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Group Repetition Interval Selection for eLoran

Jan Šafář[1], Paul Williams[2], Seung Gi Gug[3] , Sally Basker[2] and František Vejražka[1]

[1]Czech Technical University in Prague

[2]The General Lighthouse Authorities of the UK and Ireland

[3]Korea Maritime University

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Towards eLoran in Europe

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- Complement and backup to GPS
- Demanding system performance requirements
  - Accuracy of (8 – 20) m for harbour entrance and approach required by USCG
  - Availability, integrity and continuity requirements set down by FAA
- Substantial changes are needed on both the system and user equipment side
  - Mini-Loran stations deployed in critical areas
- When considering new stations we have to take into account
  - Stations location
  - Signal field strengths
  - HDOP with other stations
  - Group Repetition Intervals (GRI)
    - Continuous Wave Interference (CWI)
    - Cross-Rate Interference (CRI)

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Loran Signal Structure

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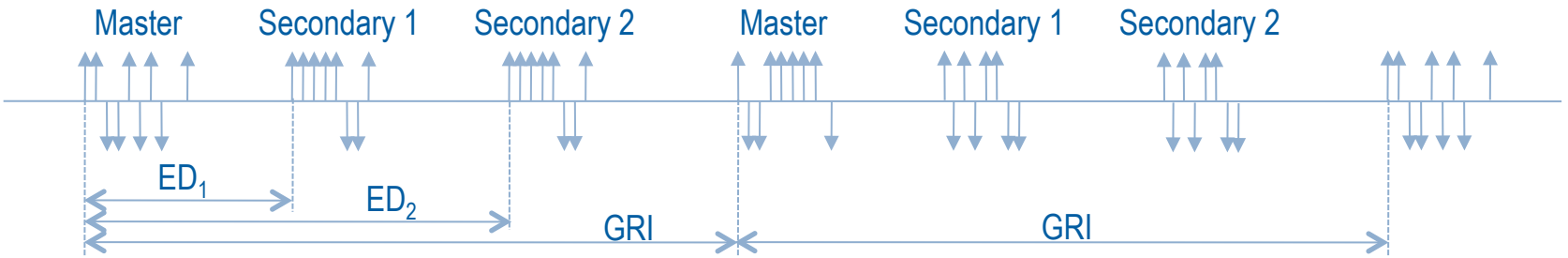

- Transmitters are usually grouped together in a chain of 3 to 6 stations
  - 1 Master station, several Secondary stations
- Groups of pulses with a carrier frequency of 100 kHz (same for all transmitters)
- Signals of different stations are distinguished in the time domain
  - Within a chain – Emission Delay (ED)
  - Between different chains – Group Repetition Interval (GRI)
- **GRI is the amount of time between successive transmissions of the groups of pulses of a single station** (commonly expressed as a 4 digit number in 10 of μ s, e.g. 7499 - Sylt)
- Phase coding
  - Reversing the carrier phase in a predetermined pattern which is repeated every **2 GRIs**
- Navigation solution is obtained from Time of Arrival (ToA) measurements of signals coming from at least 3 Loran stations

Factors Affecting GRI Selection

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- Continuous Wave Interference
  - Other transmitters close to the Loran frequency band
- Cross-Rate Interference
  - Transmitters of other Loran chains
- Other GRI Constraints
  - USCG Signal Specification
  - Transmitter Constraints
  - UTC Time of Coincidence
  - Loran Data Channel data rate (eLoran addition)

Factors Affecting GRI Selection

Continuous Wave Interference

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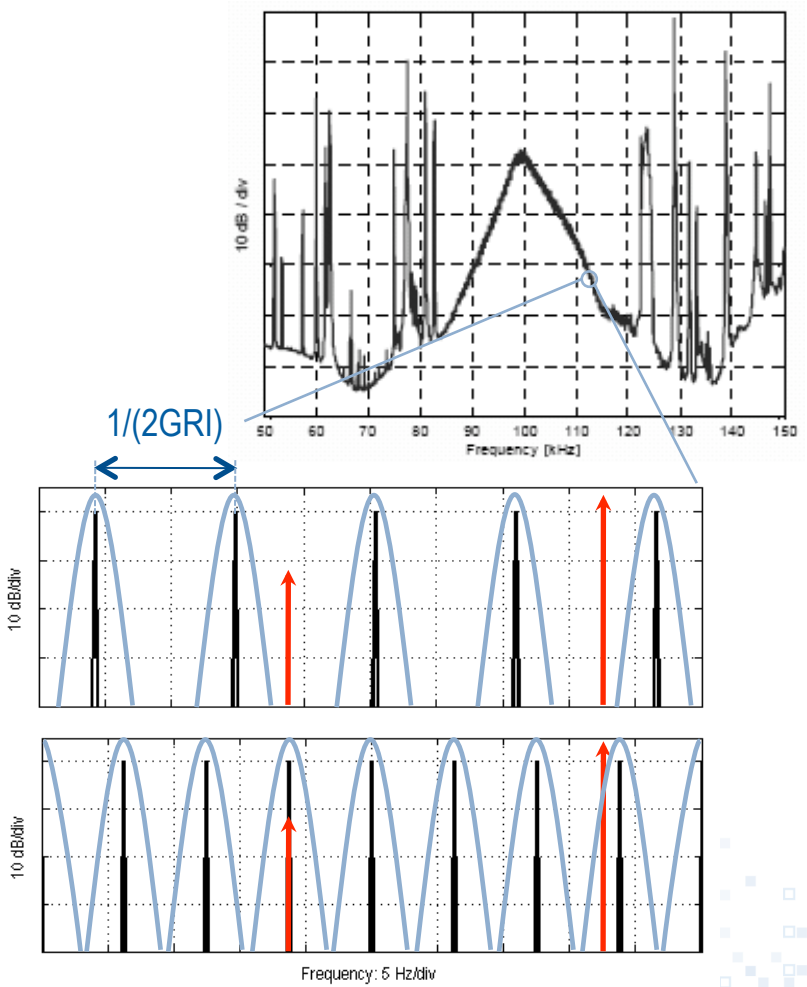
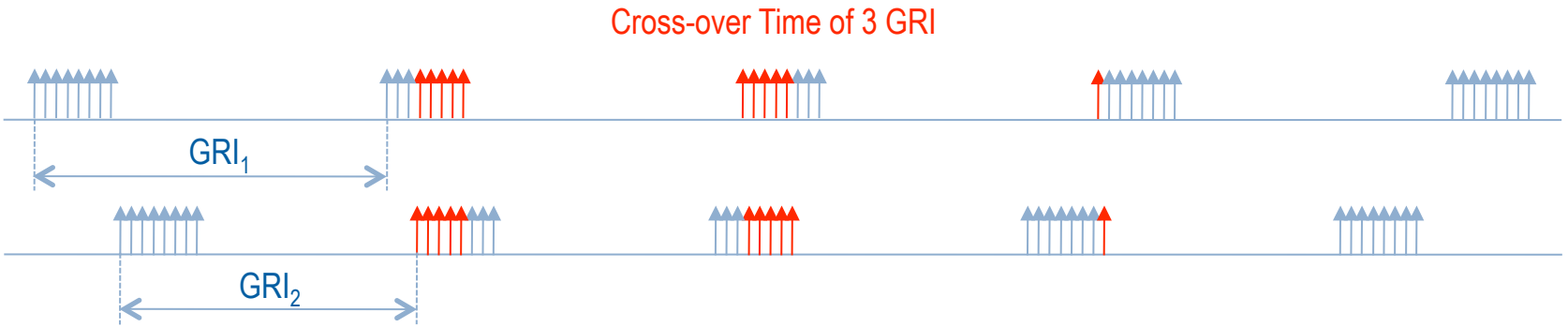
- In Europe - Hundreds of transmitters broadcast close to Loran frequency band
- Periodicity of Loran signal (2GRI)
  - Spectrum is discrete
  - Interval between 2 spectral lines: 1/(2GRI) Hz
- Continuous (Carrier) Wave Interference
- Modelling the effects of signal processing on CWI in Loran receiver
  - Receiver's sensitivity characteristic, GRI-dependent
  - (Near-)synchronous and asynchronous interference
- With a given set of potential interferers some GRIs are more susceptible to CWI than others



Factors Affecting GRI Selection

Cross-Rate Interference



- The biggest interferer to Loran is Loran itself
- All Loran transmitters use the same pulse shape broadcasted on the same carrier frequency
- Transmissions of different chains (different GRIs) overlap
  - The overlap can severely distort ToA measurements in the receiver
- We cannot prevent the signals from overlapping, but we can minimize the negative impact of this overlap by selecting GRIs according to:
  - Long Overlap Time
  - Short Cross-over Time
  - Other complicated timing effects depending on the GRIs

Other GRI Constraints

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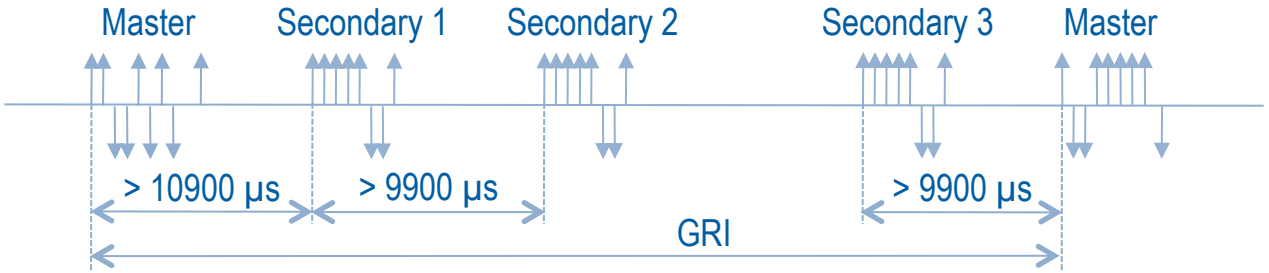

- USCG Signal Specification
  - GRI may range from 4000 to 9999
  - Constraints on spacing between transmissions within one chain
    - Have to be met anywhere within the coverage area
    - For a given configuration of Loran transmitters, this implies existence of some minimal permissible value of GRI
- Transmitter Constraints
  - Maximum number of pulses transmitted per second (NELS - 300 pulses/second)
- UTC Time of Coincidence
- Free Windows for Simulators

Building a List of Candidate GRIs

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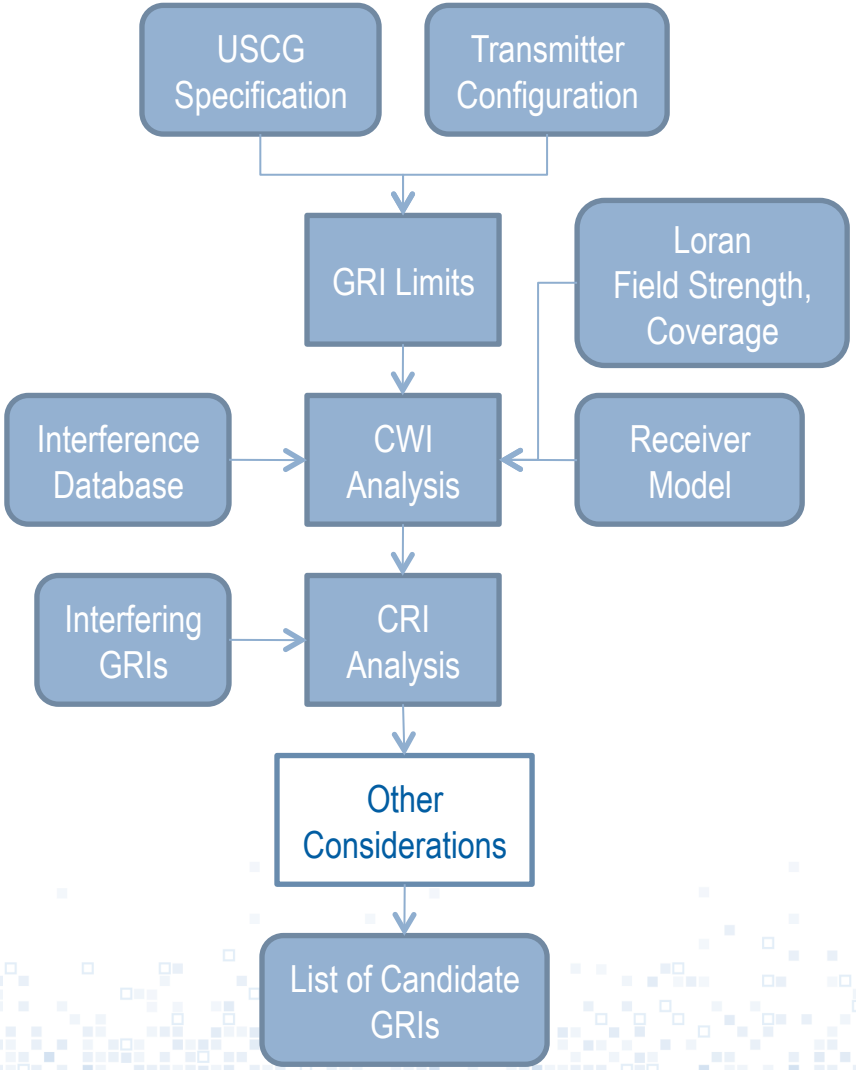
- Given a particular configuration of Loran transmitters and potential interferers, a list of promising GRI values can be compiled following presented procedure
- Resources
  - Selecting Group Repetition Intervals for North-West European Loran-C Chains, *TU Delft*
  - GRI Selection – Minimum GRIs and Coverage Diagrams for Comparison of GRIs, *NODECA*
  - Determining Cross-Rate Interference for the North-West European Loran-C Chain, *TU Delft*
  - GRIs Selection in the NELS, *DCN Brest*



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```
    error(generatemsgid('InvalidRange'),'Filter order too large.');
end

% step 1: get analog, pre-warped frequencies
if ~analog,
    fs = 2;
    u = 2*fs*tan(pi*Wn/fs);
else
    u = Wn;
end

Bw=[];
% step 2: convert to low-pass prototype estimate
if btype == 1  % lowpass
    Wn = u;
elseif btype == 2  % bandpass
    Bw = u(2) - u(1);
    Wn = sqrt(u(1)*u(2));  % center frequency
elseif btype == 3  % highpass
    Wn = u;
elseif btype == 4  % bandstop
    Bw = u(2) - u(1);
    Wn = sqrt(u(1)*u(2));  % center frequency
end
```

IMPLEMENTATION & VALIDATION

Three MATLAB Tools

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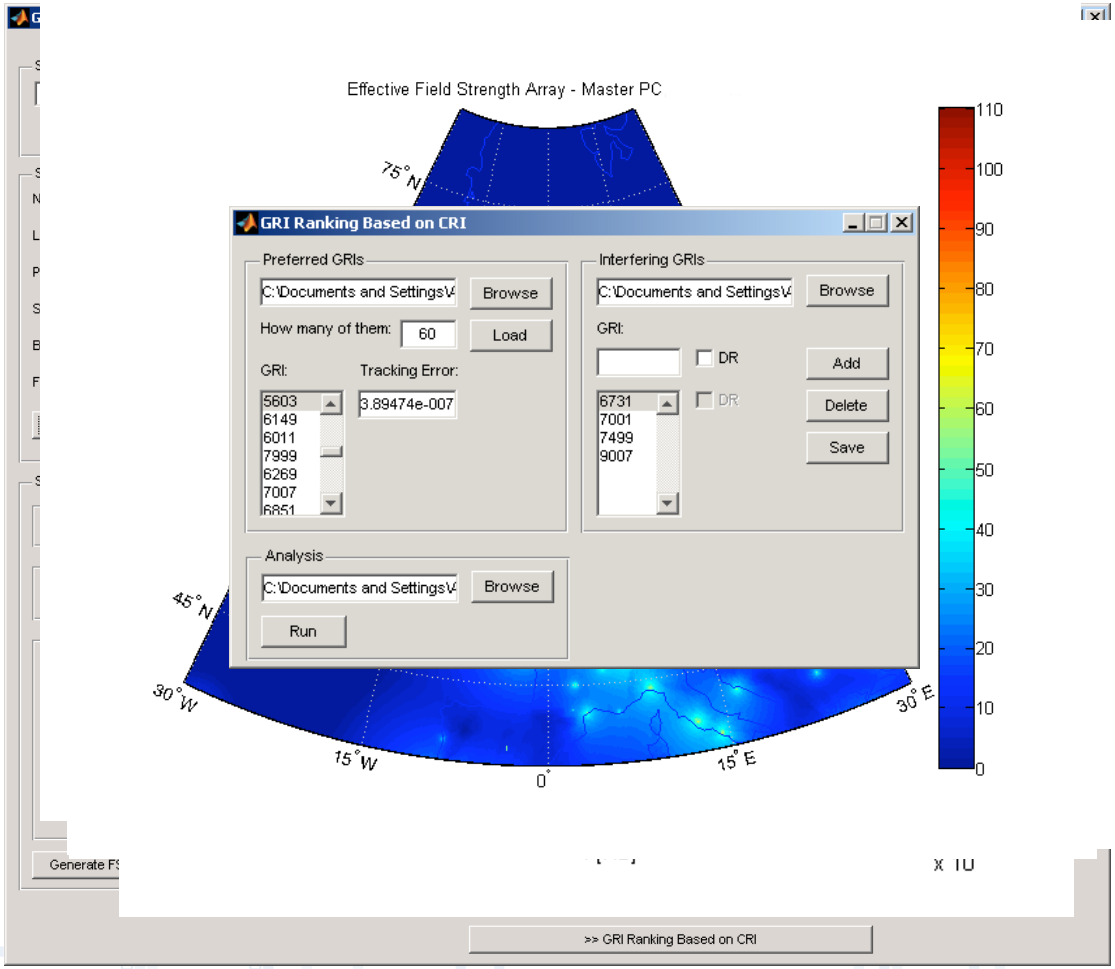

- Minimum GRI for a given configuration of transmitters
- CWI Analysis
  - Information on interferers
    - ITU Int. Frequency List
  - Field strength plots
  - Receiver sensitivity
  - Effective field strengths
  - Coverage area
  - Tracking error estimate
- CRI Analysis

Three MATLAB Tools

List of Surviving GRIs

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A	B	C	D	E	F	G	H	I	J	K	L	M	N	O	P
gria	grib	gridiff	grigcd	to	tc	tpr	tprper	sprgria	sprgriaper	sprgrib	sprgribper	nibf	nio	rtd	dr
5603	6731	1128	1	377,1	2	241,5	92,3	122,6	85,9	98,7	83	4,9672	0	0	0
5603	7001	1398	1	392,3	2	237,7	92,5	123,4	86,4	94,9	83	4,00787	4	110	0
5603	7499	1896	1	420,2	1	231,4	92,7	124,7	87,3	88,6	83	2,95517	0	0	0
5603	9007	3404	1	504,7	1	216,5	93,5	127,7	89,4	73,7	83	1,646	0	0	0
6149	6731	582	1	413,9	3	230,6	92,6	111,7	85,9	100,5	84,5	10,56529	0	0	0
6149	7001	852	1	430,5	2	226,7	92,8	112,4	86,4	96,6	84,5	7,21714	0	0	0
6149	7499	1350	1	461,1	2	220,3	93	113,6	87,3	90,2	84,5	4,55481	0	0	0
6149	9007	2858	1	553,8	1	205,2	93,7	116,4	89,4	75,1	84,5	2,1515	0	0	0
6011	6731	720	1	404,6	2	233,1	92,5	114,3	85,9	100	84,2	8,34861	0	0	0
6011	7001	990	1	420,8	2	229,3	92,7	115	86,4	96,2	84,2	6,07172	0	0	0
6011	7499	1488	1	450,8	1	222,9	93	116,2	87,3	89,8	84,2	4,03965	0	0	0
6011	9007	2996	1	541,4	1	207,9	93,7	119	89,4	74,8	84,2	2,00634	0	0	0
7999	6731	1268	1	538,4	2	204,7	93,5	85,9	85,9	104,7	88,1	5,30836	0	0	0
7999	7001	998	1	560	2	200,7	93,7	86,4	86,4	100,7	88,1	7,01503	7	150	0
7999	7499	500	1	599,8	3	194	93,9	87,3	87,3	94	88,1	14,998	15	10	0
7999	9007	1008	1	720,5	2	178,3	94,4	89,5	89,4	78,3	88,1	7,93552	0	0	0
6269	6731	462	1	422	4	228,4	92,7	109,6	85,9	100,8	84,8	13,56926	0	0	0
6269	7001	732	1	438,9	2	224,5	92,8	110,3	86,4	96,9	84,8	8,56421	0	0	0
6269	7499	1230	1	470,1	2	218,1	93,1	111,4	87,3	90,5	84,8	5,09675	0	0	0
6269	9007	2738	1	564,6	1	203	93,8	114,1	89,4	75,3	84,8	2,28963	0	0	0
7007	6731	276	1	471,6	6	216,9	93,1	98	85,9	102,7	86,4	24,38768	0	0	0
7007	7001	6	1	490,6	234	212,9	93,2	98,7	86,4	98,8	86,4	1166,833	0	0	0
7007	7499	492	1	525,5	3	206,4	93,4	99,7	87,3	92,2	86,4	14,24187	0	0	0
7007	9007	2000	1	631,1	1	190,9	94,1	102,1	89,4	76,8	86,4	3,5035	7	140	0
6851	6731	120	1	461,1	12	219,1	93	100,3	85,9	102,4	86,1	56,09167	0	0	0
6851	7001	150	1	479,6	10	215,2	93,1	100,9	86,4	98,4	86,1	45,67333	0	0	0
6851	7499	648	1	513,8	3	208,6	93,4	102	87,3	91,9	86,1	10,57253	0	0	0
6851	9007	2156	1	617,1	1	193,3	94	104,4	89,4	76,5	86,1	3,17764	0	0	0
5539	6731	1192	1	372,8	2	242,9	92,2	124	85,9	98,4	82,8	4,64681	0	0	0
5539	7001	1462	1	387,8	1	239,1	92,4	124,8	86,4	94,7	82,8	3,78865	0	0	0
5539	7499	1960	1	415,4	1	232,8	92,7	126,1	87,3	88,4	82,8	2,82602	0	0	0
5539	9007	3468	1	498,9	1	218	93,5	129,2	89,4	73,6	82,8	1,59717	0	0	0
5501	6731	1230	1	370,3	2	243,7	92,2	124,9	85,9	98,3	82,7	4,47236	0	0	0
5501	7001	1500	1	385,1	1	239,9	92,4	125,7	86,4	94,5	82,7	3,66733	11	30	0
5501	7499	1998	1	412,5	1	233,7	92,7	127	87,3	88,2	82,7	2,75325	0	0	0
5501	9007	3506	1	495,5	1	218,9	93,4	130,1	89,4	73,5	82,7	1,56902	0	0	0

Long Cross-over Time

Near-integer Overlaps

Validation

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- Implemented tools were validated by replicating the results of TU Delft report on GRI selection for NELS
- CWI analysis performed for the Lessay chain showed that 22 out of the top 30 resulting GRI values were found in the list of top 30 GRI values recommended by TU Delft
  - Differences in configuration of transmitters (Loop Head replaced by Anthorn)
  - Different coverage area
- Values obtained by the tool for minimum GRI calculation compare very well with TU Delft reports
- CRI analysis correspond excellently with the results published in TU Delft reports

1	5993
2	5723
3	6001
4	6499
5	5519
6	6277
7	5999
8	7499
9	5549
10	6061
11	5909
12	5359
13	5641
14	7001
15	6007
16	6091
17	5939
18	7723
19	7501
20	5989
21	8723
22	5461
23	7277
24	6451
25	6731
26	5603
27	6149
28	6011
29	7999
30	6269

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CASE STUDY

New GRI in FERNS

The Selection Procedure

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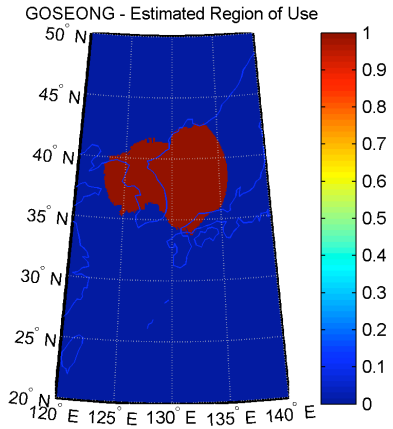

- Let us assume a chain of 2 stations
  - Kwangwhado and Goseong
  - Minimum GRI for this configuration: 4220
- CWI Analysis
  - Updates
    - All-in-view receiver model
    - Coverage area substituted by **Estimated Regions of Use**
    - Current version of ITU International Frequency List
  - Analysis was run on the two new stations and a list of preferred GRI values showing minimal CWI was compiled
- CRI Analysis
  1. Preferred GRIs were compared with other FERNS GRIs and those showing high cross-rate interference were rejected producing a shorter list of preferred GRIs
  2. This shorter list was compared with other GRIs from all existing chains and applying less strict criteria than for the neighboring FERNS chains the final list was produced

New GRI in FERNS

Proposed Values

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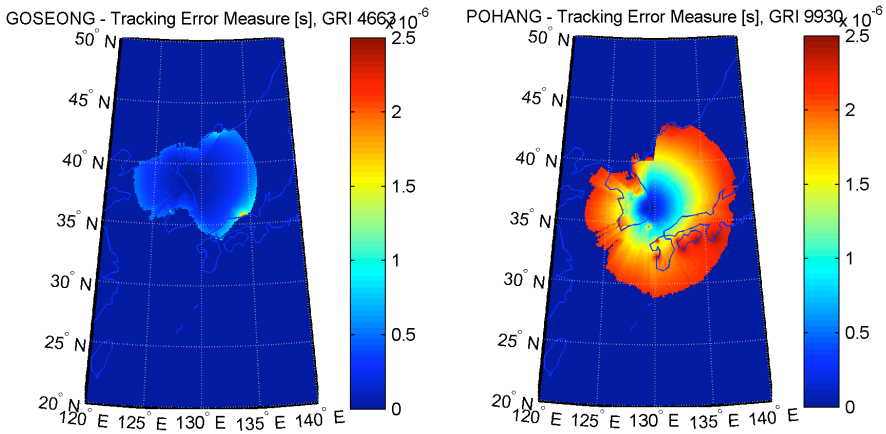

- 4663
  - The lowest CWI in the are of interest
  - Cross-over time of 4 GRI and 3 GRI with 8930 and 9930 FERNS chains
  - Cross-over time of 3 GRI with the 9990 North Pacific chain
- 5281
  - Lower CRI relative to the strong FERNS chains and most of the more distant chains
  - Cross-over time of 6 GRI with the 5543 Calcutta chain and 5 GRI with the 4970 North Western Chayka chain

FUTURE WORK

Future work

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CWI Analysis

- Data on interferers
  - Reliability of ITU International Frequency List
    - Some decommissioned stations are still listed (e.g. Decca)
    - Antenna efficiency values and radiation patterns are missing
  - Influence of modulation
- Receiver modelling
  - Notch filters (modern receivers handle up to 60 notches)

CRI Analysis

- Implemented method assumes blanking of interfering Loran signals whenever they overlap
  - Suitable for dual-rated transmitters
  - Improved methods for assessment of CRI from distant transmitters should be investigated
- Data channel considerations
  - Data channel is a key component of eLoran

Future work

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Other Considerations

- Time of Coincidence repetition period
  - Synchronization
  - Time/Frequency users
- Maximum pulse rates for dual-rated transmitters
- Changing Phase Codes
- Re-examination of current chain assignments and single-rating all stations

Summary

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- When considering new stations (new GRIs) we should take into account
  - Minimum GRI for the given transmitter configuration
  - Continuous Wave Interference
  - Cross-Rate Interference
- MATLAB Tools for CWI and CRI assessment were implemented and validated
- First eLoran updates were introduced, some others were suggested
  - All-in-view receivers
  - Receiver processing performance
- Candidate GRIs for a new chain in South Korea were proposed with GRIs 4663 and 5281 being the most promising

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Thank you!

Jan Šafář
Czech Technical University in Prague
+420 728 460 848
safarj2@fel.cvut.cz