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Cost IC1004 TD(14)11018

Krakow, Poland , 24-26 September, 2014

Block Acknowledgment in IEEE 802.15.4 by Employing DSSS and CSS PHY Layers

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Outline

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- IEEE 802.15.4 MAC Channel Access
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Introduction

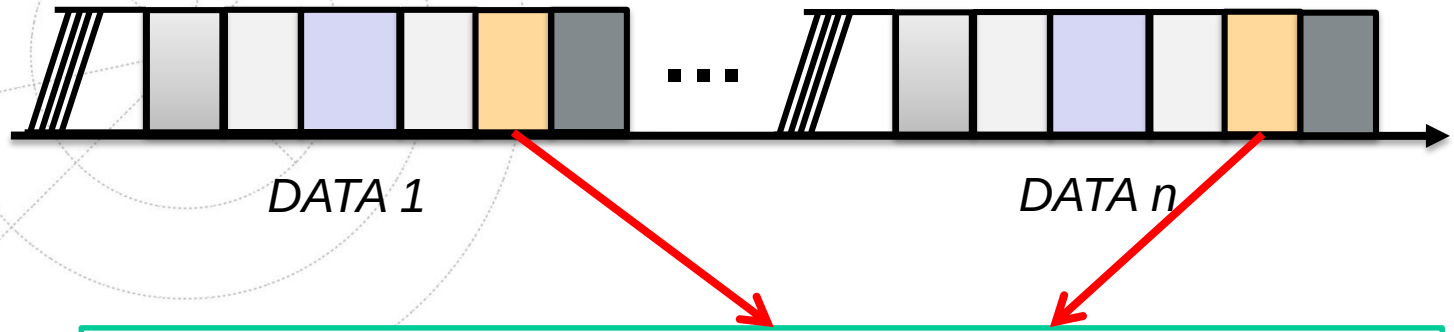
- Wireless Sensor Networks (WSNs) have faced a tremendous advance both in terms of energy-efficiency as well as the number of available applications.
- In order to fulfil the requirements of the set of different applications, new Medium Access Control (MAC) protocols and channel efficient mechanisms needs to be developed in order to respond to the demands from the next generation of WSNs.
- Even by using optimized MAC protocols, if the WSNs platforms do not allow for minimizing the energy consumption in the idle and sleeping states, energy efficiency and long network lifetime will not be achieved.

Introduction (Cont.)

- One of the fundamental reasons for the IEEE 802.15.4 standard 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.
- The Sensor Block Acknowledgment MAC (SBACK-MAC) protocol has been proposed allowing for the aggregation of several acknowledgment (ACK) responses in one special Block Acknowledgment (BACK) Response packet.
- Two different solutions are considered: The first one considers the SBACK-MAC protocol in the presence of BACK Request (concatenation) while the second one considers the SBACK-MAC in the absence of BACK Request (piggyback).

IEEE 802.15.4 MAC Channel Access

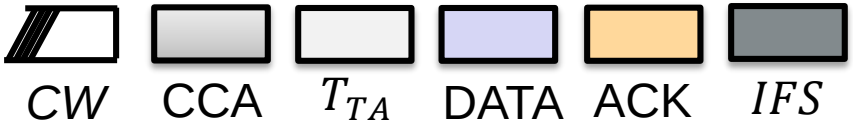
- IEEE 802.15.4 at the Best-Case Scenario (no collisions)



$$macAckWaitDuration = LastSymbol + aTurnaroundTime + phySHRDuration + [6 \times phySymbolsPerOctet]$$

$$macAckWaitDuration = 1 + 12 + 10 + [6 \times 2] = 35\ symbols$$

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



IEEE 802.15.4 MAC Channel Access

- Parameters, symbols and values for IEEE 802.15.4 by considering the DSSS and CSS PHY Layers, 2.4 GHz band

Description	Symbol	DSSS	CSS
PHY length overhead	L_{H_PHY}	6 bytes	7 bytes
MAC overhead	L_{H_MAC}	9 bytes	9 bytes
TX/RX or RX/TX switching time	T_{TA}	192 μs	72 µs
Short Interframe spacing (SIFS) time	T_{SIFS}	192 μs	72 µs
Long Interframe spacing (LIFS) time	T_{LIFS}	640 μs	240 µs
Backoff period duration	T_{BO}	320 μs	120 µs
Data Rate	R	250 kb/s	1Mb/s

IEEE 802.15.4 MAC Channel Access

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

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

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

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

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

Average Maximum Throughput

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

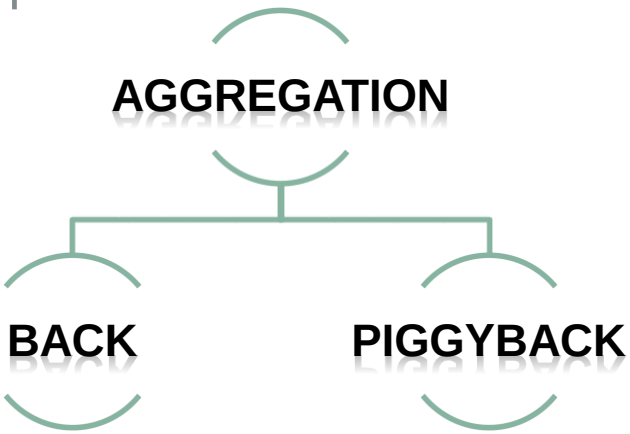
Average Minimum Delay

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

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

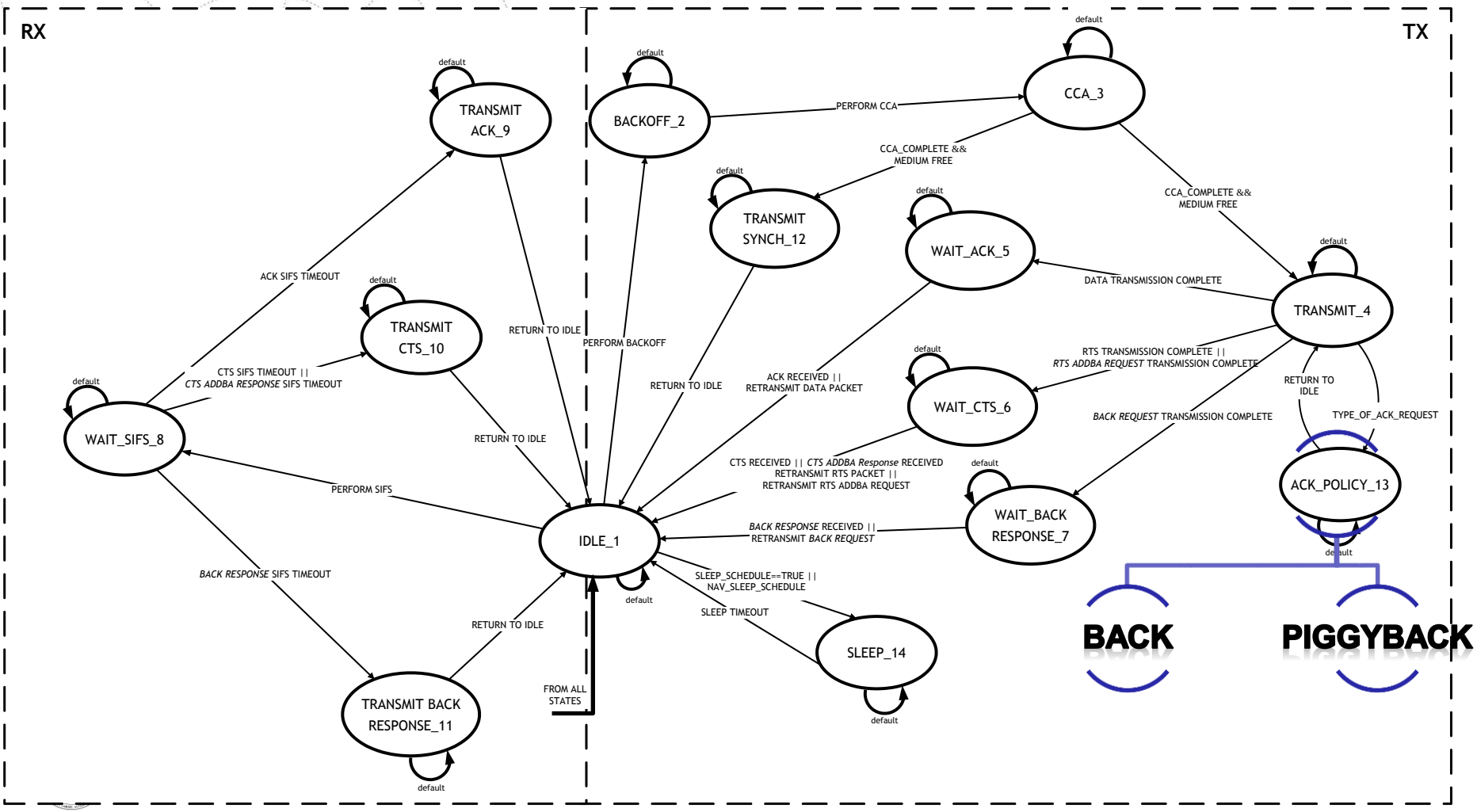
- The Block Acknowledgment (BACK) mechanism was previously introduced in the IEEE 802.11e standard.

- The SBACK-MAC allows the aggregation of several acknowledgment (ACK) responses in one special frame called BACK Response.

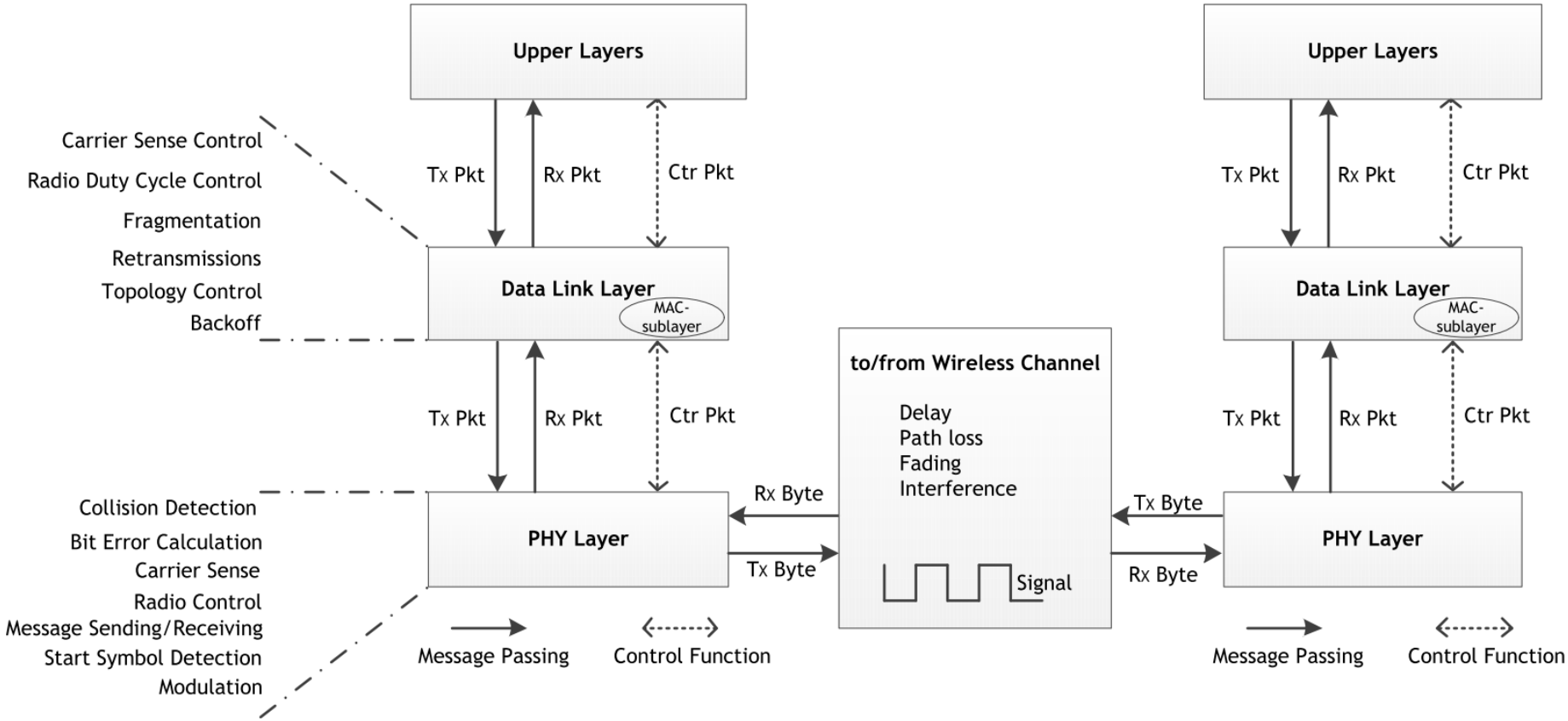


- Energy consumption will be greatly reduced because it is not needed to transmit and receive several ACK control packets (one for each data packet) which would lead to an extra energy waste.

IEEE 802.15.4 and SBACK-MAC – State Diagram

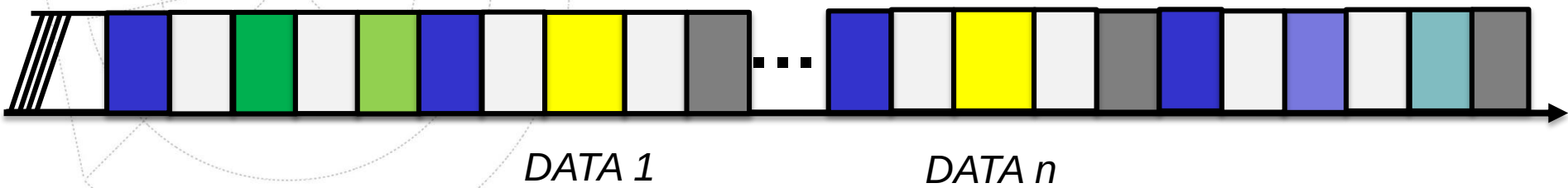


Layered Model Considered by IEEE 802.15.4 and SBACK-MAC

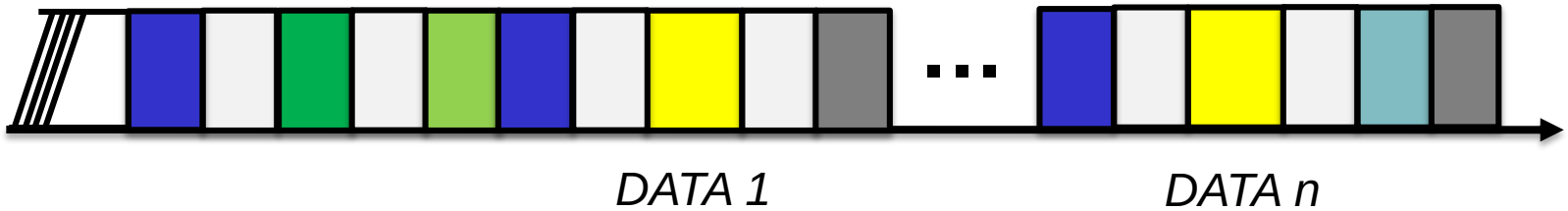


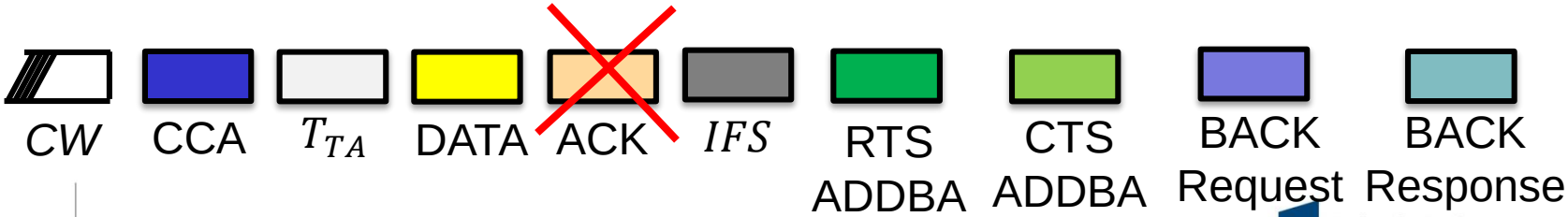
SBACK-MAC – Block ACK Sequence

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



- SBACK-MAC ***without BACK Request*** (piggyback)





SBACK-MAC – Block ACK Sequence

SBACK-MAC with *BACK Request*

$$S_M = \frac{8\,L_{DATA}}{\overline{(CW} + (ccaTime + T_{TA} + T_{RTS_{ADDBA}} + H_3))/n}$$

Average Maximum Throughput

$$D_{min} = (\overline{CW} + ccaTime + T_{TA} + T_{RTS_{ADDBA}} + H_3)/n$$

Average Minimum Delay

$$H_3 = T_{TA} + T_{CTS\_ADDBA} + n \times (ccaTime + T_{TA} + T_{DATA} + T_{TA} + T_{IFS}) + \\ + ccaTime + T_{TA} + T_{BRequest} + T_{TA} + T_{BResponse} + T_{IFS}$$

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*

$$S_M = \frac{8\,L_{DATA}}{\overline{CW} + (ccaTime + T_{TA} + T_{RTS_{ADDBA}} + H_4))/n}$$

Maximum Throughput

$$D_{min} = (\overline{CW} + ccaTime + T_{TA} + T_{RTS_{ADDBA}} + H_4)/n$$

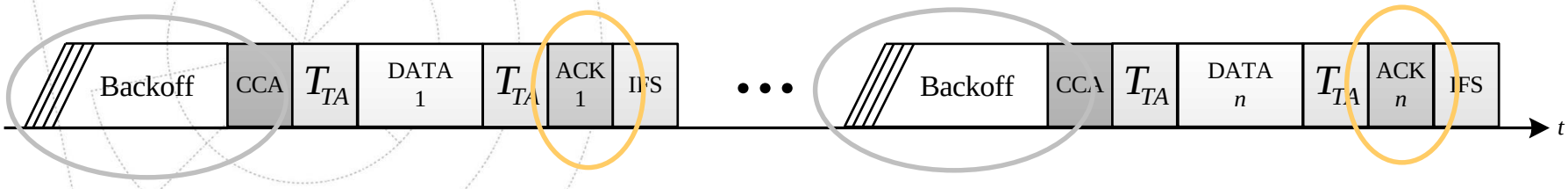
End-to-End Delay

$$H_4 = T_{TA} + T_{CTS\_ADDBA} + [(n-1) \times (ccaTime + T_{TA} + T_{DATA} + T_{TA} + T_{IFS})] + ccaTime + T_{TA} + T_{DATA} + T_{TA} + T_{BResponse} + T_{IFS}$$

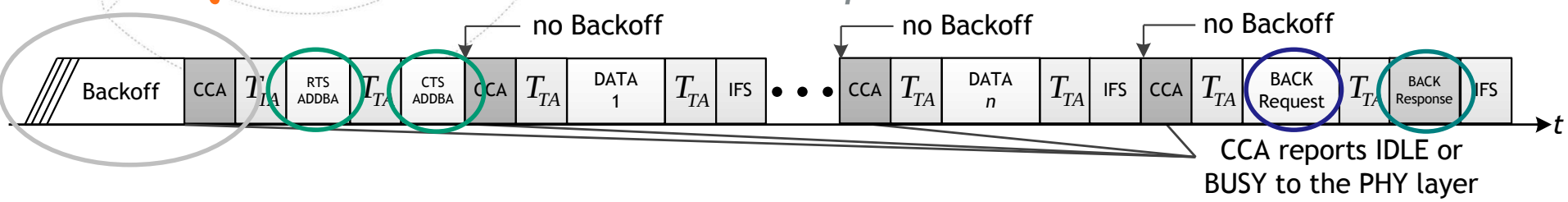
Description	Symbol
Time delay due to CCA	$ccaTime$
TX/RX or RX/TX switching time	T_{TA}
RTS/CTS ADDBA transmission time	T_{RTS_ADDBA} / T_{CTS_ADDBA}
BACK Request/ BACK Response transmission time	$T_{BRequest}$ / $T_{BResponse}$

SBACK-MAC – Block ACK Sequence

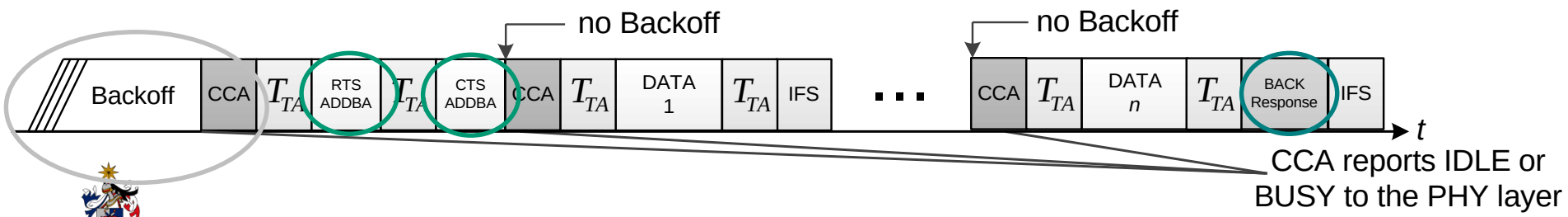
- IEEE 802.15.4



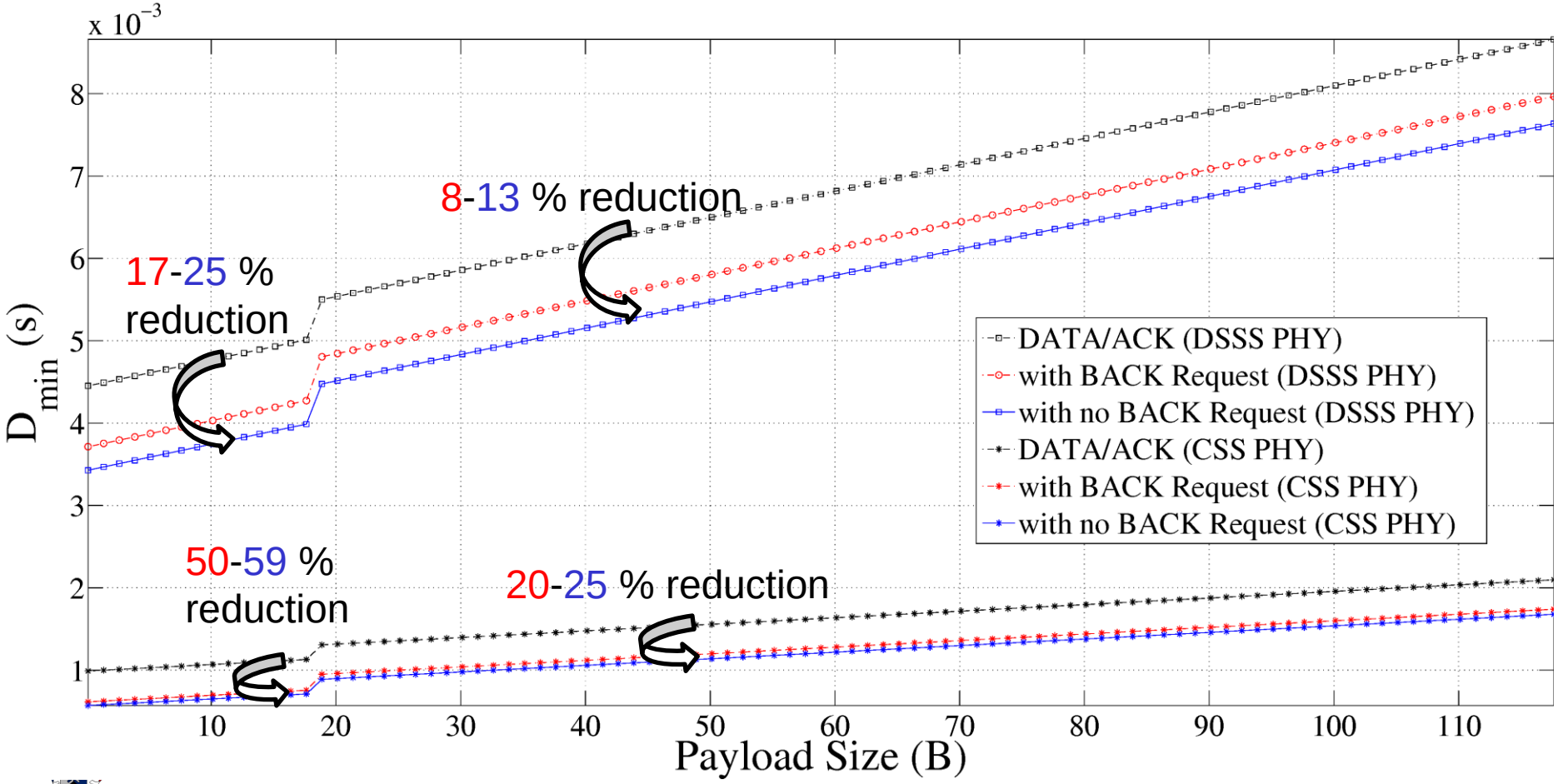
- SBACK-MAC with *BACK Request*



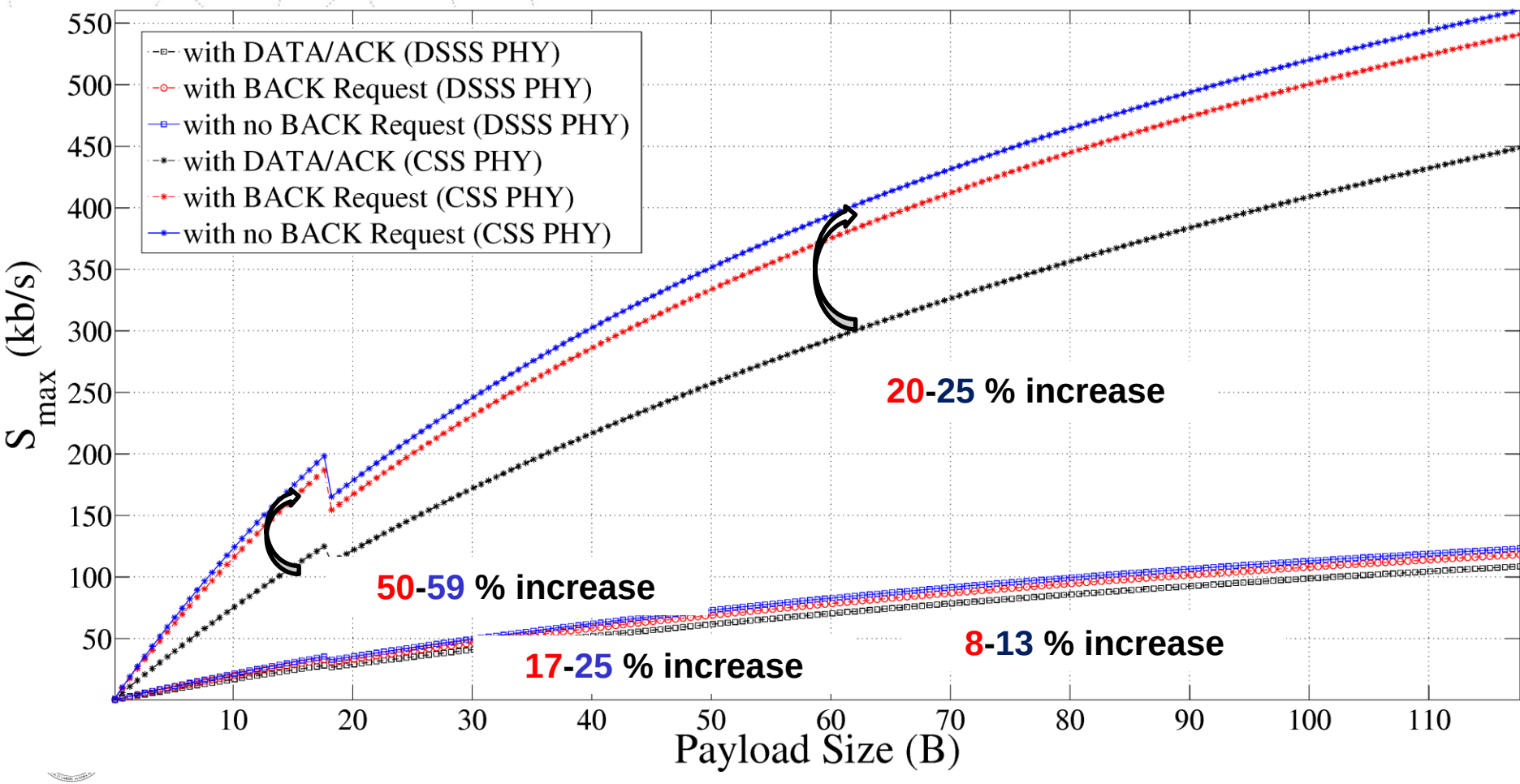
- SBACK-MAC with no *BACK Request*



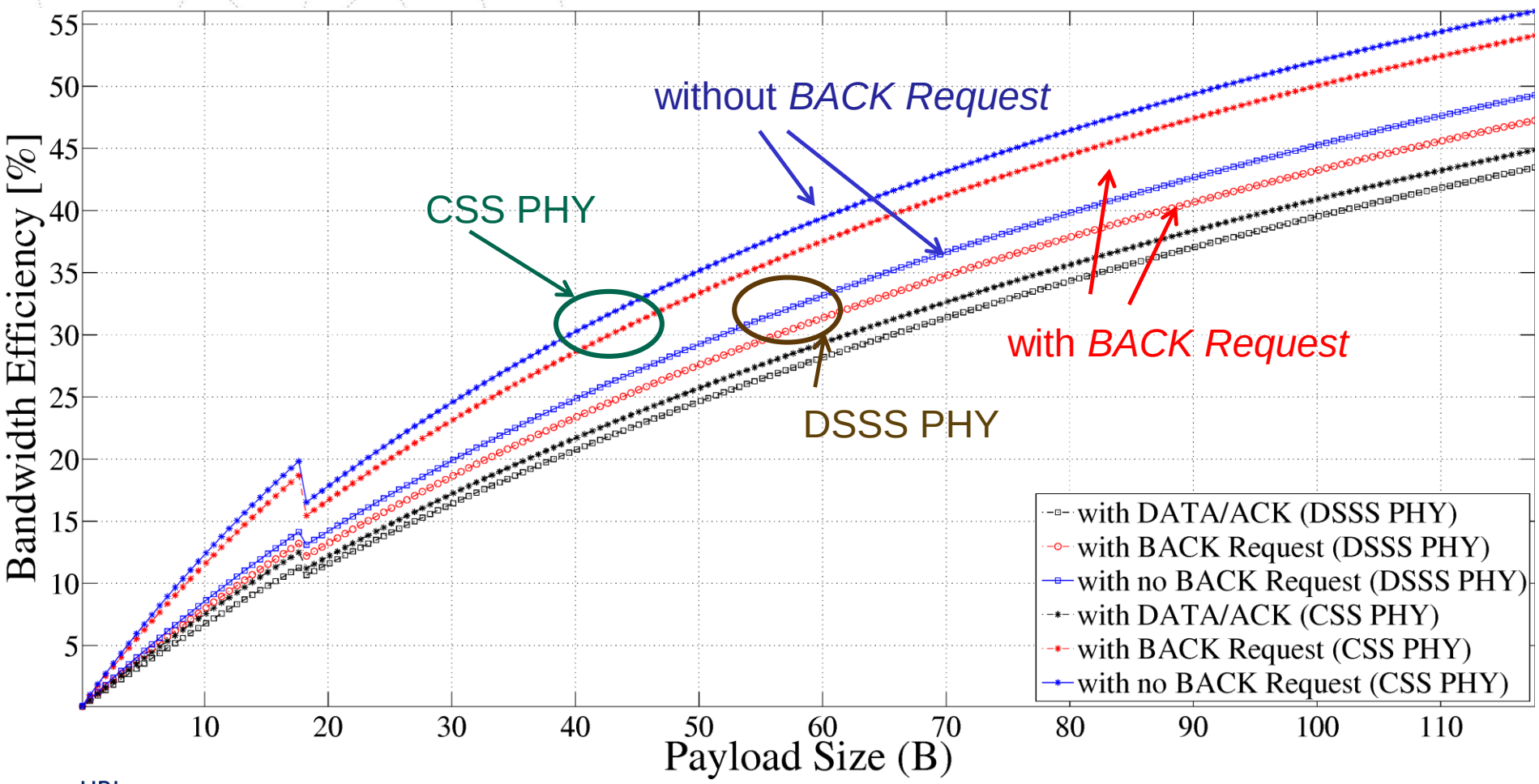
Minimum average delay as a function of the payload size (in Bytes)



Maximum average throughput as a function of the payload size (in Bytes)



Bandwidth efficiency as a function of the payload size (in Bytes)



Conclusions

- The SBACK-MAC protocol in the presence (concatenation) and absence (*piggyback*) of BACK Request has been proposed allowing for the aggregation of several ACK responses in one special packet.
- By using the proposed BACK mechanisms we improved the channel use optimization by decreasing the overhead when compared to the actual payload size for all the cases.
- The SBACK-MAC protocol is compliant with the IEEE 802.15.4 standard. Therefore, the proposed solutions can be integrated in the IEEE 802.15.4 standard or serve as the basis for the *Wireless Next Generation Networks*.
- This work compared the use of DSSS (250 kb/s) and CSS (1 Mb/s) PHY layers and has shown the differences in the performance improvement between the absence of BACK Request and its use.

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Suggestions for Further Work

- Verify the results experimentally by using WSN platforms (e.g., Waspmote platform).

Thank you,
Questions are Welcome

Make everything as simple as possible, but not simpler. - Albert Einstein (JF)

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