Embracing Adjacent Channel Interference in Next Generation Wi-Fi Networks

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Abstract—**Emerging Wi-Fi Standards have incorporated growing channel widths to meet the proliferation of wireless services. Wider channel, unfortunately, increases the probability of partial channel overlap, and thus introduces more adjacent channel interference (ACI) than ever. Prior work either tries to avoid ACI, or neglects it in a brute-force way. In this paper, we carefully investigate the interference pattern at physical layer (PHY), and propose interference randomization (InterRandom) to strategically harness ACI for simultaneous transmission. The key insight behind InterRandom is to randomize the interference according to the overlapped ratio, and utilize coding redundancy to recover the corrupted data. To demonstrate the effectiveness of InterRandom, we further propose an InterRandom-enabled Media Access Control layer (MAC) protocol to facilitate Wi-Fi infrastructure mode transmission. We verify the feasibility of InterRandom on GNU radio testbed. Furthermore, our trace-driven simulations show that, InterRandom-aware MAC achieves** 190% **throughput gain compared to the legacy 802.11ac.**

I. INTRODUCTION

Over the decades, Wi-Fi has taken over from wired Ethernet as the primary edge connection. The popularity of Wi-Fi is largely attributable to the widespread use of tablets and Wi-Fi equipped smartphones. As IEEE 802.11ac becomes a standard interface on PCs, tablets and smartphones, the wireless services used by these devices have continued to progress. Wi-Fi network has encountered the next frontier C large volume traffic under dense deployment. Such scenarios include stadium, airports and large conventions, where there are a significant number of people accessing the Internet via these Wi-Fi hotspots [1].

To meet the emerging high speed high density wireless service requirements, 802.11ac standard incorporates a variety of channel widths ranging from 20 MHz to 160 MHz. However, the spectrum is barely adequate. To avoid co-channel interference and adjacent channel interference, it is important to ensure certain separation between channels used by every co-located WLAN [2]. Currently there are only ten orthogonal 40 MHz channels, and five orthogonal 80MHz channels in 802.11ac [3]. Furthermore, as transmissions in wider bandwidth channels create higher-power spectral density, higher levels of adjacent channel interference are introduced. Consequently, more adjacent channel isolation is required, which highly degrades the spectrum utilization.

A common solution to improve the spectrum usage efficiency is from the view point of reusing the non-orthogonal channel. The first attempt to leverage non-orthogonal channels for simultaneous transmissions is [4]. By a careful use of some partially overlapped channels, the authors demonstrated significant improvements in 802.11b WLAN with DSSS (direct sequence spread spectrum) at PHY layer. However, when it comes to 802.11n/ac with OFDM (orthogonal frequency division multiplexing), the above feasibility fails. Unlike DSSS that spread every single bit information over an entire spectrum, OFDM divides the spectrum into multiple subcarriers, each encodes with individual bit information. As such, the overlapped channel portion is much more vulnerable to adjacent channel interference, and thus difficult to be recovered.

One question is whether we can borrow the wisdom of DSSS for non-orthogonal simultaneous transmissions in OFDM-based Wi-Fi networks. The key insight behind is to spread the detrimental impact over the entire channel. As such, even the SINR (signal to interference and noise ratio) on overlapped portion is lower than that on non-overlapped portion, we can rely on coding redundancy to recover the corrupted data. Therefore, instead of isolating the adjacent channel interference, we should embrace it to facilitate simultaneous transmissions .

Inspired from the aforementioned observation, we propose interference randomization (InterRandom) to harness adjacent channel interference in next generation Wi-Fi networks. It intentionally spreads the corrupted symbols on overlapped portion within the “clean” ones according to the overlapped portion, and extracts the useful information from the corrupted symbols for reliable decoding. The extra coding redundancy enables us to conduct simultaneous transmissions in non-orthogonal channels. To elaborate how to benefit from InterRandom, we also propose an InterRandom-aware MAC protocol for Wi-Fi infrastructure mode transmissions. The MAC protocol is capable of assigning the non-orthogonal channel to multiple clients based on their channel condition, and thus maximizes the spectrum usage efficiency.

We have implemented InterRandom on a GNU Radio testbed. Experiments with our software radio prototype illustrate that InterRandom recovers 80% of the corrupted packet in 1/4 overlap, and 60% in 1/2 overlap. We also conduct trace-driven simulations to evaluate the performance of InterRandom-aware MAC protocol, which demonstrate throughput gain of 190%, 140% and 130% compared to 802.11n/ac, Remap and ASN. The performance gain stems from InterRandom’s ability to exploit the coding redundancy to recover the packets corrupted by adjacent channel interference, and harness more simultaneous transmission opportunities.

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II. RELATED WORK AND MOTIVATION

InterRandom builds on top of extensive research works in simultaneous transmission through non-orthogonal channels. The growing demand for high speed wireless services overburdens the spectrum usage, and leads to dense deployed wireless networks and spectrum shortage. Therefore, researchers put their efforts into simutaneous transmissions in non-orthogonal channels. In [4], the authors first promoted the idea that simultaneous use of partially overlapped channels is not always harmful. This contra-intuitive design demonstrated significant improvements by a careful use of some partially overlapped channels in 802.11b WLAN with DSSS (direct sequence spread spectrum) at PHY layer. The authors in [5] further proposed a complete design in wireless sensor networks to encourage non-orthogonal transmissions, which was also built atop DSSS modulation and improves the system throughput by utilizing adjacent channel interference.

The above feasibility cannot be directly applied to 802.11n/ac. The reason stems from the distinct PHY layer. Unlike DSSS that spread every single bit information over an entire spectrum, OFDM adopted by 802.11n/ac divides the spectrum into multiple subcarriers. The overlapped portion has a much lower SINR compared with that in DSSS modulation. Thus, it is very difficult to recover the collided portion. In [6], the authors tried to enable the partially overlapped transmissions in TV white space with different channel widths. Remap in [7] took a detour to leverage the partially concurrent transmissions, which exploit collision-free subcarriers for decoding through multiple retransmissions. On the other hand, MPAM [8] and ASN [9] directly nulled the overlapped portion used by neighboring Wi-Fi subcarriers, and utilized spectrum fragments for partially concurrent transmission. Unlike previous works, our proposed InterRandom aims to exploit extra coding redundancy from the collided subcarriers, and leverage it for partially concurrent transmission in Wi-Fi networks.

III. INTERFERENCE RANDOMIZATION IN DEPTH

In this section, we first present an overview of Interference Randomization along with design challenges. Detailed components, including interference randomizer, weighted ML decoder and InterRandom-aware MAC are demonstrated later to see how we address these challenges.

A. Overview and Design Challenge

To begin with, we summarize two necessary assumptions: 1) InterRandom is compatible with the existing error correcting codes. It is also orthognal with MIMO system (Multiple input Multiple output) 2) We assume the channel is slowly time-varying with a coherence time of tens of milliseconds.With a transmitted frame of several microsecond, the channel will be approximately constant within thousands of frames.

With these assumptions in mind, we propose InterRandom, a novel paradigm to facilitate simultaneous transmission in next generation Wi-Fi networks. Unlike previous works that focus on the collision-free subcarriers for parallel transmissions, InterRandom claims that the symbols on collided subcarriers still have redundancy to exploit. It aims to randomize the adjacent channel interference, and extract the useful decoding information to recover the corrupted data.

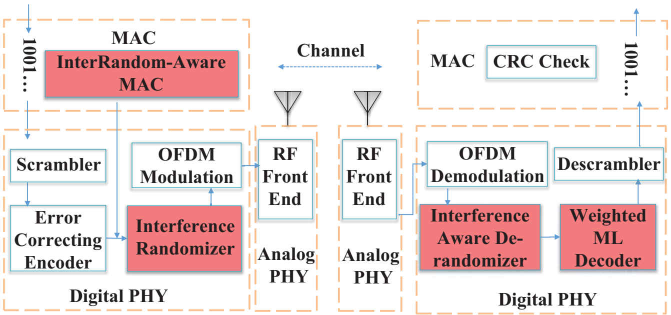


Fig. 1: The block diagrams of InterRandom transmitter and receiver. The colored blocks are the extensions to 802.11g/n.

The basic idea of InterRandom is simple, yet there remain several challenges for implementation. First, under different overlap scenarios, adjacent channel interference has diverse influence on the decoding performance. Thus, the interference randomizer should be designed properly without degrading the original transmission. Second, how to extract as many useful information as we can from the corrupted symbols remains concern. Third, with the assistance of InterRandom, we need to design an efficient channel allocation algorithm to facilitate simultaneous transmissions.

Fig. 1 demonstrates the transmitter and receiver block diagram. InterRandom incorporates three components to address the above challenges: **Interference Randomizer** that creates uniform error distribution according to the adjacent channel interference ratio, **Weighted ML Decoder** that exploits the useful information from corrupted symbol for decoding, and **InterRandom-Aware MAC** that enables partially simultaneous transmissions for infrastructure mode Wi-Fi.

B. PHY Layer Encoder

To create uniform error distribution under adjacent channel interference, InterRandom aims to leverage the wisdom of interleaver. Interleaver plays a key role in exploiting spatial diversity and frequency diversity in communication systems. Yet under non-orthogonal concurrent transmission, fix-interleaver adopted by 802.11n/ac cannot adjust the interleaving method according to the overlapping ratio. Interference randomizer is essentially an adaptive interleaver. It intentionally spreads the collided subcarriers among the collision-free ones according to the overlapping ratio. Thus, uniform error distribution can be provided to exploit coding redundancy for data recovery.

For ease of explanation, we instantiate 802.11n channel for illustration. A 20MHz channel is divided into 4 groups, each with 12 data subcarriers, donated as $G_i, i \in [1,2,3,4]$. Assume Ψ is the overlapping set, and contains $n_{overlap}$ groups $(0 \leq n_{overlap} < 4)$. The goal is to uniformly distribute the subcarriers within Ψ among the non-overlapped portion $N\Psi$, where $N\Psi = \complement\Psi$ is the complementary set of Ψ and has $n_{non-overlap}$ groups.

Interference randomizer is a modification on 802.11n interleaver. It consists of two permutations. The first step is group reshaping used to sperate two adjacent overlapped groups. This is very simple to achieve. We illustrate the procedure in Fig. 2. The second step is block interleaver, which aims to isolate the overlapped subcarriers and ensures their uniform distribution among the non-overlapped subcarriers. We adopt a row-by-column block interleaver for uniform error distribution. Given a matrix of length $N = N_{row} \times N_{col}$, the inputs bits are written row-wise and read column-wise row-wise. N_{row} is the number of the reshaped groups. N_{col} is the number of subcarriers in each reshaped group. The permutation π is,

$$\pi(i) = k = N_{col}(i \bmod N_{row}) + \left\lfloor \frac{i}{N_{row}} \right\rfloor \tag{1}$$

where $i = 0, 1, \cdots, N$ indicates the original bit location in the reshaped groups, and k is the bit location after interleaving. The modulo operation is denoted by $\bmod$, and $\lfloor x \rfloor$ searches for the largest integer not exceeding x. Without loss of generality, we use $N = 4 * 4$ to illustrate the idea in Fig. 2.

The deinterleaver at the receiver side performs the inverse rotation defined by the two-step interleaver, which defined as,

$$\pi^{-1}(k) = i = N_{row} \times k - (N-1) \times \left\lfloor \frac{k}{N_{col}} \right\rfloor \tag{2}$$

After the rotation of the first permutation, the original group before reshaping can be easily obtained.

When the interfered portion is larger than the clean portion, the errors clearly exceed the affordable coding redundancy. Thus, InterRandom only takes $P \leq 1/2$ into consideration. The 802.11ac incorporates a variety of channel widths ranging from 20MHz to 160MHz. According, the possible overlapping ratio here is ranging from 1/8 to 4/8.

C. PHY Layer Decoder

To leverage adjacent channel interference for data recovery, we propose a weighted Maximum-likelihood (ML) decoder. Weighted ML decoder also incorporates overlapping radio. It aims to extract as much useful information as it can for decoding. ML decoder is commonly adopted in wireless communications. Given a received symbol y, we need to pick up a codeword x_t^d from codebook C to maximize the following conditional possibility,

$$\mathcal{P}(y \,\text{received} \,|\, x_t^d \,\text{sent}) \tag{3}$$

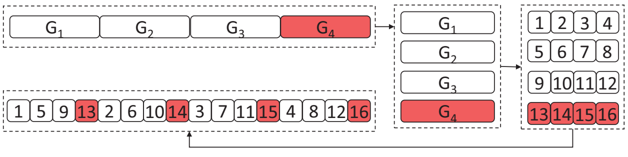
Given a received message $\overline{y}$, the ML decoder tries to find out the estimated message $\hat{M}$ according to the following rule,

$$\hat{M} \in \underset{M' \in \{0,1\}^n}{\operatorname{argmin}} \|\overline{y} - \overline{h}_t \overline{x}_t^d(M')\|^2. \tag{4}$$

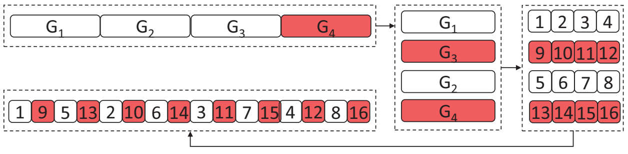
where $\overline{x}_t^d$ is the transmitted bit sequence. n is the length of the message and $\overline{h}_t$ is the channel response of the desired signal.

To decode message M, we break $\overline{y}$ into sub-vector $[y(1), ..., y(n)]$, each contains a transmitted symbol. We also break $\overline{x}_t^d(M')$ into n coded bit $x_t^d(m_i')$. Thus, for the ith symbol, the cost function based on MSE criterion is,

$$J = E[\|y(i) - h_t(i)x_t^d(m_i')\|^2], \tag{5}$$



(a) 1/4 overlap



(b) 1/2 overlap

Fig. 2: Illustration of two-step interleaver, including group reshaping and block interleaver. The groups in red are the overlapped portion.

where $h_t(i)$ is the channel response of the ith symbol.

In partially overlapped channel, the channel condition is unbalanced. Weighted ML decoder is able to leverage such diversity for decoding. As the symbols corrupted by partial-channel interference actually have abundant information to exploit, we should treat them differently from the clean symbols. Unlike the previous works that either discard them or use them in a brute-force way for decoding, the weighted ML decoder strategically extracts the useful decoding information from the corrupted symbols based on their reliability. Specifically, confidential level (CL) is adapted as the metric to measure symbol reliability. Clearly, the symbols on overlapped portion have less reliability than those on non-overlapped portion. We define a weight variable $\overline{w}$ to restrict the information provided by the collided symbol. The cost function on the i symbol is modified as,

$$J_w = E[\|w(i)y(i) - h_t(i)x_t^d(m_i')\|^2]. \tag{6}$$

In order to deduce the value of $w(i)$, we take the derivative of J_w with respect to $w(i)$. The result is given by,

$$\frac{\partial J_w}{\partial w(i)} = 2w(i)E[\|y(i)\|^2] - 2E[y(i)h_t(i)x_t^d(m_i')]. \tag{7}$$

Assume the gradient is 0, the weight is computed as,

$$\begin{aligned} w(i) &= \frac{E[\|y(i)h_t(i)x_t^d(m_i')\|]}{E[\|y(i)\|^2]} \\ &= \begin{cases} \frac{P_{h_t}P_t}{P_{h_t}P_t+\sigma_n^2}, & i \text{ is on non-overlapped portion} \\ \frac{P_{h_t}P_t}{P_{h_t}P_t+P_{h_i}P_I+\sigma_n^2}, & i \text{ is on overlapped portion} \end{cases} \\ &= \frac{P_{h_t}P_t}{P_{h_t}P_t + P_{hin}}. \end{aligned} \tag{8}$$

where P_{hin} denotes the total noise power, which equals $(P_{h_i}P_I + \sigma_n^2)$ on the overlapped portion and σ_n^2 on the non-overlapped portion.

D. InterRandom-Aware MAC

To demonstrate the effectiveness of InterRandom, we show how to use InterRandom to benefit transmissions in the infrastructure mode Wi-Fi. The InterRadom MAC is a simple AP driven MAC protocol. An AP is responsible to decide

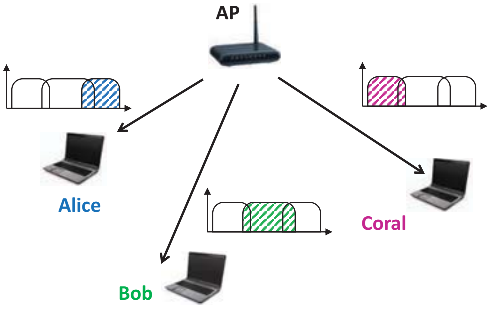


Fig. 3: Illustration of InterRandom-aware MAC.

how to conduct simulations transmissions via non-orthogonal channels among multiple clients.

To trigger simultaneous transmission with its clients in the next slot, the AP appends a short contention advertisement at the end of its transmission (either data or ACK). The contention advertisement announces that n clients that may transmit concurrently in the next slot. Upon receiving the contention advertisement, clients that have outstanding traffic enter into a contention period. We abstract the basic idea of frequency domain backoff [10] for contention resolution. Each client randomly picks a subcarrier out of all available ones, and sends a single tone on that subcarrier. To guarantee the robustness, each client repeats its tone in 2 time slots. After receiving the tones, the AP selects n clients with the n smallest subcarriers. If the contention window is not adequate for the network size, we add time slot dimension for contention other than subcarrier dimension. Thus, the probability that two clients pick the contention number can be exponentially reduced.

After choosing the transmitting clients in parallel, the AP should decide how exactly the non-orthogonal portion is assigned to each client. This is a non-trivial task. The allocation algorithm should take a client's channel condition into consideration. If a client experiences poor channel condition, say has relatively low SNR, assigning too much adjacent channel interference will even degrade the SINR, and lead to packet decoding failure. On the other hand, if a client experiences good channel condition, say has relatively high SNR, it is capable of enduring more adjacent channel interference. To ensure the transmission reliability as well as user fairness, we formulate an optimization problem whose objective is to maximize the bandwidth utilities of all clients.

Our goal is to maximize $\sum_{i=1}^{n} U_i(c_i)$, with constrains $\sum_{i=1}^{n} c_i \leq c_{total}$ and $\forall c_i \geq 0$. To achieve a fair and efficient allocation, the principle is to guarantee the clients with poor channel condition assigned less or no adjacent channel interference, and the clients with good channel condition assigned more adjacent channel interference. We define $c_{non-orthogonal}$ as the amount of residual resource to be given to client with orthogonal channel recourse, and ΔU_i is the utility gain by allocating c_i to orthogonal client i. We allocate non-orthogonal channels for clients with channel quality under a certain threshold, in the meanwhile choose the clients exceeds the threshold with adjacent channel interference. As such, we ensure that clients with various channel condition can benefit from simultaneous transmissions.

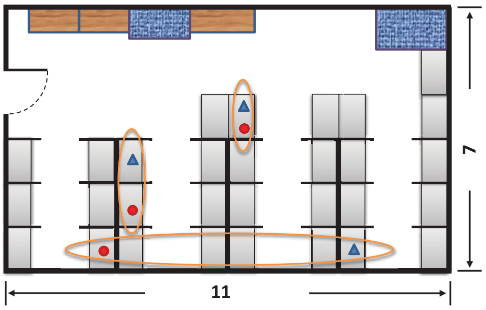


Fig. 4: Experimental environment. 3 sets of nodes are distributed in different locations.

IV. PERFORMANCE EVALUATION

In this section, we evaluate the performance of InterRandom through extensive experiments and simulations. We first validate our PHY layer components on GNU radio platform. The universal software radio peripheral 2 (USRP2) uses the RFX2450 daughterboard as RF frontend, which operates in the 2.4-2.5GHz range. As depicted in Fig. 4, different sets of USRP2 nodes were tested to verify the experiment. 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. In the following evaluations, We use a 64-point FFT on a 20MHz channel. Channel 1-4 are selected with center frequency 2.412GHz, 2.417GHz, 2.422GHz and 2.427GHz. 802.11n [1], the de facto Wi-Fi standard used today, Remap [7] and ASN [9], two research algorithms with the best published results, are selected as comparisons under different channel conditions.

A. Evaluation Methodology

Remap: Remap's core idea is to utilize retransmission permutation to decode the collision-free subcarriers under partial-channel interference. We adopt LDPC encoder and sum-product decoder are adopted as the basic coding scheme. Upon detecting a partially concurrent transmission, the transmitter uses a different bit-to-subcarrier mapping to avoid the same portion of collision. Accordingly, the receiver selects the collision-free subcarriers to decode the packet. We augment partial-packet recovery on top of Remap to enhance its performance.

ASN: ASN is a direct scheme to avoid partial-channel interference by nulling the overlapped portion. ASN follows the 802.11g specifications, but removes the interleaver and error-correcting encoder and decoder. To ensure fair comparison, we add the module back to ASN. The transmitter maps the data bits and pilots on the non-overlapped portion according to the MAC layer carrier sense. The control information is appended in 802.11g preamble. It also adopts partial-packet recovery for retransmission.

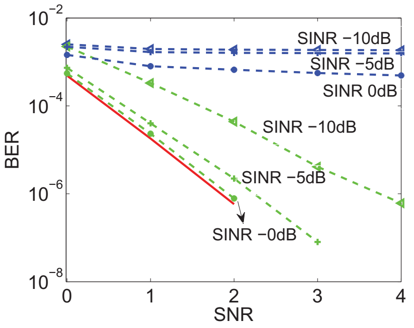


Fig. 5: Decoding capacity of interference-aware interleaver. The dotted blue lines and dash green lines are BERs with fix and interference-aware interleaver. The red solid line is BER without interference.

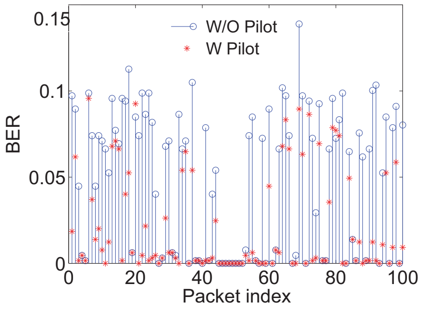


Fig. 6: The BER with (W) and without (W/O) pilot-assisted symbol recovery. 1/4 overlap, SNR = 0dB and SINR = 0dB.

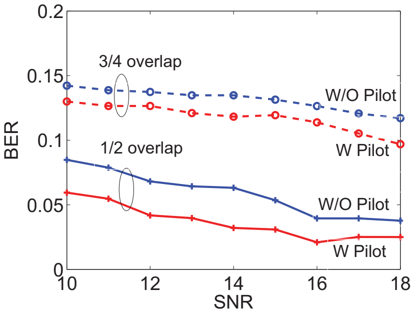


Fig. 7: BER with (W) and without (W/O) pilot-assisted symbol recovery under different overlapped portions.

InterRandom: Our InterRandom design aims to exploit the coding redundancy to combat partial-channel interference through several PHY layer components. InterRandom follows 802.11 g/n specification, with some modifications on the interleaver and decoder. We adopt several error-correcting codes, including LDPC and convolutional codes to validate the PHY layer components. Through time-frequency sense, the transmitter detects a partially concurrent transmission, and applies interference-aware interleaver to the encoded message. The control information is conveyed to the receiver through the modified preamble.

B. Feasibility of PHY Layer Components

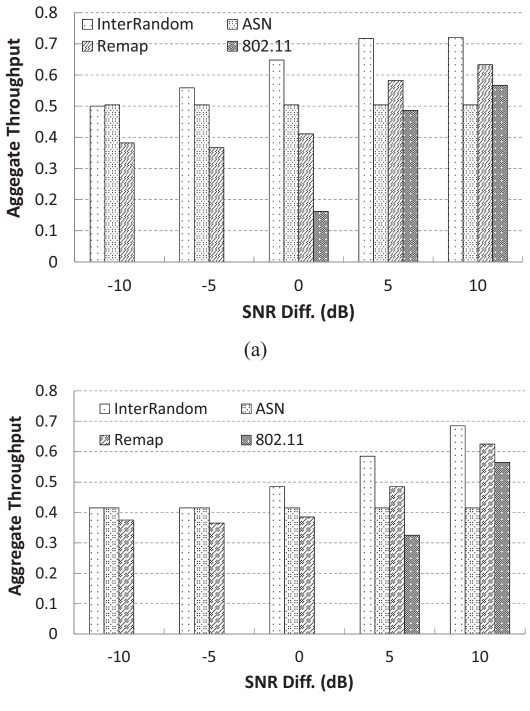
In this subsection, we first verify the feasibly of three PHY layer components, including interference-aware interleaver, pilot-assisted symbol recovery and weighted ML decoder.

1) Decoding Capacity of Interference-aware Interleaver: To evaluate the interference-aware interleaver, we use 3 USRP nodes, transmitter (N_t), receiver (N_r) and interferer (N_i). N_i resides on channel 1, and keeps replaying the real-life trace. N_t and N_r then conduct transmission on channel 3 and 4 with carrier-sense disabled. For transmission on channel 3, N_t adopts interleaver for 1/2 overlap after data encoding. While for transmission on channel 4, N_t adopts interleaver for 1/4 overlap. Accordingly, N_i applies corresponding deinterleaver and normal decoder to decode the packet. We compare the decoding performance of interference-aware interleaver with 802.11g/n fix interleaver, which adopts random permutation for all overlapped portions. It is noted that LDPC naturally has good self-interleaving capacity thanks to its sparse matrices. Thus, we adopt convolutional encoder as the channel coding scheme to demonstrate the performance of intereference-aware interleaver, and accordingly Viterbi hard decision decoder is chosen as the channel decoding scheme.

Fig. 5 gauges the BER as a function of SNR under different SINR. The dotted blue lines are BERs with fix interleaver. The dash green lines are BERs with interference-aware interleaver. We also plot a red solid line, which is the BER without interference. This is set as a baseline to see how good we can achieve. The fix interleaver has a constantly high BER as SNR increases. With higher SINR, BER has not seen an obvious reduction, which remains to 10^{-2}. On the contrary, our proposed interference-aware interleaver greatly reduce the BER under all circumstances. As SNR increases, the resulting BER rapid declines below to 10^{-5}, which is rather satisfactory for any communication systems. It is worth to mention that even N_i has comparable transmission power with N_t (SINR = 10dB), interference-aware interleaver approaches the baseline. This verifies that our proposed scheme has the capacity to leverage coding redundancy to recovery the corrupted packets under overlapped interference.

2) Performance of Pilot-assisted Symbol Recovery: At the receiver side, it first performs interference-aware deinterleaving to obtain the coded symbols. Then two components, including pilot-assisted packet recovery and weighted ML decoder are applied to help recover the corrupted packet. In this part, we first validate pilot-assisted symbol recovery. We use the same testbed in Sec. IV-B1. N_i resides on channel 1, and keeps replaying the real-life trace. N_t and N_r then conduct transmission on channel 2, 3 and 4 with carrier-sense disabled. We would like to know how pilot-assisted symbol recovery can help reduce the decoding error rate.

We first illustrate the performance of pilot-assisted symbol recover under 1/4 overlap. As depicted in Fig. 6, 100 packets are collected from our trace. The blue lines are the BERs without pilot-assisted symbol recovery. Their values fluctuate around 10^{-1}. With the help of pre-knowledge, the BERs, donated by the red dots, quickly drop to a certain small value in every packet. Some even drop to below 10^{-3}, which verifies that besides the recovered symbol by interference cancellation, we also successfully exploit the extra coding redundancy to recover more symbols. Fig. 7 further depicts the decoding performance of pilot-assisted symbol recovery under 1/2 and 1/4 overlap. Compared with 1/4 overlap, these two scenarios can leverages more pre-knowledge for packet recovery as the overlapped portion grows. Yet the BER reduction is smaller in 3/4 overlap than that in 1/2 overlap. That is because the number of data subcarrier superpositions dominates the decoding data bits, and the collision certainly exceeds the affordable decoding capacity. Thus, the partially concurrent



(a)

(b)

Fig. 8: Aggregate throughput of a typical WLAN cell with non-orthogonal simultaneous transmission. (a) only 1/4 overlap permitted (CH 1 &c 4), (b) only 1/2 overlap permitted (CH 1 & 3).

transmission with 3/4 overlap is not suggested right now. We will leave it as further work to discover other possible schemes for that kind of concurrent transmission.

C. InterRandom with Multiple Channel Access

Due to the latency constraint in USRP/GNURadio, we cannot directly intergrade our PHY layer components with MAC layer protocol to evaluate the network layer throughput. Thus, we use trace-driven simulations interconnected with C++ and Matlab to enable the MAC-layer protocol in multiple collision domains. A SINR-based interference module is implemented to detect the on-going transmissions. The collision module also takes frequency domain overlapped portion into consideration. The network topology is a typical WLAN cell, with a AP and several clients. Without loss of generality, we assume that they have saturated traffic. Besides InterRandom, we also run 802.11n, Remap and ASN on the simulator as comparisons. Each run lasts for 1000 seconds, and we repeat 50 times to calculate the MAC layer aggregated throughput.

Fig. 8 gauges the aggregate throughput in a topology where clients have SNR differences. We would like to see the individual performance gain of InterRandom over other protocols. As for 1/4 overlap, it can recovers most of the packets corrupted by adjacent channel interference, and thus achieves a rather desirable performance. It outperforms other protocols even the SNR difference is large, and achieves a 190% performance gain over 802.11n. This verifies that InterRandom has the ability to exploit the extra coding redundancy under adjacent channel interference, and successfully utilizes it to recovery corrupted packets. As for 1/2 overlap, the available coding redundancy decreases as the collision portion increases. Yet InterRandom is still able to exploit such redundancy.

V. CONCLUSION

Partially concurrent transmission is always considered harmful. However, the dense deployment of Wi-Fi networks makes the concurrent use of partially overlapped channels inevitable. In this paper, we observe that the actual corrupted symbols by partial-channel interference in OFDM-based Wi-Fi 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 InterRandom, to embrace the partial channel interference in next generation Wi-Fi networks. InterRandom includes four components: interference-aware interleaver, pilot-assisted symbol recovery, weighed ML decoder and time-frequency domain sense. These four components together exploit more partially concurrent transmission opportunities in OFDM-based Wi-Fi networks. We verify the feasibility of InterRandom on GNU radio testbed, and conduct trace-driven simulations to evaluate the MAC layer protocol. The results reveal that compared with 802.11g/n, InterRandom achieves 190% throughput gain.

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REFERENCES

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

[2] A. Akella, G. Judd, S. Seshan, and P. Steenkiste, “Self-management in chaotic wireless deployments,” *Wireless Networks*, vol. 13, no. 6, pp. 737–755, 2007.

[3] E. Perahia and R. Stacey, *Next Generation Wireless LANS: 802.11 n and 802.11 ac*. Cambridge university press, 2013.

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

[5] 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.

[6] P. Bahl, R. Chandra, T. Moscibroda, R. Murty, and M. Welsh, “White space networking with wi-fi like connectivity,” *ACM SIGCOMM Computer Communication Review*, vol. 39, no. 4, pp. 27–38, 2009.

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

[8] Y. He, J. Fang, J. Zhang, H. Shen, K. Tan, and Y. Zhang, “Mpap: virtualization architecture for heterogenous wireless aps,” *ACM SIGCOMM Computer Communication Review*, vol. 41, no. 4, pp. 475–476, 2011.

[9] 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.

[10] S. Sen, R. Choudhury, and S. Nelakuditi, “Listen (on the frequency domain) before you talk,” in *ACM SIGCOMM Workshop on Hot Topics in Networks*, 2010, p. 16.