Enabling Fine-Grained Channel Access in WLAN

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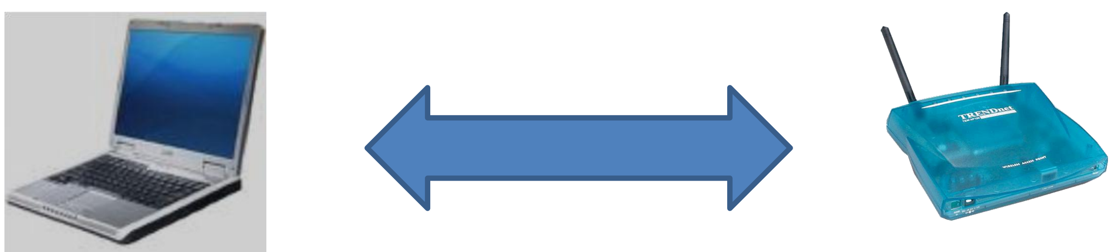
The Problem

How we can improve the access efficiency in high-speed wireless network?



IEEE 802.11n; 144.4Mbps

(20MHz channel; 2x2MIMO;
1500B frame size; aggregation disabled)

The Problem

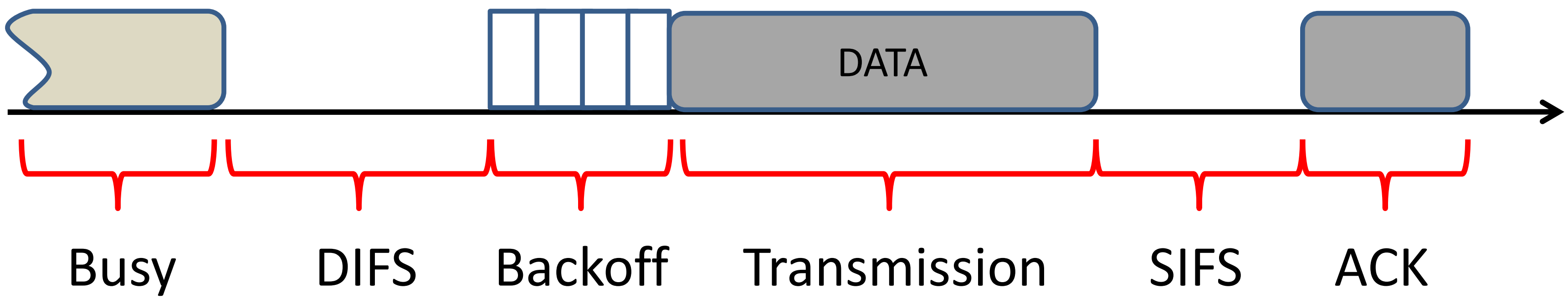
How we can improve the access

```
D:\tool>iperf -s -w 1M -i 1
------------------------------------------------------------
Server listening on TCP port 5001
TCP window size: 1.00 MByte
------------------------------------------------------------
[1224] local 192.168.0.19 port 5001 connected with 192.168.0.101 port 40827
[ ID] Interval       Transfer     Bandwidth
[1224]  0.0- 1.0 sec  4.87 MBytes  40.8 Mbits/sec
[1224]  1.0- 2.0 sec  4.97 MBytes  41.7 Mbits/sec
[1224]  2.0- 3.0 sec  5.24 MBytes  44.0 Mbits/sec
[1224]  3.0- 4.0 sec  4.90 MBytes  41.1 Mbits/sec
[1224]  4.0- 5.0 sec  5.17 MBytes  43.4 Mbits/sec
[1224]  5.0- 6.0 sec  5.08 MBytes  42.6 Mbits/sec
[1224]  6.0- 7.0 sec  5.40 MBytes  45.3 Mbits/sec
[1224]  7.0- 8.0 sec  6.16 MBytes  51.7 Mbits/sec
[1224]  8.0- 9.0 sec  6.00 MBytes  50.4 Mbits/sec
[1224]  9.0-10.0 sec  6.04 MBytes  50.7 Mbits/sec
[1224]  0.0-10.0 sec  53.9 MBytes  45.2 Mbits/sec
```

(20MHz channel; 2x2MIMO;
1500B frame size; aggregation disabled)

Understanding the Overhead

CSMA MAC



$$\eta = \frac{t_{data}}{t_{DIFS} + t_{slot} \cdot \overline{W} + t_{data} + t_{SIFS} + t_{ACK}}$$

Useful air time for data transmission

Coordination overhead

Understanding the Overhead (cont.)

- When PHY data rate increases high, the useful air time (t_{data}) reduces, but
- Coordination overhead remains almost constant

$$\eta = \frac{t_{data}}{t_{DIFS} + t_{slot} \cdot \bar{W} + t_{data} + t_{SIFS} + t_{ACK}}$$

$$t_{DIFS} = t_{SIFS} + 2t_{slot}$$

$$t_{SIFS} = t_{RFDelay} + t_{proc} + t_{TxRx}$$ ⇒ 10~16μs

$$t_{slot} = t_{CCA} + t_{TxRx} + t_{prop}$$ ⇒ 9~20μs

Ability to resolute collisions ⇒ > 8

Understanding the Overhead (cont.)

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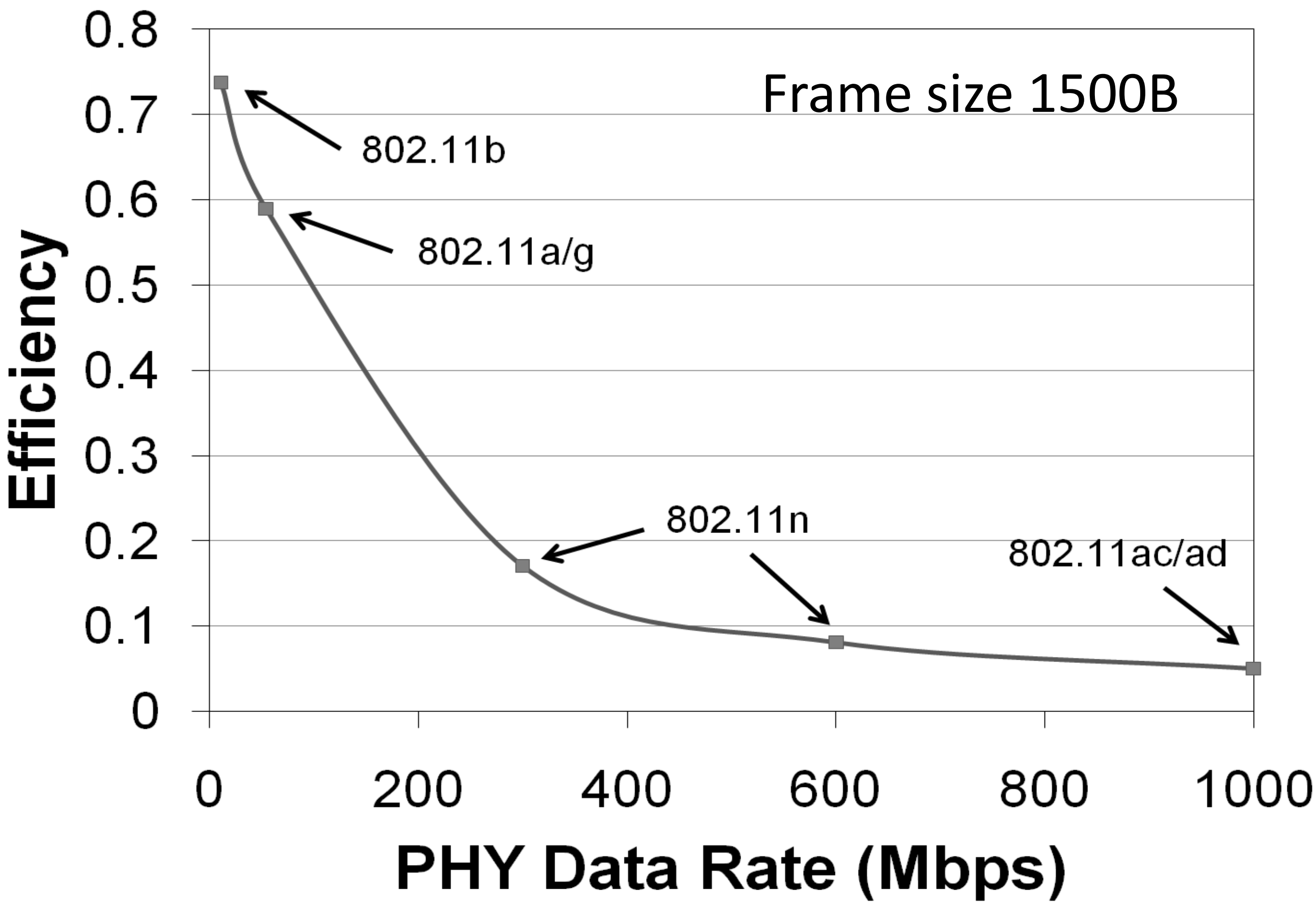

Existing MAC Limitations

- Always allocate whole channel to a single user at a time
  - Single carrier: too coarse when data rate is high and bandwidth is wide
  - Significant overhead with small data transmission

- Aggregation cannot solve the problem completely
  - Requires a large aggregation size (e.g. 23KB per frame for 80% efficiency at 300Mbps data rate
  - Increases latency - adversary interaction w/ RT, interactive, Web traffic, etc.

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Calls for a fine-grained channel access model!

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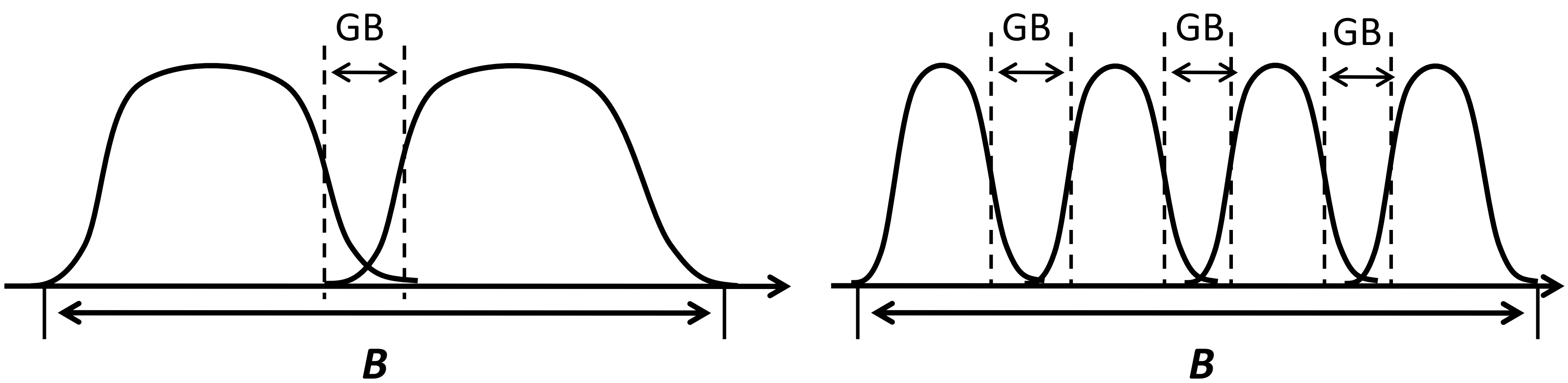
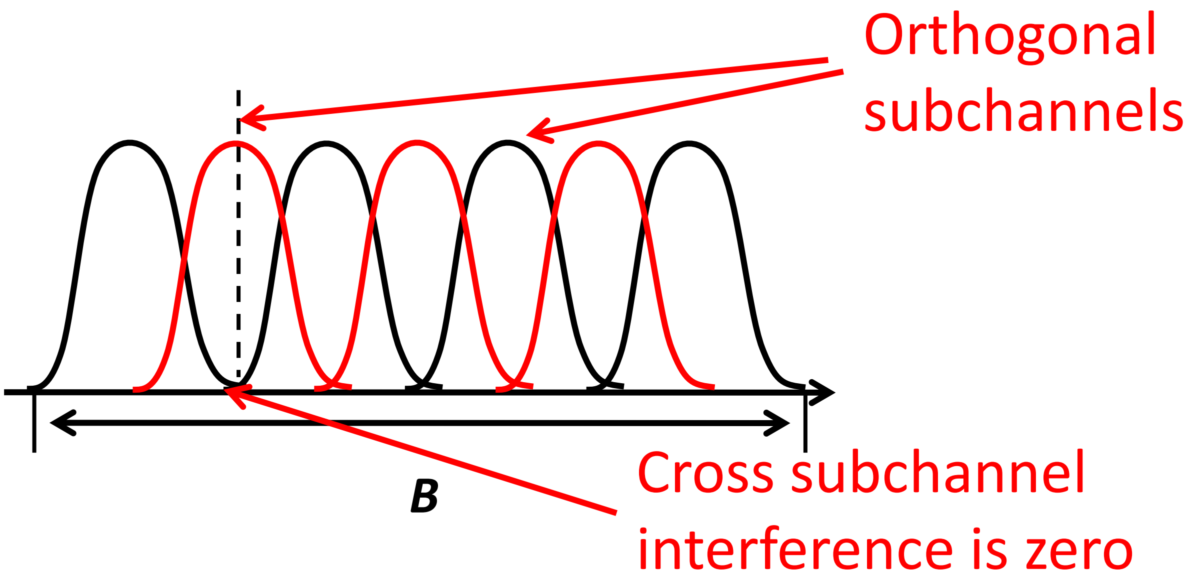
Fine-Grained Channel Access

- Basic idea
  - Divide the spectrum band into small fine-grained slices
  - Allow different nodes to contend and transmit on different slices
  - Amortize the coordination overhead among multiple users
- Direct reduce the channel width does not work
  - Guard-band creates significant overhead



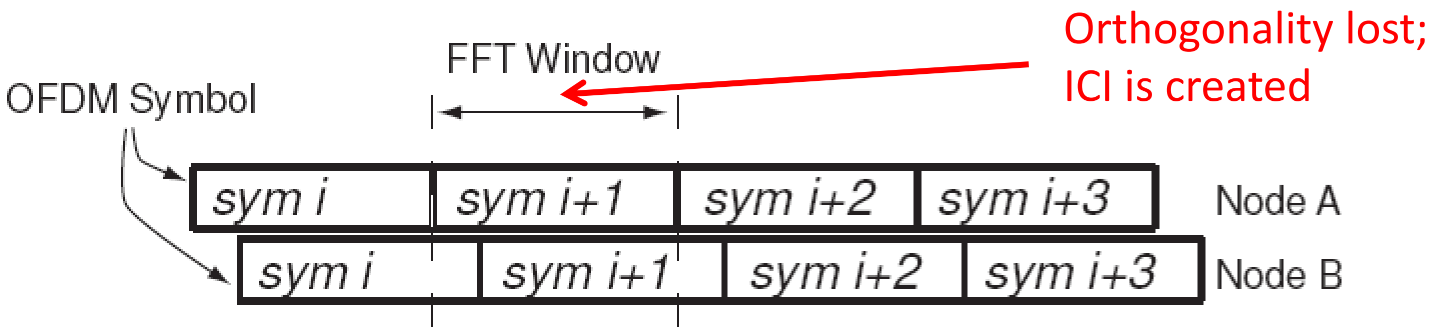
Our Approach: Using Orthogonal Subchannels

- Based on OFDM
  - Overlapped subchannels, but
  - Cross-subchannel interference is zero
- Remove the need of guard-band



Challenges

- Loss of orthogonality among asynchronous nodes



- How to coordinate transmissions in random access networks like WLAN
- How to handle contentions
  – Conventional time-domain backoff becomes very inefficient

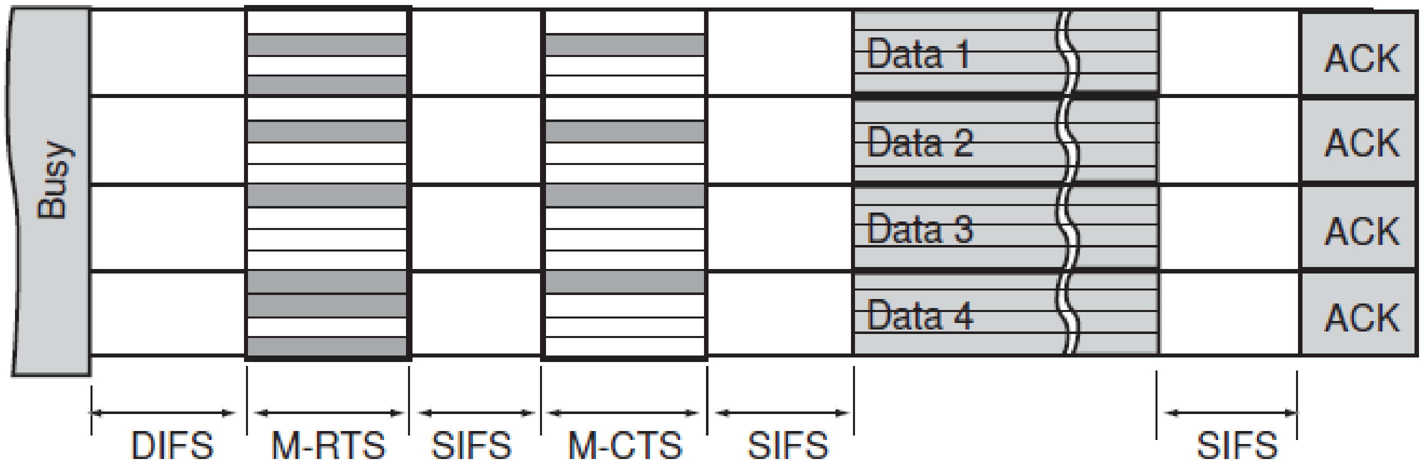
FICA Approach

- A new PHY architecture
  - Rely on carrier-sensing and broadcasting for synchronization
  - Adopt new symbol structure to accommodate the time misalignment

- A new MAC contention and backoff scheme
  - Frequency-domain contention and backoff

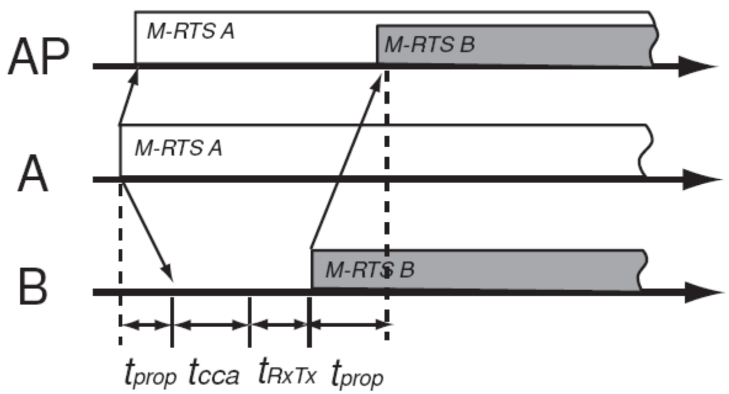
Overview

- Divide wide-band channel into orthogonal subchannels
- M-RTS/M-CTS/DATA/ACK access sequence

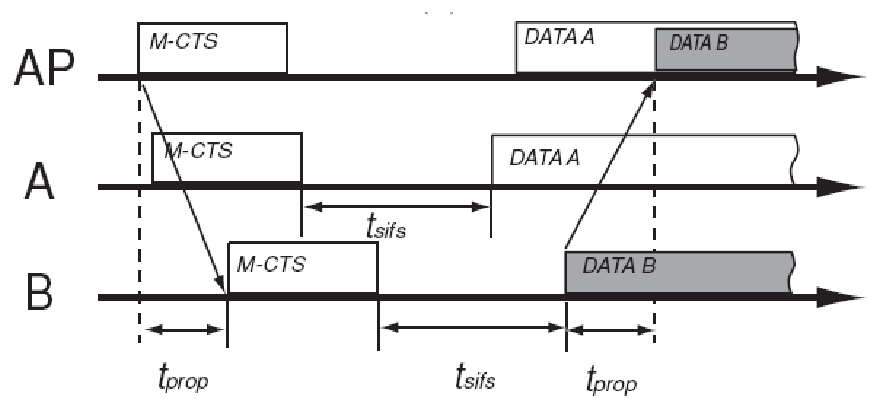


FICA PHY Architecture

- Analyze the timing misalignment in WLAN with carrier-sensing and broadcasting



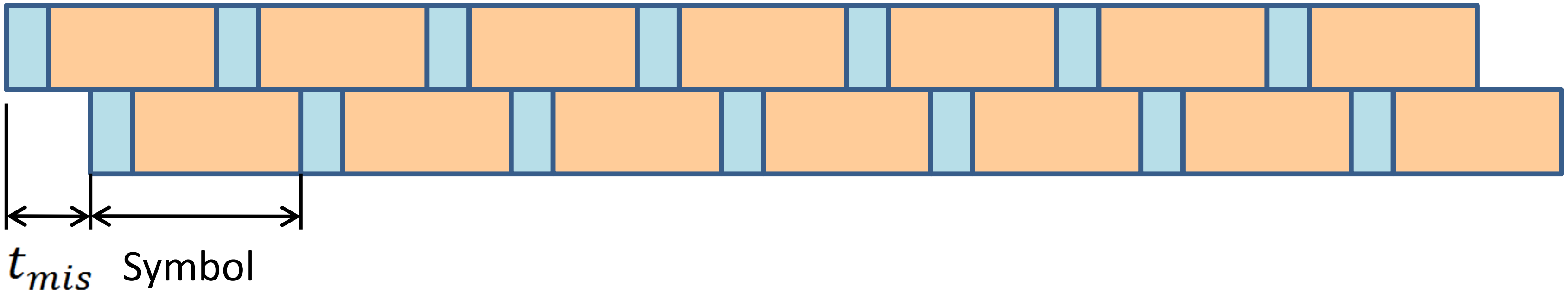
Carrier-sensing $t_{mis} < 11\mu s$



Broadcasting $t_{mis} < 2\mu s$

FICA PHY Architecture (cont.)

- Design a proper cyclic-prefix to accommodate the timing misalignment



FICA PHY Architecture (cont.)

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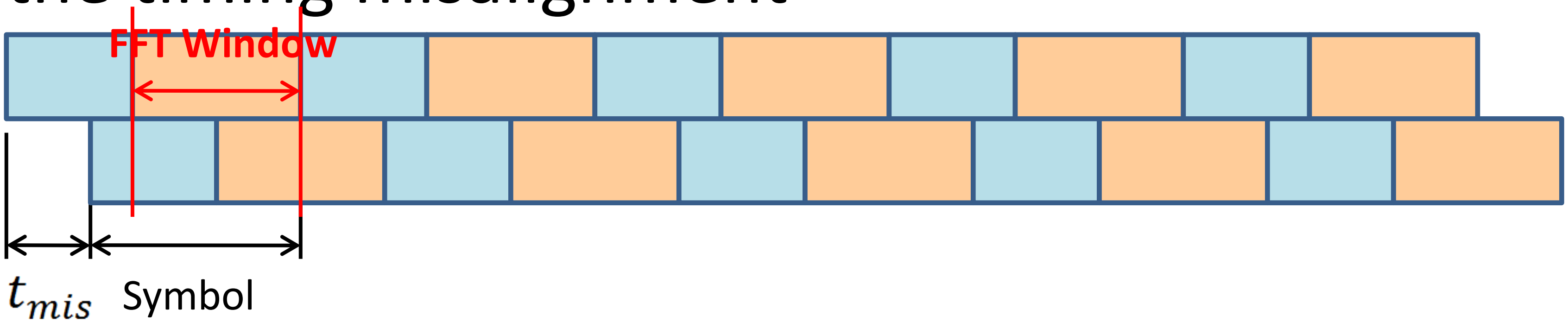
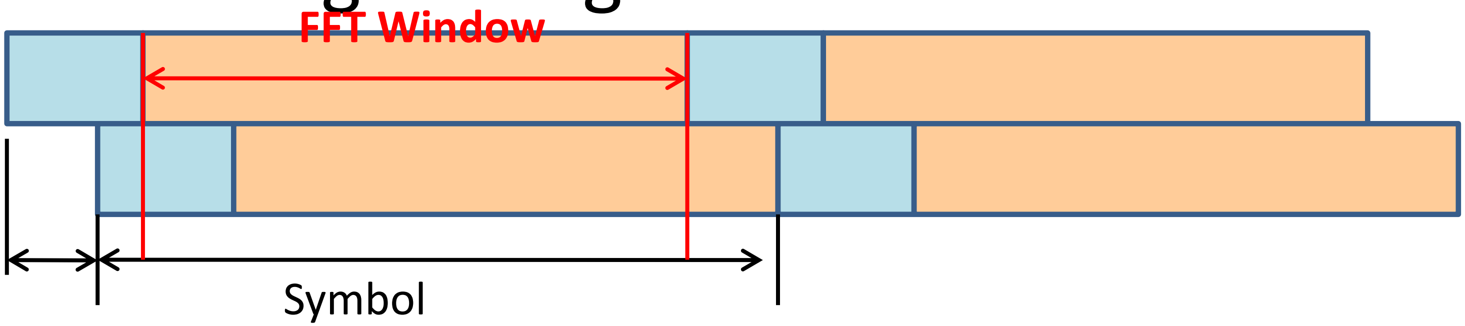


  – Enlarged CP size to be longer than the misalignment
    - Long CP for M-RTS - coordinated with carrier sensing
    - Short CP for M-CTS/DATA/ACK – synchronized by previous broadcasting signals

FICA PHY Architecture (cont.)

- Design a proper cyclic-prefix to accommodate the timing misalignment



  - Enlarged CP size to be longer than the misalignment
    - Long CP for M-RTS - coordinated with carrier sensing
    - Short CP for M-CTS/DATA/ACK – synchronized by previous broadcasting signals
  - Extend symbol time accordingly to offset the CP overhead

PHY Design Details

OFDM Symbol Parameters

Parameter	Value
$N_{\text{fft\_data}}$	256 points
$t_{\text{fft\_data}}$	12.8 μs
$N_{\text{fft\_mrts}}$, $N_{\text{fft\_mcts}}$	512 points
$t_{\text{fft\_mrts}}$, $t_{\text{fft\_mcts}}$	25.6 μs
$t_{\text{long\_cp}}$	11.8 μs
$t_{\text{short\_cp}}$	2.8 μs
$t_{\text{data\_sym}}$	15.6 μs
$t_{\text{mrts\_sym}}$	37.4 μs
$t_{\text{mcts\_sym}}$	28.4 μs

Data subcarrier width: 78KHz

Subchannel width: 1.33MHz (17 subcarriers)

20 MHz channel: 14 subchannels

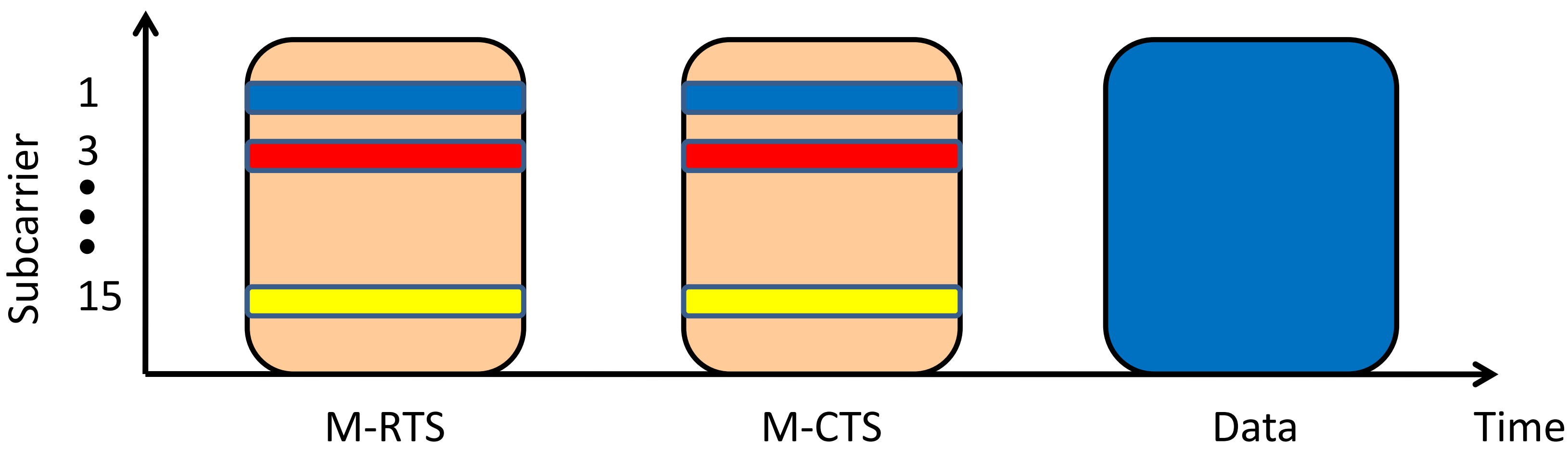
40 MHz channel: 29 subchannels

Configuration	FICA (Mbps)	802.11n (Mbps)
20MHz channel	71.8	72.2
40MHz channel	145	150
40MHz channel, 2xMIMO	290	300
40MHz channel, 4xMIMO	580	600

More details are explained in the paper

Contention and Resolution

- Time domain backoff is inefficient
  - Very large symbol, e.g. 37.4 us for M-RTS → very large backoff slot
- Our solution: frequency-domain contention
  - Physical layer signaling: M-RTS/M-CTS



Frequency Domain Backoff

- Basic idea:
  - Reduce num. of subchannel to contend if collision
  - Increase num. of subchannel to contend if success
  - Analog to congestion control mechanisms

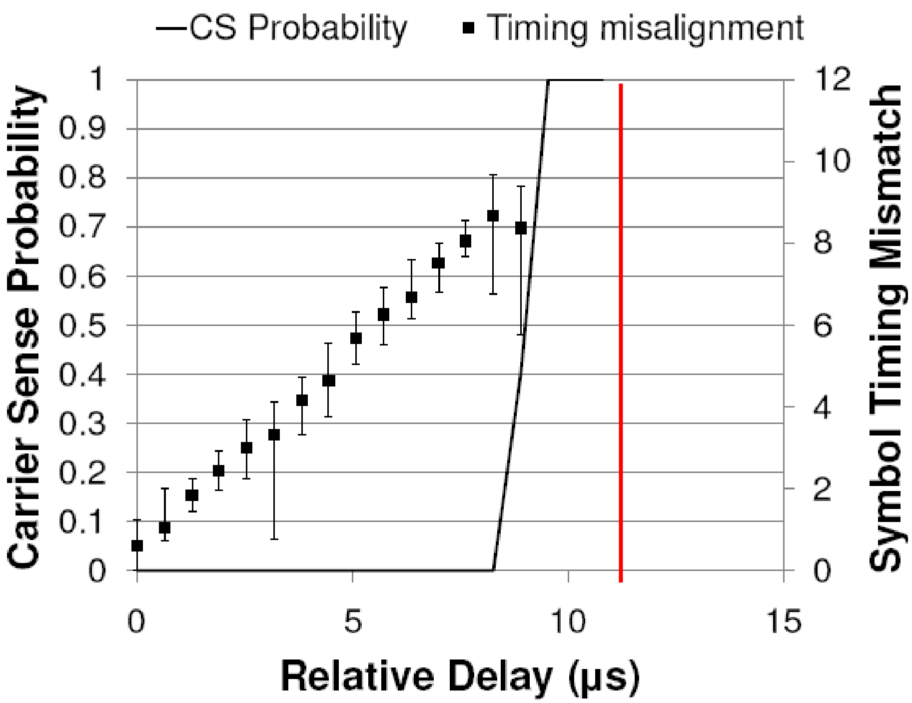
Update1: Reset to max
if *collision detected in any subchannel* **then**
  $C_{\text{max}} = \max(C_{\text{max}}/2, 1)$;
else
  $C_{\text{max}} = C_{\text{total}}$;
end if

Update2: AIMD
if $p\%$ *subchannels have collisions* and $(p > 0)$ **then**
  $C_{\text{max}} = \max(C_{\text{max}} \times (1 - p/100), 1)$;
else
  $C_{\text{max}} = min(C_{\text{max}} + 1, C_{\text{total}})$;
end if

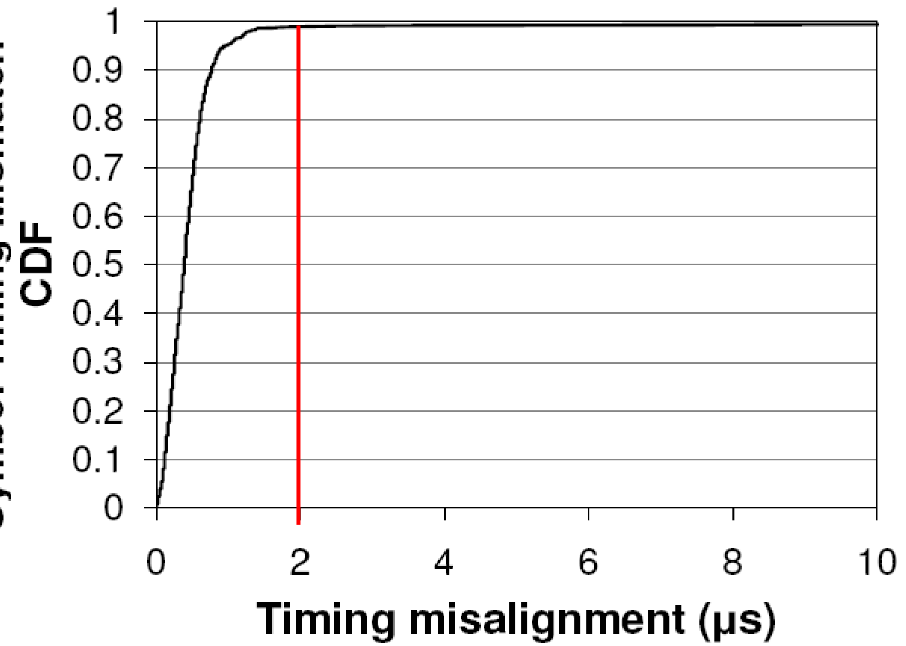
Implementation and Evaluation

- Prototype using the Sora software radio platform
  - Based on SoftWiFi implementation
- Hybrid-evaluation strategy
  - Prototype → feasibility
    - How well timing synchronization can be done with CSMA?
    - How reliable to detect OOK in PHY signal symbols?
    - What is the decoding performance?
  - Simulation → performance gain in large scale networks

Results – Symbol Timing Misalignment

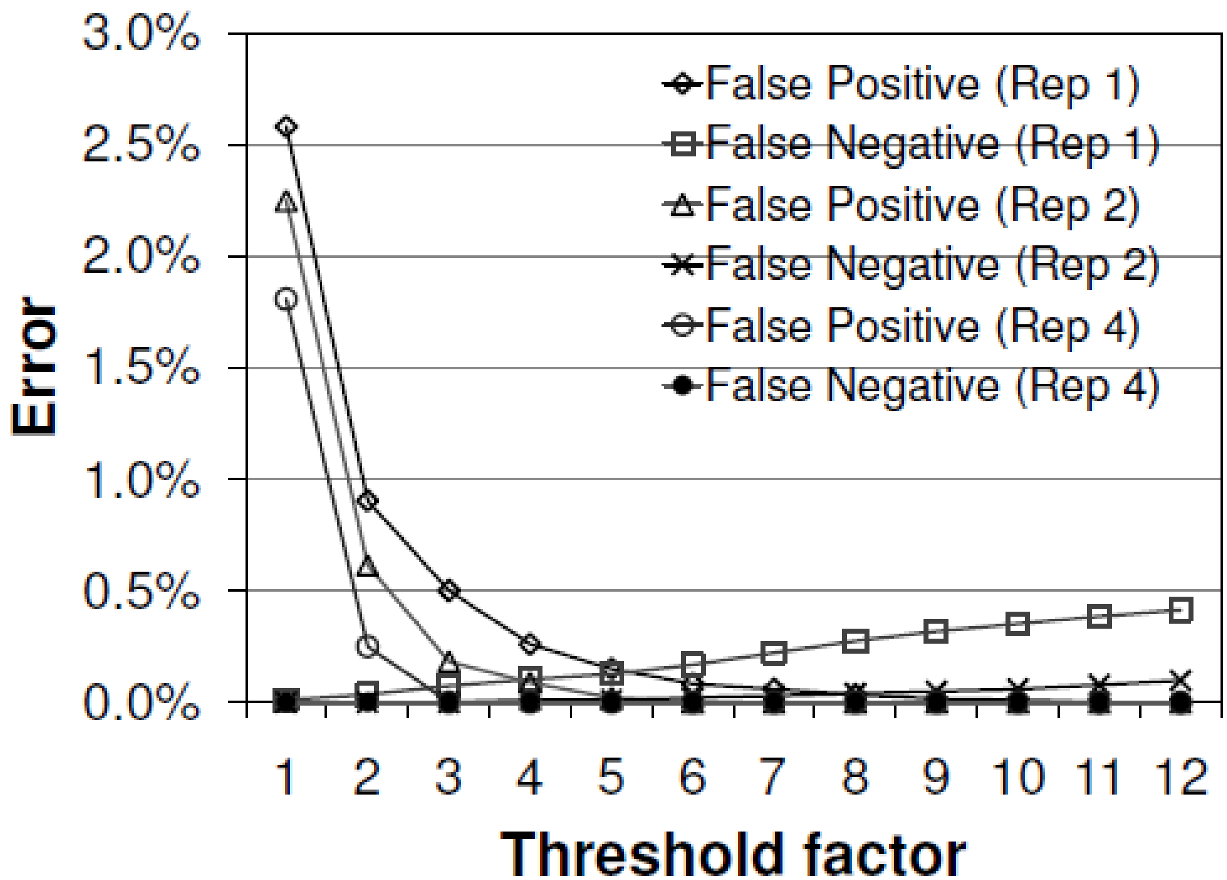


Carrier sensing

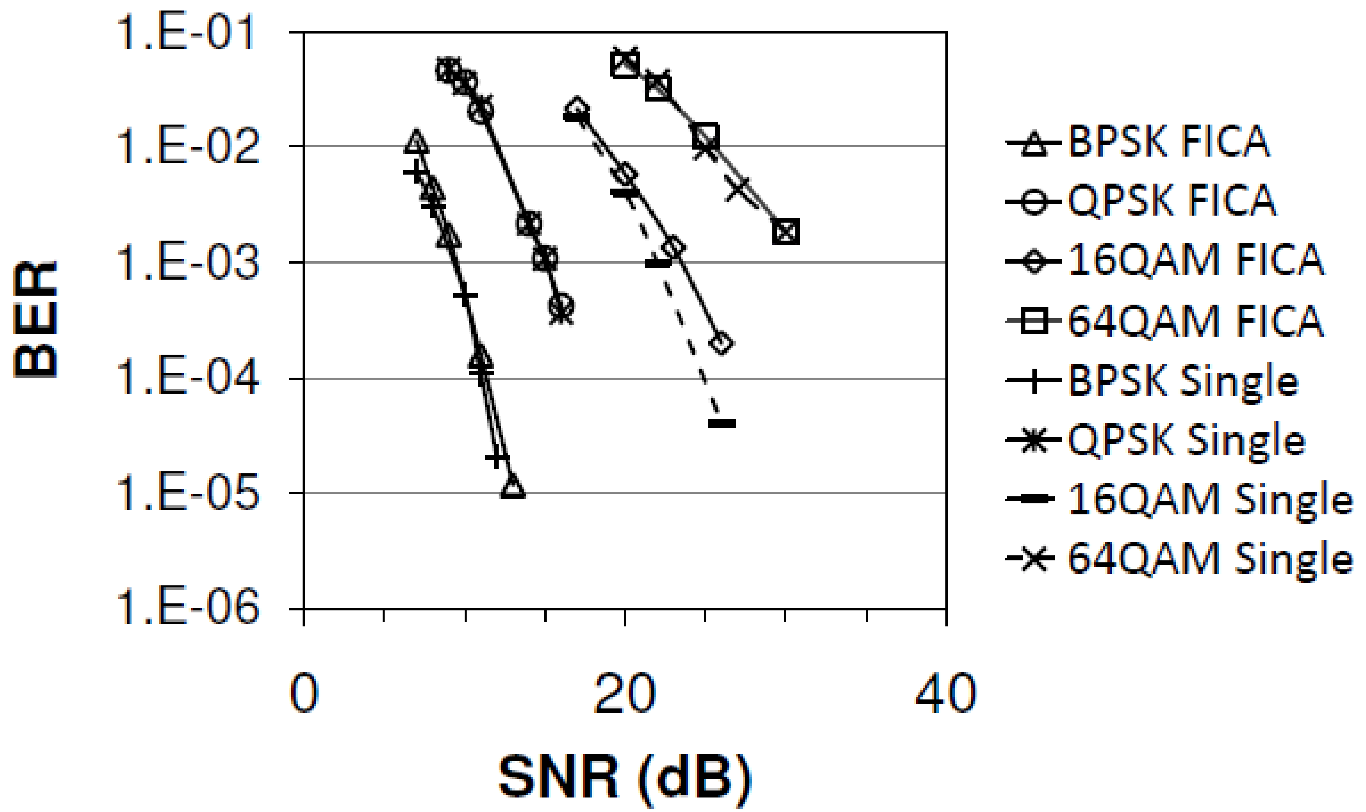


Broadcasting

Results – Signaling Reliability

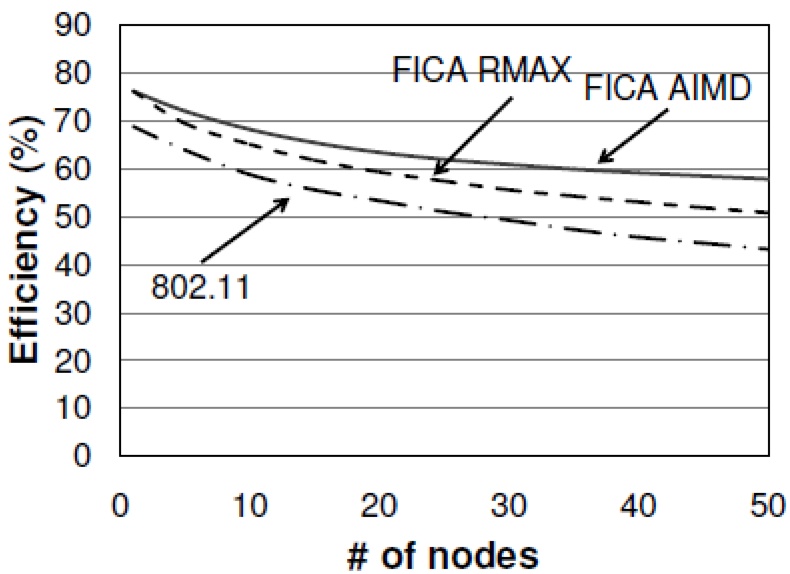


Results – Decoding Performance

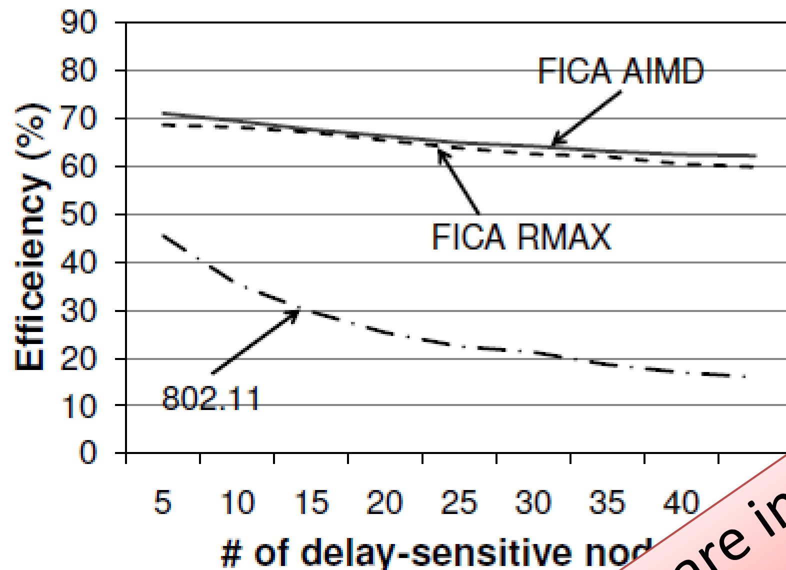


Simulation – Performance Gain

- Full aggregation



- Mixed traffic: 5 saturated with delay sensitive traffic



11n PHY: 600Mbps; FICA PHY: 580Mbps

More results are in the paper!

Related Work

- OFDMA in tight synchronized network
- FARA implements downlink OFDMA in WLAN
- SMACK uses OFDM signaling to send ACK
- MCBC uses OFDM signaling for multi-round contention
- Multi-channel MAC designs

- Voice over IP in WLAN

Conclusions

- MAC efficiency is critical
- Fine-grained channel access is the key
  – Aggregation among different nodes
- FICA: first cross-layer design to enable fine-grained channel random access
  – New PHY architecture based on OFDM
  – New frequency-domain contention and backoff

Thanks!
Take you questions!