Dedicated Processors for Wireless Systems

Prof. Dr. Rolf Kraemer

IHP
Im Technologiepark 25
15236 Frankfurt (Oder)
Germany
New Institute and Cleanroom

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What is the IHP?

• German National Lab focused on broadband and mobile connectivity
  200 staff, $30M annual base budget
  Core competencies in technology, circuit design, systems

• Successor to Institute of GDR Academy of Sciences
  Major role in developing microelectronics technologies
  Winner of 17 GDR national prizes

• Refounded 1991 as classic German research institute
  “Application-oriented fundamental research”

• Focus on innovation, major re-engineering started 1996
  Prof. Abbas Ourmazd leads the institute with US spirit

• Customer base of 30 international companies
  Intel, Motorola, Lucent, Infineon, Alcatel, Siemens, et al.
IHP in a Nutshell

- **Strategy**
  
  focus on wireless communication (initially in the 2 - 10 GHz range)  
  going up to 60 GHz and RADAR using high performance SiGeC technology

  collaborate closely with strategic industry partners

  core competencies range from system and circuits design to technology and process development

  seek synergy between material physics, process technology, circuit design, systems, and applications (vertical approach)

  prototype forward-looking, system-level solutions with secured migration paths into the market
IHP in a Nutshell

• Competencies

System Activities started 1999 (now 26 people)
Wireless Internet applications and protocols; Broadband radio LANs (up to 1Gb/s); Body area networks; System on Chip

Circuits started 1997 (now 10 people)
CMOS for RF 2.4 GHz level
Wireless LAN 5.8 GHz, a domain for SiGe technology
60 GHz components for Gb WLAN
Radar Circuits for automotive applications (76-124 GHz)
UWB Frontends for ultra low power systems (e.g. body area networks
LDMOS Power Electronics (integrated power amplifiers, switches power control circuits)

Process Technology (86 people)
SiGe:C HBT module for post-CMOS Integration
Performance (>200GHz $f_t$, $f_{max}$) comparable with IBM with much simpler process
Wireless Internet
Location-Awareness in Concept

Local world

Objects

Local Application Mapping

Locator database

Object profiles

Application behavior

Areas

Local applications

Applications
Services

• Local information delivery
  Push and pull modes

• Location-dependent services
  Train information at the station, etc.

• Tagging (attachment and selective use of information to objects)
  Tell me, but not Jane, it is her birthday as she goes by

• Third party notification
  Your teenage daughter has gone into the disco

• Location & navigation services
  Complex, property-based queries
## Wireless Internet Challenges

<table>
<thead>
<tr>
<th>Attribute</th>
<th>Now</th>
<th>Needed</th>
<th>Challenges</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Bandwidth</strong></td>
<td>9.6 Kb/s</td>
<td>20-50 Mb/s</td>
<td>1000x</td>
</tr>
<tr>
<td></td>
<td>140 Kb/s GPRS</td>
<td>1 Gb/s planned</td>
<td>10000</td>
</tr>
<tr>
<td><strong>Processing</strong></td>
<td>100 MIPS</td>
<td>10,000 MIPS</td>
<td>100x</td>
</tr>
<tr>
<td><strong>Power consumption</strong></td>
<td>1 mW/MIPS</td>
<td>0.01 mW/MIPS</td>
<td>100x</td>
</tr>
<tr>
<td><strong>No. of chips</strong></td>
<td>10-50</td>
<td>1</td>
<td>Not possible at present</td>
</tr>
<tr>
<td><strong>Form factor</strong></td>
<td>Brick</td>
<td>Single chip</td>
<td>Internal comms., Power distr., Package</td>
</tr>
<tr>
<td></td>
<td>Distributed</td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>Software</strong></td>
<td>Win Ce, PalmOS</td>
<td>Java/Jini</td>
<td>HW independent SW</td>
</tr>
<tr>
<td><strong>Services</strong></td>
<td>VOICE + data</td>
<td>TRANSACTIONS + DATA + voice</td>
<td>Integrated, seamless, secure</td>
</tr>
<tr>
<td><strong>Features</strong></td>
<td>Undifferentiated</td>
<td>Location, Context Environment aware</td>
<td>Need platform</td>
</tr>
<tr>
<td><strong>Cost</strong></td>
<td>$299</td>
<td>$99</td>
<td>Margin too low for service pricing</td>
</tr>
</tbody>
</table>
Non Functional Requirements

Basic Communication Processing

Management Plane
- Appl
- TCP/IP
- DLC
- BB
- Phy

Prot. Eng.
Java Eng.
Power Mang.
Test Eng.

DLC
BB
RF
Wireless Engine


LLC MAC BB RF

RISC Core Coproc. DSP Core Coproc.

SiGe CMOS process/device development

60 GHz broad band wireless communication engine
WBN system modules

DLC
- Components ready
- Layout ready
- Design ready
- Software ready
- Accelerator ready

PHY

Medium Access Control

Viterbi Decoder + Descrambler
Demodulation Deinterleaver
Guard interval Extraction FFT

A/D

Analog Front End

A/D

D/A

IFFT+

Guard interval Insertion

Interleaver Modulation

Scrambler + Forward Error Correction (FEC) Coder

Synchronization
MAC Accelerator

- **RISC processor**
  (MIPS, NetARM)
  - Control of protocol operation, management functions

- **HW accelerator**
  - Timers
  - **PHY Interface**
    - **Tx**, **Channel State**, **Rx**
    - Byte stream processing, timers
  - Digital baseband processing
  - Channel encoding, synchronization

- **Interface**
  - 32 bit Interface
  - 8 bit Interface
MIPS Target Architecture for 802.11a

- MIPS
- Bus slave
- Memory controller
- EC bus
- 802.11 MAC
- RAM
- HW accelerator
- UART
- Par. port
- GPIO
- PCMCIA
- Bus interface
- SRAM
- Flash
World first: 1st Single-Chip 5 GHz Modem

Main Components:
1. 5 GHz Analog Frontend (5,8 GHz Superhet., IF 810 MHz)
2. A/D and D/A Converters (7 Instances)
3. OFDM Baseband Processor with Synchronisation and Channel Estimation
4. MAC-Processor (MIPS-4kE) with Hardware-Accelerator
5. PCMCIA (CardBus) Interface plus 2x UART and 1x I²C-Bus Interface
6. Cache-Memory for MIPS und Data Buffers (44 kByte in total)
7. Built-in Self-Test (BIST) with various specific test-modi
8. EMI protection: n-well Ring, GND-Ring, Buried Layer inside AFE

Main Parameters:
- Chip-Area: ca. 90 mm²
- No. of Pins: 240
- Power dissipation: 2W (simulated)
- Clock frequency: 80 MHz
Single chip 5 GHz IEEE 802.11a Photo
Digital Coprocessors

- Certain basic protocols cost GIPS
  E.g., Viterbi costs 3.5 GIPS

- Indicates need for “hardwired” implementation
  Particularly for frequently used algorithms

- Hardwired solutions often eaten up by general purpose processors
  Moore’s law is cruel

- Processors evolve by integrating such functions
  E.g., floating point accelerators (386 -> 486 transition)

- Develop accelerators for key functions
  To work with standard processors and DSP’s
M-business Engine Project

M-business Engine
Multimedia Engine
Gaming Engine

DLC
BB
RF

Prot. Eng.
Power Man.
Test Eng.

Prot. Eng.
Power Man.
Test Eng.
Overview of the work packages

Architectures: Security, Privacy, Payment
TCP/IP for wireless

• TCP has been initially designed for wired low error rate communications
• Back-off behaviour after faults often not appropriate for wireless
  Slow start after faults solves router congestion but not temporary channel interference
• TCP is useful for end-end semantics in Internet application scenarios
  A chance of TCP semantics requires changes in billions of client and is not feasible
• Other solutions are needed to overcome the problems
Minimal change and maximal use scenarios

Modified TCP

TCP
IP
LLC
MAC
PHY

TCP
IP
LLC
MAC
PHY

Modified Link Layer

TCP
IP
LLC
MAC
PHY

TCP
IP
LLC
MAC
PHY

Split Connection

TCP
IP
LLC
MAC
PHY

TCP
IP
LLC
MAC
PHY

Modified Mobile

TCP
IP
LLC
MAC
PHY

TCP
IP
LLC
MAC
PHY
Combining Defective Packets: Principle

BER = p

BER = 3p^2

1. Retry
2. Retry
3. Retry

Memory 1
Memory 2
Memory 3

Weighted Average

Cyclic Redundancy Check

Data

Data with errors

Data without errors

10^{-3} \rightarrow 3 \times 10^{-6}
RF Blocks

• RF I/O one of the biggest challenges
  RF design is an art
  RF designers behave like artists

• Large range of frequencies
  From 2.4 - 60 GHz

• Lots of discussion about new architectures, few results
  Alcatel direct-conversion phones stink!

• Need library of RF “transceiver macros”
  Technology dependent, high value

• Must solve cross-talk problem
  By brute force, or finesse; circuit or technology tricks
5.8 GHz Transceiver

RF Transceiver Block Diagram

- Antenna (5 - 6 GHz)
- Filter
- Mixer
- LNA
- Preselector
- VCO
- PLL
- Power Amplifier
- Mixer
- Filter
- RX-IF
- TX-IF
- RX-Data
- TX-Data

Color Codes:
- Red: SiGe
- Yellow: CMOS
- Pink: External
Body Area Networks

- **BAN**: Assembly of wirelessly connected devices worn on the body
  - All devices share common "BAN engine"
  - All devices share distributed intelligence
  - Enables new applications: e.g. "Personal Trainer"

  ![Diagram of Body Area Networks showing pulse-meter, head set, walkman, and step(frequency)-counter connected through wireless communication system. The diagram includes an application engine, I/O engine, and inter-module communication.]
Distributed Wireless Engine (Body Area Networks)

Inter Module Communication

Processors for external communication
(Bluetooth, DECT, IEEE802.11, GSM, etc.)
Example of a body area system

Distributed Middleware
BAN with Wake-up using 802.15.4/4 in 2.4 GHz

802.15.3 MAC

- Differential Encoder
- 11, 33-55 Mb/s

802.15.4 MAC

- 22 Mb/s
- 250 kbps
- 20/40 kbps

8-state Trellis Encoder

- QPSK, 16/32/64-QAM Modulator
- 11 Msps

QPSK Modulator

- 2.4 GHz RF

16-ary PN Spreading

- O-QPSK Modulator
- 1 Msps

Differential Encoder

- 300/600 kchip/s

15-Chip Spreading

- BPSK Modulator

- 868/915 MHz RF

- 300/600 ksp/s
From Protocol Stack to Functional Network

**OS/Appl.**
- Encryption

**RPC Interface**

**Transport**
- Fragm./Reass.
- Error Check
- ARQ
- Conn.-Mgmt
- Flow Control

**Network**
- Addressing
- Routing

**LLC**
- Addressing
- Fragm./Reass.
- Error Check
- ARQ
- Conn.-Mgmt
- Flow Control
- Encryption

**MAC**
- Coding
- Modulation
- ...

**Digital BB**
- Coding
- Modulation
- ...

**Analog FE**

**Medium**

**OS/Application**

**RPC Interface**

**Medium**

**Control/Configuration Module**

- Addressing
- ARQ
- Error Check
- Modulation
- Encryption
- Analog FE
- Coding
- Flow Control
- Fragm.-Reass.
- Conn.-Mgmt
VCO Circuit Principle

\[ \text{Virtual AC ground} \]

\[ V_{\text{ctrl}} \]

\[ \text{Varicap or MIM} \]
## Measurement Results

<table>
<thead>
<tr>
<th>Parameter</th>
<th>60 GHz VCO</th>
<th>76 GHz Oscillator</th>
</tr>
</thead>
<tbody>
<tr>
<td>Supply voltage</td>
<td>-3.0 V</td>
<td>-4.0 V</td>
</tr>
<tr>
<td>Supply current</td>
<td>24.6 mA</td>
<td>32 mA</td>
</tr>
<tr>
<td>Center frequency</td>
<td>63.6 GHz</td>
<td>76.1 GHz</td>
</tr>
<tr>
<td>Tuning range</td>
<td>9.8 GHz</td>
<td>-</td>
</tr>
<tr>
<td>Output power</td>
<td>-17dBm</td>
<td>-7 dBm</td>
</tr>
<tr>
<td>Phase noise at 1MHz offset</td>
<td>- 87 dBC/Hz</td>
<td>-91 dBC/Hz</td>
</tr>
<tr>
<td></td>
<td>- 84 dBC/Hz*</td>
<td></td>
</tr>
<tr>
<td>Chip size</td>
<td>750x400 μm²</td>
<td>750x400 μm²</td>
</tr>
</tbody>
</table>
60 GHz VCO Micrograph

\[ A_{\text{chip}} = 750 \times 400 \: \mu\text{m}^2, \quad L = 126 \: \text{pH}, \quad C_{\text{max}} = 150 \: \text{fF} \]
Tuning Range

![Graph showing the tuning range of a device with frequency on the y-axis and control voltage on the x-axis. The graph demonstrates an upward trend as the control voltage decreases.]
$A_{\text{chip}} = 750 \times 400 \ \mu\text{m}^2, \ L=90 \ \text{pH}, \ C_{\text{MIM}}=120 \ \text{fF}$
Measured Spectrum

Ref Lvl: -5 dBm
Marker: -6.98 dBm

Center: 76.13 GHz
RBW: 200 kHz

1 MHz/
VBW: 20 kHz

Span: 10.0 MHz
SWP: 50 ms

-91 dBc/Hz
C Suppresses B Diffusion

- B outdiffusion
- Barriers in conduction band
- Reduced collector current
  - Electrons accumulate in base
  - Reduction of $f_T$
Conclusions

• IHP is a highly innovative research institute with
  Vertical structure for full system solutions
  Modern equipment including class-1 clean-room
  Highly educated/motivated people

• Start-ups and Spin-offs are part of the strategy to create sustainable jobs in east Brandenburg

• Industrial relations in high end systems, circuits and technology are key to our success