Flashback: Decoupled Lightweight Wireless Control

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Control Plane

- Carry signaling traffic to serve the data plane
- Functionality: QoS, efficient scheduling, differentiated services, handoffs, access control, power duty cycling ...

  **It enables rich set of applications!**

- Cellular Network Control Plane: decoupled from data plane, dedicated spectrum for explicit control signaling between the base stations and clients
Wifi Control Plane

- Goal: Simple, cheap, distributed, low overhead and asynchronous
- State of Art: coupled
  - Implicit: CSMA random back off -> inefficient
  - Explicit: RTS/CTS control frames -> consume significant channel time
- Decoupled dedicated control channel? No!
  - unlicensed band is scarce (require guard band)
- How to get the benefits of centralized control while retaining wifi’s asynchronous and distributed properties without designating spectrum?
Flashback: Decoupled Control Plane On Top of Data Plane

- Control: high-powered flashes
- Decoupled: send control messages concurrently with data on the same channel
- Lightweight: barely impacts network performance (induce <1% packet loss)
- How’s that possible? -- exploit properties of OFDM (orthogonal frequency-division multiplexing)
Wifi packet: OFDM Grid

Redundancy Protects from errors!
Rate Adaption Adds Redundancy

- The lower the coding rate, the higher the redundancy
- Rate adaptation according to SNR, which is based on packet loss estimates
- SNR measurement error on conservative side

\[
\text{link margin} = \frac{\text{actual SNR}}{\text{minimal SNR required to decode}}
\]
Exploiting Link Margin

- Key insight: intentionally interfere as long as smaller than the tolerable link margin
- The grid structure, localize interference
- Flashes: high powered single sinusoid of a specific subcarrier frequency on particular time slot
Control Packet Encoding

- Messages encoded by relative distance between consecutive flashes
  - Each digit is relative distance
  - Digit 1: 60-3=57
  - Digit 2: 62-60=2
  - Base-N (#subcarriers)
- Robust to carrier frequency offset
Control Packet Encoding

Diagram:
- Data Packet
  - Encoder
  - Modulator
- Control Message
  - Flash Modulator
  - Flash Inserter
- 64 IFFT
  - Cyclic Prefix
  - DAC
- MUX

Base-2 and Base-N paths
Control Flashes Detection

- Flash has much higher power than data transmission symbols
- Just need a simple peak detection algorithm
- Frequency selective fading ➔ use differential value
Control Message Decoding

- Time Offsets:
  - The receiver synchronizes to the data transmitter’s grid
  - But the flash transmitter doesn’t!
- Solution: two flash detectors at whole and half samples
- Then convert the base-N number into binary representation
- Require 6dB to decode
Data Message Decoding

- Erase the symbols at the same coordinates as the flashes.
- Erasures are easier to handle than bit errors and require half the redundancy to correct.
Detection and Decoding

Diagram:

1. ADC
2. Sync
3. 64 FFT
4. Equalizer
5. Demodulator
6. Flash Detector
7. Flash Eraser
8. Viterbi Decoder
9. Flash Demodulator
10. Control Message
11. Data Packet
Protocols for Sending Flashes

- Assume no synchronization among nodes
- At any point, only one node can send a flash-based control message on the control plane → nodes sense for “start-of-message” flash subcarriers for other nodes. If sensed, random back off; otherwise, flashes
- Nodes can sense whether the AP (half-duplex) is currently transmitting a data packet → nodes decode data packets to verify
- Control message acknowledgement → AP piggybacks control ACK flashing
Evaluation with 3 nodes

• What’s the **maximum flash rate (R)** without harming data throughput (loss rate < 1%)?
• \( R = f(\text{link margin}) = f(\text{actual SNR, SNR estimation error, discrete available bit rates, interference}) \)
• Evaluate R with **SoftRate bit adaptation algorithm**

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Maximum Flash Rates Using Optimal Bitrates

- QPSK 1/2
- QPSK 3/4
- 16-QAM 1/2
- 16-QAM 3/4

Minimum = 5,000
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- SNR increases, more fault tolerable.
- Lose redundancy with sudden Coding rate increase.
Evaluation

- External interference 5-10dB
- Conservative rate adaptation: support lower flashing rate in calmer environment
Flashback enables centralized enterprise wifi

- Seamless hand-offs
- Better interference management: centralized scheduling and eliminate overhead related to medium access
- Differentiated services: delay-sensitive or throughput-sensitive
Flash-MAC

• Demand Map

<table>
<thead>
<tr>
<th>Demand Map</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Node 5</td>
<td>150 KB, Bulk Transfer</td>
</tr>
<tr>
<td>Node 1</td>
<td>20 KB, Low Latency</td>
</tr>
</tbody>
</table>

Node 5 ➔ Node 1

Data Data Data Data
Throughput Gains with FIFO Queue

Flashback-MAC's Throughput Improvement vs. Wi-Fi

Centralized scheduling → 4X throughput

CSMA/CA suffers from collision due to hidden nodes
QoS-aware Queue

Queue Latency of Priority Traffic

Latency [ms]

Number of Nodes

- Flashback, 100% Uplink Traffic, 2 Latency Sensitive Nodes
- CSMA/CA, 100% Uplink Traffic, 2 Latency Sensitive Nodes
- RTS/CTS, 100% Uplink Traffic, 2 Latency Sensitive Nodes

Flashback enforces QoS in extreme scenarios
Summary

• What: FlashBack is a decoupled lightweight control plane
• How: cause localized interference to send control flashes based on OFDM by taking advantage of the link margin
• Why: centralized control facilitates lots of applications