Lock Detectors; Navigation Data Processing

GPS Signals And Receiver Technology MM14

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Today’s Subjects

• Lock detectors
• Bit, frame synchronization
• Navigation data decoding
  – Parity check
  – Finding TLM word (Sub-frame Synchronization)
  – Z-count (time determination)
• Forward Error Correction (FEC)
• Block interleaving
Lock Detectors
Lock Detector

• Lock detectors indicate:
  – Presence or absence of signal power (for example in case there was a false acquisition)
  – If the tracking loops have successfully converged – the tracking errors are minimized and the loops are in a stable state
  – Situations when receiver has lost lock on the signal (excess receiver motion, signal obstructions)

• A combination of different detectors enables to use several channel states (if needed) to adopt to different tracking situations or conditions
Receiver Channel States

• An example of basic receiver states and transitions between states

![Diagram showing states and transitions]

• Examples of additional states (or state flags): code lock, PLL lock, bit synchronization, frame synchronization, ephemerides received, high dynamics, data wipe-off, ...
Lock Detector Types

– PLL lock detector:
  \[\text{LPF}(I^2 - Q^2) > \text{threshold}\]

– Signal power detector (does not require PLL lock):
  \[\text{LPF}(I^2 + Q^2) > \text{threshold}\]

– Detection based on discriminator output variations – not always are reliable

– Bit error rate based detectors

– SNR based detector
Processing Of Navigation Bits
• Tracking loops produce one GPS navigation data bit value each ms
• Navigation bit length is 20ms (GPS) (if Doppler is 0)
• The value of each bit in the navigation message must be read, but where? If the show case here is easy, take a look at the next slide…

![Graph of Prompt I output (strong signal)](image-url)
Examples Of Raw Nav Data

An example of a strong signal. Bit transitions are clearly visible.

An example of a weak signal. Bit transitions are not so clear.
Bit Synchronization

• There are two main problems while reading data bit values:
  – The bit value is corrupted by noise
  – The bit boundaries must be found

• Bit value for can be found by taking a sum (no need for a mean) of several ”bit samples”, if bit boundaries a known
Bit Synchronization

• The bit synchronization task is to find the bit boundaries

• It can be implemented:
  – By correlation of known bit pattern with the incoming stream of bit values (convenient in post processing mode)
  – By chopping the input stream into 20ms long (20 cells) bins and evaluation of statistics where the bit values change sign
  – Maximum likelihood (ML) type estimation is based on calculating the average correlation result over one data bit interval
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Histogram Method

• An example of the histogram method
• There is an error in the code. Where?

transCount = zeros(1, 20);
index = 2;

for ms = 2 : someNumberOfMs
    if sign(I_P_stream(ms -1)) ~=
        sign(I_P_stream(ms))
        transCount(index) = transCount(index) + 1;
    end

    index = index + 1;
end

[junk, bitBoundaryPosition] = max(transCount);
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GPS Navigation Data
Navigation Data Contents

- **TLM**
  - Clock corrections and SV health/accuracy
  - Ephemeris parameters
  - Ephemeris parameters
  - Almanac, ionospheric model, dUTC
  - Almanac

**Time (minutes)**

- 0.5
- 1.0
- 12.0
- 12.5

**Subframes**

**Frames**

2009 Danish GPS Center
First Words Of a Subframe

TLM Word

MSB
Preamble
1 0 0 0 1 0 1 1

Reserved

LSB
Parity

1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20 21 22 23 24 25 26 27 28 29 30

Hand Over Word (HOW)

MSB
TOW-Count Message (Truncated)

LSB
Sub-Frame ID

Parity

1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20 21 22 23 24 25 26 27 28 29 30
Navigation Data Decoding

- Locating the preamble [1 0 0 0 1 0 1 1]
- Representing the data sequence with [-1;1]
- Calculate correlation with preamble [1 -1 -1 -1 1 -1 1 1]
- Search for peaks of [-8;8]
An Example Of A Sub-frame

SUBFRAME NO. | PAGE NO. | TLM 22 BITS | HOW 22 BITS | C1c 16 BITS | 8 BITS | 24 BITS | C1s 16 BITS | 8 BITS | P
--- | --- | --- | --- | --- | --- | --- | --- | --- | ---
3 | N/A | 31 | 61 | 77 | 91 | 121 | 137 | P

DIRECTION OF DATA FLOW FROM SV 150 BITS 3 SECONDS MSB FIRST

WORD 1 | WORD 2 | WORD 3 | WORD 4 | WORD 5

\[ \Omega_0 - 32 \text{ BITS TOTAL} \]

\[ i_0 - 32 \text{ BITS TOTAL} \]

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SUBFRAME NO. | PAGE NO. | 24 BITS | \( C_{rc} \) 16 BITS | 8 BITS | 24 BITS | \( \Omega \) 24 BITS | IQDE 8 BITS | IDOT 14 BITS | t | P
--- | --- | --- | --- | --- | --- | --- | --- | --- | --- | ---
3 | N/A | 151 | 181 | 211 | 241 | 271 | 279 | P

DIRECTION OF DATA FLOW FROM SV 150 BITS 3 SECONDS MSB FIRST

WORD 6 | WORD 7 | WORD 8 | WORD 9 | WORD 10

\[ i_0 - 32 \text{ BITS TOTAL} \]

\[ \omega - 32 \text{ BITS TOTAL} \]
## Ephemerides

<table>
<thead>
<tr>
<th>Parameter</th>
<th>No. of bits</th>
<th>Scale Factor (LSB)</th>
<th>Units</th>
</tr>
</thead>
<tbody>
<tr>
<td>$IODE$</td>
<td>8</td>
<td>$2^{-5}$</td>
<td>meters</td>
</tr>
<tr>
<td>$C_{rs}$</td>
<td>16*</td>
<td>$2^{-43}$</td>
<td>semi-circles/sec</td>
</tr>
<tr>
<td>$\Delta n$</td>
<td>16*</td>
<td>$2^{-31}$</td>
<td>semi-circles</td>
</tr>
<tr>
<td>$M_0$</td>
<td>32*</td>
<td>$2^{-29}$</td>
<td>radians</td>
</tr>
<tr>
<td>$C_{uc}$</td>
<td>16*</td>
<td>$2^{-32}$</td>
<td>dimensionless</td>
</tr>
<tr>
<td>$e$</td>
<td>32</td>
<td>$2^{-33}$</td>
<td>radians</td>
</tr>
<tr>
<td>$C_{us}$</td>
<td>16*</td>
<td>$2^{-29}$</td>
<td></td>
</tr>
<tr>
<td>$(A)^{1/2}$</td>
<td>32</td>
<td>$2^{-19}$</td>
<td>meters$^{1/2}$</td>
</tr>
<tr>
<td>$t_{oe}$</td>
<td>16</td>
<td>$2^4$</td>
<td>seconds</td>
</tr>
<tr>
<td>$C_{ic}$</td>
<td>16*</td>
<td>$2^{-29}$</td>
<td>radians</td>
</tr>
<tr>
<td>$(\text{OMEGA})_0$</td>
<td>32*</td>
<td>$2^{-31}$</td>
<td>semi-circles</td>
</tr>
<tr>
<td>$C_{is}$</td>
<td>16*</td>
<td>$2^{-29}$</td>
<td>radians</td>
</tr>
<tr>
<td>$i_0$</td>
<td>32*</td>
<td>$2^{-31}$</td>
<td>semi-circles</td>
</tr>
<tr>
<td>$C_{rc}$</td>
<td>16*</td>
<td>$2^{-5}$</td>
<td>meters</td>
</tr>
<tr>
<td>$\omega$</td>
<td>32*</td>
<td>$2^{-31}$</td>
<td>semi-circles</td>
</tr>
<tr>
<td>$\Omega DOT$</td>
<td>24*</td>
<td>$2^{-43}$</td>
<td>semi-circles/sec</td>
</tr>
<tr>
<td>$I DOT$</td>
<td>14*</td>
<td>$2^{-43}$</td>
<td>semi-circles/sec</td>
</tr>
</tbody>
</table>
Z-count / GPS Time

- GPS time begins midnight between January 5 and 6, 1980
- Z-count has 29 bits
- 19 LSBs are the TOW-count
- 10 MSBs are the GPS week number (modulo 1024)
- Transmitted Z-count is truncated to 17 LSB
Data For Pseudorange Measurements

• The pseudoranges measurement procedure must know when a GNSS signal was transmitted.
• Therefore navigation data processing must provide information at which ms/codePhase a subframe was detected and what is TOW of that subframe.

This slide contents is only available to the listeners of our courses.
Galileo vs. GPS Data

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Navigation Data Error Detection And Correction
Error Detection And Correction

• Three types of techniques that deal with bit errors in transmitted/received signals:
  – Error detection: CRC, parity check
  – Error detection an correction: parity check, FEC
  – Techniques to mitigate loss or corruption of a series of bits (burst errors): block interleaving
Parity Check Algorithm

\[ D_1 = d_1 \oplus D_{30} \]
\[ D_2 = d_2 \oplus D_{30} \]
\[ D_3 = d_3 \oplus D_{30} \]
\[ D_{24} = d_{24} \oplus D_{30} \]
\[ D_{25} = D_{29} \oplus d_1 \oplus d_2 \oplus d_3 \oplus d_5 \oplus d_6 \oplus d_{10} \oplus d_{11} \oplus d_{12} \oplus d_{13} \oplus d_{14} \oplus d_{17} \oplus d_{18} \oplus d_{20} \oplus d_{23} \]
\[ D_{26} = D_{30} \oplus d_2 \oplus d_3 \oplus d_4 \oplus d_6 \oplus d_7 \oplus d_{11} \oplus d_{12} \oplus d_{13} \oplus d_{14} \oplus d_{15} \oplus d_{18} \oplus d_{19} \oplus d_{21} \oplus d_{24} \]
\[ D_{27} = D_{29} \oplus d_1 \oplus d_3 \oplus d_4 \oplus d_5 \oplus d_7 \oplus d_8 \oplus d_{12} \oplus d_{13} \oplus d_{14} \oplus d_{15} \oplus d_{16} \oplus d_{19} \oplus d_{20} \oplus d_{22} \]
\[ D_{28} = D_{30} \oplus d_2 \oplus d_4 \oplus d_5 \oplus d_6 \oplus d_8 \oplus d_9 \oplus d_{13} \oplus d_{14} \oplus d_{15} \oplus d_{16} \oplus d_{17} \oplus d_{20} \oplus d_{21} \oplus d_{23} \]
\[ D_{29} = D_{30} \oplus d_1 \oplus d_3 \oplus d_5 \oplus d_6 \oplus d_7 \oplus d_{10} \oplus d_{11} \oplus d_{14} \oplus d_{15} \oplus d_{16} \oplus d_{17} \oplus d_{18} \oplus d_{21} \oplus d_{22} \oplus d_{24} \]
\[ D_{30} = D_{29} \oplus d_3 \oplus d_5 \oplus d_6 \oplus d_8 \oplus d_9 \oplus d_{10} \oplus d_{11} \oplus d_{13} \oplus d_{15} \oplus d_{19} \oplus d_{22} \oplus d_{23} \oplus d_{24} \]
Forward Error Correction (FEC)

Some Of Information Is Taken Form Lecture “Sipcom8-1 Information Theory And Coding“
Forward Error Correction

- FEC encodes each bit by a number of symbols (two symbols in Galileo and SBAS). The actual symbol values depend on past values of bits.
- FEC technique in telecommunication is called convolutional encoding/decoding.
- The FEC can be shown using a special state machine diagram - trellis diagram. The same diagram is used for encoding and decoding.
- The particular coder/decoder (state machine) is described by a generator polynomial (similar way like for the PRN generators).
FEC Notation – A General Trellis Diagram

- Solid lines are transition paths if incoming bit value is 0 (for encoder, for decoder it is the decoded bit)
- Dashed lines are transition paths if incoming bit is 1 (for encoder, for decoder it is the decoded bit)
- Numbers inside diagram show next transition path from current state given received set of symbols
Constrain length = 3
G1 = [101] → g(D) = 1 + D^2
G2 = [111] → g(D) = 1 + D + D^2
Forward Error Correction

• At the decoder, a path metric is computed for each transition path between states
• The algorithm then tries to find the way over all states with having the smallest possible path metric
• Bits are decoded according to the detected shortest path through the states

Refer to lecture “SIPCom8-1 Information Theory and Coding” for more details (lecture 5)
Constrain length = 7

\[ G1 = [1111001] \implies g(D) = 1 + D^1 + D^2 + D^3 + D^6 \]

\[ G2 = [1011011] \implies g(D) = 1 + D^2 + D^3 + D^5 + D^6 \]
Effect Of FEC On Structure Of Navigation Data

- This is an example of Galileo page (equivalent to GPS sub-frame) excluding synchronization word (GPS equivalent – the preamble)
- The page contains 6 zeros at the tail
- This allows the receiver to start reading navigation data at start of any page
- Later FEC decoder can continue reading frame by frame, without resets
Block Interleaving
Block Interleaving

• FEC is not able to restore corrupted bits if a too long continuous block of bits is corrupted (so called burst errors)
• Block interleaving task is to mix, scramble the bits of the navigation messages
• At the receiver side the bits are descrambled
• If a block of bits is corrupted of the transmitted signal, then after descrambling it will result in “random”, scattered bits that are corrupted and then the FEC is able to correct these bits
Block Interleaving

- Block interleaving can be implemented by use of a matrix
  - A matrix is filled column by column by a block of bits
  - Bits are then transmitted by reading the matrix row by row
- At the receiver side an opposite operation is performed
- Galileo E1 data page (“sub-frame”) consist of 240 symbols – the interleaving matrix size is 30x8
An Example of The Block Interleaving Steps

- Numbers denote steps through signal processing path
- Steps 2, 3 and 4 are done “at the same time”
An Example Of Interleaved Data Corruption

Deinterleaving

... , 0 1 0 1 1 1 0 1 1, 1 0 1 0 1 1 0 1 0, 0 0 0 1 1 0 1 1 0, 0 1 1 0 0 1 0 1 1, 1 0 1 1 0 0 1 0 1, ...

0 1 0 1 1 1 0 1 1
1 0 1 0 1 1 0 1 0
0 0 0 1 1 0 1 1 0
0 1 1 0 0 1 0 1 1
1 0 1 1 0 0 1 0 1

... , 0 1 0 1 1 1 0 1 1, 1 0 1 0 1 1 0 1 0, 0 0 0 1 1 0 1 1 0, 0 1 1 0 0 1 0 1 1, ...

... , 0 1 0 1, 1 0 1 0, 0 0 1 1, 1 1 0 1, 1 1 0 0, 1 0 1 0, 0 1 0 1, 1 0 1 1, ...
Questions and Exercises