On the Performance of Calibration Techniques for Cognitive Radio Systems

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Objective: Analyze algorithms, for reciprocity calibration in Cognitive Radio

1. Cognitive Radio (CR)
2. Interweave CR TDD transmission scenario
3. TDD reciprocity
4. Calibration
5. Simulations
6. Future works
The emergence of multiple wireless communication systems
Availability of radio resources
Increase the spectrum occupancy, interferences
Optimize the use of radio resources: Cognitive Radio
Cognitive Radio

- Optimal radio resource management, Primary (licensed) and secondary (unlicensed) share the same spectrum
- Interference avoidance: Secondary link should cause no interference

Spatial Interweave: transmit in the "spatial gaps"
MIMO TDD Frame specification

- Primary: Long Term Evolution Time Division Duplex (LTE-TDD) frame structure
- Secondary: Synchronization, TDD frame structure
- Channel reciprocity in TDD communication
Zero Forcing Beamforming (ZF-BF) \((N2 > N1, R_{s-p} = H_{12}F.T_s = 0)\)

- \(H_{12}\) is required at secondary in order to cause zero interference towards the primary and transmit \(N2 - N1\) streams
- * Impossibility to Feedback crosslink CSI (Tx/BF)
- Exploit the channel reciprocity (due to TDD)
Reciprocity is destroyed by: *channel estimation error, latency between channel estimate and signal transmission, RF front-ends, ...

\[ G_{dl} = R_B \cdot C \cdot T_A \]
\[ H_{ul} = R_A \cdot C^T \cdot T_B \]

Need to calibrate
How to calibrate?

- Absolute calibration
- Relative calibration
  - * Listen and estimate UL/DL channel, feedback the CSI
  - * Derive calibration parameters using **calibration algorithms**

**Compensate the RF impairments**

**Problem:**  
\[
\text{argmin}_{\{P_A, P_B, \|\tilde{G}\|^2, \|\tilde{H}\|^2\}} \left\| P_B^{-1}(G + \tilde{G}) - P_A(H + \tilde{H}) \right\|_F^2.
\]

\[
G_{dl} = P_B \cdot H_{ul}^T \cdot P_A
\]

\[
P_A = R_A^{-T} \cdot T_A, \quad P_B = R_B \cdot T_B^{-T}
\]
Algorithm 1: MxN-SISO

Each link \((i,j)\) is a single channel with one calibration factor \((i \in [1, M], j \in [1, N])\), \(G_{ij} = P_{Bi}H_{(j,i)}P_{Aj} = P_{Bi}P_{Aj}H_{(j,i)} = P_{ij}H_{(j,i)}\) (TLS: Total Least Square)

\[
\arg \min_P (||\tilde{H}||^2 + ||\tilde{G}||^2) \text{ s.t } (\hat{H} + \tilde{H})P = (\hat{G} + \tilde{G}).
\]

* \(K\) channel measurements to over-parametrize the TLS problem
Algorithm 2: Alternating TLS (Alt TLS MIMO)

* Suppose $P_A = I_N$ (or $P_B = I_M$) determine

$$P_B \text{ s.t } \arg \min_{P_B} \|P_B^{-1} G - H^T\|,$$ TLS, SVD solution

* Using $P_B$, find

$$P_A \text{ s.t } \arg \min_{P_A} \|P_B^{-1} G - H^T P_A\|$$

* Iterate until convergence
Algorithm 3: TLS MIMO problem

\[ P = \left[ \text{vec}\{P_A^{-1}\}^T \text{ vec}\{P_B^T\}^T \right]^T \]

\[ E_k = [\Omega \mid -\Theta], \Theta = \begin{bmatrix} I_N \otimes h_1^T \\ \vdots \\ I_N \otimes h_M^T \end{bmatrix}, \Omega = I_M \otimes G, \text{ and} \]

\[ E = [E_1^T, \ldots, E_K^T]^T \in \mathbb{C}^{(KM\cdot N) \times (M^2+N^2)} \]

* Recast such a TLS problem defined by:

\[ \min_{\tilde{E}} \|\tilde{E}\|_F \text{ s.t. } (E + \tilde{E})P = 0_{K\cdot MN \times 1} \]
Channel $M \times N = 2 \times 2$-MIMO

Simulation in MIMO OFDM environment

Two main cases simulated:
* Channel matrix generated according to a Normal distribution
* Real channel matrix estimated using EMOS (Eurecom MIMO OpenAir Sounder) in OpenAirInterface project

$P_A, P_B$: Diagonal (*negligible cross-talk between RF Tx, Rx circuit*) and Non-Diagonal assumption

Given $K_{\text{max}}$ channel estimates, use $K$ estimates to derive $P$
Reconstruction of the $G_{dl}$ with: $K_{max} = 40$, $K = 3$, $K = 10$

Comparison with a Maximum Likelihood Estimator (MLE) of $G_{dl}$

Diagonal parameters

Non diagonal parameters
$K = 10$

- The $M \times N$-SISO collapses

- Around [10 15] channel estimates are required to determine $P$
Complexity and execution time
Real channel measurement from EMOS

- Real channel result
- Further investigations
Conclusions

- $K=[10\ 15]$ channel measurements allow to determine calibration parameters.
- The TLS MIMO successfully performs full calibration, whereas the less complex $M \times N$ SISO fails to mitigate antenna coupling effect.
- Calibration: real opportunity to improve the channel estimation techniques and feedback overhead in MIMO systems.

Prospects

- Implementation of algorithms on EURECOM’s OpenAirInterface real-time platform (on going).
- Study and solve the other reciprocity disturbance sources.