A Reconfigurable Linear Feedback Shift Register for Software Defined Radio Terminal

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A Reconfigurable Linear Feedback Shift Register for Software Defined Radio Terminal

Summary:

I. Framework: Techniques of Parameterization and Common Operators (CO)
   1. Ideas of Reconfigurability
   2. Techniques of Parameterization

II. The Reconfigurable Linear Feedback Shift Register
   1. Design
   2. Parameterization
   3. Implementation
A Reconfigurable LFSR for SDR Terminal.

I. Framework: Techniques of Parameterization and Common Operators (CO)
   1. Reconfigurability: Velcro Method – First Steps of SDR

   Principle: Coexistence of all the required standards implementations
               Switch to select the one required

Standard 1:

- Emission Chain – Standard 1
- Channel
- Reception Chain – Standard 1

Standard 2:

- Emission Chain – Standard 2
- Channel
- Reception Chain – Standard 2
A Reconfigurable LFSR for SDR Terminal.

I. Framework: Techniques of Parameterization and Common Operators (CO)

1. Reconfigurablility: Velcro Method – First Steps of SDR

   Principle: Coexistence of all the required standards implementations
   Switch to select the one required

Standard 1:

CTC → Modulation BPSK → IFFT64 → Channel → FFT64 → Demodulation BPSK

Standard 2:

Turbo Coder → Modulation QPSK → IFFT128 → Channel → FFT128 → Demodulation QPSK
A Reconfigurable LFSR for SDR Terminal.

I. Framework: Techniques of Parameterization and Common Operators (CO)

1. Reconfigurablility: Velcro Method – First Steps of SDR

   Principle: Coexistence of all the required standards implementations
   Switch to select the one required

Standard 1 and Standard 2:
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I. Framework: Techniques of Parameterization and Common Operators (CO)

1. Reconfigurability: Sharing of Functions

   Principle: Specific Reconfigurable General Functions

Standard 1:

CTC → Modulation
BPSK → IFFT64 → Channel

Standard 2:

Turbo
Coder
→ Modulation
QPSK → IFFT128 → Channel

FFT128 → Demodulation
QPSK

FFT64 → Demodulation
BPSK
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I. Framework: Techniques of Parameterization and Common Operators (CO)

1. Reconfigurability: Sharing of Functions

   Principle: Specific Reconfigurable General Functions

Standard 1:
CTC → Modulation (BPSK) → IFFT64 → Channel → FFT64 → Demodulation (BPSK)

Standard 2:
Turbo Coder → Modulation (QPSK) → IFFT128 → Channel → FFT128 → Demodulation (QPSK)
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I. Framework: Techniques of Parameterization and Common Operators (CO)

1. Reconfigurability.
2. Techniques of Parameterization: Parameterizable Functions

Standard 1:

- FEC: CTC
- Modulation: BPSK
- IFFT: 64
- Channel
- FFT: 64
- Demodulation: BPSK

Parameters Downloading:

- Turbo Coder
- Modulation: QPSK
- IFFT: 128
- Channel
- FFT: 128
- Demodulation: QPSK
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I. Framework: Techniques of Parameterization and Common Operators (CO)

1. Reconfigurability.
2. Techniques of Parameterization: Parameterizable Functions
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I. Framework: Techniques of Parameterization and Common Operators (CO)

1. Reconfigurablility.
2. Techniques of Parameterization: Common Operators

Parameters Downloading

Common Operator 1
Common Operator 2
Common Operator 3
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II. Framework: Techniques of Parameterization and Common Operators (CO)

1. Reconfigurability.
2. Techniques of Parameterization: Common Operators

<table>
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<tr>
<th>Function 1</th>
<th>Function 2</th>
<th>Function 3</th>
<th>Function 4</th>
<th>Function 5</th>
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<tr>
<td>Channel</td>
<td>Common Operator 1</td>
<td>Common Operator 2</td>
<td>Common Operator 3</td>
<td>Channel</td>
</tr>
<tr>
<td>Common Operator 4</td>
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A common operator is a HW parameterizable architecture. It carries out several operations of distinct functions of different standards, could be used on different time in the same chain at the same time.
I. Framework: Techniques of Parameterization and Common Operators (CO)

1. Reconfigurability.
2. Techniques of Parameterization: Common Operators

Standard 1:

Common Operator 2 → Common Operator 3 → Common Operator 2 → Channel → Common Operator 1 → Common Operator 3

Standard 2:

Common Operator 1 → Common Operator 2 → Common Operator 3 → Channel → Common Operator 1 → Common Operator 2

A common operator

is an HW parameterizable architecture.

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could be used on different time in the same chain at the same time.
II. The Reconfigurable Linear Feedback Shift Register: Design

1. Design & Definition

   • Schematic: R-LFSR General Architecture – Transpose IIR Filter

   

   $$y_n = \sum_{k=0}^{N} b_{N-k} \cdot x_{n-k} - \sum_{k=1}^{N} a_{N-k} \cdot y_{n-k}$$

   • Equation:
II. The Reconfigurable Linear Feedback Shift Register: Design

1. Design & Definition

   - Equation: \[ y_n = \sum_{k=0}^{N-1} b_{N-k} x_{n-k} - \sum_{k=1}^{N} a_{N-k} y_{n-k} \]
II. The Reconfigurable Linear Feedback Shift Register: Design

1. Design & Definition

- **Schematic:** R-LFSR General Architecture – FIR Filter

\[
y_n = \sum_{k=0}^{N} b_{N-k} \cdot x_{n-k} - \sum_{k=1}^{N} a_{N-k} \cdot y_{n-k}
\]
A Reconfigurable **LFSR** for SDR Terminal.

II. The Reconfigurable Linear Feedback Shift Register: Design

1. Design & Definition.
2. Design & Fulfilled Structures:

   - Pseudo Random Sequences Generator
   - Scrambler
   - Non Systematic Convolutional Coder
   - Recursive Systematic Convolutional Coder
   - Cyclic Redundancy Check Coder
   - Cyclic Redundancy Check Decoder
   - Error-Correcting Cyclic Coder
   - Error-Correcting Cyclic Decoder
   - Galois Field Generator
   - Reed Solomon Coder/Decoder
A Reconfigurable LFSR for SDR Terminal.

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A Reconfigurable LFSR for SDR Terminal.

II. The Reconfigurable Linear Feedback Shift Register: Parameterization

1. Pseudo Random Sequences Generator & Scrambler

\[
\begin{align*}
\text{Data Flow} & \quad \text{Output - Scrambler} \\
X & \rightarrow + \quad + \quad + \\
& \quad -1 \quad -1 \quad -1 \\
Z & \quad Z & \quad Z \\
S_{r-1} & \quad S_{r-2} & \quad S_0 \\
& \quad a_1 \quad a_2 \quad a_r \\
& \quad \sum_{j=0}^{m=r} a_k Y_{(j-k)} \\
\end{align*}
\]

Pseudo Random Sequences Generator = Fibonacci LFSR

Generalized Equation:

\[
Y(j) = \sum_{k=0}^{m=r} a_k Y_{(j-k)}
\]

Equation of R-LFSR:

\[
Y_{(j)} = \sum_{k=0}^{m=r} a_{(j-k)} Y_{(j-k)}
\]

Pseudo Random Sequence with R-LFSR:

Reversing coefficients: \( a^{R\text{-LFSR}}_{(j)} = a_{\text{Fibonacci}}^{(j-k)} \) and Fitted Initial Values.
A Reconfigurable LFSR for SDR Terminal.

II. The Reconfigurable Linear Feedback Shift Register: Parameterization

1. Pseudo Random Sequences Generator & Scrambler
2. Convolutional Coder: Non Systematic Coder (NSC)

Non Systematic Coder = FIR Filter

Equation: \[ Y_n = \sum_{0}^{N} b_k \cdot X_{n-k} \]

Equation of R-LFSR (Transpose FIR Filter): \[ Y_n = \sum_{0}^{N} b_{N-k} \cdot X_{n-k} \]

Pseudo Random Sequence with R-LFSR:

- Reversing coefficients: \[ b_{R-LFSR}^{(j)} = b_{CTC-NSC}^{(j-k)} \]
A Reconfigurable \textbf{LFSR} for SDR Terminal.

II. The Reconfigurable Linear Feedback Shift Register: Parameterization

1. Pseudo Random Sequences Generator & Scrambler
2. Convolutional Coder : Recursive Systematic Coder (RSC)

Recursive Systematic Coder = IIR Filter

Equation: \[ Y[n] = \sum_{k=0}^{N} b_k \cdot X[n-k] - \sum_{k=1}^{N} a_k \cdot Y[n-k] \]

Equation of R-LFSR (Transpose IIR Filter): \[ Y[n] = \sum_{k=0}^{N} b_{N-k} \cdot X[n-k] - \sum_{k=1}^{N} a_{N-k} \cdot Y[n-k] \]

\textbf{Pseudo Random Sequence with R-LFSR:}

• Reversing coefficients: \[ a^{R-LFSR}_{(j)} = a^{IIR-Filter}_{(j-k)}, \quad b^{R-LFSR}_{(j)} = b^{IIR-Filter}_{(j-k)} \]
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II. The Reconfigurable Linear Feedback Shift Register: Parameterization

1. Pseudo Random Sequences Generator & Scrambler
2. Convolutional Coder: NSC & RSC
3. Cyclic Redundancy Check: R-LFSR and Coding

Equation:
\[ C(x) = x^{n-k} M(x) + \text{remainder} \left( \frac{x^{n-k} M(x)}{g(x)} \right) \]

Generation of the Remainder:
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II. The Reconfigurable Linear Feedback Shift Register: Parameterization

1. Pseudo Random Sequences Generator & Scrambler
2. Convolutional Coder: NSC & RSC
3. Cyclic Redundancy Check: R-LFSR and Coding

Equation:
\[ C(x) = x^{n-k} M(x) + \text{remainder} \left( \frac{x^{n-k} M(x)}{g(x)} \right) \]

Generation of the Remainder:

\[ M(x) \]

\[ r_0 \rightarrow \bigoplus \rightarrow z^{-1} \rightarrow g_1 \rightarrow r_1 \rightarrow \bigoplus \rightarrow z^{-1} \rightarrow \bigoplus \rightarrow z^{-1} \rightarrow \bigoplus \rightarrow \]
A Reconfigurable LFSR for SDR Terminal.

II. The Reconfigurable Linear Feedback Shift Register: Parameterization

1. Pseudo Random Sequences Generator & Scrambler
2. Convolutional Coder: NSC & RSC
3. Cyclic Redundancy Check: R-LFSR and Decoding

Equation:
\[ C(x) = x^{n-k} M(x) + \text{remainder} \left( \frac{x^{n-k} M(x)}{g(x)} \right) \]

Generation of the Syndrome:
II. The Reconfigurable Linear Feedback Shift Register: Implementation


   Shortest R-LFSR Structure (SRS)

   - Definition: «This architecture is the shortest R-LFSR structure with the Minimal number of registers required to replace in turn the whole 20 structures referenced in the standards»

   - Purpose: Suitable Duplication and Comparison with the Velcro Method
II. The Reconfigurable Linear Feedback Shift Register: Implementation


   Shortest R-LFSR Structure (SRS)
   - Definition: «This architecture is the shortest R-LFSR structure with the Minimal number of registers required to replace in turn the whole 20 structures referenced in the standards»
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II. The Reconfigurable Linear Feedback Shift Register: Implementation


   Shortest R-LFSR Structure (SRS)
   
   • Definition: « This architecture is the shortest R-LFSR structure with the Minimal number of registers required to replace in turn the whole 20 structures referenced in the standards »
   
   • Purpose: Suitable Duplication and Comparison with the Velcro Method
   
   • Constituent Elements: Subdivision

       Size of the Minimal Operator : 4
       Size of the most Restated Operator : 8

   Two Constituent Elements : R-LFSR4 and R-LFSR8
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II. The Reconfigurable Linear Feedback Shift Register: Implementation


   Shortest R-LFSR Structure (SRS): Constituent Elements - Subdivision
II. The Reconfigurable Linear Feedback Shift Register: Implementation


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Shortest R-LFSR Structure (SRS): Constituent Elements - Subdivision
II. The Reconfigurable Linear Feedback Shift Register: Implementation

2. Common Operators Approach: Results of Implementation
   1. Software Defined Radio Terminal
      • Tri-Standard: IEEE 802.11g, IEEE 802.16-2005 (WiMax), 3GPP LTE
   2. Structures to Replace:
      • 24 different, which 20 feature different designs

<table>
<thead>
<tr>
<th>Class of Functions</th>
<th>Polynomial Degrees</th>
<th>Numbers of Structures</th>
</tr>
</thead>
<tbody>
<tr>
<td>Scrambler/Descrambler</td>
<td>7 - 11 - 15 - 22</td>
<td>6</td>
</tr>
<tr>
<td>CRC Coder/Decoder</td>
<td>8 - 12 - 16 - 24 - 32</td>
<td>14</td>
</tr>
<tr>
<td>Convolutional Coder/Turbo Coder</td>
<td>2x4 - 2x6 - 2x9 - 3x8</td>
<td>4</td>
</tr>
</tbody>
</table>
A Reconfigurable LFSR for SDR Terminal.

II. The Reconfigurable Linear Feedback Shift Register: Implementation

2. Common Operators Approach: Results of Implementation

3. Results:

Tools of Implementation: ALTERA/Cyclone II with Quartus synthesis

Comparison:
- Velcro Method and ONE SRS:
  - Velcro Method: 100%
  - R-LFSR4: 14%
  - R-LFSR8: 12%

Comparison:
- Velcro Method and Duplication of SRS:
  - Velcro Method: 100%
  - R-LFSR4: 95%
  - R-LFSR8: 83%
A Reconfigurable LFSR for SDR Terminal.

Conclusion
- We propose a practical view of the Common Operators Approach.
- We design a Common Architecture to carry out:
  - Pseudo Random Sequences Generator
  - Scrambler
  - Convolutional Coder: NSC ans RSC
  - CRC Coder/Decoder
  - Galois Filed Generator
  - Reed Solomon Coder/Decoder

Comparison with Velcro Method:
- We create scalable and « time-tested » Operators.
- The Common Operator Approach with Shortest R-LFR8 Structure as a Common Operator give a first save of space of 17%
- The SRS is oversized for many operations to substitute, the implementation is not the most optimized one.

Standard 3:
Conclusion

In future articles, we will present:

- An optimized R-LFSR4/8 structure to map all the operations required by each standard.

Standard 1:

- Three other architectures and associated operators dedicated to specific functional perimeters.
- The evaluation of operators with unspecified functional perimeter.
- The comparison between Common Operator and Common Function approach.