A Distributed Relay-Assignment Algorithm for Cooperative Communications in Wireless Networks

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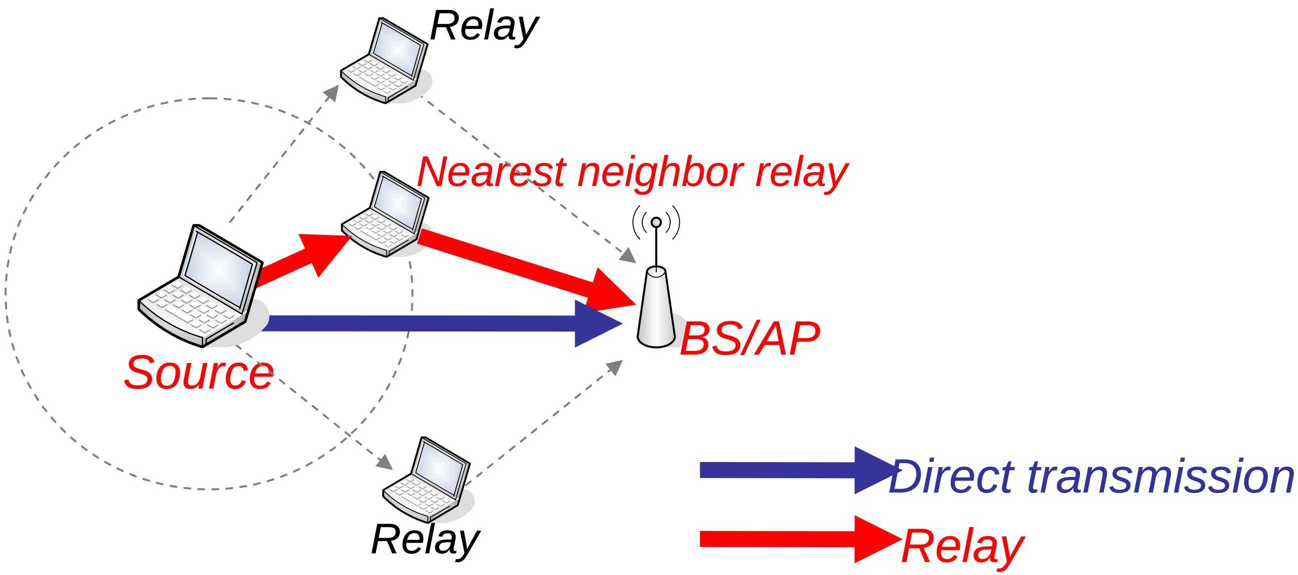
Nearest Neighbor Protocol (NNP) Scheme

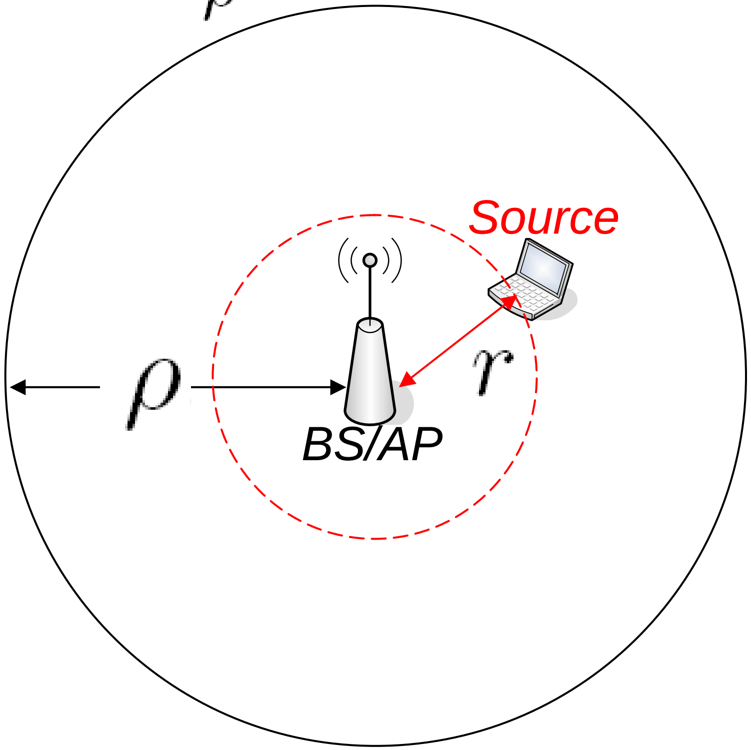
- **Is the relay assignment scheme at the cooperative networking**
  - Selects the nearest neighbor from the source as the relay node
  - Considers only the uplink (toward the BS/AP)
- **Neighbor discovery**
  - Each relay sends out "Hello" message
  - Each source node can know its distance to the BS/AP using TOA (Time of Arrival)



Source's Location Distribution Model

- **Derive PDF for the source location distribution when the distance between the user and the BS/AP is r**
    - The user's angle is uniformly distributed between, [0, 360^o)

$$q(r) = \frac{2r}{\rho^2}, \qquad 0 \le r \le \rho$$

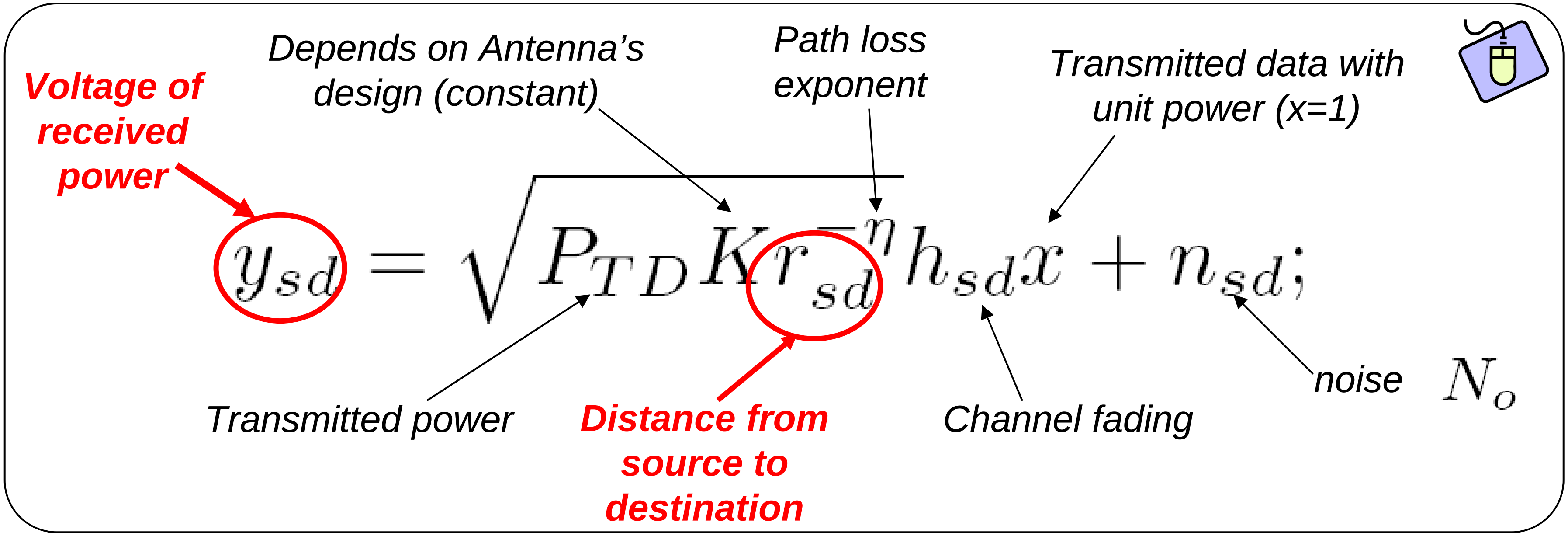


ρ : Cell radius

r : the distance from the source to BS/AP

Received Signal Model

- **Considered wireless link characteristics for received signal model**
  - Random Rayleigh fading channel between two nodes - h_{sd}
  - Propagation path loss – path loss exponent - η
  - Additive white Gaussian noise n_{sd}
  - No mutual interference because the nodes use the orthogonal channel
    - Each node has a single-element antenna and half-duplex mode



$$y_{sd} = \sqrt{P_{TD} K r_{sd}^{-\eta}} h_{sd} x + n_{sd};$$

Voltage of received power

Depends on Antenna's design (constant)

Path loss exponent

Transmitted data with unit power (x=1)

Transmitted power

Distance from source to destination

Channel fading

noise N_o

(K, η, and P_{TD} are assumed to be the same for all nodes)

Metric: Outage

- **Is the event that the received SNR falls below a certain threshold γ**
  - It the received SNR is higher than the threshold, the receiver is assumed to be able to decode the received message with negligible probability of error
  - If the outage occurs, the packet is considered lost

- **Outage probability**

threshold

$$\mathcal{P}_O = \mathcal{P}(\mathrm{SNR}(r) \leq \gamma)$$

- **For comparing the bandwidth efficiency, "outage probability" is computed for both the direct transmission and the nearest neighbor based cooperative transmission**

Outage Probability for the Direct Transmission

$$y_{sd} = \sqrt{P_{TD} K r_{sd}^{-\eta}} h_{sd} x + n_{sd}; \dashrightarrow \mathrm{SNR}(r_{sd}) = \frac{|\, h_{sd} \,|^2 \; K r_{sd}^{-\eta} P_{TD}}{N_o}$$

Outage probability for the direct transmission when the source locates with the distance r_{sd} from BS/AP

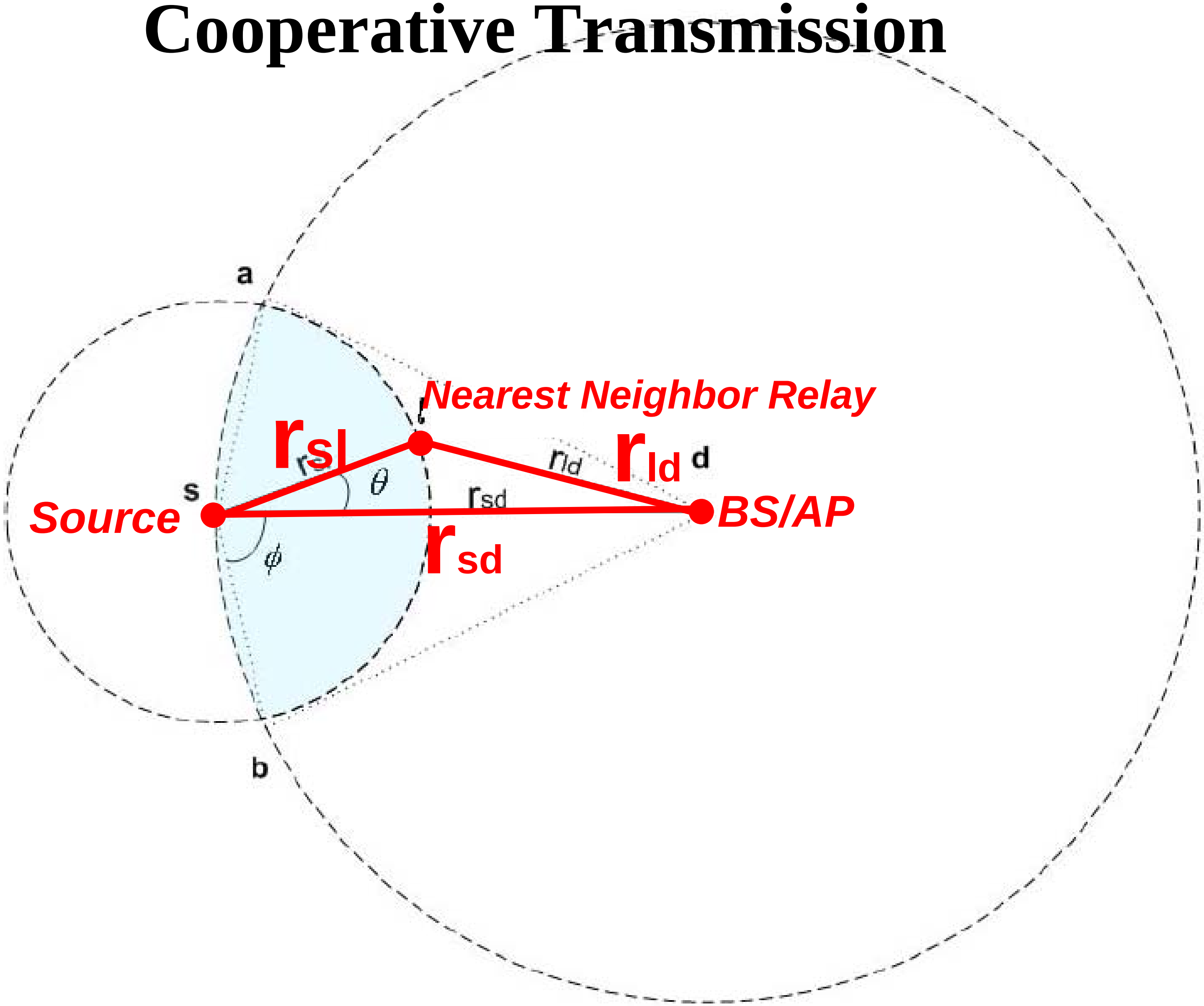
$$\mathcal{P}_{OD}(r_{sd}) = \mathcal{P}\left(\mathrm{SNR}(r_{sd}) \leq \gamma\right) = 1 - \exp\left(-\frac{N_o \gamma r_{sd}^{\eta}}{K P_{TD}}\right)$$

Average outage probability over the cell

The probability that the source is at the distance r_{sd}

$$\mathcal{P}_{OD} = \int_0^{\rho} \mathcal{P}_{OD}(r_{sd}) q(r_{sd}) dr_{sd}$$

Outage Probability for NNP-based Cooperative Transmission



Outage Probability for NNP-based Cooperative Transmission

Outage probability for NNP-based cooperative transmission

$$\mathcal{P}_{ONN}(r_{sd}, r_{sl}, r_{ld}) = \left(1 - \exp(-\frac{N_o \gamma r_{sd}^{\eta}}{KP_{TC}})\right) \times \left(1 - \exp(-\frac{N_o \gamma \left(r_{sl}^{\eta} + r_{ld}^{\eta}\right)}{KP_{TC}})\right)$$

Outage probability for the direct transmission r_{sd}

Outage probability for the transmission through relay r_{sl}, r_{ld}

Average outage probability over the cell

depends on r_{sd}, r_{sl}

$$\int_0^{\rho} \int \underline{\mathcal{P}_{ONN}(r_{sd}, r_{sl}, r_{ld})} \times \mathcal{P}_{rn}(r_{sl}) \times \underline{q(r_{sd})} dr_{sl} dr_{sd}$$

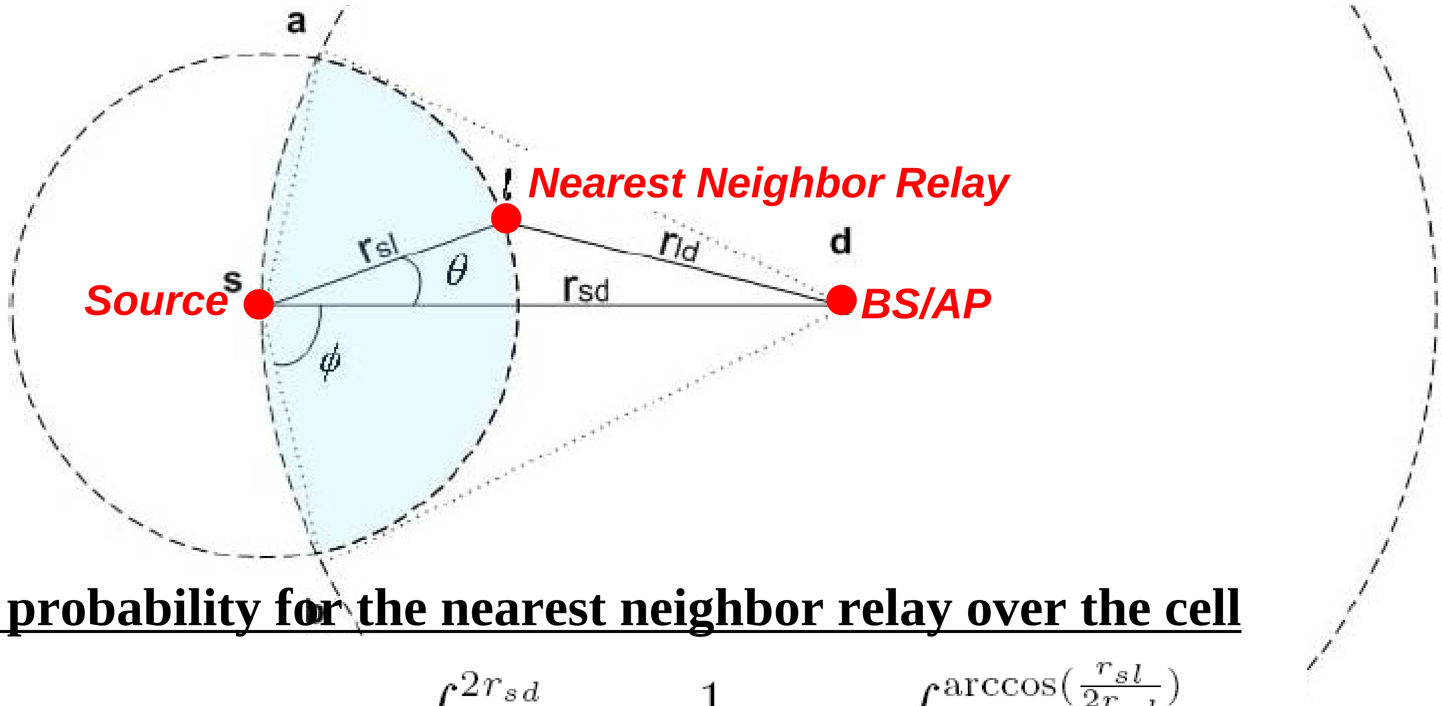
Outage probability

PDF of source location

PDF of the nearest neighbor relay's location?

Outage Probability for NNP-based Cooperative Transmission

- **The probability that the nearest neighbor is at distance r_{sl} from the source is equivalent to "the probability that the shaded area is empty"**



Average outage probability for the nearest neighbor relay over the cell

$$\int \mathcal{P}_{rn}(r_{sl})\,dr_{sl} = \mathcal{P}_{ONN}(r_{sd}) = \int_0^{2r_{sd}} \frac{1}{2\arccos(\frac{r_{sl}}{2r_{sd}})} \int_{-\arccos(\frac{r_{sl}}{2r_{sd}})}^{\arccos(\frac{r_{sl}}{2r_{sd}})} \mathcal{P}_{ONN}(r_{sd}, r_{sl}, \theta)\mathcal{P}_{rn}(r_{sl})\,d\theta\, dr_{sl}{}^2$$

Approximated Outage Probability Formula for NNP-based Cooperative Transmission

- **Because the formula in the previous slide can only be calculated numerically, they derive an approximated expression**

- **Assumption for the approximation**
  - 1. The outage probability at the nearest neighbor relay is very low
  - 2. Consider the worst case of the nearest neighbor selection, “a” or “b” when $r_{ld} = r_{sd}$

$$\mathcal{P}_{ONN}(r_{sd}, r_{sl}, r_{ld}) = \left(1 - \exp(-\frac{N_o \gamma r_{sd}^{\eta}}{KP_{TC}})\right) \times \left(1 - \exp(-\frac{N_o \gamma \left(r_{sl}^{\eta} + r_{ld}^{\eta}\right)}{KP_{TC}})\right)$$

$$\xrightarrow{}$$

Approximation

$$\mathcal{P}_{ONN}(r_{sd}) \simeq \left(1 - \exp(-\frac{N_o \gamma r_{sd}^{\eta}}{KP_{TC}})\right)^2$$

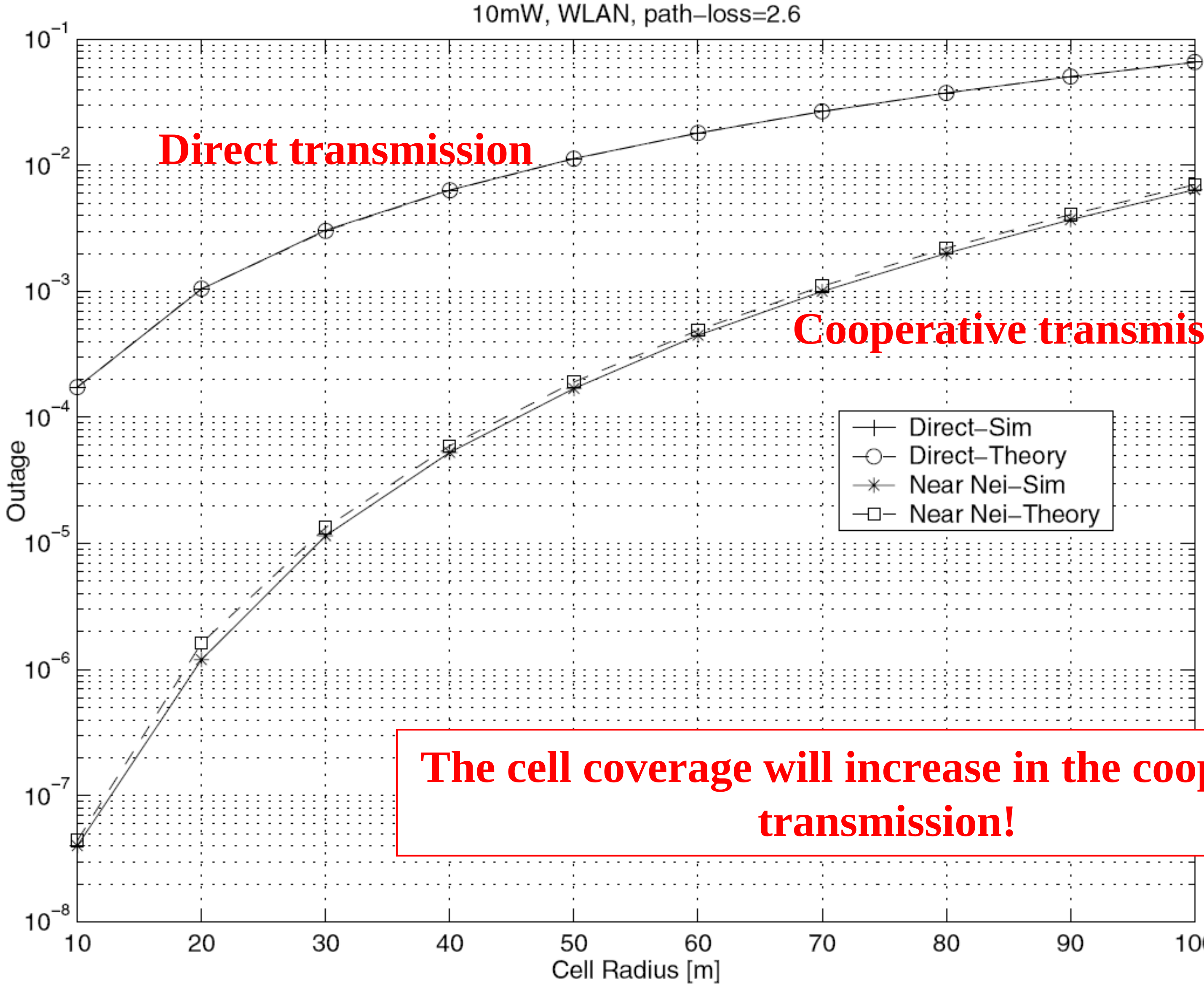
Simulation Setup

- **Is modeled as a random Rayleigh fading channel**
  - Similarly configures with the indoor WLAN
  - Cell radius is taken between 10m and 100m
  - AWGN (Additive white Gaussian noise): variance = -70dBm
  - Path loss exponent = 2.6
  - The number of users in the cell attached to the AP = 10
  - SNR threshold γ = 20dB

- **For comparing the bandwidth efficiency (low outage probability), the average transmitted power is kept equal in the direct transmission and the cooperative transmission**
  - The transmitted power does not affect the outage probability?

- **Plotted the theoretical outage performance and the simulation results for both direct transmission and cooperative transmission**
  - Which simulator?

Average Outage Probability (y-axis) vs. Cell Radius (x-axis)

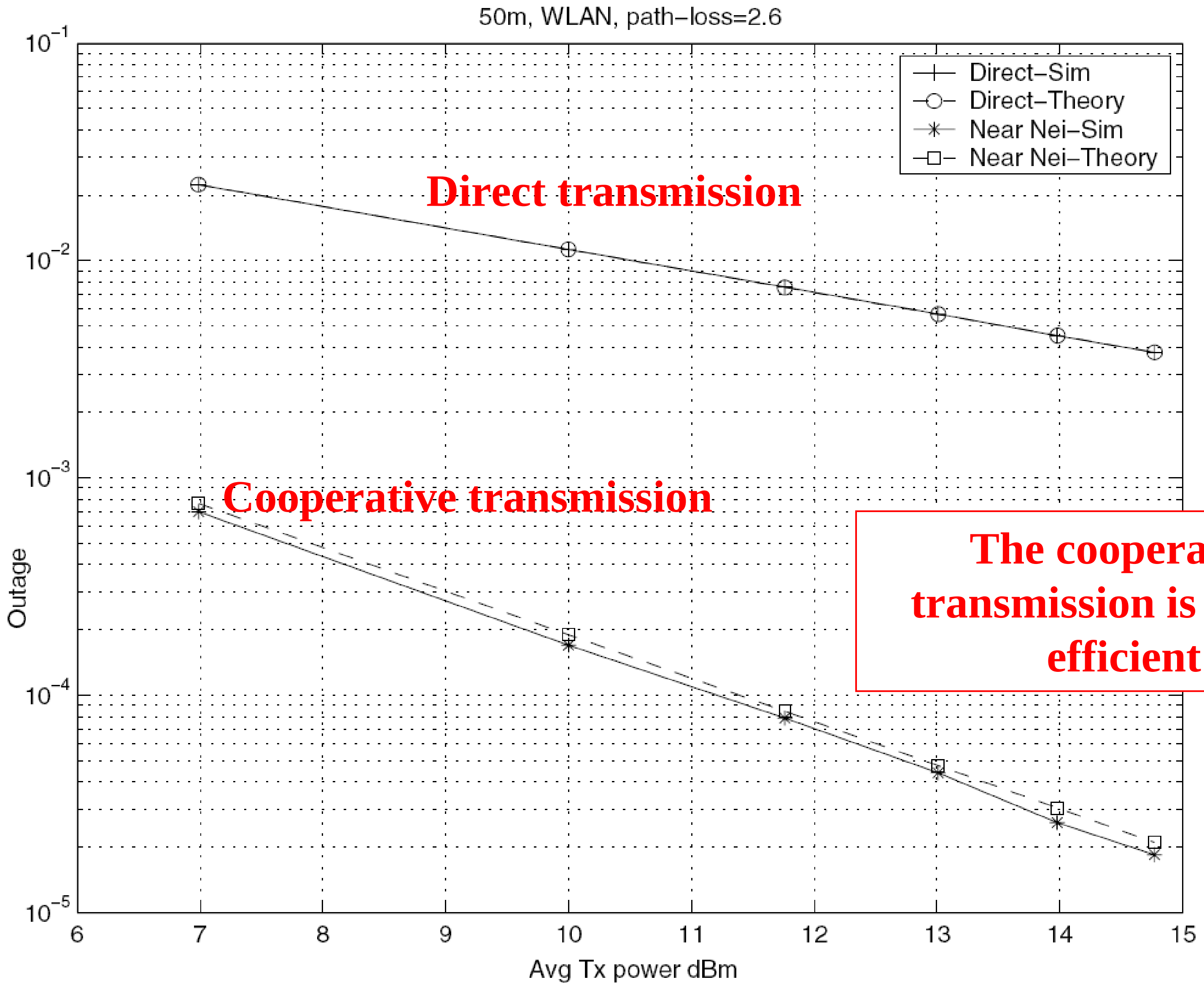


Direct transmission

Cooperative transmission

The cell coverage will increase in the cooperative transmission!

Average Outage Probability (y-axis) vs. Transmission Power (x-axis)



Direct transmission

Cooperative transmission

The cooperative transmission is energy efficient

Discussion

- **They did not show that the nearest neighbor can have the best performance comparing with the other neighbors**
  - What about the neighbor which locates in the middle between the source and the BS/AP?

- **They fixed the transmitted power as the same in both cases?**
  - They considered the orthogonal channels for the cooperative transmission, so the direct transmission will use less transmitted power than the cooperative transmission

$$\mathcal{P}_{ONN}(r_{sd}, r_{sl}, r_{ld}) = \left(1 - \exp(-\frac{N_o \gamma r_{sd}^{\eta}}{K \boxed{P_{TC}}})\right) \times \left(1 - \exp(-\frac{N_o \gamma \left(r_{sl}^{\eta} + r_{ld}^{\eta}\right)}{K \boxed{P_{TC}}})\right)$$

Q&A

(1) $y_{sd} = \sqrt{P_{TD} K r_{sd}^{-\eta}} h_{sd} x + n_{sd};$

Received power

Transmitted power

$$P_r = \frac{P_t}{4\pi} r_{sd}^{-2} \times A$$

Distance

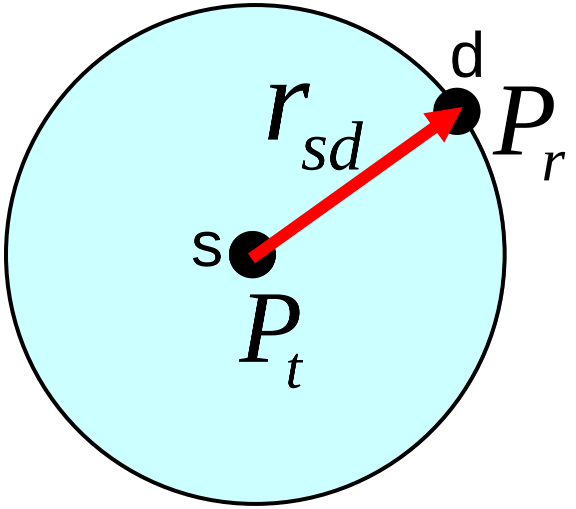
$$P_r \propto P_t \cdot r_{sd}^{-\eta}$$

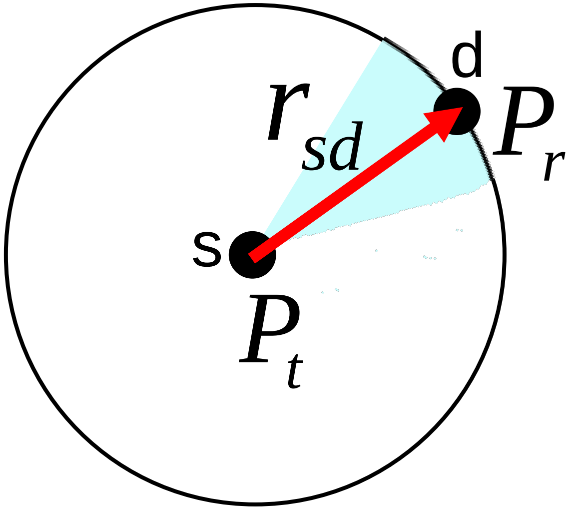
Path loss exponent

For transmitting the data, the antenna focuses on the specific direction (antenna directivity)

$$P_r \propto K \cdot P_t \cdot r_{sd}^{-\eta}$$

Depends on Antenna design





(1) $y_{sd} = \sqrt{P_{TD} K r_{sd}^{-\eta}} h_{sd} x + n_{sd};$

From the previous slide

$$P_r \propto K \cdot P_t \cdot r_{sd}^{-\eta}$$

The relationship between Voltage and Power

$$y_{sd} = \sqrt{P_r}$$

Voltage

$$y_{sd} \propto \sqrt{K \cdot P_t \cdot r_{sd}^{-\eta}}$$

$$y_{sd} = \sqrt{K \cdot P_t \cdot r_{sd}^{-\eta}}\, h_{sd}\, x + n_{sd}$$

Multi-path fading

Noise

Transmitted data per unit power
(Usually x is set as “1”)

Go to the next slide

$$\textbf{(2)}\ y_{sd} = \sqrt{P_{TD} K r_{sd}^{-\eta}}\, h_{sd} x + n_{sd}; \xrightarrow{?} \mathrm{SNR}(r_{sd}) = \frac{|\, h_{sd} \,|^2\ K r_{sd}^{-\eta} P_{TD}}{N_o}$$

From the previous slide

$$y_{sd} = \sqrt{K \cdot P_t \cdot r_{sd}{}^{-\eta}}\, h_{sd}\, x + n_{sd}$$

Compute the voltage of signal without noise, where x=1

Voltage

$$y_{sd} = \sqrt{K \cdot P_t \cdot r_{sd}{}^{-\eta}}\, h_{sd} = \sqrt{P_{signal}}$$

Power

$$P_{signal} = K \cdot P_t \cdot r_{sd}{}^{-\eta} \cdot \left| h_{sd} \right|^2$$

$$SNR(r_{sd}) = \frac{P_{signal}}{P_{noise}} = \frac{K \cdot P_t \cdot r_{sd}^{-\eta} \cdot \left| h_{sd} \right|^2}{n_{sd}} = \frac{K \cdot P_t \cdot r_{sd}^{-\eta} \cdot \left| h_{sd} \right|^2}{N_0}$$

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(3) $\mathcal{P}\left(\mathrm{SNR}(r_{sd}) \leq \gamma\right) = 1 - \exp\left(-\frac{N_o \gamma r_{sd}^{\eta}}{K P_{TD}}\right)$

From the previous slide

$$SNR(r_{sd}) = \frac{K \cdot P_t \cdot r_{sd}^{-\eta} \cdot \left|h_{sd}\right|^2}{N_0}$$

$$P(SNR(r_{sd}) \leq \gamma) = P\left(\frac{K \cdot P_t \cdot r_{sd}^{-\eta} \cdot \left|h_{sd}\right|^2}{N_0} \leq \gamma\right) = P\left(\left|h_{sd}\right|^2 \leq \frac{\gamma \cdot N_0}{K \cdot P_t \cdot r_{sd}^{-\eta}}\right)$$

Use $f_{\left|h_{sd}\right|^2}(x) = e^{-x}, F_{\left|h_{sd}\right|^2}(x) = 1 - e^{-x}$

(h^2 is exponential distribution)

$$P(SNR(r_{sd}) \leq \gamma) = P\left(\left|h_{sd}\right|^2 \leq \frac{\gamma \cdot N_0}{K \cdot P_t \cdot r_{sd}^{-\eta}}\right) = F_{\left|h_{sd}\right|^2}\left(\frac{\gamma \cdot N_0}{K \cdot P_t \cdot r_{sd}^{-\eta}}\right)$$

$$= 1 - e^{-\left(\frac{\gamma \cdot N_0}{K \cdot P_t \cdot r_{sd}^{-\eta}}\right)} = 1 - e^{-\left(\frac{N_0 \cdot \gamma \cdot r_{sd}^{\eta}}{K \cdot P_t}\right)}$$