Decentralised High-Throughput Non-Orthogonal Interleaved Random Space-Time Coding for Multi-Source Cooperation

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Outline

- Introduction
- IR-STC aided MSC
- Benefits of IR-STC aided MSC
- Practical issues
- Discussion and Conclusion
MIMO systems → provide diversity/coding gain as well as multiplexing gain.

Hardware limitation → results insufficient colocated antenna spacing.

Virtual MIMO → allow the MIMO elements geographically separated.

Objective: → simultaneously achieve both a high multiplexing gain and a high diversity gain in a flexible decentralised manner for multisource cooperation.
Consider a cluster of \( K \) Active Sources (AS) out of \( N \) available Cooperating Sources (CS) transmitting information to the destination in the uplink in a half-duplex TDD manner.

Following assumptions are made:

- Every source and the destination employs a single antenna.
- No loss in the inter-source channel, perfect synchronisation.
- i.i.d Rayleigh fading of all channels evolved and full Channel State Information (CSI) at all CSs and destination when receiving.
Introduction - MSC v.s. SSC

<table>
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<tr>
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<th>SSC</th>
<th>MSC</th>
</tr>
</thead>
<tbody>
<tr>
<td>(SE, DP)</td>
<td>(1/2, N)</td>
<td>(N/N+1, N+1)</td>
</tr>
<tr>
<td>cost</td>
<td>-</td>
<td>complex receiver</td>
</tr>
</tbody>
</table>

It can be seen that MSC provides higher Slot Efficiency (SE), when $N \rightarrow \infty$, SE approaches unity.

Each CS simultaneously transmits multiple ASs’ information with the aid of their superposition, resulting in a high throughput.

Each AS is served simultaneously by multiple CSs and hence the entire set of ASs benefits from a high diversity gain.

$N = K = 3$ ASs, where $S$ denotes source and $R$ denotes relay and $D$ denotes destination.
Each AS employs two repetition codes $C_1$ of rate $r_1$ and $C_2$ of rate $r_2$, which are separated by a AS-specific interleaver $\pi_k$. Each CS employs a CS-specific interleaver set $\{\pi_n,k\}_{k=1}^K$. 
IR-STC aided MSC - Strategy

- Each of the $K$ BPSK modulated AS employs two repetition codes $C_1$ of rate $r_1$ and $C_2$ of rate $r_2$, which are separated by a AS-specific interleaver $\pi_k$

$$x_k^{(1)} = \pi_k[C(b_k)], k \in [1, K].$$

- Then each of the $N$ CSs detects all the $K$ ASs' bit-streams, resulting in $\hat{x}_k^{(1)}, k \in [1, K]$. When considering the $n$th of $N$ CSs, the joint IR-STC codeword is constructed as follows:

  - The $n$th CS forms $K$ parallel streams

$$c_{n,k}(i) = \hat{x}_k^{(1)}[N(i - 1) + n], i \in [1, M/N], k \in [1, K],$$

where $M$ is the length of bit-stream $\hat{x}_k^{(1)}$.

  - These $K$ streams are interleaved by $K$ distinct interleavers of the CS-specific interleaver set $\{\pi_{n,k}\}_{k=1}^{K}$ and are then Parallel-to-Serial (P/S) converted into $c_n$.

- Then the signal transmitted from the $n$th CS is

$$x_n^{(2)}(i) = \sum_{l=1}^{L_n} \rho_{n,l} e^{j\theta_{n,l}} c_n[L_n(i - 1) + l], i \in [1, MK/N L_n].$$

  - $L_n$ is referred to as the number of layers contributed by the $n$th CS
  - $\rho_{n,l}$ and $\theta_{n,l}$ denotes the layer-specific power and phase allocation
  - we assume $L_n = L$ and $\rho_{n,l} = \rho_l, \theta_{n,l} = \theta_l, n \in [1, N]$. 
Setting 1 is a high-throughput multiplexing-oriented configuration, while Setting 2 is a low-throughput diversity-oriented configuration.
Effective Throughput

- Aiming at demonstrating the performance gain of IR-STC aided MSC compared to that of OSTBC aided MSC, we define the effective throughput as $\eta$ excluding the overhead imposed by the Phase-I cooperation.

The effective throughput of OSTBC is

$$\eta_{OSTBC} = \frac{r_{OSTBC} \times \mathcal{M}}{K}$$

(1)

$\mathcal{M}$ denotes number of bits/symbol transmitted by OSTBC using conventional modulation schemes.

The effective throughput of IR-STC is

$$\eta_{IR-STC} = \frac{r_{IR-STC} \times \mathcal{L}}{K}$$

(2)

$\mathcal{L}$ denotes number of layers superimposed and $r_{IR} = N \times R$, where $R = r_1 \times r_2$ is the channel coding-rate.
The maximum number of layers \( \mathcal{L} \) supported was \( \mathcal{L} = 7 \), which is equivalent to a \( G_4 \) OSTBC scheme using a large and hence error-sensitive 128-QAM constellation, while requiring a lower power than the 4 bit/symbol \( G_4 \) OSTBC aided 16-QAM scheme, as observed at \( BER \leq 10^{-5} \).
Consider non-uniform power allocation over $L$ layers obeys $\rho_{l+1}^2 = \rho_l^2 / \beta$
subject to $\sum_{l=1}^{L} \rho_l^2 = P_n$, where $\beta \geq 1$ is the scaling factor and
$P_n = P, \forall n$ is the maximum total power of the $n$th CS.

$\beta = 1.2$ was experimentally found to be adequate and the number of
layers was found to be as high as $L = 8$, corresponding to a 256-QAM
modulated 8 bits/symbol $G_4$ OSTBC scheme, while requiring a lower power
than the 6 bits/symbol $G_4$ OSTBC aided 64-QAM scheme.

Even higher throughput can be achieved by optimum power
allocation schemes.
<table>
<thead>
<tr>
<th>$\eta$</th>
<th>$G_4$ / IR-STC</th>
<th>$\Delta^b_1$</th>
<th>$\Delta^b_2$</th>
</tr>
</thead>
<tbody>
<tr>
<td>4/8</td>
<td>$M = 16 / L = 4$</td>
<td>6</td>
<td>-</td>
</tr>
<tr>
<td>5/8</td>
<td>$M = 32 / L = 5$</td>
<td>5</td>
<td>-</td>
</tr>
<tr>
<td>6/8</td>
<td>$M = 64 / L = 6$</td>
<td>4</td>
<td>9</td>
</tr>
<tr>
<td>7/8</td>
<td>$M = 128 / L = 7$</td>
<td>2</td>
<td>7</td>
</tr>
<tr>
<td>8/8</td>
<td>$M = 256 / L = 8$</td>
<td>-1</td>
<td>4</td>
</tr>
</tbody>
</table>

Table 2: The power gain $\Delta$ in dB of IR-STC compared to $G_4$ OSTBC in MSC, where $\Delta_1$, $\Delta_2$ denotes the power gain corresponding to 16-QAM and 64-QAM in $G_4$ OSTBC, respectively.
Benefit 3 - Flexibility

The design flexibility of IR-STC allows the employment of an arbitrary number of CSs without designing different matrices when the traditional OSTBC code was employed.

This flexibility is beneficial in terms of forming a flexible cluster of CSs, allowing CSs to freely join or disjoin the cluster of cooperation.
Comparison of AF, DF and DDF relaying techniques employed in the 4-layer IR-STC aided MSC scheme having $\Delta = \gamma_{s,s}/\gamma_{s,d} = 5$, when $h_{s,s}$ is subjected to Nakagami fading associated with $m = 1$ and $m = 2$.

The AF technique is only preferable at high SNRs when $m = 1$. DDF performs consistently worse than DF due to the doubled noise variance of non-coherent detection.

When the fading is benign, non-coherent DDF without the cost of estimating all inter-source channel knowledges outperforms the coherent detected AF technique.
Conclusion

The employment of multilayer IR-STC in MSC has several properties:

- **High-throughput** as a benefit of MSC with the aid of the multilayer mapping concept.
- **Low-error-rate** thanks to the powerful low-complexity iterative receiver employed.
- **Non-orthogonality** is capable of operating at the high spectral efficiency regime.
- **Flexibility** is beneficial in terms of allowing sources to freely join or disjoin the cluster of cooperation.
Conclusion

◆ These properties render our IR-STC design eminently:
  ■ applicable for dense *ad hoc* networks, where no fixed relay is deployed (infrastructure-free), such as tactical, police, rescue, emergency applications.
  ■ applicable for *cellular* networks, a cluster of mobile relays complement to the fixed wireless relay or a cluster of fixed relays in possible a hierarchical cellular structure.

◆ Compared to the traditional OSTBC based cooperative design, our proposed system is power-efficient and is capable of achieving a high throughput, especially in the case of non-uniform power allocation. Our scheme is flexible in terms of forming a cluster of cooperating sources.
Thank You

Questions?