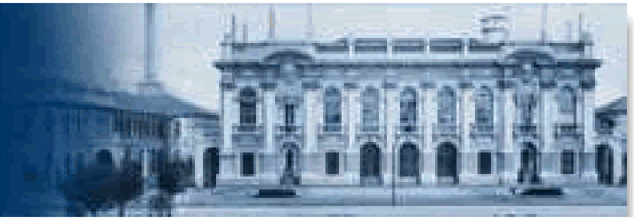
POLITECNICO DI MILANO
Piazza Leonardo da Vinci, 32 - 20133 Milano
Tel. +39.02.2399.1 - http://www.polimi.it



Optimizing base station location and configuration in 3G cellular (UMTS) networks

Edoardo Amaldi
Antonio Capone
Federico Malucelli

Dipartimento di Elettronica e Informazione

Outline

1) Network planning for UMTS systems with CDMA interface

   Base station location and configuration

2) Mathematical programming models and complexity

   Capture main features (service quality constraints, power control mechanism) at different levels of detail

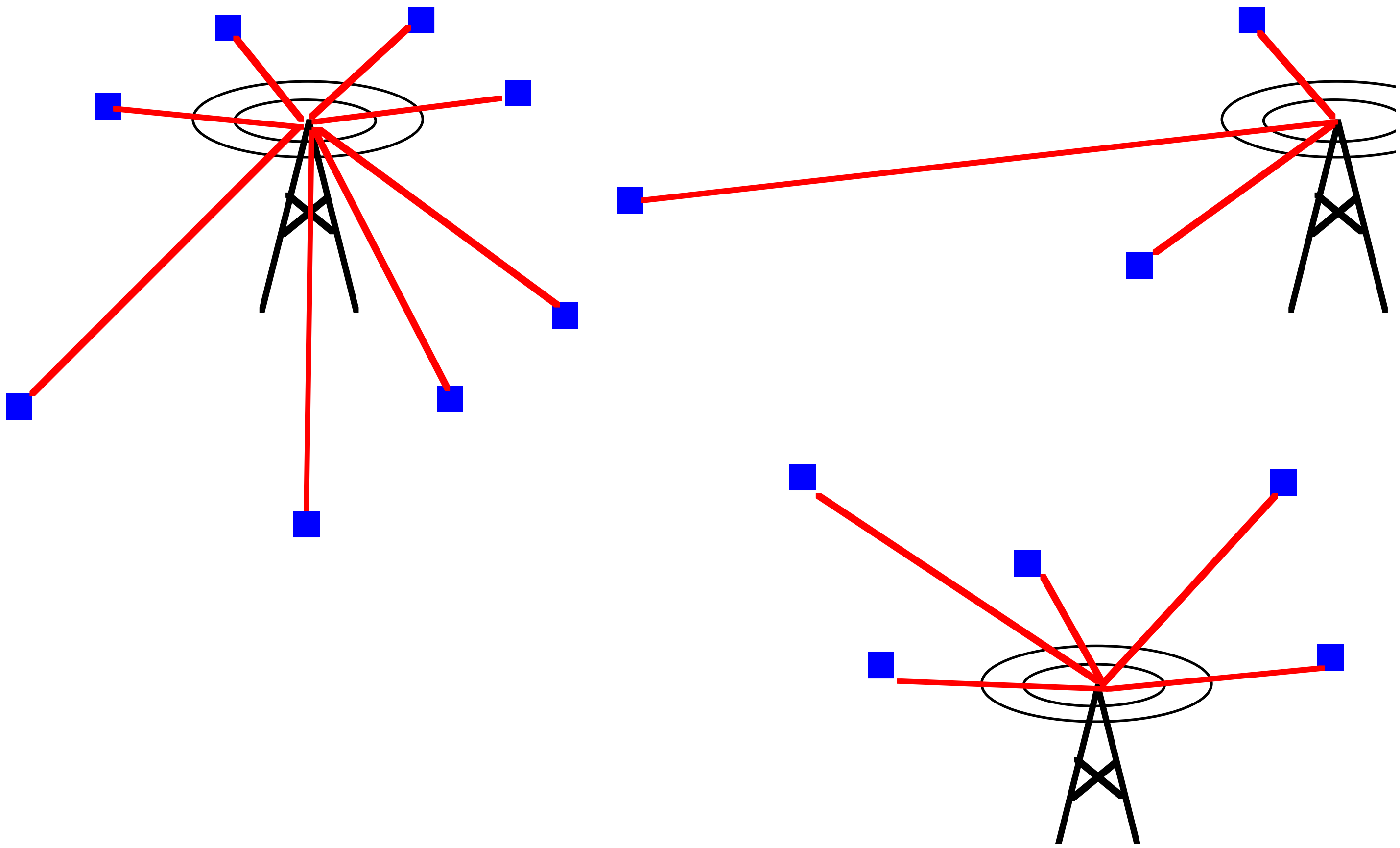
3) Heuristic algorithms

   Randomized greedy and Tabu Search

4) Computational results

   Compare models and algorithms on instances generated according to classical propagation models

1) Network planning for UMTS systems



Select Base Station (BS) location and configuration (height, tilt, sector orientation,...) so as to minimize costs and maximize traffic coverage

GSM

Two-phase approaches

i) Coverage based on propagation predictions

ii) Frequency assignment based on traffic demand and service quality

UMTS

- CDMA air interface (no frequency assignment since shared wide band)
- Power Control mechanism

⇓

Base Station location and configuration must also consider traffic distribution and service quality

1.1 Service quality constraints

Signal-to-Interference Ratio (SIR)

$$SIR = \frac{P_{received}}{\alpha\, I_{in} + I_{out} + \eta} \geq SIR_{min}$$

α : code orthogonality loss factor ($0 \leq \alpha \leq 1$)

I_{in} : intra-cell interference (depends on assignments to the cell)

I_{out} : inter-cell interference (depends on assignments to the other cells)

η : thermal noise

In UPLINK no code orthogonality (α=1)

1.2 Power Control (PC) mechanism

Transmitted power adjusted so as to reduce interference (account for "cell breathing" effect)

Two ways to model the dynamic PC mechanism

1) Power-based PC

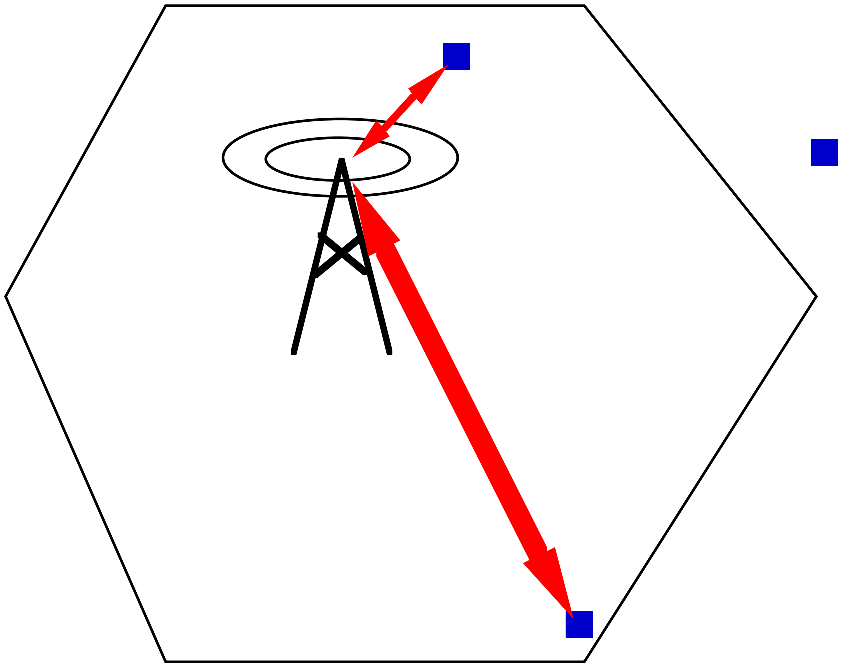
emission powers adjusted so that all received powers are equal to a given P_{target}

2) SIR-based PC

emission powers adjusted so that all SIRs are equal to a given SIR_{target}

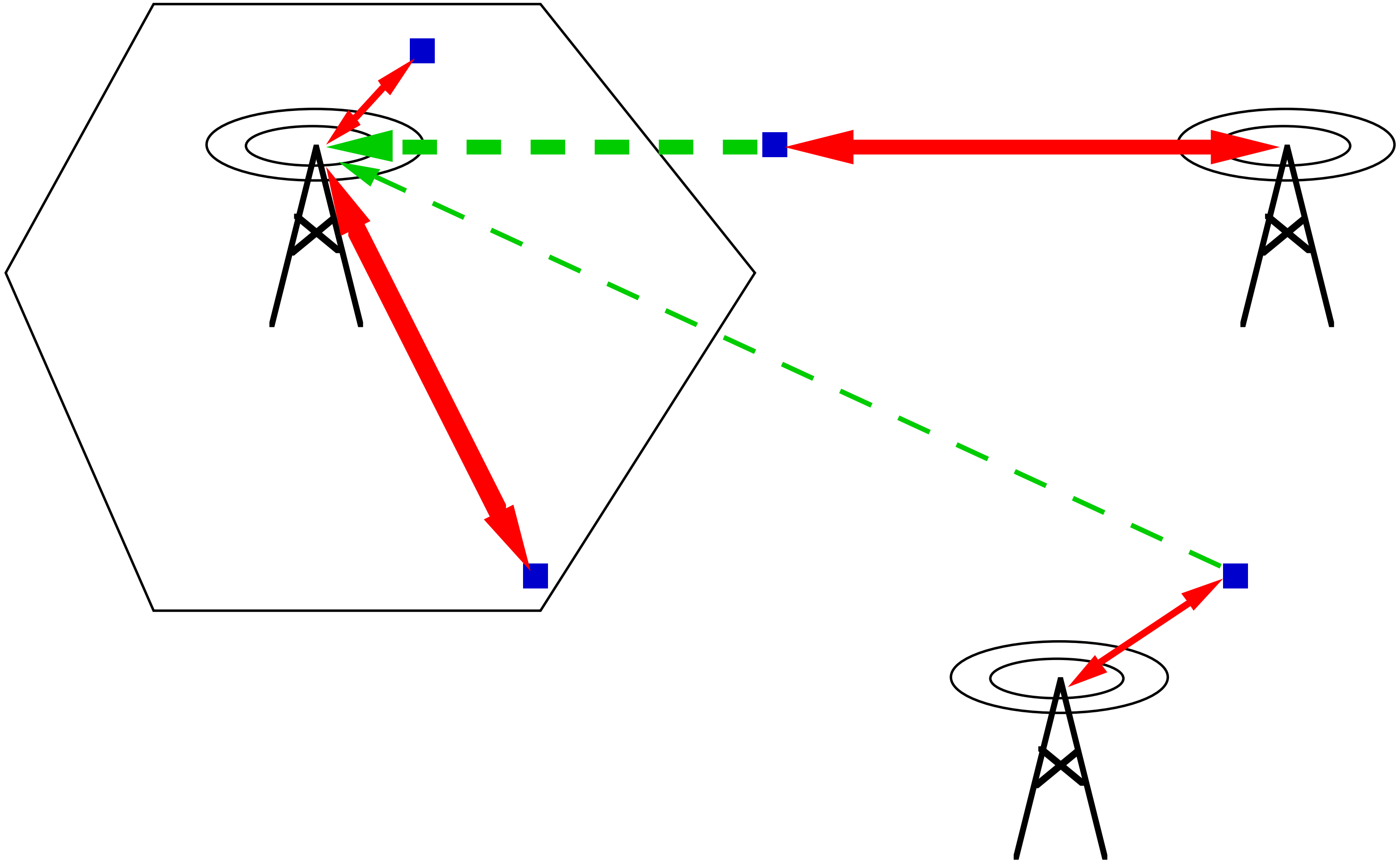
Power Control (PC) mechanism

Transmitted power dynamically adjusted so as to reduce interference while guaranteeing signal quality



Mobile stations closer to BS use lower emission powers

Inter-cell interference in UPLINK (mobile to base station) direction



Previous and parallel work

Some crucial features of UMTS with W-CDMA are not accurately captured:

- Service quality measure (e.g. Calégari et al. 97, Lee et al. 00, Galota et al. 01, Mathar et al. 01)
- PC mechanism

Simplified SIR constraints

In

$$SIR = SF \frac{P_{received}}{I_{in} + I_{out} + \eta} \geq SIR_{min}$$

I_{out} is either omitted or $I_{out} = f\, I_{in}$ where $f \approx 0.4$

this amounts to limit the number N_j of connections to each BS j by

$$N_j \leq \frac{SF}{(1+f)\; SIR_{min}} + 1 \approx 23$$

standard capacity constraint (SF=128 and SIR_{min} = 6 dB).

2) UMTS BS location and configuration problem

Given

- set of candidate sites $j \in S$ where to install a base station (BS) and installation cost c_j,
- set of test points (TPs) $i \in I$ with traffic demand u_i
- propagation gain matrix $G = [g_{ij}]$, $i \in I$, $j \in S$

$$0 \leq g_{ij} \leq 1$$

Select a subset of candidate sites where to install BSs as well as their configuration, and assign TPs to BSs so as to minimize total cost and/or maximize satisfied traffic demand

In this presentation

UPLINK direction which is more stringent from the traffic point of view for balanced connections (Viterbi et al. IEEE TVT 91,…)

We discuss three location models:

- power-based PC model with simplified SIR constraints
- enhanced power-based PC model
- SIR-based PC model

Common model components

Decision variables:

$$y_j = \begin{cases} 1 & \text{if a BS is installed in } j \in S, \\ 0 & \text{otherwise} \end{cases}$$

$$x_{ij} = \begin{cases} 1 & \text{if test point } i \in I \text{ is assigned to BS } j \in S, \\ 0 & \text{otherwise.} \end{cases}$$

Objective function:

$$\min \sum_{j \in S} c_j\, y_j + \mu \sum_{i \in I} \sum_{j \in S} u_i\, x_{ij}$$

The second term aims at maximizing the traffic covered

1. Power-based PC model with simplified SIR

Constraints:

$$\sum_{j \in S} x_{ij} \leq 1 \qquad \forall\ i \in I \qquad \text{(assignment)}$$

$$x_{ij} \leq y_j \qquad \forall\ i \in I,\ \forall\ j \in S \qquad \text{(coherence)}$$

$$\sum_{i \in I} u_i\, x_{ij} \leq 23\ y_j \qquad \forall\ j \in S \qquad \text{(cardinality)}$$

$$x_{ij},\ y_j \in \{0,1\} \qquad \forall\ i \in I,\ \forall\ j \in S \qquad \text{(integrality)}$$

variables x_{ij} only needed for "close" enough TP-BS pairs,
i.e. $P_{target}/g_{ij} \leq P_{max}$

2. Enhanced power-based PC model

Constraints:

$$\sum_{j \in S} x_{ij} \leq 1 \qquad \forall\ i \in I \qquad \text{(assignment)}$$

$$x_{ij} \leq y_j \qquad \forall\ i \in I,\ \forall\ j \in S \qquad \text{(coherence)}$$

$$\frac{P_{target}}{\sum_{h \in I} u_h\, g_{hj} \sum_{t \in S} \frac{P_{target}}{g_{ht}} x_{ht} - P_{target}} \geq SIR_{min}\, y_j \qquad \forall\ j \in S \qquad \text{(SIR)}$$

$$x_{ij},\ y_j \in \{0,1\} \qquad \forall\ i \in I,\ \forall\ j \in S \qquad \text{(integrality)}$$

The service quality (SIR) constraints

$$\frac{P_{target}}{\sum_{h\in I} u_h\, g_{hj} \sum_{t\in S} \frac{P_{target}}{g_{ht}} x_{ht} - P_{target}} \geq SIR_{min}\, y_j \qquad \forall\, j\in S$$

signal received in BS j from TP h

can be linearized:

$$\sum_{h\in I}\sum_{t\in S} u_h \frac{g_{hj}}{g_{ht}} x_{ht} \leq \frac{1 + M(1-y_j)}{SIR_{min}} \qquad \forall\, j\in S$$

for a suitably large M

Generalized C Facility Location problem

Classical capacity constraints:

$$\sum_{h \in I} a_h \, x_{hj} \leq B_j \, y_j \qquad \forall \; j \in S$$

SIR constraints:

$$\sum_{h \in I} \sum_{t \in S} a^{j}_{ht} \, x_{ht} \leq B_j \, y_j \qquad \forall \; j \in S$$

"client" *h* absorbs capacity from each "facility" and amount from each one depends on the "facility" to which *h* is assigned

Features of the power-based PC model for UPLINK:

- Unsplittable assignments (0-1 *x variables*)
- "Generalized" capacity constraints

Property: Given a set of active BSs, TPs can be assigned to "closest" BSs (lower emitted powers » higher SIRs)

Theorem: NP-hard but admits a Polynomial Time Approximation Scheme (can be approximated within any factor $1+\varepsilon$, $\varepsilon>0$)

Galota's et al. (01): PTAS for simple covering model without PC mechanism and inter-cell interference

3. SIR-based PC model

Constraints:

$\sum_{j \in S} x_{ij} \leq 1 \qquad \forall\ i \in I \qquad$ (assignment)

$x_{ij} \leq y_j \qquad \forall\ i \in I,\ \forall\ j \in S \qquad$ (coherence)

$$\frac{p_i\, g_{ij}}{\sum_{h \in I} u_h\, g_{hj} \sum_{t \in S} p_h\, x_{ht} - p_i\, g_{ij} + \eta} \geq SIR_{target}\, x_{ij} \qquad \forall i \in I, \forall j \in S$$

$x_{ij},\ y_j \in \{0,1\} \qquad \forall\ i \in I,\ \forall\ j \in S \qquad$ (integrality)

$0 \leq p_i \leq P_{max} \qquad \forall\ i \in I \qquad$ (power limits)

Observations

i) Assignments to "closest" BSs don't guarantee largest SIRs

ii) Given a solution (x,y) the emitted powers p can be computed by solving the following equality system:

$$\frac{p_i\ g_{ij}}{\sum_{h\in I} u_h\ g_{hj} \sum_{t\in S} p_h\ x_{ht} - p_i\ g_{ij} + \eta} = SIR_{target}\ x_{ij} \qquad \forall i\in I, \forall j\in S$$

3) Heuristic algorithms

- Randomized greedy procedures
  Add and Remove in which one of the "best choices" is randomly picked at each step

  min cost - μ traffic covered - σ additional connections

- TABU Search
  Use memory to avoid cycling and try to escape from local optima
  Neighborhood structure: Add, Remove, Swap

multistart or single run setting

Subproblem for power-based PC model

Given a subset $\overline{S}$ of active BSs, assign TPs to activated BSs so as to maximize the traffic covered

Variables: $z_h = \begin{cases} 1 & \text{if test point } h \text{ is assigned to a "closest" BS } (b(h)) \\ 0 & \text{otherwise} \end{cases}$

$$\max \sum_{h \in I} u_h z_h$$

$$\sum_{h \in I} u_h \frac{g_{hj}}{g_{hb(h)}} z_h \leq \frac{1}{SIR_{min}} \qquad \forall j \in \overline{S}$$

$$z_h \in \{0,1\} \qquad \forall h \in I$$

Multidimensional knapsack problem (general case NP-hard: Magazine et al 84) tackled by PTAS (Frieze et al. 84) or...

4) Computational results

Problem instances:

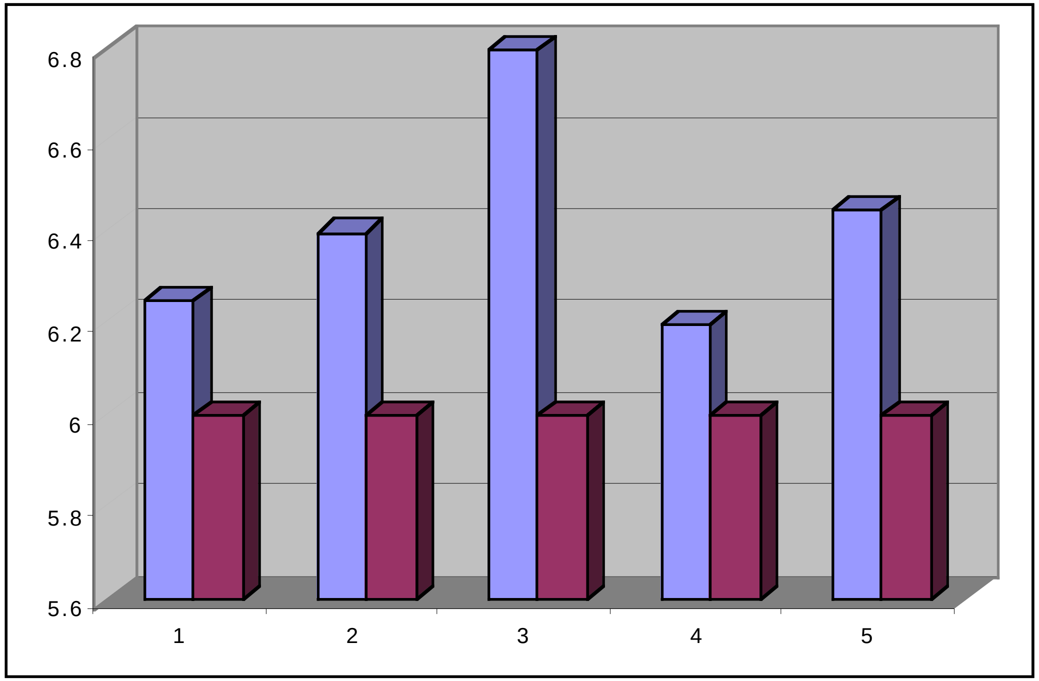
- Urban and Rural settings (Hata's propagation models)
- areas of three different sizes:

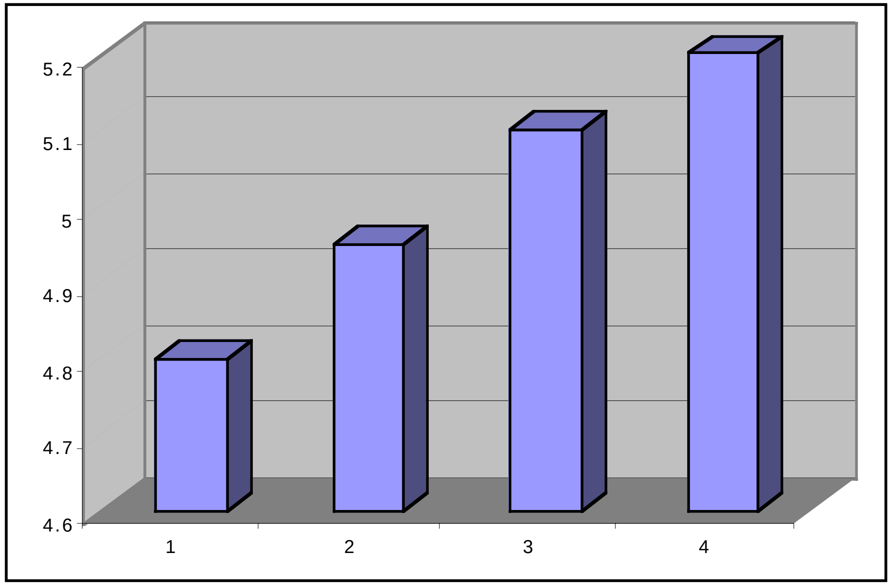
400 X 400 m	($|S|=22$, $|I|=95$)
1 X 1 km	($|S|=120$, $|I|=400$)
1.5 X 1.5 km	($|S|=200$, $|I|=750$)

- $u_i \in \{1,2,3\}$ or $\{1,2\}$ randomly generated

#Mobile Stations= 95 (small), 800 (medium) and 1125 (large)

4.1 Shortcomings of simplified SIR





f=0.4 (at most 23 MSs per BS)
=> 5 BSs activated

f=0.35 (at most 24 MSs)
=> 4 BSs activated

Exact solution obtained with CPLEX

4.2 Results for power-based PC model

	Add	Remove	multi TS Add	multi TS Remove	Tabu Search Remove
MU-1	47*	50	46	48	47
MU-2	46	46	43	43	43
MU-3	45	43	41	41	41
MU-4	45	44	42	42	42
MU-5	44	46	42	42	42

MR-1	44	42	40	41	40
MR-2	44	45	43	43	43
MR-3	43	44	41	41	41
MR-4	45	45	42	42	42
MR-5	44	46	42	42	42

4.3 SIR-based vs. power-based models

	Power-based	SIR-based
MU-1	47	39
MU-2	43	36
MU-3	41	35
MU-4	42	36
MU-5	42	36
MR-1	40	35
MR-2	43	36
MR-3	41	35
MR-4	42	36
MR-5	42	36

1 run TS (MU-MR): ~ 1:20 hours for power-based model
up to 8 hours for SIR-based model

Extended power-based PC model

- Directive BSs with three 120° sectors (with e.g. four orietations corresponding to 0°, 30°, 60° or 90° rotations)
- BS height (e.g. 10, 20, 30, 40 m)
- BS tilt (e.g. 10°, 20°, 30°, 40° with respect to vertical axis)
- Different types of service

Consider as many copies of each candidate site (CS) as there are alternative BS configurations and different SIR_{target} (e.g. 6, 9, 12 dB)

Concluding Remarks

- New class of capacitated facility location models since standard capacity constraints can yield meaningless solutions
- More realistic models for optimizing BS location as well as configuration (tilt, height, sector orientation) in UMTS networks
- Randomized greedy and Tabu Search heuristics which provide good approximate solutions in reasonable time
- Model with SIR-based PC allows for better use of resources but computationally more expensive

web: www.elet.polimi.it/upload/malucell

Some related papers:

Amaldi E., A. Capone and F. Malucelli (2002). "Planning UMTS Base Station location: Optimization models with power control and algorithms" IEEE Transactions on Wireless Communications : in press.

Amaldi E., A. Capone and F. Malucelli (2001). Optimizing Base Station Siting in UMTS Networks. VTC Spring 2001, Vol. 4, 2828 -2832.

Amaldi E., A. Capone and F. Malucelli (2001), Discrete models and algorithms for the capacitated location problems arising in UMTS network planning, DIALM’01, 1-8.

Amaldi, E., A. Capone, F. Malucelli (2002). Optimizing UMTS radio coverage via Base Station configuration. PIRMC 02, Lisbon.