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Centralised and Distributed Methods for Dynamic Spectrum Allocation

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Outline

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- Background
- Research problem
- Developed methods
- Results
- Conclusions
- Future work

Motivation (I)

- Almost all new devices are becoming portable and wireless, demanding more and more frequency channels
  - This is leading into a spectrum scarcity and a subsequent search of new and unused spectral bands (beyond the 3GHz band)
- However, some studies have proven that most of the spectrum currently allocated is in fact underused
- Several techniques are arising in order to use the spectrum in a more efficient manner, such as Dynamic Spectrum Allocation (DSA)

Motivation (II)

- DSA access technique proposes the whole spectrum as a common pool to be allocated on demand
- The users will demand their spectrum necessities. Once the access is granted, they will transmit in the given frequency band as long as they need it (ask-transmit-release)
- DSA offers higher flexibility in the spectrum utilisation while the resources adapt to real-time demands and variations in spatial and temporal spectrum loads, incrementing the efficiency in the spectrum usage

Background (I)

- Several projects (such as DRiVE, OverDRiVE, WINNER, DIMSUMnet) have studied the possibility of a step towards DSA and its introduction as the allocation technique (instead of fixed spectrum allocation)
- Each project has proposed a different DSA scheme. All of them have proved a higher spectral efficiency using DSA

Background (II)

- DSA can be divided in two major categories, depending on the way in which the spectrum is being shared:
  - **Coordinated sharing** – the radio systems share the spectrum in a coordinated fashion
  - **Uncoordinated sharing** – no coordination exist among the systems sharing the spectrum. Two sub-types of uncoordinated sharing can also be considered depending on the priority of the systems accessing:
    - **Priority access**: one or several systems are targeted as primary systems and they have the priority when accessing the spectrum. The systems without priority are targeted as secondary systems
    - **Equal right access**: all the systems sharing the spectrum have the same right when accessing the spectrum

Research problem (I)

- The gain in the spectrum utilisation in terms of efficiency is going to be analysed. The results obtained when DSA is applied will be compared to the case when just fixed allocation techniques are used
- Uncoordinated sharing with priority access has been the DSA scheme chosen. The scenario consist of:
  - Two primary systems:
    - Two analogue TV broadcasting systems
    - Several wireless point-to-point (p2p) connections
  - A secondary system, composed by a certain number of secondary users

Research problem (II)

- The primary users will have the priority to access the spectrum. Therefore, the secondary users will be provided with sensing capabilities in order to decide if their transmissions will disturb the primary users. They will initiate calls between them without a specified purpose.
- The secondary users should perform DSA in one of the following two methods:
  - **Centralised method**: the secondary users will perform DSA in a centralised manner
  - **Distributed method**: in this situation, the secondary users will perform DSA in a distributed way

Developed methods (I)

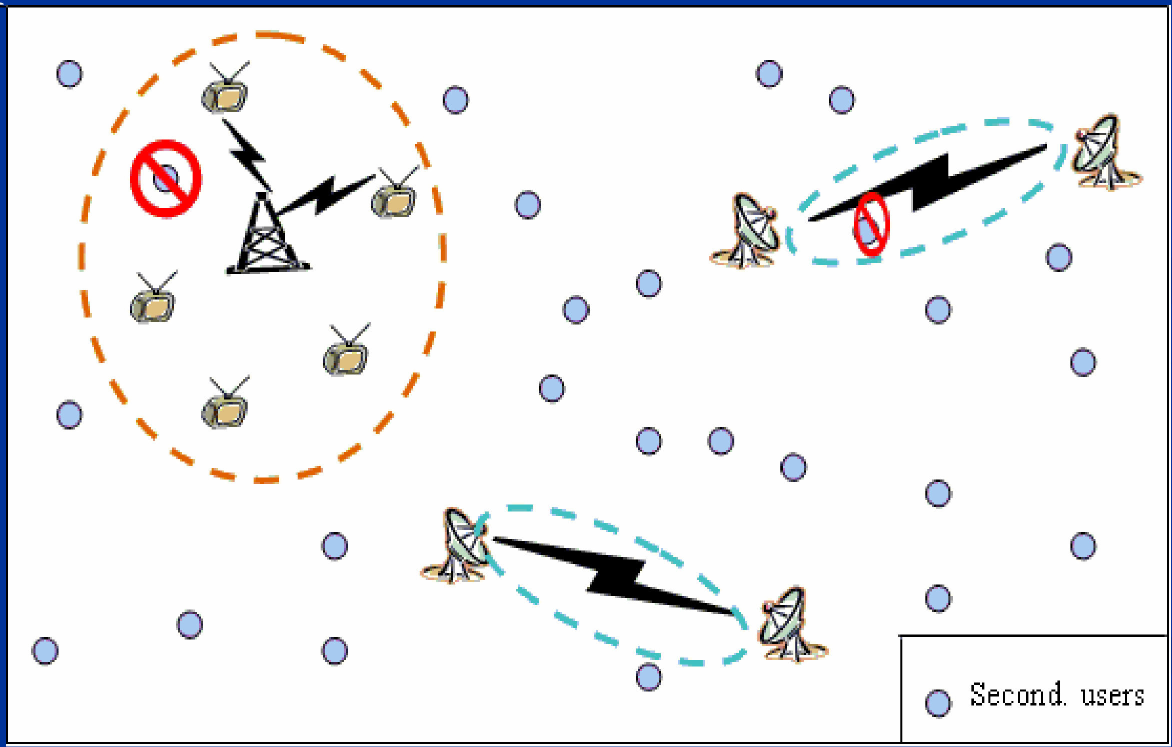
- In order to evaluate the differences in the spectral efficiency when DSA is applied, two simulators have been developed in C-language:
  - Centralised DSA simulator (developed by Vanessa Sánchez)
  - Distributed DSA simulator (developed by Yalton Ruiz)
- Both of them have been carried out on top of a core simulator that will perform all methods but DSA. They come together with two Matlab files in order to obtain graphical information about the results

Developed methods (II)

- The simulator is composed by several input parameters, which values can be changed
  - The simulated area is a 50km x 50km square
  - The whole spectrum considered for the simulator has been 10 MHz divided into 50 frequency channels (200kHz bandwidth each)
- When the simulation starts, the primary systems will be allocated, as well as the secondary users, spread over the simulation area

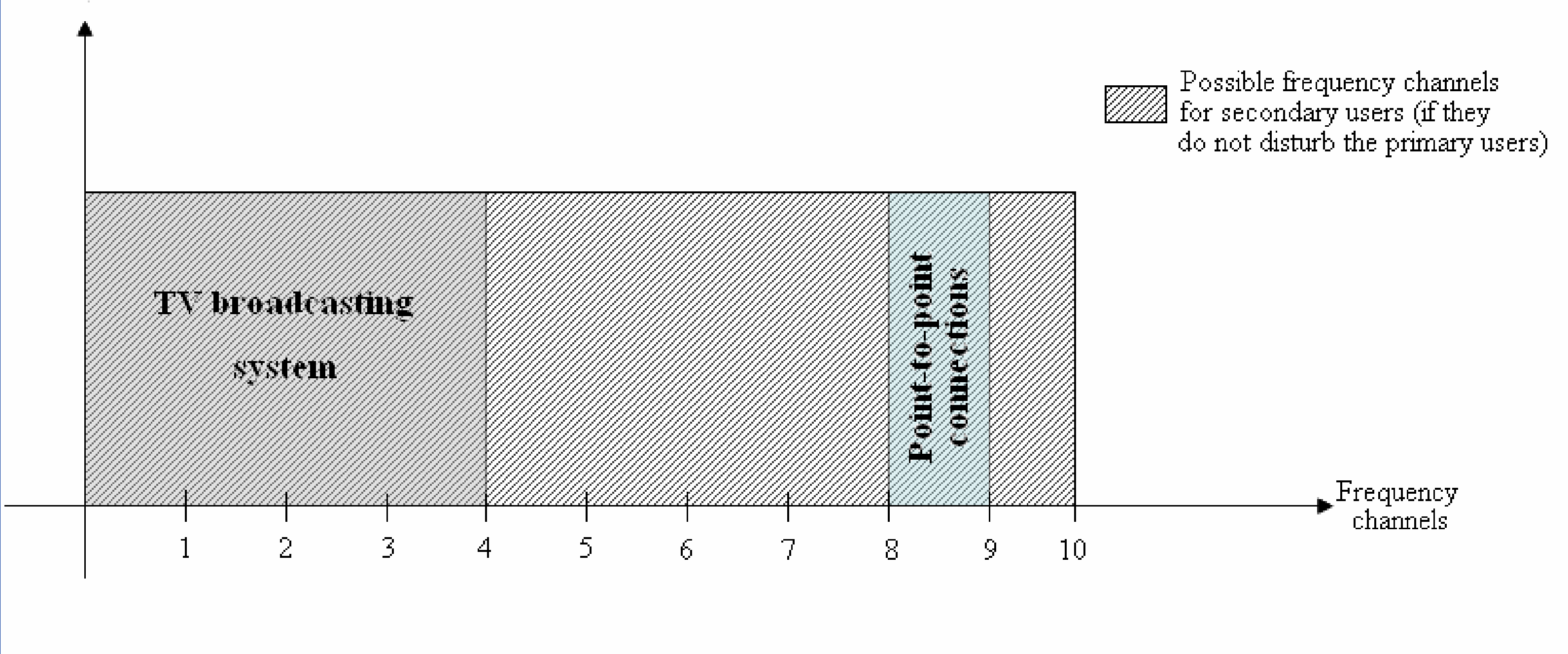
Developed methods (III)

- Each analogue TV broadcasting system will have 500 TV receivers
- The secondary system will comprise 1000 secondary users spread over the simulation area



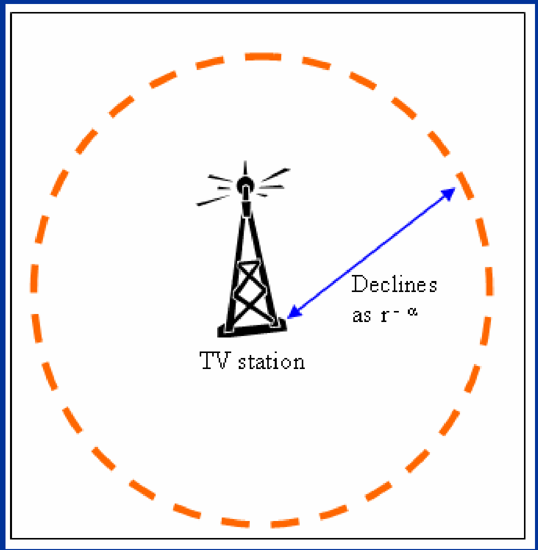
Developed methods (IV)

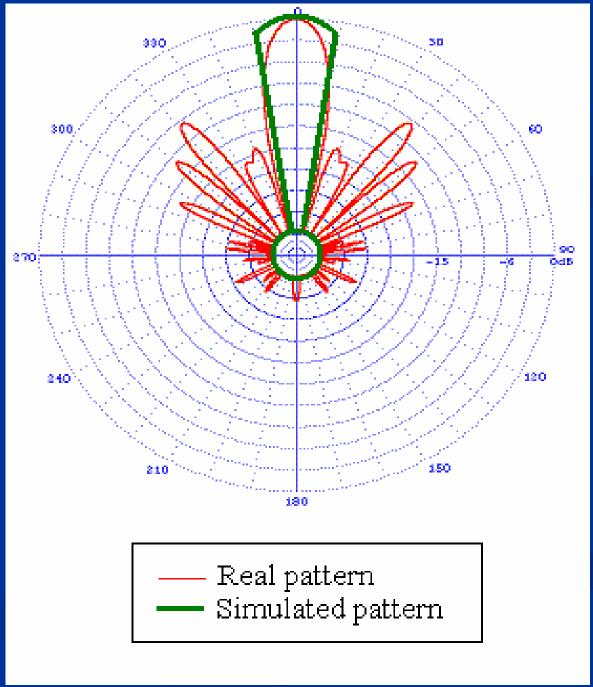
- The analogue TV broadcasting systems and the wireless p2p will be using fixed part of the spectrum (fixed frequency channels), and continuous in time
- The secondary users will measure the spectrum and will decide if they can transmit (if their transmissions do not affect the primary users)



Developed methods (V)

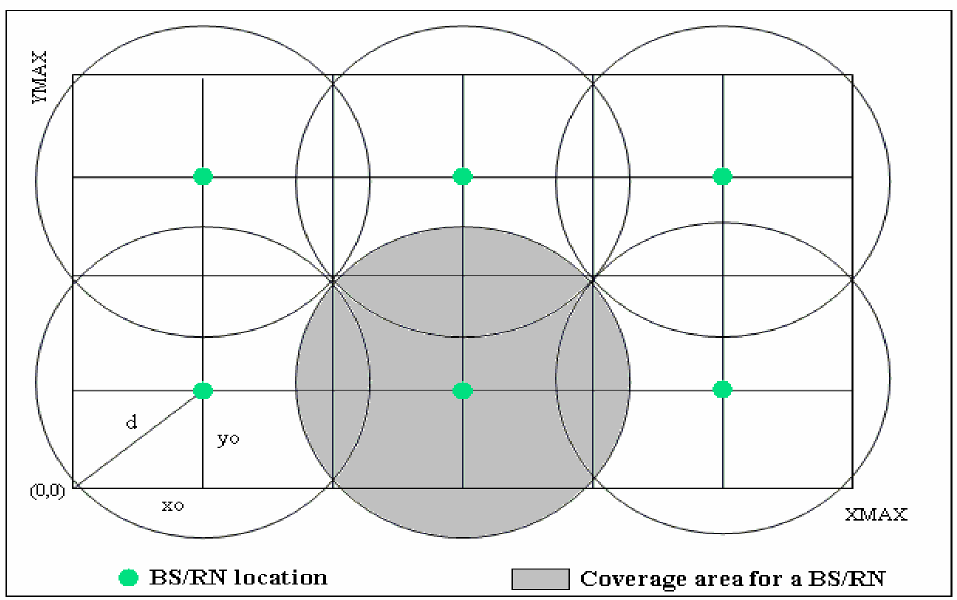
- The secondary users will generate calls following a M/M/m queuing system
- Two antenna types have been considered:
  - **Omni-directional antennae**: these antennae describe the behaviour of the analogue TV transmitter and the secondary users transmitters
  - **Directional antennae**: these antennae describe the behaviour of the p2p transmitters





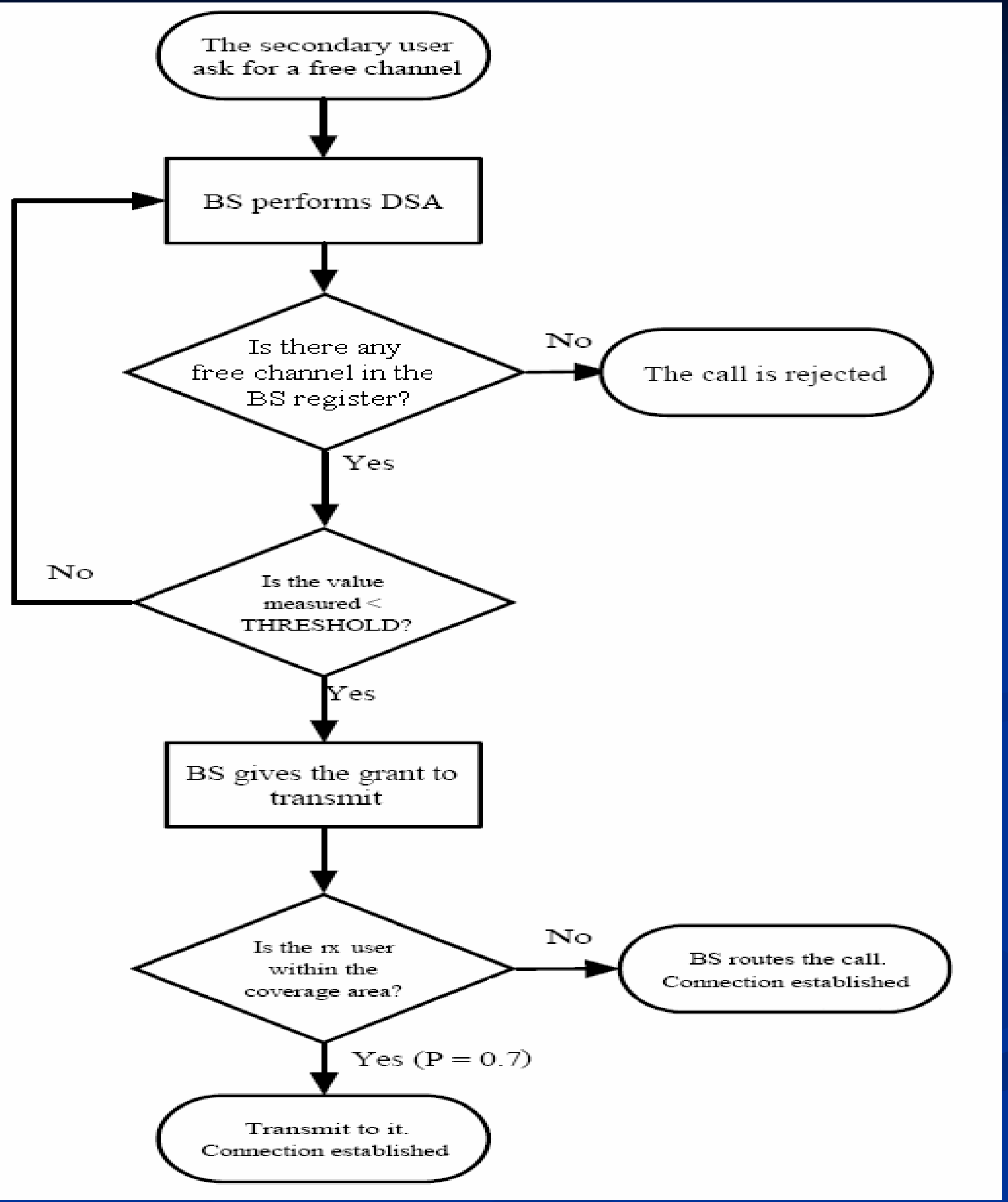
Call establishment

- **Centralised method**: a special entity (base station - BS) is allocated in order to perform DSA, being the only one with sensing capabilities. The secondary users will request the channels to its serving BS, which will grant the access after performing DSA. Also, this entity will route the calls when the “called” user is located in a region where a different BS is serving (this will occur with a probability equal to 0.3)
- **Distributed method**: all the secondary users will have sensing capabilities and they will measure the spectrum and decide which channels are free. A special entity called routing node (RN) will be allocated in order to route the call (as done in the centralised method)



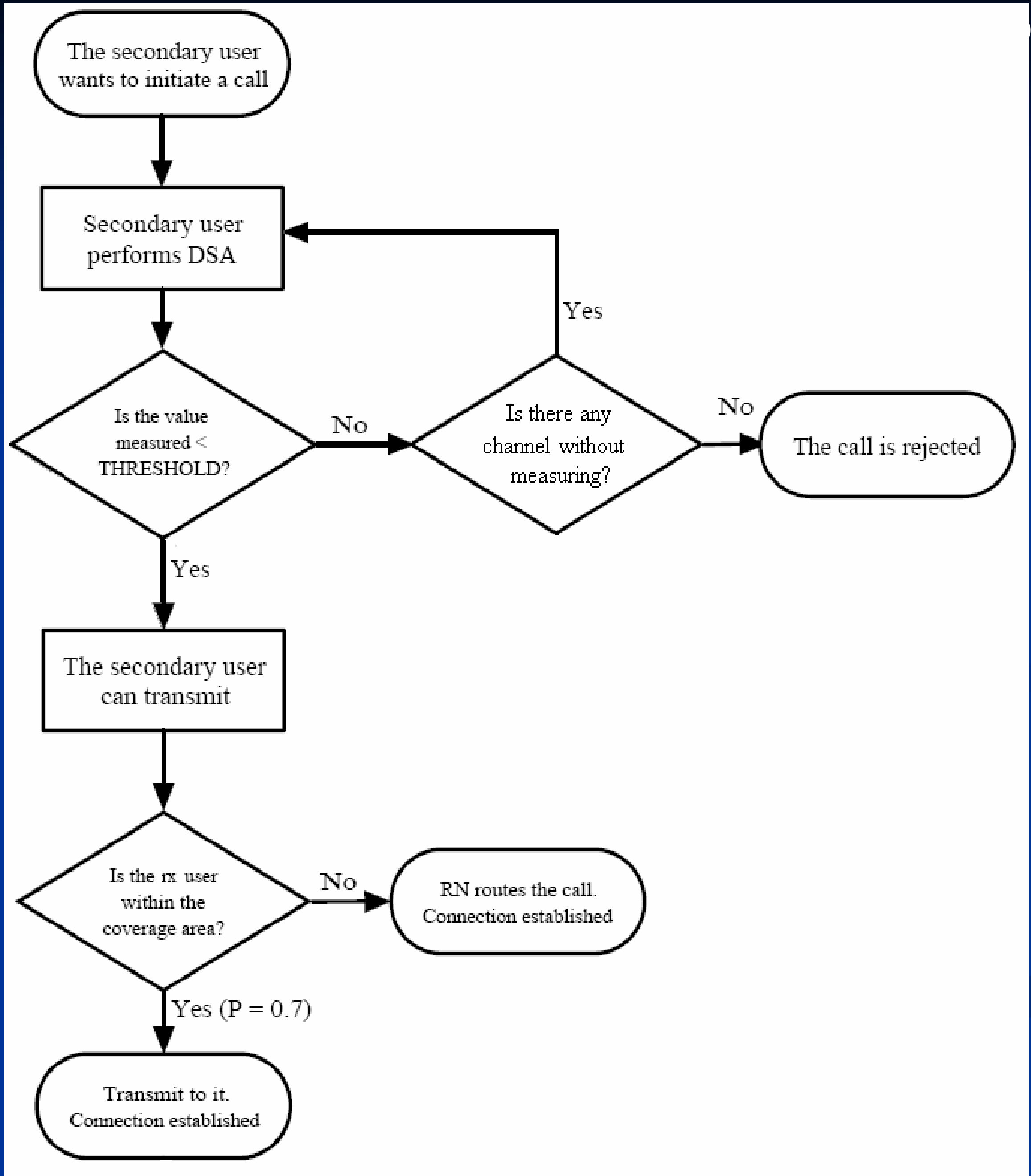
Centralised method Call establishment

- The secondary user asks a free channel to the BS
- The BS keeps a register with the used and unused frequency channels
- The channel is said to be free if the measured value is lower than the THRESHOLD value



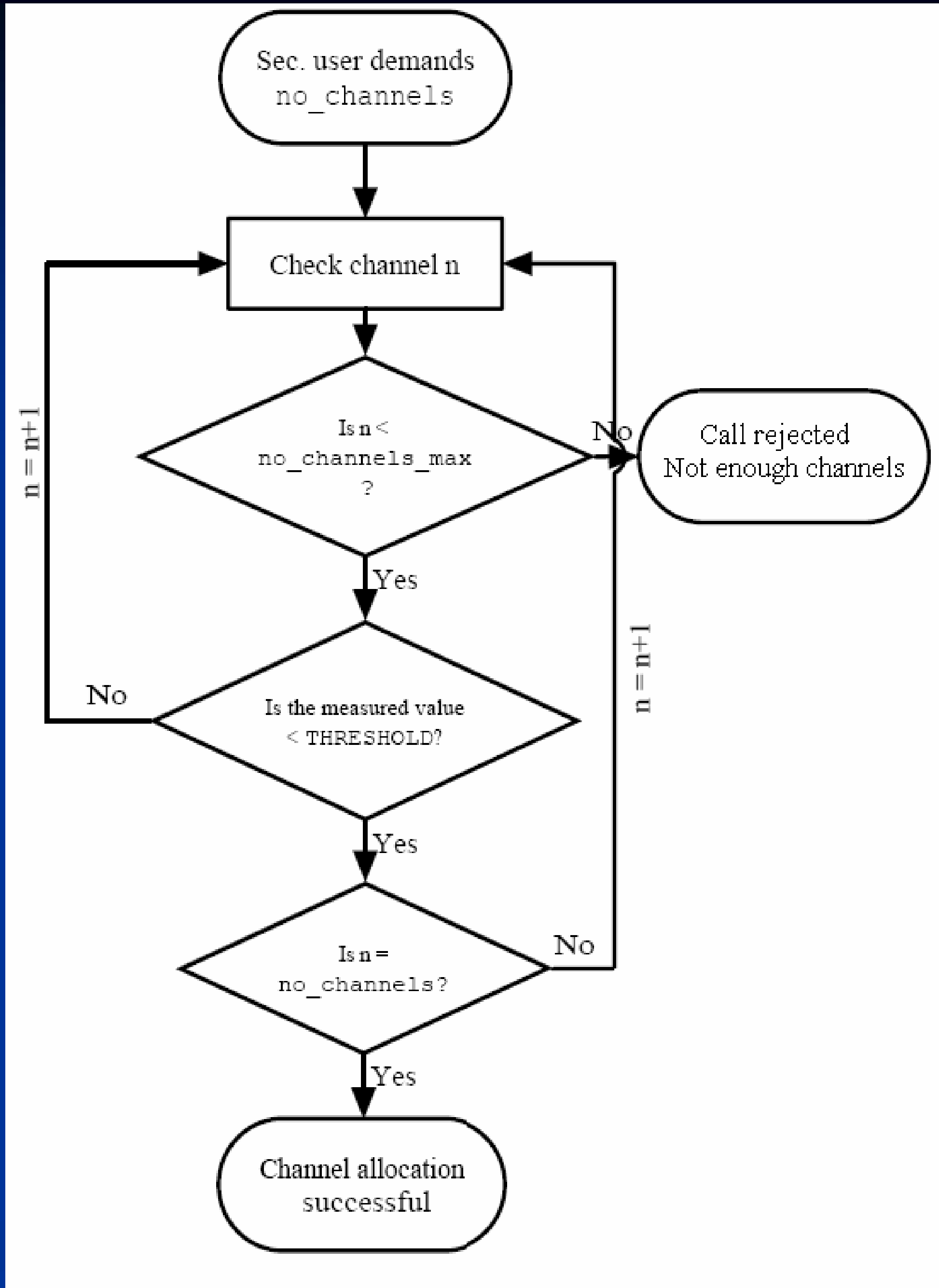
Distributed method
Call establishment

- The secondary user will perform DSA
- The channel is free if the measured value is lower than the THRESHOLD value



DSA operation – channel allocation

- The secondary user demands n channels where allocate its call
- The call is successfully allocated if there are n free channels without spectral holes between them (the channels are allocated together)

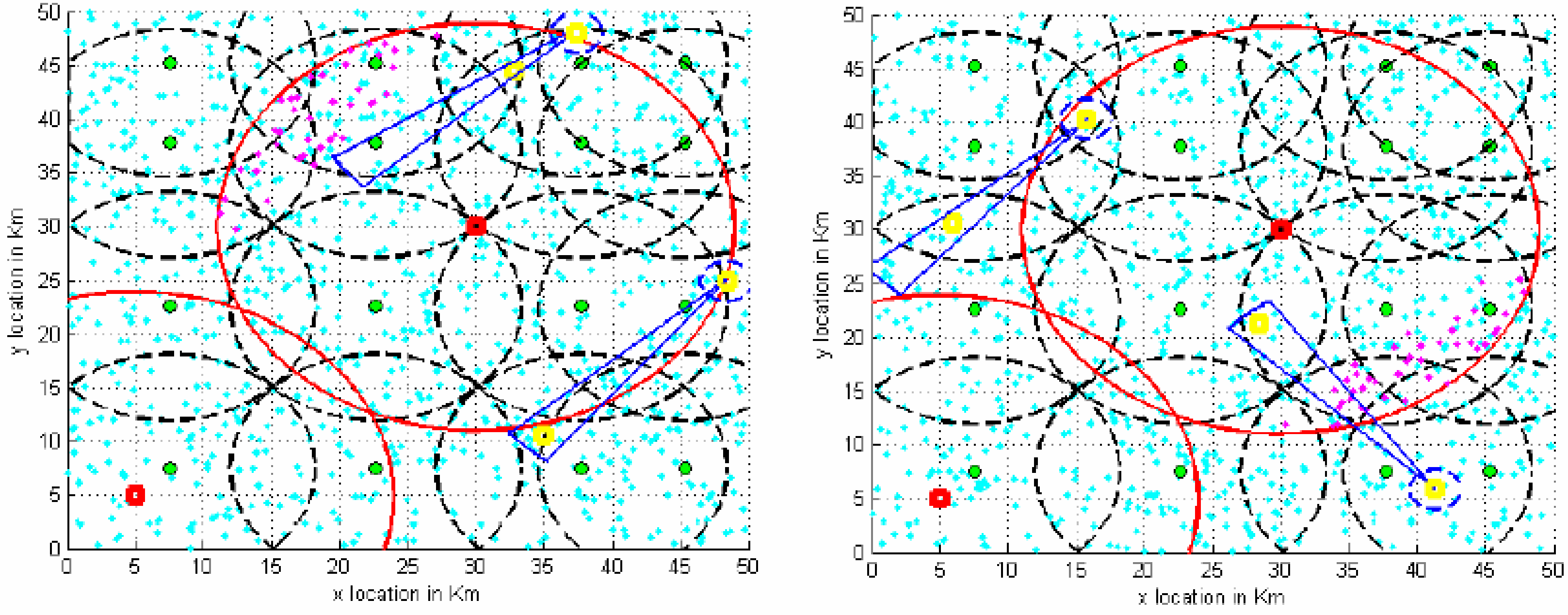


Results

- Two situations have been simulated:
  - When the parameter MAXCHANNEL is equal to 3: the secondary user will demand a variable number of frequency channels, from 1 to 3, being chosen randomly
  - When the parameter MAXCHANNEL is equal to 1: the secondary users will demand always just 1 frequency channel
- Both situations have been analysed for the centralised and the distributed methods

Results – Centralised simulator MAXCHANNEL = 3

- Situation 1: THRESHOLD = -37.35 dBm (low outage)
- Situation 2: THRESHOLD = -37.3578 dBm (minimum outage)

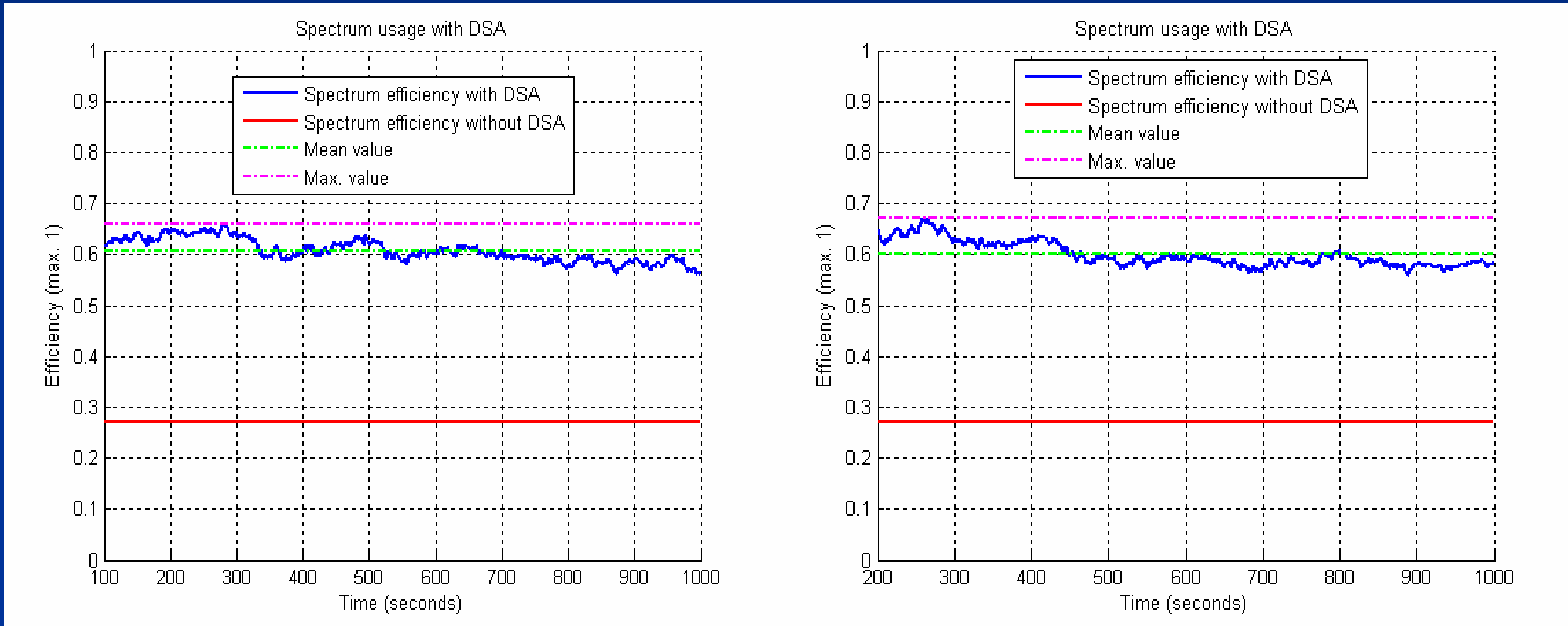


a) Situation 1

b) Situation 2 - minimum outage

Simulated scenario

Results – Centralised simulator MAXCHANNEL = 3



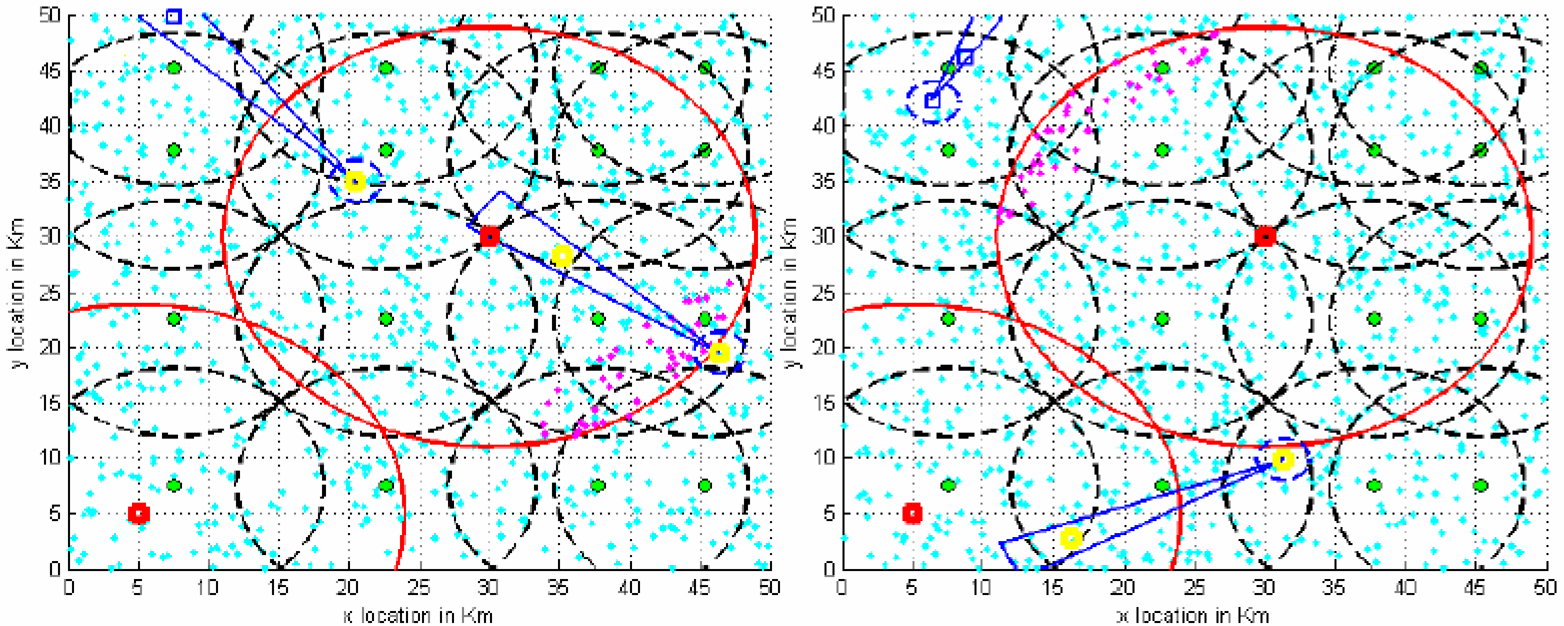
a) Situation 1 b) Situation 2

Results – Centralised simulator MAXCHANNEL = 3

Parameter	THR = -37.35 dBm	THR = -37.3578 dBm
Mean number of channels used (secondary users)	269.0023	262.9525
Maximum number of channels used (secondary users)	311	320
Spectral efficiency without DSA (%)	27.07	27.07
Mean efficiency with DSA (%)	60.70	59.94
Maximum efficiency with DSA (%)	65.95	67.07
Mean DSA gain (%)	33.63	31.97
Maximum DSA gain (%)	38.88	40.00
Total number of secondary users accepted	1561	1527
Total number of secondary users rejected	1894	1753
Blocking probability for secondary users (%)	54.8191	53.4451
Outage probability, TV rx system 1 (%)	0	0
Outage probability, TV rx system 2 (%)	5.5351	5.4706
Combined outage probability to TV rx (%)	2.7675	2.7353
Probability of no outage to TV rx (%)	97.2325	97.2647

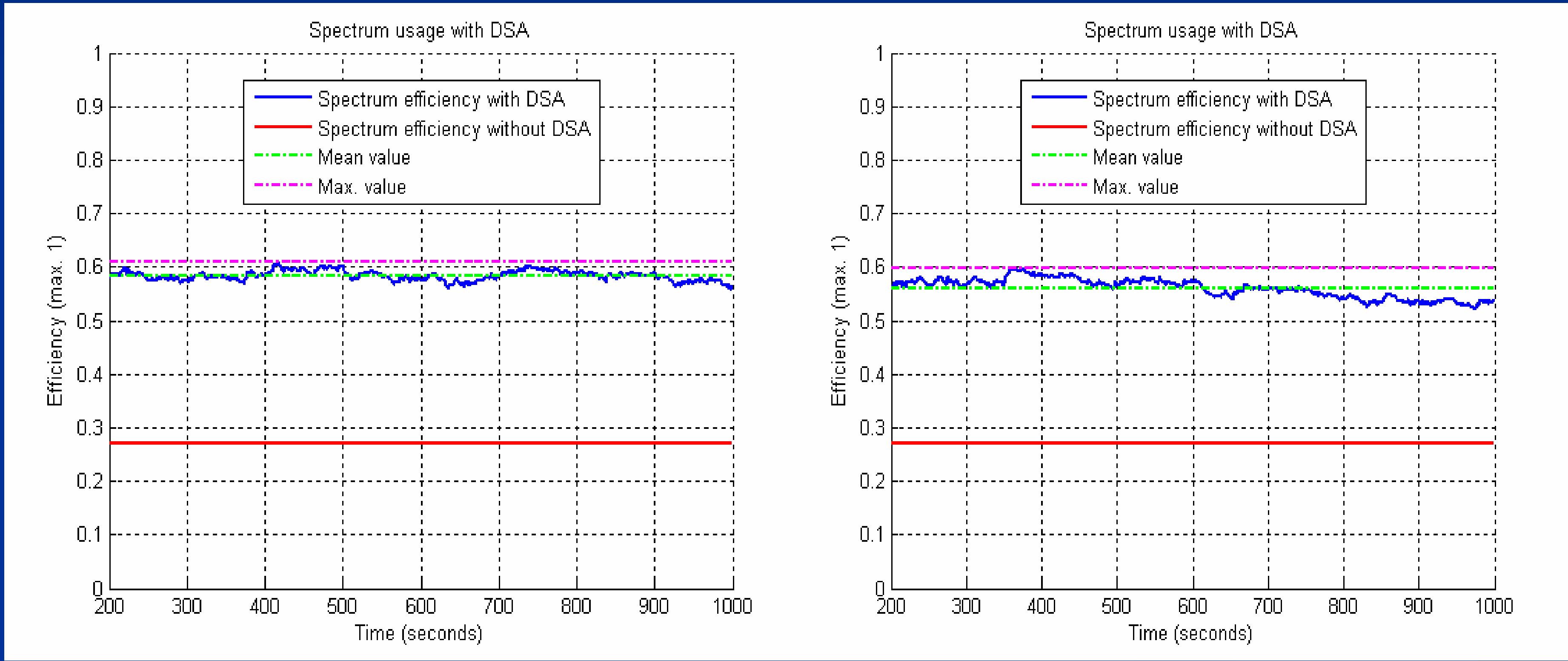
Results – Centralised simulator MAXCHANNEL = 1

- Situation 1: THRESHOLD = -37.358 dBm (low outage)
- Situation 2: THRESHOLD = -37.3597 dBm (minimum outage)



a) Situation 1   b) Situation 2 - minimum outage

Results – Centralised simulator MAXCHANNEL = 1



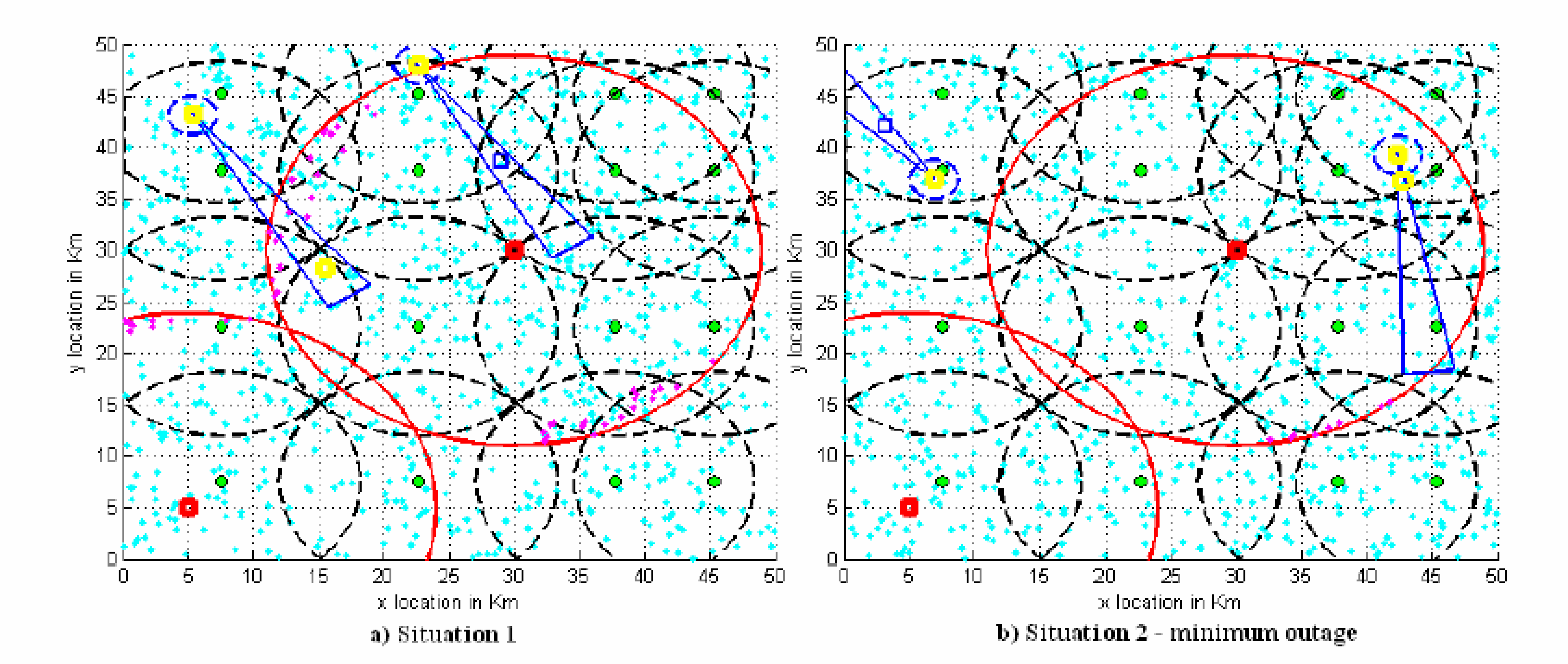
a) Situation 1 b) Situation 2

Results – Centralised simulator MAXCHANNEL = 1

Parameter	THR = -37.358 dBm	THR = -37.3597 dBm
Mean number of channels used (secondary users)	250.2843	231.8615
Maximum number of channels used (secondary users)	270	262
Spectral efficiency without DSA (%)	27.07	27.07
Mean efficiency with DSA (%)	58.36	56.06
Maximum efficiency with DSA (%)	60.82	59.82
Mean DSA gain (%)	31.29	28.99
Maximum DSA gain (%)	33.75	32.75
Total number of secondary users accepted	2285	2112
Total number of secondary users rejected	1206	1291
Blocking probability for secondary users (%)	34.5460	37.9371
Outage probability, TV rx system 1 (%)	0	0
Outage probability, TV rx system 2 (%)	5.5324	4.5439
Combined outage probability to TV rx (%)	2.7662	2.2719
Probability of no outage to TV rx (%)	97.2338	97.7281

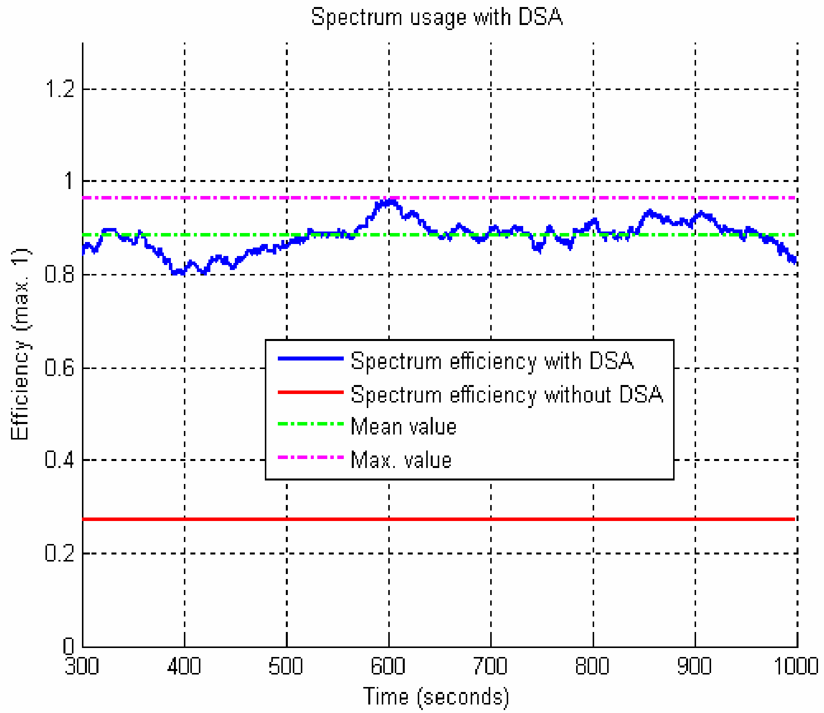
Results – Distributed simulator MAXCHANNEL = 3

- Situation 1: THRESHOLD = -38 dBm (low outage)
- Situation 2: THRESHOLD = -39 dBm (minimum outage)

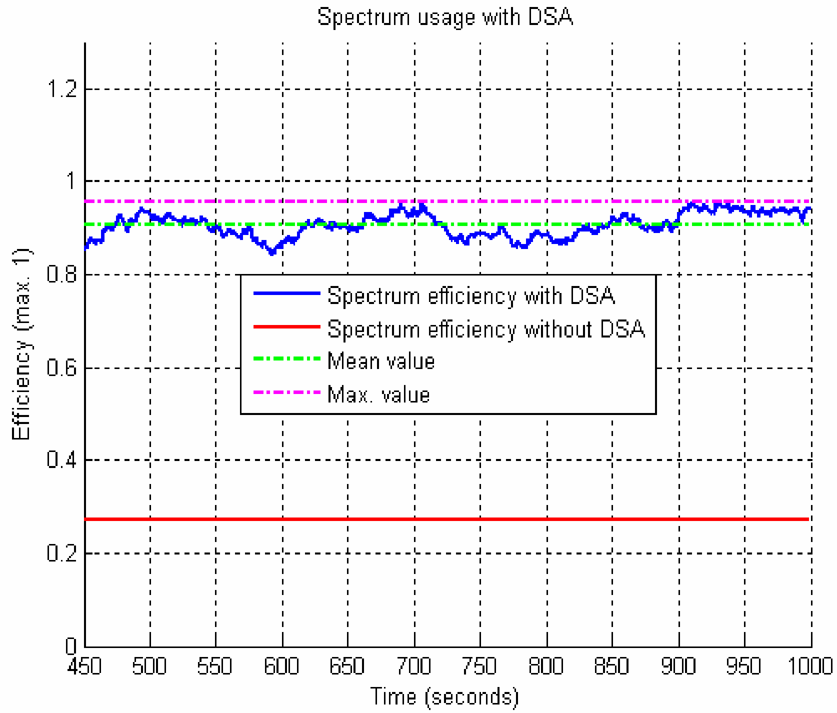


Simulated scenario

Results – Distributed simulator MAXCHANNEL = 3



a) Situation 1



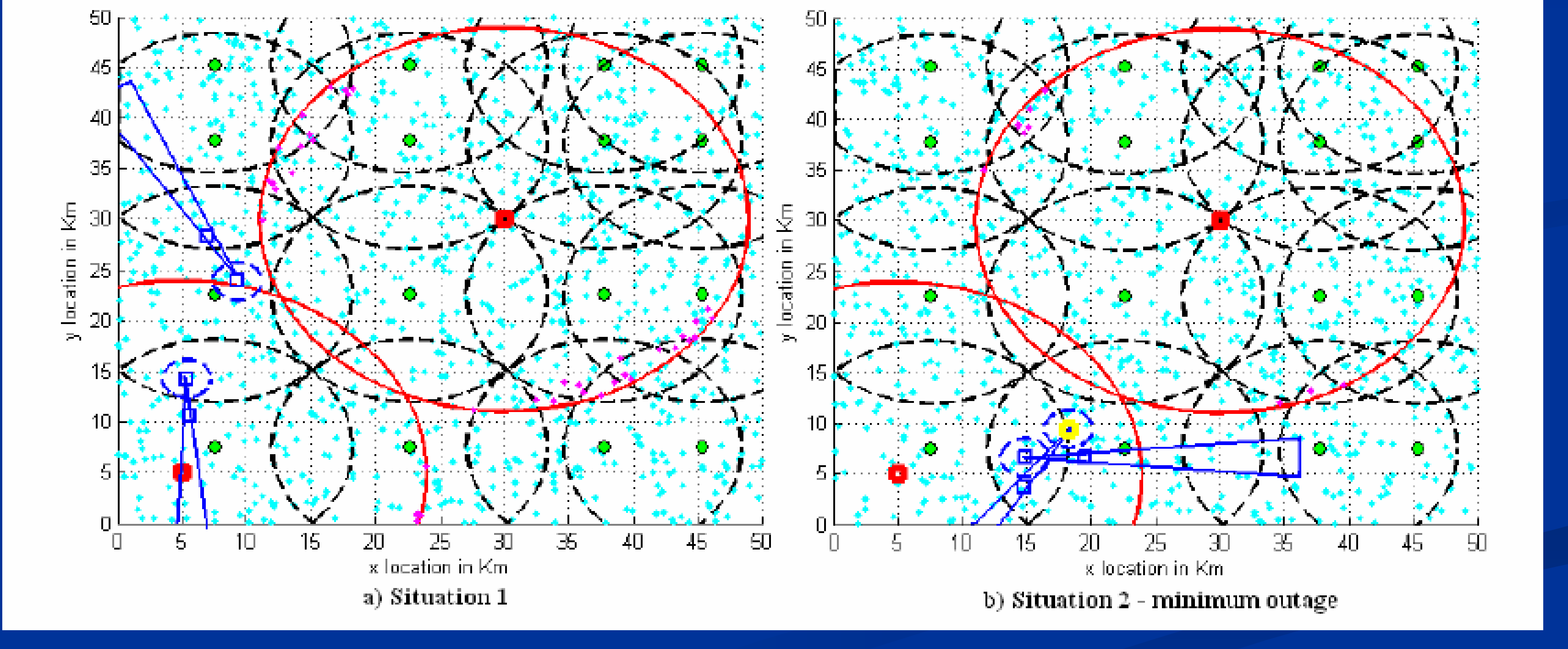
b) Situation 2

Results – Distributed simulator MAXCHANNEL = 3

Parameter	THR = -38 dBm	THR = -39 dBm
Mean number of channels used (secondary users)	490.2943	509.1345
Maximum number of channels used (secondary users)	555	549
Spectral efficiency without DSA (%)	27.07	27.07
Mean efficiency with DSA (%)	88.36	90.71
Maximum efficiency with DSA (%)	96.45	95.70
Mean DSA gain (%)	61.29	63.64
Maximum DSA gain (%)	69.38	68.63
Total number of secondary users accepted	2112	2114
Total number of secondary users rejected	95	20
Blocking probability for secondary users (%)	4.4981	0.9461
Outage probability, TV rx system 1 (%)	0.3985	0
Outage probability, TV rx system 2 (%)	2.7691	0.43
Combined outage probability to TV rx (%)	1.5838	0.215
Probability of no outage to TV rx (%)	98.4162	99.785

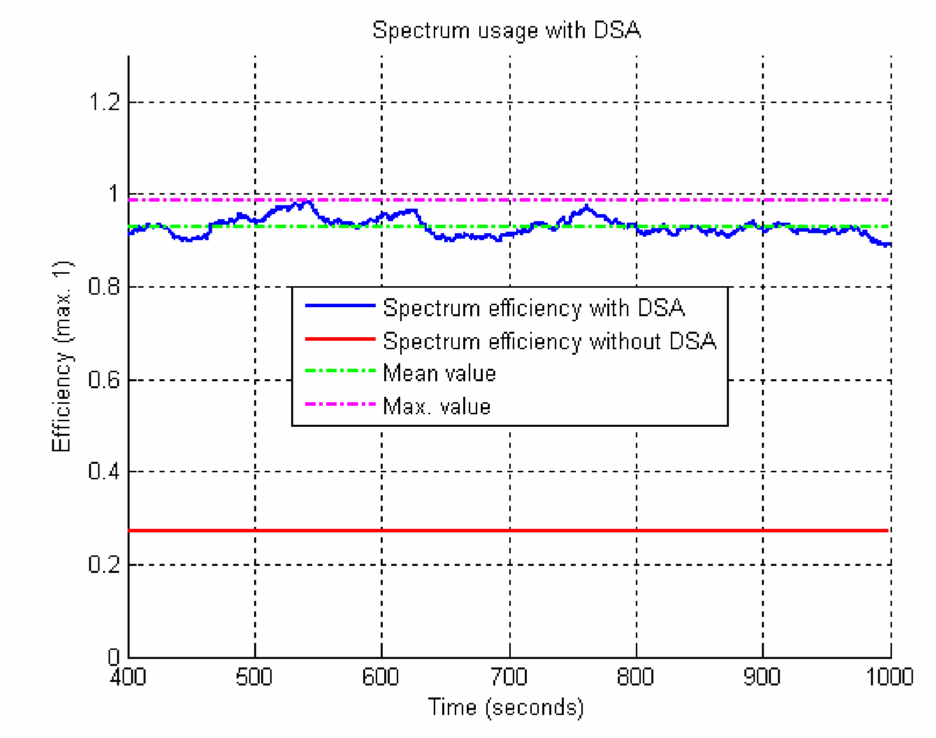
Results – Distributed simulator MAXCHANNEL = 1

- Situation 1: THRESHOLD = -38 dBm (low outage)
- Situation 2: THRESHOLD = -39 dBm (minimum outage)

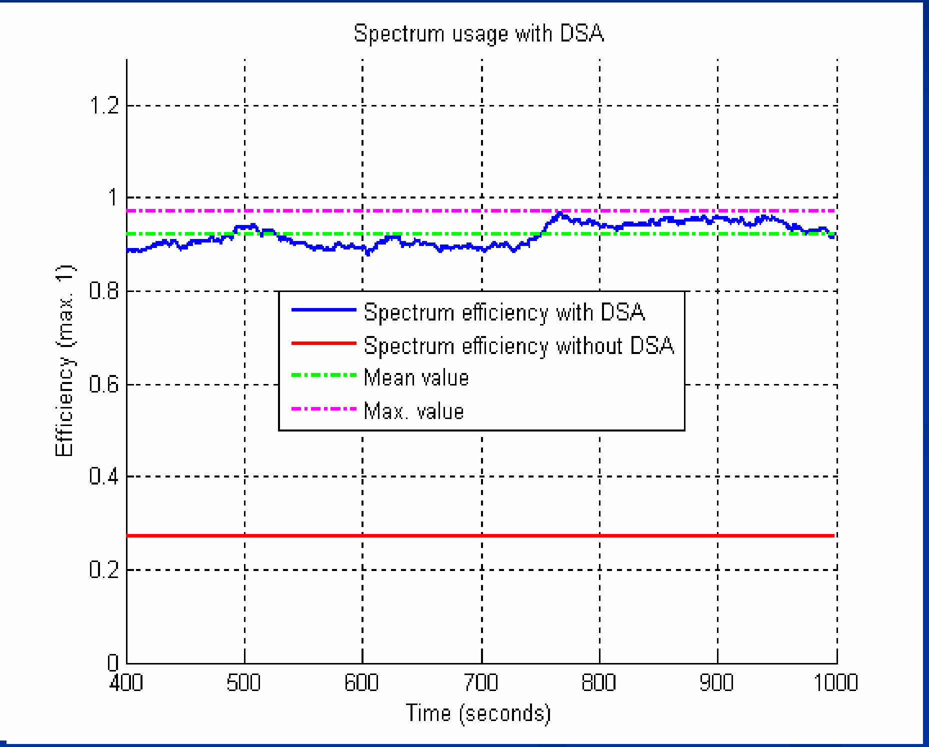


Simulated scenario

Results – Distributed simulator MAXCHANNEL = 1



a) Situation 1



b) Situation 2

Results – Distributed simulator MAXCHANNEL = 1

Parameter	THR = -38 dBm	THR = -39 dBm
Mean number of channels used (secondary users)	528.167	520.5721
Maximum number of channels used (secondary users)	572	560
Spectral efficiency without DSA (%)	27.07	27.07
Mean efficiency with DSA (%)	93.09	92.14
Maximum efficiency with DSA (%)	98.57	97.07
Mean DSA gain (%)	66.02	65.07
Maximum DSA gain (%)	71.5	70.0
Total number of secondary users accepted	4458	4423
Total number of secondary users rejected	35	64
Blocking probability for secondary users (%)	0.7851	1.447
Outage probability, TV rx system 1 (%)	0.1634	0
Outage probability, TV rx system 2 (%)	2.6503	0.6194
Combined outage probability to TV rx (%)	1.4069	0.3097
Probability of no outage to TV rx (%)	98. 5931	99.6903

Results – Comparison table for both simulators

	Method	Centralised		Distributed	
MAXCHANNEL = 3	**THRESHOLD (dBm)**	**-37.35**	**-37.3578**	**-38**	**-39**
	Mean efficiency with DSA (%)	60.70	59.94	88.36	90.71
	Blocking probability for secondary users (%)	54.8191	53.4451	4.4981	0.9461
	Probability of no outage to TV rx (%)	97.2325	97.2647	98.4162	99.785
MAXCHANNEL = 1	**THRESHOLD (dBm)**	**-37.358**	**-37.3597**	**-38**	**-39**
	Mean efficiency with DSA (%)	58.36	56.06	93.09	92.14
	Blocking probability for secondary users (%)	34.5460	37.9371	0.7851	1.447
	Probability of no outage to TV rx (%)	97.2338	97.7281	98.5931	99.6903

Conclusions (I)

- The system created is totally viable. A scenario where primary and secondary users are coexisting can be created, ensuring a minimum outage probability for the primary users (keeping QoS requirements)
- The results obtained have proven that the distributed method provides much better results than the centralised one, but it however entails bigger expenses in system deployment, fact that could make a point in order to choose a centralised DSA

Conclusions (II)

- The distributed simulator performs much better than the centralised one in the main parameters analysed: mean and maximum spectral efficiency (90% versus 60%), mean and maximum spectral gain (60% versus 30%) and blocking probability (2% versus 40%)
- However, the outage probability for the primary users is kept as small as desired for both simulators
- Generally, the lower the THRESHOLD value is
  - the lower the spectral efficiency is
  - the lower the outage probability is
- Generally, the bigger the THRESHOLD value is, the lower the blocking probability is

Conclusions (III)

- The bandwidth gain varies from the parameters chosen as well as the method used:
  - From 25.39% to 33.63% in the centralised method (reaching spectral efficiency up to 60%)
  - From 61.94% to 66.02% in the distributed method (reaching spectral efficiency of almost 100%)

Suggestions for future work

- This research has been the beginning of a huge investigation branch, and therefore some suggestions can be done in order to continue this work:
  - The path-loss model assumed in the simulator is the one declining as the inverse of the distance. A more complex model, such as Okumura-Hata could be introduced in the simulator
  - The secondary users could use directional antennae instead of the directional ones
  - The p2p users can also initiate calls following a traffic model, as it was done with the secondary users
  - Users mobility
  - Some quality parameters can be introduced and evaluated for the secondary users

Questions

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Thank you!