Wireless Communication Systems
@CS.NCTU

Lecture 9: MAC Protocols for WLANs

Fine-Grained Channel Access in Wireless LAN (SIGCOMM'10)

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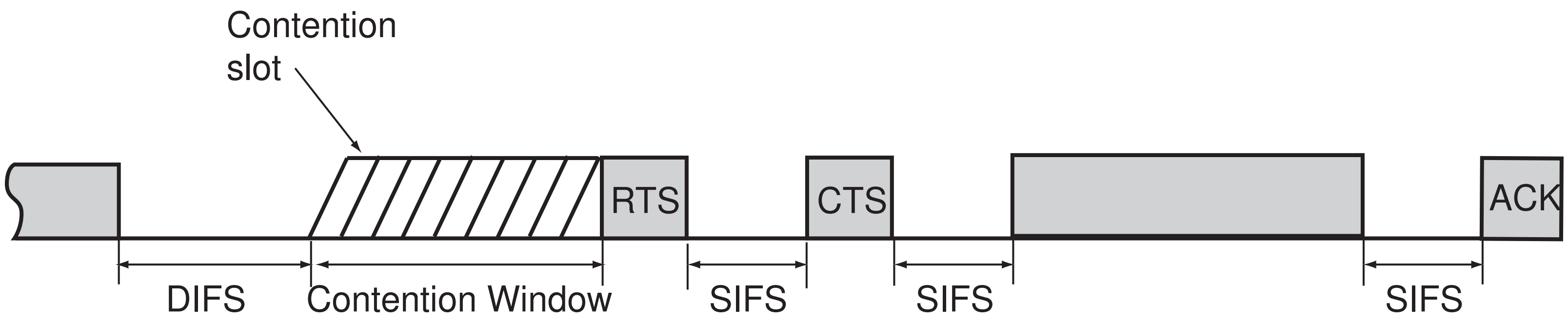
Physical-Layer Data Rate

- PHY layer data rate in WLANs is increasing rapidly
  - Wider channel widths and MIMO increases data rate, e.g., 802.11n supporting up to 600Mbps
  - Data rates for future standards like 802.11ac & 802.11ad are expected to be >1Gbps
- However, throughput efficiency in WLANs is degrading
  - Senders with small amount of data still contend for whole channel
  - Entire channel (single resource) allocated to a single sender

Inefficiency of 802.11MAC



- Heavy overhead
  - DIFS: the minimum time a sender has to sense the channel idle before trying to transmit
  - SIFS: the time for the sender to receive the ACK from the receiver
  - Contention Window: used for the back-off mechanism
  - Contention slot: useful time during which data is transmitted
  - RTS/CTS: used for resolving the hidden terminal problem

Inefficiency of 802.11MAC

- t_{slot}: sending time
- t_{sifs}: SIFS time
- t_{cca}: time to reliably sense a channel
- t_{TxRx}: time needed to change from rcv/snd mode & vice-versa
- t_{prop}: signal propagation time
- $t_{preamble}$: time for sending training symbols (channel estimation)

Parameter	Value
t_{slot}	$9\mu s$
t_{sifs}	$10\text{–}16\mu s$
t_{cca}	$4\mu s$
t_{TxRx}	$\leq 5\mu s$
t_{prop}	$\leq 1\mu s$
t_{preamble}	$20\text{–}56\mu s$

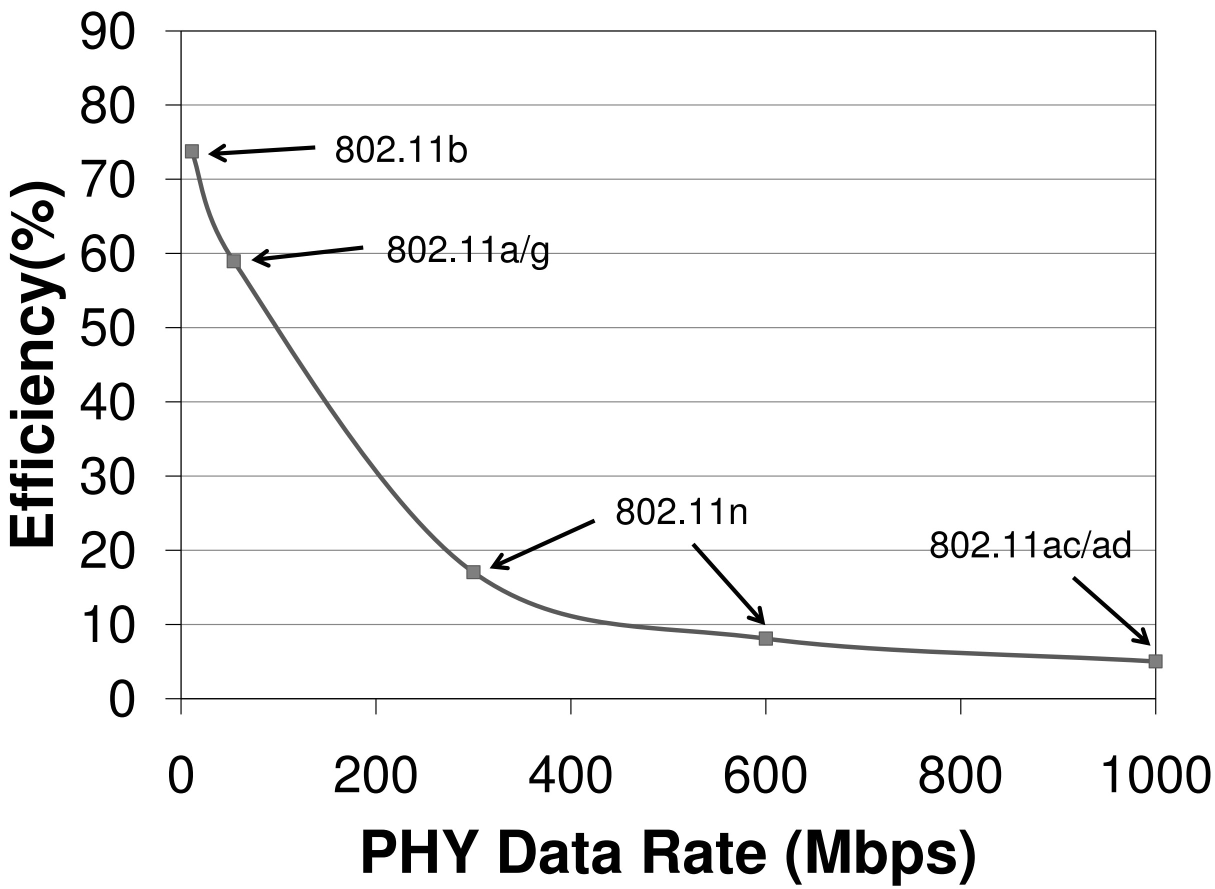
Inefficiency of 802.11MAC

Channel efficiency:

$$\eta = \frac{t_{\text{data}}}{\underbrace{t_{\text{slot}} W + t_{\text{DIFS}} + t_{\text{PLCP}} + t_{\text{SIFS}} + t_{\text{ACK}}}_{\text{overhead}} + t_{\text{data}}}$$

- Only t_{data} is used for transmitting application data, the others times are overhead
- As PHY data rate increases, only t_{data} decreases proportionally while the overhead remains the same
  - (100bits) need 17us for 6Mb/s, but only 1.85 us for 54Mb/s

Inefficiency of 802.11MAC



Efficiency decreases as the PHY data rate increases

How to solve inefficiency

- Frame aggregation : Transmitting larger frames decreases the inefficiency
  - What about low latency applications?
- Divide the channel in multiple subchannels
  - Senders can transmit simultaneously
  - One sender can transmit on more channels than the others (similar to OFDMA)
  - ☺ each STA has a lower PHY rate, but the aggregate rate is unchanged
  - ☺ all the STAs only need one round of the contention procedure, as a result lowering the overhead on average

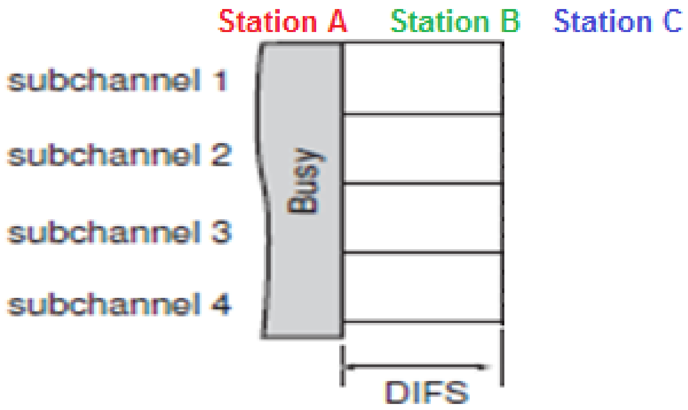
OFDM

- Divide the available spectrum into many partially overlapping narrowband subcarriers
- Choose subcarrier frequencies so that they are orthogonal to one another, thereby cancelling cross-talk
- Thus, eliminating the need for guard bands
- Used in 802.11a/g/n, WiMax and other future standards

Fine-Grained Channel Access

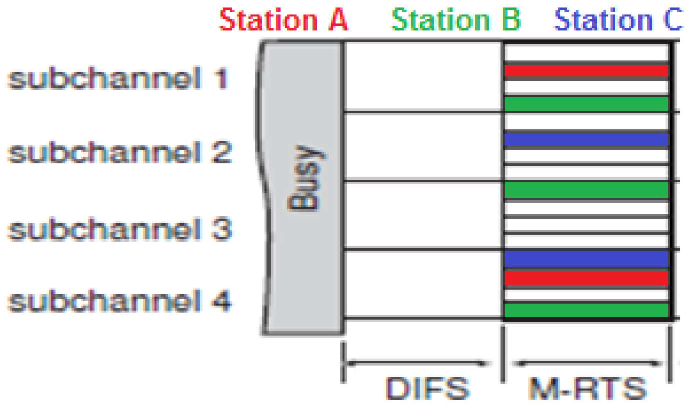
- OFDMA does not support random access
- Design a system OFDM like that allows random access
  - Split channel width into multiple subcarriers
  - A number of subcarriers form a sub-channel
  - Each subcarrier can use a different modulation scheme
  - Assign each sender a number of sub-channels according to their sending demands
  - Apply OFDM on the whole channel to eliminate the need of guard bands
  - Revise the MAC contention mechanism used in 802.11

Basic Idea



- Transmission opportunity arises when the whole channel becomes idle
- All STAs contend for different sub-channels after DIFS

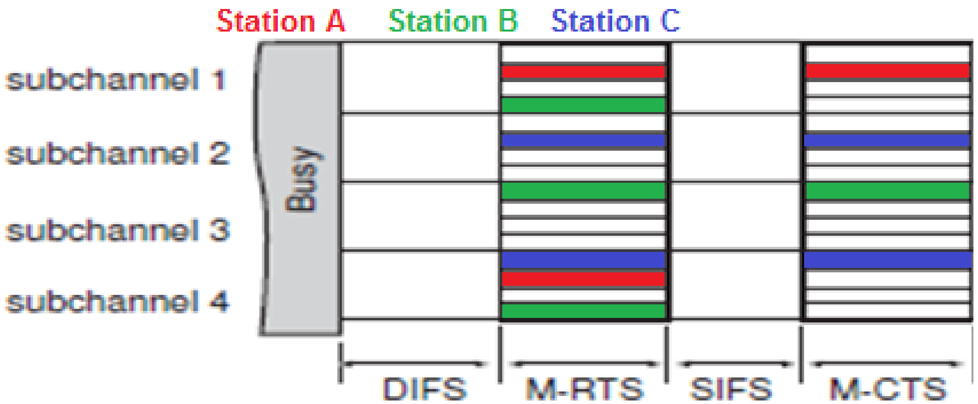
Basic Idea



Frequency-Domain Contention

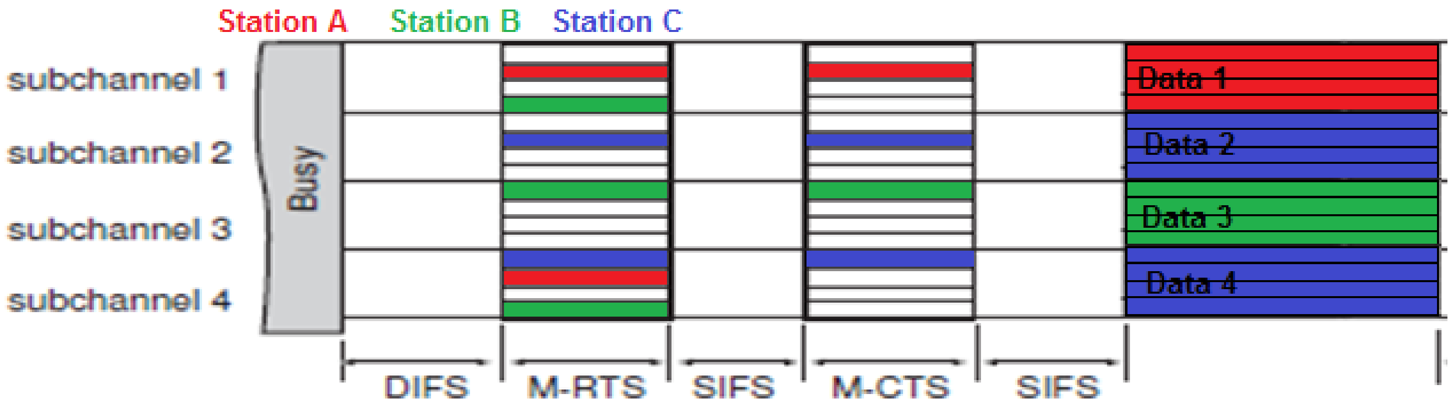
- Transmission opportunity arises when the whole channel becomes idle
- All STAs contend for different sub-channels after DIFS
- All STAs transmit M-RTS simultaneously on randomly-selected sub-channels

Basic Idea



- Transmission opportunity arises when the whole channel becomes idle
- All STAs contend for different sub-channels after DIFS
- All STAs transmit M-RTS simultaneously on randomly-selected sub-channels
- AP picks a winner for each sub-channel and broadcast the result using M-CRS

Basic Idea



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- Selected STAs start sending

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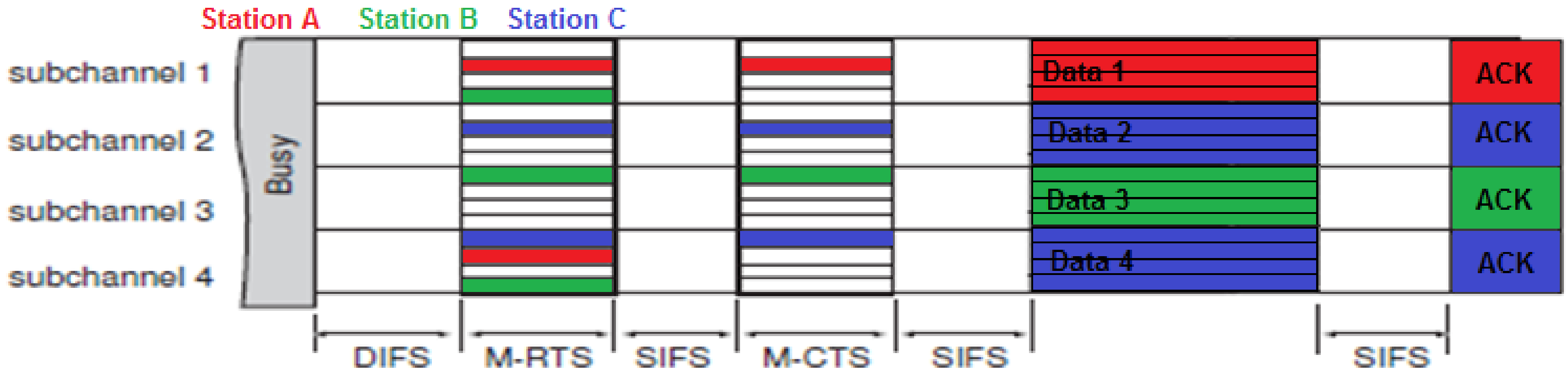

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- Selected STAs start sending
- ACK for the correctly delivered packets

Frequency-Domain Contention

- The entire channel is split into multiple subcarriers
- 16 data subcarriers + 1 pilot subcarrier form a sub-channel
- Each node contends for one or more channels by means of M-RTS/M-CTS
- M-RTS/M-CTS use simple binary amplitude modulation (BAM)
- Receivers can simply detect BAM symbol by checking energy level (zero amplitude = 0 else 1)
- *K* subcarriers from each sub-channel form a contention band

Frequency-Domain Contention

- Contending nodes randomly pick a subcarrier within the subchannel's contention band and send a signal "1" using BAM
- The AP chooses a winner based on a predefined rule (e.g. the one picking the smallest subcarrier index as the winner)
- The AP sends an M-CTS back on the same subcarrier
- The STA detects itself as the winner if the tone tagged in the returned M-CTS matching what it has selected
- Winners wait SIFS and then start transmitting

Benefits of Freq. Domain Contention

- No need to random backoff, further saving protocol overhead
- Single broadcast domain → naturally resolve the hidden terminal problem without using expensive traditional RTS/CTS

Practical Issues

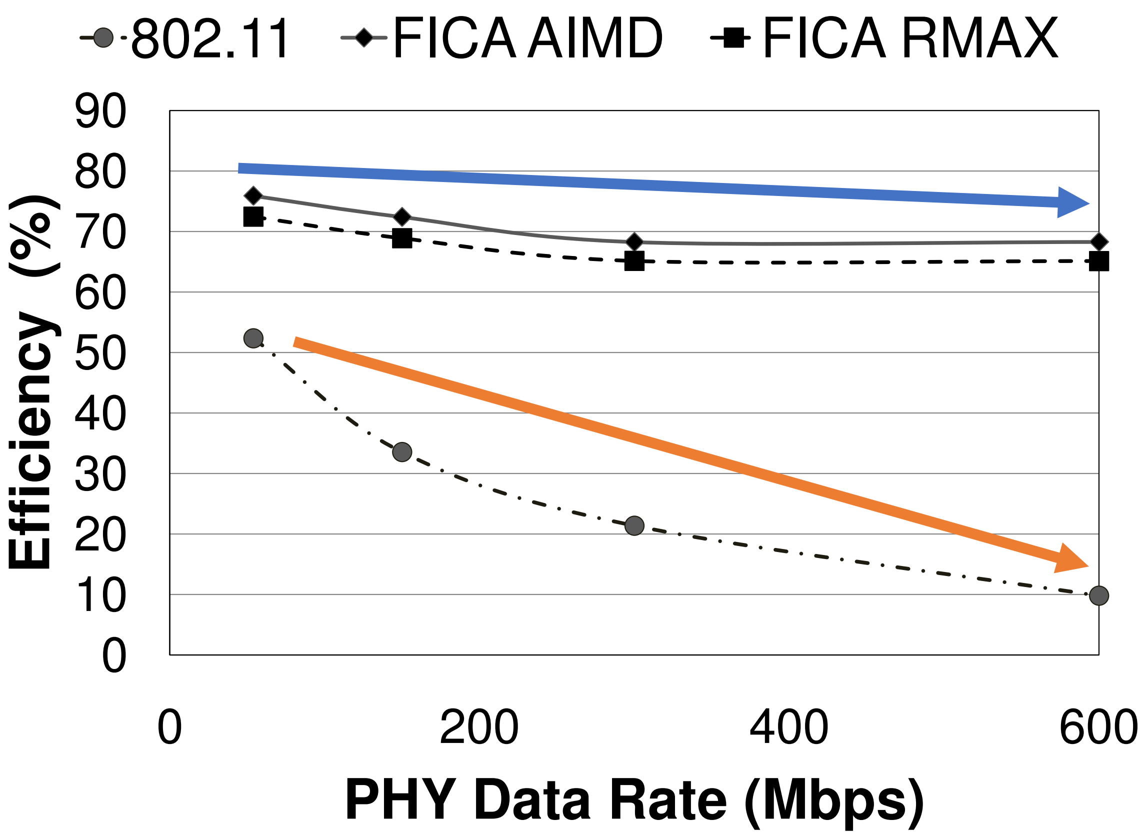
- Collisions may still occur
  - When STAs pick the same subcarrier in M-R TS
- How many subcarriers should be use for contention purposes?
  - Related to the number of STAs with traffic demands simultaneously
- Hash(receiverID) between 0 and (m-1) to represent receiver information in M-RTS
  - The AP does not explicitly know who is the winner
- Time synchronization is critical
  - STA needs to synchronize with each other to avoid inter-subchannel interference

Frequency-Domain Backoff

- In a heavily-contended network, multiple senders could contend on the same subcarrier → collisions
- Limit the number of channels a sender can contend for
  - Pick up to *n* subchannels to contend for
  - $n = \min(C_{max}, l_{queue})$
  - C_{max} decreases when collisions are detected
  - L_{queue}: the number of fragments in node's sending queue
  - Mechanism similar to exponential backoff and additive increase/multiplicative decrease

Performance – Efficiency

- Verified via simulations



Efficiency is nearly stable when the PHY data rate increases

Conclusion

- Traditional 802.11 MAC is inefficient for high PHY data-rates
- FICA addresses this inefficiency by using fine-grained channel access
- Employ a novel frequency-domain contention mechanism that uses physical layer RTS/CTS signaling
- Have shown via simulations that FICA outperformed 802.11n
- Resolve the synchronization issue