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A Model and Mapping Algorithm of Explicit Congestion Notification in Tunnel for ATN over IP Scheme

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***Abstract*—Based on the comparison of congestion control between aeronautical telecommunication network (ATN) and IP network, a new congestion avoidance model considering the explicit congestion notification (ECN) in ATN over IP scheme, called explicit congestion notification in tunnel (ECNT) model, is proposed in this paper. In addition, a new ECN/CE mapping algorithm to map ECN signal in IP sub-network onto ATN congestion management (CE) is also presented in order to solve the problem of different mechanisms of congestion management between TCP protocol in IP network and connection-oriented transport protocol (COTP) in ATN network. Simulation results show that compared with the model without ECN in tunnel, ECNT model and ECN/CE mapping algorithm can deal with congestion problem effectively.**

Key words: ATN; ATN over IP; congestion control; explicit congestion notification (ECN)

I. Introduction

The international civil aviation organization (ICAO) has developed a commercial seamless network i.e. aeronautical telecommunication network (ATN) [1], to be the infrastructure of integrating various kinds of air traffic service communications (ATSC). ATN is a special data communication network which is designed for air-ground and ground-ground data communication, however, it is not a communication network using new communication regulations, but a communication network integrating several data communication sub-networks in order to realize unified data transform service. Fully using existing data communication networks is one important goal for ATN construction. Since the ground-ground network using internet protocol (IP) has large market occupancy and highly satisfies the requirement of ATN, many countries are planning to use IP network as the tunnel of sub-network of ATN.

ATN is based on open system interconnection (OSI) model of international standard organization (ISO) [2], transport layer uses connection-oriented transport protocol (COTP) and connectionless transport protocol (CLTP), network layer uses connectionless network protocol (CLNP), specific packet formats of protocols are different from those of protocols used in popular IP protocol. ATN panel has set up a scheme that uses IP network as the tunnel of sub-network of ATN, called ATN over IP scheme as shown in Fig. 1.

Considering the compatibility between IP of IP network layer and CLNP of ATN network layer, ATN panel adds a sub-network dependent convergence function (SNDCF) in network layer (see Fig. 2) to supply SN-UNIDATA service for CLNP of ATN network layer, which makes the upper layers' data and protocol unit of ATN to meet the requirements of IP network [3].

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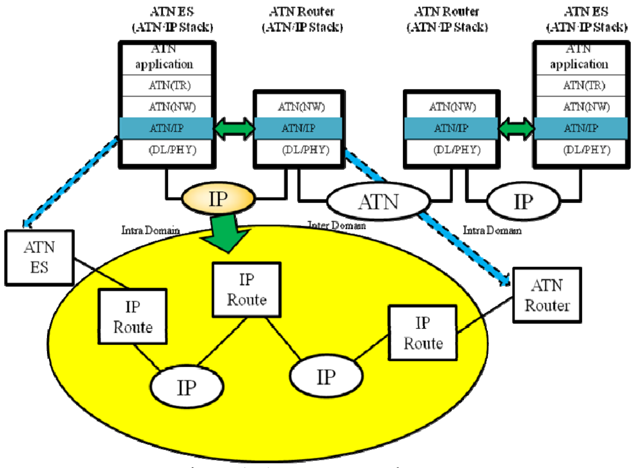

Figure 1. ATN over IP scheme.

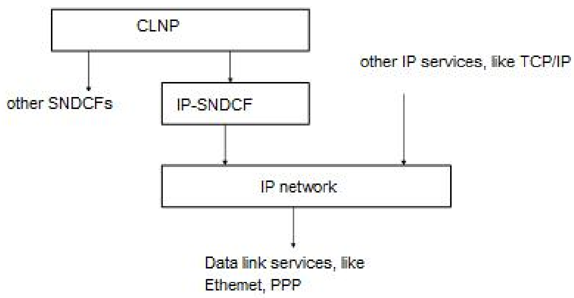

Figure 2. IP-SNDCF.

By using this ATN over IP scheme, ATN network can hold COTP/CLNP protocol stack and data which is transported by IP packet after being packed in IP-SNDCF. The similarity between ATN packet and IP packet shows that the fields of the two packets carry similar information, however, they need IP-SNDCF to map them with each other for information transporting, as shown in Fig. 3 [4].

II. Congestion Control of ATN and IP Network

Differences of protocol structure lead to a serious problem of congestion in ATN over IP scheme. The focus of our research is to solve it. At first, the congestion control of ATN and IP network are introduced below.

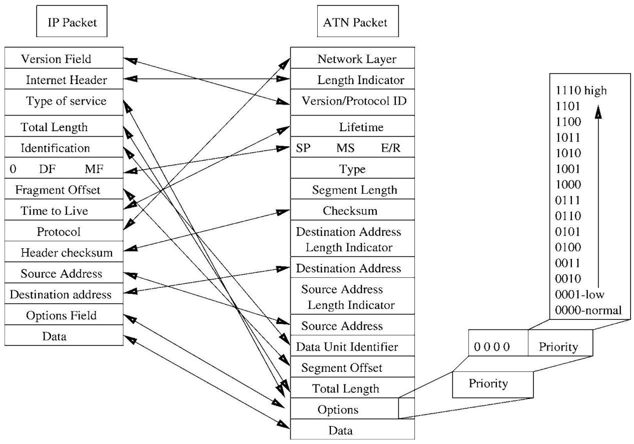

Figure 3. Similarity of IP and ATN packet.

A. Congestion Control of ATN

There are corresponding mechanisms of congestion control in both COTP of ATN transport layer and CLNP of ATN network layer.

Congestion Control of ATN Transport Layer

COTP of ATN transport layer supplies flow control service (FCS). It uses explicit flow congestion effect (EFCE) to realize congestion control. Typical process of data transportation is shown in Fig. 4.

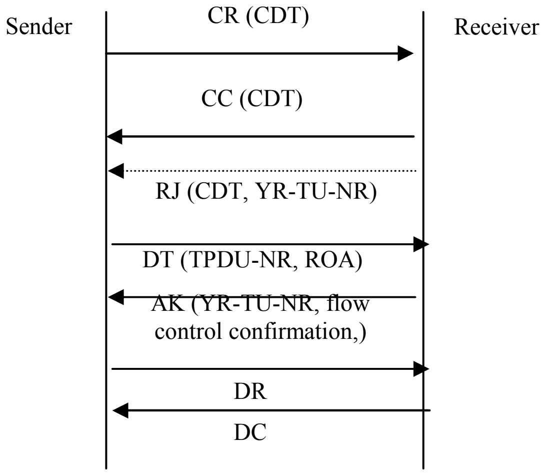

Figure 4. The transportation of EFCE.

Before data transportation, a sender sends connection request (CR) to its receiver. If the receiver accepts, it returns connection confirmation (CC). If it does not accept, it returns rejection (RJ). The process of data transportation is composed of the sender's data and the receiver's acknowledgment in dual direction. After have finished transportation, the sender sends disconnection request (DR) and the receiver returns disconnection confirmation (DC) in order to release the connection. CC and RJ both have the parameter CDT to indicate how much physical buffer needs when the connection is built up, which means the top window. As Data's parameter, PDU-NR is the symbol of CDKEY and ROA is symbol of requiring acknowledgment. EFCE is not only a process of CDKEY confirmation, but also a process of receiver's congestion control in window mechanism. Fig. 5 shows the structure of data acknowledgment (AK-TPDU) frame, YR-TU-NR means the next CDKEY that is wanted to receive, and flow control confirmation (FCC) is the real window size, which means the number of TPDUs permitted to send.

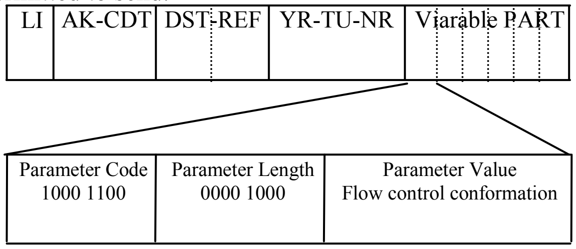

Figure 5. The frame structure of AK-TPDU.

Similar to the flow control of TCP/IP, ISO/IEC 8073 EFCE uses control of the window size of transport layer to realize flow control. Transport layer of the receiver uses AK-TPDU to send parameters to transport layer of the sender, which indicates the number of acceptable data unite of transport layer. And transport layer of the sender uses this number to alter the broadcasting window size, this process is called the broadcasting window refreshing. The specific procedure is as follows

1) The receiver sends the initial window size W (at first it is W_0) to the sender.

2) When received number of TPDUs is more than W, the receiver begins to sample.

3) N and NC begin with 0, where, N describes the total number of NPDUs in a NSDU and NC describes the number of NPDU in which CE is 1 among all NPDU.

4) When NC exceeds N by λ%, decrease W with a decrement β. Otherwise, increase W with a increment δ. Thus, we get a new W.

5) The receiver sends the new W to the sender.

6) Return to step 2) and repeat again.

Congestion Control of ATN Network Layer

The structure of CLNP frame is called network protocol data unite (NPDU). The option part of NPDU's head has maintaining parameter of quality of service (QoS) that is used to indicate different qualities of service. This parameter has a symbol of congestion indication called CE, and EFCE is realized by setting the value of symbol CE. Its setting rules are as follows

i. This symbol value is 0 in NPDU's sender.

ii. Intermediate system (IS) checks its output queue, when the length of output queue is longer than the setting length of CE, the value of exceeding part of NPDU's CE is set to 1.

In order to make network work at its best performance, which means high throughput and low time delay, the formula below is used in ATN to express transporting efficiency η

$$\eta = \text{Throughput}/\text{Delay} \quad (1)$$

IS's output queue can be regarded as a M/M/1 queuing system. Let arrival rate in queue be λ and transmitting rate in queue μ, the average waiting time in queue is

$$T = 1 / (\mu - \lambda) \quad (2)$$

The throughput of M/M/1 queue is λ. From (1), we can get the formula below

$$\eta = \lambda / (1 / (\mu - \lambda)) = \lambda(\mu - \lambda) \quad (3)$$

Obviously, to make transporting efficiency η be the largest, we have $\frac{\partial \eta}{\partial \lambda} = 0$. Based on this, we get that λ is equal to μ/2. According to M/M/1 queue, the average length of the queue is dependent on the formula below

$$N = \lambda / (\mu - \lambda) \quad (4)$$

When $\lambda = \mu/2$, N=1.

Therefore, in the congestion algorithm of ATN, when the output queue length of IS is more than 1, the value of CE in CLNP data packet is set to 1.

B. Congestion Control of IP Network

Since IP of IP network layer does not have the same CE as CLNP of ATN network layer does when IP network is used as the tunnel of sub-network of ATN, a blind spot exists in IP network. Therefore, a similar mapping of congestion control of COTP is searched in TCP.

TCP's congestion control can be divided into four phases [5]

1) Slow start phase.
2) Congestion avoidance phase.
3) Quick resend phase.
4) Resume phase.

TCP uses an addition increase max decrease (AIMD) port-to-port congestion control mechanism based on window. Experiment has proved that this mechanism has a widely applicability for best effort (BE) service for large file transporting on internet.

Congestion control of TCP uses the way that keeps increasing window size until buffer overflow of IS is detected by dropping detection, then the last packet is dropped. Though packet missing can trigger congestion control of port-to-port system, there is a period of time that IS stays overflow.

In order to avoid IS coming into congestion, active queue management (AQM) [6] is used in congestion control of TCP. A classical example is random early detection (RED) [7] algorithm: before the queue length reaches the deadline, packets are dropped by certain percentage. And this mechanism indicates the congestion to the sender implicitly.

The congestion control algorithm above uses dropping packet as the indication of network congestion. This solution is quite suitable for large amount of data transported in a short time, but it is not useful for some situations which require proper time delay. Therefore, ECN [8, 9] is added to TCP, combined with RED algorithm of AQM. When queue length of IS is smaller than the minimum of threshold in RED (min_{th}), ECN of arriving data packets remain 0. When queue length of IS is larger than the maximum of threshold in RED (max_{th}), ECN of arriving data packets is set to 1. When the queue length of IS is between min_{th} and max_{th}, ECN of arriving data packets is set by certain percentage which is related to the linear of average queue length.

After ECN is set to 1, it is sent by the receiver to the sender. And this symbol leads the sender execute congestion control mechanism of TCP.

III. ECNT Model and ECN/CE Mapping Algorithm

A. ECNT Model

There is similarity between ECN of TCP and EFCE of COTP, they are both explicit congestion control. This similarity can be used in transporting congestion information between ATN and IP network, but they are quite different in mechanism of realization. In TCP, ECN with value 1 means route is close to congest and single ECN symbol can trigger mechanism of TCP congestion control. However in ATN, a large quantity of CEs set can only lead length of broadcasting window be decreased.

In order to solve the problem of transporting of congestion control between ATN and IP network, ECNT model is presented in Fig. 6. In this model, ES1 is the sender and ES2 is the receiver, IS1 and IS2 are ATN routers, R is a IP router, G1 is the input gateway of IP network and G2 is the output gateway of IP network. Some data packets are sent from ES1 to ES2 during the IP network, when data packets arrive at IS1, CE in CLNP describes situation of congestion. If the length of packet queue in IS1 is larger than 1, this packet's CE is set to 1, otherwise, CE remains 0. When data packets arrive at G1, IP head is added to these packets and ECN in IP head begins to be used, the initial value is 0. Data packets use the form of IP packets to transport in IP network. In IP network, ECN in IP head is set to 0 or 1 which is based on RED/ECN algorithm in R (No matter whether CE in these packets is set or not.). When IP packets get to G2, they are uncovered to CLNP packets and the number of packets which ECN is set is mapped to the number of coming CLNP packets which CE is set. IS2 and ES2 are as same as IS and ES in single ATN.

During the process that data packets are sent from the sender to the receiver, ATN routers use their common way of CE to describe congestion situation. However, IP router uses ECN mechanism to decide whether the ECN symbol is set. In the output gateway of IP network, ECN symbols are mapped to CE symbols and the receiver system is no need to change. It is quite convenient and cheap for engineering realization.

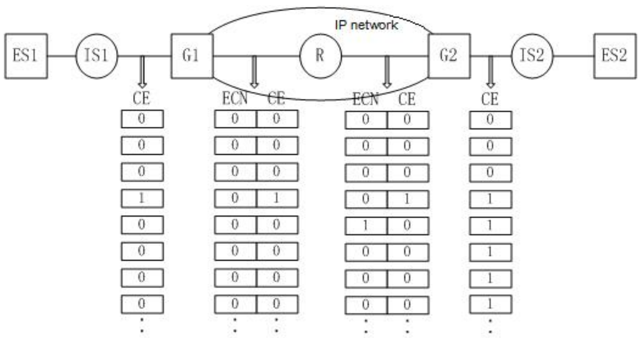

Figure 6. ECNT model.

B. ECN/CE Mapping Algorithm

In IP network, the RED algorithm is widely used in AQM, and ECN/RED can realize explicit congestion control. In ECN/RED algorithm, the probability of event Z which ECN is set is related to the average length of data queue (say avgL), as follows

$$P(Z \mid avgL = i) = \begin{cases} 0 & i \in [0, \min_{th}) \\ \dfrac{\max_p (i - \min_{th})}{\max_{th} - \min_{th}} & i \in [\min_{th}, \max_{th}) \\ 1 & i \in [\max_{th}, \infty) \end{cases} \quad (5)$$

Where, the set probability of max threshold, min_{th} is the minimum of average length of queue,and max_{th} is the maximum of average length of queue. Since it is difficult to get the number of packets set last time of IP router in output gateway of IP network, and the probability of data packets set is similar to the final probability of data packets, we replace the final probability of data packets with the probability of data packets. The influence of changing parameter is corrected by correct factor, which is set by specific situation.

1) Based on Bayes formula, the probability of average queue length which is set to specific value can be get

$$P(avgL = i \mid Z) = \frac{P(Z \mid avgL = i) \cdot P(avgL = i)}{\sum_{i=0}^{\infty} \{P(Z \mid avgL = i) \cdot P(avgL = i)\}} \quad (6)$$

2) Average queue length is actually the result of real length of queue in buffer filtered by low-pass filter, so average length of queue can be similar to actual length of queue in buffer

$$P(avgL = i \mid Z) \approx P(L = i \mid Z) \quad (7)$$

3) The estimation of actual average length of queue in buffer can be get by using (7) to obtain the probability when l is set a specific value and add them all.

$$Length = \sum_{l=0}^{\infty} \{l \cdot P(L = l \mid Z)\} \quad (8)$$

4) Considering the factors such as the replacement of the probability of data packets and CE that is mapped by ECN may exist in the waiting period but not the sample period, a correct factor α is used to correct Length. Final number of CE set by single ECN is called CountCE

$$CountCE = \alpha \cdot Length - 1 \quad (9)$$

5) Congestion information of IP network can be transported to COTP of ATN by using CE in CLNP, and the change of the number of CEs leads to broadcast window change in order to avoid congestion.

IV. Performance Evaluation

In order to prove that ECNT model and ECN/CE mapping algorithm can effectively solve the congestion problem of ATN over IP, we simulate this model and the mapping algorithm from the average length of queue, data transporting delay and fairness.

The simulation environment is shown in Fig. 7. The rate of transporting from G1 to R is 12 packets per second, other lines' transporting rate is 6 packets per second. If each packet contains 40 kbyte, the capacity of channel from G1 to R is 4 Mb/s, other lines' capacity of channel is 2Mb/s. All lines' transporting delay is shown in Fig. 7, here we assume the buffers of routers are all large enough. In COTP, λ=0.5, β=0.8. In RED algorithm, min_{th}=3 packets, max_{th}=9 packets and max_p=0.05. The length of queue is satisfied Poisson probability distribution, λ in the formula of Poisson probability distribution is set 2, correct factor α=1.3. During the simulation, S1, S2,S3, S4 send 500 data packets to D1, D2, D3, D4, each packet contains 40 kbyte.

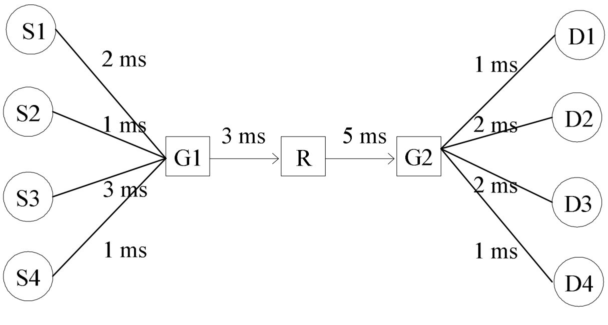

Figure 7. Simulation environment.

A. The Length of Queue in Buffer

Fig. 8 shows the length of queue in buffer of route R changes with time. From the figure, we can find that the length of queue in buffer will be very long if we do not use ECNT, which is easy to congest or drop packet. After using ECNT, the length of queue in buffer becomes short and this is good for congestion avoidance.

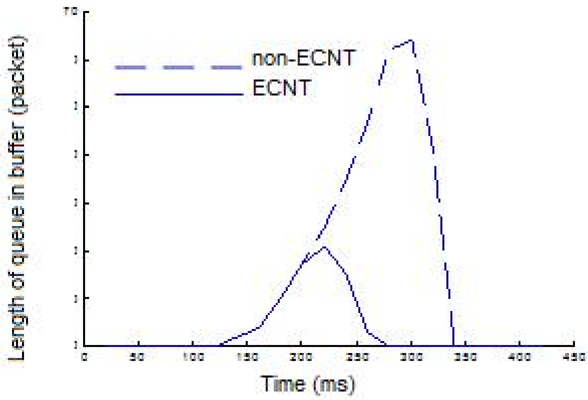

Figure 8. The comparison of length of queue in buffer.

B. Data Transporting Delay

In the environment of Fig. 7, data transporting delay is different in different size of packet. Fig. 9 shows when some different sizes of packets are delivered, the specific data transporting delay of ECNT network and non-ECNT network.

Fig. 9 shows when the size of buffer is unlimited, data transporting delay of ECNT network is only a litter larger than data transporting delay of non-ECNT network. But when the buffer size is limited, the queue length in buffer of non-ECNT network may be too long to drop packets and much time will be spent on resending packets. Data transporting delay will be so large.

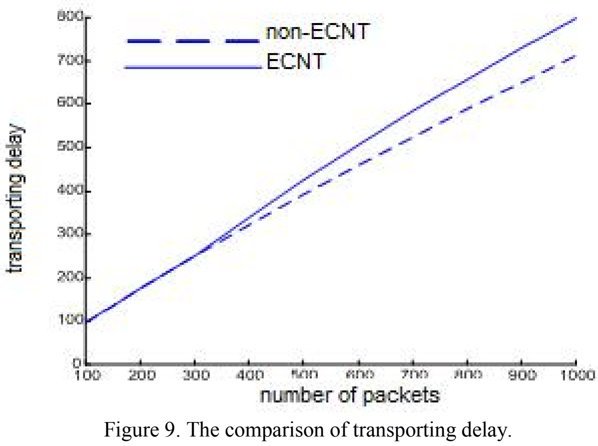

Figure 9. The comparison of transporting delay.

C. Fairness

In the connections of four senders and four receivers, we suppose the transporting rate of the receiver D_n is r_n (n=1, 2, 3, 4), the maximum is r_{max}, the minimum is r_{min}, the ratio of minimum and maximum is $q=r_{min}/r_{max}$. Obviously, when q is closer to 1, transporting rates among all connections are closer, and the fairness is better.

In Fig. 10, the values of q in different time phases are almost the same, and q of ECNT network is closer to 1 than q of non-ECNT network. Therefore, using ECNT does not decrease the fairness of connection.

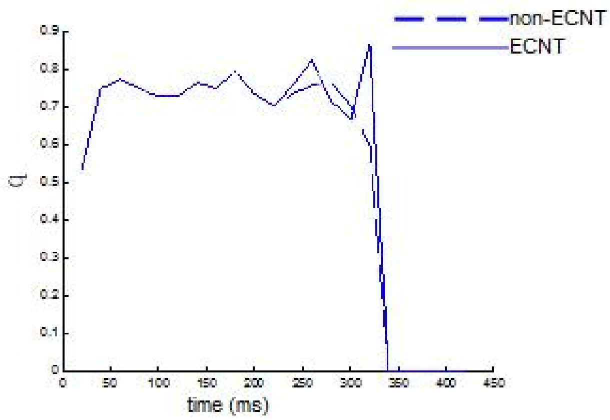

Figure 10. The comparison of fairness.

V. CONCLUSION

In this paper, we consider ECN in ATN over IP scheme. A new congestion avoidance model called explicit congestion notification in tunnel (ECNT) is proposed. Based on this, a new ECN/CE mapping algorithm to map ECN signal in IP sub-network onto ATN congestion management (CE) is presented in order to solve the problem of different mechanisms of congestion management between TCP protocol in IP network and COTP protocol in ATN network. Through the performance comparison between ECNT and non-ECNT, it has been found that ECNT network has great advantages. Simulation results show that under the condition that requires proper delay, ECNT network performs much better in congestion avoidance and has lose performance with non-ECNT network in data transporting delay and fairness. Therefore, ECNT model and ECN/CE mapping algorithm can solve the congestion problem in ATN over IP scheme effectively.

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