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Channel Adaptive ACK Mechanism in IEEE 802.15.3 Wireless Personal Area Networks

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Outline

- Introduction
- System model
- CA-ACK : Channel adaptive ACK mechanism
- Conclusion and future work

Introduction

- **Key applications in wireless personal area networks (WPANs)**
  - Wireless high definition television (HDTV) streaming / Wireless USB
    - Require high data rates up to few tens or hundreds of Mbps
- **Throughput improvement in high-rate WPANs**
  - Supporting high data rate in PHY specifications
    - Ultra Wideband (UWB) PHY amendment - IEEE 802.15.3 task group a (TG 3a)
    - milimeter wave (mm-wave) – IEEE 802.15.3 task group c (TG 3c)
  - Need to improve throughput at MAC layer
    - Overhead while a frame is transmitted
      - E.g. MAC header, preamble, guard time, interframe space (IFS), ACK, etc..

Introduction (cont.)

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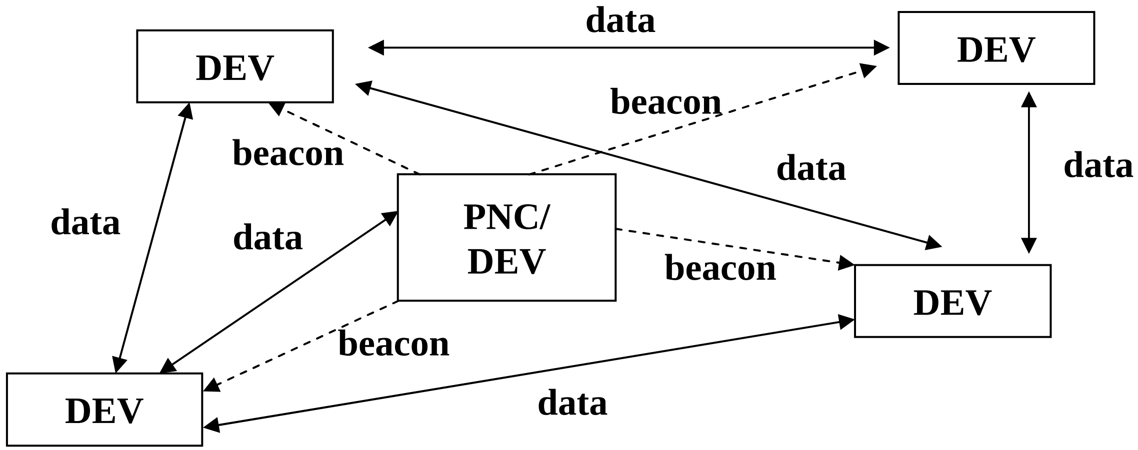
- **Research trend about throughput improvement in MAC layer**
  - Optimal payload size for maximizing the throughput [1]
  - Adaptive delayed ACK scheme for both TCP and UDP traffic [2]
  - A novel header compression method [3]
  - Frame aggregation techniques to reduce MAC and PHY overhead [4]

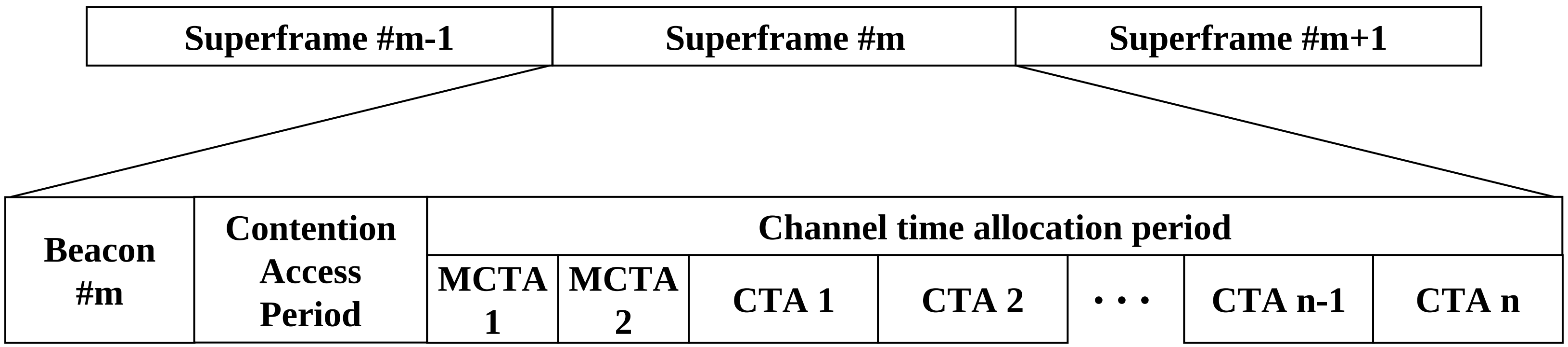
- **Our approach**
  - Pay attention to acknowledgement (ACK) mechanism that is indispensable feature in IEEE 802.15.3 MAC
  - How to optimize ACK mechanism is a still open issue
  - Especially, the performance of ACK mechanisms are effected by wireless channel conditions (e.g. frame error rate (FER))
  - Need to design an adaptive ACK mechanism

System model

- **Piconet elements in IEEE 802.15.3**



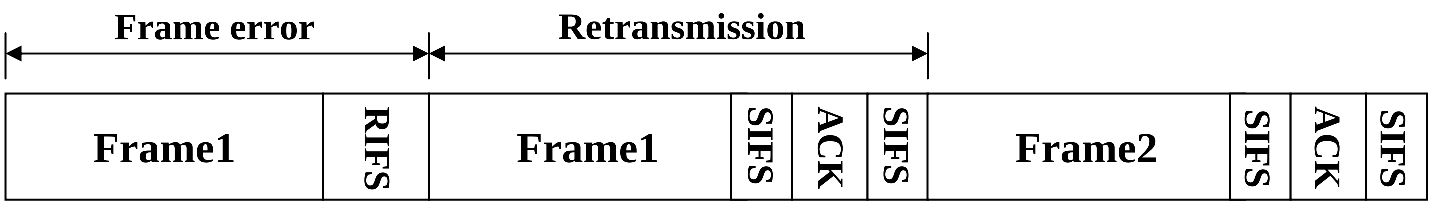
- **Superframe structure in IEEE 802.15.3**



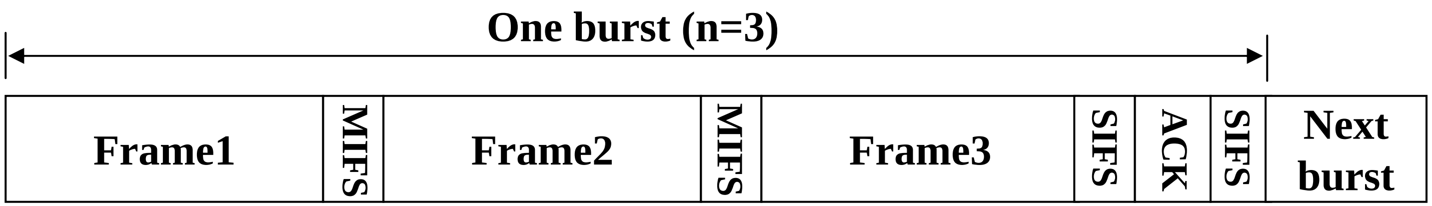
System model (cont.)

- **ACK mechanisms in IEEE 802.15.3**

(a) No-Acknowledgement (No-ACK)



(b) Immediate –Acknowledgement (Imm-ACK)

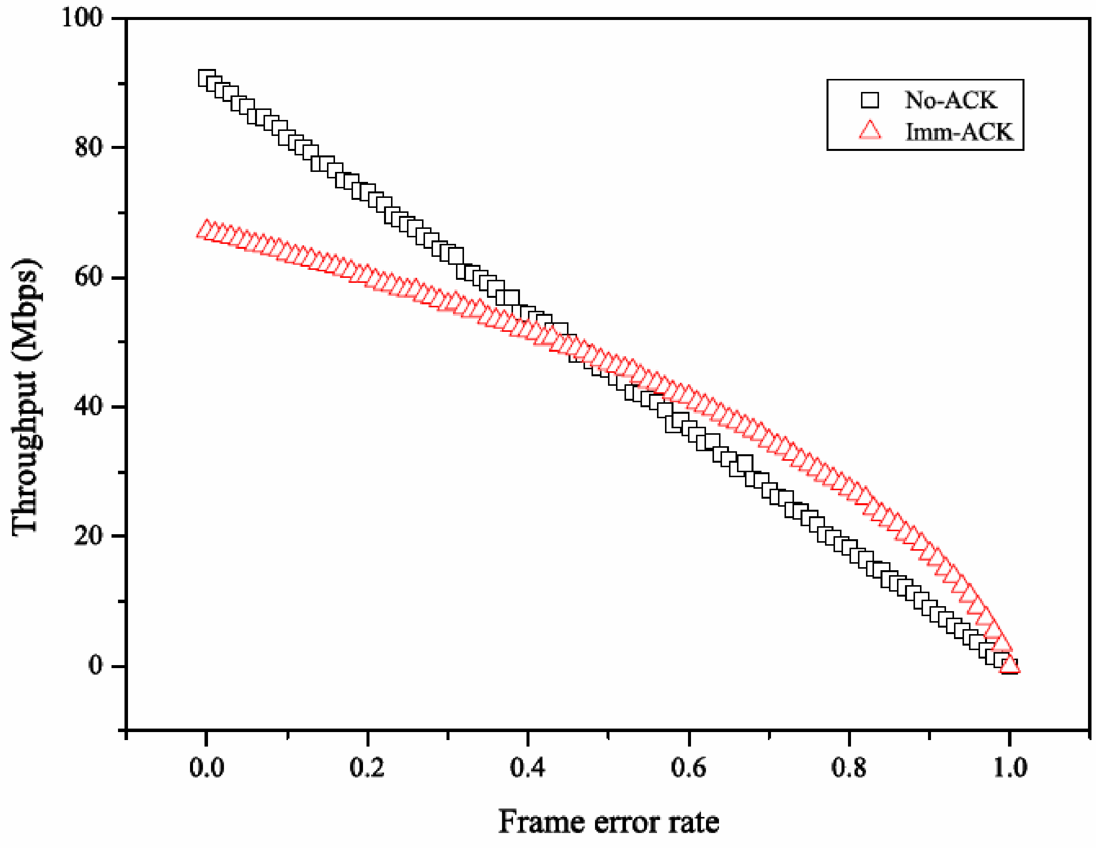


(c) Delayed Acknowledgement (Dly-ACK)

Overview
– Channel adaptive ACK mechanism

Description of CA-ACK (Channel adaptive ACK)

- **Determine FER threshold (p*)**
  - Intersection point balancing the throughputs of No-ACK and imm-ACK
- **Comparing current FER and p***
  - If (current FER < P*)
    selecting No-ACK
    else
    selecting Imm-ACK
- **Consequently, CA-ACK can provide improved throughput regardless of channel conditions**



No-ACK vs. Imm-ACK
(payload size: 1024 bytes, data rate 106.7 Mbps)

Implementation issue

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- **Estimating the FER threshold (p*)**
  - Presentation of closed form as a function of the payload size and data rate
  - According to change payload size and data rate, update the p*
- **Measuring the current FER**
  - Dividing the number of unsuccessful frames with the total number of frames
    - For Imm-ACK
      - source DEV easily obtain the number of erroneous frames by receiving ACK frames.
    - For No-ACK
      - source DEV always triggers the Imm-ACK mechanism for first frame in a CTA
      - update the current FER at least at an interval of a superframe

Derivation of FER threshold

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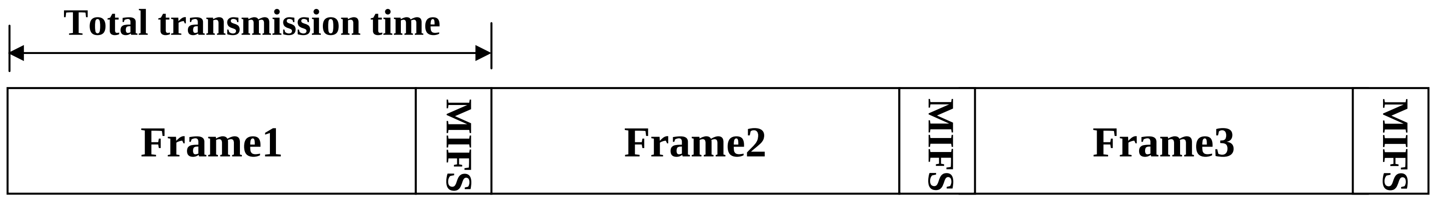
- **Assumption**
  - ACK frame is assummed as error free
    - Small length (e.g. 10bytes in IEEE 802.15.3)
    - Transmission at base rate (e.g. 53.3Mbps in UWB system)

- **Notations**

Notation	Meaning
T_{no}	Total transmission time with No-ACK
T_{Imm}	Total transmission time with Imm-ACK
L_P and L_{MH}	Length of payload and MAC header
T_{MIFS}, T_{SIFS}, T_{RIFS}	Time of a MIFS, SIFS, and RIFS
T_P	Transmission time of payload
T_{MH}	Transmission time of PHY header
T_{ACK}	Transmission time of an ACK frame
R_D and R_B	Data rate and base rate
P	Frame error probability

Derivation of FER threshold (cont.)

Throughput model of No-ACK



- Total transmission time with No-ACK

$$T_{No} = T_P + T_{MH} + T_{PH} + T_{MIFS}$$

- T_P and T_{MH} are given by

$$L_P / R_D \, , \, L_{MH} / R_B$$

- Throughput of No-ACK, S_{no} can be expressed as

$$S_{No} = \frac{L_P(1-p)}{T_{No}}$$

Derivation of FER threshold (cont.)

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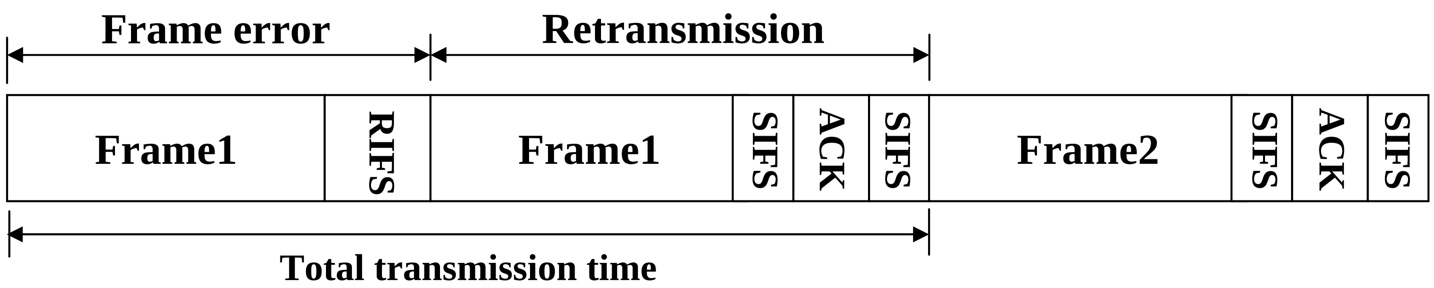
Throughput model of Imm-ACK



- Imm-ACK retransmits a corrupted frame up to N
- Consider two case:
  1) failed transmission time and 2) successful transmission time

$$T_F = T_P + T_{MH} + T_{PH} + T_{RIFS}\ ,\ T_S = T_P + T_{MH} + T_{PH} + 2T_{SIFS} + T_{ACK}$$

- Probability that a frame successfully transmitted at the i^{th} retransmission attempt ($0 \leq i \leq N$) is $p^i(1 - p)$
- Consequently, the throughput of Imm-ACK is given by

$$S_{imm} = \sum_{i=0}^{N} \frac{L_P p^i (1-p)}{iT_F + T_S}$$

Derivation of FER threshold (cont.)

Estimating FER threshold

- In IEEE 802.15.3, retransmission limit is typically equal to 5
- But, it is complicate to obtain p* that balances Equation of No-ACK and Imm-ACK
- Thus, we assume retransmission limit equal 2
  - since p^i (i ≥ 3) is sufficiently small
- Then, the balance equation for p* is given by

$$\frac{L_P(1-p)}{T_{No}} = \sum_{i=0}^{2} \frac{L_P p^i (1-p)}{iT_F + T_S}$$

- From a function of p, we can obtain p* as

$$p^* = \frac{-\frac{L_P}{T_F+T_S} + \sqrt{\left(\frac{L_P}{T_F+T_S}\right)^2 - 4\left(\frac{L_P}{2T_F+T_S}\right)\left(\frac{L_P}{T_S} - \frac{L_P}{T_F}\right)}}{2\left(\frac{L_P}{2T_F+T_S}\right)}$$

Simulation results

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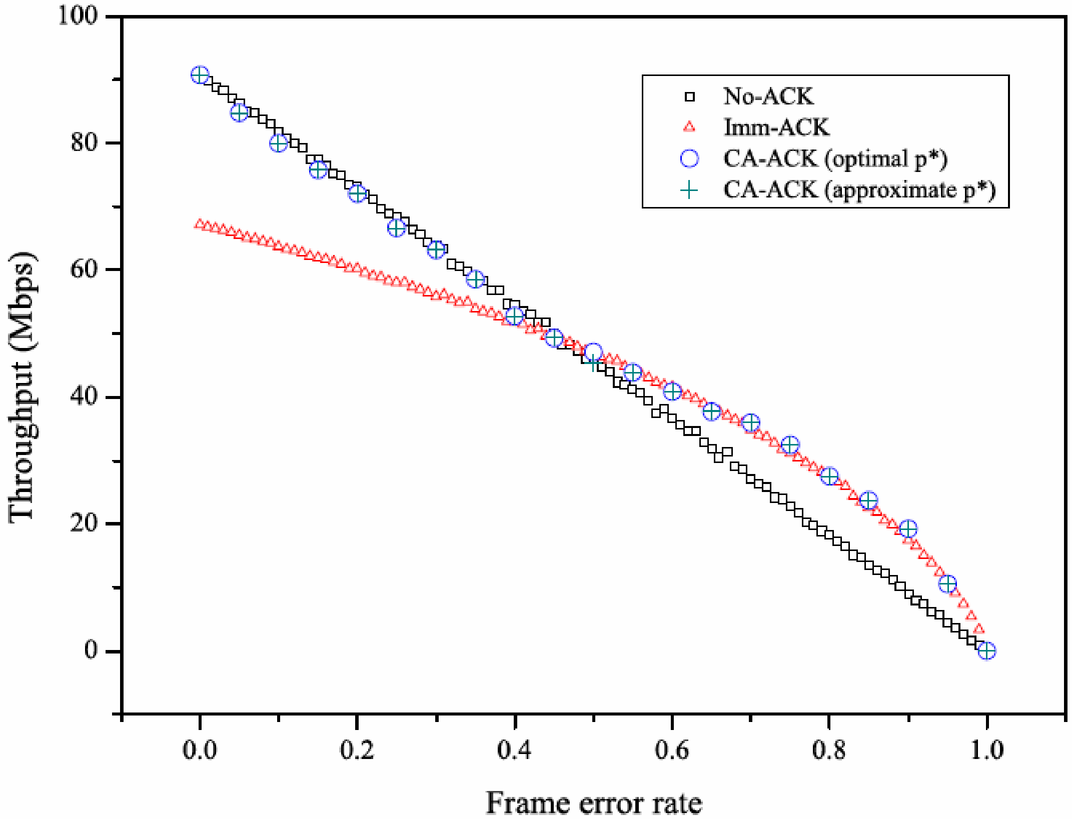
Effect of frame error rates

- CA-ACK is a more efficient and robust mechanism under different wireless channel conditions

- Throughputs of CA-ACK with approximate p* and optimal p* are almost same

 - CA-ACK with approximate p* is more practical

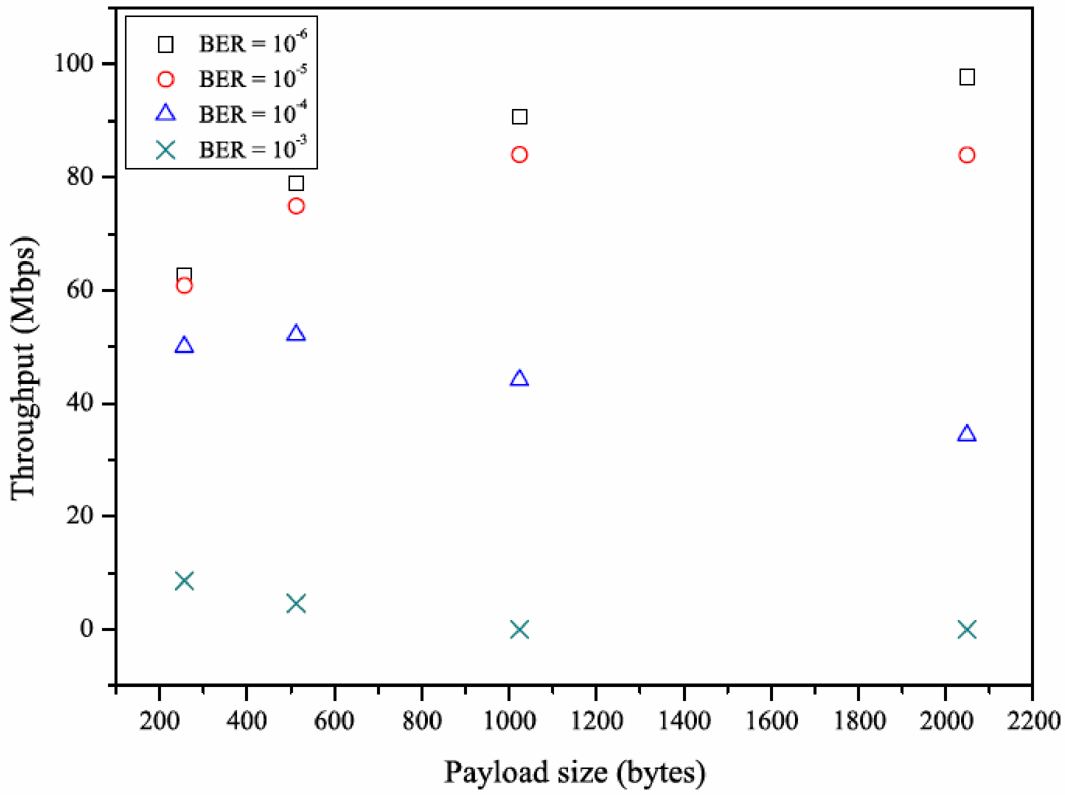


(payload size: 1024 bytes, data rate: 106.7 Mbps)

Simulation results (cont.)

Effect of payload size under different bit error rates (BERs)

- When the BER is 10^{-3}
  - throughput decreases with the increase in payload size
- When the BER is 10^{-6}
  - throughput increases with the increase in payload size
- For given BER b, FER is $1-(1-b)^{Nbit}$ (Nbit is the number of bits in a frame)
- If BER is high, large frame size results in degradation of throughput
- More interestingly, when BER is 10^{-4} and 10^{-5}, it can be found the optimal payload size to maximize the throughput



(payload size: 256, 512, 1024, 2048 bytes)

Simulation results (cont.)

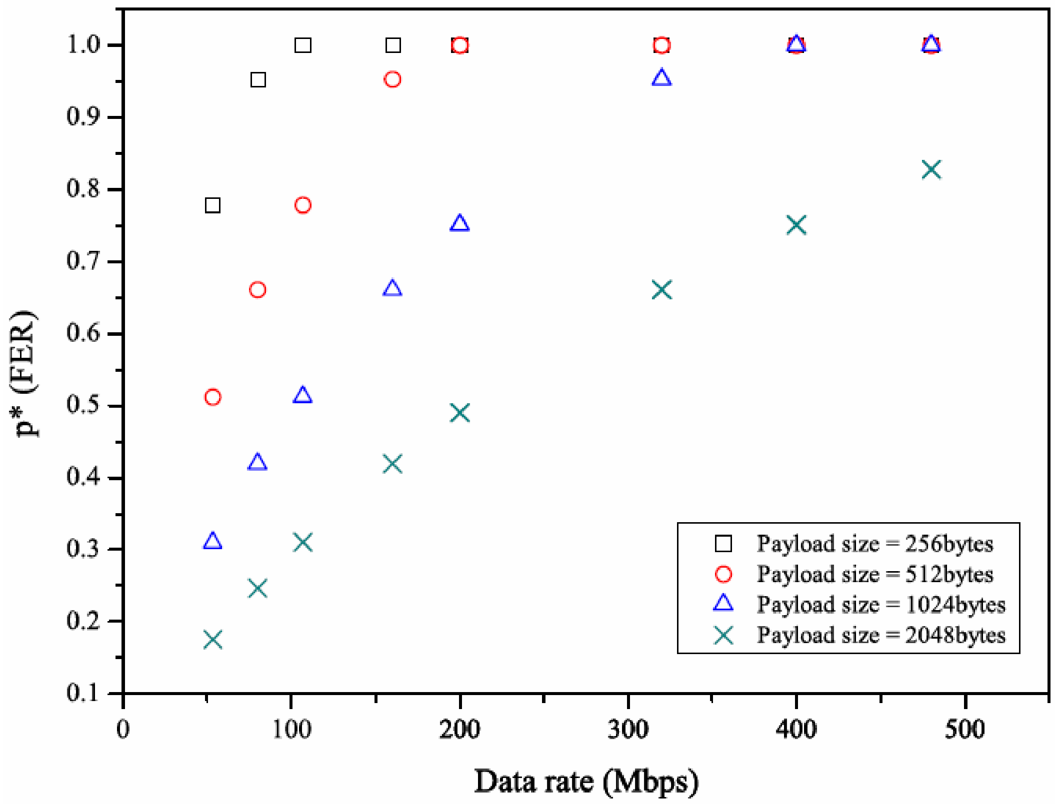
Effect of data rate and payload size on p*

- **As data rate increases, p* approaches 1.0**

  It can be explain as follows

  → increase of data rate
  → decrease of data frame transmission time
  → fixed base rate for transmitting ACK frame
  → overhead of ACK frame relatively increase
  → CA-ACK selects the No-ACK more frequently

- **As payload size decreases, p* approaches 1.0**
  → decrease of payload size
  → overhead of ACK frame relatively increase



(data rate: 53.3, 80, 106.7, 160, 200, 300, 420 and 480 bytes)

Conclusion & Future work

- **Channel adaptive ACK mechanism is proposed**
  - An ACK is selectively transmitted depending on wireless channel conditions
  - Present a closed form expression for FER threshold in CA-ACK, which makes CA-ACK a practical solution
  - By simulation, it can be shown that CA-ACK outperforms No-ACK and Imm-ACK in terms of MAC throughput

- **Future work**
  - Investigate the performance of CA-ACK under correlated wireless channel conditions

References

[1] Y. Xiao, X. Shen, and H. Jiang, “ Optimal ACK Mechanisms of the IEEE 802.15.3 MAC for Ultra-Wideband Systems,” IEEE Journal on Selected Areas in Communications, vol. 24, no. 4, pp. 836-842, April 2006

[2] H. Chen, Z. Guo, R. Yao, and Y. Li, “Improved Performance with Adaptive Dly-ACK for IEEE 802.15.3 WPAN over UWB PHY,” IEICE Transaction on Fundamentals of Electronics, Communications and Computer Sciences, vol. E88, no.9, pp. 2264-2372, September 2005

[3] E. Kwon, Y. Jeon, S. Lee, and J. Lim, “Enhancement of IEEE 802.15.3 High Rate WPAN via MAC header Compression,” in Proc. IPCCC 2005, pp. 629-630, April 2005

[4] “Part 11: Wireless LAN Medium Access Control (MAC) and Physical Layer (PHY) Specifications: Enhancements for Higher Throughput,” IEEE P802.11n/D2.0, February 2007