Cooperative Relaying with Adaptive UL Power Balancing

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Venue:

IEEE 802.16m-08/040“Call for Contributions on Project 802.16m System Description Document (SDD)”, in response to the following topics: “Relaying Model”, MAC related]

Base Contribution:

N/A

Purpose:

to be discussed and adopted by TGm for the 802.16m SDD

Notice:

Release:

Patent Policy:

Cooperative Relaying with Adaptive UL Power Balancing

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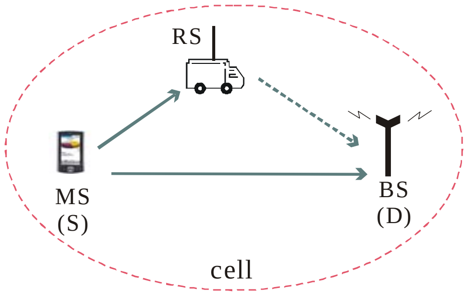
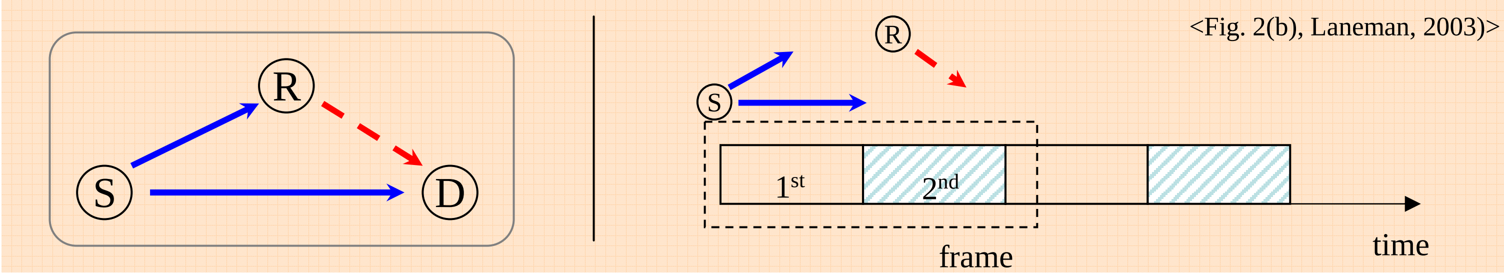
Update in Oct. 2008

Model: Relaying Mechanism



- Basic Model
  - Two types of nodes:
    - source node (transmits during 1st slot/interval);
    - relay node (relays during 2nd slot/interval)
  - Topology: Two-hop or multihop cellular network
  - Cooperative diversity scheme: Decode-and-forward scheme

- Cooperative Relaying:
  - A two-slot frame:
    - 1st slot: broadcast by source node (i.e., access duration)
    - 2nd slot: relay by relay node (i.e., relay duration)



<Fig. 2(b), Laneman, 2003)>

Power Balancing (1/4)

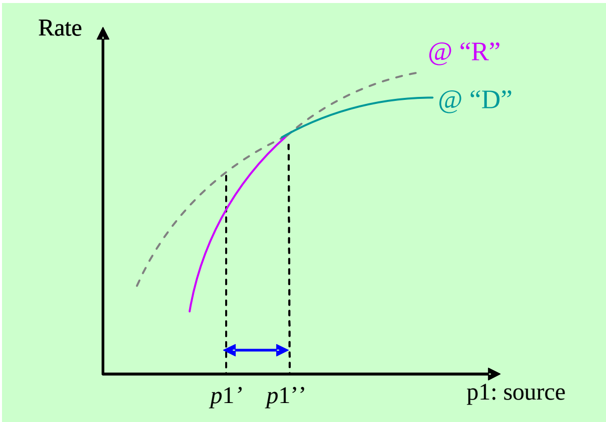
- Transmit Power Levels @ Transmitters
  - Source Node (MS): $p1$
  - Relay Node (RS): $p2$
- Achievable Rate @ Receivers
  - @ Relay Node
    - Link: S-R (distance "d")
  - @ Destination Node (after combining)
    - Links: S-D (distance "a") and R-D (distance "r")

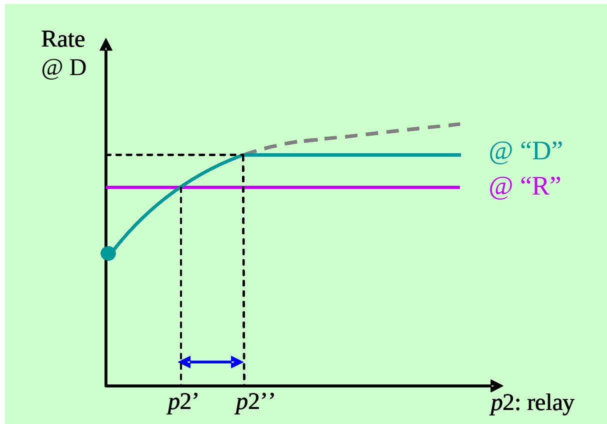
- Example of power deviations b/w MS and RS
  - When deviated (by measurement or by adopting timer), the power balancing mechanism runs

$$\frac{1}{2}\min\left\{\log_2(1+\kappa p_1 G(r)),\ \log_2(1+\kappa\cdot\{p_1 G(a)+p_2 G(d)\}) = x,\ \ p_2 \le p_M\right\}$$

Power Balancing (2/4)

- Two types of "power wastage" due to "Power Imbalance"
  - @ Source Node
  - @ Relay Node
- Examples

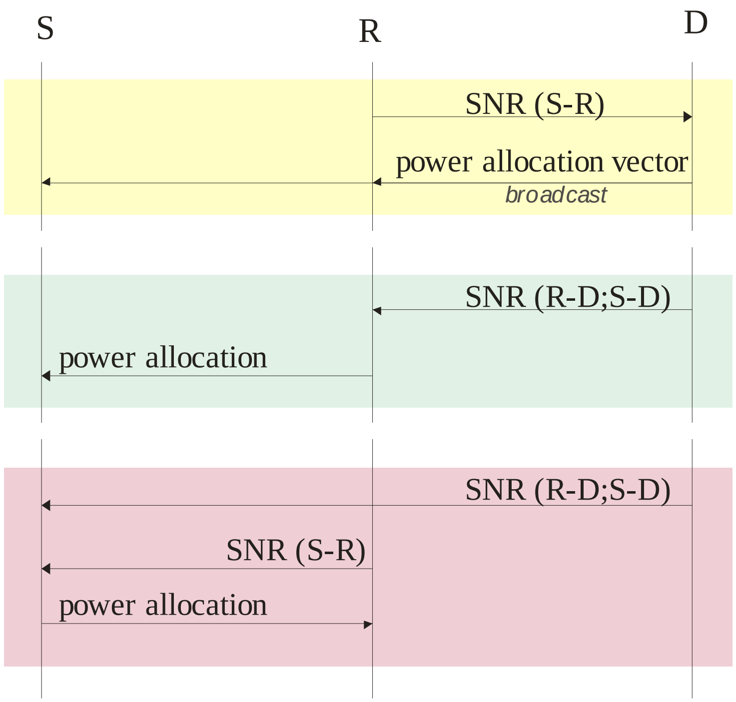


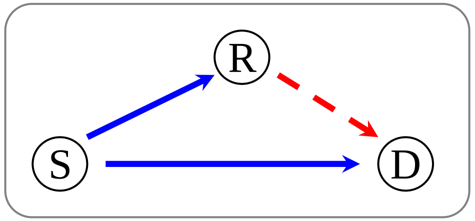


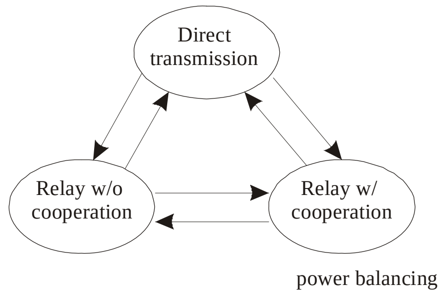
$$\frac{1}{2}\min\left\{\log_2(1+\kappa p_1 G(r),\ \log_2(1+\kappa\cdot\{p_1 G(a)+p_2 G(d)\})\right) = x,\quad p_2 \le p_M\}$$

Power Balancing (3/4)

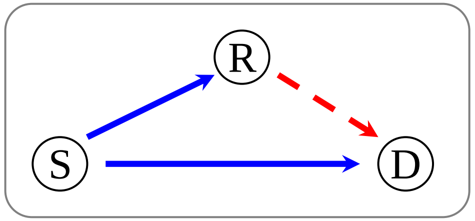
- Three possible signaling protocols (in terms of controlling unit)
  - Destination Node
  - Relay Node
  - Source Node







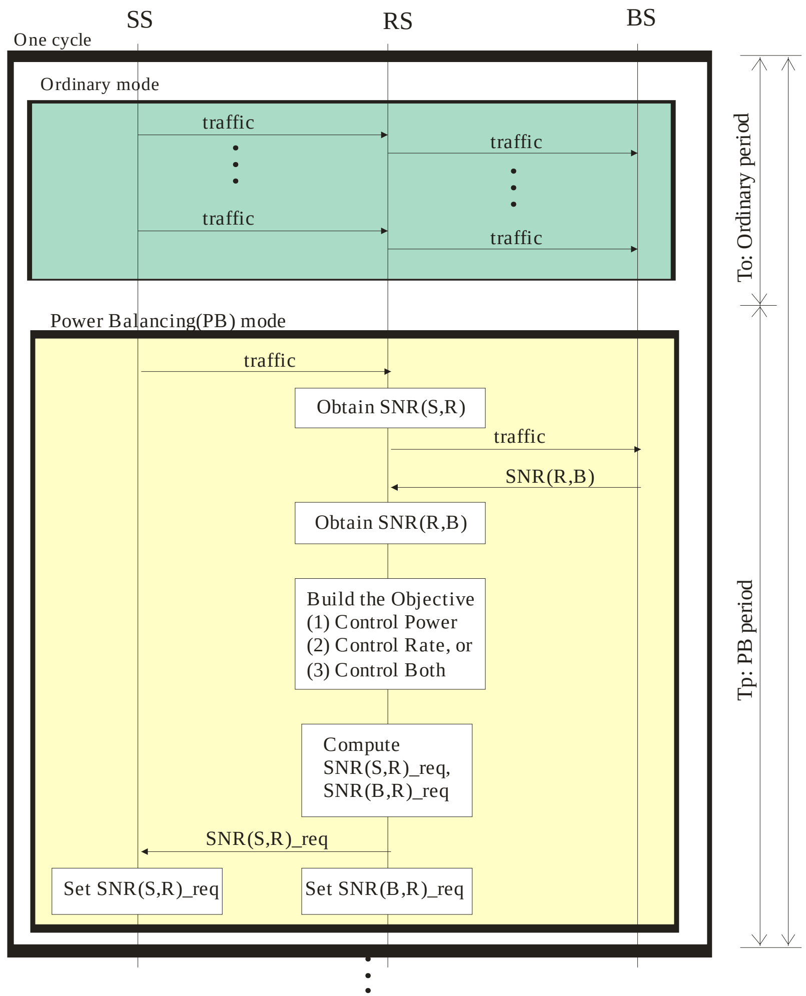
Power Balancing (4/4)



- What to control: Tx powers of “S” and “R”
- When “D” controls
  - “R” needs to report SNR (S2R) to “D”
  - “D” makes a full decision and broadcasts it
  - “D” does it in an iterative manner
- When “R” controls
  - “D” needs to report SNRs (S2D, R2D) to “R”
  - “R” makes a full decision and sends it to “S”
  - “R” does it in an iterative manner
- When “S” controls
  - (likewise…)
- When both “S-R” control
  - “D” → “R” and “S”; “R” → “S”
  - w/ and w/o negotiation: utility (or cost) functions are updated
  - exact control or iterative control

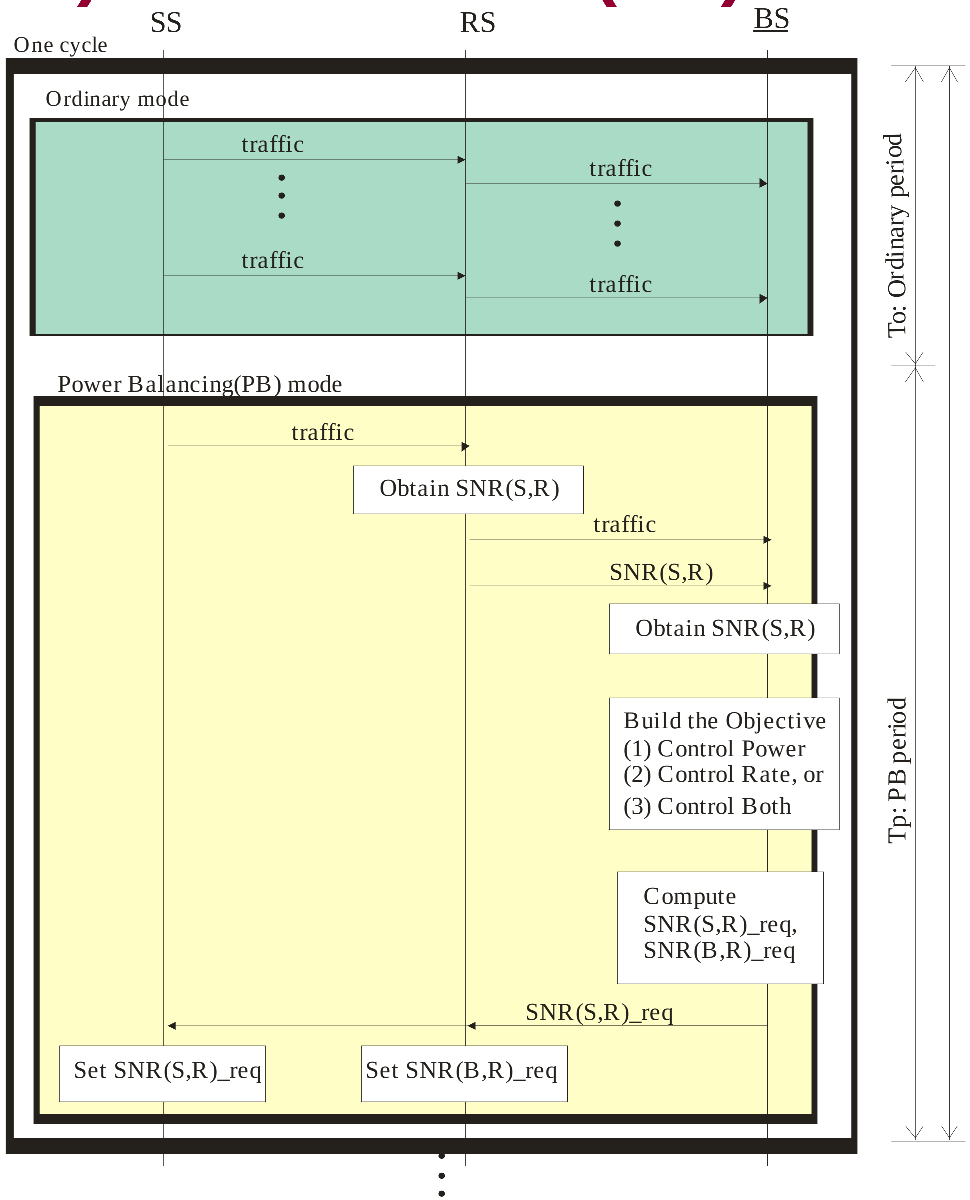
Power Balancing (PB) Mechanisms (1/2)

- Define the Objective
  - Control Rate to Keep Power
  - Control Power to Keep Rate
  - Control Both Rate and Power: to increase power at weaker party and to decrease power at stronger party (a combination of the first two above)
- Procedure
  - ➔flow diagram (Case 2: RS controls)
- Ratio of To/Tp:
  - = zero: do PB every transmission
  - = 1: do PB every 1st transmission
  - = n: do PB every (n-1)st transm.
  - = +infinity: no PB



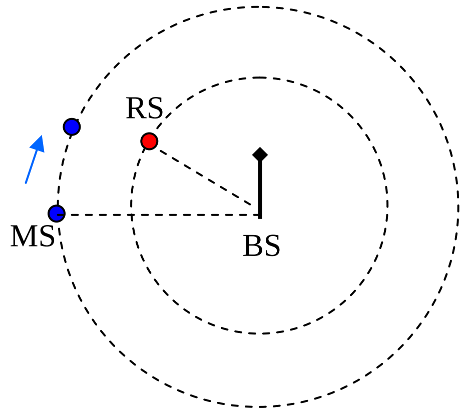
Power Balancing (PB) Mechanisms (1/2)

- BS controls



Case Examples

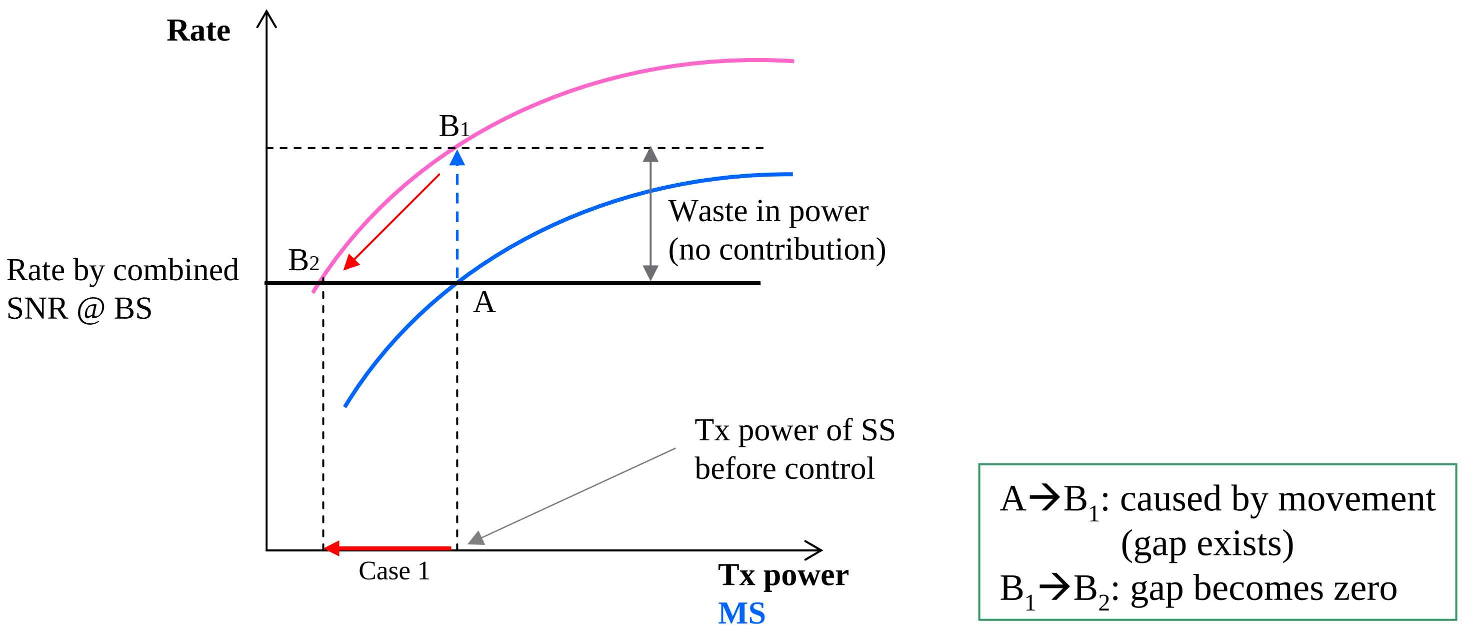
- MS gets close to RS with MS-BS distance fixed
  - Case 1: Target rate is fixed



- Before doing “Control”
  - RS Tx power is constant
  - MS Tx power is constant
  - MS moves toward RS keeping the MS-RS distance constant

Case 1

- *To reduce the wastage of power*:
- This results in a decrease in transmit power in the stronger party
- For example, if the SNR(S-R) is <u>stronger/greater</u> than SNR(combined @ BS), then the RS shall allocate power vector so that the SS can <u>decrease</u> the transmit power (by a given amount)



Gains and Operations with R-FS Options

- Gains (in Qualitative sense)
  - Achieving Power Saving @ Transmitter Node(s)
    - Power wastage reduction by balancing the power levels
    - Wastage reduction may result in a reduced level of interference

- This scheme is to be operated in both R-FS
  - FS Option 1: within two-hop
  - FS Option 2: any types

Proposed Text

- In cooperative relaying, the BS or RS should perform UL power balancing so that the MS and RS may not waste unnecessary power

Appendix: Simplified Analysis

Dropping Ratio

Link Capacity

- For the i-th user on the j-th subcarrier

$$C_{ij} = W \log_2 \left(1 + a \cdot G_{ij} p_{ij}\right)$$

$$a \approx -1.5/(\sigma^2 \cdot \log(5 \cdot \mathrm{BER}))$$

C_{ij}	Link capacity of the i-th user when using the j-th subcarrier
G_{ij}	Channel gain of the i-th user when using the j-th subcarrier **(r.v.)**
p_{ij}	Transmit power of the i-th user on the j-th subcarrier (mW)

Notation

-

	Description
W	Subcarrier bandwidth
G_{sr}	Channel gain b/w “source” and “relay” nodes
G_{rd}	Channel gain b/w “relay” and “destination” nodes
G_{sd}	Channel gain b/w “source” and “destination” nodes
$\overline{G}$	The average of G_{ij} **(r.v.)**
p_s	Average transmit power of the source node (mW)
p_r	Average transmit power of the relay node (mW)
$\overline{p}$	Max transmit power
σ^2	Thermal noise level (mW)
ϕ	Data rate requirement (Kbits/s)
BER	Target bit-error rate
C	No. of total subcarriers
F_X	cdf of r.v. X
f_X	pdf of r.v. X
γ_0	Outage threshold

The Average Rate per User (1/2)

- How much achievable rate can a user experience on average?
- How to formulate it?

The Average Rate per User (2/2)

- Approximation

$$R(y) \approx \left(\frac{C}{y} \cdot \frac{W}{2}\right) \cdot \min\left\{ \log_2\left(1 + \frac{ay}{C} \cdot \bar{G}_{s,r}\bar{p}_s\right), \log_2\left(1 + \frac{ay}{C} \cdot \{\bar{G}_{s,d}\bar{p}_s + \bar{G}_{r,d}\bar{p}_r\}\right)\right\}$$

- Re-written as a function of "y" (control variable) with three r.v.'s:

$$R(y) \approx \alpha(y) \cdot \min\left\{ \log_2\left(1 + \beta(y) \cdot \bar{G}_{s,r}\bar{p}_s\right), \log_2\left(1 + \beta(y) \cdot (\bar{G}_{s,d}\bar{p}_s + \bar{G}_{r,d}\bar{p}_r)\right)\right\}$$

$\alpha(y) \triangleq \frac{CW}{2y}$ $\quad\quad$ $\beta(y) \triangleq \frac{a}{C} y$

Dropping Ratio (1/2)

- Definition 1: the time average that the achievable rate of a connection falls below a given threshold value

- Definition 2: the probability that the achievable rate of a connection falls below a given threshold value

$$D(y) = \Pr(R(y) < \phi)$$

Dropping Ratio (2/2)

- Extension: $\rho(y) = \frac{\phi}{\alpha(y)}$

$$D(y) = \Pr\left(\min\left\{1 + \beta(y) \cdot \bar{G}_{sr}\bar{p}_s,\ 1 + \beta(y) \cdot (\bar{G}_{sd}\bar{p}_s + \bar{G}_{rd}\bar{p}_r)\right\} < 2^{\rho(y)} \right)$$

  - Pr(min{A, B} < z) = 1- Pr(min{A, B} ≥ z)
    = 1- Pr(A ≥ z)* Pr(B ≥ z)
    = 1- {1-Pr(A < z)}* {1-Pr(B < z)}

- Result:

$$D(y) = F_{\bar{G}_{sr}}\left(\frac{2^{\rho(y)} - 1}{\beta(y) \cdot \bar{p}_s}\right) + \int_0^{\frac{2^{\rho(y)}-1}{\beta(y)\bar{p}_r}} F_{\bar{G}_{sd}}\left(\frac{2^{\rho(y)} - 1}{\beta(y)\bar{p}_s} - \frac{\bar{p}_r}{\bar{p}_s} \cdot x\right) \cdot f_{\bar{G}_{rd}}(x)dx$$

$$-F_{\bar{G}_{sr}}\left(\frac{2^{\rho(y)} - 1}{\beta(y) \cdot \bar{p}_s}\right) \cdot \int_0^{\frac{2^{\rho(y)}-1}{\beta(y)\bar{p}_r}} F_{\bar{G}_{sd}}\left(\frac{2^{\rho(y)} - 1}{\beta(y)\bar{p}_s} - \frac{\bar{p}_r}{\bar{p}_s} \cdot x\right) \cdot f_{\bar{G}_{rd}}(x)dx$$

Constrained Maximization of Accommodation Capacity

Maximization of “Accommodation Capacity”

- “Accommodation Capacity”
  - “y”: no. of connections accommodated in a cell

- Constrained Optimization
  - The objective: to maximize “y”
  - The constraint: “dropping ratio” is upper-bounded

$$
\begin{aligned}
&(P) \\
&\text{maximize} \quad y \\
&\text{subject to} \;\; D(y) \leq \gamma_O \\
&\qquad y : \text{nonnegative integer}
\end{aligned}
$$

Optimal Solution of (P)

- Properties:
  - Single-variable
  - “D(y)” is strictly increasing in “y”

- Optimal Solution:

$$y^* = \lfloor \sup\{y : D(y) \leq \gamma_0\} \rfloor$$

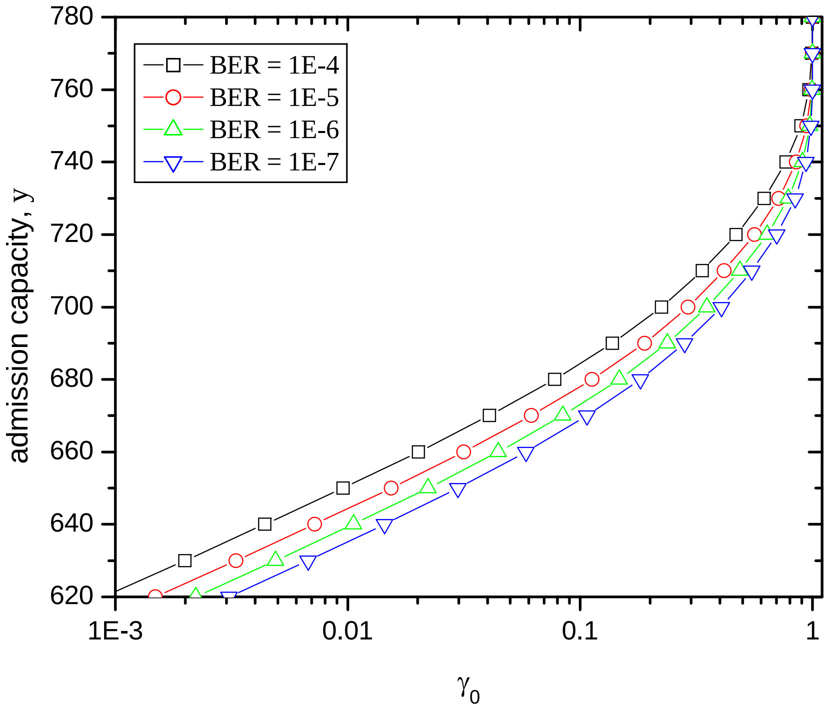
Analytical Results

Analytical Setup

item	value	description
C	128	no. of subcarriers
W	25000	bandwidth of subcarrier (Hz)
$\bar{p}_s$	50	avg. transmit power of source node (mW)
$\bar{p}_r$	50	avg. transmit power of relay node (mW)
σ^2	1e-11	thermal noise level (W)
$\bar{G}$	$\sim \mathcal{N}(100, 5)$	
ϕ	100	min. required rate per connection (Kbps)
BER	1e-5	desired bit-error rate

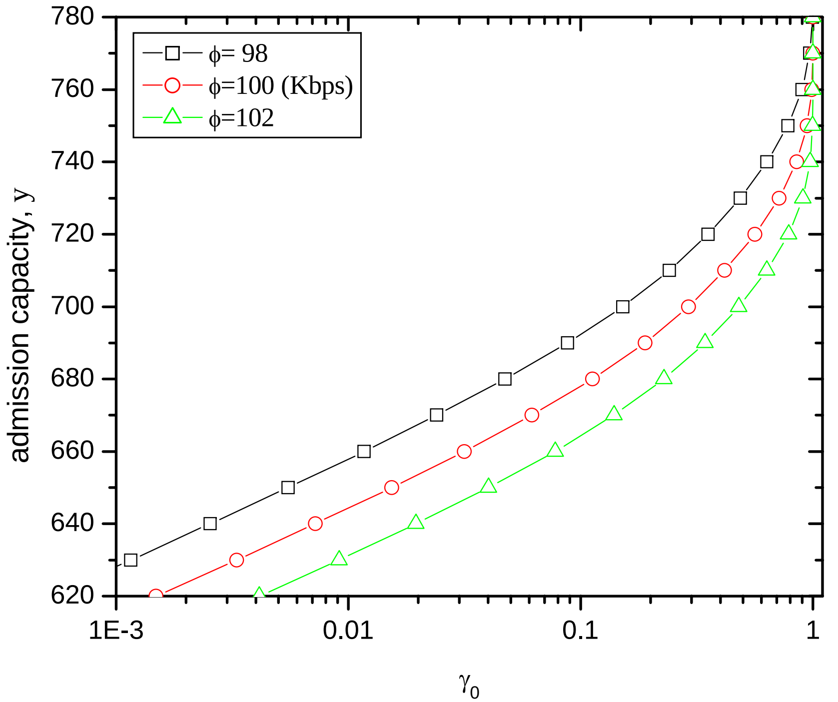
Analytical Results (1/3)

- “y” vs. “DR threshold”
  - BER
  - r_O=0.01, 8% increase in ”y” with 10-fold increase in BER



Analytical Results (2/3)

- “y” vs. “DR threshold”
  - Data rate requirement
  - r_O=0.01, 2% increase/decrease →
    - 644 @ 100Kbps
    - 659 @ 102Kbps (+2.3%)
    - 631 @ 98Kbps (-2.0%)



Analytical Results (3/3)

- “y” vs. “DR threshold”
  - Transmit power of source node; transmit power of relay node