MINISTERIO DE EDUCACIÓN Y CIENCIA

Málaga, 1 de Marzo de 2006

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Manets

AFP

RND

OPLINK
Optimización y Ambientes de Red

COLECCIÓN DE PROBLEMAS PROPUESTOS PARA EL PROYECTO

Proyecto Coordinado

TIN2005-08818-C04

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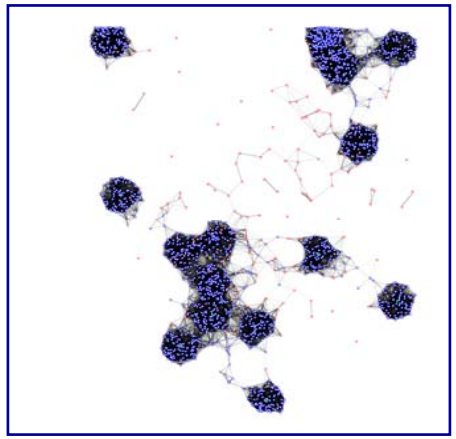
Case Study: MANETs

Mobile Ad-hoc Networks (MANETs)

- Mobile stations interconnected without pre-existing infrastructure
- Metropolitan MANETs: subclass of MANETs
- Broadcasting on MANETs
  - Operation of capital importance for the network
  - Optimization of a broadcasting strategy can be formulated as a multiobjective problem:
    - Reach as many stations as possible, and
    - Minimize the network utilization, and
    - Reduce the broadcasting time (makespan).
  - Our proposal: tuning the broadcasting service for a particular network and a particular class of application



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Case Study: MANETs

MANETs

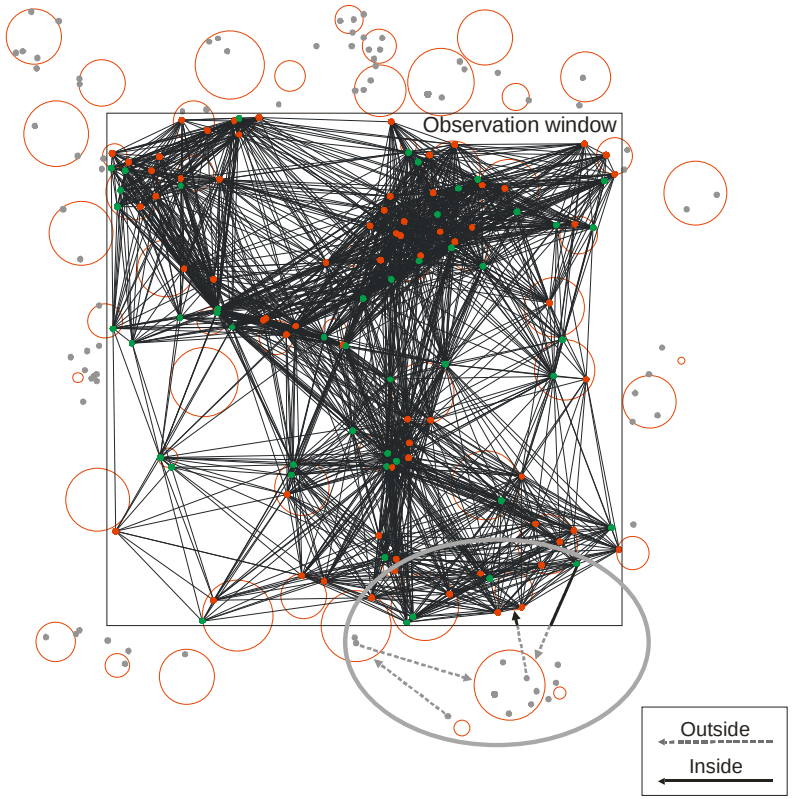
- Stations usually are laptops, handholds, PDAs, or mobile phones
- Mobility of stations → dynamic topology of the network

Metropolitan MANETs

- High Density Areas (HDA): areas with high station density
- HDAs can appear and disappear from the network

Madhoc Simulator

- *Network size*: size of the simulation area
- *Node density*: number of devices
- *Environment*: mobility and wave propagation models



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Case Study: MANETs

Random Assessment Delay

- [*lowerBoundRAD, upperBoundRAD*] defines the range for RAD values
- *lowerBoundRAD, upperBoundRAD* $\in$ *[0.0 ms, 10.0 ms]*

minGain

- Ratio between the number of neighbors which do not have received the message and the total number of neighbors
- *minGain* $\in$ *[0.0, 1.0]*

Set of parameters to optimize

safeDensity

- Minimum number of devices for which DFCN always rebroadcasts
- *safeDensity* $\in$ *[0 devices, 100 devices]*

proD

- Maximal density for which the proactive behavior is still needed
- *proD* $\in$ *[0 devices, 100 devices]*

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Case Study: MANETs

Optimization Problem

- Fine-tune of a broadcasting strategy called DFCN (Delayed Flooding with Cumulative Neighborhood)
- Target: metropolitan MANETs

MOP1: DFCNT (unconstrained)

- Objectives:
  - Reach as many stations as possible
  - Minimize the network utilization
  - Reduce the makespan
- Constraints: none

MOP2: cDFCNT (constrained)

- Objectives:
  - Minimize the network utilization
  - Reduce the makespan
- Constraints:
  - 90% stations covered

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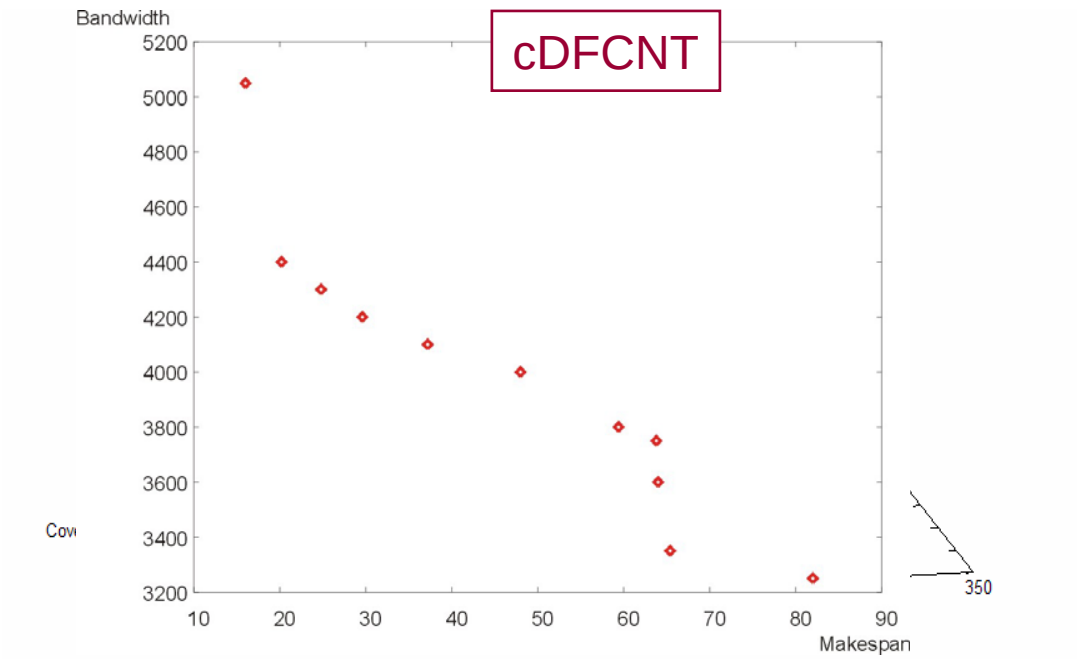
Case Study: MANETs

Multi-Objective Optimization Illustration (MO)

- Not restricted to find a unique solution, but a set of non-dominated solutions known as the Pareto optimal set
- Non-dominated solutions:
  - Best solution concerning the network utilization
  - Best one concerning the makespan
  - Best one in terms of coverage (only DFCNT)
- Pareto fronts



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Using Madhoc

Main parameters for Madhoc

- **network_environment: Kind of network to use**
  - **org.lucci.madhoc.network.env.mall.OpenAreaEnvironment**

Parameters:

simulation_area_surface
Size of the simulation area

network_phone_density
Density of phones in the simulation area (devices/km^2)

random_waypoint_mobility_velocity_interval
Devices move in random speeds in the given interval (meters/second)

random_waypoint_mobility_pause_interval
Devices stop at arbitrary places a random number of seconds into the given interval

Features:

Theoretical problem
No HDAs
No paths
No walls

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Using Madhoc

Main parameters for Madhoc

- **network_environment: Kind of network to use**
  - **org.lucci.madhoc.network.env.mall.HumanEnvironment**

Parameters:

simulation_area_surface
Size of the simulation are

network_phone_density
Density of phones in the simulation area (devices/km^2)

human_environment_spot_density
Density of HDAs in the simulation area (HDAs/km^2)

human_environment_spot_radius
Radius (in meters) of the HDAs (HDAs are circles)

human_environment_wall_obstruction
Obstruction of walls in the signal strength (between 0.0 and 1.0)

human_mobility_out_spot_speed
Speed of devices out of HDAs randomly choosen from an interval

human_mobility_in_spot_speed
Speed of devices inside HDAs randomly choosen from an interval

Features:

Realistic
Existence of HDAs (shops, crossroads, ...)
Existence of paths between HDAs
Allow existence of walls, floors in buildings, ...

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Using Madhoc

Main parameters for Madhoc

- broadcasting_protocol_class: The protocol to use is DFCN
  - org.lucci.madhoc.broadcast.impl.research.dfcn.DFCN
- network_technologies_available: Network technologies of devices
  - Available technologies: wifi, bluetooth, wusb
  - Devices have these technologies with given probabilities
- broadcasting_termination_condition:
  - Termination condition of DFCN
  - org.lucci.madhoc.broadcasting.malaga.TerminationConditionMalagena
    - 100% coverage
    - 1.5 seconds of the simulation with no variations in the coverage
- window_projection_radius_ratio:
  - Size of the projection window (percentage of the whole simulation area)
  - Between 0.0 and 1.0

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Using Madhoc

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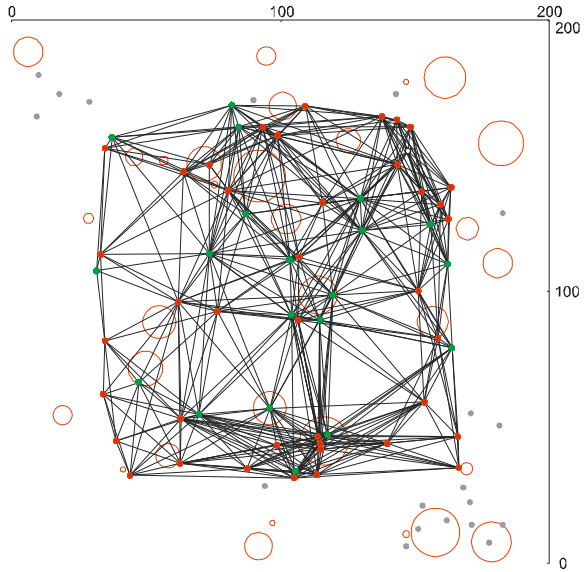
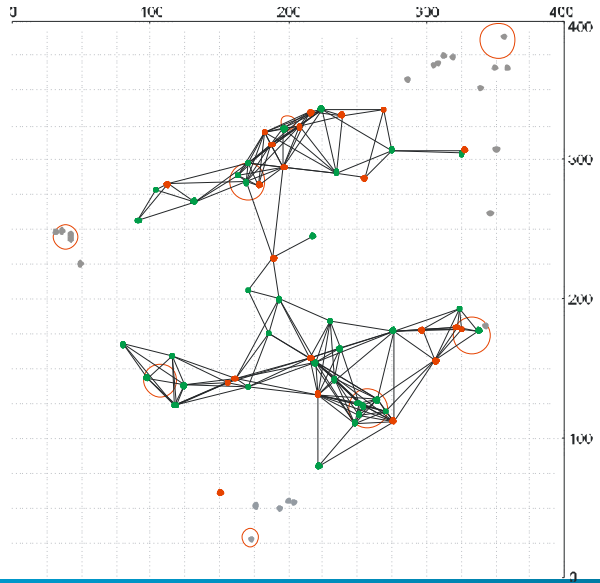
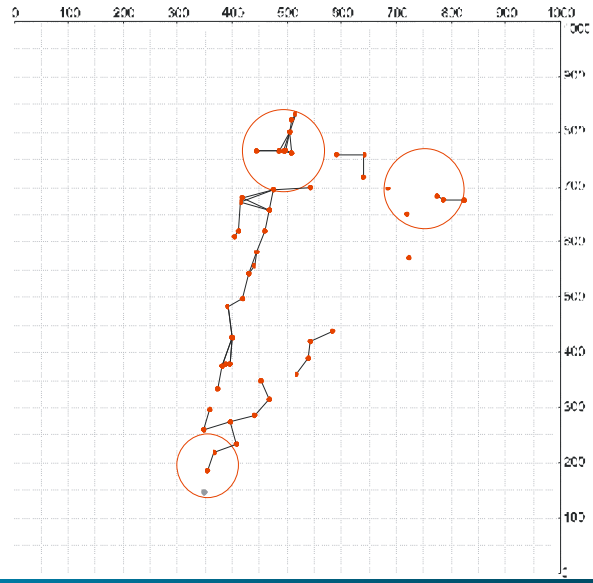
Mall



Metropolitan Area



Highway



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Using Madhoc

Using Madhoc with JAVA

Import the required classes from Madhoc

```
import org.lucci.madhoc.config.*;
import org.lucci.madhoc.config.ConfigurationKeys;
…
public static void main (String args[]){
   ConfigurationKeys confKeys = new ConfigurationKeys();
   confKeys.network_phone_density = "50";
   confKeys.random_waypoint_mobility_pause_interval = "0, 10";
   …
   TypedConfiguration config = new TypedConfiguration();
   config.load(confKeys); // Load the configuration

   MadhocSimulation simulation =
         Utilities.getSimulation(config);
   // iterate until all applications terminate
   while (!simulation.findExecutingApplications().isEmpty())
   {
         // make an iteration of the simulator
         simulation.iterate();
   }
   …
```

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Using Madhoc

Using Madhoc with JAVA

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```
import org.lucci.madhoc.config.*;
import org.lucci.madhoc.config.ConfigurationKeys;
…
public static void main (String args[]){
   ConfigurationKeys confKeys = new ConfigurationKeys();
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   // iterate until all applications terminate
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   {
         // make an iteration of the simulator
         simulation.iterate();
   }
   …
```

Set configuration parameters in ConfigurationKeys

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Using Madhoc

Using Madhoc with JAVA

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```
import org.lucci.madhoc.config.*;
import org.lucci.madhoc.config.ConfigurationKeys;
…
public static void main (String args[]){
   ConfigurationKeys confKeys = new ConfigurationKeys();
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   // iterate until all applications terminate
   while (!simulation.findExecutingApplications().isEmpty())
   {
        // make an iteration of the simul
        simulation.iterate();
   }
   …
```

Load the parameterization

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Using Madhoc

Using Madhoc with JAVA


```
import org.lucci.madhoc.config.*;
import org.lucci.madhoc.config.ConfigurationKeys;
…
public static void main (String args[]){
   ConfigurationKeys confKeys = new ConfigurationKeys();
   confKeys.network_phone_density = "50";
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   TypedConfiguration config = new TypedConfiguration();
   config.load(confKeys); // Load the configuration

   MadhocSimulation simulation =
         Utilities.getSimulation(config);
   // iterate until all applications terminate
   while (!simulation.findExecutingApplications().isEmpty())
   {
         // make an iteration of the simulator
         simulation.iterate();
   }
   …
```

Iterate the simulator

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Using Madhoc

Using Madhoc with JAVA


```
Network network = simulation.getNetwork();
Projection projection = (Projection)
   network.getProjectionMap().get(SquareWindowProjection.class);


MeasureHistory history = (MeasureHistory)
   projection.getMeasureMap().get(AverageNumberOfEmissionMeasure.class);
emissions = ((Double) history.getLastValue()).doubleValue();
fitness[0] = emissions;

history = (MeasureHistory)
   projection.getMeasureMap().get(AverageCoverageM
coverage = ((Double) history.getLastValue()).doubl
fitness[1] = coverage;

time = simulation.getSimulatedTime();
fitness[2] = time;

}
```

Get the measures of the simulator

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Using Madhoc

Using Madhoc with JAVA


```
  Network network = simulation.getNetwork();
  Projection projection = (Projection)
     network.getProjectionMap().get(SquareWindowProjection.class);


  MeasureHistory history = (MeasureHistory)
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  history = (MeasureHistory)
     projection.getMeasureMap().get(AverageCoverageMeasure.class);
  coverage = ((Double) history.getLastValue()).doubleValue();
  fitness[1] = coverage;

  time = simulation.getSimulatedTime();
  fitness[2] = time;

}
```

Get the bandwith used (number of packet emissions)

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Using Madhoc

Using Madhoc with JAVA


```
  Network network = simulation.getNetwork();
  Projection projection = (Projection)
     network.getProjectionMap().get(SquareWindowProjection.class);


  MeasureHistory history = (MeasureHistory)
     projection.getMeasureMap().get(AverageNumberOfEmissionMeasure.class);
  emissions = ((Double) history.getLastValue()).doubleValue();
  fitness[0] = emissions;

  history = (MeasureHistory)
     projection.getMeasureMap().get(AverageCoverageMeasure.class);
  coverage = ((Double) history.getLastValue()).doubleValue();
  fitness[1] = coverage;

  time = simulation.getSimulatedTime();
  fitness[2] = time;

}
```

Get the coverage

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Using Madhoc

Using Madhoc with JAVA


```
  Network network = simulation.getNetwork();
  Projection projection = (Projection)
     network.getProjectionMap().get(SquareWindowProjection.class);


  MeasureHistory history = (MeasureHistory)
     projection.getMeasureMap().get(AverageNumberOfEmissionMeasure.class);
  emissions = ((Double) history.getLastValue()).doubleValue();
  fitness[0] = emissions;

  history = (MeasureHistory)
     projection.getMeasureMap().get(AverageCoverageMeasure.class);
  coverage = ((Double) history.getLastValue()).doubleValue();
  fitness[1] = coverage;

  time = simulation.getSimulatedTime();
  fitness[2] = time;

}
```

Get the simulation time

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Using Madhoc

Using Madhoc with C++

- The fitness function is a call to ExecSimulator.
- ExecSimulator: Java program for executing madhoc. Arguments:
  - **ProD**
  - **Minimum Gain**
  - **Maximum allowed value for Safe Density**
  - **lowerBoundRAD**
  - **upperBoundRAD**
- Optimizer: System call to ExecSimulator

```
sprintf(key,
    "java ExecSimulator %d %lf %d %lf %lf > output.dat",
    (int) proD,
     minGain,
    (int) safeDensity,
    radUpperBound,
    radLowerBound);
system(key);
```

The output of the fitness function

- Output of ExecSimulator:
  - **Bandwidth, Coverage, and Broadcasting Time**

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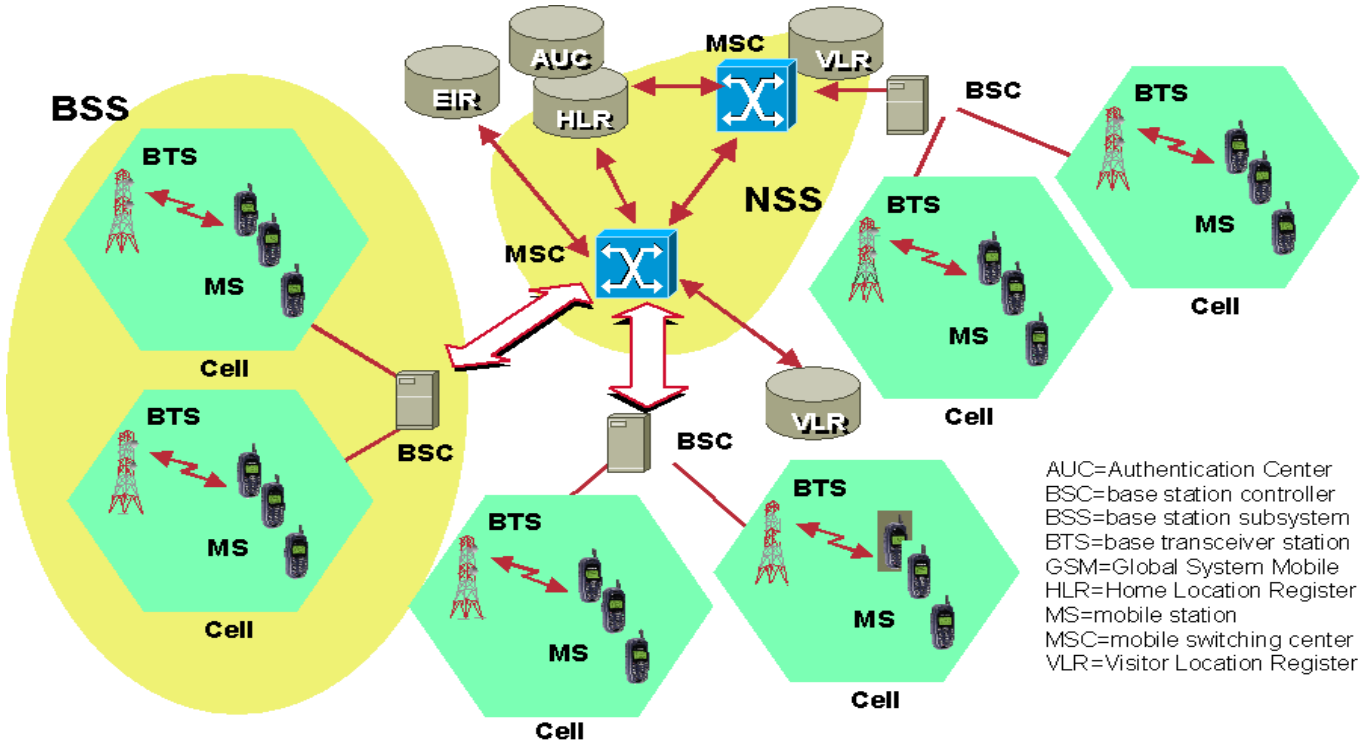
Automatic Frequency Planning

GSM (General System for Mobile Communication)

- Standard for mobile communications
- Composed of 3 subsystems
  - Base Station Subsystem (BSS)
  - Network and Switching Subsystem (NSS)
  - Operation and maintenance SubSystem (OSS)



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Automatic Frequency Planning

Assigning frequencies to channels

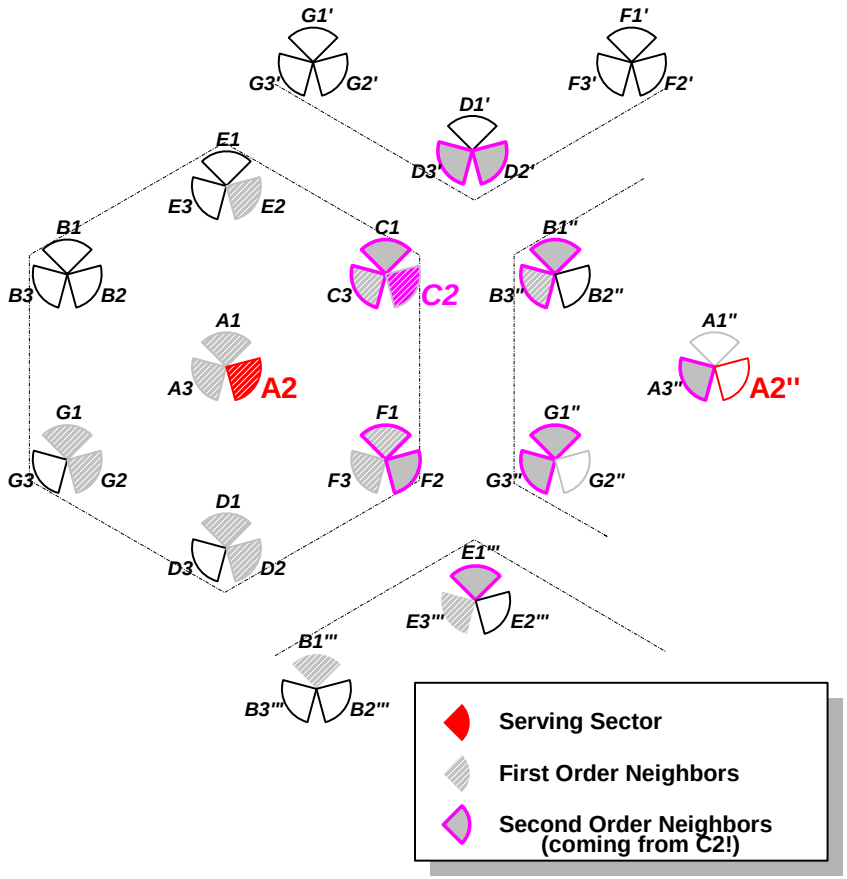
- TRXs (transceivers)
  - Two main types: BCCH (Broadcast Control CHannel) and TCH (Trafic CHannel)
  - Valid frequencies
- Sectors
  - Set of TRXs
- Sites
  - Set of sectors

Interferences

- Co-channel
- Adjacent Channel
- Interference Matrix (IM)
  - Victim – Interferer
  - Gaussian distribution

Constraints

- Channel separation
  - Sector
  - Site



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AFP Files

Instance.trx.txt

```
TRX ID, Type, Sector, Site, Number of Valid Frequencies, Frequencies
0 BCCH 0 1 18 134 135 136 137 138 139 ... 145 146 147 148 149 150 151
1 TCH  0 1 18 134 135 136 137 138 139 ... 145 146 147 148 149 150 151
2 TCH  0 1 18 134 135 136 137 138 139 ... 145 146 147 148 149 150 151
...
```

Transceiver unique identifier

Instance.sector.txt

```
Sector ID, Channel separation constraint, Number of TRXs, List of TRX IDs
0 3 4 0 1 2 3
1 3 4 4 5 6 7
2 3 4 8 9 10 11
...
```

Instance.site.txt

```
Site ID, Channel separation constraint, Number of Sectors, List of Sectors
1 2 3 0 1 2
2 2 3 3 4 5
3 2 2 6 7
...
```

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AFP Files

Instance.trx.txt

```
TRX ID, Type, Sector, Site, Number of Valid Frequencies, Frequencies
0 BCCH 0 1 18 134 135 136 137 138 139 ... 145 146 147 148 149 150 151
1 TCH  0 1 18 134 135 136 137 138 139 ... 145 146 147 148 149 150 151
2 TCH  0 1 18 134 135 136 137 138 139 ... 145 146 147 148 149 150 151
...
```

Trasceiver type: BCCH / TCH

Instance.sector.txt

```
Sector ID, Channel separation constraint, Number of TRXs, List of TRX IDs
0 3 4 0 1 2 3
1 3 4 4 5 6 7
2 3 4 8 9 10 11
...
```

Instance.site.txt

```
Site ID, Channel separation constraint, Number of Sectors, List of Sectors
1 2 3 0 1 2
2 2 3 3 4 5
3 2 2 6 7
...
```

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AFP Files

Instance.trx.txt

```
TRX ID, Type, Sector, Site, Number of Valid Frequencies, Frequencies
0 BCCH 0 1 18 134 135 136 137 138 139 ... 145 146 147 148 149 150 151
1 TCH  0 1 18 134 135 136 137 138 139 ... 145 146 147 148 149 150 151
2 TCH  0 1 18 134 135 136 137 138 139 ... 145 146 147 148 149 150 151
...
```

Sector and site IDs where it's located

Instance.sector.txt

```
Sector ID, Channel separation constraint, Number of TRXs, List of TRX IDs
0 3 4 0 1 2 3
1 3 4 4 5 6 7
2 3 4 8 9 10 11
...
```

Instance.site.txt

```
Site ID, Channel separation constraint, Number of Sectors, List of Sectors
1 2 3 0 1 2
2 2 3 3 4 5
3 2 2 6 7
...
```

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AFP Files

Instance.trx.txt

```
TRX ID, Type, Sector, Site, Number of Valid Frequencies, Frequencies
0 BCCH 0 1 18 134 135 136 137 138 139 ... 145 146 147 148 149 150 151
1 TCH  0 1 18 134 135 136 137 138 139 ... 145 146 147 148 149 150 151
2 TCH  0 1 18 134 135 136 137 138 139 ... 145 146 147 148 149 150 151
...
```

Valid frequencies of the TRX

Instance.sector.txt

```
Sector ID, Channel separation constraint, Number of TRXs, List of TRX IDs
0 3 4 0 1 2 3
1 3 4 4 5 6 7
2 3 4 8 9 10 11
...
```

Instance.site.txt

```
Site ID, Channel separation constraint, Number of Sectors, List of Sectors
1 2 3 0 1 2
2 2 3 3 4 5
3 2 2 6 7
...
```

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AFP Files

Instance.trx.txt

```
TRX ID, Type, Sector, Site, Number of Valid Frequencies, Frequencies
0 BCCH 0 1 18 134 135 136 137 138 139 ... 145 146 147 148 149 150 151
1 TCH  0 1 18 134 135 136 137 138 139 ... 145 146 147 148 149 150 151
2 TCH  0 1 18 134 135 136 137 138 139 ... 145 146 147 148 149 150 151
...
```

Instance.sector.txt

```
Sector ID, Channel separation constraint, Number of TRXs, List of TRX IDs
0 3 4 0 1 2 3
1 3 4 4 5 6 7
2 3 4 8 9 10 11
...
```

Sector unique identifier

Instance.site.txt

```
Site ID, Channel separation constraint, Number of Sectors, List of Sectors
1 2 3 0 1 2
2 2 3 3 4 5
3 2 2 6 7
...
```

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AFP Files

Instance.trx.txt

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TRX ID, Type, Sector, Site, Number of Valid Frequencies, Frequencies
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```

Instance.sector.txt

```
Sector ID, Channel separation constraint, Number of TRXs, List of TRX IDs
0 3 4 0 1 2 3
1 3 4 4 5 6 7
2 3 4 8 9 10 11
...
```

Constraint separation at sector level

Instance.site.txt

```
Site ID, Channel separation constraint, Number of Sectors, List of Sectors
1 2 3 0 1 2
2 2 3 3 4 5
3 2 2 6 7
...
```

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AFP Files

Instance.trx.txt

```
TRX ID, Type, Sector, Site, Number of Valid Frequencies, Frequencies
0 BCCH 0 1 18 134 135 136 137 138 139 ... 145 146 147 148 149 150 151
1 TCH  0 1 18 134 135 136 137 138 139 ... 145 146 147 148 149 150 151
2 TCH  0 1 18 134 135 136 137 138 139 ... 145 146 147 148 149 150 151
...
```

Instance.sector.txt

```
Sector ID, Channel separation constraint, Number of TRXs, List of TRX IDs
0 3 4 0 1 2 3
1 3 4 4 5 6 7
2 3 4 8 9 10 11
...
```

TRX IDs within the sector

Instance.site.txt

```
Site ID, Channel separation constraint, Number of Sectors, List of Sectors
1 2 3 0 1 2
2 2 3 3 4 5
3 2 2 6 7
...
```

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AFP Files

Instance.trx.txt

```
TRX ID, Type, Sector, Site, Number of Valid Frequencies, Frequencies
0 BCCH 0 1 18 134 135 136 137 138 139 ... 145 146 147 148 149 150 151
1 TCH  0 1 18 134 135 136 137 138 139 ... 145 146 147 148 149 150 151
2 TCH  0 1 18 134 135 136 137 138 139 ... 145 146 147 148 149 150 151
...
```

Instance.sector.txt

```
Sector ID, Channel separation constraint, Number of TRXs, List of TRX IDs
0 3 4 0 1 2 3
1 3 4 4 5 6 7
2 3 4 8 9 10 11
...
```

Instance.site.txt

```
Site ID, Channel separation constraint, Number of Sectors, List of Sectors
1 2 3 0 1 2
2 2 3 3 4 5
3 2 2 6 7
...
```

Site unique identifier

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AFP Files

Instance.trx.txt

```
TRX ID, Type, Sector, Site, Number of Valid Frequencies, Frequencies
0 BCCH 0 1 18 134 135 136 137 138 139 ... 145 146 147 148 149 150 151
1 TCH  0 1 18 134 135 136 137 138 139 ... 145 146 147 148 149 150 151
2 TCH  0 1 18 134 135 136 137 138 139 ... 145 146 147 148 149 150 151
...
```

Instance.sector.txt

```
Sector ID, Channel separation constraint, Number of TRXs, List of TRX IDs
0 3 4 0 1 2 3
1 3 4 4 5 6 7
2 3 4 8 9 10 11
...
```

Instance.site.txt

```
Site ID, Channel separation constraint, Number of Sectors, List of Sectors
1 2 3 0 1 2
2 2 3 3 4 5
3 2 2 6 7
...
```

Constraint separation at site level

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AFP Files

Instance.trx.txt

```
TRX ID, Type, Sector, Site, Number of Valid Frequencies, Frequencies
0 BCCH 0 1 18 134 135 136 137 138 139 ... 145 146 147 148 149 150 151
1 TCH  0 1 18 134 135 136 137 138 139 ... 145 146 147 148 149 150 151
2 TCH  0 1 18 134 135 136 137 138 139 ... 145 146 147 148 149 150 151
...
```

Instance.sector.txt

```
Sector ID, Channel separation constraint, Number of TRXs, List of TRX IDs
0 3 4 0 1 2 3
1 3 4 4 5 6 7
2 3 4 8 9 10 11
...
```

Instance.site.txt

```
Site ID, Channel separation constraint, Number of Sectors, List of Sectors
1 2 3 0 1 2
2 2 3 3 4 5
3 2 2 6 7
...
```

Sector IDs installed in the site

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AFP Files

Instance.IM.txt

```
Victim Sector, Interf. Sector, Mean, Std
0 1 30.5 14.64
0 2 27.54 15
...
1 0 40 8.
1 2 18.9
...
```

Victim sectors

Instance.opt.txt

```
Key, Value
Sector_Co_Ch_TCH          100000.000000
Sector_Co_Ch_BCCH         100000.000000
Sector_Adj_Ch_TCH         100000.000000
Sector_Adj_Ch_BCCH        100000.000000
Sector_Ch_Sep            1000000.000000
Site_Co_Ch_BCCH_BCCH     1000000.000000
Site_Co_Ch_BCCH_TCH       100000.000000
Site_Co_Ch_TCH_TCH         10000.000000
Site_Adj_Ch_BCCH_BCCH      10000.000000
Site_Adj_Ch_BCCH_TCH          10.000000
Site_Adj_Ch_TCH_TCH            1.000000
Site_Ch_Sep              1000000.000000
...
```

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AFP Files

Instance.IM.txt

```
Victim Sector, Interf. Sector, Mean, Std
0 1 30.5 14.64
0 2 27.54 15
...
1 0 40.83
1 2 18.93
...
```

Interfering sectors

Instance.opt.txt

```
Key, Value
Sector_Co_Ch_TCH          100000.000000
Sector_Co_Ch_BCCH         100000.000000
Sector_Adj_Ch_TCH         100000.000000
Sector_Adj_Ch_BCCH        100000.000000
Sector_Ch_Sep            1000000.000000
Site_Co_Ch_BCCH_BCCH     1000000.000000
Site_Co_Ch_BCCH_TCH       100000.000000
Site_Co_Ch_TCH_TCH         10000.000000
Site_Adj_Ch_BCCH_BCCH      10000.000000
Site_Adj_Ch_BCCH_TCH          10.000000
Site_Adj_Ch_TCH_TCH            1.000000
Site_Ch_Sep              1000000.000000
...
```

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AFP Files

Instance.IM.txt

```
Victim Sector, Interf. Sector, Mean, Std
0 1 30.5 14.64
0 2 27.54 15
...
1 0 40.83 15
1 2 18.93 11
...
```

Means and standard deviations of the probability distribution of potential interference from "interfering sector" in the service area of the "victim sector"

Instance.opt.tx

```
Key, Value
Sector_Co_Ch_TCH          100000.000000
Sector_Co_Ch_BCCH         100000.000000
Sector_Adj_Ch_TCH         100000.000000
Sector_Adj_Ch_BCCH        100000.000000
Sector_Ch_Sep            1000000.000000
Site_Co_Ch_BCCH_BCCH     1000000.000000
Site_Co_Ch_BCCH_TCH       100000.000000
Site_Co_Ch_TCH_TCH         10000.000000
Site_Adj_Ch_BCCH_BCCH      10000.000000
Site_Adj_Ch_BCCH_TCH          10.000000
Site_Adj_Ch_TCH_TCH            1.000000
Site_Ch_Sep              1000000.000000
...
```

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AFP Files

Instance.IM.txt

```
Victim Sector, Interf. Sector, Mean, Std
0 1 30.5 14.64
0 2 27.54 15
...
1 0 40.83 15
1 2 18.93 11
...
```

Instance.opt.txt

```
Key, Value
Sector_Co_Ch_TCH          100000.000000
Sector_Co_Ch_BCCH         100000.000000
Sector_Adj_Ch_TCH         100000.000000
Sector_Adj_Ch_BCCH        100000.000000
Sector_Ch_Sep            1000000.000000
Site_Co_Ch_BCCH_BCCH     1000000.000000
Site_Co_Ch_BCCH_TCH       100000.000000
Site_Co_Ch_TCH_TCH         10000.000000
Site_Adj_Ch_BCCH_BCCH      10000.000000
Site_Adj_Ch_BCCH_TCH          10.000000
Site_Adj_Ch_TCH_TCH            1.000000
Site_Ch_Sep              1000000.000000
...
```

User defined options and their values

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AFP Files

Instance.1-hop.neighbors.txt

```
Sector ID, Number of Neighbors Sectors, List of IDs
0 6 318 332 300 295 1 2
1 3 300 2 0
2 7 332 298 284 19 11 1 0
...
```

Sector ID

Instance.2-hop.neighbors.txt

```
Sector ID, Number of Sector Neighbors, List of Neighbors
0 40 1 2 10 11 12 19 54 55 56 119 120 135 136 137 138 282 ... 333 428 598
1 15 0 2 11 19 54 55 56 284 295 298 300 301 302 318 332
2 36 0 1 10 11 12 17 18 54 55 56 135 136 137 138 284 285 ... 425 428 598
...
```

AFP Files

Instance.1-hop.neighbors.txt

```
Sector ID, Number of Neighbors Sectors, List of IDs
0 6 318 332 300 295 1 2
1 3 300 2 0
2 7 332 298 284 19 11 1 0
...
```

Set of neighboring sectors

Instance.2-hop.neighbors.txt

```
Sector ID, Number of Sector Neighbors, List of Neighbors
0 40 1 2 10 11 12 19 54 55 56 119 120 135 136 137 138 282 ... 333 428 598
1 15 0 2 11 19 54 55 56 284 295 298 300 301 302 318 332
2 36 0 1 10 11 12 17 18 54 55 56 135 136 137 138 284 285 ... 425 428 598
...
```

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AFP Files

Instance.1-hop.neighbors.txt

```
Sector ID, Number of Neighbors Sectors, List of IDs
0 6 318 332 300 295 1 2
1 3 300 2 0
2 7 332 298 284 19 11 1 0
...
```

Instance.2-hop.neighbors.txt

```
Sector ID, Number of Sector Neighbors, List of Neighbors
0 40 1 2 10 11 12 19 54 55 56 119 120 135 136 137 138 282 ... 333 428 598
1 15 0 2 11 19 54 55 56 284 295 298 300 301 302 318 332
2 36 0 1 10 11 12 17 18 54 55 56 135 136 137 138 284 285 ... 425 428 598
...
```

Sector ID

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AFP Files

Instance.1-hop.neighbors.txt

```
Sector ID, Number of Neighbors Sectors, List of IDs
0 6 318 332 300 295 1 2
1 3 300 2 0
2 7 332 298 284 19 11 1 0
...
```

Instance.2-hop.neighbors.txt

```
Sector ID, Number of Sector Neighbors, List of Neighbors
0 40 1 2 10 11 12 19 54 55 56 119 120 135 136 137 138 282 ... 333 428 598
1 15 0 2 11 19 54 55 56 284 295 298 300 301 302 318 332
2 36 0 1 10 11 12 17 18 54 55 56 135 136 137 138 284 285 ... 425 428 598
...
```

Its set of second neighbors

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AFP Fitness Functions

First approach

- Given the interference matrix and a frequency planning which assigns a frequency to each channel, the first fitness function measures the signal quality in the network based on
  - Co-channel interference: undesirable signal energy attributed to the reuse of that frequency
  - Adjacent channel interference: undesirable signal energy attributed to "bleed over" from frequency components near the channel of interest
    - Adjacent Channel Rejection

```
for (TRX victim = interferenceMatrix.begin();
       victim != interferenceMatrix.end();
       victim++ ) {
    //traverse all the interferering TRXs
    for (TRX  interferer = (*victim).begin();
       interferer != (*victim).end();
       interferer++) {
       if (coChannel(victim,interferer)
         cost += signalingCost(mean,std);
       else if (adjChannel(victim,interferer)
         cost += signalingCost(mean – adjChannelRejection,std);
    } //for
  } //for
```

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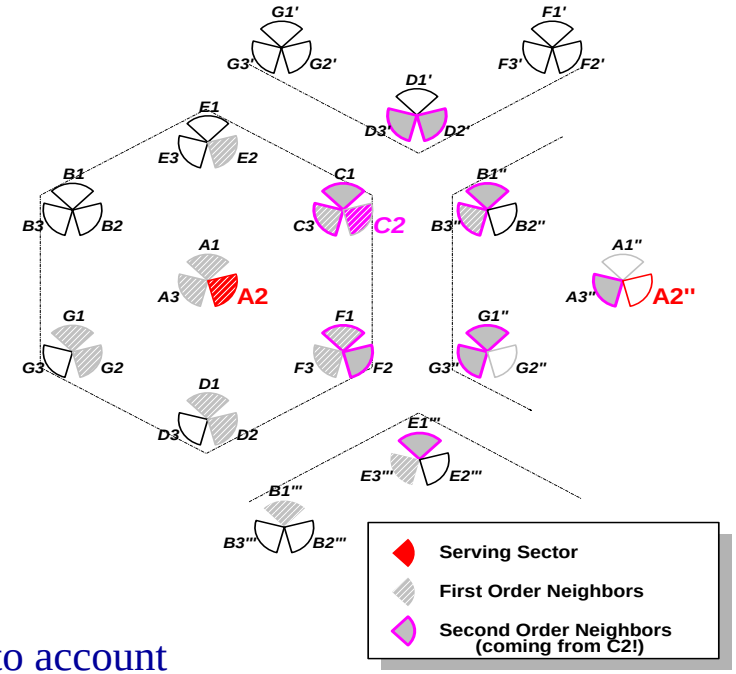
AFP Fitness Functions

Second approach

- User defined costs are now considered
  - Control channels (BCCHs) and traffic channels (TCHs) are distinguished
  - Co-channel and adjacent channels at different levels of the network
    - Sector
    - Site
    - First order neighbors
    - Second order neighbors



Third approach

- Separation constraints are taken into account
  - User defined costs for separation constraints violation are used
    - Sector
    - Site

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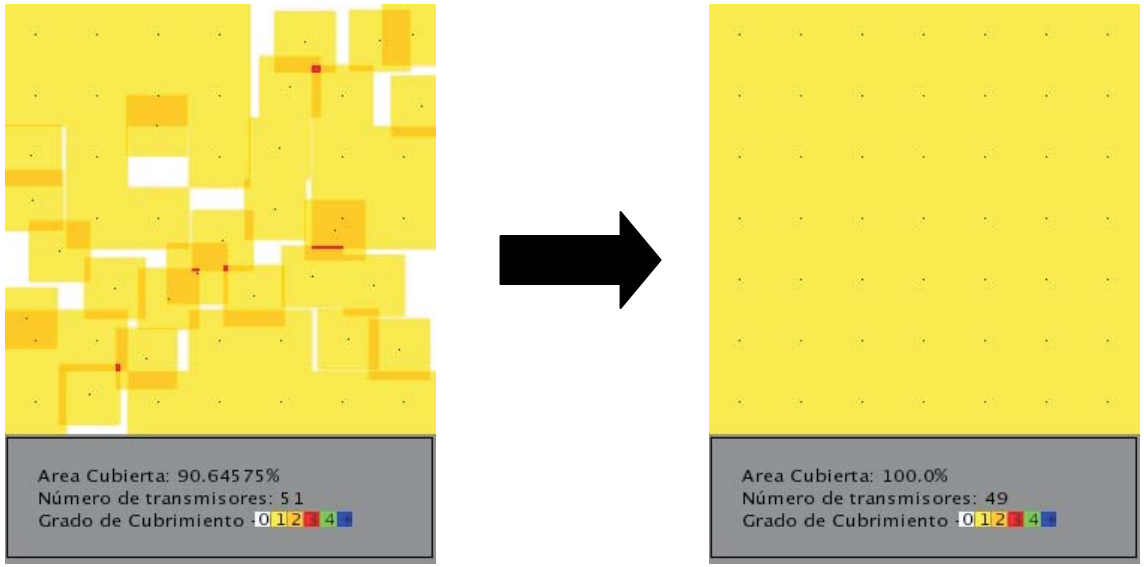
Radio Network Design

Índice

Radio Network Design (RND)



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RND description

Radio Network Design (RND)

- Problem existing in the cellular wireless technology domain
  - Cell planning design
- Give coverage to an area using a base station (BS) network
- **Design of the radio network**
  - **Task:** determine the **set of locations** for the **base stations**
  - **Objective**: Get a **high coverage** in an **efficient manner**
    - Have a **high percentage** of the area covered by *at least* one BS
    - Use the **lowest amount** possible of BSs

- Fitness parameter:

$$\text{Fitness} = \frac{Porcentaje\ de\ area\ cubierta^2}{Número\ de\ antenas\ empleadas}$$

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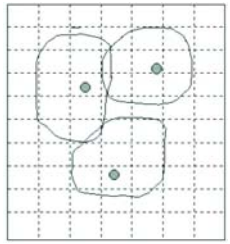
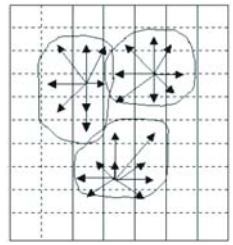
RND description

Model of the terrain

- **Discretised** model of the terrain: area divided in sectors (*atomic bits of terrain*)
- Model: rectangular area modeled by a **grid** (287*287)



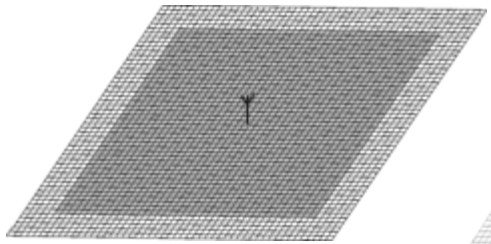


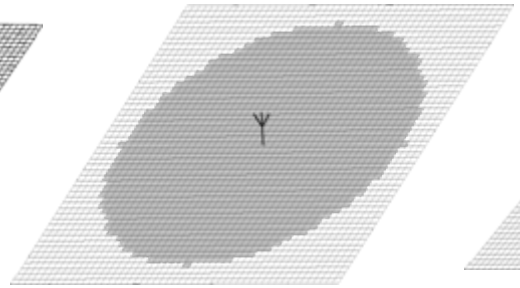
RND Parameters

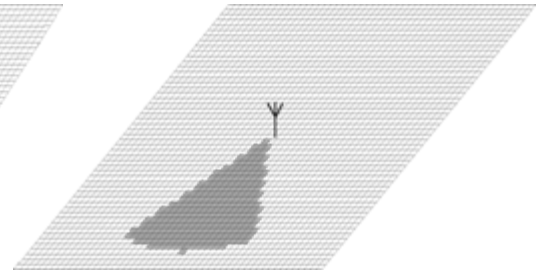
Constraint: list of available location sites

- BSs can only be placed in a **predefined** set of **available locations** (sectors)
- Set of available locations**: list of coordinates** of the grid
- The size of the list **is** the size of the problem instance

Coverage model for BS transmitters







RND models

Coding of the grid

- **Array** of chars of length 287*287

```
Definition of the terrain (grid)
#define GRID_SIZE_X  287      //Artificial grid horizontal size.
#define GRID_SIZE_Y  287      //Artificial grid vertical size.
#define GRID_SIZE    82369    //Total grid size.

static char grid[GRID_SIZE];
```

Working with the grid

- Referencing sector with coordinates (x,y):

```
grid[x*GRID_SIZE_X + y]
```

- Information stored in every position of the grid:
  - **Numerical** value (‘0’…’9’): **degree of coverage** for that bit of terrain
  - **Non-numerical** character (‘*’): **BS transmitter** is located
    - Different characters can code different kinds of transmitter

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RND Fitness function

Fitness function

Pseudocode of the fitness function

```
Initialize(grid);  //Set all the grid positions to '0'
Int Trans_used,covered_points=0;

For(all_the_available_locations)
   if(Transmitter_is_placed)
      (x,y)=location_coordinates;
      Trans_used++;                  //Count one more transmitter
      grid(x*GRID_SIZE_X+y)='*';     //Mark the transmitter
      for(all_sectors belonging_to transmitter_coverage(x,y))
         (x1,y1)=sector_coordinates;
         if((grid[x1*GRID_SIZE_X+y1]!='*')
            grid[x1*GRID_SIZE_X+y1]++;  //Increase the coverage
            if(grid[x1*GRID_SIZE_X+y1]=='1') //If new coverage
               covered_points++;              //take account

cover_rate = (100.0 * covered_points) / (GRID_SIZE);
fitness = (cover_rate * cover_rate )/used_trans;
```

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RND Instances

Instance parameters for RND

- **Size**: number of available location sites (from 149 to 349)
- **Set of available location sites** coordinates:

```
#define TRANS_TOTAL   349  //Number of total transmiters.
                           //49 transmiters distributed regulary...
                           //... the rest is distributed randomly.


static short int trans_location[TRANS_TOTAL*2]=
    {20,20,   61,20,   102,20,   143,20,   184,20,   225,20,  266,20
     ... 14,15,  131,224,  198,127};
```

- **Kind**(s) of BS **transmitter**(s) employed:
  - Square coverage: 41*41 sector cell
  - Omnidirectional coverage: 22-sector-radius circle
  - Directive coverage: sector of the omnidirectional cell of angle 60º

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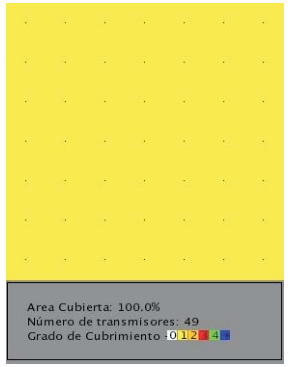
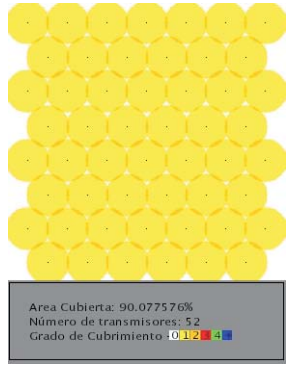
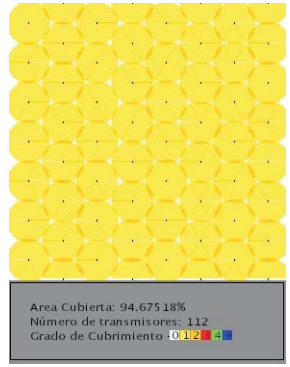
RND Instances

Results obtained

- **Optimal solutions** (for every kind of transmitter):







- **Algorithms performances** (for square coverage transmitters):