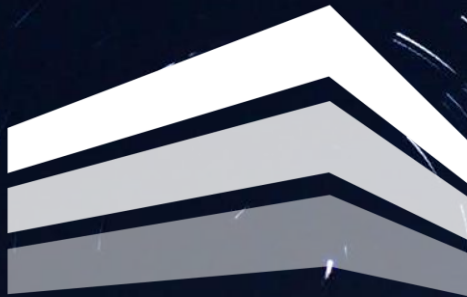


Simultaneous Transmit-Receive Multi-Channel Operation in Next-Generation WLANs



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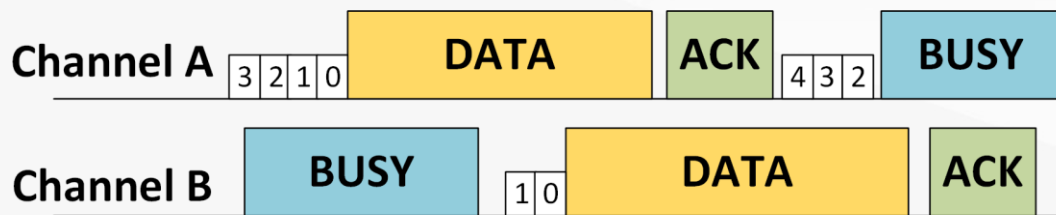


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IEEE 802.11be Multi-Channel Operation

- IEEE 802.11be
 - Next-generation IEEE 802.11 standard project after IEEE 802.11ax
 - App requirements of high throughput, low latency and high reliability
- Multi-Channel Operation
 - Emergence of dual-radio end user devices (STAs) and tri-band Access Points (APs)
 - Data from same traffic session over multiple channels using first available channel
- Asynchronous operation
 - By default, independent medium access on each channel with simultaneous transmission and reception over multiple channels

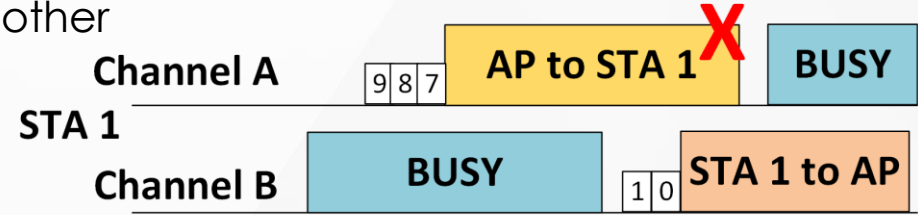


STR Capability

- **STR:** simultaneous transmission and reception over a pair of channels
- STR capability
 - Ability to support reception on one channel while transmitting on other channel
 - Depends on RF design and operation parameters including channel location, bandwidth of each channel, antenna distribution, etc.
- AP is always STR capable
 - Typically many-antenna systems and selects the channels of operation
 - Otherwise, negligible gain from multi-channel operation
- **Non-STR STAs**
 - STAs may lack STR capability due to smaller form factor and simpler design
 - Indicate capability to AP dynamically based on operation parameters
 - Example: two channels on 5 GHz band

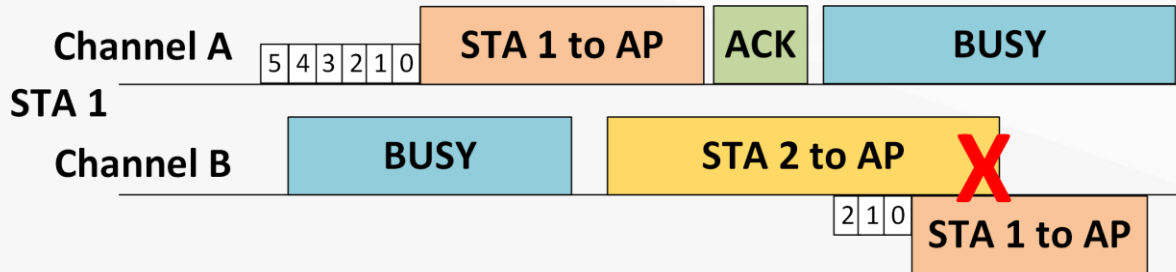
Challenging Scenarios with non-STR STAs

- Reception failure at non-STR STA
 - AP and non-STR STA transmit to each other
 - Non-STR STA fails to receive



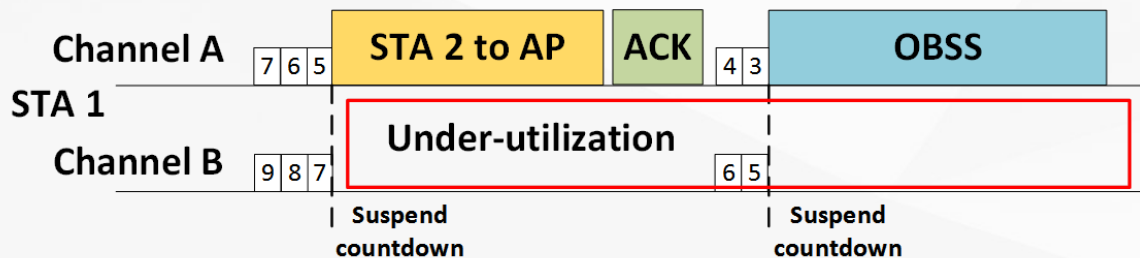
- Deafness Issue
 - Non-STR STA completes transmission on Channel A
 - Fails to detect ongoing transmission on Channel B
 - Collision at AP impacting other STAs' performance

STA 1: Non-STR STA
STA 2: other STA



Conservative Baseline Solution

- Prevention of reception failure at non-STR STAs
- Procedure at non-STR STA
 - Suspend backoff countdown on Channel A when in receive state on Channel B
- Procedure at AP
 - Do not transmit to any non-STR STA when receiving an intra-BSS frame



STA 1: Non-STR STA,
STA 2: single link STA
BSS: AP's network
OBSS: Neighboring BSS

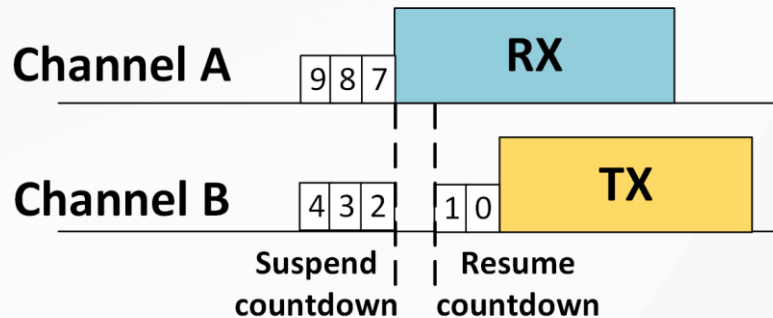
- **Medium under-utilization by non-STR STA and deafness issue not addressed**

Contributions

To maximize the multi-channel medium utilization of non-STR STAs, we propose Constraint Aware Asynchronous multi-channel operation (CA- ASYNC)

- **Opportunistic Backoff Countdown Resumption**
 - Protocol to identify suitable scenarios and resume medium access
- **Multi-Channel Busy Status Feedback**
 - Protocol to prevent non-STR STA transmission during intra-BSS reception at AP
- **Fair Transmission Opportunity Aggregation**
 - Simultaneous uplink multi-channel transmission with fairness consideration
- Using custom ns-3 simulator, we analyze CA-ASYNC's performance

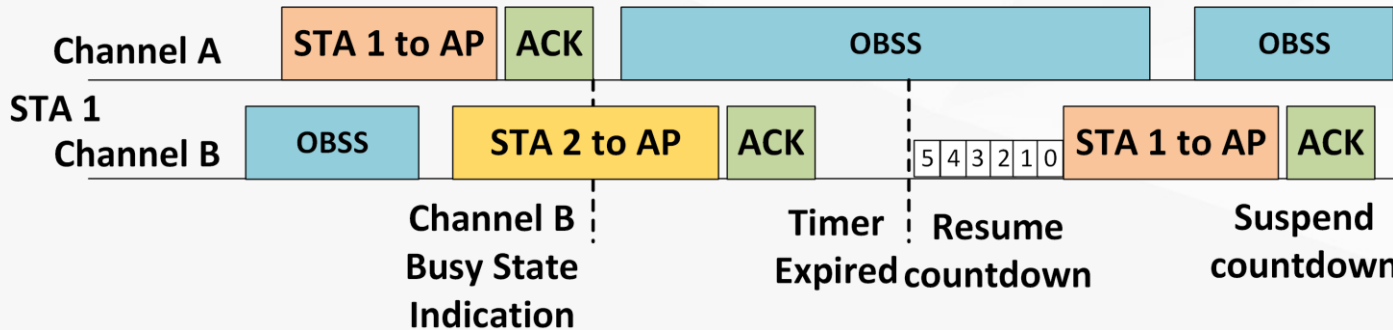
Opportunistic Backoff Countdown Resumption



- **Objective:** To help non-STR STA determine with minimum delay if it can resume backoff countdown on Channel B after switching to busy state on Channel A
- BSS Color, UL/DL flag in IEEE 802.11ax PHY header
- STA identifier in PHY header
 - In DL, backoff countdown resumed if STA ID does not match non-STR STA's ID
 - In UL, AP can transmit to other STAs on other channels instead of this non-STR STA

Multi-Channel Busy Status Feedback

- Non-STR STA is “deaf” on Channel B after its transmission on Channel A
- Objective:** To prevent non-STR STA's transmission on Channel B if there is an ongoing transmission in the BSS
- Proposal**
 - If AP is currently receiving intra-BSS frame on Channel B, AP indicates Busy Status in feedback to non-STR STA on Channel A
 - Non-STR STA suspends medium access on Channel B until the earliest event between receiving an intra-BSS frame or pre-defined countdown expiry

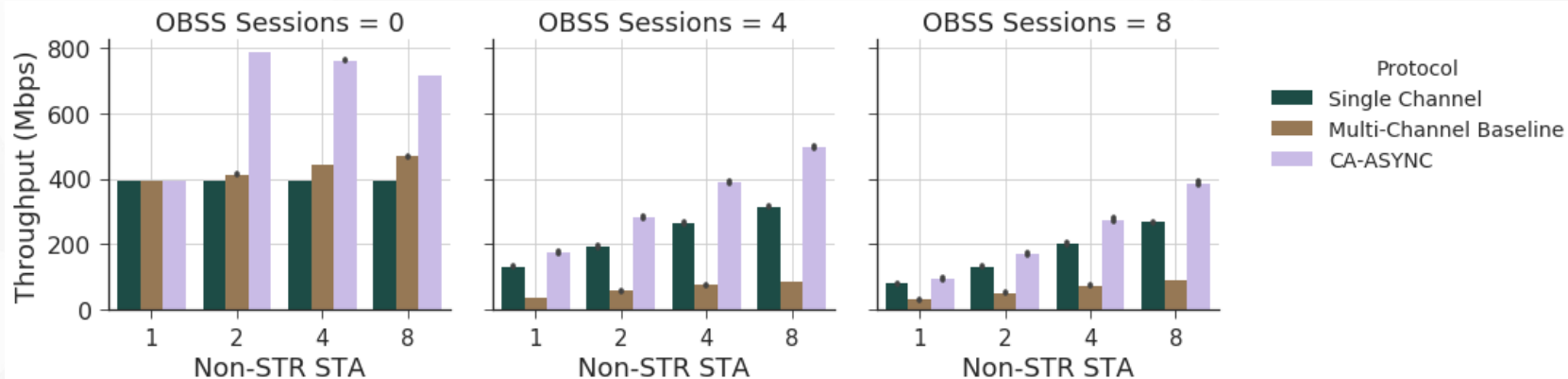


STA 1: Non-STR STA
STA 2: other STA

Performance Evaluation

- Implemented CA-ASYNC and alternative strategies in ns-3 simulator
- Network model
 - Single AP operating a two-channel BSS with varying number of non-STR STAs
 - Each channel occupies 80 MHz
 - Effective data rate of 400 Mbps on each channel including overhead
 - Varying number of single channel STAs and OBSS traffic flows
- Traffic model
 - To isolate non-STR STA medium utilization, focus on uplink traffic
 - Full-buffered traffic generated at each non-STR STA
 - Non-STR STA uses obtained channel access for 5.5 ms of data transmission
 - OBSS traffic flow uses channel access for a random duration up to 5 ms
- Over 100 separate runs of 10 seconds in network time per configuration

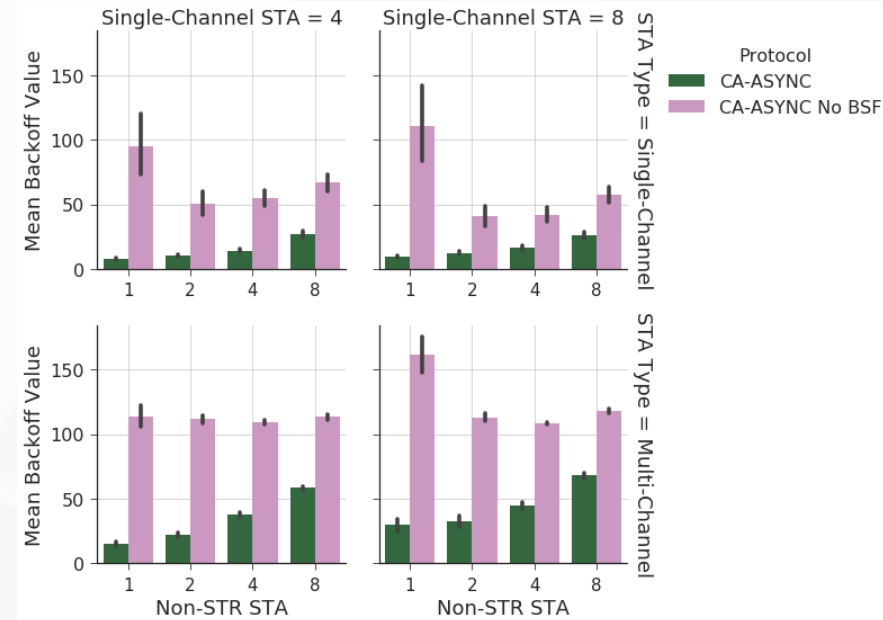
CA-ASYNC's Medium Utilization



- No OBSS traffic case
 - With single non-STR STA, only one channel used at a time
- Multi-channel baseline
 - Contention deferred on all channels when a channel is busy due to other traffic
 - Leads to worse performance than even single channel operation
- **CA-ASYNC gain**
 - Contention resumed by non-STR STA on identifying OBSS or intra-BSS uplink transmission or downlink transmission not for itself

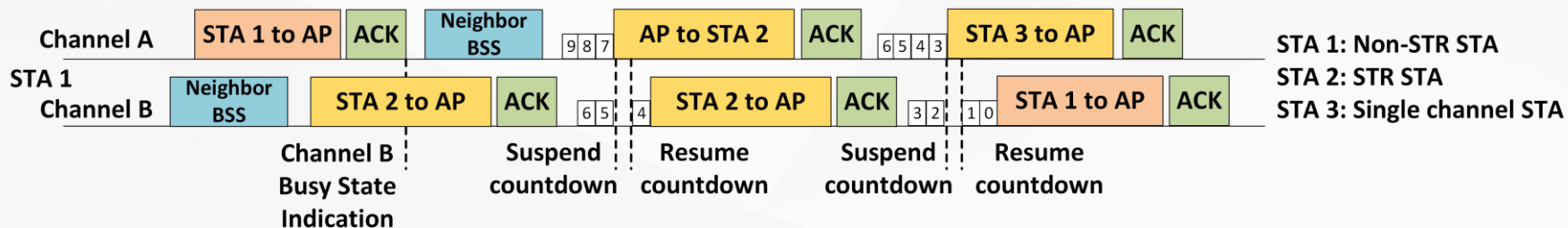
CA-ASYNC's Busy Status Feedback

- Transmission failure => doubling of 802.11 contention and backoff counter value chosen randomly from the bigger range
- CA-ASYNC No BSF = CA-ASYNC without Busy Status Feedback protocol
- The mean backoff value of single channel STAs as well as non-STR STAs is significantly lower for CA-ASYNC including Busy Status Feedback



Conclusion and Future Work

- Multi-channel operation is a key feature of next-generation IEEE 802.11be
- New challenges introduced by non-STR STAs
- **Proposed CA-ASYNC protocol to improve medium access opportunities for non-STR STAs and eliminate non-STR STA deafness problem**



- Several topics for further research including
 - Simultaneous downlink transmissions to non-STR STAs
 - Protection mechanisms for multi-channel operation