learning techniques for noise filters on these platforms to improve data transmission in further work.

In 2002, the NASA Glenn Research Center [3] prepared an architecture to spread the internet into space. However, it is only for the NASA organization. The work explains architectural elements like backbone, interspace communication, proximity communication, and internet access. Using this technology, they claimed to reduce the cost. However, developing the entire setup for a mission is not cost-effective if we create an infrastructure permanently, and gradually adding the components as per the requirement is the best solution than the previous.

In this work, the central repository system access is not added to the typical person access. In 2019 this concept will be explained as the Internet of Space Thing (IoST) (Ianf–Akhyildiz *et al.*, 2019). In the described paper, a novel architecture is presented using software-defined networking with the virtualization of the server concept. The main focus in this paper is an inter-satellite data processing and observing the earth from space like a third eye and communicating with the space IoT devices.

In 2020, Zhang *et al.* [34] suggested an architecture to integrate the space IoT world with the Terrestrial IoT world. They named it ST-IoT. This architecture explained the communication procedure and a clustering cooperative transmission strategy for integration between two separated IoT worlds. Again the same question is raised here how all the received information from the different IoT world.

In this paper, we propose an IoST architecture with cloud compatibility for information transmission. Knowledge can be generated using information and can assist the corporate and business sectors in expanding their business. Several features of IoT can be incorporated into an IoST platform. Connectivity is one of the essential features, which allows seamless communication among the interrelated components that may form the IoST ecosystems. Cross-platform technologies and services can work together to establish an active engagement among the IoST components. Scalability is yet another essential feature. Hence, IoST can integrate various cross-domain models and ensure a proper tradeoff between infrastructure and operational costs. The above-explained works are summarised below using the help of Table 1.

III. APPLICATION SCENARIOS

In the previous sections, we acquainted ourselves with the basic concept of space communication with various communication architecture types and related IoT works. We observed that IoT concerning space communication had been established, and many researchers also tried to share the internet into space.

We integrate the cloud with space communication architecture to enforce a better information management system. The explained work can help some of the applications of IoST. The application architecture finds its roots in requirement identification which software engineers and domain experts perform. The requirements may be functional as well as non-functional. Applicable requirements often go through process management, whereas non-functional requirements go through scalability management. In process management, knowledge patterns are derived from monitoring, predictive, prescriptive, and autonomic management, forming management process coordination.

Semantic management consists of semantic integration and extensive data scalability management. Semantic integration relies on data from sensory knowledge, context knowledge, and procedural knowledge. Big data scalability management incorporates big data stream detection patterns, predictive patterns, and management process patterns. Process management takes into account smart manageability, extensibility, and maintainability. While semantic integration takes into account interoperability and integration, big data and scalability management considers scalability, system performance, and cost management. The three components of management form the requirement formalization and are often taken care of by knowledge engineers.

This basic framework of application can have several uses. The cloud infrastructure bridges the gap between the general framework and specific applications. The data from the cloud

TABLE 1. Summarize of literature survey.

S/No	Year	Authors	Techniques	Discussion	Proc.
1	2001	Kul Bhasin *et al.*	Present a logical interconnection diagram for interspaced communication.	Explained a layered connection between one planet to another planet. Depending on the range of the communication, multiple relay stations are established into the space. The length of the communication is divided into different levels like L1, L2, L3, etc.	High rate data communication. Less traffic based communication. Infrastructure setup once.
2	2001	Kul Bhasin *et al.*	Designed Internet Architecture for earth space communication Protocol: FTP, TCP, IP, ATM, DVD, HDLC design tools, Internet over satellite simulation, traffic models, ISS comm. scenarios, CORBA, JAVA, UML to networks Microwave Frequency Ka-band.	For interspace, a communication backbone is designed. Explain the communication using the OSI layer. Explain all the protocols used for communication as well as the communication traffic.	High rate data communication network. Reliable communication, Costs can be minimized.
3	2002	JF Hennessy *et al.*	Protocol Used FTP, HTTP, SMTP, TCP, UDP, IP suggested HDLC protocol; Provide mass storage.	It provides IP-based communication for interspace communication and explains all its operations. End-to-end data communication is described. The work based on the data rate downlink speed 300kbps to 4Mbps.	Demonstrate in the laboratory simulated dynamic space environment using off-the-shelf - low cost. It was a highly successful experiment in January 2003.
4	2004	Kul Bhasin *et al.*	Explain all the relay satellite communication LEO, MEO, GEO, HEO.	The proposed architecture and added modular flexibility. Finding out the language point between earth, moon, and Mars is flexible enough to connect another planet.	Just design a model to simplified the interspace communication and find out the challenges.
5	2004	Kul Bhasin *et al.*	Explain about all the satellites LEO, MEO, GEO. Explain about the satellite present in Mars MSO, MHO, MLO.	Explain the communication infrastructure in the vicinity of in-space and out space like the moon and mars.	All the communication parameters are defined. All the frequency bands are calculated. All the services are defined.
6	2019	IF Akyildiz *et al.*	Access gateway, IoST gateway, IoST hub.	Designed a software-defined network architecture to connect the whole. Designing a key for identifying and authenticating the nodes. Explain software layered architecture for communication.	Realtime remotely sense data. Software Components communicating information smoothly.
7	2021	Z Gengxin *et al.*	Network exposure function. Policy control function. Space access network. Space backbone network.	An architecture to integrate the space IoT world with the Terrestrial IoT world named ST-IoT explained the communication procedure and a clustering cooperative transmission strategy for integrating two separated IoT worlds.	Integrated access and communication procedure reliable identification procedure.
9	Proposed Work		Designed Internet architecture for earth space communication. Protocol used: FTP, TCP, IP, ATM, DVD, HDLC. Cloud Infrastructure.	The proposed work design an architecture for interspace communication and explain the data communication between the ground station and satellite form communication. The critical feature of this work is to introduce the cloud for space communication.	Integrated communication procedure. Cloud-enabled TCP/ IP supported End to End communication procedure.

is relayed to the ground station, which may be further related to the IoST device. Some of the applications are listed as follows (Figure 1).

- **Habitability and Colonization:** Ever since humans were able to identify stars and planets in the night sky, there has been lingering curiosity with respect to the presence of life in space bodies other than the earth. In recent years, space technology has identified several exoplanets (Priyadarshini and Puri, 2021). Some of the planets orbiting their host stars could be potentially habitable. The presence of life is often detected by elements like water, carbon, nitrogen, phosphorus, sulfur, etc. Hence for identifying potentially habitable planets, it is necessary to gather data from the planets. Space missions are known to carry the tasks of investigating the surface of planets and scrutinizing it to find elements needed for life. However, given the length of these missions, the data transmitted to the earth is not in real-time and may take as long as several hours. While this may not be a significant issue for missions carried to nearby planets like Mars and Venus, finding signs of life on distant planets and satellites and sending the information back to Earth may take a lot of time. IoST communication across devices placed in and around the solar system may reduce this time considerably. Also, information loss may be reduced significantly since cloud infrastructure involvement, but this information could be stored in multiple locations due to distributed servers. An essential application along similar lines is colonization. The possibility that settlement of other planets could decrease the likelihood of human extinction.

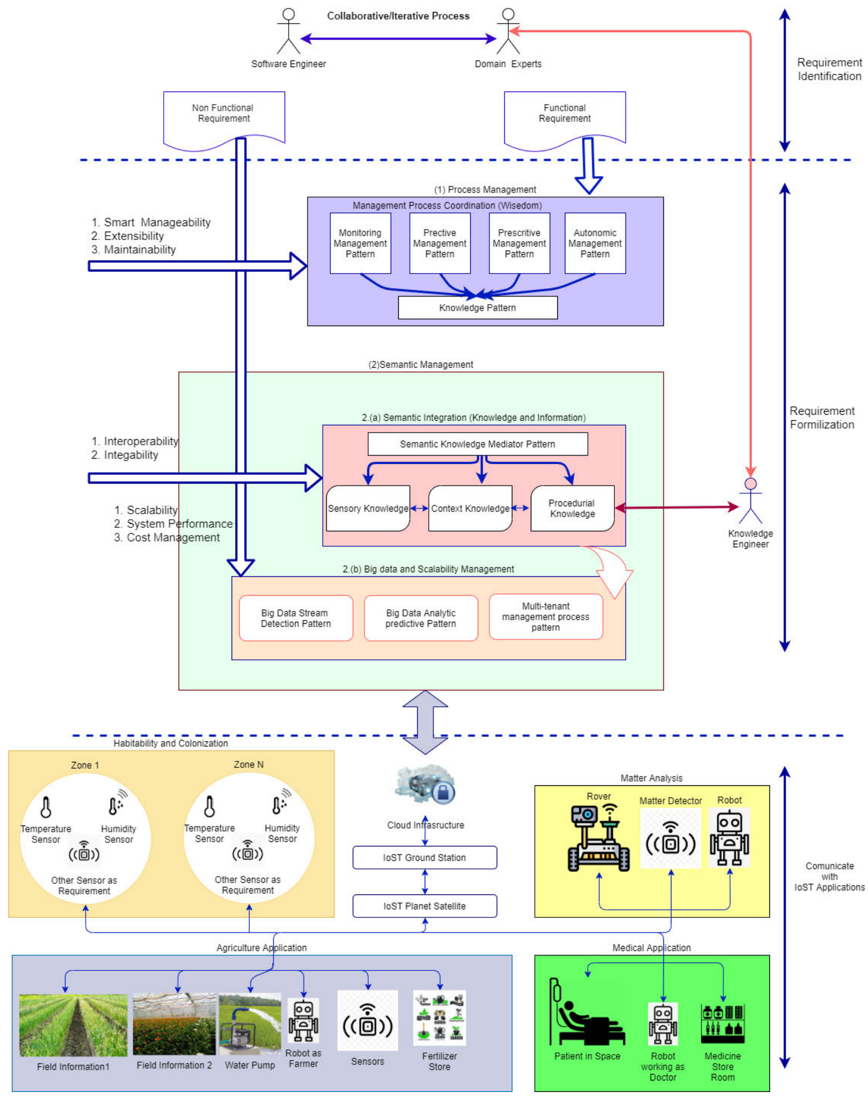

FIGURE 1. Applications of IoST.

Hence, potentially habitable planets can be terraformed to support life. Recently, SpaceX initiated the SpaceX Mars program, which aims at colonizing Mars. Rovers and drones inhabit the planet and gather data concerning climate, weather, humidity, temperature, soil toxicology, etc. While several research articles in the past give a brief account of the planet's surface (Priyadarshini and Puri, 2021), the communication between the planets is not performed in real-time, and there is a slight delay in information relay between the planets. IoST can improvise that significantly.

- **Agriculture:** Space farming has been one of the most challenging tasks. Whether growing plants in space crafts for consumption by astronauts or introducing simple plants like algae and lichens into a planets' surface for colonization, space farming requires elements like oxygen, nitrogen, carbon dioxide, soil media, water, etc. Cultivating crops for food in space or on off-Earth celestial bodies is similar to agriculture on Earth and shares similarities with the elements needed. However, in flights, plants experience a microgravity environment.

  In contrast, for growing plants on the surface of planets, the plants would experience different gravity, although average growth is possible provided light is directional. Hence many plants grown out of Earth are significantly smaller than those grown on Earth's surface and grow slower. Deploying sensors in space stations for monitoring plant growth could identify the root causes of such issues and pave platforms for overcoming the limitations. For colonization purposes, sensors can be deployed, such that crop data could be relayed across planets. Moreover, the overall agriculture could be monitored by robot farmers. Similarly, automated water pumps could be stationed at various locations over the planet.
- **Matter analysis:** Cosmologists study large-scale properties of the universe as a whole, including material components. Outer space includes but is not limited to

plasma of hydrogen and helium, electromagnetic radiation, magnetic fields, neutrinos, dust, cosmic rays, etc. Due to the presence of so many bodies, there is a fluctuation in gravity across different parts of the universe. Gravity influences the fabric of space-time. Since the composition of matter varies across the universe, it may be necessary to identify the elements and the design. Several elements are yet to be discovered and whose discovery could be a breakthrough in space technology and research. Many of these bodies may incorporate resources that may be useful for humans. Finding alternate resources on a planet could essentially decrease issues like pollution and global warming on Earth. IoST could ensure that all this information is sent to the Earth as early as possible to take appropriate, timely actions.

- **Medical Applications:** Robot-assisted surgeries could be significantly valuable in space. Medical emergencies do not differentiate between what planet a person is on and whether the person is floating in microgravity. Since space itself is a health hazard, surgical emergencies can be expected to happen anytime. While astronauts have faced such situations before, Earth was still right below for emergency landing. However, as space research expands and humans are expected to travel beyond the International Space Station, robot-assisted surgeries will be indispensable.

  Blood behaves strangely in space, and astronauts suffer from blood clots and blood flowing slowly. This is because hydrostatic pressure on Earth keeps blood flowing inside the body, which leads to bizarre changes. A surgeon who has to operate in space without the presence of gravity is yet another challenge. Since fluids become suspended in the air, it is difficult to perform any kind of operation. This may also lead to post-surgical complications. Magnetizing surgical tools and surgical bubbles are some of the solutions offered to address the issue. However, a much more efficient way could be to introduce a robot that can perform suction, irrigation, lighting, picking up instruments, and cauterizing wounds in the bubble. With communication across devices and servers in IoST, such operations could be made much more accessible. In addition, due to the real-time transmission of data, robot-operated surgeries could be much more efficient.

IV. SYSTEM ARCHITECTURE DESIGN

This part explains an integrated communication architecture that will support the IoST for communication between end-users and devices present in the space. It is based on the communication technology of the internet and TCP/IP protocols. We provide a detailed view of the communications need and the interconnection structure between the gadgets and users. Hence the result of new infrastructure will satisfy the following problems.

1. All devices are connected through a standardized environment; hence, it is scalable.

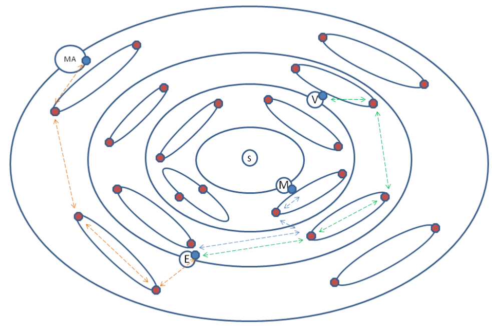

FIGURE 2. Data communication architecture to other planets.

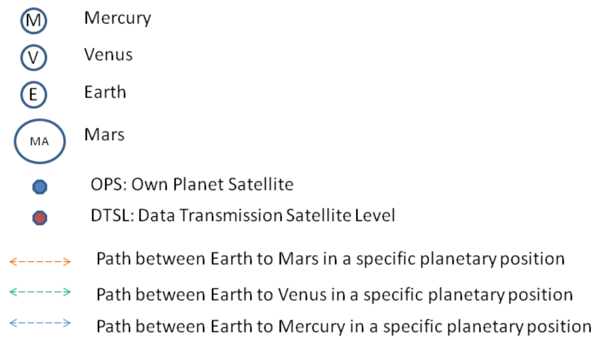

FIGURE 3. Symbol description of Figure 2.

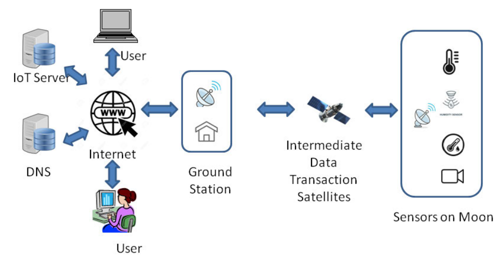

FIGURE 4. Backbone of IoST communication architecture.

2. Due to the public platform being established, the communication cost is reduced.
3. The research of all countries is focused hence the performance can be improved.
4. The concurrent satellite of different countries can be reduced; hence, it can focus on a different planet for communication.

We discuss those elements of the hypothetical IoST communication architecture that empower and strengthen the robotic and human exploration of space. Figure 2 and Figure 4 indicate the abstract model of whole communication architecture. Abstractly, suppose we explain the communication architecture using Figure 1. In that case, each planet has its satellite called Own Planet Satellite (OPS) which is pointed out in the figure using the blue filled circle. The primary function of OPS is to read the information from the planet and send it to the Data Transaction Satellite Level (DTSL), which is pointed out as a red-filled circle in Figure 2.

It means that the OPS is an intermediate communication layer between planet and DTSL. DTSLs are the intermediate communication point between earth and other planets. As per

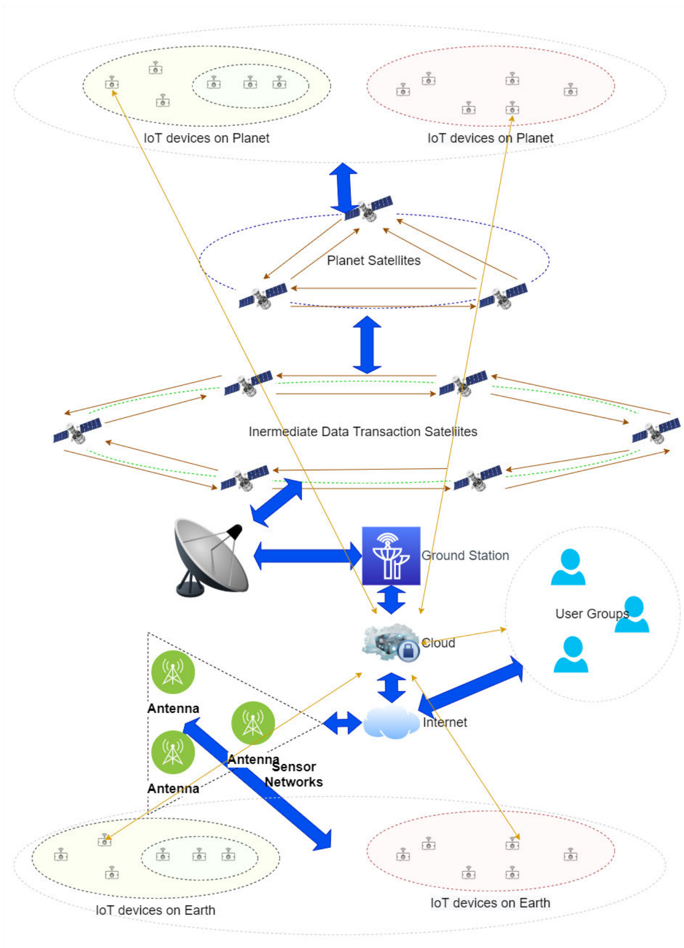

FIGURE 5. **Architecture for IoST communication.**

the instance, suppose one message sent from earth to mars then from the earth Geo station message will send to the earth satellite, again from the earth satellite message is routed using DTSL. Finally, DTSL sends the message to the OPS of mars. Red, green, and blue dotted arrows indicate the communication path between earth to the different planets mentioned in Figure 5. Figure 3 points out the explanation of all symbols used in Figure 2.

The IoST network that contains backbones indicated in Figure 4 includes the ground station of satellite (GN) and Space network called OPS Access Network and any commercial satellite system implemented to provide communication service. The ground station network's backbone also connects the internet backbone and VPN to share the information securely with users publicly. Information obtainable through the backbone network incorporates data and tasking information from sensor networks, databases, users, other space crafts, and operations centers. This information access gateway can significantly enhance the mission's science by activating the coordination of activities.

As a result, the ground network can be compatible with the space network. As per the High-level Data Link Control (HDLC), Asynchronous Transmission Mode (ATM), Digital Video Broadcasting (DVB), the protocol should be selected at the data link layer. At the network layer, IP is used for routing the information and addressing the device. TCP (Transmission Control Protocol) and UDP (User Datagram Protocols) can be used. Some standardized protocols like HTTP (Hypertext Transfer Protocol), FTP (File Transfer Protocol), SMTP (Simple Mail Transfer Protocol), NTP (Network Time Protocol) can be used for the Application layer. Moreover, further studies can be carried out regarding the application layer protocol for space communication.

Figure 5 shows the interconnection layer and the interconnection path from one layer to another layer. The Blue arrow mark pointed out the interconnection path from one layer to the above layer. The earth IoT device layer is placed at the bottom of the figure, set in an oval symbol. It mapped to all the IoT devices present on the earth. The devices may be present in the different network zones of the earth. The IoT device information is routed through the sensor network, internet and finally stored into the cloud for operation and analysis.

Cloud is the convergence point of all communication. The IoT devices present in the different planets are routed

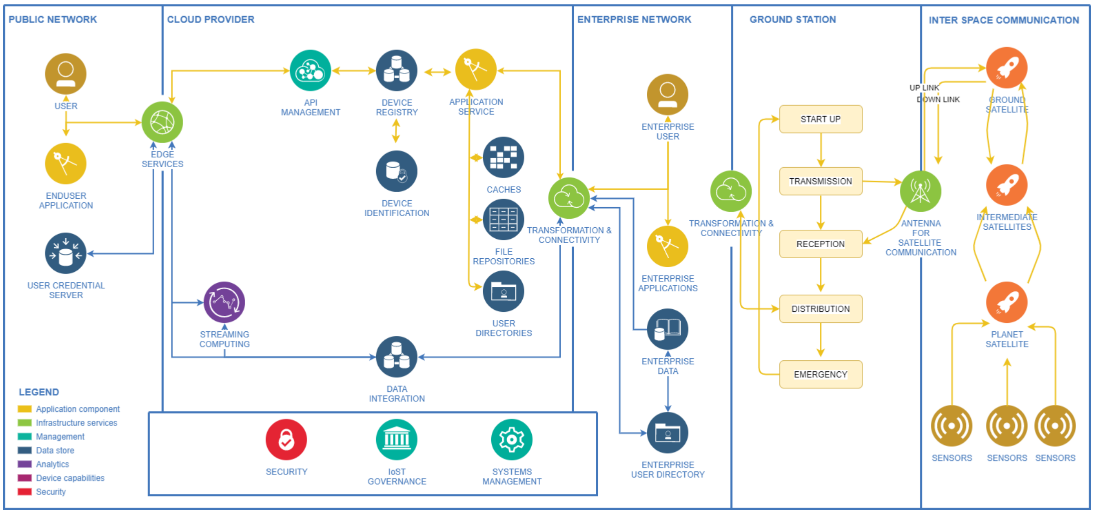

FIGURE 6. Cloud infrastructure for IoST communication.

through planet satellite and Intermediate data transmission satellite to the Ground station. Data is transmitted to the cloud from the ground station to store all the data integration and analysis for future decision-making knowledge and provide information to the user as per the user requirement. The orange arrow mark indicates the host-to-host communication. Table 2 presents all the technology and tools used in the network backbone.

V. INFRASTRUCTURE LAYER

In the year 2002, the OMNI project started investigating the data system concept for the Global Precipitation Measurement (GPM) mission to implement the IP in both ground communication and space communication. The suggested architectural concept implemented a fault-tolerant concept along with dual Ethernet LAN. It also replaces the storage concept and the device used in GPM supporting the modern operating system and file system. Our objective is that in the GPM architecture if we add the IoT architecture, it is straightforward to access the different data of the other planets. Moreover, physical architecture explains the detailed communication between the user to devices present in the space. The various aspects of IoST architecture include a public network, cloud provider, enterprise network, and ground station and interspace communication, as depicted in Figure 6.

The Cloud infrastructure diagram explains the detailed communication between the user to devices present in the space. The different aspects of IoST architecture include:

A. PUBLIC NETWORK

The public network layer includes USER, END USER APPLICATION, USER CREDENTIAL SERVER, and EDGE SERVICES. The primary function of this layer is for the interconnection of a general user or nontechnical user with IoST. The components of the public network are explained below.

- **User:** The user can interact with the IoST sensors (Sensors are placed on the planet) from a variety of different devices and systems like using a computer, smartphones, etc.
- **End-user Application:** It is an application server that contains all the device specification applications. As per the user requirement sensor placed on the space, supported applications are present in the server. In addition, all the user interfaces are also available here.
- **User Credential Server:** The user credential server contains all the registered user information. Before accessing any application of IoST, first, the user is verified using the user credential server, then the user can communicate with the IoST sensors and devices.
- **Edge Services:** Edge Services added network service capabilities and allowed processed data to transfer safely from the public network into the cloud provider and the enterprise. These functions supported by the edge services are DNS, CDN, Firewall, and Load Balancer.
- **Domain Name System Server (DNS):** It resolves the Uniform Resource Locator (URL) for particular sensor information web resources to the TCP/IP address of the receiver system from which information is transmitted.
- **Content Delivery Network (CDN):** It provides end-user applications by deploying geographically distributed servers to minimize the response time for giving resources to the user. Through this, we can achieve high availability of resources with minimum latency.
- **Firewall:** It provides an access control mechanism. It controls communication access to or from a system. For example, allowing only traffic which meets the security policy to be processed and blocking the traffic that does not meet the policy. As per the security issue, the hardware firewall can implement, or it can be implemented using the other network hardware like a router or load balancer, etc.

TABLE 2. Technology and tools used in network backbone.

Technology	Parameters	State-of-the-art	Near term	Future
Backbone network	Interconnection	User, Web server, Ground station, GEO Satellite, Transit Satellite, Planet Satellite	Existing internet backbone in the earth, Fiber Optics, Microwave	Optical smart relay (lightweight)
Communication architectures	Interoperability	Client-server architecture	Common Frequencies with IPv4 compatible protocol	IPv6 compatible
Software tools, Internet of broadband, hybrid networks	Protocol designs	TCP/IP, HTTP, FTP & ATM	Broadband tools for QoS, Commercial broadband to ISS	Sources allocation and sensor fetching
High data rate satellite network	Network design tools	Tools to large model ground communication and HDR sat. systems, traffic models, bandwidth, the allocation for multimedia, OPNET modeling of TDRSS like systems	Efficient HDR connection to ground, caching, multicasting, mirroring	Multicast catches perfecting
Software tools, modeling, simulation, and performance evaluation of hybrid networks	Design tools	Internet over satellite simulation, traffic models, ISS com. scenario, CORBA, JAVA, Python, UML to network	Algorithms and S/W for large hybrid networks and architecture trade-off analysis tools	Payload, traffic modeling and dimensioning estimation
Software IP infrastructure for distributed space system	Download and upload time occurrence	Unreliable and multiple failures due to adverse environment	Fully reliable in normal environments	Design protocols for fully reliable in adverse environment

- **Load Balancer:** The distributed network is implemented to maximize the throughput and minimize the response time load balance. It also increases the reliability and capacity of the application. It can be a balanced load locally and globally.

B. CLOUD PROVIDER

A cloud provider is a company that provides cloud computing-based services and solutions to the research organization, business environment, and individuals. In addition, this organization offers several network-related components like managed virtual hardware, software, infrastructure, and other related communication services. Usually, the IT infrastructure provided by the cloud provider is distributed in nature.

As per the business model, it provides various solutions like

- **Infrastructure as a Service (IaaS):** It may include virtual storage, virtual services, and virtual desktop computers to store the distributed information. Here we store the IoST device information placed on the earth as well as a different planet.
- **Software as a Service (SaaS):** The primary function of this type of solution is that it provides simple to complex software through the internet. It also balances the load for efficient user management of an application.
- **Platform as a Service (PaaS):** It is the combination of both SaaS and IaaS.

1) API MANAGEMENT

Application Programming Interface management or API management contains tools and a service that allows developers and companies to build, operate, analyze, and scale API in a secure environment. API management is coming under the SaaS service solution of cloud providers. On a superficial level, we can explain how an API activates communication between disparate software applications. All the IoST related API can be efficiently designed and managed here with security.

2) DEVICE REGISTRY

To connect with the IoST network first, it must be registered in the device manager of the cloud provider. Device registry containing all the registered device information. The device registry holds the following details of the device.

1. Device information and device time stamp.
2. Device identifiers IMEI number, IP Address, MAC address, etc.
3. Device metadata like serial number, manufacture information, etc.
4. Device configuration information.
5. Current status of the device.

3) WEB APPLICATION SERVERS

Web application servers provide both web server functionality and integrated application server functionality. Web Servers are the system that returns dynamically prepared information as per the user request in the form of web content and images. The communication between user and server is performed using HTTP request and HTTP response. It may be configured to handle requests from multiple IPaddress and domains.

- **Cache:** To process the user's request by the web application server, caches temporarily store information like session data and other content. The main functionality of the cache is to decrease the latency for responding to a client request.

- **File Repository:** It can be a hardware device or application used to store the information, data, etc., in the file format. The ability to store, retrieve, delete and search a particular file in a repository depends on the algorithm used for accessibility technique. It can also be used as network storage.
- **User Directory:** It stores all the credentials required to validate that the user accesses the information. The directory will be accessed by all the other integrated web components like web server, application server, databases, etc.

4) TRANSFORMATION AND CONNECTIVITY

The transformation connective is an interface component between cloud providers and enterprise networks. Its basic functionality is to make a secured connection between two layers and convert data to the compatible format. The primary function can be pointed out are

1. Secure Connectivity.
2. Scalable Messaging.
3. Scalable transformation of data from one layer to another layer.

C. ENTERPRISE NETWORK

An enterprise network consists of both virtual networks and physical networks. It realizes the user that the user is securely working on his public network. It provides some protocol through which all the users and systems present in a local area network can connect with the application in the data center and the cloud and enjoy access to network data and analysis.

Enterprise networks facilitate fast and reliable interconnectivity for the end-user and the applications. Using enterprise networks, the applications are geared up with more distribution in the modern web and reduce the networking complexity and simplified security across the wired and wireless infrastructure with the business model. It provides a single pane window for the network administrator to a monitoring data center and cloud, and it also provides some network automation frameworks for the day's network operation. The benefits of the enterprise network are

1. Increased efficiency through collaboration.
2. Provides an access control environment for company resources.
3. The productivity can be increased.
4. The network infrastructure cost can be reduced.

1) ENTERPRISE APPLICATION

An enterprise application (EA) is a massive platform for software systems to operate all space scientific organizations and provide an interface environment for business and government. EAs are distributed, scalable, complex, component-based, and mission-critical. EA software integrated with a set of programs with shared space application and organized modeling utilities. All the applications of EAs are based on enterprise architecture. It ultimately enhances efficiency and productivity through space-level support functionality.

EA software services include sending commands to the space for getting information, receiving information from space, all the satellite orbit information, the weather condition of space, etc.

2) ENTERPRISE DATA

Enterprise data is the information shared by the ground station using distribution function, generally across planets and space regions. If enterprise data loses, it can significantly lose for all the space research centers and the business related to space; hence, be very careful regarding the design of the data modeling, solution, security, and storage.

Enterprise data can be subdivided into two categories. Internal and external data categories are classified according to space research organization and lab, outer user, business user, and government. The characteristics of enterprise data are

1. Integration ensures that a single consistent version of data.
2. The data is shared by multiple different categories of users, data redundancy and disparity must be minimized.
3. The data quality should be maintained.
4. Data should be scalable, robust, and flexible to meet different organization requirements.
5. Data should be secured using authorized and controlled access.

3) ENTERPRISE USER DIRECTORY

It is a software system that stores, organizes, and manages access to the directory information to unify the network resources or bind them into one unit. It maps the network resources name to address and define a naming structure of networks. It provides a clear-cut picture of protocol and network topology. Finally, it permits the user to access the resources without knowing the device's physical location.

4) ENTERPRISE USER

All the organizations and users are involved in accessing the IoST are one enterprise user.

D. GROUND STATION

The ground station is an intermediate gateway between the enterprise network and the ground satellite. To better explain the ground station, we use a case study of N66, a satellite communication provider present in Lulea, Sweden. This company gives a new reliable communication above 660N latitude in a data rate of 10Mbps to the user. The workflow of the ground station is divided into several tasks and subtasks. The explanation of each subtask provides a clear idea about the function of the ground station.

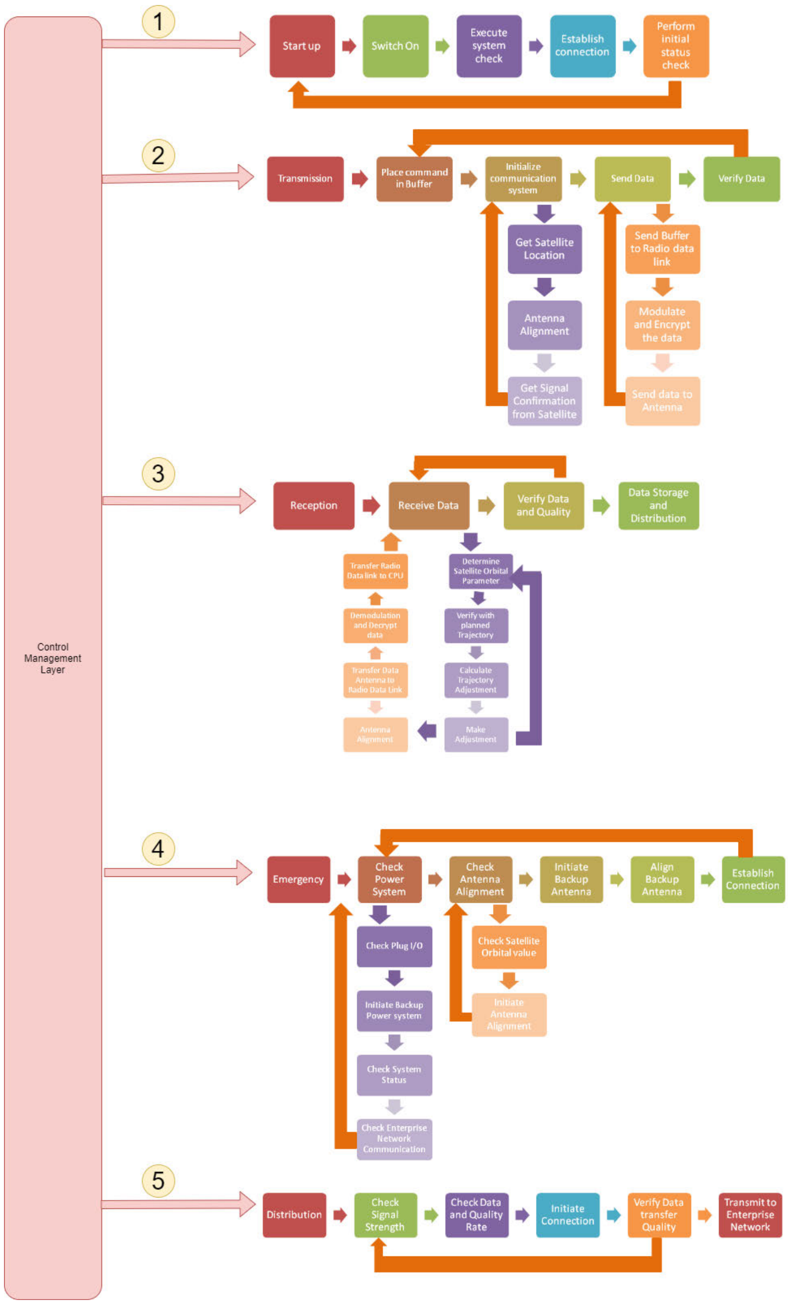

FIGURE 7. Flow diagram of control and management layer.

VI. CONTROL AND MANAGEMENT LAYER

Interconnectivity is the essential feature of IoST as it is the key to developing a connected world even beyond Earth. If devices across space could communicate, there could be endless possibilities for developers. However, there is a lack of seamless interoperability even in the basic IoTs, and interoperability allows communication between devices. Also, the compatibility of IoST devices must be taken into account due to varying controls. This section explains some controlling techniques and phases through which cloud platforms communicated with the satellite present in the different planets.

A. STARTUP FUNCTION

The basic idea in the startup function, initialize the communication system. First, it resets the communication devices then executes the system check operation. The system check operation verifies all the communicated systems whether it is working perfectly or not. Then it establishes a connection between the ground stations to the satellite and sends an acknowledgment. If the acknowledgment is received correctly, then it checks the initial status and activates the transmission task. The flow diagram of the startup function is explained in Figure 7.

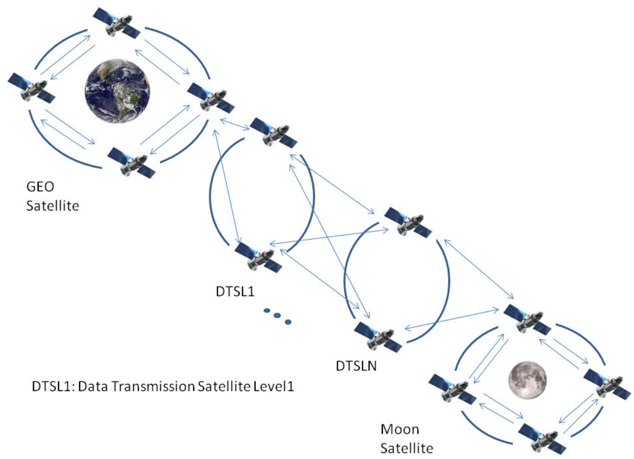

FIGURE 8. DTSL Interspace network communication.

B. TRANSMISSION

Using the Transmission function, the signal is sent from the ground station to the satellite. At the time of the sending signal first, the command is put in the command buffer. After putting the command into the buffer, the communication system is initialized. At the time of the initialization of the communication system, the first ground station gets the satellite location. After that, it aligned the antenna as per the satellite location and then got the satellite's confirmation message. By getting the confirmation message, the initialization of the communication system task is finished.

The next task of this phase is to send the data. The first ground station sends data from the command buffer to the radio data link in this task. After that, the signal modulation process is carried out. The modulation process for transmitting data in long-distance data-frequency is added with a carrier frequency and encrypted signal for security. Then it sends to the ground satellite through the antenna. After completing the sending process, it waits for the acknowledgment from the satellite to end the transmission task. The flow diagram of the transmission function is given in Figure 7.

C. RECEPTION FUNCTION

The main objective of the reception function is to receive data from the satellite. In the data reception function first, the satellite orbital parameter is determined and verifies the satellite's trajectory (Trajectory is the curved path of a satellite). If any error value is created, then it calculates the adjustment value of the trajectory and adjusts. After the adjustment procedure is completed, the receiver antenna is aligned to receive the signal from the satellite. From the antenna, data is transmitted to the CPU through the radio link. Then, the radio link signal is demodulated and decrypted. Finally, from the CPU, information is sent to storage and distribution. The flow diagram of the reception function is explained in Figure 7.

D. DISTRIBUTION

In the distribution process, the information received from the satellite is shared with the intended user through the ground station to the enterprise network and cloud provider. First, it checks the communication signal strength. After that, it checks the data and quality rate for errorless communication and verifies data transfer quality. After all the verification process is completed, then it transmits to the enterprise network. The flow diagram of the distribution process is given in Figure 7.

E. EMERGENCY

In the emergency process, it checks all the parts of the communication system. First, it checks the power system. The power system checking procedure checks all the connected I/O systems. After that, it takes the backup of all the initial executed operations and checks the system's status whether all devices are communicated perfectly or not. The second phase of the emergency procedure is to check the antenna alignment. For the alignment of the antenna first, the satellite orbit value is calculated, the antenna aligned as per the orbital value of the satellite. Then the initial backup is taken from an antenna, and the antenna aligned procedure is completed. Lastly, it establishes the connection with the satellite. Figure 7 explains the flow diagram of the emergency function.

F. ANTENNA

It is used to transmit the signal from the ground station to the earth satellite. Mainly antennas are used in wireless communication. Minimum two antennas are used for communication. One antenna is used to send the signal called an uplink, and another antenna is used to receive the signal called a downlink. Thus, there are two different types of antenna used for communication.

- **Parabolic Antenna:** The parabolic antenna consists of a curved parabolic reflector to receive the signal. The reflector reflects all the signals to appoint a focal point. The antenna will be aligned to a proper direction as per the satellite present in orbit to receive or send the signal.
- **Antenna Array:** It is a set of multiple connected antennas combined and used as a single antenna.

G. INTERSPACE COMMUNICATION

The function of the interspace communication layer is to communicate between ground station antennas to devices present in space and on different planets. The components of interspace communication are Ground Satellite, Intermediate satellite, and Planet Satellite.

- **Ground Satellite:** The Ground Satellite communication system is called here OPS Access Network. Microwave is used to communicate between a ground station and satellite named OPS Access Network. It contains the remote access modem, Antenna. Transceiver unit, In this layer, the sending information is transmitted from the

TABLE 3. Access link technologies.

Technology	Parameters	State-of-the-art	Near term	Future
Software protocol, modules, space data direct delivery to multiple clients	Multicast delivery techniques	Unsecured GEO broadcast Without acknowledgment	Unsecured, minimum number of clients	Secured, maximum number of clients
Hardware and protocol software	S/C NIC, HUB, router activities	Fastest routers which can deliver 100Gbps trunk speeds	Should be TCP/IP compatible	
Traffic management	Access control	Tier1 ISP, Tier2 ISP, Tier3 ISP	Different levels of access restriction	
Internet exchange point (IXP)	Peering points of one network to another network	Communicate between different country satellite to plane	Transit agreement	
Core network	LAN and subnetworks	Aggregation, authentication, call control/switching, charging, service invocation, gateways	It provides a path for the exchange of information between different LAN	Advanced efficient routing algorithm

GEO station to its satellite placed on the planet orbit. Each satellite communicates with other satellites using ring topology. Previously lots of research works have been conducted for satellite communication. As a result, the advanced and fastest signal transmission technology is implemented, for which the space communication performance can be improved. Still, the data is transmitted in a TCP/IP packet to communicate consistently (Table 3).

- **Intermediate Satellite:** Intermediate Satellite communication system is called here DTSL Interspace network. For communication from earth's satellite to another planet is displayed in Figure 8. Circular flying satellite clusters are created between two planets per the distance between two planets and the signal range. In a cluster, each satellite is connected with another satellite using ring topology, and each cluster is associated with another cluster using mesh topology.

  The number of clusters is called the level to communicate with the other planet. As a result of implementing mesh topology, the data transmission error can be reduced, and the speed of data transmission can be increased. As per the amount of data transmitted, we can design our cluster. Hence, it is scalable by adding one new satellite in each cluster to increase the data communication speed. Each intermediate satellite is enabled with the edge computing device. The detailed processing architecture of each satellite is explained in future work. In figure 8 'E' is denoted as Edge computing device and 'C' is denoted as cloud computing device.
- **Planet Satellite:** The primary function of a planet satellite is to communicate with the device and sensors present in the different planets. Planet satellites are placed in the orbit of distant planets. It provides a gateway to communicate between the intermediate satellite and gadget present on the other planet.

It should be noted that algorithm for inter routing between one router to another router is explained bellow.

In Algorithm 1 consider first the root node is the sender node which tried to send the message packet. Initial Dx = ∞, it means that there is no neighbor of the root node. Check all the link node 'l' which are adjacent to *R* and add the cost

Algorithm 1 For the Link Between Router to Other Router

$\boldsymbol{R} = \{\boldsymbol{T}\}$ *//T is a root node*
for *all nodes* ***l // l is the all the nodes in the network***
if l *adjacent to* ***R*** *then*
  $D(\boldsymbol{l}) = c(\boldsymbol{A}, \boldsymbol{l})$
else
  $D(\boldsymbol{l}) = \infty$
for *each node* ***R***
for *all endnode* ***e*** *in* ***R***:
  $\boldsymbol{Dx(e) = c(x,e)}$ // *if* ***e*** *is not neighbour* $\boldsymbol{c}(\boldsymbol{x}, \boldsymbol{e}) = \infty$
for *each neighbour* ***x***
  $\boldsymbol{Dx(y) = fd}$ *//**fd** is for all destination in* ***R***
for *each neighbour* ***x***
  stored distance vector ***Dx*** = [***Dx(e): e*** *in* ***R***] *to* ***x***
while(1)
  wait *(Until Dx ! = NULL)*
  for *each* ***a*** *in* ***Dx***
    Dx(a) = minv{c(l,e) + Dv(e)}
  Send Dx
End while

into the vector. If 'l' is not the link node then put ∞ in the vector. The least cost can be calculated use Bellman-Ford equation, Dx(a) = *minv*(c(l,e) + Dv(e)), in which the *minv* can be calculated by taking all 'l' neighbors, and send the distance vector for message transmission.

VII. SYSTEM PROCEDURES

For achieving traditional message communication, the message is transmitted in the client's packet within the network and obeys the seven-layer of the OSI model, as depicted in Figure 13. Hence, the whole IoST network from earth to another planet can be communicated using a unified protocol popularly known as IP protocol. At the end of the communication or host side, all seven layers are processed. For example, in the communication Application, Presentation, Session, and Transport layers communicated host to host. That means this four-layer is only processed at the end-host part. The first three layers are called the lower layer and communicated point to point. Point to point means the three layers are evaluated in each communicating device.

For example, when the packet is transmitted through a router, it is processed from the physical layer to the network layer. It finds the shortest and congestion-free route for

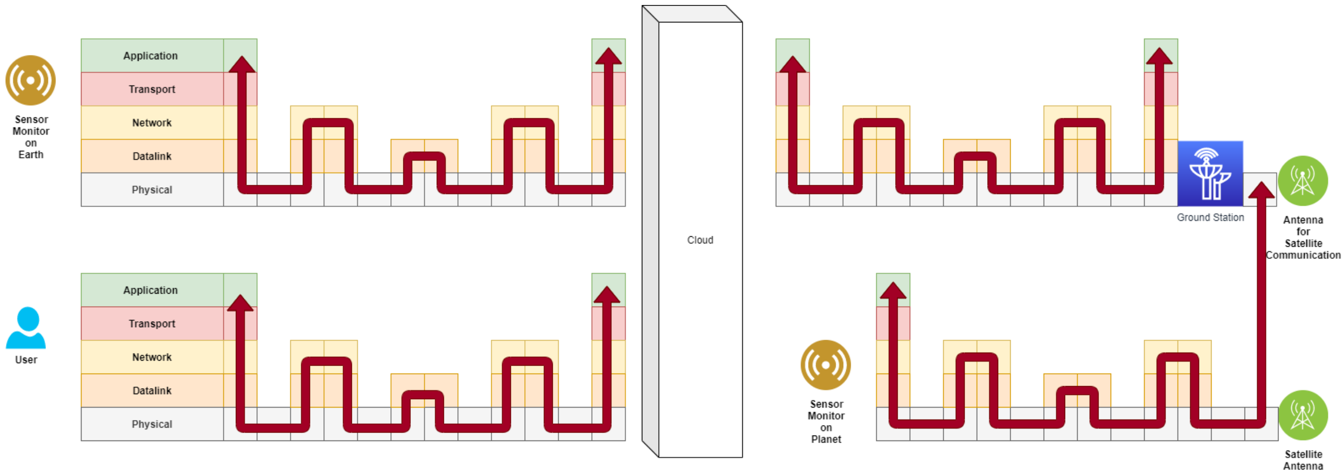

FIGURE 9. OSI reference model compatibility communication.

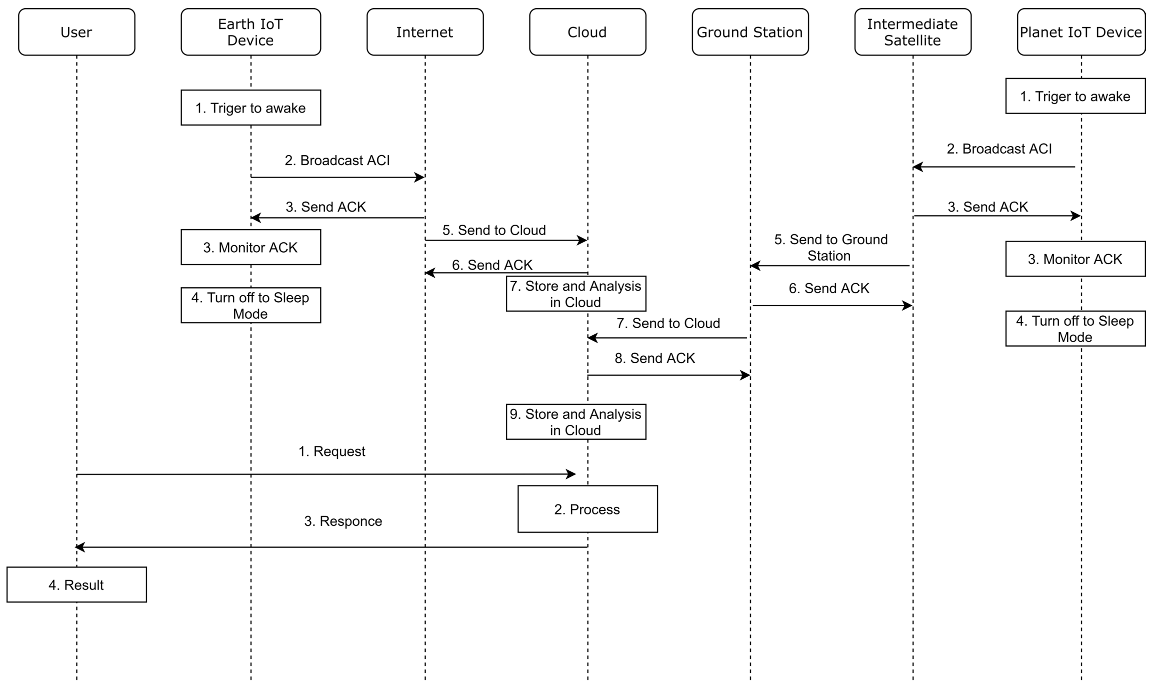

FIGURE 10. State transition diagram of the communication.

communication. But when the packet is transmitted through a bridge, it simply evaluates the first two layers, the physical and data link layers. In the case of a repeater which is used for solving the attenuation problem only works on the physical layer. Figure 9 explains the communication using the OSI reference model and the evaluation of each layer for the proposed architecture.

The IoT traffic is complicated and complex because the number of interconnected devices through the IoT network is enormous. Also, the coverage network is very high. Hence the attenuation problem and traffic problem should be adequately cared for. Explaining all the attenuation problems and traffic problems will not be possible in this scope. Therefore a separate section is required, which may also encompass future work. This subsection explained the data flow state, which is depicted in Figure 10.

Every IoT device is a trigger that activates the device for data communication. The trigger may be hardware, software, or user trigger. After activating the trigger, the earth IoT device sends the array of control information (ACI) to the Internet through a sensor network and waiting for an acknowledgment (ACK). If ACK is received successfully, it terminates the communication and puts the device into sleep mode. If ACK is not received, it transmits again and waits for ACK. Through the internet, as the information gets transferred to the cloud, reformatting takes place. Scoring and analysis are explained in the above section.

In the case of IoT devices present on the other planet, all the operations are performed the same as the earth IoT device transmission. Still, the difference is that it is routed through the intermediate satellite network rather than the sensor network. From the planet, IoT device information is transmitted to the ground station explained in the section. Data is sent to the cloud from the ground station, and the cloud prepares the report for future operation. Users interact with the cloud to get different information related to the registered IoT devices. The authentication procedure and security of the communication is the future work for the proposed architecture.

VIII. CONCLUSION AND FUTURE WORK

IoT has become an integral part of society due to its comfort level to humanity. From devices as small as smartwatches to devices as big as smart cars, IoT has left no stone unturned in providing humans with utmost comfortability. As technology combines several fields, IoT has found its use in many areas in IoMT, IoHT, IoRT, IoNT, etc. However, many such applications of IoT are yet to be established and discovered, which would add billions of devices to the network. One such area that is yet to incorporate IoT device communication is Space Technology.

The concept of IoST extends communication beyond Earth, such that the devices in outer space and other planets can communicate with each other and send information back to Earth. Given that space, research has opened its wings, and significant targets and deadlines are being discussed, ranging from Mars colonization to cellular network setup on the Moon, it is imperative to dedicate a platform for space-related IoT communication.

In this paper, we have introduced the novel concept of IoST and suggested a detailed architecture for the same. The components of the architecture have been discussed comprehensively concerning the infrastructure, devices, and communication. The paper also discusses several critical space-related applications that can be carried out efficiently with IoST. Some of these applications are analyzing space, robot-assisted surgery in microgravity, and space farming. Finally, we also discuss the challenges that may come up while designing the infrastructure and present the possible solutions.

In the future, we would like to explore more such applications in detail and identify the solutions to the same. While IoST setup at the nascent stage may be limited to nearby objects in space, it may be possible to devise strategies to extend the framework for better exploration beyond nearby objects in space. If deployed successfully, the infrastructure would be a breakthrough for space research as the universe's composition could be analyzed more deeply.

TABLE OF ACRONYMS

Acronym	Term
IoT	Internet of Things
IoST	Internet of Space Things
IP	Internet Protocol
IoAT	Internet of Agricultural Things
IoHT	Internet of Healthcare Things
IoMT	Internet of Medical Things
IoNT	Internet of Nano Things
IoRT	Internet of Robotic Things
IoDT	Internet of Drone Things
IoUT	Internet of Underwater Things
BIoT	Blockchain and IoT
SIoT	Social IoT
GIoT	Green IoT
SIoT	Satellite IoT
OPS	Own Planet Satellite
DTSL	Data Transaction Satellite Level
TCP/IP	Transmission Control Protocol/Internet Protocol
GN	Ground Station
VPN	Virtual Private Network
HDLC	High-level Data Link Control
DVB	Digital Video Broadcasting
ATM	Asynchronous Transmission Mode
UDP	User Datagram Protocol
TCP	Transmission Control Protocol
HTTP	Hypertext Transfer Protocol
SMTP	Simple Mail Transfer Protocol
FTP	File Transfer Protocol
NTP	Network Time Protocol
GPM	Global Precipitation Measurement
DNS	Domain Name System
CDN	Content Delivery Network
EA	Enterprise Application
DLP	Data Loss Prevention
API	Application Programming Interface
IaaS	Infrastructure as a Service
SaaS	Software as a Service
PaaS	Platform as a Service
ACK	Acknowledgment
OSI Model	Open Systems Interconnection Model
MSO	Mars Synchronous Orbit
MHO	Mars High Orbit
MLO	Mars Low Orbit
GEO	Geosynchronous Earth Orbit
HEO	High Earth Orbit
MEO	Medium Earth Orbit
LEO	Low Earth Orbit

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