Performance Evaluation of Double-edge Satellite Terrestrial Networks on OPNET Platform

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Performance Evaluation of Double-edge Satellite Terrestrial Networks on OPNET Platform

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***Abstract*—With the rapid development of wireless networks, the growing number of mobile applications result in massive computation task to be processed. Satellite communication system, with the merits of wide coverage and flexible multiple-link capability, breaks the limitations of terrestrial network and delivers resilient as well as high-speed connectivity across the globe. In the traditional integrated satellite terrestrial network architecture, time and frequency resource allocation is usually not adapt to customized services. To solve the problem, in this paper we propose a double-edge satellite terrestrial network architecture and a more flexible slot resource allocation scheme based on service priority to improve the resource allocation efficiency and decrease service time delay. Performance of the proposed scheme is evaluated on the OPNET platform. Simulation results show that the proposed time slot allocation scheme in the double-edge satellite terrestrial outperforms the traditional one.**

Keywords—double-edge, satellite terrestrial networks, allocation scheme, OPNET, performance evaluation

I. INTRODUCTION

According to 5G Public Private Partnership, one challenge for the next generation communication network is ensuring everyone the access to a wider panel of services everywhere and applications at lower cost [1] [2]. While Multi-access mobile edge computing (MA-MEC), as a technology provides a service environment and cloud-computing capabilities at the edge of the mobile network, meet the requirement of services with tremendous generated data to be processed instantly and effectively. Distributed MEC servers sink the computing resources to the edge of the network, not only alleviate computation ability constrained user equipment, but also reduce the latency for offloading the task to remote cloud server [3] [4].

Satellites offer a number of features not readily available with other means of communications. They usually position from a high altitude and offer a large and contiguous covering of service area [5]. These features enable satellites to provide a convenient access for remote communities in sparsely populated areas. Satellite communication system is a kind of frequency and time division combined multiple-access network. Integrated service access capability is one of its prominent features, but integrated service access has also introduced various problems. The problem of different quality of service requirements for different channels, and the indiscriminate use of various services, unified resource allocation cannot meet real-time and bandwidth guarantee requirements. High customized service quality requires non-competitive use of channel resources in multi-user competition. Thus, how to ensure certain requirements in the best effort to meet the service needs of each station while avoiding system resources being occupied by individual stations for a long time will be a vital problem. There are some researches on performance evaluation about integrated satellite terrestrial networks. In [6], performance evaluation of a multi-antenna multiuser hybrid satellite-terrestrial relay network (HSTRN) employing opportunistic user scheduling with outdated channel state information (CSI) is conducted. Analytical expressions provide efficient tools to characterize the impact of CCI, outdated CSI, and antenna correlation on the system performance of HSTRN is derived. In [7], the authors present a set of evaluations performed on virtual evolved packet core network with GEO satellite network is used as backhaul. they proposed system which is deployed in two configurations on which various telecommunication functionalities are tested in order to determine which range or applications are suited for each setup. The testbed includes the Fraunhofer CoSat satellite emulator and the Open5GCore toolkit. There are some explorations on satellite task processing. In [8], ideas of hybrid computing and reconfigurable computing are introduced, the authors also elaborate challenges and opportunities of onboard computers for small satellites. Edge computing enabled satellite and terrestrial network will be a promising architecture for the next generation communication network. However, few has done in performance evaluation of collaborative processing of MEC server on the satellite and the ground.

In this paper, we propose a slot resource allocation scheme based on service priority and focus on the performance evaluation of double-edge satellite terrestrial network. The concept of the double-edge satellite terrestrial network is depicted in Fig.1. To explain the proposed architecture specifically, we introduce the simulation platform and the parameters for performance analysis.

The rest of this paper is organized as follows. The double-edge satellite terrestrial network architecture is presented in

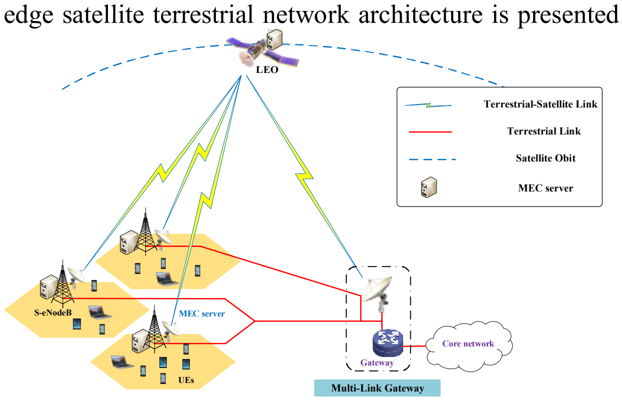

Fig. 1. Double-edge satellite terrestrial networks

section II. Slot resource scheduling based on customized service priority is proposed in section III, Simulation platform is introduced in section IV, section V presents the performance simulation and the evaluation results. Finally, we conclude in section VI.

II. Double-edge satellite terrestrial networks

In this section, a double-edge satellite-terrestrial network is presented. The architecture of double-edge satellite terrestrial network is proposed to address the problem of incomplete service area coverage and to alleviate the conflict between resource-constrained devices and intensive computation tasks.

Integrated satellite and terrestrial network is aiming at enhancing end-to-end communication between any user equipment (UE) and to meet user service requirements. The network structure focuses on two major issues: resources isolation and resource mismatch with services. On one hand, resources of isolated satellite or space communication network and terrestrial communication networks are characterized by many levels of hybrid and heterogeneity. On the other hand, varied services need specific priorities of resource assurance. Moreover, some remote areas still are located in out-of-service area, users there are limited to service coverage area and cannot enjoy a network aiming at access anywhere yet. Double-edge satellite terrestrial network is projected to reap the benefits of integrated satellite terrestrial network and edge computing on a large scale, and thereby support the requirement of next generation communication network. Note that distributed MEC server could sink the resources near to the users, while satellite could provide a large service area geographically, to solve the problems mentioned above, double-edge satellite terrestrial network will be a promising solution. Besides, taking satellite into consideration can resolve congestion problem as it could provide a flexible backhaul for services.

As shown in Fig 1, In the proposed architecture, MEC servers are deployed in both satellite eNodeBs (S-eNodeB) and satellite. Thus, S-eNodeBs and satellite allocate bandwidth to various type of services adaptively. The future 5G communication system requires higher computation capability for a better quality of service, the proposed satellite and the terrestrial network can provide an efficient, reconfigurable architecture to support RAN processing.

In summary, the advantages of the double-edge satellite terrestrial network are:

a) Flexible backhaul: Compared with traditional satellite terrestrial network, the double-edge satellite terrestrial network can provide a flexible backhaul to balance the load, while MEC servers can help select optimal backhaul route for specified type of service.

b) Distributed task offloading: By offloading tasks to more powerful distributed MEC servers which compute tasks more effectively and cooperatively, double-edge satellite terrestrial networks break the limitation of power-constrained and computation resource-limited user equipment (UE) devices.

c) Resources sink to the edge: MEC servers provide compute, storage and network resource to various applications, they cache the file resources with high popularity, relieve the overlod traffic flow from evolved packet core (EPC) network directly.

d) Caching with localized computing: Double-edge satellite terrestrial network cache the files with the localized computing and can predict the requirement trend of the resource in relevant area.

III. Slot Resource scheduling based on custimized service priority

In this section, we propose a slot resource scheduling based on customized service priority considering the MF-TDMA system frame structure. When UEs require services, they send the requirements to S-eNodeB, and satellite leverages the merit of high altitude to make a global resource allocation for S-eNodeB located in its coverage, then S-eNodeBs re-allocate the resource according to the time and frequency arranged by satellite.

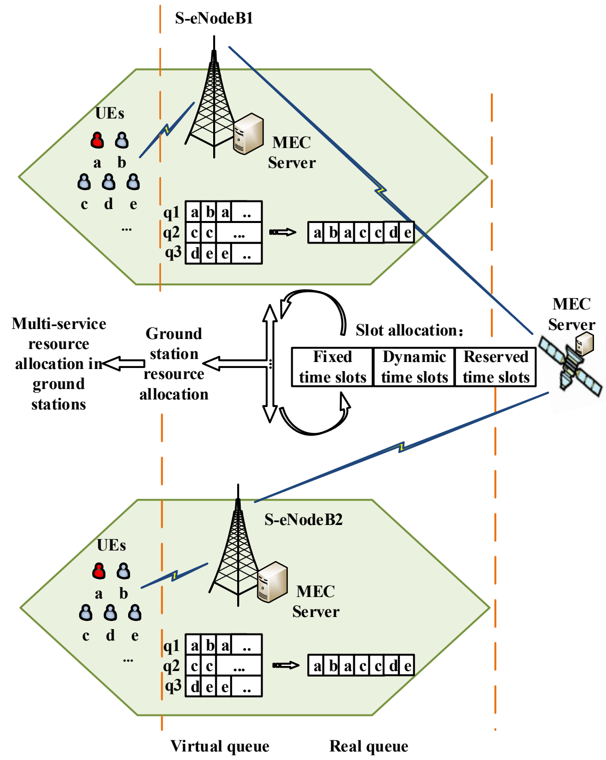

Fig. 2. Slot resource scheduling based on customized service priority in double-edge satellite terrestrial network

In our proposal, a cycle of slot resource scheduling is manipulated in the range of one TDMA frame and one time slot is the basic application allocation unit of the channel resources. The resource scheduling request is made by the S-eNodeB, and the satellite allocates the channel resources according to the application requirements.

As shown in Fig.2., the procedure of slot resource scheduling based on customized service priority can be divided into following four steps:

STEP1: Identify custimized service priority.

The service requirements from UEs received by each S-eNodeB can be divided into categories with different priority. The voice services are real-time services, then the assigned corresponding time slot type is real-time time slot. The IP service's corresponding time slot priority type is non-real time slot. Services for critical emergency is a high-priority service and the corresponding time slot type is a guaranteed time slot.

STEP2:Requirements collection

S-eNodeB calculate the slot resources need for varied application according to configuration of real-time service, non-real-time service and high-priority service, respectively. Then the results of slot resource that the customized services need are sent to the satellite.

STEP3: Slot resource scheduling

After receiving the results of slots required from each S-eNodeB, the satellite collects the slots requirement information of all S-eNodeB in coverage and allocate channel resources.

When the remaining time slots are not enough, global allocation obeys the preemption rules. Real-time time slots are allocated by the rules of first-come first-served order. Non-real-time time slots allocation is implemented using a weighted average for resource distribution balance. Satellite creates an allocation sequence in a table, which contains the linked list records of the S-eNodeB number, the number of customized services in each S-eNodeB, and the weighted average number of customized services. Time slots are first allocated to the first unsatisfied S-eNodeB. At the same time, satellite statistics all non-real-time service amount and the time slot remaining in the frame. When the total time slots need by application is greater than the remaining slot amount, the distribution process distributes services in a balanced manner. When the remaining time slots run out in one TDMA frame, satellite record the unserved application requirement. In the next round, they have the priority to be allocated the slot resource. After that, the time slot allocation result is sent to the reference in the form of a frame plan.

STEP4: Multi-service resource allocation

After the S-eNodeB receives the frame plan delivered by the satellite, S-eNodeB operates secondary allocation. Specific rules are proposed to ensure that the customized service can make use of the guaranteed time slots efficiently. For instance, voice service is sent by using real-time time slots, while IP data service is sent by non-real time slots. When the real-time service of S-eNodeB allocation is completed, if there are real-time time slots left unused, non-real-time service are permitted to take up the slots. When non-real time slots are in used, the high priority data can be sent anytime preferentially.

As there are different slot allocation schemes in S-eNodeB, here we summary four slot scheduling schemes for hybrid services:

a) FIFO (First Input First Output)

After the services of all terminals arrive at the base station, they are sorted in the base station queue according to the first-in-first-out method.

b) PBM (Priority based mode)

For all services that arrive at the base station, classify the service by judging the real-time nature and urgency of the service. Different graded services enter their own virtual queues. The base station scans each virtual queue and sends it to the satellites in accordance with the priority.

c) SBM (Size based mode)

For all services that arrive at the base station, classify the service by judging the packet size of the service. Different graded services enter their own virtual queues. The base station scans each virtual queue and sends it to the satellites in accordance with the priority.

d) HBM (Hybrid based mode)

For all services that arrive at the base station, the services are tiered by calculating the service priority and service packet size weighting. Different graded services enter their own virtual queues. The base station scans each virtual queue and sends it to the satellites in accordance with the priority.

IV. SIMULATION PLATFORM

A. Model overview

In this paper, the double-edge satellite terrestrial network is simulated on OPNET. The terrestrial and satellite groups are responsible for routing the data from the ground to the target subnet through the satellite above. In the simulation, the constellation of satellite network adopts the design of Iridium constellations. The Iridium system constellation is designed as 66 low orbit satellites to orbit the earth at 6 near poles (86 degrees) at an altitude of about 780km. There are 11 satellites on each track plane, 31.6 degrees apart from the same rotation surface, and 22 degrees from the opposite rotation surface. The three-level modeling mechanism can make the simulation system clear and reasonable in structure.

B. Network model domain

Satellite network model is the basis of simulation and routing algorithm. It is mainly used to describe the topology of satellite network, which is dependent on routing algorithms. For simplicity, in the simulation we assume that two subnets are placed on the ground, and satellite constellations are set according to the parameters of iridium system. In the iridium system, each satellite has four inter satellite links.

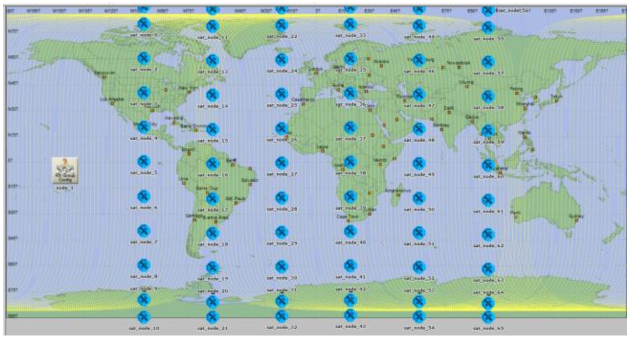

Fig. 3. Satellite communication network model domain

Fig.3. shows the network layer model in OPNET. The blue point represents the satellite, while the yellow line in the background is satellite orbit which is designed and imported through the physics-based software package STK. In Fig.3., satellites in the same orbit plane is arranged in column, the links between the two satellites in the same column are inter-orbital links which is always in communication sate, while the ones between different columns are intra-orbit links, which communicate outside the polar region.

C. Node domain of satellite communication model

The satellite node layer model mainly simulates the communication function of the satellite node when the routing algorithm is implemented, such as receiving and sending data through infinite simulation module. Fig.4. shows the node layer model of the satellite, which mainly includes satellite status update clock module, routing processing module, wireless transmitter and wireless receiver module. The specific functions are:

rr_up, **rt_up**, **rr_down**, **rt_down**: Receiving and sending packets from the same orbit satellite;

rr_inter, **rt_inter**: Receiving and sending packets from adjacent orbit satellites;

rr_gnd, **rt_gnd**: Receiving and sending the uplink and downlink packages of the ground subnet;

SAT_UPDATE_TIMER: Periodically updating the state of the satellite;

router: To deal with the received packets and achieve the routing algorithm;

local_cntl: Collect the information of ground stations and control the uplink slot allocation.

The four sets of wireless transceivers use frequency division multiplex settings to ensure that they do not interfere with each other while working.

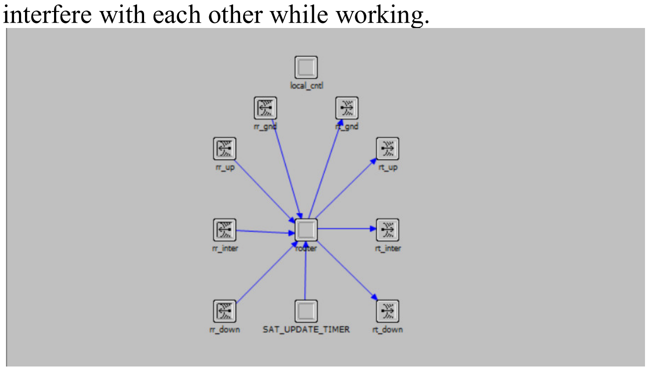

Fig. 4. Node domain model of satellite communication

D. Ground node domain model

As Fig.5. shows, only node_0 can transmit pilot signal to determine whether the subnet is in communication with the satellite and with which satellite, while all 5 base stations can complete the uplink work in their assigned time slots. Let us take the node model of node_0 as an example to illustrate the operation flow of the base station.

M1, M2, Voip, wx, web: In order to simplify the model and highlight the key issues, we ignore the users' part and integrate all types of services at the base station, such as IOT services (M1, M2), VOIP services, SNC (Social Network Communication) services (wx) and web services;

Multi_source_switch: All kinds of services flow to this node, in which we categorize incoming traffic packets and make specific tags we need for them, such as priority;

Center_switch: A central forwarding node, receiving the packets from sat, users and core network;

TD-CONTROL: core processing node, completing the queue processing and packets' uploading.

rt_2, rr_2: send and receive the pilot signals (only exist in node_0);

rt_sat, rr_sat: send and receive the packets from ground;

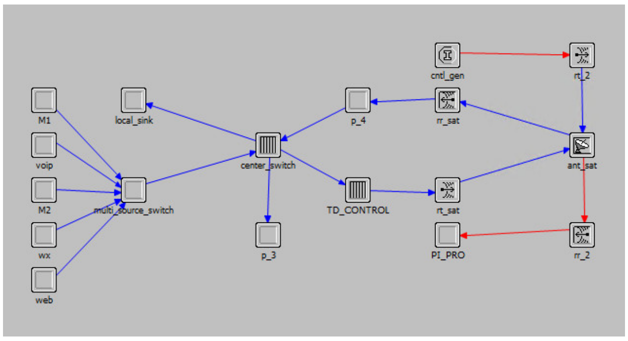

Fig. 5. Node domain model of communication between satellite and S-eNodeB

E. Routing process domain

The process domain realizes the function of each module in the satellite node domain by the state transition of the finite state machine. The satellite status cycle update clock uses OPNET's own process area. Fig.6. is shown as the routing process domain of the routing module, the specific functions are:

init: Configuring relevant parameters for routing process area during process startup, initializing global variables, etc.

idle: If no interruption occurs, it will remain in this state; otherwise, different operations will be carried out according to different conditions.

update_sat: Update the satellite's current state according to the update time interval of satellite status, and simulate the change of satellite communication link state.

pretreat: Some screening work is carried out to ensure the accuracy of routing.

dest_estimate: In this state, the delay of inter satellite link ISL is assumed to be consistent, and the values of intra rail transport hops and inter rail transport hops are estimated for the destination satellite nodes, and the next hops are determined based on whether or not in the polar regions.

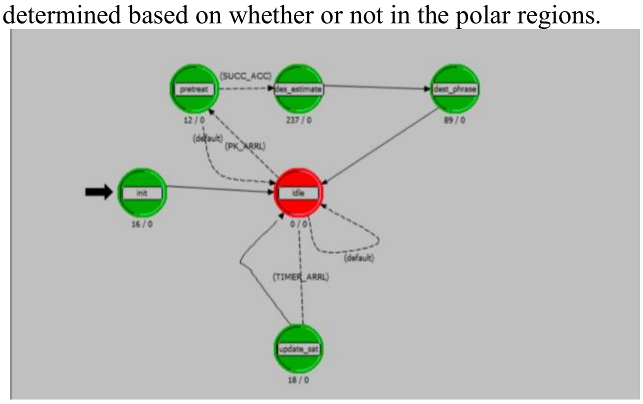

Fig. 6. Communication model of routing process domain

F. TD-CONTROL process domain

Fig.7. is shown as the process domain of the TD-CONTROL node module, the key states are the switch and slot.

Switch: This state is triggered when a packet arrives, in which we can decide on the packets' queuing method and which queue to enter based on a specific strategy.

Slot: In this state, we should first determine whether the current uplink time slot belongs to this base station, and then select the packet to be transmitted according to the queuing result of switch.

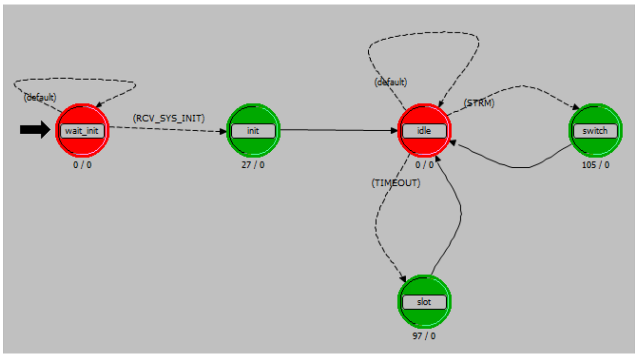

Fig. 7. Process domain of TD-CONTROL node

V. SIMULATION AND RESULTS

In this section, simulations are proposed in comparison with conventional satellite terrestrial architecture which takes no MEC server into consideration. In Table 1. and Table 2., we list important parameters. In order to focus on the issue of upload time slot allocation between the gateway station and the satellite and the multi-service scheduling when a base station is assigned to a time slot, the scenario neglects the access part of users with the gateway station.

A. Slot scheduling for uplink services between satellites and grounds.

TABLE I. SIMULATION CONFIGURATION

Parameter	***Value***
Number of BSs	5
Number of services	3

The first part of the simulation is about the optimization of slot allocation for uplink services between satellites and grounds. The traditional slot allocation method is operated according to fixed polling rules, it is suitable only when each base station has similar amount of traffic to be uploaded within the satellite coverage area. Once there is a large difference in traffic between base stations, there is no way to achieve a balanced scheduling, which may result in a phenomenon that a certain base station generates a large number of services, leading to poor delay conditions. In this case, a three-level slot allocation (a slot cycle) is adopted to solve the problem.

The time slots assigned to all ground stations by a satellite in one cycle are divided into three parts. The first part is the time slot fixedly allocated to the access ground base station. The second part is used to balance the traffic volume difference between ground stations after monitoring the ground station traffic. The reserved time slots in the third part are for emergency services. Here for example, we set the three types number of time slot ratios are 2:5:1. In the simulation, the base station traffic is divided into two types, the traffic volume of one type of base station is kept unchanged, and the service generation rate of another type of base station is continuously changed, which is reflected as the arrival time interval of the packet. To evaluate the proposed allocation scheme, we identify two parameters in the simulation. As shown in the Fig.8., the horizontal axis represents mean square deviation of traffic flow in each S-eNodeBs and the vertical axis represents load balancing index:

$$B = \max_{i\in[0,4]} b_i - \min_{i\in[0,4]} b_i \qquad (1)$$

$$b_i = throughput_i \,/\, traffic_i \qquad (2)$$

, which $traffic_i$ is the input traffic flow of S-eNodeB i ,and $throughput_i$ is the output traffic flow of S-eNodeB i .

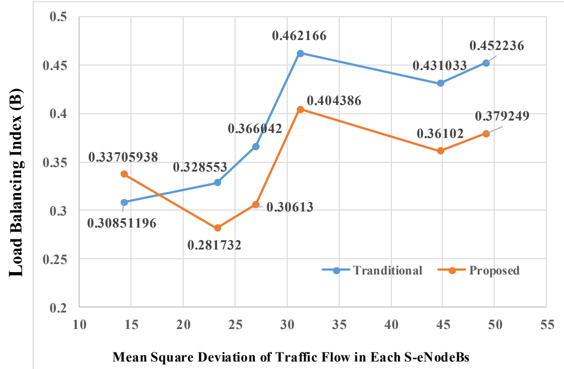

Fig. 8. Load balancing index of traditional allocation scheme and proposed allocation scheme under different mean square deviation of traffic flow in each S-eNodeB.

When the traffic flow is large, the ground station services thus have a large queuing delay due to the unreasonable bandwidth allocation. Moreover, as the service flow gap increases, the base station accessed to fixed-allocation satellites will cause large queuing delays, resulting an increase in the average queuing delay of the entire sub-network. However, the satellites with the ability to monitor S-eNodeB traffic can allocate the bandwidth resources according to the traffic conditions. When services are unevenly distributed, satellites that dynamically allocate subnet resources can maintain a certain queuing delay for the base station data services of the access satellites in the subnet. Satellites with fixed subnet resources can cause subnet access to the base stations of the satellites. Data traffic arises from the queuing delays that are positively related to poor service traffic.

B. Multi-service scheduling

The second part of the simulation focused on the problem of multi-service scheduling when a base station is assigned to a time slot. Simulation configuration is listed in Table II. We mainly pay attention to the scheduling strategy of a certain base station, and the target to be optimized is the average delay of all the services. Three types of services (i.e. VoIP, SNC, Web) are set in the simulation, using ON/OFF source models with different parameters. In addition, the three services have different priorities and packet sizes. We set the index of the three services as 1, 2, 3, respectively. Then the priorities correspond to p_1, p_2, p_3, the packet sizes are set as s_1, s_2, s_3, respectively. And the relationship is $p_1>p_2>p_3$, and $s_1>s_2>s_3$.

As shown in Fig.9., there are four strategies compared in

TABLE II. SERVICE CONFIGURATION

Parameter	*VOIP*	*SNC*	*WEB*
Start Time (s)	Uniform (2,7)	Uniform (2,7)	Uniform (2,7)
ON State Time (s)	exponential (0.352)	Pareto (50,1.5)	Pareto (40,1.5)
OFF State Time(s)	exponential (0.65)	Pareto (100,1.5)	Pareto (40,1.5)
Interarrival Time(s)	constant (0.02)	exponential (0.12)	exponential (0.036)
Packet Size(bits)	Uniform (35,49)	constant (30)	constant (20)
Priority	1	2	3

the second simulation. In FIFO mode, the sequence of the queue is the same as the order of the service generation. And transmission is carried out within the allocated time slot. While in PBM mode, services queue is ordered according to the priority, and in SBM mode according to the packet size, preferring to select smaller packet to transmit, in order to ease the congestion of the queue. HBM mode is the strategy with a comprehensive consideration of both priority and packet size. The evaluation performance is set as the delay of each kind of service and the overall system, which are d_1, d_2, d_3, d_s, respectively. It is noted that the delay composes of the queuing time and the outputting time.

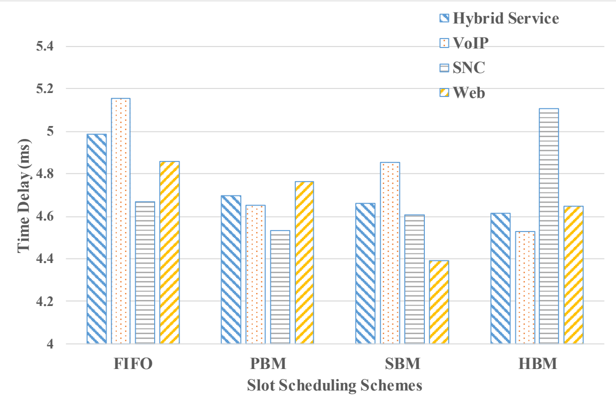

Fig. 9. Time delay of different modes under different service types

In FIFO mode, the overall simulation result is $d_1>d_3>d_2$. In PBM mode, service VoIP has the highest priority with the fastest rate, and service WEB has the lowest priority, with the slowest rate. Therefore, service VoIP has the shortest delay and service WEB has the largest. Considering the packet size $s_1>s_2>s_3$, the packets of service VoIP need longest outputting time, so the overall time delay will not differ significantly. In SBM mode, since smallest packets are output first, service SNC has the smallest queuing delay and as the smallest packet, outputting delay is also the least. Therefore, $d_1>d_2>d_3$, and the contrast is relatively obvious. In HBM mode, the priority and the packet size of service SNC are all in the middle level. On average, the delay is greater than that of service VoIP and service WEB, and this ratio will vary with the consideration weight of the priority and packet size in the algorithm. By observing the average delay of the four modes, it can be seen that time delay in FIFO mode, without any special measures, is the largest. In other modes, since the service priority and the packet size are sorted differently, the overall delay will not be much different after the queuing delay and the transmission delay are summed. However, it can still be seen that in HBM mode, with both aspects are considered, adjusting the weight parameters can reduce the system delay and increase the overall performance.

From the simulation above, we can conclude that considering the integration of the satellite channel conditions, remaining service time and the congestion degree of ground stations, we can choose different uplink scheduling strategies for optimal service efficiency. If channel is in bad condition, HBM mode can be used to achieve the minimum system delay and speed up business flow. If the condition of the channel is good, the service with higher priority can be preferentially transmitted. If the channel conditions are not good, but the S-eNodeB is not very congested, SBM mode can be selected to prioritize small packet transmission.

VI. CONCLUSION

As a new trend for the next generation communication networks, satcom systems are the solution to provide seamlessly integrated network of the future 5G architecture. In the paper, we proposed a double edge satellite terrestrial network architecture, after introducing a slot resource allocation scheme based on customized service priority, the performance of the scheme is evaluated on OPNET. Simulation shows that the new network structure and proposed time slots allocation scheme can improve the efficiency of service and decrease service time delay effectively.

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