Improving performance of wireless networks using collision resistant modulations

Joint work by:

Giuseppe Caire **Emilio Leonardi** **Emanuele Viterbo**

Dipartimento di Elettronica – Politecnico di Torino – Italy

E-mail: {caire,leonardi,viterbo}@polito.it

Presentation outline

- Introduction
- The multiple access protocol
- Markovian model for voice
- Collision Resistant Modulation
- Results
- Conclusions and future work

Introduction

- Using random-access protocols collisions occur among different users accessing the same channel slots (e.g. slotted ALOHA).
- We consider a signal set with D-dimensional signals. Each component is sent over a different channel slot and can be independently affected by a collision.
- CRMs have the property that even if $k < D$ slots collide the signal can still be correctly detected, in the absence of noise, from its $D - k$ un-collided components.
- We combine CRM with a PRMA-like protocol to improve the system capacity.

The slotted multiple access collision channel

- N_u number of active users
- $N_s = N_t \times N_f$ number of available slots where N_f is the number of carriers and N_t is the number of time slots per frame
- L_s number of real dimensions per slot
- $N_s L_s = 2WT$ where T is the time duration of a frame and W is the overall system bandwidth
- Users transmit at a constant bit rate when active.
- *Random access slots*: for reservations at the beginning of a talk spurt
- *Reserved slots*: are released at the end of a talk spurt

Markovian Model for voice

- Voice activity is modeled by a two state Markov chain
  - $\boxed{\textit{on-state}}$ voice packets are transmitted at a fixed rate
  - $\boxed{\textit{off-state}}$ the terminal is silent
- Transition *off-state* to *on-state* ($p_{off \to on}$): the terminal transmits the first voice packet of the talk-spurt by filling D non reserved slots of the first incoming frame. Starting from the following frame $K \leq D$ slots will be reserved to the terminal for the following voice packet transmissions.
- Transition *on-state* to *off-state* ($p_{on \to off}$): the reserved slots are released
- Markov chain state (i, j) with $0 \leq i \leq N_u$ (calling terminals) and $0 \leq j \leq N_r$ (active terminals = reserved slots)

The Gaussian collision channel model

$$\boxed{\mathbf{y} = \mathrm{C}(\mathbf{x}+\mathbf{n})}$$

- $\mathbf{y} = (y_1, \ldots y_D)^T$ is a received vector
- $\mathbf{x} = (x_1, \ldots x_D)^T$ is a transmitted vector taken from the signal set (signal-space code) S of cardinality $|S|$
- $\mathbf{n} = (n_1, \ldots n_D)^T$ is additive white Gaussian noise with i.i.d. components $n_i = \mathcal{N}(0, N_0/2)$
- $C = diag(c_1, \ldots c_D)$ represents the collision pattern and $c_i = 0$ or 1 are Bernoulli i.i.d. random variables with $P_{col} = P(c_i = 0)$.

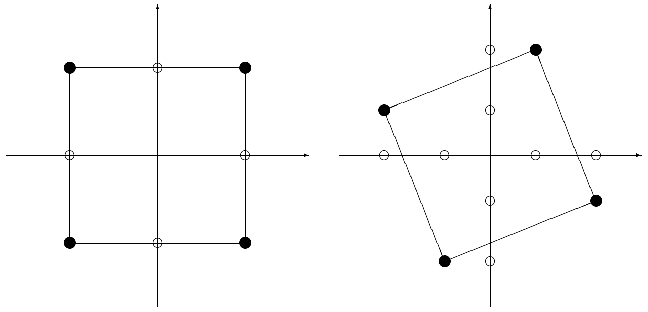
Collision Resistant Modulation

- The receiver has perfect channel state information (CSI) on both the collisions and the fading. ML detection is obtained for

$$\min_{\mathbf{x} \in S} d_C^2(\mathbf{x}, \mathbf{y}) = \min_{\mathbf{x} \in S} \sum_{i=1}^{D} c_i (y_i - x_i)^2$$

- Let $S(C)$ be the projection of S on the subspace generated by the $D - k$ axes corresponding to the non zero c_i's
- A **Collision Resistant Modulation** (CRM) is a signal-space code S with the property that any projection on any coordinate subspace has the same number of distinct points as the original set, i.e., $|S(C)| = |S|$ for all non-zero collision patterns C.

A 2-D Collision Resistant Modulation

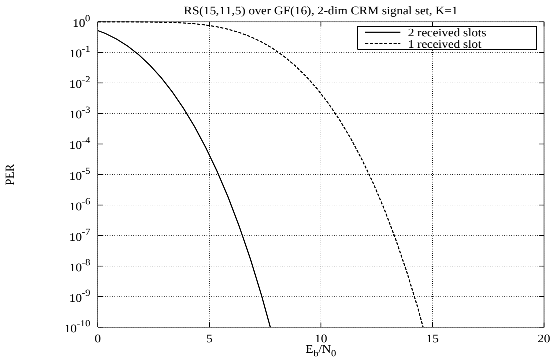


Reed-Solomon coding on the CRM

- RS code (15,11,5) over GF(16) corrects $t = 2$ errors
- Every RS symbol (4 bits) is mapped onto 2 CRM 2-dimensional symbols
- Every RS codeword is corresponds to 30 CRM symbols i.e. 60 real dimensions
- The first 30 components of each symbol are transmitted in one slot while the other 30 components in a different slot.

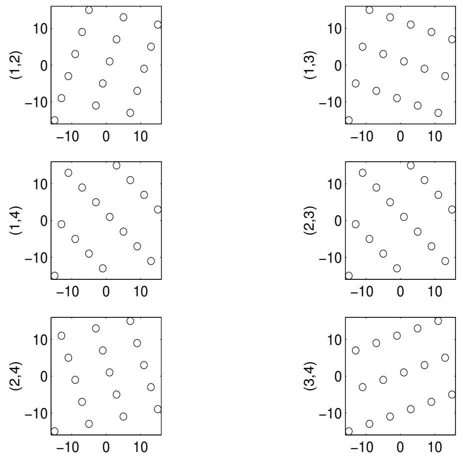
Emanuele Viterbo
DELN - Politecnico di Torino

Gaussian channel for different numbers of collisions, for the RS-encoded 2-dimensional CRM scheme



Emanuele Viterbo
DELN - Politecnico di Torino

2D projections of the 4D-CRM signal set



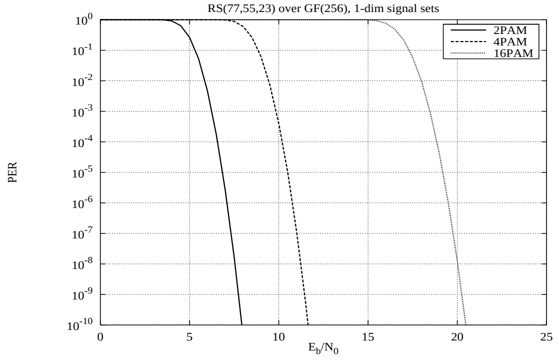
Emanuele Viterbo
DELN - Politecnico di Torino

Baseline conventional system

- Packets are 55 bytes long (wireless ATM)
- Shortened RS code (77,55,23) over GF(256) corrects $t = 11$ symbol errors
- Every RS symbol (8 bits) is mapped onto $8\times$2-PAM, $4\times$4-PAM or $1\times$16-PAM 1-dimensional signal set
- $L_s = 8 \times 77$, 4×77 and 2×77 real dimensions for 2-PAM, 4-PAM and 16-PAM
- Fix $N_s^{(2)} = 2WT/(8 \times 77) = 40$ for the 2-PAM, then the number of slots in the case of 4-PAM and 16-PAM is $N_s^{(4)} = 80$ and $N_s^{(16)} = 160$

Emanuele Viterbo
DELN - Politecnico di Torino

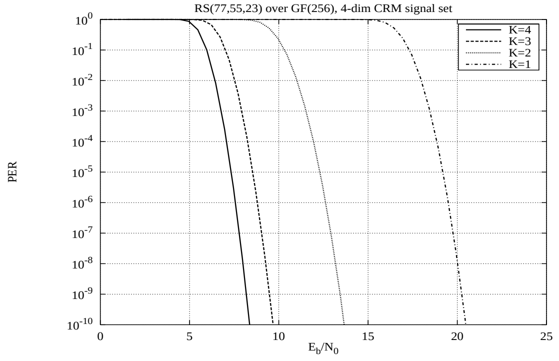
Gaussian channel for RS-encoded PAM schemes



System based on 4-D CRM

- Packets are 55 bytes long (wireless ATM)
- Shortened RS code (77,55,23) over GF(256) corrects $t = 11$ symbol errors
- Every RS symbol (8 bits) is mapped onto $2\times$4D-CRM signal set
- Every packet uses K slots of length $L_s = 2 \times 77$ real dimensions. $K = 4$ for random access packets and $K \leq 4$ for reserved packets depending on desired PER and SNR operating point.

Gaussian channel for different number K of transmitted slots, for a RS-encoded 4-dimensional CRM scheme



Blocking probability

- The blocking probability for admitted calls is the probability that the base station is not able to reserve slots to a terminal that has switched from the *silent period* to the *talk period* because of a bad reception of the data packet transmitted on a contention slot, or because of the lack of available channel slots.

Blocking probability 2-PAM versus 4D-CRM

N_u	2-PAM	4D-CRM $K=4$
$\boxed{15}$		$\boxed{0.01005}$
...	...	...
55	0.008892	0.063654
$\boxed{60}$	$\boxed{0.010693}$	0.075448
65	0.012924	0.090118
70	0.015862	0.108141
75	0.020325	0.131028

N_u	4D-CRM $K=3$
72	0.005280
80	0.007384
$\boxed{88}$	$\boxed{0.009818}$
96	0.016810
104	0.034495

For BP$<10^{-2}$ both systems 2-PAM and 4D-CRM $(K=4)$ operate at SNR=7dB while 4D-CRM $(K=4)$ operates at SNR=8dB.

Blocking probabilities 4-PAM versus 4D-CRM with $K=2$

N_u	4-PAM	4D-CRM $K=2$
90	0.005431	0.000121
100	0.007850	0.000182
$\boxed{110}$	$\boxed{0.010101}$	0.000283
120	0.011891	0.000428
130	0.013549	0.000689
140	0.016562	0.001374
$\boxed{150}$	0.020091	$\boxed{0.004025}$

For BP$<10^{-2}$ 4-PAM operate at SNR=10dB and 4D-CRM with $K=2$ at SNR=12dB.

Conclusions and Future Work

- This is an attempt of bringing together the design of the coding scheme and the protocol in a wireless network.
- Adaptive CRM schemes are an effective technique to increase the system capacity at no expense of bandwidth.
- The only price to pay is an additional demodulator complexity which needs to process higher dimensional symbols and a moderately larger power consumption in some cases.
- Future work: fading, capture, variable K as power control.