Passive Radar on fixed and mobile platforms exploiting digital Broadcast signals

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Outline of the presentation

- Digital broadcast signals
- DVB-T passive radar model
- DVB-T passive radar processing
- FHR PCL systems
- PCL measurement results
- A multi-band PCL concept
- Conclusions
Digital Broadcast Signals (DVB-T, DAB)

- Channel coding by OFDM-technique (Orthogonal Frequency Division Multiplex)
- Spectrum resembles white Gaussian noise within channel band-width.
- Transmission of 'long' symbols, separated by guard intervals, to avoid multi-path losses.
- Single or multiple frequency network
- Synchronized to GPS-clock
DAB Digital audio broadcast

- Modulation QPSK
- Single frequency network
- Synchronization by Null-Symbol and reference symbol
- 4 DAB-channels of 1.5 MHz bandwidth, each, with notches of 0.2 MHz fit into one analogue TV channel of 8 MHz.
- 72 symbols build 1 frame
- In each channel 2.4 Mbit/s is broadcasted with 1536 carrier frequencies.
Digital radio  DAB (VHF and L-band)

DAB Reference modell with closed hexagon (VHF)  
(directed antennas)

DAB Reference modell with open hexagon (L-band)  
(omni-antennas)

Peripheric transmitters: 1kW
DVB-T Digital television

- modulation QPSK, 16-QAM, 64-QAM.
- 2048, 4096, or 8192 carriers (2k, 4k, 8k mode, respectively)
- 68 blocks form a frame, 4 frames = superframe
- Single frequency network
- Synchronization by specific pilot carriers in sub-frame (4 blocks)
- Tx power ca. 10 dB higher than for DAB (in Europe)
- Band-width ca. 7.6 MHz (high range resolution)
Measured Constellation map of 16QAM DVB-T signal
DVB-T Passive radar model

\[ r(t) = s(t) \ast \sum_{i=1}^{I} a_i \cdot \delta(t - t_i) + \sum_{k=1}^{K} \sum_{l=1}^{L} b_{k,l} \cdot s(t - t_{k,l}) \cdot e^{j2\pi f_D t} + n(t) \]

- \( r(t) \): received signal
- \( s(t) \): the DVB-signal during one symbol
- \( i \): number of transmitters,
- \( k \): number of targets
- \( l \): number of transmitters contributing to a target echo.
- \( a_i \) and \( b_{k,l} \): complex factors representing the propagation channel influences depend on the location of the transmitters and targets with respect to the receiver.
- \( t_i \) and \( t_{k,l} \): time delay of the transmitter signals and the target echo signals
- \( e^{j2\pi f_D t} \): Doppler shift of the target.
DVB-T processing model

- Comparing the received signal with the expected signal by exploiting the reference information (pilots)
- Compensating for the transfer function of the propagation channel
- Reconstruction of the transmitted signal from the direct signal
- Correlating the received signal with the reconstructed clean direct signal (symbol wise)
- Integrating multiple cross-correlation (e.g. FFT)
- Applying CFAR detection and detection clustering
- Tracking in the bistatic range – Doppler domain (R/D)
- Using target bearing information to shift R/D-tracks to the cartesian domain.
- Apply cartesian tracking
Basic PCL Signal Processing with digital transmissions of opportunities

- **Synchronization**
- **Decode of the transmitted signal**
- **Reconstruct the original transmitted signal**
- **Cleaned surveillance signal is cross-correlated in RD domain.**
- **One range-Doppler map per Coherent Integration Interval (CPI)**
- **Target Detection**
- **Detections from multiple CPIS produce tracks**
PCL System ATLANTIS (I)

- PCL System for DAB/DVB-T
- 11 RX channels (external calibration)
- 1 Reference channel
- 32 MHz digitized
  - (only 8 MHz processed at a time)
PCL System ATLANTIS (II)

- Multi-channel RF frontend
- Low Phase Noise multi-channel RF synthesizer
- GPSDO as frequency reference and for positioning
- 16-bit data acquisition units
- High-performance computer cluster for data processing and raw data storage
- Instrument Control Center software for remote control of all attached components
- Flexible and high performance signal processing software
LORA11: Uniform Linear Array

- Uniform Linear Array
- From 450 MHz up to 900 MHz
- 11 Discone elements (V-pol)
- Reference antenna on the back
- Adjustable element spacing
- 90° Field of View (Azimuth)
- Calibration via external antenna

- Hydraulic mast
  - up to 15 meters height
  - > 360° mechanical rotation
  - transportable
CORA11: Circular Array

- Circular Array
- From 450 MHz up to 900 MHz
- 11 Discone elements (V-pol)
- Calibration antenna in the middle
- Adjustable element spacing
- 360° Field of View (Azimuth)

- Hydraulic mast
  - up to 15 meters height
  - > 360° mechanical rotation
  - transportable

circular array enables azimuth and elevation DOA estimation
Measurement scenario with fixed and mobile PCL platforms
Targets

*Ultralight aircraft Delphin of Fraunhofer FHR*

*2 speed boats of WTD71*
Resolution of two manoeuvring speed boats
Resolution of two manoeuvring speed boats

Cell resolution:
- Range = 32m
- Doppler = 2Hz

Legend:
- Track history
- Current tracked point

Time
videos of measurement
Atlantis on work boat

3 channels:
Reference channel
horizontal channel
vertical channel
DVB-T SAR experimental setup

- Site: Eckernförde harbour, Germany, conducted by FHR
- DVB-T station: “Kiel”, 22km away from receiver
- Receiver: On moving (5m/s) boat- single channel receiver, capturing direct signal+echoes
Image detail 1: coastline

- Obtained results with 20s of acquisition
- Back-projection only, no MoComp- full decoding of DVB-T data\(^1\) prior to image formation
- Tx 22km away- \(~0.5\)deg grazing,
- Rx on sea surface- \(~0.5\) deg grazing
- But image not limited to front face of buildings on shore

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Image detail 2: wind turbine

- Obtained results with 80s of acquisition
- Target area of interest: a wind turbine around 7 km away from receiver

in cooperation with University of Birmingham
Exploiting Reciprocal Filter and DPCA approach for Clutter Removal and Target Detection

Active and passive radar:
- Clutter Doppler spread (due to moving moving receiver) covers target echoes

Passive radar:
- Exploitation of communication signals not created for radar purposes
- Common processing with matched filter does not remove the waveform characteristics
Reciprocal filter versus matched filter

- Matched filter: \[ Y_M(f) = S_r(f)H_M(f) = S_r(f)S_t(f)^* \]
- Reciprocal filter: \[ H_R(f) = S_t(f)^{-1} \]
  \[ Y_I(f) = S_r(f)H_R(f) = S_r(f)S_t(f)^{-1} \]

Time-invariant pulse!

One DVB-T symbol after reciprocal filtering

Ambiguities still present after matched filtering

Ambiguities removed with reciprocal filter
Application of DPCA

Basic principle:

Range-Doppler maps of leading- and trailing antennas

Clutter filtered range-Doppler map
Application of DPCA - Targets

Targets covered by clutter and ambiguities will be found by using reciprocal filtering!
Application on real measurements in cooperation with: Norwegian Defence Research Establishment (FFI)

- Oslofjord, Norway 2016
- DVB-T Transmitter:
  - $f_{Tx} = 650$ MHz

Receiver:
- Receiver system ``Parasol“ on boat.
- Two surveillance antennas.
- $v_{Rx} \approx 9$ m/s
Application on real measurements

Before DPCA

After DPCA

Matched filter

Reciprocal filter
Multi-band PCL concept

**DVB-T PCL Atlantis**
- CORA11 antenna
- PCL signal processing
- Target detection, localization and tracking

**DVB-S PCL SABBIA**
- Surv antenna cueing
- PCL signal processing
- ISAR signal processing

**Detection & Tracking Stage**

**Imaging Stage**
Atlantis signal processing

Atlantis multi-channel DVB-T antenna and receiver

- Decoding of received signal
- Reconstruction of the original transmitted signal
- Cross-correlation of received signal with clean replica in RD domain.
- Target detection
- Target tracking
- Cueing of DVB-S PCL component
SABBIA: signal processing

- surv antenna pointing via GPS/ADS-B
- "Range compression" via correlation surv/ref
- Generation of Range/Doppler Map
- CFAR detection in Range/Doppler
**SABBIA**

- DVB-S based passive radar
- Frequency range: 10.7 GHz – 12.75 GHz (DVB-S, DVB-S2, DVB-SH)
- Up to 130 MHz bandwidth
- 2 Rx channels (Surv + Ref)
- Automatic antenna alignment (GPS-/ Mode-S-/ AIS-Based)
Conclusions

- The basics of digital broadcast transmissions have been introduced and the processing steps, which are required in order to exploit such signals in passive radar have been highlighted.
- Stationary passive radar radar systems as well as passive radar systems on moving platforms (boats) have been presented.
- Measurement results obtained from fixed and moving platforms were shown.
- Signal processing for clutter removal and target detection has been proposed and evaluated.
- A concept for a multi-band passive radar system, which can be used on moving platforms has been introduced as a future perspective.