Piros: Pushing the Limits of Partially Concurrent Transmission in WiFi Networks

Lu Wang*, Xiaoke Qi†, Jiang Xiao*, Kaishun Wu*, Jin Zhang*, Mounir Hamdi* and Qian Zhang*
*Department of Computer Science and Engineering, Hong Kong University of Science and Technology
†Institute of Automation, University of Chinese Academy of Sciences

***Abstract*—Partially overlapped channels are barely used for concurrent transmission in WiFi networks, since they lead to collisions where the collided packets cannot be decoded successfully. In this paper, we observe that the actual corrupted symbols by partial-channel interference in OFDM-based WiFi networks are not as severe as we expected. There remains extra coding redundancy that can be exploited from the corrupted symbols, and utilized for packet recovery. Accordingly, we present a novel paradigm termed Piros, in order to Push the lImits of paRtially cOncurrent tranSmission in WiFi networks. Piros strategically leverages the coding redundancy according to the overlap portion in a distributed manner, and extracts useful decoding information from the corrupted symbols to decode the packet with partial-channel interference.**

***keywords*—Partially Overlapped Channel, Coding Redundancy, Symbol Recovery, OFDM Modulation**

I. Introduction

The ultimate goal of WiFi network is to leverage as much available spectrum as they can for high speed transmission. However, due to the shared nature of wireless spectrum, the interference among multiple transmissions that use the same spectrum becomes a fundamental issue. Therefore, in current 802.11 standards, non-overlapping channels should be guaranteed for concurrent transmissions to avoid collisions.

As the deployment of WiFi networks becomes much denser, the limited spectrum cannot ensure non-overlapping between channels used by every co-located WLAN. Consider 802.11g/n, where only 3 orthogonal channels exist with no spectrum intersection [1]. It is inevitable that multiple 802.11 access points (APs) in range of each other use overlapped channels. Furthermore, the 802.11 standards incorporate more heterogeneous channel widths, such as 40Mhz in 802.11n and 80Mhz/160Mhz in the emerging 802.11ac. This variable-length channelization in limited spectrum resource also makes concurrent transmissions on overlapped channels unavoidable.

The first attempt to leverage overlapped channels for concurrent transmission is presented in [2]. It verifies that with DSSS (direct sequence spread spectrum) at PHY layer, simultaneous transmission is feasible in 802.11b WLANs. However, the above feasibility cannot be directly applied to 802.11g/n for the following reason [3]. Unlike DSSS that spread every single bit information over an entire spectrum, OFDM (orthogonal frequency division multiplexing) adopted by 802.11g/n divides the spectrum into multiple subcarriers. The overlapped portion has a much lower SINR (signal to interference and noise ratio) compared with that in DSSS modulation. Thus, it is very difficult to recover the collided portion. To enable partial spectrum sharing in OFDM modulation, Remap [4] introduces a retransmission permutation to exploit collision-free subcarriers for decoding through multiple retransmissions. Besides, ASN [5] enables partially concurrent transmission through spectrum fragments, where the subband used by neighboring WLANs is nulled on a per-packet basis. Nevertheless, none of the existing works leverages the collided subcarriers for partially concurrent transmission in OFDM-based WiFi networks.

In this paper, we observe that even with OFDM modulation, the partial-channel interference is not always fatal to the overlapped portion as we expected. In 802.11g/n, the entire 20 MHz channel is divided into 64 subcarriers, where 48 subcarriers are data subcarriers, and others are pilots, null and guard band. When two neighboring WLANs have overlapped transmissions, the collided portion consists of various types of subcarrier superposition, such as data and data subcarrier superposition, data and pilot superposition as well as data and null superposition. Among which, only data and data subcarrier superposition leads to collision that cannot be recovered. This kind of collision accounts for only 10% of the entire data subcarriers in 1/4 overlap, which is a rather small portion. In addition, it accounts for 35% and 60% in 1/2 and 3/4 overlap. Based on the above analysis that the actually collided portion is data subcarrier superposition, we further measure the bit error rate (BER) under partial-channel interference using a GNU radio testbed. When $P_t - P_i < 10$dB, the partial-channel interference is harmful to the data transmission. Yet small overlapped portion (such as 1/4 or 1/2 overlap) results in an acceptable BER, i.e., less than 10^{-1} when $P_i \le P_t$, and even close to 10^{-2} in 1/4 overlap. This effect reveals that, current coding schemes still have the capacity to tolerate extra errors. If we exploit such coding redundancy properly, the packet corrupted by partial-channel interference can be successfully recovered.

Inspired from the aforementioned observation, we propose Piros, a distributed algorithm to push the limit of partially concurrent transmission in OFDM-based WiFi networks. When saying "partially concurrent transmission", we mean simultaneous transmission in partially overlapped channels. To exploit the extra coding redundancy, Piros leverages the un-balanced channel condition in partially concurrent transmission. It intentionally spreads the corrupted symbols within the "clean" ones according to the overlapped portion, and extracts the useful information from the corrupted symbols for decoding based on their reliability.

1063-6927/15 $31.00 © 2015 IEEE
DOI 10.1109/ICDCS.2015.103

II. Motivation and Piros in Depth

After we exploit the partially concurrent transmission, we observe that the collided symbols are not as severe as we expected. The reason stems from the OFDM subcarrier structure adopted by 802.11g/n. Among the entire 20MHz bandwidth of 64 subcarriers, 48 subcarriers are used for data transmission. The reminders are guard band, pilot and null. These subcarriers either carry “0 or “1, and can be considered as pre-known knowledge at the receiver side. If they collide with data subcarriers, the corrupted data can be easily recovered using interference cancellation technique. Thus, only the collision of two data subcarriers is our primary concern.

The fundamental question is whether we can leverage these “rescued” bits to improve the performance of partially concurrent transmission. Thus, we use a GNU radio testbed to measure the effect of data subcarrier superposition under partial-channel interference. The results reveals that the BER in 1/4 overlap is close to 10^{-2} when $P_i \leq P_t$, which is rather acceptable in communication system. In addition, for 1/2 and 3/4 overlap, the BER is less then 10^{-1} when $P_i \leq P_t$. This motivates us to further exploit the coding redundancy to recover the corrupted packets.

Motivated by this, we propose Piros, a novel paradigm to enable partially concurrent transmission in OFDM-based WiFi networks. Unlike previous works that focus on the collision-free subcarriers for partially concurrent transmission, Piros claims that the symbols on collided subcarriers still have redundancy to exploit. It aims to extract the useful decoding information from the coding redundancy, and utilize it to recover the packets corrupted by partial-channel interference. Thus, the fundamental idea of Piros is: *to exploit extra coding redundancy from the corrupted symbols to enable partially concurrent transmission.*

The basic idea of Piros is simple, yet there remain several challenges for implementation. First, under different overlap scenarios, partial-channel interference has diverse influence on the decoding performance. Thus, the interference-aware interleaver should be designed properly, so that we can extract as many useful information as we can from the corrupted symbols. Second, as we tend to use pre-knowledge to recover data symbols from partial-channel interference, how to cancel out the noise and interference with minimum cost remains great concern. Third, with the assistance of Piros, we need to design an efficient channel access method to enable distributed partially concurrent transmission. Piros incorporates four components to address the above challenges: **Interference-aware Interleaver** that creates uniform error distribution according to the overlapped portion, **Weighted ML Decoder** that exploits the useful information from corrupted symbol for decoding, **Pilot-assisted Symbol Recovery** that utilizes pre-knowledge to recovery the corrupted symbols at minimum cost, and **Piros-Aware Multiple Access** that enables partially concurrent transmissions in multiple collision domains. These four components together exploit more partially concurrent transmission opportunities in OFDM-based WiFi networks.

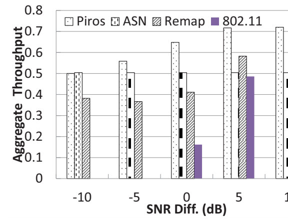

Fig. 1: Aggregate throughput when two neighboring WLANs are 1/4 overlapped.

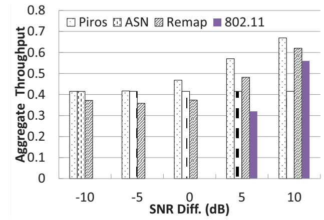

Fig. 2: Aggregate throughput when two neighboring WLANs are 1/2 overlapped.

III. System Evaluation

We implement Piros on a GNU Radio testbed. Experiments with our software radio prototype illustrate that Piros recovers 80% of the corrupted packet in 1/4 overlap, and 60% in 1/2 overlap. Due to the latency constraint of the platform, we use trace-driven simulations interconnected with C++ and Matlab to evaluate the MAC-layer performance in multiple collision domains. 802.11n, Remap and ASN are selected on the simulator as comparisons. Fig. 1 and Fig. 2 gauge the aggregate throughput in a topology where when two neighboring WLANs are overlapped with different SNR differences. As for 1/4 overlap, it recovers most of the packets corrupted by partial-channel interference, and outperforms other protocols even the SNR difference is large. The performance gain over 802.11n is 190%. As for 1/2 overlap, the available coding redundancy decreases as the collision portion increases. Yet Piros is still able to exploit such redundancy. For 3/4 overlap, since the erroneous symbols dominate the entire packets, we leave it as future work to design more robust system.

IV. Conclusion

Partially concurrent transmission is always considered harmful. In this paper, we observe that the actual corrupted symbols by partial-channel interference in OFDM-based WiFi networks are not as severe as we expected. There is extra coding redundancy that can be leveraged for packet recovery. Accordingly, we present a novel paradigm termed Piros, Push the lImits of paRtially cOncurrent tranSmission in WiFi networks. We verify the feasibility of Piros on GNU radio testbed, and conduct trace-driven simulations to evaluate the MAC layer protocol. The results reveal that compared with 802.11g/n, Piros achieves 190% throughput gain.

References

[1] *IEEE 802.11-2012: Wireless LAN Medium Access Control (MAC) and Physical Layer (PHY) Specifications*, 2012.

[2] A. Mishra, V. Shrivastava, S. Banerjee, and W. Arbaugh, “Partially overlapped channels not considered harmful,” in *ACM SIGMETRICS Performance Evaluation Review*, vol. 34, no. 1. ACM, 2006, pp. 63–74.

[3] X. Xu, J. Luo, and Q. Zhang, “Design of non-orthogonal multi-channel sensor networks,” in *Distributed Computing Systems (ICDCS), 2010 IEEE 30th International Conference on*. IEEE, 2010, pp. 358–367.

[4] L. Li, K. Tan, H. Viswanathan, Y. Xu, and Y. Yang, “Retransmission≠ repeat: simple retransmission permutation can resolve overlapping channel collisions,” in *ACM Mobicom*, 2010.

[5] X. Zhang and K. G. Shin, “Adaptive subcarrier nulling: Enabling partial spectrum sharing in wireless lans,” in *Network Protocols (ICNP), 2011 19th IEEE International Conference on*. IEEE, 2011, pp. 311–320.