A Combined Time and Space Division Multiple Access Scheme in a prototypical OFDM-based WiMAX Demonstrator

Benedikt Wolz, Benjamin Strang

Chair of Communication Networks (ComNets)
Prof. Dr.-Ing. Bernhard Walke
RWTH Aachen University, Faculty 6, Germany

13th of March, 2009

Overview

- Motivation
- SDMA
- Design and Implementation
- Performance and Complexity Analysis
- Conclusion & Outlook

Motivation & Framework

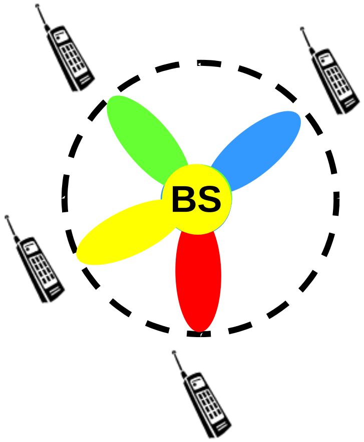
Motivation

- Beamforming and SDMA technologies have high potential to increase future communication system performance
- Investigate feasibility of MAC algorithms developed at ComNets

Framework

- Development of a WiMAX based demonstrator for a real air interface in cooperation with Institute of High Frequency Technology (IHF) at RWTH Aachen
- Development and implementation of SDMA/TDMA enabled MAC protocol

SDMA and Scheduling Approach



SDMA
Space Division Multiple Access

- Beamforming allows to focus power to one user (both Tx/Rx)
- Multiple beamforming units allow concurrent transmissions
- Multiple users served
- Intra-cell interference

Channel is not orthogonal concerning SDMA

→ SDMA-scheduling in two step approach (simple & flexible) :

1. Grouping of spatially separable users
   - Users of the same group concurrently served
   - Different groupers implemented at ComNets such as Greedy Grouper
2. TDMA scheduling of these spatial groups

→SDMA grouping gain is realized

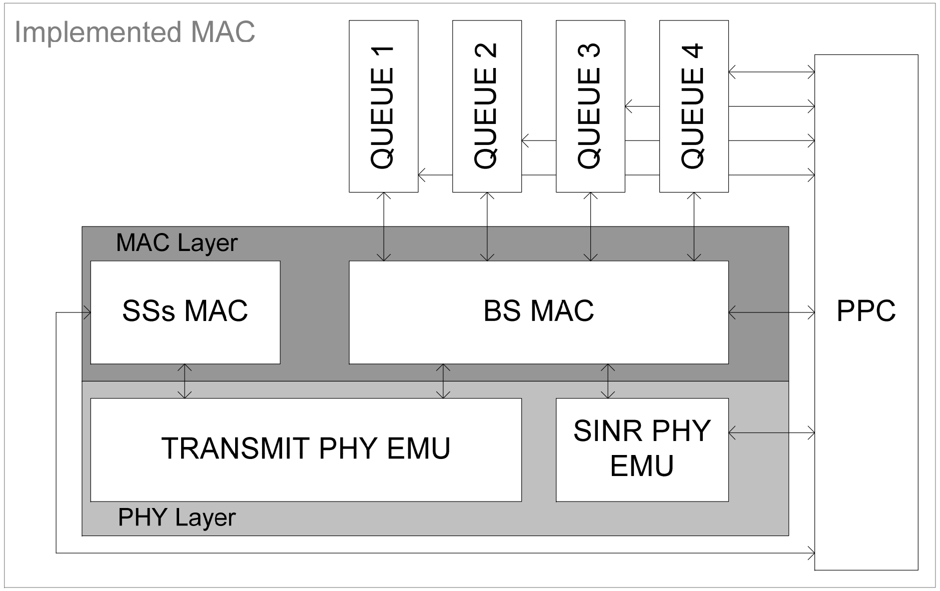
- group members might achieve lower SINR

Implementation
Hardware/Software Co-Design

- Target platform: Field Programmable Gate Array (FPGA) allows for
  - Dedicated hardware solution (VHDL, VERILOG) high-performance with high cost
  - Software-based solution (C, C++) flexible and low cost
- One software and one hardware dominated approaches were evaluated
- Requirements:
  - Performance, Costs and Power
  - Flexibility, Reuse
  - Real-time operation
- Scenario with 4 SSs and 1 BS

Implementation
Hardware-based Solution

Structure of implemented MAC

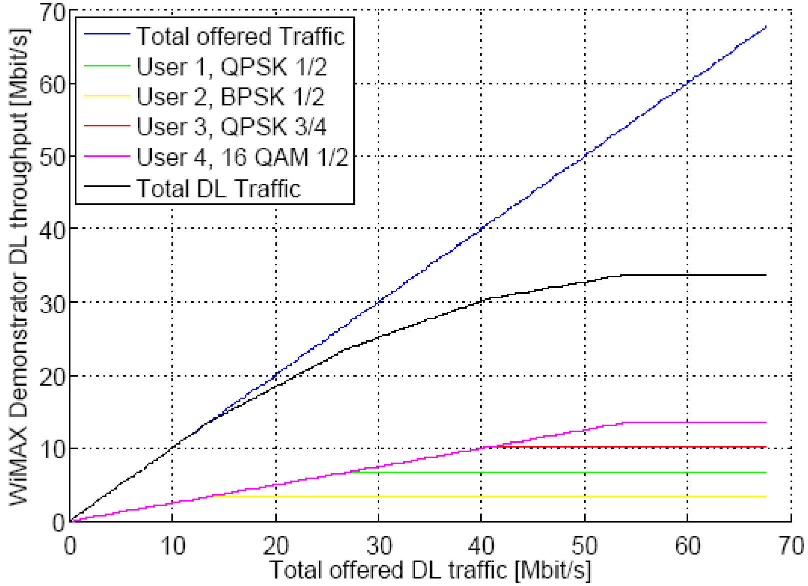


DL test scenario

- SDMA enhanced BS MAC
- emulators of adjacent layers
  - Constant Bit Rate (CBR) traffic implemented in Queues
  - PHY emulator models radio channel & emulates data transmissions (to be replaced by IHF PHY)
- SSs MAC evaluates frame

Performance and Complexity Analysis (1/4) - MAC Layer

Throughput in example DL scenario



- DL cell- and user throughput with four parallel users
- Measured on development board
- User TP depends on assigned MCS
- Maximum cell TP in DL of 33,79 Mbit/s
- First user in saturation at 13.52 Mbit/s

Performance and Complexity Analysis (2/4) - Intermediate Results

- MAC successfully installed on target platform
- Throughput measurements as expected
(+ validation by VHDL-test bench)
- Support of TDMA/SDMA scheduling with 4 users
(on frame-basis (2.5ms), up to 61.44 Mbit/s DL traffic)

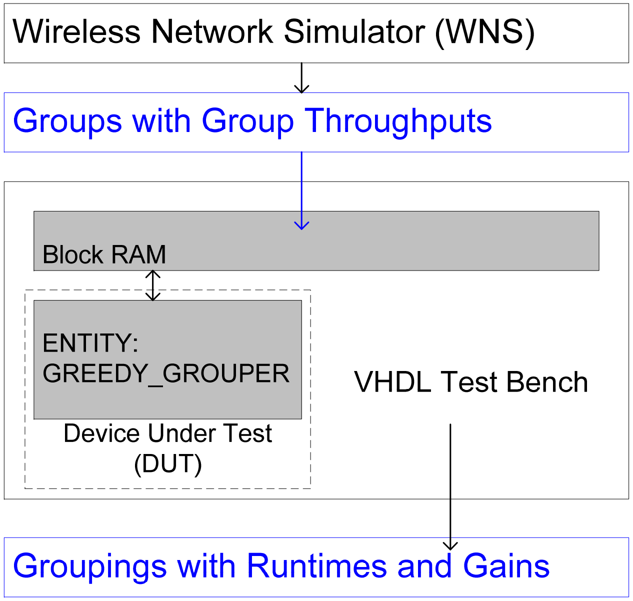
→ Real-time MAC with combined TDMA/SDMA is feasible

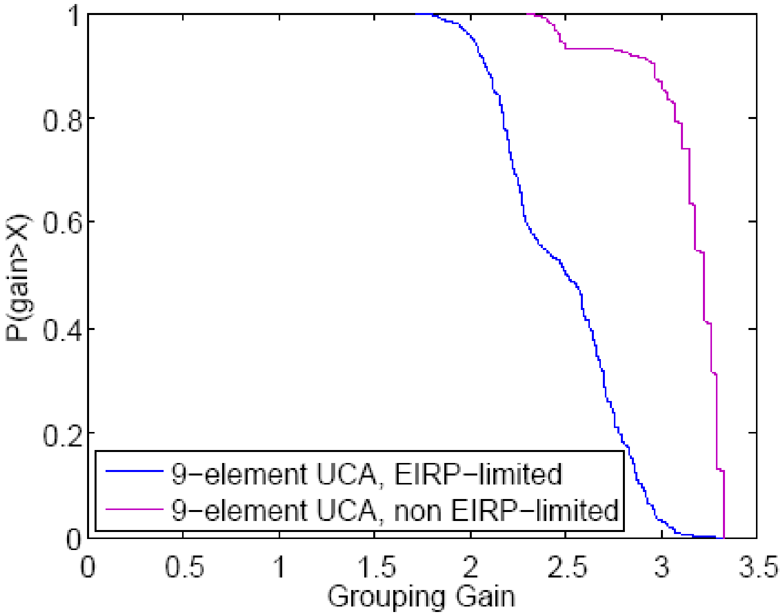
Are modules sufficient for real system requirements?

- Higher data rates by higher MCS & bandwidth
  - Hardware data path suffice (800Mbit/s)
- More users
  - TDMA scheduling (strategy) uncritical
  - SDMA scheduling (grouping) critical

Performance and Complexity Analysis (3/4) - Grouper

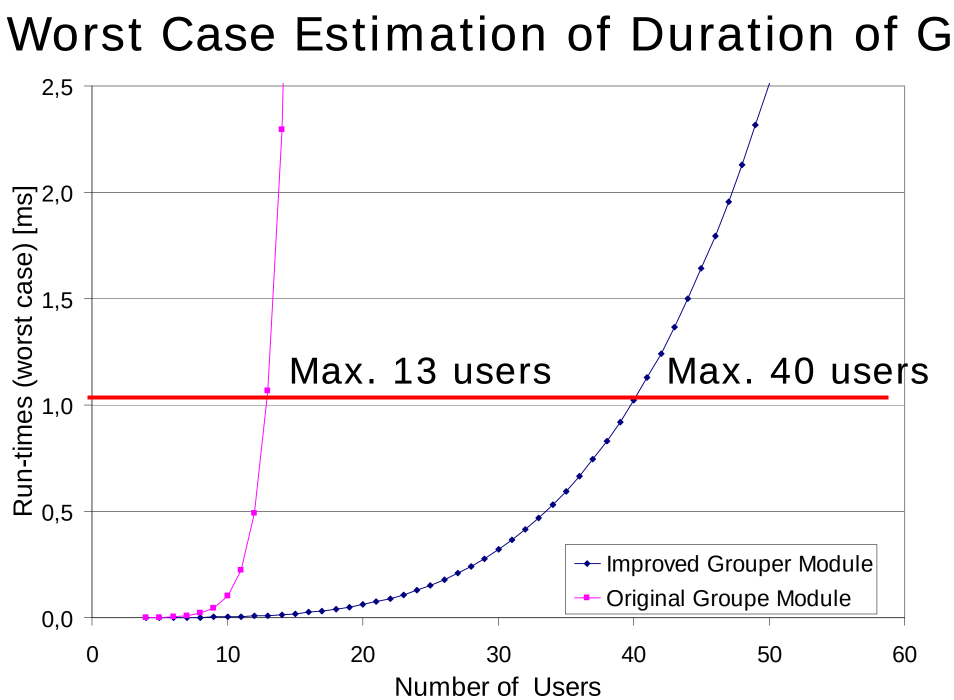
Grouping Gain CCDF - Monte Carlo Simulations





- Hardware module groups 10 users in 200 different scenarios
- Grouping gain is decreased by limited EIRP
- Grouping gain remains between values 1 and 3.3 as expected (Average grouping gains: 2.48 / 3.15)
- Average run times: 35.44µs / 31.59µs
- Worst case run time: 102,4 µs

Performance and Complexity Analysis (4/4) - Grouper



- Grouping should not last more than approximately 1ms for 2.5ms frame (frame-by-frame)
- Original grouper works on un-sorted list of groups → max. 13 users
- Improved grouper works on pre-sorted list of groups → max. 40 users

→ combined TDMA/SDMA is even feasible for ambitious scenarios (30Gbit/s & 120 User per cell)

Conclusion and Outlook

Conclusion

- Software-based solution does not meet performance requirements
- Hardware-based solution meets requirements, real-time TDMA/SDMA scheduling feasible even for ambition scenarios (up to 30Gbit/s & 120 user)
- Combination of both will give performance and flexibility required for WiMAX systems

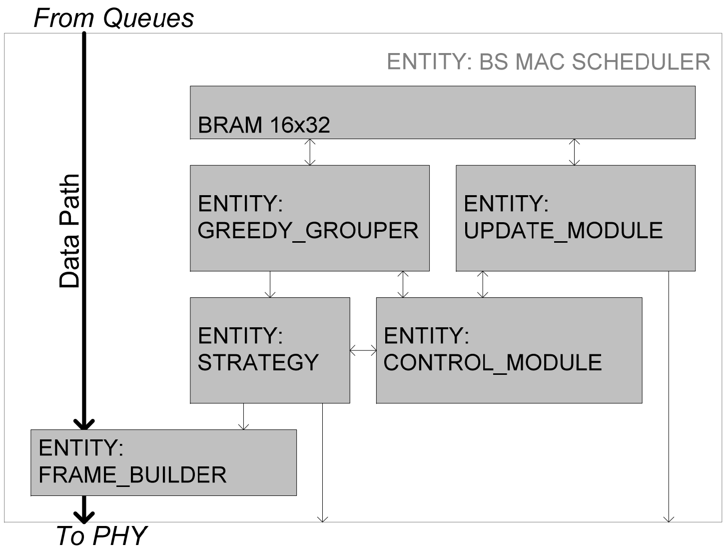
Outlook

- Check possibility of Tree-based Heuristic grouper implementation
- Full integration on IHF demonstrator for further optimizing MAC-PHY interaction (e.g. study SINR-estimation cost)
- Study of QoS support on layer 2 with real traffic load, e.g., Voice or Video (over on board Ethernet interface)

Thank you for your attention!

Implementation
Hardware-based Solution (2/2)

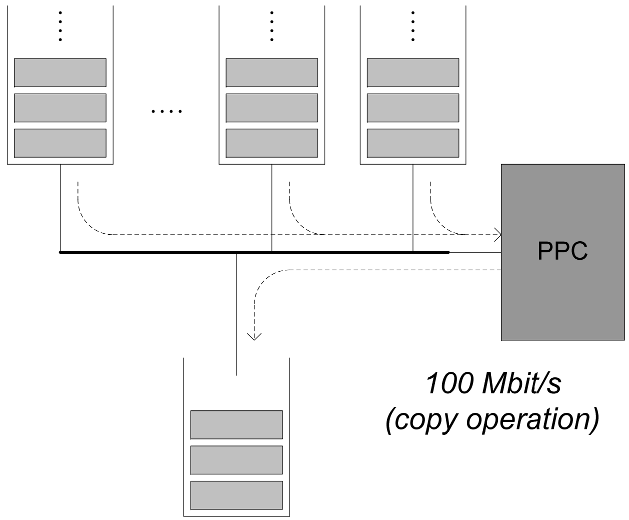
Structure of SDMA/TDMA scheduler



- Structure adopted from WNS scheduler – two step scheduling with grouper and strategy
- SINR estimation decoupled from grouping calculation by Block RAM
- Generic design
  - Grouper extendable to more users
  - Exchangeable modules

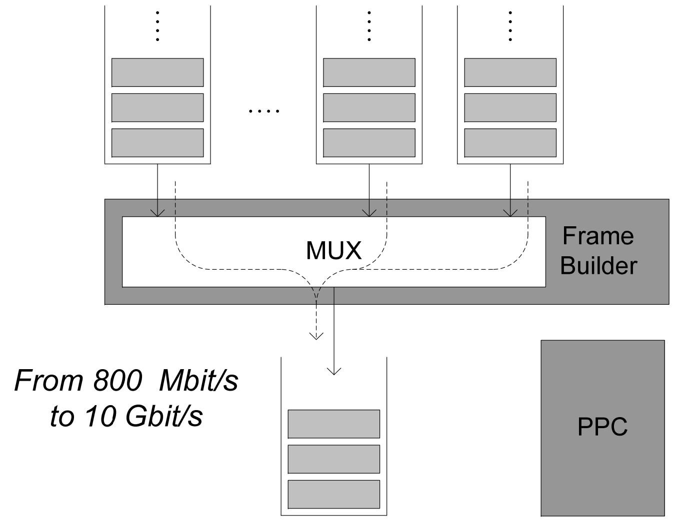
Performance Analysis (1/6) - Data Path

Software-based Design



- Only applicable for moderate data rates (100 Mbit/s)
- Blockades PPC with simple copy operation

Hardware-based Design

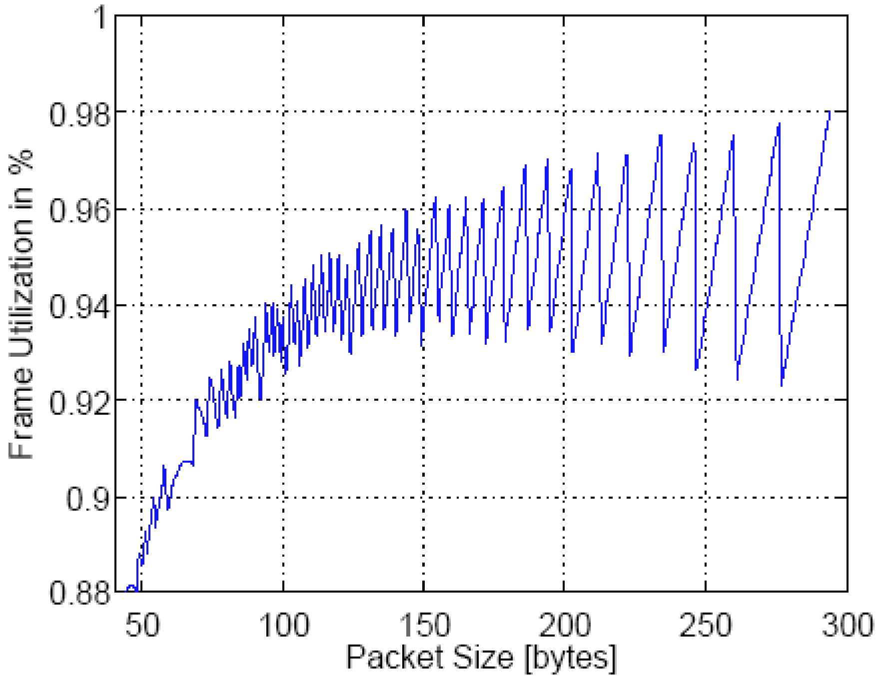


- Data path bandwidth of up to 10 Gbit/s will suffice for ambitious scenarios
- PPC not employed due to Direct Memory Access (DMA)

→ Realization of data path in DMA manner is worth keeping

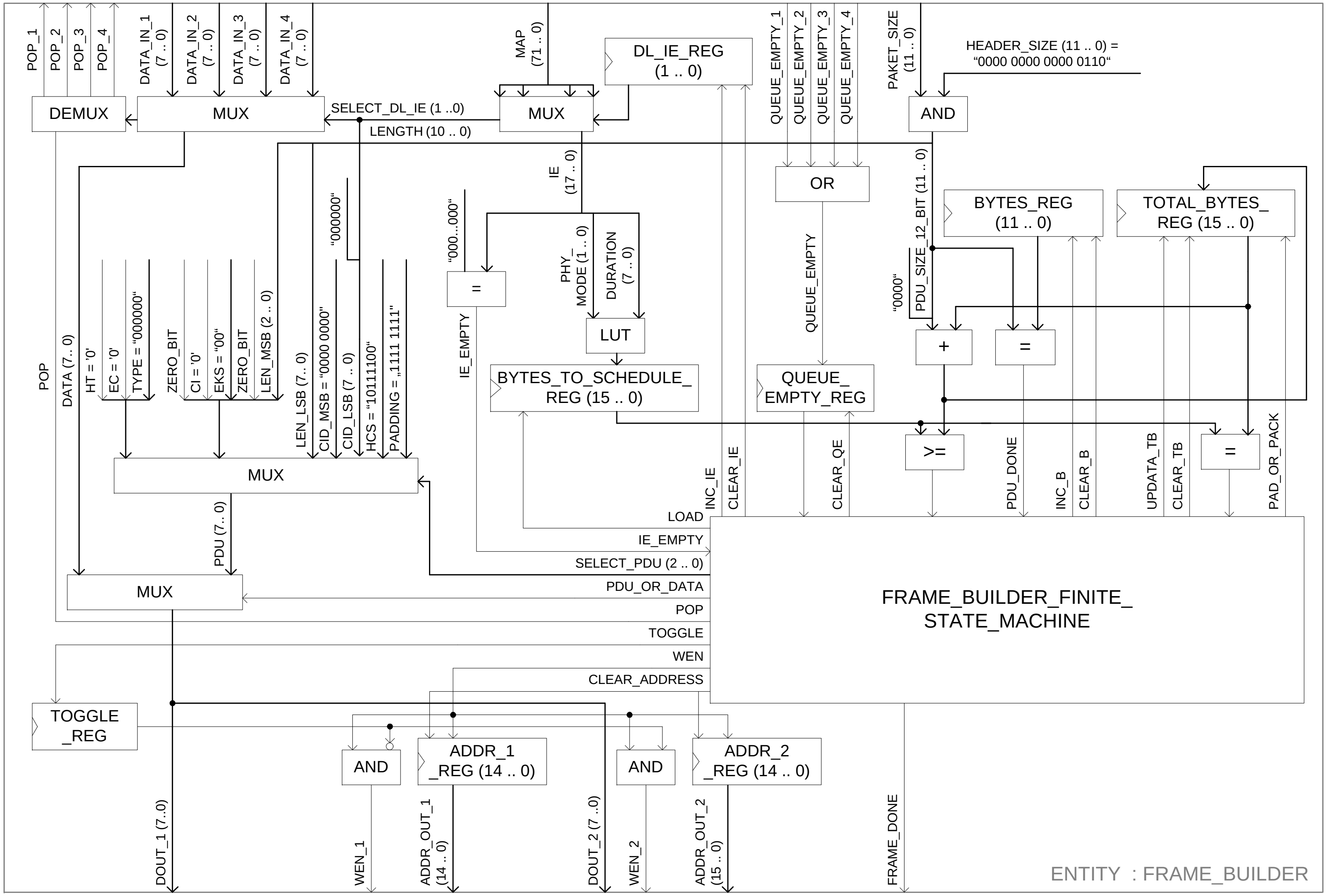
Performance and Complexity Analysis (3/6) - MAC Layer

Frame Utilization



- Results measured on development board
- Packet size varied from 44 to 294 bytes (PDU size 50 to 300 bytes)
- Four users concurrently in frame of 100 OFDM symbols with 16 QAM½
- Frame Util. depends on padding and relative size of PDU header

Frame Builder



Frame Utilization-Sampling