Switched beam antennas in millimeter-wave band broadband wireless access networks

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J. Herrera, V. Polo, J. M. Martinez, Voice: +34 963879768
P. Sanchis, J. L. Corral, J. Marti Fax: +34 963877279
Universidad Politécnica de Valencia E-mail: jmarti@dcom.upv.es
Instituto ITACA, Edificio I-4
46022 - Valencia (SPAIN)

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Purpose:
Contribution to the proposed new concepts in Session #26

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Switched beam antennas in millimeter-wave band broadband wireless access networks

J. Herrera, V. Polo, J. M. Martinez, P. Sanchis, J. L. Corral, J. Martí

Universidad Politécnica de Valencia
OBANET IST-2000-25390

More information at
mailto:jmarti@dcom.upv.es
http://ist-obanet.upv.es
OUTLINE

• Motivation
  — OBANET IST-2000-25390 project
• Objectives
• Switched-Beam Antenna scenario
• Performance improvement
  — Interference reduction
  — Multi-path reduction
  — Antenna Gain control
• Protocol adaptation to SBA scenario
• Remarks and conclusion
MOTIVATION

• Broadband Wireless Access (BWA) Networks
  — High bit rates (>50 Mbps) only to operate in the millimetre-wave band (targeted band 40-43 GHz)
  — Frame duration 1 ms, channel size 28 MHz and M-QAM modulations formats target >50 Mbps
  — Natural and artificial conditions drastically impair at mm-wave frequencies: rain, vegetation, man-made obstacles

• Flexibility and Efficiency ➔ Smart Antennas
  — Dynamic antenna gain and coverage area
  — Reduced multi-path and interferences
  — Higher spectral efficiency and SDMA

Smart Antennas at 40 GHz?


**MOTIVATION**

**Smart Antennas at 40 GHz**

- **Adaptive antennas: DSP and RF/IF**
  - Very high speed DSPs (not yet available)
  - Beam-squint (radiation pattern depends on frequency)
  - High speed switches required for beam-switching.
  - Bulky hardware is required

**Proposed approach**

- **Switched-Beam Antennas (SBA)**
  - Simplified architectures: optical beamforming, Butler matrix
    - however, the proposed strategies are technology-independent
  - True-Time Delay is achieved ➔ no beam-squint
  - Ultra-fast switching times up to nanoseconds
OBJECTIVES

• SBA is the simplest smart-antenna technology at 40 GHz suited as first implementation

OBJECTIVE 1: To demonstrate the benefits of introducing SBA in BWA networks

• However, BWA protocols must be adapted to introduce SBA → overhead

OBJECTIVE 2: To propose a adaptation to introduce SBA scenario in the BWA protocols

OBJECTIVE 3: To introduce an strategy to reduce the overhead
SWITCHED BEAM ANTENNA SCENARIO

• Scenario defined fitting IEEE/ETSI draft standards (2001)
  — Operation frequency: 42.7 GHz
  — IEEE/ETSI fixed frame format
  — TDD and TDM/TDMA operation mode

• SBA control and performance evaluated
  — Interference and multipath reduction
  — Antenna gain control
  — Adaptation of BWA protocols reducing overhead
  — Pointing directions and beamwidths
**PERFORMANCE OPTIMISATION**

- **Interference reduction**
  - Outage probability as a function of the required C/I for different SBA configurations \((SLL^{{BS}} = 20 \text{ dB}, SLL^{{SS}} = 15 \text{ dB and } \Delta \phi^{{SS -3dB}} = 3^\circ)\) in the downlink direction.

Cellular reuse pattern:
- 2 Frequencies
- 2 Polarisations
PERFORMANCE IMPROVEMENT

• Interference reduction
  — C/I required to obtain an outage probability of 1% as a function of the radius of the coverage area for different SBA configurations

**Higher order modulation formats can be employed in a larger coverage area**

<table>
<thead>
<tr>
<th>$\Delta \phi_{-3dB}$</th>
<th>CA</th>
</tr>
</thead>
<tbody>
<tr>
<td>90°</td>
<td>1200 m</td>
</tr>
<tr>
<td>22.5°</td>
<td>2000 m</td>
</tr>
<tr>
<td>11.25°</td>
<td>&gt;2500 m</td>
</tr>
</tbody>
</table>

For a BER=$10^{-11}$ at 16-QAM (required C/I 21 dB)

**Overall capacity enhancement**
PERFORMANCE IMPROVEMENT

• **Multipath reduction**
  — BER improvement
  — Temporal dispersion of the channel is reduced
  — Easier equalisation → simplified wireless modem design

![Graph showing performance improvement](image)

**Quality of service improvement**
PERFORMANCE IMPROVEMENT

• Dynamic antenna control
  — Useful to counteract temporary channel impairments
  — Less interferences than Power Control techniques
  — Sector reconfiguration possible

<table>
<thead>
<tr>
<th>MODE</th>
<th>$\Delta \phi_{-3dB}$</th>
<th>$\Delta G$</th>
</tr>
</thead>
<tbody>
<tr>
<td>I</td>
<td>22.5°</td>
<td>0 dB</td>
</tr>
<tr>
<td>II</td>
<td>11.25°</td>
<td>3 dB</td>
</tr>
<tr>
<td>III</td>
<td>5.65°</td>
<td>6 dB</td>
</tr>
</tbody>
</table>

Availability and Flexibility improvement
**PROTOCOL ADAPTATION**

- **Broadcast and contention access**
  - Clearly unfeasible in the SBA scenario
  - Solution: replication of broadcast and content intervals in each beam
  - Introduces overhead, specially the broadcast of control information

- **Adaptation to the SBA scenario**
  - Slot-based beam switching approach preferred
  - Replication minimization using location

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**standard downlink subframe**

- **TDM portion in robustness order**
  - QPSK, 16-QAM, 64-QAM

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**Slot-based beam-switching approach**

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**PROTOCOL ADAPTATION**

- **Map minimisation**
  - Local DL_MAP and UL_MAP to each beam pointing direction
  - Location may be easily obtained in the SS registration
  - Only SS present in each beam are mapped in the local DL_MAP
  - Only SS present in each beam are allocated in the local UL_MAP
  - Different preamble sequences

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**DL_MAP and UL_MAP format**

Low impact for high loads

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REMARKS AND CONCLUSION

• Several strategies making use of beam-forming and fast beam-switching capabilities are possible with adaptive beam-formed BS antennas

• The use of such strategies lead mainly to:
  — interference reduction, capacity improvement
  — better quality of service
  — improved system flexibility

• These benefits are of key importance for next generation multimedia fixed broadband wireless access networks
REMARKS AND CONCLUSION

• A strategy to adapt the SBA scenario and to minimize the protocol overhead introduced in BWA protocols has been proposed:
  — slot-based beam-switching
  — minimization using location
  — efficient for high-loads

Thanks for your attention
More information at http://ist-obanet.upv.es