Field Trial of A Space-Time Equalizer

Takeshi Toda
YRP Mobile Telecomms Key Tech. Labs

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• Space-Time (ST) equalizer
• Measured results
• ST equalizer w/ delayed diversity transmission (DDT)
• Measured results
• Conclusions
• Future works
Intersymbol Interference (ISI)

Combating ISI is critical in wideband radio communications

ISI spans several symbol periods

A Space-Time Equalizer

Array processor (spatial filter) → Equalizer (temporal filter)

- First-arrival path (desired)
- Short-delay path (desired)
- Long-delayed paths (not desired)

<table>
<thead>
<tr>
<th></th>
<th>Array</th>
<th>Equalizer</th>
<th>Array + Equalizer (ST equalizer)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Maximum delay-time</td>
<td>〇</td>
<td>〇</td>
<td>〇</td>
</tr>
<tr>
<td>Path diversity</td>
<td>〇</td>
<td>〇</td>
<td>〇</td>
</tr>
</tbody>
</table>
Training sequence: \( d(k) \)

Sample-matrix-inversion (SMI) algorithm

\[ \sum \]

\[ w_1^0(k), w_2^0(k), w_3^0(k), w_4^0(k) \]

Array

- MMSE-optimization:
  \[
  \min_w \left\{ E \left[ w^T x(k) - d(k) \right]^2 \right\}
  \]

CIR vector with first-arrival-path timing: \( r_{xd} \)

First arrival path (desired)

1\( T_s \)-delayed path

2\( T_s \)-delayed path (Undesired)

Suppressed First arrival path

Extracted
Training sequence: $d(k)$

Adaptive weights controller

Constraint-SMI algorithm

ST-processor for 1$T_s$-delayed path constraint

ST-processor for first arrival path constraint

Branch metric combining MLSE (BMC-MLSE)

First arrival

1$T_s$ delayed
(Desired)

2$T_s$-delayed

3$T_s$-delayed
(Undesired)

Signal candidate: $s_m(k)$

CIR vector with first-arrival-path timing: $r_{xd}$

Branch-metric-combining coefficient

MMSE-optimization

with constraint:

$$\min_{W_i} \left[ P_{out} = W_i^H R_{uu} W_i \right]$$

Subject to

$$C_i^T W_i = 1$$

$$C_i = \left[ \left( \hat{r}_i^T \right), 0, 0 \right]^T$$

Space-Time Equalizer
Photograph of Testbed

Transmitter  Fading simulator  Receiver
# Field Trial Specifications

<table>
<thead>
<tr>
<th>Feature</th>
<th>Specification</th>
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</thead>
<tbody>
<tr>
<td>Radio frequency</td>
<td>3.35 GHz</td>
</tr>
<tr>
<td>Modulation</td>
<td>QPSK</td>
</tr>
<tr>
<td>Transmission rate</td>
<td>4.096 Mb/s</td>
</tr>
<tr>
<td>Frame format</td>
<td>TDM</td>
</tr>
<tr>
<td>Pulse shaping</td>
<td>Root rolloff filter ($\alpha=0.5$)</td>
</tr>
<tr>
<td>Training/data length</td>
<td>48/208 symbols</td>
</tr>
<tr>
<td></td>
<td>(32 symbols for training)</td>
</tr>
<tr>
<td>Tx. antenna</td>
<td>Omni-directional</td>
</tr>
<tr>
<td>Rx. Antenna array</td>
<td>Four-element circular</td>
</tr>
<tr>
<td></td>
<td>(0.5, 8 $\lambda$ element-spacing)</td>
</tr>
</tbody>
</table>
Experimental System

Baseband data generator

Mod.

RF amp.

D-GPS + Autonomous navigation sensor

FM GPS

10 Hz

Autonomous navigation sensor

Log-amp unit

Amplitudes

Array processor

Viterbi equalizer

Delay profile measuring

Data logger w/ DSP

10 base-T

Bit error detector

1 Hz

Bit error detector

TTL

Base station
Array Antenna for Base Station

8λ element-spacing array antenna
Mobile Station (Transmitter)
Antenna for Mobile Station

Tx antenna
Field Test Environment

Tx. mobile (Ave. 20km/h)

Rx. antenna array (h = 32 m)

NLOS -A

NLOS -B
Course driven by mobile station

Array Antenna on Top of Building

Radio propagation (?)

0.5λ element spacing array antenna
Delay Spread • Bit Error /Burst (Tx = 0.125 w)

- Delay spread
- Bit error for the array
- Bit error for the ST equalizer

Times:
- NLOS -A
- NLOS -B
Delay Profile

NLOS -A

NLOS -B
BER Performances (Array v.s. ST equalizer)

![Graph showing BER performances for NLOS -A and NLOS -B](image)

**NLOS -A**

- **Array processor**
- **ST equalizer**

**NLOS -B**

- **Array processor**
- **ST equalizer**

- **Symbols**:
  - : BER/burst
  - □, □ : BER averaged by 0.5 dB step

**Axis Labels**:
- **Y-axis**: Average bit error rate
- **X-axis**: Average $E_b/N_0$

**Legend**:
- **Blue** (Array processor)
- **Red** (ST equalizer)
Widely spaced Antenna Array for Receiver

0.5\(\lambda\) element spacing

8\(\lambda\) element spacing
BER Performances for Element Spaceing (0.5\(\lambda\) v.s. 8\(\lambda\))

![Graph showing BER performances for different element spacings](image)

- **Array**
- **Array + MLSE**

Average BER vs. Average \(E_b/N_0\) (dB)
Delayed Diversity Transmission (DDT)

Training sequence: \(d(k)\)

Adaptive weights controller

\[ w_1(k) + w_2(k) + w_{30}(k) + w_{40}(k) \]

Constraint-SMI algorithm

\[ g_1(k) g_2(k) \]

ST-processor for 1Ts-delayed path constraint

\[ y(k) + e^T(k) \]

Branch metric combining MLSE (BMC-MLSE)

\[ b_m(k) \]

MLSE (Viterbi algorithm)

Signal candidate: \(s_m(k)\)

CIR vector with first-arrival-path timing: \(r_{xd}\)

First arrival 1Ts delayed (Desired)

2Ts-delayed

3Ts-delayed (Undesired)

Baseband

Data gen. Delay Mod. Mod. RF amp. RF amp.
Mobile Station with tow antennas for DDT

Antenna #1  Antenna #2
Delay Profile with DDT in LOS

Delay = 0.5 Ts

Without DDT

With DDT
Delay Profile with DDT in NLOS

Delay = 0.5 Ts

Without DDT

With DDT
BER Performances with DDT

Average BER

Average $E_b/N_0$ (dB)

w/ DDT

w/o DDT

array

ST equalizer

w/ DDT

w/o DDT
Conclusions

ST equalizer: better than 10 dB of $E_b/N_0$ improvement at BER = $10^{-3}$ as compared with the array, for a channel with an delay spread of less than 1 msec.

ST equalizer with DDT: Effective in an environment with a small delay spread.

Future works (joint works with Takada lab. and Araki lab.)
Future Works (1/3)

Measurement of ST propagation characteristic

Behavior of MMSE-array processing?
Behavior of Viterbi equalizing?
→ ST diversity mechanism?
under various ST propagation characteristics

→ Computer simulation with the measured ST prop. characteristic
→ Computer simulation with ray tracing
Future Works (2/3)

Optimization of parameter of ST equalizer according to the measured ST propagation characteristic

The measured ST propagation characteristics

- Number of antenna elements?
- Element spacing?
- Number of taps?
- Array processing algorithms?
- MLSE, DFE, LE?

→ Computer simulation
→ Implementation and field test
Future Works (3/3)

MIMO space-time (ST) processing

→ Computer simulation
→ Implementation and field test