PhD Thesis: Wideband Wireless Full-Duplex transceivers for 5G communications

Abstract: In recent years, the concept of full-duplex (FD) communications has been the subject of a large attention from the scientific community. Recent advances in both analog and digital parts of radio transceivers offer now the possibility to consider the use of the full-duplex approach for operational systems. Unfortunately, current developments are mainly focused on narrowband systems. The heart of this thesis will be to target wider band systems, and reconfigurable or multiple bands. This choice has major impacts on the design of the system architecture level, be it analog or digital parts. In addition, the thesis aims to experiment with such architectures and evaluate performance in the context of applications such as real-time relaying for cellular systems and secure communications through self-jamming.

Keywords: wireless communications, RF architecture, digital processing, full-duplex.

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Context and main objectives

Usually in wireless communications, the wireless medium is a shared and limited resource. Current wireless standards always share the medium with Half-Duplex principle: the transmission and reception of signals are done in two separate time slots or two different frequency bands. Besides, the transceiver can only transmit and receive one signal at the same time at the same frequency.

More recent research works are focusing on an alternate approach: instead of sharing the medium with Half-Duplex principle, the entire licensed frequency band is shared for simultaneous transmission and reception, what is called Full-Duplex. The major drawback of this kind of Full-Duplex system is therefore that a very high level of interference is created by the transceiver itself while trying to receive a distant signal (known as the self-interference). Besides, the design concept for a wideband flexible radio transceiver which can process two different types of signals at a time is still very challenging.

In recent years, the concept of in-band full-duplex (IBFD) communications has attracted considerable attention in the scientific community. Recent advances in both analog and digital parts of radio transceivers offer now the possibility to consider the use of concurrent bi-directional communication for real-world systems and in particular for next generation of wireless communication.

In-band full-duplex wireless not only offers the potential to double spectral efficiency, but also provides new means for flexible use of spectrum and better radio access protocols, and could drastically reduce the latency. Furthermore, most benefits of IBFD go far beyond the physical layer. It is thus widely considered as a promising technology building block for the new 5G air interface.

However, even today, current developments of the 4G network could take a large advantage of using IBFD mechanisms. Inband relaying could greatly improve the efficiency of the spectrum usage,
by smartly reusing subcarriers or more generally resource blocks. Moreover, FD can offer a
tremendous increase in the use of the cognitive radio paradigm: the ability to continuously sense the
spectrum, even when transmitting data is an enabling technology for this type of systems.

Finally, the FD principle offers a completely new way of thinking wireless networking, not only
dedicated for cellular networks. Of course, IBFD will not always be the best way of improving
wireless connectivity, but it will certainly be one important option to consider in any kind of future
radio systems. The capacity increase, the reduction of latency, the continuous capability of sensing are
the main advantages, but also from the physical layer security point of view, IBFD could offer the
ability to continuously jam the medium while communicating.

In the past years, considerable efforts have been devoted to prove the potential of using in-band
full-duplex for future wireless communications, both from the hardware side and the networking side.
The major difficulty of IBFD being the large amount of self-interference (SI), this interference is
mitigated at three levels in the transceiver: antenna cancellation, analog cancellation, and digital
cancellation. However, most of the proposed structures are inherently limited to fixed narrowband
operations and almost no system-level demonstrations exist that prove the value of IBFD beyond a
straightforward bi-directional link. Moreover, most of existing studies are based on theoretical
analyses, simulations, or simple experimental testbeds.

Therefore, the goal of this thesis is threefold:
- To propose and develop some wideband and/or flexible radio architectures dedicated to full-
duplex communications, from the antenna to the digital compensation implementation;
- To develop new facilities of experimentations for wideband Full-duplex based on the proposed
architectures, enabling a large scale testbed integrating several parallel FD communications, i.e.,
integrating self and external interference;
- To establish some reference scenarios to be tested with these facilities, for specific
applications in practice beyond the usual toy-example of a straightforward bi-directional. In particular,
we plan to explore and demonstrate applications such as secure communications through self-
jamming, the use of primary-user detection in Cognitive Radios, or also the combination of Spatial
Modulation with FD.

Previous knowledge

Our laboratory has already a strong and recognized background on Full-Duplex communications.
A first thesis was dedicated to this subject, paving the way for more realistic developments and
applications. Besides, another thesis has started this year, to study the theoretical bounds of physical
layer secrecy by using FD.

Therefore, we have already proposed an architecture enabling FD communications. To approach
this goal, we use an active analog radio frequency self-interference cancellation (AARFSIC) method
or a combination scheme of the AARFSIC and active digital self-interference cancellation in time
domain (ADSICT) to cancel the strong self-interference (SI) induced by the Full-Duplex principle.
Based on the Full-Duplex radio, we proposed a flexible Full-Duplex Dual-Band (FDDB) OFDM radio
transceiver by combining the Dual-Band RF front-end with Full-Duplex.

These proposed architectures have been studied in theory and in simulations, thus the main goal of
this thesis will be to develop some practical experimentations of Full-Duplex communications, based
on Vector Signal Generators and Vector Signal Analyzers, in connection with simulated parts for
digital processing purpose. Furthermore, some experiments in the Cortexlab facility is a main
objective of this work (www.cortexlab.fr).
Apart from the material part, the proposed tools are the Matlab and the Keysight’s ADS software. The thesis will take place within the Socrate team of the CITI laboratory (http://www.citi-lab.fr/).

**Working plan**

The overall schedule of the thesis is quite simple. The first six months will be dedicated to an exhaustive state-of-the-art not only on Full-Duplex systems but also on all progress on wideband and flexible radio systems and on interference cancellation algorithms. The remaining of the first year will focus on building the framework of theoretical studies and the associated simulation tools.

The second year will be devoted to extensive theoretical and simulation investigations, as long as choice of the required equipment for experimentations. By the end of this second year, everything should be fixed in order to be able to begin experimentations in the third year.

The third and final year of the thesis will see the production of scientific results via publications of the most significant works, extensive experimentations with feedback on theoretical and simulation studies and global drawing of the potentialities of exploitation of the proposed techniques. A large dissemination to the community is planned in order to encourage the use of these approaches in future communication networks. Finally the thesis manuscript will be written and the thesis will be defended.

Of course, a large dissemination of the proposed works will be ensured in international conferences, high quality journals and potentially via patents. Our goal is also to collaborate in COST actions, particularly we are strongly involved in the new IRACON action (merge of the NEWCOM# and COST IC1004) and therefore this will offer a good place of interaction with other European partners. We also expect that this project will be a first step to build a larger consortium for future H2020 calls and to participate in the definition of new standards, particularly to encourage the integration of Full-Duplex in the 5G networks.

**Bibliography:**


