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Raptor Code for Wireless Ad Hoc Vehicular Safety Broadcast

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Presentation Outline

- Introduction
- Raptor codes
- System model
- Numerical Analysis
- Conclusion

Introduction

Wireless Access for Vehicular Environment (WAVE)

- WAVE is a new draft standard with enhancements to IEEE 802.11 family for fast & reliable message exchange, longer range <1000 m, operation in extreme multipath channel and high speed of up to 200 km/h.
- Direct communication between V2X (V2V, V2I, I2V).
- 7 channels of 10 MHz each at 5.9 GHz band (half IEEE 802.11a bandwidth) for better tolerance to delay spread and multipath fading.
- Currently drafted in 2 standards: IEEE 802.11p (PHY & MAC) and IEEE 1609 (higher layers).

Importance of WAVE (1)

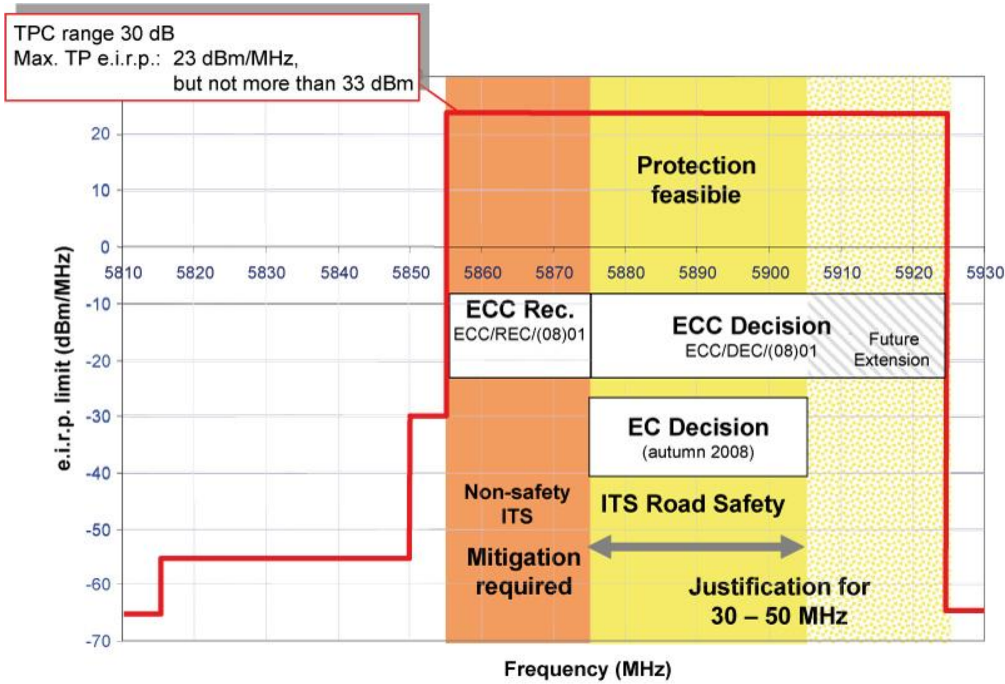
- Millions of road fatality and injury every year around the world

  (EU 2007: ~43000 deaths, 1.6mil injuries, €160B property loss).

  European Road Safety Observatory, “Community road accident (care) database.” http://ec.europa.eu/idabc/en/document/2281/5926.html
- Increasing car ownership (EU: >200mil vehicles): leads to traffic congestion, reduced air quality, unpredictable travel time, increased petrol cost.
- Demands for new applications (safety, traffic management, infotainment)

Importance of WAVE (2)

- Commitment and interest from many organizations
  - FCC allocated 75 MHz band for WAVE
  - EU (FP6 & FP7) projects: C2C-CC, COOPERS, CVIS, SAFESPOT, etc
  - Other regions (US and Japan) actively involved.
- Lowering cost of GPS and WiFi.



R. Bossom *et al.*, *"European ITS Communication Architecture - Overall Framework,"* *COMeSafety System Architecture, Oct. 2008; http://www.comesafety.org*

Safety broadcast calls for fountain codes implementation (1)

- Most WAVE safety applications are broadcast in nature, with simplified MAC
  - No virtual carrier sensing (RTS/CTS).
  - No acknowledgement.
- If repetition codes is used (current standard proposal), the network will suffer from:
  - high latency.
  - inefficient use of bandwidth.
  - network congestion problems.
- Fountain codes / rateless codes
  - do not need fixed coding rate & do not require prior channel condition information.
  - suitable for vehicular environment (rapidly varying link loss condition).

Safety broadcast calls for fountain codes implementation (2)

- Fountain codes / rateless codes
  - can generate a limitless number of unique encoding symbols, depending on channel conditions
  - provide reliable safety data dissemination without the need of a complex routing protocol.
  - low complexity design.
  - low coding overhead (as long as slightly more than the original number of encoded packets are received, the vehicle receiver can successfully decode the original source block).
  - suitable for erasure channel implementation (packet transmission at the application layer behaves similarly to a binary erasure channel)
- Limited work on fountain codes for WAVE, mostly for infotainment applications (I2V).
- This is the first work on fountain codes for safety broadcast.

Raptor codes

Raptor codes, most successful of fountain codes family…

- Raptor codes have been formally adopted as the application layer FEC (forward error correction) scheme in multiple standards
  - 3GPP MBMS (Multimedia Broadcast Multicast Service).
  - DVB-H for IP Datacasting and commercial IPTV services.
- Raptor code is a concatenated code approach with LDPC as the precode or outer code and a weakened LT code as the inner code
  - Weakened LT code reduces complexity but introduce error floor at decoder.
  - Robust LDPC code correct symbols not recovered by LT code.
- Improvement to Luby Transform (LT) code
  - Linear encoding and decoding time.

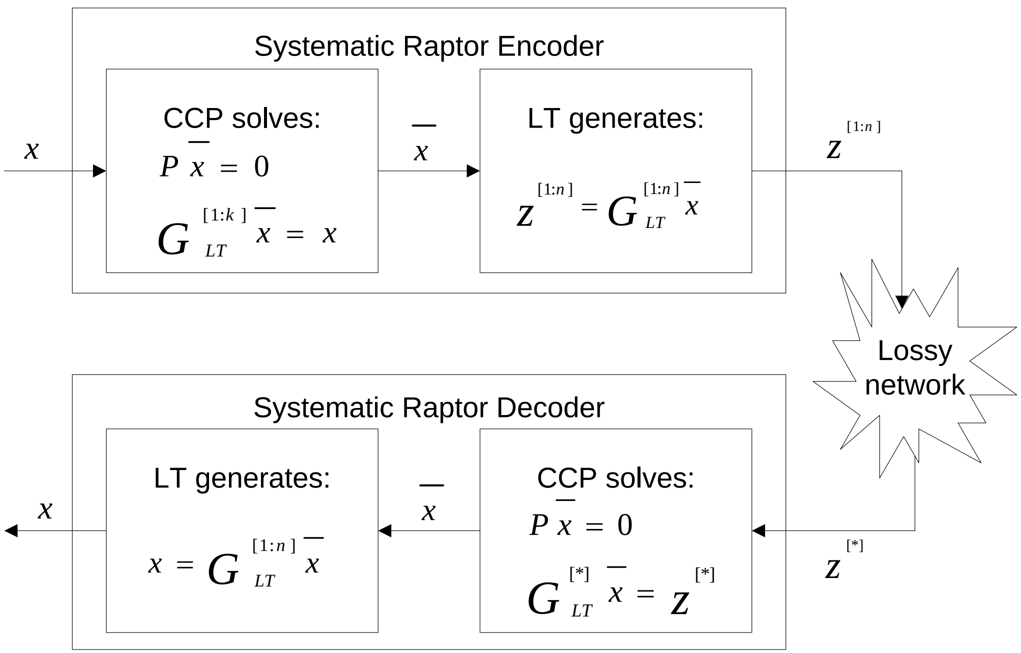
$$O(K\log_e K) \longrightarrow O(\log_e K)$$

  - K = number of source symbols (SSs) in the source block (SB).

A. Shokrollahi, "Raptor Codes," IEEE Transactions on Information Theory, vol. 52, no. 6, pp. 2551–2567, Jun 2006.

Systematic Raptor codes (1)

- Systematic construction using CCP (code constraint processor) linear transformation so that 1st K encoded symbols (ESs) are similar to the SSs.
    - direct access to the original data for nodes with good channel conditions.
- Remaining symbols are the repair symbols.
    - users which do not observe the systematic symbols invert the predescribed linear transformation to reconstruct the set of the intermediate symbols.
- P is the parity check matrix consisting of S LDPC symbols and H half-Gray symbol



Systematic Raptor Encoder

x

CCP solves:

$P\bar{x} = 0$

$G_{LT}^{[1:k]}\bar{x} = x$

$\bar{x}$

LT generates:

$z^{[1:n]} = G_{LT}^{[1:n]}\bar{x}$

$z^{[1:n]}$

Lossy network

$z^{[*]}$

Systematic Raptor Decoder

CCP solves:

$P\bar{x} = 0$

$G_{LT}^{[*]}\bar{x} = z^{[*]}$

$\bar{x}$

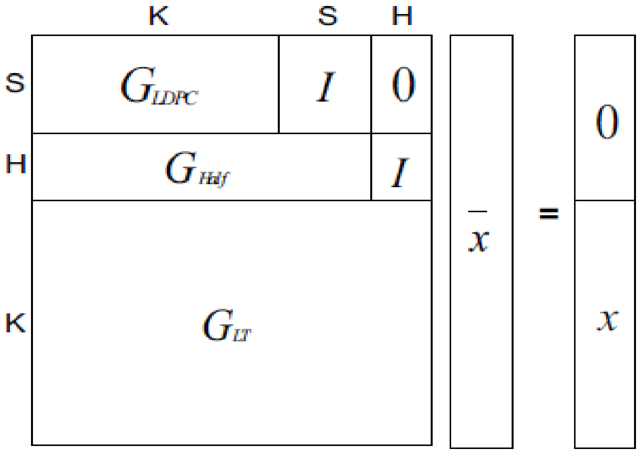
LT generates:

$x = G_{LT}^{[1:n]}\bar{x}$

x

Systematic Raptor codes (2)

- For a given K source symbols, *GLDPC*, *GHalf* and *GLT* only calculated once & stored as the precode matrix, A (of size LxL) for future reference.
- Crucial design assumption: precode matrix A is invertible i.e. has full rank L over GF2.
- Efficient method for matrix binary inverse for small K values: Enhanced Gaussian elimination.
- Encoder and the decoder are equipped with a similar pseudorandom number generator.



$$X = min\{x \in \mathbb{N} : x(x-1) > 2K\}$$

$$S = min\{s \in \mathbb{N}, s' : s \geq \lceil \frac{K}{100} \rceil + X\}$$

$$H = min\{h \in \mathbb{N} : \binom{h}{\lceil \frac{h}{2} \rceil} \geq K + S\}$$

3GPP TS 26.346, Multimedia Broadcast/Multicast Service (MBMS); Protocols and codecs, Std., Rev. 9.3.0, Jun 2010. http://www.3gpp.org/ftp/Specs/html-info/26346.htm

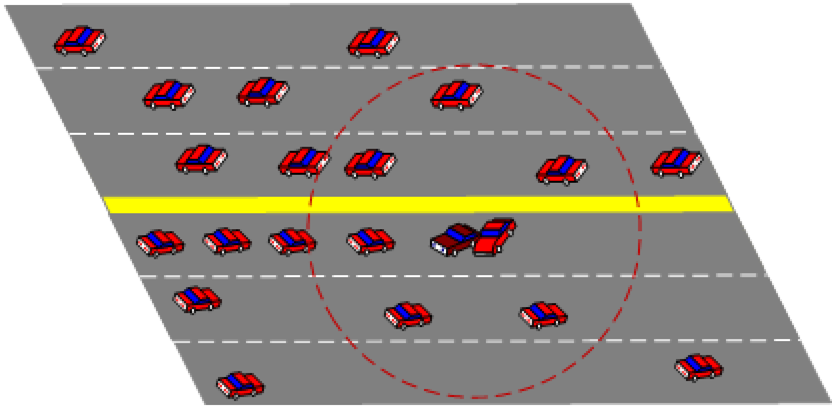
System model

Scenario assumptions: Post-crash warning

- 3 lanes bidirectional highway with 2 types of traffic density models
  - Low: 6 cars/km/lane, $\bar{v}=50km/h$
  - High: 11 cars/km/lane, $\bar{v}=100km/h$
- Fast fading time-correlated channel using Clarke's model

$$h(t)=\sum_{n=1}^{L} A_n \cdot exp(j(\phi_n - 2\pi f_d t \cdot cos(\alpha_n)))$$

  - modified ETSI channel B* power delay profile
  - RMS delay spread: 103ns according to V2V highway measurements**



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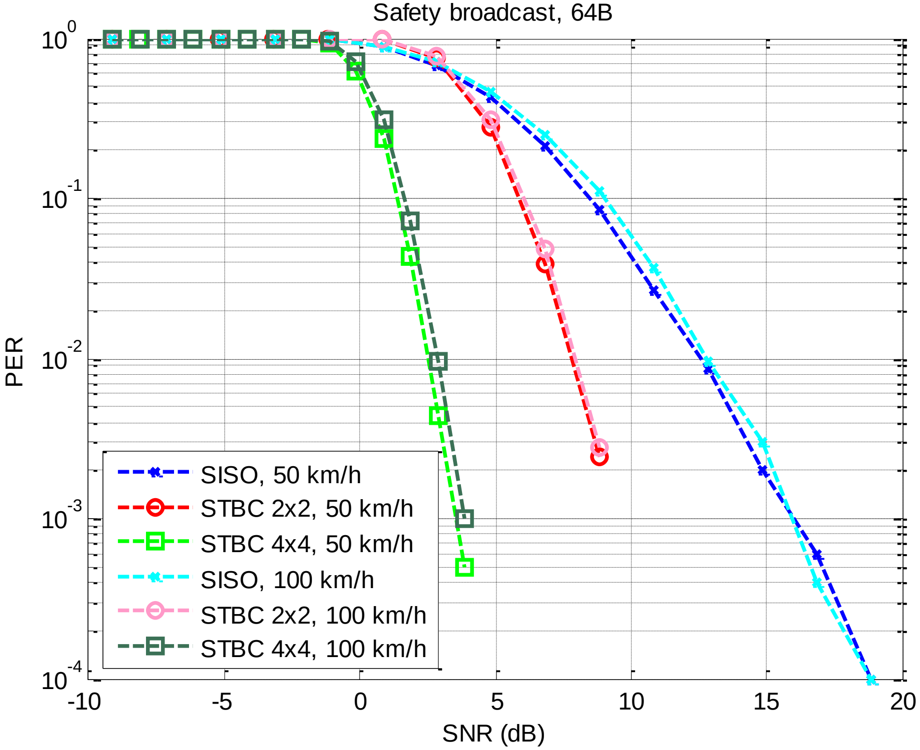
* J. Medbo and P. Schramm, "Channel Models for HIPERLAN/2 for Different Indoor Scenarios," ETSI EP BRAN/3ERI085B, Mar 1998.

** D. W. Matolak, et.al., "5GHZ Wireless Channel Characterization for Vehicle to Vehicle Communications," Proceedings of IEEE Military Communications Conference (MILCOM '05), vol. 5, pp. 3022–3016, NJ, USA, Oct 2005.

Cross-layer simulator (1)

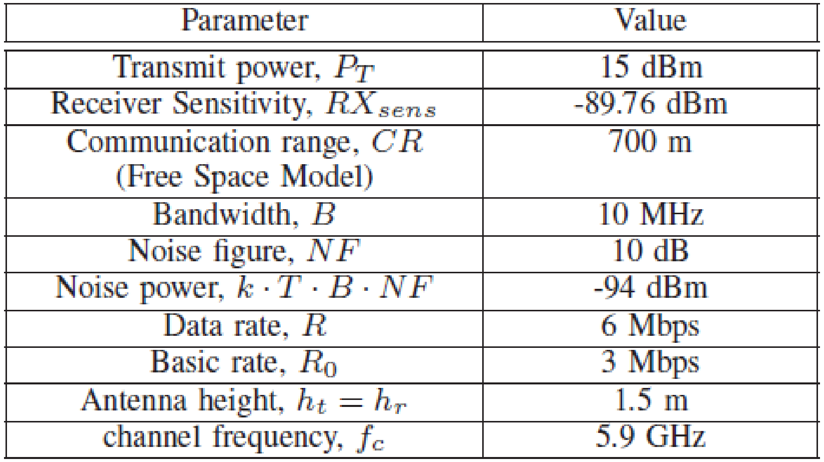
- IEEE 802.11p detailed physical layer simulator
  - OFDM scheme, fast fading channel, channel tracking (midamble)*, specific IEEE 802.11p parameters, etc.
  - Developed for single antenna & space-time block code (MIMO) scheme.
  - PER vs. SNR curves for different antenna schemes at different average speeds
    - At 10% PER, STBC 2x2 and STBC 4x4 gives 5-10 dB coding gain against SISO scheme



* S. I. Kim, H. S. Oh, and H. K. Choi, "Mid-amble Aided OFDM Performance Analysis in High Mobility Vehicular Channel," *IEEE Intelligent Vehicles Symposium, Eindhoven, Netherlands, Jun 2008.*

Cross-layer simulator (2)

- PER vs. SNR curves translated to distance for using free space propagation assumption*.
- Broadcast contention window within range ~Uniform(0,CWmin)
- Assume broadcast MAC without interferenc with average backoff.



Parameter	Value
Transmit power, P_T	15 dBm
Receiver Sensitivity, RX_{sens}	-89.76 dBm
Communication range, CR (Free Space Model)	700 m
Bandwidth, B	10 MHz
Noise figure, NF	10 dB
Noise power, $k \cdot T \cdot B \cdot NF$	-94 dBm
Data rate, R	6 Mbps
Basic rate, R_0	3 Mbps
Antenna height, $h_t = h_r$	1.5 m
channel frequency, f_c	5.9 GHz

$$T_{DATA} = T_{PLCP\,preamble} + T_{PLCP\,header} + \left\lceil \frac{N_{layer\,headers} + N_{payload}}{N_{DBPS}} \right\rceil \cdot T_s$$

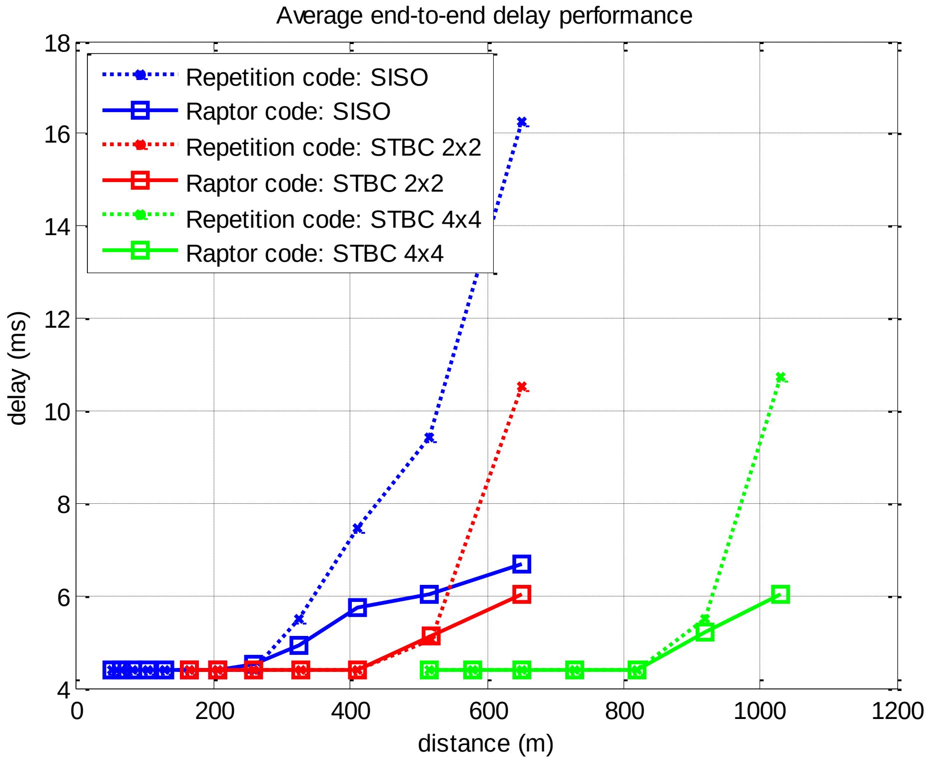
$$T_{safety} = (DIFS + \frac{CW.T_{slot}}{2} + T_{DATA} + SIFS) \cdot K \cdot (1 + \varepsilon)$$

N. F. Abdullah, A. Doufexi, and R. J. Piechocki, “Spatial Diversity for IEEE 802.11p Post-Crash Message Dissemination in a Highway Environment,” VTC-Spring, Taipei, May 2010, pp. 1–5.

Numerical Analysis

Raptor code vs. repetition code: delay performance

- Raptor codes always outperforms repetition codes.
- Raptor codes reduced the end-to-end delay performance vs. repetition code:
  - 53% reduction for SISO & 32% reduction for STBC 2x2 scheme (600m)
  - STBC 4x4 reduce delay by 38% (1000m)
- Combination of Raptor codes and spatial diversity (STBC-MIMO) provides communication range extension:
  - At 6ms delay, the communication range is extended by ~30% with STBC 2x2 and ~100% with STBC 4x4 vs. SISO.



Conclusions

- Performance evaluation of systematic Raptor codes against repetition codes with multiple antenna against single antenna schemes for ad hoc vehicular safety broadcast messages have been presented.
- This is the first paper to evaluate a rateless code in a VANET safety broadcast application.
- Preliminary results show a strong motivation for consideration of safety broadcast using rateless codes.
  - Raptor code improves up to 53% of end-to-end delay performance
  - Delay performance falls below the 100ms latency requirement specified for most WAVE safety applications.

ETSI TR 102 638, Intelligent Transport Systems (ITS), Vehicular Communications (VC), Basic Set of Applications, Definitions, Std., Rev. 1.1, Jun 2009.

- Future work will consider interference from other transmissions by surrounding vehicles.

Thank You.
Questions?

Appendix

Appendix: 11p vs. 11a

- Half bandwidth resulted in doubling of time-domain parameter
  - Better tolerance to delay spread/ multipath fading).

PHY and MAC Parameter	**IEEE 802.11a**	**IEEE 802.11p**
Frequency band	5 GHz	5.9 GHz
Bandwidth	20 MHz	10 MHz
Data rate	6-54Mbps	3-27 Mbps
OFDM symbol duration	4us	8 us
Tg	0.8us	1.6us
SIFS	16us	32us
DIFS	34us	58 us
Slot time, *Tslot*	9us	13 us

Appendix: PER vs. distance

- Free space propagation: $$P_R = P_T G_T G_R \left(\frac{\lambda}{4\pi d} \right)^2$$