An Improved Double Retransmission Scheme to Deferred NAK CFDP

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***Abstract*—In this paper, we put forward an improved scheme based on deferred NAK (Negative Acknowledgement) mode in CCSDS (Consultative Committee for Space Data Systems) file delivery protocol, to make a trade-off between the file delivery time and the throughput. We employ K retransmissions on the missing packets to decrease the packet error probability and lower file delivery time. We define a ratio $\Delta(K-1)$ to evaluate the performance trade-off, which denotes the decrement of file delivery time by one extra retransmitted PDU (Protocol Data Unit) relative to standard deferred NAK for different K. We determine the proper retransmission times $K=2$ by calculating the ratio of different K via a bulk of simulations. The simulation results indicate the performance of this scheme outperforms the standard deferred NAK mode in terms of file delivery time, especially in the scenarios with small connectivity time, long propagation delay and high Packet Error Rate (PER>0.1) greatly.**

Keywords-CCSDS file delivery protocol; deferred NAK mode; double retransmission; file delivery time; power management

I. INTRODUCTION

Over the recent years, Consultative Committee for Space Data Systems (CCSDS) has standardized a set of communication protocols based on state-of-the-art techniques. Indeed, since the needs of different missions, a single type of standard would not satisfy all scenarios and possible selections will be offered to users [1].

Currently there are two kinds of reliability mechanisms for various mission scenarios, respectively based on retransmission and redundancy schemes. The ultimate frontier for ensuring reliable data transfer is represented by the joint application of ARQ and erasure codes, so as to provide a two-level protection in deep space communication[1]. Coding solutions applying the concept of digital fountain, such as LT, Tornado, and Raptor codes, yet deserve great attention and were initially considered within the CCSDS standardization process. Despite the virtues they may offer in terms of rateless coding, they still require the availability of a feedback channel for signaling the completion of the decoding procedure to the sender, which otherwise would continuously transmit new redundancy symbols, wasting power and link bandwidth[2].

As one type of reliability mechanisms based on retransmission, the CCSDS File Delivery Protocol (CFDP) offers end-to-end transport services for the file transfer to/from onboard mass memories. It is designed to get reliable transfer of files by following an FTP-like paradigm. Its implementation spans the application and transport layers. It consists of two operative procedures: core and extended. CFDP adopts an ARQ (Automatic Repeat reQuest) mechanism, while uses NAK (Negative Acknowledgement) to replace ACK (Acknowledgement). Considering the features of links and transmission requirements, CFDP offers four selectable modes: deferred, immediate, prompted and asynchronous [3].

The remainder of this paper is organized as follows. Section II presents the related work. Section III describes and analyzes *K*-retransmission-based deferred NAK scheme. Section IV defines a reasonable ratio to validate and evaluate our scheme, and determines the proper K value. Section V makes a comparison between standard deferred NAK and our scheme based on $K=2$. Finally, conclusions are drawn.

II. RELATED WORK

Some work have been done to analyze the performance of CFDP. W. Baek and D. C. Lee evaluate the expected file delivery time in deferred and immediate NAK modes [4][5]. All parameter values are set under the constraint that the throughput is never compromised. T. de Cola proposes Repeated Transmission (RT) mechanism to extend the CFDP features, transmitting the same CFDP PDU for K times consecutively [6]. The relationships between packet loss rate, packet size, throughput and the number of transmissions are merely discussed under the cislunar scenario, whereas the file delivery time is not mentioned. G. Papastergiou and I. Psaras advance the Deep-Space Transport Protocol (DS-TP), which transmits each packet twice importing some delay between the original transmission and the retransmission. Although DS-TP can obtain two times faster than conventional protocols in terms of file delivery time, it induces high overhead [7].

From the above work, we find that the same PDU allowed to be delivered either two or K times consecutively during the whole period of file transfer. As a result, extraordinary power will be consumed in the context of multiple repeated transmissions. How to measure the compromise between the file delivery time, extraordinary power and throughput of CFDP, is an open issue. The purpose of this paper is to bring forward an improved scheme to standard deferred NAK CFDP, in which we use a *K*-retransmission-based strategy to make a trade-off between the file delivery time and the throughput. We measure the

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proposed scheme under several typical scenarios, such as GEO, Earth to Moon and Earth to Mars.

III. *K*-RETRANSMISSION-BASED SCHEME OF CFDP

In CFDP, file-transfer is called a "transaction". Each file is segmented into PDUs of variable length before transmission. For the first transmission attempt, a meta-data PDU is sent at the beginning, followed by the file data PDUs sent out in sequence with an end-of-file (EOF) PDU, which marks the end of the first transmission attempt and signals the receiver to respond. If missing or error-corrupted PDUs were detected, a NAK message is issued back to the sender, with a list of PDUs that need to be retransmitted. Upon reception of the NAK, the sender will retransmit the requested PDUs until all missing PDUs have been correctly received. If all PDUs are successfully received, the receiver will send a Finished (FIN) message to the sender, signaling the completion of the transaction. As a widely used mode, in this paper we regard deferred NAK CFDP as an improved object. We consider the transport layer channel of CFDP to be an erasure channel and make some assumptions as follows, details refer to [4][5]:

- Link is full-duplex and power budget is fixed.
- Processing delay of PDU is neglected.
- The meta-data PDU and all file data PDUs have an identical length.
- Each EOF is transmitted successfully at a time.

Notations we use in this paper are specified in Table I.

TABLE I. NOTATIONS.

Symbol	Definition
K	Retransmission times for each PDU in retransmission stage
N	Total number of PDUs in a transaction
P_{ef}	Probability of PDU error or lost
P_{er}	Probability of error in delivering NAK
T_{prop}	One-way propagation time
T_{PDU}	Transmission time of meta-data or file data PDU
RT	Transmission time of the PDUs in retransmission stage
P	Probability
H	A random variable, transmission number of a PDU in retransmission stage

A. Scheme Description

As depicted in Fig. 1, we chronologically divide the total file delivery time into two stages: first sending stage and retransmission stage. The first sending stage starts at the sender's transmission of meta-data initiating the transaction and ends after EOF reception at the receiver entity. The retransmission stage begins at the transmission immediately following ACK (EOF) transmission and finishes at the instant when all missing PDUs have been correctly received. Note that our definition of file delivery time does not include the time for FIN-ACK(FIN) procedure. Let us have a quick overview of *K*-retransmission-based deferred NAK scheme. The algorithm is described as follows:

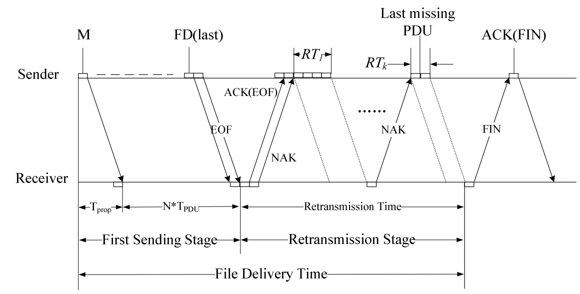

Figure 1. Delay time diagram of *K*-retransmission-based deferred NAK.

Step I: In first sending stage, sender entity transmits a meta-PDU and all file data PDUs in sequence to receiver entity, after finishing sending all the data PDUs, the sender entity sends a EOF PDU to the receiver entity, then waits ACK(EOF) and NAK. Upon receiving the ACK(EOF) and NAK, if there is no missing PDU, the transaction is closed, details refer to [3][4], otherwise goes to Step II.

Step II: In retransmission stage, upon receiving a NAK, the sender entity immediately retransmits each missing PDU K times consecutively. If missing PDUs still remain, the receiver entity issues another NAK. This process repeats until the receiver entity receives all necessary PDUs successfully, then the transaction is closed.

Here, K is a meaningful parameter, which is counted by a counter at the sender entity and influences the overall performance and helps increase the probability of data delivery at cost of power waste (proportional with K).

B. Theoretical Analysis

Before the theoretical analysis of *K*-retransmission-based deferred NAK, we address the setting rules on EOF timer and NAK timer. Considering CFDP over a direct hop-to-hop link, in order to prevent unnecessary duplicate retransmission, the time-out value of the EOF timer should be $2T_{prop}$. The time-out value of the NAK timer set upon issuance of the NAK that causes the k^{th} retransmission spurt in the retransmission stage, should be $2T_{prop} + RT_k$, where RT_k denotes the transmission time of the PDUs requested by the receiver for the k^{th} retransmission spurt in the retransmission stage [4]. From the aforementioned assumptions, the EOF delivery time can be T_{prop} because it is transmitted successfully at a time.

Now let us focus on analysis of the retransmission stage, we denote random variable H_i^K the number of transmissions of the i^{th} PDU up to and including its first successful transmission during the period of *K*-retransmission-based. Under our channel assumption, H_i^K has a geometric distribution, and H_i^K is equal or larger than 0 because some possible PDUs have been successfully delivered to the receiver during the first sending stage. The retransmission spurts will reoccur until all PDUs are delivered to the receiver, so $\max(H_1^K, H_2^K, \cdots, H_N^K)$ is the number of retransmission spurt. Then, we define random variable H_M^K as $H_M^K = \max(H_1^K, H_2^K, \cdots, H_N^K)$.

Considering the minimum setting value of NAK timer is $2T_{prop} + RT_k$, the expected retransmission time during the first retransmission spurt can be obtained as

$$\sum_{i=1}^{\infty} \left[i(2T_{prop} + RT_1) \right] P_{er}^{i-1} (1 - P_{er}) = \frac{2T_{prop} + RT_1}{1 - P_{er}} \quad (1)$$

So the expected time during the whole retransmission stage is given as

$$E\left(\sum_{k=1}^{H_M^K} \frac{2T_{prop} + RT_k}{1 - P_{er}} \right) = \frac{E(H_M^K) \cdot 2T_{prop}}{1 - P_{er}} + \frac{E\left(\sum_{k=1}^{H_M^K} RT_k \right)}{1 - P_{er}} \quad (2)$$

For the calculation of $E(H_M^K)$, we have

$$\begin{aligned} E\left(H_M^K\right) &= \sum_{m=1}^{\infty} P(H_M^K \geq m) \\ &= \sum_{m=1}^{\infty} \left[1 - P(H_M^K < m) \right] \\ &= \sum_{m=1}^{\infty} \left[1 - \prod_{i=1}^{N} P(H_i^K < m) \right] \\ &= \sum_{m=1}^{\infty} \left[1 - \left(1 - P_{ef}^{K(m-1)+1} \right)^N \right] \end{aligned} \quad (3)$$

Note that $E(\sum_{k=1}^{H_M^K} RT_k)$ is the expected total time needed for transmission of the missing PDUs until all of them have been successfully received. Thus we have

$$E\left(\sum_{k=1}^{H_M^K} RT_k \right) = \sum_{i=1}^{N} E(H_i^K) T_{PDU} = (K \cdot N \cdot T_{PDU}) \left(\frac{P_{ef}}{1 - P_{ef}^K} \right) \quad (4)$$

So the number of PDUs required in the K-retransmission-based retransmission stage is

$$K \cdot N \frac{P_{ef}}{1 - P_{ef}^K} \quad (5)$$

Therefore, the expected total file delivery time of a transaction can be given as

$$N \cdot T_{PDU} + T_{prop} + \frac{E(H_M^K) \cdot 2T_{prop}}{1 - P_{er}} + \frac{K \cdot N \cdot P_{ef} \cdot T_{PDU}}{(1 - P_{er}) \cdot (1 - P_{ef}^K)} \quad (6)$$

In general, we have a better understanding of K-retransmission-based deferred NAK mode. We will validate the K-retransmission-based scheme in Section IV, and determine the proper K value.

IV. Simulation and Discussion

This section includes both analytical and experimental evaluations of our scheme. To that purpose, we define a ratio expressed in terms of the decrement of file delivery time by one extra retransmitted PDU to validate the performance of K-retransmission-based scheme, and the proper K is determined.

A. Validation

Under the aforementioned analysis, we have constructed our simulation scenarios. We consider a single link file-transfer operation. The typical configurations of parameters are listed in Table II.

We denote T_K the time spent in K-retransmission-based retransmission stage (with T_1 is corresponding to retransmission time needed in standard deferred NAK CFDP), and P_K the number of PDU requested in K-retransmission-based retransmission stage (with P_1 is corresponding to retransmission number of PDU needed in standard deferred NAK CFDP).

We then define a ratio as follows:

$$\Delta(K-1) = -\frac{T_K - T_1}{P_K - P_1} \quad (7)$$

where $K \geq 2$, refers to the decrement of file delivery time by one extra retransmitted PDU transmitted in the K-retransmission-based stage, relative to the standard deferred NAK CFDP. We utilize this ratio to evaluate the performance of our scheme. Here we only consider the ratio of the Earth to Mars scenario to see general. The tests are performed in order to show how the performance changes with different packet error probability ranging from 0.01 to 0.5 and retransmission times K from 2 to 10. Combining (2), (3), (5) and (7), we plot a figure, as shown in Fig. 2, by using MATLAB tool.

It is straightforward that increasing the times of retransmissions, the values of ratio $\Delta(K-1)$ decrease. We observe that the values of $\Delta(2-1)$ under different PER are all superior to the other cases. If the number of transmissions is further increased, from 3 to 10, when PER ranging from 0.1 to 0.5, the curves will tend to be flat. As highlighted in the previous case, best results are provided, when K is equal to 2, with maximum decrement of file delivery time at the cost of same number of PDUs. More precisely, the contribution to lower the file delivery at the cost of power is maximal in the case of $K = 2$. The peak values under different K and PER appear in the vicinity of $P_{ef} = 0.05$, the reason causing this phenomena will be a contribution in future work.

On the basis of above mentioned, we choose the proper K equal to 2, and name this scheme as Double Retransmission (DR) deferred NAK. We make some simulations in Section IV.B for a supplementary validation.

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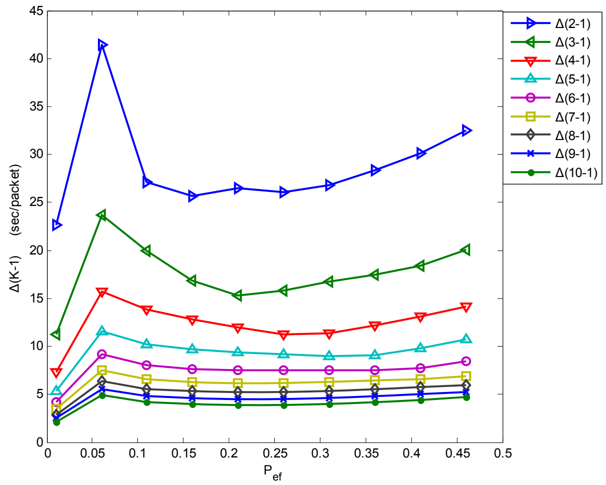


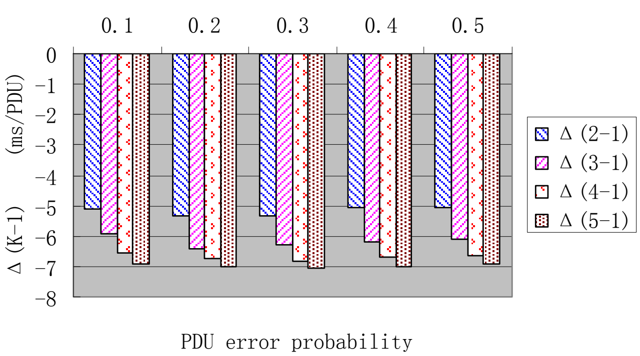
Figure 2. Validation of *K*-retransmission-based deferred NAK. Earth to Mars scenario: File size = 1MB, transmission rate = 20kb/s, and one way propagation delay = 2.5 a.u. (1 a.u. = 480s).

TABLE II. CONFIGURATION OF SIMULATION PARAMETERS.

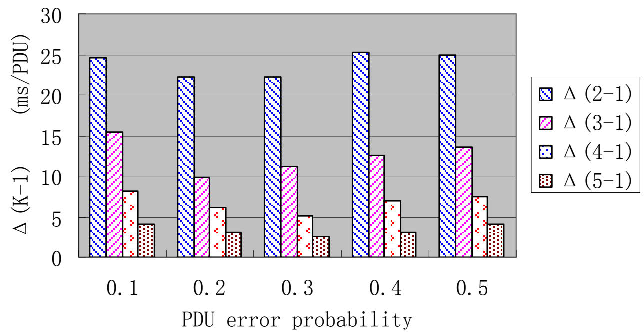
Items	**Scenario A**	**Scenario B**	**Scenario C**
	GEO	***Earth to Moon***	***Earth to Mars***
File size	1MB		
N	1000		
P_{ef}	0.01: 0.05: 0.5, 0.1: 0.1: 0.5		
T_{prop}	0.12 sec	1.352 sec	2.5 a.u. (1200 sec)
T_{PDU}	0.008 sec	0.008 sec	0.4 sec

B. *Simulation and Analysis*

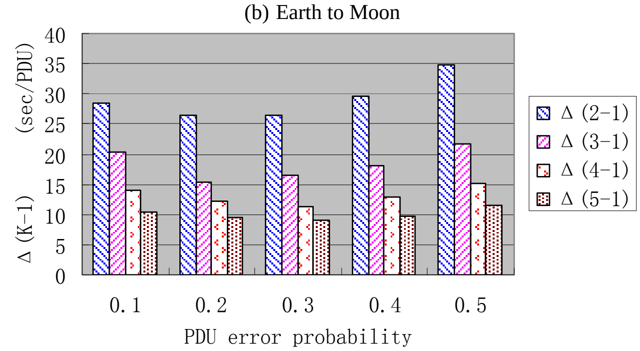
From the above Fig. 2, it is clear that increasing the K, the decrement becomes smaller and smaller. Thus, we confine the maximum K down to 5, and the packet error probability in the range of 0.1 to 0.5, to make a supplementary validation under three typical scenarios which have been listed in Table II.



(a) GEO



(b) Earth to Moon



(c) Earth to Mars

Figure 3. Simulation results under three typical Scenarios: (a) GEO. (b) Earth to Moon. (c) Earth to Mars

From Fig. 3, it shows that the values of ratio $\Delta(K-1)$ decrease with the increase of K under different P_{ef} gradually, and the maximum decrement of file delivery time appears at $K = 2$ .Moreover, the maximum values emerge when the packet lost rate is higher, especially in "deep-fading period". For scenario A, we note that the values of ratio are negative in Fig. 3(a). This is easily explained by the fact that the retransmission time is ruled by the number of retransmitted PDUs, in the case of one way propagation time is small. As far as scenario B and C are concerned, when $P_{ef} = 0.4, 0.5$, the value of $\Delta(2-1)$ is 25.3*ms* and 35*s* respectively, which are both the maximum. The longer distance from the earth to destination and the higher PER, the larger decrement of file delivery time can be realized, which can be informed by comparing the scenarios B and C. These are also in line with the previous results shown in Section IV. A.

V. COMPARISON MEASUREMENTS

This section derives the numerical presentation of DR deferred NAK, and makes a validation between numerical analysis and random simulation. We carry out several tests to compare DR deferred NAK with standard deferred NAK.

A. *Numerical Analysis and Random Simulation*

From (3) and (6), the expected total file delivery time of a transaction based on the DR deferred NAK scheme can be easily obtained as

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$$T_{prop} + N \cdot T_{PDU} + \frac{E(H_M^2) \cdot 2T_{prop}}{1 - P_{er}} + \frac{2N \cdot P_{ef} \cdot T_{PDU}}{(1-P_{er}) \cdot (1-P_{ef}^2)} \quad (8)$$

Where

$$E(H_M^2) = \sum_{m=1}^{\infty} \left[1 - (1 - P_{ef}^{2m-1})^N \right] \quad (9)$$

We compare the numerical evaluation of (8) and the results of random simulation. The simulation results closely match the mathematically derived results, as can be observed form Fig. 4.

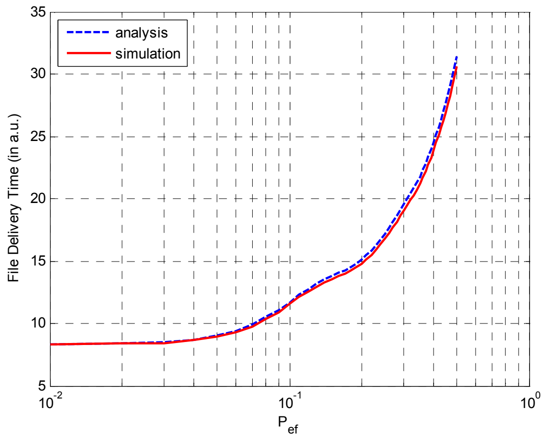
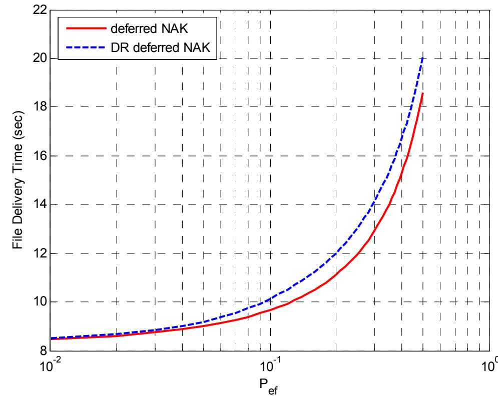


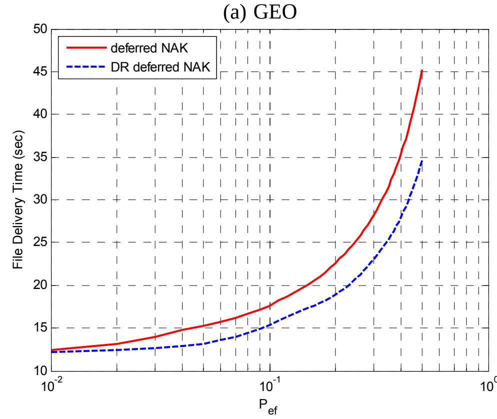
Figure 4. DR deferred NAK: analytic and simulation results. File size = 1MB, transmission rate = 20kb/s, and one way propagation delay = 2.5 a.u.

B. Deferred NAK vs DR Deferred NAK

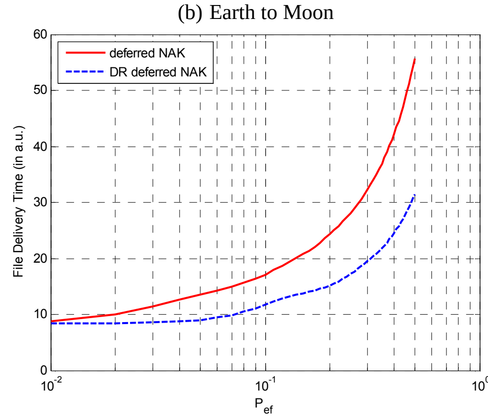
Under the simulation parameters presented in Table II, we implement several experiments to compare DR deferred NAK with standard deferred NAK. We only consider the formula (6) in this paper and the formula (7) in [4] (in Section III. C). The comparisons between them under three typical scenarios are shown in Fig 5. From Fig 5, we notice that the file delivery time ascends with the increase of packet loss rate. Although the DR deferred NAK does not fit the GEO scenario, it quite suits the latter two scenarios, especially when the packet loss rate is larger than 0.1. As discussed in [3] (in Section II. C, proposition 1), the $E(H_M^2)$ increases in logarithmic order with N. The expected file delivery time in (8) has a term that increased with N and a term that has the factor $E(H_M^2)$. For very long propagation delay, the product of multiplicative factor $E(H_M^2)$ and one way propagation time is much larger than that of the term linear of N, which is on the order of the PDU transmission time. In such an environment, as the number of PDUs in the file increases, the expected file delivery time is initially ruled by the term logarithmically growing with N, and the order of growth later becomes linear with a small multiplicative factor for larger values of N. Given as N is fixed, the expected file delivery time is absolutely dominated by the multiplicative factor and long one way propagation delay. For a small one way propagation delay (relatively to the PDU transmission time), the order of growth is always ruled by the term linear of N. Generally, the DR deferred NAK is especially suited to scenarios with very long propagation delay, or high packet error rate, or both in deep space communication.



(a) GEO



(b) Earth to Moon



(c) Earth to Mars

Figure 5. Comparison between deferred NAK and DR deferred NAK: (a) GEO. (b) Earth to Moon. (c) Earth to Mars

VI. CONCLUSION AND FUTURE WORK

Future space communication needs simple, effective and reliable protocols. A single type of protocol would not meet the needs of all scenarios in future Delay-Tolerant Network (DTN). We have reconsidered the deferred NAK CFDP and integration of the retransmission concept. We have put forward an improved scheme utilizing double retransmission mechanism to standard deferred NAK CFDP. The protocol make an efficient trade-off between the file-delivery time and the throughput efficiency under several typical scenarios. Our theoretical evaluation and preliminary simulation results reveal that DR deferred NAK outperforms standard deferred NAK mode in terms of file delivery time. This improved scheme favors the scenarios with small connectivity time, long propagation delay and high PER greatly.

Future work will emphasize on the joint use of our scheme with erasure coding particularly. A deeper analysis of channel model combined with rain attenuation will also be tackled in our future work.

ACKNOWLEDGMENT

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