MIMO Telecommunications with Near Ultrasounds

Arthur Aubertin1,2,3, Julien de Rosny1, Pierre Jouvelot2

(1) Stimshop, 14-16 rue Soleillet, 75020 Paris, France (e-mail: arthur@stimshop.com)
(2) MINES ParisTech, Université PSL, Paris, France
(3) ESPCI Paris, Université PSL, Institut Langevin Ondes et Images, Paris, France

Abstract

Ultrasound telecommunications are a relevant alternative when radio frequencies are not allowed or appropriate. Performance of a near-ultrasound (15 - 20 kHz) telecommunication system with linear-frequency-modulated symbols (LFM), or chirps, is studied:
- formal study of BER (Bit Error Rate) with varying chirp-symbol time and chirp-overlap ratio;
- comparison with numerical simulations.

We designed an 8-element linear network to achieve MIMO telecommunications, using Beam Forming (BF) and Time Reversal (TR) for focalization:
- assessment of the propagation channel (impulse response IR) of the environment;
- comparison of BF and TR, at a constant emission power, in several LOS (Line Of Sight) and NLOS (Non Line Of Sight) configurations.

Chirp and overlap

Chirp:
- Linear, from f1 to f2
- Narrow band
- Tuckey windowing
- or – frequency slope, for bit encoding

Optimal overlap:
Successive chirps overlap without SNR degradation (constant signal amplitude at emission)

Simulation results:
- LFM optimal overlap on 10811 sequence = 24 %
- Related rate gain = 19.2 %

BER model

Analytical model:

\[ BER = \frac{1}{2} \text{erfc} \left( \frac{R_n - R_{cc}}{2\sqrt{0.5}} \right) \]

\[ p_n: \text{spectral power density of noise} \]
\[ R_{cc}: \text{chirp auto-correlation} \]

Approximation (constant noise in B):

\[ BER = \frac{1}{2} \text{erfc} \left( \frac{1}{2} \left( \frac{(N\lambda)^2}{2p_nB} \right) \right) \]

B: bandwidth
f: symbol time
A: symbol amplitude
N: number of focalized sources

Results:
- Good fit between analytical model and simulation (Fig. 1 and 2)
- SEO-to-MIMO gain ~15 dB for N = 8 (Fig. 3)

Conclusion

MIMO setup:
- Element = speaker + mic
- 8-element base station
- Two 1-element receptors
- 1 mic for control on a linear rail

Beam Forming and Time Reversal

Hardware and software setup:
- Custom-made phantom mic power
- Custom-made amp
- Ø 0.4 electret mic and Ø 3.3, 10W tweeter
- Processing in Python

Calibration using known chirp x(t):

\[ y_n(t) = h_{pq}(t)\delta(t) \]  

\[ \delta(t) \text{ is Kronecker delta} \]

\[ y_n(t) = \phi_n(t) \]  

\[ \phi_n(t) = \phi_n(f_2) \]  

Focalized signals \( z^F_n(t) \) for user signal \( s(t) \):

\[ z^F_n(t) = FT^{-1}[\text{DTFT}(s(t))] \]

\[ \text{DTFT}(s(t)) = \sum_{k=0}^{N-1} s(k) e^{-j2\pi kf} \]

\[ s^F_n(t) = y_n(t) \delta(t) \]  

\[ y_n(t) = \delta(t) \]  

Measured acoustic field levels (Fig. 4)

Time Reversal:
- Focalized signals \( z^F_n(t) \) for user signal \( s(t) \):

Telecommunication results:
- LOS
- Small distances (l, d)
- S-symbols signals
- Long symbol as prefix for synchronization
- BF and TR BER = 0 %

Future work:
- Various configurations of 2-axes distance between receptors
- Measurements in various room configurations
- Adaptive f2 to avoid antenna-lobes overlap
- Passive focalization: focalization from a network of receptors

Fig. 1: Numerical integration of BER

Fig. 2: Simulation of BER (9th iteration)

Fig. 3: BER approximation for 8 sources

Fig. 4: Acoustic levels for Beam Forming

Fig. 5: Acoustic levels for Time Reversal

BER model:
- Accurate BER model approximation

Comparison of focalization methods:
- Time Reversal better fitted (includes the environment IR)