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Using Network Coding Strategy to Repair Decoding Failure in Multi-hop Wireless Networks

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Abstract– Wireless network has become more and more popular in our daily life. But the unreliability of wireless link is a bottleneck that restricts the development of wireless network. Network coding has been considered as an effective approach to improve the wireless network throughput, but the loss of transmitting packets may cause the decoding failure due to the lack of receiving enough native packets. This paper proposes a novel method to solve the decoding failure, named as CBCR (Coding-Based Coding Recovery). CBCR can make use of the network coding technology to encoded the lost native packets, then retransmit them to the decoded node to fix the decoding process, which can reduce the recovery time compared to the conventional recovery technology. The experiment results indicate that the CBCR has a better performance than the conventional recovery methods.

Keywords- wireless network; network coding; coding recovery;

1. Introduction

Network coding (NC) has been proposed as an effectively technology to improve the network throughput since Ablswede [1] et al proposed the NC concept in 2000. Recently the NC has been used in lots of applications. The ARQ is a main method to solve the problem of packet retransmission. However, the ARQ has many drawbacks which influence the network performance. So the NC-based [4-10] retransmission has been proposed to replace ARQ-based retransmission. In these methods, multiple destination nodes with multiple lost packets, which are encoded into one packet and are, retransmitted, instead of retransmission the lost packets individually. The COPE [2] is proposed that used the opportunity coding strategy. The basic idea of opportunity coding is to discover the coding opportunity by overhearing the wireless channel and storing the necessary native packets. This scheme requires the decoded node can receive enough native packets for decoding.

The unreliability of wireless link is a significant feature of wireless network. So the packets loss is common issue in wireless network. The use of NC should ensure that the decoded node owes enough native packets. However, the fallibility of wireless link may cause some native packets loss, so the decoded node fails to decode the coding packets. In this paper, this issue is named as "Decoding Failure". In order to repair the decoding failure, the decoded node should retrieve the lost native packets again from its neighbor nodes or the source nodes. Such a problem is called *Network Coding Recovery*.

2. Related work

COPE [2] is the first mechanism to bridge the theory of network coding and the wireless network protocol, not considered the coding recovery issue when the decoded node decoding failure. During in the coding recovery, the packet retransmission is a key course. Currently, the ARQ-based and the NC-based are the major retransmission schemes.

ARQ-based [3] is a conventional retransmission scheme. In this scheme, when a packet is lost, it is repeatedly retransmitted until a pre-defined limit. Therefore, this mechanism needs at least once one retransmission time per lost packet. In order to reduce the retransmission time, NC-based retransmission scheme has been put forward. The ER [6] adopts the NC-based retransmission scheme firstly, but the retransmission request node is to source node of the original flow. This rule limits the scope of application of the ER. Yosuke et al [7] proposed a novel retransmission scheme used in the wireless LAN, while multiple stations lose one or more packets, the stations would request the base station to retransmit the lost packets by XOR-packet. This scheme needs to ensure the base station can overhear all the buffer information of the stations. The paper [8-9] proposed an NC-based retransmission scheme based on the array computing, the base station builds an array after it obtains the information of the received packet and the lost packet for the neighbor nodes. The paper [10] adopted a NC-based retransmission scheme too, but these retransmission schemes have a common characteristic that multiple destination nodes request the retransmission packets to the same source node. However, the network coding recovery always occurs in the model that decoded node requests retransmission packets from multiple neighbor nodes.

3. Design of the CBCR

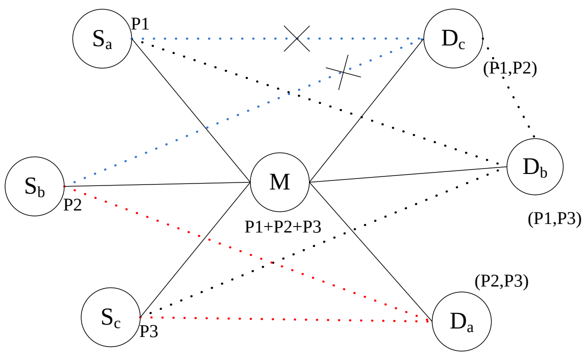

Fig1. An Example Network Topology

3.1 Basic Idea

We first present several observations to illustrate several design considerations. Consider the example the network topology shown in Fig.1. There are three data flows, which are from the node S_a, S_b and S_c. The node D_a, D_b and D_c are the destination nodes, and the node M is the intermediate node, which is the coding node. The bracket near the node in Fig1 denotes the node can monitor these packets, such as the (P1, P2) shows the node D_c can overhear the packets P1 and P2 from node S_a and S_b respectively. The node M broadcasts the coding packet P1⊕P2⊕P3, and the destination node D_c can decode the coding packet after node D_c overhears the packets P1 and P2. However, due to the unreliability of the wireless links, we assume the D_c cannot overhear the packets P1 and P2 from node S_a and S_b respectively. In other words, the destination node D_c can not decode for the link status. This problem is the decoding failure shown as previously described.

As the conventional retransmission scheme, the node D_c would request the neighbor node to retransmit the packets P1 and P2. In Fig1, the node D_b and node M is the neighbor nodes of the node D_c. there are all or part of the required packets of node D_c. So it retransmits the packet P1 and P2 from node M and node D_b respectively. It obviously that the packet P1 has been transmitted two times, so it wasted the wireless link resource. As shown in Fig1, if node M transmits coding packet (P1⊕P2) to node D_c, and node D_c can decode the coding packet by (P1⊕P2⊕P3)⊕(P1⊕P2) = P3. So the conventional retransmission scheme cost three times to finish the decoding recovery, but our scheme only cost one time for retransmitting required packets. It is obviously that our scheme decrease coding recovery expenses compared with the conventional method.

3.2. Design of CBCR

A. Basic definition for CBCR

The CBCR technology is based on the packets exchange, so it is necessary to define some different data structures. In this paper, three data structure has been defined, which are *NFI* (Node Fundamental Information), *NNI* (Node Neighbor Information) and *RACK*. The *NFI* contains the Node ID (denotes the ID of local node) and the PI (denotes the native packets information of local node), it records the node local packet information. And the *NNI* is constructed after the node received the *NFI* from its neighbor nodes, so it contains all of the information of *NFI*, the *NNI* contains Node ID (records the neighbor node ID), PI (packet information of the neighbor node), and the LS (denotes the link status at present). The *RACK* contains the Type (denotes the type of retransmission packets and we define two types which are ‘C’ and ‘S’, the ‘C’ means the type of retransmission packet is coding and the ‘S’ means the type of retransmission packet is native)、 RNN (denotes the ID of neighbor nodes which would be requested) and RP (denotes the kinds of the request packets to different neighbor nodes). The *Table1* expresses the nomenclature of the CBCR algorithm.

Table1 The Nomenclature of the CBCR Algorithm

I	The set of lack packet for local node
U	The set of NNI and remove the elements not belong to the set I

B. Techniques in CBCR

CBCR incorporates the following techniques in its design.

1) Decoding failure and Request phase for the decoded node

CBCR is to solve the decoding failure problem, so when more and more decoding failure appears, CBCR should firstly makes judge whether the network coding would be continually proper at the moment. The wireless link may lose efficacy temporarily or forever, so the decoded nodes should analyze and judge whether the use of network coding in current network scenario has advantage or not. Due to the limitation of the paper length, the analysis result is directly given, which is the network coding will bring more benefit than conventional ‘store and forward’ mechanism when the successful decoding rate (SDR) is greater than 75%.

So, the first step of the CBCR is that the decoded node receives 16 or more coding packets and gets the success rate of decoding. If the SDR is greater than 75%, which shows the network coding has more advantages than conventional routing technology. Or when SRD is less than 75%, the cost of network coding is greater than the cost of the conventional store and forward technology. So the decoded node would send an update packet to its neighbor nodes, that changing the current transmission mode. After the decoded node judge whether the network coding has advantage in current network topology, the decoded node obtains the set of the required native packets which are from the decoding failure packets. Then the decoded node structures the required packet and broadcasts it to the neighbor nodes.

2) The reply phase for the neighbor nodes

After the neighbor nodes receive the request packet, and the request packet contains the required native packets of the decoded node. The neighbor node owns its *NFI* and determines whether it will send its *NFI* to the decoded node based on whether its *NFI* contains the required packets. If containing, the neighbor node send its buffer information to decoded node. Or the neighbor node discards the request packet.

3) The Computing phase and send of the RACK for the decoded node

Decoded node receives the neighbor nodes' *NFI* and structure the NNI. After the node obtains the neighbor nodes' information, it implements the CBCR algorithm to achieve the retransmission scheme. The CBCR algorithm is shown as following:

1. $K = 0$;
2. *For i = 1 to S* (we assume there are *S* decoding failure packets)
3. *For j = 1 to m* (we assume there are *m* neighbor nodes suit the condition)
4. *While* $I_i \mathrel{!}= \varnothing$
5. $I_i = catch;$
6. $I_i \leftarrow I_i - I_i \cap U(j);$
7. *If* $I_i \mathrel{!}= catch$
8. $Q[K] = I_i \cap U(j);$ (we define *Q[]* as recovery record with node_id and packets information)
9. *K++;*
10. *return;*
11. *Else return;*

The CBCR algorithm is to obtain the optimal recovery combination packets, and the decoded node created a new set which consists of the set of recovery packets and node ID for each decoding failure packet. The time complexity of CBCR algorithm is $O(n^2)$, so it increases the computational overhead in exchange for the lower communicational overhead.

The results of CBCR algorithm are the set *Q[]*, which consist of retransmission set of packets. So the decoded node structures the *RACK* packet. The *RACK* packet contains retransmission *Type*, retransmission *node ID* and retransmission packets. The retransmission Type is obtained by the length of the *Q[]*. If the length of *Q[]* is greater than 1, the retransmission *Type* is 'C', or the retransmission *Type* is 'S'. And the retransmission packet is the element of the *Q[]*.

After the decoded node finished the computing process, then broadcasts the *RACK* packet to its neighbor nodes.

4) The Retransmission phase for neighbor nodes

The neighbor nodes receive the *RACK* packet, which consists of the node ID. So the neighbor node selects whether have its ID from the node ID of the *RACK* packet. If have, checking the *Type* of the same item of the record, which *node ID* equals to the neighbor node *ID*. While the *Type* is 'C', retransmit the packet by coding packet, or if the Type is 'D', retransmitted by single packet. If there is no the neighbor node *ID* in the records of the *RACK' node ID*, then discard the RACK packet and do nothing.

4. Performance Evaluation

The COPE is a classic network coding protocol used in the wireless network. In this experiment: we simulate COPE protocol and add the recovery process which uses the CBCR. The result as Fig2 shows that the COPE+CBCR have a striking increase in throughput compared with the conventional COPE protocol. The NCCR is a novel NC-based retransmission method and it performs better than COPE, because the COPE+CBCR increase the coding opportunity than the conventional COPE protocol. The experimental result shows the throughput of COPE+CBCR is higher than the NCCR. However, the throughput of COPE+CBCR is lower than the NCCR when the value of offered load equals to approximately 30, because the control packet exchanges increase the cost of the link bandwidth for COPE+CBCR.

The Fig3 and Fig4 show the recovery time and throughput in different cases. It has less recovery time and higher network throughput for NC+CBCR compared with the NC+ARQ. This result shows the advantage of using the batch during the network coding recovery, for the CBCR scheme add the computing phase that decrease the retransmission possible of same native packets. Although the numbers of decoding failure packet are increasing, the recovery time is scarcely increased. This phenomenon is due to the same amount of the recovery packets, just different combination of coding packets. The throughput of NC+ARQ is decreasing along with the reducing of the SRD. Because the same recovery packets might be retransmitted repeatedly, this increases the interference of channels and the waste of the bandwidth.

In summary, the CBCR reduces the cost of recovery by decreasing the amount of the retransmission packets which are used to form the encoded packet. The results of the experiment verify the correctness of our analysis.

5. Conclusion

Network coding has been considered as a promising technology to improve the network performance in wireless network. However, the unreliability of the wireless link perhaps causes the decoded node decoding failure, because the decoded node may not receive enough native packets successfully. So the coding recovery is a key issue to enhance the effectiveness of network coding. This paper proposes a novel coding recovery scheme to reduce the recovery time, which takes use of network coding method again during the coding recovery process. The theory analysis and the experimental results show the effectiveness of CBCR, which improve the overall throughput and the rate of recovery.

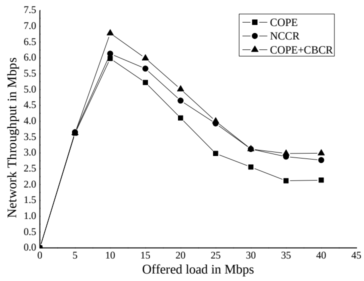

Fig 2. The Overall Throughput Based on Diverse Number of Decoding Failure Packet

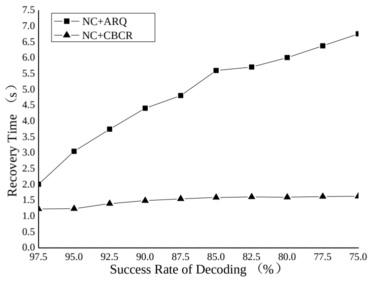

Fig 3. The Recovery Time Based on Different SRD

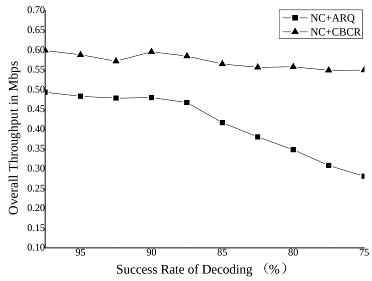

Fig 4. The Overall Throughput Based on Different SRD

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