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Enabling Edge Computing Ability in Mobile Satellite Communication Networks

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Abstract. Mobile Satellite Service (MSS) can provide users reliable communication abilities wherever they are on earth surface, even in a high-speed motion status, which can either be stand-alone or a complementary service to the terrestrial communication systems. In the recent past, diverse MSS applications have been emerging rapidly. Some introduce unprecedentedly heavy traffic transmission pressure, and some others require real-time response, both of which cannot be satisfied by legacy mobile satellite communication networks anymore. This paper proposes an enhanced strategy to enable edge computing ability on the existing satellite networks. More precisely, this paper re-architects a GEO satellite node to become a cloudlet which possesses a set of computation, storage and networking resources, and can accomplish a certain amount of computing jobs which are typically happened on centralised cloud centre on the ground. A test-bed containing the emulated cloudlet-enabled GEO satellite has been built on a single PC. Functional test and performance evaluation are conducted for FTP file transmission and HTTP web browsing services. Experimental results show that the enhanced edge computing ability can effectively and efficiently decrease bandwidth consumption and lower the response latency in mobile satellite networks.

1. Introduction

Limited by the building costs and technology restrictions, ground base stations of terrestrial communication networks cover only 1/5 of the total land area. Mobile satellite communication system is a vital complement to terrestrial networks in desert, polar, ocean surface, and other geographical locations where terrestrial base stations are difficult to be installed. Mobile satellite communication service leverages microwave broadcasting feature to seamlessly cover the major part of earth surface, although the transmission bandwidth is relatively low and the latency is much higher than typical terrestrial networks. In the past decade, as the emerging of diverse novel applications such as HDTV, VR/AR, interactive online gaming, etc., increasingly more transmission bandwidth consumption and shorter responding latency are required in communication networks. Legacy mobile satellite communication networks are not able to satisfy these needs anymore.

This paper mainly focuses on alleviating the bandwidth shortage and long response delay problems. It innovatively integrates the edge computing framework to the traditional mobile satellite communication networks. More specifically, the paper leverages a set of promising ICT technologies such as SDN, NFV, light-weight virtualization technologies to re-architects a GEO satellite node to be a cloudlet which is equipped with a pool of computation, storage and networking resources, so to handle a number of computing tasks which originally run on the central cloud located behand the gateway station on the ground. A test-bed containing an emulated cloudlet-enabled GEO satellite is developed on a single physical machine. Functional test and performance evaluation are conducted for two typical applications, namely FTP based file transmission and HTTP based web browsing. The results illustrate that the introduced edge computing ability can effectively and efficiently decrease bandwidth consumption and lower the response latency in mobile satellite networks.

The remaining part of this paper proceeds as follows: First of all, Section 2 introduces the state-of-the-art followed by challenges faced by legacy mobile satellite networks in Section 3. Then, as the major contribution, Section 4 enhances mobile satellite communication network with edge computing ability by re-architect the GEO satellite nodes. Functional test and performance evaluation are conducted in Section 5. Finally, Section 6 summaries the paper and gives the outlook.

2. Related work

Research on edge computing's application in ground terrestrial networks has recently gained much attention in both academia and industry. In the meanwhile, a promising topic of enabling edge computing ability in satellite networking domain also start to attract increasingly more attentions. Denby et al. in [1] propose orbital edge computing. Within the framework of this concept, satellite clouds and corresponding TV and Radio programs available for users, as well as new opportunities and their potential influence on the information resources development have been discussed. Kanev et al. in [2] elaborate the concept of satellite-based cloud computing, which integrates virtualized information resources from satellites and the Internet. Within the framework, satellite clouds and corresponding television and radio programs available to users are discussed, as well as new opportunities and their potential impact on the development of information resources. Zhang et al. in [3] introduce the architecture and application scenarios of satellite-terrestrial network, and proposed to integrate the satellite mobile edge computing (SMEC) technique in STN-base mobile communication systems to improve QoS of STN. To improve the performance of 5G satellites, Yan et al. in [4] propose a 5G satellite edge computing framework (5GsatEC) to reduce latency and to expand network coverage. The framework consists of an embedded hardware platform and edge computing micro services in the satellite. To improve the flexibility of the framework in complex scenarios, authors unify the resource management of central processing units (CPUs), graphics processing units (GPUs) and field programmable gate arrays (FPGAs). Wang et al. in [5] present a new type of satellite terrestrial network with double edge computing to gain the benefits of providing computing services in remote areas. The strategy aims to solve the problem of effectively scheduling edge servers distributed in satellite terrestrial networks to provide more powerful edge computing services. Wang et al. in [6] describe edge computing to ease the pressure on the data center. A new approach called Edge Computation Based Differential Positioning (ECDP) does not send location information to the data center, but instead selects the nearest reference station to perform edge calculations and transmits the difference value directly to the mobile receiver.

The aforementioned research efforts on combining edge computing and satellite network are just staying in the concept designing stage, the concrete emulation or implementations are rarely to be discussed. Therefore, this paper not just focuses on the architecture design but also on prototype implementation leveraging on a bunch of promising ICT technologies.

3. Challenges in legacy mobile satellite communication networks

3.1. Typical mobile satellite communication network

Currently, mobile satellite communication systems can be either GEO satellite based (e.g. Inmarsat) or LEO satellite based (e.g. Iridium & GlobalStar). This paper focuses on the former one due to its commercial success. Figure 1 illustrates a typical mobile satellite system, which is consist of three major components, namely a number of terminal stations, a GEO satellite, as well as a gateway station. In particular, terminal stations can be small devices handheld by users or be larger ones mounted on vehicles, ships, and planes. GEO satellite serves as the signal relaying node either in digital mode or analogue mode, which is merely a networking node. As the name indicates, the gateway station is the gateway for terminal stations to the backbone network on the ground.

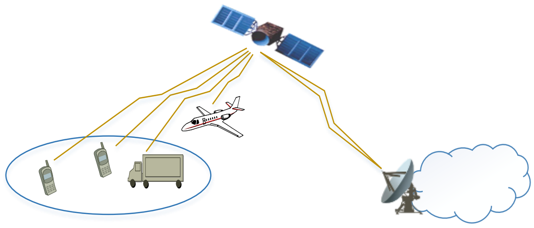

Figure 1. A typical mobile satellite system.

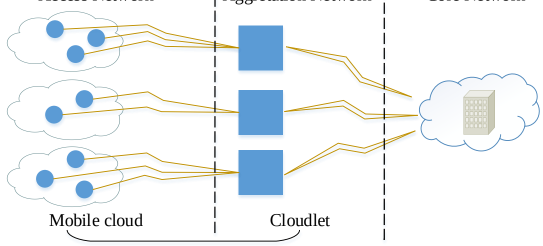

Figure 2. Concept of edge computing.

3.2. Analysis on Existing challenges

Originally, mobile satellite system shown in figure 1 are designed to support legacy voice, video and data transmission application for users. In the recent past, as the fast development of smart devices, diverse novel applications appear and develop rapidly which consequently introduce much higher bandwidth consumption, as well as need lower response latency. Legacy mobile satellite system cannot satisfy these increasingly difficult requirements anymore. Therefore, it is vital to decrease the consumed network bandwidth and to accelerate the task responding speed from the backend.

4. Enhancing mobile satellite communication network with edge computing ability

4.1. Concept of edge computing

Edge computing has attracted quite a lot of research interests in the past five years. It was originally motivated by IoT (Internet of Things) and telecommunication applications in terrestrial communication networks on the ground. The basic idea is to deploy computation resources on the networking nodes located at the networking edge. These edge nodes can either be the aggregation nodes (each of which connects and serves a number of terminal devices), or directly be the terminal nodes themselves. In this sense, some parts of the data or tasks generated by the terminal users or devices can be processed at the networking edge, which consequently has a potential to decrease the bandwidth consumption of the backhaul networks, and in the meanwhile to lower the response delay of the upper layer real-time applications. It is worth noting that edge computing technology is not proposed to completely replace the legacy centralized cloud computing framework. On the contrary, edge computing is a decent complement to the centralized computation architecture. Figure 2 presents the concepts of edge computing, as well as its integration with cloud computing centres located in the core network. At present, applying edge computing technology in existing satellite networks start to attract research attentions from both academia and industry, as indicated in Section 2.

4.2. Re-architect legacy mobile satellite communication network to support edge computing

A basic illustration of mobile satellite communication network has been given in figure 1. Aiming at enhancing the legacy mobile satellite communication network to support edge computing, this paper focuses on the GEO satellite node, which service a number of terminal stations distributed on a wide geographic area of the earth surface. The principle idea is to deploy a certain computation and storage resources on each GEO satellite node plus with its original networking functionalities, so some parts of the data and tasks generated at the ground terminal stations can be processed and accomplished on networking edge nodes just one hop away.

In order to re-architect the GEO satellite nodes, a set of promising ICT technologies are employed to transfer a legacy GEO satellite node to be a cloudlet, These ICT technologies mainly include software-defined networking (SDN), light-weight virtualization (i.e. Docker container), network functional virtualization (NFV), cloud and service orchestration technologies. More precisely, SDN divides the control plane from the data plane in the satellite networks, which makes the network to be programmable so to satisfy the flexibility requirements in cloud computing domain. Light-weighted virtualization (i.e. Docker container) can utilize the underlay physical computation and storage resources in a much more efficient manner compared with traditional Virtual Machine (VM) methods. All the edge computation tasks will happen on these light-weighted virtualization instances. NFV moves the data plane from hardware device to light-weighted virtual instances running on commodity servers, which permits more agile software-based resource and service orchestrations. Cloud technology implements best practices in scalable services, leveraging software-based solutions, micro-services, virtualized commodity platforms, elastic scaling, and service composition, which allows network operators to innovate more rapidly [7]. Service orchestration technology assembles and composes (micro) services. It unifies cloud infrastructure services, SDN control plane services, and NFV services. Figure 3 demonstrates the architecture of the edge computing framework in mobile satellite communication systems, integrating the above technologies.

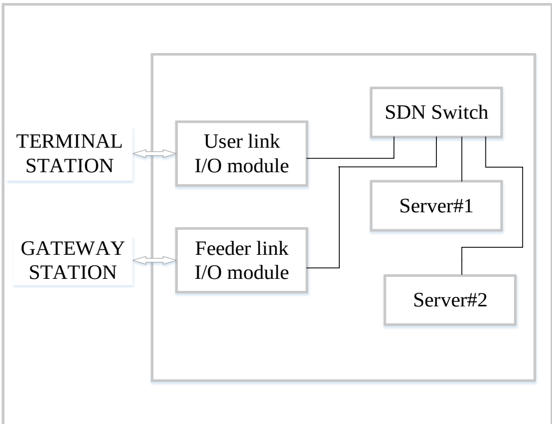

Figure 3. Edge Computing framework in Mobile Satellite Communication Systems.

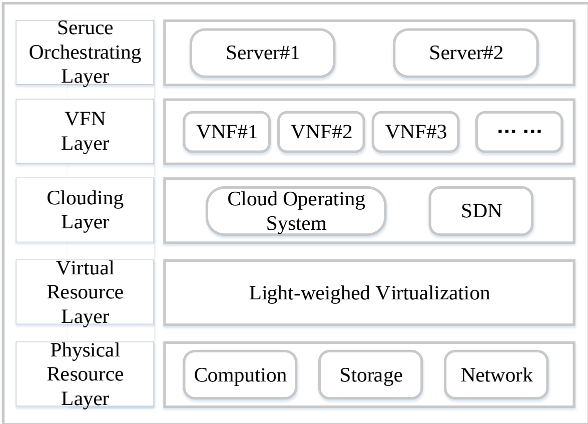

Figure 4. Reference payload

The advantage of re-architecting the GEO satellite node can fully utilize its feature of aggregating traffic of all the ground terminals, namely the GEO satellite naturally is a suitable node to deploy cloudlet and to conduct edge computing. On the other hand, only the satellite backhaul bandwidth consumption can be saved and due to the distance between a ground terminal and a GEO satellite is still long (at least ~35,786 kilometres), the decrease of response latency is limited to one half of the previous delay. However, it is believed that the exploration carried out in this paper is still valuable in mobile satellite system domain.

4.3. Implementation details

As already discussed, the key point of this design is to reconstruct the legacy GEO satellite node to be a cloudlet. Without loss of generality, this paper implements the above architecture on commodity hardwires. Figure 4 illustrates a reference payload implementation of edge computing ability enabled GEO satellite. It mainly includes:

- Physical servers: ARM architecture based computers with commodity RAMs and Discs, which are robust enough to be deployed in space environment;
- SDN switches: Ethernet based switch supporting OpenFlow protocols and can be configured remotely via southbound interface;
- User link I/O module: Interface module between the GEO satellite and the user terminal stations on the ground, realizing data transmission switch between wireless and Ethernet;

- Feeder link I/O module: Interface module between the GEO satellite and the Gateway stations on the ground, realizing data transmission switch between Ethernet and wireless.

In this reference implementations, all the adopted software are open source based. In particular. Operating systems on physical servers are Ubuntu 16.04; Light-weighted virtualization are using Docker container technology; Kubernetes is selected as the cloud OS; SDN controller adopts ONOS controller; Open vSwitch (OVS) is chosen as the software switch; Service orchestration uses XOS.

5. Functional Test and Performance Evaluation

5.1. Test-bed Setting up

An emulation test-bed is developed on a single physical machine for functional tests and performance evaluation. The architecture of the test-bed is demonstrated in figure 5, where only one terminal station (TERM), one GEO satellite and one gateway (GW) station are considered. More precisely, Kubernetes & Docker are installed on this physical machine, a POD is generated to emulate the TERM node. Mininet emulator is adopted to construct the network connecting GEO and GW nodes. In fact, GEO and GW nodes are LXCs (Linux Containers) generated by the mininet emulator, which again is a POD in Kubernetes. By configuring the link between the GEO and the GW nodes, as well as the link between two PODs connecting the GEO and the TERM nodes, the emulation test-bed is established. Detailed configurations are summarised in Table 1.

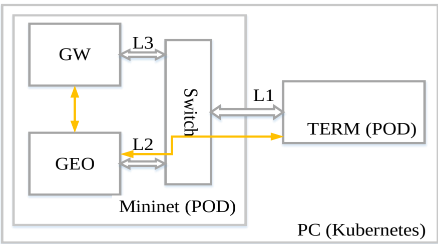

Figure 5. Architecture of Emulation Test-bed.

Table 1. Configuration of the emulation test-bed.

Item	Value
Bandwidth(L1)	1Mbps
Bandwidth(L2)	4Mbps
Bandwidth(L3)	4Mbps
Delay(L1)	40ms
Delay(L2)	270ms
Delay(L3)	135ms

5.2. Functional Test

The key point of the re-architected network is the edge computing ability in the GEO node. To test this enhanced architecture, this paper chose two most common applications: FTP file transfer and HTTP web browsing. A file server and a web server are installed on the emulated GEO node in the above test-bed. FTP and HTTP Client programs running on the TERM node are tested to fetch files from the GEO node. The snapshots of the testing results are given in figures 6 and 7, respectively. It is indicated that by enabling the edge computing ability in GEO nodes, applications can be conducted in a position more closing to users, which will definitely introduce potential advantages.

```
root@rg-6b5bb69d8b-cj7qf:/# ftp 172.18.0.10
Connected to 172.18.0.10.
220 (vsFTPd 3.0.3)
Name (172.18.0.10:root): ftp
230 Login successful.
Remote system type is UNIX.
Using binary mode to transfer files.
ftp> get test.txt
local: test.txt remote: test.txt
200 PORT command successful. Consider using PASV.
150 Opening BINARY mode data connection for test.txt (8 bytes).
226 Transfer complete.
8 bytes received in 0.01 secs (0.5439 kB/s)
```

Figure 6. FTP file transfer.

```
root@rg-6b5bb69d8b-cj7qf:/# curl -I 172.18.0.10
HTTP/1.0 200 OK
Server: SimpleHTTP/0.6 Python/2.7.13
Date: Fri, 12 Jul 2019 06:46:32 GMT
Content-type: text/html; charset=ANSI_X3.4-1968
Content-Length: 1182

root@rg-6b5bb69d8b-cj7qf:/# █
```

Figure 7. HTTP web browsing.

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5.3. Performance evaluation

On one hand, bandwidth is precious in mobile satellite network. On the other hand, transmission delay is unavoidable due to long distance between GEO node and Earth. Particularly, bandwidth consumption (BC) is the sum of data delivered via all links, and transmission delay (TD) refers to the E2E latency, which are two most important performance metrics. This paper carried out comparative evaluation experiments for legacy and edge computing ability enabled mobile satellite network.

For the bandwidth consumption metric, FTP file server program is installed in the GEO node and the GW node, respectively. 5 files of different sizes ranging from 0.5MB to 2MB are transferred from the FTP server program to the TERM node. The results are present in figure 8, which shows that around half bandwidth can be saved by the edge computing enhanced network architecture.

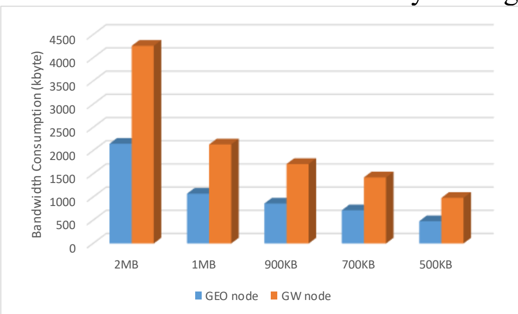

Figure 8. FTP test results.

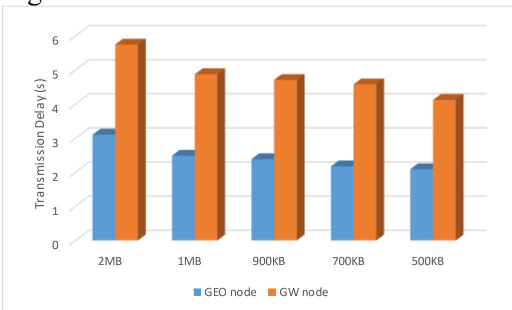

Figure 9. HTTP test results.

For the transmission delay metric, HTTP Web server is deployed in GEO and GW nodes, respectively. 5 HTML files of different size ranging from 0.5MB to 2MB are delivered from the Web server to the TERM node. The transmission delay is the latency from the moment a HTML file request sent by a TERM node to the instance the TERM node receives the requested file. The results in figure 9 illustrated that significant latency decreasing can be achieved by the enhanced network architecture.

6. Conclusions

Edge computing has attracted many research efforts in the past few years. This paper investigates its application in mobile satellite communication network domain to decrease bandwidth consumption and lower the response time. A set of promising ICT technologies are employed to reconstruct the legacy GEO satellite node to be a cloudlet so to accomplish some real-time tasks locally. Experimental results demonstrate the proposed edge computing framework's effectivity and efficiency. The next step of this work could focus on more complicated GEO-LEO double layer satellite networks, deploying cloudlets on both GEO and LEO layers, which is technically more challengeable.

Acknowledgments

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