Cooperative Relaying with Adaptive UL Power Balancing

IEEE 802.16 Presentation Submission Template (Rev. 9)

Document Number:

[IEEE S802.16m-08/1356r1]

Date Submitted:

[2008-11-10]

Source:

Ki-Dong Lee, Li-Hsiang Sun Voice: +1-858-635-5300
LG Electronics E-mail: kidonglee@lge.com

*<http://standards.ieee.org/faqs/affiliationFAQ.html>

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:

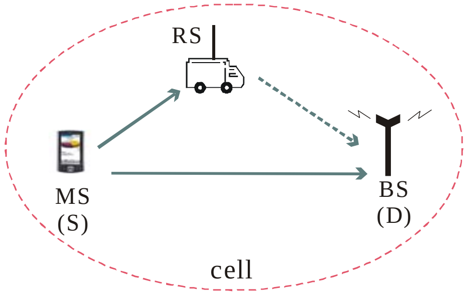
Patent Policy:

Cooperative Relaying with Adaptive UL Power Balancing

Ki-Dong Lee and Li-Hsiang Sun
LG Electronics

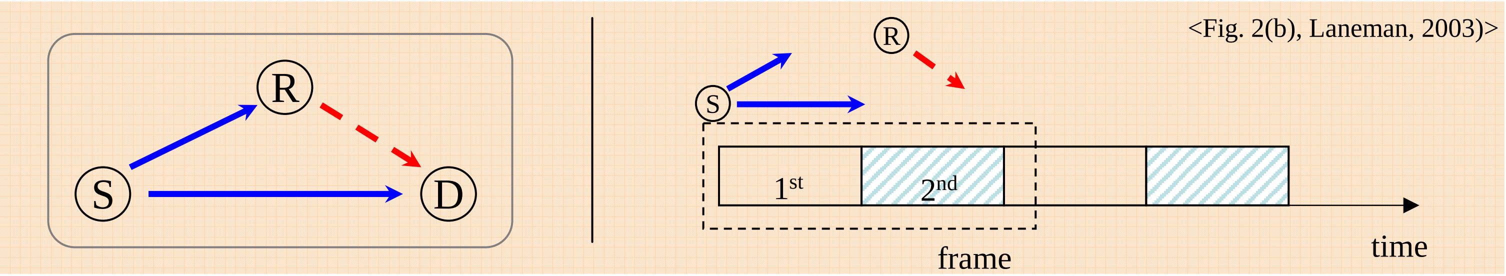
Update in Oct. 2008

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)

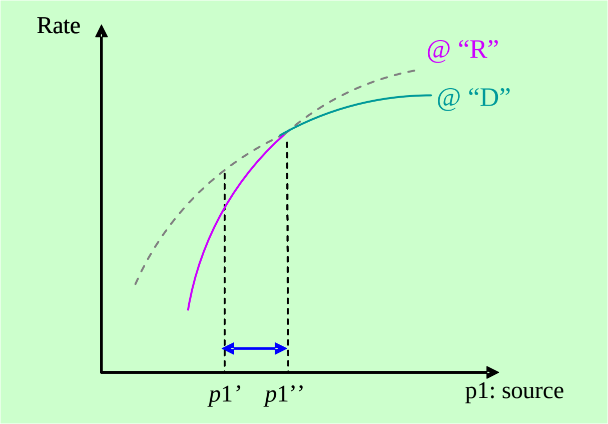
- Transmit Power Levels @ Transmitters
  - Source Node (MS): $p1$
  - Relay Node (RS): $p2$
- Achievable Rate @ Receivers
  - @ Relay Node
    - Link: S-R (distance “*d*”)
  - @ Destination Node (after combining)
    - Links: S-D (distance “*a*”) and R-D (distance “*r*”)

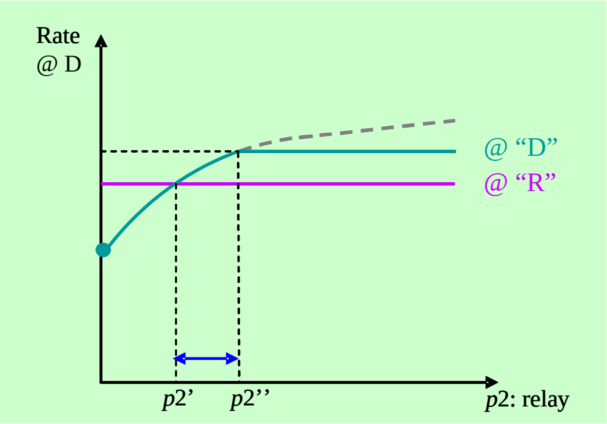
- Example of power deviations b/w MS and RS
  - When deviated (by measurement or by adopting timer), the power balancing mechanism runs

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

Power Balancing (2/4)

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

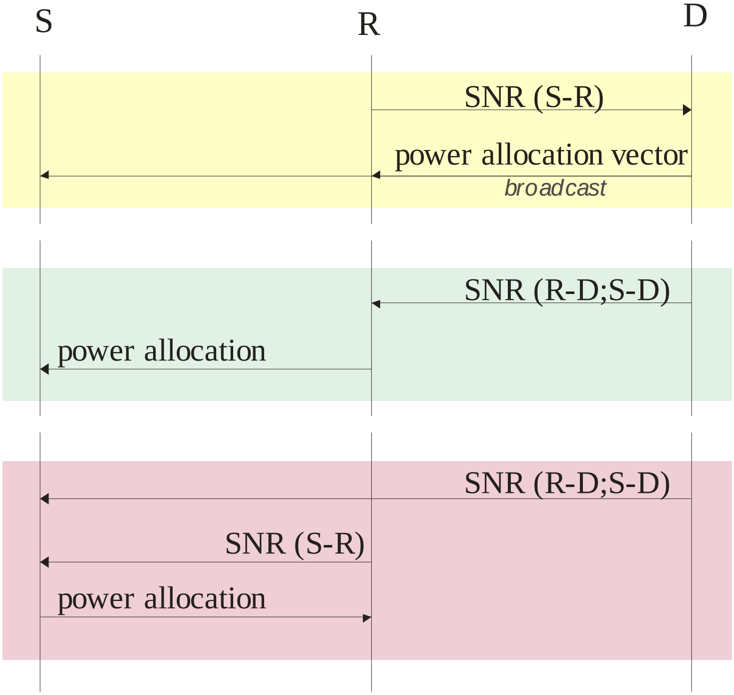


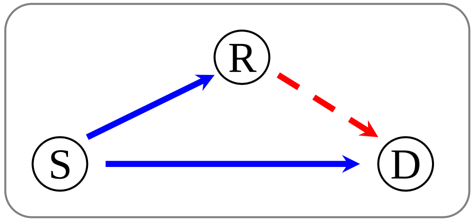


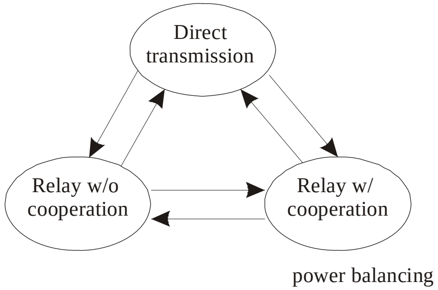
$$\frac{1}{2}\min\left\{\log_2(1+\kappa p_1 G(r),\ \ \log_2(1+\kappa\cdot\{p_1 G(a)+p_2 G(d)\}) = x,\ \ p_2 \le p_M\right\}$$

Power Balancing (3/4)

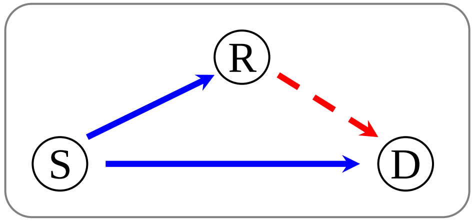
- Three possible signaling protocols (in terms of controlling unit)
  - Destination Node
  - Relay Node
  - Source Node







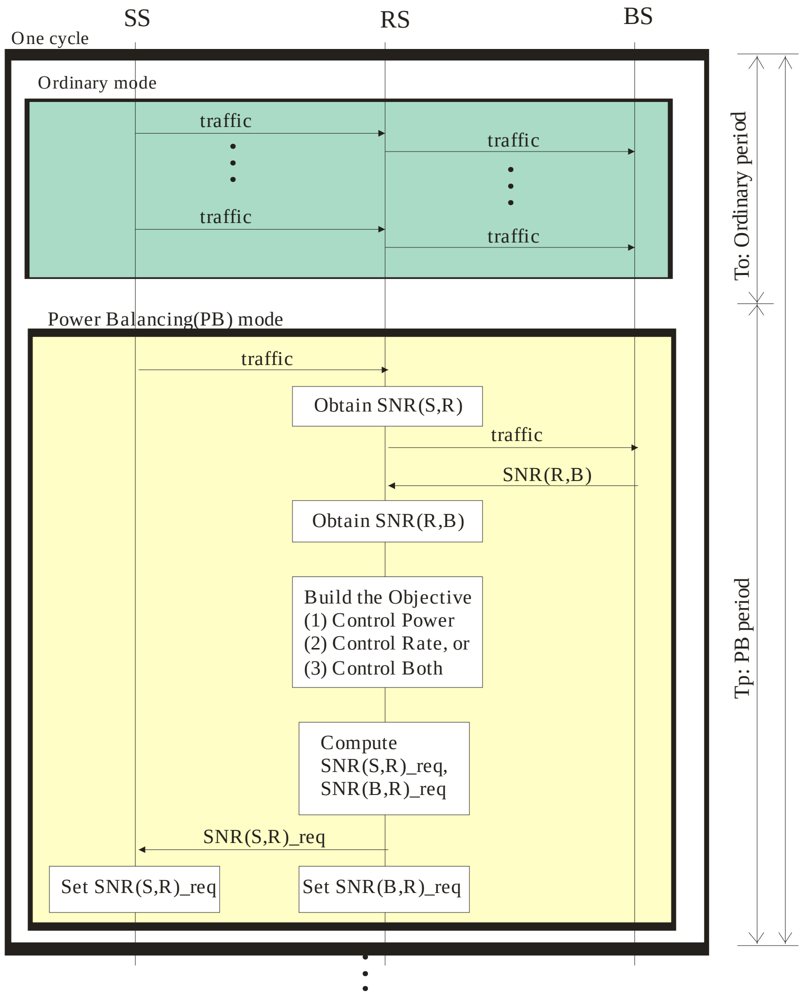
Power Balancing (4/4)



- 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

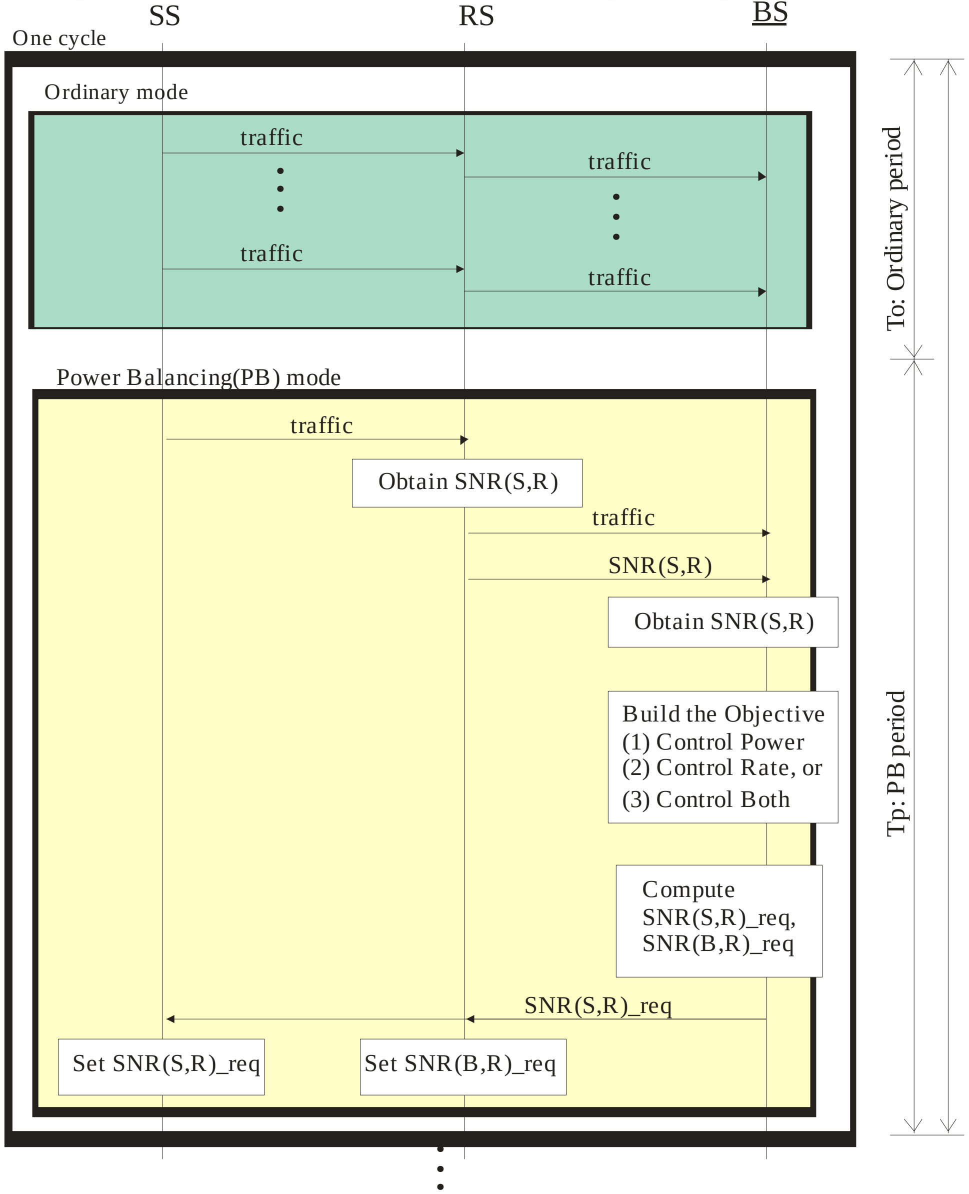
Power Balancing (PB) Mechanisms (1/2)

- 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



SS

RS

BS

One cycle

Ordinary mode

traffic

traffic

traffic

traffic

Power Balancing(PB) mode

traffic

Obtain SNR(S,R)

traffic

SNR(S,R)

Obtain SNR(S,R)

Build the Objective
(1) Control Power
(2) Control Rate, or
(3) Control Both

Compute
SNR(S,R)_req,
SNR(B,R)_req

SNR(S,R)_req

Set SNR(S,R)_req

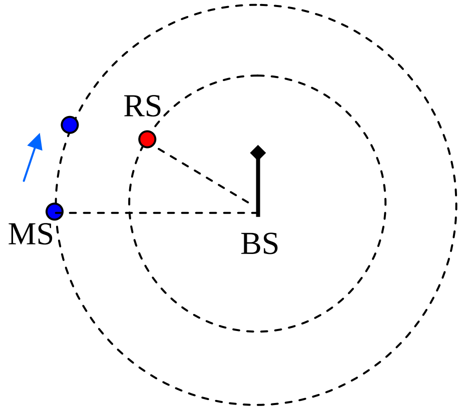
Set SNR(B,R)_req

To: Ordinary period

Tp: PB period

Case Examples

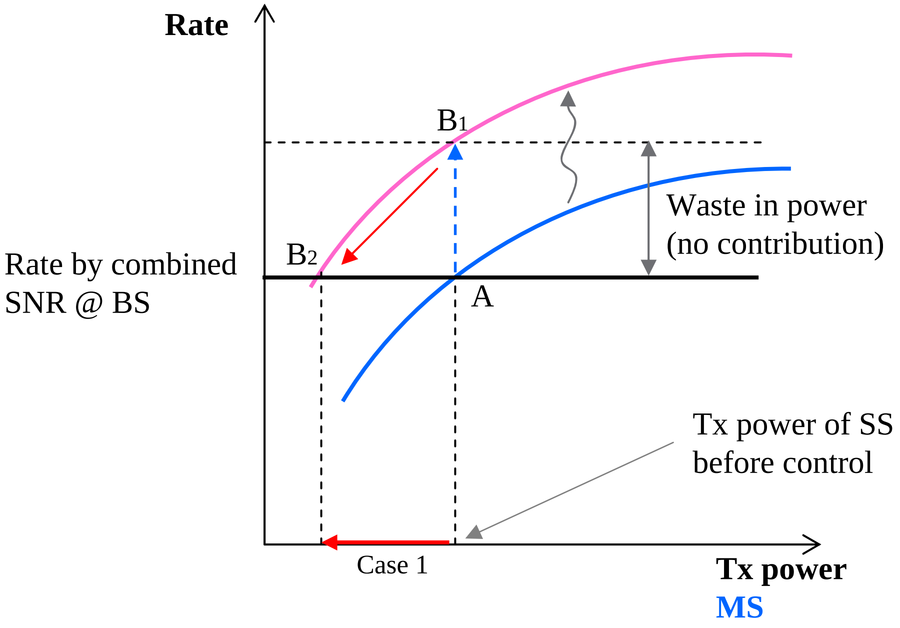
- MS gets close to RS with MS-BS distance fixed
  - Case 1: Target rate is fixed



- Before we do the “Control”, (assume that) we observed the followings:
  - RS Tx power is constant
  - MS Tx power is constant
  - MS moves toward RS keeping the MS-RS distance constant

Case 1

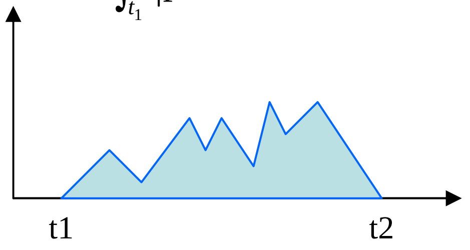
- *To reduce the Tx power wastage (as well as unnecessary interference)*:
- This results in a decrease in transmit power in the stronger party
- For example, if the SNR(S-R) is <u>stronger/greater</u> than SNR(combined @ BS), then the RS shall allocate power vector so that the SS can <u>decrease</u>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



A→B_1: caused by movement
(gap exists)
B_1→B_2: gap becomes zero
(control is preferred)

- Expected energy wastage w/o UL PB during a reference time period (t1, t2):

$$\int_{t_1}^{t_2} \left| \text{pwr. diff. b/w A and B1} \right| dt$$



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:

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

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

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} $\geq$ z)
    = 1- Pr(A $\geq$ z)* Pr(B $\geq$ 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

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

Optimal Solution of (P)

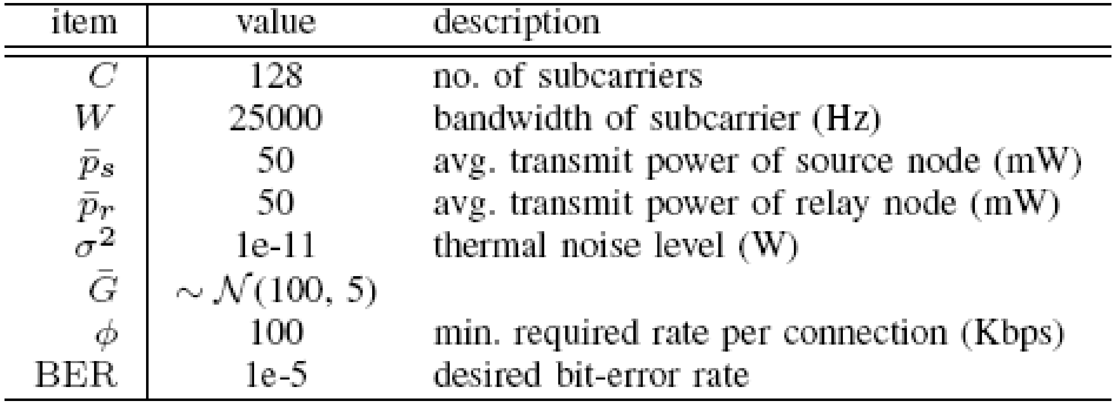
- Properties:
  - Single-variable
  - “D(y)” is strictly increasing in “y”

- Optimal Solution:

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

Analytical Results

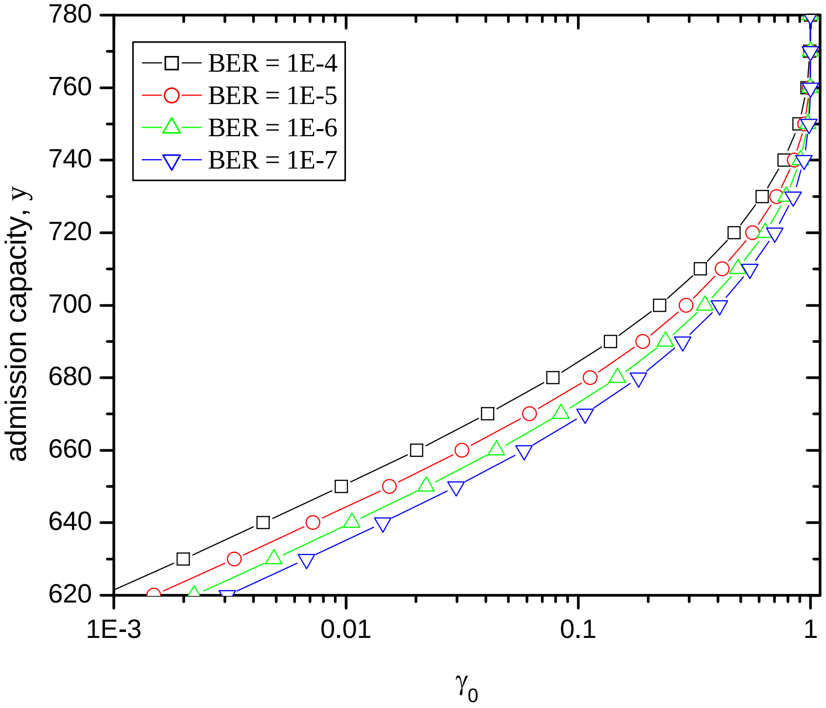
Analytical Setup



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

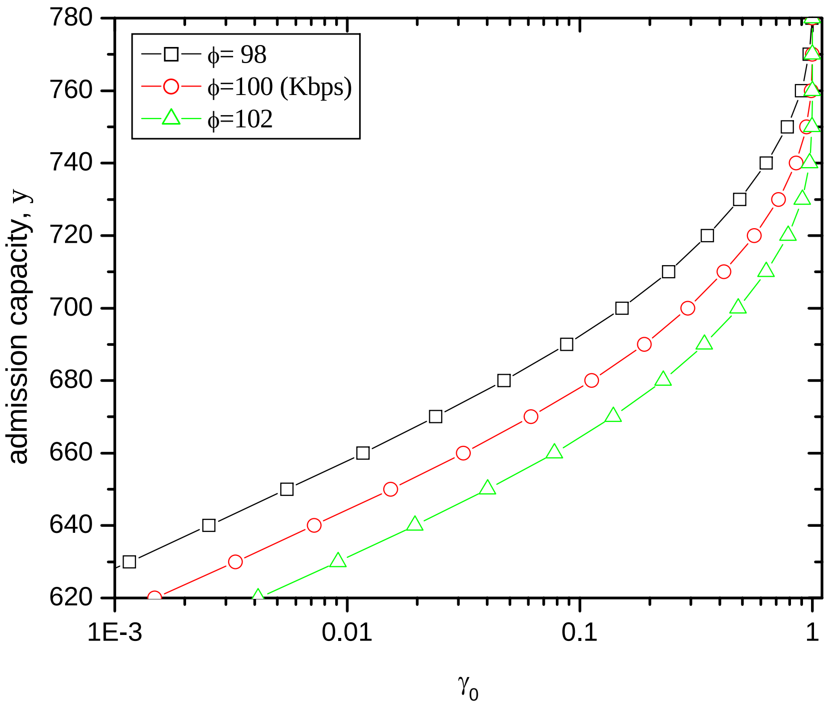
Analytical Results (1/3)

- “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