Frame Asynchronous Coded Slotted ALOHA for Vehicular Communications

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Coded Slotted ALOHA (CSA) – Uncoordinated Multiple Access Scheme

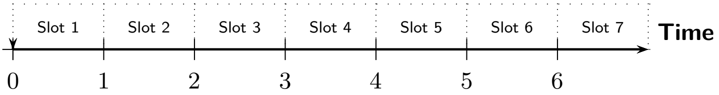
- Frame-synchronous CSA (FS-CSA):
  - Asymptotic analysis using density evolution (DE) [Liva 2011]
  - Finite-length analysis of the error floor (EF) and all-to-all broadcast [Ivanov *et al.* 2016]
- Frame-asynchronous CSA (FA-CSA)
  - Simulation of throughput and delay [Meloni *et al.* 2012]
  - Asymptotic analysis using (approximate) DE [Sandgren *et al.* 2016]
  - Finite-length analysis of the EF and delay [Sandgren *et al.* 2016]

Outcome: FA-CSA vs. FS-CSA

- Better performance in the waterfall and error floor region
- Better delay

[Liva 2011] G. Liva, "Graph-based analysis and optimization of contention resolution diversity slotted ALOHA," *IEEE Trans. Commun.*, Feb. 2011.
[Ivanov *et al.* 2016] M. Ivanov, F. Brännström, A. Graell i Amat, and P. Popovski, "Broadcast coded slotted ALOHA: A finite frame length analysis," *IEEE Trans. Commun.*, (to appear) 2016.
[Meloni *et al.* 2012] A. Meloni, M. Murroni, C. Kissling, and M. Berioli, "Sliding window-based contention resolution diversity slotted ALOHA," GLOBECOM, Anaheim, CA, Dec. 2012.
[Sandgren *et al.* 2016] E. Sandgren, A. Graell i Amat, and Fredrik Brännström, "On Frame Asynchronous Coded Slotted ALOHA: Asymptotic, Finite Length, and Delay Analysis," submitted to *IEEE Trans. Commun.*, 2016 available in arXiv.

System Model



- Time is divided into slots and users are slot-synchronous.
- Users join the system according to a Poisson random process with mean g

$$\Pr(k \text{ users joining}) = \frac{e^{-g} g^k}{k!}$$

- Each user selects a repetition factor l according to the degree distribution

$$\Lambda(x) = \sum_l \Lambda_l x^l.$$

- Each user picks l out of n slots (local frame) to transmit in.

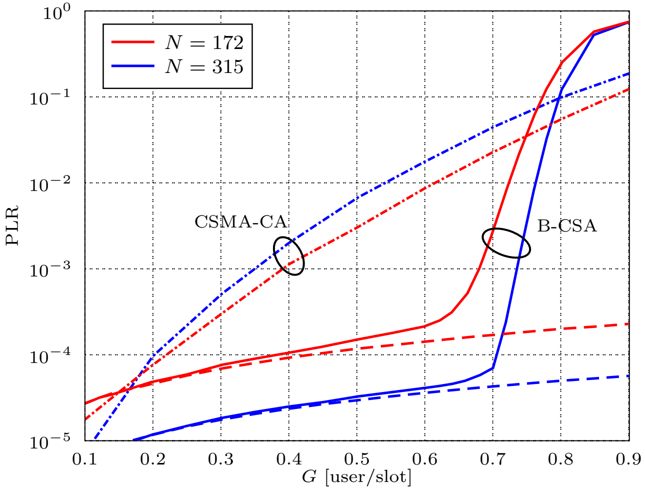
Two main performance metrics

- Packet loss rate (PLR).
- Delay: number of slots between a user joining the system and its packet being decoded.

WWVC 2014 – CSMA vs. Broadcast-CSA (B-CSA)

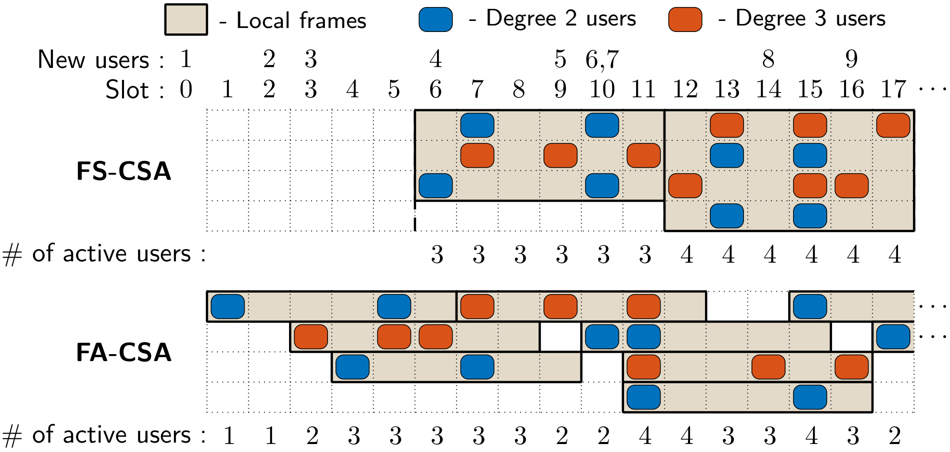
Example: $\Lambda(x) = 0.86x^3 + 0.14x^8$

- B-CSA has much better PLR than CSMA used in 802.11p.



Encoding – FS-CSA vs. FA-CSA

- $\Lambda(x) = 0.6x^2 + 0.4x^3,\ n = 6,\ g = 0.5.$



Decoding

- A common receiver.
- Packet in slots without collision can be reliably decoded.
- Iterative decoding using successive interference cancelation.
- The replicas of a received packet can be perfectly removed from the signal.

Decoding – FS-CSA vs. FA-CSA

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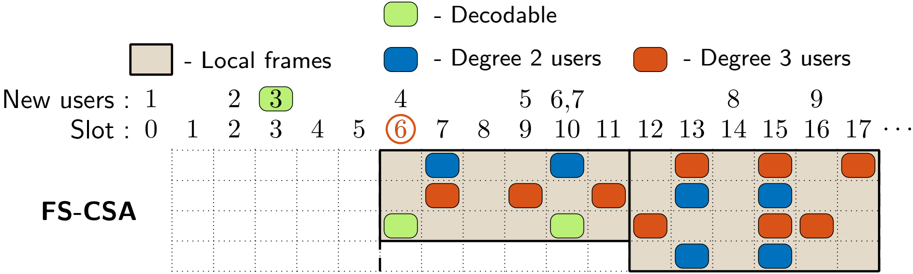

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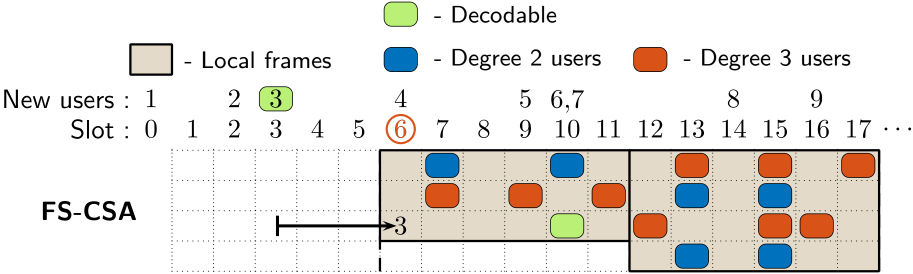

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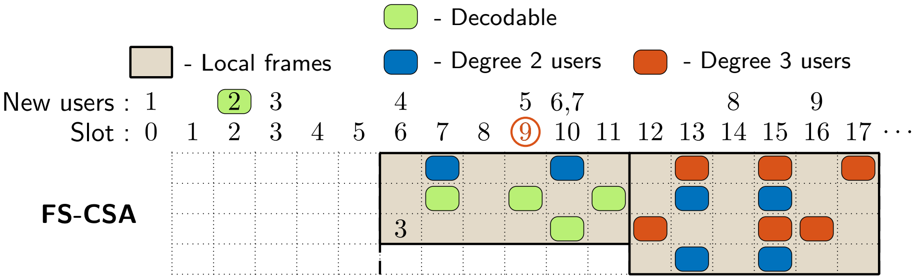

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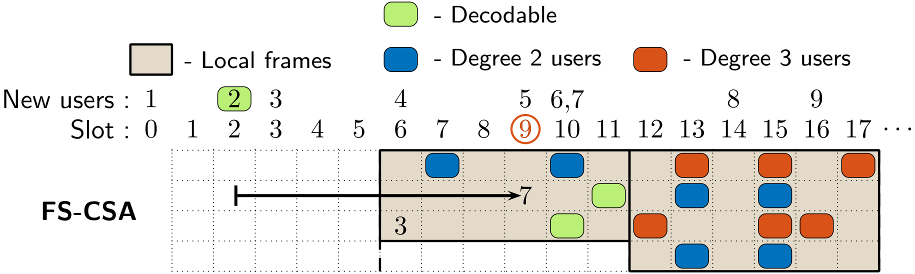

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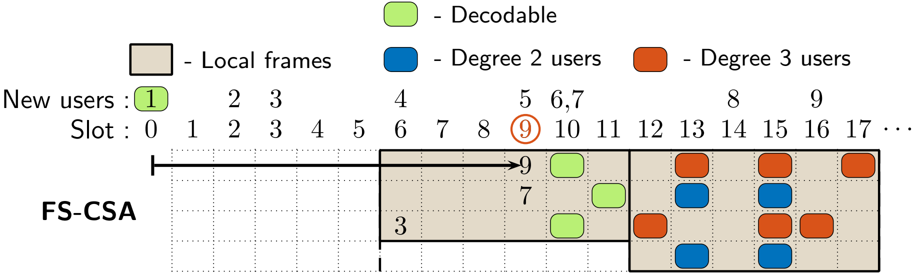

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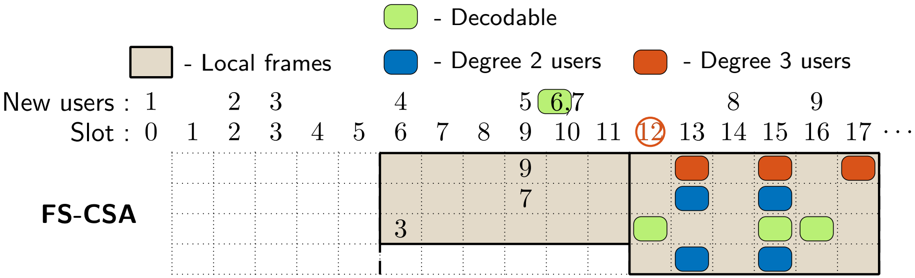

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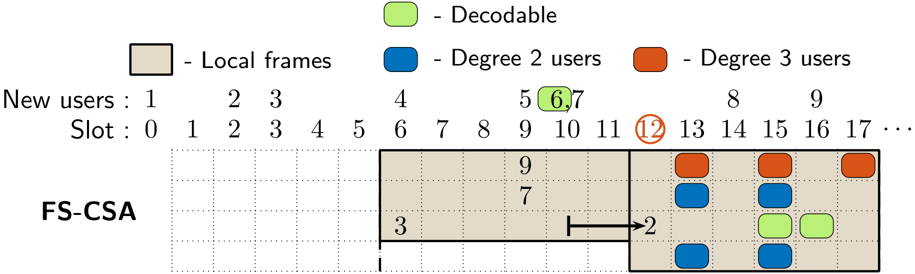

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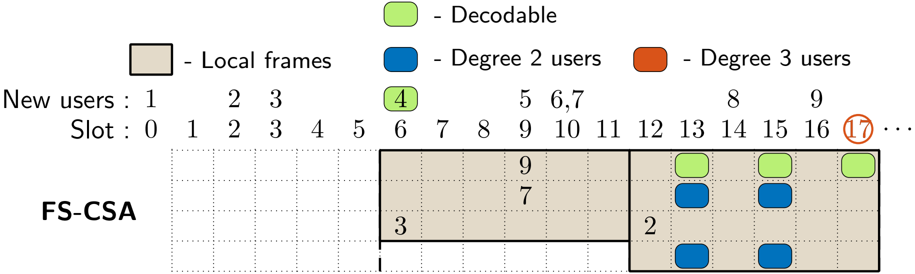

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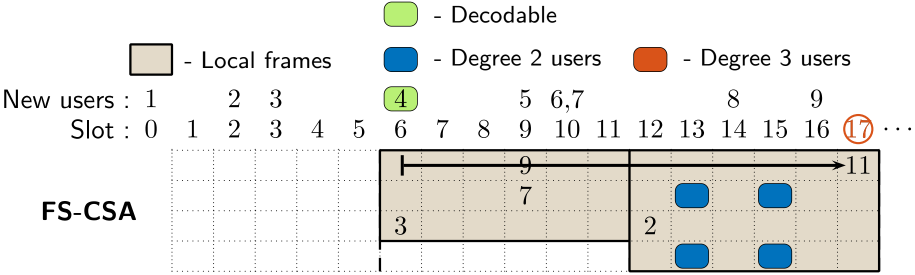

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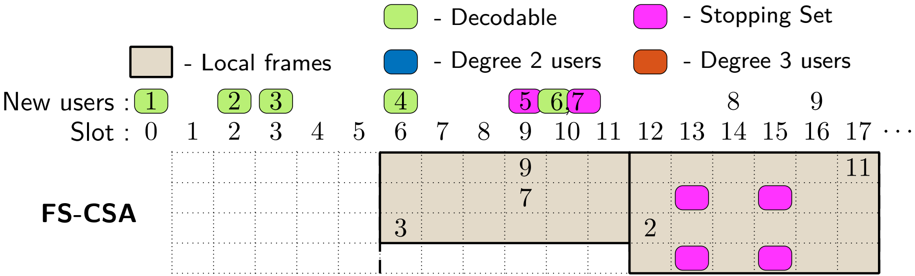

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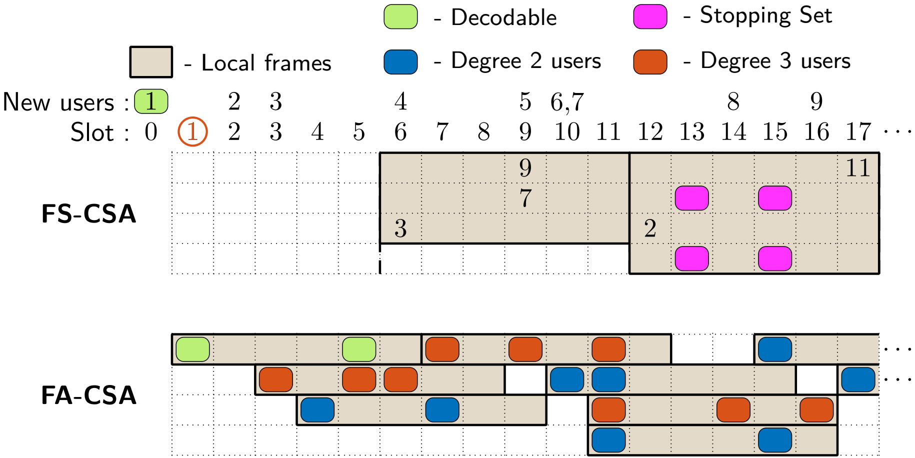

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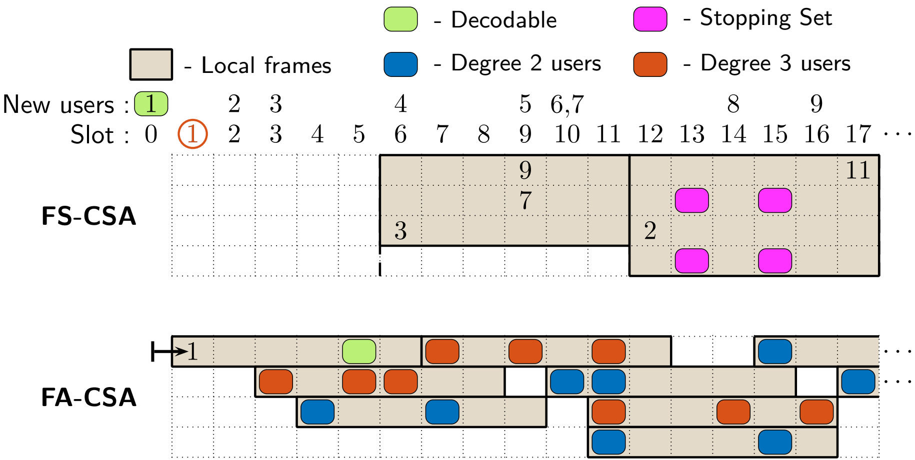

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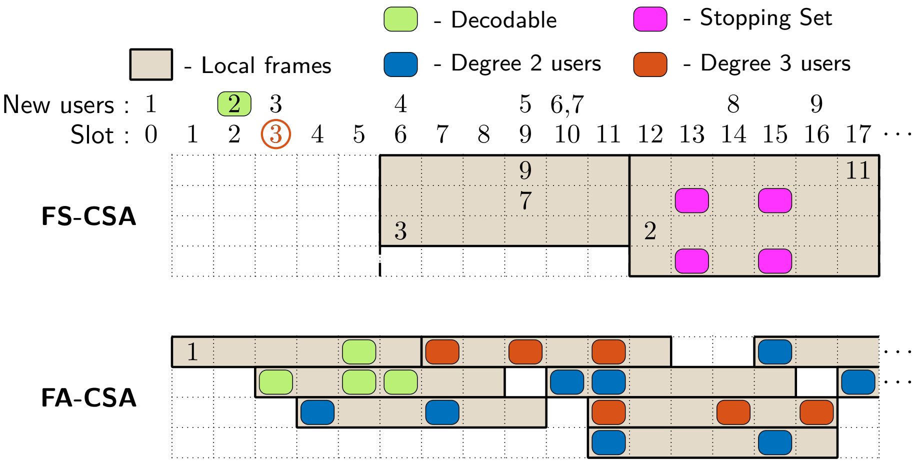

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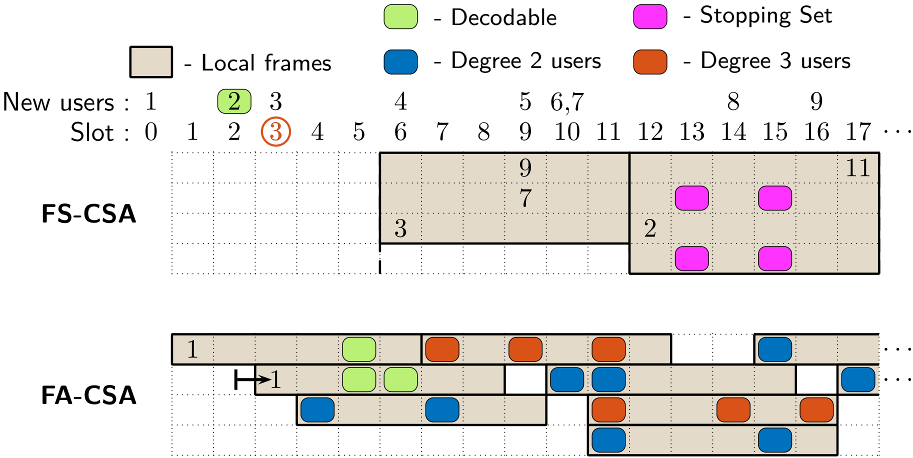

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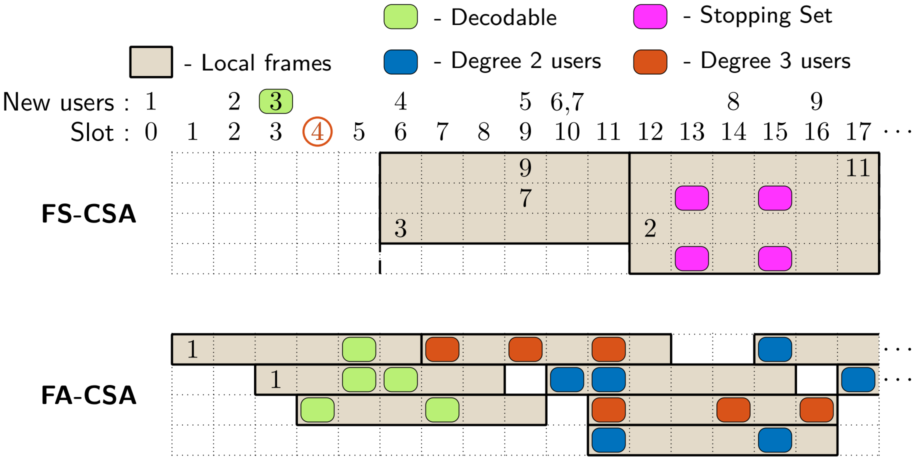

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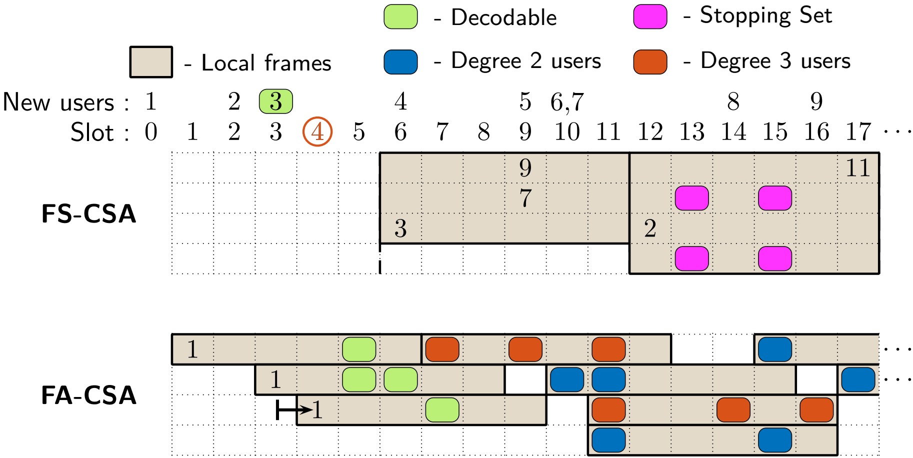

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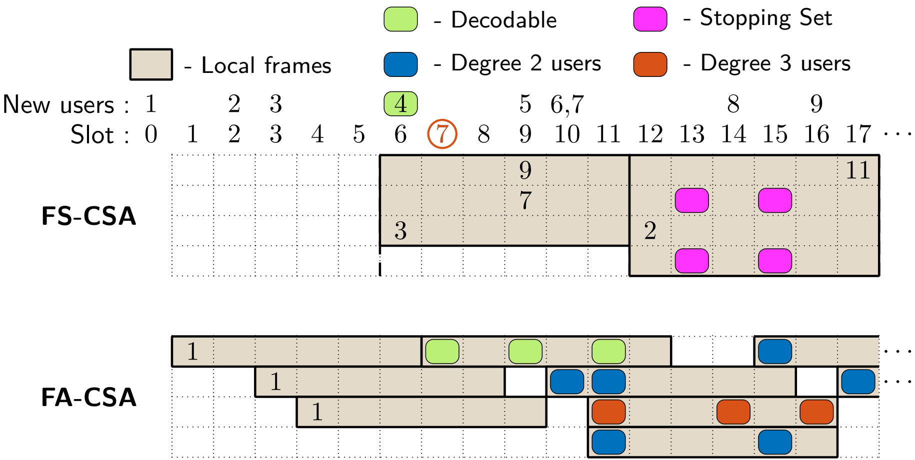

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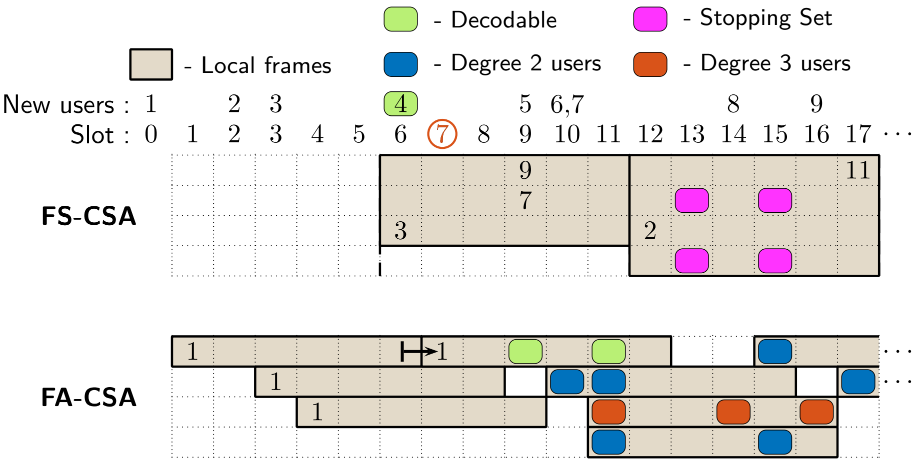

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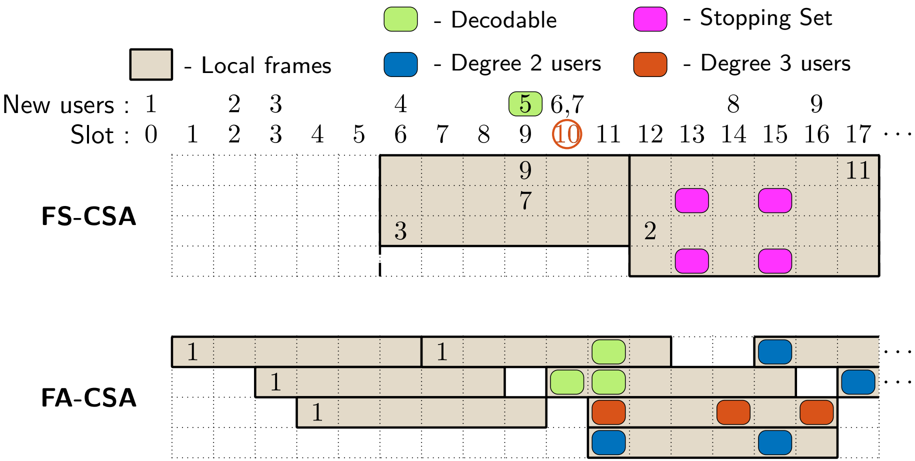

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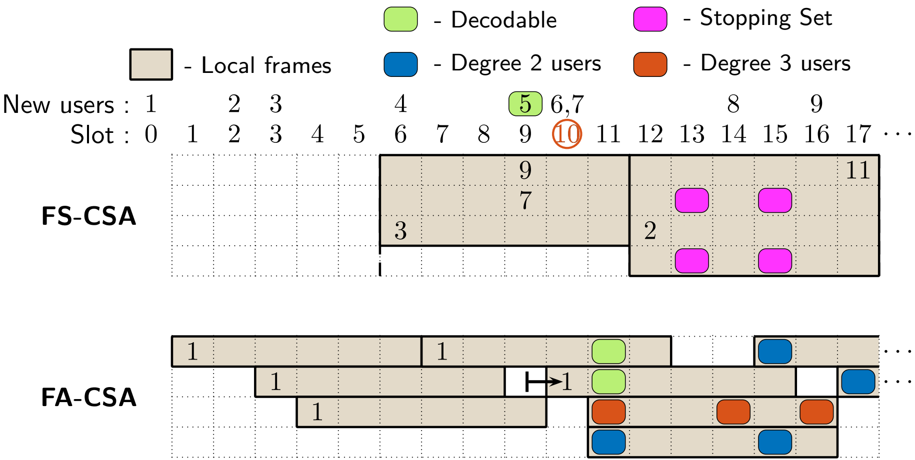

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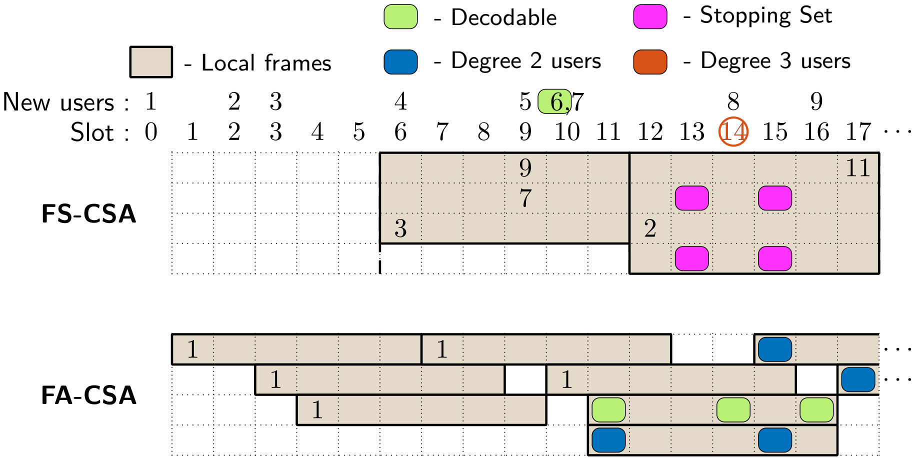

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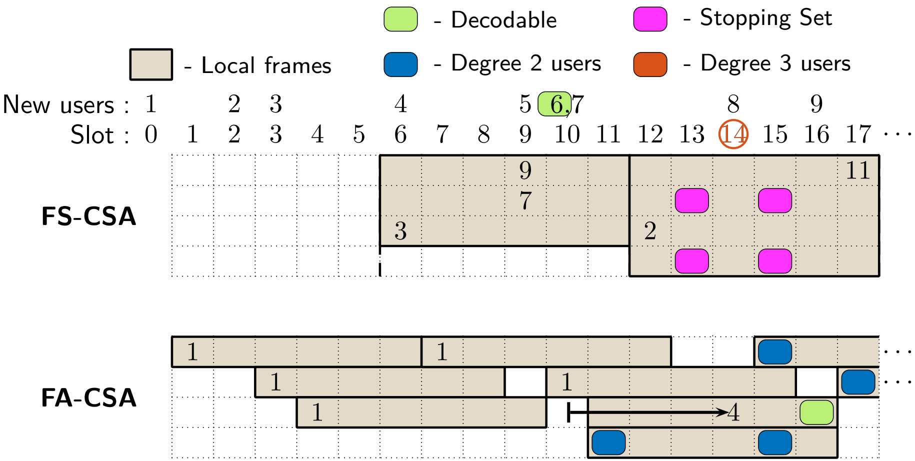

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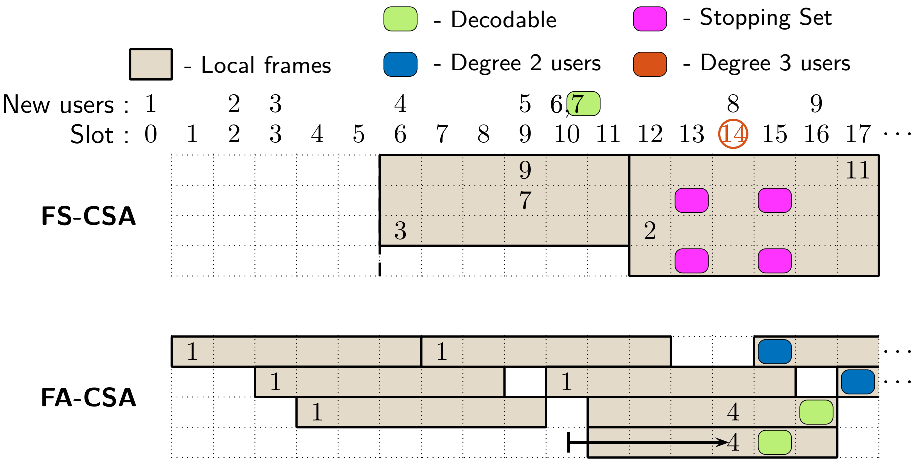

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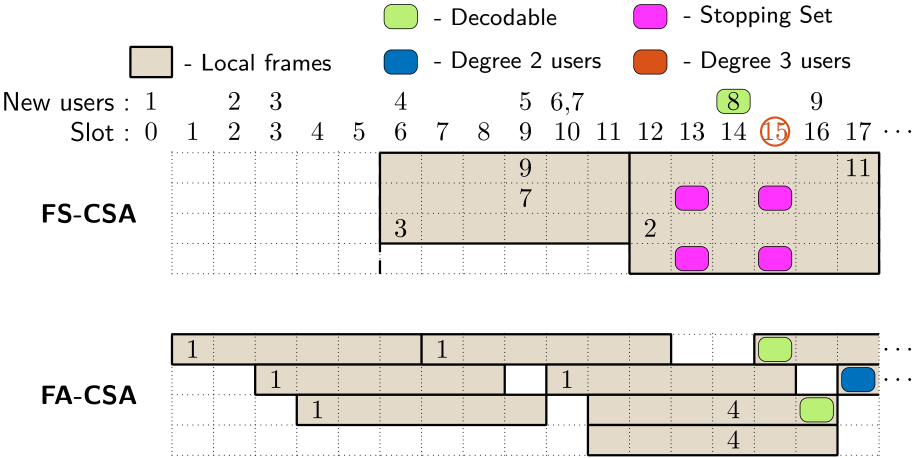

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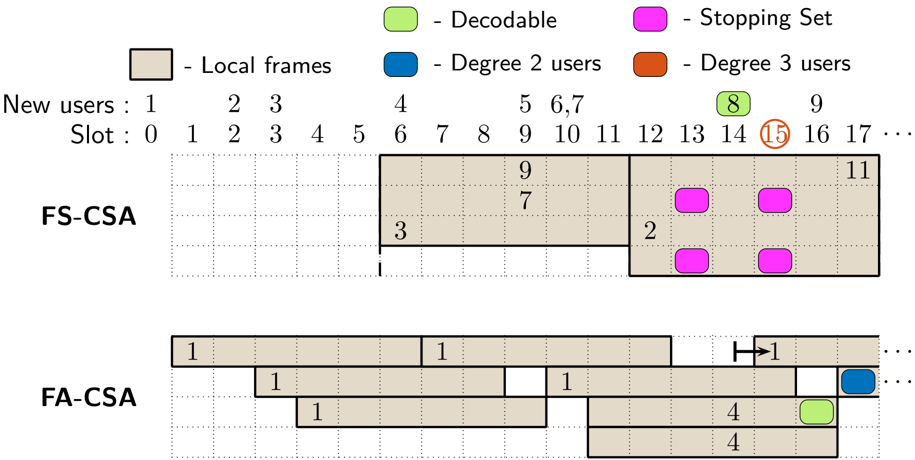

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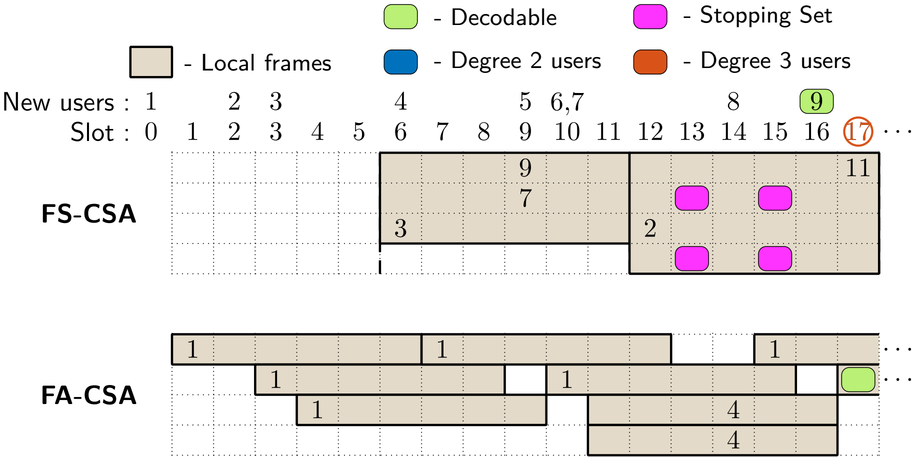

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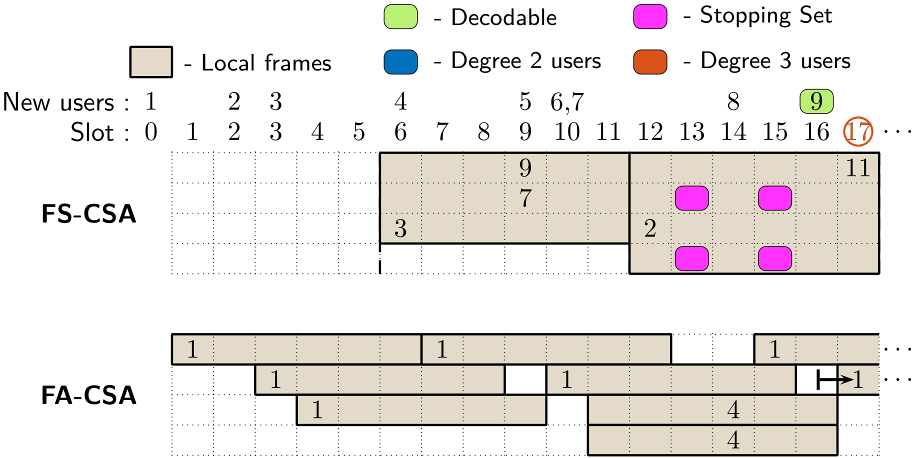

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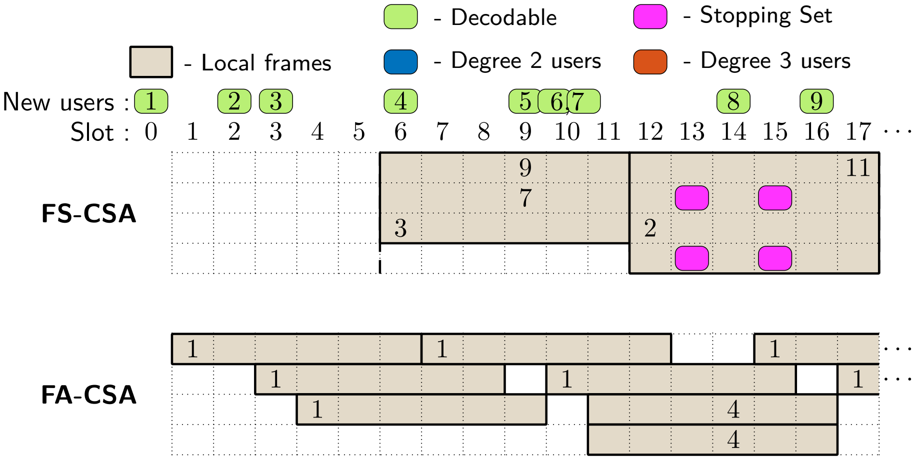
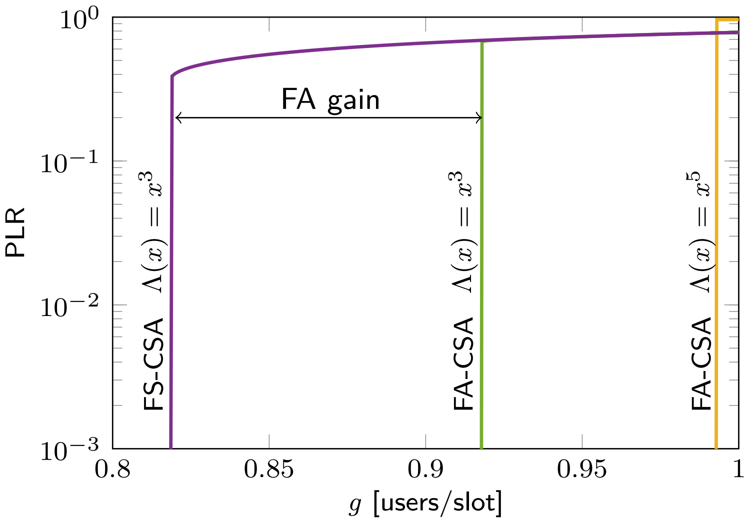


Belief Propagation Thresholds

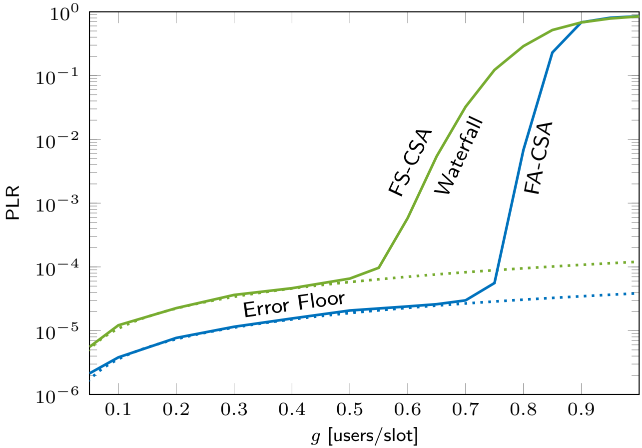
- Number of slots per frame: $n \to \infty$



Error Floor

Example: $\Lambda(x) = 0.86x^3 + 0.14x^8$ and $n = 200$

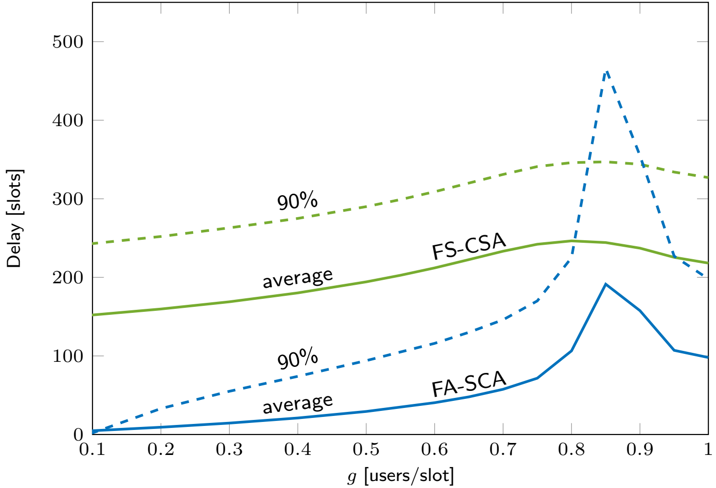
- Accurate approximation of the error floor (due to stopping sets).
- FA-CSA achieves better performance in the WF and EF than FS-CSA.



Delay Performance

Example: $\Lambda(x) = 0.86x^3 + 0.14x^8$ and $n = 200$

- FA-CSA yields better delay than FS-CSA.



Conclusions CSA

Take-Home Messages

- For finite-frame length, FA-CSA outperforms FS-CSA in the waterfall region, error floor region, and delay.
- FA-CSA outperforms FS-CSA in the waterfall and error floor regions also with a maximum delay constraint.
- B-CSA has much better PLR than CSMA used in 802.11p.