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A Line-of-Sight Optimised MIMO Architecture for Outdoor Environments
Presentation Outline

• MIMO notation
• Performance of MIMO in LoS
• Rank-one and full-rank LoS response
• Maximum capacity criterion
• Measurement procedure
• Results
• Conclusions
System Model and MIMO Capacity

The input-output relationship in an $n_t \times n_r$ MIMO system is represented mathematically by:

$$y = Hx + n$$

$y$ - received signal vector

$H$ - channel response matrix

$x$ - transmitted signal vector

$n$ - noise at the receiver

The capacity of such a system is given by:

$$C = \log_2 \left( \det \left( I_{n_r} + \frac{\rho}{n_t} HH^H \right) \right)$$
Channel Response Matrix (LoS)

• In LoS conditions the channel response matrix is commonly modelled as:

\[ H = \sqrt{\frac{K}{K+1}} H_{\text{LoS}} + \sqrt{\frac{1}{K+1}} H_{\text{NLoS}} \]

• In systems with inter-element spacing of the order of a wavelength the capacity reduces with increasing \( K \)
Rank-One vs Full-Rank LoS Channel

- It is possible to achieve a full-rank LoS channel response by increasing the inter-element spacing.
- The capacity then increases with increasing $K$.

$$H_{LOS} = \begin{pmatrix} \frac{\pi}{2} & 0 & 3\frac{\pi}{2} & \pi \\ \frac{\pi}{2} & 0 & 3\frac{\pi}{2} & \pi \\ \frac{\pi}{2} & 0 & 3\frac{\pi}{2} & \pi \\ \frac{\pi}{2} & 0 & 3\frac{\pi}{2} & \pi \end{pmatrix}$$
Maximum Capacity Criterion

- It is trivial to show that for a static MIMO channel the capacity is maximised when

\[ HH^H = n_t I \]

Using the above formula and assuming a free-space channel a simplified maximum capacity criterion for Uniform Linear Arrays was previously derived:

\[ s_1 s_2 = \frac{\lambda D}{n_t \sin \omega \sin \theta} \]

This equation gives the required inter-element spacing to achieve the maximum capacity in a MIMO system in free-space as a function of the T-R distance \( D \) and the orientation of the arrays \( (\theta, \omega) \).
Previous Work and Motivation

• The performance of LoS-optimised antenna array structures has been previously investigated using MIMO measurements in an anechoic chamber an office environment and a home environment

• Here we present an investigation on the performance of a distributed MIMO architecture suitable for an outdoor deployment corresponding to a hotspot scenario

• The channel response is modelled using a MIMO-capable ray-tracing software

• The operating frequency for the simulation was chosen to be 5.2 GHz
Scenario 1 (narrow-spaced arrays)

- Lamppost-level (h=10m) access-points (AP) are employed
- Each AP consists of two omni-directional antenna elements spaced by 20 cm and downtilted by 45 degrees facing the middle of the road
- At the mobile terminal (MT) a 2-element ULA with 4 cm spacing is used
- At each point in the route the MT communicates with the nearest AP
Capacity Results (Scenario 1)
Scenario 2 (LoS-optimised arrays)

- A LoS-optimised architecture was employed where the AP elements were distributed at 10 m intervals along the deployment area.
- At each point in the route the two successive elements that are nearest to the MT are used for communication.
- At the MT the same array as in Scenario 1 is used.

![Scenario 2 Diagram](image_url)
Capacity Results (Scenario 2)
Results (Fixed SNR = 20 dB)

Mean capacities for Scenarios 1 and 2 along different parts of the route (r.p. = route point):

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<thead>
<tr>
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<tbody>
<tr>
<td>Scenario 1</td>
<td>9.59 bps/Hz</td>
<td>9.02 bps/Hz</td>
<td>9.10 bps/Hz</td>
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<tr>
<td>Scenario 2</td>
<td>10.56 bps/Hz</td>
<td>13.08 bps/Hz</td>
<td>11.45 bps/Hz</td>
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<tr>
<td>Improvment</td>
<td>10.1%</td>
<td>45.3%</td>
<td>25.7%</td>
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</tbody>
</table>
Fixed SNR vs Measured SNR

• The results presented correspond to a system with normalised channel response (fixed SNR = 20 dB)

• This assumption corresponds to a system employing optimal power control

• In reality the SNR varies considerably especially between LoS/NLoS positions

• To investigate the effect of the path loss on the capacity the capacity was also calculated for a system with fixed transmit power (variable SNR)
Results (Fixed Tx Power – Variable SNR)

### Chart 1: Mean Capacities for Scenarios 1 and 2

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<tbody>
<tr>
<td>Scenario 1</td>
<td>1.61 bps/Hz</td>
<td>9.31 bps/Hz</td>
<td>5.54 bps/Hz</td>
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<tr>
<td>Scenario 2</td>
<td>1.37 bps/Hz</td>
<td>13.44 bps/Hz</td>
<td>7.22 bps/Hz</td>
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<tr>
<td>Impr/ment</td>
<td>-14.9%</td>
<td>44.4%</td>
<td>30.3%</td>
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Conclusions

• LoS-optimised arrays can be used to overcome the problem of excessive correlation in environments with strong LoS signal such a LoS hotspot scenario

• Capacity improvements of the order of 45.3% were observed in the deployment area

• Even though the array geometry influences the capacity very considerably, when designing practical systems the SNR needs also to be taken into account

• Future work needs to focus on the verification of the presented findings using MIMO measurements and in identifying potential implementation issues