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Instantaneous Forwarding Capacity under Different Interference Models

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AWA final seminar   25 May 2011

Instantaneous forwarding capacity

- Network that consists of randomly (Poisson point process) distributed nodes on a plane
  - nodes communicate over a wireless medium
  - each node has one transceiver
  - node density is denoted by n

- Target is to find the transmission mode, $m \in M$, that maximizes the sum capacity of the links per area
  - transmission mode is a set of links that transmit simultaneously
  - capacity is measured as bit-meters per second: progress of the link to a given direction times the data rate

Outline

- Interference models

- Objectives

- Simulated annealing

- Results

Interference models

- Boolean interference model
    - fixed transmission radius

- SINR interference model
    - aggregate interference
    - threshold for minimum SINR
    - fixed data rate

- SINR-determined data rates
    - data rates from Shannon's formula

Boolean interference model

- Transmission radius, ρ, equals the interference radius

- Transmission interferes with all the receptions inside its range
  - successful transmission if the receiver hears only one transmitter

- There is only one independent dimensionless parameter
  - the most natural one is the mean number of neighbors,
    $$v(n,\rho) = \pi\, n\, \rho^2$$

Signal-to-interference-and-noise-ratio

- All the nodes transmit with the same constant power, P
  - node can participate in one transmission at a time

- Attenuation factor between transmitter t and receiver r

$$g(t,r) = (|x(t) - x(r)| / \rho_0)^{-\alpha}$$

  - $x(t)$ and $x(r)$ are the positions of t and r respectively
  - α is the attenuation coefficient
  - ρ_0 is a reference distance

- $SINR(r(l),m) = P\, g(t(l),r(l)) / (\sum_{l' \in m\setminus\{l\}} P\, g(t(l'),r(l)) + \sigma^2)$
  - σ^2 is the thermal noise power

SINR-based interference

- SINR interference model

  - spectral efficiency of links with $\text{SINR}(r(l),m) \geq \theta$ is
    $R_l(m) = R(\theta) = \log_2(1 + \theta)$ [zero otherwise]

  - length unit $\rho(P) = \rho_0 (P_0 / \theta\sigma^2)^{1/\alpha}$ is the transmission radius with zero interference [mean number of neighbors: $v(n,\rho) = \pi n \rho^2$]

- SINR-determined data rates

  - spectral efficiency $R_l(m) = \log_2(1 + \text{SINR}(r(l),m))$

  - length unit $\rho(P) = \rho_0 (P_0 / \sigma^2)^{1/\alpha}$ is the distance where the received signal power equals the noise power [$v(n,\rho) = \pi n \rho^2$]
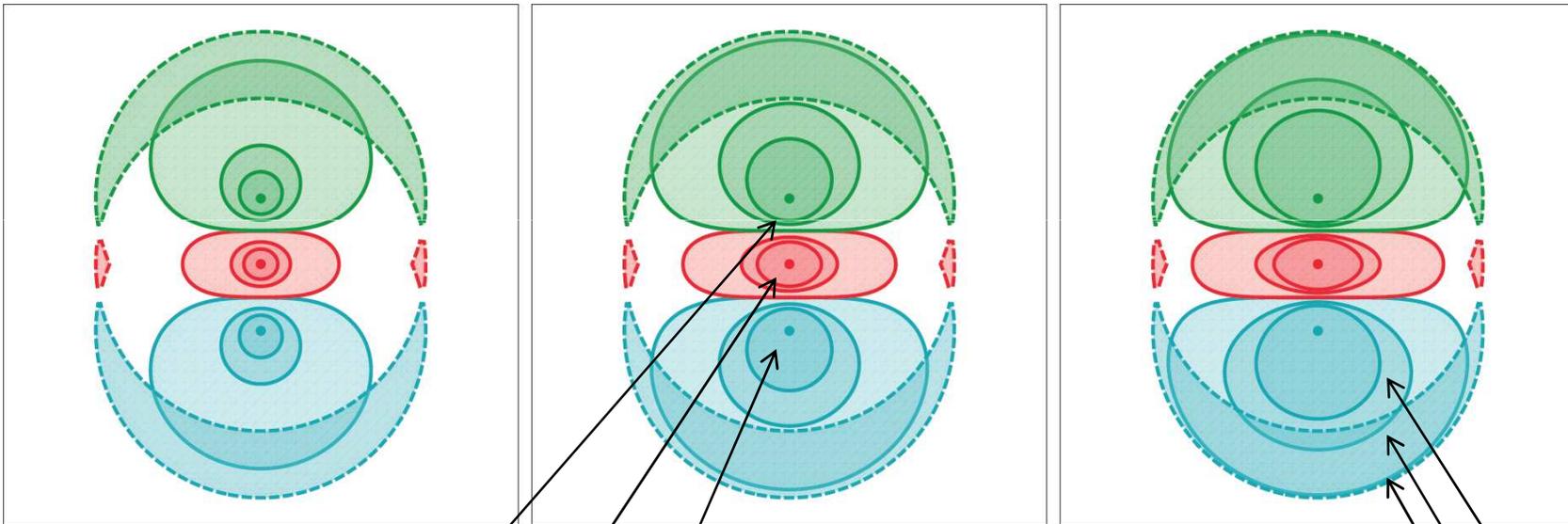
Comparison of the reception areas

Reception possible under the
Boolean interference model

Reception possible under the
SINR interference model

α = 3

α = 5

α = 7

Three transmitters: green, red, blue

Three thresholds: θ ∈ {1,7,31}

Objectives

- Goal is to find the maximum capacity of a transmission mode per unit area, I [bit/s/m], as a function of the neighborhood size $v = \pi n \rho^2$

  - capacity is measured in bit-meters per second
  - contribution of a transmitting link is the progress of the link, w_l, times the spectral efficiency, $R_l(m)$

- $I(v) = C_0 \sqrt{n}\, u_x(v(n,\rho))$

  - $C_0 = B_0 R_0$ is the nominal link capacity [bit/s]
    - B_0 is the nominal bandwidth [Hz]
    - R_0 is the reference spectral efficiency [bit/s/Hz]
  - problem: find dimensionless function $u_x(v)$

Simulated annealing

- Markov chain M_t with state space M is formed

- Steady-state probability of transmission mode m' is chosen to be $\pi(m') = \exp\{a\,w(m')\} / \exp\{a * \sum_{m \in M} w(m))\}$
  - $w(m)$ is the capacity of mode m:
    $w(m) = \sum_{l \in m} w_l\, R_l(m) / \rho_0\, R_0$
  - a is a parameter

- To assure the required steady-state distribution, the transition probabilities, $p(m,m')$, are chosen so that π shows detailed balance
  - $p(m,m')\, \pi(m) = p(m',m)\, \pi(m')$

Proposal distribution

- Proposal distribution $q(m,m')$ gives the probability that transmission mode m' is the candidate to be selected as the next transmission mode when the current transmission mode is m

- Proposal with higher capacity is accepted with probability 1

- Transition to a lower capacity is accepted with probability r that can be solved from the detailed balance equation

$$p(m,m')\ \pi(m) = p(m',m)\ \pi(m')$$
$$\Leftrightarrow r * q(m,m')\ \pi(m) = 1 * q(m',m)\ \pi(m')$$
$$\Leftrightarrow r = q(m',m)\ \pi(m')\ /\ (q(m,m')\ \pi(m))$$

Simulation algorithm

- Markov chain M_t is simulated using a stochastic optimization method called simulated annealing
  - idea is to increase parameter $a(t)$

- When a is large, $\pi(m) \sim \exp\{a * \sum_{l \in m} w(l)\}$

- The probability $\pi(m^*) \to 1$, when $a \to \infty$
  - $m^* = \arg\max_m \sum_{l \in m} w(l)$

- Proposal obtained by randomly choosing a link
 - $r = \exp\{-a * (w(m) - w(m'))\}$

Simulation parameters

- Network size: 250 … 1000 nodes in a torus

- Simulation length: 10 million jumps

- Cooling strategy: linear increase of a from 0 to an interference model dependant value
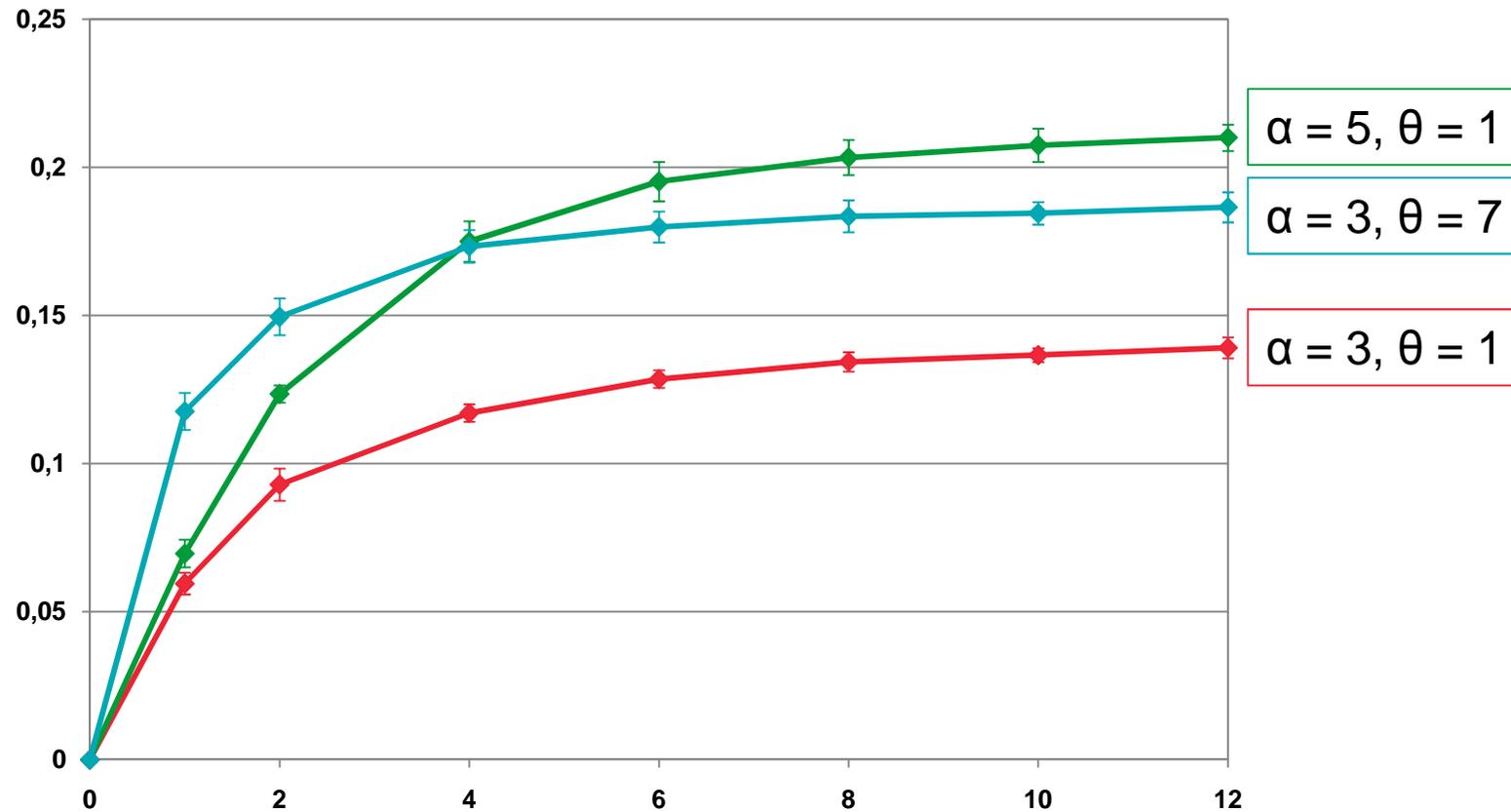
- Network realizations: 10 … 100

Cooling strategy

end value of the annealing parameter a
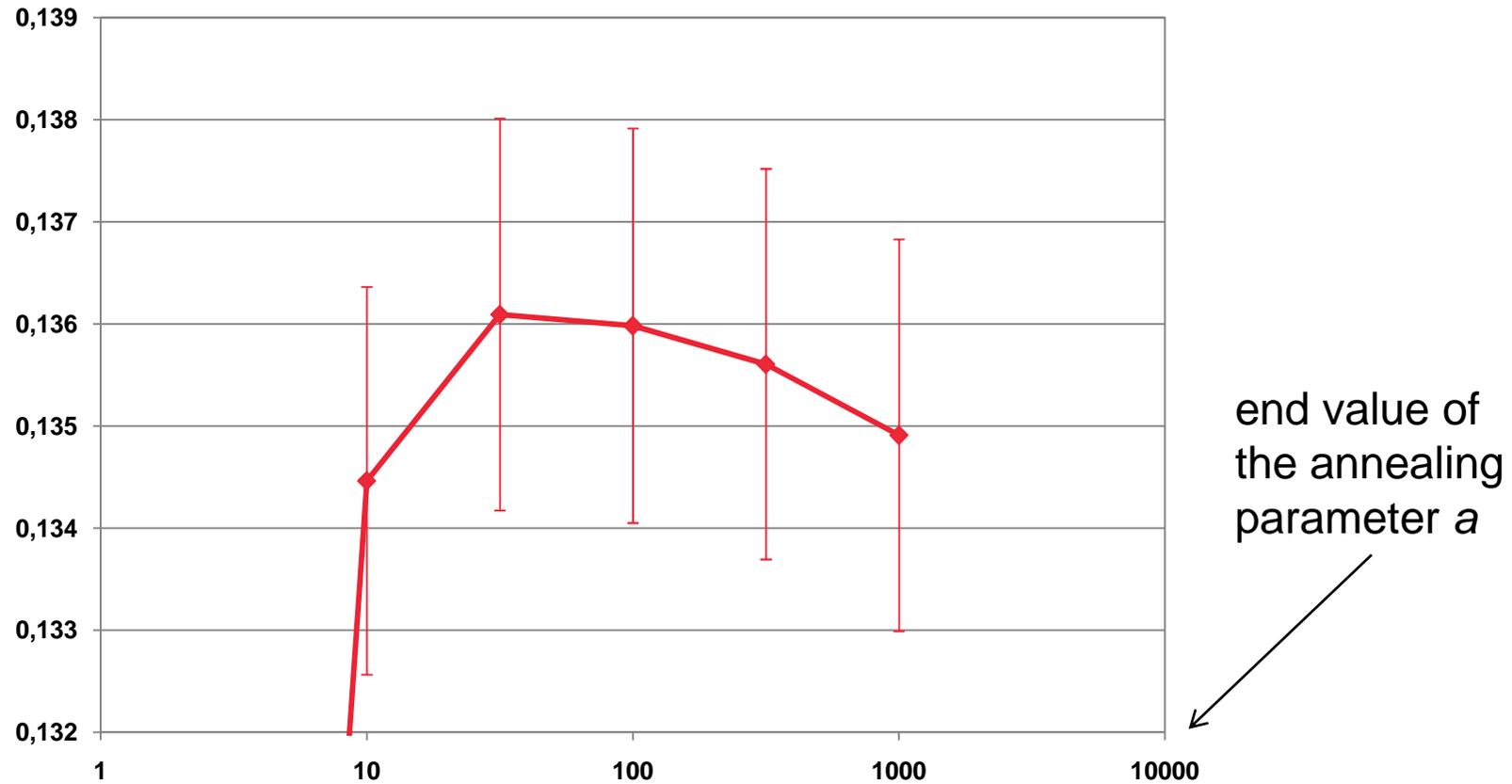
Results: Boolean interference model $u_x(v)$

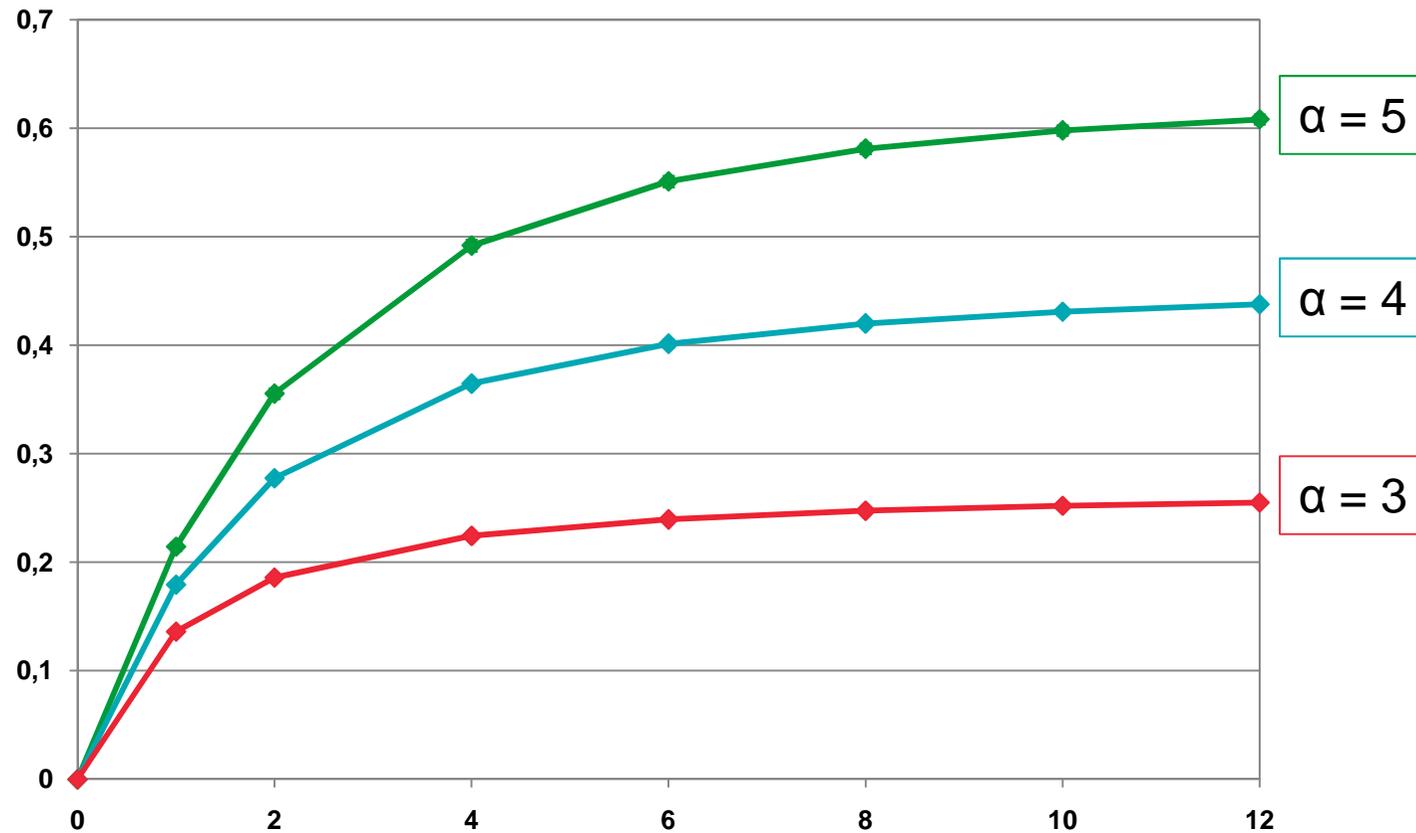Moving window algorithm

Simulated annealing
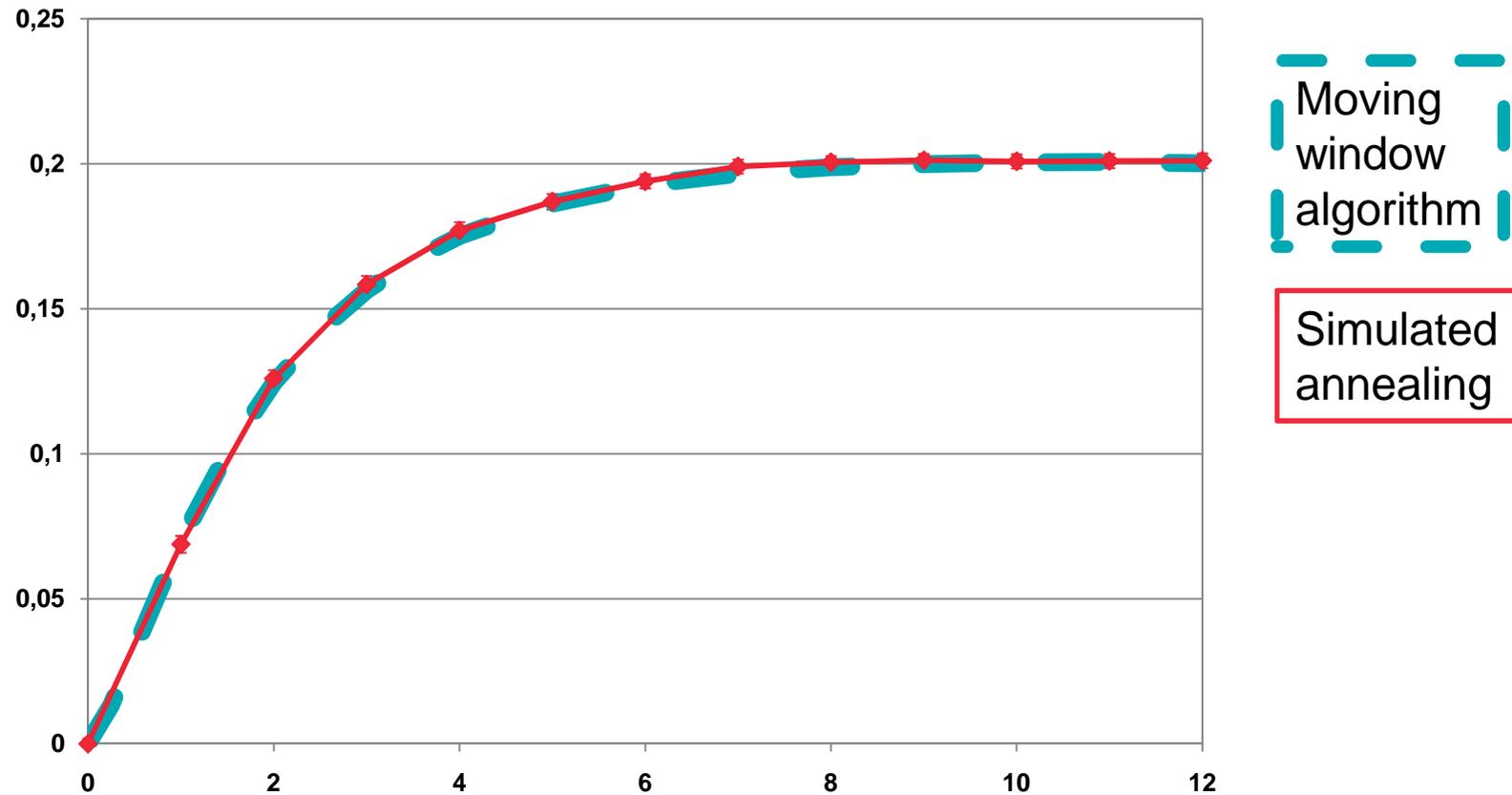
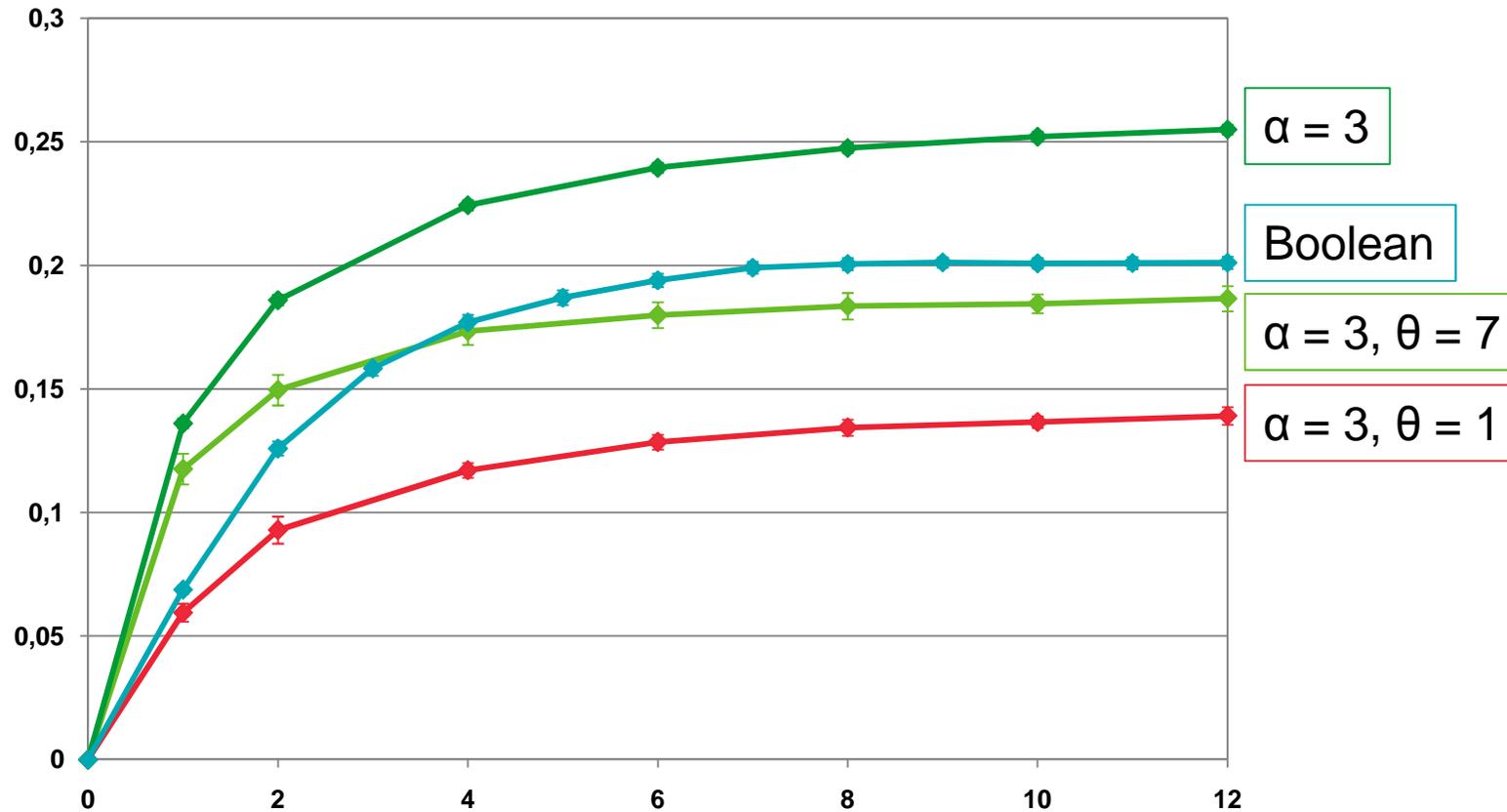# Results: SINR interference model $u_x(v)$

Results: SINR-determined data rates $u_x(v)$

Results: Comparison $u_x(v)$

Thank You!

- Questions?