Optimize Bundle Size in Satellite DTN Links with Markov Method

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Abstract. Disruption-tolerant networks (DTN) are very useful in situations that links are unstable and bandwidth is precious, i.e. inter satellite links. Both distance and the size of transmitted bundles can affect the performance of network. As the distance of two satellites is predictable, we can optimize the size of bundle to achieve shorter delivery time. In this paper, we proposed a Markov method to optimize bundle size and tried to simplify the algorithm and improve its performance.

Keywords: Disruption-tolerant networks · Bundle size optimization Markov decision · Inter-satellite-link

1 Introduction

In a inter satellite link (ISL), there many restrictions, i.e. limited resource of nodes, intermittent connection, long latency due to distance. Traditional TCP/IP protocol no longer works in such situation and delay tolerant network (DTN) was proposed to solve this kind of problems [1] and it has lots of advantages in space communication [2]. DTN networks use a custody transfer mechanism (intermediate node keeps a copy of received bundle until it was forwarded to next hop successfully) so that bundles can be delivered under terrible transmission conditions. Bundle protocol can be compatible with other underlying protocols and applied to many fields as an overlay layer protocol, which makes DTN more suitable for inter satellite links.

The Protocol Data Unit of bundle protocol is called bundle, which is sent to the convergence layer and fragmented into smaller segments. Bundle protocol provides reliable delivering service of bundles and the convergence layer, which works below bundle layer, provides fast and reliable data transmission. Bundle size and segment size are different in different protocols, which have significant impact on the performance of DTN as shown in recent studies. Sending messages with large bundles can reduce the transfer time of a file but on the other hand, if bundle is too large, it may even not be delivered due to the long latency of inter satellite link and lead to zero throughput. Sending with smaller bundles can improve the probability of a bundle is delivered successfully but also leads to longer transfer time. We can improve the performance of DTN by optimizing the size of bundles.

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2 Related Work

Recently, a lot of studies focus on bundle size optimization in DTN links. In [3], a method is proposed to calculate the delivery time of bundle in space communication. Works has been done on message fragmentation in single links, such as solving the problem of in-time transmission of fragmented messages in single link disrupted networks [4] and the impact of fragmentation on message forwarding over a single link is investigated in [5]. In [6], the relationship between packet size and the performance such as delay and goodput at the convergence layer and the bundle layer is analyzed and formulated. The work in [7] evaluated the impact of transport segmentation policy on DTN performance and proposed a generic method to determine packet size in DTNs. The work in [8] proposed a fragmentation algorithm which divides the original packets into smaller ones whose size is bounded by the kth largest value among the last k + m channel availability periods. In [9], a bundle fragmentation policy for vehicle networks is presented and tested in a laboratory environment.

3 System Model

3.1 DTN Structure and Bundle Size Selection

In a satellite DTN network, BP layer receives message from application and encapsulate them into bundles, then LTP agent receives bundles from BP layer, encapsulate them into blocks and slice them into segments. Figure 1 shows the message transfer procedure in a DTN over two-hop ISL in which segment is considered as a basic data unit. The source node is only responsible for sending message and the intermediate node is only responsible for forwarding. The dotted lines represent path of acknowledgement character (ACK) while the solid lines represent path of bundle custody transfer. In the custody transfer mechanism, intermediate node keeps a copy of the received bundle and deletes it when the bundle is transferred successfully to the next hop.

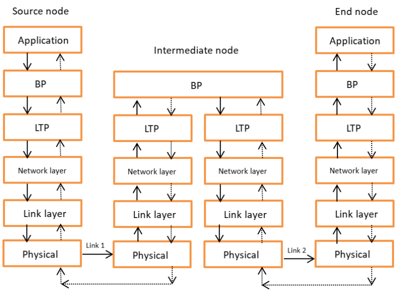

Fig. 1. DTN protocol model

To find a series of optimal bundle size, our Markov algorithm operates in BP layer and will return an optimal size of bundle at each moment (according to time-varying channel parameters). As the relative position of two satellites changes very fast over time and distance of two nodes has direct impact on propagation delay, we consider that other parameters of two links are stable and simplify the problem as optimizing the bundle size under time-varying distance. Link I and link II are two independent channels and have different channel parameters, so we should optimize the bundle size of two links jointly.

The optimal bundle size is selected from a set of optional bundle sizes which is related to the size of message. It can be integer times of the minimal bundle size and the algorithm decide the optimal bundle size according to the current state of transmission (Fig. 2).

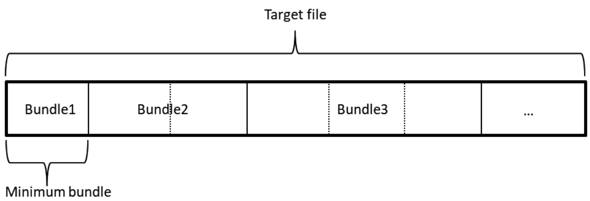

Fig. 2. Bundle size selection

3.2 Delivery Time Calculation

In this paper we intend to minimize the total delivery time of a file by optimizing the bundle size, so we need to calculate the round trip time (RTT) of one bundle. RTT consists of bundle and ACKs transmission delay and propagation delay, which is calculated as follows

$$\mathrm{RTT(t)} = 2 \cdot \mathrm{T}_p(\mathrm{t}) + \mathrm{T}_{ca} + \mathrm{T}_b(\mathrm{t}) \tag{1}$$

If a bundle is lost during transmission, retransmission will start after custody-confirm timer (CTRT) is timeout

$$\mathrm{CTRT(t)} = 2 \cdot \mathrm{T}_p(\mathrm{t}) + \mathrm{T}_{ca} \tag{2}$$

Propagation delay (Tp) can be calculated through distance D(t) and propagation speed c (speed of electromagnetic wave)

$$\mathrm{T}_p(\mathrm{t}) = \mathrm{D(t)/c} \tag{3}$$

ACK transmission delay T_{ca} and bundle transmission delay T_b is calculated as follows

$$T_{ca} = L_{ca}/R_{ca} \tag{4}$$

$$T_b = L_{bundle}/R_{data} \tag{5}$$

As a result, taking bundle loss probability $P_{ef}(t)$ into consideration, round-trip time of one bundle should be calculated as follows

$$RTT_{ev}(t) = \left(1 - P_{ef}(t)\right) \cdot RTT(t) + P_{ef}(t) \cdot CTRT(t) \tag{6}$$

Bundle loss probability P_{ef} is related to bundle size and bit error rate Pe(t).

$$P_{ef}(t) = 1 - (1 - P_e(t))^{8 \cdot Lbundle} \tag{7}$$

In which

$$P_e(t) = 1/2 \cdot erfc\left(\sqrt{SNR(t)}\right) \tag{8}$$

The function 'erfc' is complementary error function. Signal to noise ratio (SNR) is calculated by a series of channel parameters such as free space path loss (L_{space}) and other constant variables. SNR is calculate as follows

$$SNR(t) = E_0 - 10lgL_{space}(t) \tag{9}$$

In which

$$10lgL_{space}(t) = cons + 20lgD(t) + 20lgf \tag{10}$$

(Frequency is expressed as f) Thus, $P_e(t)$ can be represented as

$$P_e(t) = 1/2 \cdot erfc\left(\sqrt{E0 - (cons + 20lgD(t) + 20lgf)}\right) \tag{11}$$

Let

$$C_0 = E0 - (cons + + 20lgf) \tag{12}$$

(The constant $'cons'$ equals to 92.45 dB) In conclusion, RTT can be represented as

$$\begin{aligned} RTT_{ev}(t) = {} & \left(1 - 1/2 \cdot erfc\left(\sqrt{C_0 - 20lgD(t)}\right)\right)^{Lbundle} \times \left(2 \cdot T_p(t) + T_{ca} + T_b(t)\right) \\ & + \left(1 - \left(1 - 1/2 \cdot erfc\left(\sqrt{C_0 - 20lgD(t)}\right)\right)^{Lbundle}\right) \times CTRT(t) \end{aligned} \tag{13}$$

Actually, some parameters including interference noise and transmit power are not considered, the only time-varying parameter left is distance between two nodes.

4 Markov Decision Based Algorithm

In most cases, a fixed optimal bundle size can achieve best network performance because channel parameters don't change rapidly. But in inter satellite links, the relative position of each satellite is always changing and the distance between two satellite changes rapidly and a fixed optimal bundle size is not able to cope with different situations. Thus we propose a Markov decision based method which could continuously update the optimal bundle size under time-varying channels such as two-hop ISL.

4.1 Problem Formulation

As shown in Fig. 3, the source node determines the optimal bundle size of current period and forwards the bundle to intermediate node. Intermediate node does not change the bundle size and just forward the received bundle to destination node. For convenience of analysis, we assume that the intermediate node can only restore one bundle, which means another bundle will not be received until the former bundle is forwarded successfully. First, we set a sampling period of channel parameters and in each sampling period we will find an optimal bundle size. Then at the beginning of a period, source node select a bundle size with shortest total round-trip-time from the action set as optimal bundle size of current period. The total RTT includes both RTT of link1 and RTT of link2. Once an optimal bundle size is found, the algorithm output the bundle size into the strategy set and messages will be transmitted with current bundle size until next period.

A relatively small bundle can easily be transmitted and leads to faster transfer of bundle but leads to longer total time of delivering a file. Meanwhile, a relatively big bundle size needs longer continuous connecting time which will cause difficulty in bundle transfer and even zero throughputs. It is very difficult to find a function relationship between the optimal bundle size and distance in the iteration algorithm (which will be stated later), so we choose to traverse all the optional bundle size and find the optimal bundle size the shortest total RTT.

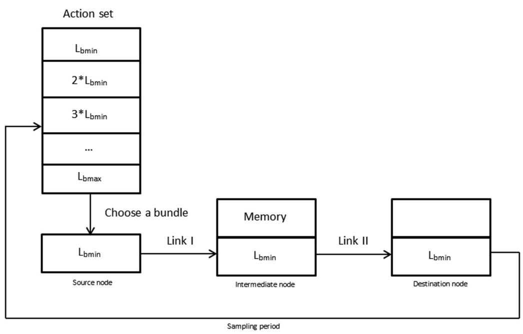

Fig. 3. Decision process in two-hop-DTN

4.2 Markov Decision Strategy

A standard Markov model consist of five sets: state set, action set, strategy set, transition probability and reword function. In this paper these five set are defined as follows.

State Set

The state set is defined as S: {S0, S1}. In state S0, memory of intermediate node is empty and source node is forwarding a bundle to the intermediate node. In state S1, intermediate node has already restored a bundle and the memory is occupied, the intermediate node is forwarding a bundle to the destination node. In other words, S0 represents the procedure of transferring bundles from source node to intermediate node while S1 represents the procedure of transferring bundles from intermediate node to destination node.

S0 and S1 are further divided into a number of child states, each of which contains $\mathrm{Max}_r + 1$ grandchild states. The number of child state determined by minimum bundle size and file size. The remaining file size can be expressed as follows

$$\mathrm{R}_{file} = L_{file} - i \cdot Lb_{min}$$

And the total number of divided states is

$$\mathrm{N}_s = \frac{L_{file}}{Lb_{min}} \times (\mathrm{Max}_r + 1)$$

Action Set

The action set A contains all the optional bundle sizes. Optional bundled size can be integer times of the minimum bundled size Lb_{min} which is defined as a basic data unit. Optional bundle size varies from Lb_{min} to $\mathrm{n} \times \mathrm{Lb}_{min}$ ($\mathrm{n} \times \mathrm{Lb}_{min}$ is the maximum acceptable bundle size).

Strategy Set

The strategy set is all the bundle sizes outputted by Markov decision algorithm.

Transition Probability

Transition probability is related to the grandchild state and bundle loss probability. It is expressed as follows

$$\mathrm{P}_{nr} = \left(1 - P_{ef}\right) \cdot P_{ef}^{nr-1}$$

In which *nr* represents sequence number of grandchild state, which also means how many times retransmission occurs. For example, if next state is the 3^{rd} grandchild state of the first child state of S_0, it means this bundle is retransmitted twice. In addition, the $(\mathrm{Max}_r + 1)_{\mathrm{th}}$ grandchild state means the bundle is abandoned.

In particular, state S_0 and S_1 occurs alternatively. If the current state is $S_{0,i,j}$, the next state must be a child state of S_1 whose remaining file size is the same as $S_{0,i,j}$, if the current state is $S_{1,i,j}$ and the selected bundle size is a_i, the next state must be a child state of S_0 whose remaining file size is $R_{file} - a_i$.

Reward Function

The reward function is the required time of a bundle to be successfully delivered from the source node to the destination node (Fig. 4).

$$r = RTT(a) + (n_r - 1) \times CTRT(a)$$

RTT and CTRT can be calculated by (1) and (2).

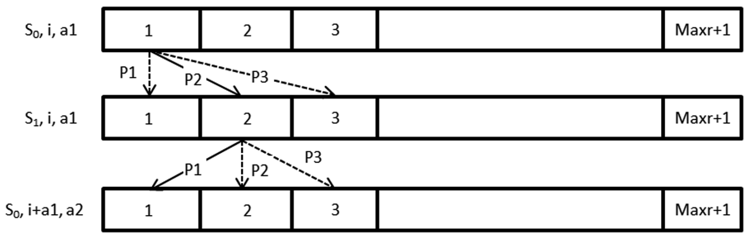

Fig. 4. State transition process

4.3 Iteration Algorithm

Our goal is to find an optimal bundle size 'a' that minimizes the reward function 'r'. With a set of optional bundle sizes and transition probability, we can infer the whole transition procedure by an iteration algorithm and calculate the corresponding reward function. By comparing all the reward functions produced by different bundle size, we can find the optimal bundle size that minimizes the reward function.

If the current state is S_0

$$v0(s_{current}) = \sum_{s\_next} P_{nr}(a) \cdot [r(a) + v1(s\_next)]$$

If the current state is S_1

$$v1(s_{current}) = \sum_{s\_next} P_{nr}(a) \cdot [r(a) + v0(s\_next)]$$

The iteration algorithm start from S_0 and ends when remaining file size is zero. After calculating the sum of all these terms, the reward function is equal to v0 and bundle size 'a' which produces smallest 'r' is selected as the optimal bundle size. As the distance parameter keeps changing, we update the optimal bundle size using iteration algorithm every sampling period.

The complexity of this algorithm is related to variables such as file size,Max_r, minimum bundle size Lb_{min}. One of the most important variables is Max_r and number of child states sc because the complexity has an exponential relationship with Max_r and sc.

4.4 Algorithm Simplification

The algorithm in Sect. 4.3 is written according to the Markov method directly. In fact its complexity has an exponential relationship with Maxr and sc which can cause huge number of calculations. As Maxr and sc increase, the complexity of former algorithm will become terrible, so we must find a way to reduce the complexity (Table 1).

Table 1. Iterative algorithm

```
Input S0,S1,A
While (res_file>0)
    For each s ∈ sum {
        (p_trans1,trans_round1)←(link_state1,a);
        (p_trans2,trans_round2)←(link_state2,a);
    If (trans_round1≤max_trans_round)&( trans_round2≤max_trans_round);
    v0(s) = min_a ∑_{n_next} p_trans1 × (r(trans_round1, a) + v1(s_next))
    v1(s) = min_a ∑_{n_next} p_trans2 × (r(trans_round2, a) + v0(s_next));
    output(s)←a;
    link_state1←new_state1;
    link_state2←new_state2;
    time_current←new_time;
    res_file←res_file_new;
    End if
  End for
End while
```

We found that the transition probability and bundle size are fixed in each attempt to find the optimal bundle size of each period of the algorithm. Thus, the number of child states can be calculated by sc = res_file/a. The transition probability of i_{th} grandchild state of j_{th} child state is the same as the transition probability of i_{th} grandchild state of $(j + n)_{th}$ child state. So the problem can be simplified as the expected value of sc independent events and the reward function can be calculated as follows

$$r = sc \times \sum_{1}^{maxr} P_{nr1}(a) \times r_1(a) + sc \times \sum_{1}^{maxr} P_{nr2}(a) \times r_2(a)$$

In this way, the complexity of algorithm is reduced to a linear relationship of Maxr and sc.

5 Simulation and Numerical Results

We make comparison of performance between Markov method and traditional method, and studied the impact of some parameters in the Markov algorithm. In particular, Lca = 100 Byte, Rca = 8000 bps and C0 = 104.22. We consider the bundle is delivered successfully if the bundle loss probability is less than 0.01. In this paper, Markov method is applied to two-hop LEO-GEO-LEO inter-satellite-link.

In Fig. 5, minimum bundle size of Markov method is 1 Mb and maximum bundle size is 10 Mb. Traditional method take more time to deliver because a bigger bundle size may cause much more delivery time in long distance, and Markov method chooses 1 Mb as optimal bundle size when the distance is longer. The relationship between optimal bundle size and distance is shown in Fig. 6

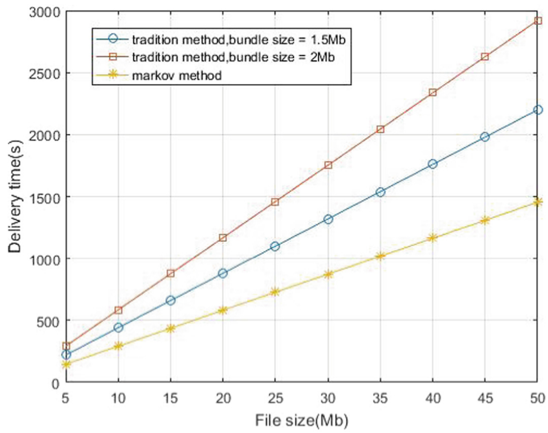

Fig. 5. Delivery time comparison

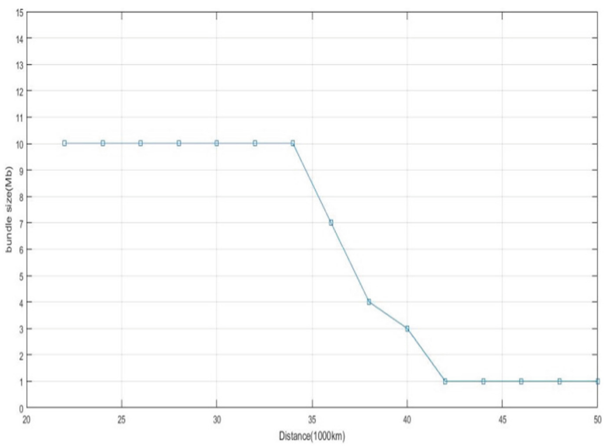

Fig. 6. Relationship between optimal bundle size and distance

As the distance gets longer, throughput of both Markov method and traditional decrease to zero, but throughput of Markov method has better resistance of it, as shown in Fig. 7. The performance of Markov method is influenced by Lb_{max} and Lb_{min}, and Fig. 8 shows that when the distance reaches 40000 km, the difference of Lb_{max} can be ignored. Figure 9 shows that decreasing Lb_{min} can slightly reduce the delivery time, but if we increase Lb_{min}, as shown in Fig. 5, delivery time will increase rapidly.

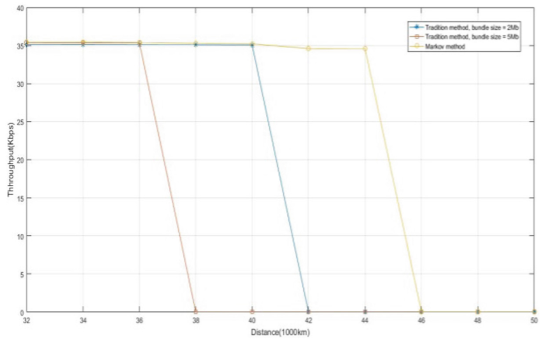

Fig. 7. The impact of distance on throughput

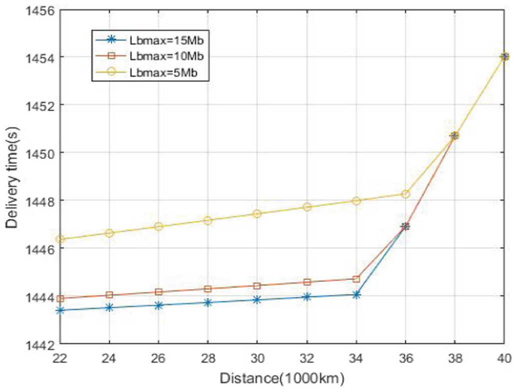

Fig. 8. Impact of maximum bundle size

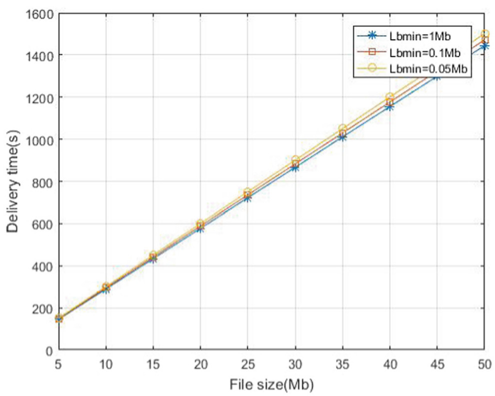

Fig. 9. Impact of minimum bundle size

6 Conclusions

In this paper, we proposed a bundle optimizing method based on Markov algorithm for two-hop inter-satellite-links and solved the problem of complexity. A dynamic optimal bundle size can adapt to continuously changing channel conditions and make up for the disadvantage of fixed bundle size. The performance of this algorithm can be improved by optimizing some parameters which need further study.

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