A Packet-based Load Balancing Scheme for Network Coding in Tactical Heterogeneous Wireless Networks

Jiejie Xie, Chao Dong, Hai Wang* and Weijun Wang
College of Communications Engineering, PLA University of Science and Technology, Nanjing, China
jiejiex1992@gmail.com, dch999@gmail.com, hai.wang@gmail.com, weijunwang_paper@163.com
*Corresponding author: Hai Wang

***Abstract*—Network coding has been proven to be an effective technique to increase the throughput and enhance robustness of various wireless networks including tactical heterogeneous wireless networks. Usually, the tactical heterogeneous wireless networks consist of different wireless links including high bandwidth links like IEEE 802.11 and low bandwidth links like UHF and VHF. Load balancing is an effective way to mitigate the network loading and improve overall performance of heterogeneous network. Traditional flow-based load balancing scheme performs poor and has a negative effect when applying network coding in tactical heterogeneous wireless networks. How to enhance the performance of network coding over tactical heterogeneous network is worthy of research.**

In this paper, with full consideration of different channel propagation characteristics and distinct transmission demands of different packets in a single stream, we propose a packet-based load balancing scheme, making appropriate use of highly unbalanced links by transmitting different types of packets on different channels. By making full use of the propagation characteristics of low bandwidth channels, our scheme can significantly shorten the end to end delay of feedback packets and improve the transmission reliability of feedback packets. Compared with flow-based load balancing, our scheme can reduce 63.47% of the redundant transmissions on average and achieve 15.53% improvement of throughput.

***Index Terms*—heterogeneous network, load balancing, network coding.**

I. Introduction

During the past decade, network coding [1] has been proposed to improve the network resource utilization. With the notion of mixing received packets before forwarding, network coding provides a good solution to effectively exploit the broadcast nature of wireless channel [2]. And it has been proven to be an effective technique to increase the throughput and enhance robustness of various wireless networks including tactical heterogeneous wireless networks [3]-[6].

To meet different demands in diverse tactical scenarios, there are a variety of wireless channels in tactical wireless networks, such as IEEE 802.11b channels, very high frequency (VHF) channels, ultra high frequency (UHF) channels, etc. Even with distinct propagation characteristics, these channels coexist and constitute tactical heterogeneous wireless networks. To maximize the network resource utilization, we intend to utilize all of these unbalanced links to improve the performance of network coding.

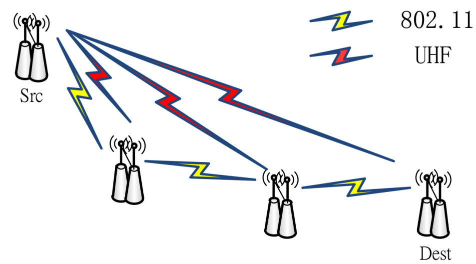

Fig. 1. tactical heterogeneous wireless networks

Load balancing is a common way to share heterogeneous channel resources and mitigate the network loading [7]. Traditionally, most of load balancing scheme divide the traffic into subflows, each of which flows into different links [8]. This kind of load balancing is based on traffic flow. With contribution of each links, we can obtain a better network performance. However, the bandwidth of each channels varies greatly in tactical heterogeneous networks. In our simulations, we find that traditional flow-based load balancing scheme performs poor and has a negative effect when applying network coding in highly unbalanced links. And the distinct channel characteristics are utilized inadequately..

How to make appropriate use of the highly unbalanced links in tactical wireless networks? In this paper, we take full consideration of different channel propagation characteristics and distinct transmission demands of different packets in a single stream, and propose a packet-based load balancing scheme, transmitting different types of packets on appropriate channels. Benefiting from distinct channel features in tactical wireless networks, our scheme can significantly improve the transmission of feedback packets and enhance overall performance of network coding.

The main contributions are listed as follows:

1) We examined and concluded that for highly unbalanced links in tactical wireless networks, traditional flow-based load balancing performs poor and can't promote the performance of network coding.
2) We design the scheme which shares the heterogeneous wireless network resources, making appropriate use of the transmission characteristics of each channels and

transmitting different types of packets on appropriate channels.

3) The scheme improves the efficiency and reliability of network coding in tactical heterogeneous networks, not only efficiently reducing 63.47% of the redundant transmissions on average, but also achieving 15.53% improvement of throughput compared with flow-based load balancing.

The remaining of the paper is organized as follows. In Section II, we review the related work concerning our scheme. In Section III, we analyse the performance of flow-based load balancing on highly unbalanced links and introduce the motivation of our scheme. Then, we propose the details of our scheme in Section IV. In Section V, we make performance evaluation and discuss the performance of our scheme. Finally, we conclude the paper in Section VI.

II. Related Work

In this section, we review the related work in the following two aspects: the packet type of network coding and the utilization of heterogeneous resources .

A. the packet type of network coding

In network coding, there are two most common types of packets, coded packets and feedback packets.

Coded packets **:** A coded packet is a random linear combination of a batch of native packets. In network coding, intermediate nodes broadcast coded packets that are linear combination of previously received packets, benefiting from the broadcasting feature of radio channel [1]. And destination nodes can decode the original packets with a sufficient number of innovative coded packets, no matter which coded packets are received [12]. Therefore, coded packets have the characteristics of high robustness. And with opportunistic routing, coded packets can make full use of the multipath propagation characteristics [12], increasing the transmission reliability of messages.

Feedback packets **:** Feedback packets are critical for network coding [13]. First, feedback packets from the destination node can reliably inform the source node its transmission accomplishment. Second, according to the destination node's feedback packets, the source node can also learn the previous reception. Thus, the source node can adjust its transmission policy more intelligently [13]. Compared with coded packets, feedback packets are with small size and have the character of delay sensitive. They are transmitted along the shortest path toward the source and given priority over coded packets at every nodes [2]. However, feedback packets may experience a long delay during the trip back to the source due to the lossy and multi-hop characteristics of tactical wireless networks.

B. the utilization of heterogeneous resources

With different channel characteristics, heterogeneous resources have great potential in enhancing the network capacity. Many existing works focus on resource management, allocating appropriate resources for different users [9], service types [10] and so on. And these works are based on flow, providing one or more channel resources for each traffic flow. Meanwhile, there are some other works based on packet type, like HTPPR [11], sending data packets and feedback packets over wired channel while performing partial packet recovery on the wireless link. With providing appropriate heterogeneous resources for different objects, all these scheme achieve a better network performance.

To the best of our knowledge, there is no previous study enhanced the performance of network coding by making appropriate use of heterogeneous resources. In this paper, we intend to utilize the highly unbalanced links in tactical wireless network with full consideration of different channel propagation characteristics and distinct types of packets in network coding.

III. Motivation

Load balancing is a common way to share heterogeneous channel resources. Traditionally, flow-based load balancing divides the traffic into subflows, and makes each of them flow into different links, improving the network resource utilization and the end to end throughput.

Nevertheless, in tactical wireless heterogeneous networks, the bandwidths of different channels vary greatly, and there are some low bandwidth channels like shortwave channel and some high ones like 802.11 channel. Traditional flow-based load balancing takes little account of distinct channel characteristics, and each channel may be allocated the same type of subflow. Due to the different bandwidths of highly unbalanced channels, the transmission delay of each subflow is far difference. For example, the average delay of ten packets transmitted on a 40 Kbps channel is about 3 ms, while the one on a 2 Mbps channel only needs 0.06 ms.

We performed some experiments on highly unbalanced links with flow-based load balancing. (Experimental topology is similar to Fig.1. The high bandwidth channel is with shorter transmission distance compared with the low bandwidth channel. Fig.2 uses the number of hops required by short-transmission-distance channel as X-axis. And the following figures are similar.) As Fig.2 shows, the transmission delay of a batch of coded packets (the batch size is 8) on high

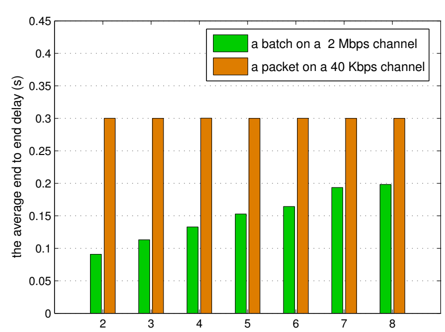

Fig. 2. the average delay of a batch or a coded packet

bandwidth links, is less than the delay of one packet transmitted on low bandwidth links. When the packet arrives at the destination node through a low bandwidth link, the destination node has received enough innovative packets for the current batch and moves to next batch. The packets transmitted on low bandwidth channel have a negligible effect in this case. Therefore, flow-based load balancing is not suitable for such highly unbalanced links in tactical wireless networks. Other performance simulations are showed in Section V.

How to make appropriate use of such highly unbalanced links in tactical wireless networks?

In tactical wireless heterogeneous networks, different channels have its own channel propagation characteristics. For example, the energy of low frequency wave propagation attenuation is very small and it can propagate to a much longer distance than the high frequency wave, despite the rate of low frequency wave is much lower. As each channels has its own propagation characteristics, we intend to treat these links differently. Relevantly, there are different types of packets in network coding, even in the same stream. And different types of packets have different transmission requirements, including propagation delay, loss probability and so on. Therefore, we intend to use appropriate channels to transfer different types of packets, distributing the traffic load based on packet instead of traditional traffic flow.

IV. Packet-based Load Balancing

A. Load balancing strategy

In tactical wireless network, the transmission characteristics differ greatly in many aspects. In this paper, we mainly focus on the bandwidth and transmission distance, and distribute the traffic load according to these two attributes.

$\boldsymbol{Bandwidth}$ **:** The messages in tactical wireless network have the high demand of timeliness. If the transmission delay is larger than expected, the messages would lost their value. It needs amounts of channel bandwidth to achieve a low transmission delay. Accordingly, we would select those channels which have enough bandwidth and then form a channel set before transmitting this type of packets. After that, we distribute this type of packets among those channels in the set.

$\boldsymbol{Transmission\ distance}$ **:** In battlefield environment, nodes are not static. Mobile nodes will cause topology changing and route flapping, resulting in larger delay or interrupt during transmission. Using long-transmission-distance channels can expand communication coverage, reducing the influence of node's movement. Meanwhile, transmitting on long-propagation-distance channels can reduce the hops between source nodes and destination nodes. With a constant packet lose rate, a reduction of transmission number can reduce the number of packet loss. Therefore, on the precondition of meeting bandwidth need, we can use long-transmission-distance channels to increase the transmission reliability.

Certainly, some long-transmission-distance channels are with smaller bandwidth than other channels in the set. Whether transmitting on long-transmission-distance channels or not is decided by the requirements of each type of packets.

B. Packet-based load balancing scheme for network coding

Coded packets and feedback packets are two main types of packets in network coding, and we will distribute the traffic based on these two types of packets.

Suppose that there are a set of channels $\{c_1, ..., c_t\}$ (sorted by the size of bandwidth) in tactical wireless networks. And there a subset $\{c_1, ..., c_k\}$ (k<t) which satisfy the bandwidth requirement of coded packets. In network coding, destination nodes can decode the original packets with a sufficient number of innovative coded packets no matter which coded packets are received. Coded packets have the characteristics of high robustness, and determine the transmission speed of the message. Hence, we are more involved with transmitting coded packets on high-bandwidth channels to shorten the transmission delay. As for feedback packets, they have the character of delay sensitive while they may experience a long delay due to the lossy and multi-hop characteristics of tactical wireless networks. Therefore, we intend to send them on long-transmission-distance channels. Due to the small size of feedback packets, more channels ($\{c_1, ..., c_n\}, k$<n<t) meet the requirement of feedback packets, but the channels in subset $\{c_m, ..., c_n\}$ (k<m<n<t) are with large transmission distance. To avoid suffering from a long delay, we intend to distribute feedback packets among $\{c_m, ..., c_n\}$ (Some related performance simulations are showed in Section V).

The following are the implementation process:

$\boldsymbol{Source\ nodes}$ **:** When a source node has messages to transmit, it will create a random linear combination of K original data (the batch size is K). And then, the source node would select a idle high-bandwidth channel from $\{c_1, ..., c_l\}$, using that channel to send the coded packet.

$\boldsymbol{Intermediate\ nodes}$ **:** The intermediate node receives coded packets from the upstream node, and then, it will determine whether to send a new packet or not. If yes, it will create a new coded packet by making a random linear combination of its stored packets. After that, it would select a idle high-bandwidth channel from $\{c_1, ..., c_l\}$ to send the coded packet.

$\boldsymbol{Destination\ nodes}$ **:** When the destination node has received a sufficient number of innovative coded packets, it is able to decode the original packets of the current batch. Before it starts to decode the packets, it would forward a feedback packet to acknowledge the current batch. Therefore, it would select a long-transmission-distance channel from $\{c_m, ..., c_n\}$ to send the feedback packet.

V. PERFORMANCE EVALUATION

To validate our scheme, we use a model with two heterogeneous links in this section, like UHF links coexist with VHF in tactical wireless networks. In our simulations, we assume that there are two certain channels, Channel FAR and Channel FAST. Channel FAST is with the transmission speed of 2 Mbps, while Channel FAR has a only 40 Kbps transmission

TABLE I
CHANNEL UTILIZATION

	Coded Packets		Feedback Packets	
	FAST	FAR	FAST	FAR
FAST ONLY	✓		✓	
FLOW-BASED	✓	✓	✓	✓
PACKED-BASED	✓			✓

speed. Like the transmission distances of VHF is about ten times that of UHF, the far transmission distance of Channel FAR is about 100 km, ten times that of Channel FAST. To reduce decoding delay, we use a batch size of 8 for network coding, and the size of coded packets is 1500 bytes while the one of feedback packets is 14 bytes.

In our scheme, we would transmit coded packets on Channel FAST. To improve the transmission of feedback packets, we send them on Channel FAR (PACKET-BASED). And we will compare it with the other two schemes. Scheme FAST ONLY uses Channel FAST only, sending coded packets and feedback packets both on Channel FAST. Scheme FLOW-BASED means the implementation of traditional flow-based load balancing scheme, loading the traffic flow based on flow. The channel utilization is showed above.

A. the end to end delay of feedback packets

Due to the small size of feedback packets, Channel FAR and Channel FAST both meet the bandwidth requirements. However, Channel FAST shoulders the work of transmitting big size packets (coded packets). When sending feedback packets on Channel FAST, feedback packets have to contend the channel with coded packets at each hop. If failed, feedback packets have to wait for a time of transporting a coded packet, which is more than ten times its own. By contrast, due to the characteristic of long transmission distance, feedback packets transmitted on Channel FAR need only a hop to arrive at the source node, avoiding contending with big size packets.

Fig.3 shows us the average end to end delay of the feedback packets. From Fig.3, we can know that the end to end delay of feedback packets transmitted on Channel FAR is less than that on Channel FAST, even the bandwidth of Channel FAR is much less than Channel FAST. In addition, we give feedback packets priority over coded packets at every nodes when transmitted on Channel FAST. But the target node may be receiving a coded packet from upstream node when a node want to transmit a feedback packet to it, and feedback packets still have to wait a long transmission delay of coded packets in this case. From Fig.3, we can know that transmitting feedback packets over Channel FAR is feasible and effective.

B. the transmission reliability

With a constant packet lose rate, each transmission of feedback packets has a probability of losing packets and retransmitting the lost packet. And the retransmission number raises with the increase of the number of hops. In our scheme, we make full use of the characteristic of long transmission distance and transmit feedback packets on Channel FAR, in which case feedback packets can arrive at source nodes with only a hop. We can reduce the number of packet loss by reducing the number of transmissions. Fig.4 shows the average retransmission number of a feedback packet at different packet loss rates. From Fig.4, we can know that using long-transmission-distance channels to transmit feedback packets can significantly reduce the number of retransmission, increasing the transmission reliability of feedback packets.

C. the throughput

Traditional flow-based load balancing scheme uses both links to transmit coded packets. However, due to the character-

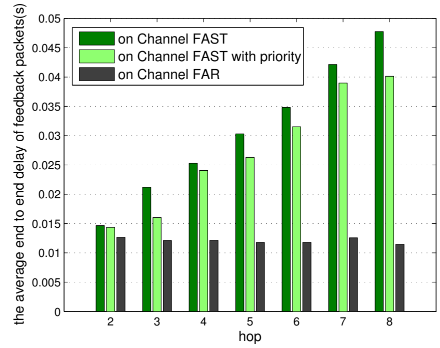

Fig. 3. the average end to end delay of feedback packets

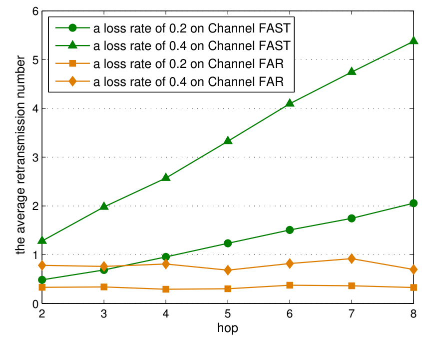

Fig. 4. the average retransmission number of feedback packets

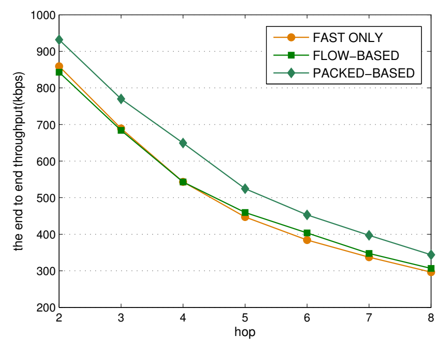

Fig. 5. the end to end throughput

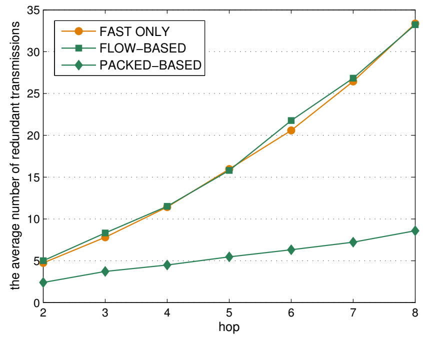

Fig. 6. the average number of redundant transmissions

istic of low bandwidth, coded packets transmitted on Channel FAR cost a long delay. When the coded packet reaches the destination node through Channel FAT, the destination node has received enough innovative packets and does not need anymore, and that packet has little value. Meanwhile, as coded packets occupy Channel FAR for a long time, feedback packets have little chance to use that channel. Therefore, Channel FAR makes little contribution in traditional flow-based load balancing. As Fig.6 shows, the throughput of FLOW-BASED is similar to FAST ONLY.

In our scheme, we distribute the traffic with full consideration of different channel propagation characteristics. Transmitting coded packets on Channel FAST makes coded packets be able to take advantage of the characteristics of high bandwidth. Meanwhile, feedback packets are transmitted on Channel FAR. With the contribution of Channel FAR, we improve the transmissions of feedback packets and achieve a shorter end to end delay. As Fig.5 shows, the overall performance of network coding has been improved, and the average throughput of our scheme achieve a 15.53% improvement compared with flow-based load balancing.

D. the redundant transmission

In network coding, source nodes keep transmitting coded packets to make sure destination nodes receive enough innovative coded packets. When destination node receive enough coded packets, coded packets of current batch is still transmitted in the network. Therefore, it is important to acknowledge source nodes as quickly as possible. We call these unnecessary transmission in the process of acknowledging the source as redundant transmission. Fig.6 shows the count of the redundant transmission of each scheme. Resulting from the appropriate utilization of both channels, our scheme achieve a shorter feedback delay, reducing most of redundant transmissions. Compared with flow-based load balancing, our scheme reduces redundant transmission of 63.47% on average.

As the simulation results show, our scheme significantly shorten the feedback delay and improve the transmission reliability of feedback packets. With full consideration of different channel propagation characteristics, we distribute the traffic based on packets, improving the performance of network coding.

VI. Conclusion

To make full use of each channels to enhance the performance of network coding in tactical wireless network, we proposed a packet-based load balancing scheme, making appropriate use of highly unbalanced links and putting different types of packets on different propagation characteristics channels. Thanks to the long-transmission-distance channels, we can implement reliable and efficient transmissions for feedback packets. And with full use of the characteristics of each channels, our scheme significantly improve the performance of network coding in tactical heterogeneous wireless network. In the simulations, our scheme reduce the end to end delay of feedback packets, increasing the total bandwidth and achieving about 15. 53% improvement compared with flow-based load balancing. What's more, we can reduce 63. 47% of redundant transmissions on average, significantly improving the channel utilization.

Acknowledgment

This work is partially supported by the National Natural Science Foundation (NSF) of China (61103224, 61371124, 61472445, 61571463) and the Jiangsu Province NSF (BK2011118, BK20140076).

References

[1] Ahlswede R, Cai N, Li S Y R, Yeung R W. Network information flow. Fundamenta Informaticae, 2006

[2] Chachulski S, Jennings M, Katti S, Katabi D. Trading structure for randomness in wireless opportunistic routing. Acm Sigcomm Computer Communication Review, 2008

[3] Ghaderi M, Towsley D, Kurose J. Reliability benefit of network coding. Department of Computer Science, 2007.

[4] Ghaderi M, Towsley D, Kurose J. Reliability gain of network coding in lossy wireless networks. The 27th Conference on Computer Communications, 2008.

[5] Guo Z, Wang B, Xie P, Zeng W, Cui J H. Efficient error recovery with network coding in underwater sensor networks. Ad Hoc Networks, 2009

[6] Ma L, Lin Z, Zhang Z, Mao Get, Vucetic B. Improving reliability in lossy wireless networks using network coding. 2013 IEEE International Conference on Communications Workshops, 2013

[7] Yanmaz E, Tonguz O K. Dynamic load balancing and sharing performance of integrated wireless networks. IEEE Journal on Selected Areas in Communications, 2004

[8] Son H, Lee S, Kim S C, Shin Y S. Soft Load Balancing Over Heterogeneous Wireless Networks. IEEE Transactions on Vehicular Technology, 2008

[9] Penmatsa S, Chronopoulos A T. Dynamic Multi-User Load Balancing in Distributed Systems. International Parallel and Distributed Processing Symposium, 2007

[10] Lee K, Park S. A service path selection and adaptation algorithm for QoS assurance and load balancing in context-aware service overlay networks. International Journal of Web & Grid Services, 2015

[11] Badam A, Kaminsky M, Han D, Papagiannaki K, Andersen D G, Seshan S. The hare and the tortoise: taming wireless losses by exploiting wired reliability. Twelfth ACM International Symposium on Mobile Ad Hoc NETWORKING and Computing, 2011

[12] Chachulski S, Jennings M, Katti S, Katabi D. MORE: A Network Coding Approach to Opportunistic Routing. Network Coding Opportunistic Routing Wireless Networks, 2006

[13] Fragouli C, Lun D, Medard M, Pakzad P. On Feedback for Network Coding. Information Sciences and Systems, 2007