在深空通信中，信息主要以电磁波形式传输，因此我们假设数据传播速度为c，在t时间内数据传播的距离为ct，如果用数学表示，即为二维坐标系内的传播距离d与时间的成正比且斜率为c的一条斜线。在二维坐标系中，部分链路中断则可以表示为平行于时间轴的矩形，包含其时间跨度和距离跨度。

In deep space communication, information is mainly transmitted in the form of electromagnetic waves. Therefore, we assume that the data propagation velocity is C and the distance of data propagation in time T is C ×t, which is a diagonal line with a slope of C and the distance d is proportional to the time a in the two-dimensional coordinate system. In this coordinate system, some link interrupts can be expressed as rectangles parallel to the time axis, including their time span and distance span.

如图4-1所示，横轴表示时间，纵轴表示距离，0点表示源节点，距离D表示源节点和目的节点之间距离。其中斜线表示bundle的数据传播，表示的是数据的发送时间，在时间内，数据都在发送，但是我们研究的BP/UDPCL/UDP/IP下的数据传输模型，UDP的数据报的最大长度是65535字节，假设通信中下行速率2 Mbit/s，可以得出一个最大尺寸的bundle发送时间为0.26 s，相比较深空中的长时间中断，基本可以忽略，也就是说，我们假设在时间内中断不发生改变，因此，可将bundle的发送简化为一条斜线。图4-1中，灰色矩形表示中断，发生在时刻，时长为，并且是在距离源节点长度为的位置，中断距离长度为。黄色部分代表一个传输周期，红色实线代表数据的一次发送，由于高误码的影响数据到达目的节点已经损坏，红虚线表示的是数据受到中断影响，绿线表示数据发送成功。

As shown in Figure 4-1, the horizontal axis represents time and the vertical axis represent distance, the point 0 represents source node, and distance D represents distance between source node and destination node, the slash represents the data propagation of the bundle, represents the data transmission time. Data is being sent for as long as time. However, for the data transmission model under BP/UDPCL/UDP/IP that we studied, the maximum length of UDP datagram is 65535 bytes. The sending time of the bundle with the maximum size will be 0.26s if we assume that the downlink rate in communication is 2 Mbit/s, which is basically negligible compared with the long interruption in deep air, in other words, we can assume that the interrupts don’t change for time and we can simplify the sending of the bundle to a slash line. In Figure 4-1, the gray rectangle represents the interruption, which occurs at time and lasts for , and is at the point with a distance from the source node and the interruption distance is . The yellow part represents a transmission cycle and the red solid line represents one transmission of data. Due to the influence of high error code, the data has been damaged when reached the destination node. The red dotted line indicates that the data was affected by the interruption, while the green line indicates that the data was sent successfully.

在没有中断情况下，bundle数据在内被源节点发送到链路上，经过时间数据通过链路传播到目的节点。在有中断的情况下，中断是否会影响本次数据的发送，这取决于中断发生的时刻、时长、位置和距离。如图4-1，中断发生的第一个传输周期，当数据到达中断区域，中断仍然持续，此次中断对数据造成影响。在中断发生的第二个传输周期内，中断在整个传输周期内持续，中断对数据造成影响，数据发送失败。第三个传输周期，在中断会持续一段时间，但是中断在数据到达中断位置之前已经结束，对中断发生的第三个周期的数据不产生影响。在第三章我们讨论的是只要中断发生在内就会对数据传送造成影响，而本章讨论中断发生在内对数据传输是否造成影响视具体情况而言，相比较而言，本章的模型更为具体。

In the case of no interruption, the bundle data is sent to the link by the source node in time and propagated to the destination node through the link during the time. In the case of an interrupt, whether the interrupt will affect the data transmission depends on the time, duration, location, and distance of the interrupt. As shown in Figure. 4-1, in the first transmission cycle of an interrupt, when the data reaches the interrupt area, the interrupt still persists, and this interrupt affects the data. In the second transmission cycle of the interrupt, the interrupt lasts in the whole transmission cycle. The interrupt affects the data and the data transmission fails. In the third transmission cycle, the interrupt in will last for a period of time, but the interrupt will end before the data reaches the interrupt position, which will not affect the data in the third cycle of the interrupt. In Chapter 3 we discuss that the data transfer will always be affected as long as interrupts occur within , while in this chapter we discuss whether interrupts in have an impact on data transmission, depending on the specific situation. Therefore, the model in this chapter is more specific.

若要讨论中断对数据传输是否有影响，重点是研究中断发生时的第一个周期和最后一个周期的数据影响情况，而其它中断持续的传输周期内的数据确定会受影响。

To discuss the impact of interrupts on data transmission, it is important to study the data impact in the first and last cycles when the interrupts occur, while data determined to be affected in the transmission cycles in which other interrupts persist.

经过认真观察和思考，发现中断是否会对中断发生时第一个传输周期产生影响可以分3种情况讨论，中断发生时数据还没有到达中断处、中断恰好发生在数据传输这段链路上和中断发生时数据已经经过了中断链路。虽然中断发生时数据还没有到达中断处和中断恰好发生在数据传输这段链路上都会对数据造成影响，但由于中断方式的不同，我们仍然将其视为两种情况。

After careful observation and consideration, we found that whether the interrupt will affect the first transmission cycle when the interrupt occurs can be discussed in three cases: the interrupt occurs before the data reaches the break point, the interrupt happens right on the data transmission link and the interrupt occurs when the data has passed through the interrupt link. Although the interruption occurs before the data has reached the break point and the interruption happens on the data transmission link will affect the data, we still regard it as two cases due to the different interrupt mode.

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在深空通信中，信息主要以电磁波形式传输，因此我们假设数据传播速度为c，在t时间内数据传播的距离为ct，如果用数学表示，即为二维坐标系内的传播距离d与时间的成正比且斜率为c的一条斜线。在二维坐标系中，部分链路中断则可以表示为平行于时间轴的矩形，包含其时间跨度和距离跨度。

Information is mainly transmitted in the form of electromagnetic waves in deep space communication,so we assume that the data propagation speed is c, and the distance of data propagation in time t is c×t.If expressed mathematically, it is a diagonal line with a slope of C and a propagation distance d proportional to time in the two-dimensional coordinate system.In the two-dimensional coordinate system, link disruptions can be expressed as rectangles parallel to the time axis, including their time span and distance span.

如图4-1所示，横轴表示时间，纵轴表示距离，0点表示源节点，距离D表示源节点和目的节点之间距离。其中斜线表示bundle的数据传播，表示的是数据的发送时间，在时间内，数据都在发送，但是我们研究的BP/UDPCL/UDP/IP下的数据传输模型，UDP的数据报的最大长度是65535字节，假设通信中下行速率2 Mbit/s，可以得出一个最大尺寸的bundle发送时间为0.26 s，相比较深空中的长时间中断，基本可以忽略，也就是说，我们假设在时间内中断不发生改变，因此，可将bundle的发送简化为一条斜线。图4-1中，灰色矩形表示中断，发生在时刻，时长为，并且是在距离源节点长度为的位置，中断距离长度为。黄色部分代表一个传输周期，红色实线代表数据的一次发送，由于高误码的影响数据到达目的节点已经损坏，红虚线表示的是数据受到中断影响，绿线表示数据发送成功。

如果讨论中断对数据传输是否有影响，重点是研究中断发生时的第一个周期和最后一个周期的数据影响情况，而中断持续的传输周期内的数据一定会受影响。

If the impact of disruptions on data transmission is discussed, the focus is on the impact of data in the first and last cycles when interrupts occur, while the data in the transmission cycle during which interrupts persist will certainly be affected.

设为中断发生时数据距源节点的距离，为中断结束时数据距源节点的距离.

Let be the distance of the data from the source node when the disruption occurs, be the distance of the data from the source node at the end of the diruptions.

经观察和思考，发现中断是否会对中断发生时第一个传输周期产生影响可以分3种情况讨论，中断发生时数据还没有到达中断处、中断恰好发生在数据传输这段链路上和中断发生时数据已经经过了中断链路。中断是否会对中断发生时最后一个传输周期产生影响可以分2种情况讨论

由上面分析，中断发生时对第一个传输周期的影响分为三种情况，而中断持续的最后一个周期的数据会不会被影响分为两种情况，因此我们将分六种情况进行讨论单中断“时间-位置因素”的数据传输模型。

According to the above analysis, the effect of the first transmission round when the disruption occurs can be divided into three cases, and whether the data of the last transmission round when the disruption lasts will be affected is divided into two cases.Therefore, we will discuss the data transmission model of "time-position factor" of single link disruption in six different cases depending on the relationgship between lstart and l and lend and l.

Fig1



第一种情况：当且时。 在此种情况下，中断发生时数据还未到达中断处(链路中断事件之前可用于数据传输的第一个传输轮中的时间间隔的持续时间小于一个束在链路上传输和传播所需的时间长度)。因此中断只要持续一定时间就会对中断发生的第一个传输周期的数据造成影响，但是不会影响中断持续的最后一个周期。

Case1： and

Fig. 1 illustrates general transmission scenarios of BP in Case 1. In this case,the duration of the time interval in the first transmission round available for data transmission prior to the link disruption event is shorter than the time length needed for a bundle to be transmitted and to propagate through the link. Therefore, the bundle transmission in the first transmission round that is affected by the disruption fails to deliver the bundle.Because of , it will not affect the last transmission round of the disruption.

Given that the total time duration of each transmission round is (TBundle +TRTO ), define the number of time-out retransmissions due to disruption is NB-Effect,can be approximated as

(4-1)

By counting the total number of transmission rounds that are affected (or wasted) by the link disruption, then calculating the effective time length of link disruption to the total bundle delivery time (or simply, the total effect of the disruption), TB-Effect. It can be formulated as

(4-2)

Let NB-Delivery be the total number of transmissions rounds needed for successfull data delivery,including the average number of successful transmissions and the number of retransmissions due to disruptions .Therefore , NB-Delivery can be calculated as

(4-3)

Then,the total bundle delivery time ,TB-Delivery,can be approximated as

(4-4)

Fig2



在此种情况下，中断会影响第一个传输周期，也会影响中断持续的最后一个周期。因此，在这种情况下，要比第一种情况多重新传输1次.假设表示由于中断引起的发送方托管信息超时重传数据的次数，可以表示为：

Case 2： and

Fig. 2 illustrates general transmission scenarios of BP in Case 2. In this case，similar to Case 1, the bundle transmission in the first transmission round that is affected by the disruption fails to deliver the bundle.However, the transmission round following the end of link disruption is affected and thus wasted by the disruption event due to .Thus, in this case, there is one more retransmission than in Case 1.

Therefore, the number of time-out retransmissions NB-Effect can be approximated as

(4-5)

The total effect of the disruption on the delivery time TB-Effect. can be formulated as

(4-6)

The total number of transmissions rounds needed for successfull data delivery NB-Delivery can be calculated as

(4-7)

Then,the total bundle delivery time can be formulated as

(4-8)

Fig 3



在此种情况下，中断会影响中断发生时第一个传输周期，不会影响中断持续的最后一个周期

Case 3: and

Fig. 3 illustrates general transmission scenarios of BP in Case 3. In this case,the duration of the time interval in the first transmission round available for data transmission prior to the link disruption event is equal to the time length needed for a bundle to be transmitted and to propagate through the link. In simple, the bundle transmission in the first transmission round that is affected by the disruption fails to deliver the bundle.Because of , it will not affect the last transmission round of the disruption. Therefore, the total number of transmission efforts that are wasted due to the link disruption are the same as in Case 1. Therefore, NB-Effect should be formulated as the same as in (4-1), TB-Effect. should be formulated as the same as in (4-2), NB-Delivery should be formulated as the same as in (4-3) and the total bundle delivery time TB-Delivery should be formulated as the same as in (4-4).

Fig 4



在此种情况下，中断不会影响第一个传输周期，也不会影响中断持续的最后一个周期。

Case 4: and

Fig. 4 illustrates general transmission scenarios of BP in Case 4. As is shown in fig 4, because , the time interval in the first transmission round available for data transmission prior to the link disruption event is longer than the time length needed for a bundle to be transmitted and to propagate through the link. Therefore, the first transmission effort (i.e., in the first transmission round) is able to complete prior to the start of the link disruption. Therefore, the first transmission round is not wasted. Because of ,the round following the end of link disruption is not affected by the disruption event. This leads TB-Effect to be one-round shorter than in Case 1.

Thus, the number of time-out retransmissions NB-Effect can be rewritten as

(4-9)

The total effect of the disruption on the delivery time TB-Effect. can be formulated as

(4-10)

The total number of transmissions rounds needed for successfull data delivery NB-Delivery can be calculated as

(4-11)

Then,the total bundle delivery time can be formulated as

(4-12)

Fig 5



在此种情况下，中断会影响第一个传输周期，也会影响中断持续的最后一个周期。

Case 5: and

Fig. 5 illustrates general transmission scenarios of BP in Case 5. In this case,similar to Case 3, the time of link availability is not long enough for a bundle to be sent and delivered at the receiver through the deep-space data link. In other words,the bundle transmission in the first transmission round that is affected by the disruption fails to deliver the bundle. The transmission round following the end of link disruption is the same as in case 2. As we can see in Fig 5, in this case, the number of time-out retransmissions due to disruption, the total effect of the disruption on the delivery time, the total number of transmissions rounds needed for successfull data delivery and the bundle delivery time are the same as case2. That is, all the parameters and formulas are the same as in Case 2. That is,NB-Effect should be formulated as the same as in (4-5), TB-Effect. should be formulated as the same as in (4-6), NB-Delivery should be formulated as the same as in (4-7) and the total bundle delivey time TB-Delivery should be formulated as the same as in (4-8).

Fig6

在此种情况下，中断不会影响第一个传输周期，会影响中断持续的最后一个周期。

Case 6: and

Fig. 6 illustrates general transmission scenarios of BP in Case 6. In this case,similar to Case 4,the time interval in the first transmission round available for data transmission prior to the link disruption event is longer than the time length needed for a bundle to be transmitted and to propagate through the link. Therefore, the first transmission effort is able to complete prior to the start of the link disruption.Thus, the first transmission round is not wasted. Because of , the transmission round following the end of link disruption is the same as in case 2. As we can see in Fig 6, the number of time-out retransmissions due to disruption, the total effect of the disruption on the delivery time, the total number of transmissions rounds needed for successfull data delivery and the bundle delivery time are the same as case 1. That is, all the parameters and formulas are the same as in Case 3. That is, NB-Effect should be formulated as the same as in (4-1), TB-Effect should be formulated as the same as in (4-2), NB-Delivery should be formulated as the same as in (4-3) and the total bundle delivery time TB-Delivery should be formulated as the same as in (4-4).

分析上面六种情况，我们发现可以将这六种情况归纳为三大种情况。其中，将第一、第三和第六种情况归纳为一种情况，称之为case X。我们可以总结出，case x的条件为A或B。我们可以将第二和第五两种情况归纳为一种情况，归纳条件为，称之为Case Y。我们将第四种情况，条件归纳为a，称为Case Z。

Analyzing the above six cases, we find that these six cases can be summarized into three major cases.Among them, the first, third, and sixth cases are summarized as a case, called case X. We can conclude that the condition for case X is either  and  or  and ****.

We can summarize the second and fifth cases into one case, called Case Y.The condition for case Y is and .

The fourth case is called Case Z, and the condition is summarized as and .

Case X : and  or  and ****.

Observing the first, third, and sixth cases, the total number of bundle transmissions and the total bundle delivery time are the same when bundles are delivered successfully.Therefore, in case X, the total number of transmissions rounds needed for successfull data delivery NB-Delivery can be written as

(4-13)

Then,the total bundle delivery time can be formulated as

(4-14)

Case Y :and .

Observing the second, and fifth cases, the total number of bundle transmissions and the total bundle delivery time are the same when bundles are delivered successfully.Therefore, in case Y, the total number of transmissions rounds needed for successfull data delivery NB-Delivery can be written as

(4-15)

Then,the total bundle delivery time can be formulated as

(4-16)

Case Z: and .

The fourth case alone is summarized as a case.Observing the fourth cases, the total number of bundle transmissions when bundles are delivered successfully is less than case X and case Y, the total bundle delivery time is shorter than case X and case Y. Therefore, in case Z, the total number of transmissions rounds needed for successfull data delivery NB-Delivery can be written as

(4-17)

Then,the total bundle delivery time can be formulated as

(4-18)

Goodput is sometimes needed as a measure of transmission efficiency for a DTN protocol. Goodput is defined as the ratio of delivered unique data bytes to the total data delivery time. With the total bundle delivery time derived, the goodput for the transmission of BP can be easily formulated as

 (4-19)