Optimale Platzierung von Decode-and-Forward Relays zur Maximierung der Zellspektraleffizienz

21. ComNets-Workshop Mobil- und Telekommunikation

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Outline

Motivation
Capacity Model
Simulated Annealing
Results
Conclusions

- Mobile Internet applications are becoming more and more popular
  - ➔ Increasing capacity demands for mobile radio networks

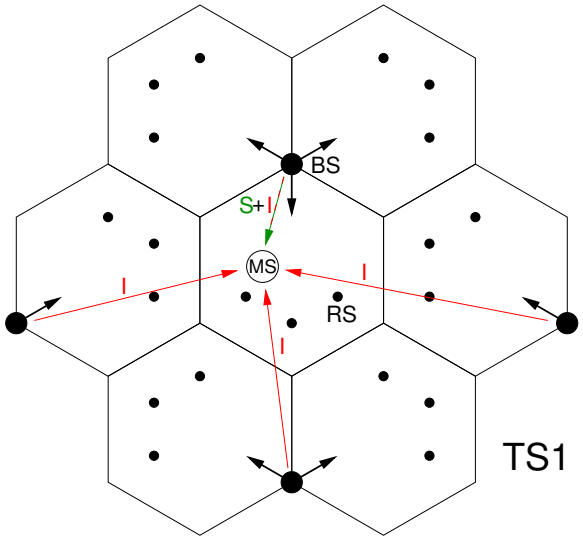
  But: Radio resources are scarce

  - ➔ Increase Cell Spectral Efficiency (CSE) through frequency reuse-1
  - ➔ Strong interference at cell edges
  - ➔ Idea: Relay Stations (RSs) for interference management
- Ubiquitous mobile services require same quality of service independent of current Mobile Station (MS) position
  - ➔ Rate Fair (RF) scheduling
- Down-Link (DL) transmission is expected to become the bottle neck (compare to fixed access technologies like ADSL)
  - ➔ Focus on DL transmission

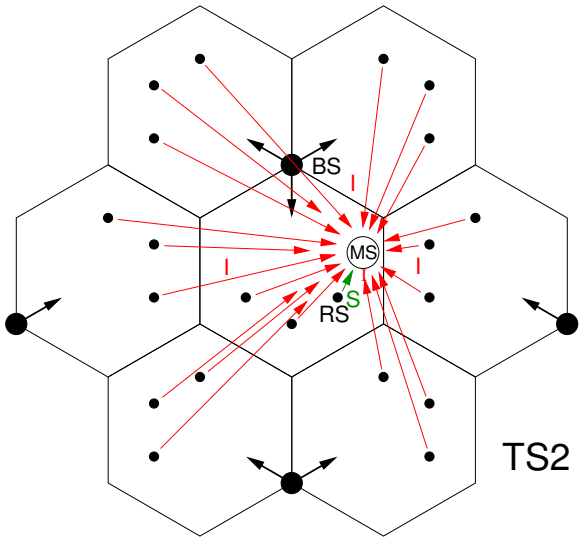
How many RSs and where shall they be placed within a cell to maximize CSE and what are potential gains under RF scheduling in DL direction?

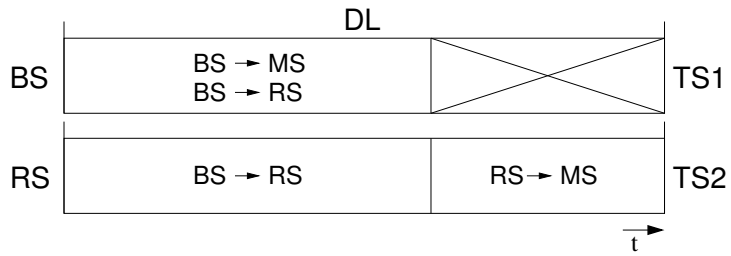
Transmission Schemes (TSs)

- TS 1 - All BSs operate simultaneously
  - BSs serve MSs and RSs associated to them
  - MSs receive strong interference from cells co-located to their serving Base Stations (BSs)
  - MSs at cell edges receive harmful interference from neighboring sites



- TS 2 - All RSs operate simultaneously
  - All RSs serve associated MSs concurrently within the same cell
  - No interference from co-located stations
  - More interferer in closer distance than during TS 1





Capacity Calculation

The link capacity C calculates to:

$$C = M \cdot \mathrm{ld}\left(1 + \min(SINR_{eff}, 20\,\mathrm{dB})\right)$$

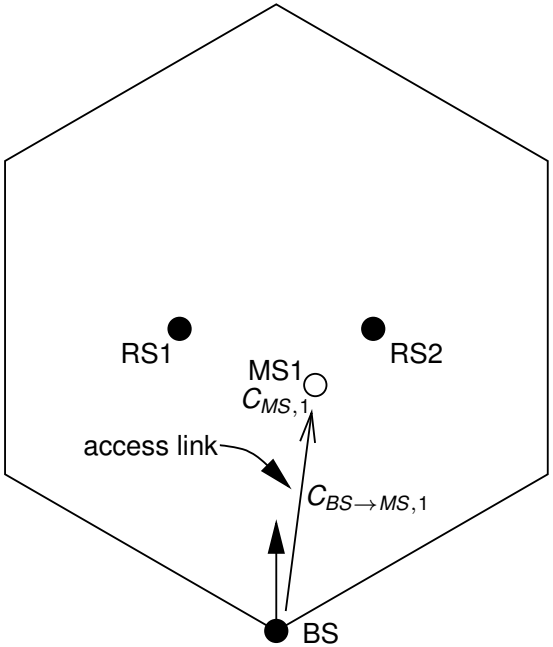
- MIMO channel with M spatial streams
- SINR mapped to $SINR_{eff}$ owing to MIMO transmission
- Clipping at 20dB as no current standard exploits higher levels

The CSE under RF scheduling calculates to:

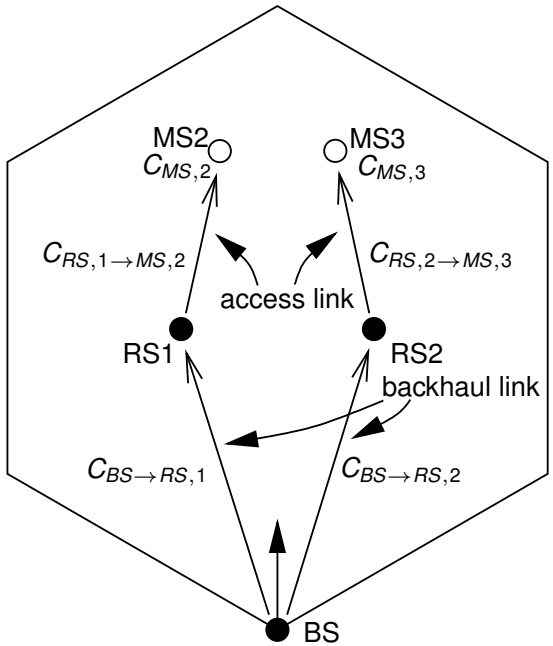
$$C_{RF} = \left(\frac{1}{N}\sum_{i=1}^{N} C_{MS,i}^{-1}\right)^{-1}$$

- N MSs regularly distributed across the site
- Amount of resources needed by each MS under RF scheduling is proportional to the time per bit needed for transmission which in turn is the inverse of link capacity.

Link Capacity



Single-hop transmission



Multi-hop transmission

- Single-hop Transmission: $C_{MS,1} = C_{BS\rightarrow MS,1}$
- Multi-hop Transmission
  - Backhaul link transmissions are successive
  - Access link transmissions are simultaneous

Assuming symmetry the link capacities calculate to:

$$C_{MS,2} = \left(C_{BS\rightarrow RS,1}^{-1} + \frac{1}{2} C_{RS,1\rightarrow MS,2}^{-1}\right)^{-1}, C_{MS,3} = \left(C_{BS\rightarrow RS,2}^{-1} + \frac{1}{2} C_{RS,2\rightarrow MS,3}^{-1}\right)^{-1}$$

Association Strategies

1. Maximum SINR (max. SINR)

$$\max_{i \in BS \cup RS} (SINR_{eff,i \to MS})$$

   - Common in current mobile radio networks
   - Easy to implement

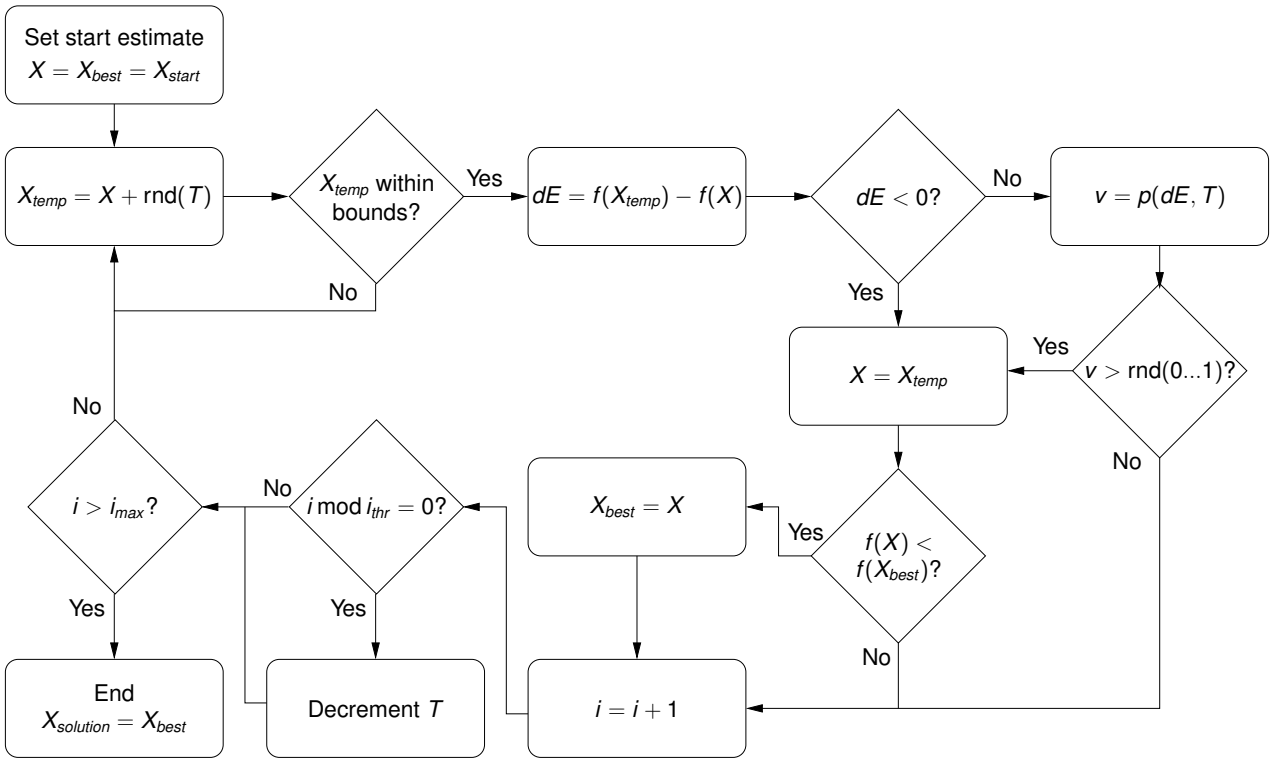
2. Maximum capacity (max. Cap)

$$\max_{\substack{i \in BS, \\ j \in RS}} \left(C_{i \to MS}, \left(C_{i \to j}^{-1} + \frac{1}{N} C_{j \to MS}^{-1} \right)^{-1} \right)$$

   - N is the number of RSs per cell
   - Leads to theoretical upper bound capacity
   - Hard to implement

Algorithm

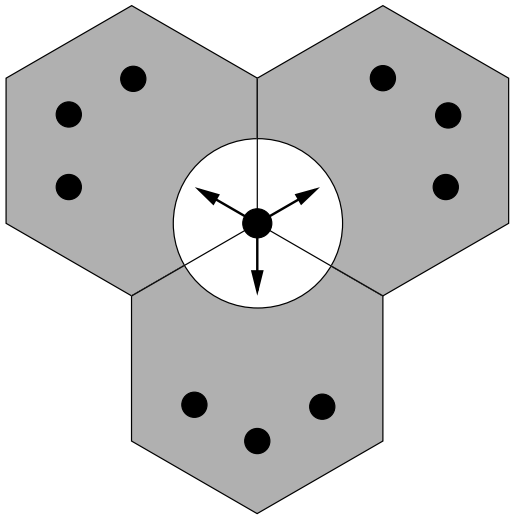
- **f**(**X**): Cost function to be minimized
- $\mathbf{X} = (\mathbf{x_1}, \mathbf{x_2}, \ldots.)$: Parameters to be optimized over
- **T**: Current "temperature" of the system
- **rnd**(**Y**): Random number generating function
- **p**(**dE**, **T**): Probability threshold function
- **i**: Number of iterations representing time



Application

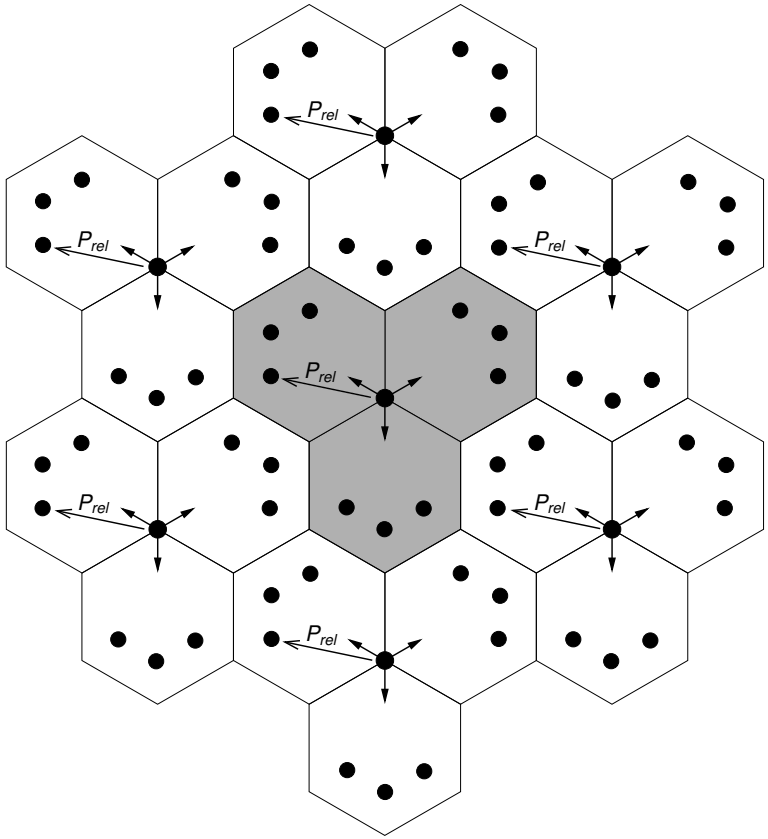
Goal: Optimize placement of RSs within the cells of a site

- Each RS may move within the grey-colored area of its serving BS cell (bounding function)
- CSE for mean SINR is optimized (cost function)
- In each simulated annealing iteration step the position of only one RS is changed (problem is assumed to be separable)
- RS height is optimized for all stations together
- Evaluation by Monte-Carlo simulation
  - ➔ Multiple runs with different seeds for the random number generator
  - ➔ Confidence levels for results can be provided

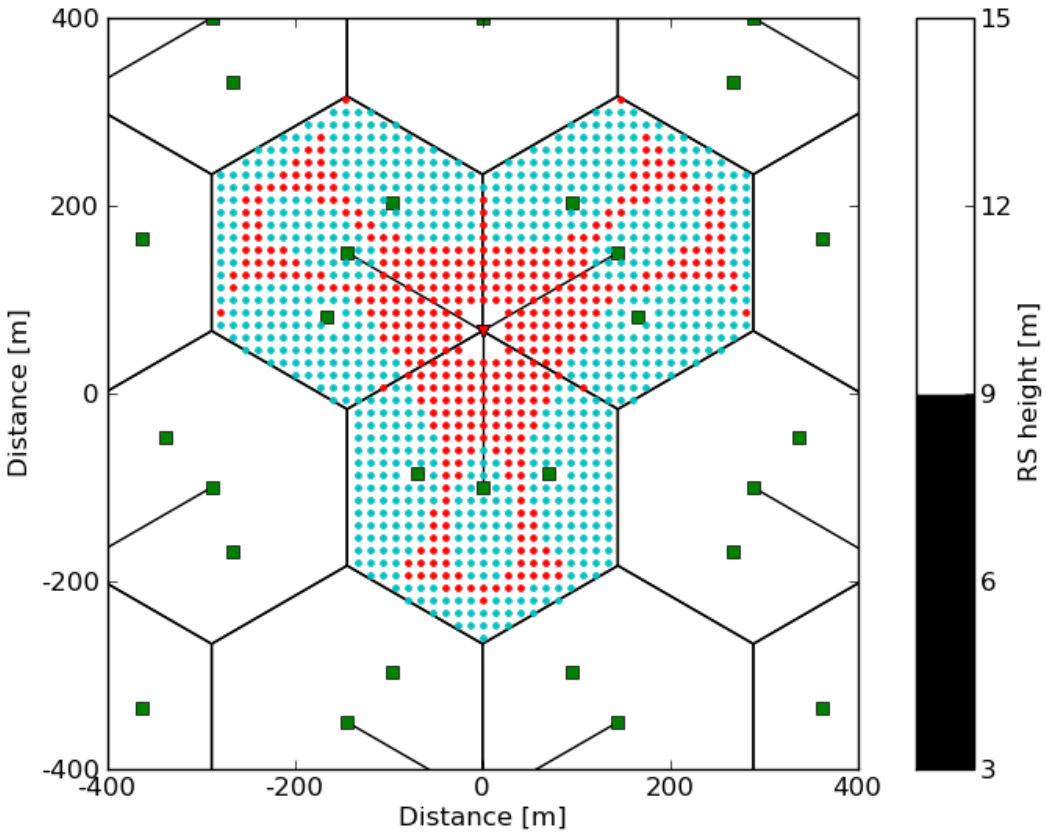


Scenario

- IMT-Advanced compliant setup
  - Hexagonal cells with 500 m inter-site-distance
  - Urban-Macro (UMa) channel model for BS→MS and BS→RS links
  - UMa channel model with probability for LoS/NLoS decision taken from Urban-Micro channel model for RS→MS links
- Various numbers of RSs per cell (0...5)
- RSs are properly placed
  - LoS link to serving site
  - NLoS links to interfering sites
- Evaluation of grey-colored cells, only, to correctly model interference also at cell edges
- Relative positions P_{rel} of RSs in surrounding sites match P_{rel} in center site
- BS transmit power: 47 dBm
- RS transmit power: 30 dBm
- Full buffer traffic model

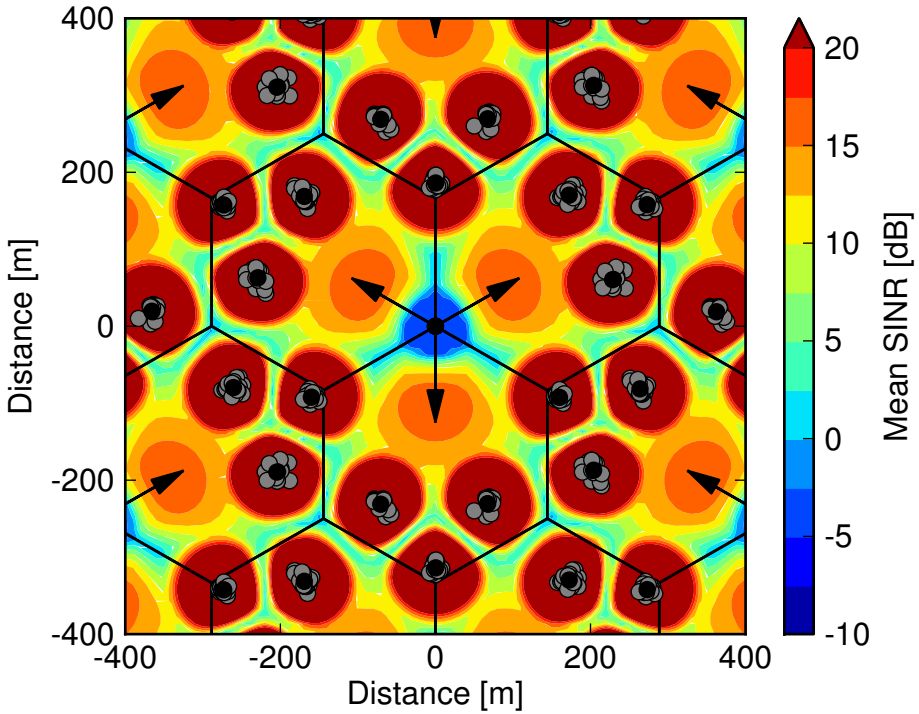


Simulated Annealing Run



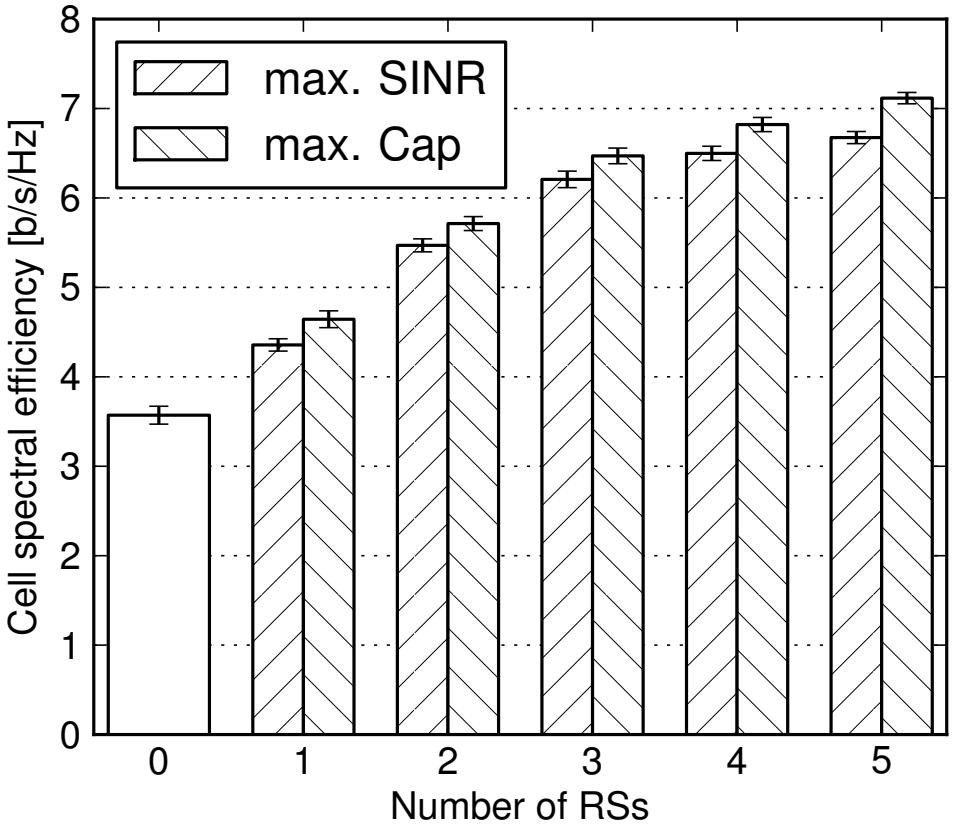
- MSs are placed in a regular grid (dots)
- Red dots indicate MSs associated to BSs blue dots MSs associated to RSs
- Initially, all RSs are placed on a circle around site center
- Each run takes 4,000 iteration steps

Optimal Placement and SINR Distribution



- Grey-colored dots represent results for 20 different Monte-Carlo simulation runs
  - Results of runs match very well
  - Confidence levels are invisible
- Best server chart of mean SINR for mean RS positions (black dots)
  - Areas served by RSs are mainly noise-limited
  - More away from RSs the SINR drops significantly
  - RSs at BS antenna boresights serve substantial areas of neighboring sites
- Optimal RS height is about 5 m

Cell Spectral Efficiency



- CSE increase up to a factor of two considering the full IMT-Advanced channel model (LoS/NLoS links, shadowing)
- Only minor additional gain for more than 3 RSs per cell
- Capacity under “max. SINR” close to “max. Cap”
- Small variance in results (error bars indicate 95 % confidence levels)

- RSs almost double CSE under RF scheduling
- 3 RSs per cell seem to be a good trade-off between RS cost and CSE gain
- RSs shall be mounted at low heights (around 5 m) so that they operate mostly noise-limited
- RSs at cell edges also serve substantial areas of neighboring sites

➔ **RSs efficiently increase CSE in frequency reuse-1 mobile radio networks under RF scheduling**

Thank you for your attention.

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