Traffic Aware Inter-layer Contact Selection for Multi-layer Satellite Terrestrial Network

Wenfeng Shi*, Deyun Gao*, Huachun Zhou*, Qi Xu*, and Chuan Heng Foh†

*School of Electronic and Information Engineering, Beijing Jiaotong University, Beijing, 100044, China
Email:{14111038, gaody, hchzhou, 15111046}@bjtu.edu.cn
†5GIC, Institute of Communication, University of Surrey, UK
Email: c.foh@surrey.ac.uk

Abstract—Satellite networks form part of the modern mobile network. In multi-layer satellite-terrestrial networks, Contact Graph Routing (CGR) enables to calculate an efficient delivery path which depends on the contact information configured in the contact plan. Due to the rapid relative motion between satellites which belong to different layers, the inter-layer contacts can suffer frequent disruption. In order to keep the integrity of the network, the inter-layer contact must be carefully selected to maintain connectivity yet avoid congestion. In this paper, we propose a traffic aware inter-layer contact selection method (TACS) by considering the flow situation of the associated nodes which contains the queue size, flow size, the number of connected nodes and the contact duration. We verify the performance of the proposed design in our Identifier/Locator (ID/Loc) split based satellite-terrestrial network tested with 95 simulation nodes. Experiments show that the proposed design is able to achieve balanced flow distribution among MEO layer, improve the delivery ratio and reduce the delivery delay.

I. INTRODUCTION

Thanks to the extensive usages of satellite communication in navigation, disaster emergency communication and internet access for sparsely populated areas, the combination of satellite and terrestrial network have received great attention [1] [2]. Its unique property provides complementing solutions to other technologies in the modern mobile network. However, in satellite network whose environment is characterized by frequent link disruption, long delivery delay and high bit error, traditional TCP/IP stack used in terrestrial networks can hardly be adopted directly [3]. Although some modified TCP protocol are developed to cope with such challenging environment, they have introduced other drawbacks in security and mobility [4]. Considering above, Delay and Disruption Tolerant Networks (DTN) can provide an alternative selection for future satellite networks [4].

DTN works as an overlay above the transport and other lower layer. It deals with the frequent link disruption and long delay using a hop by hop mechanism, instead of the solution which is adopted on the delivery path from the source node to the destination node. When one link in the path is disrupted, messages will be stored at the intermediate nodes and wait for the next transmission opportunity. In addition to the application in satellite networks, DTN has also been widely used in many other areas, including the vehicular networks[5], social networks[6], remote village communication[7], etc.

Since satellite nodes and their moving trajectories are scheduled, it is possible to acquire the knowledge of contact characteristics which contains the communication duration, the rate, and other information. By using the predictable contacts information, CGR [8] can calculate a delivery path efficiently. CGR have drawn a great research attention such as the work of investigating the fitness of CGR in satellite disruption networks [9], the improvement of the accuracy [10] [11], the contact plan design problem[12] [13], etc. However, most of these works are centralized with small scale topology, the usage of CGR in multi-layer satellite network which is characterized by the large scale disruption topology have received very little attention.

According to orbit altitude, satellites can be classified into GEO, MEO and LEO layer nodes. Satellites in these layers will express diverse characters as the orbit height varies. The GEO nodes provide wide coverage areas while they also result in longer delivery time. The lower altitude LEO and MEO nodes contribute to short communication delay but their connectivity is not easy to manage. Thus, the combination of the multiple satellite layers as MLSN (Multi-Layer Satellite Network) [14] can achieve various advantages. Despite that many works have been done on the design of IP based multi-layer satellite routes, such as QoS enhancement and load balancing routings [15], they only focus on the routing enhancements, neglecting the feature of space environment such as delay and high bit error.

In MLSN, there exists many potential inter-layer links. However, the limited resources of satellites such as the power and antenna forbid all these inter-layer links being used and usually only an inter-layer link is selected. Considering the rapid relative motion between nodes which belong to different layers, the inter-layer links could suffer frequent disruptions and handover problems. Therefore, how to select the suitable inter-layer links is crucial to keep the network integrity when the former link is disrupted. However, this problem receives very little attention. Besides, since the MEO and LEO layer nodes usually take charge of delivering user messages, the data flow can be huge in the two layers. If an unsuitable inter-layer contact is selected, a MEO node may be congested as a result of the centralized flows from the LEO layer.

Considering the above, in this paper we use DTN and CGR to deal with the special features of satellite environment.
and propose a dynamic traffic aware inter-layer link selection algorithm to handle the disruption problem of links among satellites. We consider the flow situation which contains the queue size, the flow size, the number of neighbor nodes that the candidate MEO node connect with and the contact duration when select a new inter-layer contact. The main contributions of this paper are summarized as follows:

1) A flow weighted space time graph is proposed to model the multi-layer satellite network.
2) A traffic-aware inter-layer contact selection algorithm is proposed to handle the disruption problem of inter-layer links.
3) The inter-layer contact selection algorithm is verified on our testbed with 95 nodes and experiments show that the method achieves a more balanced flow distribution among MEO layer, improves the delivery ratio and reduces the delivery delay.

The rest of the paper is organized as follows: In Section II, we introduce the enhancements of CGR. Section III presents the model for the satellite network using a flow weighted space time graph. In Section IV, our proposed inter-layer contact selection algorithms are presented. Section V, reports the experiments on our satellite-terrestrial network test bed. Finally, we summarize our work and draw important conclusions in Section VI.

II. RELATED WORK

DTN and CGR have received significant attention recently. In [5], authors studied the optimization problem for mobile routers in vehicular delay tolerant networks. They proposed a constrained Markov decision process based formulation to maximize the benefits of the source nodes and guarantee the QoS requirements. In [6], authors summarized the routing protocols in social delay tolerant networks. Meanwhile, a summary of existing CGR enhancements is also reported in [8].

In [10], the authors proposed CGR-ETO and overbooking management which have considered the queue size of the local nodes to obtain a more accurate delivery time. In [11], the authors focused on the problem of overlooking the future contacts in CGR and applied a modified temporal graph to model the dynamic connectivity of the satellite network. They proposed EAODR algorithm to find a delivery path which considered both the earliest arrival time and the optimal delivery ratio.

Considering that the resource constraints can forbid all the contacts to be configured into contact plan, authors in [12] proposed a fairness contact plan design algorithm to minimal the all-to-all routes delays. In [13], the authors modeled the average network throughput optimization problem using time-expanded graph and proposed a dynamic contact plan design algorithm (DCPDA) to optimize the throughput by considering time-varying of contact capacity.

In [16] the authors focused their work on topology control problem. They used a directed space-time graph to model the predictable DTN whose topology is continuously changeable over time.

III. SYSTEM MODEL

In this paper, we use space time graph [16] by introducing contact flow weight to model multi-layer satellite network and describe the inter-layer contact selection problem.

A. Flow Weighted Space Time Graph Model for Multi-Layer Satellite Network

Due to the rapid relative motion among nodes in multi-layer satellite network, the satellite links can suffer frequent disruption and reconnection. The topology exhibits an unstable feature. Applying static graph to model such a network may fail. However, at a particular time period where the nodes and links have not been disrupted, the topology is temporarily stable and static graph model is valid for that instance.

Fig. 1 is a simple example of space time graph illustrating that the topology evolution can be partitioned into five time slots where the partitioning occurs at time $t_1, t_2, \cdots, t_5$ when link disruption is about to happen. With this partitioning, the topology can be seen as static within each time slot. The topology can be divided into five subgraphs from $gr_1$ to $gr_5$ each of which is modeled as a static graph.

We assume that there are $N_g$ GEO satellites, $N_m$ MEO satellites and $N_l$ LEO satellites in the multi-layer satellite network. Define the $i$th $j$th and $k$th node in GEO MEO and LEO layer to be $v_{gi}$, $v_{mj}$, $v_{lk}$ respectively. Let $V$ and $E$ be a set collecting all nodes and all links in the multi-layer satellite respectively. Let $\overrightarrow{v_i v_j}$ denote the link between node $i$ and node $j$. We assume that the queue length and flow size between node $i$ and node $j$ at time $t$ be denoted as $q(\overrightarrow{v_i v_j}, t)$ and $f(\overrightarrow{v_i v_j}, t)$ respectively. Define the entire system period to be $T$, it can be divided into $N_T$ time slots denoted as $t_i$ where $i = 1, 2, \cdots, N_T$. Note that a partitioning of time slot occurs only when links among nodes are about to be disrupted.

Let $G(t_i) = (V(t_i), E(t_i), w(t))$ denote the graph of the satellite topology in time slot $t_i$. The $V(t_i)$ and $E(t_i)$ reflect the topology of the multi-layer satellite network during time slot $t_i$. The quantity $w(t)$ denotes the flow character of links including queue length and flow size. Then, the multi-layer satellite network can be modeled as flow weighted space time graph $G(V, E, w)$ with $N_T$ static graphs $\{G(t_i)|i = 1, 2, 3, \cdots, N_T\}$ in time sequence.
B. Inter-layer Contact Selection Problem

In order to avoid a LEO node being connected with a congested MEO layer node, we consider the queue length and accessed flow size of the MEO layer nodes when we select a new inter-layer contact. From the flow weighted space time graph $G(V, E, w)$, we can obtain the flow information of the MEO nodes. At the same time, we can acquire the number of LEO nodes which are connected with the MEO. Besides, the potential contact duration can also be obtained. Using this information, we can select an inter-layer contact to achieve that goal.

IV. TRAFFIC AWARE INTER-LAYER CONTACT SELECTION ALGORITHM

Considering the fact that GEO layer can provide extensive coverage to low layer satellites, we use GEO layer as the control layer to take charge of inter-layer contact selection. We use LEO layer to access messages for ground stations and deliver short hop count data. The MEO layer is used to deliver long hop count data.

Satellite in the lower layer usually maintains only one inter-layer contact between itself and the higher layer satellite in each time slot. For example, a LEO node maintains a contact between itself and the MEO layer node as well as a contact between itself and the GEO layer node. When the inter-layer contacts are disrupted, GEO nodes will select a new one for the disrupted nodes and update the contacts dynamically. In order to realize the inter-layer contact selection, nodes in GEO layer should maintain a Contact Plan (DCP) which contains all the selected inter-layer contacts information of the satellite network. Meanwhile, the GEO nodes should also maintain a Handover Contact Plan (HCP) which contains all the potential inter-layer contacts in the future. The DCP and HCP are formulated using flow weighted space time graph $G(V, E, w)$ discussed in Section III.

In order to avoid a LEO node being connected to a congested MEO node when select new inter-layer contacts, we first formulate inter-layer contact selection into an optimization problem given in part A. In part B, we further propose a flow updating scheme of the MEO layer nodes to realize the updating of flow situation. In part C, we propose a traffic aware inter-layer contact selection algorithm based on the prior two parts. Using the flow information obtained in part B, the GEO selects a candidate inter-layer contact which is subject to the flow constraints and objective functions.

A. Inter-Layer Contact Selection

We consider four flow characters of the candidate MEO nodes including the queue size of contacts between it and the MEO layer nodes, the contact duration, the number of inter-layer contacts maintained by it and the accessed flow size from LEO layer. The meanings of the variables are shown in Table 1. The selection problem of inter-layer contacts can be formulated as multi objective optimization problem as follows:

Objective functions:

\[
\begin{align*}
&\text{min} \sum_{k=1,k\neq j}^{N_m} q(v_{m_j}^\rightarrow, v_{m_k}^\rightarrow, t) \quad (1)
\\&\text{min} \sum_{p=1}^{N_i} f(v_{i_p}^\rightarrow, v_{m_j}^\rightarrow, t) \quad (2)
\\&\text{min} \sum_{p=1}^{N_i} u(v_{i_p}, v_{m_j}) \quad (3)
\\&\text{max} d(v_{i_p}, v_{m_j}) \quad (4)
\end{align*}
\]

We consider four objective functions to select the most suitable inter-layer contact for the disrupted LEO node. The first objective attempts to select a MEO with minimum queue size in MEO layer. The second objectives attempts to select a MEO with the least accessed flow from LEO layer. The third objective attempts to select a MEO with the least LEO nodes. The last objective attempts to select a MEO which has the longest coverage duration for the LEO in next time slot.

Assuming that a contact $c$ which connects a LEO node $v_{i_j}$ with MEO layer node is about to be disrupted. In order to select a suitable inter-layer contact in next time slot, the candidate MEO node $v_{m_j}$ should satisfy the following constraints:

\[
\begin{align*}
s_{v_{i_j}, v_{m_j}} &\leq \epsilon t_c, \forall i_j, v_{m_j} \quad (5)
\\e t_{v_{i_j}, v_{m_j}} &\geq \epsilon t_c, \forall i_j, v_{m_j} \quad (6)
\\\sum_{p=1}^{N_i} u(v_{i_p}, v_{m_j}) (t) &\leq n_{\text{max}}, \forall p, j, t \quad (7)
\\d_{v_{i_j}, v_{m_j}} (t) &\geq t_{\text{min}} \quad (8)
\end{align*}
\]

The first and the second constraints describe that the start time of the contact between $v_{i_j}$ and the candidate MEO node $v_{m_j}$ should appear before the end time of the disrupted contact $c$ while the end time of it should appear after the end time of contact $c$. With this two constraints, a contact between the
disrupted LEO \( v_l \) and a MEO layer node \( v_m \) can be used in next time slot. The third constraint describes that the number of inter-layer contacts which the candidate MEO node \( v_m \) connects with should be no more than a preset value \( n_{max} \). The fourth constraint describes that the duration of the new contact should be longer than a preset value \( t_{min} \). In this way we can avoid selecting a contact that will be disrupted quickly.

In order to simultaneously meet different objectives, we assign different weights to each objective:

\[
f_m(t) = k_1 \cdot \sum_{k=1,k\neq j}^{N_m} q(v_{m,j}^{-1}v_{m,k}^{-1}, t) + k_2 \cdot \sum_{i=1}^{N_l} f_l(\overline{v}_i, v_{m,j}^{-1}, t) + k_3 \cdot \sum_{i=1}^{N_l} u_{i,m_j} + k_4 / d_{k,m_j}
\]

(9)

Considering that the effects of the four factors are becoming less important in turn, we use the following values for the weights where \( k_1 = 0.8, k_2 = 0.15, k_3 = 0.04, k_4 = 0.01 \). By assigning the weights in this way, the MEO with the minimum queue length will be firstly selected. If the queue length is the same, the one with the lowest assessed flow will be selected. The accessed LEO numbers and the contact duration will be matched similarly.

### B. Flow Update for MEO Nodes

In order to realize the traffic aware inter-layer contact selection, the GEO should receive the information about the flow situation of MEO layer nodes. We modify the original contact plan to add queue size and flow size for contacts. Also, we create a LEO flow list to record the flow size accessed from LEO layer for each MEO node. The MEO node will go through the contact plan in a fixed period to check if the flow situation have changed. If the recorded flow information have changed over a preset ratio, a flow updating message will be sent to the GEO layer. In this paper, the detection period is set to be 5s, the change ratio is set to be 5%.

Firstly, a MEO node will open contact plan to check whether the queue size of the intra-layer contact which is connected with the neighbor node has changed. We use node number to identify which layer the node belongs to. If the start node is the local node and end node belongs to \( \{v_{m_0}, \ldots, v_{m_N} \} \), then the contact can be recognized as an intra-layer contact in MEO layer. In CGR, every node maintains one queue to each neighbor node. We compare the queue size with the queue size recorded in DCP. If the queue size have changed by 5 percent, then the GEO will update the recorded queue size in contact plan and then send an updating message which is identified by the reserved flag bit of bundle protocol to GEO nodes. If the change ratio is less than 5 percent, the MEO will check that in the next contact.

Secondly, the MEO should check the change ratio of the accessed flows from LEO layer. If the contact start node belongs to \( \{v_{l_0}, \ldots, v_{l_N} \} \) and the end node is the local node, the contact will be recognized as an inter-layer contact between LEO node and detecting MEO node. Then we compute the change ratio between the flow size recorded in contact plan and the flow record list. The flow size recorded in flow list is an average value during the checking period. If the change ratio is more than 5 percent, the MEO will update the recorded flow size in contact plan and send an updating message to GEOs.

### C. Inter-Layer Contact Selection for the Next Time Slot

When a GEO node receives a bundle, it will check whether this is a flow updating message according to the reserved bit flag. If so, the GEO will find the contact from DCP and update the flow information.

**Algorithm 1**: traffic aware inter-layer contact selection

- **Input**:
  - data contact plan; handover contact plan

- **Output**:
  - contact updating message list CUML

1: Open DCP, CUML= \( \emptyset \)
2: for all \( c_j \) such that \( c_j \in DCP \) do
3:   if \( et_{c_j} - ct < 5s \) & \& \( en_{c_j} \) is connected with the GEO then
4:     if \( sn_{en_{c_j}} \in \{v_{l_0}, \ldots, v_{l_N}\} \) & \& \( sn_{c_j} \in \{v_{m_0}, \ldots, v_{m_N}\} \) then
5:       for all \( c_j \) such that \( c_j \in HCP \) do
6:         if \( sn_{en_{c_j}} \in \{v_{m_0}, \ldots, v_{m_N}\} \) & \& \( sn_{en_{c_j}} \) is connected with the GEO then
7:           if \( st_{c_j} \leq et_{c_j} \& \& sk_{en_{c_j}} \) & \& \( et_{c_j} - ct \geq t_{min} \) then
8:             if \( \sum_{p=1}^{N_l} u_{p,c_j} \cdot en_{c_j} + v_{p,c_j} \leq n_{max} \) then
9:               Calculate the \( f_m(t) \), \( ACS = ACS \cup c_j \)
10:          end if
11:        end if
12:     end if
13:   end for
14:   Select the MEO node with lowest \( f_m(t) \), ACS=\( \emptyset \), add the new contact into DCP, create the contact updating message, \( CUML = CUML \cup message \)
15:   end if
16: else
17:     if \( et_{c_j} - ct < 5s \) & \& \( sn_{c_j} \in \{v_{l_0}, \ldots, v_{l_N}\} \) then
18:        for all \( c_j \) such that \( c_j \in HCP \) do
19:          if \( sn_{en_{c_j}} \in \{v_{l_0}, \ldots, v_{l_N}\} \) & \& \( en_{c_j} \) is connected with the GEO then
20:             if \( st_{c_j} \leq et_{c_j} \& \& sk_{en_{c_j}} \geq et_{c_j} \) then
21:               \( ACS = ACS \cup c_j \)
22:             end if
23:          end if
24:        end for
25:        select the contact with the longest duration, ACS=\( \emptyset \), add the new contact into DCP, create the contact updating message, \( CUML = CUML \cup message \)
26:     end if
27: else
28:     end if
29: return CUML;
nodes, then a contact with the longest duration is the most suitable one. Let \( c_i \) denote the \( i \)th contact in contact plan, \( s_{c_i} \) and \( e_{c_i} \) denote the start and end node of contact \( c_i \), \( st_{c_i} \) and \( et_{c_i} \) denote the start and end time of \( c_i \), \( v_{local} \) denotes the local node processing the algorithm, \( ct \) denotes the current detection time. The selected processes are shown in Algorithm 1 which is described as follows.

Step 1: GEO will open DCP to go through the inter-layer contact between low layer and high layer nodes. If the residual time is less than 5 seconds, the contact is regarded as to be disrupted and then go to step 2. If not, then go to check next contact. When all the contacts in DCP are checked completely, the algorithm will wait for 5 seconds before starting a new detecting round.

Step 2: The GEO checks which layer the disrupted contact belongs to. The process continues in step 3 for inter-layer contact between LEO and MEO layer nodes, or step 6 for inter-layer contact between lower layer nodes and GEO layer nodes.

Step 3: GEO nodes open HCP and go through HCP to find each candidate contact for the disrupted LEO node starting with the disrupted GEO and ending with a MEO layer node. When a candidate contact meets time constraints described in part A, the process continues in step 4.

Step 4: GEO nodes open DCP to check whether the candidate contact satisfies the MEO flow constraints described in part A. Firstly, GEO checks if the residual communication duration is longer than a preset value. In this paper we set the value to 100s. Secondly, GEO computes the LEO numbers that the candidate MEO has already connected with. If the number is less than 10, then the MEO has been subject to the flow constraint. If either of this two constraints is not satisfied, the process continues in step 3 to check the next inter-layer contact in HCP. Otherwise, the GEO calculates the flow weight value \( f_m(t) \) described in part A and add it into Alternative Contact Set (ACS) and go back to step 3. When all contacts in HCP are checked completely, the process proceeds to step 5.

Step 5: We select the MEO node with the lowest \( f_m(t) \) value as the candidate node for the LEO to connect with. Then GEO nodes add the new inter-layer contact into DCP as well as send the contact updating message to the LEO, all the MEO and all the GEO nodes. Next we clean ACS and return back to step 1 to check next inter-layer contact.

Step 6: GEO opens HCP to find all contacts that start with the disrupted low layer node and end with a GEO layer node as well as be subject to time constraint described in step 3. Then it select the contact with the longest duration as the inter-layer contact in next time slot. As soon as the contact is selected, the contact updating message will be sent to the associated nodes including the disrupted low layer nodes and all the GEO layer nodes. The process returns back to step 1 to check next inter-layer contact.

When LEO, MEO and GEO receive the contact updating message, they will add the new contact in data contact plan DCP. The time complexity of algorithm 1 is \( o(n^2) \).

V. PERFORMANCE EVALUATION

We use a satellite-terrestrial testbed to evaluate the performance of our proposed traffic aware inter-layer contact selection algorithm. As for the constellation of multi-layer satellite network, we apply the design method described in [17] which contains 66 LEO nodes, 10 MEO nodes and 3 MEO nodes. The orbit parameters and delay among these nodes are described in Tables II and III. We use STK [18] to obtain the contacts information among these satellites. The OpenStack is used to implement our testbed[19]. We further use 79 virtual nodes which operate Ubuntu 15.04 to simulate the satellite network. Meanwhile, we use 16 nodes to simulate the terrestrial network which consists of mobile access network and Identify/Location split network. ION3.3.1 [20] is used to realize DTN protocol and the inter-layer contact selection algorithms. Here we focus on the inter-layer contact selection problem of multi-layer satellite network, the communication details of Identifier/Locater split satellite terrestrial network are described in our previous work in [21]. The experiment topology is shown in Fig. 2. The data rate is set to 250kB/s and the bit error is set to \( 10^{-6} \).

We evaluate the performance of traffic aware inter-layer contact selection algorithm (TACS) by comparing its performance with that of the duration based inter-layer contact selection scheme (DCS) which is proposed in our previous work in[22]. DCS selects the inter-layer contact with the longest duration,
without the consideration of the flow situation. For the first time slot, the 10 MEO nodes will select six different inter-layer contacts with the longest duration. The rest of LEO that have not been selected will connect to a MEO which has the longest duration. In this way, the flow can be balanced. Since the inter-layer contacts between GEO and lower layers are only used for updating contact messages, we configure the one with the longest duration into the contact plan.

A. The Impact of Bundles with Different Sizes

We first evaluate the performance of TACS with different bundle sizes. We use 10 LEO nodes to send bundles to the other 10 LEO nodes. All these bundles will be delivered through MEO layer. Due to the fact that most disruption of inter-layer contacts for the first time occurred between 3000s and 4500s, the bundle sending time is set to 3800s after the ION starts. The sending duration is set to 600s. Each node sends one bundle every second. The priority of these bundles is set to be urgent, standard and bulk in turn. The bundle size is set from 70k to 140k.

In Fig. 3, the D-bulk, D-std, D-urg and D-avg curves represent the delivery delay of bulk, standard, urgent and the average value when GEO adopts DCS respectively. The TA-bulk, TA-std, TA-urgent and TA-avg curves represent the delivery delay of these bundles when GEO adopts TACS respectively. As can be seen, when we adopt DCS, with the increase of bundle size, the delivery delay of bulk and standard bundles increases rapidly. This is because when an inter-layer contact is disrupted, the contact with the longest duration between the disrupted LEO node and the MEO layer will be selected, neglecting the flow condition of the candidate connected to MEO node. This may result in a LEO node being connected to a congested MEO node. Considering the limited transmitted bandwidth, the bundles which have no opportunity to delivery will be queued at the congested MEO nodes and this causes a long queue delay. When GEO adopts TACS, once an inter-layer contact is disrupted, GEO will select a MEO which matches the objective functions for more balanced flow distribution among MEO layer. Consequently, we see reduction of as high as 74% delay of bulk bundles for TACS against DCS.

B. The Impact of Bundles with Different TTL Values

Here we evaluate the effects of TACS on the bundles with different Time To Live (TTL) values. The data is sent using the similar scheme in the previous subsection. The bundle size is set to 140kB. The TTL is set from 30s to 240s.

Fig. 5 shows the delivery ratio of the bundles with different TTL when GEO adopts TACS and DCS. We see higher delivery ratio for TACS compared with that of DCS. In Fig. 6, we further present the delivery delay of the bundles with different TTL when GEO runs TACS and DCS. We again see that TACS offers lower delay compared with that of DCS.
C. Throughput Performance

We use a server to communicate with a Mobile Node (MN) located in mobile access network through the multi-layer satellite network. In the experiment, the server uses iperf to send data at the 4000s after ION started and the duration is set to be 300s. The data rate is set to 100kB/s. The other 10 LEO nodes will also send data using the similar way as in the previous subsection. The bundle size is set to be 100kB, the TTL is set to be 300s. In Fig. 7, TA-MN represents the throughput of MN when GEO uses DCS and D-MN represents the throughput when GEO uses DCS. We clearly see a more stable throughput for TACS. This is because flows from LEO will be accessed to MEO node in a balanced manner whereas in DCS, flows from LEO may be centralized to a congested MEO.

VI. CONCLUSION

In this paper, we focused on the disruption problem in multi-layer satellite network and proposed a traffic aware inter-layer contact selection algorithm. Addressing the connectivity and potential bottleneck issue, our design considered flow characteristics including queue size, flow size, the number of LEO nodes that a candidate MEO node connects and the duration of the candidate contact. To show the effectiveness of our design, we built a testbed and implemented our proposed algorithm. Our test results showed achievement of a more balanced flow distribution among MEO layer, improved the delivery ratio and reduced the delivery delay of bundles by comparing with the duration based inter-layer contact selection scheme.

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