Research Article

Review of Satellite based Internet of Things and Applications

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Abstract: The world has been witnessing a significant growth in the field of Internet of Things (IoT), associated technologies and applications. This emerging technology promises solutions to several existing and futuristic applications. These smart objects having their own 'identity' can communicate in large numbers over the network for multiple applications. Different geographical locations are covered with different levels of IoT sensors. For a much wider and global coverage, where the topographical complexities are very high, and access is difficult, space-based platforms are extremely useful. This paper reviews some of the works on use of satellites for Internet of things (SIoT) for delay sensitive and delay tolerant applications. The advantages of Low Earth Orbit (LEO) satellites over the Geostationary Earth Orbit (GEO) satellites and usefulness of LEO satellite constellations supplemented with terrestrial communication networks are discussed. Several applications including mission critical and military applications are also covered.

Keywords: Internet of Things (IoT), Internet of Remote Things (IoRT), Satellite for IoT, Space based IoT (SIoT), LEO satellite constellation

1. Introduction

The Internet of Things (IoT) is a system where many physical objects having an IP address are connected through internet, so that they can collect and exchange information without manual intervention. As shown in Fig.1, these 'things' could be an environment monitoring sensor, an automobile with sensors, house-hold electrical appliance, an actuator etc. IoT uses several types of sensors depending on the applications for interconnecting them together. This enables the information exchange between living and non-living things. It is estimated that such everyday life 'things' could be soon numbering in tens of billions which need to be connected using Low Power Wide Area Networks (LPWAN). This facilitates innumerable applications in multiple domains and has become an important aspect of modern and digitally connected ecosystem [1], [2].

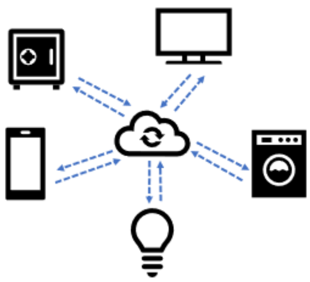

Fig. 1. Basic idea of Internet of Things (IoT)

In the IoT system, large number of heterogeneous networks having different user data are integrated seamlessly using appropriate protocol stacks. IoT is proving to be a universal technology for many existing and newer applications. The IoT is gaining momentum exponentially due to technological advancements in wireless networks. IoT is getting integrated into our daily life and will have a significant influence on our society. The essential elements of IoT are the 'thing' or the sensing device with its own identity in the form of IP address, the gateway where the communications between the sensors are gathered and routed, the cloud where the data is stored, the analysis that does the data processing and finally the user interface. These are described in Fig. 2 [3].

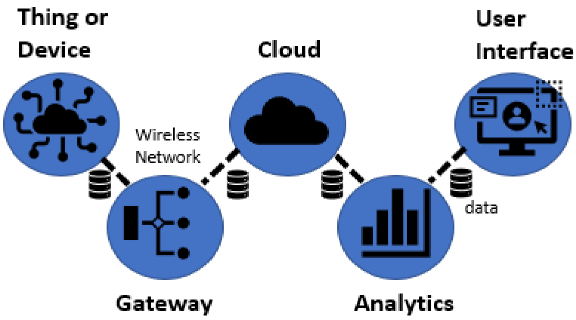

Fig. 2. Major components of IoT [3]

With the advancement of communication and networking technologies, the IoT systems can be classified based on the networks deployed as shown in Fig. 3 [4].

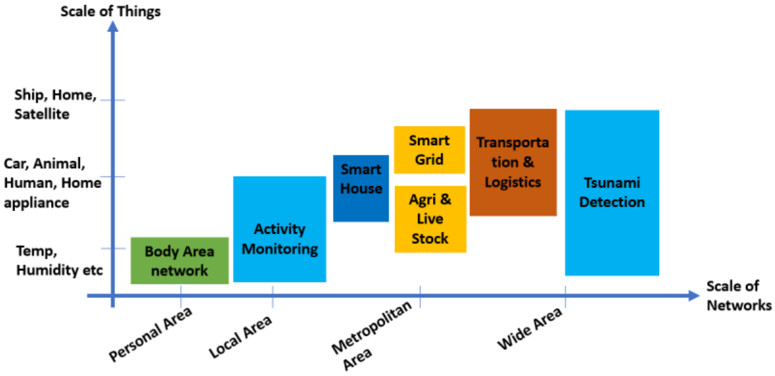

Fig. 3. IoT system classification based on networking technologies [4]

Different wireless networking technologies are deployed in the IoT domain [5]. ZigBee, the open packet-based protocol, is the popular wireless mesh networking standard. Sigfox is the French wireless technology with a range of 10-40 kms and 140 messages per day transmission capability, NB-IoT is the narrow band technology deployed inside an LTE carrier. LoRa (Long Range) is a low power, machine to machine, long range wireless technology. Table I provides the additional details for each of these sensor network technologies.

TABLE I. COMPARISON OF WIRELESS SENSOR NETWORK TECHNOLOGIES [5]

Ref	IoT Technology	Range, uplink-downlink data rate	Licensing Requirement	Traffic capacity
[12], [13], [14], [17]	ZigBee (IEEE 802.15.4)	10m indoor, 100m outdoor, 250kbps	Unlicensed spectrum	----
	LoRa	5km urban, 15km semiurban, 20km rural, 50kbps	Unlicensed spectrum	150K to 1.5 M packets per day depending on payload size, coding rate, symbol rate
	Sigfox	10km urban, 40km rural, 600 bps	Cellular like, unlicensed spectrum	3 times bigger than LoRa capacity
	NB-IoT	35kms 200kbps downlink and 20kbps uplink	Licensed frequency band	----

There are wide range of fields of the new applications of IoT such as energy efficiency, industrial processes, remote assistance, environment monitoring and eco-sustainability [6]. Table II provides the details of the application and devices involved.

TABLE II. IOT SERVICES, APPLICATIONS AND DEVICES

Ref	Service sector	Application group	Location	Devices

[6], [16]	Health	Home care, Public care	Home, Hospitals	Medical Equipment
	Industrial	Process control, automation	Manufacturing plant	Valves, Motors, Pumps
	Energy	Generation and distribution	Power grid, Solar power plants, Wind power plants	Power meters, Turbines, Windmill, Batteries, UPS
	Buildings	Industrial, Institutional, Commercial	School, Office, Airport, Hospital, Stadium	Fire safety tools, Lighting
	Transportation	Maritime, Aeronautical	Road, Air, Sea, Rail	Airplanes, Ships, Cars, Traffic lights, toll booth
	Retail	Stores, Hospitality	Cinema, Fuel station,	Vending machines, Tags

2. Need for Space based IoT

Though satellites and IoTs are two different entities and systems, their pairing has been possible due to the communication between the two. In the IoT domain, the data is gathered from sensors and control messages are sent to the actuators. In several applications, the sensors and actuators are spread over a large area and in certain cases, they are located remotely where the access to the terrestrial networks is not available. As a result of this, the communications becomes viable using the satellites for the Internet of Remote Things (IoRT) as shown in Fig. 4 [6].Thus, the IoRT coupled with the use of satellites can also be classified as SIoT, which is divided into (1) space segment (2) user segment and (3) ground segment.

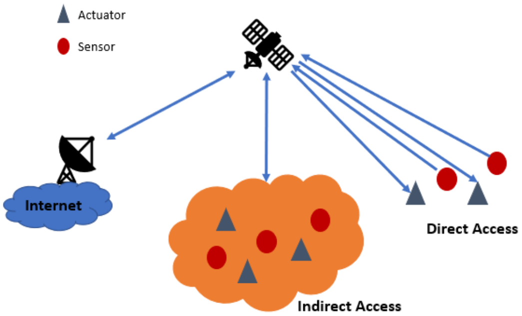

Fig. 4. Satellite based Internet of Remote things (IoRT) [6]

Some of the advantages of satellite based IoT (SIoT) are as follows. (1) In extremely remote topographies like steep slope, mountains, valley where the terrestrial networks are not viable and where geological disasters are a possibility, the SIoT offers tremendous advantages. (2) SIoT becomes cost efficient solution compared to terrestrial networks in many remote areas. (3) SIoT can be the only supplementing (and in many cases, redundant) option for terrestrial IoT to achieve global coverage. (4) Where there is a need to groupthe smart objects for a given task, for information exchange, the network operators must optimize the data volume when the grouped devices must receive the messages. In such cases, the SIoT system can support better. (5) The transmission data rate in IoT domain is low, the low bandwidth satellite can be very effectively used. (6) With the lifespan of satellites increasing, the SIoT offer additional advantages of extended availability of service, superior reliability, wider coverage, remote control of resources, speedier operations, easier integration, and lower costs. (7) The SIoT can be extremely useful and critical during the emergency and combat times and hence become essential for military applications [1], [6], [7], [8].

The satellite in a SIoT system can be a Geo-Stationary Orbit (GEO) or Low Earth Orbit (LEO) satellite constellation. The LEO SIoT has the following advantages compared to the GEO systems. (1) Extreme topographies bring constraints on the Geo-SIoT due to the static positions between GEO satellite and terminals. Any obstacle in the path between the satellite and the terminal, both of which are relatively stationary, will result in the loss of communication, whereas the LEO satellites are moving relative to the terminals. (2) LEO SIoT can manage with the terminals having smaller size, lower power consumption with better performance due to lesser signal loss. (3) The propagation delay (round trip delay) of LEO is almost one sixth of GEO and hence LEO-SIoT performs more efficiently.

The LEO SIoT can be further broadly classified into the following two categories [1], [15].

Delay Tolerant Applications (DTA): Applications such as forecasting and water temperature, tide, and pollution monitoring, where the frequent and prolonged disconnections and longer propagation delays do not affect the performance. These DTAs that use IoT devices, when applied for remote locations or widespread locations, satellites become most useful. Hence such applications are categorized as delay tolerant SIoT (DT-SIoT).

Delay Sensitive Applications (DSA): Applications like Military, Current grid where the stringent requirements of lower latency and higher reliability are critical for the performance. When such applications where non-accessible areas are managed using satellites, we categorize them as delay sensitive SIoT (DS-SIoT).

In addition to satellites, the space platforms such as Unmanned Aerial Vehicles (UAV), Airships and High-Altitude Platforms (HAP) form an important part of the Space Information Networks (SINs). With their ability to provide wider coverage, the SINs support many applications in SIoT domain. Fig. 5 gives the details of altitude versus different space platforms and their applications [9].

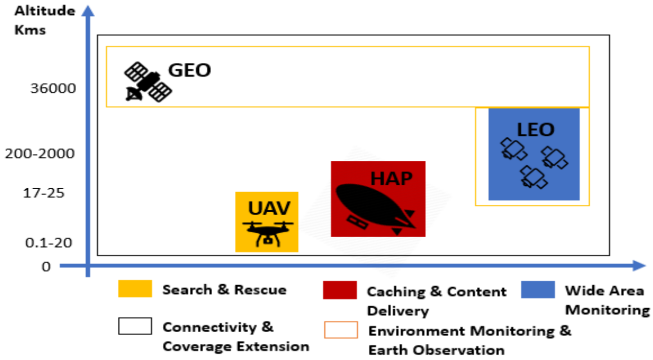

Fig. 5. Altitude v/s Space platforms and their applications [9]

3. Applications of Space based IoT

There are many applications of SIoT as shown in Fig. 6. In this section, we select representative applications where the satellite use is important and critical for the successful performance and for reaping the benefits. Some of these applications are currently existing and others are futuristic.

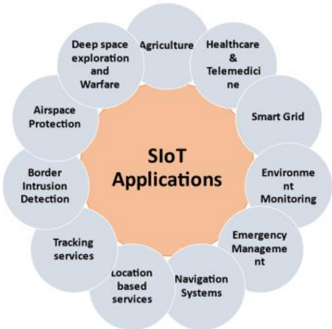

Fig. 6. SIoT applications

A. Agriculture

Farmers and technologists are continuously working towards increasing the crop yields. The SIoT can help the farmers for precision farming, by providing guidance on improving their yields. This is achieved by gathering the crucial parameters like temperature, soil moisture, water content and others and satellite backhaul can help the data get processed at the processing center. Fig 7. Explains this smart agriculture application using SIoT [10], [11].

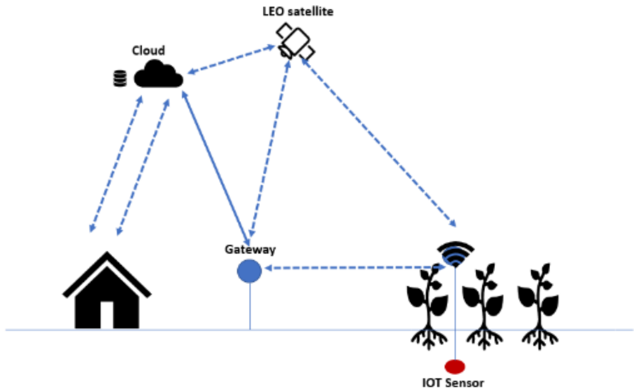

Fig. 7. SIoT based smart agriculture.

The advantage of Satellite based IoT systems for Agriculture are the high spatial resolution which enables to extract extensive data [17]. Large area imaging is also covered in this method. The disadvantage of this SIoT application are the higher cost, revisiting time of the satellites and the sensitivity to the weather conditions.Precision Agriculture, where the harvest is increased by proper feeding of resources to the plants also uses SIoT. The data collected from satellite is used to provide the spatial variability [18]. Satellite based monitoring of irrigation water is also an interesting application. For sustainable water management, the reliable accounting of water is critical. In many regions worldwide, the metering of irrigation is limited. Satellite based solution can fill the wide gaps in monitoring the irrigation water. Remote sensing using satellites significantly improves agriculture water monitoring that helps regulation, planning and management [19].

B. Healthcare and Telemedicine

Not too long ago, the diagnosis of a patient was possible only after a physical analysis in the hospital. Using the SIoT, health parameters of a patient can be remotely gathered for premedical treatment, prior to the individual arriving at the hospital. This remote health monitoring application can be very useful even at places where there is no cellular network [10], [11], [20]. The advent of IoT has transformed the hospital-centric system to a patient-centric system. This is possible with the help of smart watches and clinical analysis like blood sugar, blood pressure and saturation oxygen levels being done at home.

C. Smart Grid

The main objective of the smart grid is to have a low-carbon society. For this, there is a need for bidirectional information flow amongst multiple elements of the system. These could be automated monitoring systems, smart meters, and power measurement system. The gird becomes smart once the power generation, transmission, distribution, and consumption are measured and the system can react and adapt to the situations as shown in Fig. 8 [6].

Satellite in this application can help gather information related to the offshore wind farms or solar systems in deserts. This helps in automatic control of substations located in remote areas. This is a delay sensitive application SIoT (DS-SIoT) application [1].

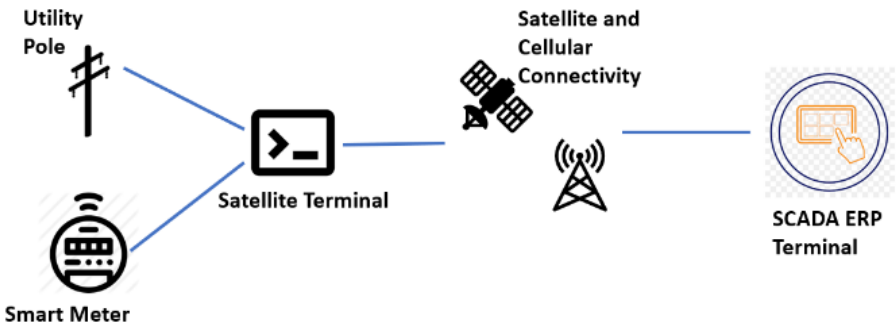

Fig. 8. DS-SIoT based smart grid.

D. Environment Monitoring

This application is intended to enhance the quality of the environment where we live. With the monitoring of air and water pollution, wildlife position, forest fires, floods, earthquakes, cyclones, hurricanes, landslides, and avalanches, the SIoT system helps faster detection [6].

Smart cities services depend on huge data gathered by sensors, connected devices and social applications. In these scenario, integration of satellite is important for data gathering, since the terrestrial communication will have limitations on reliability in environmentally harsh areas like mountains, countryside, and seas. Sometimes this SIoT application may face disadvantages like the inability of the sensors to communicate with the satellite due to the presence of local obstacles preventing satellite line of sight communication [21]. In this application, tremendous volumes of data are generated by IoT and necessitate “big data” referring to the new architectures and topologies for data management [22], [24].

The Industrial advancement has impacted on the ecological balance and natural resources. This has resulted in the use of smart sensors in IoT with increased interest in the Industry 4.0 era [23]. The collection and processing of massive data particularly in danger zones and mountainous areas, is effectively done by SIoT. Dangerous factories like chemical plants are generally installed in areas where the communication infrastructure is not good. In such cases, the data collected by IoTs are delivered to the satellite through the base stations.

E. Navigation and Maritime Systems

Using the SIoT, the navigation systems receive exact information relating to their surroundings both in air and water [10], [11]. In the recent years, the maritime communication is helping the modernization of maritime mobile services with techniques like Automatic Identification System (AIS) that provides identification of the ships and reporting and tracking of their position [25].

Maritime SIoT service covers the Search and Rescue (SAR) that enables link between the rescue coordination center and the ships. SIoT helps precision piloting to passing ships in the dangerous coastlines, hazardous shoals, and reefs. Ship locating, container tracking that helps geo-locating a particular container in the ship and other such advantageous applications lead to the concept of autonomous shipping.

With maritime SIoT, the huge amount of data coming from various sources can generate different applications using technologies like artificial intelligence, big data and block chain provides actionable intelligence for making data driven decisions. This SIoT is also expected play a dominant role in the meteorological and oceanographic information gathering using the maritime sensors [25].

F. Tracking Systems

Tracking of the transportation and delivery in logistics area, planes tracking for their safety and navigation, animal tracking to avoid their theft, kids tracking by parents for their safety and security, police tracking the criminals and other such applications use SIoT [10], [11]. Fig. 9 describes SIOT tracking.

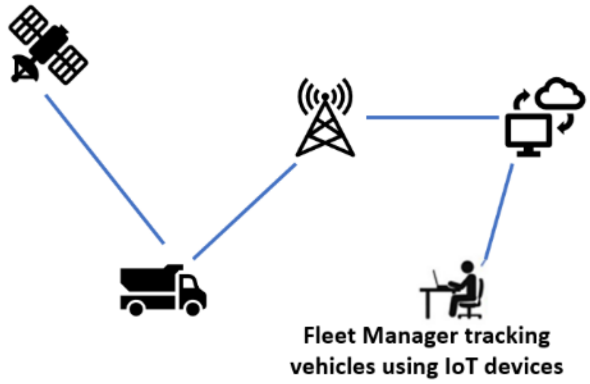

Fig. 9. SIoT based tracking systems in Logistics application.

G. Emergency Management

Terror attacks, explosions, fire, flood, and earthquakes generally lead to emergency situations. These necessitate the intervention of authorities who manage the emergency response system. SIoT system helps in gathering the data from different sensors and IoT devices deployed in different parts [6].

H. Location based services.

In a connected living environment like surveillance, security and maintenance of law and order, localization is one of the important value-added services. In conventional location-based services, the specific location of a movable or immovable object is determined with the help of GPS. In SIoT based localization, there is further simplification using IoT infrastructure that improves the accuracy and location details compared to the cellular networks. This is helpful where the location accuracies are critical [10], [11] [26].

Using this SIoT, trajectory of an object or human or animal is available where IoT and cellular network coverage exists. This enables applications such as smart policing, pets and kids monitoring, green detection, surveillance, and security monitoring. Many of these are useful in military and mission critical applications as explained in the subsequent subsections [26].

I. Enhanced Quality of Life applications

One of the important objectives of technology development is the improvement in everyday life. The technological and societal changes result in a future where the telecommunication entities are integrated with heterogenous systems with sensing and localization capabilities. Some of the SIoT based advanced architectures are proposed in the futuristic applications. The integration of communication, positioning, and monitoring functionalities by means of heterogeneous networks will be enabled. This will enhance the quality of everyday life [27]. Another area of interest in this application is the sports activities. The sportsmen can share their information about their experiences and activities while they are connected and monitored by sensing devices. Fig. 10 gives the enhanced quality of life scenario.

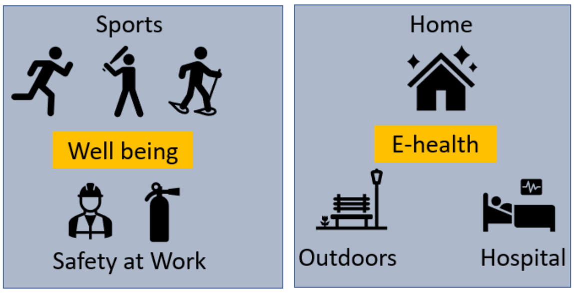

Fig. 10 gives the enhanced quality of life [27].

There are many mission critical and military applications of SIoT which are described below.Until now, the deployment of IoT-related technologies for defense has been essentially focused on applications for Command, Control, Communications, Computers,Intelligence, Surveillance and Reconnaissance (C4ISR), and fire-control systems [28].

J. Border Intrusion Detection

Many times, the intrusions across the borders happen and this can be the threat from terrorists, illegal migrants, trans-border drug smugglers. The intruders can be detected by the appropriate sensors of the SIoT system. The system can trigger the border security police or the autonomous actuation mechanism as shown in Fig. 11 [8]. Also, the quality of the images and videos gathered by SIoT are better than those gathered by satellites alone.

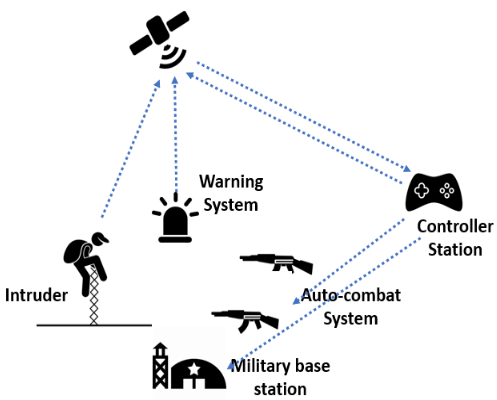

Fig.11 Border Intrusion Detection system

K. Airspace Protection

Using the SIoT, the navigation information of the airplanes and control information can be provided. The pilot generally uses Radio navigation and GPS. Here the SIoT can serve a mission critical role in case of malfunction of the navigation system [8].

L. Deep Space Exploration and Warfare

SIoT with their accurate sensors and actuators, can be of immense help during the different stage separation of a rocket, remote maneuvering and decommissioning, debris mitigation, navigation control and guidance. In these critical applications, accuracy of data collection and its processing are the key success factors [8], [10].

4. Conclusion

In this paper, we presented the main advantages and motivation for Space based IoT. With the advancement in both the satellite technology and their constellation and with upgrades happening in IoT sensors, the overall applications emerging from the SIoT technology are ever increasing. Many small and LEO satellites are getting launched keeping in mind the IoT applications as their prime objectives. The SIoT is an area exploding with multi-directional research possibilities. The improvement in SIoT related to spectrum and energy efficiency is a critical issue to be addressed. Investigations relating to the resource optimization solution to smoothen the connection between satellite networks and terrestrial IoT are in progress.

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