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MC MEETING AND 4TH WORKSHOP
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Modeling Heterogeneity of SUs in a Distributed MAC for CRNs

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Outline

- MOTIVATION
- SYSTEM DESCRIPTION
- HOMOGENEOUS SCENARIO - Model and Results
- HETEROGENEOUS SCENARIO - Modeling
- CONCLUSIONS

Outline

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Motivation

- Challenge:
  - How to design efficient MAC schemes for distributed CRNs?
    - first step: model
    - second step: model-based optimization
  - Assumptions
    - distributed control (without a central coord.)
    - what kind of policies to regulate the access of the SUs? contention and reservation

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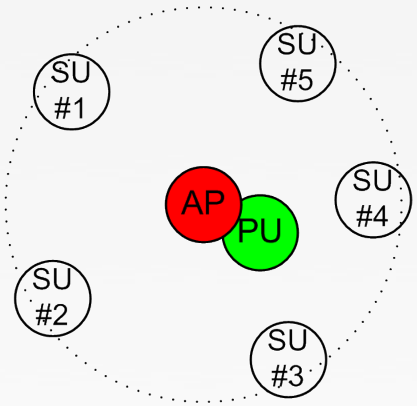
Motivation

- Main challenge of this work:
  - ➡ How to model the heterogeneity introduced by the different SUs?

  - different SUs obtain the same sensing results

homogeneity



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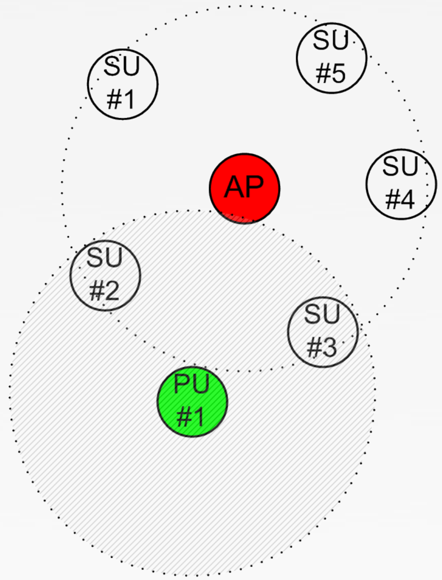
Motivation

- Main challenge of this work:
  - ➡ How to model the heterogeneity introduced by the different SUs?

- the different SUs obtain the **different** sensing results

heterogeneity

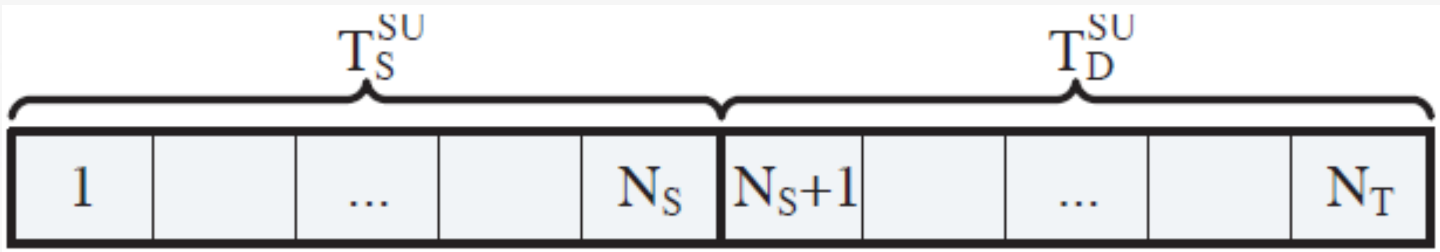
- SUs must be characterized individually, since they sense different channel activity



Outline

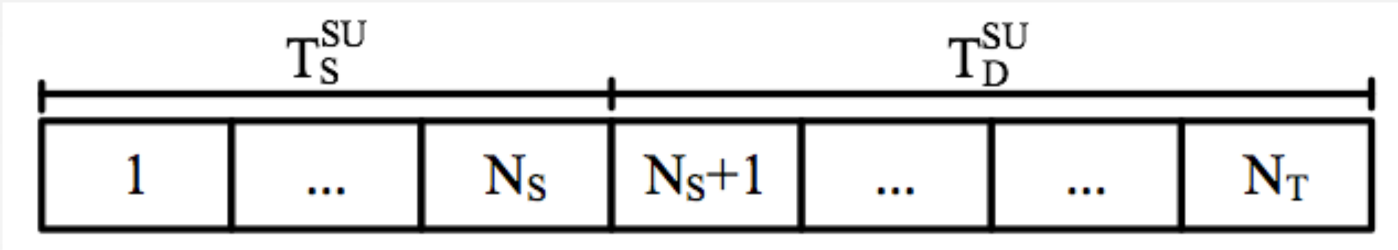
SUs' Framing & Sensing

- Single-radio cognitive nodes follow an operation cycle that includes
  - the sensing period
  - the hypothetical transmission period
- SUs operation cycle:



Sensing Assumptions

- SUs operation cycle



- Energy-based sensing

$$P_D = Pr(Y > \gamma|\mathcal{H}_1) = \mathcal{Q}\left(\frac{\gamma - (N_S + \lambda)}{\sqrt{2(N_S + 2\lambda)}}\right)$$

$$P_{FA} = Pr(Y > \gamma|\mathcal{H}_0) = \mathcal{Q}\left(\frac{\gamma - N_S}{\sqrt{2N_S}}\right)$$

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MAC

- SUs start to decide their medium access from the moment when the present frame is declared idle

$$P_{idle} = P_{OFF}^{PU}(1 - P_{FA}) + P_{ON}^{PU}(1 - P_D)$$

Busy frame: SUs do not perform any operation until the sensing decision of the next frame;

Idle frame: SUs may access the medium depending on a random decision (*e.g.* adopting the traditional ”slotted-aloha” protocol).

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MAC

- This work presents a MAC protocol for the SUs which uses a double stage mechanism to schedule each SU's transmission:
  - 1st stage - optional stage, which is used to reduce the number of competing SUs (only advantageous when the number of SUs is high);
  - 2nd stage - used to schedule (using reservation) the SUs competing for the medium, eliminating the situations of underutilization of idle frames from SUs
  - 3rd stage - medium access

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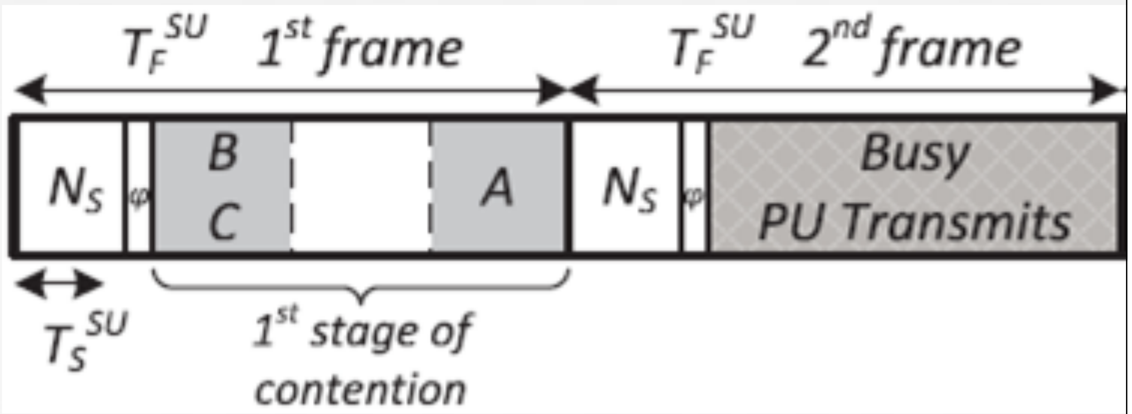
MAC

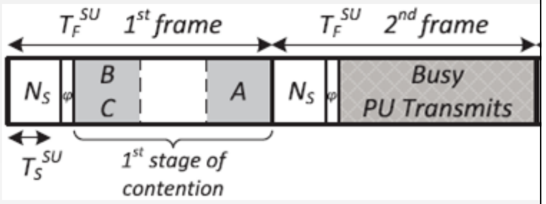
- 1st stage - used to reduce the number of competing SUs



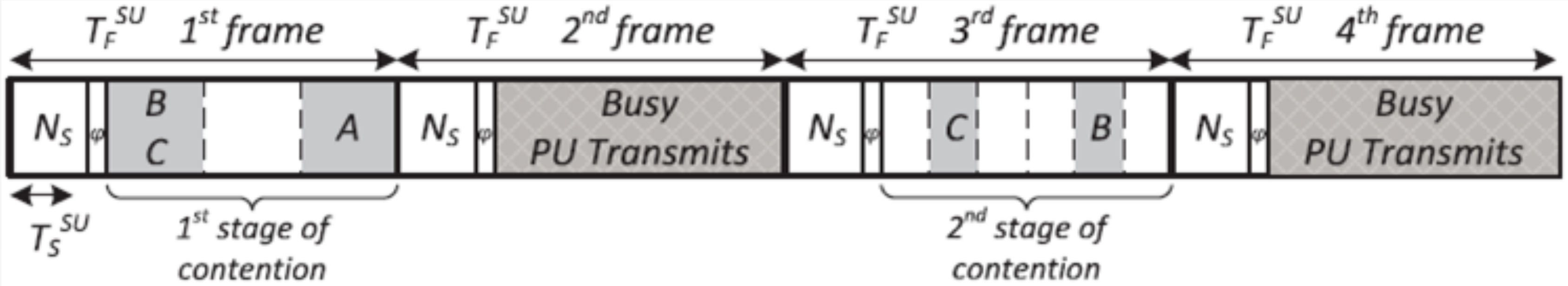
Outline

MAC

- 1st stage - used to reduce the number of competing SUs



- 2nd stage - used to schedule the SUs



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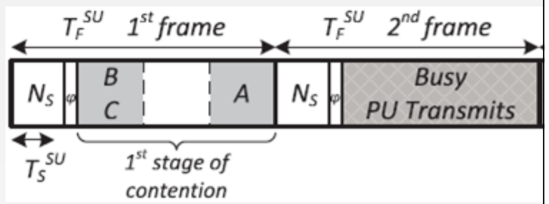
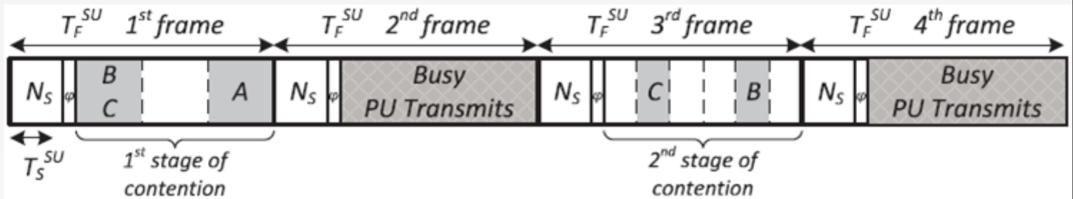
Outline

MAC

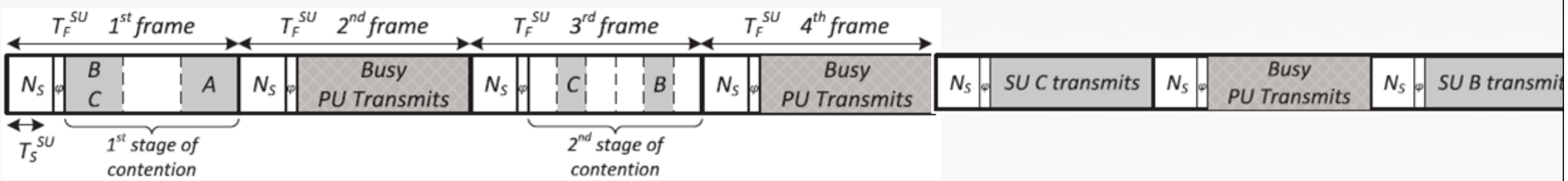
- 1st stage - used to reduce the number of competing SUs (cw1=3)



- 2nd stage - used to schedule the SUs (cw2=6)



- 3rd stage - medium access



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Homogeneity

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- Since n_2 SUs compete in the 2nd stage, the expected number of mini-slots found idle in the 2nd stage is:

$$\Gamma_{iddle} = cw_2(1-\tau_2)^{n_2}$$

- The expected number of idle frames reserved for SUs access during the cw_2 mini-slots is given by:

$$\chi_{res} = cw_2 - \Gamma_{idle}$$

- Finally, the throughput can be approximated by:

$$S_{hom} = n_2\tau_2(1-\tau_2)^{n_2-1}P_{OFF}^{PU}(1-P_{FA})\alpha_S\alpha_C$$

where:

$$\alpha_C = cw_2/(2+\chi_{res})$$

$$\alpha_S = (T_D^{SU}-\varphi)/(T_S^{SU}+T_D^{SU})$$

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Homogeneity

- MAC scheme is optimized to:
  Achieve the maximum aggregated throughput in the secondary network;
  Guaranteeing a given level of protection to PUs.

- For that, we find the optimal number of sensing samples N_S and mini-slots (cw_1 and cw_2), for different channel conditions (SNR):

$$\begin{aligned} \max_{cw_1, cw_2, N_S} \quad & S_{hom}, \\ \text{s.t.} \quad & P_D \geq P_D^{min} \\ & N_S^{min} \leq N_S \leq N_T \\ & 1 \leq cw_1 \leq cw_1^{max} \\ & 1 \leq cw_2 \leq cw_2^{max} \end{aligned}$$

Outline

Homogeneity

- Optimized double-stage MAC protocol vs. optimized traditional “slotted-aloha”-like scheme:
  - SU’s Throughput (*S*);
  - Prob. of Misdetection
- Parameters used in the PU’s transmitting signal and in the SU’s energy detector.

Sensed band	$10\ kHz$	Channel Sampling Period	$50\ \mu s$
$T_S^{SU} + T_D^{SU}$	$20.0\ ms$	N_S^{min}	20
μ_s	3.16 (5dB)	σ_s^2	3
μ_w	1 (0dB)	σ_w^2	1
λ (SNR)	$5\ dB$	γ	38.3 J

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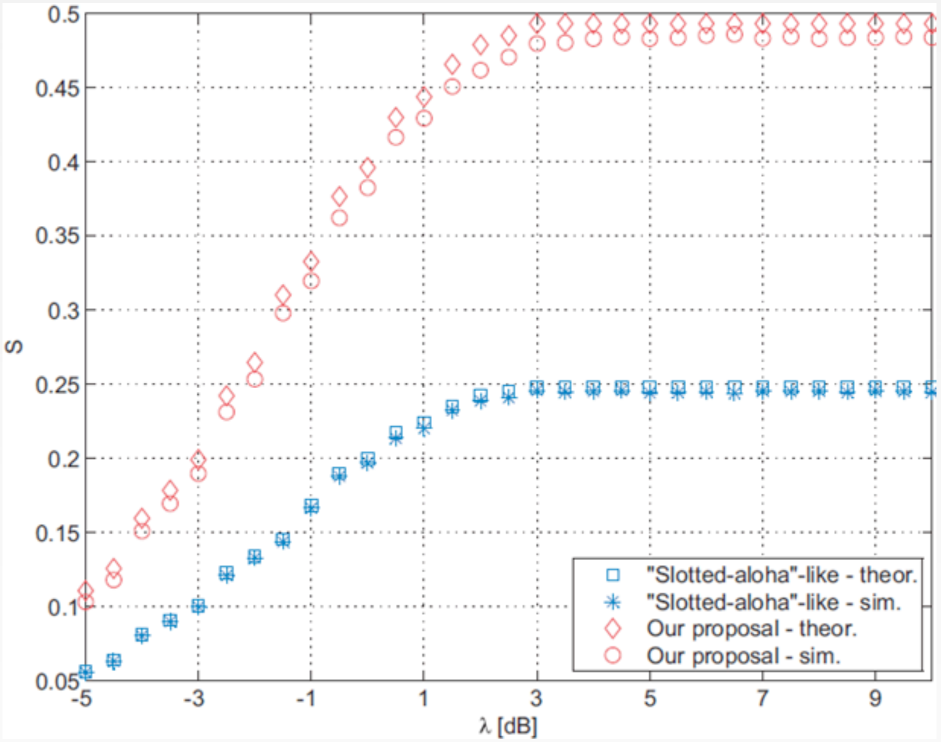
SUs Aggr. Throughput

SU's Aggr. Throughput (P_ON^{PU}=0.3; P_D^{min}=0.95; n=25)



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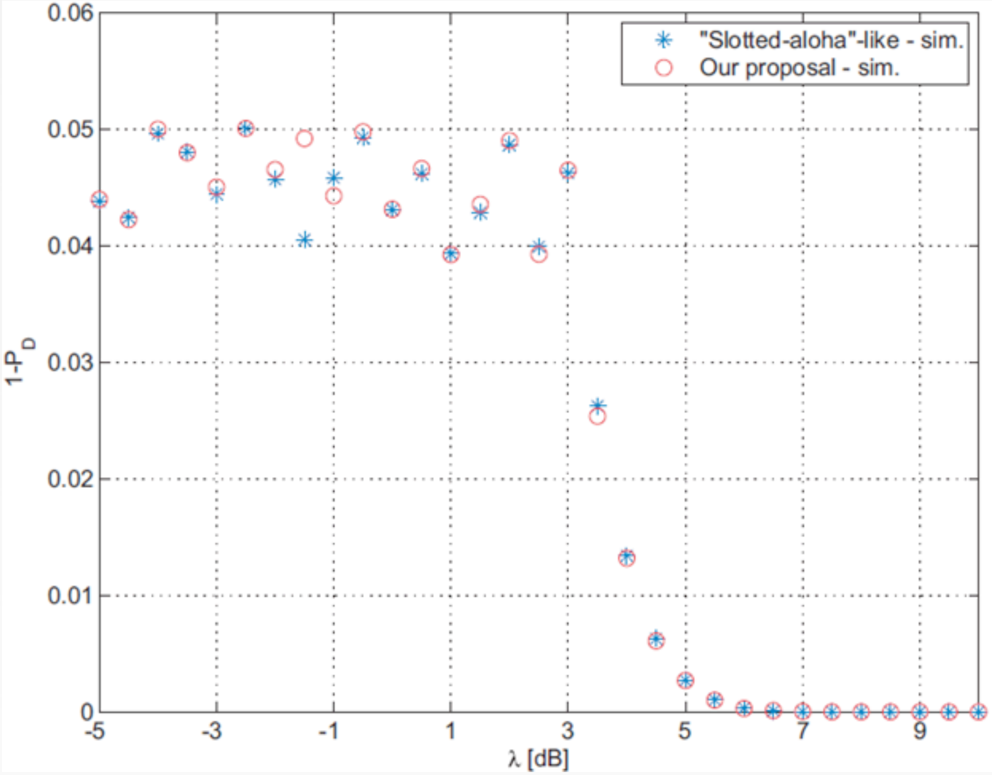
Interference to PUs

Prob Miss-detection



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Outline

1. Motivation

2. System Description

3. Homogen. Scenario

4. Heterogen. Scenario

5. Conclusions

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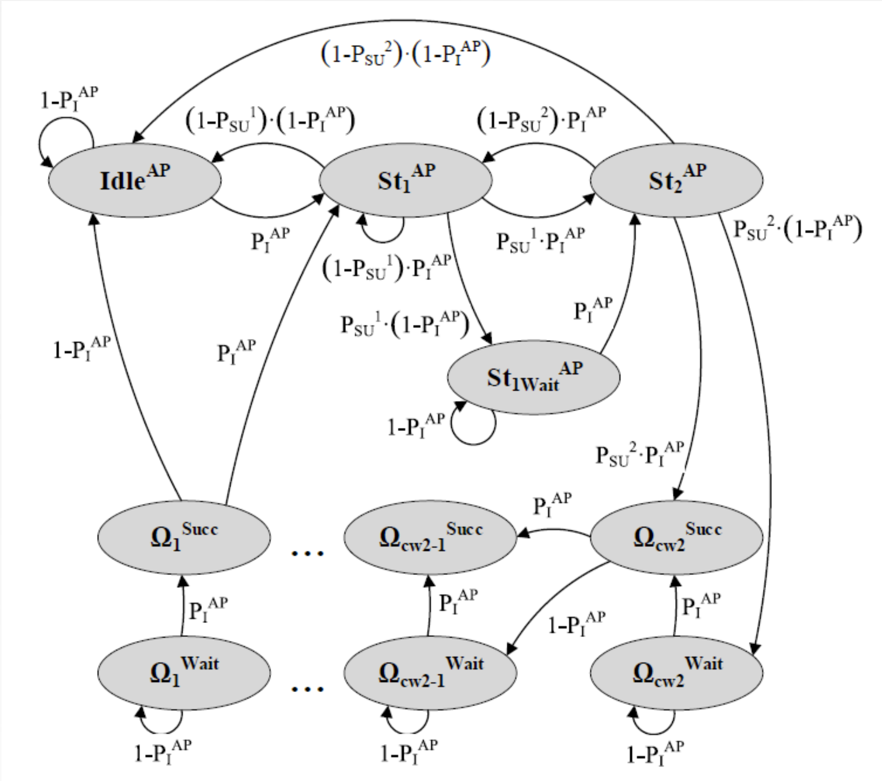
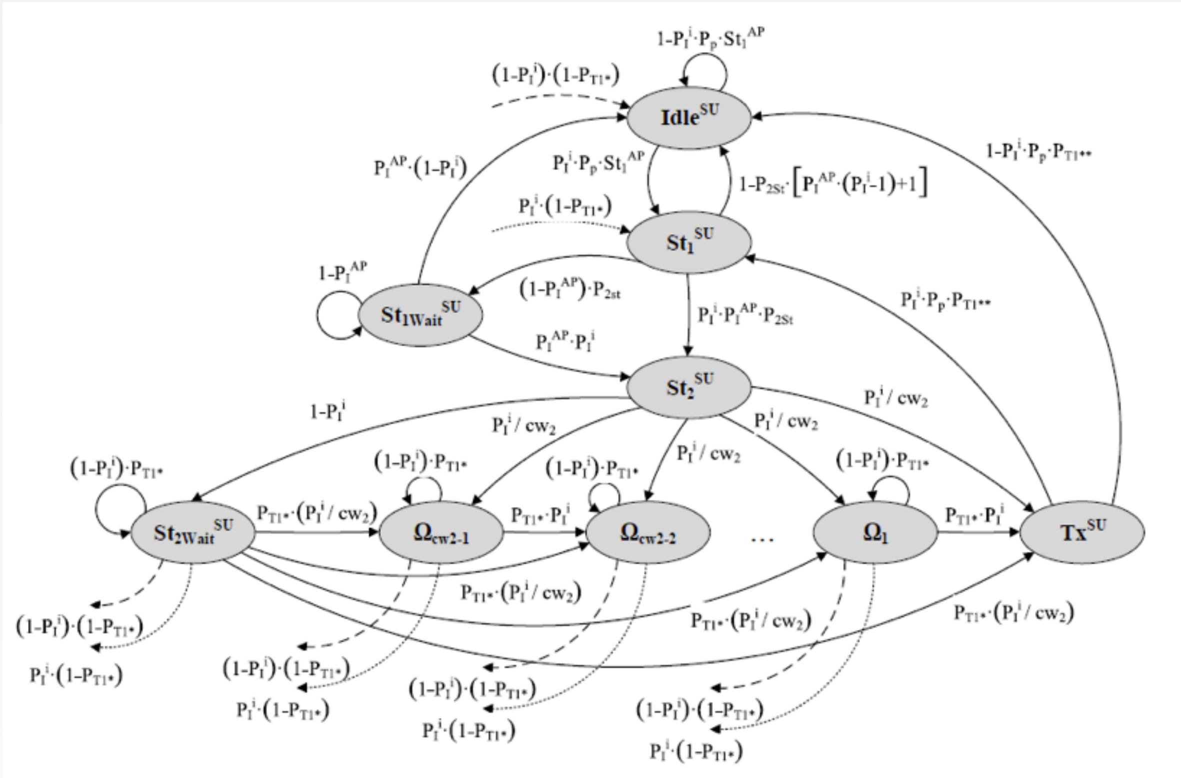
Heterogeneous model

➡ AP's behavior is modeled as a Markov Chain



Heterogeneous model

- Each SU is modeled as a Markov Chain



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Heterogeneous model

- Main goals
  - achieve a closed form for the individual probability of medium access of the SUs
  - definition of throughput in an heterogenous model
  - throughput validation

Conclusions

- The proposed MAC was successfully modeled for an homogeneous scenario

- The protocol was optimized using the model
  - it almost doubles the throughput of a classical "sloted-aloha" MAC;
  - ... and PU's pre-defined interference constraints are effectively imposed

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Conclusions

- The proposed MAC is being modeled for an heterogenous scenario
  - The model is more complex
  - A proposed model is being validated
- Future work: use the model to maximize the throughput in an heterogenous scenario

Thanks for your attention!

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