Performance Analysis of IEEE 802.11ac Wireless Mesh Backhaul Networks

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Outlines

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- IEEE 802.11ac default MAC scheme
- Proposed handshaking scheme
- Frame scheduling schemes
- Throughput evaluation

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Scenario

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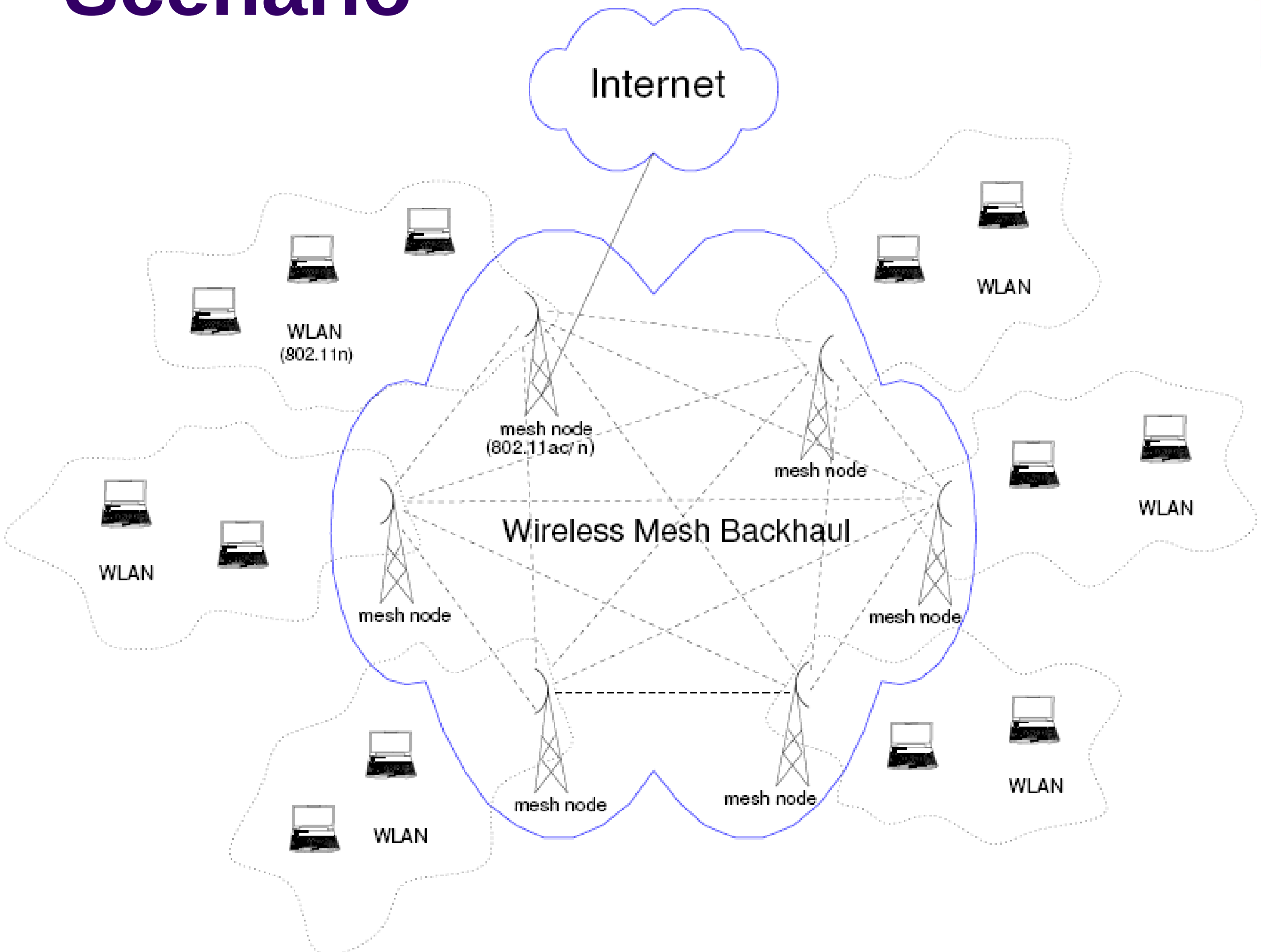

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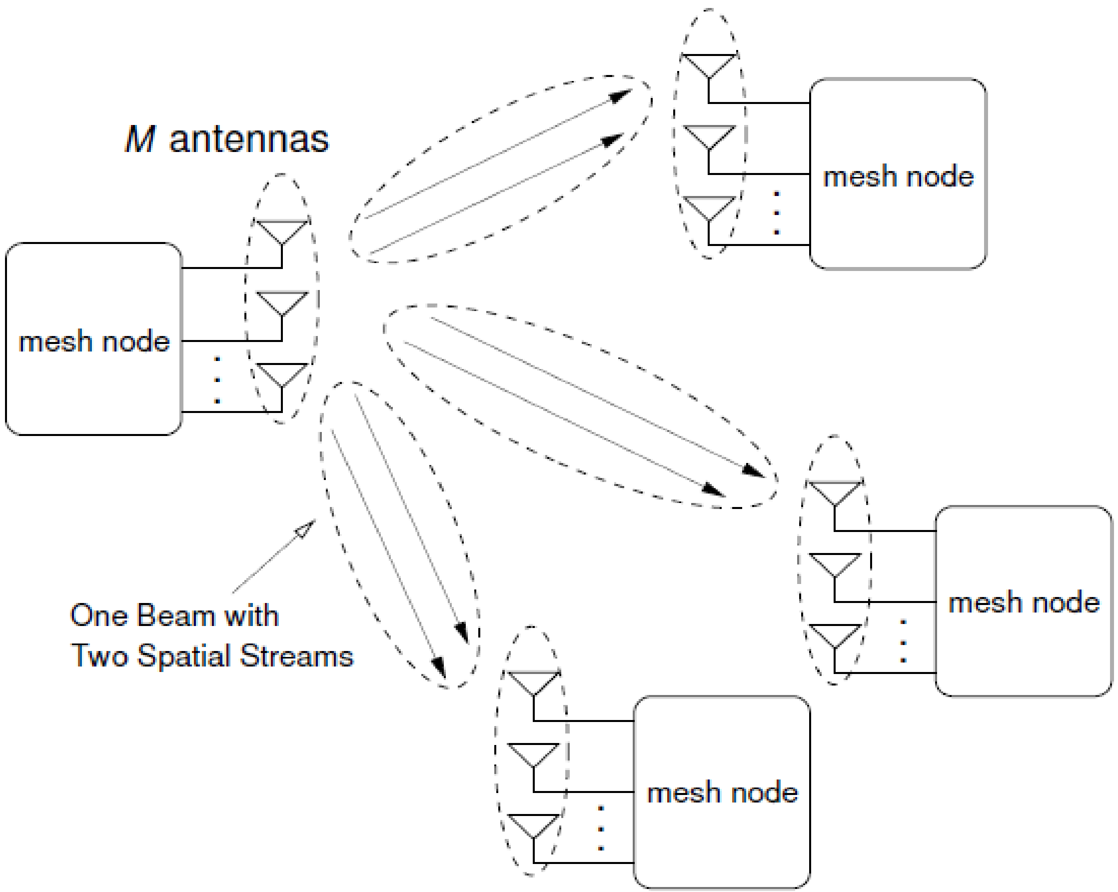
Mesh backhaul networks



- *n* identical mesh nodes
- Equipped with *M* antennas
- Fully-connected & saturated
- A mesh node can send N_b beams in parallel
- Each beam can contain up to N_s streams

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IEEE 802.11ac Basic Access

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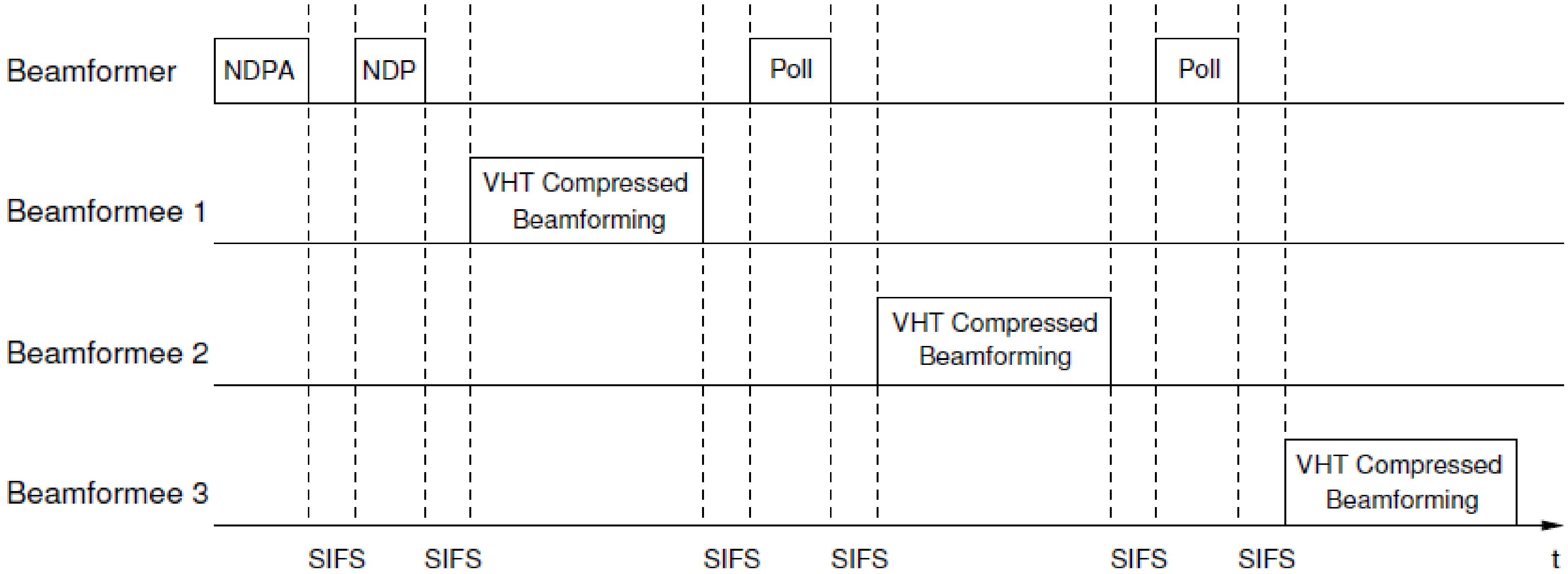
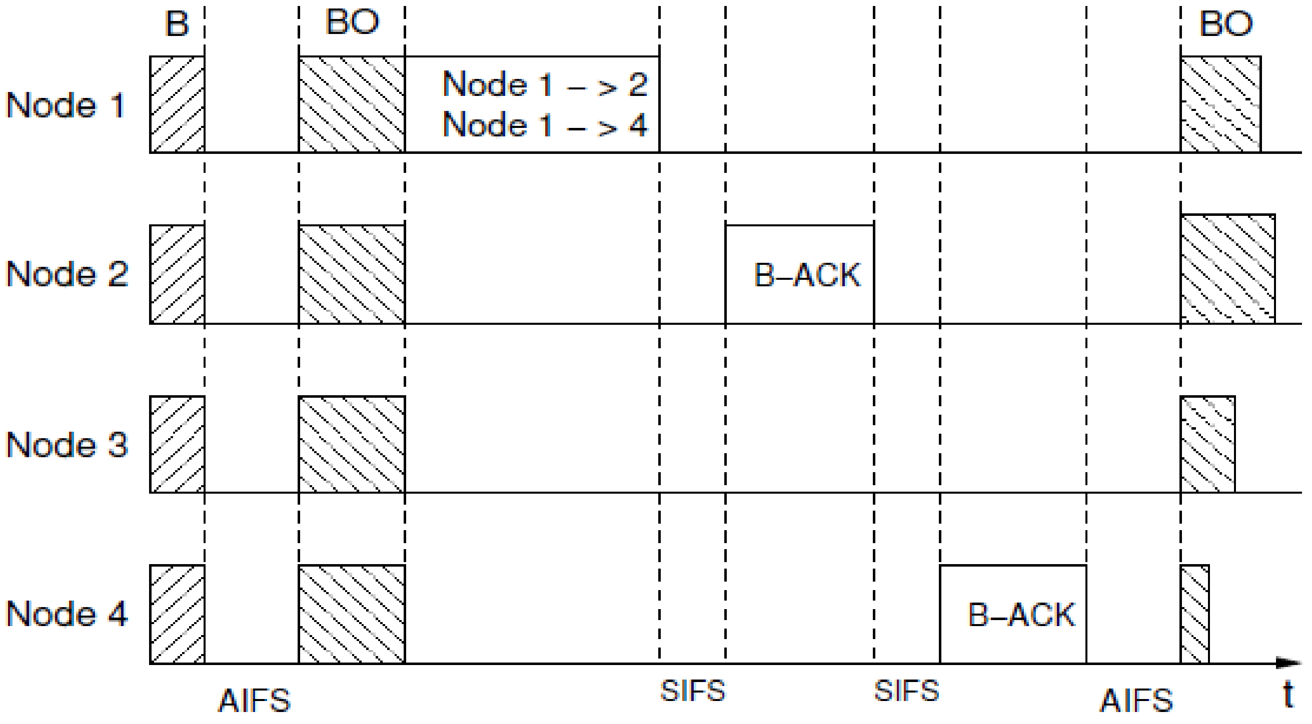
1. Obtain channel information for Multi-user beamforming



Explicit Compressed Feedback Protocol (ECFB)

IEEE 802.11ac Basic Access

2. Multi-user data transmissions



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MU-RTS/CTS: An integrated way

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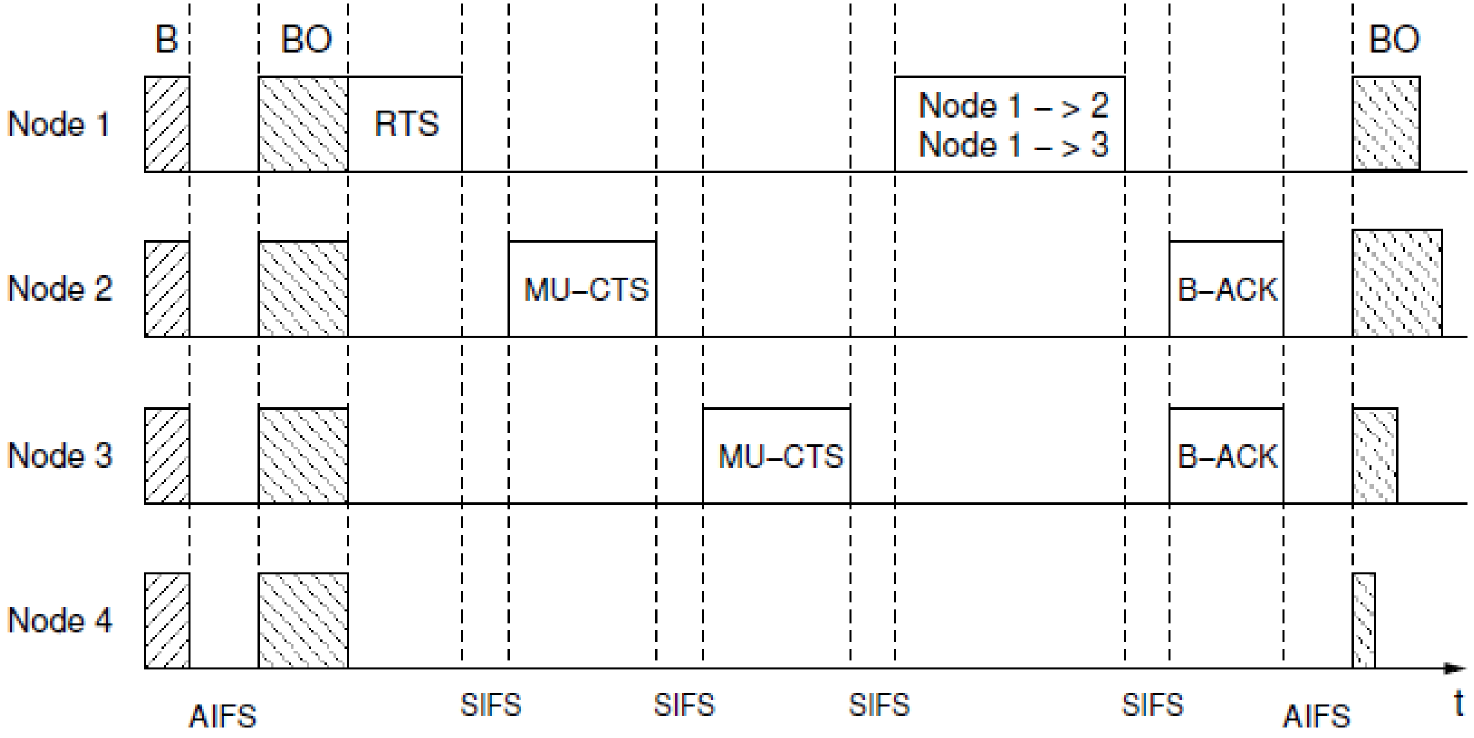
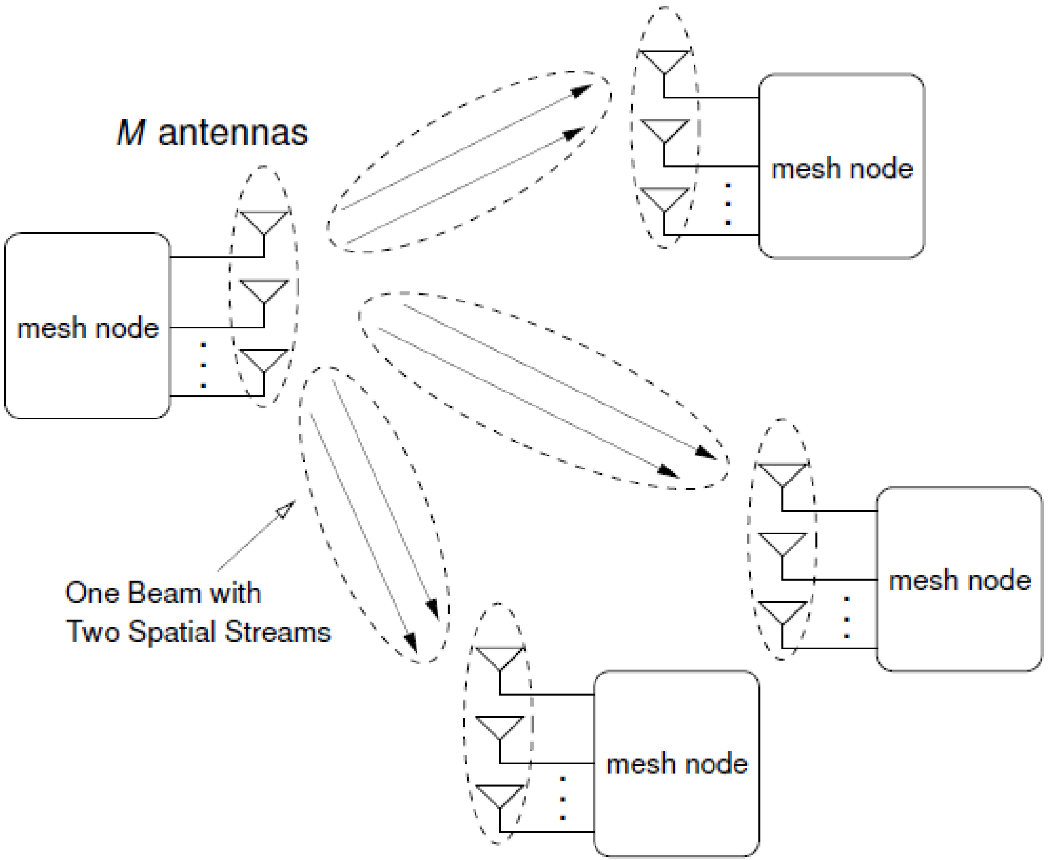
Integrate the channel information and data transmissions



More Beams or More Streams?



- *n* identical mesh nodes
- Equipped with *M* antennas
- N_b no. of beams
- N_s no. of streams

$$\begin{aligned} &\text{maximize} && N_b \cdot N_s \\ &\text{subject to} && N_b \le \min(M, \min(n-1, 4)) \\ &&& N_s \le \min(M, 4) \\ &&& N_b \cdot N_s \le \min(M, 8) \\ &&& N_{s,i} = N_{s,j} \end{aligned}$$

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More Beams or More Streams?

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$$\text{maximize} \quad N_b \cdot N_s$$

$$\text{subject to} \quad N_b \le \min(M, \min(n-1, 4))$$

$$N_s \le \min(M, 4)$$

$$N_b \cdot N_s \le \min(M, 8)$$

$$N_{s,i} = N_{s,j}$$

e.g., $M = 8$, $n = 8$

$N_b = ?$, $N_s = ?$

- Stream-greedy algorithm: maximize N_s, $N_b = 2$, $N_s = 4$

- Beam-greedy algorithm: maximize N_b, $N_b = 4$, $N_s = 2$

- Stream-independent algorithm: An extension of Beam-greedy, eliminating the limitation that max N_b are 4
  $N_b = 8$, $N_s = 1$

$$N_b \le \min(M, \min(n-1, 4)) \longrightarrow N_b \le \min(M, n-1)$$

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The throughput *S*

γ the probability that a slot contains ECFB traffic.

p_s, p_c, p_e the probability that a slot contains successful, colliding and no traffic; τ the probability that a node transmits in a random slot.

$T_{csi,s}$, $T_{csi,c}$, $T_{data,s}$, $T_{data,c}$, σ are corresponding slot durations.

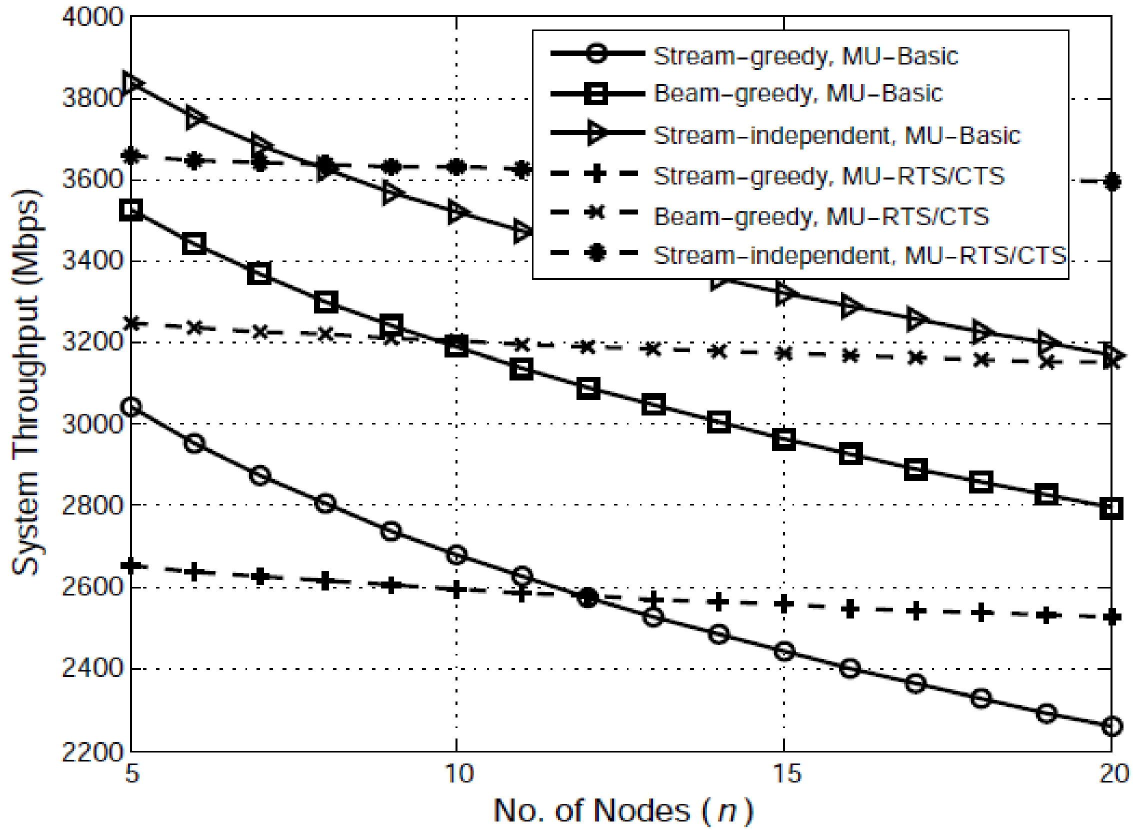
L the frame length, N_f the number of frames in A-MPDU.

$$p_{\mathrm{e}} = (1-\tau)^n \quad p_{\mathrm{s}} = \binom{n}{1}\tau(1-\tau)^{n-1} = n\tau(1-\tau)^{n-1} \quad p_{\mathrm{c}} = 1 - p_{\mathrm{e}} - p_{\mathrm{s}}$$

$$S = \frac{(1-\gamma)\cdot p_{\mathrm{s}} \cdot N_{\mathrm{f}} \cdot N_{\mathrm{b}} \cdot L}{\gamma \cdot (p_{\mathrm{s}} T_{\mathrm{csi,s}} + p_{\mathrm{c}} T_{\mathrm{csi,c}}) + (1-\gamma)\cdot(p_{\mathrm{s}} T_{\mathrm{data,s}} + p_{\mathrm{c}} T_{\mathrm{data,c}}) + p_{\mathrm{e}}\sigma}$$

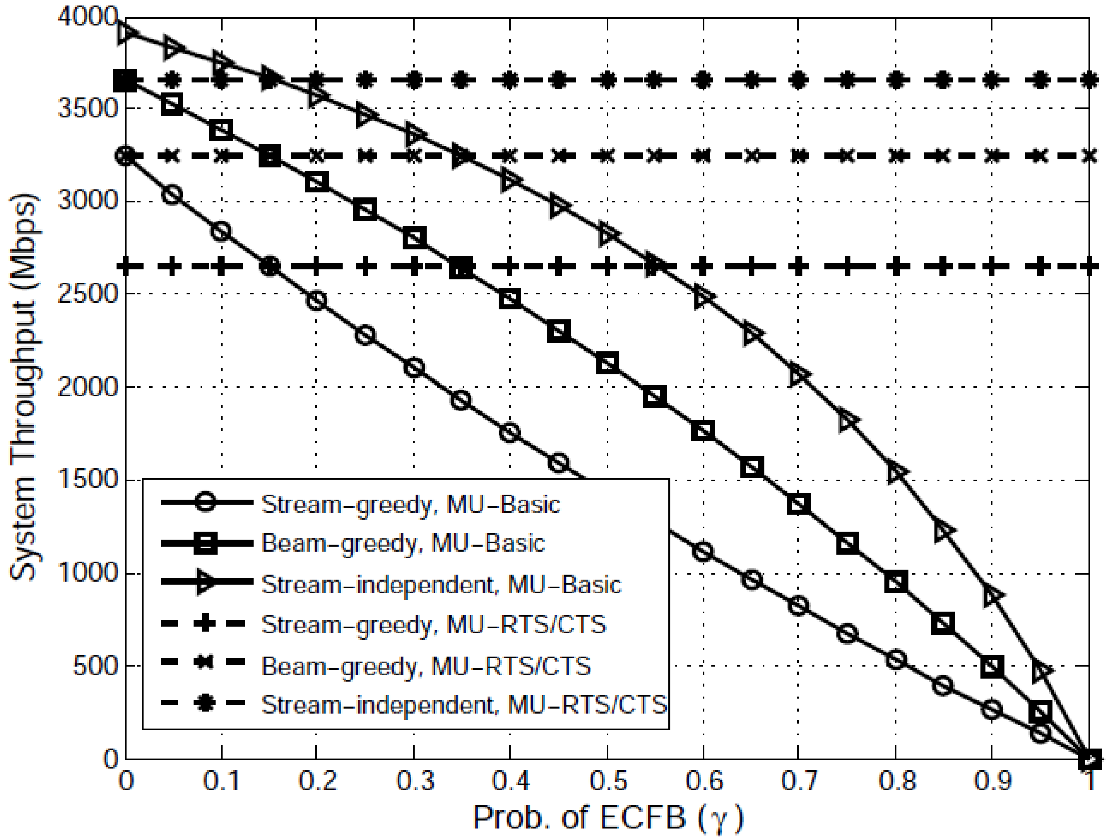
Throughput against *n*

$\gamma = 0.05$, $N_f = 64$, $M = 8$



The proper γ

γ has big impact to the performance!



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γ to $T_{2\text{-ECFB-Slots}}$

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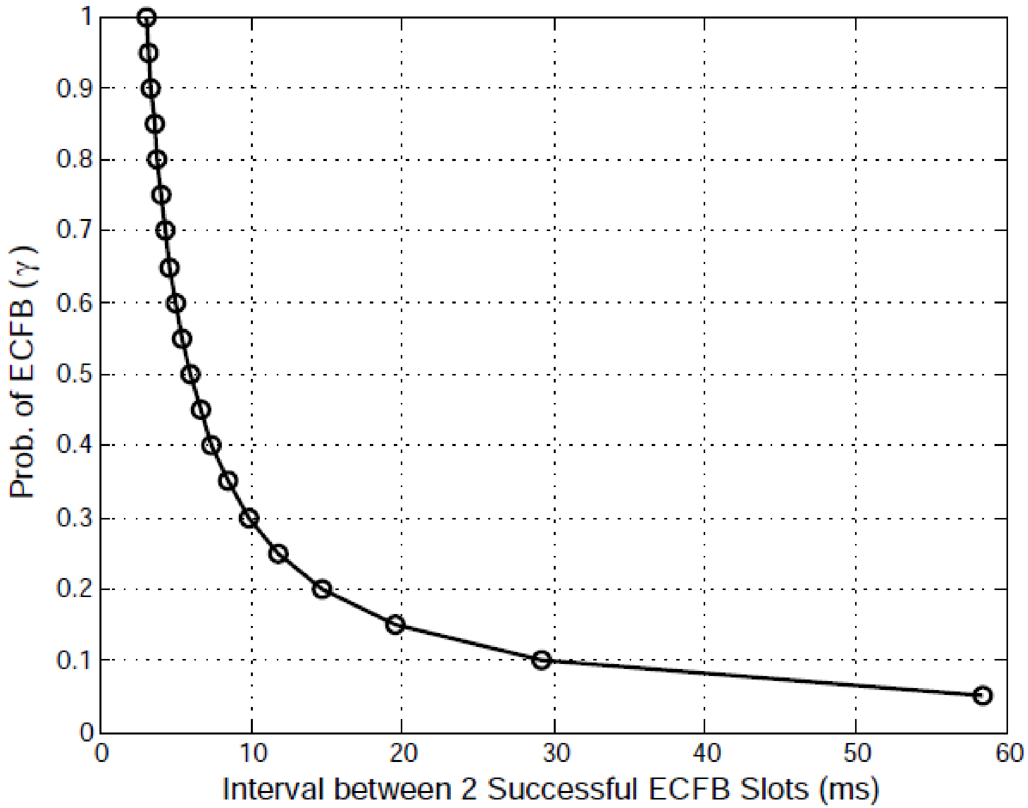
1. Total no. of slots in one second: $\dfrac{1}{E[T_{\text{slot}}]}$

2. Total no. of successful ECFB slots in one second: $$\gamma \cdot p_s \cdot \frac{1}{E[T_{\text{slot}}]}$$

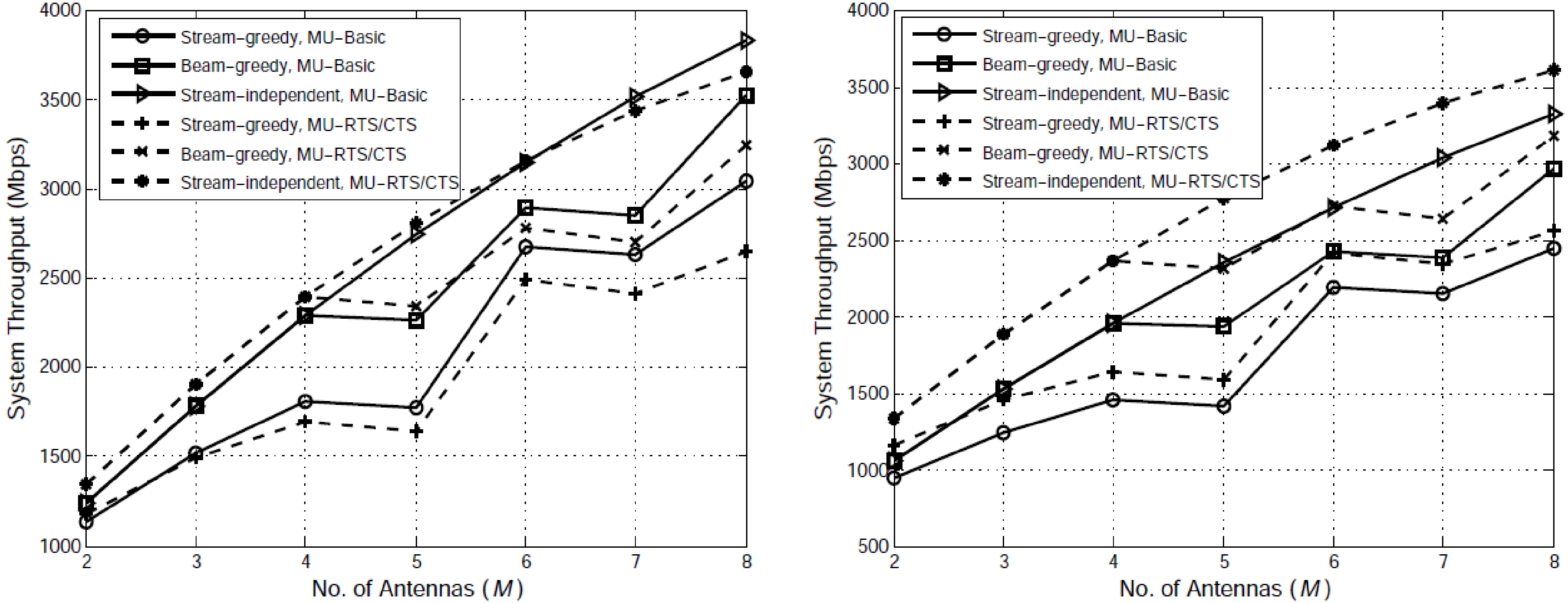
3. Interval between 2 successful ECFB slots: $$\frac{E[T_{\text{slot}}]}{\gamma \cdot p_s}$$



The coherence time of 5 GHz channels is in the range of 50 ms to 80 ms in case of slow mobility scenario

Throughput against *M*

$\gamma = 0.05$, $N_f = 64$, $n = 5, 15$



(a) $n = 5$ (b) $n = 15$

Throughput against N_f

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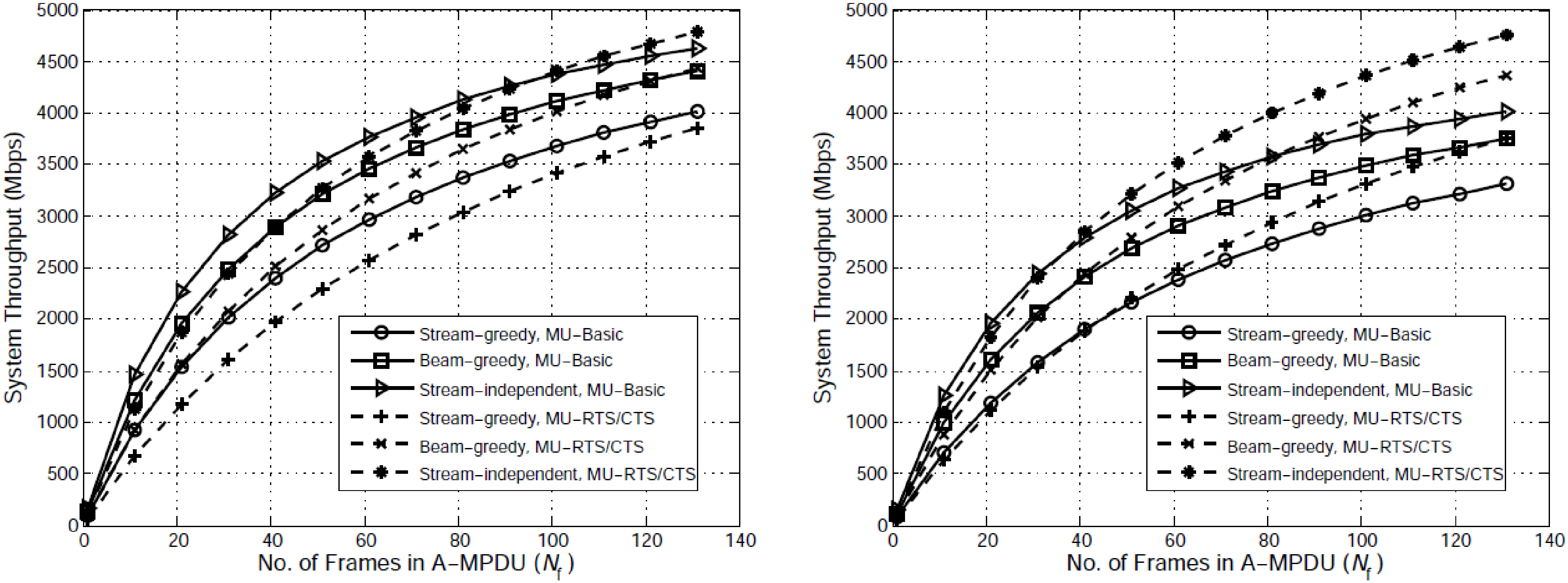
$\gamma = 0.05$, $M = 8$, $n = 5, 15$



(a) $n = 5$ (b) $n = 15$

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Benefits of handshaking

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1. Eliminate the need to periodically execute the ECFB protocol

2. Decrease the collision time

3. Node can also estimate CSI of reverse channels, which enables It to receive parallel uplink transmissions

Conclusions

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1. IEEE 802.11ac default basic access & MU-RTS/CTS schemes

2. Three scheduling algorithms are designed to compare the two MAC schemes

3. MU-RTS/CTS is more efficient as n or N_f increase

4. Beam-greedy algorithm outperforms the Stream-greedy one, while the ideal Stream-independent algorithm remains the best

5. The importance of the scheduling algorithm and γ

Thank you!

Questions & Comments

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System parameters

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Parameters	Values
Channel Bandwidth	160 MHz
Modulation Scheme	256-QAM
Coding Rate	5/6
Available Data Sub-carriers	468
Guard Interval	0.4 μs
Frame Length (L)	20000 bits
MAC Header	272 bits
Frame Check Sequence	32 bits
Service Bits	16 bits
Tail Bits	6 bits
RTS	160 bits
MU-CTS	$112 + (M \cdot 3744)$ bits
B-ACK	256 bits
NDPA	$152 + n \cdot 16$ bits
NDP	$36 + M \cdot 4$ μs
VHT Compressed Beamforming Frame	$40 + (M \cdot 3744)$ bits
Poll	168 bits
Slot Time (σ)	9 μs
SIFS	16 μs
AIFS	34 μs
$CW_{\min}$	16
$CW_{\max}$	1024
Maximum Back-off Stage (m)	6

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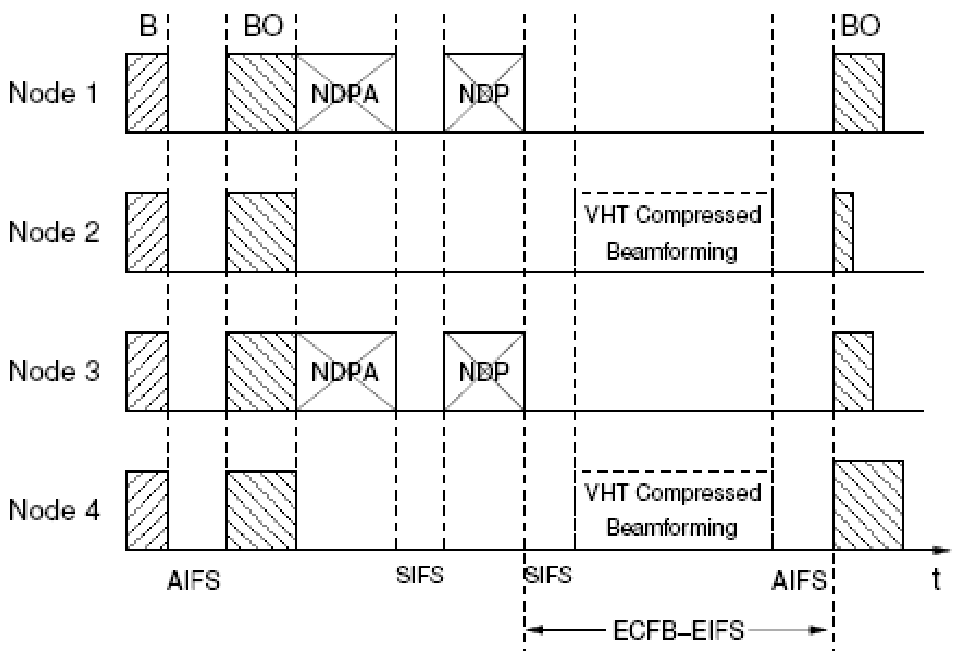
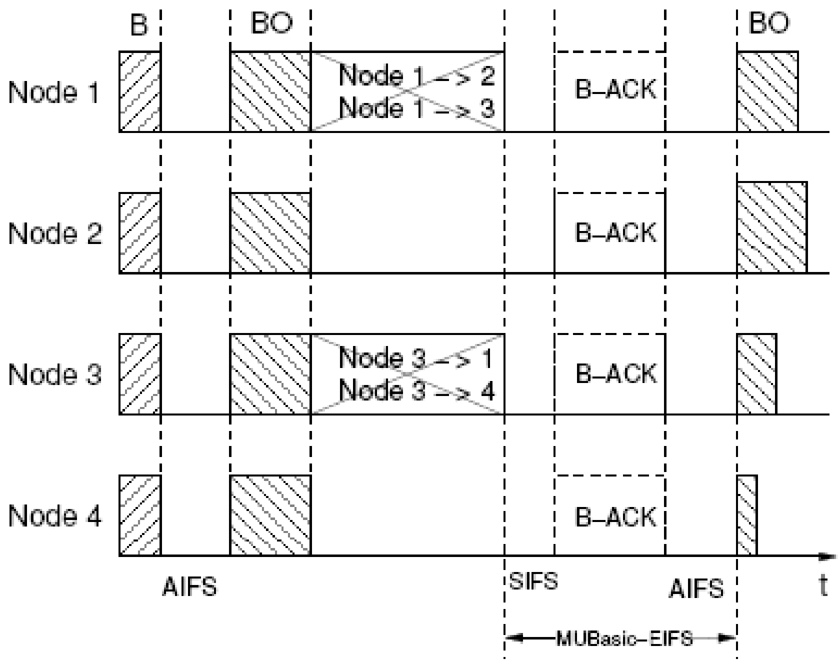
Collisions

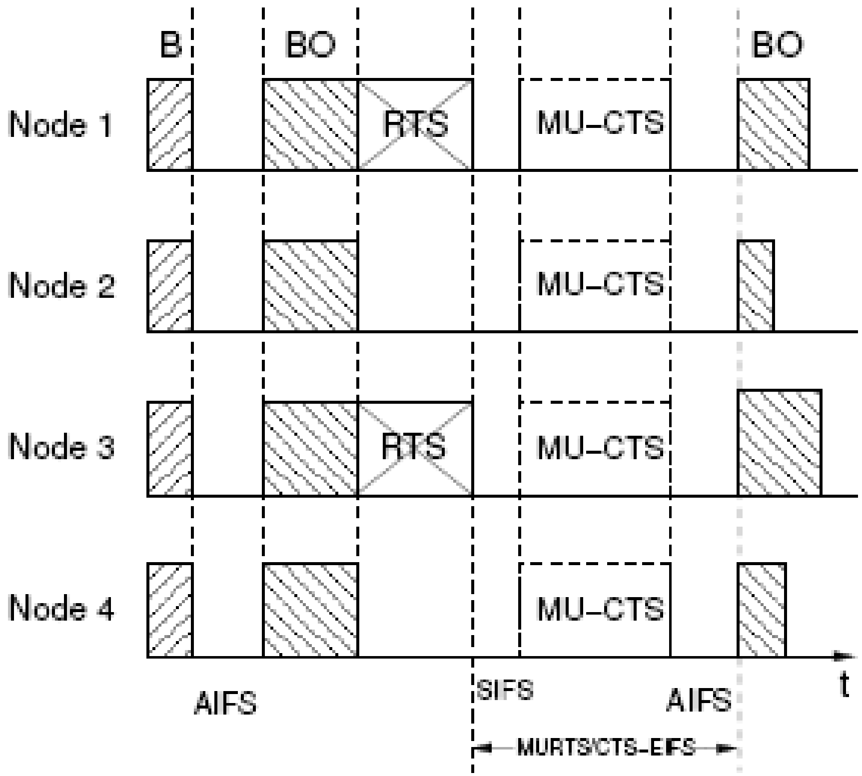


(a) Collisions between Multiple NDPAs



(b) Collisions between Multiple Data Frames

Collisions



(b) Collisions between RTSs