Flashback: Decoupled Lightweight Wireless Control

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How to Schedule a Wireless Network?

File Sync

VoIP
Cellular: Decoupled Control Plane

File Sync

VoIP

I want to transmit sync

Data Plane

Control Plane

Control Plane
Cellular: Decoupled Control Plane

File Sync

Data Plane

Control Plane

VoIP

I want to transmit VoIP

Data Plane

Control Plane
Cellular: Decoupled Control Plane

File Sync

VoIP

Data Plane

Data Plane

Control Plane

Control Plane

You go first
Cellular: Decoupled Control Plane

File Sync

Data data data

Data Plane

Control Plane

VoIP

Data Plane

Control Plane

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Cellular: Decoupled Control Plane

Cellular networks pay high price for centralized control
Wi-Fi: Implicit Control

VoIP

File Sync

Is anyone transmitting? No. Let’s go!

Data data data data

Data Plane

Data Plane
Wi-Fi: Implicit Control

VoIP

Is anyone transmitting? Yes. I must back off.
1 Mississippi, 2 Mississippi...

Data data data data

File Sync

Data Plane

Data Plane

Data data data data

Data Plane
Wi-Fi: Implicit Control

- VoIP: Data data data data
- File Sync: Hidden Node

Data Plane
Wi-Fi: Implicit Control

VoIP

Data Plane

Collision

Data data data data

Hidden Node

Drop Shadow

File Sync

Data Plane

Drop Shadow
The Challenge: the Best of Both Worlds

Can we get the benefits of centralized control?
- While retaining Wi-Fi’s asynchronous and distributed properties
- Without designating spectrum

I want to transmit

Data data data
Flashback

• Flashback is a **decoupled, lightweight control plane**
  
  – **Decoupled**: send control messages concurrently with data messages on the same channel
  
  – **Lightweight**: barely impacts network performance (<1% packet loss)
  
  – **Control Plane**: enables rich set of applications (efficient scheduling, QoS enforcement, power savings, fast association, etc.)
How can we send control messages without interfering with data packets?
OFDM is a Grid

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Subcarrier Position

\[20 \text{ MHz}\]

Time [\mu s]

0 4 8 12 16

0 1 2 3 60 61 62 63
Redundancy Protects from Errors

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Redundancy Protects from Errors

Wi-Fi Packet

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Rate Adaptation Adds Redundancy

- Rate adaptation trades off redundancy and throughput
  - Redundancy is added in significant discrete chunks
  - Dropping a packet is very costly

- Rate adaptation errs on the conservative side
Exploiting Margin

- Key insight: intentionally interfere
- Leverage OFDM grid structure
  - Localize interference in the OFDM grid
- Flashes: high powered single subcarrier signal
  - Single sinusoid of a specific subcarrier frequency on particular time slot
Receiver Detects Flashes in Parallel

1. Flashes are easy to detect at receiver
   – Power spike on single subcarrier
2. Erase flashes from data packet
3. Decode flash and data packet in parallel
How is the Control Message Encoded?

- Messages encoded by relative distance between consecutive flashes
  - Each digit is relative distance
  - Digit 1: 60 - 3 = 57
  - Digit 2: 62 - 60 = 2
Practical Concerns

• Flash transmitter is not synchronized to receiver
  – CFO problem solved using relative frequencies
  – Time sync problem solved by detecting flashes at whole and half samples

• AGC
  – Commodity ADCs have sufficient dynamic range to accommodate both data and flashes
Implementation

• Implemented OFDM PHY supporting Flashback
  – Receiver + transmitter
• Implementation using NI Virtex-5 LX30 FPGA based software radios
  – Designed with LabVIEW
Transmitter Implementation

1. Data Packet
   - Encoder
   - MUX
   - Modulator

2. Control Message
   - Flash Encoder
   - 64 IFFT
   - Cyclic Prefix
   - DAC

The diagram shows the flow of data from the data packet and control message through various stages such as encoding, multiplexing, and modulating, culminating in the transmission through an antenna.
Receiver Implementation

Diagram:

- ADC
- Sync
- 64 FFT
- Equalizer
- Demodulator
- Viterbi Decoder
- Data Packet
Receiver Implementation

Modular, requires minimal changes

ADC → Sync → 64 FFT → Equalizer

Demodulator → Flash Detector → Flash Eraser → Viterbi Decoder

Flash Decoder

Control Message

Data Packet
Maximum Flash and Data Rate

Packet Loss Rate [Percentage]

- 50,000 flashes per second
  - 175 kb/sec
- 125,000 flashes per second
  - 400 kb/sec

Flashes per Second

- Red: Overall Packet Loss Rate of Data Plane, Quiet Environment
- Blue: Overall Packet Loss Rate of Data Plane, Typical Noisy Environment

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Flashback-MAC

Node 5

Flash

Node 1

Data Data Data Data
Flashback-MAC

Node 5

Node 1

ACK + piggyback

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Flashback-MAC

Node 5

Node 1

Data Data Data

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<td>Low Latency</td>
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Flashback-MAC

Node 5

Node 1

Demand Map

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

Centralized scheduling → 4X throughput

Flashback over CSMA/CA

Flashback over RTS/CTS

Relative Throughput Gain

Number of Nodes

- CSMA/CA 20-80% Uplink-Downlink Data Traffic
- CSMA/CA 100-0% Uplink-Downlink Data Traffic
- RTS/CTS, 20-80% Uplink-Downlink Data Traffic
- RTS/CTS 100-0% Uplink-Downlink Data Traffic

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Queue Latency of Priority Traffic

Latency [ms]

Number of Nodes

Flashback enforces QoS in extreme scenarios

- 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

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Broader Implications of Flashback

• Decoupling is key property of Flashback
• Enables hitherto impossible applications
  – Power duty cycling
  – Fast association
  – Coexistence across networks
  – Peer discovery
  – ...

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Summary

• What: Flashback is a decoupled lightweight control plane
• How: Cause localized interference to send control messages
• Why: Centralized scheduling facilitates many applications