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A Study on Priority-based Dynamic TDMA Protocol Simulation

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Abstract: With the development of military technology, satellite communication plays an increasingly important role. Satellite communications has been unable to meet the growing demand and study for finding a communication protocol to meet great of business data is very necessary. A priority and demand based dynamic TDMA (Time Division Multiple Access) protocol is presented and using OPNET software to build an environment to simulate this experiment. The satellite obtains information from each ground station and allot time slot to every ground station dynamically, based on their needs and priority. Simulation results show that, several most important parameters, e.g., end-to-end delay, throughput of system, meet the demand of rapid data communication in space-based tactical network. Therefore, this research for the TDMA protocol has great reference value, on setting up the space-based communications network.

Key words: Space-based, tactical network, demand-based, priority, network simulation

INTRODUCTION

Compared with a wired communication network, satellite communications system can provide users kinds of services worldwide. Satellite channel resources are often relatively scarce, therefore, this is the core of the study that how to effectively utilize the limited channel resources to serve as many as possible users. And multiple access TDMA technology can solve the problem very well (Lu *et al*., 2009a).

TDMA (Time Division Multiple Access) is divided time into periodic frames, each frame is divided into several time slots allocated to ground station for transmitting signal, the ground station can receive signals from the different mobile terminals without interference in each slot (Xin *et al*., 2011). TDMA multiple access control technology has important feature of real-time, dynamic allocation, intercept resistance and anti-jamming, which made TDMA used widely in the military mobile communication network.

TDMA multi-user access is used frequently, in the satellite channel of uplink. Downlink usually send data using broadcasting mode, Both mode of transmission use two different radio frequency respectively, to avoid collision (Mohammed and Le-Ngoc, 1994). In this study, the author take a studies on dynamic TDMA protocol that is mainly focus on the uplink of satellite network, in the downlink, satellite broadcast data to ground sites.

SATELLITE-BASED MOBILE COMMUNICATIONS NETWORK ARCHITECTURE

Be different from the traditional planar topology structure of the land mobile communication network, satellite mobile communication network is a three-dimensional topology structure. In this network, aircraft nodes keep moving, which make the whole network topology structure change along with time and with cyclical regularity and predictability. Satellite mobile communication network can be flexibly connected by all kinds of land military sites and has high-speed transmission of information and is a very good extensibility of information system, its structure diagram as shown in Fig. 1.

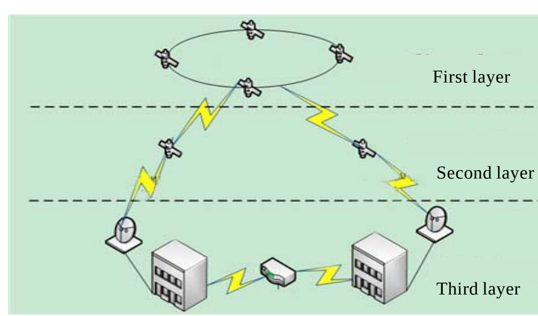

Fig. 1: Satellite-based mobile communications network architecture

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The first layer is a satellite backbone network, composed of several satellite nodes which connect each other with inter-satellite link network. Its function lies in the processing and forwarding data communication between ground sites terminal and gateway complete sites, is the core of satellite mobile communication network.

The second layer is the geositesary satellites, has 24 h all-weather communication ability and two-way communication between the first layers. It is mainly responsible for the communication with the ground command center.

The third layer is the ground command network, including the command center and management center (Chen and Zhang, 2009).

PROTOCOL ALGORITHM DESIGN

With TDMA multiple access methods, a key problem of satellite mobile communication is time slot allocation. In TDMA mode, different user is distinguishing different time slot. In the case of a certain number of users, the methods, to allocate the limited channel resources with high response speed and less collision rate, play important role in the entire communication network. In traditional fixed TDMA network, Channel allocation strategy is to allocate all time slot according to the maximum current user demand, before sites communicate with each other. Owing to this strategy, network can work without Collision detection. But when the network traffic load is heavy, efficiency and reliability will become so low that not suitable for military applications.

TDMA dynamic the reservation access strategy design: Dynamic TDMA reservation access can be achieved by improves the function of the fixed TDMA access mode. The summary method is that, in a fixed TDMA way, idle time slot contention is allowed, to improve channel utilization. The Shared channel is divided into a certain number of frames. The duration of frame must be greater than the channel propagation delay, the amount of slot in each frame must be greater than or equal to the nodes, in each slot, only one data packet can be sent. Each node has its own fixed time slot only one. If there is a data packet to be transmitted, the node first occupies its slot. If their time slot is not enough, they can content idle time slot. Until the data packet transmission is completed and then node releases all time slots into the idle state pool.

This has two principles:

- If node finds its own time slot to be applied by others, then shouldn't retreat, insist to use this slot. In the corresponding time slot of next frame, original configuration packet should be retransmitted
- If the node applies for a time slot which not belongs to this node, at the same time, owner of this time slot apply for. The first node should immediately retreat and release slot to ensure no longer compete to obtain this slot in the next frame, but continue to search for other idle slot

In detail of this method, each frame is composed of synchronous time slot, control slot and data slot. The control slot is located in the head of each frame and is divided into several equal-length micro slot in a networking system startup, each site compete to broadcast their ID number in its own micro slot, when the state of entire network keep convergence all sites will know the whole micro slot allocation information.

A micro slot node status table can be automatically generated according to the ID of all the sites, as shown in Fig. 2, sites confirm its elves' relative position in reservation time slot and send Request packets in their own micro slot packet.

In the fixed TDMA mode, one micro slot is assigned to one ground sites, micro slot should be long enough to send an slot-applying packet. If a node has data to transmit, first, in micro slot it should send slot-applying packet, publishing that it need a data slot in next frame. All the nodes in the network must be able to detect the signal channel, in order to accurately understand the network time slot allocation situation. Including the amounts of site to apply micro slot, site's ID and sort order.

After ground sites apply time slot successfully, they has gotten their number of time slot. According to their order of addresses and send data packet once in a data slot. This frame comes to a close and that cycle repeats. After time slot is appointed to one site and is fixedly assigned to it until the end of data transmission. Then this time slot will be retrieved by system, in next turn, satellite assigns this time slot to ground sites which needed (Lu *et al*., 2009b).

Network control principles: In the dynamic TDMA protocol of the network, the system in centralized control mode, implement the network time slot allocation function, data is forwarded from one ground site to another directly by satellite, without the need to adjust the ground sites.

0 (id)	1 (id)	2 (id)	.....	i (id)	.....	M-2 (id)	M-1 (id)

Fig. 2: Micro slot node's status table

In the network, there is only one satellite and several ground sites. Network control information transmitted by the satellite in the tail micro slot of slot-applying slots which in each frame. For example, there are amounts of M ground sites, so slot-applying slot will be divided into M+1 micro slot.

- **Network boot:** With internal timer, Satellite send synchronization control frame twice and initialize network. Ground sites must receive two successive, effective synchronous control frames at least. The synchronous control frame can help ground sites adjust themselves' local timer, in order to sync with satellite. After all, they form a network
- **Time slot application:** When a ground site need to apply a new time slot, just fill its address in the corresponding field of the application packet and then send to satellite in its own micro slot. When it receives the reply from the satellite, it means that the application is successful and in next frame a new time slot can be used
- **Time slot retrieve:** The last field of the data packet is to identify transmission over or not. If transmission is over, the satellite retrieve time slot allocated to the site
- **New sites access:** In order to achieve time synchronization with satellite, new site must receive twice successive, effective synchronous control frame at least, before joins in the network. Satellite allocate time slot for the new site and scan the slot list. If find idle slots, assign to the site; If there is no idle time slot, in next turn, this site's slot application will be priority (Wang, 1992)

Priority-based time slot allocation strategy: Usually the transmission of intelligence information requires a relatively high real-time and intelligence information transmission services is an important part of what services the mobile communication network provide. The packet size is generally a few dozen bytes, the characteristics of targets is uncertainty in the general, so the intelligence traffic may mutation. Real-time transmission of intelligence information is particularly important. This requires the site is a higher priority to send such information, to avoid the backlog of site data or lost.

The system set up two priority levels: High-priority sites and mobile communication web sites. The system maintains a polling sequence, to save the ID number of each site. The assignment of time slot starting from the head of the queue for ordinary mobile site after the successful of time slot allocation, its corresponding ID number transplant to the queue tail for high-priority site, using the different type of polling sequence. This cycle until the time slot assignment completed the satellite generates the reply packet, the packet including the time slot assignment information and a request sequence of the next frame (included in the structure). The algorithm is shown in Fig. 3 (Lu *et al*., 2009a, b).

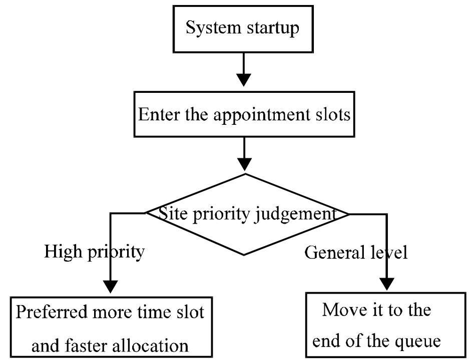

Fig. 3: Priority algorithm flow chart of satellite mobile communications network

Within the reservation time slot in each frame, the system according to priority level of different packets, use different allocation strategies at High-priority packets, the give high priority site priority allocation of rights and a greater number of time slot allocation rights. Therefore, the high-priority group site's requests are able to get a faster response. So, urgent business data can be delivered in a timely manner, this will supply low priority site other than the site with the better transmission characteristics.

ESTABLISHMENT OF SIMULATION MODEL

Protocol and packet format frame design

- **Frame of protocol design:** In the TDMA protocol, the length of each frame is fixed, each frame is divided into 10 data slots. The length of each data slot is 1.0 sec. At beginning of the system simulation, 10 data slot are allocated to every ground site. To dynamic TDMA protocol, the first data slots are as appointment slots and are divided into 10 equal-length micro slot which of length is 0.1 sec. Micro slot is allocated with fixed TDMA protocol. No. 9 of micro slot used by satellite to sends a response to ground sites for the reply their time slot application (Zhu *et al*., 2009), as shown in the frame format shown in Fig. 4
- **Data package format design:** The network design three different types of data packets, which means that three different types of data packet, the three data packets: Data packet, the time slot request packet and satellite reply packet

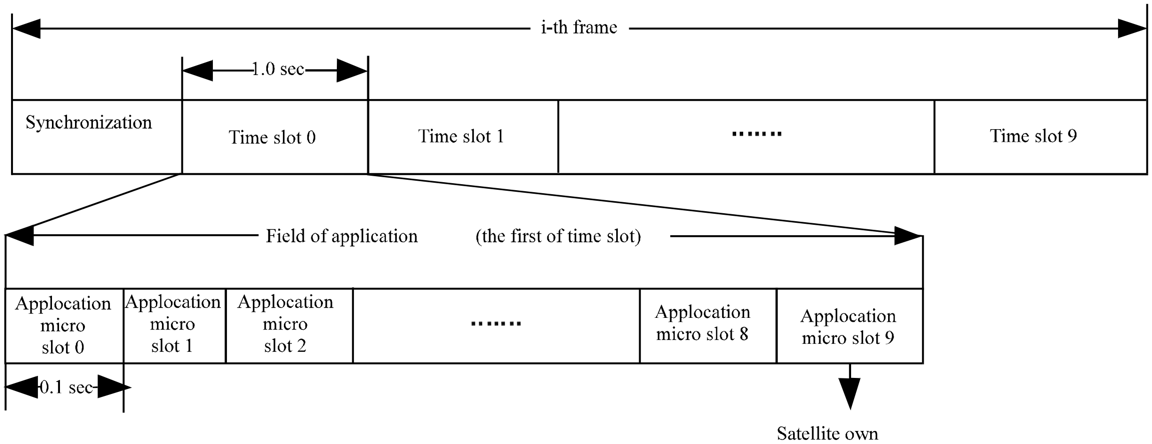

Fig. 4: Format of dynamic TDMA protocol frame

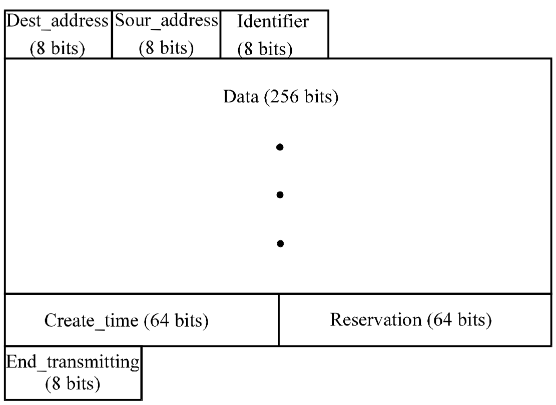

Fig. 5: Data package format

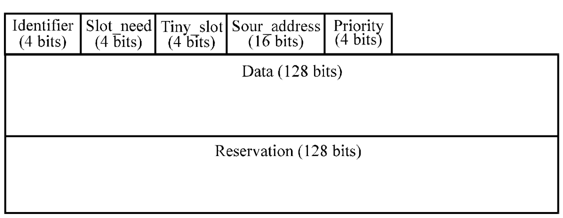

Fig. 6: Application packet formats

The data packet is produced by the source in the note model contains the site have to transmit the actual data information setting data packet length 416 bit. In the simulation, as shown in Fig. 5, the data packet contains the following fields:

- **Field of dest_address:** Destination address of packet
- **Field of sour_address:** The source address of the packet
- **Field of end_transmitting:** Flag of send completed, satellite according to the sign decide whether retrieve data time slot occupied by the current site

The application packet is used by ground sites to apply data time slot from satellite, package includes the number application of time slot, sites' ID and the site index of micro slot. Format as shown in Fig. 6, the package contains the following fields:

- **Field of slots_need:** The number of time slots need to apply for
- **Field of tiny_slot:** The current site of micro slots index
- **Field of sour_address:** The source address of the packet, the value will be as a reply address sent from satellite
- **Field of priority:** Indicates the priority level of the current site

Satellite maintains a list of unassigned time slots, satellite receive a ground site request packet and then add the corresponding information of the site to the unallocated list. When all sites has been completed requests, the satellite will be ordered by the list, the high-priority sites will be moved to the head of list, so that the satellite can handle its request first, so as to improve the speed of access of high-priority sites into the network.

Satellite reply packet is generally sent in the micro slot No. 9, the package include detail of current time slot allocation for each of sites. Allocation information include in time slot allocation table, embodied in the form of structure, as shown in the following:

```
#define N 10
typedef struct slots_Assignment
    {
    int nodeID[N];
    int start[N];
    int slotNum[N];
    }Slots_Ass;
```

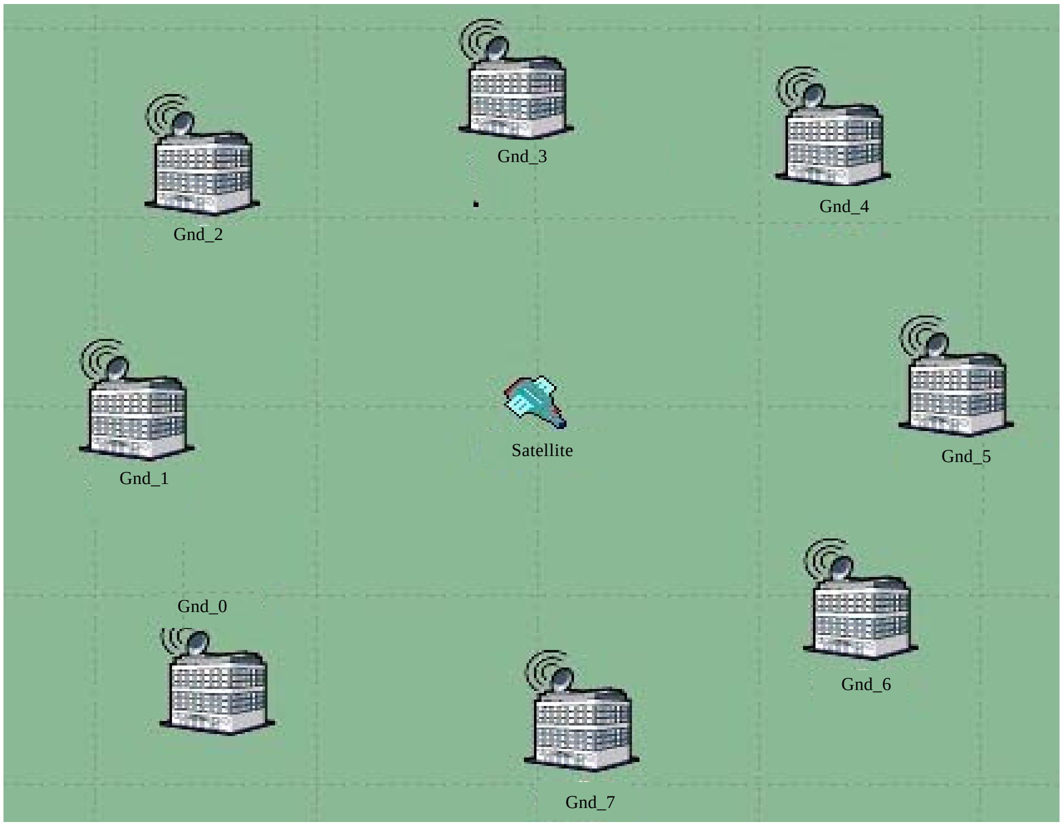

Fig. 7: Network layer models

Node ID array preserve the requesting site ID, the start array holds position the slot start which has been assigned to a site. Slot_num array save number of time slot assigned to one site.

Network layer model: The network model indicates the position of each node in the network, connecting links between nodes and node-specific configuration information. Network model is shown in Fig. 7, for the dynamic TDMA protocol, the first time slot is divided into 10 micro time slot for transmitting the time slot request packet, the remaining 9 slots as the data slots for transmitting data packets. Micro slot is allocated according to a fixed TDMA protocol, the system has been set up at the beginning of the simulation and remains unchanged in the whole process, once the site needs to send the data packet, it can be in allocated micro slot transmit request packet (Mitchell *et al*., 2004):

- **Ground station process model:** Ground station process model is the core of dynamic TDMA protocol; it is responsible for the realizing function module of distribution according to one's needs. ground station node model is specific implementation process of the satellite dynamic TDMA protocol, the model shown in Fig. 8 above

Workflow of ground sites with dynamic TDMA protocol shown in Fig. 8. As can be seen, the method of fixed distribution blend into the dynamic TDMA protocol. Its mean is that a micro slot is allocated in fixed TDMA way. Each ground station must send request packet in micro slot specified. In the model two states should be introduced:

- **The status of the request:** In data queue, there are application packets need to send to satellite. According to the fixed TDMA protocol, ground site keep making micro slot access judge and satellite make reply information judge. Until application is successful, then ground sites enter the sending state to send data
- **Sending status:** After time slot application is succeed. It is waiting for their time slot to send data in the data slot of each frame. The process will judge the data time slot constantly and send data

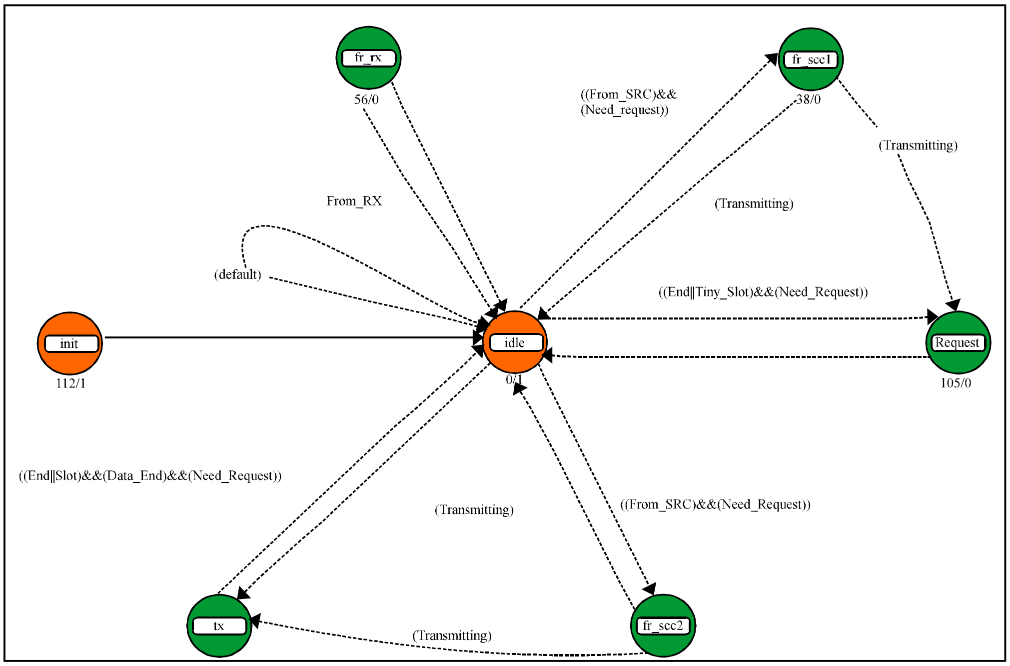

Fig. 8: Flow chart of time slot allocation algorithm

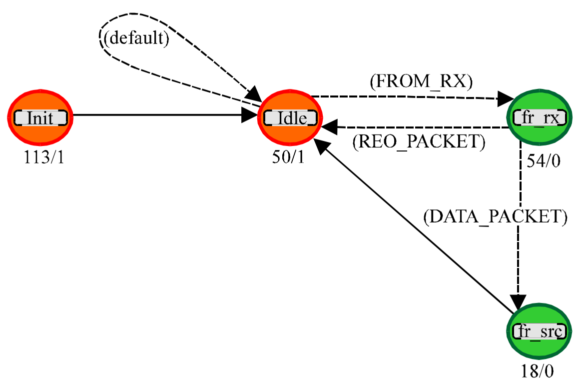

Fig. 9: Satellite process model

- **Satellite process model:** Unlike fixed TDMA protocol, satellite in addition to forward data, has the time slot allocation and recovery function. The satellites take centralized control on the slot allocation; can take a variety of time slot allocation strategy to meet the needs of different businesses, greatly improving the protocol flexibility. The model is shown in Fig. 9
  - **Initial state:** Initializing a number of variables, including: Length and amounts of data time slot, length and amounts of micro slot and slot list
  - **Idle state:** Waiting for the stream interruption arrival then jumping to the next step. When it enters the code area, it needs the judgment of the micro slot, in number of 0-8 micro slot, satellite need to record request information of ground stations. The position of Satellite micro slot is 9. After entering the micro slot, satellite based on request information of applications data packet received by the first 8 micro slot data and allocation of time slots in accordance with the time slot allocation algorithm. After assignment is completed, generate a reply packet and fill the satellite reply data packet with slot allocation information and broadcasts the packet (Mohammed and Le-Ngoc, 1994)

SIMULATION AND RESULT ANALYSIS

In order to analyzing the performance of the dynamic TDMA protocol in detail. The simulation set up two global statistics: Average of end-to-end delay (end_to_end_delay_handle) and the amounts of packets sent (Sum_Packets_send).

Average end-to-end delay of the network: The large volume of business, the site generated packets at a rate

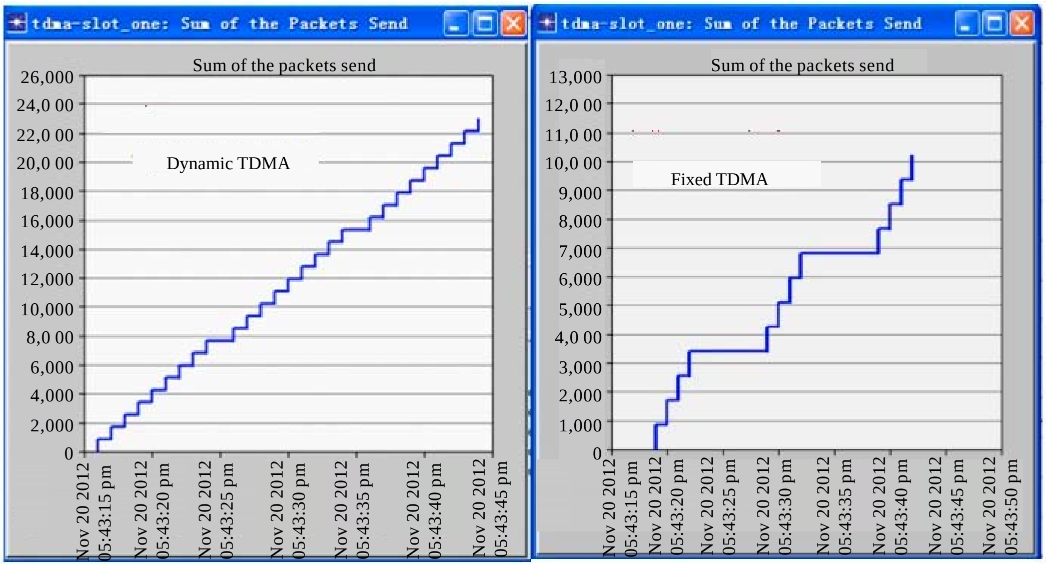

Fig. 10: Average end-to-end delay result

Table 1: Setting of nodes table (for verifying priority policy)

Ground station transmitter rate	256 kb sec^{-1}
Interval in gnd_0	0.0001 (sec)
Interval in gnd_1	0.0001 (sec)
Interval in gnd_2	0.0001 (sec)
Interval in gnd_3	0.0001 (sec)
Interval in gnd_4	0.0001 (sec)
Interval in gnd_5	0.0001 (sec)
Interval in gnd_6	0.0001 (sec)
Interval in gnd_7	0.0001 (sec)
Length of package	416 bit
Amounts of packets sent in one slot	1456

faster, date packets rapidly increasing in the queue. Usually sites cannot complete the task transmitted from the queue data packet in an even number of time slots, as shown in Table 1.

Interval of time between with each two data packages generated by gnd_0~gnd_7 site is 0.0001 sec, these packages have 7 times to be sent completely. In the fixed allocation, each site can only be assigned one time slot, so 7 frames have to be used to send.

A less increasing with dynamic allocation can be seen from Fig. 10 in the fixed allocation increasing is very significantly. This is because when the system is in a busy state, the data packets in queue continue to increase rapidly. In fixed TDMA, site only be allow transmit data packets in belong its own time slot (only one), for site without sending, its idle slot do not allow the busy site to occupy. The idle time slot resources waste so greatly that increased waiting time of the data packet. For dynamic allocation, the channel utilization is high, the system assigns some slots for heavy business site and idle time slot does not exist. It can greatly reduce the waiting time of the data packet.

Comparison between priority with not: In the network, setting up gnd_5 site is a high priority. The rest of the site is the normal priority site. Verification of priority strategy in large volume of business is shown in Table 1. All sites maintain a rapid rate of generating data packets, prompting each site emit slot application to the satellites. Without use of priority assignment strategy, satellite record site information according to each site request sequence. It is Using a first-come first-served principle for all ground station for time slot allocation when satellite allocate time slot for gnd_5 site. Maybe there is no idle time slot to be allocated. The gnd_5 site is a high priority sites although, gnd_5 site for high-priority sites, but can only wait for the re-allocation in the next frame. After joining the priority allocation policy the high-priority site requests will be priority disposed and it'll get more time slots than the average site.

From the graph of Fig. 11a and b something can be seen, in the same simulation conditions, sites of gnd_5 can send more data packets using priority strategy than nor-priority. Because of the high level of priority in

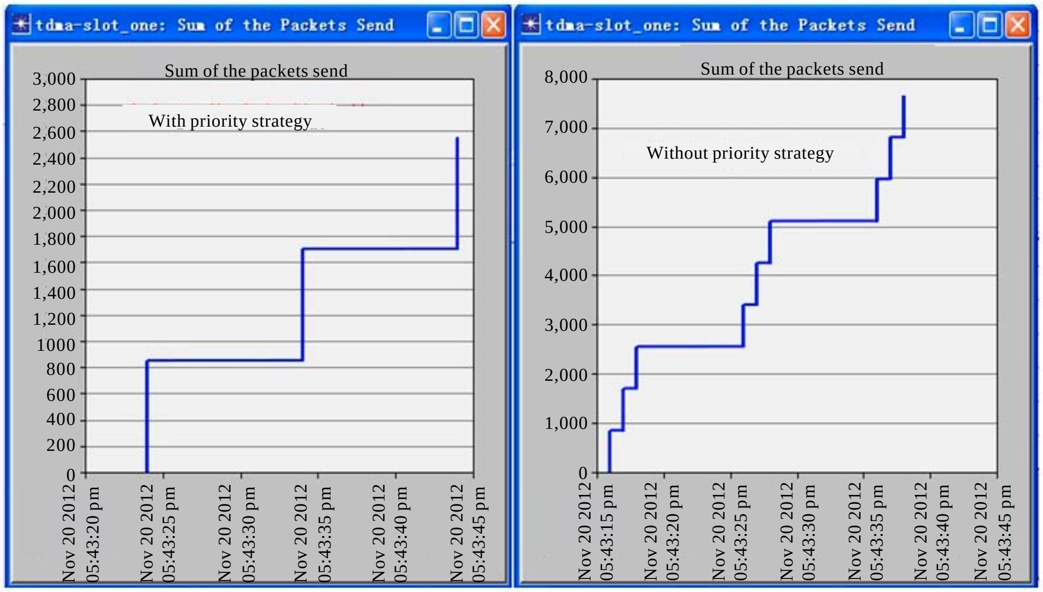

Fig. 11: Number of packets sent in gnd_5, (a) Amounts of packet sent with priority strategy, (b) Amounts of packet sent without priority strategy

the allocation and more slots allocated, this allows high-priority sites rapid access and sends data packets in the network.

CONCLUSION

In this study, it presents a simulation study on priority TDMA protocol based on a suitable space-based tactical communications network. It can be seen from the simulation results; the high-priority sites have relatively low end-to-end delay and faster access into network. So, it solve the real-time requirements of tactical communications network and transmission of emergency data. The overall performance of system, meet the target and requirement.

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