Candidate Architecture for MIMO LTE-Advanced Receivers with Multiple Channels Capabilities and Reduced Complexity and Cost

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***Abstract*— In this paper, a candidate architecture for LTE-Advanced receiver is proposed. Based on the combination of MIMO techniques and flexible spectrum access, LTE-Advanced terminals will require the increasing of the analog front-end complexity. To reduce the complexity of the analog front-end, an innovative architecture based on the merge between the double IQ and the code multiplexing structures is proposed. Simulation and measurement results show that, in a Gaussian case, the bit error rate is similar when using the proposed architecture and the state of the art front-end stack-up structure. A complexity evaluation study reveals significantly reduced power consumption of the proposed single front-end architecture.**

***Index Terms*— Low complexity front-end, LTE-Advanced, Double IQ structure, Code multiplexing structure.**

I. Introduction

Internet of things: this is the greatest challenge of mobile communications. All incoming standards need to provide higher throughputs in compact terminals. One can see that all proposed solutions converge towards the same techniques: OFDM, MIMO, adaptive coding and modulation, as well as scalable bandwidths. These techniques require an increasing complexity of terminals, leading to additional cost and power consumption. Particularly from the RF front-ends point of view, OFDM imposes high PAPR constraints and good linearity [1], MIMO conducts to the multiplication of RF chains, scalable bandwidth imposes wider bandwidth characteristics of RF components [2].

Recently, we have proposed several solutions meant to reduce complexity of multi-band [3][4] and multi-antenna [5][6] front-ends. In this article we look forward merging these solutions in order to propose a novel architecture for simplified LTE-Advanced terminals. This matter is treated by the 3GPP [7] working groups that are studying the future mobile phone standards with very high data rates and mobility. In fact, in current propositions for LTE-Advanced PHY-layer, the use of combined multiple-antenna capabilities and multiple separated frequency channels are very seducing for the downlink transmission. Meanwhile the use of these combined techniques supposes high cost architectures for the user embedded terminal.

This paper is organized as follows. Sec. 2 summarizes the main LTE-Advanced key points, focusing on multi-band and multi-antenna needs. The novel architecture is presented in Sec. 3 along with a comparative complexity study. This architecture is dedicated to the multiple-antenna reception of signals composed of two arbitrarily distributed frequency channels. Sec. 4 details simulated and measured performance. Finally, conclusions and forthcoming works are drawn in Sec. 5.

II. LTE-Advanced specifications

A. Requirements

LTE-Advanced, an evolved version of LTE, is currently under investigation in order to fulfill the requirements defined by the International Telecommunications Union (ITU) for next generation mobile communication systems [7].

Requirements for LTE-Advanced are similar to those imposed by LTE, excepting peak data rates and therefore spectral efficiency that should be increased. The goal is to provide peak-data-rates reaching 1 Gbit/s in local areas. Such high data rates require a special spectrum allocation for a 100 MHz range in order to obtain a spectral efficiency reaching a 10 bps/Hz level. This spectrum allocation of the 100 MHz system bandwidth will use the aggregation of individual component carriers [8].

B. Radio access techniques for LTE-Advanced PHY-layer

The very high data rates targeted by the LTE Advanced impose an important increase of the transmission capacity. Based on the Shannon model capacity, the two parameters that allow LTE-Advanced to reach the 1 Gbit/s data rate are the bandwidth and the Signal to Noise Ratio (SNR). In order to improve these two parameters, it is necessary to find tools that can realize these tasks at reasonable cost. The 3GPP working groups are currently starting to take into consideration the technical proposals that can be implemented in order to achieve these requirements such as [9]:

- Wider-band transmission and spectrum sharing,
- Multi-antenna solutions,
- Coordinated multi-point transmission,
- Layered OFDMA multi-access.

The upper part of Fig. 1 illustrates the case of contiguous component carriers. Access to large amounts of contiguous spectrum, reaching up to 100 MHz, may not always be possible. LTE-Advanced could therefore allow the allocation of discontiguous component carriers in separate spectrum. This can be useful for handling scenarios involving the need of large amounts of contiguous spectrum which are not available

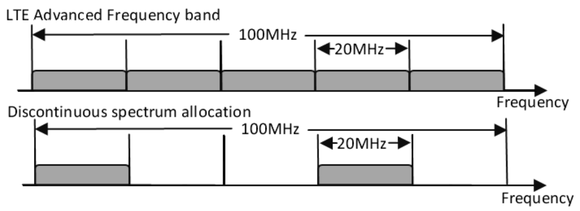

Fig. 1. LTE-Advanced spectrum decomposition and one possible discontinuous spectrum allocation.

(Fig. 1). However, it should be noted that allocation of discontiguous spectrum is challenging from an implementation perspective. Thus, although spectrum allocation would be supported by the basic specifications, the actual implementation will be strongly constrained and should be added to the high constrained implementation of multi-antenna solutions [9].

Multi-antenna techniques and multi-band allocation have a direct influence on the front-end part of the receiver. This study assesses the multi-antenna receiver structure capable of processing a discontinuous spectrum signal (as shown in Fig. 1).

III. LTE-ADVANCED RECEIVER ARCHITECTURE

A. Prior works: low complexity front-end

The analog complexity issue concerning advanced receiver using digital processing has been very little addressed [2]. For both multi-antenna solutions and multi-band allocations, the performance gain implies an increase of the complexity and of the consumption of the analog front-end [10].
Therefore our previous studies aim to improve the performance-consumption-complexity trade-off offered by the analog front-end architectures dedicated to the new radio techniques. Two independant studies explore the use of a single common front-end for the processing of signals received by several antennas:

- The double IQ architecture dedicated to the simultaneous reception of two separate frequency band signals [3][4],
- The code multiplexing architecture for the multi-antenna reception [5][6].

As mentioned in Sec. 2, the future LTE-Advanced standard takes in consideration a discontinuous spectrum usage, as well as multi-antenna techniques for the downlink transmission. In order to answer to these specifications the actual state of the art of radiofrequency receivers imposes the use of dedicated front-end stack-up architectures. For example, if we consider a dual-band discontinuous spectrum scenario where two antennas are used for the reception of a 2x2 MIMO transmission, the receiver will have to integer a four front-end stack-up. Each of these front-ends is dedicated to the processing of one of the contributions obtained from the combination of two antennas and two non-adjacent frequency bands. It becomes obvious that this method imposes high complexity, but especially high power consumption.

Based on the dual band simultaneous reception and the RF code multiplexing architectures, we propose a unique front-end architecture dedicated to the LTE-Advanced receivers. In this paper, we chose to process the two antennas reception of a dual band signal. Meanwhile, the structure can be easily generalized for several antennas by increasing the length of the codes.

B. Structure introduction

The proposed structure is shown in Fig. 2. It consists of 4 main parts: the RF dedicated chains, the RF code multiplexing, the double IQ structure and the digital part including code demultiplexing and multi-antenna processing.
We consider that the two input signals S and S' are the result of the propagation of a bi-band signal through two different channels. Let Band$_1$-Band$_2$ and Band'$_1$-Band'$_2$ be the two pairs of contribution composing S and S' respectively, such as:

$$S = \text{Band}_1 + \text{Band}_2, \quad (1)$$
$$S\text{'} = \text{Band'}_1 + \text{Band'}_2. \quad (2)$$

Once received, each of the two input signals are separately filtered and amplified by a dedicated RF filter and a dedicated LNA, as shown in Fig. 2.
The multiplexing of the four contributions is realized by a two step method. First, we use the RF orthogonal code spreading technique in order to multiplex the two input signal as described in [5]. Let c_1S, c_2S' be the signals resulting from the coding technique:

$$c_1S = c_1\text{Band}_1 + c_1\text{Band}_2, \quad (3)$$
$$c_2S\text{'} = c_2\text{Band'}_1 + c_2\text{Band'}_2. \quad (4)$$

The orthogonal codes must have a chip time two times smaller than the symbol time of each of the two bands. When multiplied with the orthogonal codes, each of the frequency bands Band$_1$ and Band$_2$ of the signal c_1S (respectively Band'$_1$ and Band'$_2$ for the signal c_2S') will be spread in the same manner around their own central frequency, as shown in Fig. 2. This multiplexing step is concluded by the addition of the c_1S and c_2S' signals. Therefore, by using the code spreading technique, the antennas' contributions having the same central frequency are multiplexed two by two.

The second block of the architecture assessed is implementing the double IQ technique. While this technique is generally used in image frequency rejection front-ends [11], we have recently proposed a novel architecture dedicated to the simultaneous reception of two separate frequency band signals [3]. The double IQ structure multiplexes the two band during the translation from RF to baseband, it consists of two IQ translations as described in Fig. 2.
An important aspect is the choice of the first local oscillator LO$_1$ frequency. This frequency is chosen in such a manner that each of the useful signals has its spectrum situated in the image frequency band of the other. In the baseband domain, the four obtained signals are digitized. The baseband component of the two useful signals is obtained by using two dedicated basic operations processing described in [3]. Theses digital

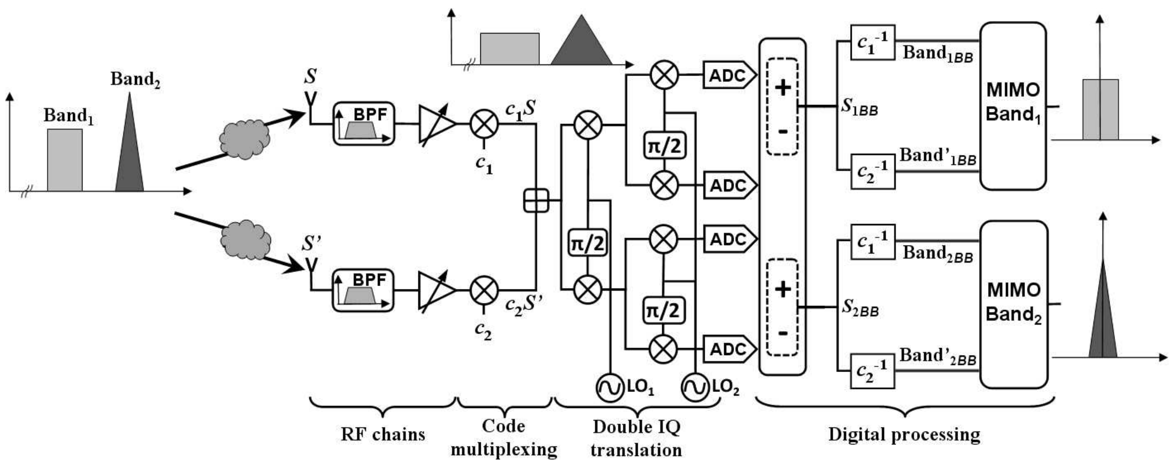

Fig. 2. Candidate Architecture LTE-Advanced Receivers capable of realizing a multi-antennas processing of a discontinuous spectrum signal.

outputs S_{1BB} and S_{2BB} are the baseband contribution of the two coded frequency bands:

$$S_{1BB} = c_1 \text{Band}_{1BB} + c_2 \text{Band'}_{1BB}, \quad (5)$$

$$S_{2BB} = c_1 \text{Band}_{2BB} + c_2 \text{Band'}_{2BB}. \quad (6)$$

In order to demultiplex each of these two pairs of signals, we apply two digital filters matched to the codes.
Once we separately obtain the two pairs of signals corresponding to the two antennas reception of a dual band signal, two antennas SIMO processing are used, one for each band. The antenna diversity digital processing used in this study is the classical Sample Matrix Inversion (SMI) [12]. It uses the training sequence in order to compute the optimal combination of different signals using an adaptive algorithm based on a Minimum Mean Square Error (MMSE) criterion.

C. *Power consumption study*

In order to evaluate the complexity gain of the structure, a comparative power consumption study was made. We considered that the single proposed architecture, as well as the front-end stack-up imposes the same constrains to the basic blocks (LNA, filters, amplifiers, mixers and oscillators). A bibliography research allowed us to choose the state of the art of these basic components in terms of performance-power consumption trade-off. The conclusion of this study shows a 33% power consumption gain in favor of the proposed architecture (211 mW instead of 315 mW). The main reason of this gain is due to the use of fewer basic blocks. In order to illustrate this idea, Fig. 3 shows the consumption of the different types of basic blocks used by the proposed architecture and the front-end stack-up. Adding that the complexity is significantly smaller (fewer components and image frequency filter free), it becomes obvious that the proposed structure offers an excellent performance-consumption-complexity trade-off.

IV. SIMULATED AND EXPERIMENTAL VALIDATION

The single front-end receiver presented above is capable of answering to the LTE-Advanced requirements concerning the MIMO reception of a discontinuous spectrum signal. In order

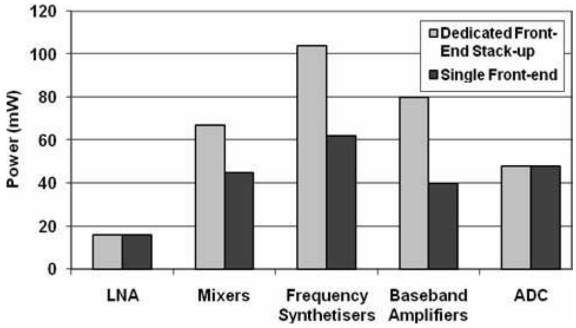

Fig. 3. Consumption of the different types of basic blocks used by the single front-end architecture and the dedicated front-end stack-up.

to validate the theoretical study, we realized several simulations and measurements. First, two complete LTE-Advanced transmission systems have been modeled using the Advanced Design System (ADS) software: one using the front-end stack-up, the other using the proposed single front-end. Then, a connected solution [13] has been realized for both solutions in order to obtain realistic measurements.

A. *Simulations results*

Knowing that the physical layer requirements concerning LTE-Advanced are not yet finalized, we choose to use a particular RF signal model for these simulations. In order to obtain an OFDM signal having a discontinuous spectrum, we use a signal composed of the addition of two 802.11g non-overlapping channels. The transmission channel is an AWGN (Additive White Gaussian Noise) one.
The results presented in Fig. 4 show the BER evolution for different $\frac{E_b}{N_0}$ of the antenna input signal. The receivers are using either the proposed unique front-end architecture ("DoubleStructure") or the dedicated front-end stack-up architecture ("Stack-up"). The results shown in Fig. 4 are mainly concerning the SIMO receivers using the two different architectures when receiving the dual-channel signal. Meanwhile we also show the BER evolution when the receivers are realizing a SISO reception. Both in the SIMO and SISO case, the performance obtained when using the front-end stack-up architecture are slightly better compare to those obtained with

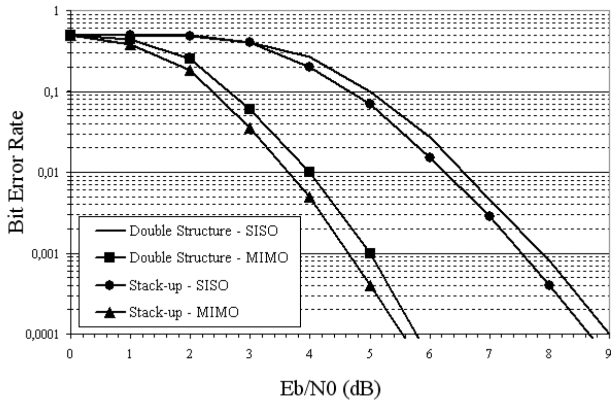

Fig. 4. Simulated BER evolutions during the simultaneous SIMO reception of a signal composed of two non-overlapping 802.11g channels.

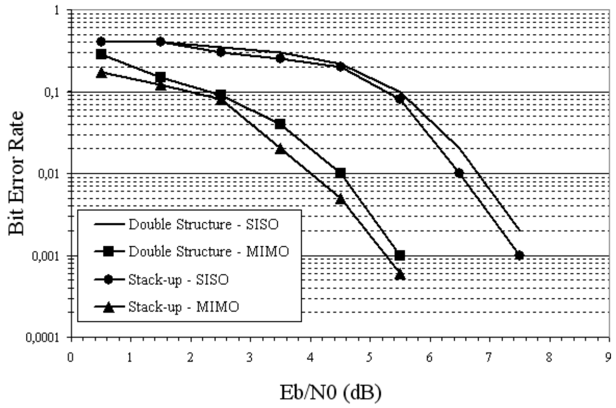

Fig. 5. Measured BER evolutions during the simultaneous SIMO reception of a signal composed of two non-overlapping 802.11g channels.

the unique front-end structure. This is due to the fact that the codes used by the proposed structure are not perfectly orthogonals during simulation. We observe that the SIMO reception offers the same performance gain when using the two architectures, it turns around 3 dB. This processing gain is the theoretical result that a two antennas system should reach in a AWGN channel. In conclusion we consider that the performance of the proposed architecture are the same as those of the dedicated front-end stack-up.

B. Experimental results

BER measurements are realized for an AWGN channel and for different SNR of the antennas inputs. The measures are given for both the proposed unique front-end architecture ("DoubleStructure") and the dedicated front-end stack-up architecture ("Stack-up"). The BER evolutions of the second antenna are shown in Fig. 5 for both SISO and SIMO receivers.

Compared to the simulated results shown in Fig. 4, the measured results are somewhat degraded, the difference is due to the channel used for the measurement which may not exactly be an AWGN one. The $\frac{E_b}{N_0}$ gap between the classical and code multiplexing structures is almost the same during the measurements as that obtained during the simulations. It turns around 1 dB for a BER=10^{-2}. A SIMO gain of 2.5 dB is reached for the two structures.

V. CONCLUSIONS

In this paper, a novel low complexity architecture was presented. We consider that this type of architecture is a good candidate to the integration in the receivers dedicated to the future LTE-Advanced standard. One of the major advantages of this architecture is its low complexity and therefore low power consumption. Indeed, despite the use of a demultiplex block in the digital domain, the proposed architecture offers a significant 33% of power gain compared with the solution proposed by the actual state of the art.

The proposed architecture joins two separate innovating methods: the RF orthogonal coding and the double IQ dual band simultaneous reception technique. Expected performance of its implementation has been presented for a particular study case - SIMO reception of an OFDM discontinuous spectrum signal. The simulation results show similar performance when comparing the proposed unique front-end structure and the dedicated front-end stack-up.

The forthcoming of our study is to address the adjacent channel case by increasing the code rate or implementing an interference rejection algorithm.

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