A Multi-granularity Design Exploration for Multi-standard SDR Terminals

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Presentation outline

- **Multi-standard Design Issue**
  - Design Trends
    - Velcro to Multi-granularity Exploration
- **Overview of Our Methodology**
  - Common Operators Approach
  - Graph Approach for Architectural Exploration
  - Cost Parameters
    - Types of costs
    - Cost Function
  - Optimization
    - Exhaustive Search
    - Simulated Annealing
  - GUI Tool
- **Design Examples**
  - DMFFT
  - LFSR
  - Channelizers
- **Conclusion**
- **Publications**

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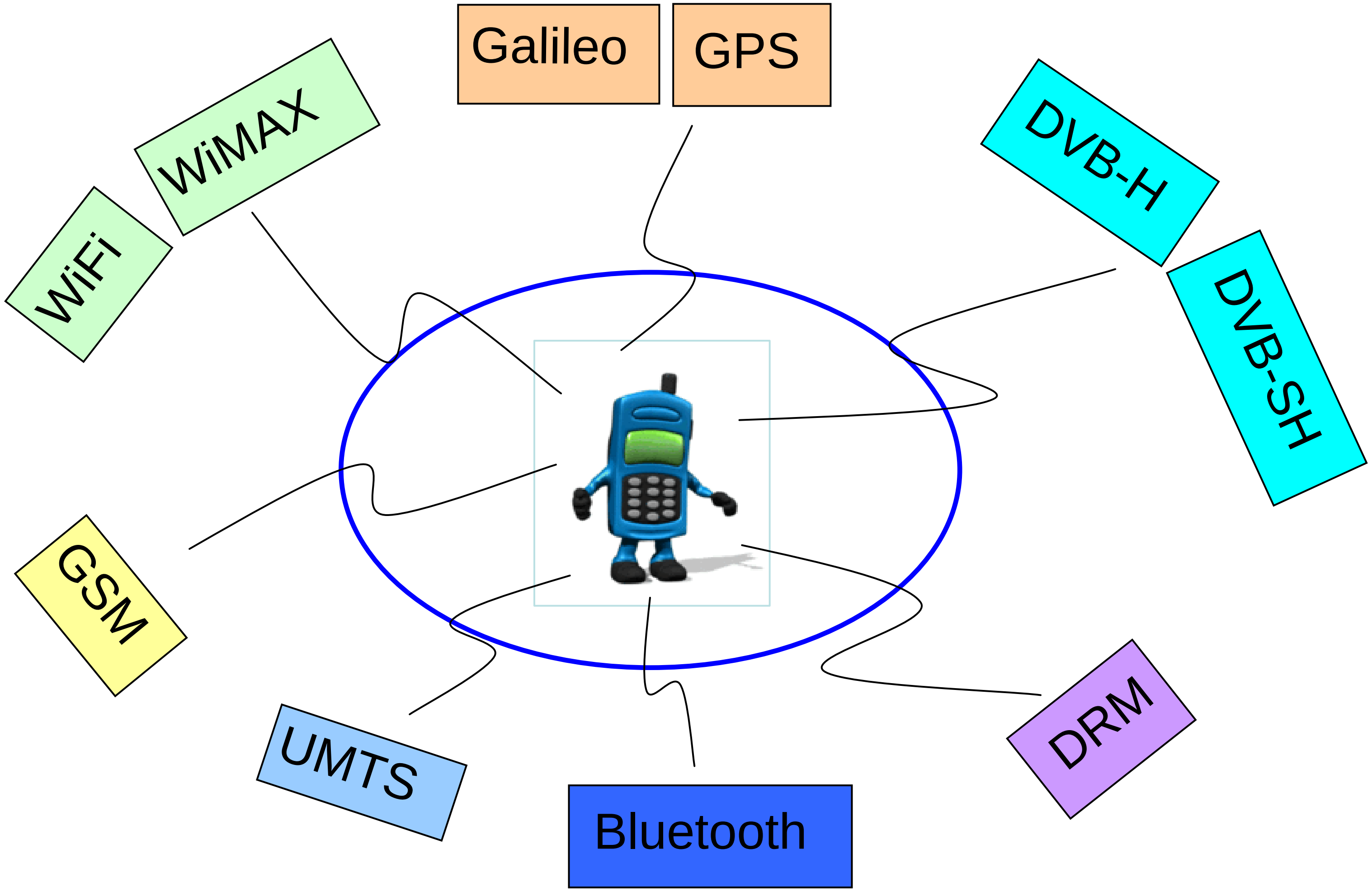
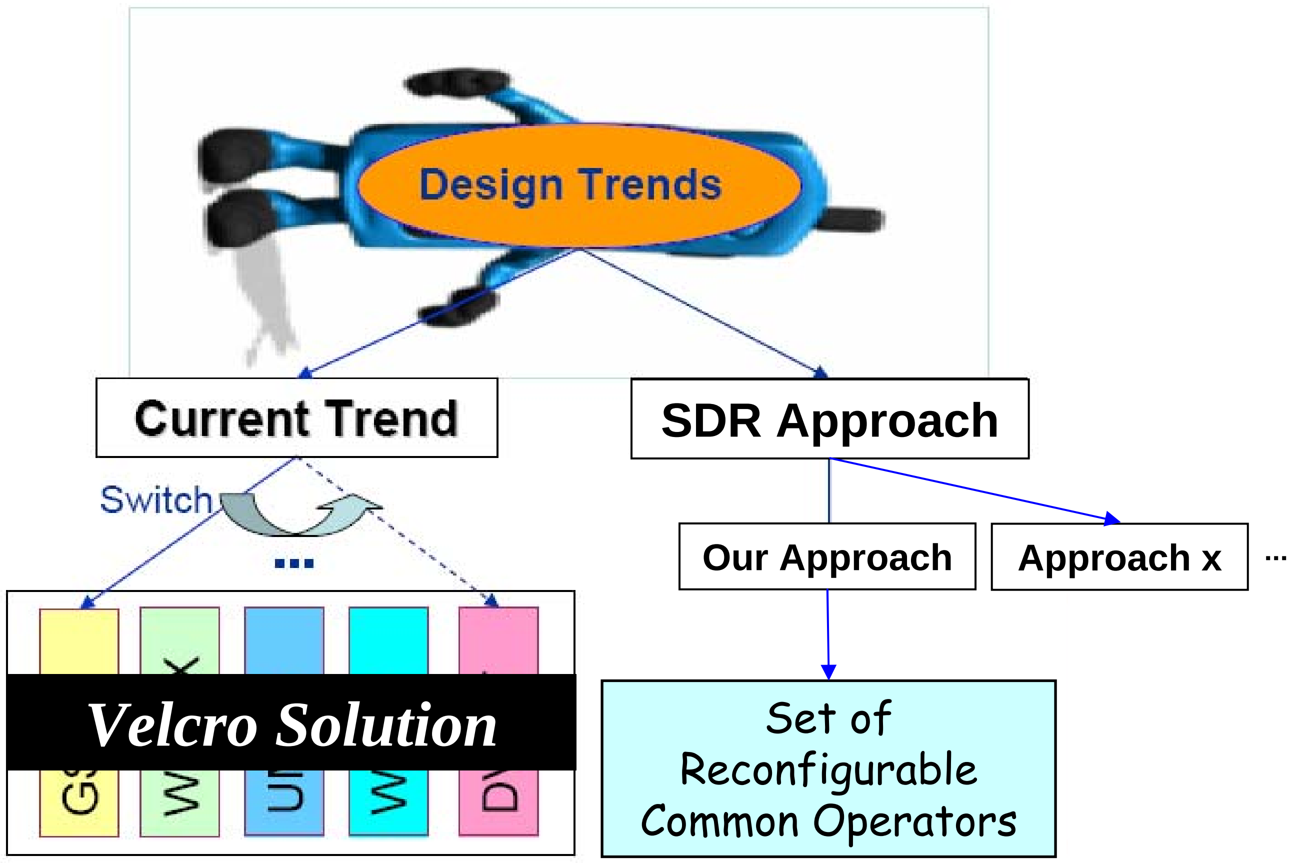
Multi-standard SDR design



Multi-standard SDR Design



- **In a nutshell to design multi-standard reconfigurable radio, we have choice between two extremes**
  - One extreme: go **“Velcro”**
    - One self-contained module per standard.
  - Other extreme: go **“Primitive”**
    - Use only adders, multipliers, etc.
    - Provide ”higher” functionality by multiple calls of simpler modules.
- **There may be other choices**
  - intermediate granularity (e.g. in NoC, SoC etc.)

➔ formalization at an intermediate granularity

- **"Velcro" is costly but efficient.**
- **"Primitive" is cheaper but it has to meet deadlines of standards.**
- **Our aim is to find:**
  - Best trade-off between "Performance and Cost."
- **One of the many possible solution is:**
  - Build a mathematical model in form of a graph to find the optimal point between two extreme architectures.

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Overview of Our Methodology

- **Our objective is to find commonalities and hence Common Operators**
- **We want to optimize graphs of multi-standard systems based on these Common Operators**
- **Our procedure consists of three steps:**
  1. Drawing graphs of a radio system
  2. Assigning cost parameters to various blocks of radio system
  3. Running optimization algorithms to find the optimum solution

1. **Common Operators' (COs) Approach**
   - Identification of an optimal level of granularity for operations
2. **Graph Approach for Architectural Exploration**
   - Model radio as graph of progressively simpler processing elements (PE).
   - When necessary, a PE is called multiple times (not replicated).
   - 2 critical parameters per PE:
     - cost and time (computational delay)

Common Operator

- **A common operator is a tuneable hardware operator which can carry out some common functions of several standards.**
  - FFT/Butterfly[1], DMFFT[2] and LFSR[3] are strong candidates for common operators.

[1]. J. Palicot, C. Roland, "FFT: a Basic Function for a Reconfigurable Receiver," *ICT'03 Conference*, Thaiti, France, 2003.

[2]. Ali Al Ghouwayel, Yves Lou¨et and Jacques Palicot, A Reconfigurable Butterfly Architecture for Fourier and Fermat Transforms, IEEE WSR'2006, Karlsrhue, 1179 Germany, March 2006.

[3]. L. Alaus, D. Noguet and J. Palicot, A Reconfigurable Linear Feedback Shift Register Operator for Software Defined Radio Terminal, ISWPC, Santorini, Greece, May 2008.

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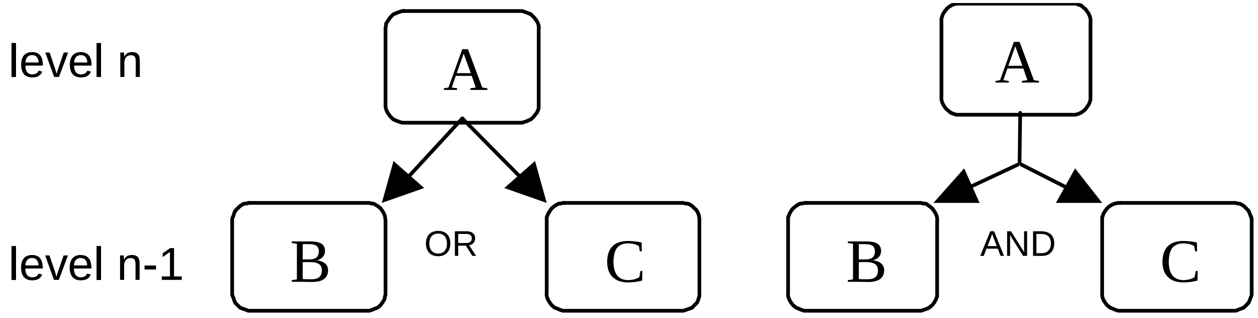
Graph Modeling

To model the system as graph, it is necessary to use a *"hypergraph"* instead of a simple graph in order to introduce two different types of dependencies between the nodes:

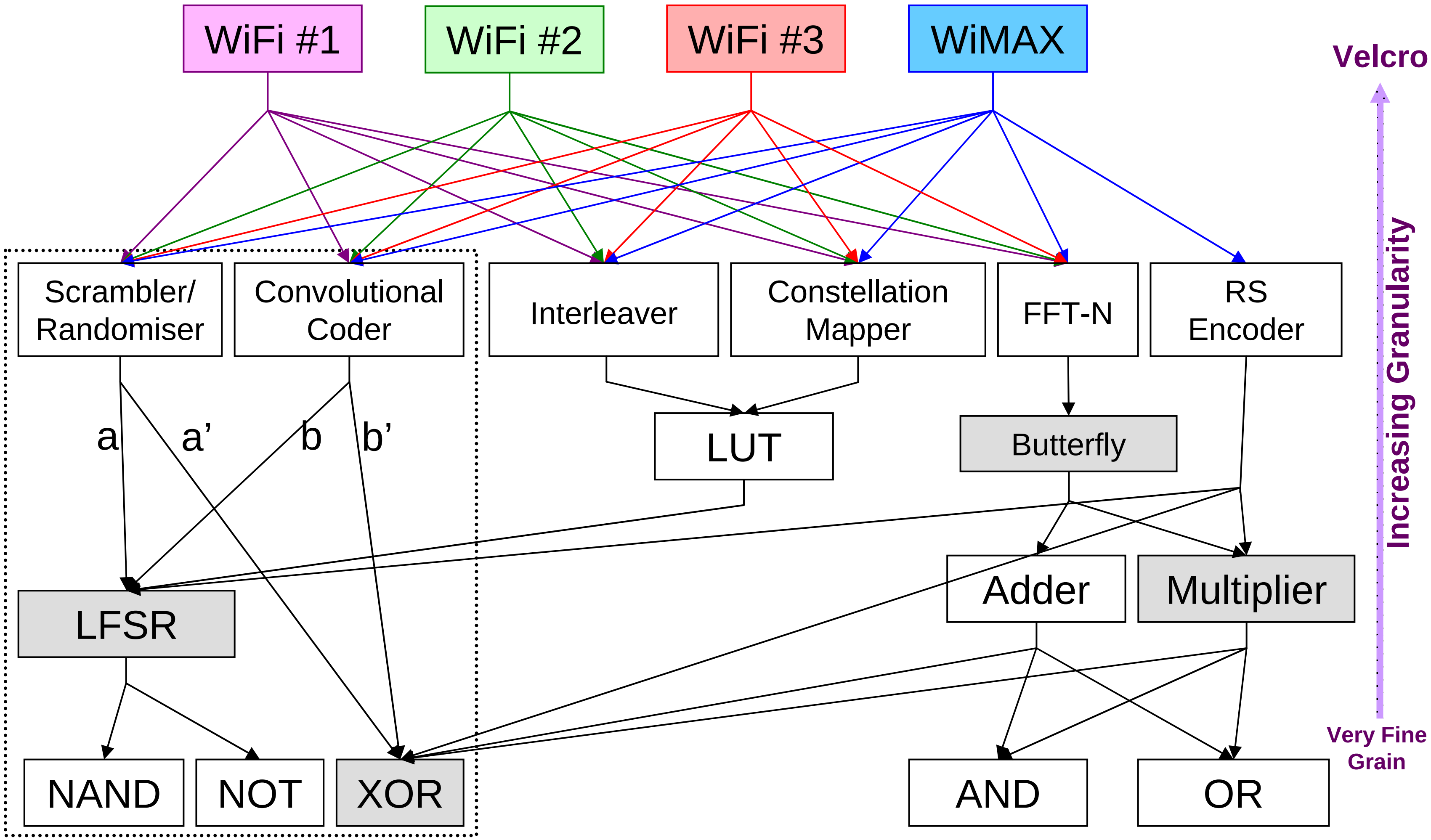
Two Possible Dependencies in Graph



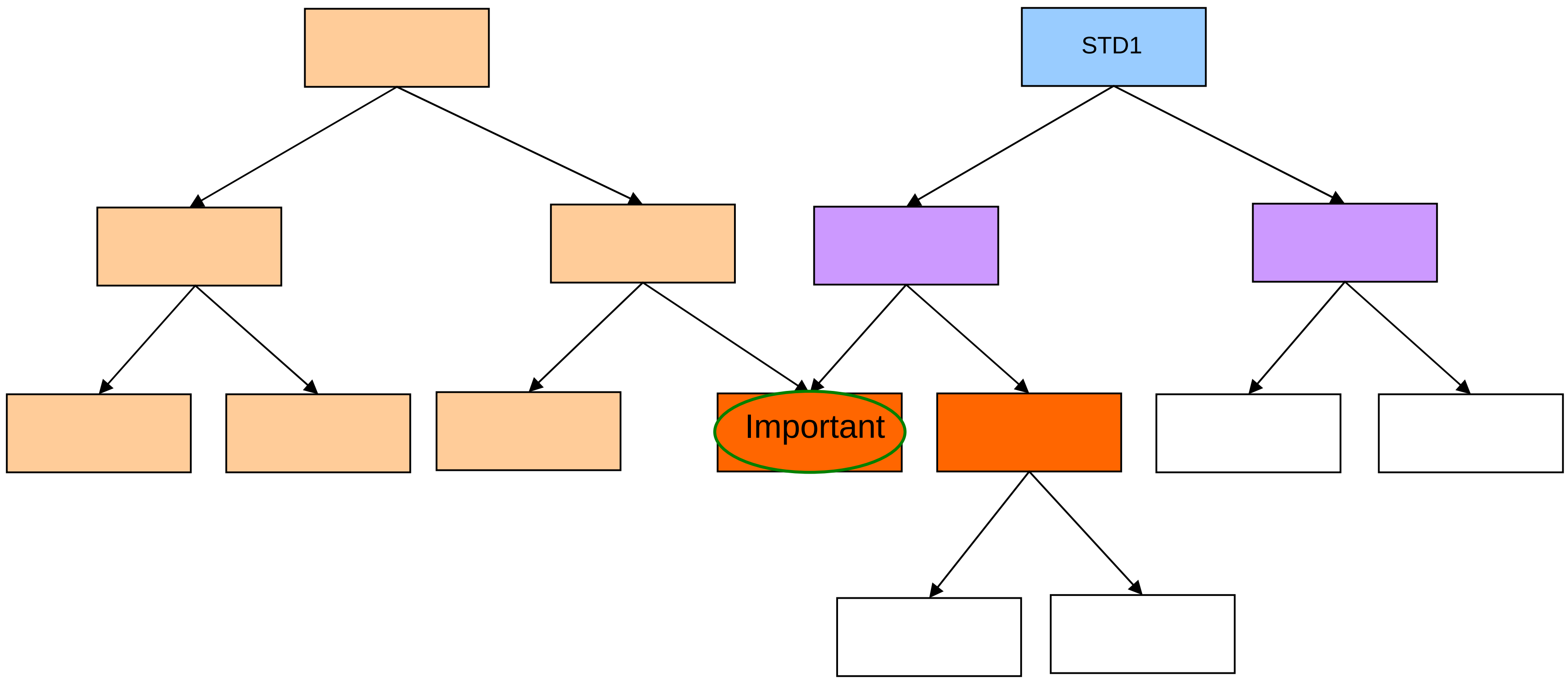
Left:
PE A *needs:*
Either B ***OR*** C

Right:
PE A *needs:*
Both B ***AND*** C

Graph Modeling



Graph Modeling



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Types of Costs

- **Need to consider 3 types of costs**
  - $\text{Cost}_{\#1}$: In terms of equations (analytical approach)
    - Number of multiplications and/or additions; generic cost; (both HW, SW)
  - $\text{Cost}_{\#2}$: FPGA/ASIC implementation
    - In terms of gates/LUT/Slice/hardware synthesis (HW)
  - $\text{Cost}_{\#3}$: DSP(SW)/HW implementation
    - In terms of number of cycles/Time of execution
- **Almost as many costs as investigated implementations**
- **How to use these costs?**

Types of Costs

- **In order to solve the optimization problem that finds balance between *economy* and *computing efficiency* we consider two parameters in our cost/objective function:**
  - The cost of the module/block capable of computing a function, called ***building cost (BC)*** and it is paid once during the useful life of a radio.
  - The computing time required to perform a particular function, called ***computational cost (CC)*** and it is paid every time a component is brought into play.

Cost Function

$$\sum_i BC_i.N_i + \sum_n \sum_k CC_k((S_n)_{n \in N})$$

BC_i denotes the building cost of i^{th} component in the system.

$N_i \in \{1,0\}$ indicates if the i^{th} node is present in the system or not.

$\sum_i BC_i.N_i$ is the total building cost of all the components that are present in the SDR system.

$((S_n)_{n \in N})$ indicates that there may be n standards present in an SDR where $n = \{1,2,\ldots,N\}$ i.e. if we choose N=3 then it means that there are three standards present namely S_1, S_2, and, S_3 in an SDR system.

CC_k denotes the computational cost of k^{th} component in the system.

$\sum_k CC_k((S_n)_{n \in N})$ is the total computational cost of any of S_n, where $n = \{1,2,\ldots,N\}$

Cost Function

$\sum_{n}\sum_{k} CC_k((S_n)_{n\in N})$ is the total computational cost of all of S_n , where $n = \{1,2,\ldots,N\}$

$$C_{SDR} = \min_{bool((S_n)_{n\in N})}\left(\bar{w}\sum_{i} BC_i.N_i + \sum_{n}\sum_{k} w_n.CC_k((S_n)_{n\in N})\right)$$

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Exhaustive Search

- All exact methods known for determining an optimal solution require a computing effort that increases exponentially with number of nodes, so that in practice exact solutions can be attempted only on problems involving fewer nodes (say 10 nodes).

Simulated Annealing

- To obtain a near-optimal solution we use the method of simulated annealing (SA). SA is a random-search technique which exploits the analogy between the way in which metal cools and freezes into a minimum energy crystalline structure and search for a minimum in a more general system.

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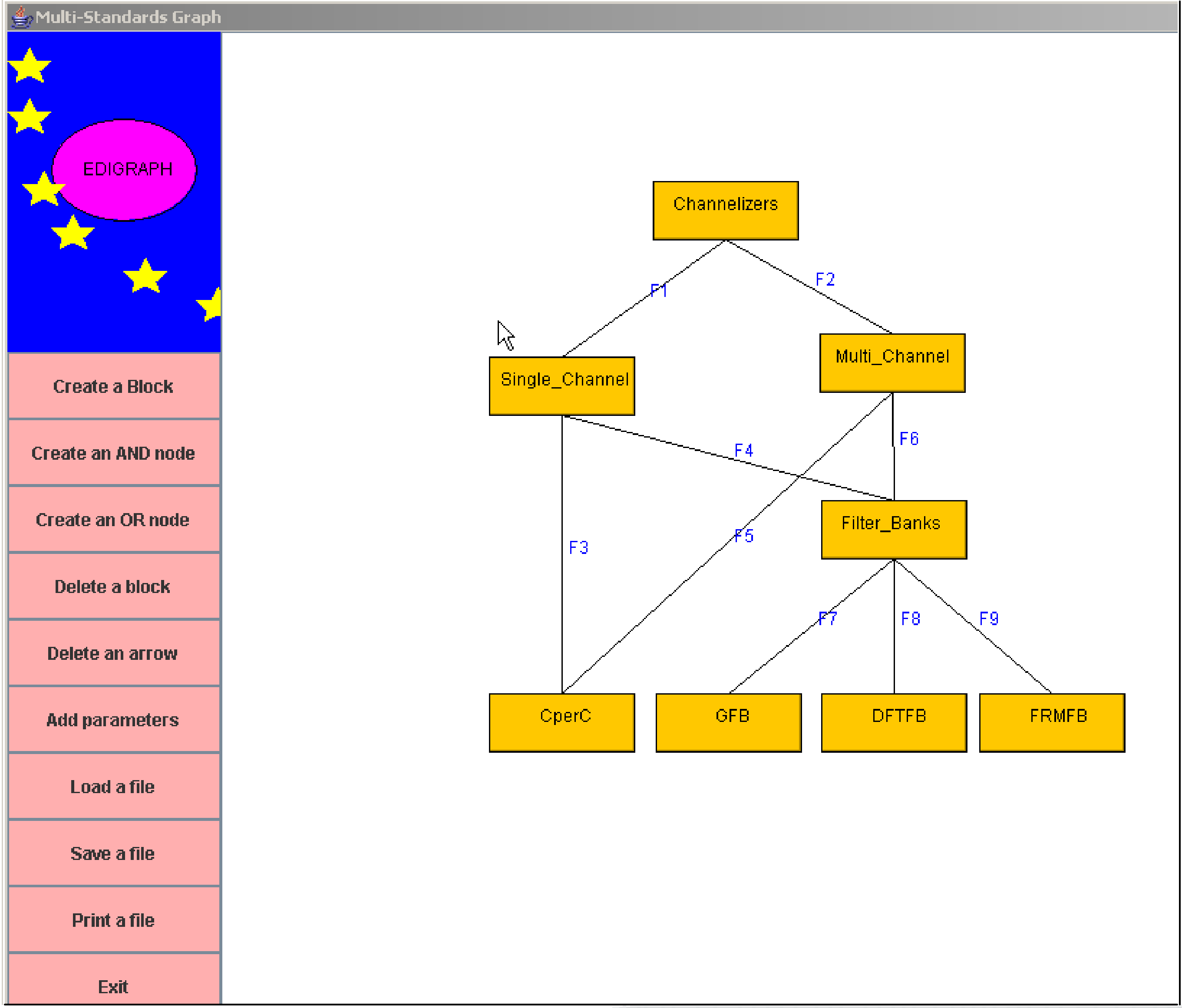
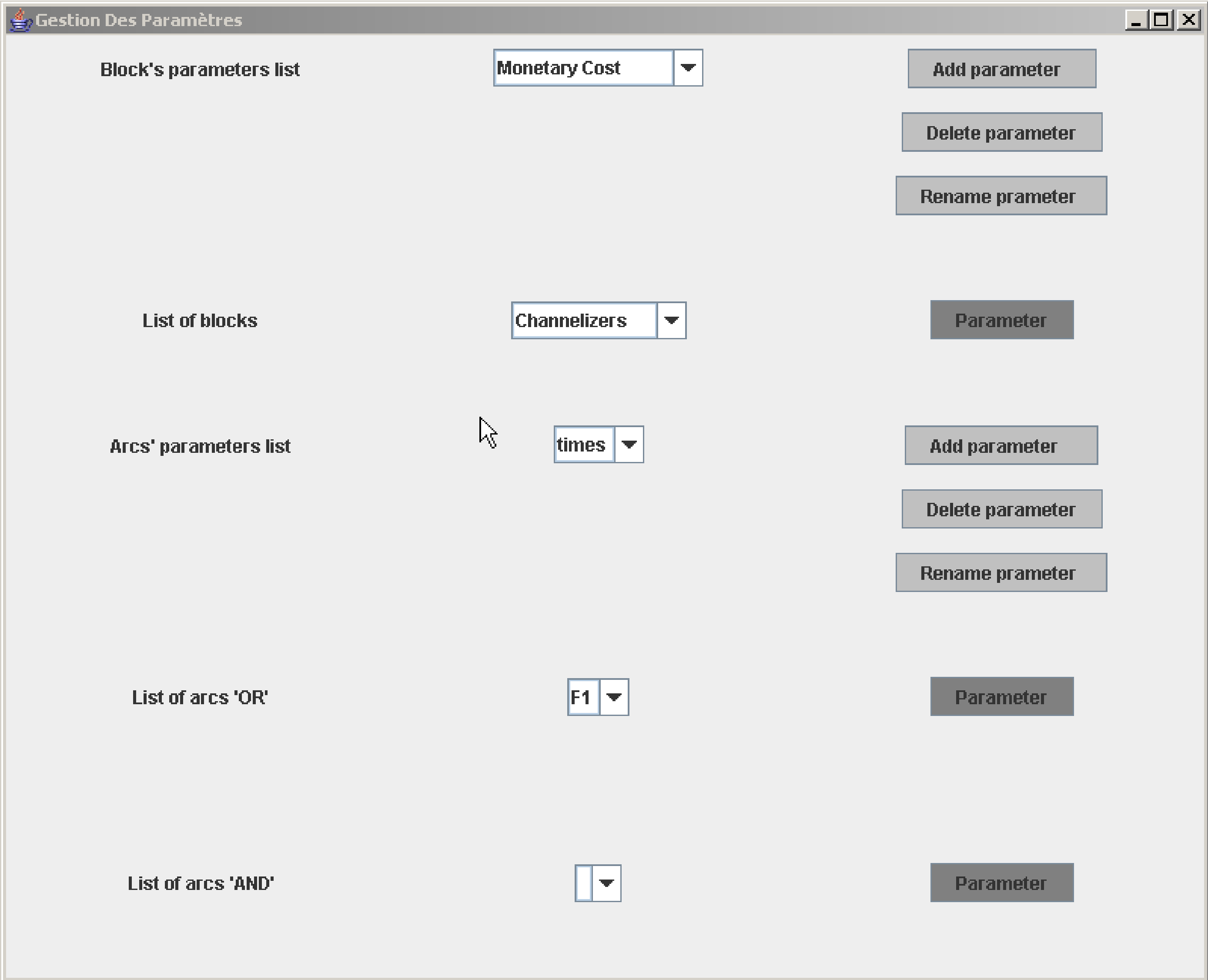
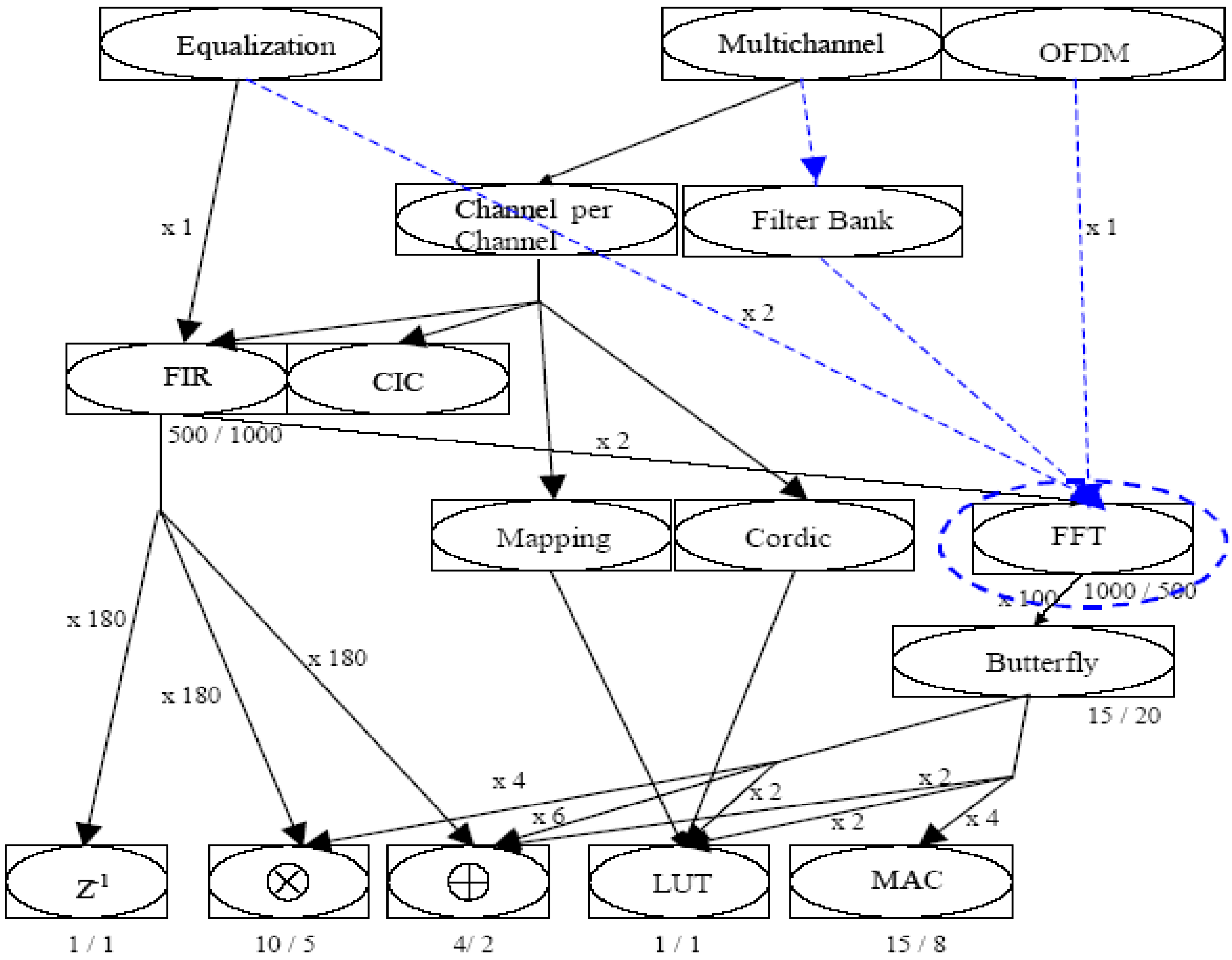
GUI Tool


Multi-Standards Graph
EDIGRAPH
Create a Block
Create an AND node
Create an OR node
Delete a block
Delete an arrow
Add parameters
Load a file
Save a file
Print a file
Exit
Channelizers
F1
F2
Single_Channel
Multi_Channel
F4
F6
F3
F5
Filter_Banks
F7
F8
F9
CperC
GFB
DFTFB
FRMFB

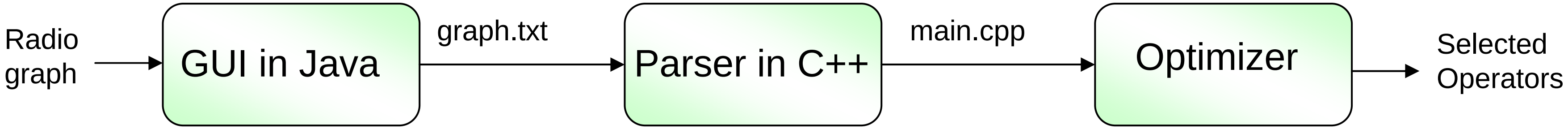
GUI Tool


Gestion Des Paramètres
Block's parameters list
Monetary Cost
Add parameter
Delete parameter
Rename prameter
List of blocks
Channelizers
Parameter
Arcs' parameters list
times
Add parameter
Delete parameter
Rename prameter
List of arcs 'OR'
F1
Parameter
List of arcs 'AND'
Parameter

GUI/Optimization Tool



Developing Environment



- Development of the software (in GUI style) for drawing graphs
- Development of parser for converting the output of GUI to be used in Optimizer
- Making optimizer run for generating results

Summary

1. **Use graph to list each possible design.**
2. **For each design, calculate its total: cost, and time to perform each top PE.**
3. **Use Algorithms e.g. exhaustive search, simulated annealing, etc. to *optimize* design.**
4. **Choose least expensive design that satisfies the *"deadline"* of each top PE.**

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Sub-design examples

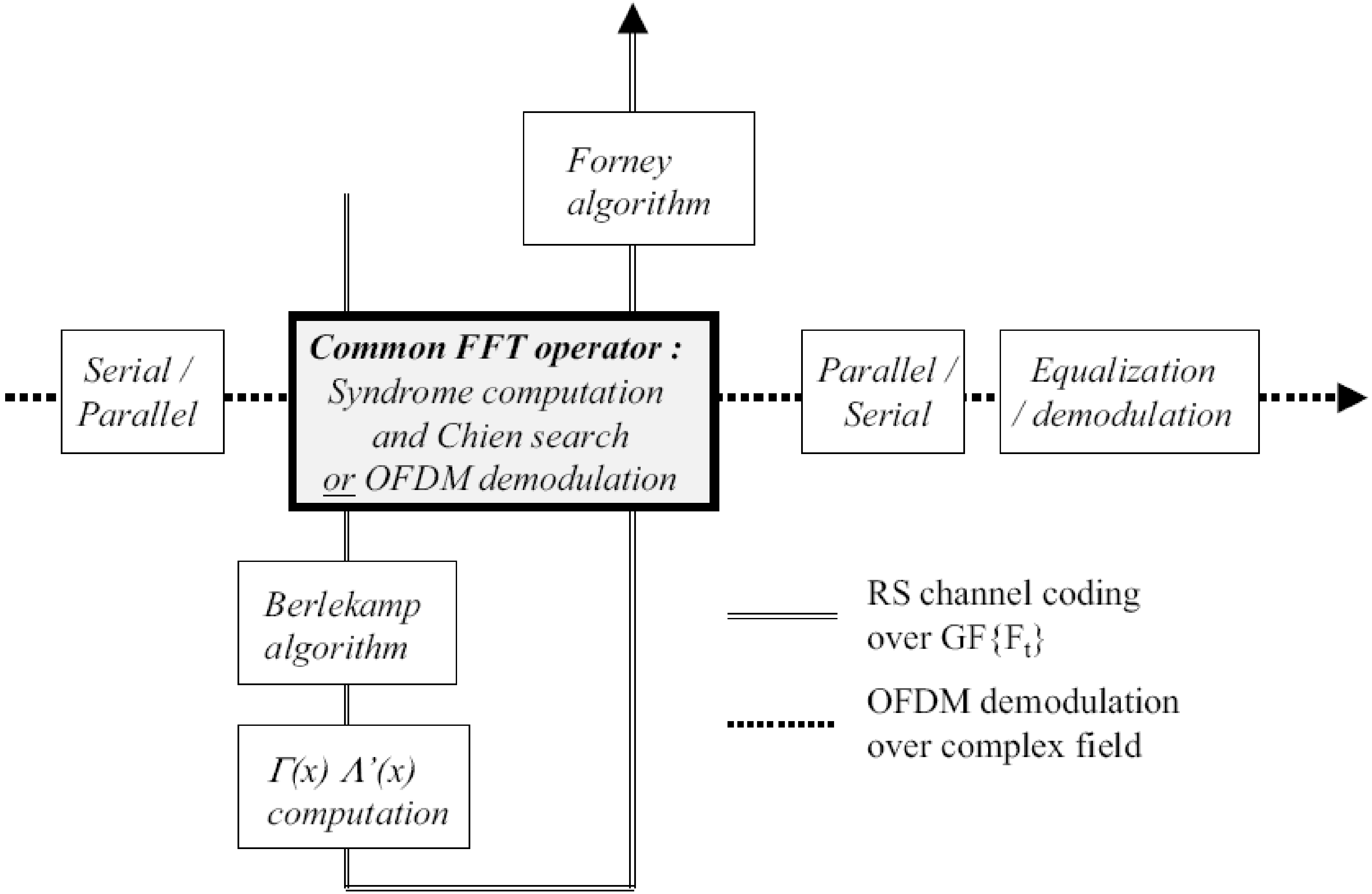
- **Goal: validate our approach**

  Means: integrating other PhD students results

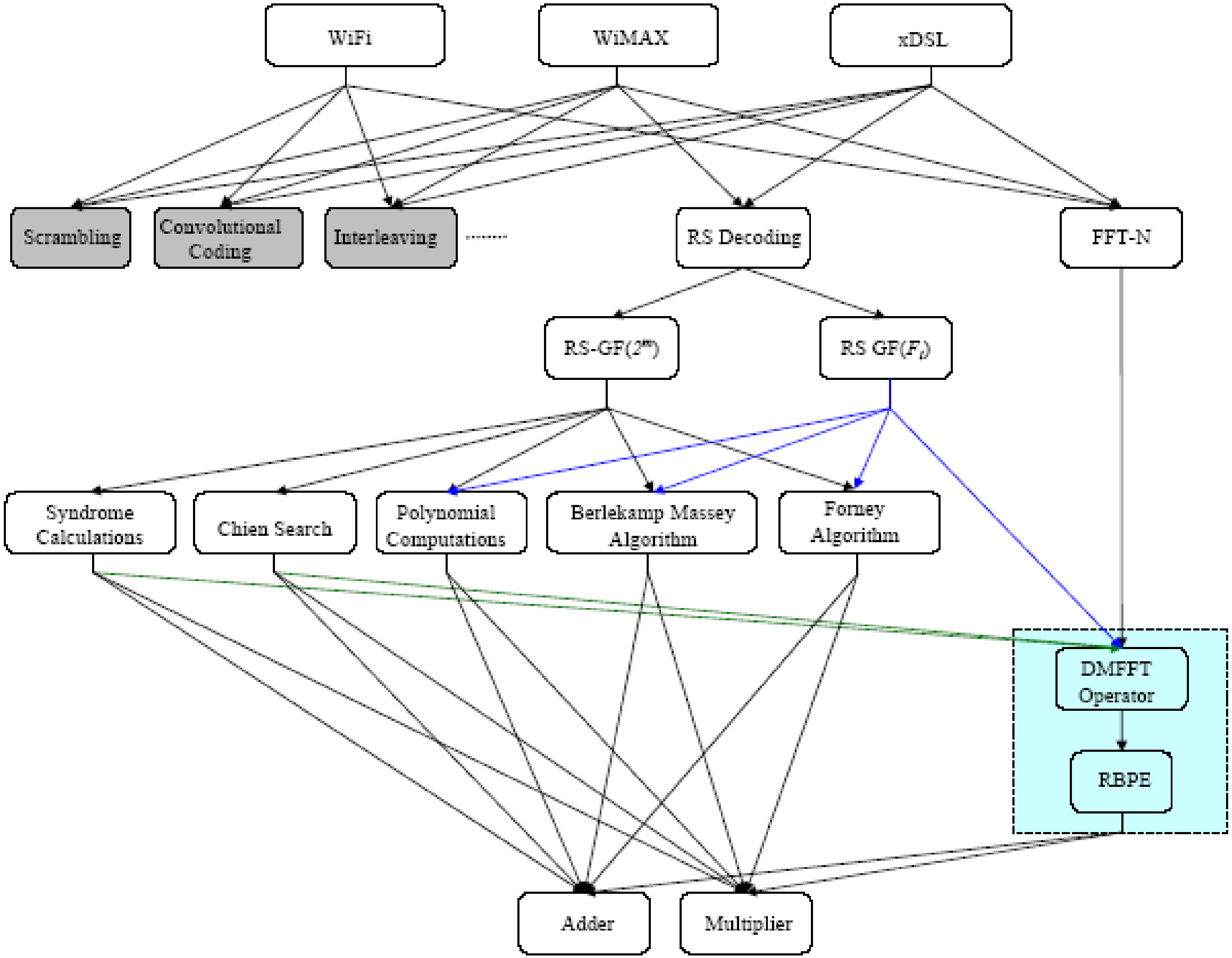
➔ **Also permits to mature our approach**

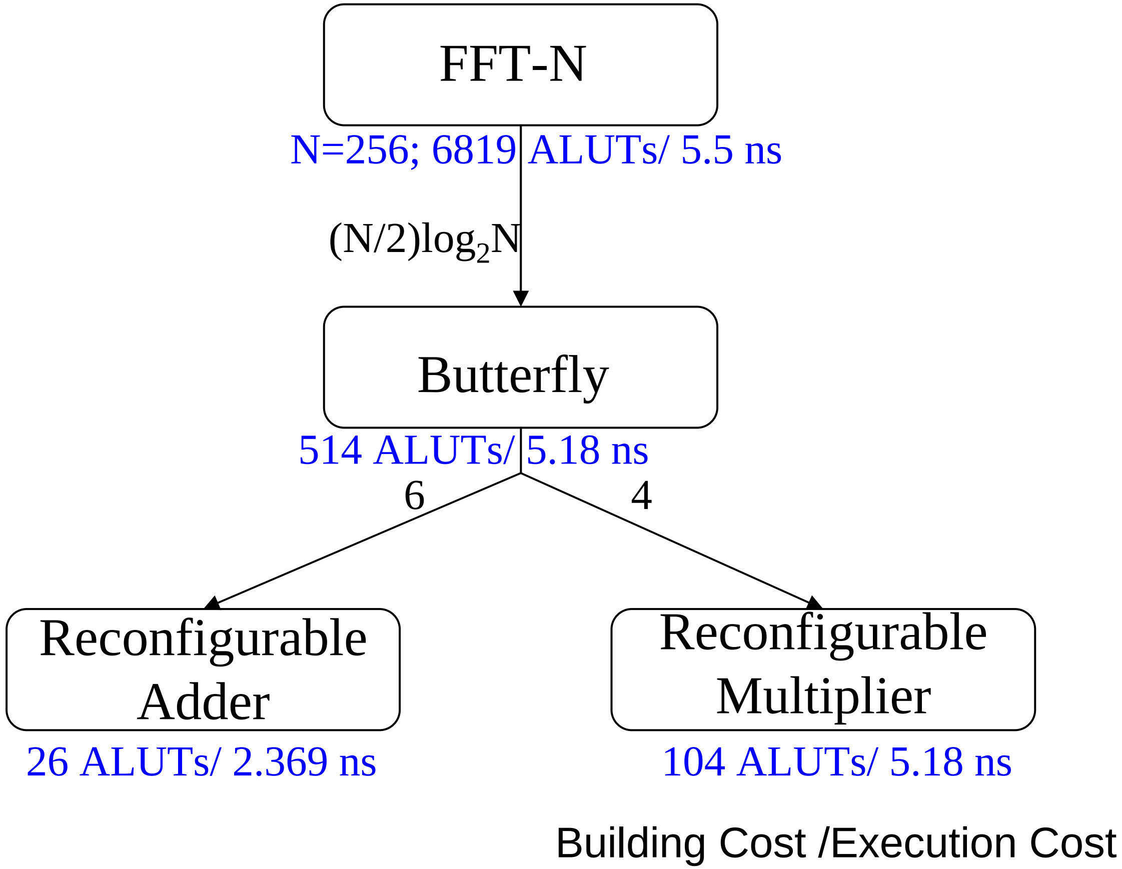
- **DMFFT: In collaboration with ALI AL GHOUWAYEL**
- **LFSR: In collaboration with Laurent ALAUS**
- **Channelizer: In collaboration with MAHESH**

Example #1: DMFFT



Example #1: DMFFT




FFT-N
N=256; 6819 ALUTs/ 5.5 ns
(N/2)log2N
Butterfly
514 ALUTs/ 5.18 ns
6
4
Reconfigurable Adder
26 ALUTs/ 2.369 ns
Reconfigurable Multiplier
104 ALUTs/ 5.18 ns
Building Cost /Execution Cost

Example #2: LFSR

A linear feedback shift register (LFSR) is a shift register whose input bit is a linear function of its previous state.

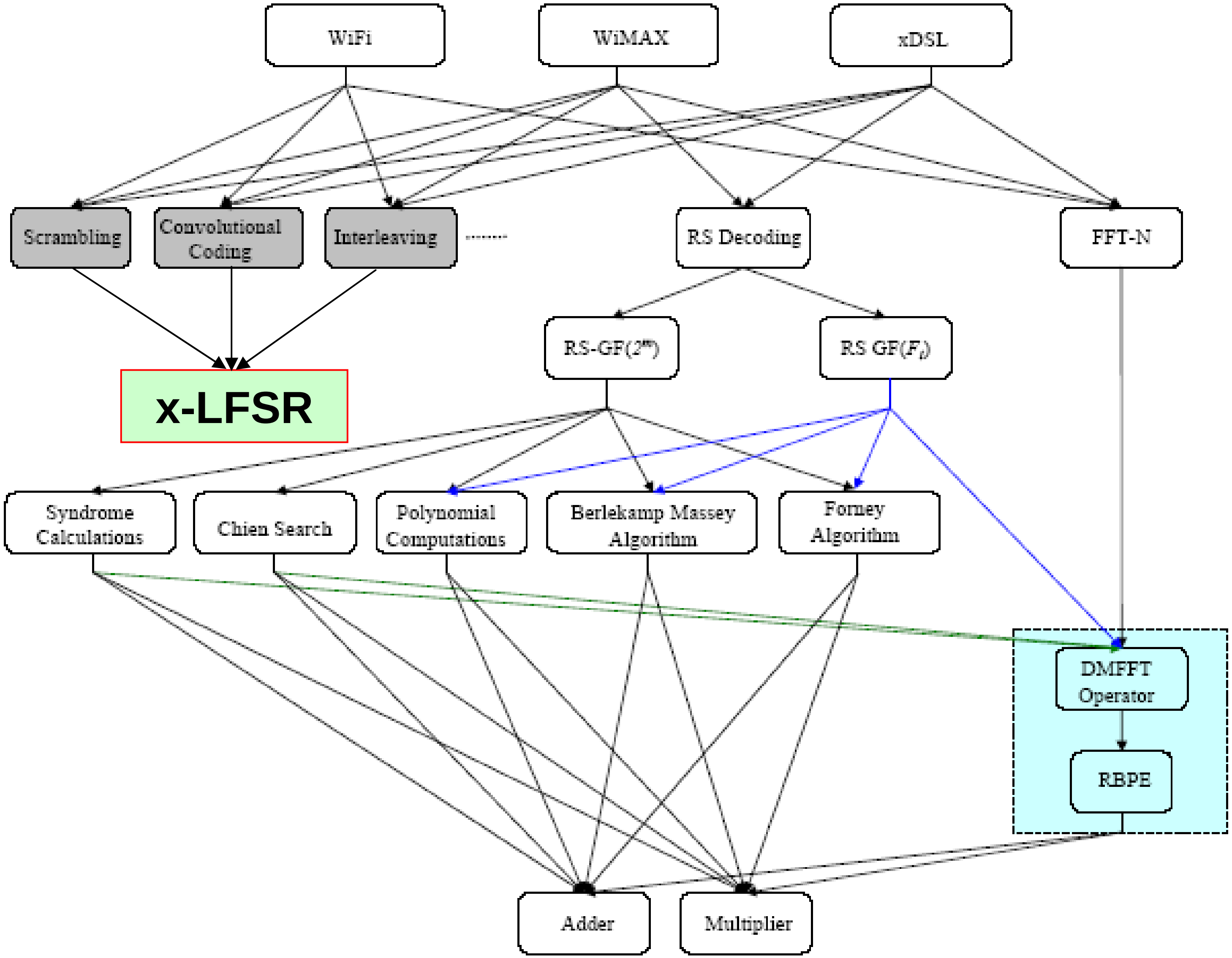
There are two implementation styles of LSFRs: Fibonacci RF-LFSR and Galois RG-LFSR.

The study of common operators has lead us to build the architectures called R-LFSR and ER-LFSR respectively.

LFSR common operators	Logic cells
RG-LFSR4	5
RG-LFSR8	10
RF-LFSR4	5
RF-LFSR8	10
R-LFSR4	6
R-LFSR8	10
ER-LFSR4	11
ER-LFSR8	16

Standards	Function name	Polynomial degree
IEEE 802.11g	Scrambler	7
IEEE 802.11g	Descrambler	7
IEEE 802.11g	CCIT CRC-16 Coder	16
IEEE 802.11g	CCIT CRC-16 Decoder	16
IEEE 802.11g	Convolutional Coder PBCC	2×6
3GPP LTE	CRC-24 Coder	24
3GPP LTE	CRC-16 Coder	16
3GPP LTE	CRC-12 Coder	12
3GPP LTE	CRC-8 Coder	8
3GPP LTE	CRC-24 Decoder	24
3GPP LTE	CRC-16 Decoder	16
3GPP LTE	CRC-12 Decoder	12
3GPP LTE	CRC-8 Decoder	8
3GPP LTE	Convolutional Coder, Rate 1/2	2×8
3GPP LTE	Convolutional Coder, Rate 1/3	3×8
3GPP LTE	Turbo Coder	2×4
IEEE 802.16	Scrambler	15
IEEE 802.16	Scrambler Spreading BPSK	22
IEEE 802.16	Scrambler Pilot Modulation	11
IEEE 802.16	Convolutional Coder	6
IEEE 802.16	CRC-32 Coder	32
IEEE 802.16	CRC-16 Coder	16
IEEE 802.16	CRC-32 Decoder	32
IEEE 802.16	CRC-16 Decoder	16

Example #2: LFSR

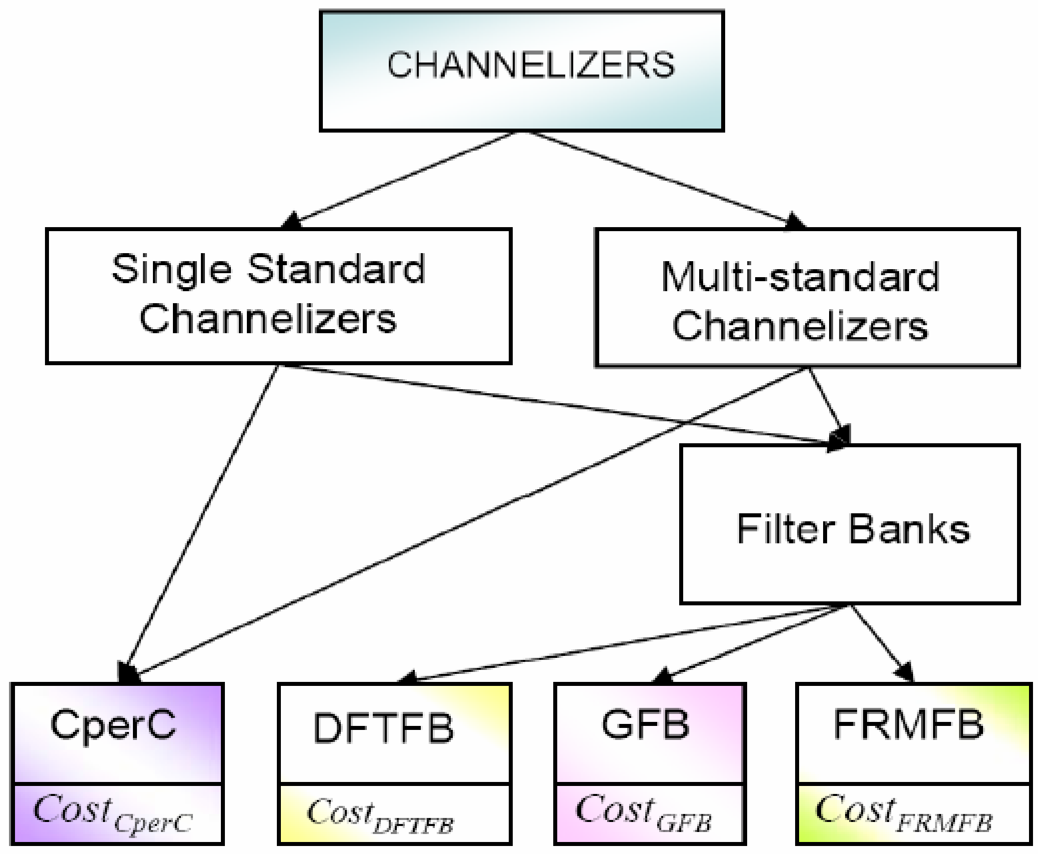


Example #2: LFSR

Table 3. Operations of WiFi and Number of LFSRs

Function	RG-LFSR4	RG-LFSR8	RF-LFSR4	RF-LFSR8	R-LFSR4	R-LFSR8	ER-LFSR4	ER-LFSR8
WiFi-Complexity in terms of number of LFSRs								
Scrambler	4	2	4	2	4	2	4	2
CRC16	-	-	8	4	8	4	8	4
CC-802.11b	-	-	-	-	4	2	4	2
CC-802.11g	-	-	-	-	-	-	6	6
IEEE 802.16 d/e (WiMAX) Complexity in terms of number of LFSRs								
Scrambler-15	8	4	8	4	8	4	8	4
+Scrambler-11	6	4	6	4	6	4	6	4
or +Scrambler-22	12	6	12	6	12	6	12	6
CRC32	-	-	16	8	16	8	16	8
CRC16	-	-	8	4	8	4	8	4
CC-1/2	-	-	-	-	4	2	4	2
TC-1/2	-	-	-	-	-	-	1	1
TC-1/3	-	-	-	-	-	-	2	2
3GPP LTE Complexity in terms of number of LFSRs								
Scrambler-UL	8	4	8	4	8	4	8	4
+Scrambler-DL	6	4	6	4	6	4	6	4
CRC32	-	-	12	6	12	6	12	6
CRC24	-	-	8	4	8	4	8	4
CRC16	-	-	6	4	6	4	6	4
CRC8	-	-	-	-	4	2	4	2
CC-1/2	-	-	-	-	4	2	4	2
CC-1/3	-	-	-	-	6	3	6	3
TC	-	-	-	-	2	2	2	2

Example #3: Channelizers

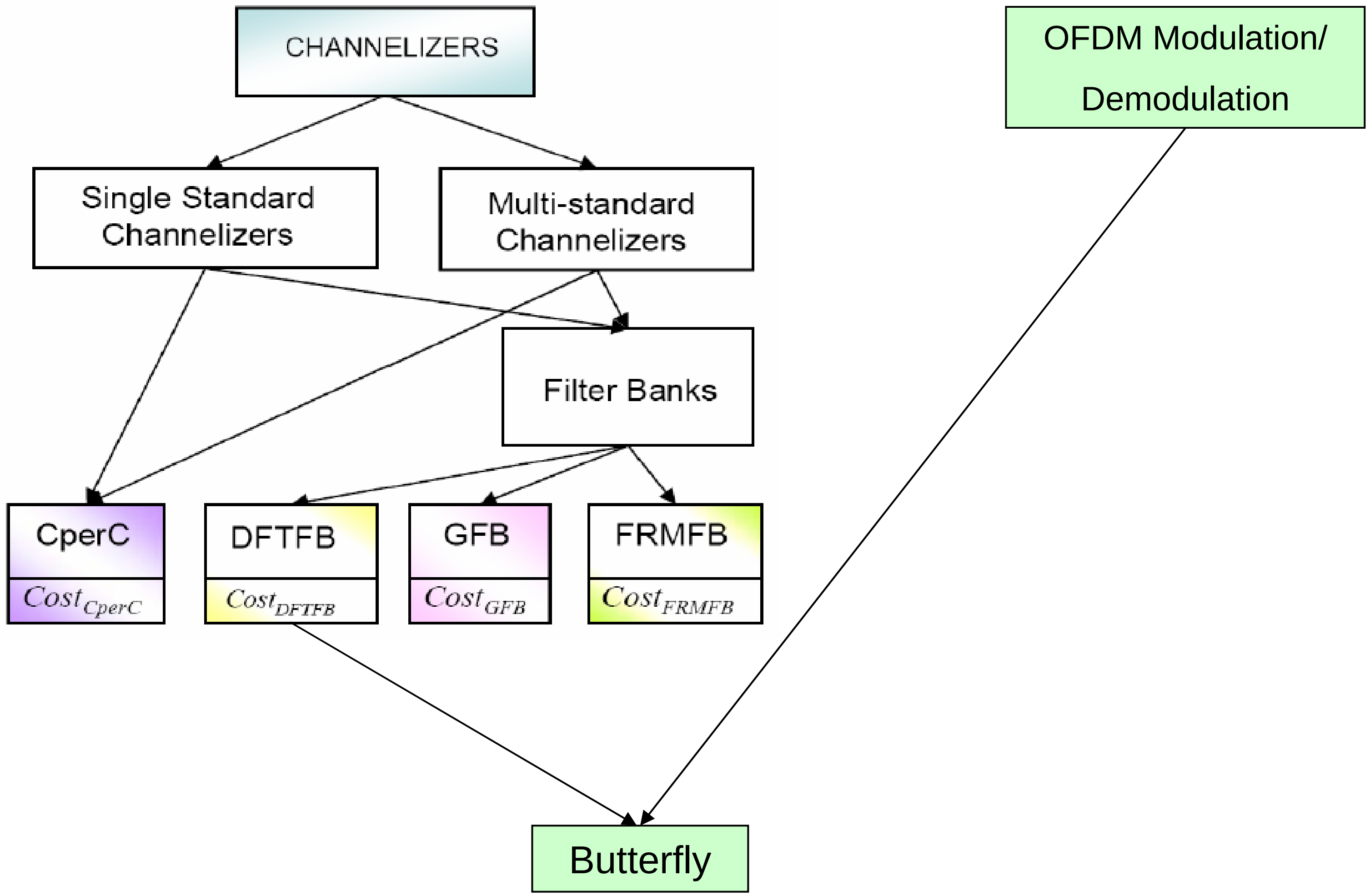


Example #3: Channelizers

Costs of the channelizers in terms of million of multiplications per second

Standard	No. of Channels	Chip Rate	Sampling Frequency	$Cost_{CperC}$	$Cost_{DFTB}$	$Cost_{GFB}$	$Cost_{FRM\ FB}$
TD-SCDMA	1	1.28 Mcps	5.12 MHz	139	256	256	149
WCDMA-FDD/TDD	1	3.84 Mcps	15.36 MHz	415	768	768	446
IEEE 802.11b-DSS	1	11 Mcps	22 MHz	594	1100	1100	638
TD-SCDMA	2	1.28 Mcps	5.12 MHz	1009	994	999	415
WCDMA-FDD/TDD	2	3.84 Mcps	15.36 MHz	3026	2980	2996	1245
IEEE 802.11b-DSS	2	11 Mcps	22 MHz	4334	4268	4290	1782
TD-SCDMA	10	1.28 Mcps	5.12 MHz	27418	5469	5520	702
WCDMA-FDD/TDD	10	3.84 Mcps	15.36 MHz	82253	16405	16559	2105
IEEE 802.11b-DSS	10	11 Mcps	22 MHz	117810	23496	23716	3014

Example #3: Channelizers



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Conclusion

- Contribution to the design of *future multi-standard phones*.
- Exploiting *commonalities* between standards we may have 10 or even more standards in phones simultaneously because using commonalities do not require duplication.
- Using commonalities/common operators, *switching* from one standard to another standard is achieved simply by change of parameters.
- In a nutshell, we have to *identify new common operators* and use them to design systems.

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Journal Publications

- Sufi Tabassum GUL, Ali Al GHOUWYEL, Christophe MOY, Yves LOU¨ET, ***"A Novel Design of Reconfigurable Fourier Transform Operator Over C and GF(F_t) for Future Multi-standards SDR Equipments,"*** Submitted in Elseiver, Computer and Electrical Engineering Special Issue on Emerging Wireless Networks, July, 2008.

Conference Proceedings

- Sufi Tabassum GUL, Christophe MOY, Jacques PALICOT ***"Two Scenarios of Flexible Multi-Standard Architecture Designs Using a Multi-Granularity Exploration,"*** The 18th Annual IEEE International Symposium on Personal, Indoor and Mobile Radio Communications (PIMRC'07), September 2007, Athens, Greece.

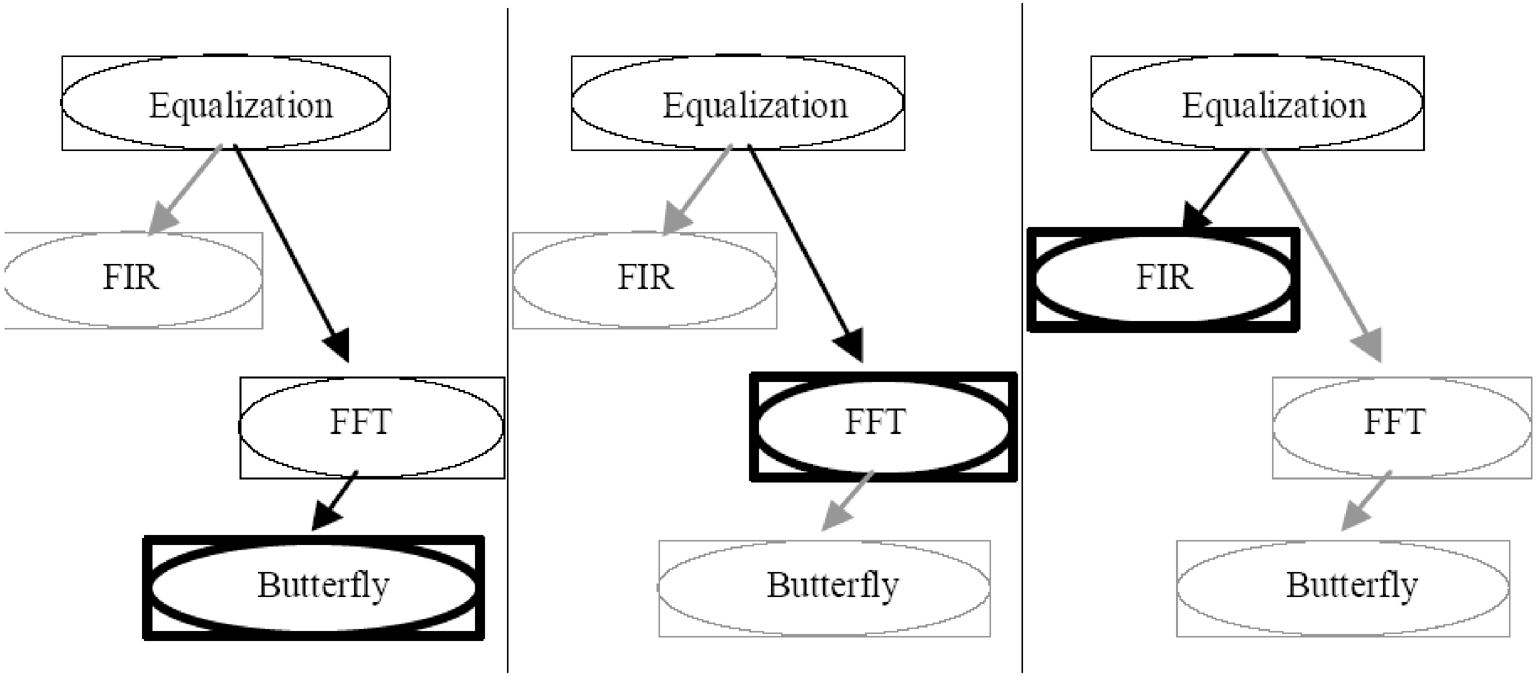
- Sufi Tabassum GUL, Raveendranatha P. MAHESH, Christophe MOY, Prasad VINOD, Jacques PALICOT ***"A Graphical Approach for the Optimization of SDR Channelizers,"*** URSI 08, The XXIX General Assembly of the International Union of Radio Science, Chicago (USA), August 2008.

- Sufi Tabassum GUL, Christophe MOY, Jacques PALICOT, ***"Graphical Modeling and Optimization of Air Interface Standards for Software Defined Radios,"*** 12th IEEE International Multitopic Conference (IEEE INMIC), Karachi , Pakistan , December 2008.

Thanks for your attention

Questions?

Relative Weights of BC & CC



(a) - $\tilde{I}$ high (b) - $\tilde{I}$ medium (c) - $\tilde{I}$ low