Frame Acquisition for Continuous and Discontinuous Transmission in the Forward Link of Ka-band Satellite Systems

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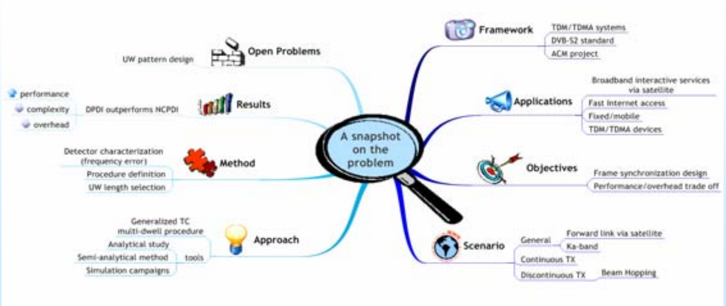
Abstract

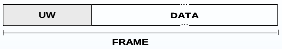
This paper presents a novel frame acquisition design procedure for the forward link of Ka-band satellite systems. *Multi- and single-dwell* procedures are considered for *continuous and discontinuous transmission*, respectively. To cope with *large frequency errors*, the detector employs *post detection integration* and is based on the threshold crossing (TC) criterion. In particular, non coherent and *differential post detection techniques* are considered. The design procedure applies to TDM/TDMA networks in general, and it is applied here to the forthcoming *DVB-S2* standard.

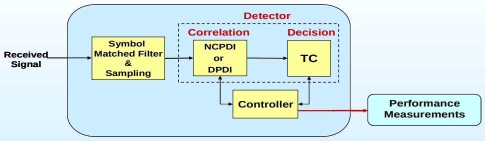
Introduction
a snapshot on the problem



The frame synchronization problem

- ❑ The **Unique Word** marks the start of the frame
  - ➢ performance/overhead trade-off

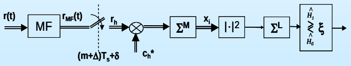




- ❑ Frame Synchronization → detection problem: UW presence/absence
  - ➢ correlation between the received signal and the known pattern
  - ➢ Threshold Crossing (**TC**) criterion
- ❑ Continuous TX → continuity allows for a verification phase
- ❑ Oversampling is required to cope with non-ideal sampling with discontinuous TX

Detectors

- ❑ Residual frequency error
  - ➢ TX-RX oscillators mismatch, terminal motion
  - ➢ Detection in phase and frequency uncertainty
  - ➢ Degradation of coherent correlation
  - ➢ Post detection integration
    - ✓ NCPDI
    - ✓ DPDI

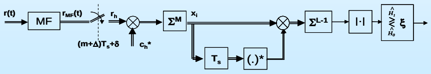


NCPDI

- ❑ NCPDI analytical performance
  - ➢ Impairments: ISI, SN, frequency error, SRRC filtering
  - ➢ AWGN channel

$$P_d = Q_L\left(\frac{\sqrt{d}}{\sigma_{x|H_1}}, \frac{\sqrt{\xi}}{\sigma_{x|H_1}}\right) \qquad P_{fa} = \exp\left\{-\xi/2\sigma^2_{x|H_0}\right\}\sum_{k=0}^{L-1}\frac{(\xi/2\sigma^2_{x|H_0})^k}{k!}$$

$\sigma^2_{x|H_1}$: AWGN+ISI $\qquad \sigma^2_{x|H0}$: AWGN+SN



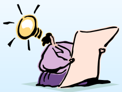
DPDI

The *CHILD* rule

- ❑ **CoHerent Integration Length Dimensioning**
- ❑ Optimization criterion
  - ➢ maximum SNR outside coherent correlation
- ❑ Effective rule

$$\cot(\pi M\Delta f\, T_s) = \frac{1}{2\pi M\Delta f\, T_s}$$

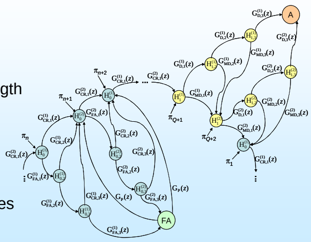
$$\Rightarrow \quad \boxed{M \cong \frac{3}{8}\frac{1}{\Delta f\, T_s}}$$



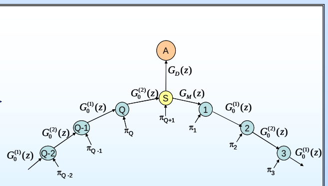
- 🙂 Useful upper bound for overall performance
- 🙂 Independent from the particular PDI scheme

Generalized TC procedure

- ❑ General multi-dwell procedure
  - ➢ *N* dwells
  - ➢ Study cases
    - ✓ **1TC**: discontinuous TX
    - ✓ **3TC**: continuous TX
- ❑ Uncertainty region: frame length
- ❑ Flow-graph approach
- ❑ Immediate rejection
- ❑ Non-absorbing false alarm
  - ➢ Penalty time: $T_p = 2\ T_F$
- ❑ Uniform a priori probabilities
- ❑ General number of hypotheses per symbol (*h*)



Equivalent flow-graph



- ❑ Equivalent collective synchronous state
- ❑ Mean acquisition time performance

3TC (*N*=3, *h*=1): $$\overline{T}_A = \frac{\overline{T}_D}{P_D} + \frac{\overline{T}_M}{P_D} + \frac{2-P_D}{2P_D}(N_c - 1)\overline{T}_R$$

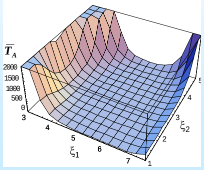
1TC (*N*=1, *h*=2): $$\overline{T}_A = \frac{1}{P_D}\left\{T_d\left[1+\frac{Q}{2}(2-P_D)\right] + T_p\frac{Q}{2}P_{fa}(2-P_D)\right\}$$

Thresholds optimization

Objective: **minimization of the mean acquisition time** at the lowest SNR (-2.3 dB)

- ❑ CFAR normalization
- ❑ **NCPDI**: fully analytical procedure
- ❑ **DPDI**: fitting procedure for single-cell performance (MMSE)
- ❑ Need to reduce false alarm events because of the large uncertainty region
  - ➢ search mode threshold larger than verification thresholds

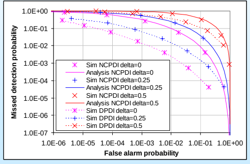
Example:
NCPDI, 3TC
L_F= 2’880’000, L_{UW}=96, M=6
Δf=5MHz, Baud rate=90 MBaud
Th2=Th3



Single cell performance

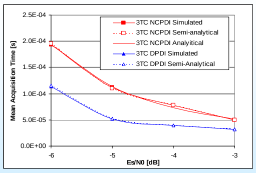
- ❑ Receiver Operating Characteristics
- ❑ NCPDI: analysis/simulation match
- ❑ DPDI: performance improvement (robust against large frequency offsets)
- ❑ Degradation with non-zero timing displacement

- ❑ Parameters:
  - L_{UW}=96
  - M=6
  - roll-off=0.3
  - Δf=5MHz
  - Baud-rate=90MBaud
  - E_s/N_0= -2.3 dB



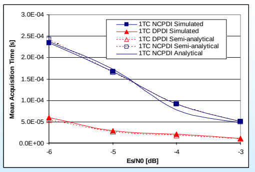
Simulation/semi-analytical/analytical cross-validation

- ❑ Threefold approach
  - ➢ Fully analytical
  - ➢ Semi-analytical
  - ➢ Simulated
- ❑ With large uncertainty regions, simulations of the entire procedure are very time-costly!
- ❑ Need to speed-up the evaluation:
  → semi-analytical approach
  - ➢ Accurate study of actual cases
  - ➢ Single-cell performance with impairments



- 3TC procedure -

- ❑ Cross-validation done with limited frame length: L_F=1000

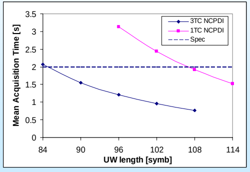


- 1TC procedure -

- ❑ Very good match is observed for both 3TC and 1TC

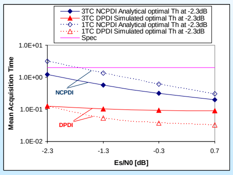
Conservative UW length selection

- ❑ NCPDI allows fully analytical design
- ❑ Conservative wrt DPDI
- ❑ Specification: 2s of mean acquisition time
- ❑ Tentatively UW length: 96 symbols
- ❑ Worst case SNR: -2.3dB
- ❑ 1TC requires at least L_{UW}=108
- ❑ 3TC in-spec from L_{UW}=84



1TC or 3TC?

- ❑ Dependence on the detector type
- ❑ L_{UW}=96 symbols
- ❑ NCPDI:
  - ➢ 1TC out-of-spec in [-2.3;-1.7]dB
  - ➢ 3TC outperforms 1TC
- ❑ DPDI: both in-spec
  - ➢ **1TC is better than 3TC**
    🙂 Complexity reduction
  - ➢ MODCOD detection after frame sync
  - ➢ Very low P_{fa} in search mode (in the order of 10^{-7}-10^{-8})



Conclusions

- ❑ Frame synchronization design for continuous and discontinuous TX
- ❑ Detector characterization
  - ➢ Impairments:
    - ✓ SN, frequency error, SRRC filtering, non-ideal sampling (ISI)
  - ➢ The *CHILD* rule
- ❑ General TC procedure model
  - ➢ Applicability to all DVB-S2 actual scenarios and beyond
  - ➢ Extendibility to mobile environments
- ❑ Analysis/simulation: very good match
  - ➢ Accurate parameter optimization
  - ➢ Semi-analytical approach allows fast performance evaluation
- ❑ DPDI outperforms NCPDI

🙂 Performance 🙂 Overhead 🙂 Complexity