Optimal Relay Deployment for Robust Multihop Multicast Scheduling in Cellular Wireless Networks

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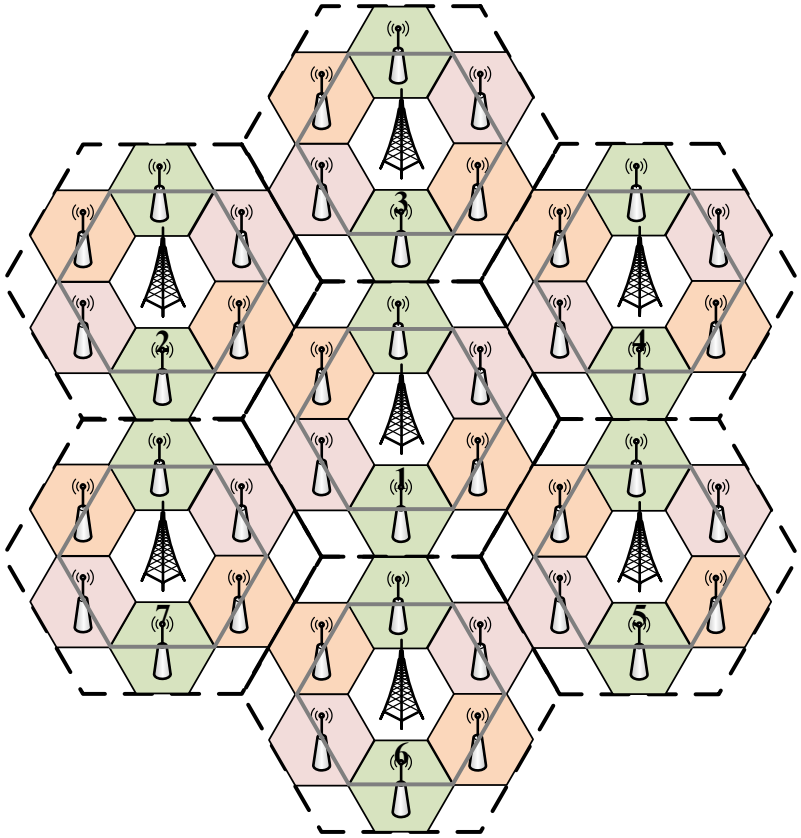
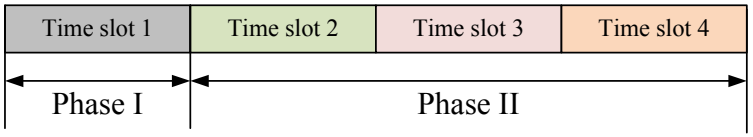
Introduction and Objectives

- Efficiently **multicasting critical messages** is very important in cellular wireless network especially **a base station failed**.
- **Two-Phase Coloring oriented adaptive-rate relay-aided scheduling algorithms** are proposed.
- The **optimal locations** of relay station nodes to **maximize system throughout rate** in each cell are studied.





System Model - Some Assumptions

- Channel propagation gain:

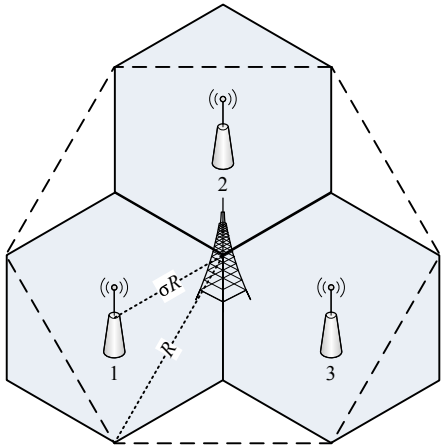
$$G_{ij} = \frac{K}{d_{ij}^{\alpha}}, \qquad (1)$$

  - K is pass loss factor
  - α is path loss exponent
  - d_{ij} is the distance between node i and j

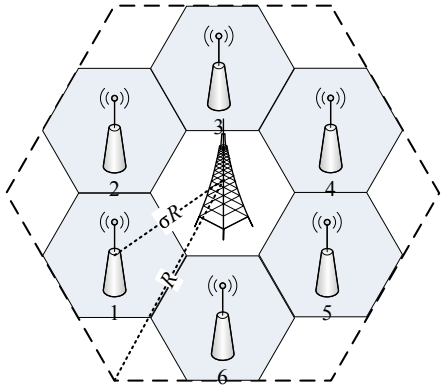
- Shannon Formula:

$$\eta = W \log_2 (1 + \gamma), \qquad (2)$$

  - W is prescribed bandwidth
  - γ is measured SINR
  - AWGN channel model



(a) 3 RSs



(b) 6 RSs

Throughput Capacity Rate Analysis

- Four operations:
  - Operation 1: Pre-failure without Relay Stations (RSs)
  - Operation 2: Pre-failure with Relay Stations (RSs)
  - Operation 3: Post-failure without Relay Stations (RSs)
  - Operation 4: Post-failure with Relay Stations (RSs)
- Full coverage:
  - Guaranteeing the most critical position (CM) experiencing the worse signal to noise plus interference ratio (SINR).

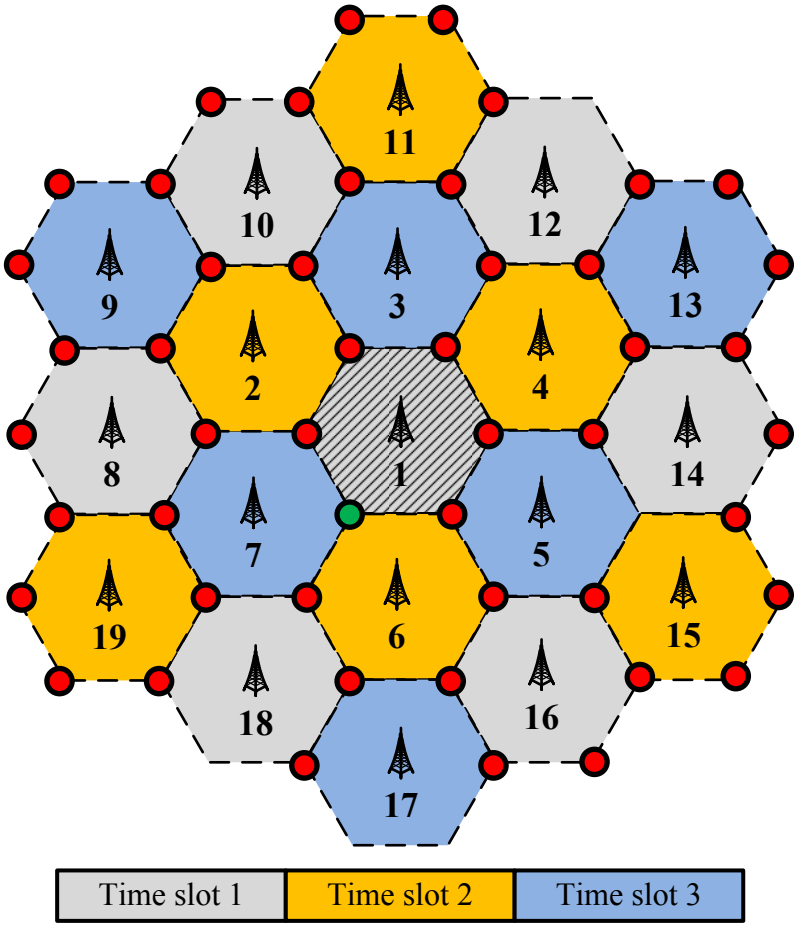
Operation 1: Pre-failure without Relay Stations

- The SINR at CM under the use of a reuse-k scheduling scheme is given by

$$\gamma_k = \frac{\frac{P_M K}{d^{\alpha}_{(1,\mathrm{CM}_1)}}}{\sum_{i \in B_k \setminus \{1\}} \frac{P_M K}{d^{\alpha}_{(i,\mathrm{CM}_1)}} + N}. \quad (3)$$

- The system's (per BS) throughput capacity rate is given as:

$$\eta_k = \frac{1}{k} \log_2 (1 + \gamma_k) \left[\frac{\mathrm{bps}}{\mathrm{Hz} \cdot \mathrm{Cell}} \right]. \quad (4)$$



Operation 2: Pre-failure with Relay Stations - Phase I

- The SINR (γ_{I,k_1}) during phase I:

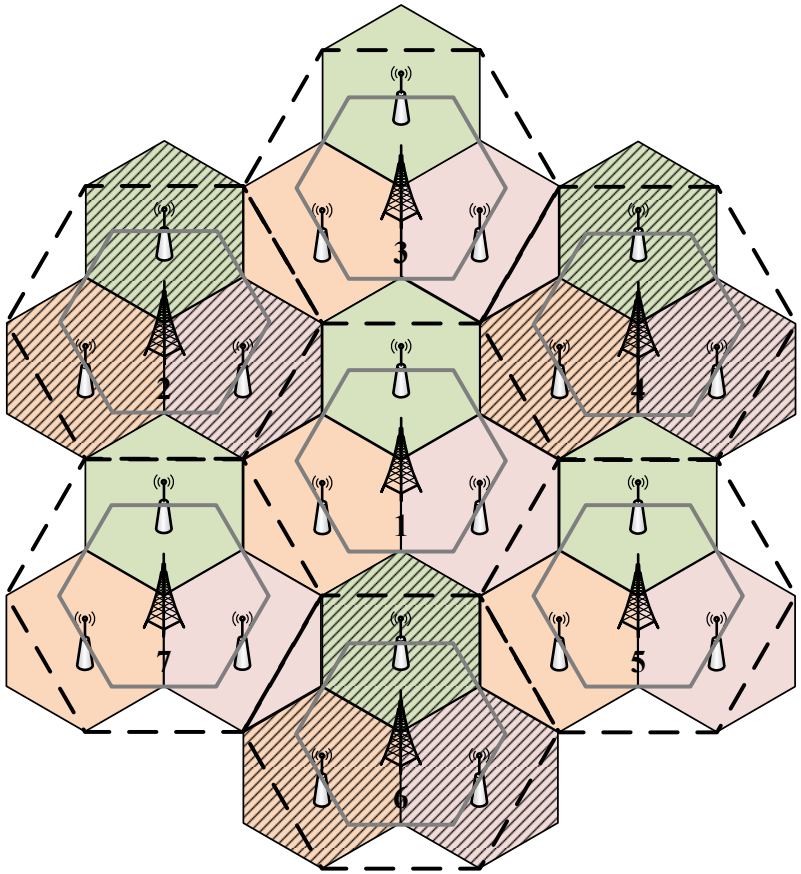
$$\gamma_{\mathrm{I},k_1} = \frac{\frac{P_M K}{d^{\alpha}_{(1,\mathrm{RS}_1)}}}{\sum_{i \in B_{k_1} \setminus \{1\}} \frac{P_M K}{d^{\alpha}_{(i,\mathrm{RS}_1)}} + N}, \quad (5)$$

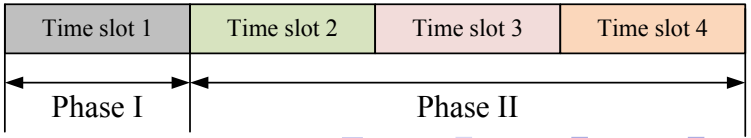
where N is the noise power.

- The time period (T_{I,k_1}) during phase I:

$$T_{\mathrm{I},k_1} = \frac{L}{\frac{1}{k_1} \log_2 \left(1 + \gamma_{\mathrm{I},k_1}\right)}, \quad (6)$$

where L is the average packet length.





Operation 2: Pre-failure with Relay Stations - Phase II

- The SINR (γ_{II,k_1}) during phase II:

$$\gamma_{\mathrm{II},k_2} = \frac{\frac{P_m K}{d^{\alpha}_{(\mathrm{RS}_1,\mathrm{CM}_1)}}}{\sum_{(i,j)\in R_{k_2}\setminus\{(1,1)\}} \frac{P_m K}{d^{\alpha}_{(\mathrm{RS}(i,j),\mathrm{CM}_1)}} + N}. \tag{7}$$

- The time period (T_{II,k_1}) during phase II:

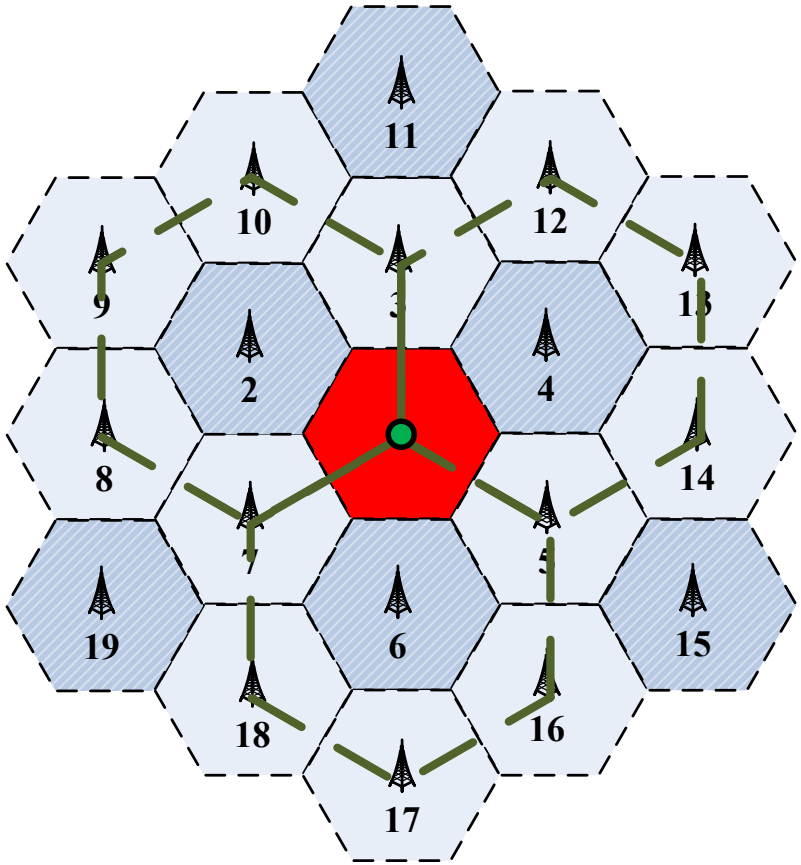
$$T_{\mathrm{II},k_2} = \frac{L}{\frac{1}{k_2}\log_2\left(1+\gamma_{\mathrm{II},k_2}\right)}. \tag{8}$$

- The attained system's throughput:

$$\eta_{k_1,k_2} = \frac{L}{W\left(T_{\mathrm{I},k_1} + T_{\mathrm{II},k_2}\right)} \left(\frac{\mathrm{bps}}{\mathrm{Hz}\cdot\mathrm{Cell}}\right). \tag{9}$$

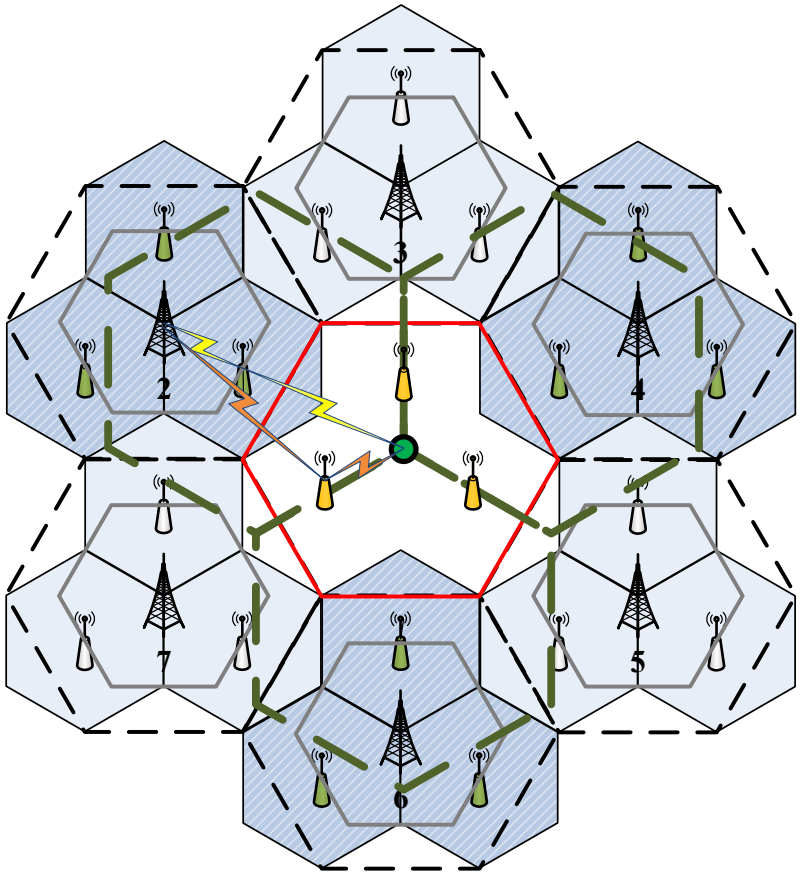
Operation 3: Post-failure without Relay Stations

- A BS that manages the central cell is failed.
- Only half of the BS nodes are activated and scheduled by using reuse-k.
- In analyzing such schemes, we have followed the methods described above.
  - The critical point is located at the failed cell's center.



Operation 4: Post-failure with Relay Stations

- During Phase I, it is the same with the case under pre-failure.
- During phase II, only a subset of the (shaded) relay nodes is activated and scheduled by using reuse-k.

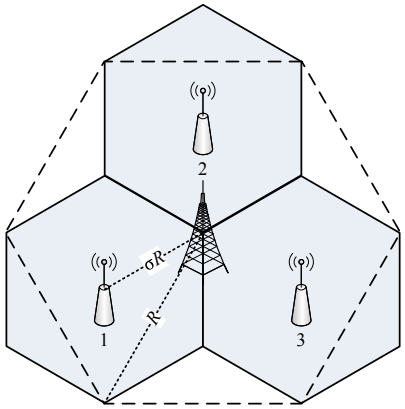


Optimal Deployment Problem Formulation

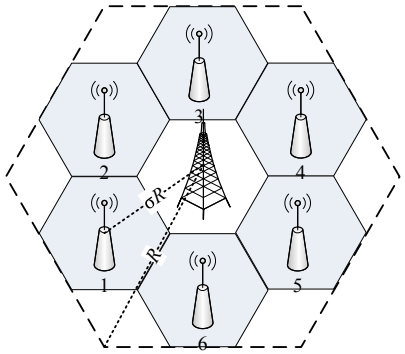
- The optimal deployment problem formulation:

$$\max_{\sigma:0\leq\sigma\leq\frac{\sqrt{3}}{2}} \eta_{k_1,k_2}(\sigma), \qquad (10)$$

where $k_1 = 1, 3, 4, 7$, $k_2 = 1, 3, 4, 7$ under 3-RS scenario, and $k_2 = 1, 2, 3, 6$ under 6-RS scenario.



(c) 3 RSs

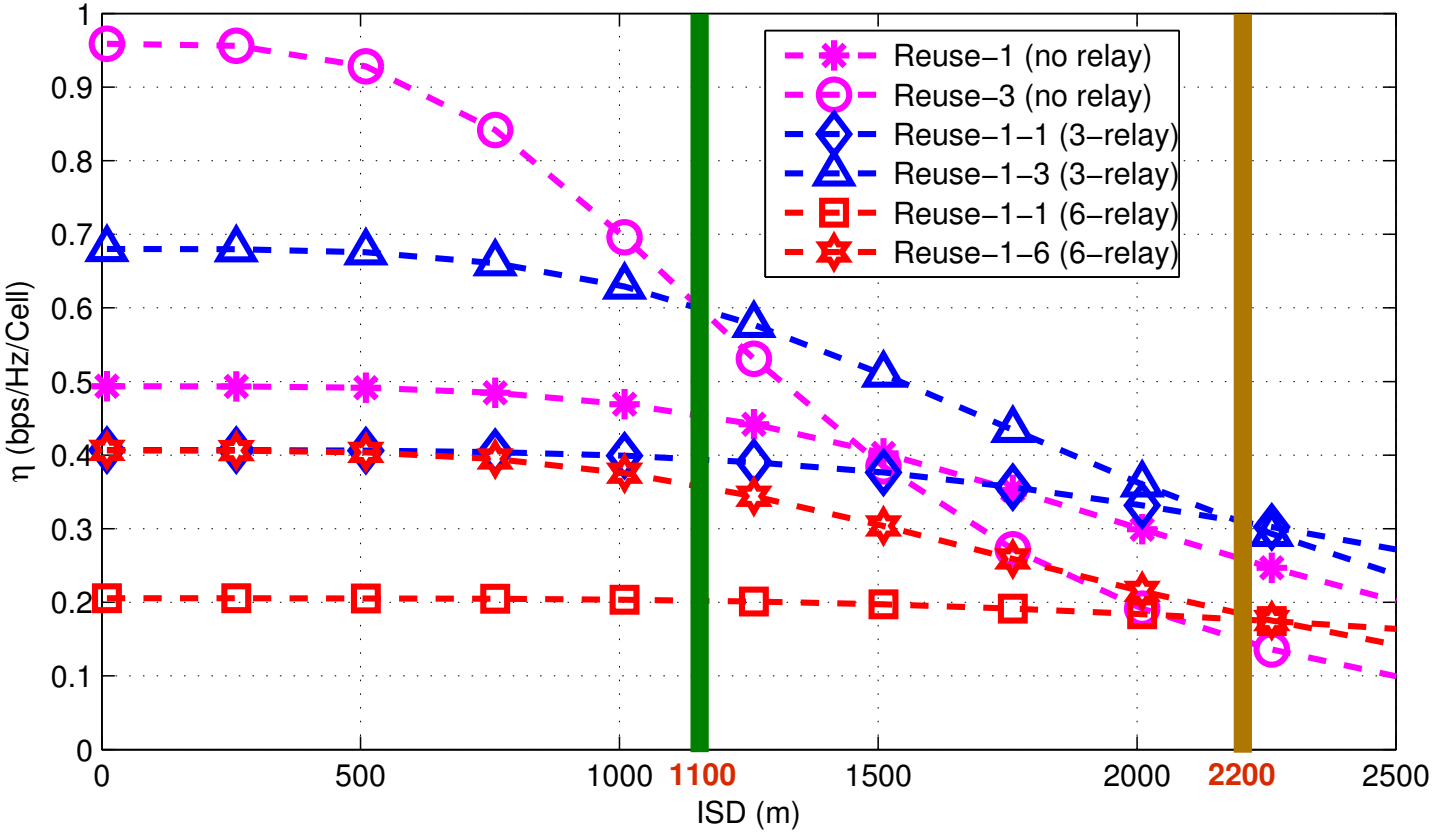


(d) 6 RSs

Performance Evaluation - Parameter Setup

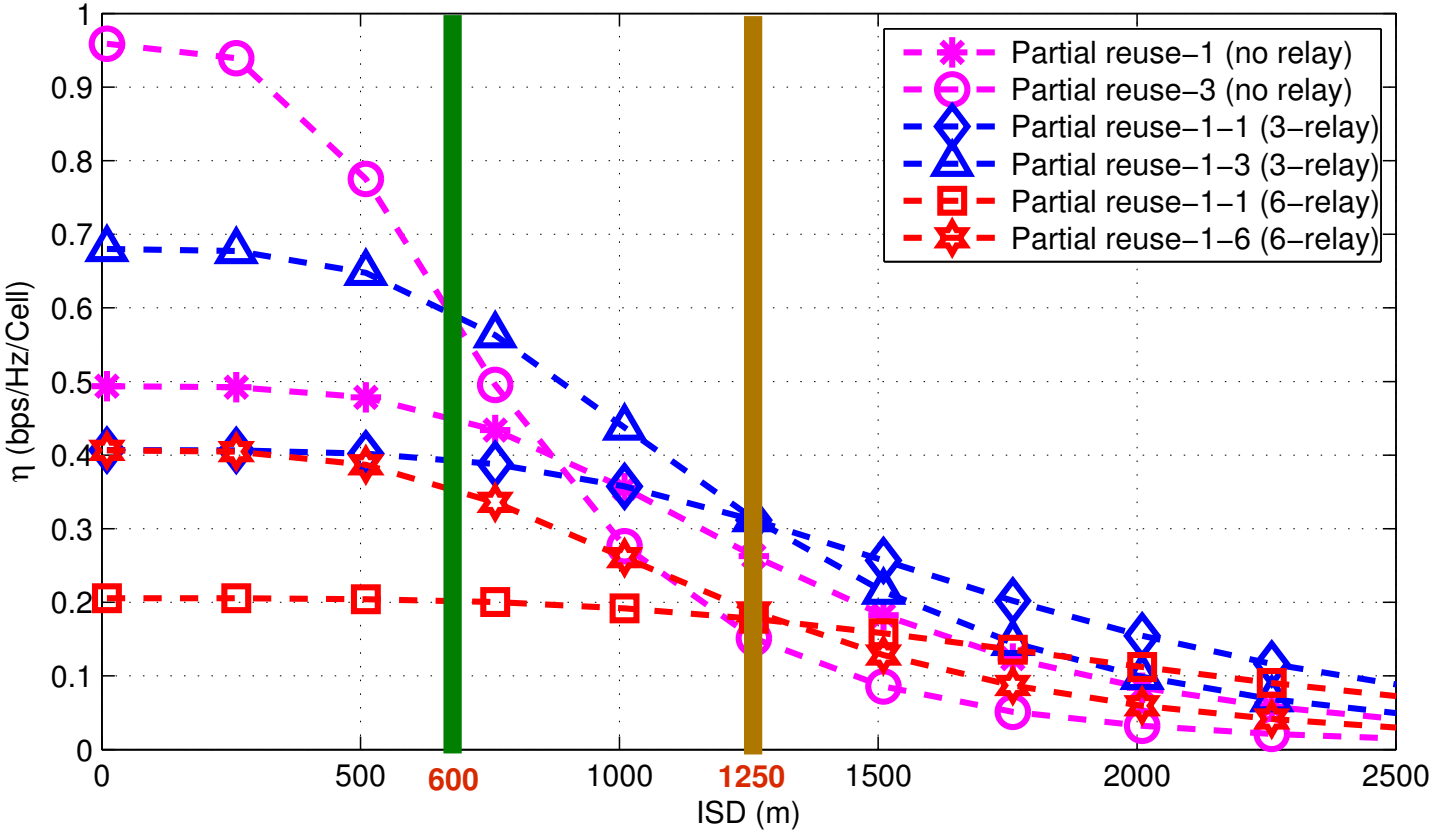
- $P_M = 20$ W, $P_m = 10$ W.
- The noise power density level N_0 is set to be -174 dBm/Hz, as often assumed for LTE models [8, 9].
- The bandwidth for multicasting service is 5 MHz.
- The ISD range varies from 10 m to 2500 m.
- The path loss exponent (α) is set equal to 3.68, and the path loss constant level (K) is -40 dB.
  - Corresponding to a version of the urban COST Hata model [13]

Throughput Rate vs. ISD under **Pre-failure** Scenario



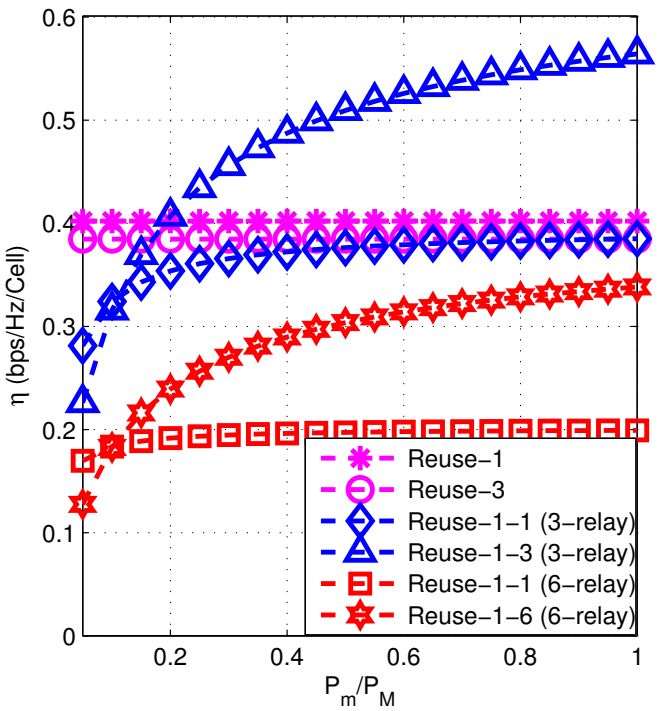
- For example, under ISD = 1500 m, the reuse-1-3 scheme attains an upgrade of 29.28%.
- The performance under 3-relay is better than that under 6-relay.

Throughput Rate vs. ISD under **Post-failure** Scenario

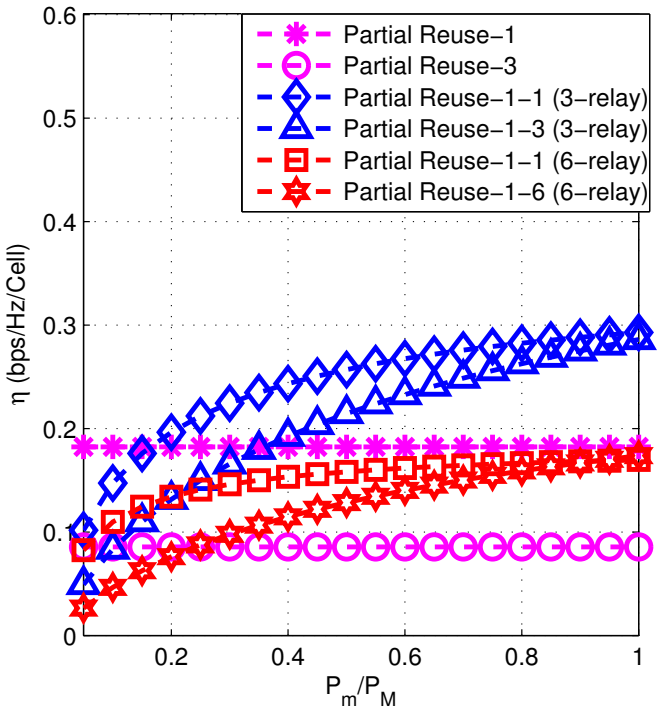


- For example, under ISD = 1500 m, the reuse-1-1 scheme improves 40.95%.
- The performance under 3-RS is also better than that under 6-RS.

Throughput Rate vs. $\frac{P_m}{P_M}$ at ISD = 1500m



(e) Pre-failure operation



(f) Post-failure operation

- Once $\frac{P_m}{P_M} \geq 0.2$, it leads to enhanced system performance.

Conclusions

- We investigate the **optimal locations of the RS nodes** such that they can yield the **highest throughput rate** for ***multicast services*** under pre-failure and post-failure operations.
  - When ISD level is short, it is best to adopt a *direct* reuse-3 adaptive rate multicast scheduling scheme.
  - When ISD level is long, we show that it is highly beneficial to employ RS nodes and to place them at optimal locations.
- The performance under 3-RS optimally placed per cell yields better performance than that under 6-RS nodes.

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