TECHNISCHE UNIVERSITÄT DRESDEN

vodafone chair Mobile Communications Systems

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Finite Length Reconstructible ASK-Sequences Received with 1-bit Quantization and Oversampling

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Background

Analog-to-digital conversion for Multi-gigabit/s communication:

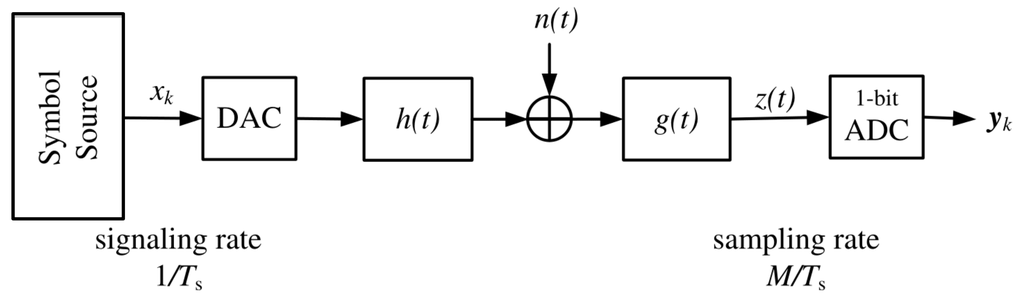
- Beyond 100 MHz, energy required per conversion-step begins to increase linearly with frequency [1].
- Low precision ADCs are a good solution as these can be designed more easily and are more power efficient [2].
- Especially for short range, intra-chip communications where the energy consumption of the ADC is dominating.
- In special case of 1-Bit Quantization at the receiver, quantization losses can be partially compensated with oversampling [3].
  (e.g. based on BiCMOS technology with transit frequency ≥ 500GHz)

Challenge
Generation and detection of finite length reconstructible sequences received with 1 bit quantization and oversampling

Different kinds of Source Models

- Markov Symbol Source [4]
- Super-Symbol Source Model

System Model



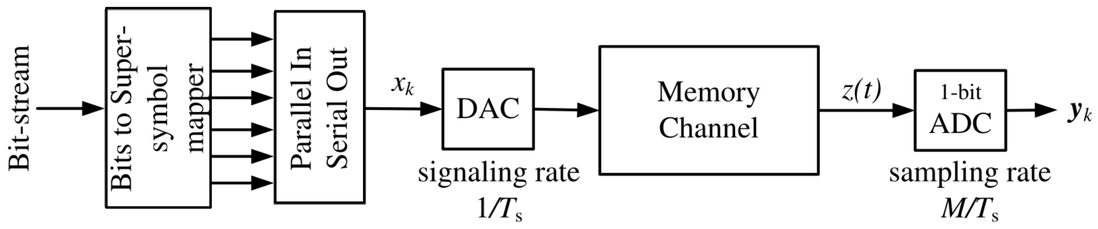
System Model with a 4-ASK symbol source, AWGN finite memory channel, matched filters and 1-Bit quantization & oversampling at the receiver

$$z_k = \boldsymbol{V}\boldsymbol{U}x_{k-L}^{k} + \boldsymbol{G}\boldsymbol{n}_{k-\xi}^{k}$$

$$\boldsymbol{v} = \left[\frac{1}{3}, \frac{2}{3}, 1, \frac{2}{3}, \frac{1}{3}, 0\right]^T, \quad \boldsymbol{g} = \left[\frac{1}{\sqrt{3}}, \frac{1}{\sqrt{3}}, \frac{1}{\sqrt{3}}\right]^T$$

Oversampling factor, M = 3
Channel Memory, L = 1
Receive filter length, ξ = 1

Super-Symbol Source



System Model with super-symbol source and detection

- Detection done independently for each symbol block called super-symbol.
- There is no interference in the detection of current symbol block by the ones transmitted before or after it.
- This ensures an unambiguous detection while reducing the complexity of the receiver and transmitter design.

Bits to Super-Symbols Mapping

Super-symbol length	$S = 2$	$S = 3$	$S = 4$	$S = 5$	$S = 6$	$S = 7$	$S = 8$	$S = 9$
Number of Super-symbols	8	28	96	328	1120	3824	13056	44756
Source entropy without bit-mapping	1.5	1.603	1.646	1.672	1.688	1.700	1.709	1.716
Source entropy with bit-mapping	1.5	1.333	1.5	1.6	1.667	1.571	1.625	1.667

No. of reconstructible super-symbols and source entropy

- S=6 is the best choice till S<10
- One super-symbol $\bar{x}$ needs to be selected out of various super-symbols leading to the same quantized out. The method of selection is as follows:

$$\bar{X}_\delta = \{\bar{x}\colon \bar{x} \text{ has } S = 6, \text{ output } \boldsymbol{q}_\delta\}$$

$$Q_\delta = \{\boldsymbol{q}_\delta\} \cup \{\boldsymbol{q}'_i : \arg\min_{\boldsymbol{q}} |\boldsymbol{q}_\eta - \boldsymbol{q}'_i| = \boldsymbol{q}_\delta\}$$

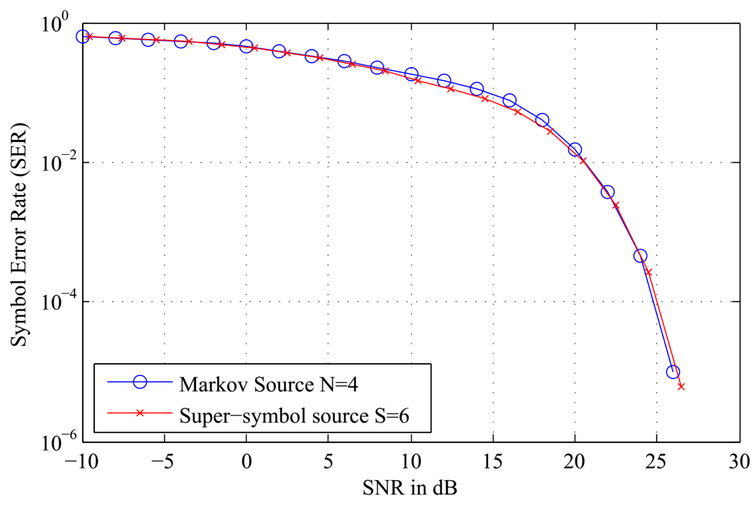
$$\bar{x}_\delta = \bar{x}_\eta \in \bar{X}_\delta \text{ such that}$$

$$\eta = \arg\max_{\phi} \left(\min_{\boldsymbol{e},\ \boldsymbol{q} \in \left(\bigcup_{i=1}^{1120} Q_i \setminus Q_\delta\right)} |\boldsymbol{e}| \text{ s.t. } \text{quant}(\boldsymbol{u}_\phi + \boldsymbol{e}) = \boldsymbol{q} \right)$$

where, q_δ are the permissible quantized output vectors,
q'_δ are the non-permissible quantized output vectors

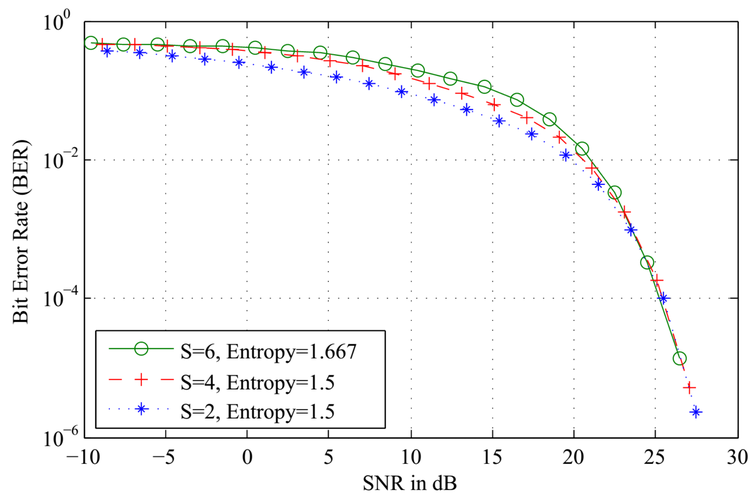
- In order to map 10 bits to one super-symbol, 1024 super-symbols need to be selected out of 1120. For this the first 1024 super-symbols are chosen whose unquantized output sequence has the maximum of the minimum distance to any quantization region not associated to its set.

Numerical Results



Comparison between Symbol Error Rates (SER) of Markov source (entropy=1.768, N=4) [4] and Super-symbol source (entropy=1.667, S=6)

Dependence of Bit Error Rate performance of the super-symbol source on super-symbol block-length.



- Super-symbol source provides a slightly lower source entropy than the Markov source but at in return greatly reduces the receiver complexity.
- In terms of SER performance, super-symbol source performs equally good as a Markov source.

[1] Murmann, B., "Energy limits in A/D converters," *Faible Tension Faible Consommation (FTFC), 2013 IEEE* , vol., no., pp.1,4, 20-21 June 2013
[2] Singh, J.; Ponnuru, S.; Madhow, U., "Multi-Gigabit communication: the ADC bottleneck[1]," *Ultra-Wideband, 2009. ICUWB 2009. IEEE International Conference on* , vol., no., pp.22,27, 9-11 Sept. 2009
[3] Krone, S.; Fettweis, G., "Communications with 1-bit quantization and oversampling at the receiver: Benefiting from inter-symbol-interference," *Personal Indoor and Mobile Radio Communications (PIMRC), 2012 IEEE 23rd International Symposium on* , vol., no., pp.2408,2413, 9-12 Sept. 2012
[4] Landau L.; Fettweis G.,"On reconstructible ask-sequences for receivers employing 1-bit quantization and oversampling," in *Proc. of the 2014 IEEE International Conference on Ultra-Wideband (ICUWB)*, Paris, France, Sept 2014.

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