Stability Analysis of APRCA and APRCA2 for ABR Congestion Control in ATM Networks *

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Abstract: The APRCA (Adaptive Proportional Rate Control Algorithm) and APRCA2 are explicit rate based congestion control algorithm which indicates congestion by the change of queue length. Some researchers have concluded they have better performance than EPRCA. But in this paper, we show that these protocols are unstable in some conditions.

Key words: congestion control; stability; controller; APRCA

ATM 网络中用于 ABR 拥塞控制的 APRCA 和 APRCA2 的稳定性分析

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摘要: 自适应比例控制算法(APRCA)和 APRCA2 是基于显式速率(ER)的拥塞控制算法,它们通过检测排队长度的变化来确定是否拥塞.一些学者的工作表明它们具有比增强比例控制算法(EPRCA)更好的性能.但在本文中,我们证明了这种算法是不稳定的.在一些情况下,队长会常常超过严重拥塞门限.

关键词: 拥塞控制; 稳定性; 控制器; APRCA

1 Introduction

In ATM networks, the ABR (Available Bit Rate) service[1] has been defined for supporting best effort applications. There are many proposed congestion control protocols for Available Bit Rate (ABR) service for ATM networks. Among them, the EPRCA (Enhanced Proportional Rate Control Algorithm) and APRCA2[2] are the improvements of EPRCA[4,5]. Some research work has concluded APRCA has better performance than EPRCA[3].

In APRCA, congestion in the switch is detected by evaluating the change of queue length in a fixed time interval rather than by comparing queue length with a threshold value used in EPRCA. If the queue length increases in N cell times, the switch is expected to fall into congestion. This modification improves the responsiveness to congestion and therefore can reduce the maximum queue length. It also improves the fairness among connections. But in this paper we will show APRCA is unstable in some conditions.

2 Background on APRCA

The detail of APRCA protocol is provided in [2].

3 System assumption

In order to analyze the stability of APRCA, we consider a network consisting of one switch and N transmission links as shown in Fig. 1. Each transmission link i has an available capacity C_i cells for the ABR traffics.

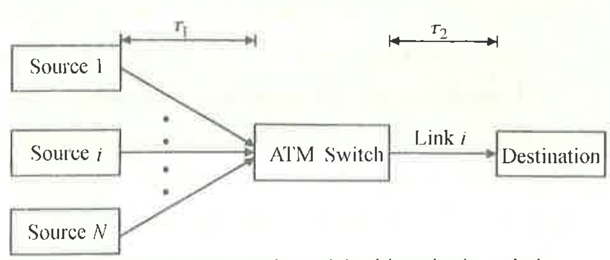

Fig. 1 Network model with a single switch

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The set of VCs passing through link i is $\{1,2,\cdots,N_i\}$, denoted as $N(i)^{**}$, where N_i is the number of all connections which traverse link i. The switch has, for each of its outgoing links, a buffer for storing cells waiting to be transmitted. Let Q_i denote the number of cells buffered for transmission on link i. The switch has a congestion controller associated with each transmission link. For simplicity, we will use R as a short form for MACR, E as a short form for ER, and A as a short form for ACR in the rest of the paper. In this paper, we take into account a traffic scenario with N_i identical ABR sources, i.e., all of the N_i connections, which share a common transmission link, have the same values of MCR (Minimum Cell Rate), PCR (Peak Cell Rate), ICR (Initial Cell Rate), and they are in phase during their whole lifetime. We further assume that RTT (Round Trip Time) is negligible. In fact, it can be a good approximation in a LAN (Local Area Network) environment.

In this paper, we assume that priority is given to the RM cells. If we give no priority to the RM cells, RM cells will queued up together with the data cells[7]. This assumption simplifies the analysis.

The system is described by a set of discrete-time dynamic equations which are similar to [6]. In [6], it assumed that two consecutive discrete time instants are given by T, during each T units of time, at all sources that, there is exactly one reception of one backward RM cell, and that exactly one transmission of a forward RM cell, and furthermore, during each T units of time, there is exactly one reception of a forward RM cell from each VC and exactly one reception of one backward RM cell from each active VC at each link. The implication of the above assumptions of [6] is that the delay for each RM cell traversing the network is uniformly bounded. In this paper, we assume that there exists an infinite sequence of increasing discrete-time instants, $\{t_0, t_1, t_2, \cdots, t_{k-1}, t_k, \cdots\}$. During each time interval $[t_{k-1}, t_k)$, $k = 1,2,\cdots$, at each source, there is exactly one reception of one backward RM cell, and exactly one transmission of a forward RM cell. Furthermore, during each time interval $[t_{k-1}, t_k)$, $k = 1,2,\cdots$, there is exactly one reception of a forward RM cell from each VC and exactly one reception of one backward RM cell from each active VC at each link.

Our main concern is with the receptions transmissions of the same type of RM cells (either backward or forward) at a source, or at a link, and the change of queue length. Our assumption will exhibit the essentials of our stability analysis.

3.1 System equations

In this section, we will present the system equations. From the system equations, we can get the overall dynamics of the entire network. Then according to the dynamics of the entire network, we can derive what we need (such as the evolution of queue length etc.) to analysis the stability of APRCA.

First, we will focus on link i.

Let $Q_i(t_{k+1})$ denote the average number of cells in link i is buffer during the time period $[t_k, t_{k+1})$, the buffer equation for link i can be described by the following difference equations, which are similar to [6]:

$$Q_i(t_{k+1}) = \max\{Q_i(t_k) + N_i \cdot A_i(t_k) - c_i, 0\}, \tag{1}$$

where $A_i(t_k)$ denotes the average ACR during the time period $[t_k, t_{k+1})$. We consider two traffic sources. Under the persistent source assumption*, we get:

$$A_i(t_k) = E_i(t_k), \tag{2}$$

$E_i(t_k)$ is the feedback explicit cell rate contained in the feedback RM cell during the time period $[t_k, t_{k+1})$.

Let $R_i(t_k)$ denote the MACR at link i at the beginning of the period $[t_k, t_{k+1})$. Let $\hat{R}_i(t_k)$ be the newly computed MACR right after the computation of MACR resulting from the arrival of the RM cell during the time period $[t_k, t_{k+1})$. In this paper, we take into account a traffic scenario with N_i identical ABR sources, i.e., all of the N_i connections, which share a common transmission link, have the same values of MCR (Minimum Cell Rate), PCR (Peak Cell Rate), ICR (Initial Cell Rate) and they are in phase during their whole lifetime. According to the outline of APRCA, it replaces its MACR by $(1-\alpha) \times \mathrm{MACR} + \alpha \times \mathrm{ACR}$ under some conditions

* Persistent (and greedy) sources are the sources which always have cells waiting to be sent and each source transmits data cells at the rate of its maximum allowed cell rates, and every source does not continuously decrease its ACR while waiting for the returning RM cells.

** The number of active VCs is assumed to be constant during the congestion resolution time.

as follows:

$$\hat{R}_i(t_k) = \begin{cases} (1-\alpha)\cdot R_i(t_k) + \alpha \cdot A_i(t_k), & \text{if condition 1,} \\ R_i(t_k), & \text{otherwise,} \end{cases} \tag{3}$$

where condition 1 is that link i is noncongested or link i is congested and $A_i(t_k) < R_i(t_k)$. From equation (3) and the definition of $R(t_k)$ as follows:

$$\hat{R}_i(t_k) \leqslant (1-\alpha)\cdot R_i(t_k) + \alpha \cdot A_i(t_k). \tag{4}$$

Consider the case where a congested link i receives a backward RM cell from a destination. Let $\tilde{R}_i(t_k)$ denote the latest MACR stored in the switch for link i right before the backward RM cell arrives from the destination during the time period $[t_k, t_{k+1})$. The feedback explicit cell rate E will be updated according to:

$$E(t_k) = \begin{cases} DPF \cdot \tilde{R}_i(t_k), & \text{if condition 2,} \\ \tilde{R}_i(t_k), & \text{if condition 3,} \\ \tilde{E}(t_k), & \text{otherwise,} \end{cases} \tag{5}$$

where $\tilde{E}(t_k)$ is the explicit rate carried in the backward RM cell during time period $[t_k, t_{k+1})$ arriving at link i.

Condition 2 is the situation where link i is very congested and

$$A_i(t_k) > \mathrm{DPF}\cdot \tilde{R}_i(t_k)$$

and

$$\mathrm{DPF}\cdot \tilde{R}_i(t_k) < \tilde{E}_i(t_k).$$

Condition 3 is the situation where link i is congested and

$$A_i(t_k) > \tilde{R}_i(t_k)$$

and

$$\tilde{R}_i(t_k) < \tilde{E}_i(t_k).$$

Note that from equation (10), if link i is very congested, we have

$$E_i(t_k) \leqslant \mathrm{DPF}\cdot \tilde{R}_i(t_k). \tag{6}$$

On the other hand, if link i is congested, $E_i(t_k) \leqslant R_i(t_k)$.

4 Stability analysis

In the usual stability analysis, one can consider the stability of the equilibrium points. However, the system is highly oscillatory and there exist no such points. Therefore, we consider the queue length in the switch instead and adopt queue length threshold as [6] to analyse the stability of APRCA.

When studying the stability of APRCA in the following, we assume that the network is undisturbed. That means the following events will not occur:

1) a new VC is admitted to the network;

2) a VC terminates its existence;

3) a VC changes its maximal data rate;

4) The available bandwidth at a link decreases or increases.

We will partition the queue into two regions according to one threshold: DQT (Fast Down Queue Threshold). The two regions are as follows:

Region C (Congested): DQT > Q_i;

Region SC (Severely Congested): $Q_i \geqslant$ DQT.

Definition The network is said to be unstable if the following statement is true: Suppose the network is undisturbed, if under persistent traffic sources there exists a link permanently oscillate around DQT.

Lemma 1 Under persistent source assumption, if Q_i is in region SC or the congestion controller detects the increase of queue length during $[t_k, t_{k+1})$, $R_i(t_{k+1}) \leqslant R_i(t_k)$; if there exists $A_i(t_k) < R_i(t_k)$, then $R_i(t_{k+1}) < R_i(t_k)$.

Lemma 2 Under persistent source assumption, if Q_i is in region SC during $[t_{k0}, t_{k0+1})$, there exists $t_k > t_{k0}$, such that DQT > $Q_i(t_k)$, i.e. Q_i is in region C.

Lemma 3 Under persistent source assumption, if Q_i is in region C during $[t_{k0}, t_{k0+1})$, then there exists $t_k > t_{k0}$, such that Q_i will enter into region SC.

Theorem 1 Under persistent source assumption, APRCA is unstable.

The proofs of the lemmas and theorem are omitted due to limited pages.

Fig.2 is the simulation result.

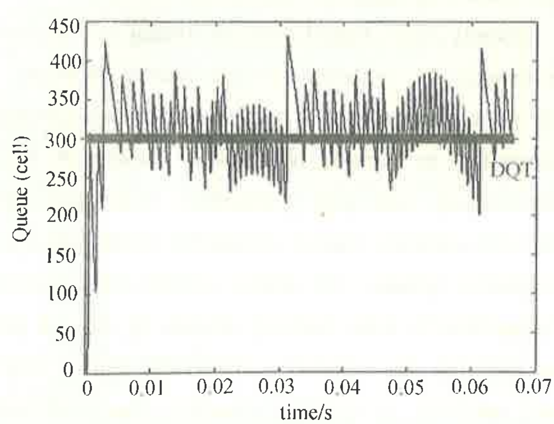

Fig. 2 Five greedy sources sharing a 155Mbps link, RTT is negligible, very congested threshold is 300 cells

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characteristics: adaptation and learning. It can handle some nonlinear, slow time-varying, and stochastic disturbed process control problem, and can obtain good control performance. The proposed control scheme can also be applied to complex process control.

References

1 Lec Chng-chien. A self-learning rule-based controller employing approximate reasoning and neural net concepts. Int. J. Intelligent Systems, 1991, 16(3): 71 – 93

2 Kosko B. Neural networks and fuzzy system. Prentice Hall, 1992

3 Jang J S. ANFIS: Adaptive-network-based fuzzy inference system. IEEE Trans. System Man and Cybernetics, 1993, 23(3): 665 – 685

4 Goldberg D E. Genetic algorithms in search optimization, and machine learning. Addison-Wesley, Reading, 1989

5 Wang Yaonan. Intelligent control intergrating expert system and neural networks. Advances in Modelling & Analysis France Press, 1994, 43 (4): 23 – 28

6 Wang Yaonan. An adaptive control using fuzzy logic neural network and its application. Control Theroy and Application, 1995, 12(4): 437 – 444

7 Wang Yaonan and Tong T S. Real-time expert intelligent control system REICS. Proc. of IFAC AARTC'92, 1992, 1: 307 – 312

8 Wang Yaoman. Intelligent Control System. Changsha: Hunan University Press, 1996(in Chinese)

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Stability analysis of APRCA2: The intelligent marking capability of APRCA was incorporated into EPRCA and a new scheme called APRCA2 was produced. APRCA2 solves the problem of source-bottleneck. The other parts of APRCA2 is the same as APRCA. So from the proof of instability of APRCA, we can see APRCA2 is unstable too.

5 Conclusion

In the present work, the stability of APRCA and APRCA2 were studied. From the analysis of APRCA and APRCA2, we found they are unstable in some conditions. This is the first paper that has made the discovery and we hope it will give useful advice in practical engineering.

References

1 Sathaye S. ATM Forum traffic management specification version 4.0. ATM Forum: aftm – 0056.000[EB/OL]. http://www.atmforum.com., 1996-04

2 Siu K Y and Tzeng H Y. Adaptive proportional rate controls (APRC) with intelligent congestion indication, ATM Forum Contribution 94-0888 [EB/OL]. http://www.atmforum.com., 1994-09

3 Siu K Y and Tzeng H Y. Limits of performance in rate-based control schemes, ATM Forum Contribution 94-1078[EB/OL]. http://www.atmforum.com., 1994-11

4 Siu K Y and Tzeng H Y. Intelligent congestion control for ABR service in ATM networks, Computer Communication Review, 1995, 24(5):

5 Roberts L. Enhanced PRCA (Proportional Rate-Control Algorithm), ATM Forum Contribution 94-0732R1[EB/OL]. http://www.atmforum.com.

6 Tsai W K, Ge Y and Huang G. Stability analysis of intelligent marking EPRCA for ABR congestion control in ATM. Inforcom'97, Kobe Japan, 1997

7 Ritter M. Network buffer requirements of the rate-based control mechanism for ABR Service. IEEE Infocom'96, San Francisco, USA, 1996

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