A Simulation Package for an Energy-Aware Comparison of ARQ Protocols

9th Annual Industrial Simulation Conference, ISC'2011

Gian-Luca Dei Rossi Andrea Marin Matteo Rosati
Simonetta Balsamo

Dipartimento di Scienze Ambientali, Informatica e Statistica
Università Ca' Foscari, Venezia

June 6, 2011

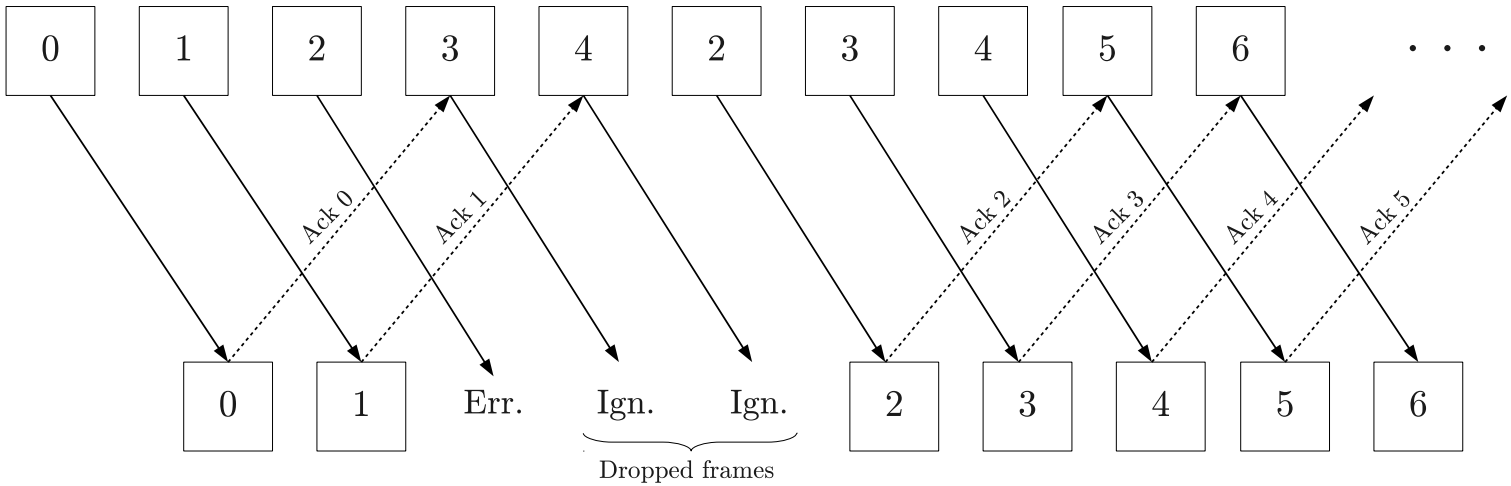
Outline

- Context and motivations
- Background
- Theoretical Model
- Simulation Package
- Validation
- A Heuristic for energy efficiency optimisation
- Simulation results and heuristic comparison
- Conclusions

Context and motivations

- ARQ protocols are widely used
- Used in different networking stack layers to achieve reliability
  - data link
  - transport
- Throughput vs. Energy efficiency (mobile applications)
- Error prone channels, correlation of errors in wireless networks

Go-Back-N

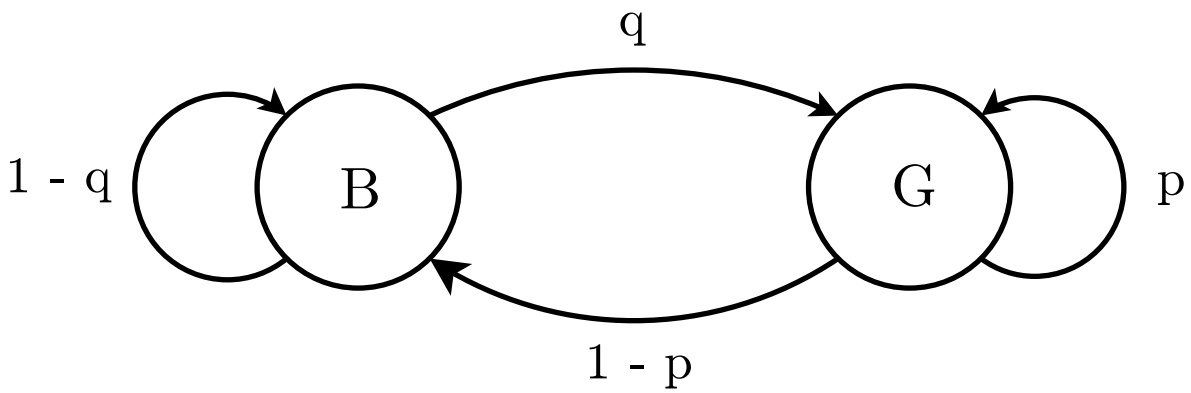


- Sliding window protocol
- Automatic Repeat Request (ARQ)
- See Tanenbaum (2002)

Theoretical Model: assumptions

- Two agents: Sender S and Receiver R
- Noisy channel C with bandwidth b and propagation delay d
- S is always ready to send packets unless window is full
- All packets have size s, time to send a single packet is $f = \frac{s}{b}$
- Optimal window size $N = \frac{f+2d}{f}$
- ACKs have a negligible size (modelled as 0) and are never lost
- Optimal time-out $t = 2d + f$
- Two states of the channel: good (G) or bad (B)
- At each transmission:
  - if the channel was in G, it remains in G with probability p or switches to B with probability $1 - p$
  - if the channel was in B, it switches to G with probability q or it remains in B with probability $1 - q$

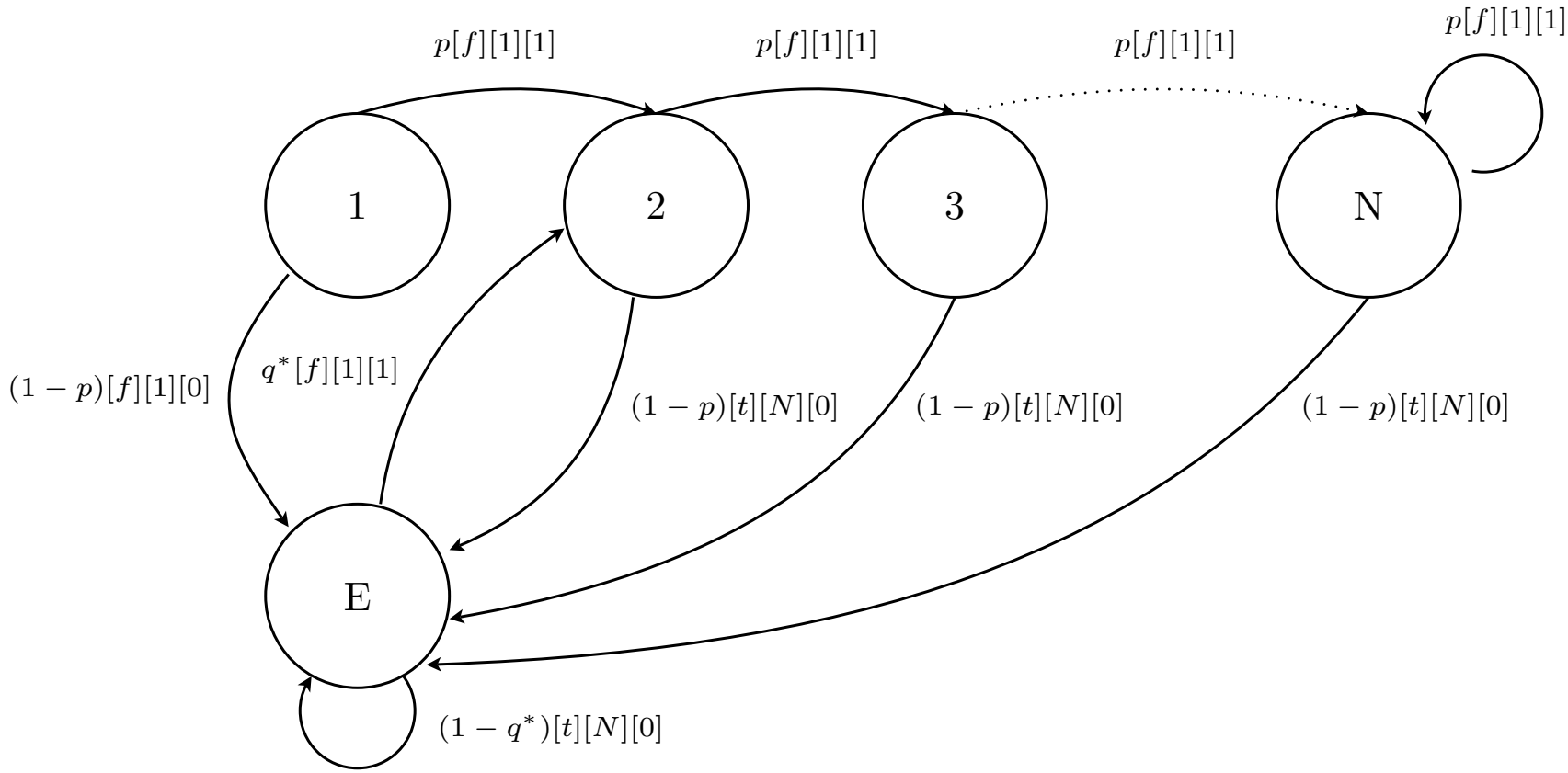
Theoretical Model: channel



$$P_e = \begin{pmatrix} 1-q & q \\ 1-p & p \end{pmatrix} .$$

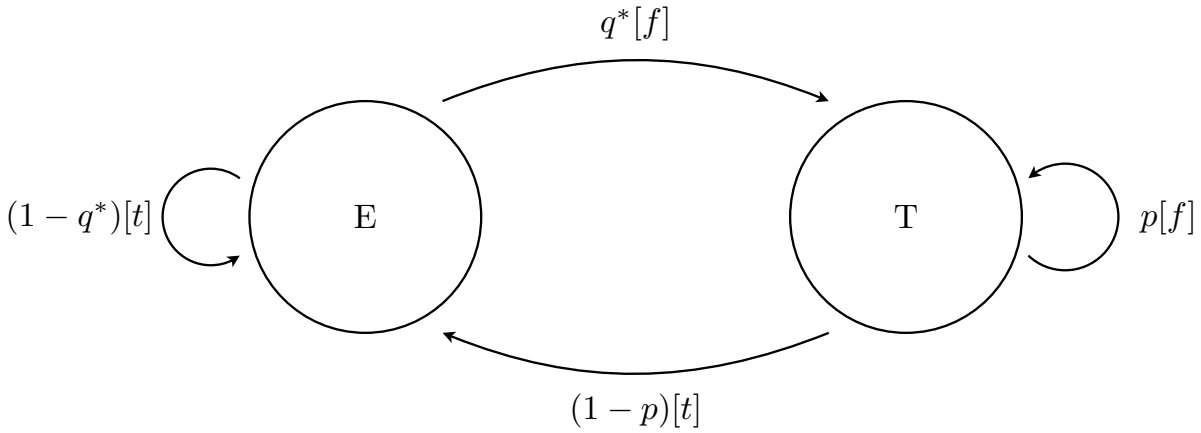
$$\pi(B) = \frac{1-p}{1-p+q} \qquad \pi(G) = \frac{q}{1-p+q} .$$

Theoretical Model: sender



$$q^* = P_e^N(1,1) \ .$$

Theoretical Model: lumped sender model



$$P = \begin{pmatrix} 1-q^* & q^* \\ 1-p & p \end{pmatrix} ,$$

$$\pi(E) = \frac{1-p}{1-p+q^*} \qquad \pi(T) = \frac{q^*}{1-p+q^*} .$$

Theoretical Model: performance indices

Energy efficiency:

$$E_{\mathsf{eff}} = P_T = \frac{f(\pi(E)q^* + \pi(T)p)}{\pi(E)[fq^* + t(1-q^*)] + \pi(T)[fp + t(1-p)]} \ .$$

Throughput:

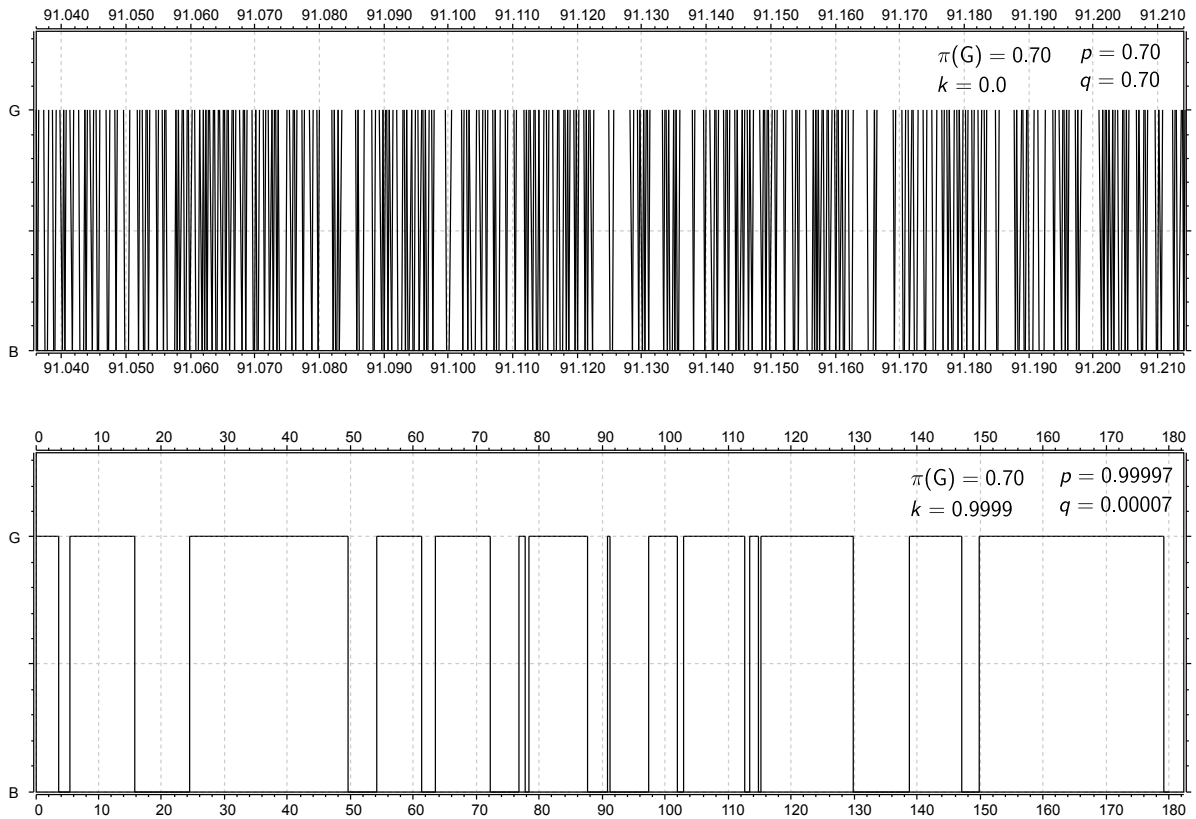
$$\mathsf{Th} = \frac{1}{f} E_{\mathsf{eff}}.$$

Theoretical Model: correlation

Correlation expressed in terms of $\pi(G)$ and a *correlation parameter* k.

$$p = (1 - \pi(G))k + \pi(G) \qquad q = \frac{\pi(G)(p-1)}{\pi(G) - 1} \ .$$

$-1 \leq k \leq 1$, $k = 0$ when $p = q$

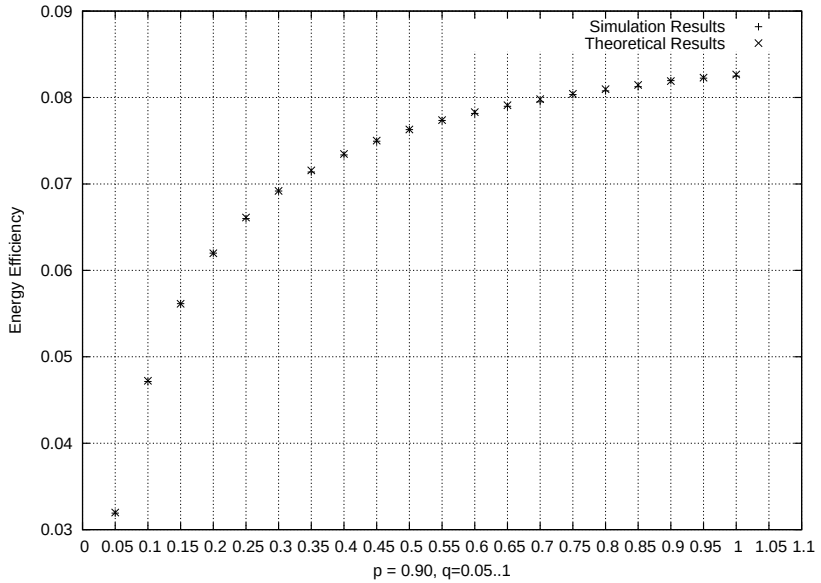


Simulation Package

- Based on OMNeT++ (see Varga (2010))
- Extensible software Components for sender, receiver and channel with error correlation
- In the next examples used for Go-Back-N, but it can be extended to model other ARQ protocols
- RNG: Mersenne Twister (see Matsumoto and Nishimura (1998)).

Simulation Metodology and Validation

- Each measurement is the mean of $r = 100$ repeated runs without resetting the RNG.
- Simulation time: $300s$ per run
- Transient phase elimination (see Welch (1981))
- Measurements are assumed to be IID
  - Normal distribution
  - Confidence intervals
- Validation: theoretical model prediction vs. simulator outcome
  - All theoretical predictions inside confidence intervals for $c = 0.95$



A Heuristic for energy minimisation

- Strong correlation $\rightarrow$ error concentration
- Trying to send packets continuously is a bad strategy for energy saving
- Not transmitting packets continuously is a bad strategy for throughput.
- If the channel is in a bad state, at the next packet transmission it will remain in bad state with probability (1-q), or it would move to the good state with probability q.
  - Residence time modelled as a geometric random variable, expected value $E[X] = \frac{1}{q}$
- We can skip those $\frac{1}{q}$ transmission
- Sender notices errors in the channel after $\frac{t}{f}$ transmissions, so it should skip only the s remaining packet transmission that are estimate to be *bad*:

$$s = \max\left(\left\lfloor \frac{1}{q} \right\rfloor - \frac{t}{f}, 0\right).$$

Simulation results and heuristic comparison

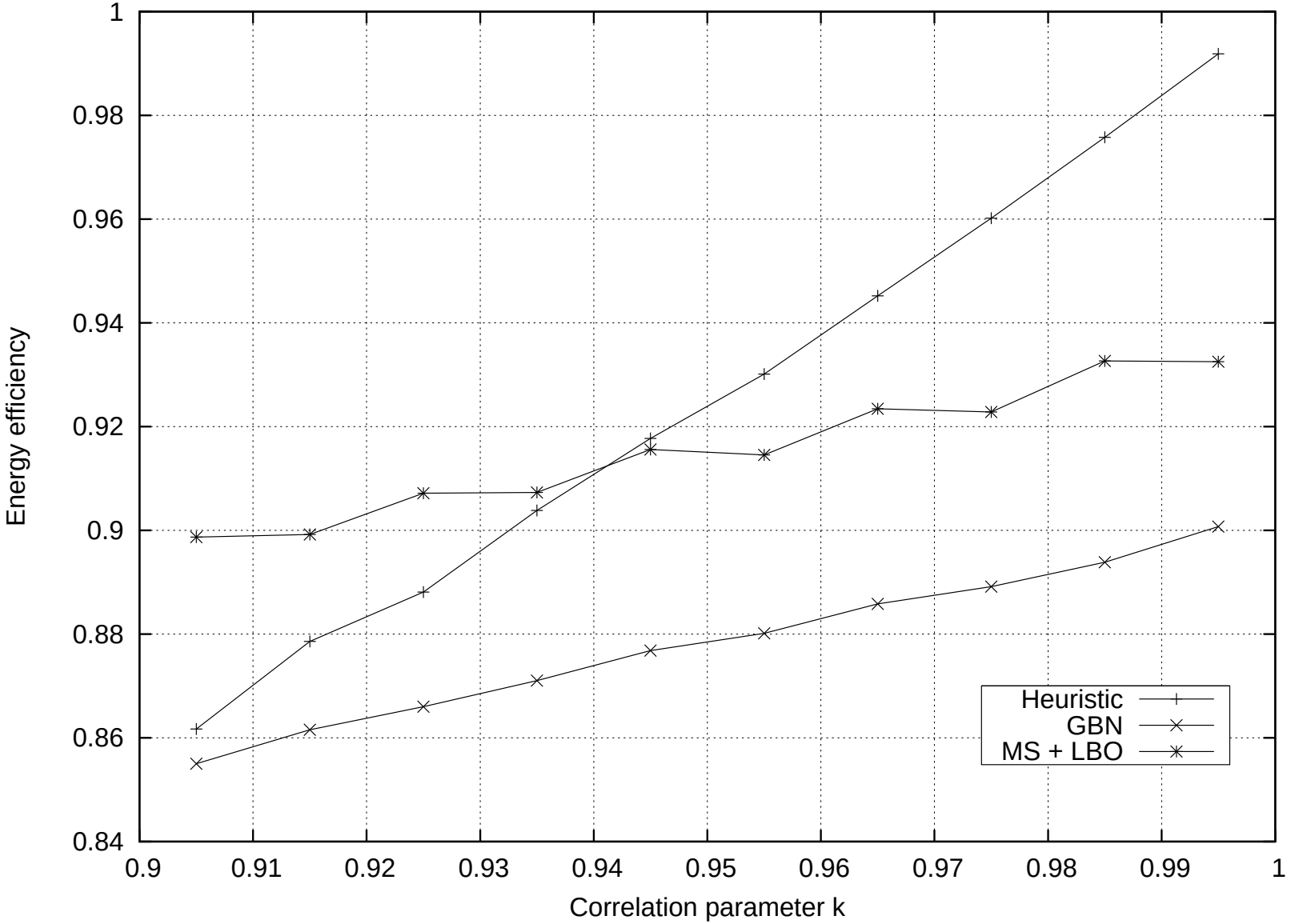
We can use the simulator to compare the performances indices of our heuristic with the one described in Chockalingam and Zorzi (2008) and with the naive Go-Back-N implementation.
Simulation parameters:

Parameter	**Value**
Bandwidth	54Mbps
Delay	0.99ms
Frame size	1492 B
Timeout	2.21ms
$\pi(G)$	0.9

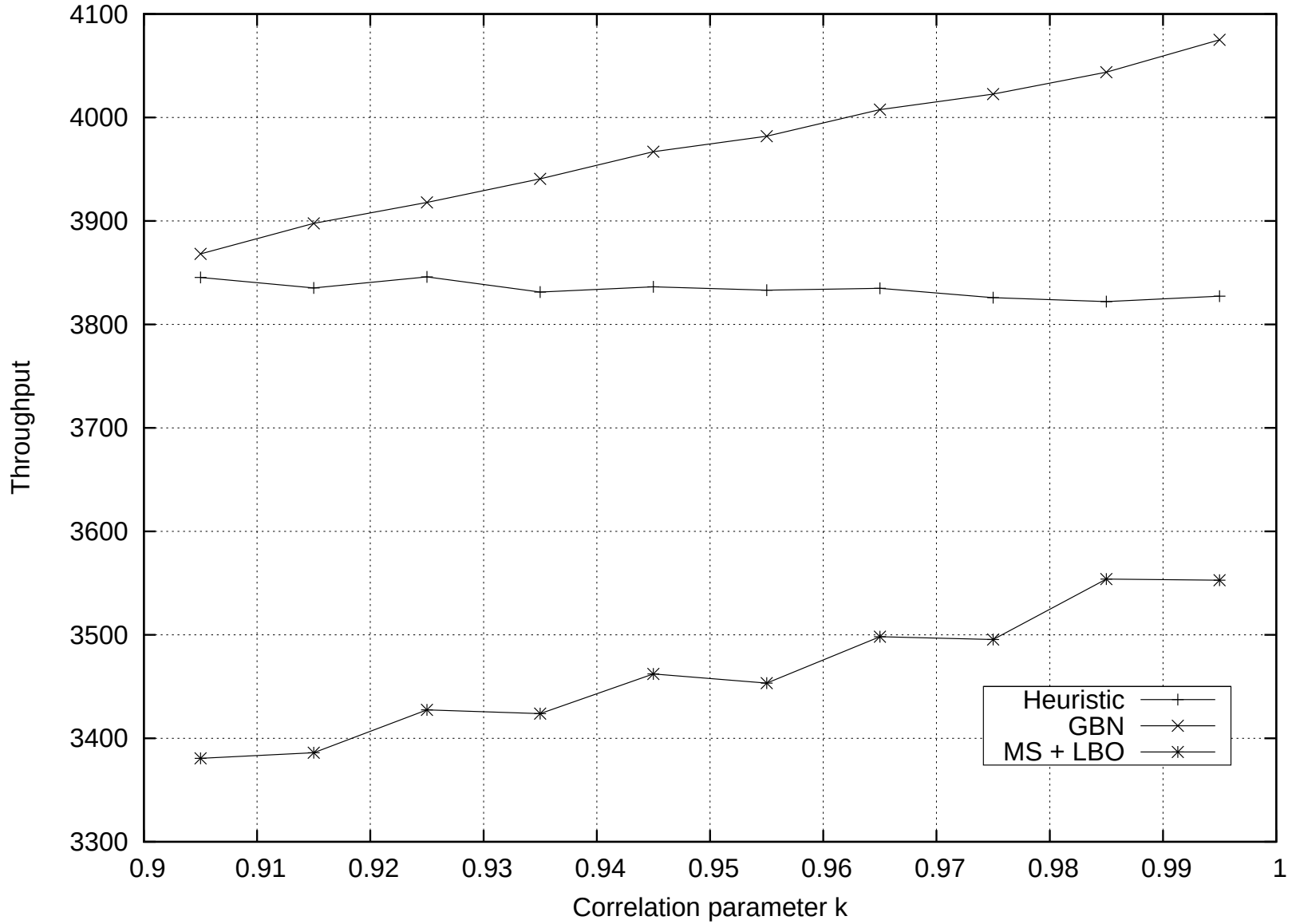
Table: Parameter values for the simulation.

All simulations were done according to the previously described criteria.

Simulation results: Energy efficiency



Simulation results: Throughput



Conclusions

- A simulation package to analyse energy efficiency and other performance indices of ARQ protocols
- A theoretical model for Go-Back-N on optimality condition
- A novel heuristic for energy efficiency optimisation in channel with strongly-correlated errors.
- A comparison with a state-of-the-art heuristic in this field.

Future works:

- Theoretical model extensions
- Simulation package extensions
- Heuristic modifications for weakly correlated errors
- Techniques to efficiently estimate $\pi(G)$ and k from statistics.

References

Chockalingam A. and Zorzi M., 2008. *Adaptive ARQ with energy efficient backoff on Markov fading links*. *Wireless Communications, IEEE Transactions on*, 7, no. 5, 1445–1449. ISSN 1536-1276.

Matsumoto M. and Nishimura T., 1998. *Mersenne twister: a 623-dimensionally equidistributed uniform pseudo-random number generator*. *ACM Transactions on Modeling and Computer Simulation (TOMACS)*, 8, no. 1, 3–30. ISSN 1049-3301.

Tanenbaum A., 2002. *Computer Networks*. Prentice Hall Professional Technical Reference, 4th ed. ISBN 0130661023.

Varga A., 2010. *OMNeT++*. In K. Wehrle; M. Günes; and J. Gross (Eds.), *Modeling and Tools for Network Simulation*, Springer. ISBN 978-3-642-12330-6.

Welch P.D., 1981. *On the problem of the initial transient in steady-state simulations*. Tech. rep., IBM Watson Research Center, Yorktown Heights, NY.

Any question?