Self-optimizing Strategies for Dynamic Vertical Sectorization (VS) in LTE-Advanced Networks

Abdoulaye Tall [1], Zwi Altman [1] and Eitan Altman [2]

[1]Orange Labs {*abdoulaye.tall,zwi.altman*}*@orange.com*

[2]INRIA *eitan.altman@inria.fr*
OLN/RNM/REP/REM

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Overview

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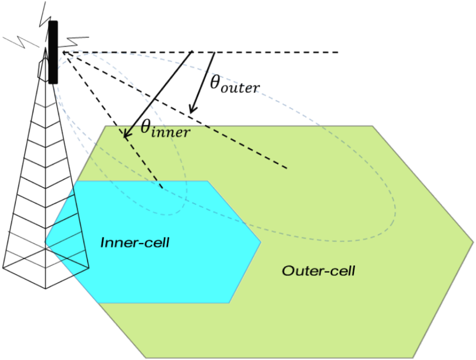
1. VS Description
2. Implementation Alternatives
3. Self-Optimizing Algorithms
4. Numerical Results
5. Conclusion

VS description

- Vertical separation of the two beams in the same sector
- Horizontal sector divided in two sectors, inner and outer cells with resp. vertical tilts θ_{inner} and θ_{outer} with $\theta_{\text{inner}} > \theta_{\text{outer}}$



- Transmit powers per Hz: P_i for inner cell and P_o for outer cell with $P_i + P_o = P$ where P is the total power budget.
- Possible implementations: bandwidth sharing or full reuse.

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VS with frequency reuse one

Description

- Both inner and outer sectors use the whole available bandwidth $W_i = W_o = W$.
- Total power budget of the original cell is split equally between inner and outer sectors $P_i = P_o = P/2$.

Advantages

- Bandwidth reuse leading to increased capacity.
- Increased antenna gain for inner cell users.

Drawbacks

- Reduced transmit power for each user.
- Inter-cell interference between inner and outer cells.

Requirement Self-Organizing Network (SON) controller for VS feature activation [1].

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[1] Trichias, K. et al., "Performance evaluation & SON aspects of vertical sectorisation in a realistic LTE network environment", ISWCS, 26-29 Aug. 2014, Barcelona (Spain).

VS with bandwidth sharing

Description

- Total frequency bandwidth orthogonally split between inner and outer sectors $W_i + W_o = W$.
- Total power budget of the original cell is not split because transmit power per Hz does not change $W_i P_i + W_o P_o = WP$.

Advantages

- No Inter-cell interference between inner and outer cells.
- Increased transmit power for each user compared to reuse one.
- Increased antenna gain for inner cell users.

Drawbacks

- Reduced capacity because there is no reuse.

Problem Which sharing proportions for the frequency bandwidth?

Overview

Optimal bandwidth sharing

- Goal: share fairly the frequency bandwidth between inner and outer cells.
- Parameter: δ - proportion of bandwidth allocated to inner cell.
- Criteria: Alpha-fair utility of all users throughputs.

$$U_\alpha(\delta) = \begin{cases} \sum_{u \in \mathcal{U}_i} \log\left(\delta \bar{R}_u\right) + \sum_{u \in \mathcal{U}_o} \log\left((1-\delta)\bar{R}_u\right) & \alpha = 1 \\ \sum_{u \in \mathcal{U}_i} \frac{\left(\delta \bar{R}_u\right)^{1-\alpha}}{1-\alpha} + \sum_{u \in \mathcal{U}_o} \frac{\left((1-\delta)\bar{R}_u\right)^{1-\alpha}}{1-\alpha} & \alpha \neq 1 \end{cases}$$

where $\mathcal{U}_{i/o}$ are resp. the sets of users in inner and outer cells, $\bar{R}_u$ is the data rate of user u when his serving cell is allocated the entire bandwidth.

- $\alpha = 0 \mapsto$ total throughput maximization
  $\alpha = 1 \mapsto$ proportional fair utility
  $\alpha = 2 \mapsto$ mean file transfer time
  $\alpha = +\infty \mapsto$ max-min fairness.

Algorithm for optimal δ ($\alpha = 0$)

Maximum throughput utility

$$U_0(\delta) = \sum_{u \in \mathcal{U}_i} \delta \bar{R}_u + \sum_{u \in \mathcal{U}_o} (1-\delta) \bar{R}_u$$

- **Problem:** find maximum of a linear function
- **Solution:** The entire bandwidth is allocated to one of the inner and outer cells.

Algorithm

$$\delta = \begin{cases} 0 \text{ if } \sum_{u \in \mathcal{U}_i} \bar{R}_u > \sum_{u \in \mathcal{U}_o} \bar{R}_u \\ 1 \text{ otherwise} \end{cases}$$

- **Interpretation:** Serve inner/outer cell only if outer/inner cell is empty.

Algorithm for optimal δ ($\alpha = 1$)

Proportional Fair utility

$$U_1(\delta) = \sum_{u \in \mathcal{U}_i} \log\left(\delta \bar{R}_u\right) + \sum_{u \in \mathcal{U}_o} (1-\delta)\bar{R}_u$$
$$= C + N_i \log(\delta) + N_o \log(1-\delta)$$

where $N_i = |\mathcal{U}_i|$ and $N_o = |\mathcal{U}_o|$ are the number of users in the inner and outer cells and C is a real constant.

- **Method:** Convex optimization (K.K.T optimality conditions).
- **Solution:** The bandwidth is shared according to the proportion of inner cell users in the total number of users.

Algorithm

$$\delta = \frac{N_i}{N_i + N_o}$$

- **Interpretation:** Logarithm function allows to decouple the utility from the channel conditions of users.

Algorithm for optimal δ $(\alpha > 0, \alpha \neq 1)$

General Alpha-Fair utility

$$U_\alpha(\delta) = \sum_{u \in \mathcal{U}_i} \frac{\left(\delta \bar{R}_u\right)^{1-\alpha}}{1-\alpha} + \sum_{u \in \mathcal{U}_o} \frac{\left((1-\delta)\bar{R}_u\right)^{1-\alpha}}{1-\alpha}$$

- **Method:** Convex optimization (K.K.T optimality conditions) + Stochastic approximation because $\bar{R}_u$ are estimated.
- **Solution:** A stochastic gradient descent which is updated every time a new estimate of average data rates is acquired.

Algorithm

$$\delta[k+1] = \delta[k] + \epsilon \frac{\partial \hat{U}_\alpha(\delta[k])}{\partial \delta}$$

- **Interpretation:** For $\alpha > 0, \alpha \neq 1$, the utility is impacted by the average data rate of each user in the system so the optimal solution must consider that.

A threshold-based SON controller

Problem At low to medium traffic demand, VS with bandwidth sharing performs better than VS with reuse one, the opposite holds for high traffic demand.
Solution Switch between the two implementations according to traffic demand.

Algorithm VS implementation SON controller

Initialization:
Activate VS feature with **bandwidth sharing**
loop:
for $k \in \mathbb{N}, k > 0$ **do**
  Estimate the inner and outer loads during time interval k
  if VS uses **bandwidth sharing** and $\max(\rho_i^{\text{no reuse}}, \rho_o^{\text{no reuse}}) \geq \rho_{th}$ **then**
    Activate VS feature with **reuse one**
  if VS uses **reuse one** and $\max(\rho_i^{\text{reuse one}}, \rho_o^{\text{reuse one}}) < \rho_{th}$ **then**
    Activate VS feature with **bandwidth sharing**

Overview

Simulation Parameters

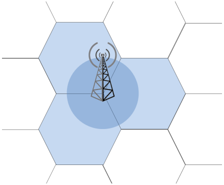

Figure: Network Layout

Table: Network and Traffic characteristics

Network parameters	
Number of interfering macros	6 $\times$ 3 sectors
Macro Cell layout	hexagonal trisector
Intersite distance	500 m
Bandwidth	10MHz
Inner Cell Antenna Tilt	18°
Outer Cell Antenna Tilt	12°
Antenna Tilt Type	Electrical only
Channel characteristics	
Thermal noise	-174 dBm/Hz
Macro Path loss (d in km)	$128 + 36.8 \log_{10}(d)$ dB
Traffic characteristics	
Traffic spatial distribution	uniform
Service type	FTP
Average file size	6 Mbits

Increased Network Stability

The loads grow more slowly as the traffic demand increases.
Baseline: No VS feature enabled.

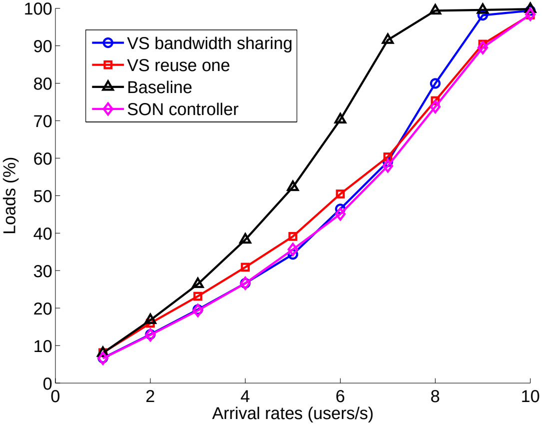

Figure: Maximum loads for increasing traffic demand

Mean User Throughput improved: always best provided by SON controller

VS bandwidth sharing improves performance for a large range of traffic demand. SON controller switch to VS reuse one allows to always get the best performance.

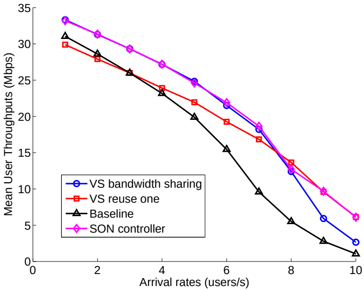

Figure: Mean User Throughput improvement

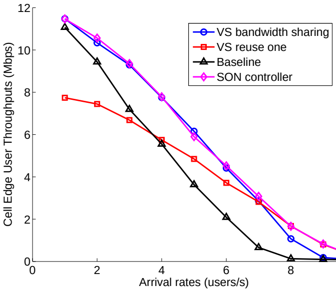

Figure: Cell Edge Throughput improvement

Overview

Conclusion

Main results

- VS with reuse one does not always improve performance.
- VS with bandwidth sharing allows to exploit down-tilted antenna for low to medium traffic demand.
- Simple algorithms based on convex optimization and stochastic approximation are provided for fair sharing of the bandwidth.
- A SON controller can be used to automatically switch between bandwidth sharing and reuse one.

Next challenges

- Learning algorithm for the threshold in the SON controller.
- Upgrade of the methods to virtual sectorization with antenna arrays (IWSON 2015).

Thank You for Your Attention!

Any questions are welcome