Energy Efficiency Analysis in Relay Assisted Hybrid-ARQ Communications

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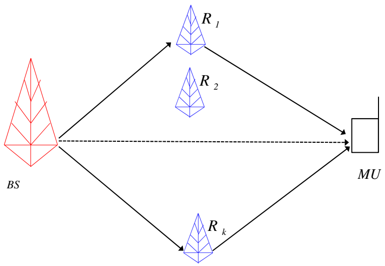
Outline

Introduction

Relay assisted cellular networks

Intermediate relays between the base station (BS) and users leads to several gains:

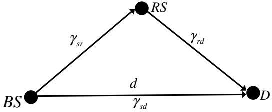
- Coverage enhancement
- Higher data rates
- High cell capacity (number of users)



Motivations and system model

- Aim: Energy efficiency analysis in relay assisted HARQ schemes

$$\eta_E = \frac{(1 - PER) \cdot N_b}{\bar{E}_{pkt}} \quad (bits/joule)$$



System protocol

- BS broadcasts the packet to RS and D
- If RS has received the packet and D not yet, RS starts retransmitting the packet
- Each receiving node combines the retransmitted packet with the previous ones by means of Chase combining
- The number of retransmissions is limited to N_{max}

Related works and contributions

Related works

- In [1], the authors studied the energy efficiency for cooperative and non cooperative HARQ schemes for users constrained in outage probability. In contrast, our analysis takes into account the PER
- In [2], the authors studied the end-to-end throughput and the energy efficiency of opportunistic and multi-hop routing protocols without considering the Chase combining technique
- In [3], the throughput of HARQ-CC protocol with cooperation has been analyzed. However, this analysis is complex in comparison to our analysis

Contributions

- New simple analytical model of PER in relay-assisted HARQ-CC schemes
- Energy efficiency analysis in HARQ-CC for relay-assisted schemes with direct link

[1]- I. Stanojev, O. Simeone, Y. Bar-Ness, and K. Dong Ho, *"Energy efficiency of non-collaborative and collaborative hybrid-ARQ protocols,"* IEEE Transactions on Wireless Communications, vol. 8, pp. 326-335, Jan. 2009.
[2]- D. Chiarotto, O. Simeone, and M. Zorzi, *"Throughput and Energy Efficiency of Opportunistic Routing with Type-I HARQ in Linear Multihop Networks,"* in IEEE Global Telecommunications Conference (GLOBECOM 2010), pp. 1-6, Dec. 2010.
[3]- X. Lagrange, *"Performance of Chase-Combining HARQ protocol with Cooperation,"* tech. rep., TRITA - ICT - COS - 1006 ISSN 1653 - 6347 ISRN KHT/COS/R-10/06-SE, 2010.

Delay theoretical model

- The average delay in cooperative scheme is:

$$\bar{N}_{t_{coop}} = \bar{N}_{t_s} + \bar{N}_{t_r} \tag{1}$$

- The average delay when the source is transmitting:

$$\bar{N}_{t_s} = \sum_{n=1}^{N_{max}-1} n\Big(Q_{sd}(n)P_{sr}(n-1) + P_{sd}(n)Q_{sr}(n)\Big) + N_{max}\Big(Q_{sd}(N_{max})P_{sr}(N_{max}-1)\Big) + N_{max}\Big(P_{sr}(N_{max}-1)P_{sd}(N_{max})\Big) \tag{2}$$

where $Q_{sd}(n) = P_{sd}(n-1) - P_{sd}(n)$ and $Q_{sr}(n) = P_{sr}(n-1) - P_{sr}(n)$.

- $\bar{N}_{t_r}$ can be expressed as:

$$\bar{N}_{t_r} = \sum_{n'=1}^{N_{max}-1} Q_{sr}(n')\left(\sum_{n=n'+1}^{N_{max}} (n-n')Q_{rd}(n,n') + (N_{max}-n')\cdot P_{rd}(N_{max},n')\right) \tag{3}$$

Probability of error (1)

- The packet error rate using HARQ-CC is defined as follows:

$$PER_{coop} = 1 - \left(\sum_{n=1}^{N_{max}} Q_s(n) + \sum_{n'=1}^{N_{max}-1} \sum_{n=n'+1}^{N_{max}} Q_r(n,n') \right) \tag{4}$$

- $Q_r(n,n')$ is as follows:

$$Q_r(n,n') = Q_{sr}(n') \left(P_{rd}(n-1,n') - P_{rd}(n,n') \right) \tag{5}$$

- $Q_s(n)$ is calculated as:

$$Q_s(n) = P_{sr}(n-1) \Big(P_{sd}(n-1) - P_{sd}(n) \Big) \tag{6}$$

- The error probability $P(n)$ can be calculated by:

$$P(n) = \int_0^\infty \int_0^\infty \dots \int_0^\infty f(\gamma_1) f(\gamma_1+\gamma_2) \cdots f(\gamma_1+\gamma_2+\dots\gamma_n) \times p_{\gamma_{sd}}(\gamma_1) \cdot p_{\gamma_{sd}}(\gamma_2) \cdots p_{\gamma_{sd}}(\gamma_n) d\gamma_1 d\gamma_2 \dots d\gamma_n \tag{7}$$

- Equation (7) can be approximated by:

$$P(n) \approx \underbrace{\int_0^\infty \int_0^\infty \dots \int_0^\infty}_{n \text{ folds}} f(\gamma_1+\gamma_2+\dots\gamma_n) \times p_{\gamma_{sd}}(\gamma_1) \cdot p_{\gamma_{sd}}(\gamma_2) \cdots p_{\gamma_{sd}}(\gamma_n) d\gamma_1 d\gamma_2 \dots d\gamma_n \tag{8}$$

Probability of error (2)

- The packet error rate $f(\gamma)$ can be fitted by:

$$f(\gamma) = \begin{cases} a \cdot \exp(-g\gamma) & \text{if } \gamma \geq \gamma_M \\ 1 & \text{otherwise} \end{cases} \tag{9}$$

where a, g and γ_M depend on the packet length, modulation and coding schemes.

- $P(n)$ can be split into three parts as [4]:

$$P(n) = A_n + \sum_{m=1}^{n-1} B_{n,m} + C_n \tag{10}$$

where A_n, $B_{n,m}$ and C_n can be proved to be:

$$A_n = 1 - \exp\left(-\frac{\gamma_M}{\bar{\gamma}_{sd}}\right) \sum_{k=0}^{n-1} \frac{1}{k!} \left(\frac{\gamma_M}{\bar{\gamma}_{sd}}\right)^k \tag{11}$$

$$B_{n,m} = \left(\frac{{\gamma_M}^m}{m!}\right)\left[\frac{1}{1+g\bar{\gamma}_{sd}}\right]^{n-m}\left(\frac{1}{\bar{\gamma}_{sd}}\right)^m \exp\left(-\frac{\gamma_M}{\bar{\gamma}_{sd}}\right) \tag{12}$$

$$C_n = \left[\frac{1}{1+g\bar{\gamma}_{sd}}\right]^n \exp\left(-\frac{\gamma_M}{\bar{\gamma}_{sd}}\right) \tag{13}$$

[4] - X. Lagrange, *"Throughput of HARQ protocols on a block fading channel," IEEE Communications Letters, vol. 14, pp. 257-259, March 2010.*

Probability of error (3)

- $P_{rd}(n, n')$ can be expressed as:

$$P_{rd}(n,n') = \underbrace{\int_0^\infty \cdots \int_0^\infty}_{n' \text{ folds}} \underbrace{\int_0^\infty \cdots \int_0^\infty}_{n-n' \text{ folds}} f(\gamma_1) f(\gamma_1+\gamma_2) \cdots f(\gamma_1+\gamma_2+...\gamma_n) \times p_{\gamma_s}(\gamma_1) \cdots p_{\gamma_s}(\gamma_{n'}) p_{\gamma_r}(\gamma_{n'+1}) \cdots p_{\gamma_r}(\gamma_n) d\gamma_1 d\gamma_2 ... d\gamma_n \quad (14)$$

- $P_{rd}(n, n')$ can be approximated by:

$$P_{rd}(n,n') \approx \underbrace{\int_0^\infty \cdots \int_0^\infty}_{n' \text{ folds}} \underbrace{\int_0^\infty \cdots \int_0^\infty}_{n-n' \text{ folds}} f(\gamma_1+\gamma_2+...+\gamma_n) \times p_{\gamma_s}(\gamma_1) \cdots p_{\gamma_s}(\gamma_{n'}) p_{\gamma_r}(\gamma_{n'+1}) \cdots p_{\gamma_r}(\gamma_n) d\gamma_1 d\gamma_2 ... d\gamma_n \quad (15)$$

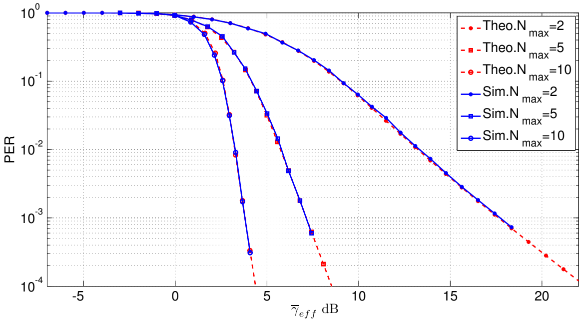
Simulation results: System model parameters

Parameters	Description	value
P_{txElec}	transmitter circuitry power	20 dBm
N_0	power spectral density of the noise	-155 dBm/Hz
N_b	number of bits in data packet	1080
R_b	transmission bit rate	150 kbps
R_c	coding rate	1
P_{rxElec}	receiver circuitry power	20 dBm
f_c	carrier frequency	2.4 GHz
τ	ACK ratio	0.08125
a	curve fitting parameter	67.7328
g	curve fitting parameter	0.9819
γ_M	SNR fitting parameter	6.3281 dB

Table: System model parameters [5-6]

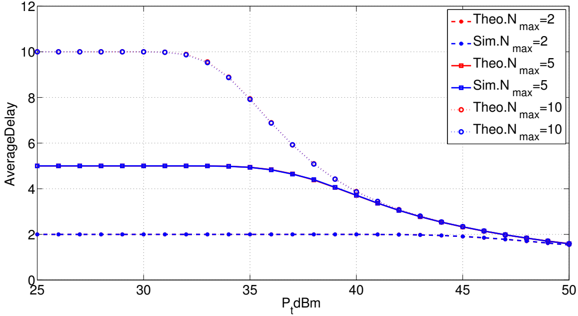
[5]- Q. Liu, S. Zhou, and G. Giannakis, *" Cross-Layer combining of adaptive modulation and coding with truncated ARQ over wireless links,"* IEEE Transactions on Wireless Communications, vol. 3, pp. 1746-1755, September 2004.
[6]- Z. Ruifeng, J.-M. Gorce, and K. Jaffres-Runser, *" Low Bound of Energy- Latency Trade-Off of Opportunistic Routing in Multi-Hop Networks,"'* in ICC'09. IEEE International Conference on Communications, 2009, pp. 1-6, June 2009.

Simulation results: PER versus effective SNR



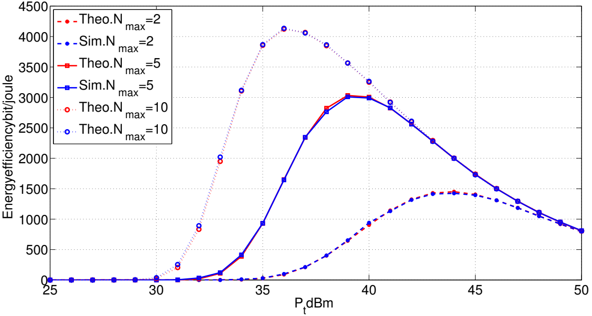
- The average effective SNR is defined as $\bar{\gamma}_{eff} = \bar{\gamma}_{sd} \cdot \bar{N}_{tcoop}$
- The angle between the line joining BS to D and BS to RS is $\pi/6$ radians
- N_{max} = 2, 5 and 10
- Propagation model: COST 231-Hata $139.90 + 34.41.\log_{10}(d_l)$ dB in each link

Simulation results: Average delay versus P_t



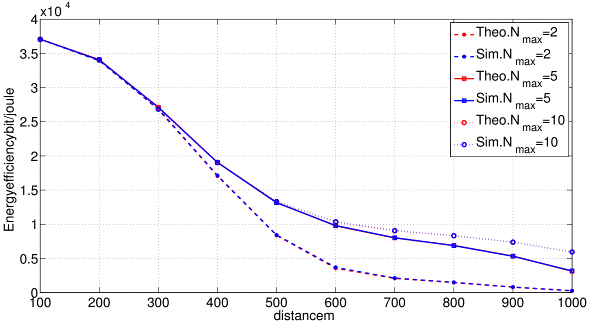
- N_{max} = 2, 5 and 10
- The theoretical approximation matches perfectly the simulated one

Simulation results: Energy efficiency versus P_t



- As N_{max} increases, η_E increases
- There is an optimal power that maximizes η_E

Simulation results: Energy efficiency versus distance



- P_t = 35 dBm
- BS, RS and D are collinear
- Higher number of retransmissions is energy efficient

Conclusions and future works

Conclusions

- A simple theoretical analysis for energy efficiency in relay network
- Higher number of allowed retransmissions leads to higher energy efficiency communications
  - Gain is assessed precisely with our model

Future works

- Resource allocation for OFDMA relay-assisted system for delay constrained users is under investigation
- This resource allocation takes into account the random distribution of users, the retransmission mechanisms and the coding scheme (LDPC)