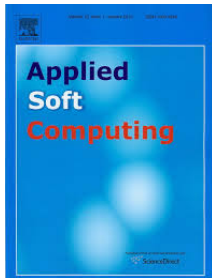


Amazon.com

## Biased random-key genetic algorithm for wireless backhaul network design

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Amazon.com, Seattle, WA – USA  
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MIC 2015, Agadir, Morocco, June 8, 2015



C.E. Andrade, M.G.C. Resende, W. Zhang, R.K. Sinha, K.C. Reichmann, R.D. Dover-spoke, and F.K. Miyazawa, *A biased random-key genetic algorithm for wireless backhaul network design*, Applied Soft Computing, vol. 33, pp. 150-169, 2015.

This research was done while the speaker was employed at AT&T Labs Research in Middletown, New Jersey.

# Agenda

- 1 Mobile wireless data usage growth
- 2 Description of the problem
- 3 Biased random-key genetic algorithm
- 4 Some results
- 5 Final remarks

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## Growth of wireless data usage

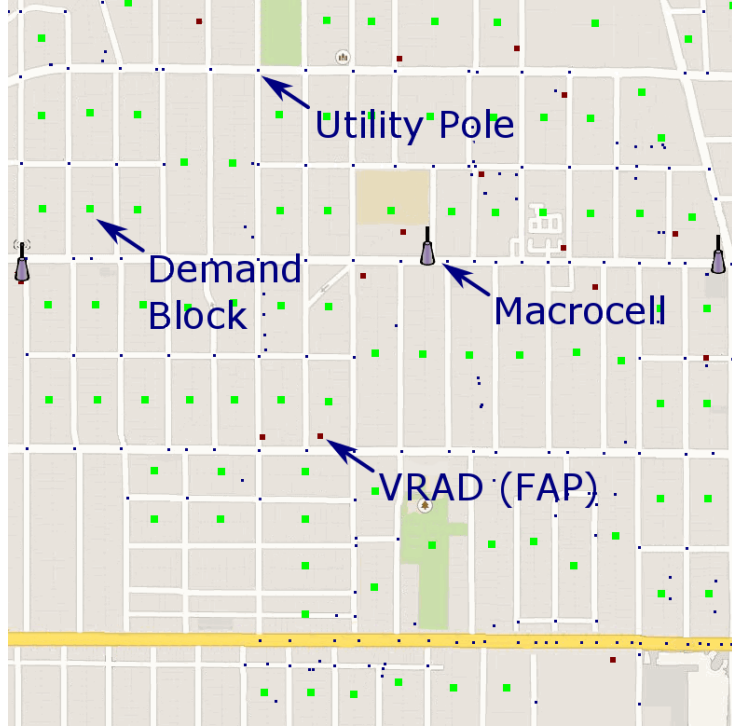
- Surge in popularity of **mobile devices** (smart-phones and tablets) for Internet access
  - ▶ **50% of Internet traffic** in the U.S. is due to mobile devices (O'Toole, 2014)
  - ▶ 50% of YouTube usage (Wojcicki, 2014)
  - ▶ **Predicted 57% annual growth rate**, resulting in an 10-fold increase from 2014 to 2019 (Cisco VNI Global IP Traffic Forecast, 2015)
- Service providers need to keep up with this growth by providing **better coverage** and **higher data rates** to customers

## Growth of wireless data usage

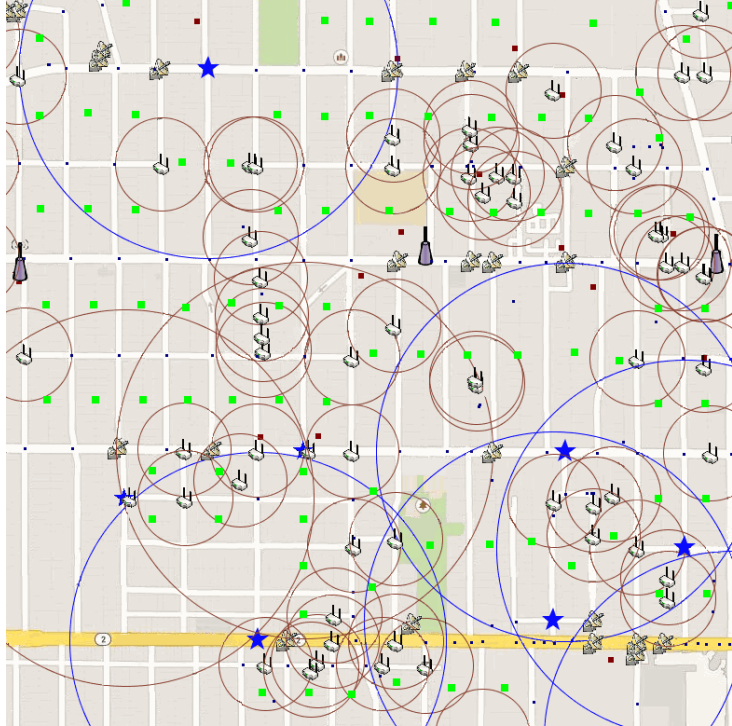
- An approach to provide coverage is to distribute (geographically) **Wi-Fi** and **LTE equipment** for data access by customers and **backhaul data** to core network
- A **naive backhaul solution** is to **run fiber to access points** and backhaul traffic to core network
- **High cost of fiber** makes this approach **prohibitive**
- Judiciously **use existing fiber and macro-cell infra-structure** together with **optimally placed wireless backhaul equipment** to backhaul traffic

# Agenda

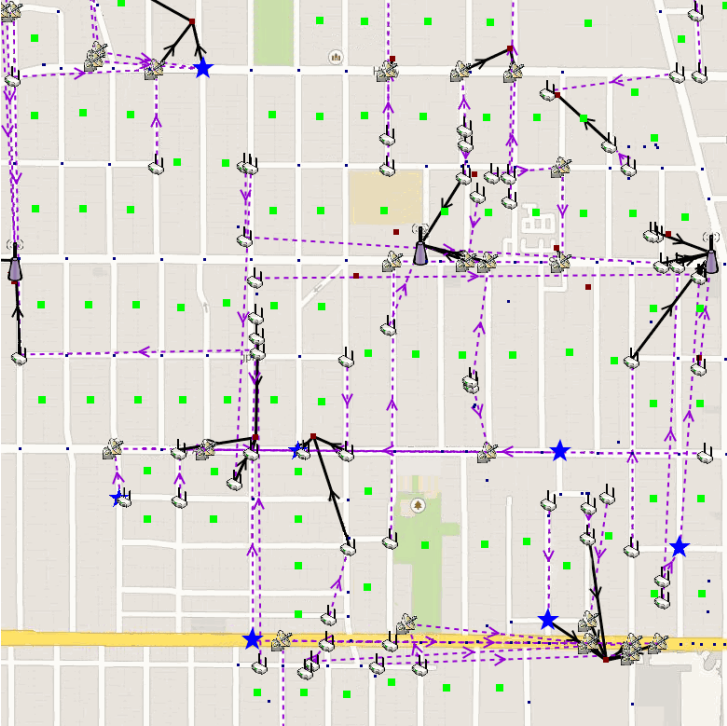
- 1 Mobile wireless data usage growth
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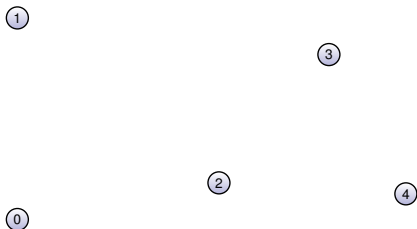


## Some constraints

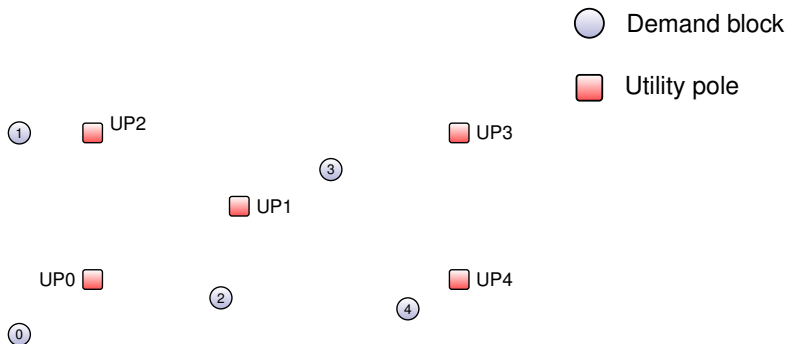
- **Coverage:** Max distance between demand and location of access equipment (Wi-Fi, LTE, and macrocells) for coverage
- **Wireless backhaul links:**
  - ▶ Max distance between antennas
  - ▶ Required line of sight between antennas
- **Interference with LTE equipment:** Required min distance between
  - ▶ LTE smallcells
  - ▶ LTE smallcells and macrocells
- **Topology of backhaul network:**
  - ▶ Max in-degree
  - ▶ Max number of hops
  - ▶ Max length of optical fiber (soft constraint)

## Description – Instance

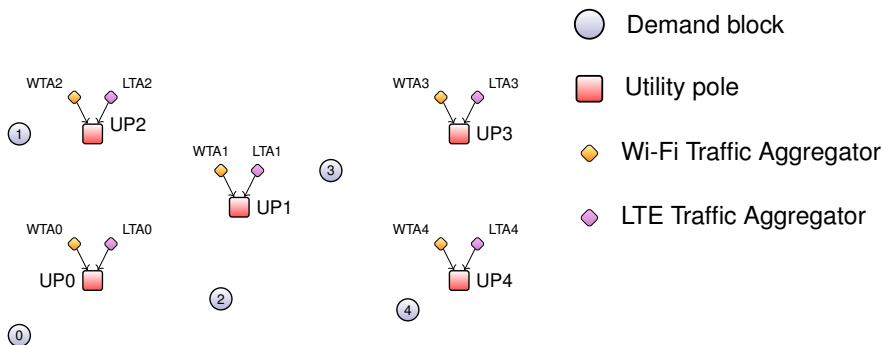
 Demand block



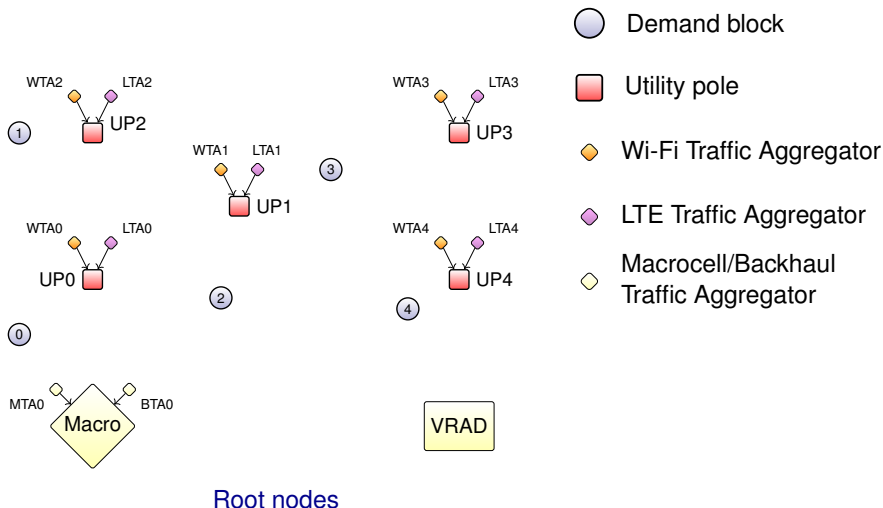
## Description – Instance



## Description – Instance



## Description – Instance



## Description – Instance

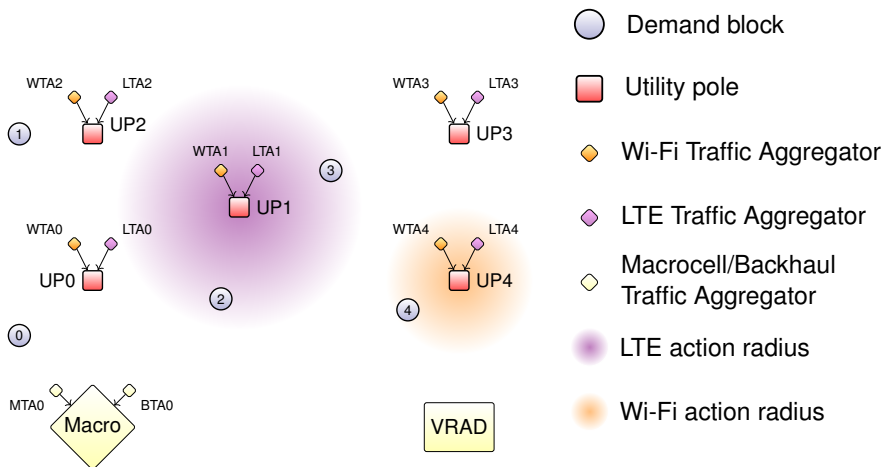
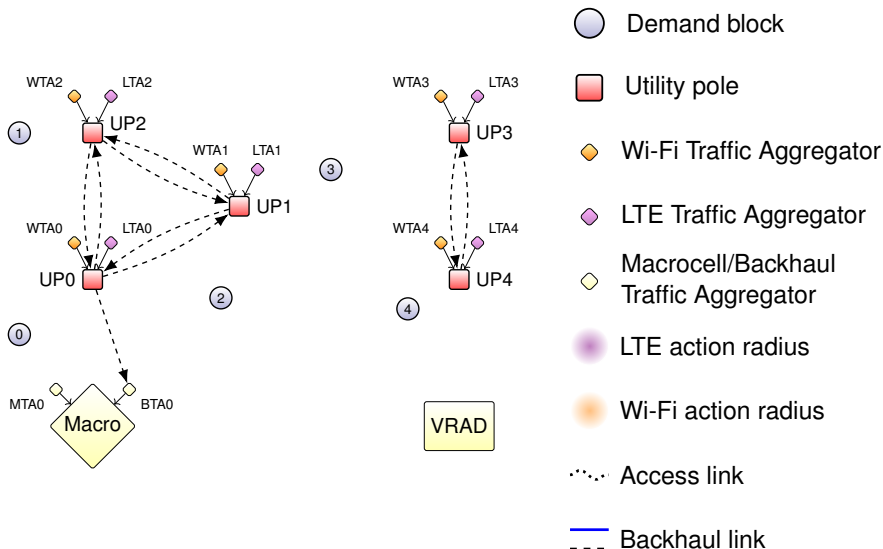


Figure 1 illustrates the network architecture, showing a multi-tier network structure. The diagram includes a legend for symbols:

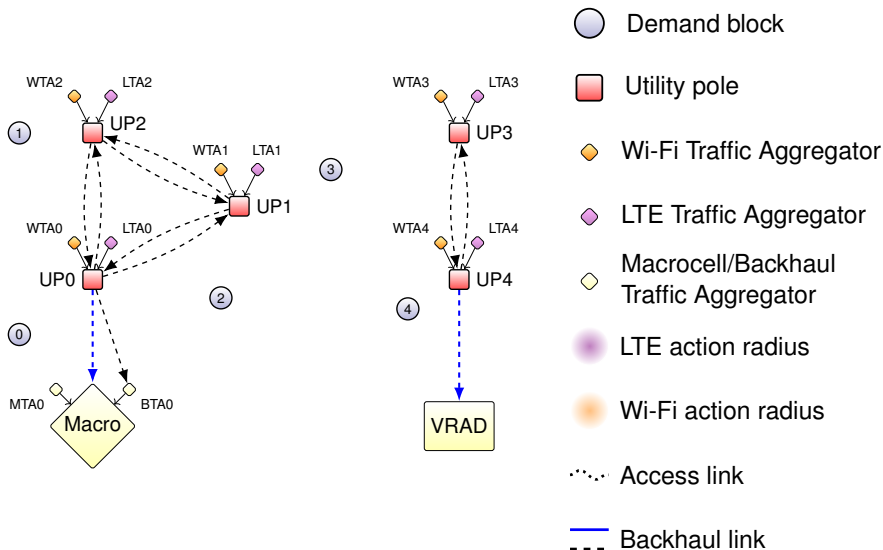
- Demand block
- Utility pole
- ◆ Wi-Fi Traffic Aggregator
- ◆ LTE Traffic Aggregator
- ◆ Macrocell/Backhaul Traffic Aggregator
- LTE action radius
- Wi-Fi action radius
- ⋯ Access link

The network consists of a Macro cell (yellow diamond) connected to a Utility Pole (UP0, red square) via a Macrocell/Backhaul Traffic Aggregator (MTA0, yellow diamond). UP0 is connected to a Demand block (1, blue circle) via a Wi-Fi Traffic Aggregator (WTA0, orange diamond) and an LTE Traffic Aggregator (LTA0, purple diamond). Demand block 1 is connected to a Utility Pole (UP2, red square) via a Wi-Fi Traffic Aggregator (WTA2, orange diamond) and an LTE Traffic Aggregator (LTA2, purple diamond). UP2 is connected to a Utility Pole (UP1, red square) via a Wi-Fi Traffic Aggregator (WTA1, orange diamond) and an LTE Traffic Aggregator (LTA1, purple diamond). UP1 is connected to a Demand block (3, blue circle) via a Wi-Fi Traffic Aggregator (WTA3, orange diamond) and an LTE Traffic Aggregator (LTA3, purple diamond). UP1 is also connected to a Utility Pole (UP4, red square) via a Wi-Fi Traffic Aggregator (WTA4, orange diamond) and an LTE Traffic Aggregator (LTA4, purple diamond). UP4 is connected to a Demand block (4, blue circle) via a Wi-Fi Traffic Aggregator (WTA4, orange diamond) and an LTE Traffic Aggregator (LTA4, purple diamond). A Macrocell/Backhaul Traffic Aggregator (BTA0, yellow diamond) is connected to the Macro cell. A VRAD (Virtual Radio Access Domain) is shown at the bottom.

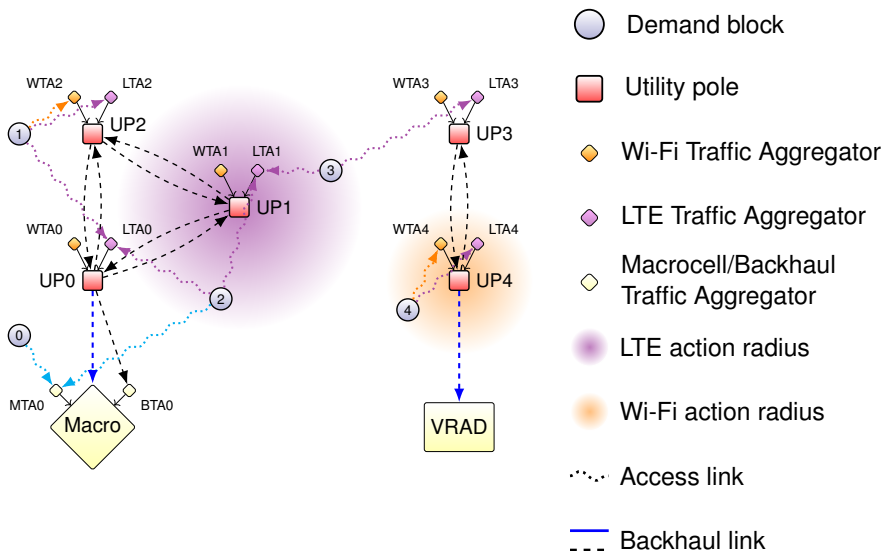
## Description – Instance



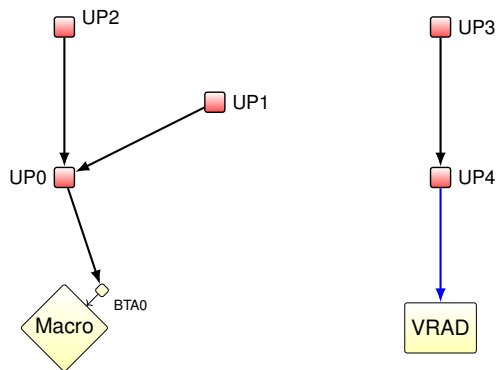
## Description – Instance



## Description – Instance

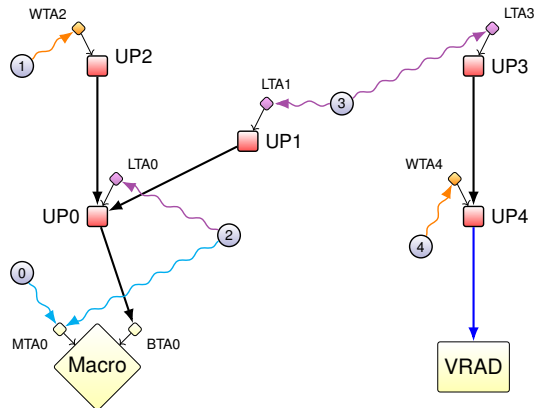


## Description — valid solution



Backhaul Forest

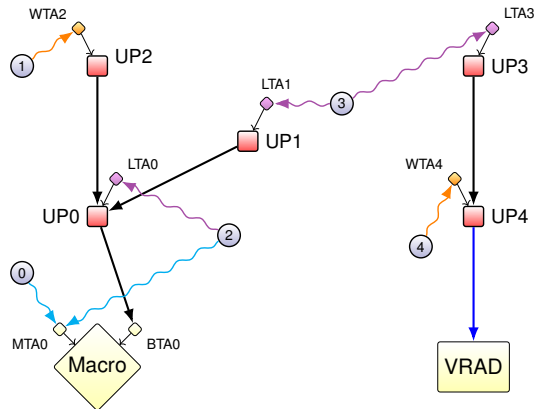
## Description — valid solution



Direct Acyclic Graph

## Description of the problem

## Description — valid solution

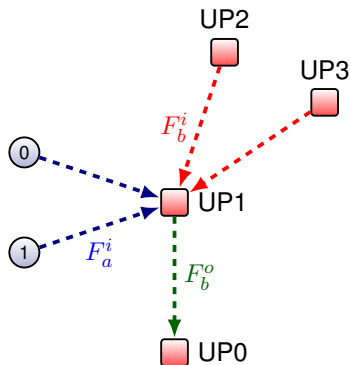


Direct Acyclic Graph

### Objective

Maximize  
 revenue(maximum flow)  
 — deployment and oper. cost

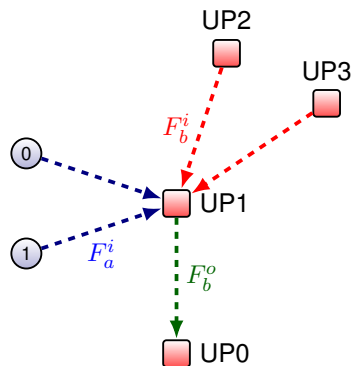
## Flow constraints



- $F_a^i$  : sum of the access traffic
- $F_b^i$  : sum of the incoming backhaul traffic
- $F_b^o$  : outgoing backhaul traffic

Flow conservation:  $F_a^i + F_b^i = F_b^o$

## Flow constraints



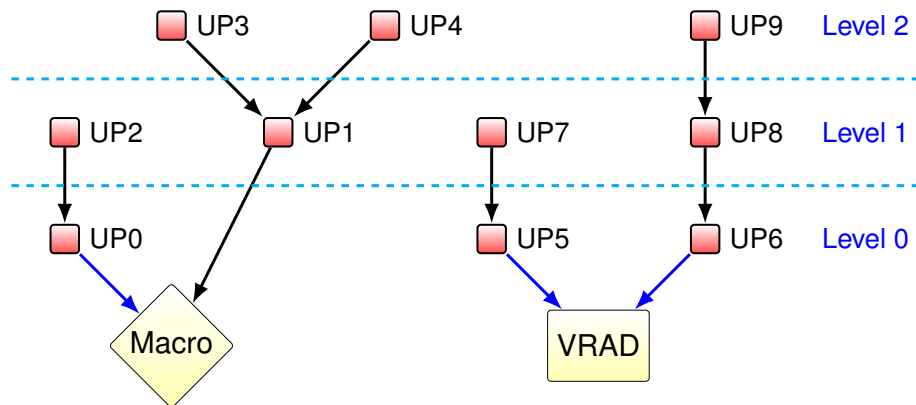
- $F_a^i$  : sum of the access traffic
- $F_b^i$  : sum of the incoming backhaul traffic
- $F_b^o$  : outgoing backhaul traffic

Flow conservation:  $F_a^i + F_b^i = F_b^o$

Maximum wireless backhaul flow:

$$F_b^i + F_b^o \leq C$$

## Forest levels



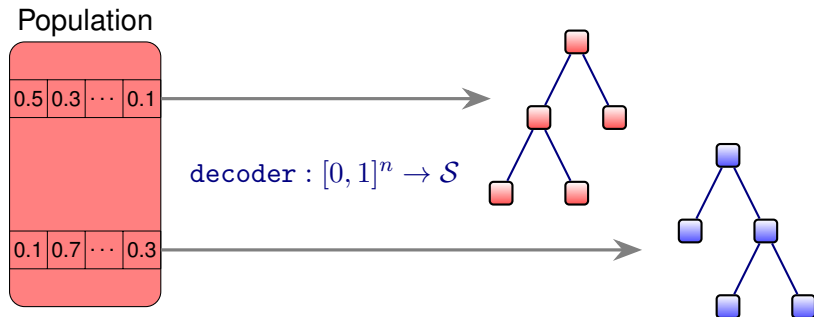
Arcs are in the level from where they depart.

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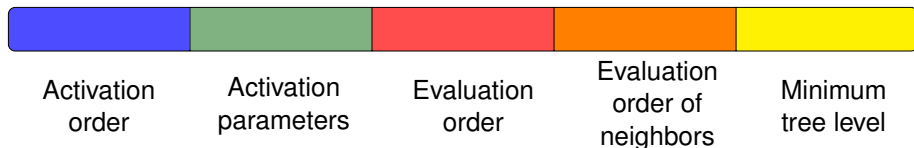
# Biased Random-Key Genetic Algorithm – BRKGA

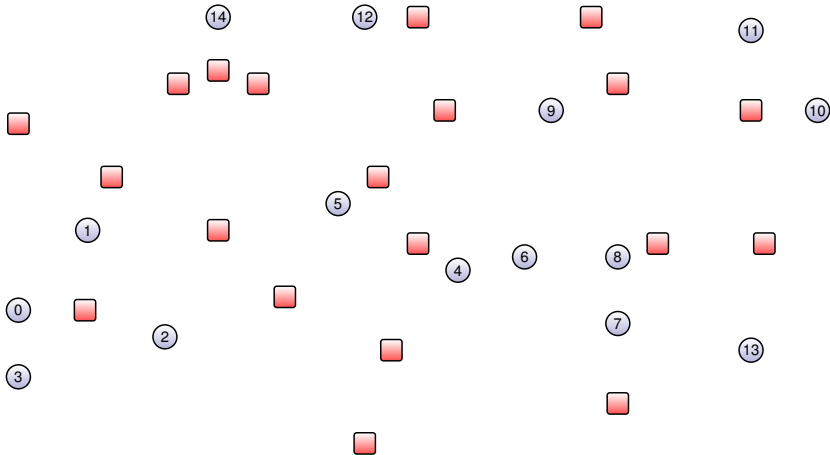
- Populational method → **pool of solutions**
- **Solution space** represented by the **unit hypercube** → chromosome is a vector  $\mathbf{v} \in [0, 1]^p$
- Exploitation by **mating** and exploration by the intro. of **mutants**



## Solution representation

- **BRKGA**: learns the best network layout and equipment placement
- A solution is represented by a vector  $v \in [0, 1]^{5n}$ , where  
 $n$  = number of poles





Macro

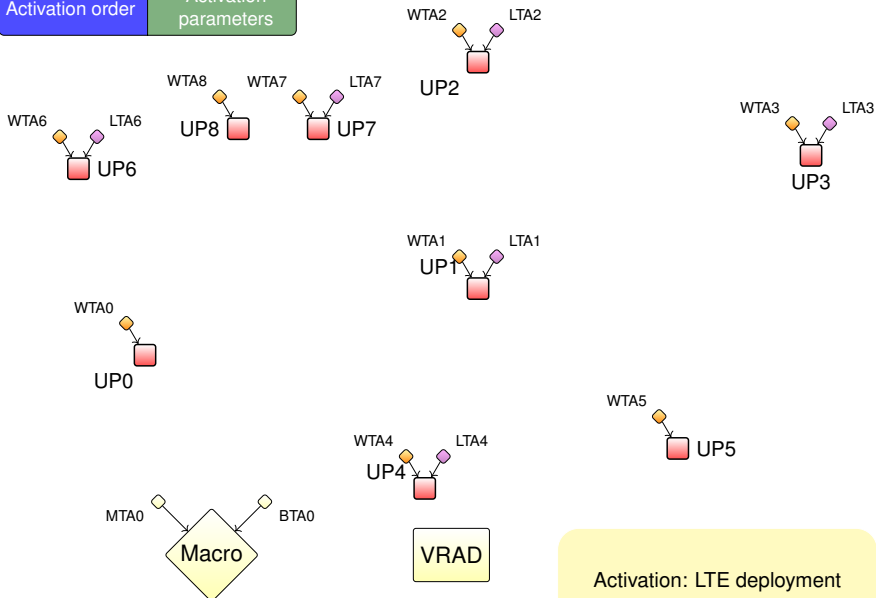
VRAD

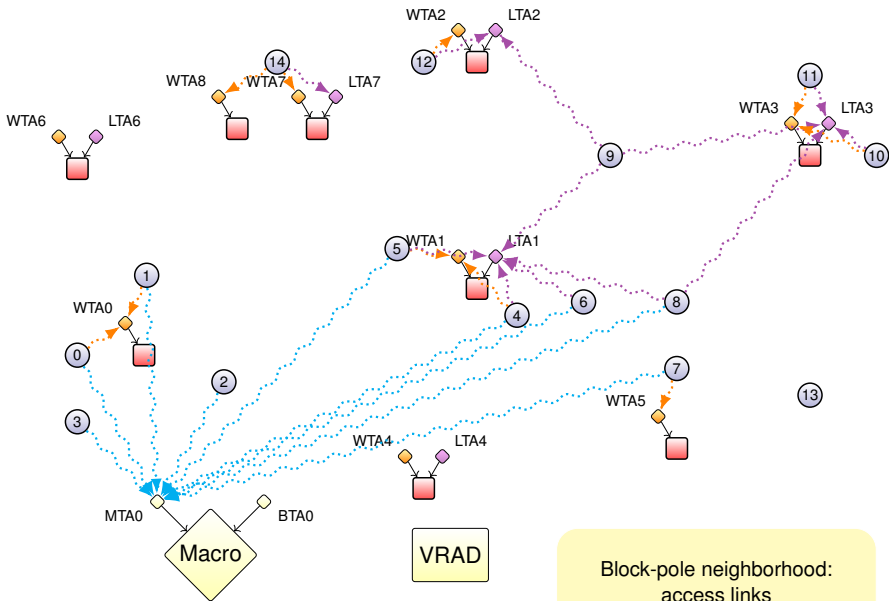
Example: 15 poles, 1 macro,  
1 VRAD, 14 demand points

## Chromosome

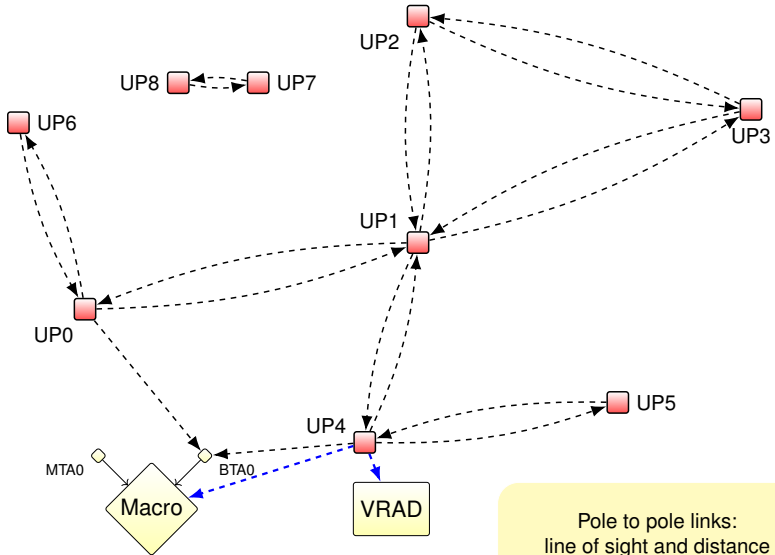
Activation order

Activation parameters

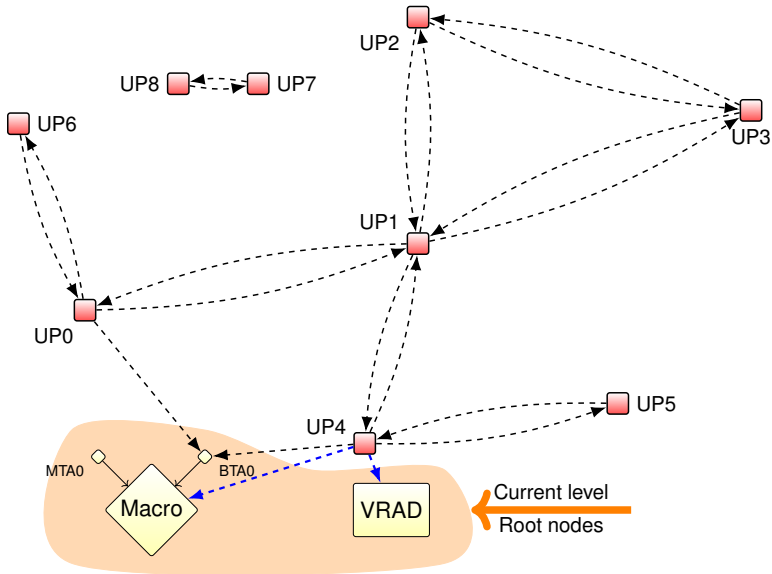




Block-pole neighborhood:  
access links



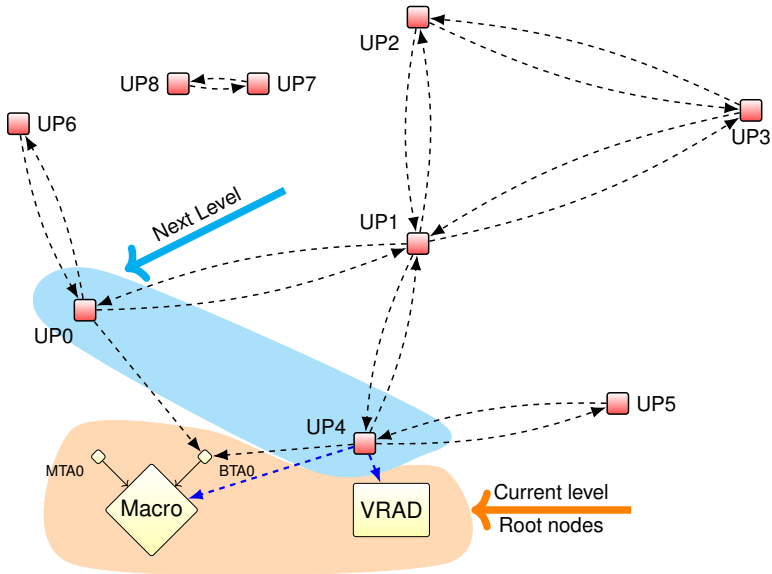
Chromosome



Chromosome

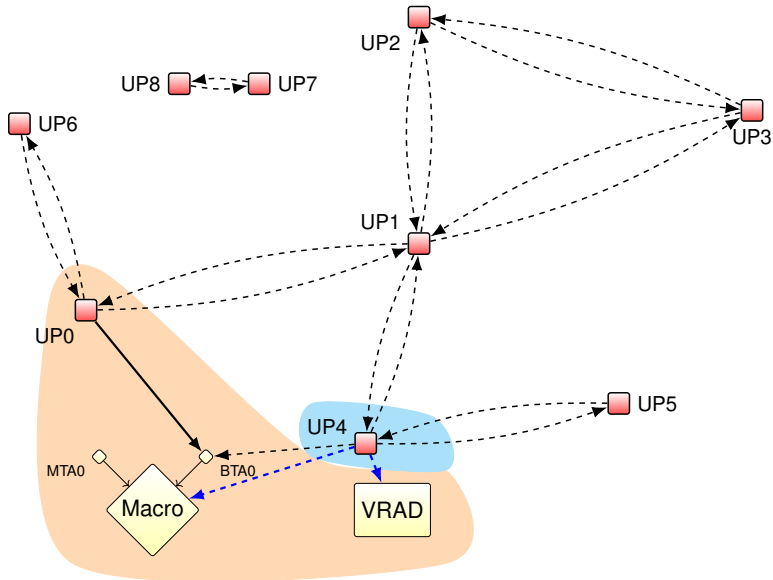
Evaluation order

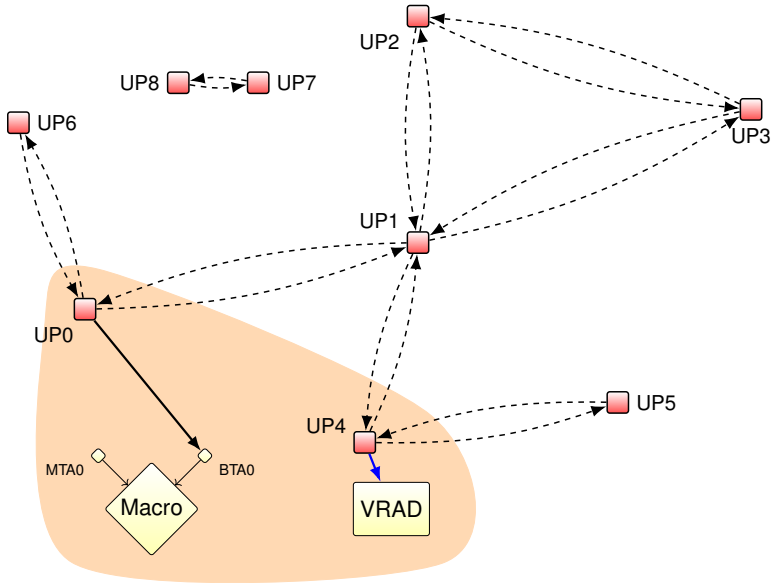
Minimum  
tree level



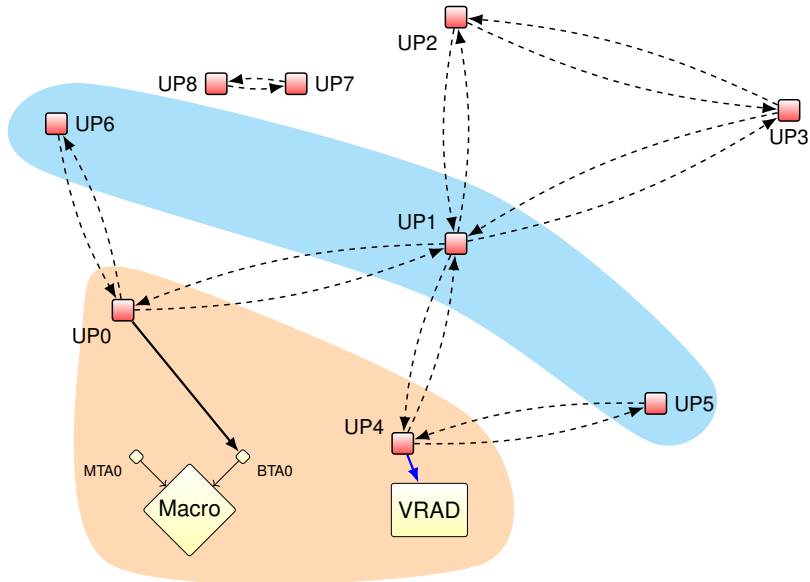
# Chromosome

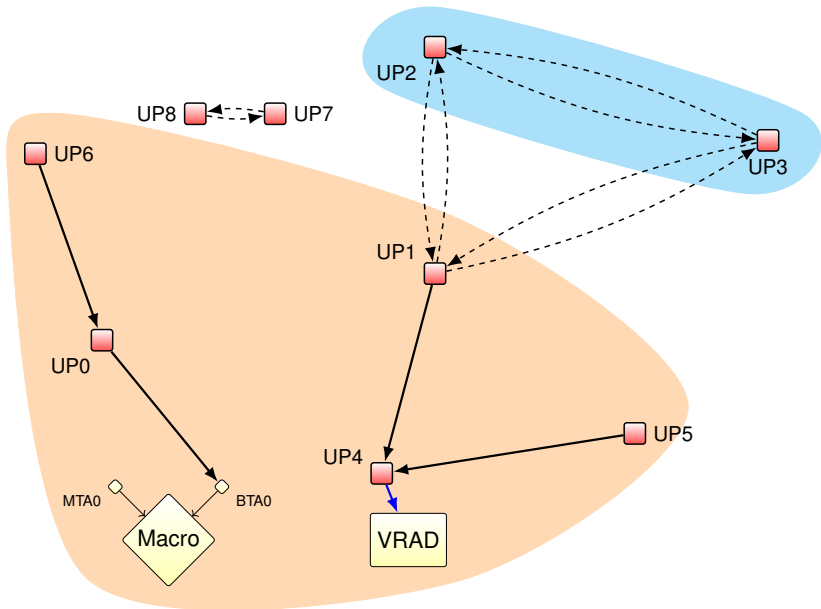
Activation parameters	Evaluation order of neighbors	Minimum tree level
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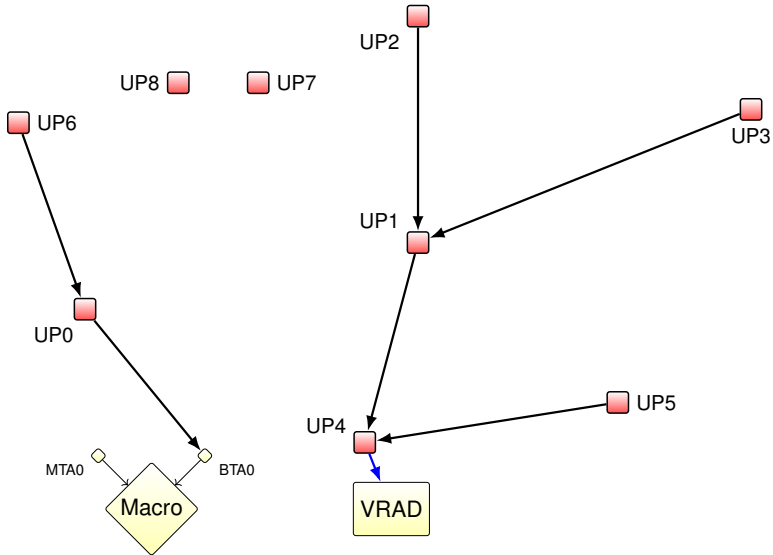


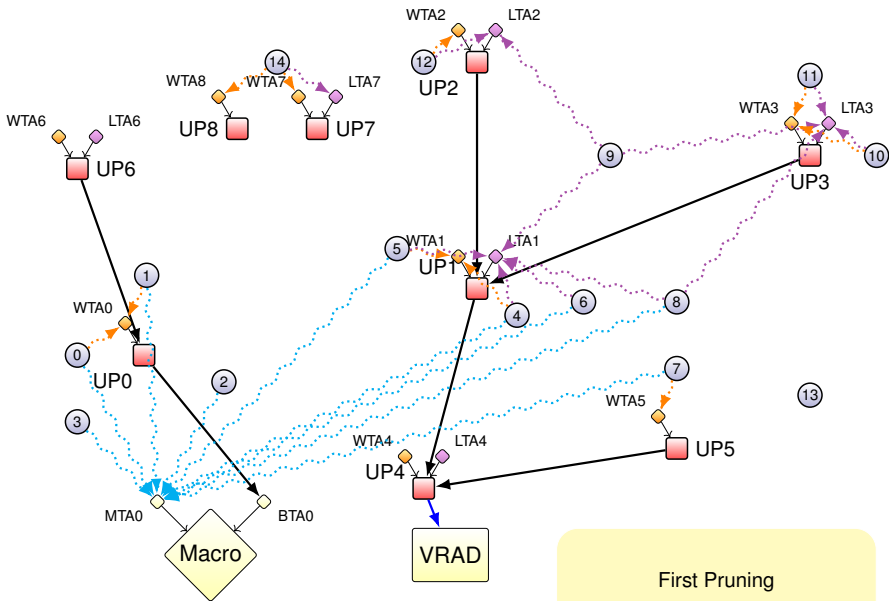


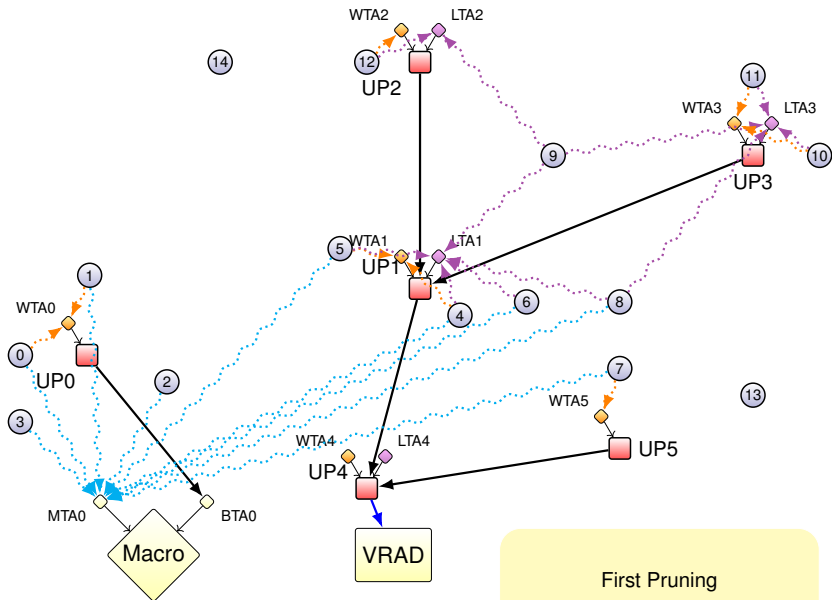
Activation parameters	Evaluation order of neighbors	Minimum tree level
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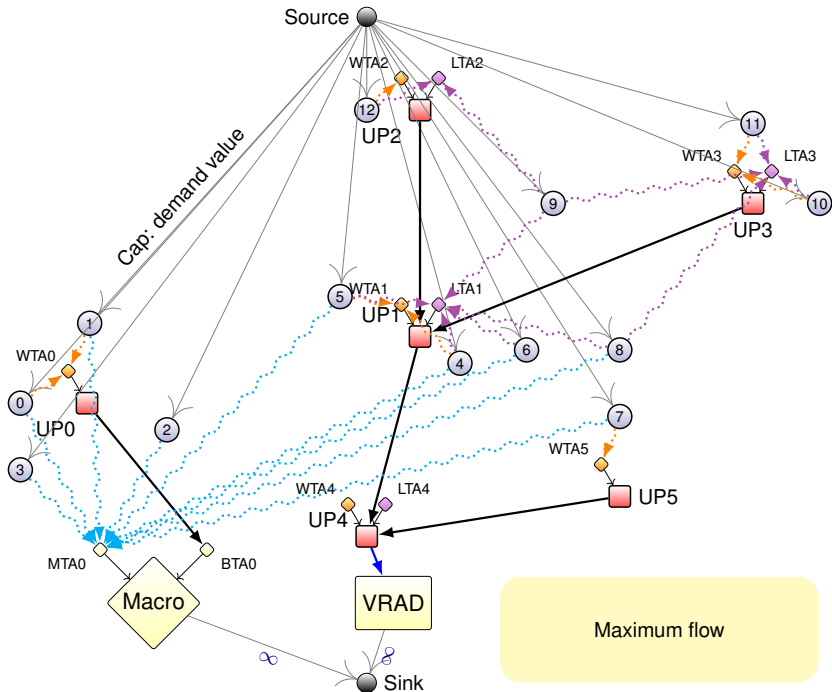


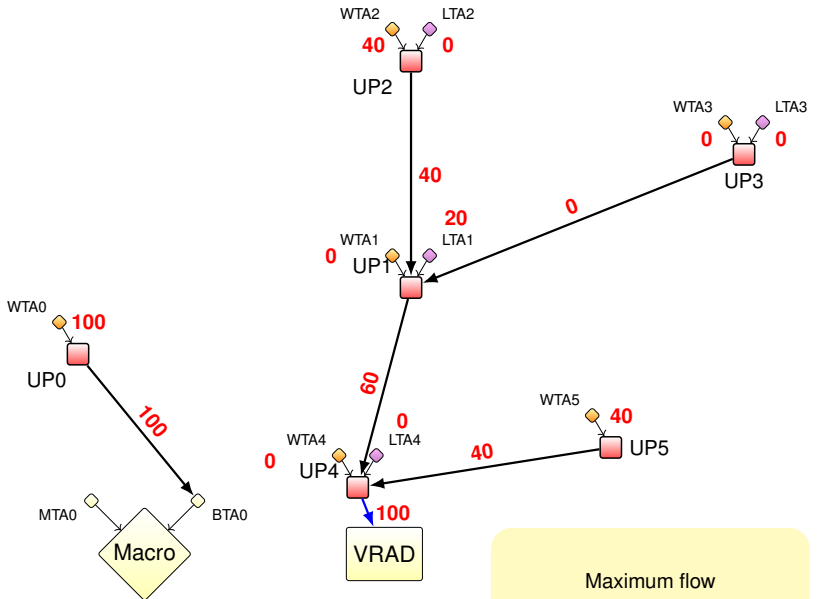


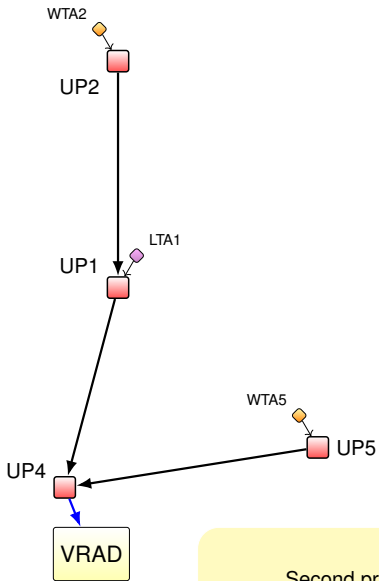
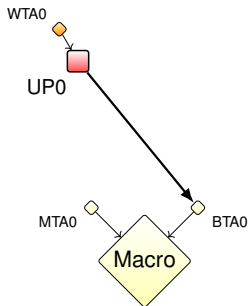


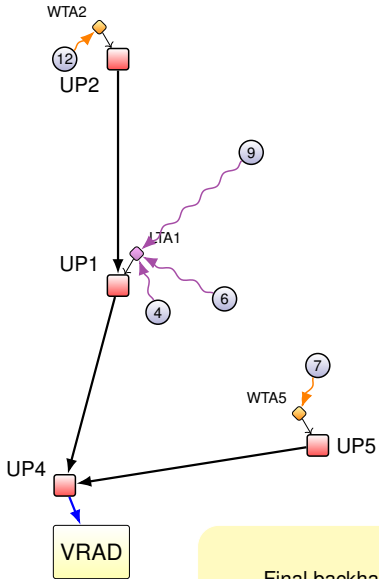
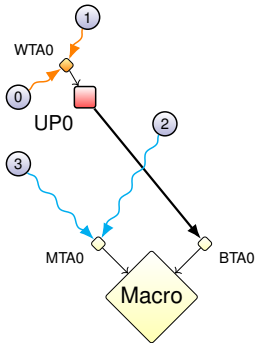












Final backhaul forest

## Maximum flow

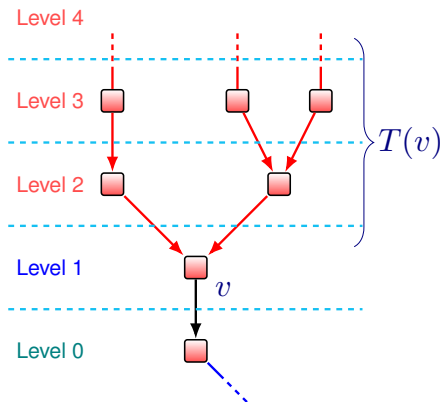
$$\begin{array}{ll}\text{Flow conservation:} & F_a^i + F_b^i = F_b^o \\ \text{Maximum wireless backhaul flow:} & F_b^i + F_b^o \leq C\end{array}$$

- Optimal maximum flow via linear programming: **Too slow** to apply in decoder!
- **Heuristic**: Limiting the backhaul capacity to  $C/2$  allows the use of fast combinatorial algorithms

# Maximum flow

## Lemma 1

If vertex  $v$  is in level 1 or above, then all **arcs above**  $v$  admit at most  $C/2$  of flow.



# Flow constraints

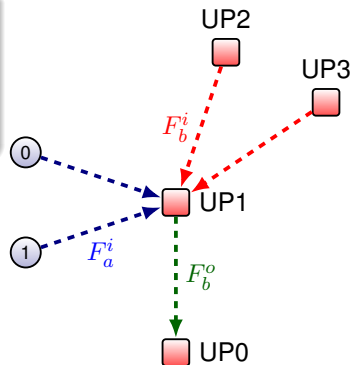
## Lemma 2

The *outgoing backhaul flow*  $F_b^o$  is maximum only if the *access flow* is maximum.

$$\begin{aligned} F_a^i + F_b^i &= F_b^o \\ F_b^i + F_b^o &\leq C \end{aligned}$$



$$F_a^i + 2F_b^i \leq C$$



# Agenda

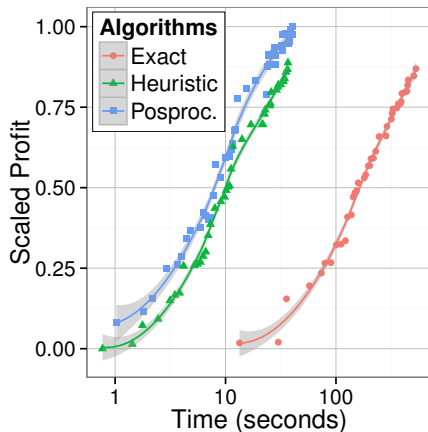
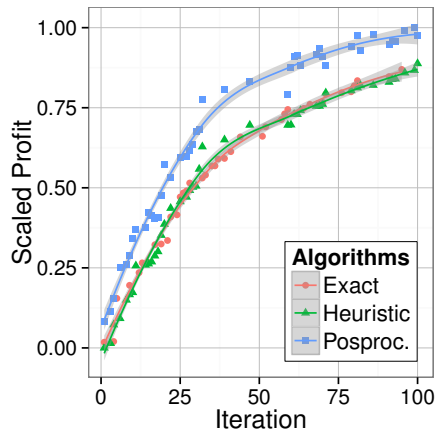
- 1 Mobile wireless data usage growth
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## Instances

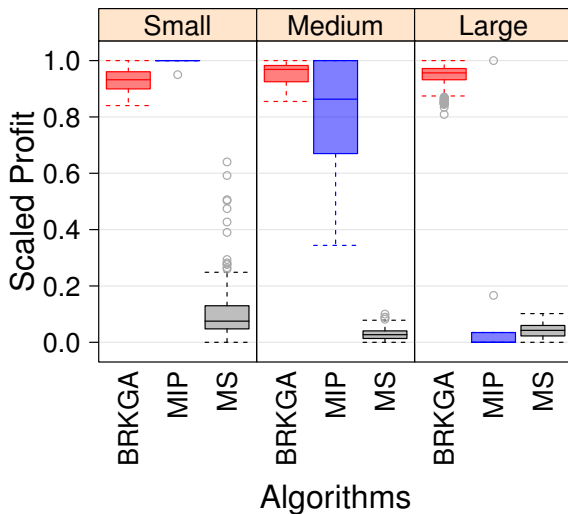
- 30 regions of the metropolitan area of a large city in the U.S.

Type	Poles	VRADs	Macros	Blocks	Demand (Mbps)	Area (km <sup>2</sup> )
Small	718	63	10	3907	8210.70	35.92
Medium	2281	86	14	17306	36348.00	72.14
Large	6396	243	22	25566	53601.00	132.87

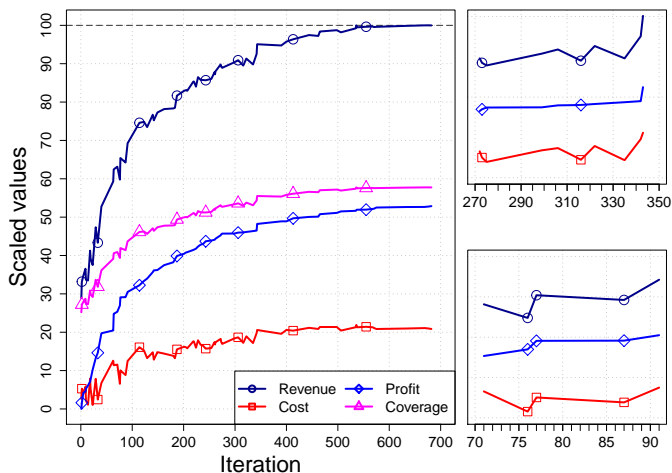
## Profit vs maximum flow



## Dispersion of profit – 1h experiment



## Evolution of revenue, cost, profit, and coverage



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## Final remarks

- Modified version of this BRKGA is used at a **large Tier 1 carrier** to design wireless backhaul networks
- Future research:
  - ▶ Introduce **local search** procedures in decoder
  - ▶ Develop a fast, exact, **combinatorial algorithm** to compute the maximum flow

# Thank you!

Tech report & slides are available at  
<http://mauricio.resende.info>

Paper is available at  
<http://bit.ly/1H1oZd4>