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Geometric Analysis for the Cell Coverage Extension with Wireless Relay

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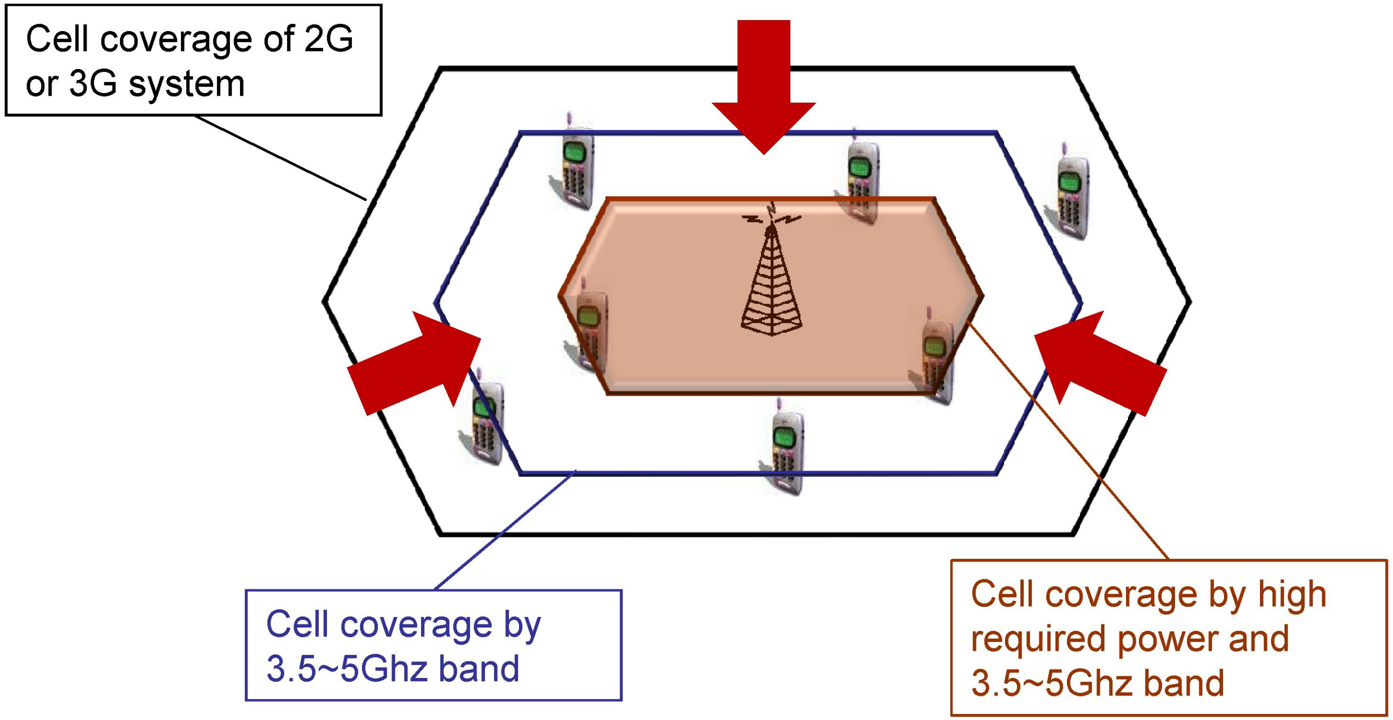
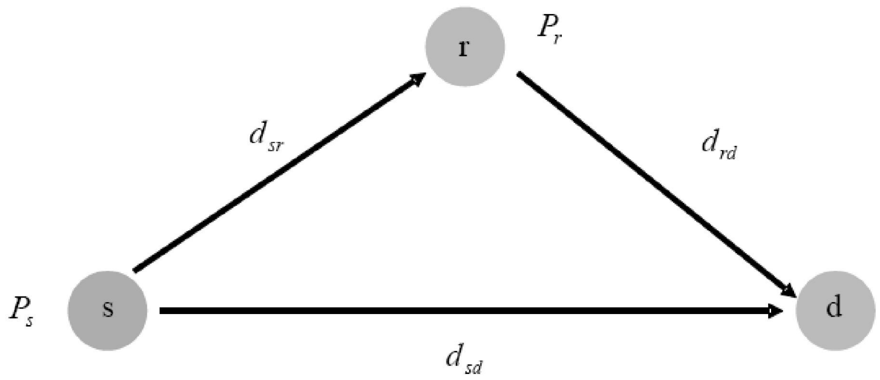
Motivation

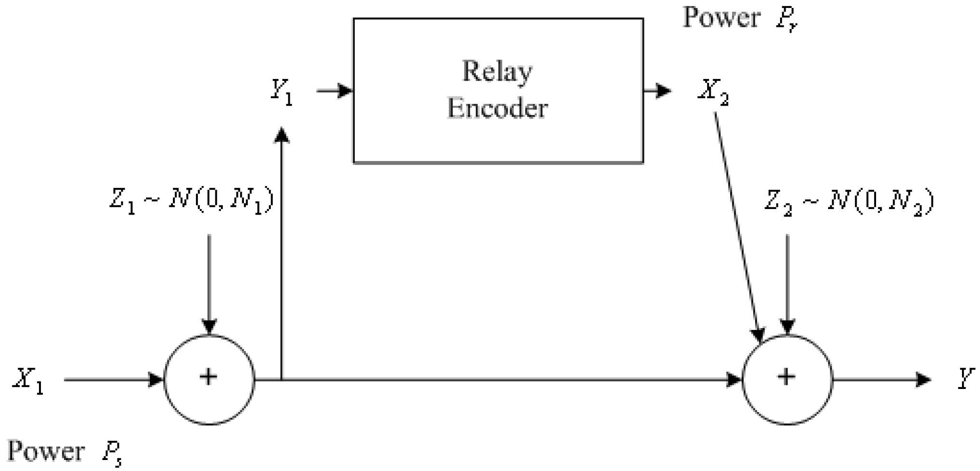
- **Cell coverage problem of 4G system**
  - High data rate service – high required power
  - 3.5~5GHz band



Geometric Model and Relaying Strategy

- **Degraded Gaussian relay channel[5]**



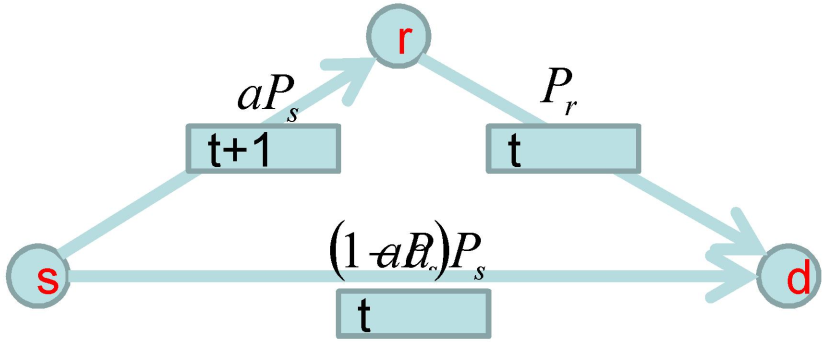


- Simple path loss model
- Transmission power assignment:
  - ✓ proportional to the square of coverage, i.e. $P \propto d^2$ [13]

[5] T. Cover and A. El Gamal (1979) , [13] A. Agarwal and P. R. Kumar (2004)

Geometric Model and Relaying Strategy

- **CRIS scheme[6]**
  - Consider the interference due to signal from source to relay
  - Cooperation ratio $0.5 < a \le 1$: represent the dependence on relaying



$$R = \max_{0 \le a \le 1} \min \left\{ S\left(\frac{\alpha_{sr}^2 a P_s}{N_1} \right), S\left(\frac{\alpha_{sd}^2 P_s + \alpha_{rd}^2 P_r + 2\alpha_{sd}\alpha_{rd}\sqrt{(1-a)P_s P_r}}{N_1 + N_2} \right) \right\}$$

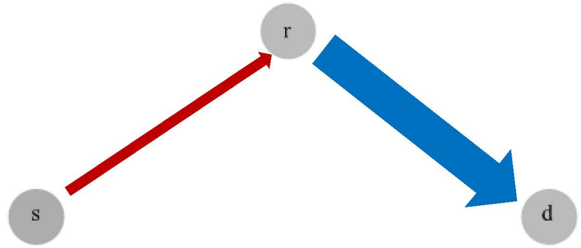
where $S(x) = 1/2 \log_2 (1+x)$.

[6] L. Xie and P. R. Kumar (2004)

Geometric Model and Relaying Strategy

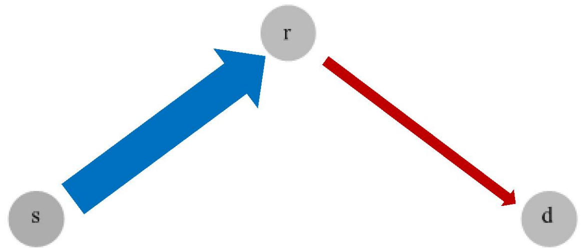
- If $SNR_{rd} \geq SNR_{sr}$, a=1, no cooperation (only repetition).

$$R = S\left(\frac{\alpha_{sr}^2 P_s}{N_1}\right),\ (a=1)$$



- If $SNR_{rd} < SNR_{sr}$, a is strictly less than 1.
  - For optimal a^*,

$$R = S\left(\frac{\alpha_{sr}^2 a^* P_s}{N_1}\right)$$



Geometric Model and Relaying Strategy

- **CRIS scheme**
  - Optimal value of $a\,(=a^*)$ can be determined from:

$$\frac{\alpha_{sr}^2 a^* P_s}{N_1} = \frac{\alpha_{sd}^2 P_s + \alpha_{rd}^2 P_r + 2\alpha_{sd}\alpha_{rd}\sqrt{(1-a^*)P_s P_r}}{N_1 + N_2}$$

  - For simplicity let $N_1 = N_2 = N$:

$$a^* = \frac{2AB - 1 + \sqrt{(2AB-1)^2 - A^2(B^2-1)}}{2A^2}$$

$$\text{where } A = \frac{2\alpha_{sr}^2 P_s}{2\alpha_{sd}\alpha_{rd}\sqrt{P_s P_r}},\ B = \frac{\alpha_{sd}^2 P_s + \alpha_{rd}^2 P_r}{2\alpha_{sd}\alpha_{rd}\sqrt{P_s P_r}}.$$

???

Geometric Model and Relaying Strategy

$$d_{rd} = kd_{sr} \ (0 < k \le 1)$$

$$d_{sd} = \sqrt{d_{sr}^2 + (kd_{sr})^2 - 2kd_{sr}^2 \cos(\pi - \theta)}$$

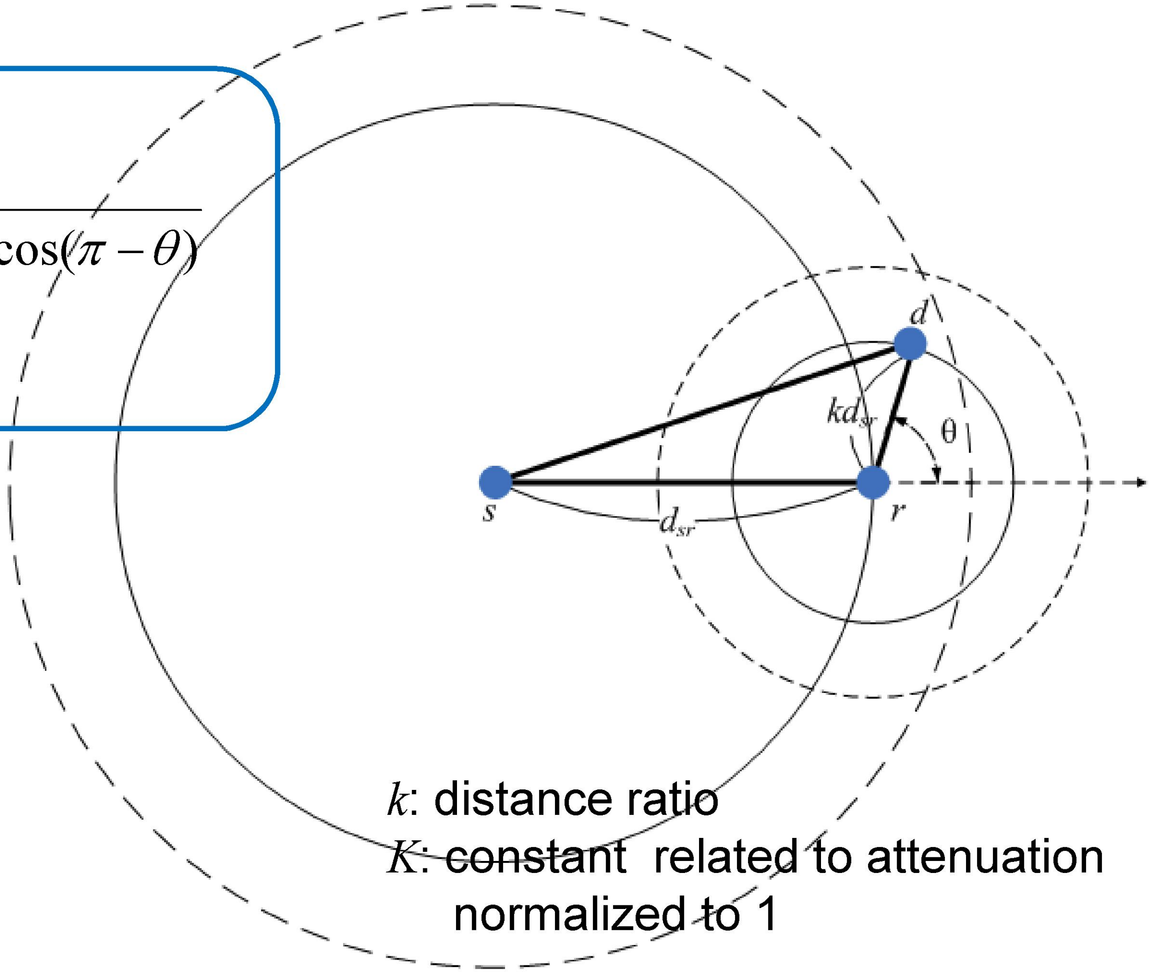
$$0 \le \theta \le \pi - \arccos\frac{k}{2}$$

$$\alpha_{sr}^2 = Kd_{sr}^{-\gamma}$$

$$\alpha_{sd}^2 = Kd_{sd}^{-\gamma}$$

$$\alpha_{rd}^2 = Kd_{rd}^{-\gamma}$$

$$P_r = k^2 P_s$$



k: distance ratio

K: constant related to attenuation normalized to 1

Capacity Theorem over Geometric Model

- **Descriptions of Optimized parameters**

$$\frac{A - AB + B \pm \sqrt{AB(A-2)(B-2)}}{2} = 1,$$

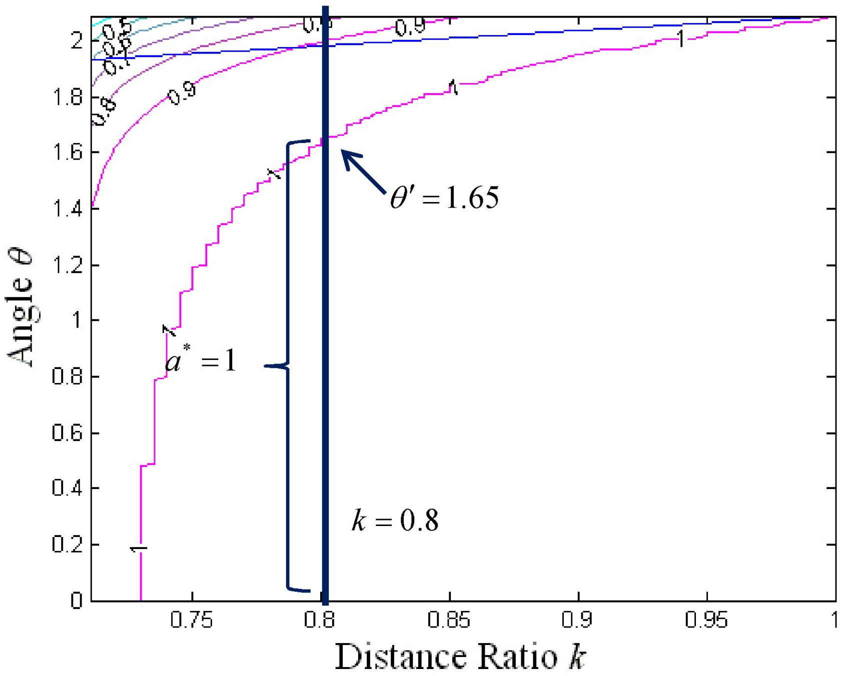
where $A = \sqrt{1 + k^2 - 2k\cos(\pi - \theta)}^{-\gamma}$ and $B = k^{-\gamma}k^2$.

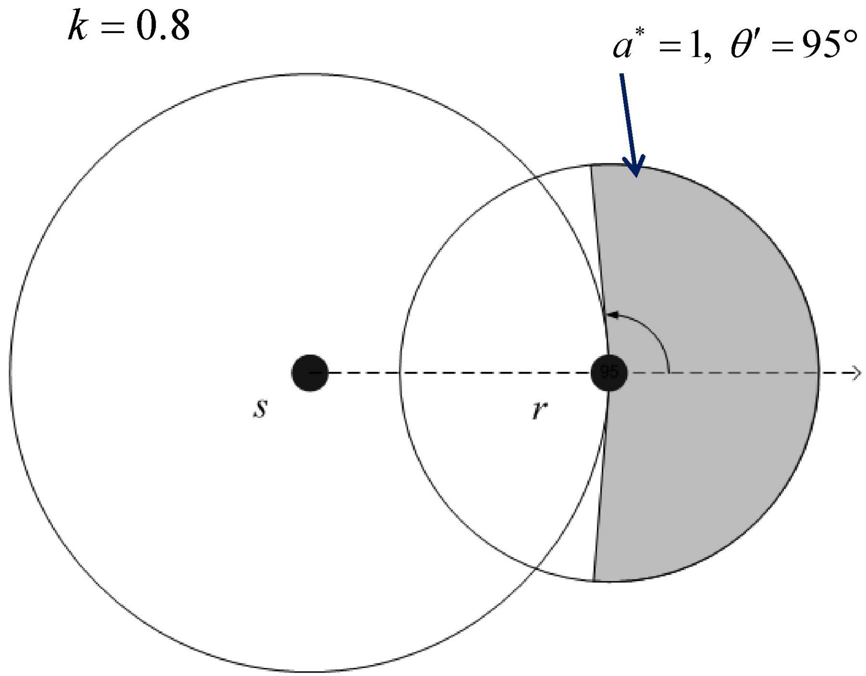
	$\gamma = 4$	$\gamma = 3$	$\gamma = 2$
k	$k > 0.7$	$k \geq 0.5$	$k > 0$
a^*	0.6~1		1
strategy	Cooperation depending on k and θ		Low cooperation, repetition

Capacity Theorem over Geometric Model

- ***θ′*** **(= maximum value of *θ*) of relay that guarantees maximum achievable rate for the given value of *k* and γ**
  - Example

$\gamma = 4$





Cell Coverage Extension with Multiple Relays

- **Coverage angle (α) and coverage range (r_2)[4]**

Coverage range:

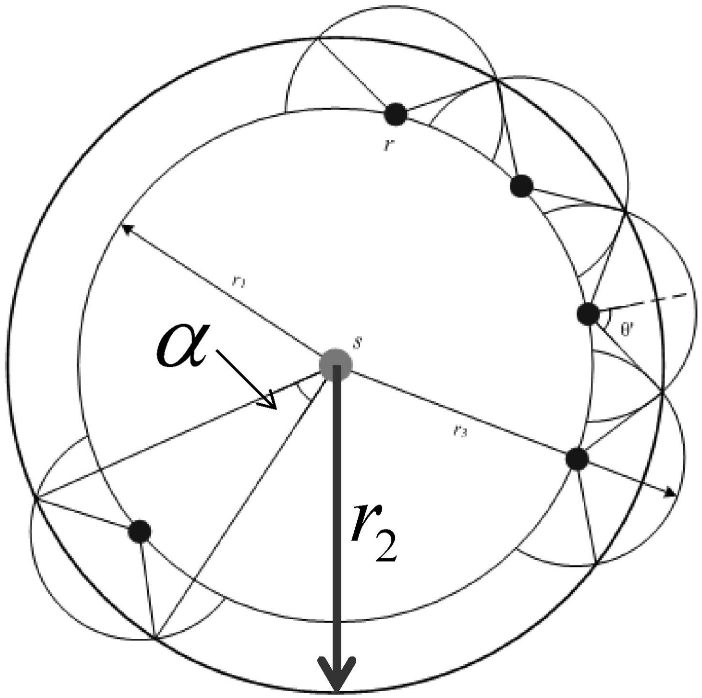
$$r_2 = \sqrt{d_{sr}^2 + (kd_{sr})^2 - 2d_{sr}(kd_{sr})\cos(\pi - \theta')}$$

Coverage angle:

$$\alpha = 2\arccos\left(\frac{d_{sr}^2 + r_2^2 - (kd_{sr})^2}{2d_{sr}r_2}\right)$$

Required number of relays:

$$N_R = \lceil 360° / \alpha \rceil$$

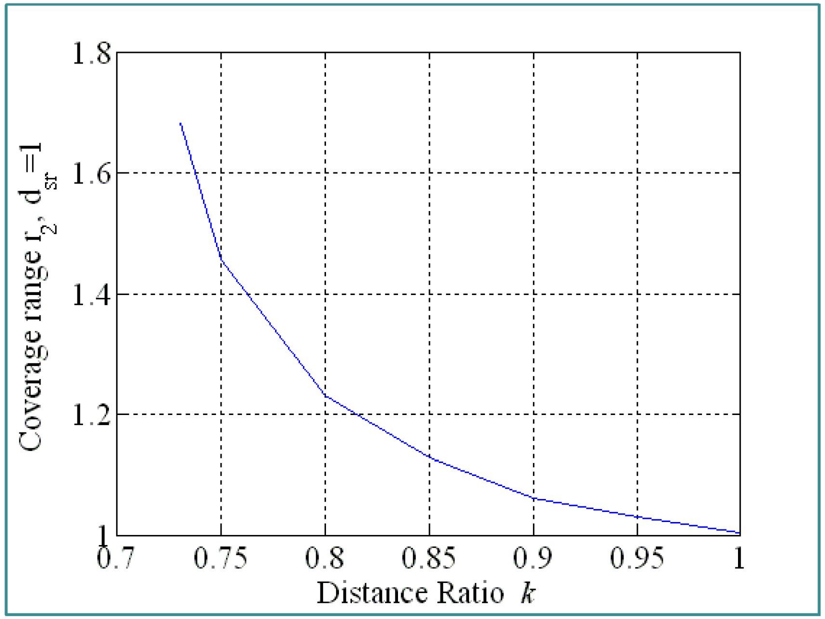


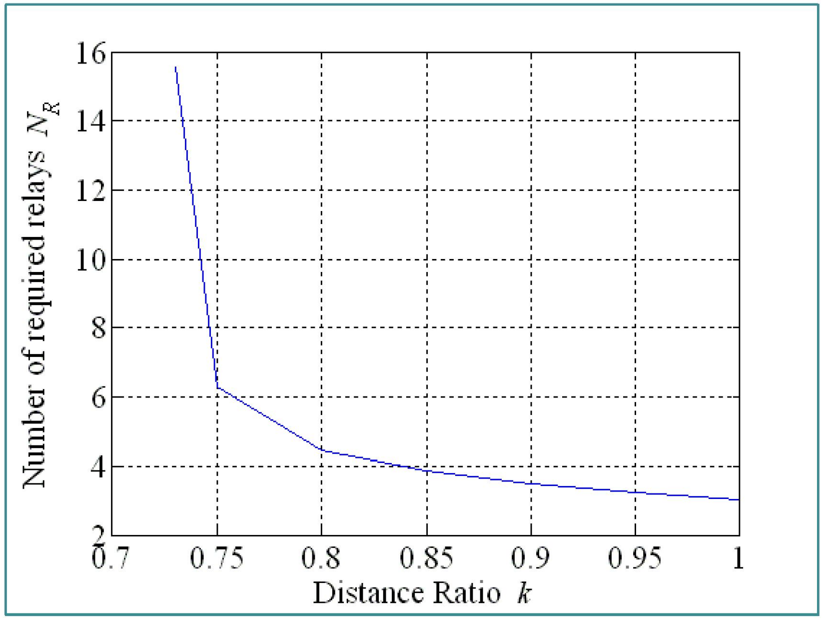
- For large coverage:
  - ✓ Decrease θ' (lower the power level)→ more relays are needed

[4] J. Zhao, et. al. (2007)

Cell Coverage Extension with Multiple Relays

- $\gamma = 4$

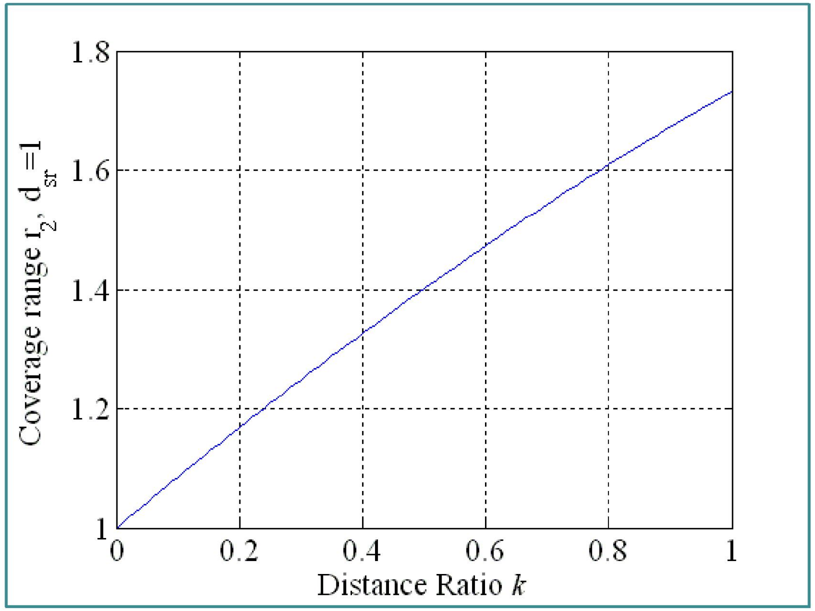


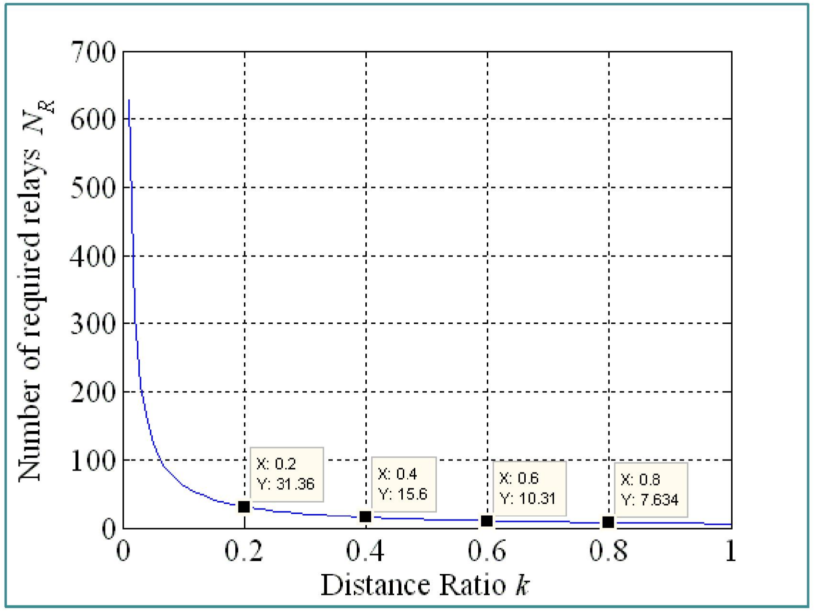


r_2 is extended .reciprocally to the increase of k.
Extend cell coverage up to r_2=1.6 with $N_R \leq 15$

Cell Coverage Extension with Multiple Relays

- $\gamma = 2$





$2N_R$ relays are used to cover circular cell shape.
r_2 is extended in proportion to the increase of k.

Cell Coverage Extension with Multiple Relays

- For maximum coverage range r_2

	γ = 4	γ = 3	γ = 2
r_2 / r_1	1.6	1.5	1.7
P_r / P_s [dB]	-2.22	-5.23	0
N_R	15	16	6

Concluding Remarks

- **Geometric analysis**
  - Relation of cooperation ratio a, distance ratio k, and θ
  - Relation of required number of relays N_R, distance ratio k, and effective coverage angle θ' to guarantee maximum achievable rate ($a^*=1$)
  - Condition to achieve maximum coverage range for $a^*=1$
    - ✓ Low attenuation regime: increase $P_r \rightarrow$ decrease N_R
    - ✓ High attenuation regime: decrease $P_r \rightarrow$ increase N_R

- **Future Directions**
  - Specific deploying scheme for the case of $\gamma = 2$
  - How about k > 1 ? (rural area)

Thank you!

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