Wlan Preamble Detection Methods in a Multi-Antenna, Multi-Standards Software Defined Radio Architecture

Laurent Alaus, Guillaume Villemaud, Pierre-Francois Morlat, Jean-Marie Gorce

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L. Alaus*, G. Villemaud*, P.F. Morlat*, J.M. Gorce*

*CITI-INSA, 21, av. Jean Capelle, 69621 Villeurbanne, France
Guillaume.villemaud@insa-lyon.fr

Abstract

This paper presents a comparison of different detection methods which could be used to sense a frequency band in order to select a particular channel and a particular communication standard in a wideband melted signal. Here we focus on a generic WLAN receiver based on SDR principles, capable of sampling several overlapping channels to demodulate simultaneously concurrent users possibly using different waveforms.

1 Introduction

Software Defined Radio (SDR) is a well-known concept, particularly promising to combine numerous communication standards in a single receiver [1]. Thus, this powerful approach could be associated with multi-antenna principles to enhance terminal capabilities by the way of SIMO or MIMO algorithms, naturally offering interference rejection possibilities.

In order to tend to a really cognitive system, a first step is to allow a wideband detection of all received signals (supposing wideband front-ends), enabling an efficient characterization of all possible standards.

This paper presents in the first part the general structure of a SDR testbed dedicated to combine multi-antenna, multi-standard and multi-channel approach. This supposes to have several antennas, with several RF front-ends and wideband ADC, enabling to sample more than only one channel. Then it appears possible to numerically select the desired channel and also characterize the standard used. Moreover, this system could allow the test of interference cancellation techniques on adjacent channels, combined with multi-antenna algorithms [2].

Then the second part will focus on the first and fundamental step of the digital receiver: detection and characterization of present signals. Therefore different methods to detect and also analyze the quality of particular frames in melted signals are discussed. The aim is there to provide a good trade-off between precision and computation cost, to offer a fast decision of the presence of useable information and, in case of several emitters, the quality of each link. Of course, the idea is to characterize the signal before any demodulation step to automatically choose which numerical blocks have to be processed to recover data.

For a practical case of study, two cohabitating standards (without any cooperation) of WLAN systems are used, 802.11b and 802.11g. Three families of detection methods have been explored: correlators with period detection, cyclostationarity and second order moment estimator detector.

To compare those methods, an indoor environment was simulated with 802.11b and 802.11g frames emitted, and one or two antennas at the receiver. AWGN or multipath channel were observed with interferer along seven different overlapping channels. Results are discussed in terms of performance versus complexity.

Finally, the impact of using a multi-antenna algorithm associated with these methods was investigated by the way of a SMI approach [3].

2 Structure of the SDR receiver

2.1 Global multi-* approach

A common view of the future for wireless communications is the trend toward systems enabling a fusion of numerous standards, always offering the highest quality. Some devices already propose several integrated functionalities by the way of hardware duplication, even in a single chip package. Of course the idealist vision of universal software radio is very seducing, but yet actual limitations in sampling capabilities can not let imagine it for high frequency systems. Even though, SDR principles are mostly applicable to design flexible multi-standard transceivers, requiring a large scale RF part and powerful common digital processing resources.

Based on well-known considerations, this part describes the use and merging of some popular concepts in the field of converged wireless systems, placed from the receiver point of view, and targeting a flexible test platform for such structures. Let us now list the most meaningful principles used in our general approach.

Multi-standard approach - To achieve the wireless convergence, as said above, a SDR architecture with a common baseband processing seems very appealing. This implies that all parts of the receiving process are done numerically, except the downconversion. In this way, each technology will no longer relies on a particular chip, but on a software package, allowing dynamical changes, parallel decoding, and also update or new bundle downloads. Then a particular attention should be paid on calculation resources, assuming a maximum reuse of basic functions for all standards (FFT, filtering...) and a precise dimensioning to achieve real time operations. This relies both on computation capabilities and on RF Front-end design. SDR proposals often suggest direct conversion architectures, arguing that heterodyne systems can not fit every standard needs. Thus, zero or lowIF designs are generally preferred, all possible RF bandwidths being transposed to the same low frequency band before sampling. These simple and cost effective architectures greatly impact on baseband signal properties, inducing numerical compensation to be processed.

Multi-antenna approach - This is a very hot topic in the area of wireless systems. Even from the only receiver point of view, multiplying antennas offers a high potential to compensate radio channel fading and interference. Indeed, receiving several copies of the same signal allows spatial diversity, with possible spatial rejection, or combined space-time processing. In large angular spread configurations (e.g. urban or indoor), a great benefit could also be taken from time or polarization diversity. All incoming works on wireless applications deal with at least both space and time combiners from the simplest forms (antenna switch, FIR...) to advanced techniques like space-time coding (Alamouti code, Trellis or block-coding for MIMO systems). Then these popular techniques have to be evaluated in realistic environments enabling an efficient tradeoff between expected performances and the increase of RF needs (multiple front-ends, power consumption...) as well as calculation needs (DSP, FPGA, processor with also an impact on energy management).

Multi-channel approach - There we talk about multiple frequency channel approach. Classical receivers, after selection of its allowed channel for communication, operate a frequency tuning in its RF part to only filter this chosen band, naturally operating an adjacent channel rejection. A global supervision of the network is needed to ensure that all co- and adjacent channel interference are efficiently reduced. A very relevant example is the 2.4 GHz bandwidth for 802.11 systems: this 84 MHz large band is shared between up to 14 overlapping 22 MHz channels. Therefore frequency-reuse is a hard point for dense networks, usually leading to high interference levels. Numerous interference rejection or multi-user detection techniques are well-known, generally dedicated to a single channel filtering. We discuss herein the opportunity of a wider sampling, offering a larger numerical information of the desired signal together with interferers. Then different techniques of interference mitigation, rejection (co- or adjacent channel), or parallel decoding can be involved. Of course, this principle comes with consequences on RF specifications (wideband operation) and digital processing (several potential additional noises).

Global combined approach - Of course all those multi-* approaches already offer meaningful performances separately. Nevertheless combining these seducing principles in a global test platform allow evaluating all possible trade-off between joint or dissociated processing. Indeed this platform must be able to support additional technologies like CDMA or OFDM. A general scheme of such a platform is described in the following part (Fig. 1), with a particular attention paid on RF architecture choice and numerical compensation techniques [4].
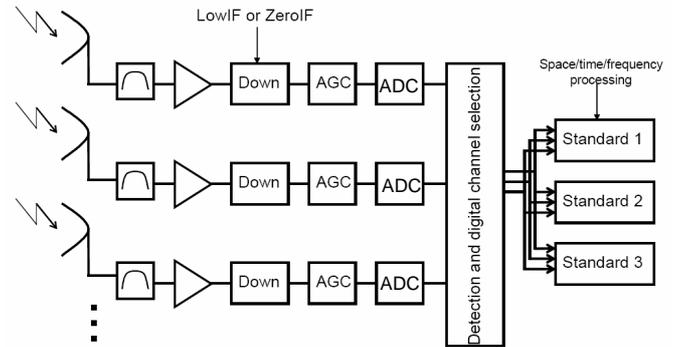

Figure 1: General architecture of a multi-* SDR receiver

2.2 General architecture discussion

The key point of such a multi-* architecture is obviously the analog to digital converter. Because a sampling frequency of few GHz is unachievable, the conversion implies a limited bandwidth. The agility of a receiver is then driven by two features: the carrier frequency tuneless and the maximal bandwidth. The first allows the receiver to process many standards as a function of the frequency band. On the opposite, the second allows the receiver to manage simultaneously several signals of same technology over adjacent channels. Note that both may converge in a near future because the radio bands are saturated and several standards should be called for co-existing on the same band.

In co-existing systems, interference plays a major role in limiting the overall capacity. There is no doubt that all techniques of interference mitigation are going to be studied in depth. The SDR framework offers a first way to increase this capability. Indeed, the use of a high sampling frequency permits interference cancelling of adjacent channels by the use of multi-user detection. Multi-antennas is also a very complementary technology to avoid or mitigate interference. Finally, a full and efficient agility depends on both RF front-end features and numerical processing.

RF Front-End features - To properly balance subsystem performance we must be aware of the limitations of the analog RF front-end considering that compensation can be made numerically. In most systems, the receiver tends to be more complex than the transmitter. The first challenge of receiver design is the Dynamic Range. RF front-end of a receiver must separate a desired signal typically from -130 dBm to –70 dBm, from a background RF environment that may be in the relative range from –20 dB to 0 dB. In many systems, the RF front-end also sets the system signal to noise ratio and should be designed to add minimal noise. Thus the

overall system must have a considerable dynamic range to accommodate both the high-power background signals and the lowestpower desired signal. Dynamic range is limited at the bottom of the range by noise that enters the system through thermals effects of the components or through non-idealities of the ADC, such as quantization noise or sampling aperture jitter. Low level signals can be masked by this noise. Dynamic range is limited at the high-end by interference. The source of this interference could be co-channel, adjacent channel, or self induced by the transceiver. High interference levels may cause the receiver to become more non-linear and introduce cross products (spurious components), which may inhibit the detection of low-level signals or reduce the desired signal bit error rate (BER). Simply attenuating the high-level signal before they drive the receiver into a non-linear operating region is insufficient since low-level desired signals also present will be attenuated until masked. The tunable radio frequency receiver consists in an antenna connected to a RF bandpass filter (BPF). The BPF selects the signal and the low noise amplifier (LNA) with the automatic gain control (AGC) raises the signal level for compatibility with the ADC. The BPF bandwidth relative to the carrier frequency must be highly selective and today it is impossible to design a filter at RF or microwave frequencies. Whatever the technology, it is clearly impractical. Firstly, the difficulty in designing a tuned radio frequency receiver is the limitation of the ADC, which must handle high frequency signals. In addition, to give the bandwidth and rolloff limitations of the RF filter, the sampling rate of the ADC must be high enough to avoid significant aliasing. The consequence of high sampling rate conversion is high power consumption. The ADC must accommodate multiple signals over the wide bandwidth of the RF filter (in tens of megahertz) with dynamic range of 100 dB and its non-idealities, such as jitter, lead to distortion of the signal.

Numerical processing - In such a framework, the signal of interest reaches the processor, over-sampled and mixed with other interfering signals. Thus, several functions have to be implemented in a multi-* SDR numerical receiver: signal detection, synchronisation, downsampling, RF impairment mitigation, beamforming, etc …

The complexity of the digital receiver is strongly related to the efficiency of the RF front-end. For multiple antennas, the balance between the RF front-end and numerical processing increases further. For each data channel, a digital demodulation is needed, providing an equivalent narrow-band signal. The over-sampling eases the time synchronisation and mitigation, but in turns is subject to an increase of the sampling noise due to possible high power adjacent channels. This loss of efficiency may be compensated by the use of multiuser detection techniques taking into account adjacent channels and several standards. In this context, the multiple antennas architecture appears promising, because more signals can be separated. The counterpart is the need of a multi-channel ADC.

3 Channel detection and characterization

3.1 Different methods

The first and fundamental step of signal processing is to detect that an interesting signal is present. Designers must pay attention to avoid expensive algorithms if there is nothing to receive all the time. Numerous methods exist to detect a desired signal, and the overall complexity essentially depends on the amount of known information and the amount of desired information. The use of singularities in a particular standard eases the detection, but that supposes a multiplication for each targeted standard. On the other hand, blind techniques are hard to implement and offer poor information on the signal quality. Let us now list the most useful techniques.

Energy based signal detection - Usually, standard detectors use power detection methods to distinguish the offset of energy, characteristic of the presence of a signal. The detection is based on some function of the received samples which is compared to a threshold. Energy detectors are often used due to simplicity and good performance, but offer limitation in the case of spread signals and produce an important level of false detections.

Matched filter and correlation detection method - The cross-correlation is a measure of similarity of two signals, commonly used to find features in an unknown signal by comparing it to a known one. If a signal is correlated with itself (autocorrelation), then the maximum value of the correlation can be found at a time shift of 0. If this maximum is above a known threshold, the detection is proved. The most utilized technique provides a matched filter and a correlation detection method that carries out a correlation on a received signal with known periodic codes inserted as in the case of a 802.11b preamble.

Cyclostastionarity Detection - A cyclostationary signal is a signal which contains a hidden periodicity [5,6]. A time-series x(t) contains a second order periodicity with frequency "a" if and only if there exists some stable Quadratic Time Invariant (QTI) transformation of x(t) into y(t) such that y(t) contains first-order periodicity with frequency a. The most obvious QTI transformation is a simple square modulus. Then cyclostastionarity detection becomes simple periodicity detection [7]. Moreover, calculating the different cyclic autocorrelation functions and identifying the non-zero values is also used to underline a cyclostastionary signal and detect the cyclic period, but this process is much more complex.

Of course various combinations of these techniques could be used depending on the desired complexity. In a multi-antenna context, some benefits could also be taken from the different copies of the signal, but considering that the synchronization is not yet performed. Until detection is proved and synchronization achieved, the full benefit of spatial diversity could be taken as describe in the following part.

3.2 Case of study

Our actual case of study is based on 802.11b and 802.11g standards. As said previously, if considered as in a non-cooperative behaviour, those two protocols presents high levels of interference in the 2.4 GHz ISM band, with strongly

overlapping channels. We are then developing a multi-* SDR receiver with 4 antennas at 2.4 GHz with a 80 MHz sampling offering an actual 40 MHz baseband. Thus we could find several overlapping channels with both possible standards in the sampled signal. Figure 2 presents the main numerical blocks required for one arm of this receiver.
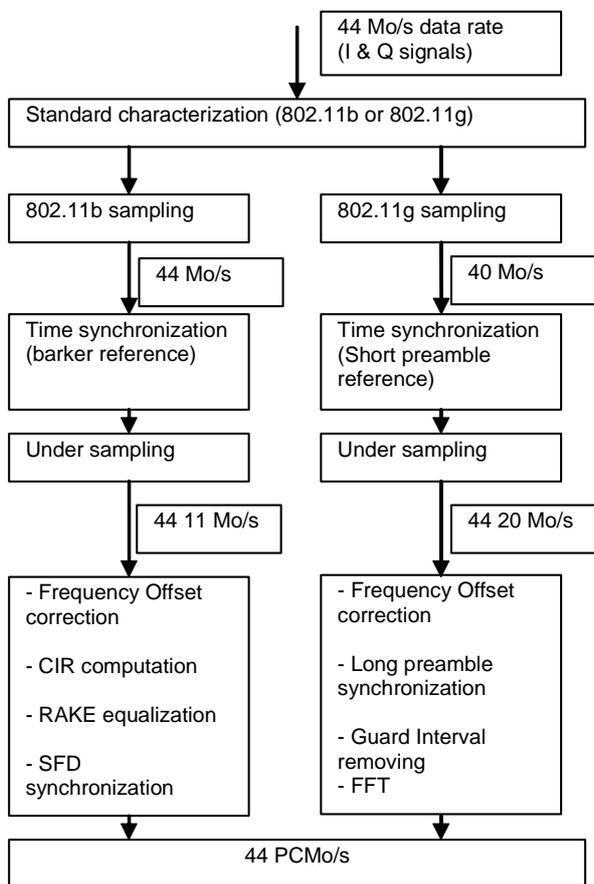

Figure 2: General structure of the software WLAN receiver

By the way, the first block consists on the characterization of potentially interesting signal. We then estimate the cost-performances trade-off of different detection methods.

Therefore, the first method is based on a classical correlation of the received signal and a reference one, but enhanced by a periodicity detection (CPD), allowing a good separation of both kinds of signals. This prevents problems on defining a detection threshold. The second method is based on cyclostationarity detection [6, 5]. Here the detection is based on the periodicity of higher order moments, and could be performed in time domain or in frequency domain based on the nullity of these moments at cyclic frequencies. Then, the third method considers fluctuations of second order moment estimators [7], detecting variation of those estimators corresponding to the symbol period.

For each method, an important consideration is to find a useable period of the signal depending of the waveform. As exposed on figure 3, the DSSS used for 802.11b present a 11

μs periodicity while the OFDM preamble of 802.11g could be characterized by a 16 μs format.

Figure 3: Frame structure for 802.11b (upper) et 802.11g (lower)

3.3 Results

To compare those methods, an indoor environment was simulated with 802.11b and 802.11g frames emitted, and one or two antennas at the receiver. AWGN or multipath channel were observed with interferer along seven different overlapping channels. Results presented on figure 4 are quite equivalent in terms of performances, but an important difference to be noticed is on complexity (Table 1). Hence, the CPD is the most robust in front of noise or interference with a low complexity but could not offer information of the better present mode, if both 802.11b and 802.11g standards are present. Frequency cyclostationarity and estimator detection characterize the quality of each signal with relatively good thresholds (ratio versus interferer considering SNR on figure 4). Thus, the estimator method is less complex but also less accurate.

After all, the use of multi-antenna capabilities by the SMI algorithm notably enhances performances of such methods with only two antennas.

4 Conclusions

SDR concept combined with multi-channel and SIMO processing in the same terminal is a very promising issue to develop future wireless receivers ensuring high data rate and robust transmissions. The aim of this work was to present a global SDR system designed to combine several multi-* capabilities in a single receiver. Then we expose performances of different detection techniques to choose channels of interest and characterize the standard to deal with. Therefore, the CPD is the most robust in front of noise or interference with a low complexity and estimator detection characterize the quality of each signal with relatively good thresholds. Obviously, combining multiple antennas enhances performances of such methods with modest additional computation cost.

Incoming works are dealing with more analysis and estimation of WLAN performances in a multi-channel configuration. Studies about implementation of more efficient multi-antenna algorithms in order to permit better interferers mitigation could also be interesting.

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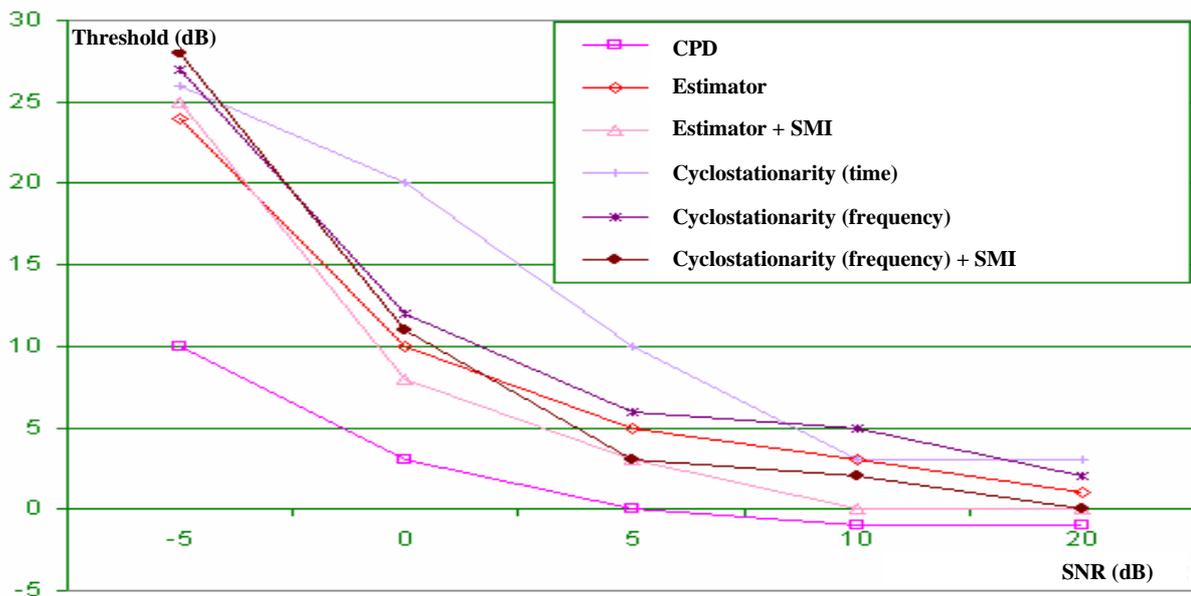
Figure 4: Obtained detection threshold in a multipath channel versus signal to noise ratio with different methods

Samples	Correlation	Estimator	Estimator - SMI -	Cyclostationarity - Frequency -	Cyclostationarity - Frequency - SMI -	Time (us)
40	1 600	1 025	2 825	2 498 380	2 690 380	0,91
80	6 400	11 600	22 800	40 457 560	41 993 560	1,82
100	10 000	26 914	47 539	99 014 950	102 014 950	2,27

Table 1: Duty cycle complexity of different methods