IEEE Access
Multidisciplinary ⋮ Rapid Review ⋮ Open Access Journal

Received January 17, 2019, accepted January 29, 2019, date of publication February 4, 2019, date of current version February 22, 2019.

Digital Object Identifier 10.1109/ACCESS.2019.2897012

Internet of Spatial Things: A New Reference Model With Insight Analysis

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ABSTRACT The Internet of Things (IoT) is the concept of everyday objects that make us live in the era of the IoT. The spatial characteristics of things around us can be considered the reins of the IoT operability. In other words, the spatial variation of a thing can be the core of the IoT reaction. For example, the spatial variation in crop indicates the requirement and characteristic of agriculture production. Also, the spatial variation of a human movement can alarm the security and monitoring systems. This issue agitates the contemplating of the ‘‘Internet of Spatial Things (IoST)’’ concept. For the first time, this paper draws an inspiration towards the perspective vision of the IoST, which is concerned with revise IoT with the spatial perspective. The IoST concept is argued by the presentation of its definition and architectural components. Besides, the IoST layers are discussed in details. Furthermore, a new proposed reference model of the IoST is proposed. Finally, the new trends and open issues regarding the IoST are aroused.

INDEX TERMS Internet of Things (IoT), Internet of Spatial Things (IoST), spatial, framework.

I. INTRODUCTION

The Internet of Things (IoT) is promising to significantly affect all life spheres and business industries. IoT is a system of interrelated heterogeneous computing objects that assure the connectivity and ability to transfer data over a network without requiring human-to-human or human-to-computer interaction. In centuries to come, ‘‘smart community’’ will become as common, vital and indispensable like smartphones [1]. The emergence in recent years of smart personal technology and people’s comfort with and dependence on their smart systems suggest the vital importance of local government adopting technologies to increase operational effectiveness, and an easier learning curve to introduce and implement digital strategies to the organization and customers.

IoT embraces the interoperability between varieties of devices via internet. The components of IoT network architecture are [2]: smart devices, fog computing, cloud, and enterprise side. Smart devices and sensors are continuously sensing the changes and gathering data from the environment and transmitting the information to a target gateway. While actuators work as action or response organs that receive and take reactions to these changes.Usually, these devices connect low power wireless networks as Wi-Fi, ZigBee, and Bluetooth. Fog/edge computing is the practice of processing data with devices’ data sharing and decision-making capabilities near the edge of network, where the data is generated, instead of processing data in a centralized warehouse. IoT gateways translate proprietary communication protocols to Internet Protocol (IP) and ensure the interoperability of the connected devices and sensors. Also, they manage the bidirectional data traffic between various networks. Cloud computing allows collect, process, manage and store huge amount of data which can be accessed remotely by users. In addition, the cloud can deliver accurate analytics while tracking events against business and operational rules that offering a historical perspective. Enterprise side uses the presentation of this analytics for the enhancement of its products and services, preventive measures for certain steps, and build their new business model accurately (see Fig. 1).

After all, a majority of people (employees and residents) already use smart technologies, so connecting to them through their devices becomes common sense. Governments can use Geographic Information System (GIS) and Internet of Things (IoT) technologies to combine a device’s location with its status and other important information that provides context at macro levels while enables stakeholders to drill down to high levels of detail. The approach delivers key inputs to support informed decisions and efficient

The associate editor coordinating the review of this manuscript and approving it for publication was Victor Hugo Albuquerque.

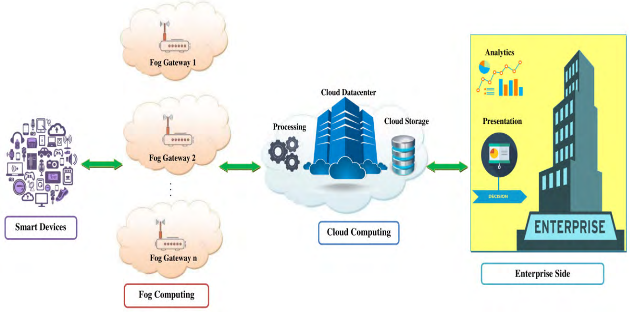

FIGURE 1. IoT Components.

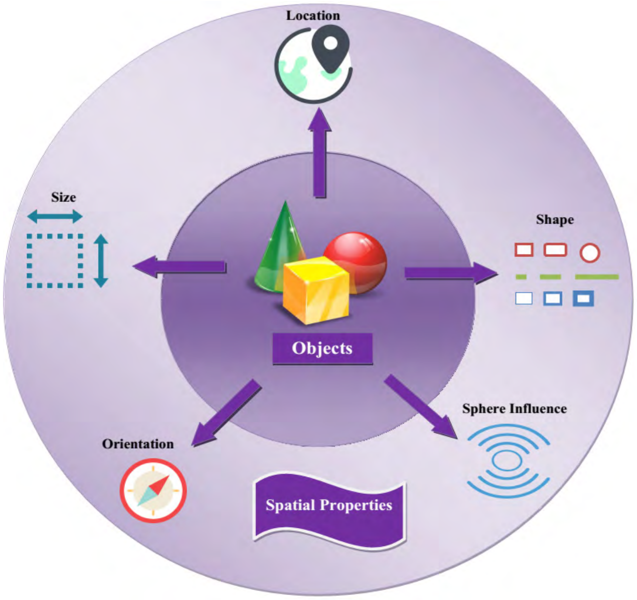

FIGURE 2. Spatial Properties of Objects.

business processes. This spatial information with the velocity and direction of any motion can effectively influence every aspect of operations and civic engagement [3]–[6]. As a matter of fact, spatial information plays an important role in keeping things moving safely and efficiently. Experts have defined the spatial properties of an object as how it is situated in space [7]. The spatial properties can be summarized as follows [8]: Location, Shape, Size, Orientation, and Sphere Influence. ‘‘Location’’ means ‘‘where an object is.’’ ‘‘Shape’’ is defined shape by three independent elements of edge, perforation, and elongation [9]. ‘‘Size’’ is the geometric quantity like length, area, and volume. ‘‘Orientation’’ means the rotation or the direction. Finally, ‘‘Sphere Influence’’ is an object range of effectiveness. Fig. 2 shows the spatial attributes of any physical (smart) object such as a building, lake, mountain or township.

For a moment, what about IoT spatial smart applications (like disaster management, environmental sampling, meteorological and oceanographic research)? How this spatial devices and sensors can be connected? What types of data

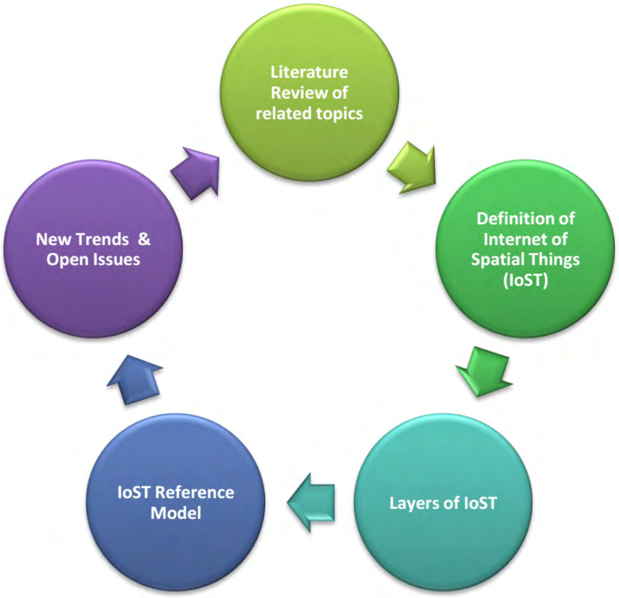

FIGURE 3. Paper Research Methodology.

is transferred? Hence, the concept of Internet of Spatial Things (IoST) is deduced here in this paper. This paper is concerned with the definition of the IoST concept via the discussion of its architectural components. In addition, a new proposed framework of IoST is introduced (See Fig.3). For the remaining of paper, a background of related IoT topics is given in section 2. The meaning of IoST is discussed in section 3. The layers of IoST are presented in section 4 while the proposed reference model of IoST is shown in section 5. The discussion of open issues is presented in section 6. Finally, the conclusion and future works are given in section 7.

II. LITERATURE REVIEW

A. CLASSIFICATIONS OF IoT

There are many general classifications of IoT that have been proposed according to the type of connected objects and transferred messages within the network. For instances, Internet of Multimedia Things (IoMT) [10] is a paradigm in which includes a connection between smart heterogeneous multimedia things through the internet to facilitate multimedia-based services and applications. IoMT has some additional challenges and stringent requirements than the traditional IoT as the need for high-power smart devices and the transformation of real-time continuous multimedia data.

Another IoT categorization is the Internet of Moving/Mobile Things (IoMT) [11], [12]. IoMT specifies the connection between moving sensors and devices instead of stationary things (as home lighting and heating systems). Thus, IoMT encompasses the majority of IoT connected things including smart phones, tablets, smart clothes, smart watches, etc. This category of IoT may face several challenges as the selecting of the appropriate number of used sensors for saving the available storage capacity and ensuring sufficient data analysis. Also, it should be considered the energy consumption, developing suitable applications for the various connected devices, and the privacy of the collected data [13].

The Internet of Robotic Things (IoRT) [14], [15] is a concept where intelligent devices (robots) can facilitate advanced robotic services/actions via events monitoring, the collection of data from different sensors, and the use of distributed intelligence. IoRT differs from the traditional cloud/networked robotics. It preserves more services through the connection, sharing, and dissemination of recourses and knowledge between robots. As a consequence, robotic systems can reach novel knowledge and skills. Obviously, sharing knowledge and resources may lead to computational problems. In other words, many issues should be considered including the organization of resources sharing pool, amount of exchanged data, a real-time delay between tasks execution, and the graphical distribution of data centers.

Scientists have begun to diminish the size of sensors and devices from millimeters or microns to the nanometer scale which is tiny enough to be blending within human life. So, the promising new generation of IoT is Internet of Nano Things (IoNT) [16]–[18]. The main challenge faces IoNT is the dealing with nanodevices as they have unique and sensitive properties as path loss and noises from molecular absorption, which affects the attenuation of propagating waves. Thus, the capacity of bandwidth and channel must take into consideration the molecular composition.

Internet of Wearable Things (IoWT) [19] /Wearable Internet of Things (WIoT) [20], as it was called, it is a connection between devices that can be worn as an accessory or as part of clothing ranging from smart wristbands, smart watches, and fitness trackers to plastic/ coin payment rings. The main challenge of IoWT is the consolidation of its appropriate operationally position in designing solutions.

Besides, different classifications of IoT have been proposed according to the application, scope, and usage of the connected devices. Thus, the previous categorizations can be treated like a hood of this classification. For example, The Internet of Underwater Things (IoUT) [21], Internet of Medical Things (IoMT) [22], Internet of Health Things (IoHT) [23], Industrial Internet of Things (IIoT) [24], and consumer internet of things (CIoT) [25], etc (see Fig.4).

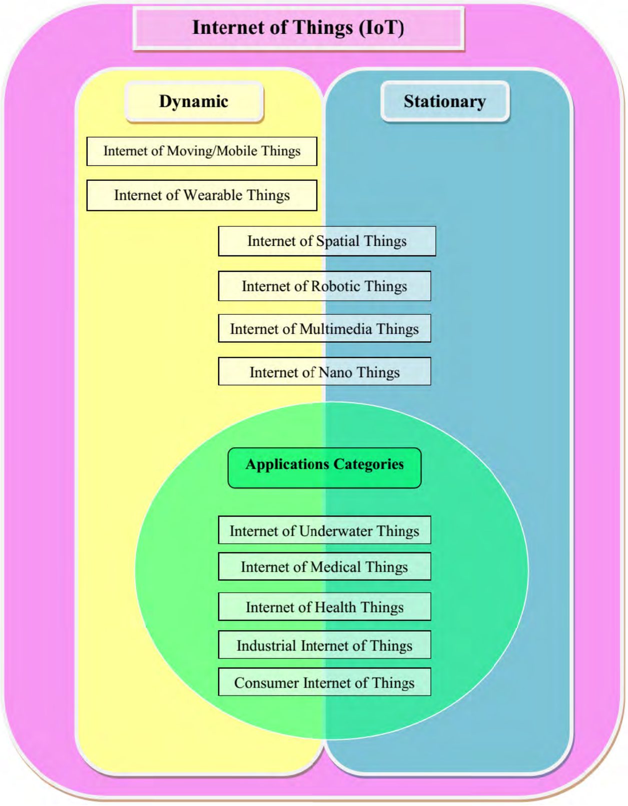

FIGURE 4. Classifications of IoT.

III. IoT WITH SPATIAL CONTEXT

Many literatures regarding IoT mentioned the role of spatial data in their proposed IoT-based architecture. Yuan and Zhao [26] proposed a framework of Spatial Data Warehouse system in IoT environments (SDWIT). Besides, the authors discussed all system layers in details which consist of data source, data processing layer, data storage layer, and application analysis layer. Also, van der Zee and Scholten [8], [27] discussed the IoT spatial technology from the perspective of the Big Data (BD). In other words, they focused on the BD conceptual modeling and the types of spatial attributes that produced from smart object. In addition, the authors illustrated the spatial BD handling in different smart city scenarios. Sun *et al.* [28] introduced an analytical framework of geospatial-temporal data with componentized service architecture. Mainly, the authors focused on the geospatial-temporal data that produced from IoT moving objects such as vehicles. Besides, the authors applied the proposed framework in connected vehicles domain including autonomous driving and Usage Based Insurance (UBI) areas. After applying the proposed framework, the authors proved its efficiency. Kamilaris and Ostermann [29] depicted a comprehensive summary of all potential geospatial analysis of IoT data. The listed analytical methods were ranging from basic geometric measures to more advanced data mining and surfaces analysis methods. The authors classified the IoT applications' fields with respect to the used analytical methods. Also, they [30] proposed a review of IoT literatures, in which geospatial analysis was employed in environmental informatics. The authors handled 26 literatures by discussing the used hardware, geospatial analysis, data types, and reliability issues. Regarding indoor IoT services, Sim and Lee [31] presented a framework. i.e. they developed a new framework that included spatial-based IoT service system. The advantage of the proposed framework is the defeat of traditional one-to-one IoT indoor services. Table 1. shows a summarization of all proposed spatial frameworks in the previously discussed literatures.

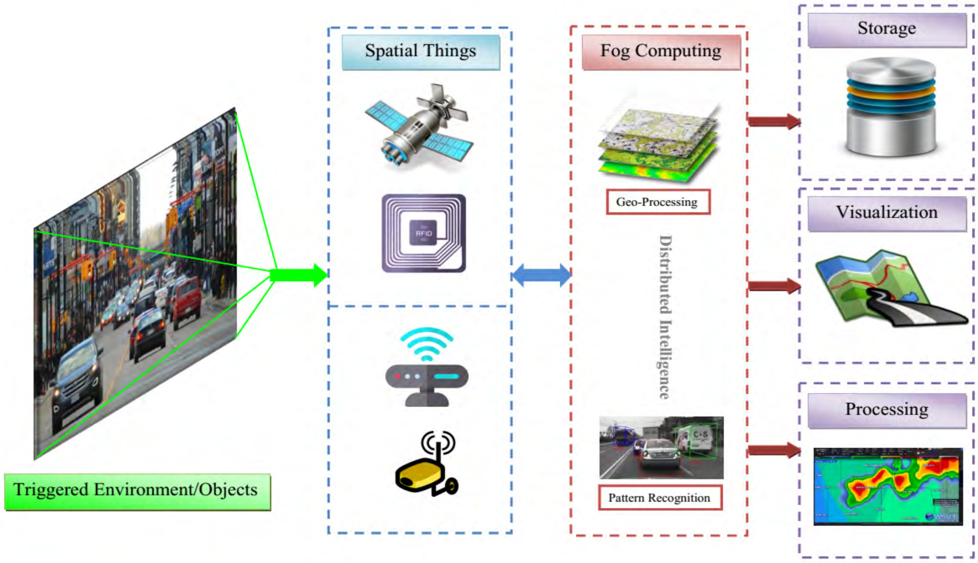

FIGURE 5. IoST Architecture Components.

TABLE 1. Literatures proposed iot spatial-based frameworks.

Literature Context	*Proposed Spatial Framework(s)*	*Reference*
Big Data (BD)	➢ Spatial Data Warehouse system in IoT environments (SDWIT). ➢ The acquisition procedure for Entity Perception Data (EPD).	Yuan and Zhao [26]
	➢ Methods to geo-enable events. ➢ Continuous loop of sensing, analyzing, predicting, and actuating in a smart city. ➢ Integration of enterprise geo-services and spatial big data analysis in a SOA-EDA architecture.	Zee and Scholten [27, 28]
Data tracking of Moving objects	➢ Moving Objects Mapping Analytics (MOMA). ➢ Dynamic Traffic Sign Learning. ➢ Targeted Weather Alter.	Sun et al. [29]
IoT indoor services	➢ An IoT service system based on spatial context. ➢ Interaction of data model of spatial context and IoT service. ➢ The possibilities of various services using spatial context	Sim and Lee [32]

A. PAPER CONTRIBUTIONS

As previously described, the literatures handling spatial context in IoT environment are almost scarce and the existing literatures only handled IoT spatial context in limited manners. Accordingly, the main contributions of this work are the following:

- The definition of IoST standard as well as the differences between the regular the IoT and IoST.
- IoST architectural components
- Deep discussion on the IoST layers.
- A reference model proposal of IoST framework.
- The discussion of future trends of IoST.

Accordingly, this paper has been adopted the spatial aspects related to IoST. Thus, due to the approach adopted in this work, it can be considered by junior, experienced researchers, specialists, as well as hobbyists who wish to learn about the spatial properties of IoT and the latest technologies that have been introduced in this field.

IV. DEFINITION OF INTERNET OF SPATIAL THINGS (IoST)

By considering the comprehensive meaning of spatiality, the Internet of Spatial Things (IoST) can be defined as follows.

Definition 1:

" ubiquitous and embedded computing devices that transmit and receive information so often includes location, shape, size, orientation, and/or sphere influence data for spatial interoperability requirements over networks."

Otherwise, if the association between IoT and geospatial properties, the Internet of Spatial Things (IoST) can be defined as follows.

Definition 2:

" ubiquitous and embedded computing devices that transmit and receive information so often includes numerical values about physical object that can be represented in a geographic coordinate system for geospatial interoperability requirements over networks."

Generally, IoST consists of four main components; First, object or environment which is targeted to seize its spatial characteristic(s). Second, Spatial Things are the sources of needed spatial data. Third, fog/edge computing which can be considered the responder of real-time rapid spatial processing with distributed intelligence. Finally, the processed data is transferred for storage, processing, or visualizing etc. Fig. 5 summarizes all the IoST Architectural components of IoST and how they operate in the application environment.

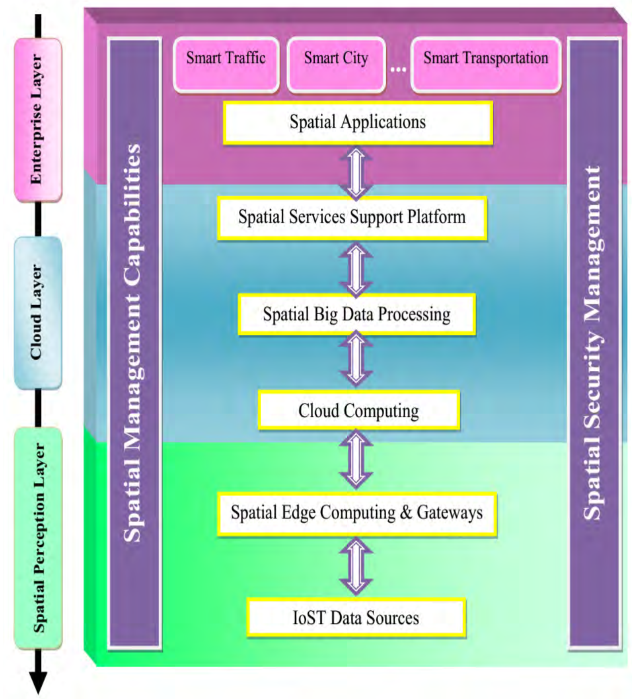

FIGURE 6. **IoST Layers.**

V. LAYERS OF IoST

Generally, different IoT platforms have been introduced from time to time by vendors. Although, the proposed IoST layers appear the same as the traditional IoT layers, there is a core difference between them. That is the variability of spatial data sources with the need of real-time processing. For simplicity, a three-layers platform of IoST is considered. i.e. IoST basically consists of three layers: spatial perception, cloud, and enterprise layer. In addition, these layers are involved by spatial network services and security management. Fig. 6 shows the general layers of IoST. Each layer may be subdivided into its own set of sub-layers. Next, each layer will be discussed in details.

A. SPATIAL PERCEPTION LAYER

The Spatial Perception is the first layer of IoST which refers to the extraction and recognition of spatial data. Thereby, this layer consists of two stages: spatial data sources and IoST edge computing. The former indicates the sources of spatial data that can be captured to be exploited in the related spatial application. IoST edge computing is the stage of in-time processing of this gathered data (if it needs). Next, each stage will be discussed in details.

1) SPATIAL DATA SOURCES

As discussed previously, spatial data includes space, size, shape, direction, and sphere influence. Thence, it can be divided according to data type into the sources of the positioning or the so-called geospatial data which produces data that reflect locations and directions of objects; and sources of other spatial metrics: size, shape, and sphere influence (as shown in Fig. 7). Thus, the two types of spatial data sources are:

- Geospatial Metric: Regarding geospatial data, the sources of position data (according to many literatures [32], [33]) are divided into indoor and outdoor positioning techniques. Indoor positioning technique is the underlying technology that shows the position and orientation of an object in obstacled environments [34], [35]. i.e. indoor positioning techniques enables the determination of locations inside buildings/urban so that they are commissioned within many applications sectors: healthcare services, marketing, smart homes, and people tracking, etc (with estimated growing up to \$4.4 billion by 2019 [36]). For instance, the most popular indoor positioning technologies are Bluetooth and Wireless Fidelity (WiFi) because they are equipped with our regularly used devices like notebooks, tablets, smartphones, or even smartwatches. WiFi is based on standards IEEE 802.11 [37] while Bluetooth is based on IEEE 802.15 [38]. Both Bluetooth and WiFi use 2.4 GHz band frequencies. Although the popularity of both technologies, they have attenuation in signal capabilities. Especially in cases where signal passes through the walls, they can only estimate the locations in their range. This limitation in signals may lead to estimated positions errors. Also, Radio-Frequency IDentification (RFID) is one of the important indoor positioning technologies as it has serious usages especially in the smart warehouse and supply chain management [39]–[42]. It consists of two main components: a reader with an antenna and tags. The reader interrogates nearby RFID tags by radio waves. Whereas, Each RFID tag has a unique ID (i.e. serial number) which can be related to available location information. By this means, the RFID positioning accuracy highly depends on the tags' distribution and the maximum reading ranges. The main indoor positioning techniques are listed with brief discussions in table 2.In contrast to the indoor positioning techniques, outdoor positioning techniques are able to determine the position and orientation of an object in the outdoor environment. Fundamentally, they can be classified to Self-Positioning and Remote- Positioning techniques.In self-positioning techniques, the position is determined by the object itself as It can calculate its position via the usage of transmitted terrestrial/satellite signals. In other words, the object makes the suitable signal measurements from geographically distributed transmitters to make positioned-based decisions via its calculated location. The remote positioning techniques depend on distributed signals receivers to determine the location of an object. Thus, the location of an object can be calculated by a receiver via measuring signals originating from or reflect off it. These signal measurements are used to determine the length and/or direction of the object radio paths, and then the object

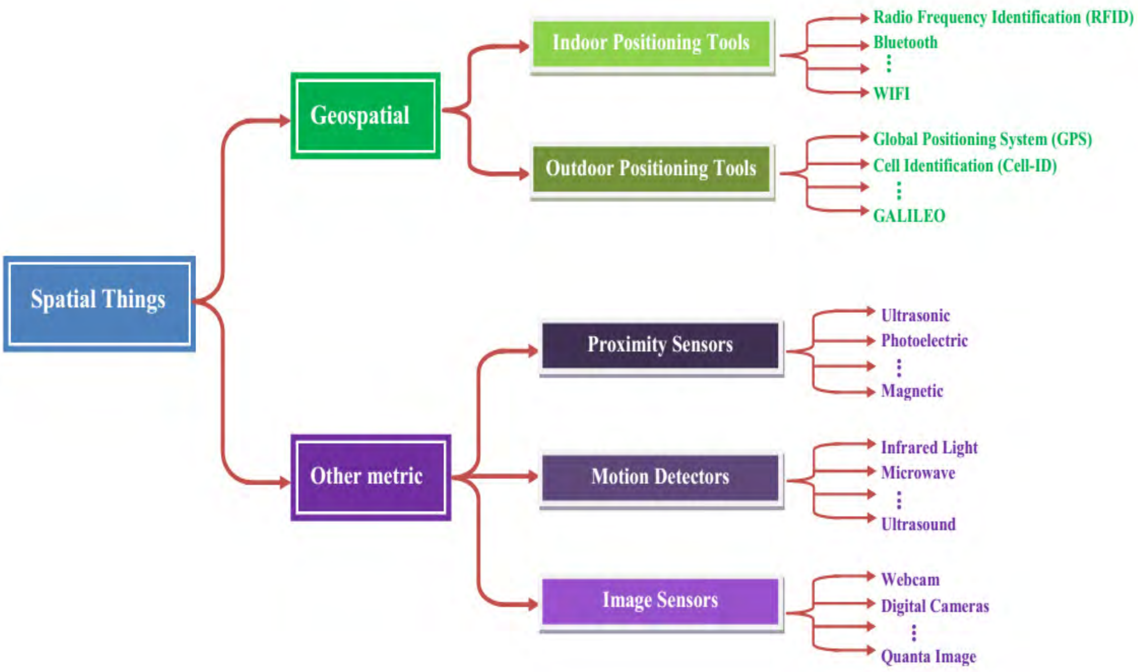

FIGURE 7. Sources of Spatial Data.

position is computed from geometric relationships. The most popular outdoor positioning technique is Global Positioning System (GPS) [43] that (Navstar GPS) was first introduced by the United States in 1983 [44]. GPS is a remote-positioning satellite-based system that consists of main parts: space, control, and user. The former means that GPS satellite sends signals from space. There are 33 available GPS satalities distributed equally above the earth. Not only the United States has a GPS system but also there are other countries has its global coverage such as Russia's GPS system (GLONASS) which is a bit more accurate at about 2.6 meters. The second part is a tracking station that measures signals from satellites which are integrated into orbital models for each satellite. The last part is the GPS signals receivers which translate these signals into three aspects position, velocity, and time estimates. Each satellite transmits a unique signal and orbital parameters. In addition, the distance to each satellite is measured by the amount of time it takes to receive a transmitted signal. These allow GPS receiver to compute the accurate location. For four dimension measurement, it required four GPS satellites. The main outdoor positioning techniques with brief discussions are listed in table 3.

- Other Spatial Metrics: Regarding other spatial metrics, which are size, shape, and sphere influence, they can be divided into three general types of sensors: proximity, motion, and image sensors [45]. The proximity sensors [46] are used for target detection and tracking without physical contacting with objects. They extract spatial metrics, movement, or presence of an object and converting them into signals which can be leveraged electrically. Proximity Sensors can be divided into three main systems, including [47]: eddy currents-based, magnets/ reed-based, and electrical capacity-based systems. As its name implies, motion detectors [48] are devices that particularly detect moving objects (e.g. people). As an illustration, when a surveillance camera senses an intruder, it sends an alert to the monitoring center. Mainly motion detectors have two types: Passive Infrared (PIR), MircoWave (MW), Area Reflective, and hybrid detectors. Image sensors (or imager) [49] are sensing devices that detect and transmit spatial data used for making an image by converting light waves or other electromagnetic radiation variation into signals. Image sensors are considered the most famous one as they are operable in webcam, digital cameras, and medical imaging tools. Besides, these cameras can construct a relation between captured images and spatial location. The captured spatial data can be stored with quality ranging from the normal pixels to the higher quality photons.

2) IoST EDGE AND FOG COMPUTING

The question here is where the spatial data are processed and should they be sent to the cloud datacenter? The answer to the question depends on the intelligence level of the smart device. i.e. If the device is intelligent enough to analyze the spatial data read, then it can make a decision based on what is read. Such as intelligent surveillance cameras that in turn read

TABLE 2. Indoor spatial positioning techniques.

Technique	*Categories*	*Brief description*	*Reference*
Infra-Red and visible light	Active Badge	The Active Badge is an indoor positioning technique that able to find an object location via determining the location of its Active Badge. Often, this small device transmits a unique infra-red signal every 10 seconds. These transmissions are detected by one or more networked sensors. The gathered information of these sensors can be used to determine the location of the badge and hence its wearer.	Want et al. [51]
	Locust System	The locust system is an infrared-based system that provides inexpensive messaging and positioning without batteries and without its own network. i.e. in locust system, the beacon transmitters are located in the environment (such as a room) and the receivers are located on the tagged objects (such as a person). Thus, This system provides "privacy aware" as the wearable computer user can control how much of his information is shared with others or the installed infrastructure.	Starner et al.[52]
	IRREAL	IRREAL is a sub-system of the pedestrian navigation system "REAL" that designed for PalmOS indoor positioning. IRREAL system characterized by uni-directional transmission with high IR coverge up to twenty meters via approach like videotext-technology, where all the information is transmitted in cycles. Although, IRREAL enables users to interact with interactive texts and graphics. In addition, IRREAL uses 3D models for indoor locations.	Baus et al.[53]
	ParcTab	The ParcTab is a small device or a personal digital assistant (PDA) that able to communicate via IR datapackets to a network of IR transceivers. Most of its applications are run on remote hosts. Thus, it depends on reliable communication through the IR cellular network. ParcTab can include location-aware applications.	Want et al.[54]
Ultrasound-based	Active bat	Active bat system is an Ultrasound-based positioning technique that uses a fixed receivers grid to detect emitting ultrasound pulses of an object. In particular, the time of transmitting ultrasound pulses to receivers is used to calculate the transmitter position.	Woodman and Harle [55]
	Dolphin System	Dolphin System is an alternative technique of Ultrasound-based Active bat. The main difference between them is that Dolphin System uses broadband Ultrasound transmissions. Thus, Dolphin System is able to reduce configuration costs.	Fukuju et al.[56]
	Cricket System	Like Active bat, Cricket System is an Ultrasound-based positioning technique but beacons emit short ultrasound pulses and periodically send messages that contain their locations. The objects use this information to calculate the distances to beacons.	Priyantha [57]
Received Signal Strength (RSS)-based	Ultra Wideband (UWB)	Ultra-wideband (UWB) is a short-range radio positioning technology that offers accuracy more than 30 cm (better than WiFi and Bluetooth) with no interferences. The main disadvantage of UWB is that it is not compatible with normal users' devices which compatible with WiFi and Bluetooth. As consequence, it is most appropriate with special components for specific applications.	Choi et al. [58]
	Wireless Fidelity(WiFi)	WiFi is the most used wireless technology. It is often used for internet connection inside buildings. One of the biggest advantages of WiFi is that it is compatable with a large range of smart devices. It can be used for inexpensive positioning as each card allows measuring some signal parameters. i.e. the so-called fingerprinting method is used to locate users of wireless networks through their wireless access points.	Yang and Shao [59]
	Radio-Frequency IDentification (RFID)	Radio-Frequency IDentification (RFID) is a positioning technique that defines an object location by electromagnetic or electrostatic coupling in the radio frequency portion of the electromagnetic spectrum to uniquely identify an object. The main disadvantages of RFID are the collision of readers and tags and privacy concern as anyone with a compatible reader can read RFID tag data.	Roberts [60]
	Bluetooth	Bluetooth is a basic wireless technology that widely used in most smart devices. Bluetooth V4 is more suitable for positioning but still has a deficiency in power sources and bandwidth. Thus, it is desirable to have a beacon in case of larger areas.	Feldmann et al. [61]
	ZigBee	ZigBee is a shortrange wireless communication that especially designed for large mesh networks counter to Bluetooth which is designed to peer to peer communication. ZigBee is an open-source wireless networking standard that allows more integrated designs with fewer external components. For positioning, ZigBee antennas are not usually directional so location based on range and bearing from a single position is not possible. Thus, the location of a ZigBee node can be calculated by measurements of range from many fixed nodes.	Kaemarungsi and Ranron [62]
GPS based	Indoor GPS	Indoor GPS aims to exploit the advantages of GPS in indoor positioning. Although, it doesn't typically work well interior because of too low signal strength. Thus, it is able to determine objects locations in an environment with fewer obstacles. In addition, pseudo-GPS may be set up for emitting navigation signals instead of real GPS.	Maisano et al. [63]
	Geomagnetic	In Geomagnetic method, the locations are identified via sensing the changes in magnetic waves. In other words, smart buildings have a unique magnetic landscape which produced by the Earth's magnetic field that interacts with steel and other materials found in structures of buildings. This Earth's magnetic field can be sensed by any smart device magnetic sensor.	Li et al. [64]
	Inertial Navigation System (INS)	Inertial navigation systems (INS) is a positioning techniques that only depends on the rules of Newton's laws of classical mechanics without any external (radio) measurements. In particular, INS uses accelerometers and gyroscopes sensors to determine an object location with its velocity, temperature, or magnetic fields.	Jekeli [65]

TABLE 3. Outdoor spatial positioning techniques.

Categories	*Method*	*Brief description*	*Reference*
Self-Positioning	Global Positioning System (GPS)	GPS is a satellite-based navigation system that includes a constellation of 33 satellites broadcasts precise timing signals by radio to the electronic GPS receiver to precisely determine their location (longitude, latitude, and altitude) in real time. GPS can be considered the most popular outdoor positioning technique as it is free, works 24 hours a day, and is embedded in a large range of smart devices especially smartphones and smart vehicles.	Ashraf et al. [66]
	Assisted-GPS (A-GPS)	A-GPS is an improved version of traditional GPS. A-GPS is more efficient than traditional GPS in reducing time cost with high accuracy positioning. The main advantage of A-GPS over the traditional GPS is that it uses assistant servers (often network resources as mobile network) with satellites signal to determine spatial positions. This greatly reduces the size of the search space , and the time-to-first-fix (TTFF) shortened from minutes to a second or less.	Djuknic and Richton [67]
	Differiential-GPS (D-GPS)	D-GPS is another enhanced version of traditional GPS that improves the accuracy of the estimated position. i.e. It is able to only increase the positioning accuracy without any reduction on the time cost. The main approach of D-GPS is that it uses two receivers to correct the detected location. In particular, D-GPS need one stationary receiver that has set up in accurate known location as it will calculate the difference between this location and GPS one. This difference and the corrected information are applied to the second roving receiver in real time.	Cosentino and Diggle [68]
	Pseudo-GPS (Pseudolite)	pseudo-satellite (or Pseudolite for abbreviation) is a dummy satellite that performs functions of common satellites. It consists of small transceivers for creating an alternative local, ground-based Global Positioning System (GPS). The range of each Pseudolite transceiver's signal is based on the available power to the unit. Thus, Pseudolite is an efficient GPS alternative when the normal GPS signals are either blocked/jammed (especially in military conflicts).	Wang et al. [69]
	GLONASS	GLONASS is the Russian satellite navigation system that was declared by the Soviet Union for the civil user community through a variety of applications such as traffic management, cartography, and ecological monitoring. Computer of GLONASS receiver process all the input data and calculate three coordinates, three components of velocity, vector, and precise time. The GLONASS has two types of navigation signal: standard precision (SP) and high precision (HP). SP positioning services are available to all civil users on a continuous, worldwide basis and provide the capability to obtain horizontal positioning. HP signal is broadcast in phase quadrature with the SP signal, effectively sharing the same carrier wave as the SP signal, but with a ten times higher bandwidth (5.11 Mbps) than the SP signal.	Angrisano et al. [70]
	GALILEO	GALILEO is the European Global Navigation Satellite System (GNSS) that is interoperable with GPS and Glonass, which are the US and Russian global satellite navigation systems. With this Europ's constellation of 24 satellites (GALILEO), GNSS users are not obliges to use non-civilian American GPS or Russian GLONASS signals and remain under civilian control.	Dion et al. [71]
	BeiDou	BeiDou is a Chinese GNSS that consists of three generations. The first BeiDou constellation, known as BeiDou-1, consists of three satellites which offered limited coverage and navigation services. Thus, Beidou-1 was withdrawn at the end of 2012. The second generation of Beidou, known as COMPASS or BeiDou-2, became operational in China with a constellation of 10 satellites that offering services to customers in the Asia-Pacific region. In 2015, China started the build-up of the third generation (BeiDou-3). As of January 2018, BeiDou-3 will eventually consist of 35 satellites and is expected to provide global services upon completion in 2020 as an alternative to GPS	Lu et al. [72]
Remote-Positioning	Cell-Identification (Cell-ID)	Cell ID (or Cell Of Origin (COO)) is a positioning technique that has located in any device with a GSM/WCDMA/CDMA modem. The main advantage of Cell ID is that it is low cost and the popular existing infrastructure. The disadvantage is low accurate that depending on the proximity of base transceiver stations.	Aly andYoussef [73]
	Direction/Angle of Arrival (DOA/AOA)	Direction of Arrival (DOA), also known as Angle of Arrival (AOA)is an angle based positioning technique that locates the object by determining the angle of incidence at which signals arrive at the receiving sensor. In other words, DOA estimates the object location by the intersection of the several pairs of angle direction lines, each formed by the circular radius from a base station. The main advantage of DOA is the need of only two measuring units for 2D positioning without the need of synchronization. The main disadvantage is the positioning accuracy is decreasing in the case of multipaths-signal reflections.	Rong and Sichitiu [74]
	Uplink-Time Difference of Arrival (U-TDOA)	Uplink-Time Difference of Arrival (U-TDOA) is a method of locating a wireless caller that depends on sensitive receivers typically located at the cell towers. In particular, it uses time difference of arrival of uplink signals by multiple cell towers to determine an object position. U-TDOA is widely used in emergency calling applications.	Ward and Anderson [75]
	Location Pattern Matching (LMP)	A caller's signal is received at various antenna sites equipped with special gear. The receivers send the voice call to the switch which analyzes the acoustic radio signal and compares it to a database of standard signal characteristics including signal reflections, echoes, and other anomalies signals. The caller's voice call and location are then sent for use by the dispatcher.	Bellavista [76]

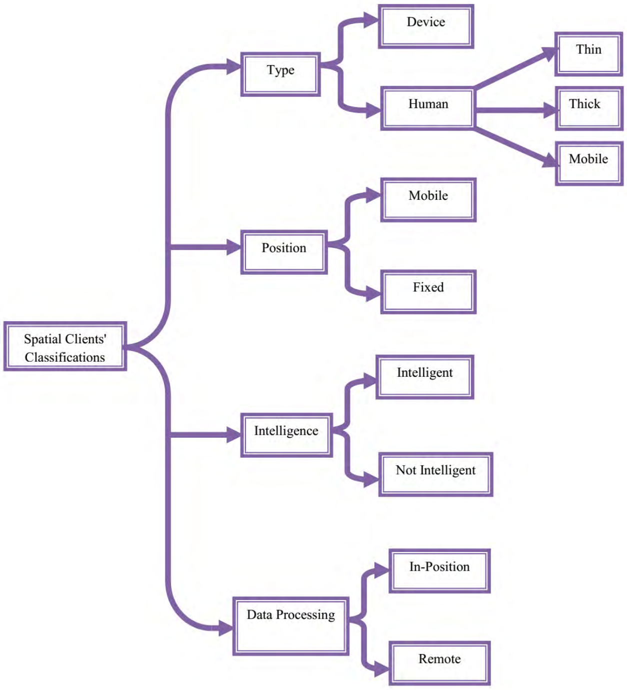

FIGURE 8. Clients of Spatial Fog Computing.

something with spatial dimensions and then go to a scene to take a more detailed picture or trigger the alarm. On the other hand, if the device is not intelligent enough to process the captured data, it needs to transmit data to nearby distributed intelligence or edge computing via a connection technology (e.g. WiFi, Zigbee, or Bluetooth) which is determined in the onboarding stage [76].

Besides, there are several spatial applications need timely responses. Fig. 8 exposes the overall classifications of spatial clients. As shown, the spatial clients can be classified according to four aspects: type, position, intelligence, and data processing. The type of fog connected objects indicates that if the connected object is a device or a human. In other words, the devices have predefined protocols or erections. Whereas humans have no predictable behaviours. Thus, the Fog host devices need to be on call with human users' requests [77]. The spatial users can be classified into three categories [78]: thin, thick, and mobile user. Thin users are the web browsers' users that need not additional software. In contrast, thick users need standalone software for processing or visualizing the spatial data. Mobile users are users that operate via mobile devices. These make the former and the latter the most in need of rapid responses. The position means that if the requester is in a fixed position or movable one which needs a synchronization of the user's current position [79]. As mentioned before, the intelligence means the degree of intelligence of an object and the object ability to handling the occurred situation [80]. The data processing means that if the object is able to process collected spatial data or it must send these data to fog computing [81].

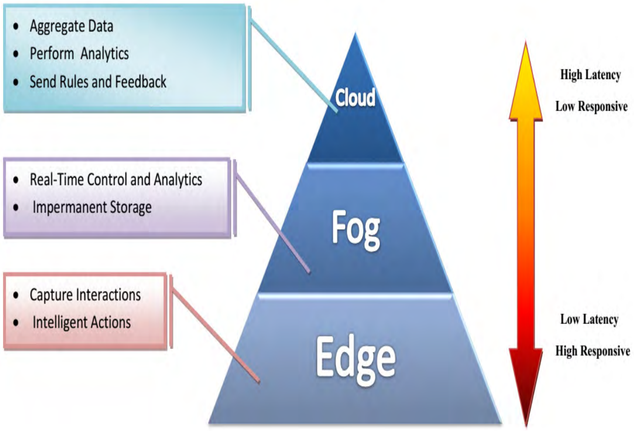

FIGURE 9. Cloud computing Vs. Fog and Edge computing.

Edge computing (or Fog computing) can store the sent data into local storage and apply robust real-time processing, data analysis, visualization, and optimization [82]–[85]. The main difference between fog and edge computing is the location of data processing. In particular, the fog computing transform the collected spatial data to be processed in processors that are connected to the Local Area Network (LAN) so they may be physically more distant from the spatial data sources. On the other hand, edge computing usually processes the collected spatial data directly on the devices to which the sensors are attached or a gateway device that is physically near to the sensors [86]. To be precious, fog computing focuses on infrastructure side while edge computing focuses on object side [87]. If the sent data needs to be enhanced as it is not clear or contains noise, the fog computing host sends a request message for the smart device to resend data (especially for image processing and pattern recognition cases). The transmitted data can be an event message such as JSON, GeoJSON object, or/and metadata which is extracted from the header of photo or text files [88].

B. CLOUD COMPUTING LAYER

Cloud computing [89]–[91] can be defined as a hosted-service paradigm over the internet. In other words, cloud computing enables clients to have services as a virtual machine (VM), storage or an application, as a utility rather than being compelled to have on-premise infrastructures [92]. Cloud computing differs from edge and fog computing as it is a large-scale data center with more storage and computing capabilities [93]. On that account, cloud computing can be considered the head of the edge and fog computing which aggregates data summaries from multiple fog nodes to perform deeper data analysis (See Fig. 9).

Predominately, cloud computing is based on the principle of speed and scale. Thus, cloud computing plays an important role in the success of IoT's mobility and widespread networking [94] (even there has been launched the so-called

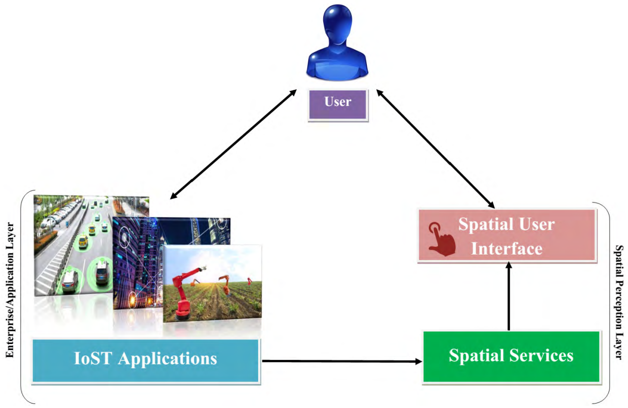

FIGURE 10. Interaction of User with Spatial Perception and Application Layers.

Cloud of Things (CoT) [95]). For IoST, cloud computing is one of the most important props of efficiency which can be seen as a perfect tool to upgrade classical spatial applications and provide a broad spectrum of services to users around the world. The integration of IoST and cloud computing allow wide leveraging of spatial applications and information with economic solutions. Whereas, virtualization allows multi-usage of the same hardware while accessing private instances of the cloud environment [96].

C. ENTERPRISE/APPLICATION LAYER

Enterprise or application layer is another terminus of the IoST layers as shown in Figure 10. This layer provides per-request services to the users with effective leveraging of the collected data. Typical applications of IoST are smart cities, smart transportation, military applications, and smart agriculture etc. The various implementations of this layer depend on an organization's requirements for cost, accessibility and maintainability. These implementations support solutions that can be delivered via the web, desktop and increasingly on mobile devices. Roughly speaking, an enterprise chooses the appropriate spatial services which ranging from merging the business with the cloud platform to more specific spatial platforms. The most popular vendor of spatial cloud platform is ESRI® that introduced ArcGIS platforms for different smart services. For instance, ArcGIS Enterprise is a mapping and analytics platform that provides a Web GIS in the infrastructure with the ability to discover, use, make, and share maps from any device, anywhere, at any time. GeoEvent Processor is an extension of the ArcGIS Server environment that enables with GPSGate Server real-time geospatial analysis on geospatial events.

D. SUPPORTIVE MANAGEMENT LAYERS

As shown before, the capabilities of spatial management permeate all the IoST layers. This management processes can be divided into two categories: Spatial Data Management and Network Management. Next, all the previous side layers will be discussed.

1) SPATIAL DATA MANAGEMENT

Note that, there are other supplementary sources of geospatial data which stored in metadata such as the header of images (e.g. GeoTIFF image files), event messages that contain toponyms (e.g. GeoJSON, GeoSMS, GML, and KML). Thus, these types of geospatial data can contain many errors as they are extracted from undirect data sources and may contain spelling errors or more than one toponym that refers to many locations. Thus, the spatial extracted data can be classified into two categories [26]: abstract data type and object recognition data type. The former includes all structured and unstructured data types that can be recognized by computer directly such as text data, the relationship data (as Oracle, SQL server, and Access). The second includes data types that extracted from various spatial sensing devices such as vehicles, mobile phones, and street, etc. i.e. Object recognition data type needs to be processed to extract spatial information and can't be recognized by computer directly (See Fig. 11).

When smart objects send their spatial properties (all or just required one), they can be modeled in two possible digital spatial representations: Raster and Vector [97]. The raster representation is suitable for continuous data (like captured images of smart cameras or satellite) because it represents objects as pixels or voxels. On the other hand, the vector representation is suitable for discrete data because it represents objects as a point, line, or polygon. For most simple IoST cases, objects are represented as 2D, 2.5D, or 3D vector models. Also, some objects are modeled by both spatial representations. Besides, there is also a subsidiary representation prototype which represents an object as a transformation matrix of spatial attributes. In addition, this prototype is connected with its coordinate base-point which usually used to represent objects within smart houses [98].

After that, the collected geospatial attributes are processed by so-called "spatial functions". The appropriate function is selected according to the needed decisions to be made. These functions ranging from basic geometric measures (such as union, intersection, clustering, buffering, and difference, etc) to more advanced operations (as networking analysis, interpolation, and kriging, etc) [99]. For more information about the geospatial analysis in IoT, see [100]. For the other types of spatial data (shape and size, etc), they can be extracted via image processing, shape identification and pattern recognition technologies [101], [102]. Generally, these technologies can identify the spatial properties by analyzing the content of fragmented pixels or voxels of the processed images.

2) NETWORK MANAGEMENT

IoT interoperability is managed in the existing internet infrastructure to provide new levels of integration, information, convenience, and security through a variety of protocols, domains, and applications. Many protocols that have been developed at all layers of the International Organization for Standardization (ISO) and Open System Interconnection (OSI) stack [103]. These protocols ranging from messaging

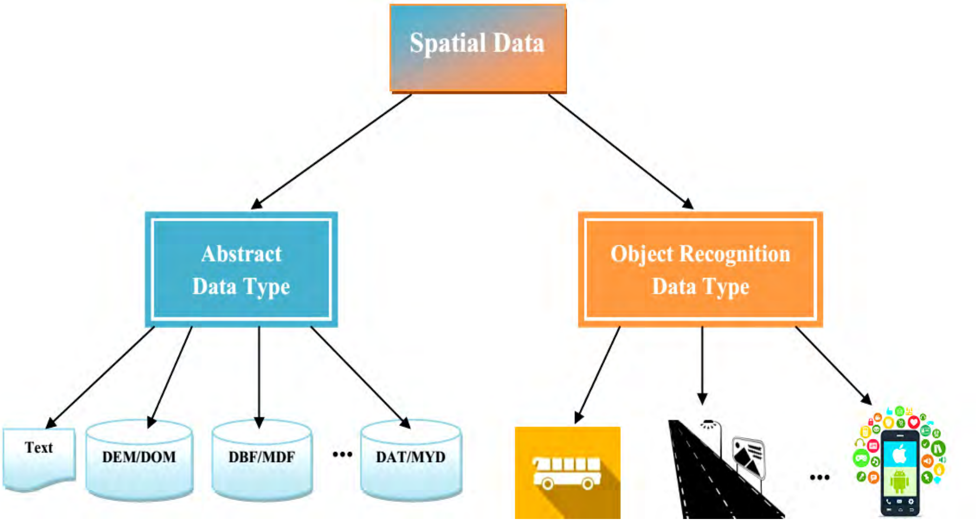

FIGURE 11. Spatial Data Types.

protocols as the Constrained Application Protocol (CoAP), to highly extensible routing protocols such as the Routing Protocol for Low-Power and Lossy Networks (RPL).

Besides previous protocols, IoST may embrace more specific routing protocols that based on geographic position information. In particular, location-based routing protocols take into consideration the specific location of objects [104]. If objects are close to each other, locations can be addressed by the strength of signals. On the other hand, the objects' coordinates are extracted from information exchanged between neighboring objects. These protocols are more efficient and scalable in case of dynamic changes in the network topology and high mobility. Some of location-based routing protocols are Location-aided routing (LAR) [105], Greedy Perimeter Stateless Routing (GPSR) [106], GRID [107],Directional Antenna Multi-path Location Aided Routing (DA-MLAR) [108], Geographic Adaptive Fidelity (GAF) [109], GeoSpray [110], and SPEED-3D [111]. For more information, see [112]–[114].

Roughly speaking, all of these protocols are designed with energy preservation, low compute, memory requirements, and adaptability with Internet Protocol version 6 (IPv6). The IPv6 Internet is can be considered the most important enablers of the IoT as it allows adding billions of devices rather than the normal IPv4 Internet. Thereby, it ensures more security considerations and implications for securing the IoT [115].

3) SPATIAL SECURITY MANAGEMENT

IoST may face several security aspects. For example, Sybil attack [116]–[118] is a cybercrime that occurs in the case of a network node is hijacked to claim multiple identities. The problem arises when the attacker with many identities maliciously uses them to steal information, disrupt communication, or make problems such as a Distributed-Denial-of-Service (DDoS) [119], [120] attack in order to make IoST infrastructure is too busy and press money from companies. Another security attack is Single Point Of Failure (SPOF) [121], [122]. In SPOF, a malicious attacker changes the spatial data in IoST by attacking the centralized cloud server. This makes all the connected sub-nodes have corrupted spatial data. The most dangerous IoST cybercrime is the IP spoofing [123]–[126]. The IP spoofing or forging occurred when an attacker maliciously replaces the original source IP address with a new fake one in order to conceal the identity of the sender or impersonate another computing system. In addition, the attacker responds to the user with a wrong IP address and block legitimate access by either exhausting server resources or saturating stub IoST access links (as a DDoS attack). These security issues can be efficiently handled by several methods of security preserving such as cryptography mechanisms [127]–[129], decentralization of IoST resources [130], and the bubbles of trust via BlockChain (BC) [131]–[133].

4) SPATIAL PRIVACY MANAGEMENT

In addition to security threats specific to IoST, due to the location information embedded in exchanged spatial data, some location privacy threats exist too. In other words, in the majority of IoST applications, the spatial data flow is completed as soon as the user has received the requested service. Thus, there is no considerable risk of losing such a message [134]. Location privacy is one of the IoST major challenges as the geospatial locations of users are not sufficiently protected. Table 4. shows some spatial privacy attacks with the way to handle them. For more information, see [135]–[137].

VI. PROPOSED IoST REFERENCE MODEL

Mainly, IoST is an integrative paradigm of embedded smart devices that concerned with collecting spatial data of objects to serve a significant purpose. The detailed functionalities of

TABLE 4. Spatial privacy attacks & solutions.

Privacy Attack	*Brief Description*	*Solution*	*Reference*
Spatial Knowledge Attack	The spatial knowledge attack occurs, if the real space semantics are ignored by geometry-based obfuscation techniques. Thus, attacker can realize the location of user which in obfuscation location.	➢ identity of location ➢ staying duration	Lee et al. [139]
Spatial Location Dependent Attack	Location dependent attacks occur when the location of users queries without effective cloaking granularity. There are two types of location dependent attacks: location linking attacks and query sampling attacks.	➢ k-anonymity ➢ Quad-tree based cloaking algorithm ➢ hilbASR cloaking algorithm	Gruteser et al. [140]
Spatial Multi Query Attack	In multi-query attack, the attacker tries to identify the actual location of the user' query with the help of a series of spatial queries with different cloaking regions that are shrunk or extended in succeeding queries.	➢ Ensuring reciprocity condition and the same cloaking regions over the time. ➢ developing disjoint sets of users dynamically with the same cloaking region over time	Talukder and Ahamed [141]
Maximum movement boundary attack	In a maximum movement boundary attack, the attacker computes the victim's whole area of movement where he could move between two succeeding snapshot queries or position updates. Thus, the update of the remaining area position can be safely excluded by the attacker.	➢ Temporal and spatial transformations	Ghinita et al. [142]
Spatial Trajectory Attacks	The problem arises in trajectory attacks as that the user privacy can't be guaranteed via only removing the location identifier while trajectory publishing. Thus, the users need trajectory anonymization in two cases: free space and in constrained space.	➢ randomization based reconstruction algorithm	Nergiz et al. [143]
Spatial Inversion Attacks	In the inversion attacks, the attackers able to extract the victim location from k users (and exclude other identifiers) by simulating attacking the cloaking algorithms.	➢ reciprocity of generalization functions.	Kalnis et al. [144]
Spatial Query Tracking Attacks	In query tracking attacks, the continuous query issuer is easily identified if he is cloaked with different users with different time instances. Whereas, the query results would be continuously returned for a query lifetime which is a designated time period.	➢ property of memorization	Chow and Mokbel [145]
Spatial Inference attacks	Inference attacks occur when the attacker extract the victim location by analyzing its data. These attacks can be classified into tracking and identification attacks.	➢ Spatial cloaking obscuration countermeasure. ➢ Introducing noise obscuration countermeasure ➢ Rounding obscuration countermeasure	Krumm [146]

each layer are extensively discussed in the previous section. The IoST begins with spatial data acquisition which varies depending on the type of the environment (indoor or outdoor) and the used smart devices. The majority of smart devices depends on GPS in identifying the geospatial location of objects in an outdoor environment. These oblige the smart device to connect to satellite to read object coordinates. On the other hand, if the inspected object in an indoor environment, many IoST systems deploy RFID to detect objects locations. For capturing other spatial criteria, it is popular to use the captured images via cameras to extract these spatial characteristics. After the data acquisition process is completed, the next step is to report the spatial data to the nearest fog node to be temporarily stored and processed. If the spatial message is unclear to the fog node, it sends a request to the sender smart devices in order to resend the corrupted spatial data. Then, the spatial content is reported to the cloud by incorporating efficient communication and gateways. The transferred spatial data is undergone to the processes of Extract Transfer Load (ETL) in order to be permanently stored in the cloud Big Data (BD). These filtered spatial data is disseminated as per end-user demand at the cloud. The analysis and post-processing tasks may be carried out at the cloud according to the enterprise requirements articulated by multi-agent systems. These make the cloud layer and the enterprise layer are dealt as a united system in IoST (See Fig. 12). There are several IoST applications such as precision agriculture [146], detection of public vehicle accidents [147], smart museum [148], smart tourism ecosystem [149], and smart transportation system [150].

VII. OPEN ISSUES AND FUTURE TRENDS

Although the Importance of the spatiality in IoT, seldom (or even none) literatures introduced a comprehensive review of IoT that relays on the spatial dimension of objects. This makes the IoST a fresh search direction that may attract new researchers. The following are the open issues in the field of IoST:

- **Privacy-preserving**

How often your location was requested when you accessed a website or request a service? Thus, there is not enough attention to spatial privacy. However, spatial privacy is a significant issue as the collected user's spatial data can be analyzed by a third party which leakage of personal privacy.

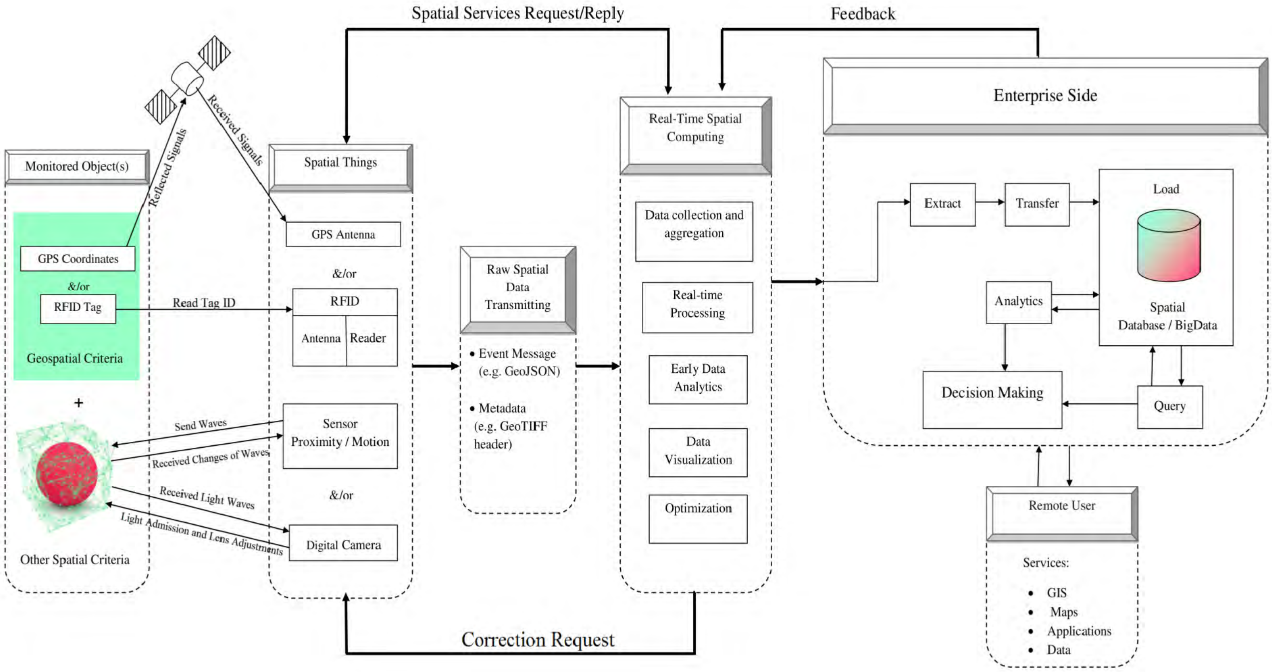

FIGURE 12. IoST Proposed Framework.

- **Handling enormous spatial big data**

The spatial big data characterizes with the huge volume of data size. Therefore, there are needed research points to address such a problem, processing, and solutions.

- **Optimization of performance**

As discussed before, IoST includes several sub-processes can be optimized to increase the overall performance of IoST. The optimization techniques is ranging from meta-heuristics as [151]–[154] to advanced machine learning techniques [155]–[159].

- **Internet of Spatial Human (IoSH)**

IoSH is a novel search topic which is concerning with connect the human spatial properties (not things). This topic needs to be handled with interested researchers.

VIII. CONCLUSION AND FUTURE WORKSÝ

In this paper, the definition of IoST concept is proposed which a special case that declare the location dimension of things. Also, its layers are deeply discussed. In addition, a new proposed framework of IoST is introduced for the first time. The IoST model proposed in this paper is designed based on the combination between several perspectives in literatures (that look upon IoT and spatial data separately). Thus, it can support a general association between different components and spatial data sources in the IoST domain.

For future works, we suggest introducing IoST reference models that combining IoST with fuzzy or neutrosophic logic. IoST with the advanced spatial data securing "BlockChain (BC)" can be proposed. Besides, several optimization techniques can be used to enhance the operability of IoST such as multi-objective artificial intelligence algorithms and parallel machine learning.

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