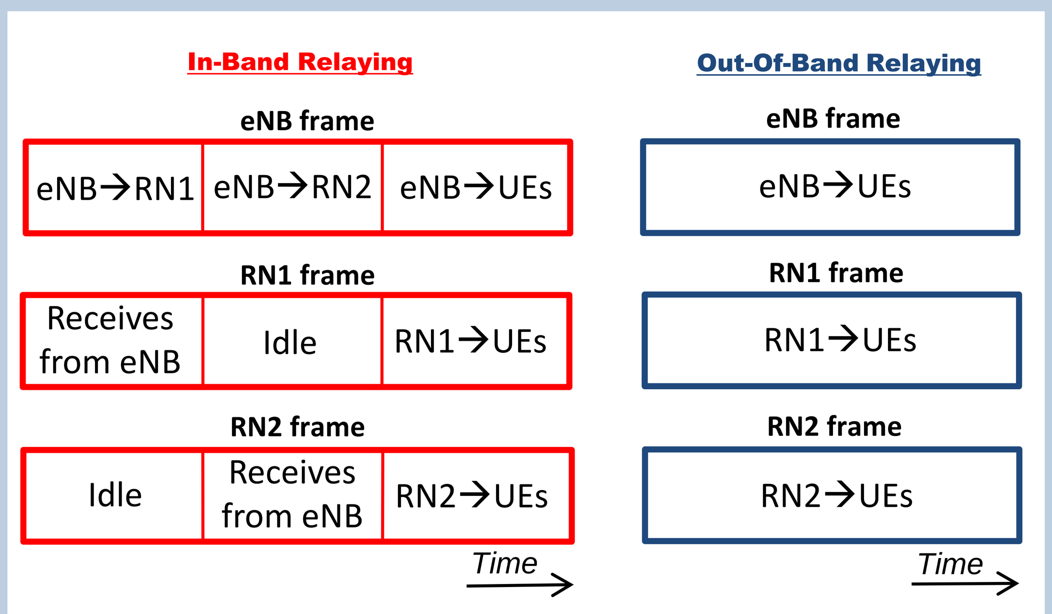
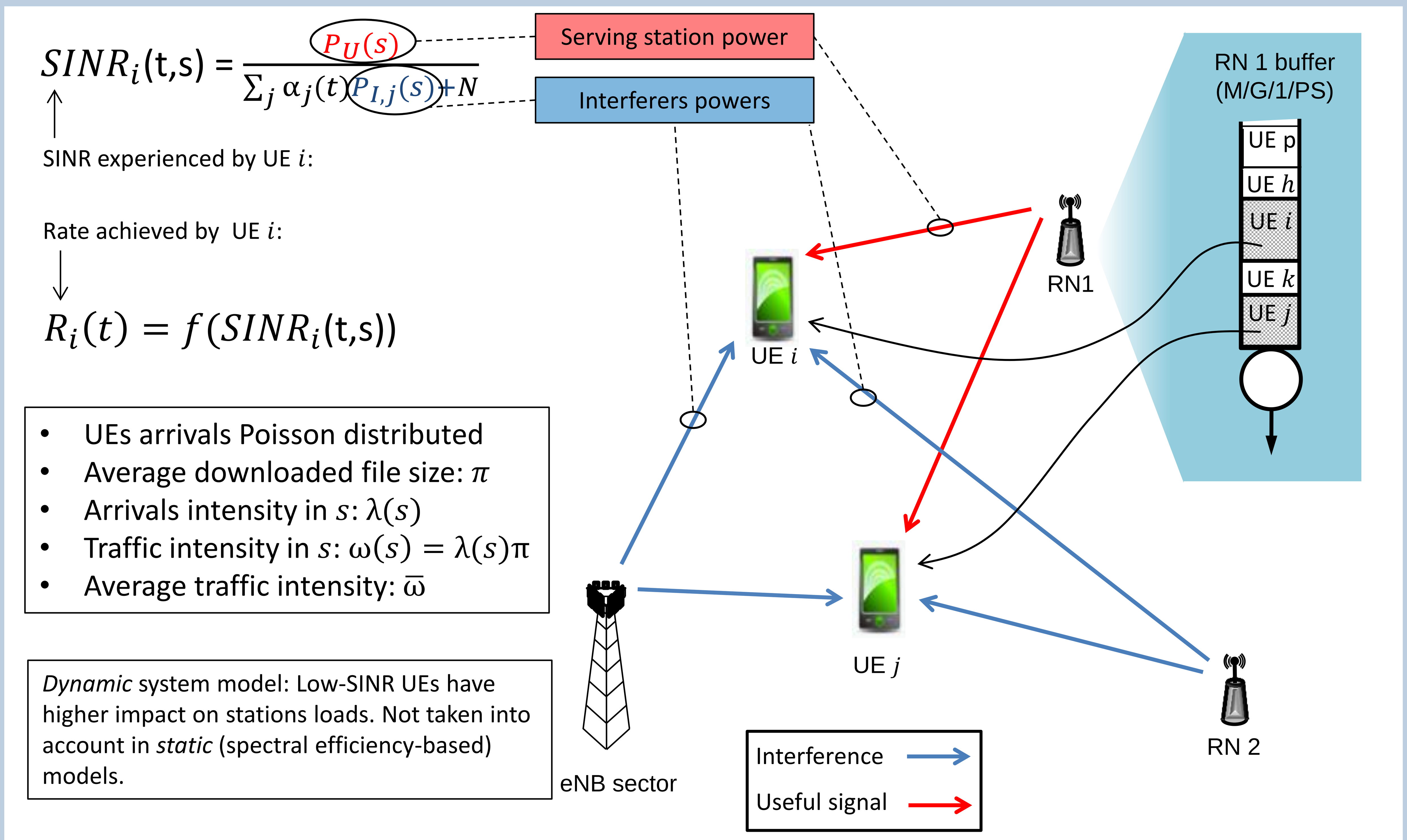
Capacity maximization in data-oriented mobile networks, through optimal placement of relay nodes

M. Minelli, M. Ma, M. Coupechoux, J.-M. Kelif, M. Sigelle, P. Godlewski

Network and Traffic Model

- **User Equipments** (UEs) arrive, download a file, and leave the network.
- A **Station** k serving at least one UE is *active*, i.e., it transmits ($\alpha_k = 1$). Otherwise, it is *idle*, i.e., it does not transmit ($\alpha_k = 0$).
- Probability that i is active: $\min\{\rho_i, 1\}$, where ρ_i is the load of i.
- In-band and out-of-band relaying:





Finding Stations Loads with Fixed Point Iterations

Load of station k:

$$\rho_k = E_\alpha\left[\int_{S_k} \frac{\omega(s)}{R(s,\alpha_{-k},\tau)} ds\right] = \frac{\varpi}{1-\tau(\varpi)} \int_{S_k} \phi(s) E_\alpha\left[\frac{1}{C(s,\alpha_{-k})}\right] ds$$

- Rate demanded at location s
- Local variation of traffic intensity, wrt ϖ
- Number of active stations depends on loads
- Sum over area controlled by station k
- Rate provided at location s
- Proportion of radio resources dedicated to backhaul link (τ = 0 for out of band relaying)
- Provided rate depends on active interfering stations

Loads of all stations expressed as:

$$\begin{cases} \rho_1 = & \mathbb{E}_\alpha\left[\int_{\mathcal{S}_1} \frac{\omega(s)ds}{R(s,\alpha_{-1},\tau)}\right] = F_1(\bar\omega, \rho_2, \cdots, \rho_n) \\ \rho_2 = & \mathbb{E}_\alpha\left[\int_{\mathcal{S}_2} \frac{\omega(s)ds}{R(s,\alpha_{-2},\tau)}\right] = F_2(\bar\omega, \rho_1, \rho_3, \cdots, \rho_n) \\ \vdots & \vdots \\ \rho_n = & \mathbb{E}_\alpha\left[\int_{\mathcal{S}_n} \frac{\omega(s)ds}{R(s,\alpha_{-n},\tau)}\right] = F_n(\bar\omega, \rho_1, \cdots, \rho_{n-1}) \end{cases}$$

- Station load depends on other stations loads
- **All loads** can be found by solving corresponding **system of dependent equations**
- System of equations has at least one **fixed point**
- Fixed point found starting from zero traffic ($\rho_i = 0, \forall i$)
- **Maximum supported traffic intensity**, for a considered RNs configuration, defined as:

$$\bar\omega^{\max} = \max\{\bar\omega : \rho_i < 1 \;\; \forall i\}$$

Objective

Define $\mathcal{R}$: the set of RNs spatial configurations
We want to find:

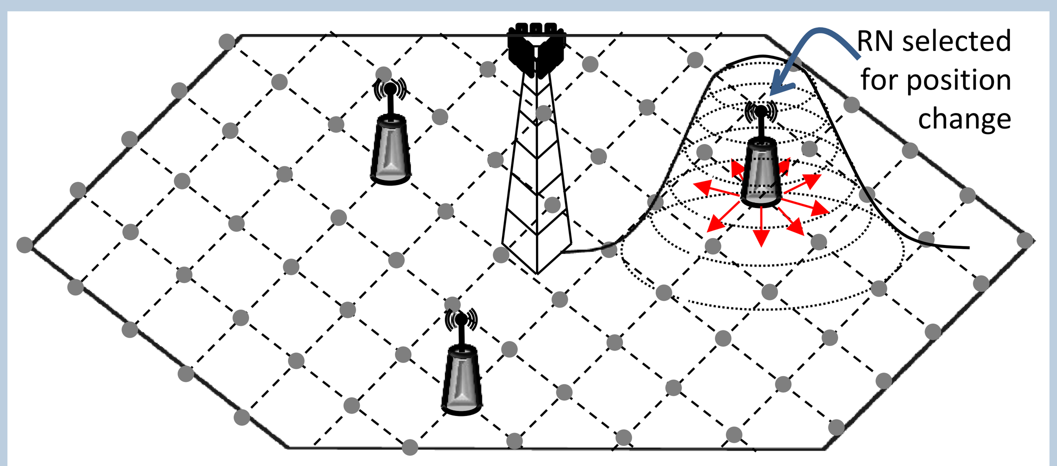
$$\underset{\mathcal{R}}{\operatorname{argmax}}\{\bar\omega^{\max}\} \qquad (1)$$

$$\textbf{subject to } \rho_i < 1, \forall i,$$

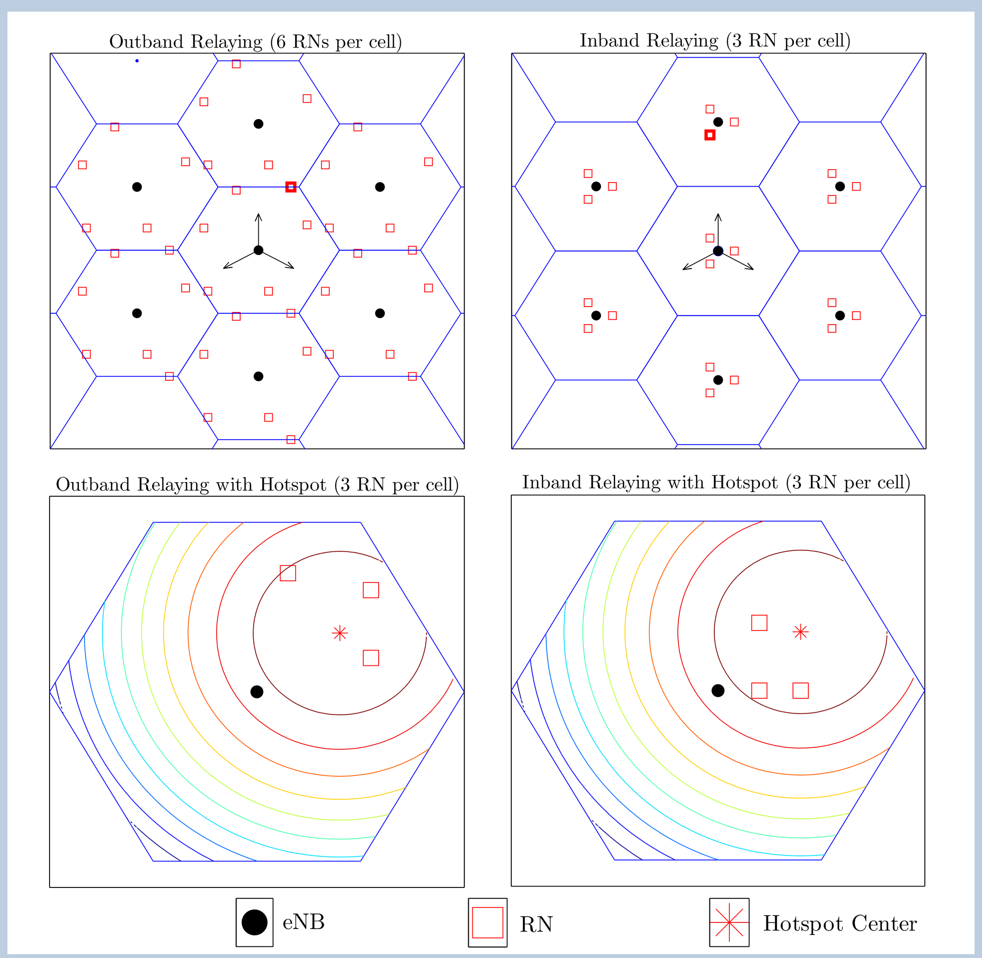
Problem: Large number of possible RNs configurations: C_n^N

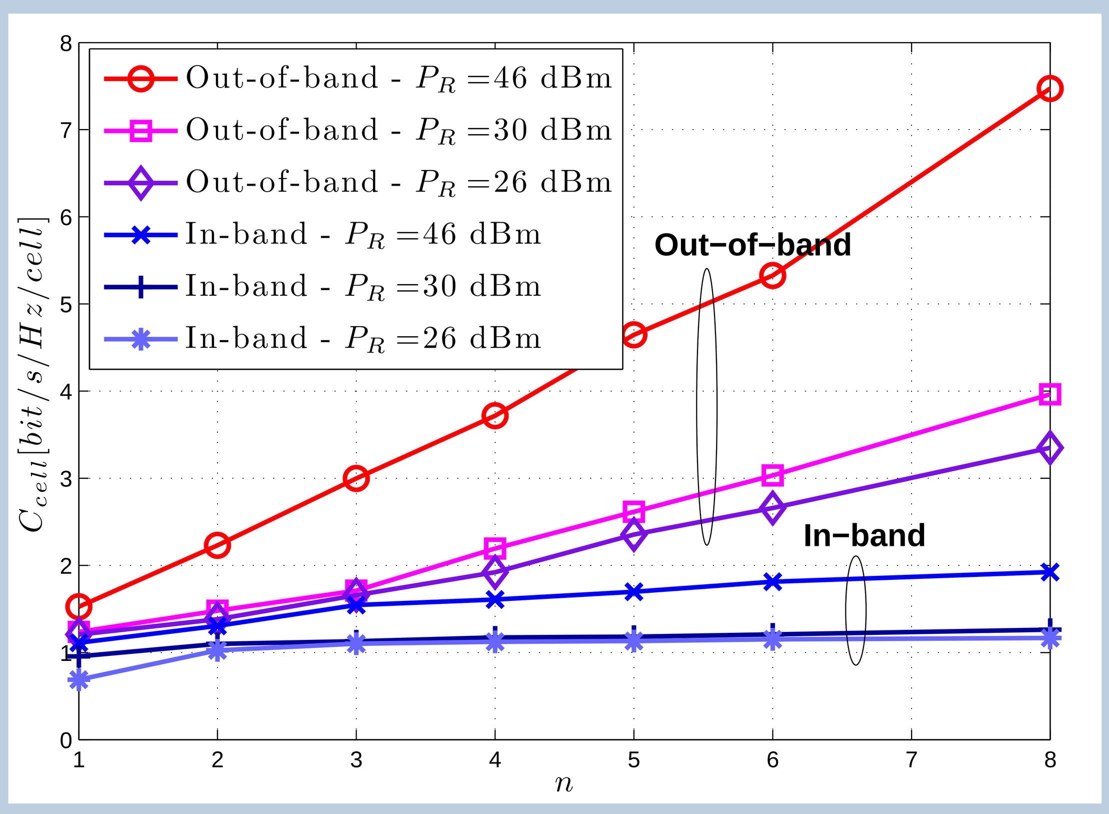
Optimal Placement Search

- **Simulated Annealing (SA) used to find optimal RNs configurations**
- **Multiscale implementation**: optimal positioning is first found on a *coarse* grid, then refined on a *fine* grid.
- At each iteration of SA, one RN position changes. New position selected using **gaussian bi-dimensional distribution**, and discretized on hexagonal grid.
- For each configuration analyzed by SA, corresponding $\bar\omega^{\max}$ is found via **dichotomic search**, trying several $\bar\omega$.
- For each analyzed $\bar\omega$, fixed point problem must be solved to find corresponding loads.



Results





- **Out of band relaying**: RNs try to cover low-rate regions, so as to unload eNB.
- **In band relaying**: RNs close to eNB, so as to enjoy good backhaul link.
- **Out of band relaying**: capacity improvement (nw *densification*).
- **In band relaying**: Increase capacity with many RNs, contrary to static models results.