SOC Design for Wireless Sensor Networks

Zoran Stamenković
IHP, Frankfurt (Oder)
Germany
Motivation

- Up to date no stable operating BASN available
  - Enable exchange between sensors for intelligent reasoning about patients state
- Smart wireless medical sensors
  - Enable continuous health monitoring
- Data rates > 1 Mbps at low power are challenging
  - Small battery-powered devices
  - Hurry-up-and-sleep approach
- Single chip solution (SOC)
  - Lowers power consumption, weight, and packaging problems
Body Area System for Medical Applications

Apps

Heart Diseases
Breast Cancer
COPD

SW

ECG Sensor
SpO2 Sensor
Lung Sound Monitor
ROS Sensor
Mobile Phone

Middleware
Application Framework

Wireless Communication Protocols
IEEE 802.15.3/4

Embedded Operating System
Reflex OS

HW

Processor
LEON2 or IPMS430
Radio
Ultra Wideband (UWB)
Generic Wireless Communication Platform

- Long-term health monitoring of chronically ill patients
IEEE 802.15.3 Wireless Sensor Node (BASUMA)
IEEE 802.15.3 MAC Protocol

- IEEE 802.15.3 standard provides
  - Ad-hoc networking, quality of service and security
  - Various power management modes
  - Physical layer data rates from 11 to 55 Mbit/s

- Medium Access Control (MAC) protocol functionality
  - Data path
    - Cyclic redundancy check (CRC) sum calculation
    - Encryption and decryption of the frame payload
    - Interfacing with the physical layer and frame buffering
  - Control path

- Profiling of the software using the processor IS simulator
  - Time-critical protocol functions are iteratively removed from the software model and put into a hardware component
Protocol Functions Designed in Hardware

- To retrieve Rx frame data from the physical layer byte by byte, perform filtering and CRC check, and store the data by means of direct memory access
- To retrieve Tx frame data from a memory location, calculate and append the check sum, and push the data to the physical layer
- To signal a successful reception or transmission of a frame by an interrupt
- To analyze received and transmitted beacons and extract information on channel time allocations
- To manage a queue of frames and select an appropriate frame for transmission
  - At the start of a time slot or following a frame transmission, to query a new frame from the queue and, in case that the frame must be acknowledged, wait for acknowledgment
- To perform the backoff procedure in the contention access period
- To send an acknowledgment at the right time upon reception of a frame that needs to be acknowledged
- To calculate the actual duration of a frame transmission based on its payload length and data rate
Architecture of MAC Protocol Accelerator
BASUMA SOC Architecture

- BASUMA MAC
- DSU+ UART
- UART 0
- UART 1
- LEON2 Core
  - 8 Reg. Windows
- Memory
  - CTL
- AHB
  - Bridge
  - APB
- 4 kByte I-Cache
- 4 kByte D-Cache
- BIST
- 64 kByte FLASH
- Scan Test
- SRAM
- FLASH
- 16 x GPIO
- 2 x Timer
- UART 0
- UART 1
- DSU+
- UART
- BASUMA
- MAC
- UART
- 64 kByte
- FLASH
- Scan Test
- SRAM
- BASUMA
- MAC
- UART
- 64 kByte
- FLASH
- Scan Test
- SRAM
- BASUMA
- MAC
- UART
- 64 kByte
- FLASH
- Scan Test
- SRAM
- BASUMA
- MAC
- UART
- 64 kByte
- FLASH
- Scan Test
- SRAM
- BASUMA
- MAC
- UART
- 64 kByte
- FLASH
- Scan Test
- SRAM
- BASUMA
- MAC
- UART
- 64 kByte
- FLASH
- Scan Test
- SRAM
IEEE 802.15.4 Wireless Sensor Node (TANDEM)
Power Consumption in WSN
Leakage Power in WSN

Leakage Power Contribution vs Activity

- Duty Cycle
- Sleep/Total (%)

- 0.25 um
- 0.18 um
- 0.13 um
Power Gating in IEEE 802.15.4 WSN

Diagram of Power Gating Controller and its connections to various functional blocks such as AFE, Baseband, MAC Hw Accelerator, ROM, CPU, RAM, Data Storage, Preprocessor, A/D, Sensors, System Timer, Timer, Start Register, Select Register, Time stamps, Control Unit, Power Gating Controller, Header, Footer, Always On Functional Block, Isolation, V_dds, Vsss, clk_gate, reset, pwr_gate, ext_intr.
SOC Implementation Steps

- Installation of the processor release
- Selection of the processor configuration and ASIC/FPGA library
- VHDL coding of MAC protocol accelerator
- Adaptation of system testbench
- Implementation of data and instruction caches including BIST
- Logic synthesis of the design
- Implementation of scan chain
- Generation and verification of the chip layout
- Simulation (functional, post-synthesis and post-layout net-list)
- Scan test vectors generation (ATPG)
- BIST and scan test simulation
- EVCD test vectors generation (with and without timing data)
BASUMA SOC Features

<table>
<thead>
<tr>
<th>Feature</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Area (mm²)</td>
<td>31.9</td>
</tr>
<tr>
<td>Signal Ports</td>
<td>126</td>
</tr>
<tr>
<td>Power Ports</td>
<td>24</td>
</tr>
<tr>
<td>BIST Ports</td>
<td>12</td>
</tr>
<tr>
<td>Scan Ports</td>
<td>1(3)</td>
</tr>
<tr>
<td>Transistors (x10⁶)</td>
<td>3.1</td>
</tr>
<tr>
<td>Scanable Flip-Flops (x10³)</td>
<td>15</td>
</tr>
<tr>
<td>Cache Memories (kbytes)</td>
<td>9.5</td>
</tr>
<tr>
<td>Flash Memory (kbytes)</td>
<td>64</td>
</tr>
<tr>
<td>Power/Frequency (mW/MHz)</td>
<td>15</td>
</tr>
<tr>
<td>Maximum Frequency limited by Flash (MHz)</td>
<td>25</td>
</tr>
</tbody>
</table>
TANDEM SOC Features

<table>
<thead>
<tr>
<th>Feature</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Power/Frequency (mW/MHz)</td>
<td>0.06</td>
</tr>
<tr>
<td>Maximum Frequency (MHz)</td>
<td>20</td>
</tr>
<tr>
<td>Memories (kbytes)</td>
<td>0.5</td>
</tr>
<tr>
<td>Transistors (x10^6)</td>
<td>5</td>
</tr>
<tr>
<td>Signal Ports</td>
<td>45</td>
</tr>
<tr>
<td>Power Ports</td>
<td>24</td>
</tr>
<tr>
<td>BIST Ports</td>
<td>9</td>
</tr>
<tr>
<td>Area (mm^2)</td>
<td>9</td>
</tr>
<tr>
<td>Memories (kbytes)</td>
<td>6</td>
</tr>
<tr>
<td>Power/Frequency (mW/MHz)</td>
<td>0.06</td>
</tr>
<tr>
<td>Maximum Frequency (MHz)</td>
<td>20</td>
</tr>
</tbody>
</table>
Summary and Open Issues

• Hardware/software co-design and implementation of the processor configured to support IEEE 802.15.3/4 MAC protocol of a wireless body area sensor network

• Implemented SOCs are good candidates for the MAC processor in respect of performance, speed, and power
  – BASUMA (LEON2 based) for IEEE 802.15.3
  – TANDEM (IPMS430 based) for IEEE 802.15.4

• Open issues
  – Testability
  – Flash integration
Links for More Information

- http://www.basuma.de
- http://www.tandem.de
- http://www.ihp-ffo.de/~stamenko