A generic and reconfigurable FEC Transceiver for Multi-RAT Platform

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Abstract— The Multi-RAT (Radio Access Technology) concept in communication devices relates to the ability of adapting to heterogeneous networks. This hardware characteristic is emphasized in the cognitive framework paradigm: “sense, learn, adapt” which specifies the requirements of wireless system modules. Indeed, the front-end module allows network sensing and gives the essential knowledge to a software learning module which selects the adequate technology (cellular, connectivity, broadcast), the resource allocation strategy, in accordance with the admitted quality of service (QoS) and the typical use-case. Then, the entire modem circuitry must adapt by switching to the suitable network which implies reconfiguration, latency and throughput capabilities.

In practice, typical embedded communication systems integrate several unitary chipsets, each of them dedicated to one network. As a consequence, the diversification of standards leads to the multiplication of the circuits, impacts compactness, complexity and price. This solution reduces the set of standards the equipment is compatible with and locks the multi-RAT strategies. However, reconsidering the architecture and signal processing units of the transceiver, a huge amount of factorization can be identified, resulting in high flexibility, complexity reduction, while avoiding performances degradation.

In this paper, we focus on typical mobile, cellular, connectivity and broadcast communication standards. We investigate the specific Forward Error Correction (FEC) functional unit, including Bit Interleaved Coded Modulation (BICM). These mechanisms classically represent up to 70 % of the chipset area. We extracted generic architectures for transmission and reception platform with a mutualized hardware resource. In addition, our work provides some criteria which allow comparing the Multi-RAT implementation. Furthermore, the hardware platform is highly flexible and allows the integration of new features which aims at contributing to the definition of advanced communication technologies.

Keywords— multi-RAT transceiver; FEC; BICM; convolutional codes; LDPC codes; Turbo codes; Wi-Fi; LTE

I. INTRODUCTION

The diversity of radio usages has caused the emergence of a large variety of Radio Access Technologies (RAT) over the past two decades. Since the 2000s, the use of smartphones has proliferated, and any device has to be connected through the internet network. In the next decade, a hyper-connection trend will transform more and more the smartphone into a hub. The current generation of smartphones aggregates both mobile and WLAN like 3GPP LTE [1] and IEEE Wi-Fi [2] radio networks. The next generation should adapt to other supports like Li-Fi or Mm-waves.

From the user point of view, these networks will adapt their protocol stack to facilitate the handover between technologies, in order to decrease the latency and to optimize user experience. From the mobile point of view, the abundance of networks will require hardware resources, by duplicating the digital modem processing units and therefore the number of dedicated chips. Single standard specialized transceivers will no longer be the solution due to the form factor constraints.

The Forward error correction (FEC) sub-layer, which in a wide sense encompasses channel coding, interleaving, rate adaptation and Automatic Repeat reQuest (ARQ) mechanisms, represents a large part of the complexity of a modem chip. The emergence of iterative codes such as LDPC and Turbo codes severely impacts this complexity, even though numerous studies have been done to merge these architectures.

II. MODEM AND FORWARD ERROR CORRECTION IN MULTI-RAT CONTEXT

A. The Multi-RAT Context

The Multi-RAT is based on the cooperation of predefined RAT within connectivity, cellular, broadcast and Internet of Things (IoT) networks. This cooperation is defined within a sub-system (S) of the whole set of radio-communication systems (E). Understanding cooperation issues requires distinguishing the network management from the modem design. The network management encompasses resource allocation strategies in (S) according to network observations (physical channel opportunity) and the user needs. Such strategies are expressed as optimization problems like minimizing criteria (energy consumption, spectral occupation...) under the constraint of QoS fulfilling (throughputs, latency...). The spectral observation yields the estimation of interference generated by the system (ES) into the system (S) as a function of time, frequency and location.

The radio resource allocation first consists in automated strategies for allocating for each user power, time, frequency and space (pre-coding, MIMO space/time coding...). Such a strategy aims, for instance, at serving the maximum number of users under the constraint of differentiated QoS requirements. Afterwards, the link adaptation tunes the adaptive Modulation and Coding Scheme (MCS) compliant with the RAT and guarantees a good throughput/error rate compromise.

Within this scope, the modem collects the corresponding information to select the resource allocation strategy. The
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detection unit must recognize signal patterns of the considered RATs. An appropriate estimation of the signal power level helps the selection of the best RAT.

Fig. 1. Generic description of the Multi-RAT Strategy

So far, for mobile devices, the variability of standards in the radio domain (cellular, connectivity, broadcast...) has led to the aggregation of multiple dedicated modems. This method endlessly raises the circuitry cost and silicon area, and prohibits feature evolutions. A global study of the physical layer for the main deployed standards is needed to enhance the Multi-RAT approach and prepare more ambitious scenarios. Since it occupies 50-70 % of the global gate count on a single standard modem, the FEC sub-layer is critical and is the subject of the following development.

B. FEC and standards

The mobile networks are constantly evolving. 3G and 4G are improving throughput with advanced technologies such as MIMO scheme, which leads to new releases and new mobile classes. GSM has been adapted for IoT usage, and will be followed by LTE [1]. Standards are in constant competition, for example the 4G race between LTE and WiMAX [3].

The connectivity networks are in effervescence. While there are noticeable throughput improvements pending in Wi-Fi networks (IEEE 802.11-2007 [4], IEEE 802.11n [2], IEEE 802.11ac ...), some groups are considering Mm-waves (IEEE 802.15.3c [5]) or Li-Fi (IEEE 802.15.7 [6]).

Broadcast networks, which have not been discussed in the scope of multi-RAT strategies so far, can now be regarded as part of cooperation scenarios including unicast networks, which could have led to better outcome for previous endeavors like DVB-H, DVB-SH or DVB-NGH [7].

III. FORWARD ERROR CORRECTION FEATURES

In a generic overview of the FEC module, three processing units emerge. When ARQ is enabled, a first unit checks the integrity of the received data, with a Cyclic Redundancy Code (CRC) computation. The second one implements the actual data protection. This feature is explained in subsection III.A. In the third one, detailed in subsection III.B, the data stream is adapted according to the quality of the reception delimited by the adaptive coding scheme and the system modulation (MIMO, waveforms, Resource Allocation ...). This stream is then converted into mapped symbols.

Fig. 2. Overview of the generic transmitter and receiver

A. Data Protection

Since the Communication Theory of Shannon [8], a large panel of coding schemes has been investigated and standardized in order to reach the theoretical limit. In coding theory, redundant bits are added to the information stream with a native rate (denoted $R_n$). Each use-case favors a specific code in accordance with a desired Quality of Service. The choice is subject to several criteria which can be divided into two categories. The first set relates to system criteria such as the spectral efficiency, the latency, the BER/PER (Bit/Packet Error Rate), the type of communication or the energy consumption. The second one focuses on channel characteristics such as the link budget, the frequency loss or the Doppler effects.

Despite this apparent heterogeneity, a common denominator can be highlighted. Once set aside the particular case of block codes used by outer coders in broadcast standards (Reed-Solomon or BCH), the remaining type of codes can be gathered into three families: Convolutional Codes (CC), Convolutional turbo codes (TC) and Low-Density Parity-Check (LDPC) codes. Here below follows the large set of standardized configurations that must be addressed. The Inner - Outer code decomposition is described in TABLE I.

<table>
<thead>
<tr>
<th>Standards</th>
<th>Inner code</th>
<th>Outer Code</th>
</tr>
</thead>
<tbody>
<tr>
<td>GSM</td>
<td>CC</td>
<td>-</td>
</tr>
<tr>
<td>UMTS</td>
<td>CC</td>
<td>-</td>
</tr>
<tr>
<td>LTE</td>
<td>CC</td>
<td>-</td>
</tr>
<tr>
<td>DVB-RCT</td>
<td>CC</td>
<td>RS</td>
</tr>
<tr>
<td>DVB-RCS</td>
<td>CC</td>
<td>RS</td>
</tr>
<tr>
<td>IEEE802.11n/ac</td>
<td>CC</td>
<td>-</td>
</tr>
<tr>
<td>IEEE802.15.4</td>
<td>LDPC</td>
<td>RS</td>
</tr>
<tr>
<td>IEEE802.15.3c</td>
<td>CC</td>
<td>-</td>
</tr>
<tr>
<td>IEEE802.15.7</td>
<td>CC</td>
<td>RS</td>
</tr>
<tr>
<td>DVB-S2/T2/C2</td>
<td>LDPC</td>
<td>BCH</td>
</tr>
<tr>
<td>IEEE802.11ad</td>
<td>LDPC</td>
<td>-</td>
</tr>
</tbody>
</table>

TABLE I Inner - Outer code decomposition

CC are characterized by their number of registers $v$ or their constraint length $K_{CC} = v + 1$, their number of inputs $k$ and of outputs $n$. The native rate is given by $R_n = k/n$. CC are
equivalent to a Markov chain, which state is determined by \( k \times n \) polynomials. Major standardized CC are non-recursive non-systematic. They are summarized in TABLE II.

<table>
<thead>
<tr>
<th>Standards</th>
<th>( k )</th>
<th>( n )</th>
<th>( v )</th>
<th>Polynomials (octal)</th>
</tr>
</thead>
<tbody>
<tr>
<td>GSM</td>
<td>1</td>
<td>2</td>
<td>4</td>
<td>23/33</td>
</tr>
<tr>
<td></td>
<td>1</td>
<td>3</td>
<td>4</td>
<td>33/25/37</td>
</tr>
<tr>
<td></td>
<td>1</td>
<td>3</td>
<td>6</td>
<td>133/145/175</td>
</tr>
<tr>
<td>UMTS</td>
<td>1</td>
<td>2</td>
<td>8</td>
<td>561/753</td>
</tr>
<tr>
<td></td>
<td>1</td>
<td>3</td>
<td>8</td>
<td>557/663/711</td>
</tr>
<tr>
<td>LTE</td>
<td>1</td>
<td>3</td>
<td>6</td>
<td>133/171/165</td>
</tr>
<tr>
<td>IEEE802.16m</td>
<td>1</td>
<td>2</td>
<td>6</td>
<td>171/133</td>
</tr>
<tr>
<td>DVB-RCT</td>
<td>1</td>
<td>2</td>
<td>8</td>
<td>561/753</td>
</tr>
<tr>
<td>DVB-RCS</td>
<td>1</td>
<td>2</td>
<td>6</td>
<td>171/133</td>
</tr>
<tr>
<td>DVB-RCS2</td>
<td>1</td>
<td>2</td>
<td>2</td>
<td>5/7</td>
</tr>
<tr>
<td></td>
<td>1</td>
<td>2</td>
<td>3</td>
<td>15/17</td>
</tr>
<tr>
<td>IEEE802.11n</td>
<td>1</td>
<td>2</td>
<td>6</td>
<td>133/175</td>
</tr>
<tr>
<td>IEEE802.15.4</td>
<td>1</td>
<td>2</td>
<td>2</td>
<td>2/5</td>
</tr>
<tr>
<td>IEEE802.15.3c</td>
<td>1</td>
<td>3</td>
<td>6</td>
<td>133/171/165</td>
</tr>
</tbody>
</table>

**TABLE II Convolutional Coding parameters**

Based on CC, TC put in parallel two Recursive Systematic Convolutional codes separated by an interleaver. The number of inputs \( k \) of the constituent CC addresses two kinds of standardized TC: binary TC \((k = 1)\) and double-binary TC \((k = 2)\). They are outlined in TABLE III. The TC native rate \( R_n \) emanates from the CC one and is given by (1).

\[
R_n = \frac{k}{2n-k}
\]

**TABLE III Turbo Coding parameters**

Just like TC, LDPC codes allow to be close to the Shannon limit performance and are standardized in several networks like Wi-Fi. They are defined by a \( K \times N \) parity matrix \( H \). Each matrix transforms \( K \) information bits into \( N = M + K \) bits (represented by the vector \( c \)). The encoding verifies (2).

\[
H \cdot c^T = 0
\]

Architecture-Aware LDPC (AA-LDPC) matrices draw a first standardized LDPC class. Quasi-Cyclic LDPC (QC-LDPC) matrices are the second one. In this latter case, \( H \) is determined by the concatenation of null and cyclic shifted \( z \times z \) identity sub-matrices, where \( z \) defines the expansion factor \( z \). Matrices are summed up in TABLE IV.

<table>
<thead>
<tr>
<th>Standards</th>
<th>Type</th>
<th>Number of matrices</th>
<th>Expansion factor</th>
<th>Max. code length ( n )</th>
</tr>
</thead>
<tbody>
<tr>
<td>IEEE 802.16m</td>
<td>QC</td>
<td>6</td>
<td>24:28:...:96</td>
<td>2304</td>
</tr>
<tr>
<td>DVB-T2</td>
<td>AA</td>
<td>15</td>
<td>360</td>
<td>64800</td>
</tr>
<tr>
<td>DVB-S2</td>
<td>AA</td>
<td>21</td>
<td>360</td>
<td>64800</td>
</tr>
<tr>
<td>IEEE 802.11n</td>
<td>QC</td>
<td>12</td>
<td>27:54:81</td>
<td>1944</td>
</tr>
<tr>
<td>IEEE 802.11ac</td>
<td>QC</td>
<td>12</td>
<td>27:54:81</td>
<td>1944</td>
</tr>
<tr>
<td>IEEE 802.15.3c</td>
<td>QC</td>
<td>4</td>
<td>21</td>
<td>672</td>
</tr>
<tr>
<td>IEEE 802.11ad</td>
<td>QC</td>
<td>4</td>
<td>42</td>
<td>672</td>
</tr>
</tbody>
</table>

**TABLE IV LDPC Coding parameters**

The profusion of configurations described above should not prevent us from considering powerful means of mutualization, as will be explained in section IV.

**B. Link Adaptation**

In spite of the large number of codes introduced in the previous section, the data stream is not perfectly adapted to the system transmission. Indeed, according to Shannon theory, for a given propagation characteristic, there is a maximal throughput which is approximated in practice by a suitable combination of code, code rate and digital constellation. Such a parameter set is referred in literature as MODulation and CODing (MDCOD) or as Modulation and Coding Scheme (MCS). Furthermore the channel characteristic can swiftly evolve inducing burst errors without an adapted protection. This is why bits are ordered by an interleaver along a transmission frame. Here follows an overview of the different techniques used for these purposes.

As exposed in section III.A, each code has its own native coding rate \( R_n \). To match the targeted rate \( R \) used by the MCS of the system \((S)\), each PHY layer has its own strategy. Several codes can be deployed to match the native coding rate and the tuned rate. Usual LDPC codes in DVB, Wi-Fi or WiMAX networks use a set of distinct parity matrices which answer to the rate adaptation. Convolutional based codes such as CC and TC are well adapted to puncturing. In Wi-Fi, WiMAX or DVB-RCS/RCT networks, an adapted cyclic puncturing pattern for both codes is selected.

The interleaver modifies the bit ordering at the end of encoder. A matrix-based interleaver consists in writing the data flow into \( n_R \) rows (resp. in \( n_C \) columns) and read it in columns (resp. in rows). The mathematical form for such a design is given by (3). Most standards integrate one (or several) such interleaver(s) with some refinement to add more randomization.
from this base, hardware architecture criteria are specified (subsection IV.A), then the transmitter (subsection IV.B) and the receiver (subsection IV.C) are optimized.

### Hardware architecture criteria

Each technological unit is required to meet a set of fundamental hardware constraints like throughput $T$ and latency $\delta$. $T$ is related to the number of input bits per unit $N_{in}$, the number of duplicated units $N_{d}$ and the system clock frequency $f_{clk}$ according to (4).

$$T = N_{d} \cdot N_{in} \cdot f_{clk}$$

A first constraint is to determine all these values in order to decrease the hardware complexity (logic cells or silicon surface area) and the energy consumption. Furthermore, latency $\delta$ is inherent to the design. This delay takes into account an incompressible pipeline time noted $\delta_{pip}$ plus a scheduling latency. For fully serial processing such as puncturing and convolutional coding, $\delta$ is equivalent to $\delta_{pip}$.

For block processing such as interleaving, LDPC and turbo coding, $\delta$ satisfies (5) where $B_{l}$ is the block length and $\delta_{B}$ the number of required clock cycles.

$$\delta = \delta_{B} \cdot \frac{B_{l}}{N_{in}} + \delta_{pip}$$

The throughput $T$ is directly depending on the latency with the relations (6-7).

$$T = N_{\Omega} \cdot \frac{B_{l}}{\Omega} \cdot f_{clk}$$

$$T \approx \frac{N_{d} \cdot N_{in}}{\delta_{B}} \cdot f_{clk}$$

This first approximation of throughput and latency quantifies the characteristics of some iterative units such as TC and LDPC decoders. In this domain, a code can be described as the serial concatenation of several decoders units with various block length. They are gathered into the set $\Omega$. One iteration describes the processing inside the entire set $\Omega$. $n_{it}$ representing the number of iterations. In this case, (8) yields the delay and (9) the throughput for blocks of size $K$.

$$\delta = n_{it} \left( \sum_{m=0}^{n_{it}} \frac{\delta_{B}}{n_{in}} \cdot B_{l}(m) + \delta_{pip} \right)$$

$$T = \frac{1}{n_{it}} \cdot \left( \sum_{m=0}^{n_{it}} \frac{K}{\delta_{B}} \cdot B_{l}(m) + \delta_{pip} \right) \cdot f_{clk}$$

For some units, the BER and PER performances are also an important criteria. The throughput can be adjusted by varying $n_{it}$.

From an architecture point of view, the data flow has to be optimized between the different units. An overview is given in Fig. 3. where both de-rempiler and FEC decoder units are working with their own set of parameters. Such a design

### IV. GENERIC TRANSCEIVER ARCHITECTURE

The generic transceiver architecture takes into account the features partition described in section III and shown in Fig. 2., resulting into three technological units. These are a generic coding module (subsection III.A), a generic module combining: RatE Matcher, Puncturer, InterLeaveVER, named rempiler and a mapping module (subsection III.B). Starting from this base, hardware architecture criteria are specified

### TABLE V Standardized Mapping constellation

<table>
<thead>
<tr>
<th>Standards</th>
<th>BPSK</th>
<th>QPSK</th>
<th>QAM</th>
<th>PSK</th>
<th>APSK</th>
</tr>
</thead>
<tbody>
<tr>
<td>IEEE 802.11a</td>
<td>✓</td>
<td>✓</td>
<td>16-, 64-</td>
<td></td>
<td></td>
</tr>
<tr>
<td>IEEE 802.11ac</td>
<td>✓</td>
<td>✓</td>
<td>16-, 64-, 256-</td>
<td></td>
<td></td>
</tr>
<tr>
<td>IEEE 802.11ad</td>
<td>✓</td>
<td>✓</td>
<td>16-, 64-</td>
<td></td>
<td></td>
</tr>
<tr>
<td>IEEE 802.16m</td>
<td>✓</td>
<td>✓</td>
<td>16-, 64-</td>
<td></td>
<td></td>
</tr>
<tr>
<td>IEEE 802.15.3c</td>
<td>✓</td>
<td>✓</td>
<td>16- 8</td>
<td></td>
<td>8-</td>
</tr>
<tr>
<td>UMTS / HSDPA</td>
<td>✓</td>
<td>✓</td>
<td>16-, 8</td>
<td></td>
<td></td>
</tr>
<tr>
<td>LTE / LTE-A</td>
<td>×</td>
<td>✓</td>
<td>16-, 64-</td>
<td></td>
<td></td>
</tr>
<tr>
<td>DVB-RC2</td>
<td>×</td>
<td>✓</td>
<td>16-, 8</td>
<td></td>
<td></td>
</tr>
<tr>
<td>DVB-RC2</td>
<td>×</td>
<td>✓</td>
<td>16- 8</td>
<td></td>
<td></td>
</tr>
<tr>
<td>DVB-S2</td>
<td>×</td>
<td>✓</td>
<td>16- 8</td>
<td></td>
<td>16- 32</td>
</tr>
</tbody>
</table>
ensures a huge flexibility during the processing. When the de-
rempiler block has processed a first codeword (corresponding
to a typical MCS), it is free to process another one with
different parameters even if the following unit (here the
coder) is not ready. Furthermore they can independently
address any standard with adapted parameters. At the end, even
if the latency $\delta$ is quite long, the reconfiguration time is much
lower than the processing one.

Fig. 3. Data flow for reconfigurable receiver

The system constraints are not equivalent between
transmission and reception architecture. Subsections IV.B and
IV.C describe the transmitter (Tx) and the receiver (Rx) side
respectively.

B. The transmitter specific challenge

The transmitter adds redundancy to the information data
flow coming from the upper layer and transforms it into
modulated symbols, in accordance with the system of standards
(S). Considering the architecture in Fig. 2, Tx performs
operations that must be compliant with (S). The main challenge
of the transmitter is to guarantee a good compromise between
latency, throughput and compactness, while ensuring
flexibility.

We propose a generic convolutional encoder which
supports recursive and non-recursive, systematic and non-
systematic CC, compliant with both CC and TC given in
TABLE II and TABLE III. It is based on shifted registers
hardware structure where polynomials are fully parametric. An
internal ARP / QPP TC interleaver has been added to set the
major convolutional based code from the literature. The
architecture of a LDPC encoder module has been integrated to
encode the double-diagonal QC-LDPC family, which fits with
the main IEEE standards. A set of parameters allow addressing
the large variety of codes.

A rempiler module is compliant with the description given
in section III.B for LTE and Wi-Fi mode. The data is also
punctured by a circular buffer-like implementation. The main
complexity for this module lies in the memory address
calculation and accessibility, so that it easily shares its resource
within (S). Hence, the current version of the module illustrates
the proof of concept of a mutualized rempiler module. Further
work is in progress to optimize the throughput of the unit.

Finally, a mapper module links the data stream into physical
symbols with a correspondence table answering BPSK,
QPSK, QAM16 and QAM64 mapping.

C. The receiver specific challenge

The receiver must recover the information sent from the
noisy received mapped symbols. It is usually not standardized
and open to the manufacturers. Nevertheless, it shall respect

the system performance criteria. Latency and throughput have
to respect the system specification. Some features like de-
interleaving or de-puncturing shall perform the invert function
described in specification. These units only have to provide
good throughput with a reasonable compactness.

Good BER/FER performance mainly holds by the FEC
decoding feature. Literature promotes a large set of algorithms
for the main advanced codes. [9] and [10] describe diverse
schedulers for iterative decoding for both LDPC and turbo
codes. [11] approximates the processing to reduce the
complexity. By considering the scheduling, the number of
iterations, the data quantization and the algorithm
approximations, any decoding structure exhibits a different
throughput/area/BER performance. Some of the technological
units, allocating specific code, set of codes or specific family
of codes are summarized in TABLE VI. [13] is using ASIC
technology to adapt the algorithm to specific use-case. Such
architecture gives good throughput with a low complexity,
but is restricted in term of on-the-fly parametrization. [14] shows
interesting properties for binary TC and LDPC decoding but
CC are not supported. Furthermore, the paper does not give
any details concerning the design flexibility.

Table: several decoding architectures

A main innovation proposed here consists in a FEC decoder
unit, based on [12], which removes most locks underlined by
the above proposals. This structure addresses a wide class of
standards and MCS. It is adapted to CC, TC, and LDPC codes.
The parallelism has been studied for both TC and LDPC codes
and summarized in TABLE VII.

Table: impact of the parallelism on the decoding latency
for LDPC and TC codes

<table>
<thead>
<tr>
<th>Codes</th>
<th>Parameters</th>
<th>Latency $\delta$ per iteration (clk cycles)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>$k$</td>
<td>$n$</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Wi-Fi LDPC</td>
<td>-</td>
<td>648</td>
</tr>
<tr>
<td>Wi-Fi LDPC</td>
<td>-</td>
<td>1296</td>
</tr>
<tr>
<td>Wi-Fi LDPC</td>
<td>-</td>
<td>1944</td>
</tr>
<tr>
<td>LTE</td>
<td>40-6144</td>
<td>-</td>
</tr>
</tbody>
</table>

TABLE VII  Impact of the parallelism on the decoding latency
for LDPC and TC codes
This table derives from (8). (9) shows that throughput differs with the diversity of the codes and the number of iterations (set to 6 for TC and 10 for LDPC codes). The main constraint is the reconfiguration latency reduction to achieve less than a decade of clock cycles while switching the circuit to another context with no a priori concerning its parameters. Such a design improves the adaptability of the FEC transceiver which ensures a good multi-RAT flexible strategy.

V. LTE/WI-FI USECASE

A. LTE System Specification

In the LTE system, the physical channel defines the structure of the FEC feature. Both Physical Downlink Shared Channel (PDSCH) and Physical Uplink Shared Channel (PUSCH) propose adaptive modulation and coding scheme with turbo coding. PDSCH checks the reception integrity with a 24-bit CRC, which is not taken back by PUSCH. Each codeword contains at most 6144 information bits. Data segmentation is done for longer payload. A set of 29 MCS which differs between Uplink and Downlink channels is proposed. But due to the large diversity of mobile, the link quality is quantified by a Channel Quality Indicator (CQI) which is referred in TABLE VIII.

Physical Broadcast Channel (PBCH) and other control channels are using CC and 16-bit CRC with a link adaptation to complete the allocated Resource Block, for an information size not exceeding several hundred of bits.

<table>
<thead>
<tr>
<th>Index</th>
<th>Modulation</th>
<th>Rate</th>
<th>Index</th>
<th>Modulation</th>
<th>Rate</th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
<td>BPSK</td>
<td>0.50</td>
<td>8</td>
<td>BPSK</td>
<td>0.50</td>
</tr>
<tr>
<td>1</td>
<td>QPSK</td>
<td>0.50</td>
<td>9</td>
<td>QPSK</td>
<td>0.50</td>
</tr>
<tr>
<td>2</td>
<td>QPSK</td>
<td>0.75</td>
<td>10</td>
<td>QPSK</td>
<td>0.75</td>
</tr>
<tr>
<td>3</td>
<td>QAM16</td>
<td>0.50</td>
<td>11</td>
<td>QAM16</td>
<td>0.50</td>
</tr>
<tr>
<td>4</td>
<td>QAM16</td>
<td>0.75</td>
<td>12</td>
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<td>0.75</td>
</tr>
<tr>
<td>5</td>
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<td>0.67</td>
<td>13</td>
<td>QAM64</td>
<td>0.67</td>
</tr>
<tr>
<td>6</td>
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<td>0.75</td>
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</tr>
<tr>
<td>7</td>
<td>QAM64</td>
<td>0.83</td>
<td>15</td>
<td>QAM64</td>
<td>0.83</td>
</tr>
</tbody>
</table>

TABLE VIII Parameters for LTE CQI

B. Wi-Fi System Specification

The mandatory Wi-Fi mode checks the integrity of the payload with 16-bit CRC. Data is coded by CC initialized to null values for each PDU. At the end of the encoding, tail information is added. The encoded data is interleaved as recalled in subsection III.B and mapped into symbols.

An optional mode favors the LDPC coding. The first step leads to the determination of the codeword length (648, 1296 or 1944). The MCS selects the rate of the LDPC matrix. The codeword length and the rate select the corresponding LDPC matrix which will encode the payload. The payload is first protected by 16-bit CRC. It is then split into several information streams of equal size and padded with null values to reach the information size required by the LDPC matrix. The LDPC processing adds the parity bits. At the end, the padded bits are deleted. An additional puncturing/repetition step adapts the stream to the system frame duration.

B. The platform

The current Wi-Fi standard specifies 76 MCS the definition of which differs from the LTE one. Here, MCS regroups modulation and coding rate but does not include the selection between the CC and the LDPC mode. The MCS combinations for Wi-Fi standards are summarized in TABLE IX. In IEEE 802.11ac, different modulation and rate are selected depending on the spatial stream. These variations depict other MCS schemes.
The information size is the coding information length in accordance with the payload size. This platform allows up to $2^{13}$ bits per codeword.

The puncturing size takes into account the rate of the code after rempler. Maximal length is set to $2^{16}$, which ensures the compatibility with LTE and Wi-Fi MCS.

The constellation selects the modulation pattern between BPSK, QPSK, QAM16 or QAM64.

- The transmission conditions are also defined by the GUI through some parameters like the SNR from -10 dB to 50 dB.
- The current version of the platform switches from a system to another with a very low latency. For synchronization purpose, the external blocks (BER and AWGN) are reset if a new configuration is set at the end of a reception. The system has been tested for several LTE and Wi-Fi MCS with performances shown in Fig. 6. and Fig. 7.

VI. PERSPECTIVES

The current version of the FEC transceiver emphasizes the feasibility of a multi-RAT transceiver at lower cost than integrating single standard chip. But this platform also underlines several upgrading tracks to help the 5G definition.

A. Architecture optimization

The current technological units benefit from a unitary optimization in term of throughput and complexity. Nevertheless, the whole transmitter (resp. receiver) throughput is bottlenecked by the slowest units. Indeed the higher speed technological units are restricted by uphill or downhill module. A better cooperation between these units will improve the generic throughput of the platform. Other improvement will also increase the throughput, by a higher parallelism or by replacing some unit by faster one. In a generic way, upgrading the platform with a set of parallelism parameters shall adapt the complexity/throughput compromise, and then address several QoS. This adaptation could mark off some multi-RAT scenario with architectural criteria, depending on whether complexity or throughput is favored.

B. Standard adaptation

The current technological units are responding to the large variety of specifications and standards. However the platform has been designed with a LTE/Wi-Fi convergence focus. Even if this platform currently supports the predefined MCS for these networks, each standard must be considered deeper to ensure the full compatibility with sub-case scenario and the evolution of the standards. Furthermore, an adaptation on the architecture can be required to target some other standards like WiGig or Li-Fi.

C. Integration

The transceiver is limited to the Forward Error Correction module. It is mandatory to demonstrate a vertical integration in a complete modem IP. A dedicated standard chain like Open Air Interface [18] is suitable to show the full compatibility of the platform with a known reference. It will also certify the feasibility of some advanced algorithms in an entire system case. The downhill modules of the communication chain are not yet integrated. A digital Front-End fitting with current frequency range (below 6 GHz) is necessary to adapt the FEC.
layer to advanced waveform model or new MIMO scheme. Furthermore, it will assess the design in a realistic channel environment.

At last, this platform is well adapted to the multi-RAT context. This version aggregates LTE and several ZWi-Fi systems, the two prevalent standards. It integrates both mandatory and optional characteristics and so it can help to define realistic scenario with a unified LTE/Wi-Fi MAC controller.

D. Research

As described in section IV, this platform is composed by generic technological units. Each unit has its own set of parameters and so the platform can easily select a non-specified Forward Error Correction strategy and prove its performance with a system overview. Such modularity can easily help developing new PHY layer specification or to merge existing ones, with a unique material design support. Moreover, each technological unit can easily be displaced. So the platform can also demonstrate the performance of a new algorithm, a new architecture, or a new coding type, in a system-like platform. The adaptability to several systems will help to push these advanced technologies in accordance with predefined scenarios.

VII. CONCLUSION

This paper has underlined the capacity of a dynamically reconfigurable hardware device to deal with the large diversity of Forward Error Correction mechanisms, with a reduced reconfiguration time. In this paper, we have focused our development on the Link Adaptation and the Data protection for the LTE and the Wi-Fi systems. In other words, we propose a flexible FEC architecture addressing CC, TC and LDPC coding schemes, widely used in standardized systems. Furthermore this architecture is easily adaptable to the future standards.

It is also a first step to help the definition of Quality of Service parameters like the latency or the BER performance with a focus on an architecture point of view for the FEC sub-layer. The extracted criteria can favor a system before a technological handover and provide efficient knowledge for the resource allocation strategies.

REFERENCES

[5] IEEE, IEEE 802.15.3c-2009 - High Rate - WPAN.