Agile & Smart MIMO Decoding

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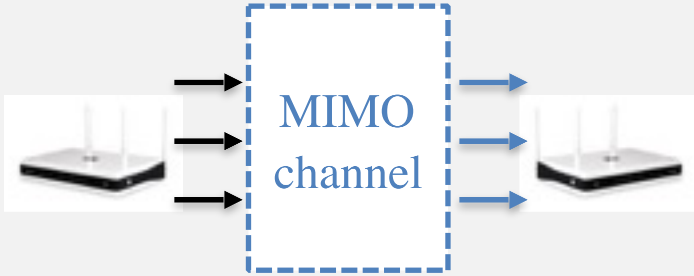
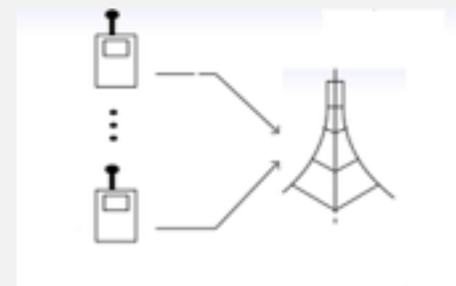
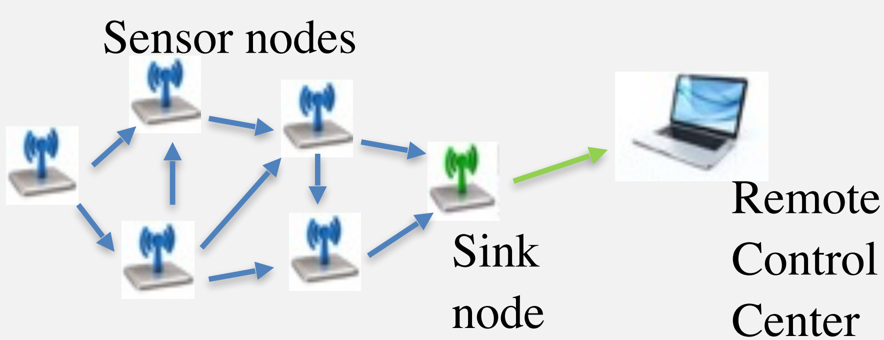
Examples of MIMO technologies



Multiple antennas systems



Multi-user communications



IOT network

Optical fiber communications

Examples of wireless standards products

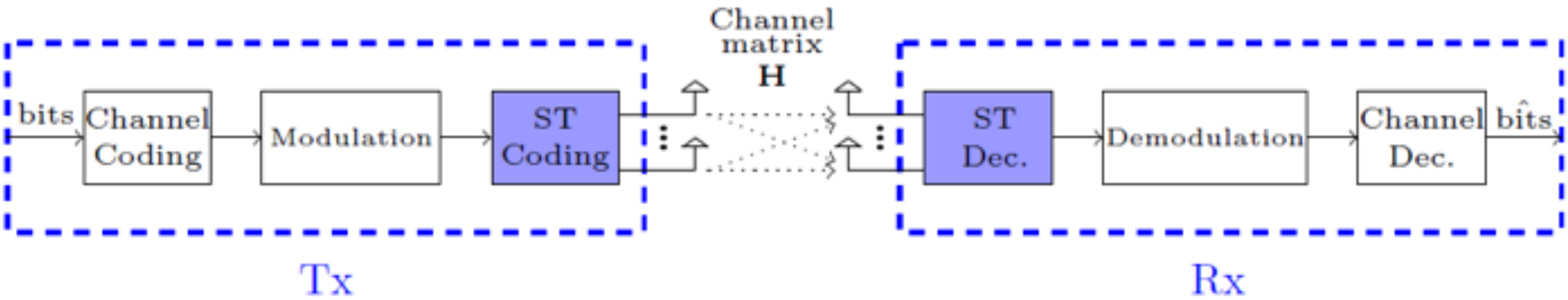
WiFi (IEEE 802.11)

- Commonly used MIMO configurations are 2 x 2, 2 x3 and 3 x 2, with high density modulations (up to 256-QAM).
- MIMO spatial streams up to 8x8 MIMO configurations.
- Simple and low complex MIMO decoders are used today (MMSE and DFE).

5G and Beyond :

- In 4G, some MIMO configurations are : in the Downlink 4x4 and 8x8, in the Uplink 2x4 and 4x4.
- MU-MIMO configurations are also considered : K users communicating with a multi-antenna Base Station.
- Massive MIMO : up to 64 antennas at the Base station.

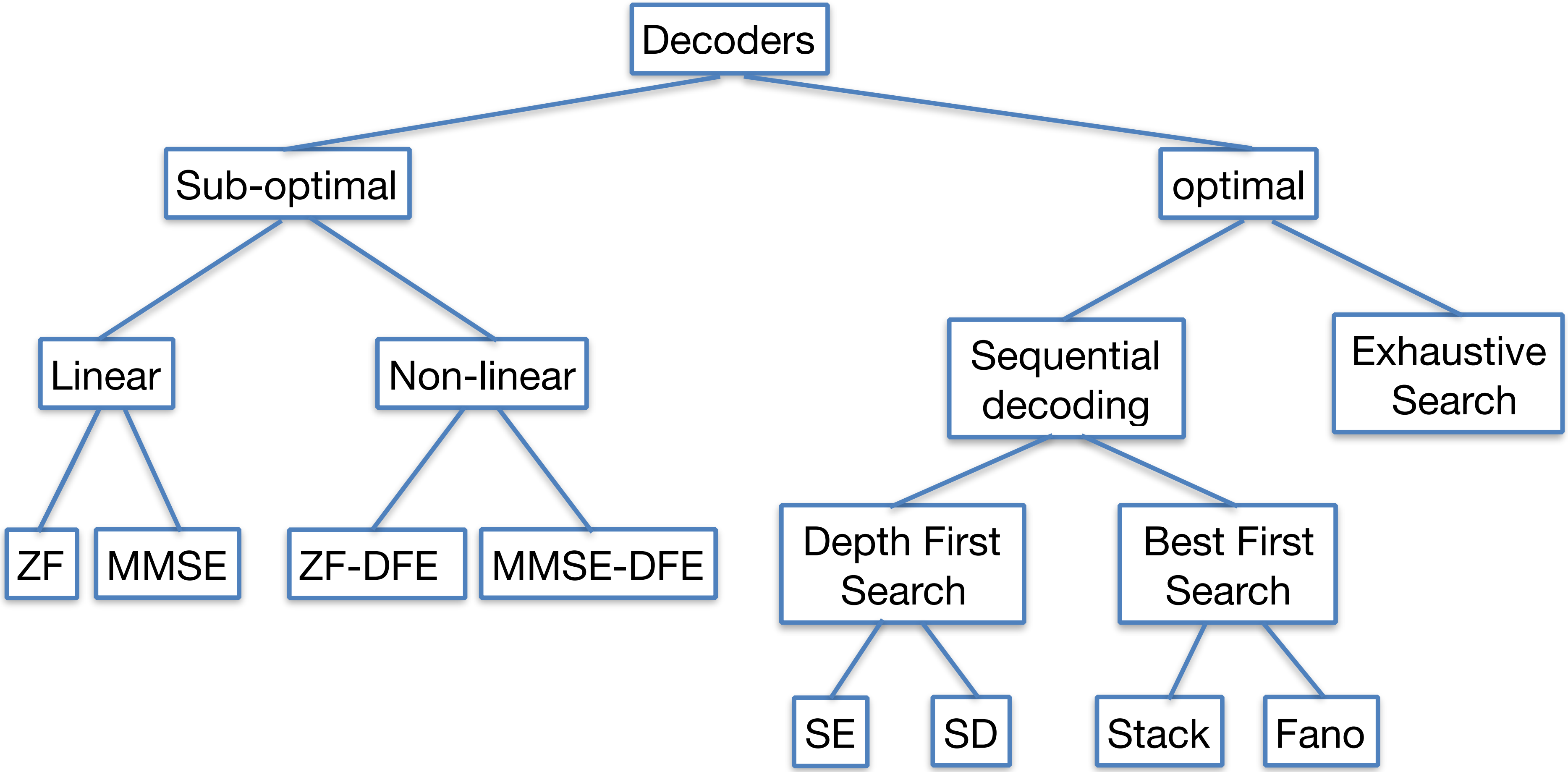
MIMO transmission chain



MIMO systems offer high throuputs and enhance the QoS

- MIMO ST coding: simple spatial multiplexing or Space-Time code
- MIMO ST decoding: Many options that could be optimal or sub-optimal

MIMO decoders



Agile & Smart MIMO Decoding (AS-MIMO)

We propose a **Smart and Agile Decoding scheme** that :

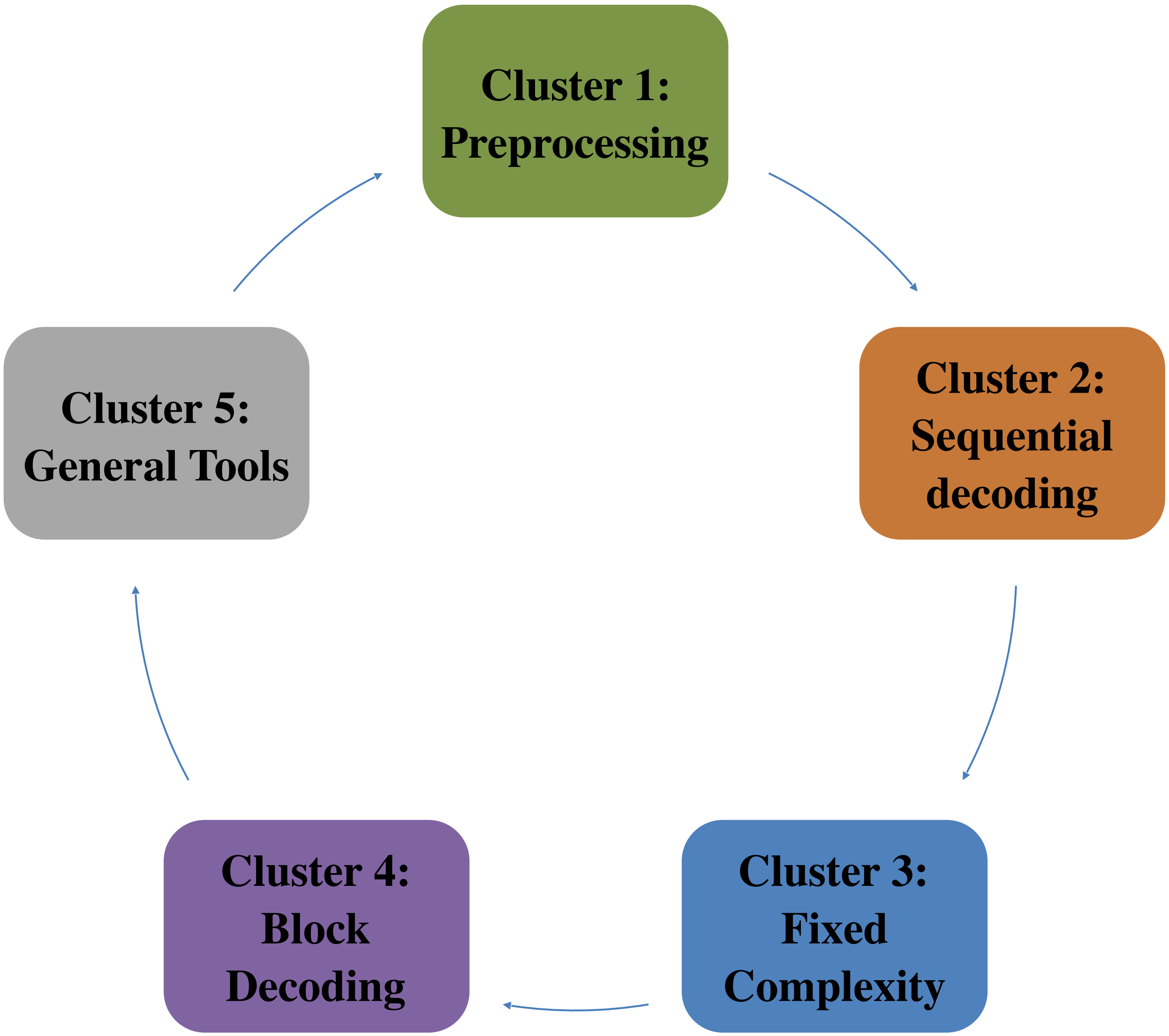
- meet the target QoS specifications for **any application**
- **and** is implementable in **any MIMO configuration,**
- **and** is reconfigurable for **multi-standards** devices**.**

Agile & Smart MIMO Decoding (AS-MIMO)

Some important figures :

- **20 patent families**
- **Countries : FR, EP, US, KR, CN**
- **87 filled patents**
- **28 patents already granted**

AS-MIMO = 5 patent clusters



Cluster 1: Preprocessing

Problem

- Some worst channel realizations can induce very high decoding complexity.

Proposed Solutions

- New techniques to improve the quality of the channel matrix before proceed to the decoding step:
  - Algebraic reduction
  - Augmented LLL reduction

Patents Outcomes

- 2 filed patents : FR0855882 (3), FR0959680 (4).

Cluster 2: Sequential decoding

Problem

- The complexity of the decoding phase increases function of the number of transmit and receive antennas and the modulation size.

Proposed Solutions

- New decoding methods allowing the generation of limited tree search.
  - SB-Stack (Hard output and Soft output)
  - Zig-zag Stack
  - Enhanced initial radius selection methods
  - Parameterized sequential decoding (level, block-dependent bais parameter)
  - Dichotomic Sphere decoder

Patents Outcomes

- 5 filed patents : EP 2274852 (2), EP14306517.5 (6), EP 15305255.0 (7), EP 15306847.3 (11), EP 16305401.8 (16).

Cluster 3: Fixed Complexity

Problem

- For real time applications, a fixed decoding complexity is required.

Proposed Solutions

- New methods allowing to have fixed decoding time with guaranteed performance.
    - Stack reordering for early termination
    - Anticipated termination

Patents Outcomes

- 2 filed patents : EP15305907.6 (9), EP 15305910.0 (10).

Cluster 4: Block Decoding

Problem

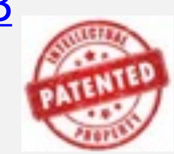
- For large MIMO systems, a parallelization of some decoding process could be a very efficient software and hardware solution.

Proposed Solutions

- A judicious division of the decoding system is proposed based on variant parameters and criterions.
  - Criteria for Block division to ensure an order of diversity, reduce error propagation, reduce sub-block decoding complexity
  - Block reordering
  - Block recursive MIMO decoding
  - Smart parallelization of MIMO block decoding

Patents Outcomes

- 8 filed patents: EP5306808.5 (12), EP 15307153.5 (13), EP 15307154.3 (14), EP 15307155.0 (15), EP 16305417.4 (17), EP16306758.0 (18), EP16306728.3 (19), EP18306628.1 (20).



Cluster 5: General tools

Problem

- Reduce the overall decoding complexity, by considering all the decoding chain.

Proposed Solutions

- We propose new tools/methods to enhance the decoding chain and offer the best complexity/performance tradeoff. These methods are available for all the presented ideas for the 4 patent families.
  - Adaptive decoding
  - MAP decoding using augmented lattice
  - Design criterion for low-complexity decodable Space-Time Codes.

Patents Outcomes

- 3 Filed patents : FR 0850690 (1), FR1359497 (5), EP5305677.5 (8).

Decoding Chain: Clusters association

- Example 1 of a large MIMO decoding chain:

- Example 2 of a real time MIMO decoding chain:

Maturity and Validation

Theoretical Validation

- Some results are validated by a theoretical study, through the derivation of the error probability.
  - Formulas of some parameters and criterion are derived.

Numerical validation

- All the decoding schemes are validated through a **program C simulator**.
  - Complexity is counted as the number of multiplications.
  - Numerical simulations give a very reliable complexity evaluation.
  - Results are mature for practical implementation and product integration.

Patent Portfolio and corresponding publications

	Patent application	Corresponding publication
1	G. Rekaya-Ben Othman, R. Ouertani and J.-C. Belfiore, "Procédé de Décodage d'un Signal Transmis Dans un Système Multi-antenne", French Application filed February 2008, **FR 0850690 Grant**, **EP09709070.8 Grant (DE, GB)** and **US8422598 Grant,** (extension CN).	- R. Ouertani, G. Rekaya-Ben Othman and J-C. Belfiore, "An Adaptive MIMO decoder", IEEE VTC, Barcelona, Spain, April 2009.
2	G. Rekaya-Ben Othman, A. Salah and S. Guillouard, "Procédé de Décodage d'un Signal Mettant en Œuvre une Construction Progressive d'un Arbre de Décodage, Produit Programme d'ordinateur et Signal Correspondants", French patent application filed May 2008, **FR0852985 Grant**, **EP 2274852 (GB,DE) Grant** and **US8421654 Grant**, **CN200980123585.3 Grant**	- R. Ouertani, G. Rekaya-Ben Othman and A. Salah, "The Spherical Bound Stack Decoder", IEEE International Conference WiMob, France, Oct. 2008. - A. Salah, G.Rekaya-Ben Othman, R. Ouertani and S. Guillouard, "New Soft Stack Decoder for MIMO Channel", Asilomar Conference on Signals, Systems and Computers, California, USA, October 2008.
3	G. Rekaya-Ben Othman, L. Luzzi et J-C. Belfiore, "Procédé de Décodage d'un Signal Ayant Subi un Codage Espace-Temps Avant Emission, Dans un Système Multi-Antennaires", French Application filed September 2008, **FR0855882 Grant**.	- L. Luzzi, G.Rekaya-Ben Othman and J-C Belfiore, "Algebraic Reduction for Space-Time Codes Based on Quaternion Algebras", Advances in Mathematics of Communications (AMC), vol. 6, n° 1, February 2012. - G. Rekaya-Ben Othman, L. Luzzi and J-C. Belfiore, "Algebraic Reduction for the Golden Code", IEEE ICC, Dresden, Germany, June 2009.
4	L. Luzzi, G. Rekaya Ben Othman and J-C. Belfiore, "Méthode de Décodage par Réseau de Points Augmenté pour Système Multi-source", French Application filed December 2009, **FR0959680 Grant**.	- L. Luzzi, G. Rekaya-Ben Othman and J-C. Belfiore, "Augmented Lattice Reduction for MIMO decoding", IEEE Transactions on Wireless Communications, vol. 9, n° 9, pp. 2853-2859, September 2010. - L. Luzzi, G. Rekaya Ben Othman and J-C. Belfiore, "Augmented Lattice Reduction for Low Complexity MIMO Decoding", IEEE PIMRC, Istanbul, Turqey, September 2010.
5	A.Mejri et G. Rekaya Ben Othman, "Méthode de Décodage MAP par Réseau de Points Augmenté", French Application filed October 2013, **FR1359497 Grant**, (extension EP,KR,CN, US)	- A. Mejri and G. Rekaya Ben Othman, " MAP Decoder for Physical-Layer Network Coding Using Lattice Sphere Decoding", ICT, Portugal, May 2014. - A. Mejri and G. Rekaya Ben Othman, "Efficient Decoding Algorithms for the Compute-and-Forward Strategy", IEEE Trans. on Com., June 2015.

Patent Portfolio and corresponding publications

	Patent application	Corresponding publication
6	G.Rekaya-Ben Othman and A.Mejri, "Methods and Systems for Decoding a Data Signal Based on the Generation of a Decoding Tree", European patent application, September 2014, **EP14306517.5** (extension HK,CN,KR,US)	A.Mejri and G.Rekaya-BenOthman, « Reduced Complexity Stack Decoder for MIMO Systems », IEEE VTC Conference, Glasgow, UK, May 2015. *(Zigzag stack)*
7	G. Rekaya-Ben Othman and A. Mejri, "Tree Search-Based Decoding", European patent application, February 2015, **EP 15305255.0** (extension HK,CH,,KR,US)	A. Mejri and G. Rekaya-Ben Othman, "Reduced-Complexity Lattice Spherical Decoding", IEEE International Symposium on Wireless Communication Systems, ISWCS, Brussels, Belgium, August 2015. (ZF-DFE radius for SD)
8	G. Rekaya-Ben Othman, A. Mejri and M-A. Khsiba, "Space-Time Coding for Communication Systems", European patent Application April 2015, **EP5305677.5,** (extension HK,CN,KR,US)	A. Mejri, M-A. Khsiba and G. Rekaya Ben Othman, "Reduced-Complexity ML Decodable STBCs: Revisited Design Criteria", IEEE ISWCS, Brussels, Belgium, August 2015.
9	G. Rekaya Ben Othman and Asma Mejri, "Anticipated Termination for Sequential Decoders", European patent application, June 2015, **EP15305907.6,** (extension HK,CN,KR,US)	A. Mejri, G. Rekaya Ben Othman and M.A. Ksiba, "Early Termination Techniques for MIMO Lattice Sequential Decoders", IEEE International Conference on Communications and Networking, November 2015, Tunisia.
10	G. Rekaya Ben Othman and Asma Mejri, "Sequential Decoding With Stack Reordering", European patent application, June 2015, **EP 15305910.0,** (extension HK,CH,,KR,US)	A. Mejri, G. Rekaya Ben Othman and M.A. Ksiba, "Early Termination Techniques for MIMO Lattice Sequential Decoders", IEEE International Conference on Communications and Networking, November 2015, Tunisia.
11	G. Rekaya Ben Othman and Asma Mejri, « Parameterized Sequential Decoding », European patent application, November 2015, **EP 15306847.3, KR10-2016-0153479 Grant, US15/355311 Grant**, (extension HK,CH)	*(bias for each tree level function of SNR, channel coefficient..)*
12	G. Rekaya-Ben Othman, A. Mejri and M-A. Khsiba, « Semi-Exhaustive Recursive Block Decoding Method and Device », November 2015, **EP15306808.5,** (extension HK,CH), **KR10-1890998 Grant, US10116326 Grant**	M.A. Khsiba and G. Rekaya-Ben Othman, "Semi-Exhaustive Reduced-complexity Recursive Block Decoding for MIMO Systems", International Conference on Telecommunications (ICT), Thessaloniki, Greece, May 2016.
13	G. Rekaya-Ben Othman, A. Mejri and M-A. Khsiba, « RECURSIVE SUB-BLOCK DECODING », 2015, **EP 15307153.5, KR1904011 Grant, US9948364 Grant,** (extension HK,CH)	A. Askri, G. Rekaya−Ben Othman and M.A. Khsiba, "Block Recursive MIMO Decoding", International Conference on Telecommunications (ICT), Saint−Malo, France, May 2018.

Patent Portfolio and corresponding publications

	Patent application	Corresponding publication
14	G. Rekaya-Ben Othman, A. Mejri and M-A. Khsiba, « REORDERED SUB-BLOCK DECODING », 2015, **EP 15307154.3, US9819404 Grant, KR1922780 Grant,** (extension CN, HK)	
15	G. Rekaya-Ben Othman, A. Mejri and M-A. Khsiba, « WEIGHTED SEQUENTIAL DECODING », 2015, **EP 15307155.0, KR10-2016-0181433 Grant, US15/390057 Grant**, (extension CN, HK)	*(bias for each sub-block)*
16	G. Rekaya-Ben Othman and M-A. Khsiba, « METHODS AND DEVICES FOR SEQUENTIAL SPHERE DECODING », 2016, **EP 16305401.8, US10284334 Grant**, (extension CN, KR)	M-A. Khsiba and G. Rekaya−Ben Othman, "Dichotomic Sphere Decoder", WCNC, San Francisco, USA, March 2017. M-A. Khsiba and G. Rekaya−Ben Othman, "Sphere Decoder with Dichotomic Search", PIMRC, Montreal, CANADA, October 2017.
17	G. Rekaya-Ben Othman, A. Mejri and M-A. Khsiba, « METHODS AND DEVICES FOR DECODING DATA SIGNALS», 2016, **EP 16305417.4, US10291438 Grant**, (extension CN, KR)	*(choose of preprocessing matrix (like LLL) to enhance sub block cahnnels)*
18	G. Rekaya-Ben Othman, A. Mejri and M-A. Khsiba, «METHODS AND DEVICES FOR SUB-BLOCK DECODING DATA SIGNALS», 2016, **EP16306758.0,** (extension CN,KR, US)	*(criteria fro block division to reduce decoding complexity of sub-block, reduced conditioning number)*
19	G. Rekaya-Ben Othman, A. Mejri and M-A. Khsiba, «METHODS AND DEVICES FOR SUB-BLOCK DECODING DATA SIGNALS», 2016, **EP16306728.3, US10250360 Grant**, (extension CN, KR)	*(criteria fro block division to reduce error propagation , function of zero position in sub-blocks)*
20	G. Rekaya-Ben Othman, «DEVICES AND METHODS FOR PARALLELIZED RECURSIVE BLOCK DECODING», 2018, **EP18306628.1**	