Performance Comparison of Switched Beam and Adaptive Beam Architectures for Intelligent Antenna Systems

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Introduction

Background:
- Nortel have conducted an extensive ‘dense urban’ measurement campaign to establish the viability of directional beam techniques for C/I enhancement
- Impact of field measurements being considered for several key applications

General Design Issues:
- Switched vs. Adaptive beam approaches
  ..........beam falsing vs. weight error loss
- Effect of angle spread
  ..........space vs. beam diversity
- Downlink beamforming
  ..........beam spreading & sidelobe impact
Typical Adaptive-Beam Configuration

- Mobile has small angle spread
- Assume Burst-mode Tx with QPSK modulation
- TS every burst

Correlated Fading at the N antenna elements due to small angle spread

Rx, and TS correlation on every element

Beamformer forms an adaptive beam matched to mobile bearing

Adaptive Beam - Governing Equations

At high SNR:

\[ F_{CR} = \frac{2(N-0.5)}{L} \]

\[ WEL(dB) = 10 \log_{10}(1 + F_{CR}) \]

where:
- \( F_{CR} \) is fractional BER increase due to beamformer weight error
- \( L \) is number of bits in Training Sequence
- \( WEL(dB) \) is 'Weight Error Loss' measured in dB


Demod. (coherent QPSK)
Target BER=1 to 3% range
Orthogonal Beam Set (e.g. Butler Matrix)

Integral facet and beamformer

Beam selection

Correlated Fading at elements (and beam outputs) due to small angle spread

Mobile in peak of beam #2
Small angle spread
Assume Burst-mode Tx with QPSK modulation
Training Sequence (TS) every burst

Training Sequence (TS) on every beam

Demod. (coherent QPSK) Target BER=1 to 3% range

Pick output with largest energy

Signal+Noise (N.B. if mobile is sitting in beam crossover region, then signal energy will appear in multiple beam outputs)

Noise only
Beam Falsing in Static and Rayleigh Channels

N.B. 16-bit TS assumed giving 12dB processing gain.
Mobile situated in beam peak with (almost) zero angle spread.
BFP - Beamformer processor.
Switched vs. Adaptive Beam in Rayleigh Fading

Switched Beam
No. of beams = 4

N.B. Cusping loss not included - mobile assumed at peak of beam.

Adaptive Beam
No. of elements = 4

Operating point with ‘Magic Genie’ processor

'Switched beam approach has minimal performance degradation due to beam falsing but suffers approximately 1.2dB loss on average due to cusping. Adaptive beam approach suffers significant weight error loss but no cusping overhead.'
Effect of Angle Spread - Adaptive Beam Theory

Angular Scattering of width $\theta_0$ radians

$$f(\theta) = \exp(-\theta^2/2\theta_0^2)$$

Space Correlation of Fading

$$C(d) = \exp(-2\pi^2\theta_0^2d^2/\lambda^2)$$

Notes:
- QPSK modulation
- $N$ element array
- $K$ time taps

Equation:

$$BER = \frac{1}{2} \sum_{m=1}^{NK} \left( 1 - \frac{1}{\sqrt{1+1/\mu_m}} \right) \prod_{j \neq m} \left( 1 - \frac{\mu_j}{\mu_m} \right)$$
Diversity Performance vs. Angle Spread

N=4, d/\lambda = 1, mobile assumed at 1km range

Adaptive/Fixed beam
10m radius

Fixed beam, 190m radius

N.B. Weight error loss ignored.
All results are adaptive beam unless indicated.

Adaptive beam approach (i.e. MRC) provides significant gain advantage when angle spread is appreciable.
Nortel Aperture Analyser

Unique propagation measurement facility has been developed to gather representative field data

- Wideband channel sounding
- Different antenna types
  - directional beam
  - multi-beam facet
  - diversity

Trials conducted for various deployment scenarios including dense urban
Urban Trials

Base station receiver located on top of 13 storey engineering faculty building at University College, London

<table>
<thead>
<tr>
<th>Antenna configuration</th>
<th>Measurement</th>
</tr>
</thead>
<tbody>
<tr>
<td>Diversity pair</td>
<td>Spatial diversity vs element separation</td>
</tr>
<tr>
<td></td>
<td>Polarisation ratio/correlation</td>
</tr>
<tr>
<td>Narrow beam antenna</td>
<td>Angle vs delay spectrum</td>
</tr>
<tr>
<td></td>
<td>Uplink/downlink correlation</td>
</tr>
<tr>
<td>Multi-beam facet</td>
<td>Downlink selection</td>
</tr>
<tr>
<td></td>
<td>Effective beam patterns</td>
</tr>
</tbody>
</table>
Example Scattering Map - Central London

Mobile in Waterloo Place, St. James’s

Charing Cross Station

The Foreign Office

Delay (microseconds)

Parliament

Millbank Tower

-93--91
-95--93
-97--95
-99--97
-101--103
-103--105
-109--107
-111--109
-113--111
-115--115
-119--117
-121--119
-123--121
Space vs. Beam Diversity
Measurement Results

Significant spread of diversity gain using Beam Diversity method in urban environment.
Downlink Beamforming

- Capacity enhancement requires C/I gain (over baseline antenna product) to be achieved on both forward and reverse links
- Radio standards influence beamformer choice
- Achievable downlink C/I improvement dictated by:
  - Design Beamwidth
  - Design Sidelobe level
  - Beam spread
  - Sidelobe distortion
  - Beamformer realisation
  - Multipath environment

*Measurement trials have been used to optimise target ‘Multi-Beam’ design for TDMA application.*
Beam Spreading due to Multipath Scatter

Mobile transmitter located at Lincoln’s Inn Field, London

Effective directivity determined by scattering rather than antenna design in urban application
Concluding Remarks

- Performance curves have been presented for switched vs. adaptive beam smart antennas – Complex tradeoff involving analysis of issues such as channel estimation errors, cusping effects, angle spread

- Nortel have conducted an extensive dense urban measurement campaign to establish the viability of directional beam techniques for C/I enhancement

- Currently preparing for a live-air trial of Multi-Beam base station antenna for a capacity enhanced TDMA network