Satellite-Enabled IoT, Low-Earth Net Centric and Its Applications for Thailand

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ABSTRACT

The IoT (Internet of Thing) is widely used in variety terrestrial applications of industrial sector, socio-economic sector and service sector. Traditional MSS (Mobile Satellite Systems) and FSS (Fixed Satellite Systems) have developed M2M and IoT services. However, the new space is now covering a globally emerging private spaceflight industry, particularly satellite enabled IoT with low cost, low power, low latency, makes well suited for direct to satellite services. In addition, the expansion of the satellite constellations that allow for global connectivity. This paper presents an approach for space IoT net centric in LEO (low earth orbit) to enable IoT services over Thailand and South East Asia. The holistic system is designed from requirements-driven of downstream applications. The mission requirement and constraint are addressed. The bus system of 6U platform and IoT payload are designed. The constellation of 8 satellites in two orbital planes near equatorial orbit is proposed with simulated orbit tracking.

Keywords: *Satellite enabled IoT, IoT applications, satellite system engineering, satellite LEO constellation*

1. IINTRODUCTION

Over the past decade, the space industry has been leveraging various opportunities from a variety demanding of industrial sector, socio-economic sector and service sector. In addition, the new space is now covering a globally emerging private spaceflight industry. Nevertheless, the heavy competition, lower prices and dwindling margins of satellite services market in voice, broadband IP connectivity and broadcasting, causes the satellite operators and manufacturers are seeking the innovative emerging applications.

Today, wireless systems are being increasingly deployed in various areas, industrial and home automation applications, smart farming, environment monitoring etc. These systems made use of transmitting-sensor data and control information across network infrastructures. In the era of the Internet of Things (IoT), people and things can be intelligently connected, leading to innovative applications.

Currently, the majority of IoT networks is for terrestrial services. The IoT innovative applications will provide various opportunities for established and newfound satellite operators. Especially in connecting remote areas that lack terrestrial infrastructure. From the research at ABI Research [1], terrestrial cellular networks only cover 20% of the Earth's surface, while satellite networks can cover the entire surface of the globe, from pole to pole. According to Statista, the number of IoT devices is projected to grow from around 10.7 billion devices today to up to 50 billion devices in 2030 [2]. The expansion of the satellite constellations that are currently in orbit and those due to take place will allow for connectivity to be more global. While the applications using satellite connection is still immature, it shows great opportunities for growth. This insisted by Riot Research, the global satellite IoT market will grow to more than US$ 5.9 billion in 2025, after taking off in the 2021-2022 period. This gives a broader picture of why many companies are investing in satellite IoT applications [3].

The substantial benefits of making use the satellite IoT compared to terrestrial IoT, are listed as follows

- connecting remote environments
- wide area coverage
- reliability and integrity in critical circumstances

- affordable for accessibility and operationality

Opportunities range from additional capacity on GEO (geostationary) satellites in C, Ku and Ka-band for direct or backhaul connectivity to deploying new LEO (low earth orbit) or HEO (highly elliptical orbit) constellations, optimised for the IoT demanding [4].

Traditional MSS (Mobile Satellite Systems) , Inmarsat, Thuraya, Iridium, Globalstar, have been dominant in the L-band M2M/IoT services, particularly on mobile and maritime applications. In the last 10 years they realised 3.5 - 4 million satellite IoT terminals in the field. Whereas FSS (Fixed Satellite Systems), Eutelsat, Intelsat or Asiasat have developed M2M and IoT services over Ku/Ka band.

IoT using GEO satellites: The challenge for using such GEO satellites in IoT applications is the path loss between Earth and satellite, and the slotted nature of the GEO orbit. This requires the large antenna with appropriate gain following the estimated link budget, and sufficient directivity to avoid interference into adjacent satellites and systems. However, on the other hand, typical IoT applications require low cost and small size terminals and should not necessitate any manual pointing toward a satellite.

IoT in LEO/HEO constellations: The LEO and HEO constellations operate closer to earth than GEO. Therefore, less power and smaller antenna are required due to less path loss. However, the higher relative velocity between LEO/HEO satellites and IoT terminal will cause a highly time variant communication channel. Thus, the IoT terminal operating in a LEO or HEO network requires both a waveform tailored for the specific communication channel and suitable antenna design.

There are two types of satellite which can enable IoT connectivity service [5].

1) Sat-IoT Backhaul Services: the satellite IoT services is currently making use of the ultra-low cost terrestrial radio transmission standards such as LoRa, Sigfox, LTE-M or NB-IoT. These networks come with low cost localised gateways to serve the larger numbers of IoT devices surrounding area of interest. For the satellite industry connecting these gateways is leading to a new satellite application segment.

2) Direct to Satellite services: the low cost and low power of IoT sensing devices can directly send the information to satellite. This type of service is ideal for wide area sensor network with sensors dispersed over wide geographical territory. The low power feature is important as they are mostly deploying in remote areas, and the low cost will enable massive networks with new data-points around the world to feed the data-analytics servers in a wide range of industries.

An alternative choice is a hybrid terrestrial-satellite system. The hybrid system is making use of many low-cost terrestrial IoT devices in combination with few satellite connected aggregation terminals. The use of terrestrial IoT technology allows to meet the cost point while the few satellite-connected aggregation terminals provide ubiquitous connectivity.

The new space companies active in IoT include Astrocast, Hiber, Kepler Communications, Kineis, Lacuna, Myrioata, and Swarm technologies. It's feature with low cost, low power, low latency, makes them well suited for direct to satellite services.

This paper will initiate an approach of LEO net centric to enable satellite IoT, and potential applications for Thailand. The design of small satellite to enable IoT in space, is proposed. The space IoT net centric will provide coverage area over Thailand and South East Asia.

2 REQUIREMENT-DRIVEN APPROACH

This part describes an approach for designing the satellite engineering system, which is driven from the requirements or demanding. The potential applications from variety sectors will be emerged to draw the holistic view.

2.1 SMART GRID MANAGEMENT

From the world bank report, during the 1990s, a new paradigm for power sector reform was put forward emphasising the restructuring of utilities, the creation of regulators, the participation of the private sector, and making the establishment of competitive power markets [6]. Additionally, the new innovative technologies were invented and utilised in the power management. Power quality and reliability issues are big challenges to both service provider and consumers in conventional power grids. The ongoing technological advancements in the IoT provide better solutions to enhance the management of these challenges and enforce the measures of a smart grid (SG) [7]. By adding IoT devices and infrastructures, advanced metering infrastructure (AMI) and smart metering (SM) technologies, are enabler technologies that can modernise the conventional power grid through exposing the hidden details of electrical power by introducing two-way communication scheme during power transaction process between utilities and consumers [8] as shown in Fig 1.

From Fig. 1, a bidirectional flow of information is needed among the different actors of the grid at different points. The elements of a smart grid are already available, including smart meters, automated monitoring systems, and power management systems. The communication network has a crucial role and its cost and performance will greatly influence utilities revenues and the capability of the new grid to meet its ambitious objectives. The communication network will be heterogeneous, including wired and wireless segments, and private and public solutions.

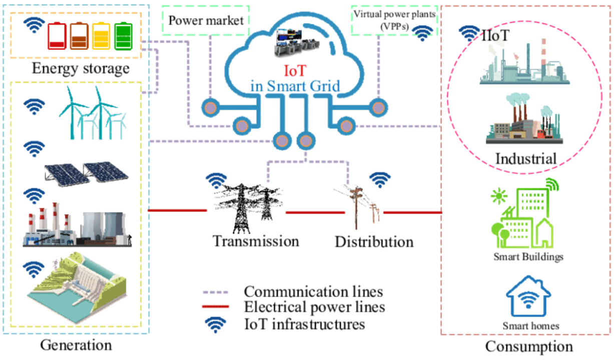


***Fig. 1** The paradigm of IoT in smart electrical grids (from https://www.researchgate.net/figure/The-paradigm-of-IoT-in-smart-electrical-grids_fig1_331103655)*

In this framework, satellite could represent a viable and cost effective solution in different scenarios, such as the following [9].

- structural and functional monitoring of offshore environments
- farms or solar energy systems in desert areas.
- remote monitoring and automated control of substations located in remote areas.

As a matter of fact, satellites are already used by utilities in the current grid and also by other types of companies involved in the deployment of renewable energy generation.

In particular, M2M (machine to machine) via satellite is mainly used today for:

- providing back-up links, when high reliability is required and
- remote monitoring and automated control of substations located in remote areas.

2.2 SMART AGRICULTURE

IoT based smart agriculture will improve the entire agriculture system by monitoring the field condition in real time. Using IoT sensors and interconnectivity, the farmers time and extravagant use of resources such as water, fertiliser, and plan seeds, will be significantly reduced. Nevertheless, the natural factors like climate conditions, humidity, temperature, wind, soil, plant disease and insect pests etc., need to be observed and traced for crop management.

An example of IoT platform for the real time monitoring of citrus soil moisture and nutrient, shows in Fig. 2 [10]. The design system is divided into four layers: perception layer, network transmission layer, information service layer, and application layer.

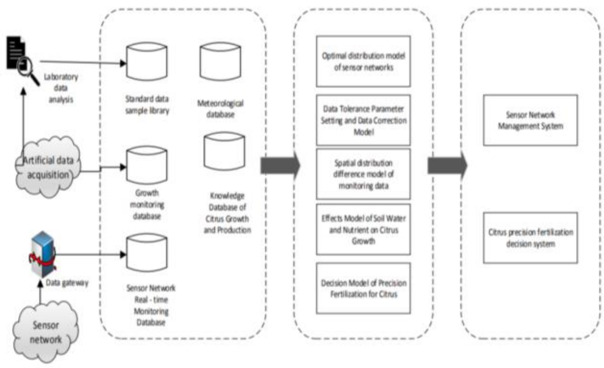


***Fig. 2** IoT Architecture for soil humidity and nutrients monitoring.*

The literature of IoT basic platforms for precision agriculture are reviewed in [11]. The most common IoT applications in smart agriculture are [12]:

- sensor-based systems for monitoring crops, soil, fields, livestock, storage facilities, or basically any important factor that influences the production.
- smart agriculture vehicles, drones, autonomous robots and actuators.
- connected agriculture spaces such as smart greenhouses or hydroponics.
- data analytics, visualisation and management systems.

2.3 SMART ENVIRONMENTAL MONITORING

With new technology, various sensors and smart devices can be exploited to obtain different measurements from the environment. The measured parameters are collected by an IoT platform through dedicated gateways (or direct to satellite) for monitoring and analytics. The cases in environmental monitoring are

- Monitoring air for quality, carbon dioxide and smog-like gasses, carbon monoxide in confined areas, and indoor ozone levels.
- Monitoring water for quality, pollutants, thermal contaminants, chemical leakages, the presence of lead, and flood water levels.
- Monitoring soil for moisture and vibration levels in order to detect and prevent landslides.
- Monitoring forests, land used, protected land for forest conservation and forest fires.
- Monitoring for natural disasters like drought, earthquake and tsunami warnings.
- Monitoring fisheries for both animal health and poaching.
- Monitoring data centers for air temperature and humidity

An example of water and wastewater treatment and management system shows in Fig. 3.

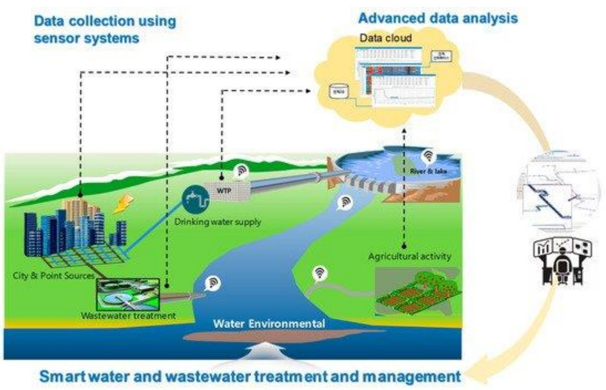
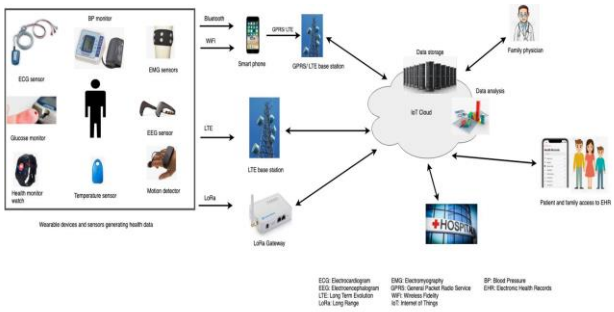


***Fig. 3** Water and wastewater treatment and management system https://www.mdpi.com/2073-4441/12/2/510/htm*

2.4 SMART HEALTHCARE

Digital healthcare systems (DHS) leverage EHRs (electronic health record) by using IoT devices to seamlessly connect patients and providers across diverse healthcare systems. Data received from IoT devices is typically recorded in a wide variety of formats (numerical, text, multimedia). A connected health scenario consists of heterogeneous connected components including user devices, networks, systems (with large data volumes), variety and velocity (collected from various sources), and veracity (uncertain data). Digital health systems need to be designed using suitable data-driven learning techniques to handle its continuously varying cyber-physical components. Proper analysis of data can give valuable information about patients' health conditions.



Sources: Gopi and Hwang (2016), Zagan *et al.* (2017), Yang *et al.* (2016)

***Fig. 4** Smart healthcare system*

The examples of IoT in healthcare are

- Cancer treatment

The IoT enabled weight scale and blood pressure cuff measurement, together with a symptom-tracking app, can be used to send updates to patients' physicians on symptoms and responses to treatment every weekday.

- Smart continuous glucose monitoring (CGM) and insulin pens

The CGM device helps diabetics to continuously monitor their blood glucose levels for several days at a time, by taking readings at regular intervals. Smart CGMs send data on blood glucose levels to an app on smart devices, allowing the wearer to easily check their information and detect trends. It also allows for remote monitoring by caregivers, which could include the parents of diabetic children or the relatives of elderly patients.

critical applications are the emergency and important services which need the availability of the networks all the time. Examples of mission critical applications are: disaster management during calamities, military data collection and transmission, real time control of important systems. These systems cannot afford the absence of the network for even a short time. During the natural disasters such as floods, cyclones, hurricanes and landslides, the wireless infrastructures are directly affected. Very often the networks go out of operation for days and in some cases even for months. However, the satellites are immune to these problems. That is why satellite based IoTs are preferred for the situation when the infrastructure is vulnerable to the natural disasters.

3 MISSION REQUIREMENT AND CONSTRAINT

Several critical applications in emergency and important services such as disaster management, command and control in military missions, and real time control of important systems, require the availability of the networks all the time. These services cannot afford the absence of the network for even a short time. During the natural disasters such as floods, forest fire, cyclones/ typhoon, and landslides, the wire and wireless infrastructures are directly affected. The satellite network/ constellation can be used to mitigate these problems. Therefore, the network or constellation of satellite enabled IoT is preferred for the circumstances when the ordinary telecommunication infrastructure is vulnerable to the natural disasters [13].

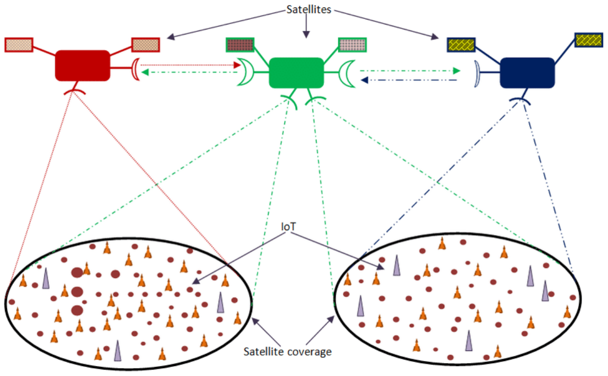


Fig. 5 *Satellite enabled IoT constellation [13]*

Another important factor is the use of allocated frequency band for IoT services. Recently, the NBTC (National Broadcasting and Telecommunications Commission) announced at least three regulations which relate to the terrestrial IoT services.

1) Regulations for using the 920-925 MHz frequency band.
2) Technical standards of telecommunication and radio equipment for the category of Radio Frequency Identification (RFID)
3) Technical standards of telecommunication and radio equipment for non-RFID which uses the 920-925 MHz frequency band.

From these regulations, the satellite enabled IoT services should to have the approval license. However, the constraint is that the 920-925 MHz frequency band is allowed for terrestrial IoT services only. NBTC allows the 435-438 MHz for uplink to satellite. Therefore, the service provider in Thailand has to config the IoT devices to the 435-438 MHz for direct link / gateway to satellite.

4 DESIGN APPROACH

4.1 SATELLITE SYSTEM

A designed 6U cubesat for IoT applications is shown in Fig. 6.

The bus system has redundant module to ensure the satellite operations in space. The IoT payload has both services; direct receiving from sensor devices, and receiving from ground gateway (in the case of different frequency band to the direct receiving service). The IoT payloads onboarded spacecraft possibly make use of LoRa technology. The reason is that LoRa can communicate more hundred kilometers and far further compared to other technologies (at a few hundred milliwatts of power transmission) . Moreover, LoRa technology has been demonstrated onboarded spacecraft in several missions [14] [15] [16].

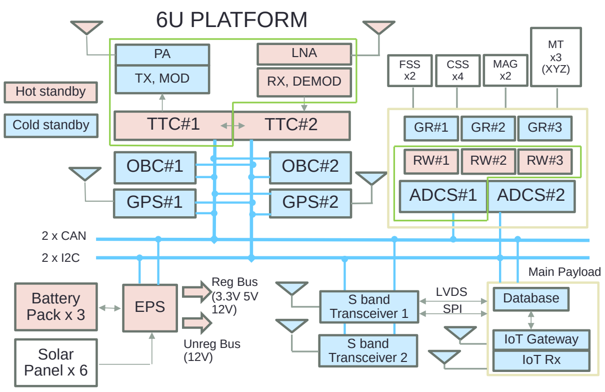


Fig. 6 *A 6U cubesat for IoT applications*

The satellite system can be redesigned to fit with 3U platform. However, the redundant module for bus and payload has to be removed.

Acronym

ADCS: Attitude Determination and Control System	LNA: Low Noise Amplifier
CAN: Controller Area Network	MAG: Magnetometer
CSS: Coarse Sun Sensor	MT: Magnetorquer
EPS: Electrical Power System	OBC: On Board Computer
FSS: Fine Sun Sensor	PA: Power Amplifier
GR: Gyro	RW: Reaction Wheel
I²C: Inter-Integrated Circuit	RX: Receiver
LVDS: Low-Voltage Differential Signaling	TT & C: Telemetry Tracking and Command
	TX: Transmitter

4.2 PROPOSED ORBIT FOR SPACE IOT NET-CENTRIC

To cover the whole part of Thailand and achieve more revisiting per day, the satellite orbit has to capable for servicing the region along the equator within 25-30 degrees latitude [17].

A constellation of two orbital planes for 8 satellites to provide 24 hours of near-real time satellite enabled IoT, over the equatorial region was proposed as shown in Fig. 7. The orbit design was a low orbital inclination at 25 degrees, and 600 km altitude. The first plane consisted of four 6U satellites separated in time. The second plane consisted of four 6U satellites. The satellite orbits were simulated in 25 degrees inclined orbit (red line) at 600 km as shown in Fig. 8.

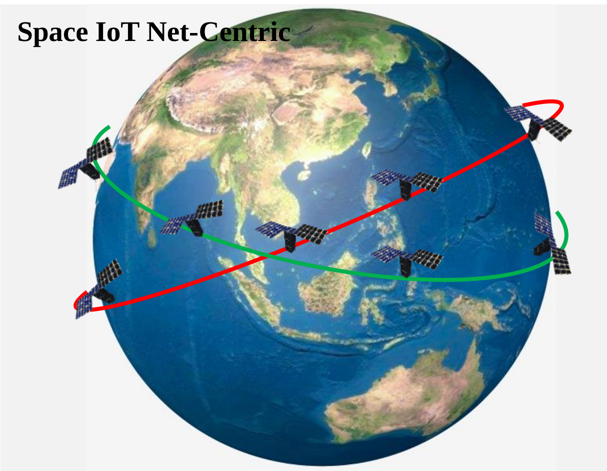


Fig. 7 Constellation of two orbital planes for 8 satellites to provide 24 hours of near-real time satellite enabled IoT

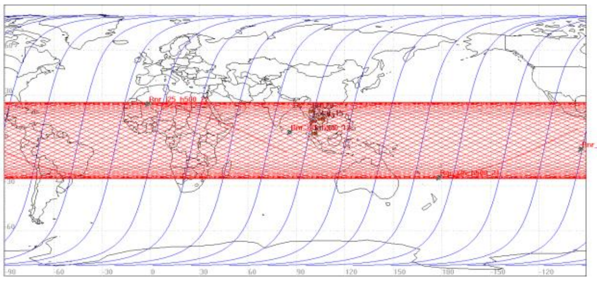


Fig.8 *25 degrees inclined orbit at 600 km altitude*

5 CONCLUSIONS

This paper presents the motivations and opportunities of satellite enabled IoT. The traditional satellite and new space for IoT applications are reviewed. The use cases and constraints of the IoT via satellite in GEO (geostationary orbit), HEO (highly elliptical orbit), and LEO (low earth orbit) are described. The potential applications such as smart grid management, smart agriculture, smart environmental monitoring, and smart healthcare are introduced and set as the requirements-driven to enable satellite IoT via LEO for Thailand. An initiative approach of LEO constellation for forming space IoT net centric is proposed with 8 satellites in two orbital planes. The preliminary simulated orbit tracking is presented.

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