CENTRE FOR WIRELESS NETWORK DESIGN

Optimisation Methods for Dynamic Frequency Planning in OFDMA Networks

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Outline

- Introduction & Motivation
- OFDMA
  - OFDMA/TDD Frame
  - Frequency Reuse Schemes
- Dynamic Frequency Planning
  - Model
  - Inputs: Demand Vector & Restriction Matrix
  - Optimization Problem: Mixed Integer Program
  - Solving DFP: Simulated Annealing, Tabu Search & Greedy Algorithms
- Results
- Conclusions

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Introduction

- OFDMA networks such as WiMAX and LTE are pointed by the industry as the most suitable technologies for the future deployment of cellular networks.

- In order to avoid inter-cell interference OFDMA networks are flexible in terms of radio resource management and *FRSs (Frequency Reuse Scheme)*.

- However, most of these techniques are not suitable for dynamic scenarios where the traffic demands and channel conditions rapidly change.

Introduction

- In this work, *DFP (Dynamic Frequency Planning)* is presented as a new approach to the frequency assignment problem tailored to OFDMA networks.
- DFP may decrease the inter-cell interference and increase the capacity of the network by dynamically adapting the radio frequency parameters to the specific scenario.
- DFP uses novel algorithms to sense the radio channel, and adapted versions of *Simulated Annealing*, *Tabu Search*, or *Greedy Algorithms* to solve the optimization problem.

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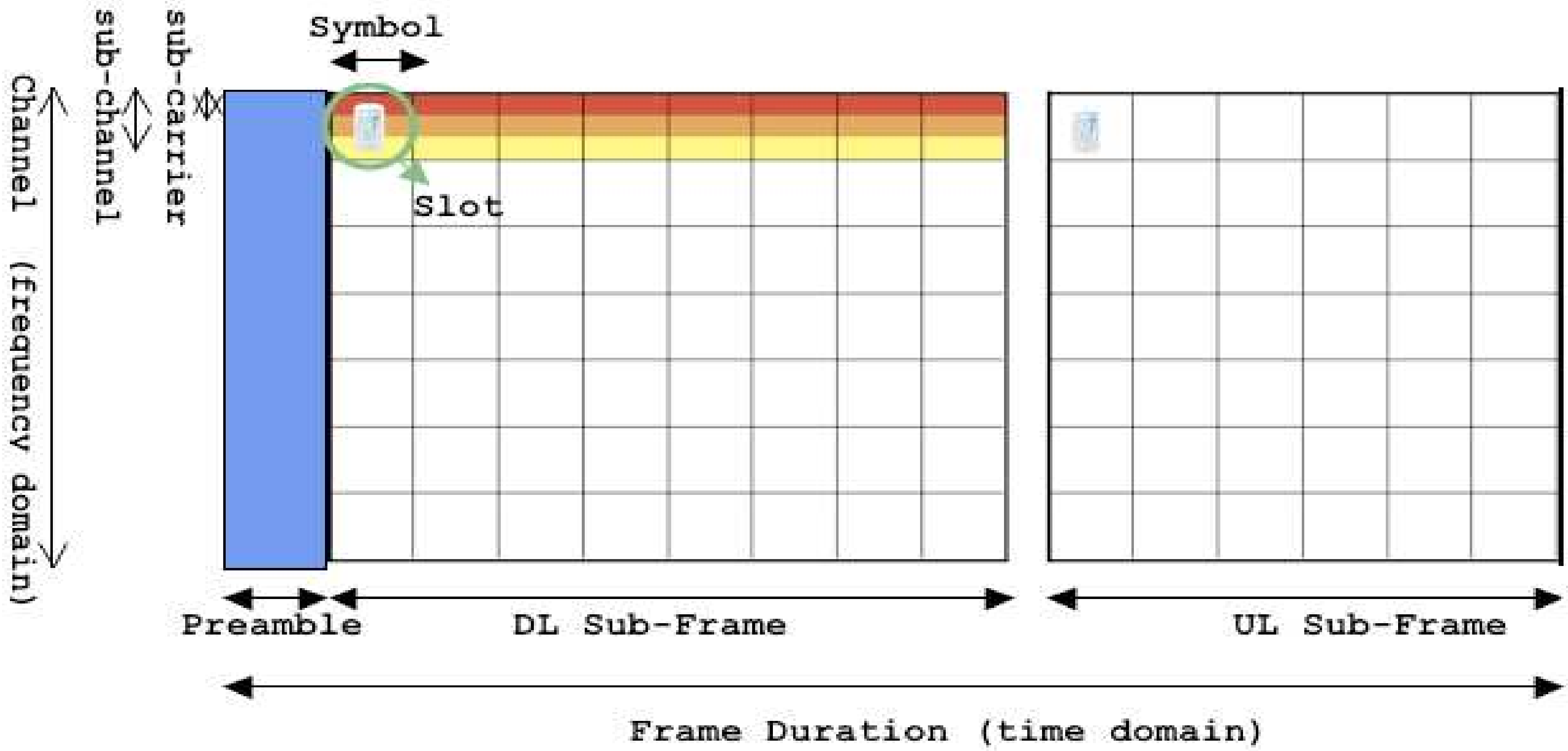
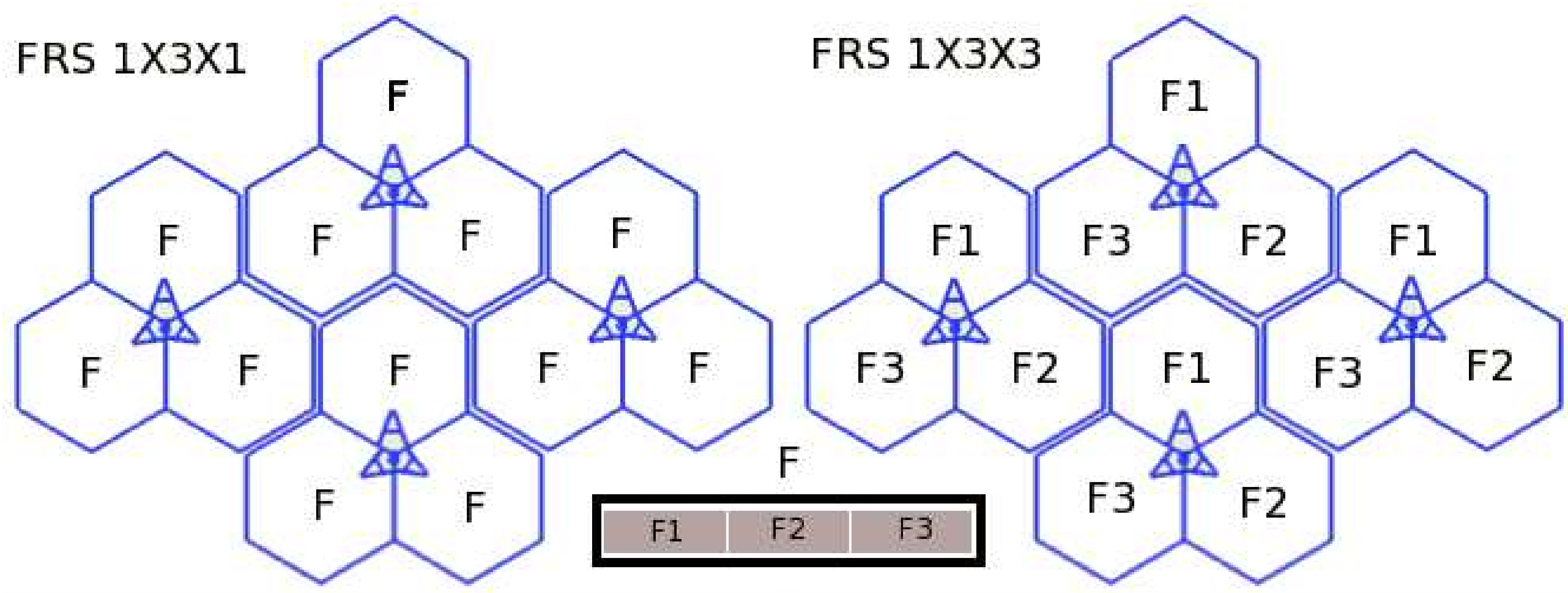
OFDMA/TDD Frame

- When using OFDMA, different users are allocated to different subsets of *sub-carriers* called *sub-channels*, allowing the use of *multi-user* or *frequency* diversity.



OFDMA Frequency Reuse Schemes

- Many FRSs have been proposed to reduce inter-cell interference. However, they are based on static forecasts. Therefore, they are not able to cope with the changing behavior of the users and the environment.



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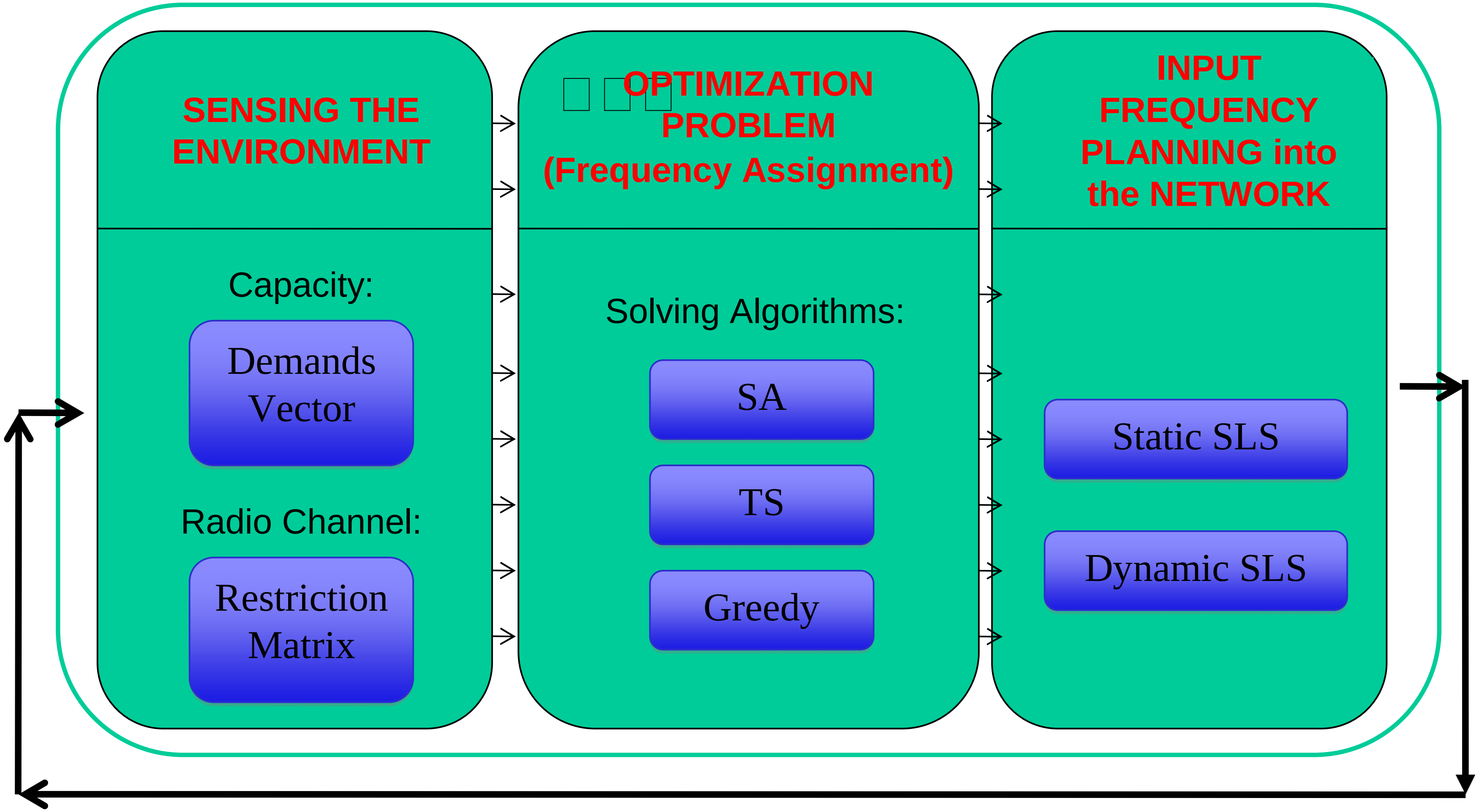
DFP - Model


SENSING THE ENVIRONMENT
Capacity:
Demands Vector
Radio Channel:
Restriction Matrix
OPTIMIZATION PROBLEM
(Frequency Assignment)
Solving Algorithms:
SA
TS
Greedy
INPUT FREQUENCY PLANNING into the NETWORK
Static SLS
Dynamic SLS

DFP – Demand Vector

- The demand vector indicates the number of sub-channels needed per sector to satisfy the users demands.
- It is calculated as follows:

- Number of users able to decode the preamble in each sector
- Requested slots for the i-th user (1)(2)
- Requested sub-channel for the S_i-th sector (3)

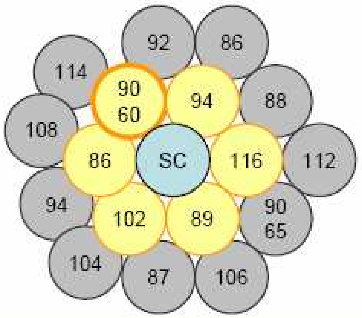
$$(1)\quad \text{Slot throughput}(Kbps) = \frac{\frac{Subcarriers}{slot} \cdot \frac{bits}{subcarrier}}{5\,ms}$$

$$(2)\quad \text{Slot}_i = \frac{\text{Requested Throuhgput}_i\,(Kbps)}{\text{Slot throughput}_i\,(Kbps)}$$

$$(3)\quad C_{S_j} = \sum_{i \in S_j} Slots_i \cdot \frac{slots}{sub-channels}$$

DFP – Restriction Matrix (I)

- Measurement Report contains information about Serving Cell and the strongest Neighbouring Cell



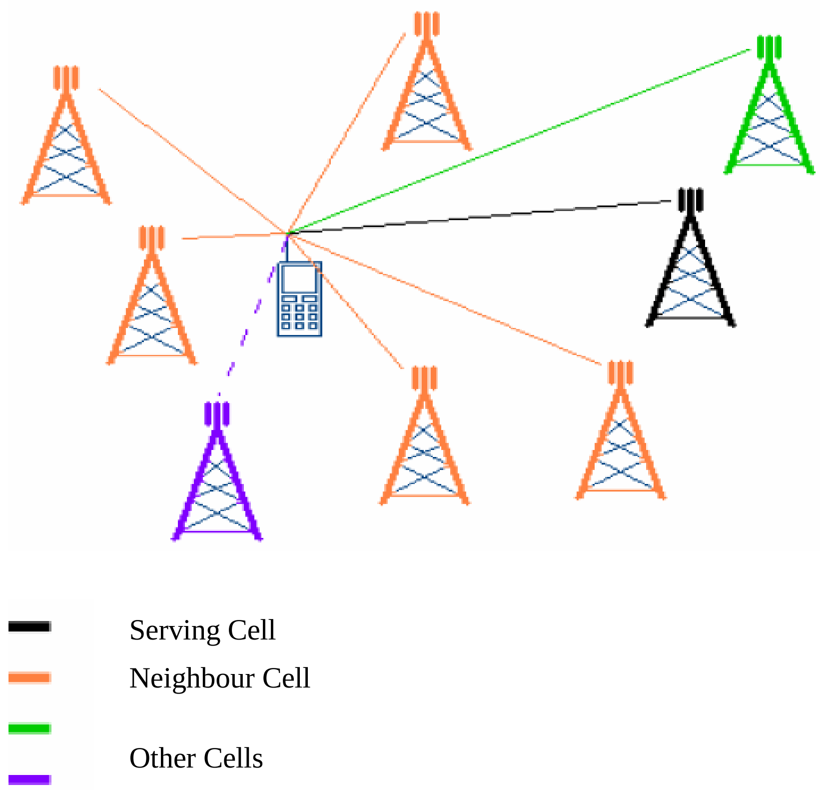
BA List (only def. HO NB):
{94, 116, 89, 102, 86, 90}

Serving Cell Measurements

	RXLEV	RXQUAL
FULL	94	6
SUB	82	1

Neighbouring Cell Measurements

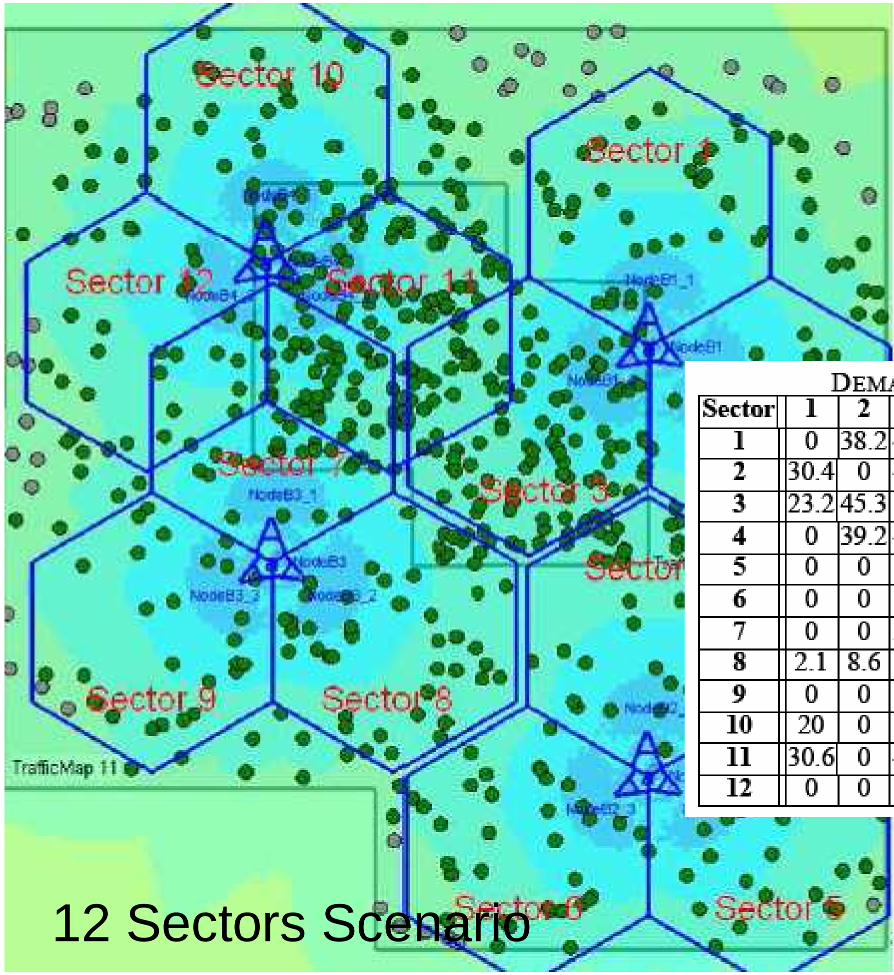
NB	RXLEV	BCCH	BSIC
1	38	94	47
2	42	116	34
3	31	89	62
4	12	102	07
5	10	86	11
6	**18**	**90**	**60**



DFP – Restriction Matrix (II)

- When a MR is received by the BS, the received signal power of the Serving Cell and the Neighbour Cell are compared.
- An Interference Event happens if the signal from the Serving Cell is stronger / weaker with respect to Neighbour Cell by specified threshold value defined by the operator.
- Dividing # I (Interference Event) by # MR (Measurement Report) for a given threshold (e.g.12dB) indicates the amount of overlapping from the Serving Cell and the Neighbour Cell in terms of % of time.
- Finally, the Restriction Matrix can be build. The size of the restriction matrix is [Sector x Sector].

DFP – Restriction Matrix (III)



12 Sectors Scenario

Example of:

Capacity Estimation

Restriction Matrix

DEMAND VECTOR AND RESTRICTION MATRIX

Sector	1	2	3	4	5	6	7	8	9	10	11	12	D_i
1	0	38.2	41.1	0	0	0	2.9	0	0	11.7	26.4	0	4
2	30.4	0	47.8	34.7	4.3	0	0	0	0	0	0	0	3
3	23.2	45.3	0	24.4	0	3.4	31.3	37.2	0	4.6	45.3	0	8
4	0	39.2	46.4	0	28.5	25	0	32.1	0	0	0	0	4
5	0	0	0	52.9	0	29.4	0	0	0	0	0	0	4
6	0	0	0	39.2	42.8	0	0	21.4	10.7	0	0	0	4
7	0	0	23.4	4.2	0	0	0	44.6	23.40	0	76.5	65.9	6
8	2.1	8.6	36.9	56.5	0	43.4	39.13	0	34.7	0	23.9	2.1	6
9	0	0	0	0	0	0	39.2	42.8	0	0	3.57	3.14	4
10	20	0	12.5	0	0	0	17.1	0	0	0	45	22.5	5
11	30.6	0	45.5	0	0	0	50.49	19.8	0	37.6	0	29.7	8
12	0	0	0	0	0	0	65.2	0	4.3	39.1	30.4	0	3

DFP – Frequency Assignment Problem

The problem is to:

$$\min \sum_{i\in N}\sum_{j\in N}\sum_{k\in NF} \frac{W_{ij}}{D_i \cdot D_j} y_{i,j,k}$$

subject to:

$$\sum_{k=0}^{NF} x_{i,k} = D_i \quad \forall i,k$$

$$y_{i,j,k} \geq x_{i,k} + x_{j,k} - 1 \quad and \quad y_{i,j,k} \geq 0 \quad \forall i,j,k$$

$$x_{i,k} \in \{0,1\} \quad \forall i,k$$

N number of sectors, $\{1,\ldots n_i,\ldots N\}$

NF number of subchannels, $\{1,\ldots f_{k},\ldots NF\}$

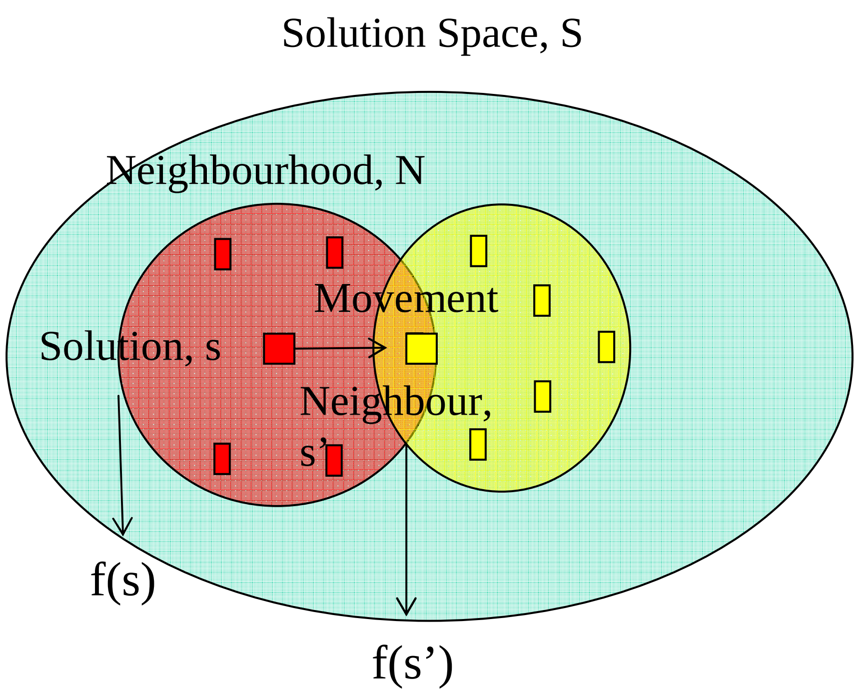
D_i requested subchannels by the i - sector

$W_{i,j}$ interference restriction between the i - sector and the j - sector

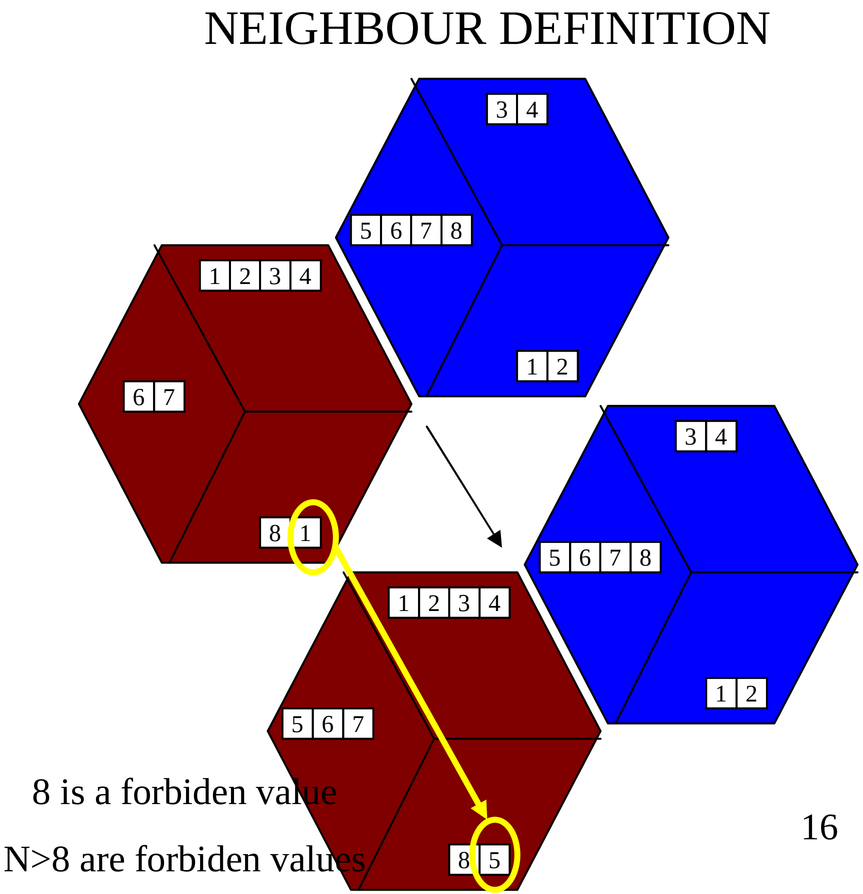
$$y_{i,j,k} \begin{cases} 1, & \text{the i - th and j - th sector are using the k - frequency} \\ 0, & \text{otherwise} \end{cases}$$

DFP – Solving Algorithms

- Meta-heuristics



best neighbour = min f(s')



DFP – Solving Algorithms (I)

- Simulated Annealing

```
s := s0; e := f(s)                      // Random Solution
sb := s; eb := e                        // Best Solution
T := high value                         // Temperature
k := 0                                  // Iterations
while T > Tmin and e > emax             // While T > T_threshold or not good enough:
    sn := neighbour(s)                  // Random neighbour
    en := f(sn)                         // Compute its energy
    if en < eb then                     // Is this a new best?
        sb := sn; eb := en              // Yes, save it.
    elseif P(e, en, temp) > rnd() then  // Should we move to it?
        s := sn; e := en                // Yes, change state.
    k := k + 1                          // Increase iterations
 T *= annealing factor                  // Update temperature
return sb                               // Return the best solution found.
```

DFP – Solving Algorithms (II)

- Tabu Search

```
s := s0; e := f(s)                   // Random Solution
sb := s; eb := e                     // Best Solution
T := 0 ; k := 0                      // Tabu List  & Iterations
while k < kmax and e > emax          // While time remains and not good enough:
    k := k + 1                                  // Increase iterations
    for (neighbourhood(s))
        sn := neighbour(s) ; en := f(sn) // Neighbour & Compute its energy
    [sbn, ebn] := select_best_neighbourh
    if ebn < eb then                   // Is this a new best?
        sb := sn; eb := en                          // Yes, save it.
    elseif ebn < e then                         // Is the best neighbour better that the current?
        s := sbn; e := ebn                          // Yes, we move to it
    else                                        // Otherwise
        s :=random(s); e := f(s)              // No, we select a random neighbour
 Update tabu list                    // Update tabu list
return sb                            // Return the best solution found
```

DFP – Solving Algorithms (III)

- Greedy Algorithms

  Operation = Insertion: We start with empty assignments. At each iteration, we first compute the frequency which increases the cost function the least for all sectors.

  Then:
  - Random Insertion (RI): Select a random sector
  - Minimum Insertion (MinI): Select the sector increasing the cost function the least.
  - Maximum Insertion (MaxI): Select the sector increasing the cost function the most.

DFP – Solving Algorithms (IV)

- Reverse Greedy Algorithms

  Operation = Remove: We start with full assignments. At each iteration, we first compute the frequency which decreases the cost function the most for all sectors.

  Then:

  - Random Insertion (RR): Select a random sector
  - Minimum Insertion (MaxR): Select the sector decreasing the cost function the most.
  - Maximum Insertion (MinR): Select the sector decreasing the cost function the least.

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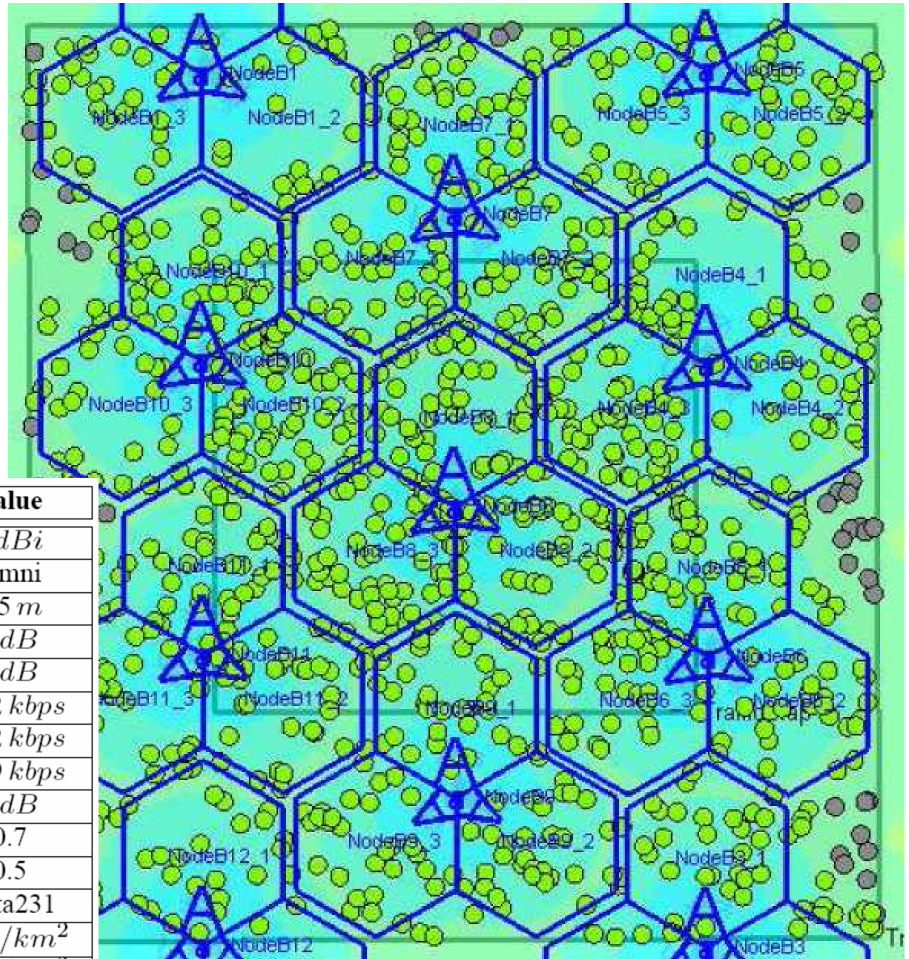
Results - Scenario

Overlapping Sectors

Heavy Interference

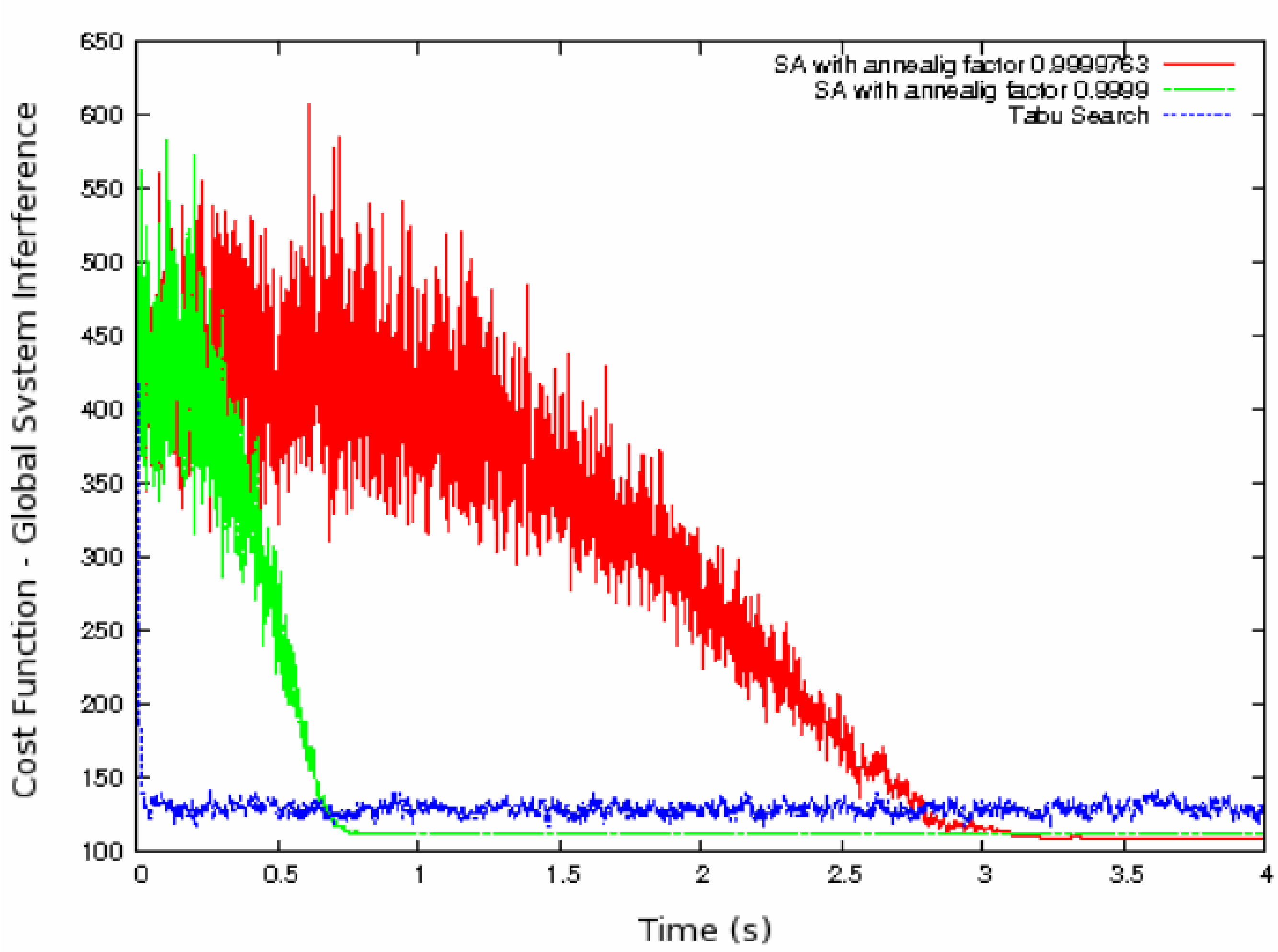
(DL case)



Parameter	Value	Parameter	Value
Sites	11	CPE Ant. Gain	$0\,dBi$
Sector/site	3	CPE Ant. Pattern	Omni
Carrier Frequency	$3.5\,GHz$	CPE Ant. Height	$1.5\,m$
Channel Bandwidth	$10\,MHz$	CPE Noise Figure	$5\,dB$
DL:UL Ratio	1:1	CPE Cable Loss	$0\,dB$
Permutation Scheme	AMC	Min Service TP	$12.2\,kbps$
Frame Duration	$5\,ms$	Max Service TP	$42.2\,kbps$
Sub-channels	16	Average Symbol Eff.	$19.9\,kbps$
DL symbols	19	σ(Shadow Fading)	$8\,dB$
BS TX Power	$43\,dBm$	Intra BS correlation	0.7
BS Ant. Gain	$18\,dBi$	Inter BS correlation	0.5
BS Ant. Beam Width	120	Path Loss Model	Hata231
BS Ant. Height	$30\,m$	Traffic Map Density	$40\,u/km^2$
BS Ant. Tilt	3	Hot spot Density	$80\,u/km^2$
BS Noise Figure	$4\,dB$	Admission	BP[1]
BS Cable Loss	$3\,dB$	Resource Allocation	CA[2]
CPE Tx Power	$23\,dBm$	Snapshots	20

[1]Best Path loss, [2]Contiguous Allocation

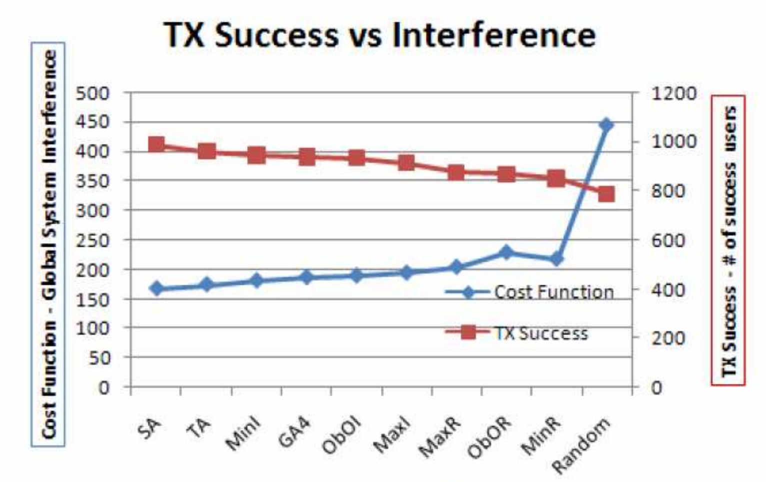
Results – SA Vs TS

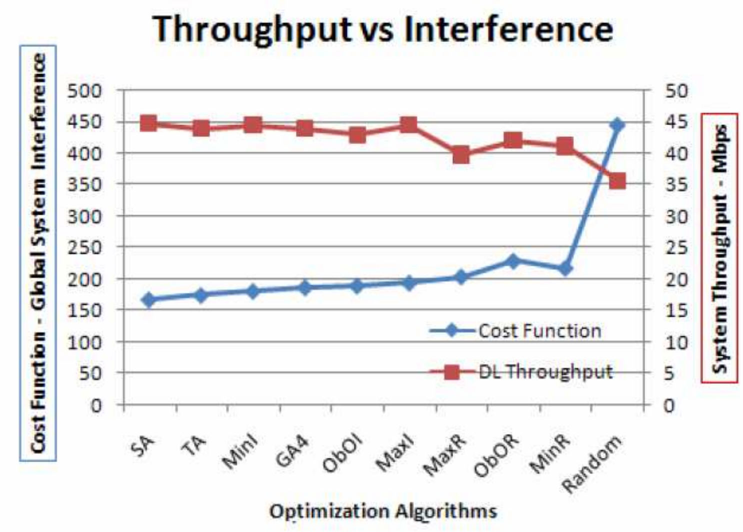


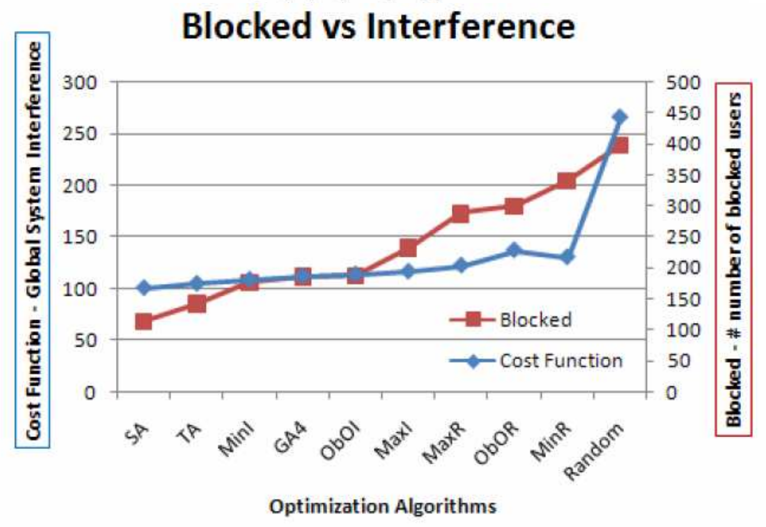
Results – Heuristics Vs Greedy Algorithm

Scenario	1^{st}			2^{nd}			3^{rd}		
$users/km^2$	**20/40**	**30/60**	**40/80**	**20/40**	**30/60**	**40/80**	**20/40**	**30/60**	**40/80**
random	397.6	374.3	353.6	1086.2	941.6	991.2	435.1	435.1	444.0
SA	56.2	**180.7**	**222.3**	**151.7**	**292.2**	**500.4**	**1.0**	**52.5**	**108.1**
TS	**55.2**	181.8	224.3	182.4	317.3	516.8	**1.0**	53.3	115.7
SI	79.5	197.7	246.2	283.4	**331.9**	**547.3**	40.9	111.5	137.5
RI	86.1	192.1	236.9	274.3	377.8	569.7	33.2	88.4	134.1
MinI	98.8	**188.4**	230.2	**222.9**	392.9	587.9	27.6	84.5	137.7
MaxI	**60.8**	199.1	249.1	231.7	343.5	579.9	**25.8**	**79.2**	151.2
RR	116.5	203.7	243.7	346.9	439.2	599.8	71.0	97.9	174.4
MaxR	80.0	215.9	**230.1**	337.1	365.1	570.4	121.2	274.6	224.4
MinR	113.4	224.4	247.3	2928.4	395.8	571.4	4192.0	105.4	**127.6**
Best MH	55.2	180.7	222.3	151.7	292.2	500.4	1.0	52.5	108.1
Improv(%)	**86.1**	**51.7**	**93.7**	**86.0**	**69.0**	**49.5**	**99.8**	**87.9**	**75.7**
Best GA	60.8	188.4	230.1	222.9	331.9	547.3	25.8	79.2	127.6
Improv(%)	**84.7**	**49.7**	**34.9**	**79.5**	**64.8**	**44.8**	**94.1**	**81.8**	**71.3**
GAvsBest(%)	**-1.4**	**-2.0**	**-2.2**	**-6.6**	**-4.2**	**-4.7**	**-5.7**	**-6.3**	**-4.4**

Results – Simulation







# of success users and throughput increases when interference decreases.

# of blocked users on the other hand decreases

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Conclusions

- This work has introduced a novel approach to the frequency assignment problem tailored to OFDMA networks.
- DFP proposed a new model for capacity and inter-cell interference estimation in OFDMA networks.
- Adapted SA, TS and greedy algorithms have been used to solve the optimization problem.
- Greedy algorithm have been demonstrated very useful since they run very fast and they produce slightly worse solutions than meta-heuristics (by around 6%).
- DFP significantly reduces inter-cell interference (by around 70%) and increases system capacity (by around 20%)

Thank You

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