University of Salford MANCHESTER

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Reliable Spectrum Sharing Management for Cognitive Radio Networks

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Outline

- **Cognitive Radio Network (CRN):** Motivation / Communication strategy.
- **CRNs Spectrum Sharing Challenges**
- **Contributions**:

1. **CogMnet Framework:** Definition / Architecture / Communication polices
2. **CRNAC algorithm:** Definition / Admission Steps of CRNAC / Performance Evaluation

Cognitive Radio Networks

Motivation: Why CRN?

1 Scarcity in the available spectrum

- Static Spectrum Allocation.
- Increasing extent in wireless services and devices.

2 Inefficient and intermittent spectrum utilizing

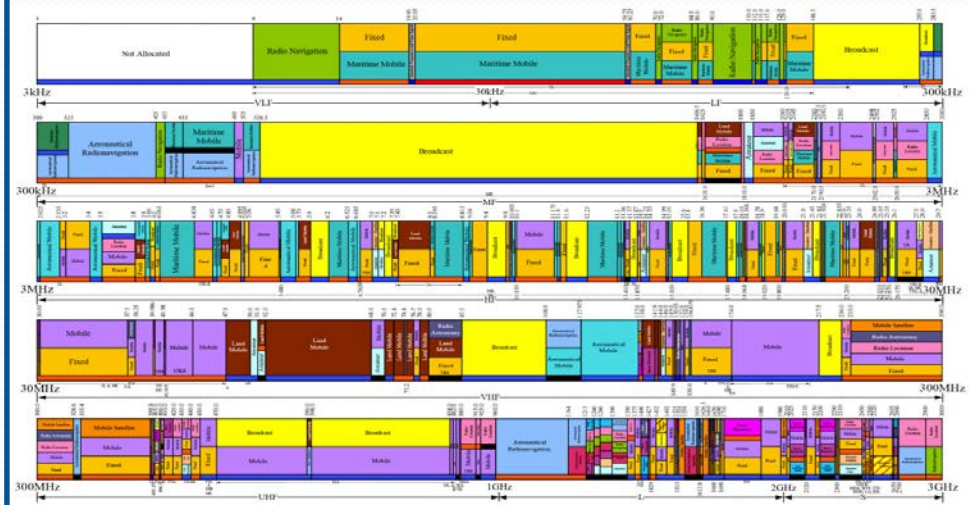


Fig. 1. UK Spectrum Allocation 3KHz – 3GHz [1]

Fig. 2. Advancements in Wireless Technologies

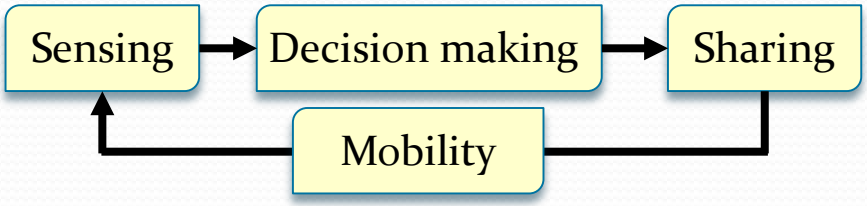
[1] **http://stakeholders.ofcom.org.uk/spectrum/information/uk-fat/**

Cognitive Radio Networks

Definition:

A promising wireless communication network proposed in 2000, capable of utilizing the residual spectrum bands of Primary (licensed) Networks (PNs) to be as a Secondary Network.

- CRN transmission strategy



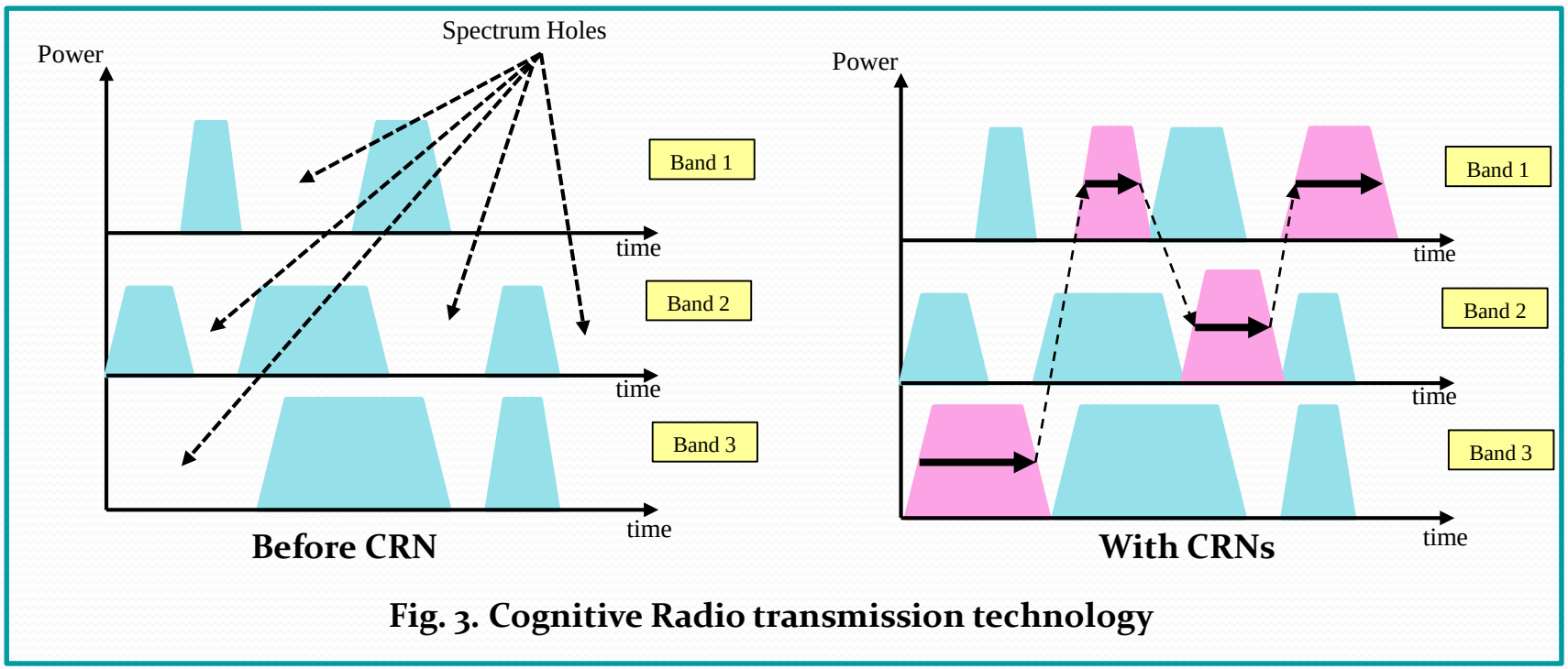


Fig. 3. Cognitive Radio transmission technology

CRNs Spectrum Sharing Challenges

1	Overcrowded CRNs	Collision
2	Inter-cell interference	Collision
3	Two or more CRNs move to utilize the same channel simultaneously	Collision
4	Primary User Emulation Attack (PUEA)	Collision

Unreliable spectrum sharing => **Degradation in QoS provisioning**

First Contribution: CogMnet Framework

1. Definition

CRNs Management (CogMnet) is an internetwork framework capable of regulating centralized CRNs spectrum sharing.

2. Implementing Procedure.

- **Divide** into locations.
- **Dedicate** a real time database (**DB**) for each location. Consists to three storage units:
  1) Networks' Locations Unit
  2) Real time Unit.
  3) Historical Unit.
- **Connect** the CRNs.
- **Record** in the **DB** in real time the transmission parameters of utilized channels.
- **limited access** to data bases:
  1) Inside network location.
  2) Outside Locations.

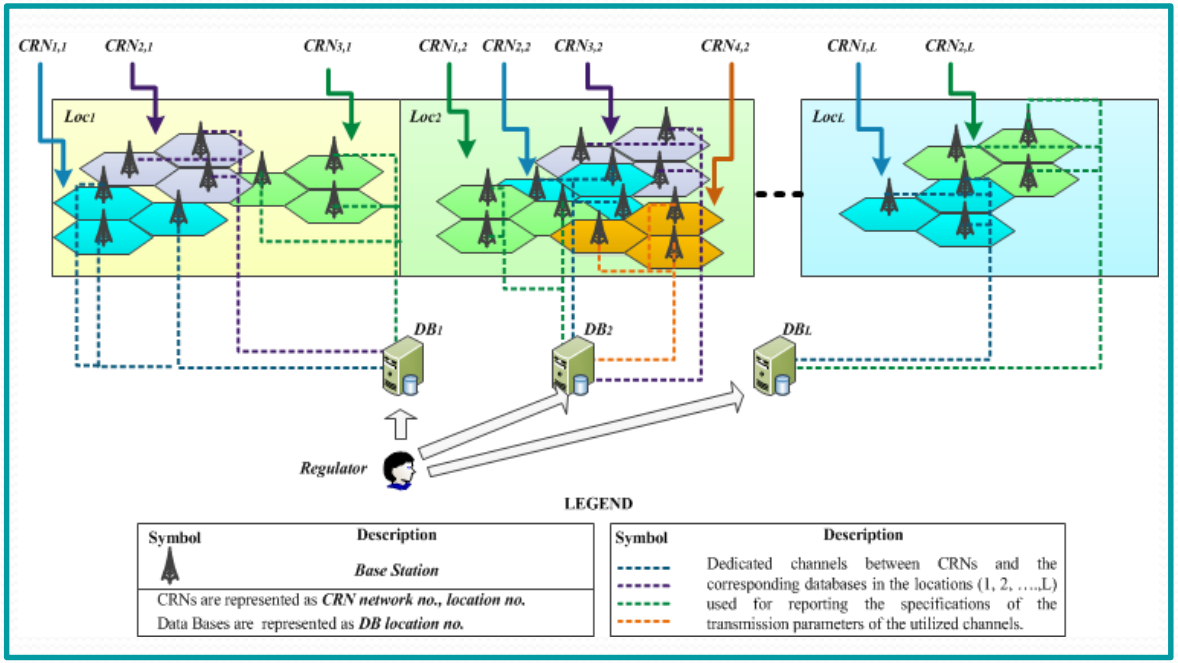


Fig. 4. CogMnet framework design.

First Contribution: CogMnet Framework

3. Coordination

a) Networks location storage unit (NL_{DB_l})

Table 1. Example of Recording Form in Networks Locations Storage Unit (example of two CRNs)

CRN	Base Station	Base Station Sequence in CogMnet	Longitude	Latitude	Status	Date of status	Communication range
1	1	1	$Lo_{BS^1_{Net_{1,5}}}$	$La_{BS^1_{Net_{1,5}}}$	Active	$D_{BS^1_{Net_{1,5}}}$	$R_{BS^1_{Net_{1,5}}}$
	2	2	$Lo_{BS^2_{Net_{1,5}}}$	$La_{BS^2_{Net_{1,5}}}$	Active	$D_{BS^2_{Net_{1,5}}}$	$R_{BS^2_{Net_{1,5}}}$
	3	3	$Lo_{BS^3_{Net_{1,5}}}$	$La_{BS^3_{Net_{1,5}}}$	Inactive	$D_{BS^3_{Net_{1,5}}}$	$R_{BS^3_{Net_{1,5}}}$
2	1	4	$Lo_{BS^1_{Net_{2,5}}}$	$La_{BS^1_{Net_{2,5}}}$	Active	$D_{BS^1_{Net_{2,5}}}$	$R_{BS^1_{Net_{2,5}}}$
	2	5	$Lo_{BS^2_{Net_{2,5}}}$	$La_{BS^2_{Net_{2,5}}}$	Inactive	$D_{BS^2_{Net_{2,5}}}$	$R_{BS^2_{Net_{2,5}}}$

First Contribution: CogMnet Framework

3. Coordination

b) Real time storage unit (RT_{DB_l})

Table 2. Example of Recording Form for the Specifications of Utilizing Channels in Real Time Storage Unit

CRN	Base Station	Base Station Sequence in CogMnet	Channel frequency (KHz)		Starting utilization time	Starting utilization date	MCS		Max. transmit power (watt)
			f_{min}	f_{max}			Modulation	Code	
1	1	1	2230	2240	23:59:24:13	08/05/15	64 QAM	2/3	16
2	1	4	720	730	23:59:32:56	08/05/15	QPSK	1/2	20
2	1	4	1470	1480	23:59:32:56	08/05/15	QPSK	1/2	18
1	2	2	1790	1800	23:59:34:15	08/05/15	16 QAM	1/2	16
2	2	5	1390	1400	23:59:51:67	08/05/15	BPSK	1/2	18
2	2	5	2130	2140	23:59:51:67	08/05/15	BPSK	1/2	16

Evacuated at 00:03:22:35

Evacuated at 00:04:43:21

First Contribution: CogMnet Framework

3. Coordination

c) Historical storage unit (HS_{DB_l})

Table 3. Example of Recording Form for the Specifications of Evacuated Channels in Historical Storage Unit: (The Channel (720-730) MHz is Evacuated in 09/05/15 at 00:03:22:35, the channel (1390-1400) MHz is Evacuated in 09/05/15 at 00:04:43:21)

CRN	Base Station	Base Station Sequence in CogMnet	Channel		Utilization time	Utilization date	Evacuation time	Evacuation date	MCS		Max. transmit power (watt)
			f_{min}	f_{max}					Modulation	Code	
1	1	4	720	730	23:59:32:56	08/05/15	00:03:22:35	09/05/15	64 QAM	2/3	14
1	1	5	1390	1400	23:59:51:67	08/05/15	00:04:43:21	09/05/15	BPSK	1/2	18

4. Roles

a) No CRN without permission from Regulator

b) No Malicious CRN.

c) Penalty against the aggressive CRN.

First Contribution: CogMnet Framework

4. Expected merits:

No.	Merit	CogMnet	Conventional Internetwork Frameworks
1.	Assign maximum number of CRNs	√	×
2.	Reliable spectrum sharing without { PUEA issue; Inter – cell interference }	√	×
3.	Enable modelling SUs activities	√	×
4.	Contribute to improve sensing efficiency	√	×
5.	Protection of non-permitted channels	√	×
6.	No CRN is used by malicious or terrorist group	√	×
7.	Determine places to expand (inside and outside the location)	√	×
8.	New source of revenue to the regulators	√	×
9.	Provide idle channels for certain fees	×	√

Second Contribution: CRNAC Algorithm

1. **Definition:** CRN Admission Control (CRNAC) is an algorithm capable of determining the maximum number of CRNs allowed in any location in CogMnet framework.

2. **Admission Steps CRNAC**

- **First CRN**

Calculate → $\overline{X}$ Spectrum availability → $Spec$ Average usage of highest performance CRN → ψ_{total} Scalability of existing CRNs → $\Delta_{PN\ scalability}$ scalability of PNs

Propose → Δ_{guard} Safety spectrum guard

Apply → $Diff = \overline{X} - Spec - \psi_{Total} - \Delta_{PN\ scalability}$

If $Diff \geq \Delta_{guard}$ then admit the first CRN, otherwise reject the request.

- **Calculate maximum allowed CRNs**

Apply → $Diff_{new} = Diff - Spec$ ← No Need to ψ_{total} and $\Delta_{PN\ scalability}$

If $Diff_{new} \geq \Delta_{guard}$ then admit a network and repeat (eq. 2) till become invalid.

Second Contribution: CRNAC Algorithm

4. CRNAC Performance Evaluation

Assumptions:

Table 4. Utilized Spectrum Bands and Expected Scalability Assigned for Existing CRNs and PNs.

Item	The Utilized Spectrum (%)	Expected Scalability (%)
CRN1	3 – 6	0.5
CRN2	6 – 9	1
CRN3	8 – 12	1.5
CRN4	5 – 8	0.6
CRN5	3 – 5	0.4
PNs	Variable	5

Table 5. Factors Assigned in the CRNAC Evaluation.

Factors	Assigned value	
Maximum spectrum occupancy before starting the experiments	Scenario 1, 2, & 3 (part 1)	Scenario 3 (part 2, & 3)
	22.57% [2]	13% [3]
Δ_{guard}	5%	
Number of location	1	
Number of runs	1440	

[2] L M. Benitez, A. Umbert, and F. Casadevall, "Evaluation of Spectrum Occupancy in **Spain** for Cognitive Radio Applications," in *Proceedings of 69th IEEE VTC*, Barcelona, Spain, pp. 1-5, April 2009.

[3] H. Almantheri, and O. Y. Alani, "Radio Spectrum Occupancy Measurement for Ruwi, **Sultanate of Oman**," in *Proceedings of PGNet2014*, Liverpool, UK, pp. 201-204, June 2014.

Second Contribution: CRNAC Algorithm

Scenario 1

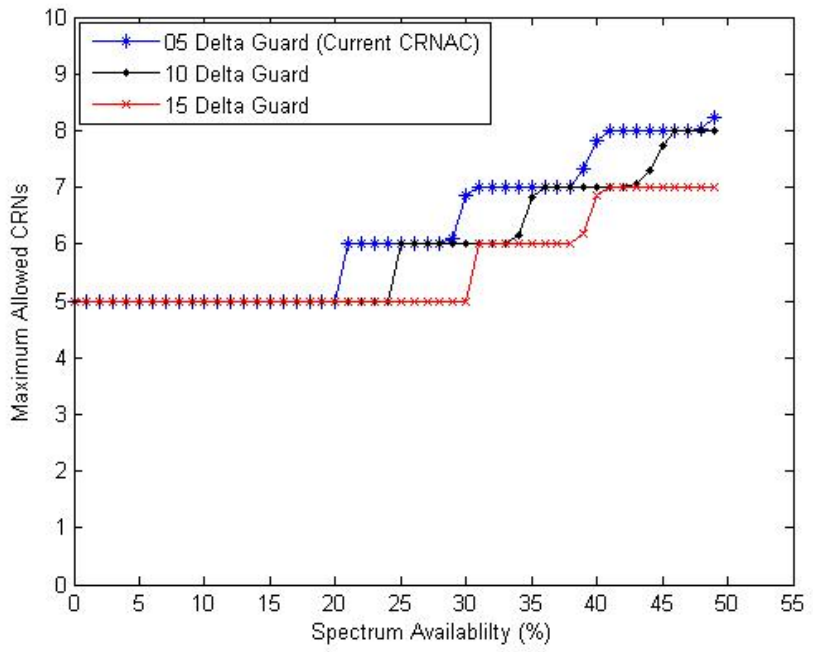


Fig. 5. Maximum allowed number of CRNs in different variations of spectrum occupancy measurements

Scenario 2

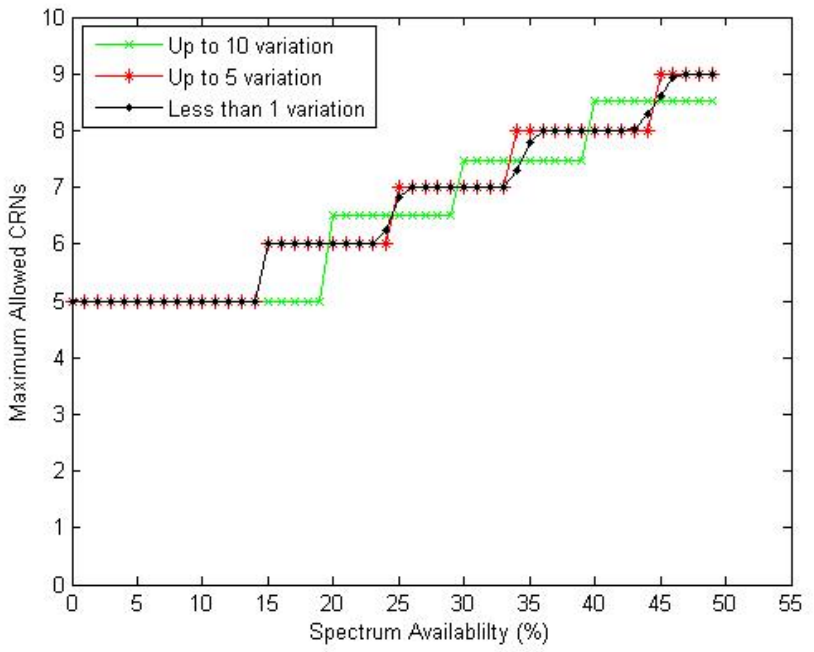


Fig. 6. Scenario 2: Maximum number of allowed CRNs according to different Δ_{guard}

Second Contribution: CRNAC Algorithm

Scenario 3: Part 1 → **change *spec*** → $Diff = X_{av} - Spec - \psi_{Total} - \Delta_{PN\ scalability}$

Highest CRN

- **Case 1:** Average of the minimum utilized spectrum of all CRNs.
- **Case 2:** Average utilization of all CRNs.
- **Case 3**: Average of the maximum utilized spectrum of all CRNs.
- **Case 4:** Minimum usage of CRNs together.
- **Case 5:** Maximum usage of CRNs together.

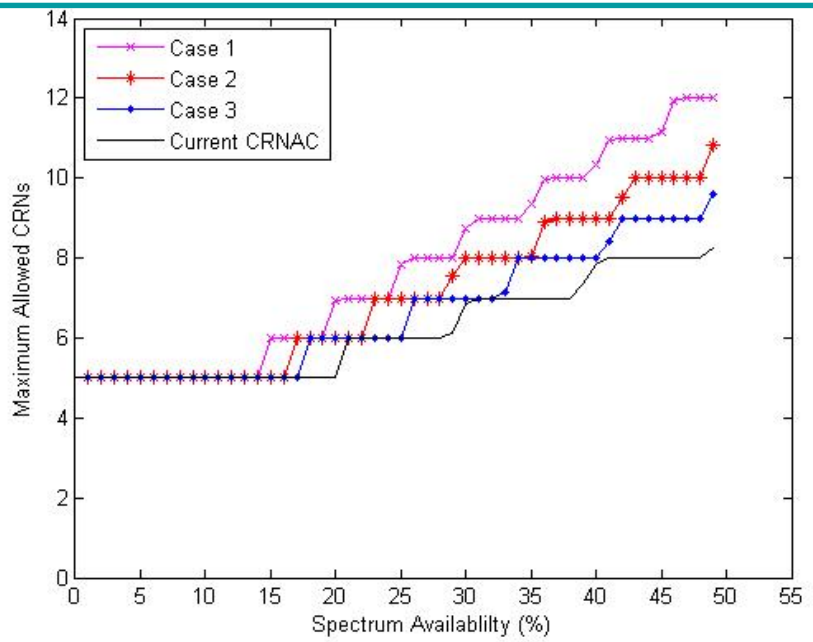


Fig. 8. Maximum number of allowed CRNs according to different admission constraints base on a particular CRN

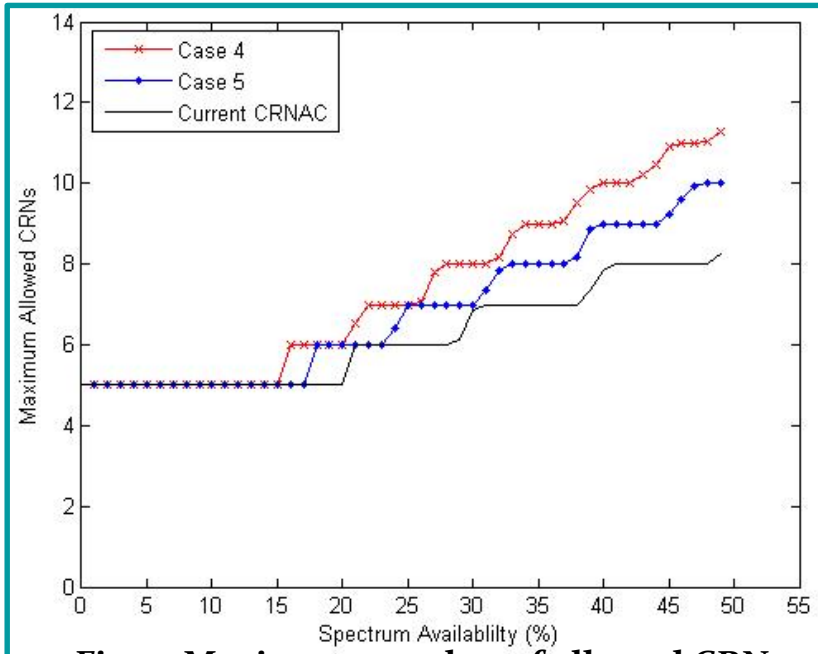


Fig. 9. Maximum number of allowed CRNs according to different admission constraints base on usage of each measurement

Second Contribution: CRNAC Algorithm

Table 6. Expected Performance of the Admitted CRNs in different admission constraints.

Scenario 3: Part 2

CRNAC Decision is based on	Maximum allowed CRNs according to Ruwi [3] (Δ_{guard}= 5%)
Case 1	10
Case 2	9.5
Case 3	9
Case 4	8.2
Case 5	8
Current CRNAC	7

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