1st Workshop - CREaTION Project
November 18, 2013 / Covilhã, Portugal

Innovative energy efficient IEEE 802.15.4 MAC sub-layer protocol with packet concatenation employing RTS/CTS and Block Acknowledgment

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creating and sharing knowledge for telecommunications

Outline

- Introduction
- IEEE 802.15.4 MAC
- Sensor Block Acknowledgment – Medium Access Control (SBACK-MAC) Protocol:
  - State Diagram;
  - Scheme design with and with no *Block ACK Request*;
  - Retransmissions Scenarios;
- Conclusions

Introduction

- One of the fundamental reasons for the IEEE 802.15.4 standard Medium Access Control (MAC) inefficiency is overhead.
- Within IEEE 802.15.4, the possible use of RTS/CTS, by itself, facilitates packet concatenation and leads to performance improvement.
- In the presence of RTS/CTS two solutions are considered, one with DATA/ACK handshake and other with no ACKs, simply relying in the establishment of the NAV

Introduction

- By considering IEEE 802.15.4 basic access mode with RTS/CTS combined with the packet concatenation feature we improve channel efficiency by decreasing the deferral time before transmitting a data packet.

- We propose two innovative mechanisms to reduce the overhead from IEEE 802.15.4 non-beacon enabled networks, i.e., block acknowledgment (BACK) and piggyback.

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State of the Art for WSNs

Protocol Requirements

Support Scalability

Energy Consumption Minimization

Self Configurability

Node Parameter	CC2420	CC2520	AT86RF231
Radio [GHz]	2.4		
Modulation	O-QPSK		
P_{Sleep} [mW]	0.000063	0.00009	0.00006
$P_{Receive}$ [mW]	56.4	55.5	36.9
$P_{Transmit}$ [mW]	52.2	77.4	34.8
Data Rate [kb/s]	250		
rxSetupTime [μs]	1792	1792	400
ccaDetectionTime [μs]	128		
ccaTime [μs]	**1920**	**1920**	**528**

WSN Node Characteristics

Manufacturer Hardware Timing Constraints

IEEE 802.15.4

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IEEE 802.15.4 MAC Channel Access

Clear Channel Assessment (CCA)

Channel BUSY

$$NB = NB + 1$$

$$cw_{NB} = [2^{BE_i} - 1]$$

$$cw_{NB} = 15$$

Channel IDLE

$$NB = 0$$

$$cw_{NB} = [2^{BE_i} - 1]$$

$$cw_{NB} = 7$$

$BE_i = 3$, i=0

$BE_i = 4$, i=1

$BE_i = 5$, i≥2

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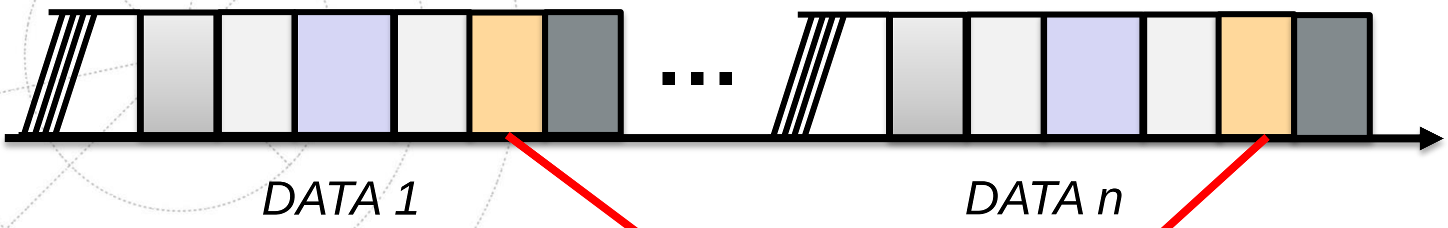
IEEE 802.15.4 MAC Channel Access

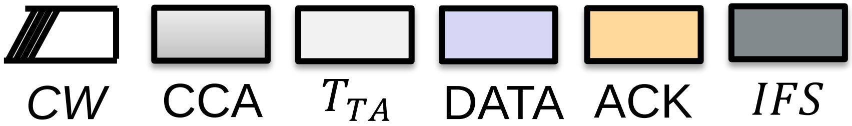
- IEEE 802.15.4 at the Best-Case Scenario (no collisions)



$$macAckWaitDuration = LastSymbol + aTurnaroundTime + physSHRDuration + [6 \times physSymbolsPerOctet]$$

$$macAckWaitDuration = 1 + 12 + 10 + [6 \times 2] = 35\ symbols = 35 \times 16\ \mu s = 560\ \mu s$$

Description	Symbol
TX/RX or RX/TX switching time	T_{TA}= $aTurnaroundTime$
Duration of the synchronization header (SHR) in symbols for the current PHY	$physSHRDuration$
The number of symbols per octet for the current PHY	$physSymbolsPerOctet$



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IEEE 802.15.4 MAC Channel Access

- IEEE 802.15.4 at the Best-Case Scenario (no collisions, *BE*=3, $CW_{max}=7$)

$$CW_{max} = (2^{BE} - 1) \Rightarrow \overline{CW} = \left(\frac{CW_{max}}{2}\right) \times T_{BO}$$

$$T_{BO} = 320\ \mu s$$

$$T_{DATA} = 8 \times \frac{L_{H\_PHY} + L_{H\_MAC} + L_{DATA}}{R}$$

$$T_{ACK} = 8 \times \frac{L_{H\_PHY} + L_{ACK}}{R}$$

Maximum Average Throughput

$$S_M = \frac{8L_{DATA}}{(\overline{CW} + ccaTime + T_{TA} + T_{DATA} + T_{TA} + T_{ACK} + T_{IFS})}$$

Minimum Average Delay

$$D_{min} = (\overline{CW} + ccaTime + T_{TA} + T_{DATA} + T_{TA} + T_{ACK} + T_{IFS})$$

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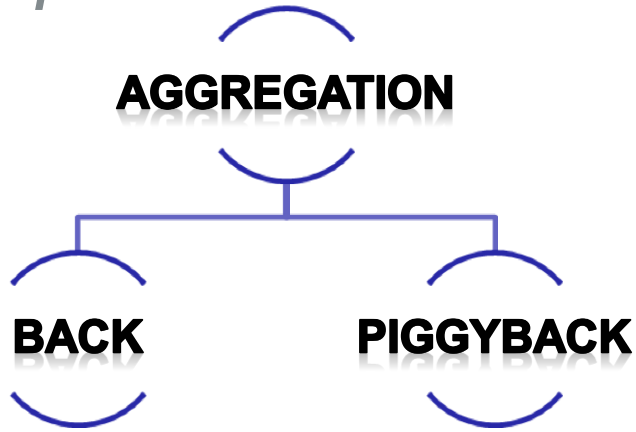
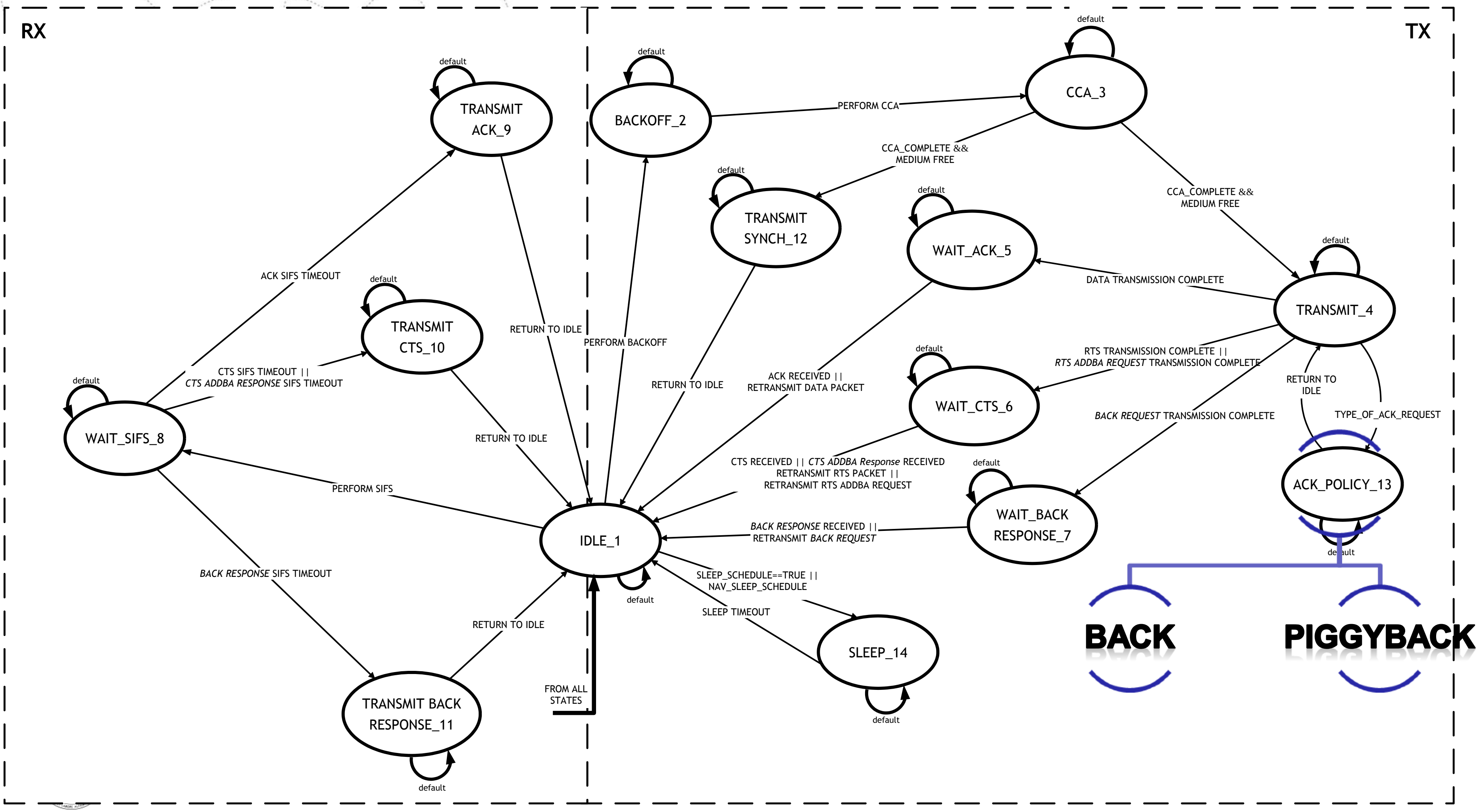
Sensor Block Acknowledgment – Medium Access Control (SBACK-MAC) Protocol

- The Block Acknowledgment (BACK) mechanism was previously introduced in the IEEE 802.11e standard.
- The SBACK-MAC allows the aggregation of several acknowledgment (ACK) responses in one special frame called ***BACK Response***.



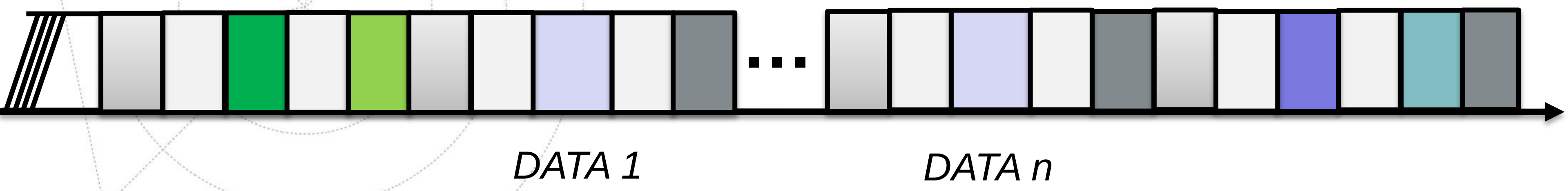
- Energy consumption will be greatly reduced because it is not needed to transmit and receive several ACK control packets (one for each data packet) which would lead to an extra energy waste.

SBACK-MAC – State Diagram

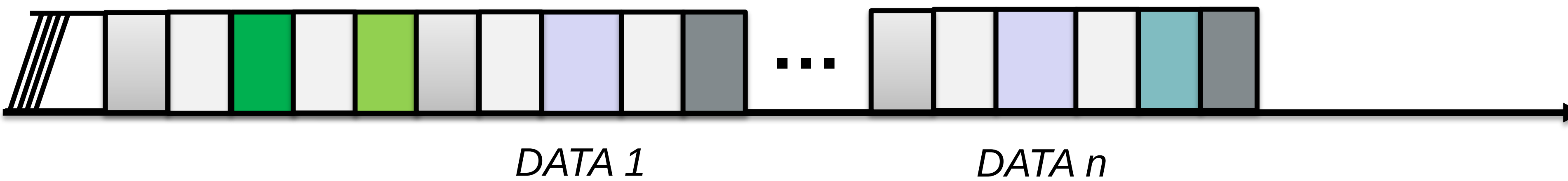


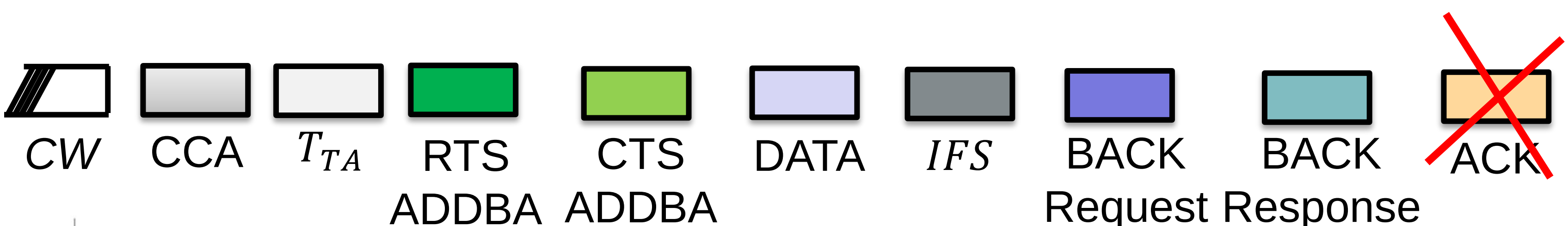
SBACK-MAC – Block ACK Sequence

- SBACK-MAC with *BACK Request (concatenation)*



- SBACK-MAC with no *BACK Request (piggyback)*





SBACK-MAC – Block ACK Sequence

SBACK-MAC with *BACK Request*

$$S_M = \frac{8\,L_{DATA}}{\overline{CW} + (ccaTime + T_{TA} + T_{RTS_{ADDBA}} + H_1))/n}$$

Maximum Average Throughput

$$D_{min} = (\overline{CW} + ccaTime + T_{TA} + T_{RTS_{ADDBA}} + H_1)/n$$

Minimum Average Delay

$$H_1 = T_{TA} + T_{CTS\_ADDBA} + n \times (ccaTime + T_{TA} + T_{DATA} + T_{TA} + T_{IFS}) + \\ + ccaTime + T_{TA} + T_{BRequest} + T_{TA} + T_{BResponse} + T_{IFS}$$

Description	Symbol
Time delay due to CCA	$ccaTime$
TX/RX or RX/TX switching time	T_{TA}
RTS/CTS ADDBA transmission time	T_{RTS_ADDBA} / T_{CTS_ADDBA}
BACK Request/ BACK Response transmission time	$T_{BRequest}$ / $T_{BResponse}$

SBACK-MAC – Block ACK Sequence

- SBACK-MAC with no *BACK Request*

$$S_M = \frac{8\, L_{DATA}}{(\overline{CW} + (ccaTime + T_{TA} + T_{RTS_{ADDBA}} + H_2))/n}$$

Maximum Average Throughput

$$D_{min} = (\overline{CW} + ccaTime + T_{TA} + T_{RTS_{ADDBA}} + H_2)/n$$

Minimum Average Delay

$$H_2 = T_{TA} + T_{CTS\_ADDBA} + [(n-1) \times (ccaTime + T_{TA} + T_{DATA} + T_{TA} + T_{IFS})] + ccaTime + T_{TA} + T_{DATA} + T_{TA} + T_{BResponse} + T_{IFS}$$

Description	Symbol
Time delay due to CCA	$ccaTime$
TX/RX or RX/TX switching time	T_{TA}
RTS/CTS ADDBA transmission time	T_{RTS_ADDBA} / T_{CTS_ADDBA}
BACK Request/ BACK Response transmission time	$T_{BRequest}$ / $T_{BResponse}$

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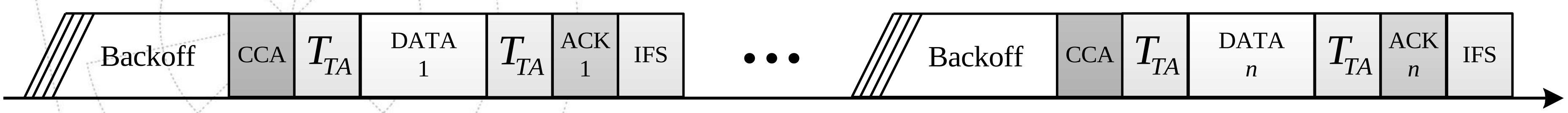
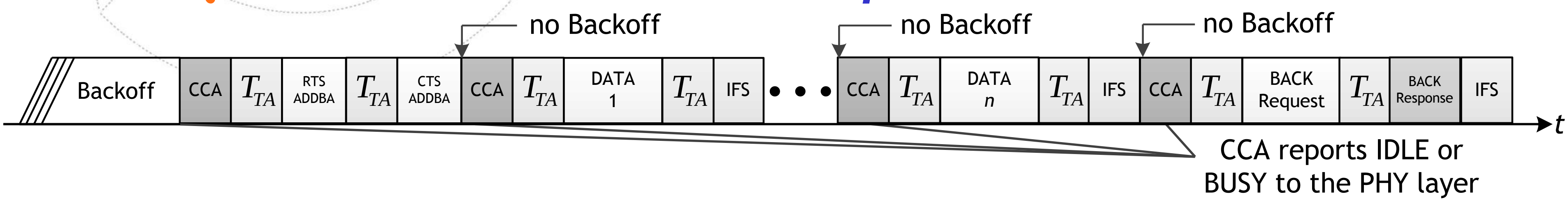
SBACK-MAC – Block ACK Sequence

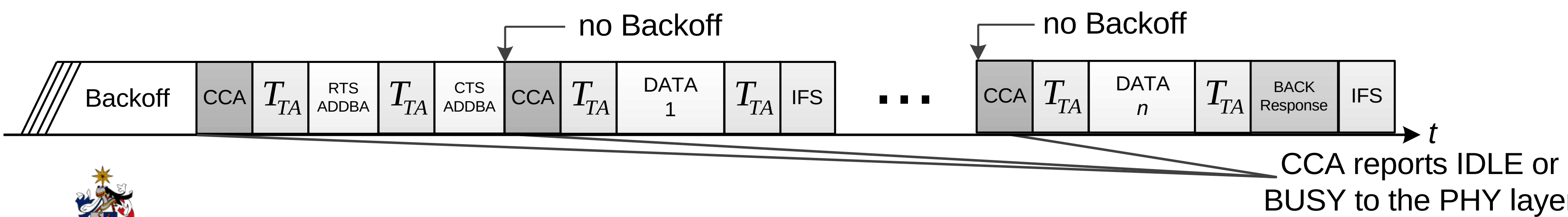
- IEEE 802.15.4



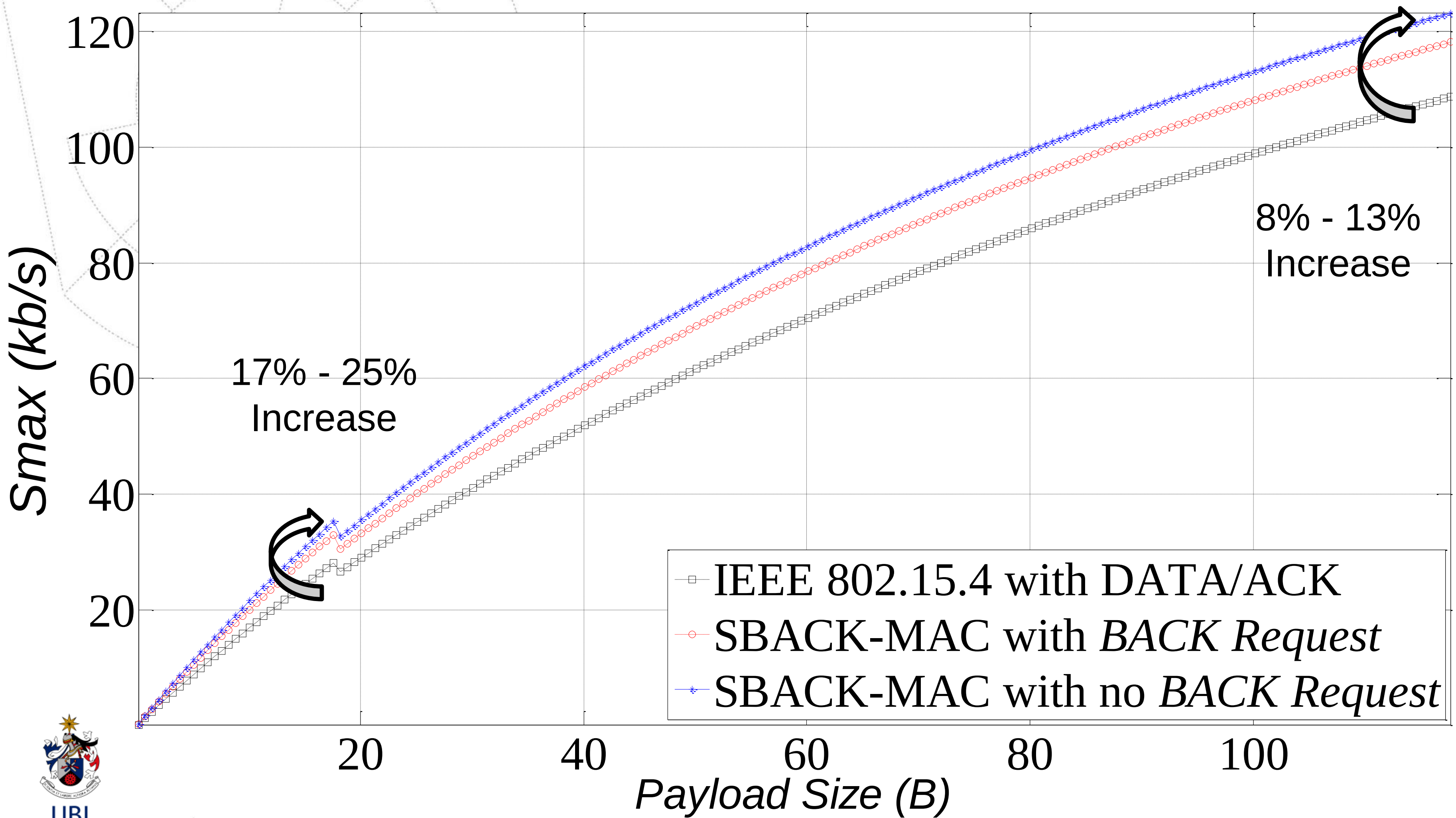
- SBACK-MAC **with *BACK Request***



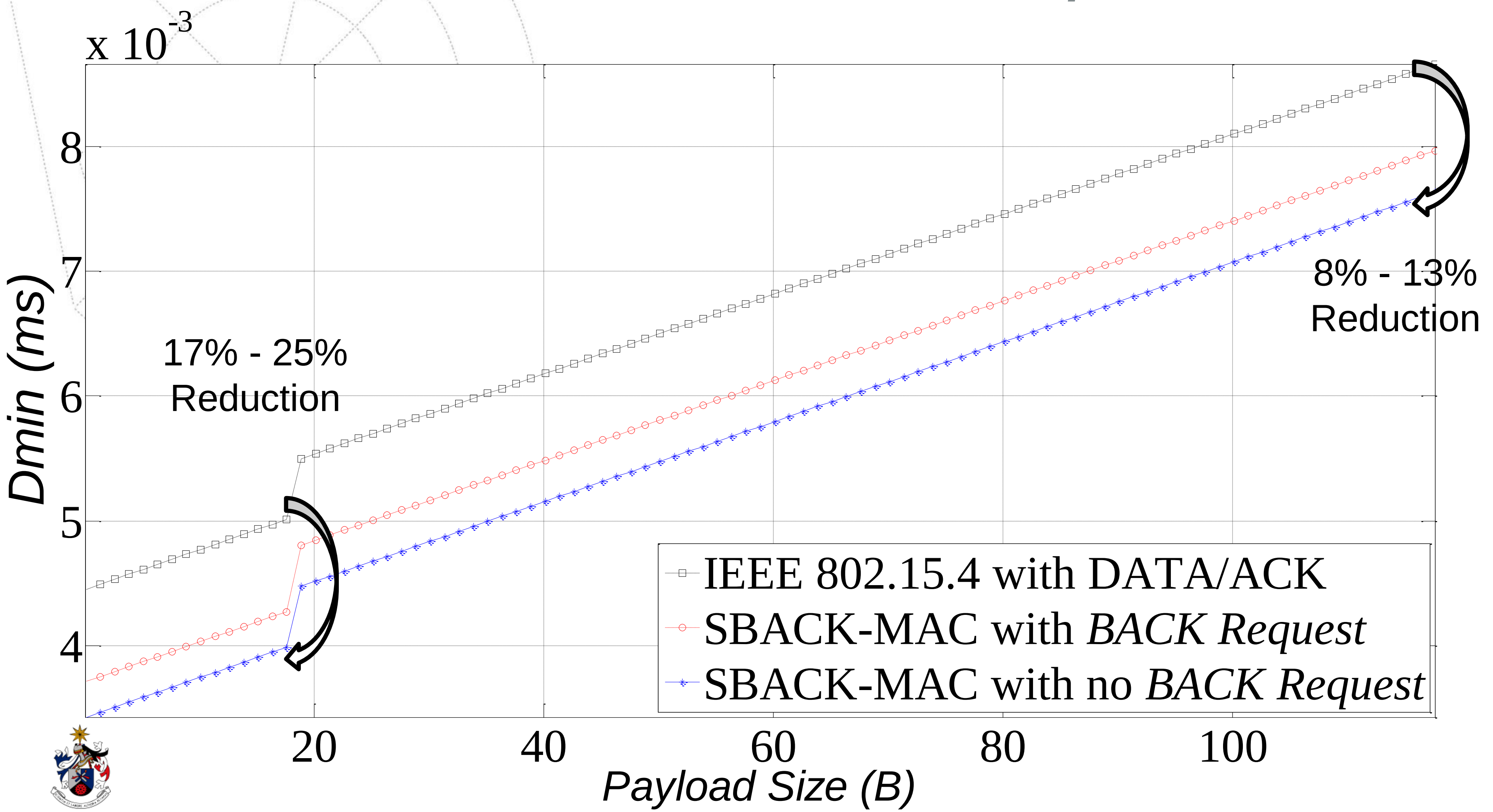
- SBACK-MAC **with no *BACK Request***



Throughput Comparison of IEEE 802.15.4 and SBACK-MAC with and without *BACK Request*



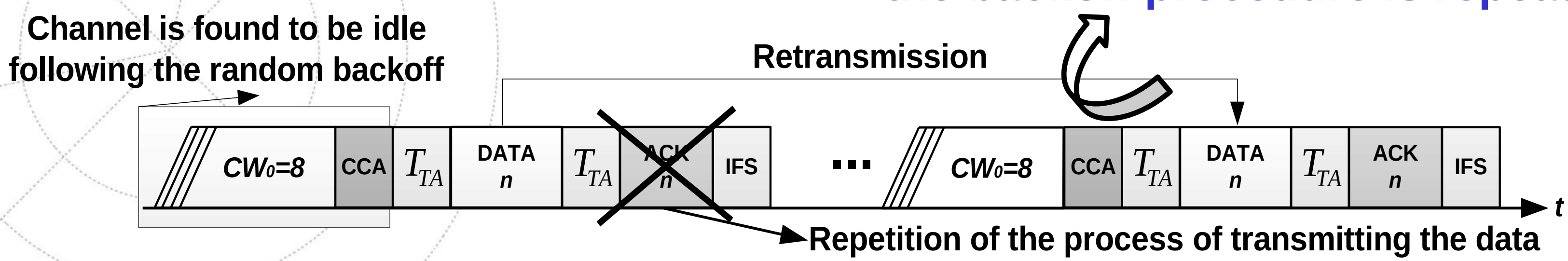
End-to-End Delay Comparison of IEEE 802.15.4 and SBACK-MAC with and without *BACK Request*



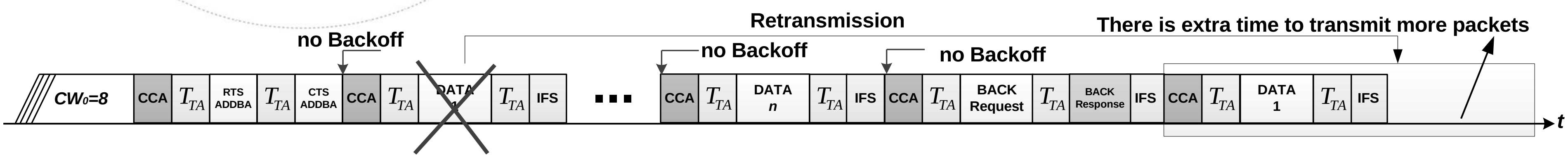
Frame sequence with retransmissions

- IEEE 802.15.4

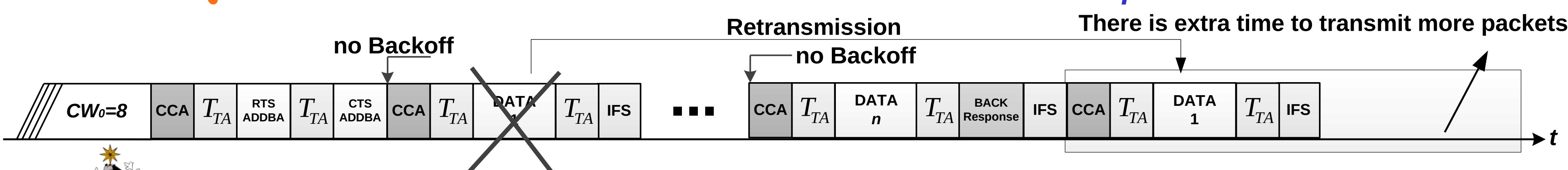
If there is no ACK reception the backoff procedure is repeated



- SBACK-MAC in the presence of *BACK Request*



- SBACK-MAC in the absence of *BACK Request*



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Conclusions

- In this work we propose two innovative mechanisms to reduce the overhead of IEEE 802.15.4, i.e., block acknowledgment (BACK) and piggyback.
- The channel efficiency is improved by using this Block ACK mechanism that aggregates several ACK into only one.
- Our study shows that the proposed aggregation schemes greatly improve the network performance in terms of throughput and end-to-end delay.

Conclusions

- In the context of Cognitive Radio (CR):
  - The SBACK-MAC protocol allows for decreasing the end-to-end delay whilst increasing throughput of the SUs, by decreasing the data transmission time. These extra time can be used to increase the sensing phase enabling for decreasing the number of packet collisions between SUs.

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Thank you,
Questions are Welcome