ATTRIBUTES OF REAL TIME INTELLIGENCE IN FLEXIBLE RADIOS

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ABSTRACT

Attributes of real-time intelligence in flexible radios are partially investigated in this article. Two design aspects of flexible transceivers are presented: the first explores concepts related to Dynamic Signal Design in an OFDM-based radio transceiver, and the second concerns blind recognition of different types of analog modulation waveforms.

1. INTRODUCTION

In future radio systems design, real-time intelligence and flexibility in the transceiver will feature prominently. Certain elements of such flexible radios are the ability of the transceiver to identify the standard, the system configuration, the channel or the type of received data with the minimum *a priori* knowledge of these parameters. In order to be real-time intelligent, a transceiver must possess the ability to identify these parameters quickly according to instantaneous system configuration, channel characteristics, etc. The concept of Dynamic Signal Design (DSD), discussed in section 2, provides real-time information for the channel state and combines adaptivity and reconfigurability techniques in the framework of flexible radios.

Flexibility, as introduced in [1], encompasses the notions of adaptivity and reconfigurability in the transceiver design. At the physical layer the scope for a flexible and reconfigurable transceiver is to be able to respond to various changes in the requirements or the specifications (present or future). These can be service (or user) requirements and their related attributes (data rates, Quality of Service, latency constraints, security, etc.), network-level requirements (e.g., efficient resource allocation), "environmental" conditions (channel changes, mobility, other user-interference, other-system interference, etc.), or system-level conditions.

Additionally, blind recognition/estimation of various parameters is another attribute of autonomous behavior in flexible radios. It provides the transceivers with the ability to recognize system and channel characteristics without any prior knowledge of those parameters, except perhaps the menu of possibilities for, say, the modulation type. In section 3, the concept of blind acquisition of various parameters is discussed and the example of analog-modulated waveform recognition is presented.

2. DYNAMIC SIGNAL DESIGN

The theoretical basis for a flexible transceiver includes link adaptation techniques, where modulation, coding and other transmission parameters are dynamically adjusted to varying channel conditions. Classical link adaptation techniques try to minimize the bit error rate (in the performance-oriented approaches) or to maximize the bit rate (in the throughput-oriented approaches), given the fixed transmission power. Another goal for optimization techniques is to satisfy user requirements for the BER and the bit rate at the lowest possible power consumption. Adaptive modulation and coding, adaptive space time frequency (STF) coding, weak sub-carrier excision (WSCE), adaptive equalization and frequency-offset/phase-noise compensation are few examples of the adaptivity concept in coded-OFDM systems [2].

Dynamic Signal Design (DSD) was discussed in the WindFlex project [1],[2] and it is an example of flexible physical-layer design approach. It refers to the optimization procedure performed in a dedicated module at the physical link layer, called *supervisor*. This module incorporates adaptive techniques and performs negotiations with the higher layers. It is related closely to the class of adaptive signal design techniques already discussed extensively in the literature [3], combined with various reconfigurability aspects of modern transceivers. It is important to note that DSD transceivers are not identical to Software Defined Radio (SDR), in particular due to a heavier emphasis on reconfigurable HW, autonomous (self) optimization and adjustment to the environment (DSD includes notions of "smart" and "cognitive" radio). This built-in intelligence within the modem directs the run-time adaptation and reconfiguration of the transceiver chain according to the physical-layer QoS requirements and the channel state.

The purpose of DSD applied to transceivers is to provide the user with a system that can dynamically (in real-time) find the best possible compromise between a number of contradictory design goals, such as minimum power consumption, robustness against reception errors due to channel variations and interference, spectral efficiency, system capacity and so forth. A system is called *dynamic* if it is either *adaptive* or *reconfigurable* (or both) in a real-time sense, based on run-time measurements and resulting actions. The analysis of one specific example of DSD is presented in [4] and it is based on the WindFlex system configuration [1],[2]. The modulation scheme is OFDM, along with a powerful turbo coded scheme. Two design constraints have been adopted: same constellation size for all subcarriers, as well as same power for all within an OFDM symbol.

Two adaptation algorithms have been proposed [4] that minimize the transmission power. The first algorithm uses an approximation of the coded system performance derived in [4] and the second employs “hard” (or on-off) bit loading by excluding from transmission the sub-carriers with the smaller channel gains. This method is called Weak Sub-Carrier Excision (WSCE). The significance of WSCE is the ability to choose between different code rates for the same target rate, a feature absent from the first version.

Algorithm #1

1. Select the code rate, constellation size based on the target bit rate.
2. Read the required uncoded BER (from a look up table) based on the target BER.
3. Find the average SNR needed in order to reach the required uncoded BER
4. Compute the power needed in order to achieve the required average SNR, based on the current average SNR.
5. If required power > maximum available power, re-negotiate QoS (lower the requirements) and go to step 1; else output the power/constellation size/code rate

Algorithm #2

1. Select the competitive triplets of: {code rate, constellation, WSCE%}, based on the target rate.
2. Read the required uncoded BER (from a LUT) for each of the choices.
3. Find the average SNR needed in order to get the required uncoded BER for each choice.
4. Compute the power in order to achieve the required average SNR based on the current average SNR for each choice.
5. If required power > max available power for all the triplets, then re-negotiate QoS and go to step 1; else, output the triplet with the min power requirement.

Simulation results [4] indicate a 2dB performance gain at operational BER of 10^{-5} by using the adaptation algorithm #1 and 4dB gain by using algorithm #2, for a NLOS indoor channel.

3. BLIND WAVEFORM RECOGNITION

For specific applications (i.e. sensor networks, ad-hoc networks, short packet communications, intelligent vehicular systems, military communications), it is of interest for the receiver to recognize the channel conditions or the type of transmitted data, with the minimum possible *a priori* knowledge of system and channel parameters. Additionally, the ability of a transceiver to respond to various changes in the requirements or the specifications (present or future), implies that the receiver will be able to receive, recognize and classify data streams from a variety of sources.

Blind acquisition and estimation works in the above mentioned direction. An essential component of this theory is Modulation Classification (MC), where the receiver chooses the right type of an unknown transmitted modulation, from a finite menu of digital options. Likelihood-based modulation classification is one of the techniques where joint channel estimation and modulation classification is performed. In this case the MC problem is viewed as a multiple-hypothesis testing problem where likelihood techniques are used for its solution. Once the correct modulation type is known, signal demodulation and information extraction can take place. For digital MC, likelihood based algorithms have already been proposed in the literature [5].

Recognition of analog modulated waveforms is a topic that is complementary to digital MC. The goal for the receiver is to be able to recognize and accept analog modulated information in addition to digital modulated streams. Under this framework, a trellis-based recognition algorithm has been developed for blind recognition between an Amplitude Modulation (DSB-SC) and a Frequency Modulation (FM) waveform. The likelihood metric calculations provide the information of the type of analog modulation used.

4. CONCLUSIONS

The aforementioned techniques aim at developing various stages and/or components of flexible and intelligent transceivers. There is a lot of research activity in those topics but also a lot of open issues. The attributes of real-time intelligence emphasized herein comprise an integral part of research activities in the broader area of flexible radios.

5. REFERENCES

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