Current WiFi Channel Contention

AP1

Random Backoff = 15

AP2

Random Backoff = 25

R1

B1=15

DIFS

R2

B2=25
Current WiFi Channel Contention

AP1
Random Backoff = 0

AP2
Random Backoff = 10

R1

R2

DIFS

B1=15
B1=0

AP1

AP2

B2=25
B2=10

Time
Current WiFi Channel Contention

AP1

Transmit

AP2

Carrier Busy

B1=15
B1=0

Data and ACK

DIFS

Wait

B2=25
B2=10

Time
Current WiFi Channel Contention

- **AP1**
  - Random Backoff = 18
  - B1 = 15
  - Data and ACK

- **AP2**
  - Random Backoff = 10
  - B2 = 10
  - Wait

- **R1**
  - B1 = 0
  - B1 = 18

- **R2**
  - B2 = 25
  - B2 = 10

- **DIFS**
Current WiFi Channel Contention

**AP1**
- Random Backoff = 8
- Data and ACK

**AP2**
- Random Backoff = 0
- Wait

---

- **R1**:
  - B1 = 15
  - B1 = 0
  - B1 = 18
  - B1 = 8

- **R2**:
  - B2 = 25
  - B2 = 10
  - B2 = 10
  - B2 = 0
Current WiFi Channel Contention

<table>
<thead>
<tr>
<th>AP1</th>
<th>B1=15</th>
<th>Data and ACK</th>
<th>B1=0</th>
<th>Wait</th>
<th>B1=18</th>
<th>Data and ACK</th>
<th>B1=8</th>
<th>Wait</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>AP2</td>
<td>B2=25</td>
<td>Wait</td>
<td>B2=10</td>
<td>Data and ACK</td>
<td>B2=0</td>
<td>Data and ACK</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

DIFS

Carrier Busy

Transmit
Current WiFi Channel Contention

High channel wastage due to backoff

35% overhead at 54Mbps
Current WiFi Channel Contention

- Backoff is not fundamentally a time domain operation
  - Its implementation is in time domain

Can we implement backoff in frequency domain? Are there any benefits in doing so?
Frequency domain contention resolution

- 802.11 a/g/n PHY adopts OFDM
  - Wideband channel divided into 48 narrowband subcarriers
  - Copes better with fast, frequency selective fading
  - Purely a PHY motivation

We propose Back2F

- MAC Opportunity: Pretend OFDM subcarriers as integers
- Emulate randomized backoff
Back2F: Main Idea

- Replace temporal with subcarrier transmission

<table>
<thead>
<tr>
<th>AP1</th>
<th>Backoff = 6</th>
</tr>
</thead>
<tbody>
<tr>
<td>R1</td>
<td></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>AP2</th>
<th>Backoff = 18</th>
</tr>
</thead>
<tbody>
<tr>
<td>R2</td>
<td></td>
</tr>
</tbody>
</table>
Back2F: Main Idea

- Replace temporal with subcarrier transmission

Both APs learn AP1 is the winner
Back2F: Scheduled Transmission

- Active subcarriers imply backoff chosen by other APs
  - Each AP knows its rank in the sequence
  - Enables back to back TDMA like transmission

API

Rank in TDMA: 3
Is there a benefit with frequency domain backoff?

- 1500 bytes at 54Mbps ~ 250 micro sec.
- Avg. temporal backoff ~ 100 micro sec.
- Frequency backoff = 1 OFDM symbol = 4 micro sec
Will APs Collide During Contention?

- Introduce a second round of contention
  - Winners of first go to second

![Diagram showing subcarriers and APs in the first round.](image-url)
Will APs Collide During Contention?

- Introduce a second round of contention
  - Winners of first go to second
Only a Few APs in Second Round?

TDMA will not be effective
Optimize for TDMA

- Instead of only winners, a few more APs to second round
Optimize for TDMA

Instead of only winners, a few more APs to second round

Subcarrier

First Round

Second Round

Rank 1

Rank 2

Rank 3

Enabling TDMA
Improved Channel Utilization

Enabling TDMA

Subcarrier

0 2 4

Rank 1

0 2 4

Rank 2

0 2 4

Rank 3

-->
Improved Channel Utilization

Enabling TDMA

Subcarrier

0 2 4

Rank 1

Rank 2

Rank 3

0 2 4

Data/ACK

Data/ACK

Data/ACK

......

802.11: Contention per packet

Frequency
Backoff

TDMA

Data/ACK

Data/ACK

Data/ACK

......

Back2F: Contention per TDMA Schedule
Does Back2F work with real-world scattered APs?
Does Back2F work with real-world scattered APs?

- **Blue** waits for **Purple**, but **Purple** waits for **Green**
- But Blue and Green should transmit simultaneously
  - Lost transmission opportunity
  - However 802.11 does not suffer from this problem
  - Blue will wait for DIFS, continue counting down and eventually transmit
Multiple Collision Domains

Does Back2F work with real-world scattered APs?

Blue waits for Purple, but Purple waits for Green.
But Blue and Green should transmit simultaneously.

Back2F Solution: Emulate 802.11

- However 802.11 does not suffer from this problem
- Blue will wait for DIFS, continue counting down and eventually transmit
Multiple Collision Domains

- Frequency Backoff, Wait for turn
- Channel idle > DIFS
- Reduce BO by winner’s BO
- Frequency Backoff
- My turn
- Transmit

- G -> 1
- DIFS
- R -> 4
- P -> 2
- B -> 2
- BO = 3
- BO = 5
- BO = 2
- BO = 3
- BO = 1

Time

25
Back2F: Performance Evaluation

Three important questions:
- Can Back2F detect subcarriers reliably?
- What is Back2F’s collision probability?
- How much throughput gain over 802.11?
Back2F: Performance Evaluation

- Three important questions:
  - Can Back2F detect subcarriers reliably?
    - Evaluated on USRP/Gnuradio
  - What is Back2F’s collision probability?
  - How much throughput gain over 802.11?
    - Evaluated using traces at 65 locations
Back2F: Performance Evaluation

- Three important questions:
  - Can Back2F detect subcarriers reliably?
    - Evaluated on USRP/Gnuradio

Practical Challenge: High Self Signal

Transmit Antenna → Listen Antenna
Self Signal Overflows into Adjacent Subcarrier

64 pt. FFT

Self Signal

SNR in dB vs. Subcarrier Number
Solution: Use a Higher Point FFT
Solution: Use a Higher Point FFT

![Graph showing SNR in dB vs Subcarrier Number with 256 pt. FFT and Self Signal marked.]
Subcarrier Detection Performance

Robust subcarrier detection at 14dB
Back2F: Performance Evaluation

Collect traces to answer:

- What is Back2F’s collision probability?
- How much throughput gain over 802.11

20 AP locations
45 client locations
Back2F: Performance Evaluation

Collect traces to answer:

- What is Back2F’s collision probability?
- How much throughput gain over 802.11

Emulate 802.11, Back2F for various topologies

1. RSSI
2. Per Subcarrier SNR
3. Optimal Bitrate
4. Traffic pattern
Back2F: Collision Probability

Small collision probability in dense networks
Throughput Evaluation

Higher throughput gain for real time traffic
Throughput Evaluation

Throughput Gain of Upto 50%

Throughput gain (%) over 802.11

Number of clients

54 Mbps w/o batch

6 Mbps
18 Mbps
36 Mbps
54 Mbps
Limitation and Discussion

- Robustness of subcarrier based backoff
  - Back2F more sensitive to channel fluctuation

- Need for additional antenna
  - Back2F is complementary to MIMO

- Gain over packet aggregation
  - Aggregation may not be possible for real time traffic
  - Back2F provides gain with aggregation at higher rates

- Interoperability with 802.11
  - May interoperate but will cause unfairness
Randomization is an effective method for contention resolution

802.11 time domain backoff requires channel to remain idle

Observation: randomization possible in frequency domain
  - Using OFDM subcarriers

Back2F: practical system realizing frequency domain contention

Prevents collisions, provides up to 50% improvement in throughput
Questions, comments?

Thank you

Duke SyNRG Research Group
http://synrg.ee.duke.edu