Dynamic precision scaling for low power WCDMA receiver

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Outline

Introduction

- Wireless communications
  - one of the most important domains for Digital Signal Processing (DSP) applications
- New and high datarate services: complexity growth of baseband digital part

- Energy-efficient implementations are required
- Fixed-point architectures are preferred for implementation

⇒ *Energy reduction by adaptation of word-length and fixed-point representation of the data*

State of the art

Energy consumption reduction by fixed-point adaptation:

- Multi-mode applications
  - In the Wi-Fi standard (802.11n): different modes (modulation scheme, coding rate) are proposed
    - Each mode has a specific fixed-point specification
  - Average energy consumption can be decreased by a factor of three [Novo08]
- Word-length reduction as a function of observed error rate
  - OFDM demodulator with word-length search symbols inserted in the frame
    - Run-time adaptation of operator word-length according to errors observed at the system output [Yosh06]
  - Between 24% and 32% of energy saving

Our approach

Fixed-point adaptation inside one mode:

- Modulation scheme and data rate are fixed
- Fixed-point specification is adapted according to external environment conditions
- External parameters are estimated inside a standard system

Applied in this paper to a WCDMA Rake Receiver

Outline

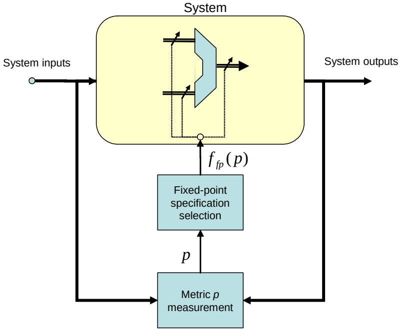
Principle of Dynamic Precision Scaling (DPS)

Principle:

- Switch between different fixed-point specifications (determined at the design-time)
- Adaptation at run-time according to an external parameter p

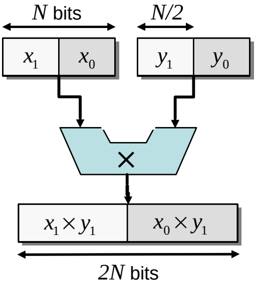
In the case of WCDMA receiver:

- SNR is used as external parameter
- SNR is determined by the help of control frames (DPCCH)



Architecture for DPS

- Programmable or reconfigurable architectures
- Flexible operators which support different word-lengths (WL)
  - e.g. multiplier: 9, 11, 14 and 16 bits [Bhard00]
- Sub-Word Parallelism (SWP) operators: number of operations executed in parallel depends on the operand WL



- Power consumption models of these operators

Outline

WCDMA standard

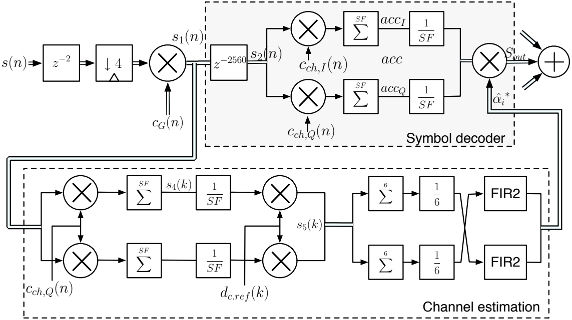
WCDMA is a standard for 3G cellular networks

- Based on DS-CDMA (Direct Sequence CDMA) technology
  - Channelization codes C_{ch}
  - Scrambling codes C_G

Two main modules

- Path Searcher: to find the delays of the different paths
- Rake Receiver: to maximize the received signal energy in the multipath channels

Rake Receiver



Rake Receiver estimates symbols in different paths and combines them

- Channel estimation by pilot symbols in DPCCH
- Correlation process amplifies the useful signal
- Decision taken by combination of different fingers

Fixed-point conversion process

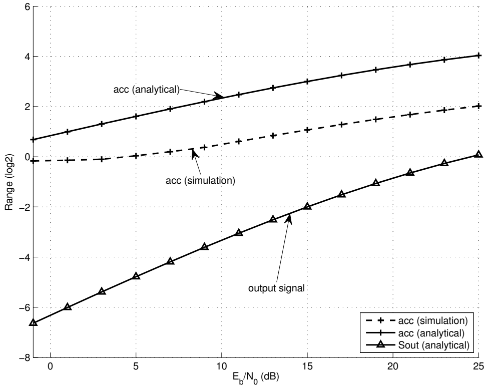
1. Fixed-point data on *b* bits: integer *plus* fractional word-lengths
2. Integer word-length determination
   - Estimates the dynamic range to guarantee *no overflow*
   - Determines the minimal integer word-length through dynamic range
3. Fractional word-length determination
   - Determines the *accuracy constraint* (according to the performance)
   - Optimizes the energy consumption under accuracy constraint (word-length optimization)

Dynamic range estimation

Input signal $s(n) = \sum \mathrm{Rx}_k = \sum \alpha_k \mathrm{Tx}_{(-\tau_k)} + ni_k$

- Input signal is normalized into $[-1, 1]$
  - Considering noise plus interference ni_k gaussian with variance σ^2, normalization is processed by dividing $s(n)$ by $1 + 3\sigma$
  - After normalization, useful signal power: $(\frac{1}{1+3\sigma})^2$
- Only the useful signal is considered when estimating range after accumulation

Dynamic range estimation (2)



Range depends on E_b/N_0: difference of 3 – 4 bits between 0 dB and 25 dB (for acc)

Accuracy constraint determination

Performance criterion:

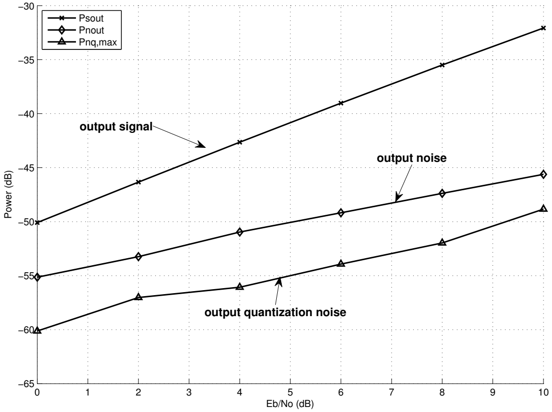
$$\mathrm{BER}_0 \leq \mathrm{BER}_{P_{n_q}(WL)} \leq (1+\epsilon)\mathrm{BER}_0 \qquad (1)$$

Fixed-point accuracy criterion:

$$P_{n_q}(WL) \leq P_{n_{qmax}} \qquad (2)$$

- $P_{n_q}(WL)$: quantization noise power for a given WL
- $P_{n_{qmax}}$: accuracy constraint
  - Obtained from the desired performances [Menard07]
- BER_0: reference Bit Error Rate (floating-point)

Accuracy constraint determination (2)

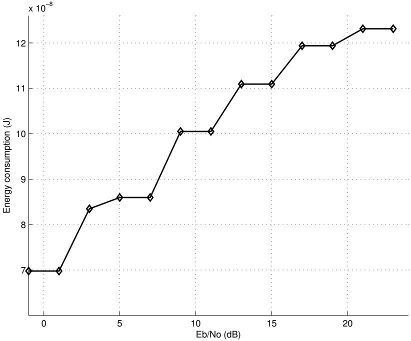


$P_{s_{out}}$: power level of desired signal s_{out}; $P_{n_{out}}$: noise power n_{out} at output

Energy consumption optimizations

Word-length optimization under accuracy constraint:

$$\min \text{Energy}(WL) \quad \text{with } P_{n_q} \leq P_{n_{qmax}}$$



Savings of 40% energy consumption between 0 dB – 25 dB

Outline

Conclusions

We have addressed:

- Concept of energy consumption reduction by adapting the fixed-point specification
- Up to 40% energy savings in WCDMA Rake receiver with DPS

Future works:

- Adaption between different data rates/spreading factors
- Other wireless communication systems

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Thank You