ARQ Protocols for the Gaussian Collision Channel

G. Caire and D. Tuninetti
Institut Eurécom
Sophia-Antipolis, France
e-mail: caire, tuninett @eurecom.fr

Abstract — **In next generation wireless communication systems, packet-oriented data transmission will be implemented in addition to standard mobile telephony. Designing efficient schemes for packet transmission on top of an existing connection-oriented CDMA system will be a challenge for system designers. In this work, we take an information-theoretic view of some simple protocols for reliable packet communication based on "hybrid ARQ".**

In order to support new sevices (e.g., wireless mobile access to the Internet), next generation wireless communication systems will implement packet-oriented data transmission in addition to standard mobile telephony. This implies bursty sporadic communication from a large population of users, that may require instantaneous large data rates and very small error probabilities for a short time. On the other hand, next generation systems will be based mainly on CDMA, which is suited to continuous-mode transmission and (at least in its current conventional implementation [1]) it requires closed-loop power control. Then, a challange for future system designers is to implement efficient schemes for packet transmission on top of an existing connection-oriented CDMA system, preserving the uncoordinated access flexibility of the latter. In essence, next generation wireless systems should be regarded as "composite" systems where several subsystems with very different power, rate, reliability and delay constraints will coexist, sharing the same bandwidth.

Motivated by the above consideration, we take an information-theoretic view of some simple protocols for reliable packet communication based on "hybrid ARQ", i.e., on combining *channel coding* and *Automatic Retransmission reQuest* (ARQ). We model low-power low-rate continuous-mode traffic as background white Gaussian noise for the high-rate high-power bursty users. Random user activity prevents closed-loop power control and user coordination. Then, we assume that users transmit their signal *bursts* at very high instantaneous power and in a completely uncoordinated way. The receiver is formed by a bank of conventional single-user decoders, and does not implement joint decoding. We refer to this model as the *Gaussian collision channel* [3]. The transmission of each user is governed by an hybrid ARQ protocol, designed in order to achieve very low error probability.

We consider a slotted multiple access Gaussian channel with fading. We study the system performance in terms of throughput (total bit/s/Hz) and average delay for three simple idealized hybrid ARQ protocols: a coded version of Aloha, a repetition scheme with maximal-ratio packet combining and an incremental redundancy scheme with general coding. By applying the *renewal-reward* thereom [4], we obtain a closed-form throughput formula under a delay constraint (time-out) and code rate constraint. Since we consider random coding and typical set decoding, our results are independent of the particular coding/decoding technique and should be regarded as a limit in the information theoretic sense. Then, we study asymptotic behaviors with respect to various system parameters. The system throughput is compared to that of a conventional CDMA with conventional decoding. Interestingly, the ARQ system is not interference-limited even if no multiuser detection or joint decoding is used (arbitrarily high throughput can be obtained by increasing the user transmit power), as opposed to conventional CDMA.

As a byproduct of this analysis, we provide a stronger operational meaning to the information outage probability of block-fading channels and we obtain the closed form probability distribution of signal-to-interference plus noise ratio (SINR) with Rayleigh fading and a Poisson-distributed number of interferers, extending the result of [5].

In the full paper [2], we give all the details of the proofs and a wide range of numerical results illustrating the performances of the examined ARQ protocols, as well as a comparison with conventional CDMA (another form of "collision channel") which shows that especially for high SNR the slotted ARQ system provides great potential advantages. In fact, it is well-known that conventional CDMA is interference limited while the slotted ARQ system is not.

As a conclusion, we can say that as far as packed data communication is concerned, it is more useful to spend the feedback channel to provide ACK/NACK for the ARQ protocol rather than to provide power control commands.

References

[1] A.J.Viterbi. *CDMA principles of Spread Spectrum Communication.* Addison-Wesley, New York, 1995.

[2] G.Caire and D.Tuninetti. ARQ protocols for the Gaussian collision channel. *submitted to IEEE Trans. on Inform. Theory*, 1999. Downloadable from http://www.eurecom.fr/ caire/

[3] E.Leonardi G.Caire and E.Viterbo. Modulation and coding for the Gaussian collision channel. *Accepted for pubblication in IEEE Trans. on Inform. Theory*, 1999.

[4] R.Wolff. *Stochastic modeling and the theory of queues.* Prentice-Hall, Upper Saddle River, New York, 1989.

[5] S.Shamai(Shitz) and A.D.Wyner. Information-theoretic considerations for symmetric, cellular, multiple-access fading channels - Part II. *IEEE Trans. on Inform. Theory*, 43(6):1895–1911, November 1997.