Random Beamforming OFDMA for Future Generation Cellular Communication Systems

C. Han, A. Doufexi, S. Armour, J. McGeehan, Y. Sun
bernice.han@bristol.ac.uk
Outline

- Introduction
- PHY Models of Random and Layered Random Beamforming OFDMA Systems
- Numerical and Simulation Results
- Conclusions and Future Work
Multi-user Diversity

- Multi-user Diversity: In a multi-user environment, it is likely to be at least one mobile station whose channel is near its peak at one time/frequency provided different mobile stations have independent fading channels.

- Exploiting the multi-user diversity by prioritizing the mobile stations with best current channel conditions can improve the overall system performance.
Opportunistic Beamforming

- Traditional eigenbeamforming (SVD)
  - achieve optimal performance
  - full channel state information (CSI) is required
  - feedback grow as a product of \( N_t \) and \( N_r \)
- Opportunistic beamforming (OB)
  - a random beamforming pattern
  - exploit multi-user diversity in combination with transmit beamforming to attain the coherent beamforming capacity
  - Only requires the feedback of SNR.
Random Beamforming (RB) and Layered Random Beamforming (LRB)

- Random beamforming (RB)
  - a combination of the OB and SVD
  - achieve spatial multiplexing gain and spatial multi-user diversity gain
  - feedback ESNR based rate.
- Layered random beamforming (LRB)
  - allow different spatial layers of the MIMO channels to be allocated to different mobile stations to achieve a further layer spatial multi-user diversity gain
  - MMSE based receiver, feedback ESINR based rate
Traditional and Random Beamforming

\[ SVD(H) = U \times D \times V^H \]

U and V are unitary matrices, D is the singular value matrix

Traditional Eigenbeam-forming:
\[ Y = HX + N = UDV^H X + N \]
\[ X' = VX \]
\[ U^H Y = U^H UDV^H X' + U^H N = DX + U^H N \]

Random Beamforming:
\[ X' = V_R X \quad \text{Randomly Pre-coding Unitary Matrix} \quad V_R \]
Combine RB and LRB with OFDMA

- OFDMA system is one of the most promising PHY and multiple access candidates for future communication systems. (WiMAX standard (802.16), Long Term Evolution (LTE) of 3GPP).
- RB and LRB-OFDMA achieves a further spectral multi-user diversity gain compared to the case of a single-carrier system.
- In an OFDMA system, feedback from every sub-carrier can be reduced by calculating the average data rate across all subcarriers in each cluster (a group of sub-carriers adjacent in frequency) and sending it to the BS through the feedback channel.
- Greedy scheduling algorithm is employed to select the best MS:
  
  RB-OFDMA: \[ r^*_{k,c} = \max \{ r_{1,c}, r_{2,c}, \ldots, r_{k,c}, \ldots \} \]
  
  LRB-OFDMA: \[ r^q_{k,c} = \max \{ r^q_{1,c}, r^q_{2,c}, \ldots, r^q_{k,c}, \ldots \} \]
RB-OFDM/A and LRB-OFDM/A

Transmitter at Base Station

User 1
ESNR Based RB-OFDM/A

\[
Y_k^s = H_k^s V_r^s X_k^s + N_k^s \quad \text{and} \quad Y_k^s = U_k^s D_k^s (V_k^s)^H V_r^s X_k^s + N_k^s
\]

\[
(U_k^s)^H Y_k^s = (U_k^s)^H H_k^s V_r^s X_k^s + (U_k^s)^H N_k^s
\]

\[
R_{k,c} = \frac{1}{m-n} \sum_{s=n}^{m} \sum_{q} \log_2 \left( 1 + \text{ESNR}_{k,s}^q \right)
\]

ESNR considers the eigenvalues of the MIMO channels and the mismatch between the random precoding matrix and the unitary matrix of the actual MIMO channels.
ESINR Based RB-OFDMA and LRB-OFDMA

\[ G_k^r Y_k^s = G_k^s H_k^r V_s^V X_k^r + G_k^s N \]

\[ ESINR_k^q = \frac{\left| (A_k)_{qq} \right|^2 E_s}{\left| (A_k)_{qj,j=q} \right|^2 E_s + \left| G_k^q \right|^2 + \left| G_k^q \right|^2} N_k \]

\[ A_k = G_k H_k V_s^s \]

\[ G_k^s = (H_k^r V_s^s)^H (H_k^s V_s^s) + \text{SNR}^{-1} I \]

\[ R_{kc} = \frac{1}{m-n} \sum_{s=n}^{m} \sum_{q=1}^{N_s} \log_2 (1 + ESINR_{k,s}^q) \]

\[ R_{k_c}^q = \frac{1}{m-n} \sum_{s=n}^{m} \log_2 (1 + ESINR_{k,s}^q) \]

ESINR indicates the eigenvalues of the MIMO channels and the mismatch between the random precoding matrix and the unitary matrix of the actual MIMO channels and it also considers the self-interference caused by the other spatial layers.
### System Parameters

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Operating Frequency</td>
<td>5 GHz</td>
</tr>
<tr>
<td>Bandwidth</td>
<td>100 MHz</td>
</tr>
<tr>
<td>FFT Size</td>
<td>1024</td>
</tr>
<tr>
<td>Useful Sub-carriers</td>
<td>768</td>
</tr>
<tr>
<td>Guard Interval Length</td>
<td>176</td>
</tr>
<tr>
<td>Sub-carrier Spacing</td>
<td>97.656 KHz</td>
</tr>
<tr>
<td>Useful Symbol Duration</td>
<td>10.24 μs</td>
</tr>
<tr>
<td>Total Symbol Duration</td>
<td>12.00 μs</td>
</tr>
<tr>
<td>Inner Channel Coding</td>
<td>Punctured 1/2 rate convolutional code, constraint length 7, ${133,171}_{octal}$</td>
</tr>
<tr>
<td>PHY Mode</td>
<td>Modulation: 64QAM, Coding Rate 3/4</td>
</tr>
</tbody>
</table>

### Channel Model

<table>
<thead>
<tr>
<th>$\tau_{rms}$</th>
<th>$\tau_{max}$</th>
<th>$\tau_{rms}$</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
Numerical Analysis - ESNR vs. ESINR

Average Numerical Throughput Performance of ESNR and ESINR based RB-OFDM systems in channel E as the Number of MSs Changes at SNR = 0dB and 10dB

Compared to ESNR, ESINR metric takes self-interference minimization into account and shows better numerical data rate.
Numerical Analysis - ESINR RB vs. LRB

Average Numerical Throughput Performance of ESINR RB-OFDM, RB-OFDMA, LRB-OFDM, LRB-OFDMA systems in channel E as the Number of MSs Changes at SNR = 0dB and 10dB

- RB-OFDMA significantly outperforms RB-OFDM shows that the spectral multi-user diversity gain plays an important role.
- LRB shows an additional layer spatial multi-user diversity gain.
Simulation Performance - Various MIMO Schemes

BER of RB-OFDM/A, LRB-OFDM, LRB-OFDMA and SVD-OFDM in Channel E (12 MSs in the Environment)

- LRB-OFDMA performs best due to its ability to effectively exploit both spectral and layer multi-user diversity gain.
Simulation Performance - Larger Number of Mobile Stations in the Environment

More MSs --- Higher spatial multi-user diversity gain.

Provided a large number of MSs in the environment, the effect of precoding matrix mismatch becomes very low.
## Feedback Comparison

<table>
<thead>
<tr>
<th>MIMO $N = \min(N_T, N_R)$</th>
<th>System</th>
<th>No. of Subcarrier</th>
<th>Cluster Size</th>
<th>Feedback Order</th>
<th>MSs in the environment</th>
<th>Supported MSs Simultaneously</th>
<th>Feedback From Every MS $k$</th>
</tr>
</thead>
<tbody>
<tr>
<td>SM</td>
<td>OFDM</td>
<td>S</td>
<td>S</td>
<td>1</td>
<td>1</td>
<td>1</td>
<td>0</td>
</tr>
<tr>
<td>SVD</td>
<td>Single Carrier</td>
<td>1</td>
<td>1</td>
<td>1</td>
<td>K</td>
<td>1</td>
<td>$N_T N_R$</td>
</tr>
<tr>
<td>SVD</td>
<td>OFDM</td>
<td>S</td>
<td>S</td>
<td>1</td>
<td>K</td>
<td>1</td>
<td>$N_T N_R$</td>
</tr>
<tr>
<td>SVD</td>
<td>OFDMA</td>
<td>S</td>
<td>C</td>
<td>1</td>
<td>K</td>
<td>K</td>
<td>$N_T N_R$</td>
</tr>
<tr>
<td>RB</td>
<td>Single Carrier</td>
<td>1</td>
<td>1</td>
<td>1</td>
<td>K</td>
<td>1</td>
<td>1</td>
</tr>
<tr>
<td>RB</td>
<td>OFDM</td>
<td>S</td>
<td>S</td>
<td>1</td>
<td>K</td>
<td>1</td>
<td>1</td>
</tr>
<tr>
<td>RB</td>
<td>OFDMA</td>
<td>S</td>
<td>C</td>
<td>1</td>
<td>K</td>
<td>K</td>
<td>S</td>
</tr>
<tr>
<td>RB (RF)</td>
<td>OFDMA</td>
<td>S</td>
<td>C</td>
<td>1</td>
<td>K</td>
<td>K</td>
<td>$(S/C)$</td>
</tr>
<tr>
<td>LRB</td>
<td>Single Carrier</td>
<td>1</td>
<td>1</td>
<td>N</td>
<td>K</td>
<td>1</td>
<td>N</td>
</tr>
<tr>
<td>LRB</td>
<td>OFDM</td>
<td>S</td>
<td>S</td>
<td>N</td>
<td>K</td>
<td>1</td>
<td>N</td>
</tr>
<tr>
<td>LRB</td>
<td>OFDMA</td>
<td>S</td>
<td>C</td>
<td>N</td>
<td>K</td>
<td>K</td>
<td>$N_S$</td>
</tr>
<tr>
<td>LRB (RF)</td>
<td>OFDMA</td>
<td>S</td>
<td>C</td>
<td>N</td>
<td>K</td>
<td>K</td>
<td>$M(S/C)$</td>
</tr>
</tbody>
</table>
Conclusions and Future Work

- Layered random beamforming MIMO-OFDMA achieves:
  * spatial multiplexing gain
  * spatial multi-user diversity gain
  * layer spatial multi-user diversity gain
  * spectral multi-user diversity in frequency selective channels.

- LRB only require achievable data rate feedback based on ESINR from every spatial layer. Feedback can be generated on a cluster basis (a group of sub-carriers adjacent in frequency) to reduce feedback for an LRB-OFDMA system.

- Future work
  * fair scheduling algorithms
  * impact of feedback reduction on performance
  * simulation based on realistic outdoor channel
• Thank you for listening.
• Any questions, please?

The authors wish to acknowledge the financial support of Dorothy Hodgkin Postgraduate Awards (DHPA) and Toshiba Research Europe Limited (TREL) and to thank Dr. Magnus Sandell of TREL and Dr. Matthew Webb of University of Bristol for their technical input.