Toward Future LoRa-Based LEO Satellite IoT: Opportunities, Framework, and Research Directions

Quantao Yu, Dongxuan He, Huazhou Hou, and Hua Wang

Abstract

Featuring energy-efficient and cost-effective communications for low power wide area network (LPWAN), LoRa (Long Range) has manifested its crucial role in the Internet-of-Things (IoT) industry. However, the existing terrestrial LoRaWAN (Long Range Wide Area Network) networks may fail to guarantee the pervasive connectivity, especially in rural and remote areas. To tackle this challenge, integrating LoRa-based low Earth orbit (LEO) satellite IoT into the LoRa ecosystem has aroused a growing interest in both academia and industry. To comprehend such a new paradigm, we investigate LoRa-based LEO satellite IoT in this article, focusing on its development opportunities, network framework and future research directions. In particular, we provide an in-depth insight into its feasibility and scalability by numerical simulations considering practical system parameters. Technical challenges are also discussed to specify its standardization progress.

Introduction

The recent years have witnessed the proliferation of low power wide area network (LPWAN) applications in the Internet-of-Things (IoT), which aims to provide pervasive connectivity worldwide [1]. Among all the state-of-the-art LPWAN technologies, LoRa (Long Range) has attracted widespread attention from both academia and industry due to its technical superiority. In general, LoRa can be categorized into two layers, namely a robust physical (PHY) layer using chirp spread spectrum (CSS) modulation and a simple medium access control (MAC) layer with ALOHA-based protocol. Facilitated by its configurable radio parameters including carrier frequency (CF), bandwidth (BW), spreading factor (SF) and code rate (CR), LoRa provides a compelling trade-off between data rate and coverage, thus satisfying various requirements of LPWAN applications. Additionally, the LoRa Alliance specifies an open LoRaWAN (Long Range Wide Area Network) standard, which empowers the construction and management of private networks without the involvement of mobile network operators. Therefore, with the technical flexibility to address a broad range of LPWAN applications, LoRa has developed its global ecosystem.

Despite its immense success in the IoT industry, it is still extremely challenging for terrestrial LoRaWAN networks to provide ubiquitous coverage and seamless connectivity in rural and remote areas. Specifically, due to the economic and engineering limitations, more than 80% of the earth's land and more than 95% of its oceans cannot be covered by terrestrial networks. To tackle this challenge, exploiting LoRa-based satellite IoT as a supplement to the terrestrial LoRaWAN networks has been regarded as a promising solution in recent years. In fact, with the emerging innovation of launch and propulsion technologies, as well as the rapid growth of miniaturized satellites known as CubeSats [2], the manufacturing cost of space infrastructure has significantly decreased. Considering that most IoT end-devices (EDs) are designed to be energy-efficient to guarantee long life expectancy, low Earth orbit (LEO) satellites are more appropriate to LoRa-based satellite IoT since they experience lower propagation attenuation compared to medium Earth orbit (MEO) and geostationary Earth orbit (GEO) satellites. Meanwhile, some experiments have already verified the feasibility of LoRa-based radio links in LEO space-to-earth communications over the past few years [3], [4]. However, little attention has been paid to the performance evaluation of LoRa-based LEO satellite IoT, and a holistic analysis of such a new paradigm is also insufficient.

Against the above background, this article provides a comprehensive investigation into the emerging paradigm of LoRa-based LEO satellite IoT. The main contributions of this article are summarized as follows.

- First, commencing from a fundamental overview of LoRa technology, we introduce the evolution of LoRa ecosystem and present the application landscape for LoRa-based LEO satellite IoT, which constitutes its unique development opportunities.
- Additionally, the conceptual network framework of LoRa-based LEO satellite IoT is illustrated. Furthermore, to obtain more intuitive insights into its feasibility and

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scalability, numerical simulations under practical deployment considerations are conducted.
- Finally, a range of open challenges are discussed to clarify the standardization progress and future research directions of LoRa-based LEO satellite IoT.

Opportunities of LoRa-Based LEO Satellite IoT

In this section, by providing a fundamental overview of LoRa technology and presenting the rapidly scaling LoRa ecosystem, the development opportunities of LoRa-based LEO satellite IoT are identified from both the technical and commercial perspective.

Overview of LoRa Technology

The LoRa PHY layer uses a derivative of CSS modulation patented by Semtech Corporation, which is commonly referred to as LoRa modulation. Although the LoRa PHY layer can be compatible with various MAC layer implementations, the LoRaWAN standard, which is developed by the LoRa Alliance, is arguably the most widely adopted protocol. Therefore, we detail LoRa technology and analyze its superiority for LEO satellite IoT.

1) LoRa Modulation: By taking the effective throughput and reception sensitivity into consideration simultaneously, LoRa CSS modulation can guarantee a compelling trade-off between data rate and coverage, thus optimizing the network performance at both link-level and system-level. For LoRa CSS modulation, the following four parameters need to be specified.

- **CF** is the carrier frequency of LoRa radio signals. Since LoRa operates in the unlicensed industrial, scientific and medical (ISM) bands (EU868 band, AU915 band, etc.), the configured CF must obey the corresponding regional regulations.
- **BW** is the occupied bandwidth of LoRa radio signals. Typical BW values are 125, 250, and 500 kHz in the ISM 868 and 915 MHz band [5].
- **SF** is the spreading factor of LoRa CSS modulation. It determines the processing gain which can be calculated as $G = 10\ \lg(2^{SF}/SF)$. A set of quasi-orthogonal SFs ranging from 7 to 12 are adopted, thus enabling multiple signals with different SFs to be demodulated at the same time on the same channel. Moreover, the raw data rate varies with the configuration of SF and BW, which can be calculated as $R_b = BW(SF/2^{SF})$.
- **CR** is the code rate adopted by forward error correction (FEC) in LoRa PHY layer whose value can be set to 4/5, 4/6, 4/7 or 4/8.

Facilitated by the above configurable parameters, LoRa modulation can support adaptive data rate (ADR) based on link quality and enable fine-grained quality of service (QoS) management. In addition, benefited from the superiority of CSS waveform characteristics, LoRa modulation shows great potential when applied to LEO satellite IoT with the following advantages.

- **Power Efficient:** CSS modulation is a constant envelope modulation scheme which is insensitive to the non-linear characteristic of power amplifier (PA). Moreover, the inherent processing gain of CSS enables the receiver to correctly recover the data information even when the received signal-to-noise ratio (SNR) is negative, which provides sufficient link budget for LEO satellite communications.
- **Interference Robust:** Due to the high time-bandwidth product of CSS signals, LoRa modulation is very resistant to both in-band and out-band interference. In general, nearly 90 dB adjacent channel interference suppression and over 20 dB co-channel interference suppression can be obtained [6], which is of great significance in bandwidth-limited LEO satellite communications.
- **Doppler Resistant:** For LoRa CSS modulation, the frequency offset tolerance is up to 25% of its BW. For example, when BW is configured as 125 kHz, the maximal tolerant frequency offset is ±31.25 kHz. Meanwhile, considering the velocity of LEO satellites is about 7.9 km/s, the maximum Doppler shifts for EU868 band and AU915 band are 22.86 kHz and 24.10 kHz, respectively.

Hence, the Doppler shift of LEO satellite communications can be tolerant by LoRa PHY layer.

2) LoRaWAN Protocol: The LoRaWAN protocol is a widely adopted LPWAN standard designed for LoRa-based networks. In order to accommodate the data transfer requirements of IoT EDs, LoRaWAN protocol is designed to prioritize the uplink communication and limit the downlink transmissions. Simple star-of-stars network topologies are adopted to simplify network deployment and maintenance, where gateways forward data packets between EDs and network server. Notably, the same data packet transmitted by an ED can be received by multiple gateways within the coverage. This diversity reception mechanism improves the packet delivery ratio and avoid the handover in LoRaWAN networks. To address the different requirements of a broad range of IoT applications, three operation modes have been defined by LoRaWAN protocol.

- **Class A:** Class A mode uses pure ALOHA access for uplink transmission, where each uplink transmission is followed by two short downlink receive windows. Although bidirectional communication is supported, downlink transmission is only allowed when a successful uplink transmission is realized. Class A is the most energy-efficient among the three modes, and all of the LoRaWAN EDs are required to be compatible with it.
- **Class B:** In contrast to Class A, Class B mode opens additional downlink receive windows according to periodic beacons broadcast by the gateway. This mode is more suitable for those applications that need scheduled downlink traffic. Typically, the power consumption of Class B mode is higher than Class A mode.
- **Class C:** Class C mode always opens the downlink receive window unless the uplink transmission is in progress. Hence, compared to Class A and Class B modes, the power consumption of Class C mode is the

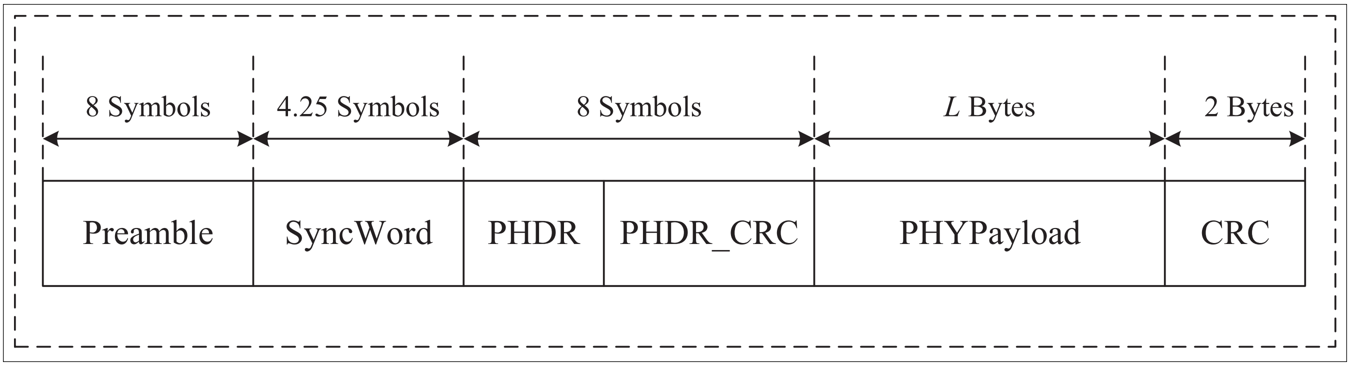

FIGURE 1. LoRa PHY packet structure.

highest, which can only be applied in mains powered applications.

In practice, the selection of operation mode is up to the specific application. However, with regard to LoRa-based LEO satellite IoT, only Class A and Class B mode can be implemented since the EDs are almost all battery powered in this scenario. Additionally, in order to be fully compliant with LoRaWAN protocol, each ED should configure its PHY data packet as depicted in Fig. 1. The LoRa physical header (PHDR) specifies the physical payload (PHYPayload) length in bytes (L) and the presence of an optional cyclic redundancy check (CRC) for the PHYPayload. For uplink transmission, the integrity of the PHYPayload is ensured using CRC.

LoRa Ecosystem

Until now, supported by its device manufacturers, solution providers, network operators, and system integrators, a global LoRa ecosystem has already been established, delivering interoperability needed to address heterogeneous IoT applications across the globe.

Originated from the development of its PHY layer technology, LoRa was gradually commercialized under the efforts of Semtech. Aiming at facilitating its development and occupying the IoT market, a global association called LoRa Alliance was founded in 2015, which actively promotes the standardization of LoRaWAN protocol. Benefited from the booming development of its ecosystem, LoRa has been widely adopted to address IoT applications with more than 160 network operators in over 170 countries. In 2021, the LoRaWAN protocol was officially recognized as a global standard for LPWAN by the international telecommunication union (ITU). The prominent market sectors of LoRa has involved smart metering, smart agriculture, smart city, and industrial IoT. According to IHS Markit's report, LoRa-based technology has been adopted by up to 43% LPWAN applications.

Inspired by its great success in terrestrial networks, the satellite IoT-oriented industrial initiatives have also emerged, which shows to be a promising evolution direction of LoRa ecosystem to facilitate remote vertical applications. For instance, the first LoRa-based satellite IoT network was deployed in Australia and Malaysia by Inmarsat and Actility, which is capable of realizing asset tracking, oil and gas exploitation, agribusiness and other specific applications. In addition, Swarm Technologies has integrated LoRa modules into its connectivity solutions to handle the two-way communications with LEO satellites. Moreover, a collaboration between Lacuna Space and Omnispace, which aims to deliver global LoRaWAN-based IoT service, has been announced. Obviously, both individuals and enterprises will benefit from LoRa ecosystem, where shorter research cycle and larger market share turn to be available.

Application Landscape

From the commercial perspective, the development of LoRa-based LEO satellite IoT is driven by the emerging demand-intensive vertical applications especially in rural and remote areas. In particular, these applications can be classified into three scenarios, namely environmental monitoring, supply chains and asset management, and energy development.

1) Environmental Monitoring: To monitor the environment, sensors are widely deployed to collect data, which is of great significance to ecological conservation like wildlife protection, pollution monitoring, and forest fire prevention. In this context, LoRa-based LEO satellite IoT can be utilized to provide ubiquitous connections regardless of the geographical divide. Moreover, in contrast to terrestrial networks which are easily paralyzed by natural disasters or malicious attacks, LoRa-based LEO satellite IoT can guarantee seamless communications even in emergency.

2) Supply Chains and Asset Management: Concentrating on identifying, locating and tracking the status of assets, LoRa has been deployed to make supply chains and asset management smarter, aiming to reap more value from the logistics. However, terrestrial LoRaWAN networks are insufficient to meet the seamless connection requirement. The main difficulty consists in linking remote sensors to the Internet across the huge geographical divide. For example, marine transportation, which accounts for almost 90% of global trade, can not be serviced by terrestrial networks. As an alternative, LoRa-based LEO satellite IoT can ensure real-time in-motion asset tracking, especially when ships, high altitude platforms, and unmanned aerial vehicles are taken into consideration.

3) Energy Development: Energy development has been receiving ever-increasing attention due to its importance in sustainable development of human society. With regard to this field, IoT-based intelligent surveillance, which appears to be effective in production efficiency improvement and pollution emission reduction, has been widely adopted in many energy industries. However, since the newly discovered fossil fuels and lately developed renewable energy are commonly distributed in remote areas, conventional terrestrial IoT networks will become powerless. In contrast, LoRa-based LEO satellite IoT can provide reliable solutions in this field, which can be utilized to various energy development scenarios, such as offshore oil wells, offshore wind farms, and desert solar power plants.

Conceptual Framework of LoRa-Based LEO Satellite IoT

In this section, we present the conceptual framework of LoRa-based LEO satellite IoT. Besides, numerical simulations are conducted to investigate its feasibility and scalability.

Network Architecture

The network architecture of LoRa-based LEO satellite IoT can be categorized into two classes, namely indirect access and direct access [7]. As for indirect access, a hybrid network involving terrestrial gateways and satellite backhauls is implemented, where the terrestrial gateways and satellite backhauls are utilized to collect data and transfer aggregated message, respectively. As for direct access, terrestrial EDs and space gateways deployed on satellites are directly connected via LoRa-based radio links. Due to the fact that terrestrial gateways are hard to be deployed in remote areas, we only focus on the direct access mode, the network architecture of which is illustrated in Fig. 2. As shown here, it consists of four links, i.e., LoRa-based user link, inter-satellite link, feeder link, and terrestrial backhaul.

1) LoRa-Based User Link: The LoRa-based user link refers to the radio link between terrestrial EDs and LEO satellites. This link mainly experiences free-space path loss (FSPL) and atmospheric impairments, the channel of which can be modeled using the combination of large-scale and small-scale fading. To depict the effect of large-scale fading over LoRa-based user link, classical log-distance path loss model is adopted in this article. Beyond that, small-scale fading is modeled using well-known Rician distributions, which arises from a line-of-sight (LoS) propagation. Moreover, the user link features highly dynamic transmissions in LEO satellite communications, the Doppler shift of which is basically tolerant by LoRa technology.

2) Inter-Satellite Link: For LoRa-based LEO satellite IoT, multiple LEO satellites collaborate together as a constellation to provide global coverage. Wherein, the inter-satellite links (ISLs) are employed to satisfy the stringent latency requirements of delay-sensitive applications (DSAs), such as real-time monitoring. Due to the transmission rate and security requirements, Terahertz (THz) and free-space optics (FSO) show to be the primary candidate technologies for ISLs. However, due to its inherent self-organized network construction and operation, the coexistence problem arises with the dense deployment of LEO satellite constellations for this new paradigm. The coordination mechanisms between the ever-increasing constellations deployed by various enterprises are quite essential to mitigate the inter-network interference. Furthermore, the routing strategies for DSAs under time-varying network topology through multiple co-existing ISLs are also important.

3) Feeder Link: Due to the resource limitation of LEO satellites with respect to power, spectrum, and hardware, it appears to be impractical to only process onboard. Therefore, the aggregated data need be transferred to the ground station via feeder link and then handled by the core network. The existing feeder link mainly operates in Ku/Ka-band, Q/V-band, and W-band. In addition, FSO has also been regarded as an alternative [8].

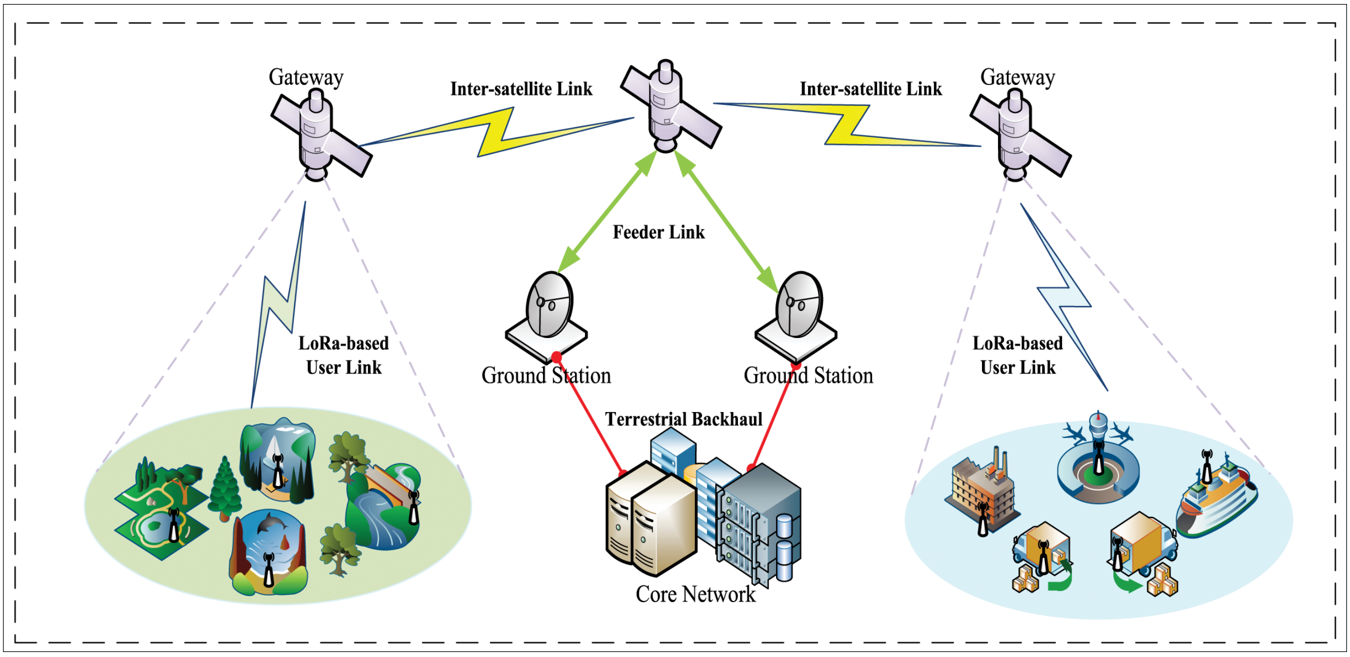

FIGURE 2. Conceptual framework of LoRa-based LEO satellite IoT.

4) Terrestrial Backhaul: In terrestrial segment of LoRa-based LEO satellite IoT, the core network, which is mainly composed of network server (NS) and application server (AS), acts as the brain of the entire system (i.e., LoRa Cloud). In particular, to coordinate ground stations with the core network, terrestrial backhaul is employed, which can be implemented by either wired (e.g., optical fiber) or wireless (e.g., cellular network) approaches.

Simulation Setup of LoRa-Based User Link

In this subsection, to investigate the feasibility and scalability of LoRa-based LEO satellite IoT, numerical simulations concerning LoRa-based user link are conducted, where the transmission parameters are listed in Table 1.

1) Traffic Model: Throughout our work, the LoRa-based user link (i.e., LoRa CSS modulation) is assumed to be operated at EU868 band, where there are 16 predefined uplink channels with a bandwidth of 125 kHz. Besides, the maximum effective isotropic radiated power (EIRP) is set to be 16 dBm [9]. Without loss of generality, the terrestrial Class A LoRa EDs, the number of which ranges from 2×10^4 to 2×10^5, are uniformly distributed within one satellite spot beam, and each ED randomly selects one predefined channel for transmission. For simplicity, we assume that each ED has a fixed SF configuration, where SFs ranging from 7 to 12 are equally assigned to the EDs. Moreover, to satisfy the limitation of radio duty cycle (e.g., ≤1%), each ED transmits its data packet once an hour, while the total simulation time is 24 hours. The structure of the data packet follows LoRaWAN protocol, which is shown in Fig. 1.

2) Channel Model: Without loss of generality, we assume that the LEO satellite operates at an altitude of 500 km in a circular orbit. Considering the LoS propagation characteristics, the satellite-to-ED channel of LoRa-based user link is modeled using the combination of large-scale log-distance path loss and small-scale Rician fading. To be noticed, the Rician factor (K) is time-varying, which is determined by ED's elevation angle [10].

3) Performance Metric: To evaluate the uplink access performance of LoRa-based user link, the access probability, which denotes the probability of successful access, is utilized. In particular, due to the capture effect, a successful access occurs only if the SNR and signal-to-interference ratio (SIR) of the received data packet exceed the demodulation thresholds. The SNR demodulation thresholds for SF range from 7 to 12 are −6, −9, −12, −15, −17.5, −20 dB, respectively. Moreover, since different SFs are considered to be quasi-orthogonal, we only consider the packet collisions on the same channel with the same SF, where the SIR demodulation threshold is set as 1 dB [11].

Simulation Results and Solution Analysis

Concerning the access probability (P_s) versus spreading factor (SF), the length of PHYPayload (L), and elevation angle (E), numerical simulations are carried out to demonstrate the feasibility and scalability of LoRa-based LEO satellite IoT. In addition, some potential solutions to improve system performance are presented.

Frequency band	EU868 band
Bandwidth (BW)	125 kHz
Channels	16
Spreading factor (SF)	7, 10, 12
Code rate (CR)	4/5
PHYPayload (L)	10,50 bytes
Duty cycle	≤1%
Maximum EIRP	16 dBm
Satellite antenna gain	10 dBi
Low noise amplifier gain	16 dB
Satellite orbital height (H)	500 km
Elevation angles (E)	20°, 50°, 80°
Number of EDs (N)	2×10^4 ~ 2×10^5

TABLE 1. Simulation parameters of LoRa-based user link.

Fig. 3 illustrates the access probability for a specific elevation angle (e.g., E = 80°), which shows the impact of SF and L on the access performance. It can be observed that the P_s for SF = 7 is always higher than 0.9 regardless of N, which demonstrates the feasibility of LoRa-based user link. However, due to the fact that the Time on Air (ToA) of a data packet increases as the increase of SF and L, multiple access interference (MAI) and packet loss therefore become more serious. As a result, P_s drops sharply as the increase of SF and L, which is the same as the phenomenon in terrestrial LoRaWAN networks [12]. In fact, as the main challenge of scalability, the ALOHA-based MAC layer protocol limits massive access seriously. To tackle this problem, it is of great significance to design a more efficient multiple access scheme for LoRa-based LEO satellite IoT, which will support a massive number of EDs contending for network access. Hereby, multiple access solutions are considered from two aspects, namely link coordination and multi-user detection.

- **Link Coordination:** To eliminate the MAI, a more efficient MAC layer protocol beyond ALOHA should be designed to coordinate links. As such, one solution is to incorporate time division multiple access (TDMA) into the MAC layer protocol, which is particularly effective to handle periodic data traffic via proper scheduling. To improve the applicability and practicability, low complexity scheduling algorithm is also required, which should juggle the satellite availability, the satellite footprint, and the specific distribution of EDs. Besides, grant-free random access exemplified by grant-free non-orthogonal multiple access (NOMA) tends to be another alternative to mitigate the MAI [13].
- **Multi-User Detection:** Due to the sporadic data transmission and dynamic channel, packet collisions are inevitable. Moreover, packets from different EDs can share the same channel and SF, and can even be received at the same time. Under this case, the packet with strongest power can be detected while other packets are lost, which is known as capture effect. To recover data from the superposed LoRa signals caused by collision, multi-user detection (MUD) is

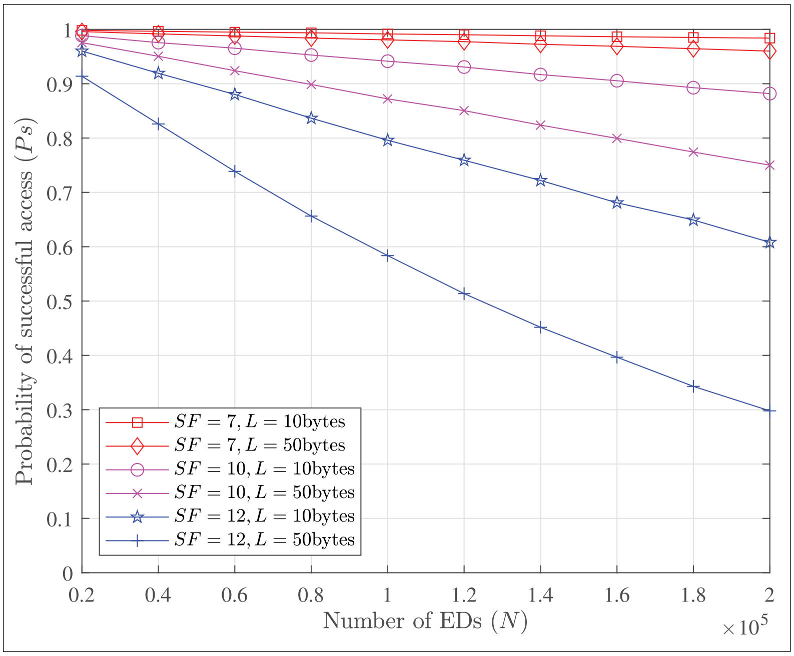

FIGURE 3. The access probability P_s for $E = 80°$ considering the impact of SF and L.

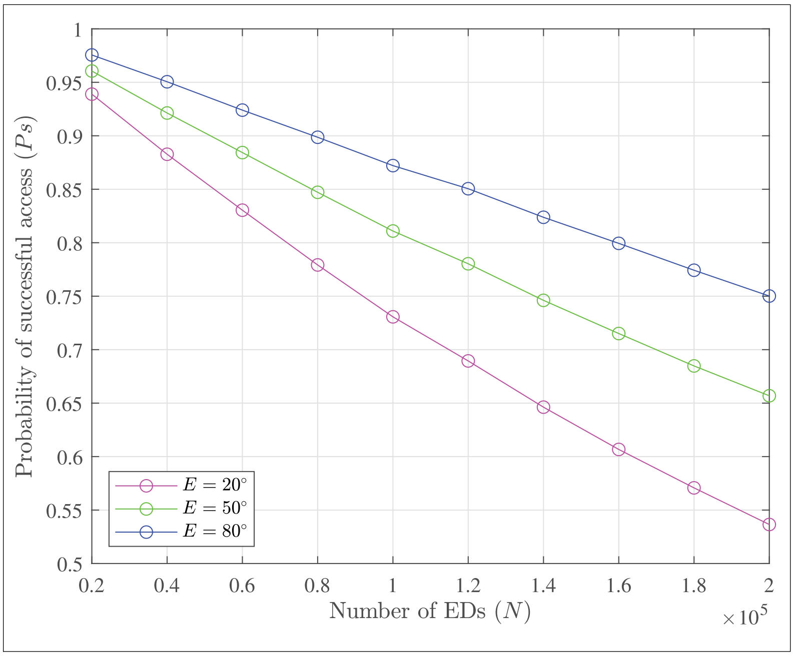

FIGURE 4. The access probability P_s for $SF = 10$ and $L = 50$ bytes considering the impact of E.

required, which makes all the useful packets could be retrieved from the superposed signals. Moreover, facilitated by the combination of grant-free NOMA and dedicated MUD algorithms, the overall network capacity can be significantly improved.

Fig. 4 demonstrates the influence of elevation angles on the access performance. Obviously, the access probability always increases with the increase of E, which reveals that the network performance can be enhanced by suitable constellation design.

- **Constellation Design:** To improve satellite availability, the constellation should be well designed for LoRa-based LEO satellite IoT to guarantee that each ED has a satisfactory elevation angle. However, the emerging state-of-the-art satellite constellation involving tremendous amounts of satellites, such as Starlink, is not suitable for this new paradigm. Even based on the low-cost CubeSats, the deployment of such a dense constellation shows to be unaffordable and unnecessary. Accordingly, a properly designed sparse constellation with fewer satellites would contribute to the resource-constrained IoT network. Moreover, aiming at satisfying the diversity of QoS requirements of IoT services, such as data traffic (periodic or aperiodic), latency requirements (delay-tolerant or delay sensitive), etc., application-oriented constellation should be taken into consideration during the design of LoRa-based LEO satellite IoT.

Challenges and Research Directions

The above analysis has confirmed the unique opportunities and great potential for LoRa-based LEO satellite IoT. However, to further promote its development, more relevant studies are still needed. In this section, some open research questions are concisely outlined to engrave our vision of LoRa-based LEO satellite IoT in the coming future.

MIMO-LoRa and Beamforming Schemes

As a main drawback of LoRa, the relatively low data rate will undoubtedly restrict its application prospects, especially in the upcoming high-data-rate IoT era. To tackle this challenge, one feasible solution is to combine LoRa with multiple-input multiple-output (MIMO) techniques to obtain additional spatial degree of freedom (DoF). However, the analytical framework of MIMO-LoRa and beamforming schemes for LEO satellite IoT has not been well explored yet. Moreover, it is also important to make an appropriate compromise between multiplexing and diversity (e.g., a tradeoff between power and spectral efficiency) under the framework of MIMO-LoRa to fulfill the QoS requirements of different IoT applications.

AI-Enabled Paradigm Design and Optimization

To coincide with the unprecedented transformation empowered by the large language model (LLM), AI-enabled paradigm design and optimization will become the holy grail for the future LoRa-based LEO satellite IoT networks [14]. Facilitated by cognitive radio, smart link adaptation, as well as edge computing, AI-based intelligent interconnections are able to collect valuable data for informed decision and automatic optimization. Moreover, AI-based encryption and authentication mechanisms are able to mitigate security vulnerabilities arising in heterogeneous vertical domains. Therefore, how to design an efficient, reliable, and safe protocol stack supported by AI is a pivotal problem to be contemplated for the future LoRa-based LEO satellite IoT networks.

Space-Terrestrial Cooperation and Standardization

The cooperation of LoRa-based LEO satellite IoT and terrestrial LoRaWAN networks will contribute to a LoRa-based integrated space-terrestrial

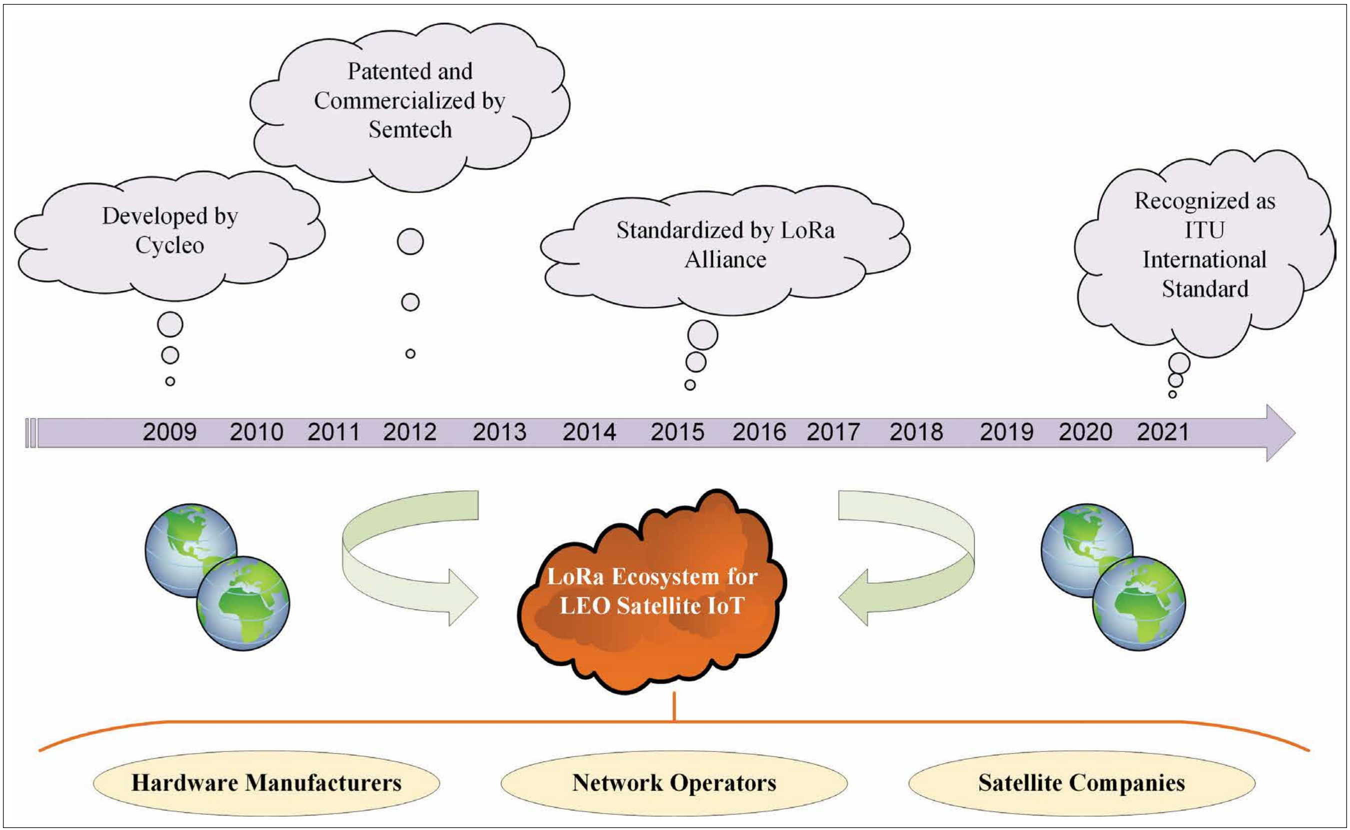

FIGURE 5. Standardization progress of LoRa-based LEO satellite IoT.

(IST) IoT network. As witnessed for the terrestrial LoRaWAN networks, the key for the success of LoRa-based LEO satellite IoT exists in a more generalized standardization [15]. The current standardization progress is illustrated in Fig. 5. However, there are still some open challenges in this respect.

- Should the terrestrial and spatial networks share the same spectrum for user link (e.g., LoRa-based radio link)?
- How to mitigate or even eliminate the intra-network interference in the integrated space-terrestrial networks under the condition of spectrum sharing?
- Whether the handover between satellite and terrestrial access should be implemented in the integrated network?
- How to manage the network between spatial and terrestrial segments in a reasonable way to make the entire system more efficient and robust?

Therefore, novel technical standards for LoRa-based LEO satellite IoT should be further investigated in the future.

Conclusion

In a summary, driven by global digitization, LoRa-based LEO satellite IoT is expected to experience a remarkable boost in the coming years. In this article, we have presented a comprehensive investigation of this new paradigm including its development opportunities, network framework, and open research directions. We have also characterized its feasibility and scalability by numerical simulations using realistic system parameters. It is highly anticipated that this article will inspire more relevant research on LoRa-based LEO satellite IoT and promote its massive deployment.

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