Dynamic precision scaling
for low power WCDMA receiver

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Introduction

Dynamic Precision Scaling

Energy reduction with DPS on a WCDMA receiver

Conclusions

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Dynamic precision scaling
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

1 Introduction

2 Dynamic Precision Scaling

3 Energy reduction with DPS on a WCDMA receiver

4 Conclusions
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

![Diagram of architecture for DPS]

- Power consumption models of these operators
Outline

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2. Dynamic Precision Scaling
3. Energy reduction with DPS on a WCDMA receiver
4. Conclusions
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 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 \( s(n) = \sum R_x k = \sum \alpha_k T x(-\tau_k) + n_i k \)

- Input signal is normalized into \([-1, 1]\)
  - Considering noise plus interference \( n_i k \) gaussian with variance \( \sigma^2 \), 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
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:

\[ \text{BER}_0 \leq \text{BER}_{P_{nq}(WL)} \leq (1 + \epsilon)\text{BER}_0 \]  \hfill (1)

Fixed-point accuracy criterion:

\[ P_{nq}(WL) \leq P_{nq_{\text{max}}} \]  \hfill (2)

- \( P_{nq}(WL) \): quantization noise power for a given WL
- \( P_{nq_{\text{max}}} \): accuracy constraint
  - Obtained from the desired performances [Menard07]
- \( \text{BER}_0 \): 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:

$$\min \text{Energy}(WL) \quad \text{with} \quad P_{nq} \leq P_{nq_{\text{max}}}$$

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