Contact Quality Aware Routing for Satellite-Terrestrial Delay Tolerant Network

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Abstract. In space delay tolerant network (DTN), the absence of adequate nodes makes the communication opportunities precious. If the messages are transmitted using a path which exists high bit error, it can increase the delivery delay and reduce the delivery ratio. Therefore, how to distinguish the contact quality and select a path with little bit error is crucial to improve the network performance. In this paper, we propose a contact quality aware routing which operates cooperatively with Licklider Transmission Protocol (LTP). We use the processing signals in LTP to reflect the contact quality. Further more, we propose a contact quality based forwarding scheme to select a path which exists little bit error. The enhancements are verified using a test-bed with 15 simulation nodes. The experiments show that the proposed schemes can reduce the delivery delay, increase the delivery ratio and improve the throughput.

Keywords: Space delay tolerant network · LTP
Contact quality aware routing

1 Introduction

With the development of space technology, how to build a satellite relay network to support the communication becomes crucial. However, the long delivery delay, frequent link disruption in satellite networks prevent the traditional TCP/IP protocols from being adopted. What's more, the high asymmetry channel rate in deep space networks is also a severe challenge to TCP/IP protocol when faced with large scale of processing signals. Thanks to the ability of batting with such tough features, DTN is extremely fit for satellite networks [1]. DTN inserts an overlay called bundle layer below the application layer to realize the reliable communication. Meanwhile, DTN introduces the convergence layer protocols such as UDPCL [2] and LTPCL to realize the communication between bundle layer and the transport layer.

Among these convergence layer protocols, the performance of LTP is proved most outstanding when faced with high asymmetry channel rate and high bit errors [3,4]. The application data is divided into bundles and delivered as the

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units in bundle layer. In order to reduce the processing signals, several bundles are aggregated into LTP blocks according the preset block length. Then the block will be divided into segments which are encapsulated as data part of transport layer protocols.

LTP adopts a retransmission mechanism which depends on the import session, export session, checkpoints and report segments to realize the reliable transmission for blocks. The sender in LTP will create an export session and send the block during that session. Meanwhile, the receiver will create an import session to receive the block. When the block is received completely, the export session and the import session will be closed. The block will be flagged with offset. The receiver can identify the missing data according to the offset. When the receiver receives a checkpoint, it will respond a report segment to notice the sender of the missing data. Then the sender will retransmit the missing data. The process will continue until the block has been transmitted correctly. LTP has drawn many attention such as the performance analyse [4], the model evaluation [5]. However, the research of LTP in other aspects such as how to use LTP to identify the link quality has received very little attention.

Contact Graph Routing (CGR) [6] is a routing scheme developed for the networks whose topology is dynamic but predictable, such as the satellite networks. Due to that the orbit and trajectories of space nodes are fixed, it can acquire the communication information such as the duration previously. CGR calculates routes depends on these pre-acquired communication information. The main factor considered by CGR when select the path is the earliest bundle arrival time. Despite that many attentions have been paid on the research of CGR, such as the performance improvement [7] and the contact plan design [8], the contact quality based selection scheme receives very little attention.

In deep space network, the satellite nodes are usually sparse. This makes the communication opportunities very precious. Meanwhile, the space environment features such as the electromagnetic interference can bring high bit error to satellite links. If the data is transmitted using a path which is suffering high bit error, it can incur a lot of retransmission and cause a great waste of transmission opportunities. Although the LTP protocol can handle the bit error, the retransmission can lead to a sharp increase in delivery delay. What's more, if the delivery delay exceeds the bundle residual survival time, it can even incur data loss and reduce the deliver ratio. Therefore, how to distinguish the contact quality and select a path with little bit error is crucial to improve the network performance.

Considering above, in this paper we use DTN and LTP to deal with the tough space network environment and propose a contact quality aware routing which cooperates with LTP protocol to select a high quality path for data. Since a higher bit error can incur more retransmission, we use the processing signal numbers in LTP during one session to represent the contact quality. Meanwhile, an updating mechanism is also proposed to update the contact quality dynamically. When computing routes, we take both the contact quality and the earliest bundle arrival time into consideration. The main contributions of this paper are summarized as follows:

(1) A contact quality aware routing which contains contact quality detecting scheme and contact quality based forwarding scheme is proposed to select a path which exists little bit error.

(2) The performance of the proposed method is verified on a testbed with 15 simulation nodes and experimental results prove that the schemes can reduce the delivery delay, increase the delivery ratio and improve the throughput.

The remainder of the paper is organized as follows: In Sect. 2, we introduce the details of contact quality aware routing. In Sect. 3, we present the experiments on our test-bed. In the last part, we summarize the works in this paper.

2 Contact Quality Aware Routing

When LTP provides reliable transmission for blocks, the sessions are determined by the original block numbers. However, the checkpoints and report segments will be increased with the rise of bit error. Therefore, we can use the checkpoint and report segment numbers to reflect the contact quality. By combining the contact quality with delay information, contact quality aware CGR could select a delivery path which exists little bit error. The contact quality aware routing includes contact quality detection scheme and contact quality based forwarding scheme. Satellites will use contact quality detection scheme to detect the contact quality and update the contact quality timely. The contact quality based forwarding scheme is used to select a path with little bit error.

2.1 Contact Quality Detection

When the sender requires reliable services, LTP will adopt a retransmission mechanism which is enabled by the checkpoints and report segments. When the transmission of the data is completed, both the associated import session and export session will be closed. When there exists bit error, the segments could suffer retransmissions, both the report and checkpoint numbers will be increased which is caused by the retransmission processes. However, the export sessions and the import sessions are mainly determined by the block numbers, the bit error has no influence on the session numbers. Thus, the ratio of checkpoint and export session numbers as well as the ratio of report segment and import session numbers can be used as the identification of the contact quality. We create a list to record the checkpoint, export session, report segments and import session for each neighbor node respectively.

Let f_c denote the ratio of checkpoint numbers and import sessions. It can reflect the contact quality in the sender node. Let f_r denote the ratio of report segments and import sessions. It can reflect the contact quality in the receiver. The contact quality factor f_c and f_r are calculated as

$$f_c = \frac{\sum checkpoint}{\sum exportsession} \tag{1}$$

$$f_r = \frac{\sum report}{\sum importsession} \tag{2}$$

Algorithm 1. Contact quality detecting

Input:
contact quality recording list
Output:
contact quality updating message
Open contact quality recording list
for all neighbor nodes in contact quality recording list **do**
  Calculate $f_c = \frac{\sum checkpoint}{\sum exportsession}$ $f_r = \frac{\sum report}{\sum importsession}$
  if $f_c > f_r$ **then**
    C=f_c
  else
    C=f_r
  end if
  Open contact plan, compare the value of C with contact quality v recorded in the contact plan
  if $\frac{|C-v|}{v} > updatingratio$ **then**
    v=C, send contact updating message to other nodes
  end if
end for
return contact quality updating message;

When there exists no bit error, the value of f_c and f_r can be 1. When there exists bit error, the value of f_c and f_r will be increased with the rise of bit error.

We modify the contact plan to add quality weight C to identify the contact quality. We compare the value of f_c and f_r periodically and select the higher one as the value of contact quality weight C. In order to reduce the updating message numbers, we use a changing ratio to determine whether to send contact updating messages to the other nodes. We calculate the change ratio of the C between the prior recorded contact quality v. When the changing ratio is larger than a preset value, an updating message will be sent to other nodes. In this paper the change ratio is set to 4%. When the nodes identify the change of C, they will send a contact quality updating message to other nodes in the network. In order to distinguish the updating message from the user message, we use the reserved flag of Bundle protocol to mark the updating messages. The contact quality updating algorithm is showed in Algorithm 1. The contact quality detection period is set to 5 s.

2.2 Contact Quality Based Forwarding

In the original CGR, the key factor considered when nodes select path is the earliest arrival time, without considering the contact quality. Although LTP protocol could deal with the bit error using its retransmission scheme, it can cause the increase of retransmissions when select a lower quality path. This will incur a long delivery delay. Thus, by coordinating with the contact quality detection scheme described in part A, we can select a path with little bit error to reduce the delivery delay.

Algorithm 2. Contact quality aware forwarding

Input:
contact plan, bundles
Output:
forwarding path

while nodes receive bundles **do**
  if bundle is contact quality updating message **then**
    update the contact quality in contact plan
  else
    compute all the candidate paths using CGR,
    compute $f_{quality} = \prod_{i=s}^{r} u_{i,i+1}a_{i,i+1}$ of all the path
  end if
  for all the potential paths **do**
    select the path with the earliest arrival time as the delivery path
    if there exists paths with the same earliest arrival time **then**
      select the one with the lowest $f_{quality}$ as the delivery path
      if there exists paths withe the same $f_{quality}$ **then**
        select the one with the lowest hop count as the delivery path
        if there exists paths with the same hop count **then**
          select the one with the lowest neighbor node number as the delivery path
        end if
      end if
    end if
  end for
end while
return the delivery path;

Let $u_{i,j}$ denote whether satellite i could communicate with satellite j at time t. Let $a_{i,j}$ denote the contact quality weight between satellite i and j. The value of $u_{i,j}$ can only be 0 or 1. Then the path quality factor from the sender s to the receiver r could be denoted as

$$f_{quality} = \prod_{i=s}^{r} u_{i,i+1}a_{i,i+1} \tag{3}$$

The contact quality aware CGR is to select the lowest path quality factor $f_{quality}$ from all the potential paths.

For nodes in satellite networks, when receiving a bundle, they will firstly identify whether the bundle is a contact quality updating message according to the reserved bundle flag. If it is, they will update the contact quality information in its contact plan. If not, they will select a path for the message using the processes as follows:

Firstly, nodes will compute all potential paths for bundles using CGR. Along with the path computation, the earliest arrival time of each potential path which considers of the queue delay and OWLT will also be calculated. OWLT is the propagation delay among nodes configured in the contact plan. Then nodes will compute the contact quality factor $f_{quality}$ of each available path use Eq. (3). When select paths, nodes will select a path with the lowest arriving time. If the arriving time of the bundles is the same, then they will select a path with the lowest $f_{quality}$ and queue the bundles into the neighbor node on the path. In this way, nodes could avoid all the bundles being concentrated to one path which has the highest contact quality. If there exists two paths with the same value of $f_{quality}$, then nodes will select the one which has the lowest hop count. If there exists two paths with the same hop count, then nodes will select the path whose neighbor node number is lower. The contact quality aware forwarding scheme is showed in Algorithm 2.

3 Performance Evaluation

In this section, we produce a satellite terrestrial test-bed with 15 Linux nodes to evaluate the performance of the contact quality aware routing. In this paper, we mainly focus on the enhancements of CGR, the communication details of the satellite terrestrial network are presented in our previous works in [9]. Figure 2 is the moon-earth experimental topology which contains a moon satellite ChangE, three China's relay satellites Tianlian [10], and the terrestrial network which is made up of core and mobile access networks.

The height of ChangE satellite is 1938 km from moonscape and the orbit inclination is 90. The parameter of the three Tianlian satellites and the gateway which locates at JiuQuan are shown in Table 1. We use STK [11] to obtain the delay and contact information among these nodes according to the orbit parameters. The contacts and the propagation delay among these nodes are shown in Table 2. The space nodes adopt the BP/LTP/UDP/IP protocol which is realized using ION.3.3.1 [12], a software developed by NASA to implement the DTN protocols.

Table 1. Parameters of the satellites and gateway

Satellite	Height	Longitude	Latitude
Tianlian01	42371 km	76.95 E	0
Tianlian02	42371 km	176.71 E	0
Tianlian03	42371 km	16.65 E	0
Jiuquan	0	103.316 E	41.118 N

The experiments include two parts. We evaluate the performance of contact quality aware CGR(CGR-CA) by comparing with CGR-ETO [7] which is a typical improvement of CGR. In the first part, we compare the delivery ratio and the delivery delay of CGR-CA and CGR-ETO when faced with different link bit error. In the second part, we evaluate the throughput of the system at the receiver.

Table 2. Contact information of satellites

Start node	End node	Start time	End time	Delay
ChangE	Tianlian01	0	1000 s	1400 ms
ChangE	Tianlian02	0	1000 s	1400 ms
ChangE	Tianlian03	0	1000 s	1400 ms
Tianlian01	Tianlian02	0	86400 s	300 ms
Tianlian01	Tianlian03	0	86400 s	300 ms
Tianlian02	Tianlian03	0	86400 s	300 ms
Jiuquan	Tianlian01	0	86400 s	300 ms
Jiuquan	Tianlian02	0	86400 s	300 ms

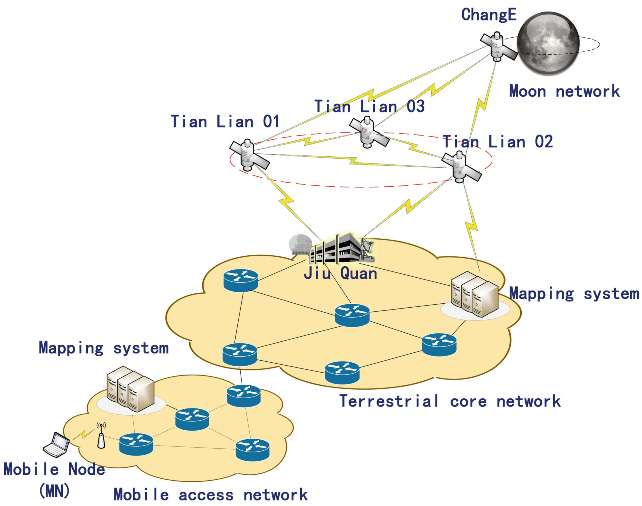

Fig. 1. Experimental topology

3.1 The Impacts of Bundles with Different Bit Errors

We use ChangE to send data to the mobile node (MN) which is located in the mobile access network. The channel rate of the links between ChangE and Tanlians is asymmetrical, the rate of links between Tianlians and gateway is symmetrical. In the links between ChangE and Tianlians, the data channel rate is set to 250 kbyte/s and the ACK channel rate is set to 500 byte/s. In the links between Tianlians and gateway, both the data channel rate and the ACK channel rate are set to 250 kbyte/s. We use the ChangE to send a bundle to MN every second. The bundle size is set to 200 kbyte. The experimental duration is 1000 s. The priority of the files is set to bulk, standard and urgent in turn. In DTN, the urgent bundle will be firstly transmitted and the bulk will be transmitted in the last turn. The bit error of links among Tianlian satellites and gateway are set to 10^{-7}, the bit error of links among Tianlian satellites and ChangE are varying.

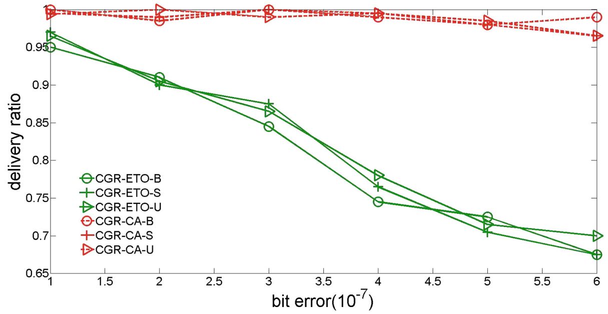

Fig. 2. The delivery ratio of bundles with different bit error

In Figs. 2 and 3 we compare the performance of contact quality aware CGR with CGR-ETO when faced with different bit errors. The bit error of the link between ChangE and Tianlian02 is set to be varying from 10^{-7} to $6 * 10^{-7}$. The bit error of link between ChangE and Tianlian03 and the link between ChangE and Tianlian01 is set to 5 times and 10 times of the bit error of the link between ChangE and Tianlian02 respectively. The time to live(TTL) of bundles are set to 8 s. Since the Tianlian03 has no direct link to gateway and the node number of Tianlian01 is smaller than Tianlian02, CGR-ETO will select Tianlian01 as the next delivery node. However, the bit error on the link between Tianlian01 and the ChangE is higher than that of the link between Tianlian02 and ChangE. While considering the contact quality factor, CGR-CA can select tianlian02 as the next delivery node.

From the figs we can see that the delivery ratio will be decreased with the increase of bit error when nodes adopt CGR-ETO. This is because that with the increase of bit error, more data will suffer retransmission. This can increase the delivery delay. When delivery delay exceeds the residual survival time, the bundles can suffer data loss. However, when nodes adopt CGR-CA, all the bundles can be delivered through a path with little bit error. This can reduce the

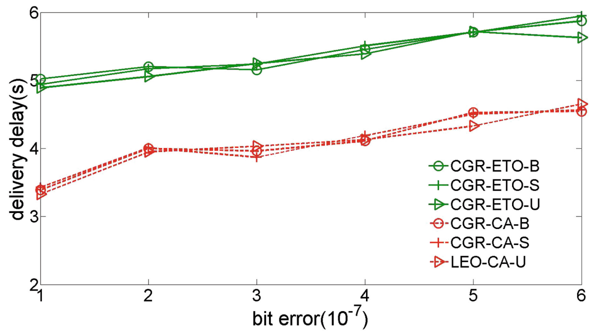

Fig. 3. The delivery delay of bundles with different bit error

retransmission. From Fig. 2 we can see that the contact quality aware CGR can increase the delivery ratio as high as 30% against CGR-ETO. From Fig. 3 we can conclude that CGR-CA can reduce almost 25% of the delivery delay compared with CGR-ETO. This is because that contact quality aware CGR can select a path with high quality which could reduce the retransmissions.

3.2 The Impacts of Throughput

In this part, we evaluate the throughput of CGR-CA and CGR-ETO. The TTL of bundles are set to 20 s. The bit error of the link between ChangE and Tianlian02 is set to be $3 * 10^{-7}$. The bit error of link between ChangE and Tianlian03 and the link between ChangE and Tianlian01 is set to 5 times and 10 times of the bit error of the link between ChangE and Tianlian02 respectively.

Figure 4 shows the throughput acquired at the MN. We can see that the throughput of MN when nodes adopt CGR-CA is more stable than that when nodes adopt CGR-ETO. This is because that CGR-ETO haven't considered the contact quality factor and select Tianlian01 as the next hop node. The bundles can suffer more retransmission.

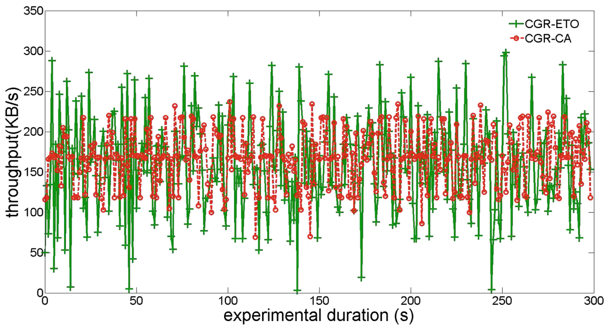

Fig. 4. The throughput at the receiver

4 Conclusion

In this paper, we focused on the contact quality based routing selection problem in satellite terrestrial network and proposed a contact quality aware CGR to deal with the impact of bit error. When compute routes, our design considers both the contact quality and the delay information to select a path with little bit error. To show the effectiveness of our design, we built a test-bed with 15 Linux nodes and implemented our proposed algorithm. The extensive experimental results demonstrate that the contact quality aware CGR can increase the delivery ratio, reduce the delivery delay and improve the throughput.

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