New CAP Reduction Mechanisms for IEEE 802.15.4 DSME to Support Fluctuating Traffic in IoT Systems

Florian Meyer and Ivonne Mantilla-Gonzalez and Volker Turau

Adhoc Now 2020
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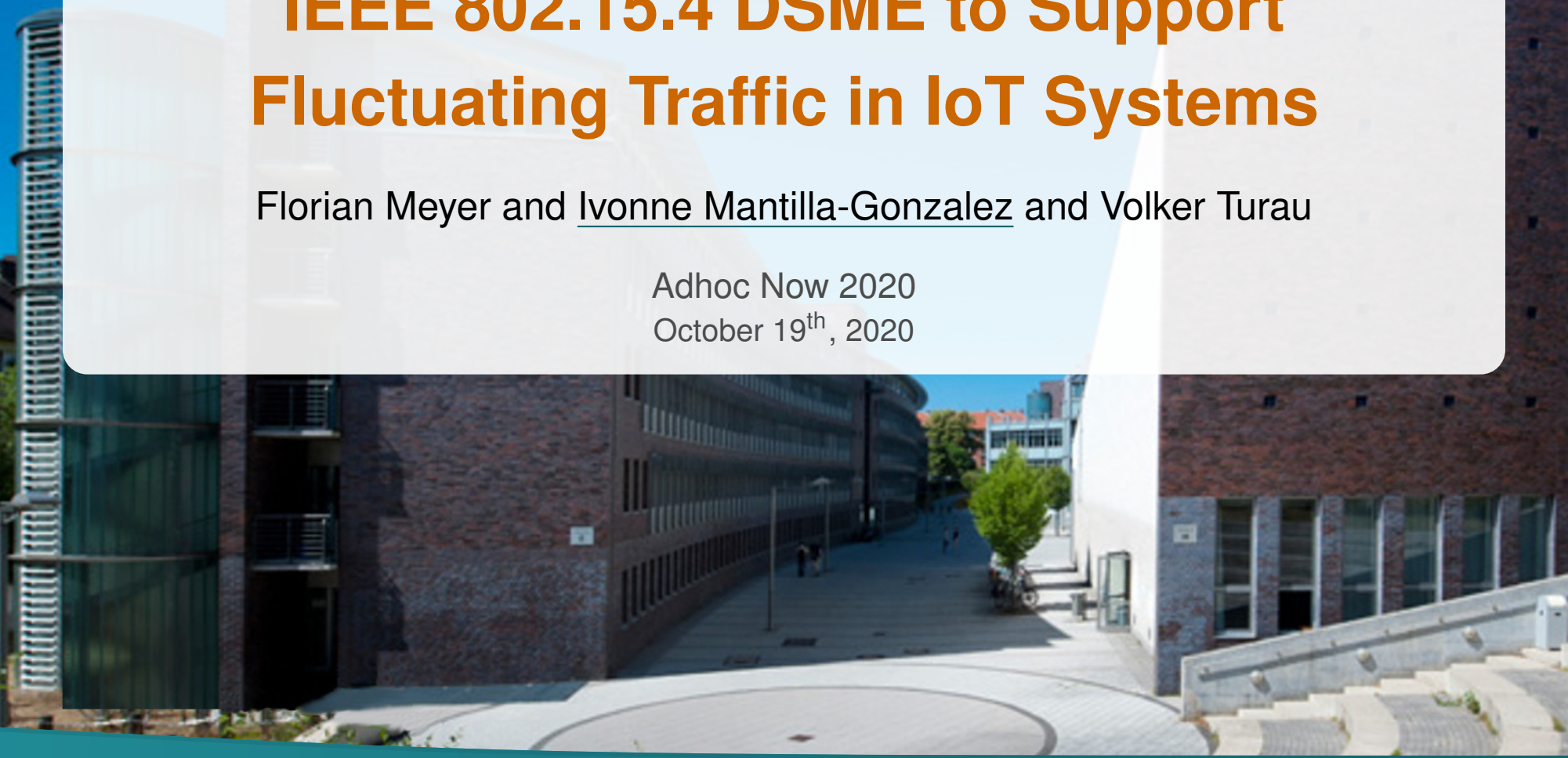

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Agenda

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- Motivation

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- Description of the New CAP reduction Mechanisms

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- Theoretical and simulative evaluation

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- Conclusions and Outlook

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- Efficient management of resources needed to avoid
  - Channel underutilization
  - Channel overload

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- IEEE 802.15.4 DSME $\Rightarrow$ reliability, scalability and energy efficiency in IoT applications
  - TDMA/FDMA reservation scheme
  - Distributed slot negotiation and collision free slot allocation
  - CAP reduction mode
  - Fixed trade-off between adaptability and throughput

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$\Rightarrow$ **We propose two extensions of DSME to provide high degree of responsiveness to traffic fluctuations while keeping throughput high**

Frame Structure

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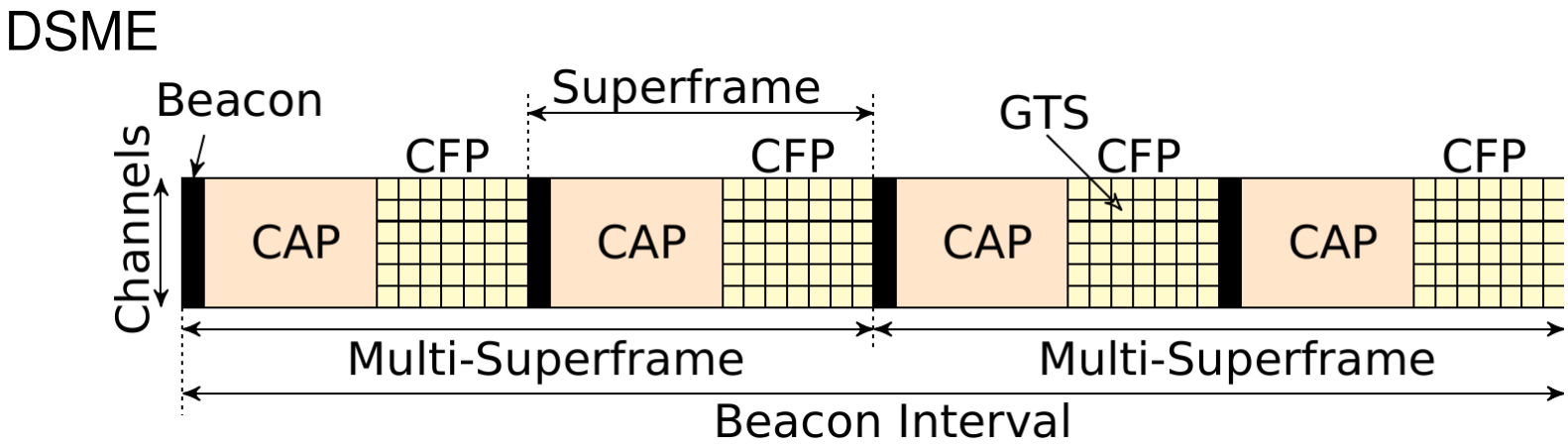


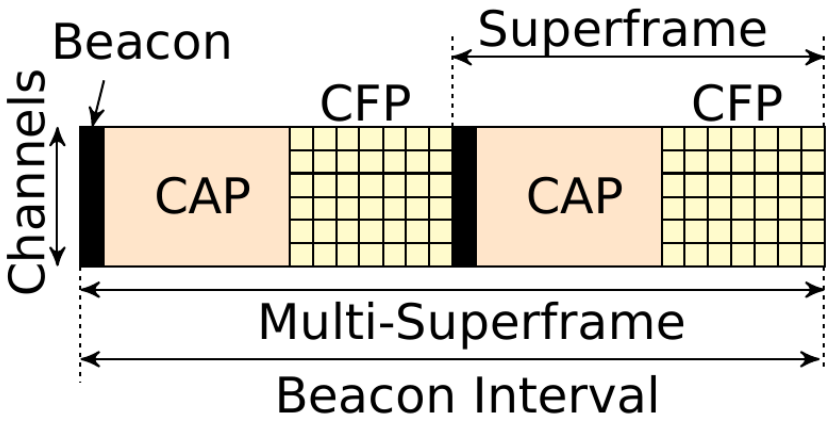
- Contention Access Period : CAP
- Contention Free Period : CFP
- Guaranteed Time slot : GTS

Parameters:

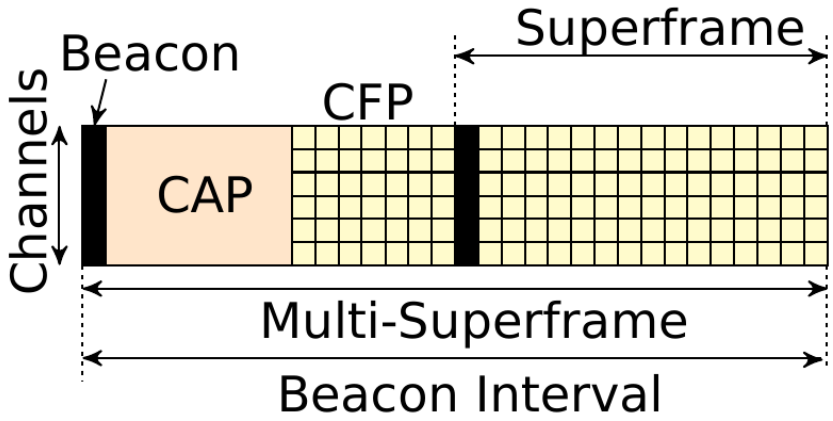
- Superframe order (*SO*):
  Length of a slot / superframe
- Multi-Superframe order (*MO*):
  Length of a Multi-Superframe
- Beacon order (*BO*):
  Length of a beacon interval (BI)

Frame Structure

DSME - no CAP reduction (NCR)



DSME - CAP reduction (CR)



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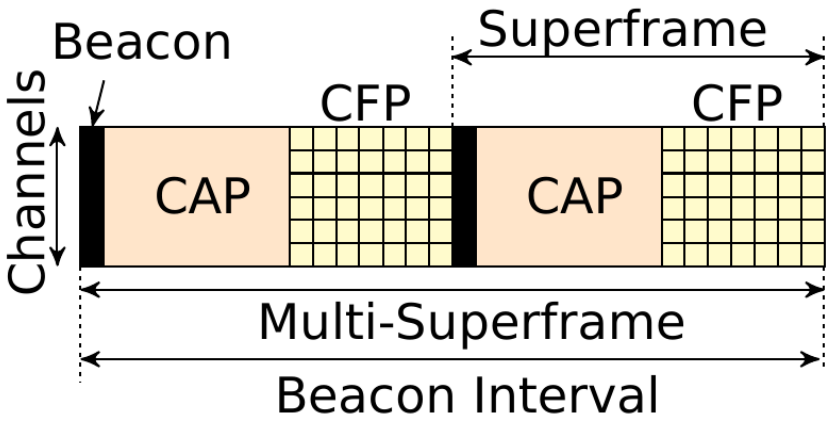

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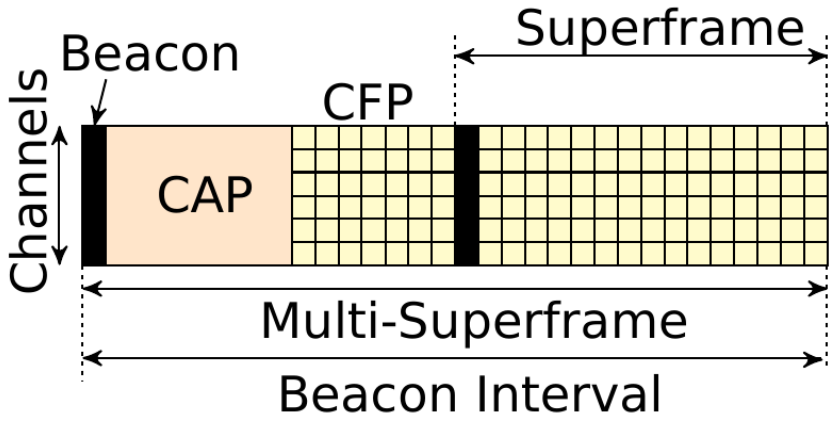

Definition: Fraction τ of CFPs time slots in a beacon interval

$$\tau = \frac{\text{Total number of CFP's time slots in a BI}}{\text{Total number of time slots in a BI}}$$

In this case, $\tau_{\text{NCR}} = 7/16$ and $\tau_{\text{CR}} = 11/16$

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Fact 2:

In DSME τ is set before deployment and cannot be changed at run-time

Challenge:

How to extend DSME such that τ can be changed dynamically with a fine granularity?

Alternating CAP reduction - ACR

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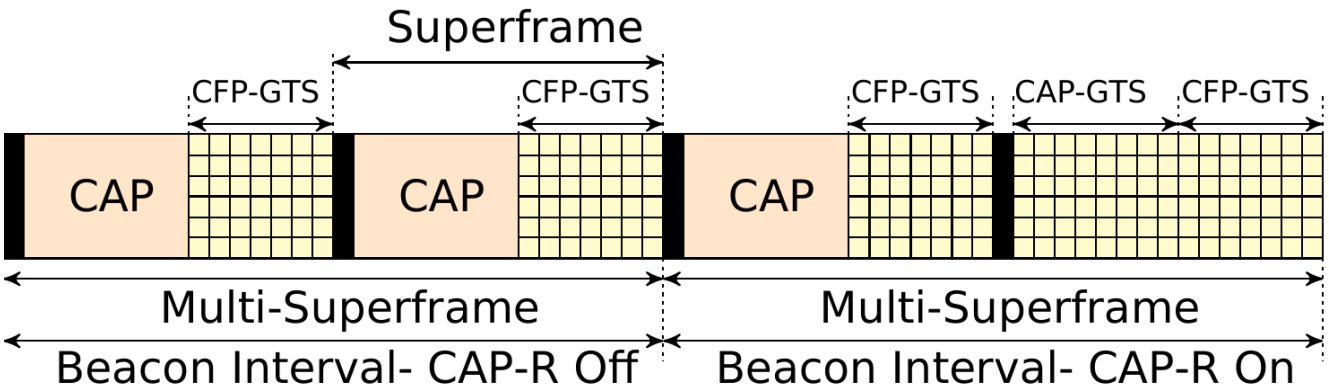
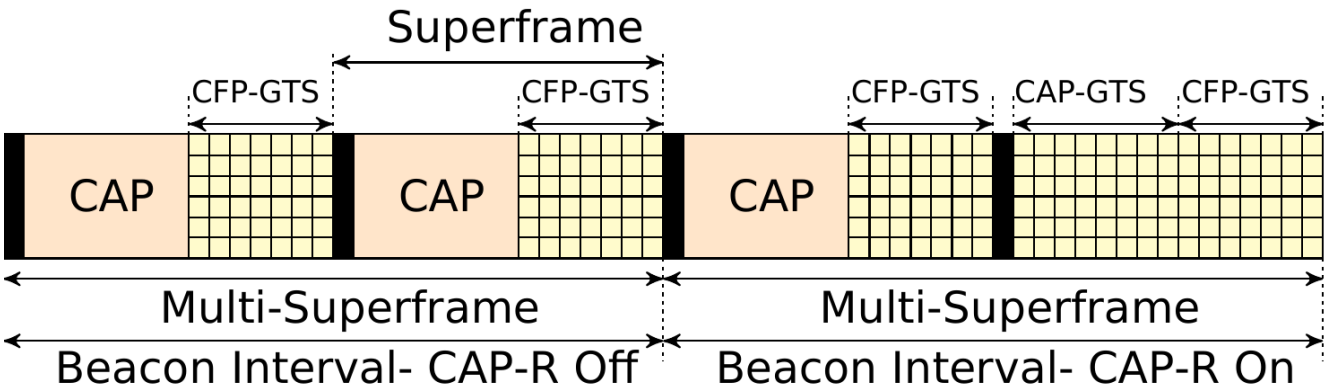


Alternation between CR and NCR every beacon interval

Alternating CAP reduction - ACR



Alternation between CR and NCR every beacon interval

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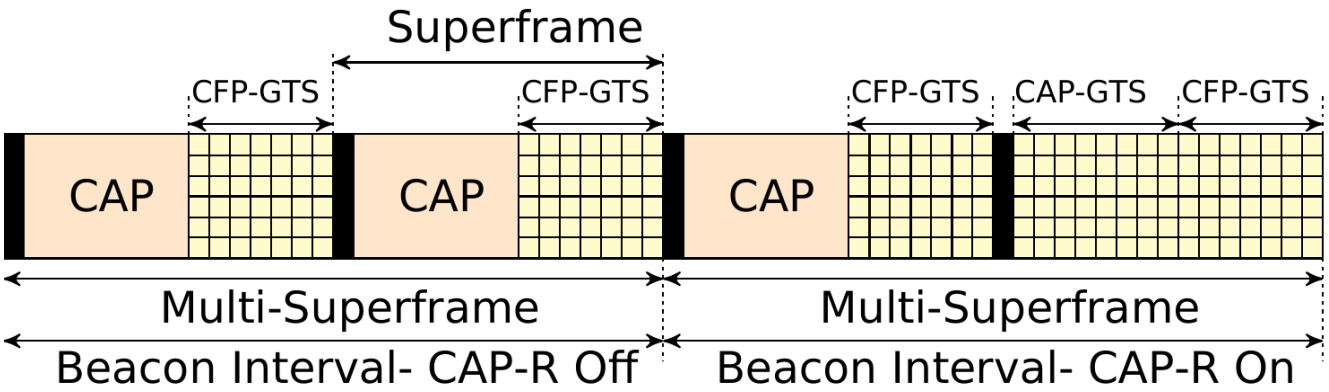

Alternation between CR and NCR every beacon interval

How is this achieved?

- PAN coordinator defines current operating mode per BI
- Operating mode is encoded in beacon messages
- Synchronization in network is guaranteed with minimum effect on CSMA traffic

Dynamic CAP reduction - DCR

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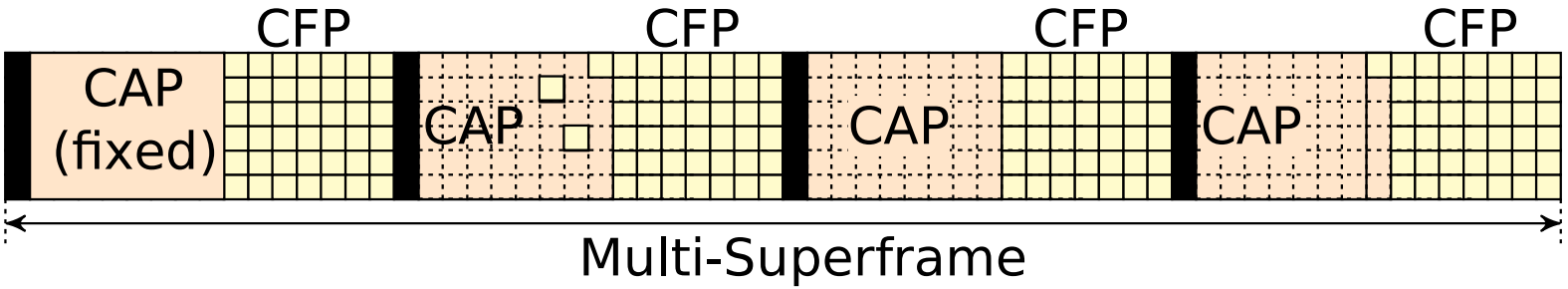
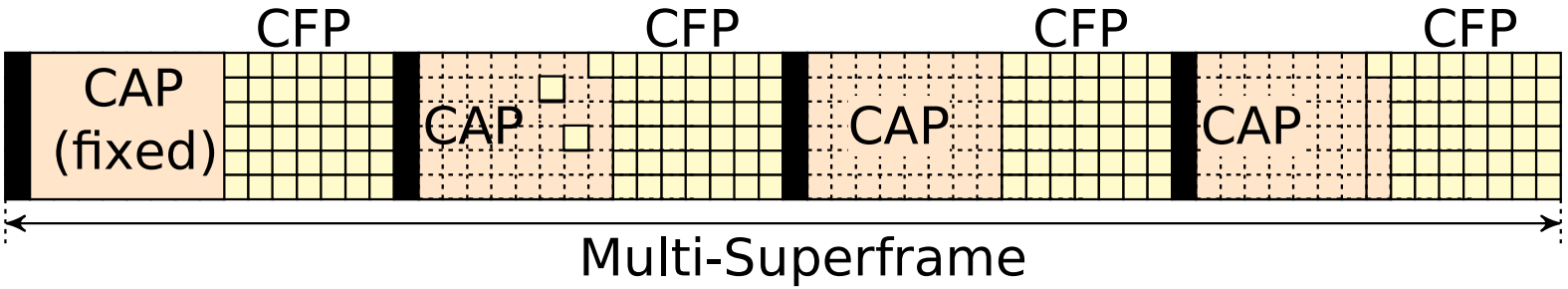


Allocation of GTSs in CAPs locally according to node's traffic demands

Dynamic CAP reduction - DCR



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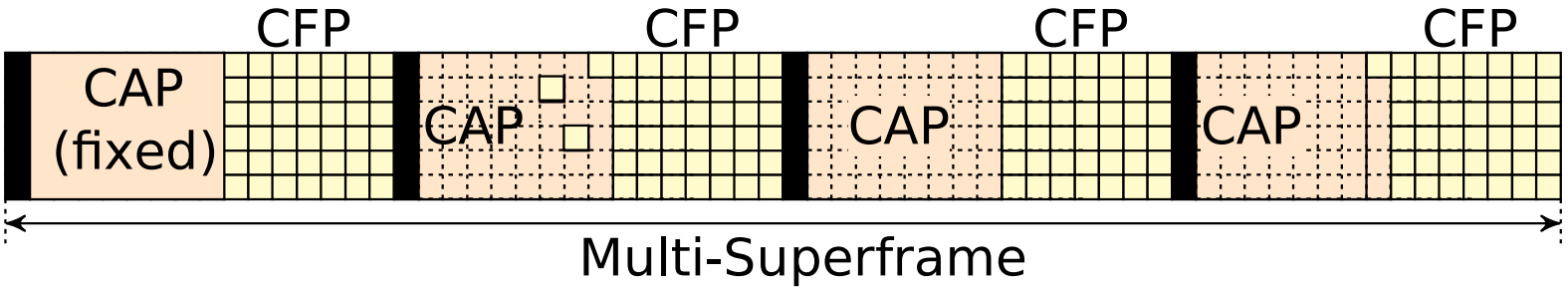

Allocation of GTSs in CAPs locally according to node's traffic demands

How is this achieved?

- DCR starts in NCR and dynamically shrinks CAPs until CR mode
- Shrinking mechanism begins once all GTSs in CFPs are used
- Channel for transmissions in reduced CAPs $\neq$ $Channel_{CAP}$

Theoretical evaluation

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Values of τ for different values of MO, $BO = 7$ and $SO = 3$

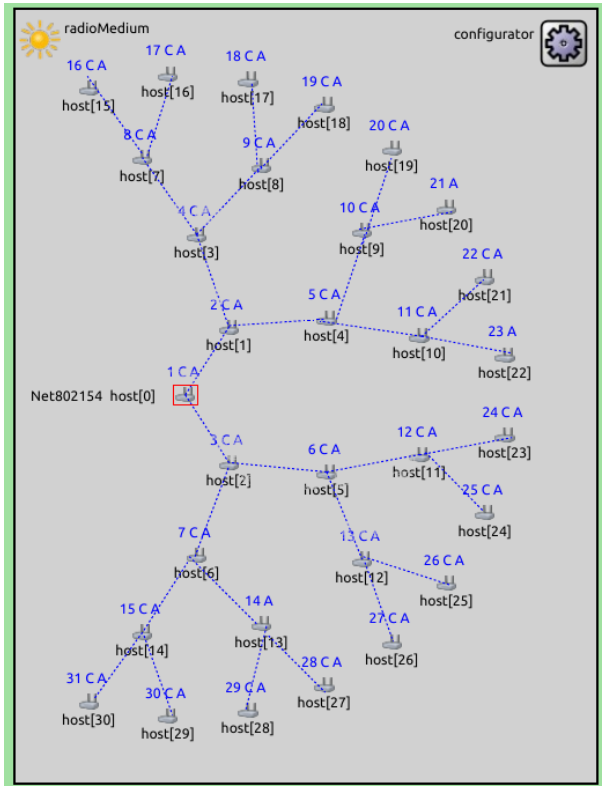
	$MO = 4$	$MO = 5$	$MO = 6$	$MO = 7$
NCR	43.75%	43.75%	43.75%	43.75%
CR	68.75%	81.25%	87.5%	90.06%
ACR	56.25%	62.5%	65.63%	67.19%
DCR	43.75% - 68.75%	43.75% - 81.25%	43.75% - 87.5%	43.75% - 90.06%

Theoretical evaluation

Expected time to send a CAP message on time slot level for different values of MO, $BO = 7$ and $SO = 3$

	$MO = 4$	$MO = 5$	$MO = 6$	$MO = 7$
NCR	2.25	2.25	2.25	2.25
CR	9.38	24.94	56.72	120.61
ACR	5.81	14.10	29.49	61.43
DCR	2.25 - 9.38	2.25 - 24.94	2.25 - 56.72	2.25 - 120.61

Simulative evaluation



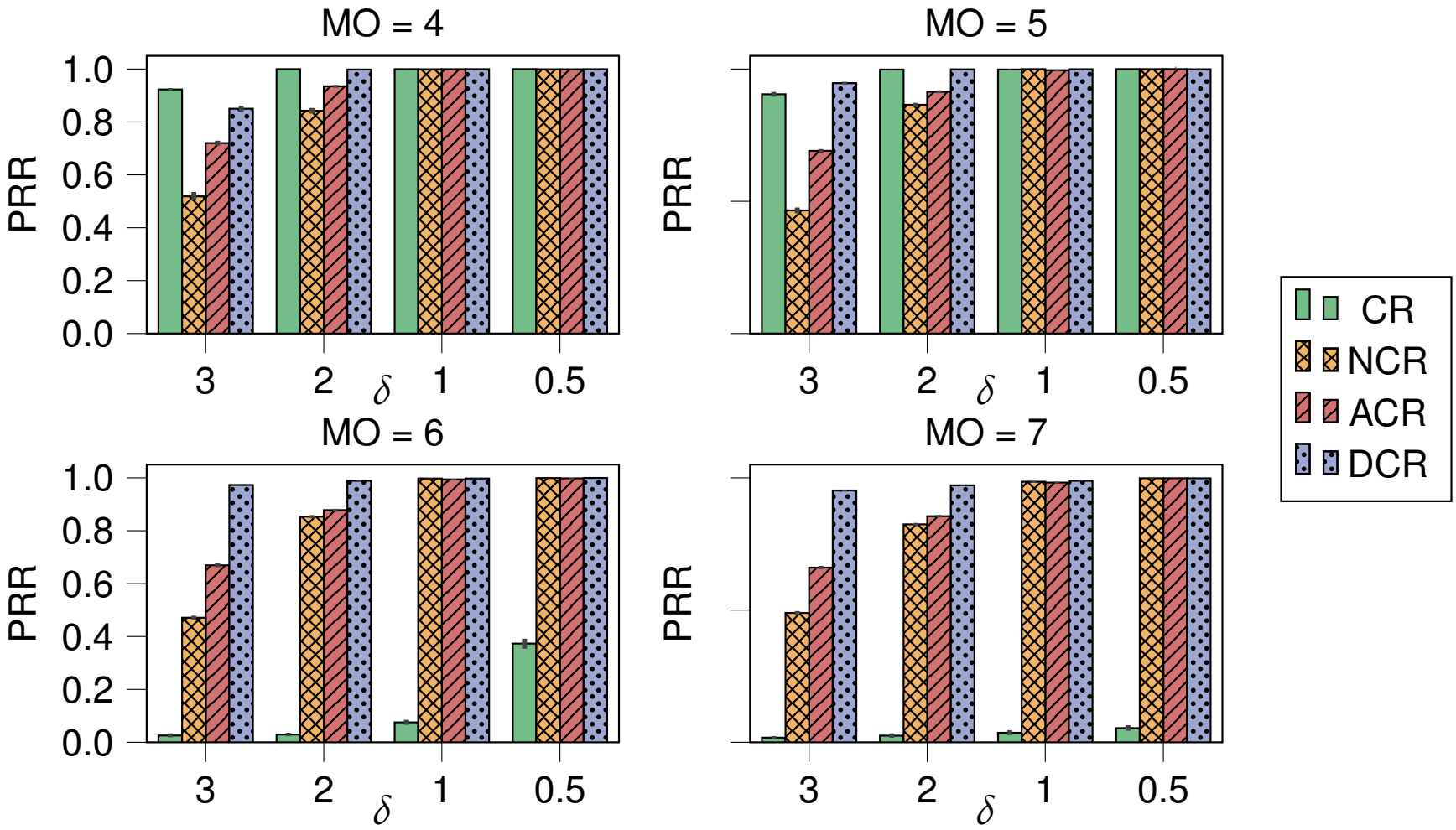
- Data collection - convergecast pattern
- Rooted binary tree (31 nodes)
- Packet generation $\Rightarrow \delta$ [packets/s]
- Packet generation $\Rightarrow$ Poisson distribution with mean$= \lambda$
  - Varying burst sizes
  - Varying δ

Parameter	*SO*	*MO*	*BO*	Q_{GTS}	δ
Values	3	{4,...,7}	7	22	{1,...,4}

Simulative evaluation

Scenario: varying δ

Packet Reception Ratio (PRR)



Conclusions and Outlook

Challenge:

How to extend DSME such that τ can be dynamically adjusted after deployment of the network?

- **ACR** $\Rightarrow$ combines strengths of CR and NCR. It is far easier to implement and remains within the original standard
- **DCR** $\Rightarrow$ is more flexible with respect to τ. It does not conform with the IEEE 802.15.4 standard

Future work

- To fully exploit the possibilities of ACR and DCR $\Rightarrow$ a powerful dynamic scheduler is required

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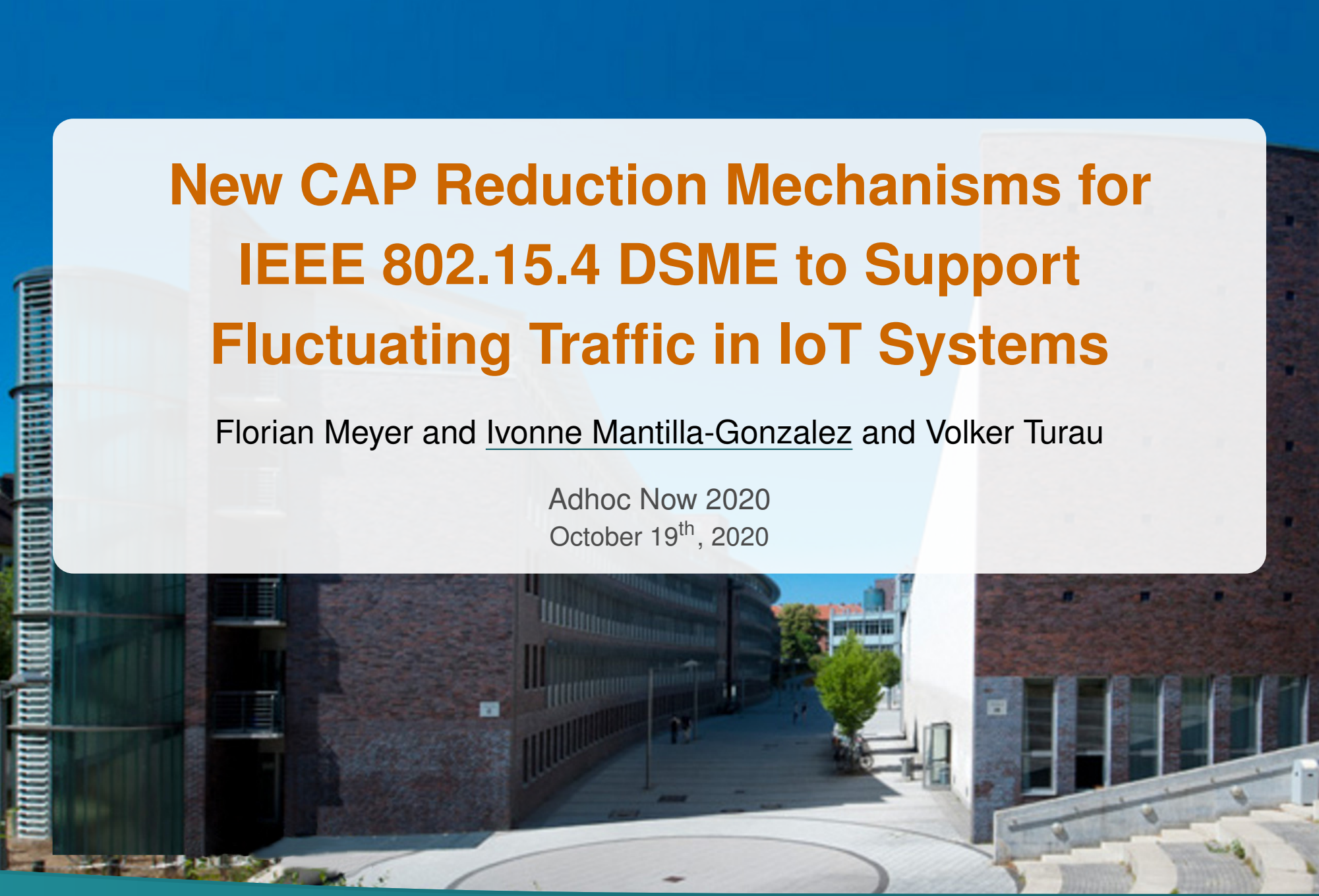

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