Potential Pitfalls of the Message in Message Mechanism in Modern 802.11 Networks

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Wi-Fi is Ubiquitous

Basic Human Needs

- Physiological Needs (survival)
- Safety and Security
- Social Needs
- Esteem
- Self-actualization

Wi-Fi
The Problem

Message in Message Mechanism (MiM)

MAC protocol

Power Control

ACK Interference
What is MiM?

MESSAGE IN MESSAGE MECHANISM
Conventional Receiver w/o MiM

Frame A

Frame B

Higher RSSI

RSSI

Time
Reception of Conventional Receiver

Both frames are lost

CRC check fails

Frame A

Frame B

Treated as noise

RSSI

Time
Message in Message (MiM)

Higher signal dominates weaker signal

- Successfully Received

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Frame B

Frame A

Time

RSSI
MiM is helpful

1. Salvaged otherwise lost frame

![Diagram showing MiM process]

- Desired Frame: Successfully Received
- Interfering Frame: Discarded
MiM is helpful

1. Salvaged otherwise lost frame
2. Desired frame is lost
MiM is helpful, at least no harm

1. Salvaged otherwise lost frame
2. Desired frame is lost

RSSI

Time

Desired Frame

Interfering Frame

Successfully Received

Discarded
However...

Consider Aggregate MPDUs
However… Consider A-MPDU
However... Consider A-MPDU

Without MiM

RX: 3  Fail: 3

Interfering frame
Key Insight: MiM can be harmful

Without MiM
RX: 3 Fail: 3

With MiM
RX: 1 Fail: 5

Worse: No Block ACK

Interfering frame
A-MPDU gets knocked out
A-MPDU

Time

RSSI
Why Use A-MPDU?

- A-MPDU reduces TX overhead
- Maximum A-MPDU size
  - 64 KB for 11n (equivalent to 40+ frames)
  - 1 MB for 11ac (600+ frames)
- A tiny interfering frame (e.g. ACK) can destroy the whole A-MPDU
How Bad is it?

SOMETIMES GOOD, SOMETIMES BAD
What Can We Do?

HOW TO EFFECTIVELY USE MIM
Our Contributions

1. How bad is it?
   A: Study the impact of MiM on A-MPDUs

2. What can we do?
   A: Adaptive algorithm to enable/disable MiM
Studying the Impact of MiM

Experimental set-up

- Sender & Interferer out-of-range
- Receiver closer to Interferer
Studying the Impact of MiM

Experimental set-up

- Sender & Interferer out-of-range
- Receiver closer to Interferer
- Sender sends an A-MPDU (w/o MAC retry)
- Interferer broadcast an Interfering Frame
Studying the Impact of MiM

Experimental set-up

- Sender & Interferer out-of-range
- Receiver closer to Interferer
- Sender sends an A-MPDU (w/o MAC retry)
- Interferer broadcast an Interfering Frame
- Measure FDR
Ensure collision

Immediately Tx A-MPDU

$t$ is uniformly distributed
Duration of A-MPDU

Max duration limited by ath9k driver

\[ \approx 3.8 \text{ ms} \]

\[ \text{Max.} \quad 4 \text{ ms} \]
Size of A-MPDU (# frames)

Depends on data rate

<table>
<thead>
<tr>
<th>Data Rate (Mbps)</th>
<th>6.5</th>
<th>13</th>
<th>19.5</th>
<th>26</th>
<th>39</th>
<th>52</th>
<th>58.5</th>
<th>65</th>
</tr>
</thead>
<tbody>
<tr>
<td>Frames</td>
<td>2</td>
<td>4</td>
<td>6</td>
<td>8</td>
<td>12</td>
<td>16</td>
<td>18</td>
<td>20</td>
</tr>
</tbody>
</table>

- 26 Mbps
  - 8 frames
  - Time $\approx 3.8$ ms

- 6.5 Mbps
  - 2 frames
  - Max. 4 ms

MCS Index 0 1 2 3 4 5 6 7

Time
The Detrimental Impact of MiM

1. Size of A-MPDU
   - # Frames per A-MPDU

2. Length of Interference Frame
   - Air-time duration

3. Channel Bonding
   - Using adjacent channels
1. Size of A-MPDU?
NUMBER OF FRAMES IN AN A-MPDU
Impact of A-MPDU size

A-MPDU of 2 frames

Interfering Frame 60 μs

≈ 3.8 ms

Probability mass function

Frames delivered

0 0.2 0.4 0.6 0.8 1

0 1

no MIM MIM

≈ 3.8 ms

0.5
Impact of A-MPDU size

A-MPDU of 4 frames

Interfering Frame 60 µs

≈ 3.8 ms

Probability mass function

Frames delivered

no MIM
Impact of A-MPDU size

A-MPDU of 4 frames

Probability mass function

Frames delivered

0 1 2 3

0 0.2 0.4 0.6 0.8 1

no MIM
MIM

0.25
Impact of A-MPDU size

A-MPDU of 20 frames

Interfering Frame 60 μs

≈ 3.8 ms

More details in the paper
Frame Delivery Ratio

Interfering Frame 60 μs

Time
Frame Delivery Ratio

Interfering Frame 600 µs

≈ 3.8 ms

No MIM

MIM

60 µs

0.9

0.5

A-MPDU size
Frame Delivery Ratio

Interfering Frame 600 μs

≈ 3.8 ms

Frame Delivery Ratio

0.5

A-MPDU size

No MIM

MIM

60 μs

600 μs
2. Length of Interference Frame

THE AIR-TIME DURATION
Air-time of Interfering Frames

Intuition:

**Without MiM**, longer $T \rightarrow$ more frames loss

**With MiM**, $T$ has no effect

\[ T \approx 3.8 \text{ ms} \]
How to set $T$

1. Vary frame length (# of bytes)
2. Vary data rate (bytes per sec)
Increasing Frame Length

Frame Delivery Ratio

Air time of interfering frame (μs)

Increasing frame length

No MIM  MIM
Increasing Frame Length

![Graph showing the relationship between frame delivery ratio and air time of interfering frame (μs) with two lines: one for No MIM and one for MIM, illustrating the decrease in frame delivery ratio as frame length increases.](image-url)
Increasing Frame Length
Increasing Data Rate

Air-time duration is what matters

Frame Delivery Ratio

Air time of interfering frame (μs)

Increasing frame length
Reducing data rate

No MIM  MIM
Air-time Duration... in the Wild
Air-time Duration... in the Wild

Frame duration (μs)

Cumulative distribution function

- Median ≈ 30 μs
- 20 μs MAC ACK
- 170 μs IPv6 Neighbor Discovery Protocol
Putting it in Perspective

Be careful what you choose
Suffer a large penalty

Frame Delivery Ratio

in the wild

Air time of interfering frame (μs)

Increasing frame length
Reducing data rate

No MIM  MIM
3. Channel Bonding

USING ADJACENT CHANNELS
Channel bonding

Sender

Receiver

Interferer

20 MHz

40 MHz
Channel bonding: Case 1

Channel bonding involves using adjacent channels to increase the effective bandwidth. In Case 1, the sender and receiver are on channel 52, while the interferer is on channel 56. This setup allows for increased data transmission capacity while minimizing interference.
Channel bonding: Case 2
Channel bonding: Case 3

- Sender
- Receiver
- Interferer
Channel bonding: Case 4

Sender

Receiver

Interferer

5250 (channel 52)  5260 (channel 52)  5270  5280 (channel 56)  5290 (MHz)
Channel bonding: Case 5

Sender

Receiver

Interferer
Channel bonding

Case 1
Sender
Receiver
Interferer

Case 2
Sender
Receiver
Interferer

Case 3
Sender
Receiver
Interferer

Case 4
Sender
Receiver
Interferer

Case 5
Sender
Receiver
Interferer
Adjacent Channel Interference

Sender
Receiver
Interferer
Adjacent Channel Interference

10 dB Threshold

Frame Delivery Ratio

Difference of received signal strength (dB)

Lesser Interference

More Interference
Adjacent Channel Interference

![Graph showing Adjacent channel and Same channel interference with frame delivery ratio vs difference of received signal strength (dB).]
Adjacent Channel Interference
Adjacent Channel Interference

![Graph showing the relationship between Frame Delivery Ratio and the Difference of received signal strength (dB)].

- **Sender**
- **Receiver**
- **Interferer**

Legend:
- **Adjacent channel**
- **Same channel**

- **MIM**
Adaptive MiM

DECIDING WHEN TO ENABLE/DISABLE MIM
Some Definitions

Good Knock-out

- Desired Frame
- Interfering Frame
- Successfully Received
- Discarded

Bad Knock-out

- Desired Frame
- Interfering Frame
- Discarded
- Discarded
Key Idea

Count Good KO and Bad KO

Compare Good > Bad

Yes → Enable MiM

No → Disable MiM*

* CATCH
Cannot count with MiM disabled

Periodically
Evaluation

Experimental Set-up

- Position 1: Desired signal is stronger
- Position 2: Equal signal strength
- Position 3: Interference is stronger

Sender

Campus AP

Interferer
Results w/o Adaptive MiM

- Sender > Interferer: MiM helpful
- Sender = Interferer: MiM neutral
- Sender < Interferer: MiM detrimental
Results with Adaptive MiM

Adaptive MiM always useful
In Conclusion

MiM not always helpful, can be harmful

1. Studied harmful effect of MiM
   ◦ on A-MPDUs
   ◦ 10 dB threshold
   ◦ Adjacent Channels

2. Adaptive MiM Algorithm
   ◦ Use MiM only when good
   ◦ Near optimal results
Future Work

1. Update the 802.11 MAC/PHY implementation in simulators like ns-3
2. Analytically model the effect of MiM on A-MPDU
3. Develop algorithm to dynamically adjust A-MPDU size
Thank You

QUESTIONS?

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