Communications Research in the Department of Electronics

Tim Tozer
Group Leader

tct@ohm.york.ac.uk

www.elec.york.ac.uk/comms/research.html
Communications Group

An integrated Group:-

Also has close potential synergy with other Research Groups in the Department in areas of:
- Intelligent Systems
- Bio-inspired computing
- Applied electromagnetics + EMC

- 6 academic staff
- c.4 salaried research staff
- c.27 postgrad research students

- Good International Reputation
- Strong publication record
- Good industrial connections
What do we do?

Main Areas of Activity and Expertise:

- **Wireless Networks**
  - Cognitive Radio and Radio Resource Management
    - Routing
    - Access schemes
    - Sensor Networks
    - Spectrum Allocation & Management
    - Cognitive Radio
  - High Altitude Platform (HAP) & Satellite systems
  - Antenna measurement & design

- **Signal Processing & Coding for Comms**
  - Modulation & Coding
  - Turbo-codes & processing
  - MIMO & virtual MIMO systems
  - Implementation-efficient algorithms
  - Frequency Estimation & Synchronisation
  - Equalisation
  - Adaptive systems
  - Smart Antennas
  - Acoustic systems
Next Generation Wireless

Transmission technologies & signal processing algorithms for 4G

- WiMAX/LTE-2/Enhanced WiFi
  - Wireless multihop, relaying and mesh networks
  - UWB
- Turbo-codes and iterative processing
  - Turbo and LDPC codes
  - Iterative interference cancellation
- MIMO
  - MIMO Channel modelling
  - Antennas for MIMO
  - Adaptive MIMO
  - MIMO-OFDMA
- Precoding - tensor modelling
Signal Processing

- **Statistical Signal Processing**
  - Detection & estimation
  - Adaptive estimation algorithms
  - Reduced-rank methods
  - Signal processing algorithms for wireless networks

- **Speech Processing**
  - Speech coding algorithms for VOIP & wideband speech

- **Defence Applications include**
  - Radar & sonar
  - Navigation systems
Reduced Rank Techniques

- for Array Processing and Communications

- Increased robustness against interference & mismatch
- Significant improvement for training
- Provide amenable adaptive implementation (no eigendecomposition)
- Applications: spread spectrum & MIMO systems, beamforming & direction finding.

![Graph showing error reduction over time comparing conventional and reduced-rank techniques.](image-url)
‘Dichotomous Co-ordinate Descent’

- Iterative solving linear systems of equations without multiplications or divisions.
- Hardware implementation: as small as 364 FPGA slices, i.e. 2.7% of a FPGA chip (to solve 64 equations with 64 unknown parameters)! This is a size of just one multiplier.

Applications:

- Communications & signal processing (equalisation, channel estimation, multiuser detection, smart antennas, MIMO detection, etc.)
- Multimedia (echo & noise cancellation, speech & image coding, microphone arrays, etc.)
- Radars & sonars, computed tomography, etc.
Coordinate Descent iterations  N=2 case

Gradient Descent:
- Short route to the solution, but with high complexity

Coordinate Descent
- Does not calculate the gradient
DCD-based Signal Processing examples

- Recursive Least Squares (RLS) transversal adaptive filter (64 filter taps): 1400 FPGA slices (<10%)
- Affine projection adaptive filter (512 filter taps): 2800 FPGA slices (<20%)
- Box-constrained multiuser detector (≈3G) (50 users): 400 FPGA slices
- Maximum likelihood performance multiuser detector with BPSK modulation (64 users): 1200 FPGA slices
- Box-constrained MIMO detector: 650 FPGA slices

Gordon Aspin from Camitri is helping us exploit the DCD
Antenna beam pattern optimisation

For HAPs (High Altitude Platforms)
Vertical Antenna Array configuration

Spot one beam to a single cell

Vertical antenna array

Cell 1
Cell 2
Cell n
Antenna beamforming for HAPs

Coverage vs. SIR (dB) graph

- 121 aperture antennas, 120 hex cells, 4 reuse
- 424 planar array, 120 hex cells, 4 reuse
- 121 vertical linear array, 61 ring cells, 2 reuse, SDP
- 171 vertical linear array, 61 ring cells, Hamming weights
- 171 vertical linear array, 61 ring cells, 2 reuse, SDP
## DCD-based antenna beamformers

<table>
<thead>
<tr>
<th>Adaptive Beamformers</th>
<th>FPGA slices</th>
<th>Update rate (kHz)</th>
</tr>
</thead>
<tbody>
<tr>
<td>16-element MVDR</td>
<td>1150</td>
<td>225</td>
</tr>
<tr>
<td>64-element MVDR</td>
<td>1250</td>
<td>32</td>
</tr>
<tr>
<td>16-element dynamically regularised MVDR</td>
<td>2800</td>
<td>191</td>
</tr>
<tr>
<td>64-element dynamically regularised MVDR</td>
<td>2800</td>
<td>31</td>
</tr>
</tbody>
</table>
Ability to flexibly assign multiple frequency bands & routes through a network on an ‘intelligent’ dynamic basis

Exploits the fact that ≈90% of spectrum is underutilised in a given location

Can integrate all layers of the protocol stack
  - Routing + Dynamic spectrum assignment + Software defined PHY

Team of 11+ researchers at York – and rapidly expanding!

Related projects include
  - Reduced complexity CR systems
  - CR for mixed multicast systems
  - CR for mixed HAP & terrestrial systems
  - WUN ‘COGCOM’
Wireless Sensor Networks

- Increasingly important, esp. for environmental monitoring

- Challenges
  - Energy-efficient protocol development
  - Data aggregation and topology design

- Topics of interest at York also include:
  - Medium access control
  - Multi-hop routing
  - Cross-layer design
  - Protocol simulation
  - Hardware implementation
  - Use of aerial platforms
Vertical Handover in TCP/IP

- RTT (round-trip time) and bottleneck bandwidth can suddenly and significantly change during vertical handover (e.g. GPRS to WiFi).
- Under-utilisation of resources, and unnecessary re-transmissions can result.
- Use of Link Channel Information (LCI) can help give advance warning to TCP end-stations.
- Current active research topic in IETF Transport WG, and IEEE 802 committees.
- York looking at ways to distribute LCI information, and adapt transport layer flow control.

Multicast in Wireless Distribution Networks

- Using Multicast routing can reduce handover latency, however many problems with reliable multicast to overcome.
High Altitude Platforms (HAPs)

- Quasi-stationary vehicles in the stratosphere
- Typically around 20 km altitude
  - Benign winds here (jet stream)
  - Above aircraft
- Supporting payloads for communications relay
  - A very tall antenna mast?
  - A very low geo satellite?
- Combine best features of Satellite & Terrestrial (e.g. FWA) services
- Applications:
  - 3G / 4G, broadband, broadcasting
  - Event servicing, disaster relief, service restoration
  - Also Surveillance + Monitoring
Considerable activity over last 9 years, including -

- **HeliNET Project (EU 5th Framework)**
  - Broadband comms from HAPs

- **CAPANINA**
  - Broadband comms from HAPs
  - + 802.11 Trials to 23 km (@28 GHz)

- **USE-HAAS**
  - European Strategy for HAPs

- **MoD ESII-WiMAX**
  - WiMAX for Urban environment

- **StratXX project payload devt.**

- **COST297** [www.cost297.org](http://www.cost297.org)
CAPANINA Scenario

Fixed BFWA particularly for rural locations

Moving Train

Up to 300km/h

Steerable/Smart Antenna

Up to 120 Mbit/s symmetric links

31/28GHz, (47/48GHz), + optical backhaul and interplatform

WLAN

17-22km
WiMAX for the stratosphere

‘StratXX’ Project in Switzerland developing a lighter-than-air High Altitude Platform. University of York tasked with WIMAX payload and comms.
Recent WiMAX Trials in Switzerland

Helicopter Trial

Long duration trial - Mt Pilatus
Practical Antennas Research (i)

• Communications to High Altitude Platforms & Satellites
• Antenna design, fabrication & measurement
• Scanning and multi-beam antenna
Practical Antennas Research (i)

MULTISCAN Lens reflector antenna with multiple independent feeds
Application for broadband Internet to trains
Underwater Communications

MIMO and other techniques have powerful application.
Problems + Challenges from York perspective

- We have talent and effort, but need Money!
- Research Council funding harder and harder to get. Ditto industry funding.
- Challenge to bridge gap between academic research & needs of sharp end companies
- We need help with this

At the same time:
- We do need to work with the end customer
- We do need to identify the right problems
- And the end customer needs to identify his problems
- We can all work together. But the key is people.

THANK YOU!

tct@ohm.york.ac.uk
www.elec.york.ac.uk/comms/research.html