

Congestion Adaptive Routing in Ad hoc Networks

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I. INTRODUCTION

¹ Reducing packet loss in MANETs typically involves congestion control running on top of a mobility and failure adaptive routing protocol at the network layer. In the current designs, routing is not congestion-adaptive. Routing may let a congestion happen, which is detected by congestion control, but, to deal with this fact, it may be too late (i.e., long delay and many packets already lost) or require significant overhead if a new route is needed. This problem becomes more visible especially in large-scale transmission of high traffic such as multimedia data, where congestion is more probable and the negative impact of packet loss on the service quality is more of significance. We argue that routing should be aware of and adaptive to congestion and therefore propose a unicast routing protocol which tries to minimize congestion in the first place and adapts to it should it occur during the network lifetime.

II. CONGESTION ADAPTIVE ROUTING (CRP)

In CRP, every node appearing on a route warns its previous node when prone to be congested. The previous node then uses a “bypass” route bypassing the potential congestion to the first non-congested node on the route. Traffic will be split probabilistically over these two routes, primary and bypass, thus effectively lessening the chance of congestion occurrence. CRP is on-demand and consists of the following components: (1) Congestion monitoring, (2) Primary route discovery, (3) Bypass discovery, (4) Traffic splitting and congestion adaptivity, (5) Multi-path minimization, and (6) Failure recovery.

A. Congestion Monitoring

A variety of metrics can be used for a node to monitor congestion status. Chief among these are the percentage of all packets discarded for lack of buffer space, the average queue length, the number of packets timed out and retransmitted, the average packet delay, and the standard deviation of packet delay. In all cases, rising numbers indicate growing congestion. Any of these methods can work with CRP in practice. We further classify the congestion status at a node into 3 levels: “green”, “yellow”, and “red”. A node is said to be “green” if it is far from congested, “yellow” if likely congested, or “red” if most likely or already congested. As later discussed, a bypass is a path from a node to its *next green node*. The next green node is the first green node at least two hops away downstream on the primary route.

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B. Primary Route Discovery

To find a route to the receiver, the sender broadcasts a REQ packet toward the receiver. The receiver responds to the first copy of REQ by sending toward the sender a REP packet. The REP will traverse back the path that the REQ previously followed. This path becomes the *primary route* between the sender and the receiver. Nodes along this route are called *primary nodes*. To reduce traffic due to route discovery and better deal with congestion in the network, we employ two strategies: (1) the REQ is dropped if arriving at a node already having a route to the destination, and (2) the REQ is dropped if arriving at a node with a “red” congestion status.

C. Bypass Discovery

A node periodically broadcasts to neighbors a UDT (update) packet. This packet contains this node’s congestion status and a set of tuples $\{\text{destination } R, \text{next green node } G, \text{distance to green node } m\}$, each for a destination R that the node has a route to. The purpose is that when a node N receives a UDT packet from its next primary node N_{next} regarding destination R , N will be aware of the congestion status of N_{next} and learn that the next green node is G which is m hops away on the primary route. If N_{next} is yellow or red, a congestion is likely ahead if data packets continue to be forwarded on link $N \rightarrow N_{next}$. Since CRP tries to avoid congestion from occurring in the first place, N starts to discover a bypass route toward node G - the next green node of N known from the UDT packet. This bypass search is similar to primary route search, except that: (1) the bypass request packet’s TTL is set to $2 \times m$, and (2) the bypass request is dropped if arriving at a node (neither N nor G) already present on the primary route. Thus, it is not costly to find a bypass and the bypass is disjoint with the primary route, except that they join at the end nodes N and G . It is possible that no bypass is found due to the way the bypass request approaches G . In which case, we continue using the primary route. However, [1] finds that the chance for a “short-cut” to exist from a node to another on a route is significant.

D. Traffic Splitting and Congestion Adaptability

At each node that has a bypass, the probability p to forward data on the primary link is initially set to 1 (i.e., no data is sent along the bypass). It is then modified periodically based on the congestion status of the next primary node and the bypass route (see Table I). The congestion status of the bypass is the accumulative status of every bypass nodes. The key is that we should increase the amount of traffic on the primary link if the primary link leads to a less congested node and reduce otherwise. An example is demonstrated by Figure 1, where

TABLE I
SPLITTING PROBABILITY ADJUSTMENT FOR CONGESTION ADAPTION

Congestion	bypass status = green	bypass status = yellow	bypass status = red
next primary node is green	$p := p + (1 - p)/4$	$p := p + (1 - p)/3$	$p := p + (1 - p)/2$
next primary node is yellow	p unchanged	p unchanged	$p := p + (1 - p)/4$
next primary node is red	$p := p - (1 - p)/2$	$p := p - (1 - p)/4$	find another bypass

TABLE II
IMPROVEMENT OF CRP OVER DSR AND AODV: POSITIVE VALUES MEAN IMPROVEMENT. E.G., 39.28% MEANS 39.28% BETTER

Rate	over DSR	over AODV	over DSR	over AODV	over DSR	over AODV	over DSR	over AODV
	Avg. delay	Avg. delay	Delivery ratio	Delivery ratio	Overhead	Overhead	Energy	Energy
10	69.98%	26.22%	42.04%	-2.8%	-31.57%	26.47%	48.54%	1.65%
20	68.93%	22.16%	78.51%	11.51%	0%	39.28%	57.08%	14.34%
40	75.17%	28.48%	118.37%	23.53%	50%	50%	62.08%	22.26%

the bypass from A is $A \rightarrow X \rightarrow Y \rightarrow C$, from B is $B \rightarrow Y \rightarrow Z \rightarrow E$, and from D is $D \rightarrow W \rightarrow F$.

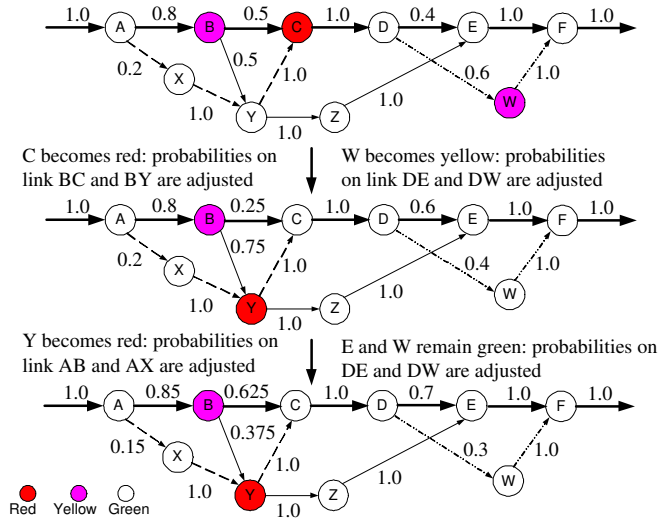


Fig. 1. Examples of splitting probability being adjusted adaptively to congestion

E. Multi-path Minimization

To reduce the protocol overhead, CRP tries to minimize using multiple paths. If the probability p to forward data on a primary link approaches 1.0, this means the next primary node is far from congested or the bypass route is highly congested. In this case, the bypass at the current node is removed. Similarly, if the next primary node is very congested (p approaches 0), the primary link is disconnected and the bypass route becomes primary. To make the protocol more lightweight, CRP does not allow a node to have more than one bypass. The protocol overhead due to using bypass is also reduced partly because of short bypass lengths. Each bypass connects to the first non-congested node after the congestion spot, which should be just a few hops downstream.

F. Failure Recovery

A desirable routing protocol should gracefully and quickly resume connectivity after a link breakage. CRP is able to do so by taking advantage of the bypass routes currently available. For instance, in Figure 1, if node C or D fails or moves away, B can take the bypass $B \rightarrow Y \rightarrow Z \rightarrow E$. Details of this recovery technique are presented in [2].

III. PERFORMANCE STUDY

Using Ns-2, we implemented CRP and compared it to AODV and DSR. The network consisted of 50 nodes moving continuously but not faster than 4m/s within a $1500\text{m} \times 300\text{m}$ rectangular field. The radio model used was Lucent's WaveLAN and the MAC layer was based on IEEE 802.11 DCF. In each 300s simulation run, 20 connections were generated and remained open until the simulation ended. Each source generated 512-byte CBR data packets at a rate chosen among 10, 20, or 40 packets/s to illustrate different traffic loads. We considered the following metrics: (1) data packet delivery ratio, (2) end-to-end delay, (3) normalized routing overhead, and (4) normalized energy efficiency. As shown in Table II, CRP outperformed both AODV and DSR in most performance metrics, especially in highly congested networks.

IV. FUTURE WORK

CRP is unique in its adaptability to congestion. Although our preliminary evaluation study has shown the promising performance of CRP, our future work will expand this study to experience with different network scenarios. We will also focus on optimization techniques for CRP and how different congestion predication and control mechanisms cooperate with it to better reduce congestion in MANETs.

REFERENCES

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