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A Study of Improved Approaches for TCP Congestion Control in Ad Hoc Networks

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Abstract

The conventional TCP was designed to wired networks on the assumption that the loss of data packet caused by network congestion, but in ad hoc networks, a large number of data packet loss due to high BER(bits error rate), nodes mobility, etc. At a consequence, The conventional TCP congestion control mechanisms are not appropriate for the wireless ad hoc networks and to large extent reduces the network performance. In this paper, we analyze the major factors affecting TCP performance in ad hoc networks, give several typical improved congestion control approaches, and compare the network performance of these different approaches. The simulation results show that the cross-layer optimal Congestion Control approach outperforms other improved approaches and achieves higher fairness and throughput in ad hoc networks.

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1. Introduction

Ad hoc network is a multi-hop temporary self-organized network consisting of many mobile radio-equipped nodes which act on terminal and router. The ad hoc networks offer users convenient, flexible and rapid deployment environment where no fixed infrastructure is available [1], e.g. base stations, and are widely applied to special situations, such as military battlefields and disaster relief.

In ad hoc networks, the loss of data packets may be caused partly by non-congestion cases[2], e.g., link failure, but traditional TCP congestion control algorithms are triggered, which will to some extent affect

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network throughput and link utilization, and result in severe network performance degradation. Thus it is not suitable to just view packet loss as the indication for network congestion. In this paper, we analyze some typical improvement approaches of TCP congestion control and compare their performance based on both TCP congestion control mechanism and ad hoc network features. The simulation results show that the network throughput and fairness will be improved obviously by considering the interactions between different layers based on optimized design to each layer of TCP protocol stack [3,4].

2. Major factors to affect TCP performance in ad hoc networks

2.1. High BER

In ad hoc networks, there exists many external interference which causes multi-path fading and shadow effect because wireless links are open loss mediums [5], moreover high BER exists in channels arising from selecting open band which causes packet loss and damage in ad hoc networks, accordingly the sender takes those non-congestion cases for network congestion case.

2.2. Node mobility

Node mobility in ad hoc networks may cause route disconnection and route failure in which route failure induced intermediate node to discard packets. As a result, the TCP sender will take route failure for congestion state and take some unnecessary actions according to congestion control mechanism. In addition, route failure causes the sender to discover new route path using route algorithm at network layer, the time used will be longer than RTO, then the sender enters slow start phase.

2.3. Unfairness in MAC layer

IEEE802.11DCF is the fact standard for medium access control in ad hoc networks. A smaller contention window will be randomly selected after a node successfully sends a data packet, and the node will be in preferential position. If the node can’t send packets successfully, a binary exponential backoff algorithm will be used and randomly choose a value between [0, 2k*CWmin-1] as the contention window of retransmission packet, where k is retransmission times. Thus, a larger contention window for the failed node is introduced and is in a disadvantage case which results in unfairness.

3. Typical improved congestion control approaches

In this section, we discuss in detail specific measures and the corresponding optimization ideas of several typical improved approaches. We mainly focus on two kinds of improved mechanisms, i.e., the internal network feedback-based improved mechanism and the end-to-end improved mechanism.

3.1. Internal network feedback-based improved mechanism

This kind of improved mechanism relies on intermediate nodes which are responsible for detecting the current network state and then sending the feedback to the sender. Accordingly, the sender distinguishes packet loss in various cases and takes corresponding actions. Researches show that the state detection accuracy of this kind of mechanism is higher.

3.1.1. ATCP improved approach

In ATCP, a layer called ATCP is inserted between network layer and transport layer. ATCP[6] can get special network state information (congestion, channel error and link failure) according to feedback from ECN or ICMP of intermediate nodes and take appropriate reactions. In the following, we describe ATCP state transition and strategies in detail.

ATCP do not deliver the third duplicate ACK to TCP layer if ATCP layer at the sender side detects that RTO is expired or receives three duplicate ACKs, and ATCP puts TCP in persist mode, ATCP enters loss state from normal state. After new ACK is received, TCP returns to retransmit mode, ATCP then returns to normal state.

If ATCP layer at the sender side receives ECN, ATCP will notify TCP layer to enter congestion control mode and not to wait timer expired, ATCP change normal state to congested state. TCP returns to retransmit mode and ATCP returns to normal state when the sender sends a new packet successfully.

ATCP puts TCP into persist mode upon receiving the ICMP destination unreachable message from intermediate node. ATCP changes normal state to disconnected state, meanwhile, the sender doesn't send packet, but TCP periodically sends probing packet to the receiver until a new routing path is rebuilt, then TCP changes to retransmit mode and ATCP returns to normal state.

3.1.2 Cross-layer optimal congestion control approach

COCC(Cross-layer Optimal Congestion Control approach) is designed to optimize TCP congestion control which applied cross-layer mechanism in ad hoc networks[4], it takes into consideration the influence on congestion control of physical layer, MAC layer, network layer and transport layer. It provides the solutions to unfairness of MAC layer, virtual link failure as well as frequent routing switch. Detailed scheme is as follows.

The link congestion prices mechanism[7] can improve MAC layer fairness of IEEE802.11DCF.The specific measures is as follows. If congestion price threshold is less than or equal to the congestion price of downlink, this approach uses the value between [0,αCWmin-1] as random delay, where α≤1 and CWmin is the smallest contention window, but the smaller random delay is introduced to the node which failed to contention, accordingly the node will be in an advantageous position and increase the probability of access channels in order to relief the channel unfairness.

In ad hoc networks, frequent route failure and route reconfiguration are caused by topological structure changing due to the features of dynamic and self-organized. Thus the network performance will be influenced if the sender stops sending packets. This approach can predict and judge link stability according to monitoring SN(signal to noise ratio), and update route using local routing recovery mechanism as much as possible before link is disconnected, reduce frequent routing switch ,improve the resistance of node mobility and communication disconnection.

SN measuring method[1,4]:there is a link state Detection table (LSDT) for each node, every record in LSDT includes two elements are the ID of sender and SN's exponentially weighted sliding average of uplink $SN_l^{ave}(n)$, $SN_l^{ave}(n+1) = \alpha SN_l^{ave}(n) + (1-\alpha) SN_l(n+1)$,where α is filter coefficient which is set for 0.85.When LSDT is refreshed every time, the node can infer whether the current link state is stable or not from comparison between the latest $SN_l^{ave}(n)$ and threshold $SN\_Threshold$. Fig1 shows the link state judgments.

According to Fig1, the sender will implement local repair process after it receives the routing repair request, the process includes two steps. Firstly, set a smaller value to TTL and the scope of flooding is limited in the local. Secondly, the RTS frame that sent to the receiver should contain an Enhanced transmission power value based on which the receiver will send feedback CTS and ACK to the sender.

In conclusion, the stability of link state between nodes can be predicted using the SN of received signal, and the corresponding routing recover scheme will be activated when the link is disconnected (i.e., link is in an unstable state) in order to reduce routing overhead and end-to-end delay ,decrease routing update times ,achieve a higher data transfer rate.

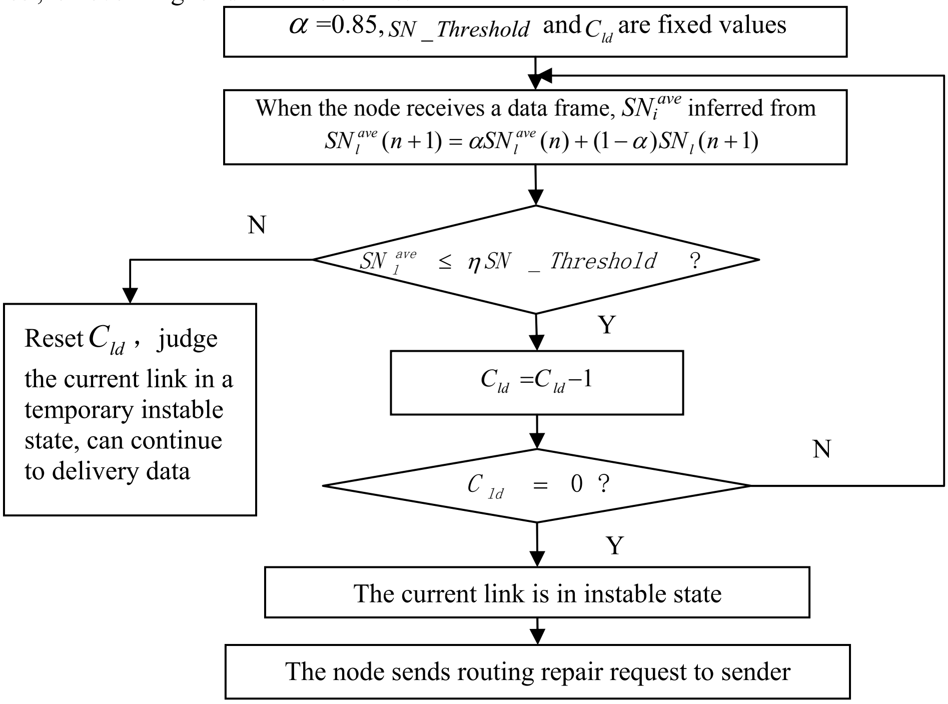

Fig.1. Link state judgment

3.2. TCP improved mechanism for end-to-end

ADTCP[8] approach: this congestion control approach identifies the network state based on multiple metrics joint identification instead of just a single metric. In ad hoc networks, the network states include congestion, route change, channel error and disconnection. The receiver consecutive collects and calculates the sample value of four metrics (IDD,STT,POR and PLR) to jointly identify the network states. The receiver feeds the inferred network state information back to the sender using ACK, the four metrics are the following.

IDD measures the delay difference between the two successive packet arrivals which to some extent reflects the congestion level along the forward delivery path. The receiver calculates the IDD value when each packet arrives,. The network congestion level is higher, the IDD value is higher.

STT is applied to transient route changes which describes network throughput over a time interval T. during a burst channel error and path disconnection, only using STT as network congestion metric is not accuracy because STT value will reduce in these cases. Generally, STT and IDD are combined to jointly identify network congestion case.

POR is caused by route changes in ad hoc networks. During the route switching period, multiple delivery paths exist in which the packets along the new path may catch up with those early packets along the old path, thus the out-of-order packet delivery will be caused. A high POR is good indication of a route change.

PLR is calculated at the receiver side during each interval T, A higher PLR indicates a higher sudden channel error occurred.

Accordingly, Table 1 show the network state identification rules using the four metrics.

Table 1. ADTCP network state identification rules

network state	IDD and STT	POR	PLR
congestion	(high, low)	any	any
channel error	not (high, low)	any	high
route change	not (high, low)	high	any
disconnection	(any, ≈0)	any	any

In the Table 1, ADTCP takes the corresponding actions according to the network state information identified by the four metrics joint, such as IDD, STT, POR and PLR. Researches show ADTCP is applicable in mobile ad hoc networks.

4. Performance evaluation and comparisons

In this section, we compared the performances of these improvement approaches using the well-known NS2 simulator [4, 8]. The simulation parameters are set as follows: IEEE802.11DCF and ADOV are used as MAC layer and routing layer protocols (see 3.1.2), data transfer rate at MAC layer is 2Mbps, communication range is 250m, and simulation time runs 300 seconds, the packet size is 1460 bytes.

100 wireless nodes forms the 10*10 grid topology, we run 4,6,8 and 10 TCP flows which lasts 300 seconds during each simulation. The distance between successive nodes is set to 200m and the number of simulation is 10.Table 2 shows the comparison of fairness among these improvement approaches.

Table 2. Comparison of fairness

Fairness index	TCP-Reno	ATCP	COCC	ADTCP
4 TCP flows	0.7906	0.8406	0.9639	0.8249
6 TCP flows	0.7157	0.8041	0.9441	0.7468
8 TCP flows	0.7375	0.7990	0.9317	0.7587
10 TCP flows	0.6938	0.8104	0.9396	0.7389

In the Table 2,COCC can perform better fairness than TCP-Reno, ATCP and ADTCP for ad hoc networks due to rapidly detecting and recovering virtual link failures. To improve the fairness of MAC layer Using link congestion price mechanism, COCC can achieve better fairness index.

ATCP,COCC and ADTCP can effectively identify different network state in ad hoc networks, such as network congestion, channel error, node mobility-induced route failure and out-of-order packet, and take the corresponding reactions. These approaches perform different performance which compared in Table 3.

Table 3 shows: These improved approaches based on feedback mechanism can accurately achieve network state information because the information directly comes from the feedback of intermediate node. These approaches increase the network overhead and security threat due to requiring deploying detection function at each node, and need to rely on the intermediate node that will result in worse compatibility with other fixed wired network. But the end-to-end improved approaches don't require the support of the intermediate node and can perform better compatible with conventional networks by maintaining the features of end-to-end TCP protocol in ad hoc networks, In ADTCP, the network state information of intermediate node achieved indirectly by detecting metrics leads to identification accuracy lower than those approaches based on feedback mechanism.

Table 3. Comparison of network performance

improvement approach	detection accuracy	throughput gain	network overhead and security	compatibility with conventional network
ATCP	high	higher	(high, low)	poor
COCC	high	high	(high, low)	worse
ADTCP	higher	higher	(low, high)	good

Note that in the simulation, COCC achieved an aggregate throughput improvement of 30% to 50% over ATCP and ADTCP.

5. Conclusions

In the paper, we first analysis the influence factors to TCP performance in ad hoc networks, then give three typical improved approaches, i.e., ATCP, COCC and ADTCP. We measured and compared the fairness, throughput and other relevant performance among these approaches. The simulation results demonstrate that COCC can achieve better fairness and throughput than other approaches. ADTCP is end-to-end improvement approach which does not rely on intermediate node, and can better cooperate with conventional networks due to its lower network overhead and higher security, but the detection accuracy of network states is lower than ATCP and COCC. Thus, the different improved approaches can be applicable to different fields, The cross-layer design in ad hoc networks need to take into account the compatibility with current wired networks, extensibility and convenient to implement. To ensure the independence between each layer of conventional networks, and further optimizing network performance in ad hoc networks is the future investigating issue.

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