Design & Analysis of MAC Protocol for IEEE 802.11n

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Joint work with Tianji, Thierry (INRIA), Prof Yang (U. of Memphis) and ongoing with Dave, Doug, Changwen (Intel), Adrian (Intel)

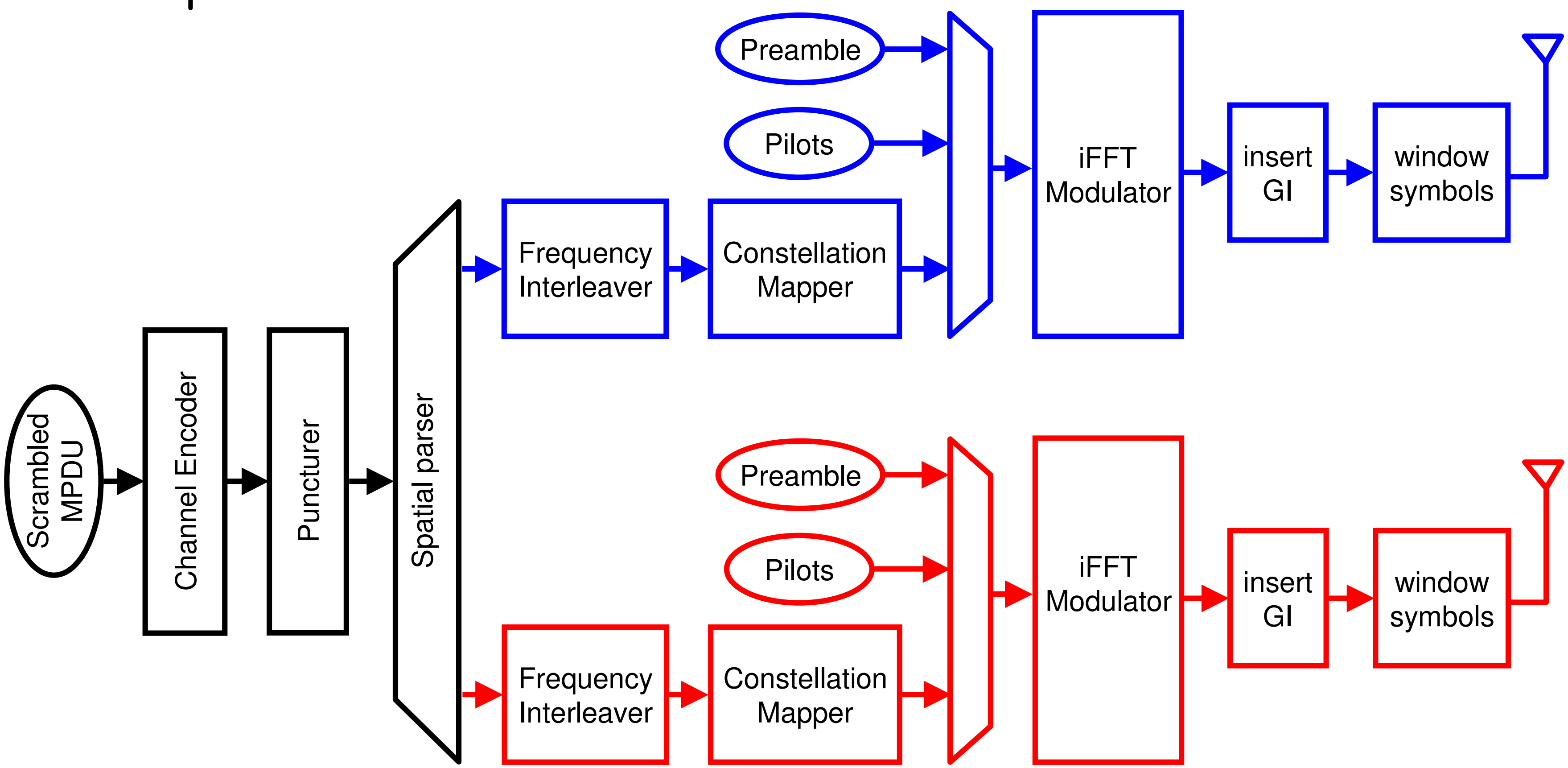
802.11n: next-generation WLAN

Summary from 802.11n Berlin meeting, Sept. 12-17, 04

- Goal: 100Mbps net throughput measured at the MAC layer.
- Smart antenna technologies (2X2 or 4X4 MIMO).
- Provide 20 MHz (existing) and 40MHz* (new) bandwidth.
- Wideband adaptive OFDM:
  - Adaptive bit and power-loading while increasing the frequency bandwidth from 20MHz (802.11a) to 40MHz.
- Advanced channel coding techniques:
  - Reed-Solomon (RS) code.
  - Low Density Parity Check code (LDPC).

2x2 MIMO - Spatial Division Multiplexing

- 2 Spatial streams with 2 TX antennas (mandatory)
- Idea: spatial channels of different antenna pairs are uncorrelated

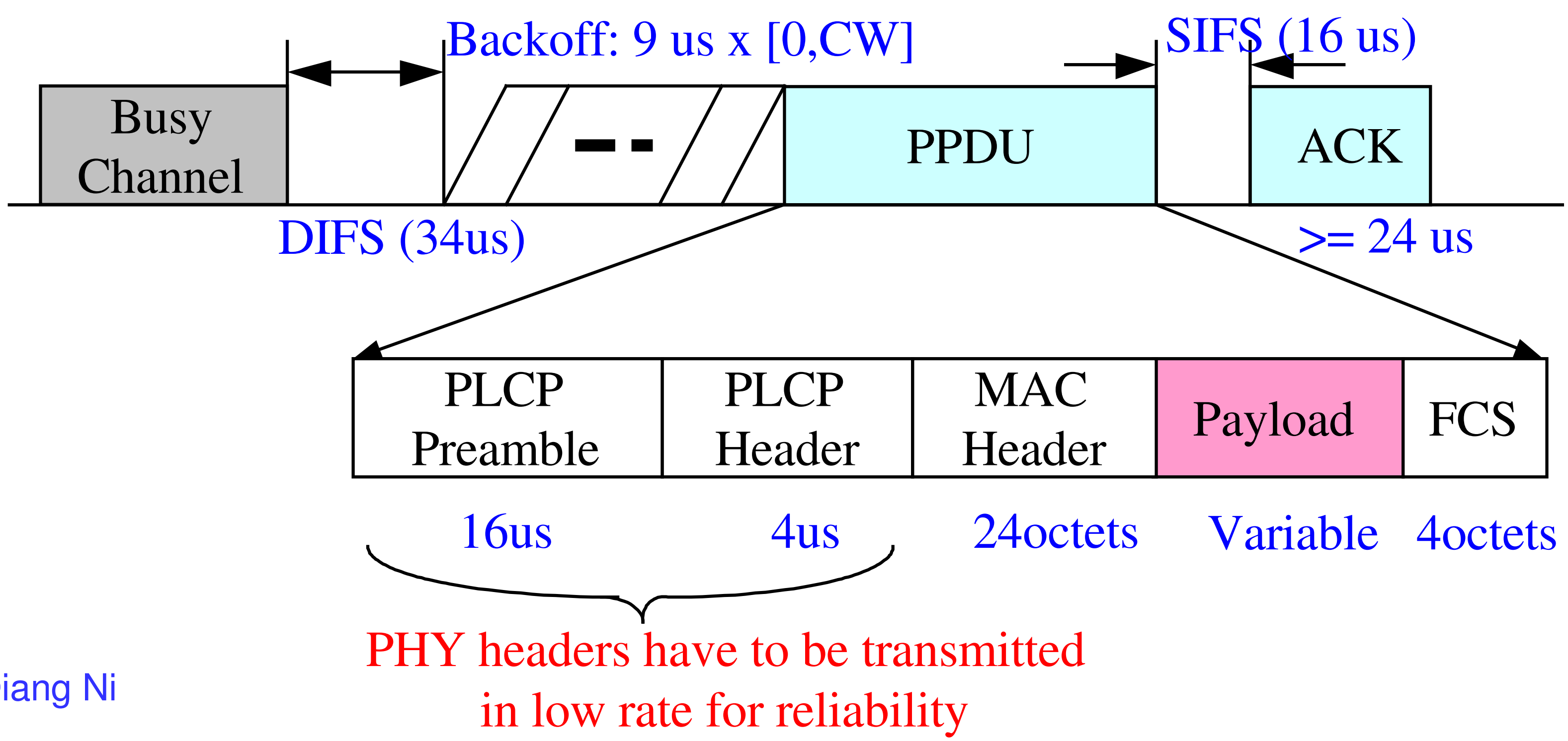


Challenge for 802.11n: MAC/PHY overhead

- To provide 100Mbps net throughput measured at the MAC layer is challenging since

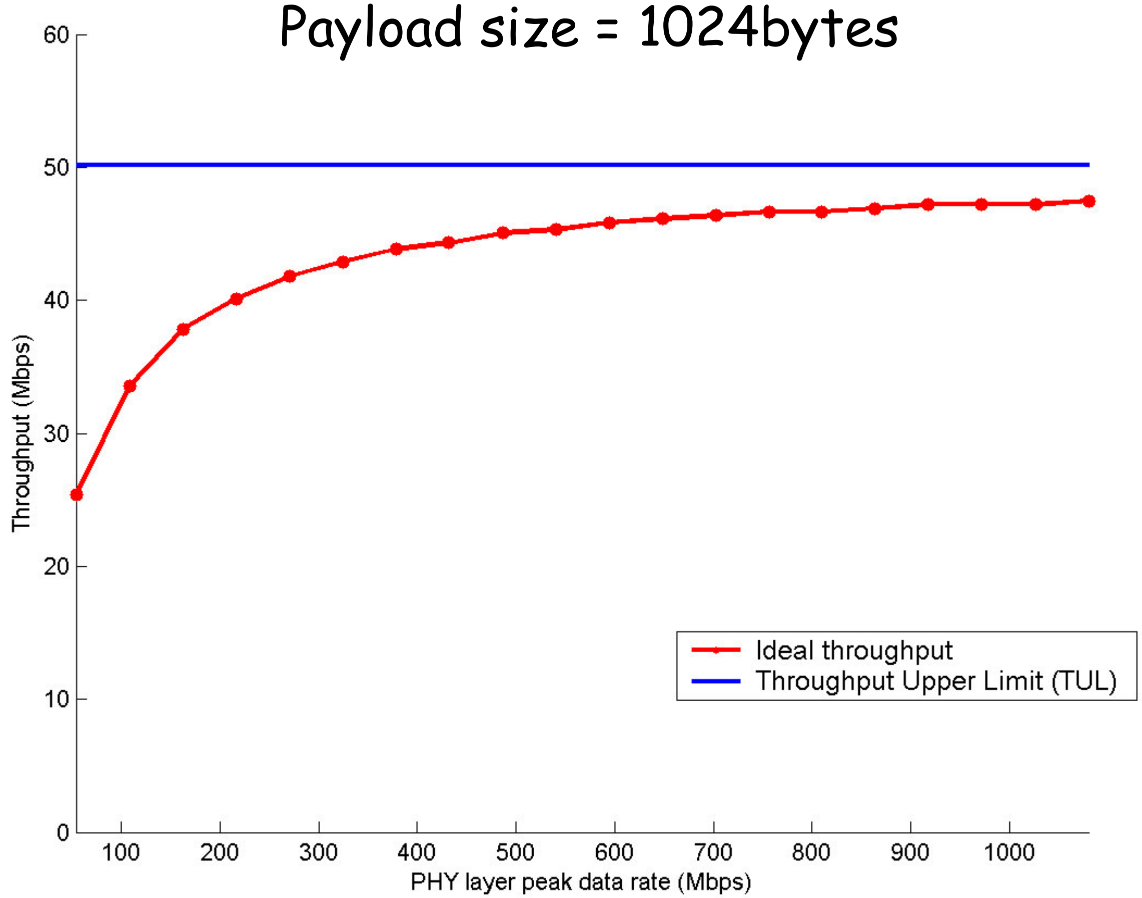
  The 802.11 MAC/PHY protocols have huge overhead:

  e.g. MAC/PHY headers, Backoffs, ACK,…



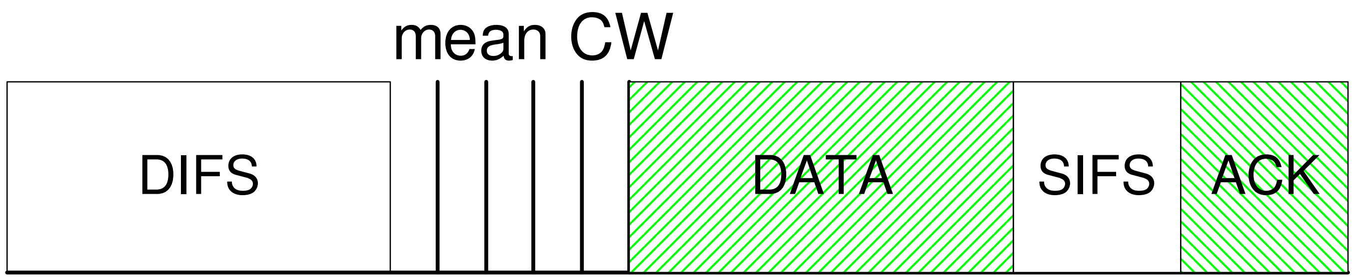
Ideal maximum MAC throughput
(no collision, no noise)

Payload size = 1024bytes



<u>Your throughput never higher than 50Mbps with 1Kbyte frame!?</u>

Ideal throughput model
(no collisions/no channel errors)



802.11 (e) MAC: DCF (Distributed Coordination Function)

Ideal throughput:

$$S_{ideal} = \frac{8L_{payload}}{T_{DIFS} + T_{\overline{CW}} + T_{PHYhdr} + \boxed{T_{payload}} + T_{SIFS} + T_{PHYhdr} + \boxed{T_{ack}} + 2\delta}$$

Throughput Upper Limit (TUL):

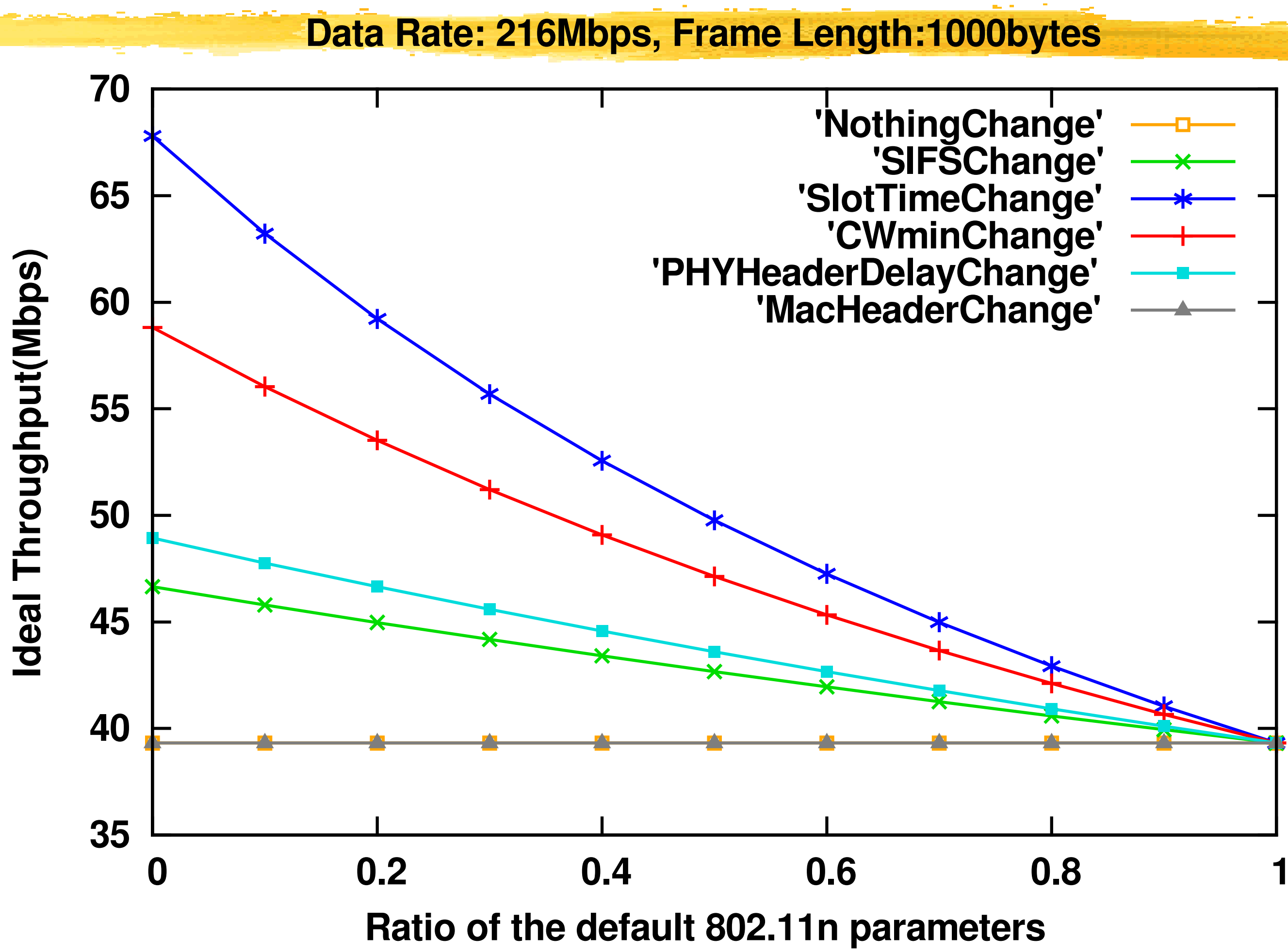
$$\Downarrow$$

$$S_{TUL} = \frac{8L_{payload}}{T_{DIFS} + T_{\overline{CW}} + T_{PHYhdr} + T_{SIFS} + T_{PHYhdr} + 2\delta}$$

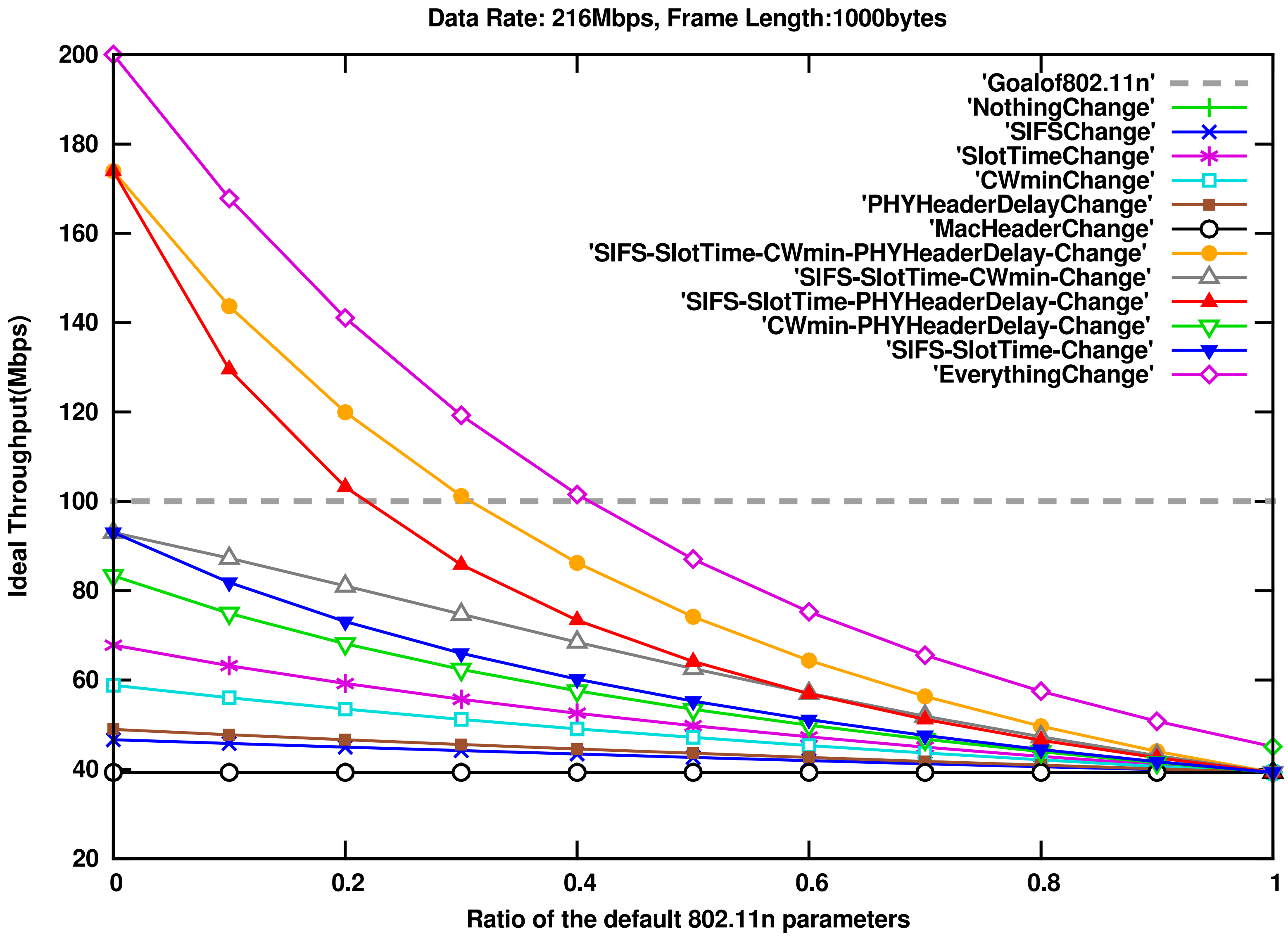
PHY/MAC parameters for 802.11a/b/n

	802.11b	802.11a	802.11n
T_{SIFS} (μs)	10	16	16
Slot time - σ (μs)	20	9	9
T_{DIFS} (μs)	50	34	34
T_{PHYhdr} (μs)	192	20	20
CW_{min}	31	15	15
MAChdr (bits)	224	224	224
CRC (bits)	32	32	32
Propagation delay - δ (μs)	1	1	1
OFDM symbol delay (μs)	-	4	4
NBpS (No. of bits per symbol)	-	216	216·k
PHY layer peak rate (Mbps)	11	54	54·k

Improving throughput by tuning PHY/MAC parameters

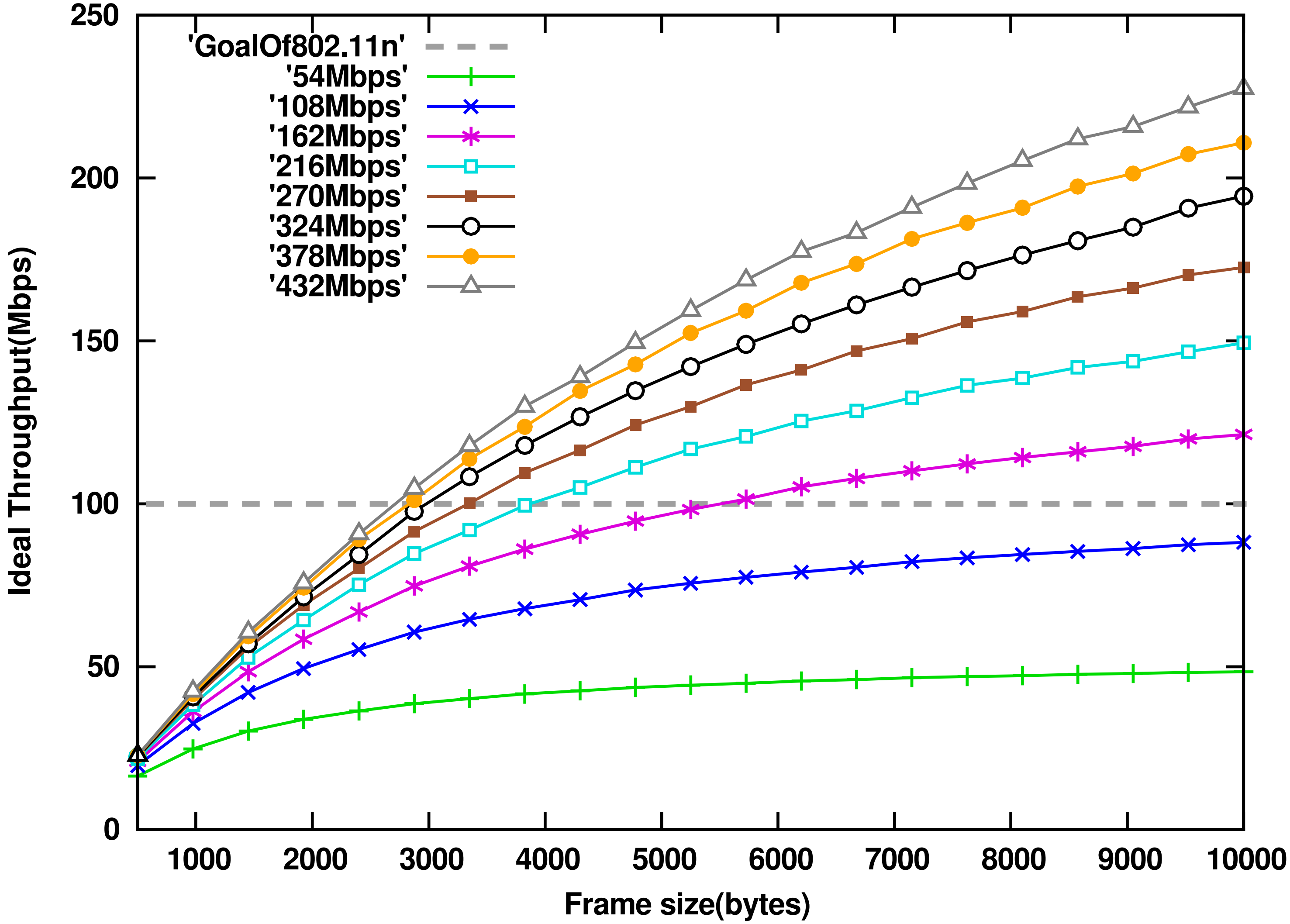


Maximum throughput while only one parameter is modified



Maximum throughput while multiple parameters are modified

Frame aggregation is promising!



Results are different if channel is noisy

- Let's assume Gaussian channel:

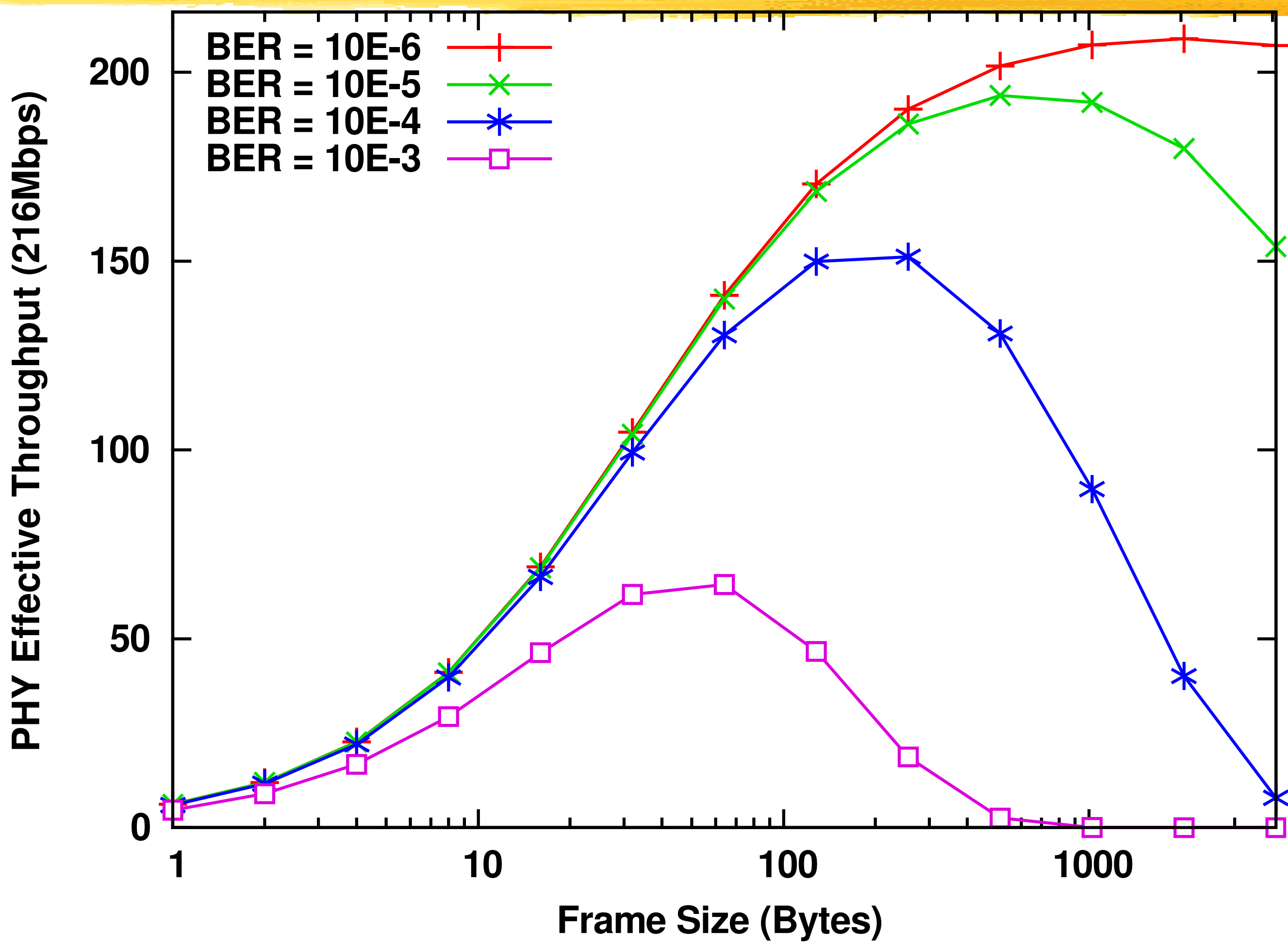
$$p_e = \sum_{i=1}^{L_{frame}} \binom{L_{frame}}{i} p_b^i (1 - p_b^i)^{L_{frame} - i} = 1 - (1 - p_b)^{L_{frame}}$$

p_e, packet error rate (PER), P_b, bit error rate (BER)

- Actual effective PHY throughput $(L_{frame} = L_{payload} + L_{hdr} + L_{crc})$

$$S_{eff} = \frac{L_{payload}}{L_{payload} + L_{hdr} + L_{crc}} \cdot R \cdot (1 - p_b)^{L_{payload} + L_{hdr} + L_{crc}}$$

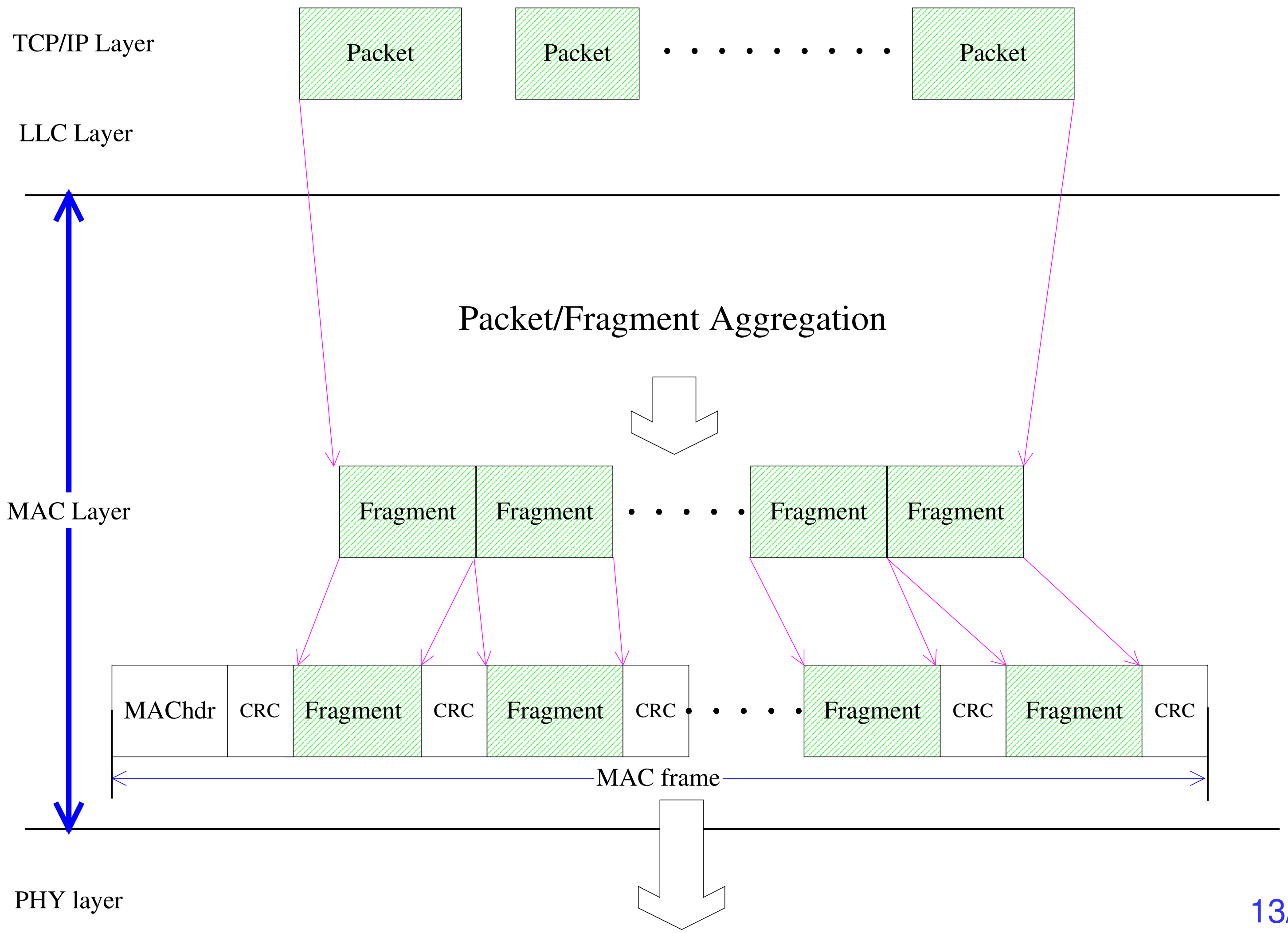
Packet aggregation is acceptable in noisy channel? Throughput degradation due to retransmissions



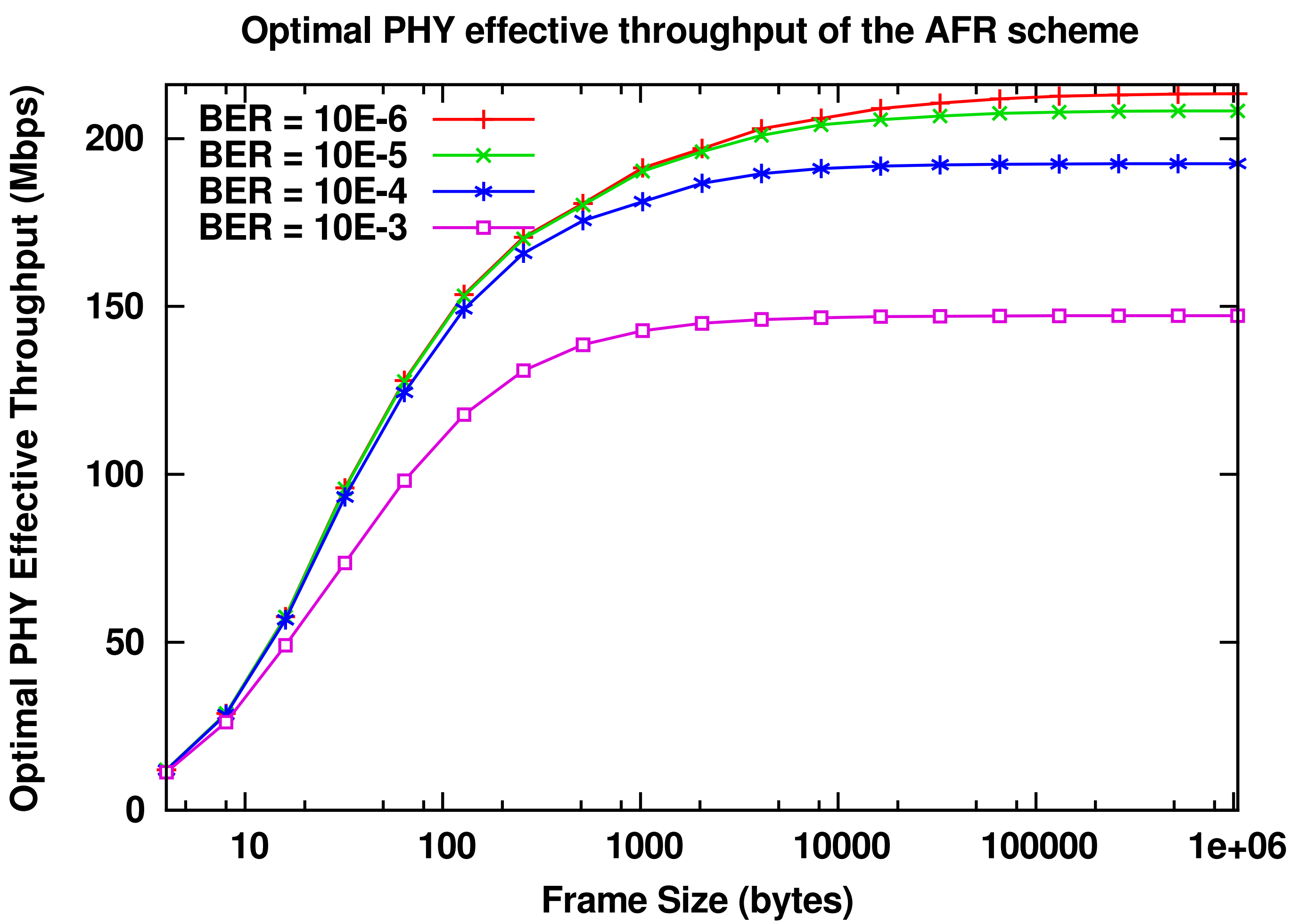
PHY layer peack rate = 216Mbps

Our 802.11n proposal:

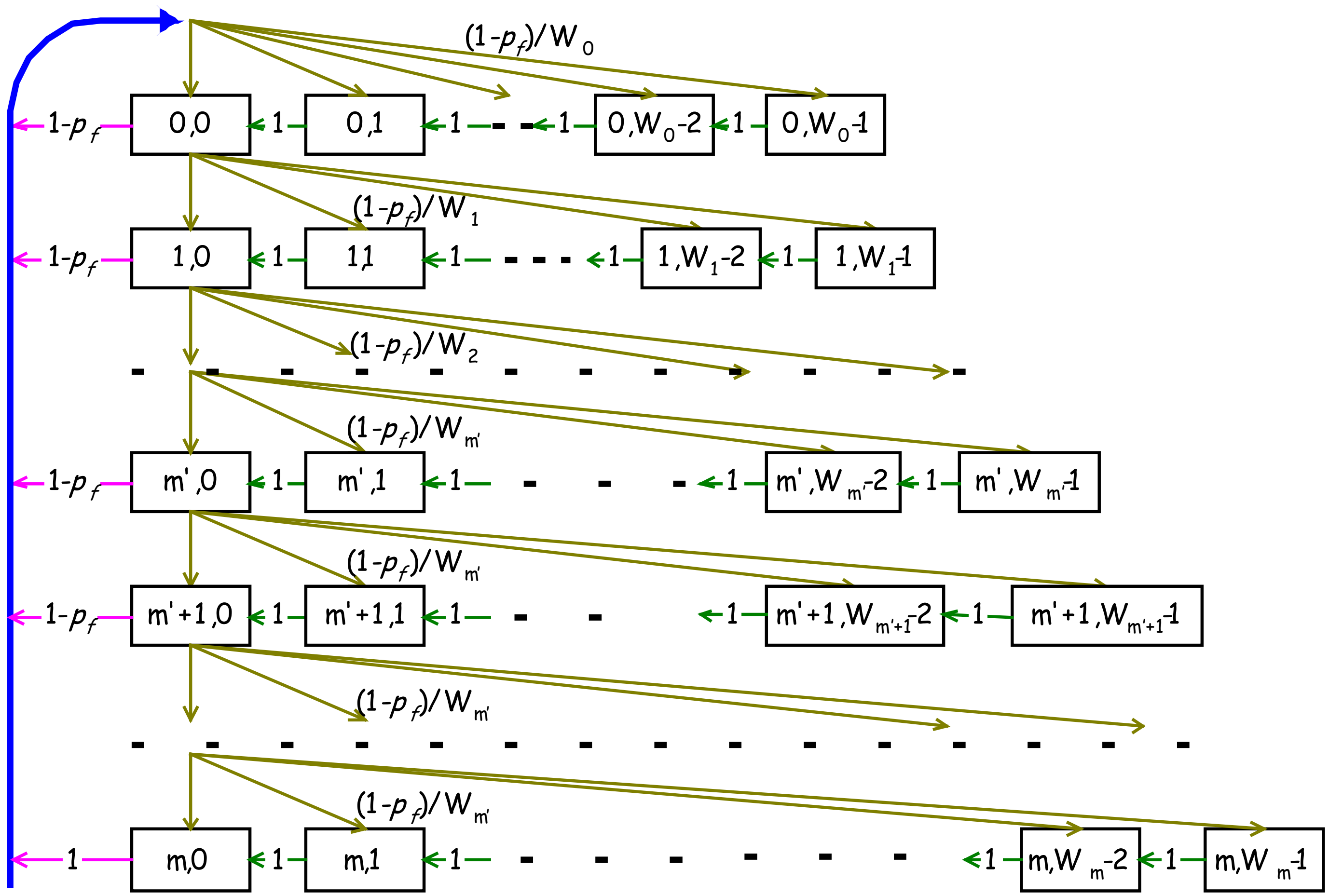
Aggregation with Fragment-Retransmission (AFR)



Maximum PHY throughput for AFR by adapting fragment size



Saturation throughput models for 802.11n (1)

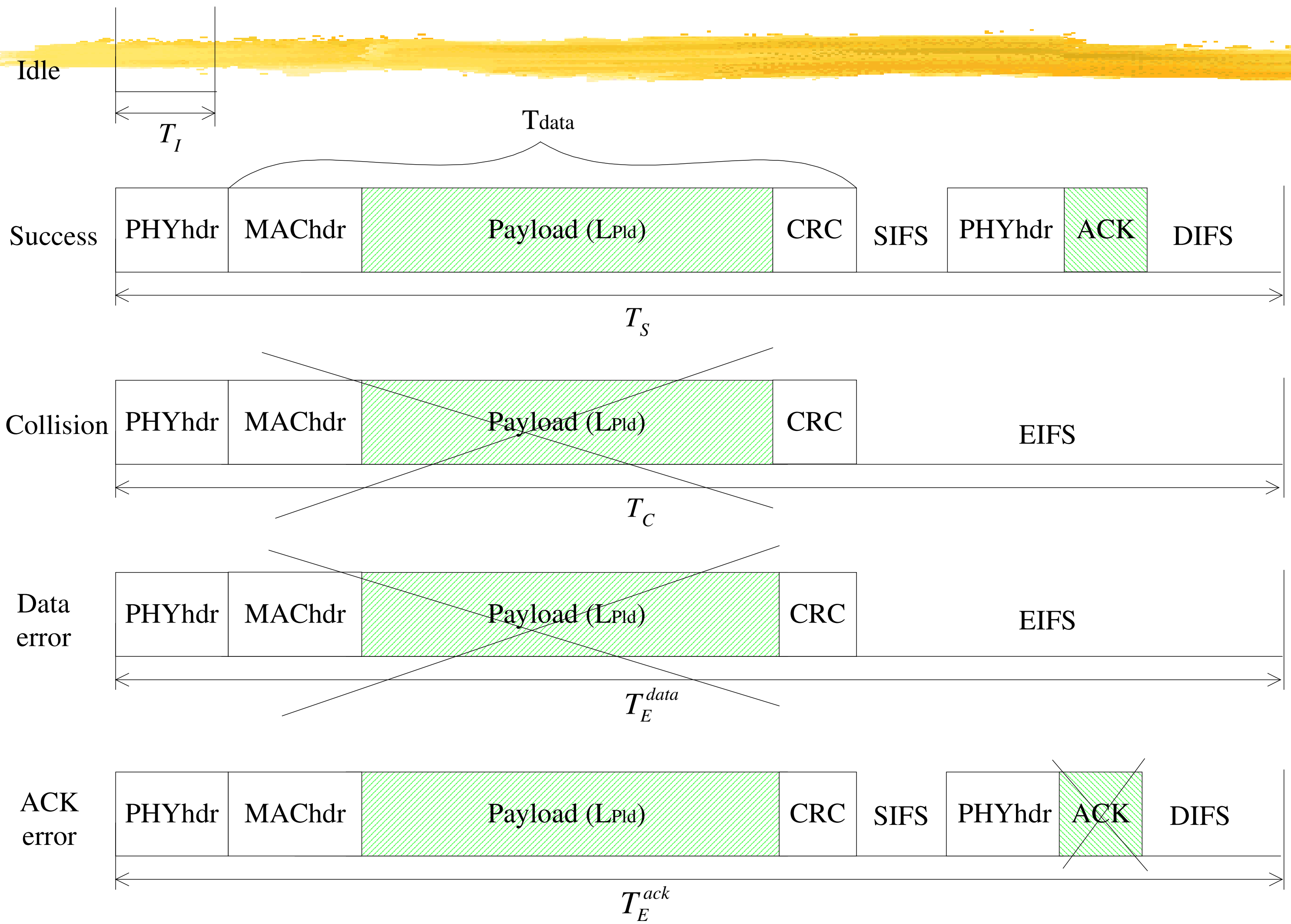


Transmission failure probability: $p_f = p_c + p_e - p_c \cdot p_e$

with $p_c = 1-(1-\tau)^{(n-1)}$

τ: Transmission probability,

Saturation throughput models for 802.11n (2)



Five kinds of slots in a noisy environment

Saturation throughput models for 802.11n (3)

$$S_{sat} = \frac{P_S \cdot L_{Pld}}{T_I P_I + T_S P_S + T_E^{data} P_E^{data} + T_E^{ack} P_E^{ack} + T_C P_C}$$

with

$$P_I = (1-\tau)^{n}$$

$$P_S = n \cdot \tau \cdot (1-\tau)^{(n-1)} \cdot (1-p_e^{data})(1-p_e^{ack})$$

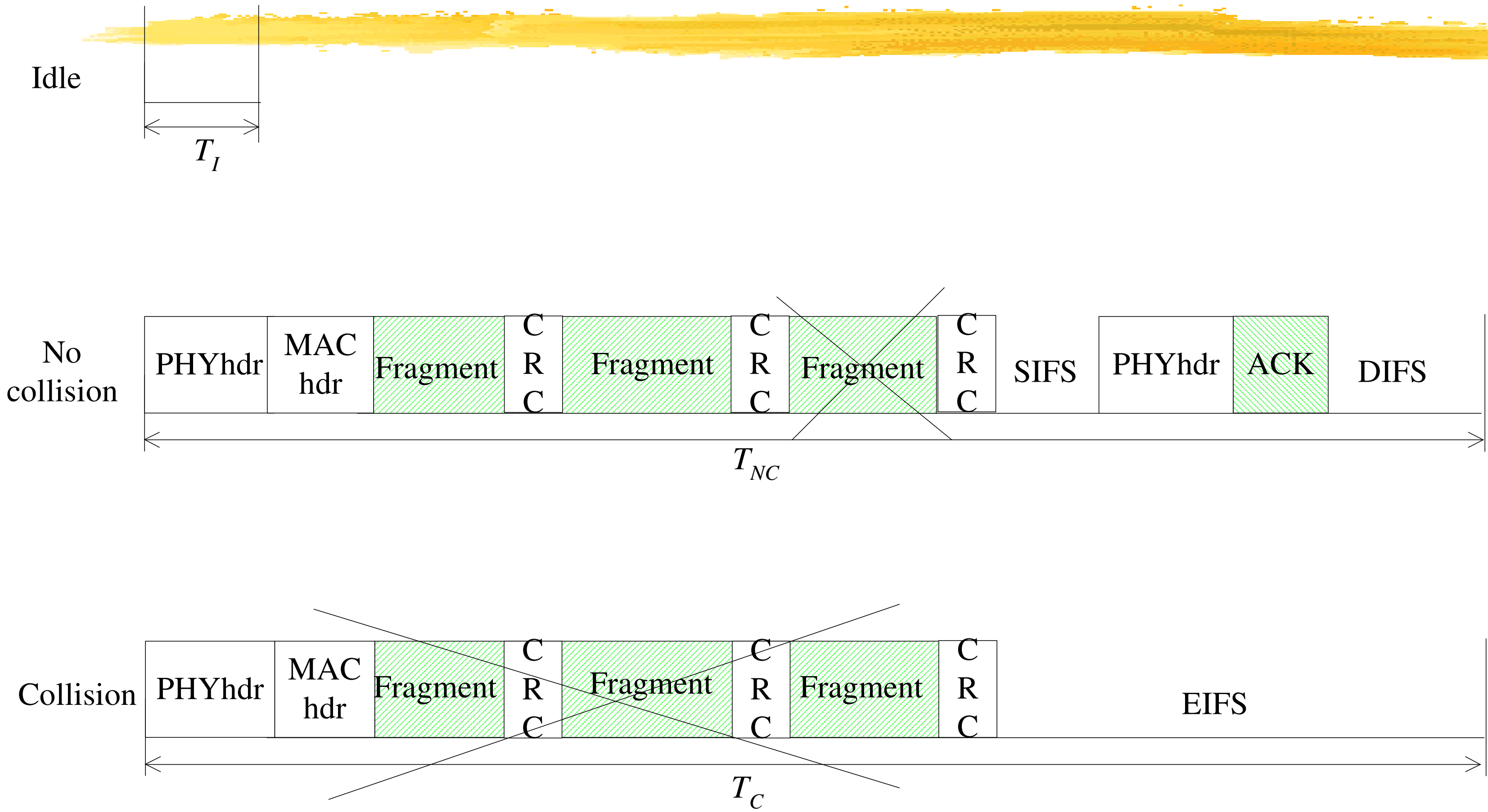
$$P_E^{data} = n \cdot \tau \cdot (1-\tau)^{(n-1)} \cdot p_e^{data}$$

$$P_E^{ack} = n \cdot \tau \cdot (1-\tau)^{(n-1)} \cdot (1-p_e^{data}) p_e^{ack}$$

$$P_C = 1-(1-\tau)^{n} - n \cdot \tau \cdot (1-\tau)^{(n-1)}$$

n : Number of stations

MAC throughput model for the AFR scheme (1)



Three kinds of slots in a noisy environment

MAC throughput model for the AFR scheme (2)

$$S_{AFR} = \frac{P_{NC} \cdot E[L_{Pld}]}{T_I P_I + T_{NC} P_{NC} + T_C P_C}$$

with

$$P_I = (1-\tau)^{\mathrm{n}}$$

$$P_{NC} = n \cdot \tau \cdot (1-\tau)^{(\mathrm{n}-1)}$$

$$P_C = 1-(1-\tau)^n - n \cdot \tau \cdot (1-\tau)^{(n-1)}$$

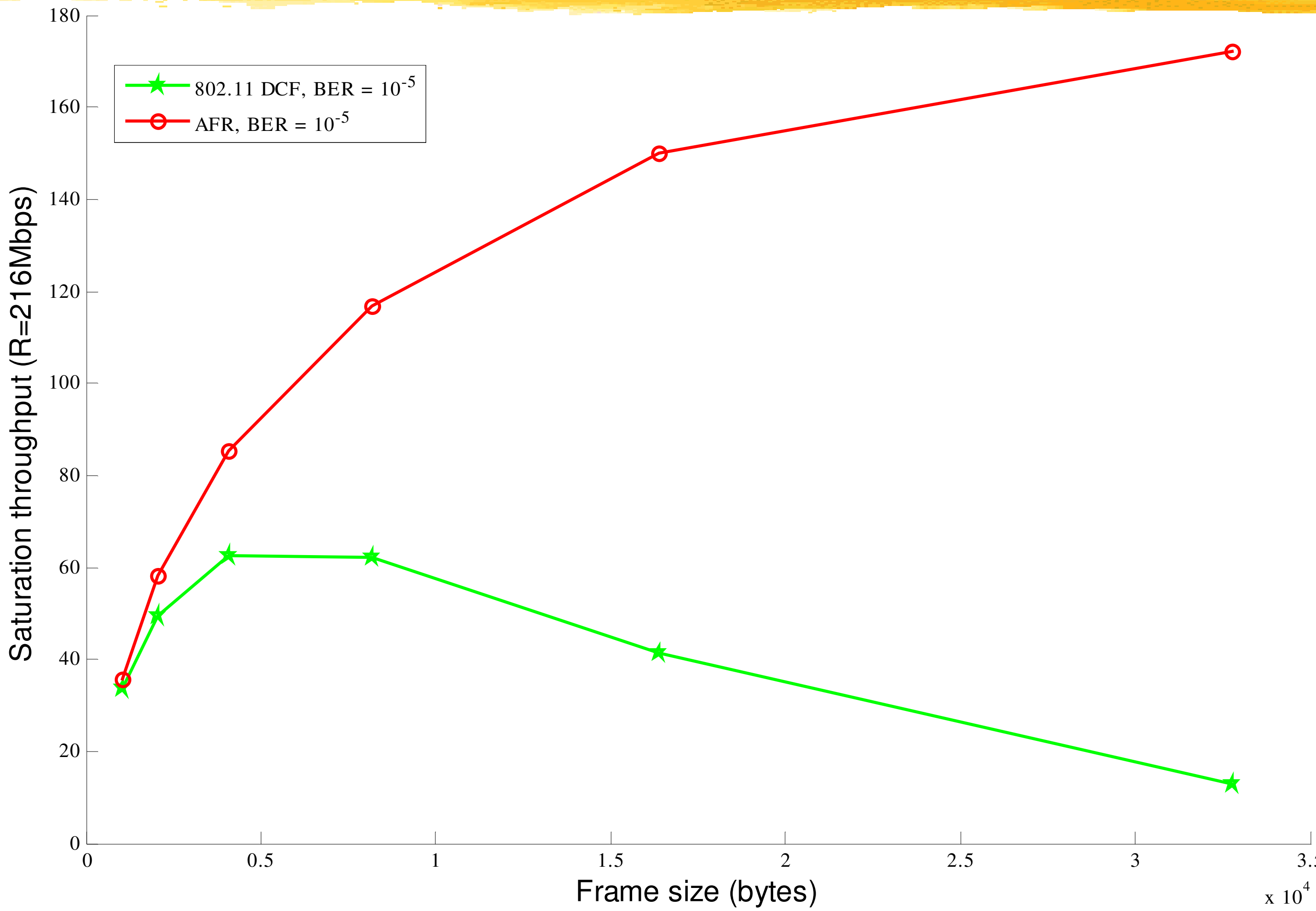
MAC throughput model for the AFR scheme (3)

$$E[L_{Pld}] = \sum_{i=0}^{N_{frag}} \binom{N_{frag}}{i} (p_e^{frag})^i \cdot (1 - p_e^{frag})^{N_{frag}-i} \cdot (L_{Pld} - i \cdot L_{frag})$$

$$p_e^{frag} = 1 - (1 - p_b)^{L_{frag}+L_{crc}}$$

MAC throughput: AFR vs. 802.11 DCF

PHY rate=216Mbps, n=50, BER=10^{-5}



Publications

- Qiang Ni, Tianji Li, Thierry Turletti, and Yang Xiao. "***Saturation Throughput Analysis of Error-Prone 802.11 Wireless Networks***". To appear in Wiley Journal of Wireless Communications and Mobile Computing (JWCMC), John Wiley & Sons Publisher, 2005.

- Tianji Li, Qiang Ni, Thierry Turletti, and Yang Xiao. "***Performance Analysis of IEEE 802.11e BlockAck Scheme in Noisy Channel***". In IEEE Broadnets Conference, Boston, USA, Oct 3-7, 2005.

- Qiang Ni, Tianji Li, Thierry Turletti and Yang Xiao. "***MAC Layer Proposal for IEEE 802.11n: Frame Aggregation with Fragment Retransmission (AFR) Scheme***". IEEE 802.11n Working Group Document No. IEEE 802.11-04-0950-00-000n, August 13, 2004.

Future work

- Delay analysis for AFR
- Realistic traffic types (TCP, Voice, Video)
- Real 802.11n PHY channel models + link adaptation
- Extension to multi-receiver case

  --with Changwen Liu (Intel Oregon), Adrian Stephens (Intel Cambridge)