Comparison of WiFi Interference Mitigation Strategies in IEEE 802.15.4 DSME Networks: Leveraging Reinforcement Learning with Expected SARSA

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Agenda

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- Simulative Assessment

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- Conclusions and Outlook

Motivation

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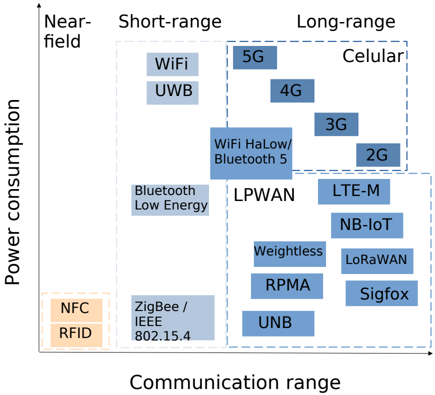
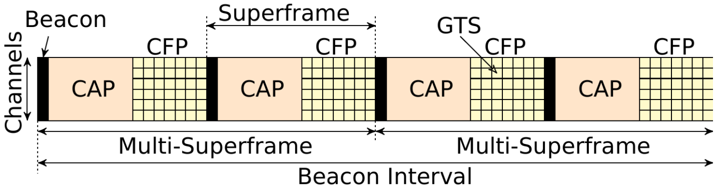
Industry 4.0 and wireless communication technologies



Source: El-Sheimy, N., & Li, Y. (2021). Indoor navigation: State of the art and future trends. Satellite Navigation, 2(1), 1-23.

Motivation

IEEE 802.15.4 DSME: Reliability, scalability and energy efficiency in IoT applications

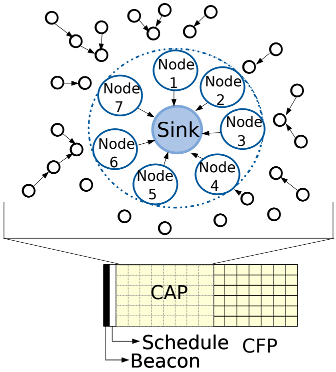


Channel diversity Mechanisms:

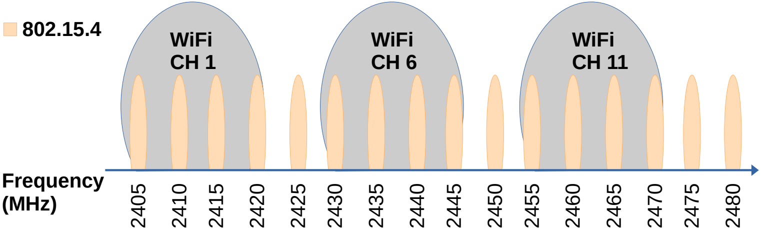
Channel adaptation and channel hopping

Motivation

Data Collection Scenario: "Virtual Sink" strategy to alleviate the funnel effect improving network reliability



Challenge


802.15.4
WiFi
CH 1
WiFi
CH 6
WiFi
CH 11
Frequency
(MHz)
2405
2410
2415
2420
2425
2430
2435
2440
2445
2450
2455
2460
2465
2470
2475
2480

WiFi Interference Model

- 3 non-overlapping channel arrangement (ch 1, ch 6 and ch 11) [1] + random interference over remaining channels to model co-channel interference
- We set $CCA_{WiFi} > P_{DSME}$ so that WiFi continuously senses the channel as idle [2]

WiFi model	*# sources*	*Traffic*	*Period*	*Idle period*	*Channel sequence*
I-1	1	periodic	20 s	-	random
I-2	2	periodic	20 s	5 s	random

[1] IEEE Standard for Information Technology - Local and Metropolitan Area Networks–Specific Requirements - Part 11: Wireless LAN Medium Access Control (MAC) and Physical Layer (PHY) Specifications," in IEEE Std 802.11-2020 (Revision of IEEE Std 802.11-2016) , vol., no., pp.1-4379, 26 Feb. 2021.

[2] Lee, J., & Jeong, W. C. (2012, October). Performance analysis of IEEE 802.15. 4e DSME MAC protocol under WLAN interference. In 2012 International Conference on ICT Convergence (ICTC) (pp. 741-746). IEEE.

Challenge

How to extend DSME so that the network can dynamically adapt to fluctuating channel conditions?
Particularly, due to coexistence with WiFi technology?

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We propose WiFi mitigation strategies using virtual sink-based networks.

Description of WiFi Mitigation Strategies

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- **Overprovisioning**

  Slot length can be adjusted so that 2 packets per GTS can be transmitted

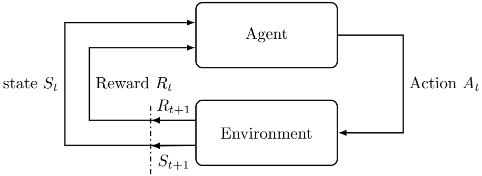
  Packet delivery ratio (PRR) with and without overprovisioning under external WiFi interference

data rate	*Channel diversity*	*Overprovisioning*	*No overprovisioning*
2 packet/s	Adaptation	0.65	0.32
	Hopping	0.42	0.20
3 packet/s	Adaptation	0.44	0.22
	Hopping	0.29	0.15
4 packet/s	Adaptation	0.25	0.18
	Hopping	0.22	0.13

Description of WiFi Mitigation Strategies

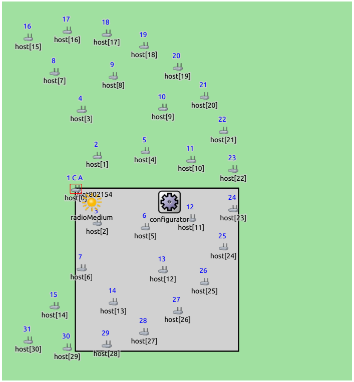
- **Frequency Selection algorithms (FSA) for a Virtual sink**
  We proposed three FSA to handle frequency selection for CAP slots:
  1. **Random:** The frequency allocation is randomly selected from the available channels.
  2. **Blacklist:** Channels with corrupted received packets are placed on a blacklist. The blacklist is maintained and updated using a counter that determines the waiting time for each channel
  3. **Machine Learning Approach:** Channel allocation is made by a Reinforcement Learning algorithm called Expected State-Action-State-Action (SARSA)

Description of WiFi Mitigation Strategies



- **Action:** the selection of a channel for transmission during a CAP slot in the virtual sink. The set of possible actions comprises the selection of a channel frequency from the 15 available channels.
- **State:** the packet delivery ratio at the sink for CAP traffic (PDR_{CAP}) is used to assess the state of the environment.

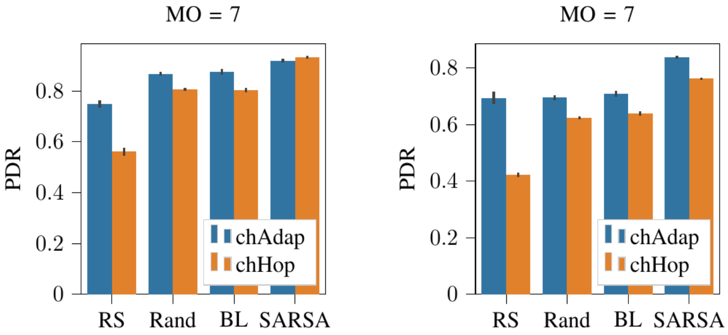
Simulative evaluation



- Data collection - convergecast pattern
- Rooted Binary Tree with 31 nodes
- Packet generation rate $\Rightarrow$ δ [packets/s]
- Packet generation $\Rightarrow$ periodic.

Parameter	*SO*	*MO*	*BO*	Q_{GTS}	δ
Values	4	7	11	22	{2,3,4}

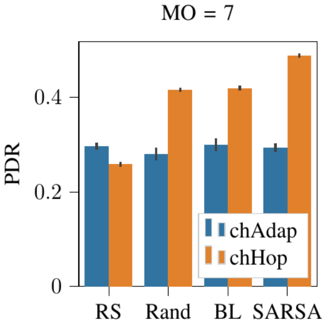
Comparison of Channel Diversity Mechanisms



Evaluation in terms of the PDR for scenarios under interference models: I-1 (left) and I-2 (right), and $\delta = 2$.

RS: Relay slot, Rand: Random, BL: Blacklist

Effect of Saturation for Channel Diversity Mechanisms



Evaluation in terms of the PDR for scenarios under interference models: I-1 (left) and I-2 (right), and $\delta = 4$

Conclusions and Outlook

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by using an **overprovisioning** and **FSA**, robustness of virtual sink-based networks are improved

Conclusions and Outlook

- Channel adaptation performs better in most of the evaluated scenarios. However, if the network is saturated and level of interference is low channel hopping is better suited
- In all cases, SARSA outperforms other strategies showcasing the potential capabilities of reinforcement learning in addressing changing environments
- Future studies can explore other reinforcement learning algorithms, e.g., Q-learning, and also extend the analysis to other sources of interference as Bluetooth

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