ICIC Express Letters
Volume **10**, Number **3**, March **2016**

ICIC International ©2016 ISSN 1881-803X
pp. **607–612**

CROSS-LAYER CONGESTION DETECTION AND OPTIMAL CONTROL SCHEME IN AD HOC NETWORK

Yanping Teng[1], Xuefeng Dai[1], Mei Jin[1] and Wencheng Gu[2]

[1]College of Computer and Control Engineering
[2]Network and Information Center
Qiqihar University
No. 42, Wenhua Street, Qiqihar 161006, P. R. China
typ2732996@163.com

Received August 2015; accepted October 2015

Abstract. *The cross-layer congestion detection and control (CL-CDAC) scheme is proposed based on single congestion detection index in Ad hoc network in this paper. And the definition of congestion metric is proposed, which detects the congestion state by using the full-load rate of intermediate node cache. Based on the explicit congestion notification (ECN) mechanism, the conventional congestion control algorithms are optimized by extracting the parameters from transmission layer and medium access control (MAC) layer for modeling so as to adjust the transmission rate of the sender. The simulation results show that compared with the conventional algorithms, the CL-CDAC scheme can accurately reflect the node congestion state to some extent, improve the network throughput, and reduce the end-to-end delay, which ensures the service quality of networks.*

Keywords: Ad hoc network, Congestion metric, Cross-layer congestion, Optimal control

1. **Introduction.** Ad hoc network is a self-organized network system composed of a group of devices with wireless transceivers and mobile nodes, and the nodes in the network also have the dual attributes of host and router. It can quickly build communication platform and provide communication support environment. Aiming at the problem of congestion detection in wireless Ad hoc network, researchers have offered numerous schemes. In these schemes, two kinds of congestion detection schemes based on the cache queue length and the transmission rate are commonly used. According to the current queue length for cache percentage, [1-3] determine whether node congestion occurs, and then the congestion degree is detected. In [4,5], according to the ratio between the sending rate and the receiving rate, the network congestion is determined in the node region. The improved random early detection (RED) algorithm, namely IRED, is proposed in [6], which combines the medium access control (MAC) retransmission mechanism with the cache queue length.

By analyzing the above researches, there still exist problems, such as adjusting rate, setting threshold of cache queue, not reflecting current congestion state in Ad hoc network. Consequently, in the paper, the congestion detection scheme is proposed, which combines the cache queue length in network layer with the input and output rate in MAC layer and the concept of congestion metric is presented. The detection scheme not only reflects the past and current congestion state, but also reflects the changing trend of node congestion. It is fairly suitable for Ad hoc network in which the network topology frequently changes. Besides, the congestion control scheme is proposed by extracting the parameters from transmission layer and MAC layer for modeling so as to solve the problem of adjusting rate. The optimal control scheme can accurately reflect the node congestion state, which improves the service quality of networks.

The remainder of the paper is organized as follows. The definition of congestion metric is presented in Section 2. The cross-layer congestion detection and control (CL-CDAC) scheme design ideas are put forward in Section 3. In Section 4, simulation results and performance analysis are demonstrated. Finally, conclusions are given with the importance and the practical value and some future work of the proposed scheme.

2. Definition of Congestion Metric.

Assume Q is the cache size of intermediate nodes, q is the instantaneous queue length, and $A = Q - q$ is the current instantaneous cache space available of nodes where $A \geq 0$. If $A = 0$, then the node cache is completely filled, the arriving packets are discarded, and the nodes are in full congestion state. Otherwise, the rate of nodes is detected in the MAC layer. Assume V_{in} is the input rate of the node, V_{out} is the output rate of the node, so $V = V_{in} - V_{out}$ is the change rate and $T = A/V = (Q-q)/(V_{in} - V_{out})$ is full time of the cache. The congestion metric is defined as $M = 1/T = (V_{in} - V_{out})/(Q-q)$. When $V_{in} > V_{out}$, if $M > 0$, then the available space of cache is smaller, the full load time is shorter and the congestion degree of the node is more serious; otherwise, the current nodes have no congestion and the available space of cache is constant or gradually becomes larger. So the congestion metric can be expressed as follows:

$$M = \begin{cases} \frac{V_{in}-V_{out}}{Q-q} & V_{in} > V_{out} \\ 0 & V_{in} \leq V_{out} \end{cases} \tag{1}$$

The input rate V_{in} and output rate of V_{out} can be expressed as time function [7]. Let T_{in} denote the arrival time interval for MAC layer packet of the node, T_{out} represents the service time required for a packet, $t_{in}(i)$ is the moment when the ith packet arrives at the node, $t_{mac}(i)$ is the moment when the ith packet comes into MAC layer and is ready to be sent, and $t_{ack}(i)$ is the moment when the ith packet is successfully sent and then receives the ACK frame. Accordingly, V_{in} and V_{out} are shown as follows:

$$V_{in}(i) = \begin{cases} \frac{1}{(1-\alpha)T_{in}(i-1)+\alpha[t_{in}(i)-t_{in}(i-1)]} & \beta \leq 1 \\ \frac{1}{\beta\{(1-\alpha)T_{in}(i-1)+\alpha[t_{in}(i)-t_{in}(i-1)]\}} & 1 < \beta \leq k \\ 0 & \beta > k \end{cases} \tag{2}$$

$$V_{out}(i) = \begin{cases} \frac{1}{(1-\lambda)T_{out}(i-1)+\lambda[t_{ack}(i)-t_{mac}(i-1)]} & \gamma \leq 1 \\ \frac{1}{\gamma\{(1-\lambda)T_{out}(i-1)+\lambda[t_{ack}(i)-t_{mac}(i-1)]\}} & 1 < \gamma \leq j \\ 0 & \gamma > j \end{cases} \tag{3}$$

where $\beta \in (0,1)$, $\gamma \in (0,1)$, $\alpha = 0.6$, $\lambda = 0.6$, $k = 4$ and $j = 4$.

3. CL-CDAC Design Ideas.

3.1. Optimal transmission rate model.

Ad hoc network is a multi-hop sharing channel which has more complex features than the general characteristics of wireless communications so as to make the traditional distribution of resources no longer suitable for such networks [8]. Therefore, this section will extract the feature parameters from transmission layer and MAC layer for mathematical modeling in order to achieve the optimal resource allocation of utility and fairness.

The directed graph $G(N, L)$ represents Ad hoc network, where N is the node set, and L is the logical link set. $D(l) = \{d \in D | l \in L(d)\}$ represents the business set which uses l, where the sufficient and necessary condition is $d \in D(l)$, $l \in L(d)$. Set each business flow to be $d \in D$, which is associated with utility function U_d, V_d is the transmission rate of business flow d, and when $V_d \geq 0$, the utility $U_d(V_d)$ is got.

Let V_d denote the transmission rate of business flow which is controlled by transmission control protocol (TCP), and P_l is the power consumed by the link l which is controlled by MAC layer. The parameters of the transport layer are combined with those of MAC layer to implement the cross-layer congestion control. Assume that the utility function $U_d(V_d)$ is monotonically increasing, strictly concave and the second-order is continuously differentiable [9-11], and then the resource allocation problem in Ad hoc network is formulated as the nonlinear optimization problem. The utility maximization model is shown as follows:

$$\text{Maximize} \sum_{d} \gamma U_d(V_d) - (1-\gamma)t_i \tag{4}$$

$$\text{Subject to} \sum_{d \in D(l)} V_d \leq C_{ij}(e)\tau_{ij}, \quad \forall l \tag{5}$$

$$\bar{e}_i \tau_{ij} \leq E_0 t_i \tag{6}$$

$$\tau_{ij} = P_{ij} \prod_{k \in N^I(ij)} (1 - P_k) \tag{7}$$

$$\sum_{j \in N_{out}(i)} P_{ij} = P_i \tag{8}$$

$$0 \leq V_d \leq V_d^{\max}, \quad \forall d \tag{9}$$

$$P_l^{\min} \leq P_l \leq P_l^{\max}, \quad \forall l \tag{10}$$

In the above (4), the corresponding resource optimization problem is given by the objective function, namely to maximize total utility of all the business flows. (5) points out that the business flow cumulative rate of the source node over the wireless link l cannot exceed the channel capacity of wireless link. (6) is used to restrict the energy consumption. (9) and (10) are used to restrict the transmission rate and link power in the sender. If the feasible region defined by four constraint conditions in the above formulas from (5) to (10) is convex and compact, the sender must be a unique optimal solution about sending rate on the basis of the theory of optimization, and make both the maximization of network utility and the fairness of business flow.

3.2. **CL-CDAC algorithm design.** According to the definition of congestion metric and the analysis in Section 3.1, the process of CL-CDAC algorithm is given, and its specific implementation steps are shown as follows.

Step 1. The unoccupied cache queue size A is obtained through the instantaneous cache queue length q got by the intermediate node i in network layer.

Step 2. If $A > 0$, according to (2) and (3), the input and output rate in MAC layer are got.

Step 3. According to (1), the congestion metric M is calculated.

Step 4. If $M > 0$, congestion experienced (CE) flag of IP header in the current packet is set to 1; otherwise, let the initial value of CE to be 0.

Step 5. The data packet is forwarded.

Step 6. After the receiver receives the data packet, explicit congestion experienced (ECE) flag of the header in TCP ACK packet returned is set to 1.

Step 7. Congestion window reduced (CWR) flag in the next sending packet is set to 1 by the sender.

Step 8. The data packet is sent.

Step 9. If the packet is lost, the receiver continues to send ACK marked with ECE.

Step 10. If the sender has received 3 repeated ACK with the ECE flag set to 1, the packet loss is caused by network congestion, so the sender adjusts the rate based on the optimal transmission rate proposed in Section 3.1, which makes network utility maximization.

Step 11. If $M = 0$, the sender receives 3 repeated ACK without the ECE flag, which shows that the packet loss is caused by non-congestion.

Step 12. According to the actual situation, the main factors causing the packet loss are further determined by the mobile node or by the high bit error rate in wireless channel, and then the sender takes the corresponding control measures.

4. **Simulation Results and Performance Analysis.** In this section, NS2 [12-14] is used as the simulation experimental platform, and the scene is set to 50 nodes which are randomly distributed in a rectangular region of $1500 \times 1000\text{m}^2$. Select a random walk model, the wireless transmission radius of each node is 250m, and the transmission rate is 2Mbps. The CBR data streams use 20 connections, and the MAC layer protocol is IEEE802.11DCF standard protocol. The routing protocol uses AODV, the business stream uses the FTP data, and the simulation time is 300s.

In the following simulations, the network throughput and end-to-end delay of three schemes are comparatively analyzed, namely CL-CDAC, IRED [6] and TCP-Reno.

TCP-Reno uses RED algorithm aiming at the wired network, which has a low quality in Ad hoc network. IRED [6] has improved RED algorithm, namely IRED, but cross-layer congestion detection and optimal control are not considered. Therefore, on the basis of IRED [6], the CL-CDAC is proposed, which obviously improves the service quality of networks. The simulation results are shown in Figure 1 and Figure 2.

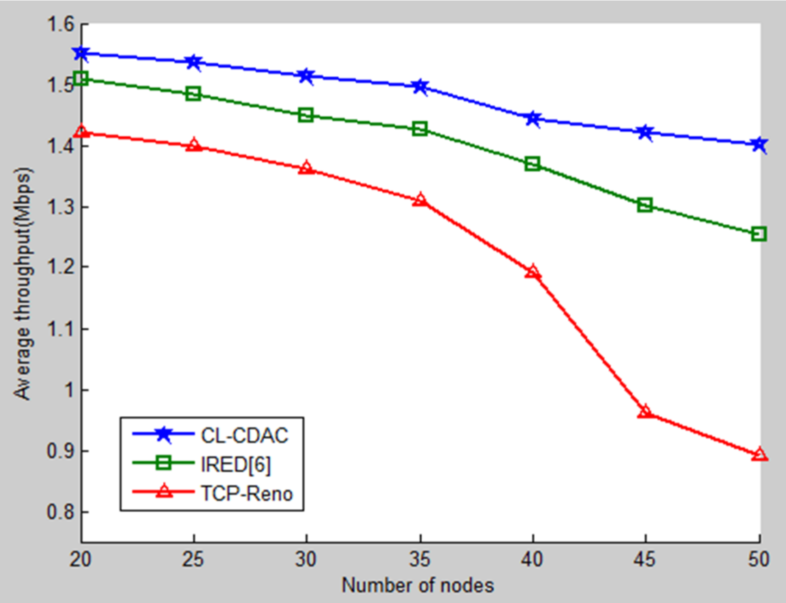

Figure 1. The average throughput comparison of three schemes

The average throughput of the three schemes is shown in Figure 1. In all the moving scenes, the throughput in the CL-CDAC is obviously higher than those in TCP-Reno and IRED [6], and the average gain is up to 29.7%. Therefore, the CL-CDAC shows better adaptability and stability in mobile environment. Although the throughput of the three schemes decreases with the increase of the number of mobile nodes, the throughput in the CL-CDAC has the lowest drop.

The average end-to-end delay of the three schemes is shown in Figure 2. With the increase of the number of mobile nodes, the average end-to-end delay of three schemes increases due to the packet loss. However, compared with the other two schemes, the end-to-end delay of the CL-CDAC is significantly reduced. In the case of 50 mobile nodes, the delay is 46.5ms lower than that of the TCP-Reno, and 12.7ms lower than that of [6].

The results show that the proposed scheme for congestion metric can accurately detect the network congestion and effectively adjust network traffic so that the total utility of network achieves the optimization.

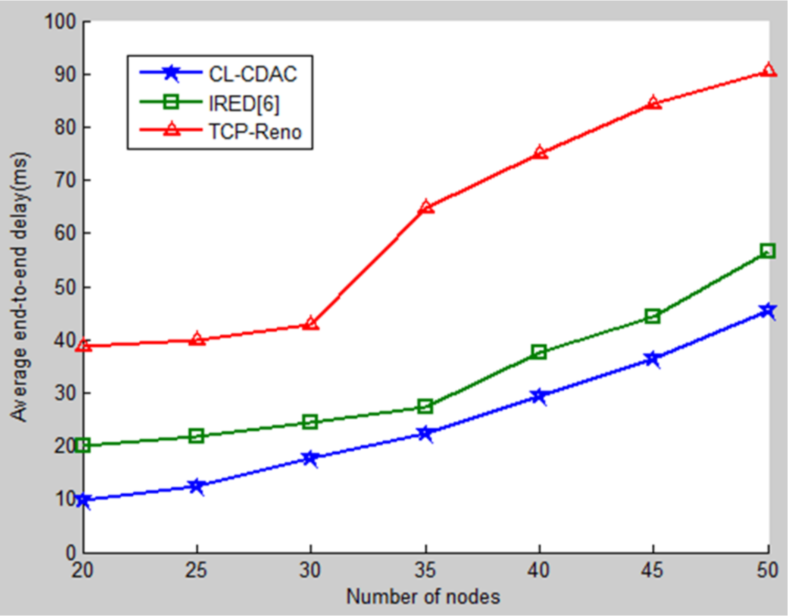

Figure 2. The average end-to-end delay comparison of three schemes

5. **Conclusions.** In the paper, the CL-CDAC is proposed on the basis of analysis on congestion detection method for Ad hoc network of single index. The scheme combines the cache queue length in network layer with the input and output rate in MAC layer, and defines the concept of congestion metric. The ECN explicit congestion feedback is integrated to make the congestion state of the intermediate node timely feedback to the sender, and the sender establishes the network effect maximization model and obtains the optimal sending rate so as to control real-time congestion. The future research is to further improve the sharing of the protocol stack information between each layer, and improve the performance of resource allocation by using a more efficient method.

Acknowledgment. The research is supported partly by Natural Science Foundation of Heilongjiang Province of China (No. F201331) and (No. F201218).

REFERENCES

[1] Q. Li, J. Q. Zhong and L. L. Huang, Method of congestion control neural network based on queue length and rate, *Computer Technology and Development*, vol.24, no.2, pp.107-110, 2014.
[2] W. X. Xiao and Z. Liu, An AQM algorithm for fast response based on queue length and load factor, *Bulletin of Science and Technology*, vol.29, no.2, pp.53-57, 2013.
[3] H. Wang, X. M. Li, W. Yan and M. H. Huang, A novel AQM algorithm based on the PI controller with minimum ISTE, *Chinese Journal of Computers*, vol.35, no.5, pp.951-963, 2012.
[4] G. Rao and J. Q. Zhou, Improved active queue management algorithm based on ARED, *Computer Technology and Development*, vol.24, no.5, pp.27-30, 2014.
[5] Z. J. Qi, W. Liu and L. L. Zhang, Rate adaptation technology of MAC layer for wireless ad hoc network, *Communications Technology*, vol.43, no.2, pp.171-174, 2010.
[6] W. Wu, *Research on Congestion Detection and Control for Ad Hoc Networks*, Ph.D. Thesis, Harbin Institute of Technology, 2011.
[7] D. Zhang and L. Gao, Simulation study of network congestion control algorithm for mobile ad hoc networks based cross-layer coordination, *Journal of Yunnan University*, vol.35, no.1, pp.26-30, 2013.
[8] Y. P. Zhang, K. Liu and G. X. Wang, Cross-layer congestion control for wireless sensor networks, *Acta Electronica Sinica*, vol.39, no.10, pp.2258-2262, 2011.
[9] Y. M. Zhang, W. Q. Xu, J. Huang, Y. M. Wang, T. Shu and L. G. Liu, Optimal cross-layer power control and congestion control providing energy saving for ad hoc networks, *Journal of Software*, vol.24, no.4, pp.900-914, 2013.
[10] L. Zhao, Q. Dong, X. Li and L. Shi, A secure asynchronous handover scheme for network mobility, *ICIC Express Letters*, vol.7, no.12, pp.3355-3360, 2013.

[11] W. Tao, Q. Yang, T. Chen, J. Xiong and D. Zhang, Link quality aware routing protocol for mobile ad-hoc networks, *ICIC Express Letters*, vol.6, no.10, pp.2565-2570, 2012.

[12] J. Ye, J. X. Wang and Q. L. Liao, Congestion control scheme based on frame transmission utility in wireless ad hoc networks, *Journal on Communications*, vol.31, no.11, pp.80-86, 2010.

[13] W. Q. Xu, Y. M. Wang, C. H. Yu, L. G. Liu and Y. H. Zhang, Cross-layer optimal congestion control scheme in mobile ad hoc networks, *Journal of Software*, vol.21, no.7, pp.1667-1678, 2010.

[14] Z. Y. Chai, R. Liu, Y. F. Wang and S. F. Zhu, Immune-based resource allocation with proportional fairness in cognitive wireless network, *Transactions of Beijing Institute of Technology*, vol.33, no.8, pp.794-800, 2013.