Design and Simulation of Separate Broadcast Control Architecture of Satellite Delay Tolerant Network for Mass Sensors

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Abstract. Satellite IoT, a combination of satellite and the IoT, will promote the unattended operation and intelligent control of systems and equipment, and provide communication support for the management of everything ubiquitously. Many countries value the research and construction of satellite IoT, for it has broad market prospects. Yet there are problems of excessive delay and bandwidth limitation in the satellite IoT. Therefore, this paper will study the satellite-tolerant network separation broadcast control architecture for mass sensors. Firstly, it analyzes the development situation and challenges of satellite IoT under the new generation of communication, summarizes the development of 5G satellites and IoT, and comprehensively analyzes the component of satellite IoT, based on which it proposes a satellite delay network separation and broadcast control method for massive sensors. Based on the software-defined network, the satellite IoT architecture was innovated, and the dynamic layered protocol and interaction process of the satellite IoT was designed. Through OPNET simulation, the architecture of this paper is improved in terms of resource utilization efficiency and latency.

1. Introduction
Satellite IoT can organically integrate different scale communication methods to achieve the ultra-long-distance cooperation of large-scale communication coverage to small-scale communication, which will promote the unattended operation and intelligent control of systems and equipment, and provide communication support for the management of every resources ubiquitously. Satellite IoT is a combination of satellite and IoT, whose development will greatly promote the key technologies such as satellite manufacturing, satellite navigation, driverless, artificial intelligence, big data, wide-area narrowband low-power wireless communication, and 5G.

Many countries value the research and construction of satellite IoT. 3GPP has included the use of satellites as the control information broadcasting channel of the IoT into the construction of 5G, which has become a crucial demonstration content for communication giants in various countries. OneWeb Inc. of the United States plans to launch more than 10,000 small satellites to form a space-based broadband communication network, an important part of which is providing control messages for the IoT. The European Space Agency plans the ARTES satellite project to build interoperability with wearable devices via satellite construction.

The use of satellites for wide-area control of the IoT have broad market prospects. With the promotion of 5G and the development of smart cities, lots of IoT devices will provide important
functions such as information storage and location tracking, and the number will increase dramatically. Machina Research predicts that the market size of satellite IoT will reach 3 trillion yuan in 2025, and about 27 billion devices will be connected via satellite.

The current research can be divided into three stages: basic architecture construction, communication quality optimization, and service cost reduction. In terms of basic architecture construction, sensor terminals can be grouped by satellite to search for sensor terminals that need to transmit data, and the data acquisition rate is of a high speed; based on the architecture of satellite and ground phased array ground stations, high-throughput transmission with low cost can be realized, yet the data collection stability of the terminal cannot be ensured. In terms of communication quality optimization, satellite IoT based on CoAP protocol stack has a relatively shorter construction period, but further optimization is needed under high-speed code rate; the satellite IoT based on LEO constellation can realize unified cross-layer routing and switching design. But we need to improve the security and low power consumption of IoT applications. In terms of service cost reduction, the selection of an appropriate data exchange format can effectively reduce the signaling specifications and greatly cut down the average data rate. The new forward link multiplexing scheme based on constellation coding and decoding can achieve the optimal spectrum utilization efficiency. However, it needs to be guaranteed at a higher signal-to-noise ratio.

In summary, the current satellite IoT research has the following major problems:
1) In the satellite IoT architecture, the transmission delay of satellite links is large, while the real-time requirements of the IoT are high, which cannot meet the requirements of integrated service quality.
2) The amount of IoT terminals is extremely large, while the bandwidth of satellite communication is limited, hence the problem of how to ensure the control and coordination of massive terminals has drawn the attention.

In the light of the problem of excessive delay and bandwidth in satellite IoT, this paper will study the satellite-tolerant network separation and broadcast control architecture for massive sensors. Firstly, it analyzes the development situation and challenges of satellite IoT under the new generation of communication, summarizes the development of 5G satellites and IoT, as well as comprehensively analyzes the component of satellite IoT, based on which it proposes a satellite delay network separation and broadcast control method for massive sensors. Based on the SDN, the satellite IoT architecture was innovated, and the dynamic layered protocol and interaction process of the satellite IoT was designed. Through OPNET simulation, the architecture of this paper is improved in terms of resource utilization efficiency and latency.

2. The development and challenge of satellite IoT

2.1 Latest developments of 5G satellite

5G satellite is expected to play an important role in wide-coverage communication, high-throughput transmission and large-scale access. The European Union has established a technology platform named NETWORLD2020, which aims to deepen the integration of terrestrial networks and satellite networks to develop a comprehensive 5G standard structure called 5GPP. The NETWORLD 2020 [1] satellite working group believes that satellite networks will be integrated in other networks to provide reliable 5G services at an affordable cost worldwide. With the inherent advantages of satellite networks, satellite networks will help enhance 5G service capabilities and support the multimedia business growth, ubiquitous coverage, M2M communication and key telecommunications mission-related challenges. Under the condition of isolation at a certain distance, the services of the satellite service earth stations such as 5G and EESS can coexist in the corresponding frequency bands with a certain interference margin. And when 5G is deployed, satellite and terrestrial systems can implement a multi-carrier waveform (EW-SC-OFDM [2], BF-OFDM [3]) as the shared spectrum of the candidate satellite physical layer. The ESOA organization believes that the three key features of satellite network (wide-area coverage, low cost, and high reliability) enable satellite networks to promote 5G services in areas that are not covered by terrestrial networks, and to improve the performance at lower cost in areas
with insufficient service performance. It also provides continuous communication services on mobile platforms such as vehicles, aircraft, ships, and high-speed trains, and improves the scalability of 5G networks by providing efficient global multicast/broadcast coverage resources for data transmission, creating a secure economical and ubiquitous communication system. In June 2017, 16 organizations (such as BT, SES, and University of Surrey), including satellite industry manufacturer, operator, and university, jointly established the SaT5G [4] alliance. The alliance aims to explore the best solutions for seamless communication between satellite communications and 5G within 30 months through a series of research, development and experiments, as well as conduct trials in Europe. The results of the alliance will greatly affect the development of 5G standard content.

2.2 The latest development of IoT communication technology

IoT communication has gradually expanded from basic theoretical research to practical applications, including cellular-based LPWA eMTC, EC-GSM-IoT, NB-IoT [5], and non-cellular LPWA technologies. LoRa, SigFox, and Ingenu-RPMA [5], as well as 5G, are playing crucial roles in their respective fields. Based on WSN, IoT is taken as the platform, the CCN [6] routing and forwarding mechanism can be implemented simultaneously with MobCCN and an icn-compatible protocol for heterogeneous environments, thereby enabling information inter-node communication. Utilizing the destination channel routing from the LBR to the cognitive radio network, based on the hybrid control channel-based cognitive AODV routing protocol with directional antennas, the restricted IoT data can be randomly transferred to an unconstrained network in the licensed PU free channel. The overall design of the network system is carried out through the web service application design flow of the (BIP) component framework representing the state transfer style. In practice, the certificate-free encryption primitives of mobile payment can be combined to improve the security and payment efficiency of transactions in the IoT. The device (D2D) is combined with the 5G to implement narrowband IoT services using 5G user equipment. The advantage is that it can operate at low bit rates with minimal configuration updates, providing continuous service for narrowband IoT services and complementing the terrestrial infrastructure. This new model can provide a high density per square kilometer of service users through the capacity provided by satellite or HAPS components, significantly increasing the number of service objects.

2.3 The challenge of integrating satellites with the IoT

The integration of satellite and IoT can fully utilize the information transmission and control coordination of massive IoT devices under the wide-area coverage of satellite communications. However, there are still two problems in interconnection under the satellite IoT:

2.3.1 The long delay of satellite transmission will affect the real-time processing of IoT devices. Since the satellite is far from the ground, the single-hop delay is 80ms~280ms, and it takes at least 160ms~560ms to send control commands from the ground to the sensor. The sensor components need to be operated in real time according to the platform instructions under unattended conditions. Long delays will cause the sensor components to fail to react in time, thus affecting system operation. In order to reduce the satellite transmission delay, it can be realized by reducing the transmission distance in a specific area and reducing the number of control information transmissions. Therefore, when designing the network architecture of the satellite Internet, a dynamic distance communication relay can be placed, and the communication relay can transmit the control information of the sensor component in real time according to the control decision; on the other hand, the network element can be optimized by optimizing the network architecture. Units requiring multiple interactions can be placed on the ground to reduce overall service delays.

2.3.2 Massive IoT device access under limited frequency resources. Unattended systems require a large amount of sensor components for state sensing, data acquisition, and information transmission. According to the 5G application description of the IoT, the number of sensors for large-scale access can
reach more than one million in one square kilometer. It is assumed that even if the control information of each IoT device is limited, the rate is 1 Kbps, and at least one million devices need at least 1000 Mbps of transmission capacity, and the spectrum width is required to be 1 GHz. The frequency of the communication system is limited. In terms of the 30MHz bandwidth resources allocated by China’s “Tiantong No.1” system, it is far from meeting the access bandwidth requirements of the IoT. Therefore, the satellite Internet should mainly play the broadcast control function for the ground equipment, transmit the common control information, and then combine the relay platform to collect the state data, which can effectively classify and transmit the message.

3. Design of satellite delay tolerant network separate broadcast control for mass sensors

3.1. The software definition network architecture of the satellite IoT

In order to effectively solve the high latency and massive access of the satellite IoT, the SDN software will be used to define the network architecture. The heterogeneous satellite network and the basic equipment and application network elements of the IoT are reorganized and connected, so as to realize the separation of the control function and the transmission function of the satellite IoT, and effectively abstract the underlying physical equipment to realize the virtualization of the network function, which can be performed according to the service. The quality requirement is to slice the service transmission channel, thereby dynamically calling all the resources of the satellite IoT to achieve optimal delay and maximum device access, as shown in Figure 1.

![Network element architecture of the satellite IoT](image)

**Figure 1.** Network element architecture of the satellite IoT

Therefore, the design idea of SDN is introduced, and the system architecture of the satellite IoT is divided into basic physical layer, control layer and application layer. The specific functions are divided as follows, as shown in figure 2:

Basic physical layer: After adopting the design idea of SDN, satellite network elements such as satellite transponder, gateway, core network and terminal, sensor collector, collection node, and aggregation node can be abstracted into communication virtual functions with different performance combinations. According to the communication service requirements of the satellite IoT, the communication capabilities of different links and different states are dynamically invoked. When
implementing the SDN architecture, it is necessary to add a programmable module outside the interface of the satellite network and the IoT component, thereby implementing network function programming without affecting the normal operation of the original network.

Control layer: the control layer is located at the center of the network, mainly implementing the control signal generation and transmission, thus ensuring the upper communication service response and the lower infrastructure invocation. The original core control rule library, virtual network manager, topology manager, exchange routing table, etc. can be referenced and inherited. In order to overcome the time delay and access bottleneck of the satellite IoT, the control layer will add the time delay control module and divide it into access control module. The time control module combines the radio resource management and authentication authorization modules of the satellite IoT, and the link establishment and maintenance control signaling modules are arranged in the same small-scale geospatial space, so that messages originally required to be transmitted over long distances are exchanged in a short time. It can be completed in milliseconds, which greatly shortens the communication delay of the satellite IoT. The access module will solve the large-scale access problem through hierarchical connection and management, and divide the control signaling into shared signaling and private signaling. The satellite broadcast function occupies the satellite traffic channel to realize all the sensor components in a large area. The control signaling is broadcasted, and some specific sensors are used to play private signaling by using the control channel, thereby solving the control problem of the large-scale access device and solving the separate management problem of the specific device.

Application layer: Since the basic physical layer shields the internal running logic and presents the network transmission function in the communication function virtualization mode, the application layer only needs to invoke the interface and configure parameters to complete the communication service. Therefore, the application layer mainly considers components, links, and performance. According to the characteristics of different application services, the application configuration coordinator calls the external interface reasonably according to different application services, reduces equipment costs, and provides diversified services.

3.2 Dynamic layered protocol for the satellite IoT
In order to fully control the SDN network, the SDN control center is used as the switching core of the protocol stack design, and the IoT control gateway is used as the origin of the protocol stack. The satellite is utilized as the relay unit for signaling transmission, and the sensor group is regarded as the transmission terminal, therefore the dynamic layered protocol stack of the satellite IoT is shown in Figure 3.
As shown in Figure 3, the core of our design is to translate the transmission requirements into separate controls for the underlying networks of satellites and sensors in the satellite IoT. Since the physical isolation of the satellite transponder and the sensor cannot be ignored, the control information of the respective network programming unit is nested by openflow. The SDN control center receives the network transmission arrangement from the IoT control module through the northbound interface, and sends control signaling to the satellite control center through the southbound interface. The front-end network is a common physical layer, MAC layer and network layer connection, and the upper layer uses openflow to encapsulate control signaling. The back-end network bottom-level connection is similar to the previous one. The upper layer then uses a layer of openflow to encapsulate the front-end openflow control signaling and then arrive at the satellite network segment. The air interface of the satellite is transparently transmitted, that is, only the electromagnetic wave is forwarded without interpreting and processing the upper layer signaling. The control command of the IoT Control Center can be obtained by satellite broadcasting to the sensor receiving end with the SDN programmable interface.

3.3. Interactive process design of satellite IoT
This section will select the RRC protocol as an analysis case to analyze the interaction process and processing mode of the satellite IoT. According to different network element distributions and protocol stacks, the RRC interaction process can also be considered in stages.

1) From IoT control to SDN control: Assuming that the fiber connection method is adopted, it can be considered that there is sufficient bandwidth resource between the two, and the openflow can be handled by using a fixed-type transmission method.

2) From SDN control to satellite control: Since the satellite beam coverage is large enough, a control center can control the satellite broadcasting capability under the coverage. Therefore, the RRC can also be set to a fixed-type transmission mode.

3) From satellite control to satellite transponder: The uplink bandwidth of the satellite is limited. When the satellite is not limited to the IoT, the competition of radio resources will be unavoidable. Under the control of SDN, the optimal allocation of transmission resources can be performed according to the link idle condition, link quality, and service priority.

4) From satellite transponders to sensor groups: Broadcast control signaling is used without the need to consider the management of radio resources.
4. Network simulation based on opnet

4.1. Simulation environment construction

In order to verify the performance of the satellite IoT architecture designed in this paper, OPNET will be used as the verification environment, and the topology, network, link and node models will be built to simulate the satellite control and IoT interaction process of the satellite IoT.

OPNET is a network simulation software package with good scalability to accurately analyze the performance and behavior of complex networks, including ItDesignionGuru user design interface, Modeler simulation engine and Modeler Radio wireless link simulation engine, which can be called by invoking external terrain simulation library. The atmospheric simulation library, etc., can better simulate the satellite environment.

According to the design of the third section, the scene in the simulation will be set to five network entities, namely sensor group, forwarding satellite, ground gateway, core network and convergence center. The network entity on the ground, the gateway station and the core network, and the aggregation center can perform link layer collision detection through the CSMA protocol, and can initiate aggregation and control functions if there is a free channel. The control center forwards the control signal by the satellite and sends the information through TDMA. As the signaling is encapsulated in the openflow mode, the signaling interpretation module of the SDN terminal needs to be added to each entity.

The sensor node is set as sensor_node_x, and the node model is shown in figure 4. Each node contains a TDMA MAC layer, and the structure of the TDMA module process model is shown in figure 5.

![Figure 4. Schematic diagram of sensor node model](image-url)
At this moment, the number of sensor groups is set as 5000, the control signaling receiving bandwidth of each sensor is 10 kHz, the downlink capacity of the satellite transponder is 1 Gbps, the uplink capacity is 250 Mbps, the satellite transmission distance is 1200 km, while the band is Ka-band. It is assumed that the elevation angle and atmospheric attenuation are both ideal. The signaling transmitted through the gateway is 10 bps each time, each lasting 120 s, with an interval of 30 s.

In the experiment, the Monte Carlo method is used, and the experiment is performed multiple times and data is collected. The main analysis contents include the performance of the protocol stack and the delay performance.

4.2. Protocol stack performance analysis
By setting the control traffic of the satellite Internet as a data message, the simulation process can be obtained after running the software. At this time, the control center uses the satellite to send the two-hop connection information to the sensor. After the connection is established and the data is transmitted by the sensor and the aggregation center for four times, the sensor enters the waiting time. When the sensor completes the task, it passes 2 hops. The control information releases the link occupation.

4.3. Time delay performance analysis
The protocol running state is collected from the sensor, and the specific results are shown in figure 6. As can be seen from figure 6, the new network architecture is applied to the satellite IoT. Compared with the separated satellite architecture and the IoT architecture, the time delay is reduced by about 0.02s on average.
5. Conclusion

In this paper, we propose a software-defined network satellite IoT architecture to realize the idea and method of satellite-tolerant network separation and broadcast control for massive sensors. We use OPNET simulation to figure out that the new network architecture is applied to the satellite IoT. The time-delayed satellite architecture and IoT architecture are reduced by an average of 0.02s. At the same time, through software analysis, it is found that the satellite IoT realizes the predetermined protocol design function, and to a certain extent achieves the large-scale access of massive sensors.

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