Performance of a Multimode, Multiband Receiver for OFDM and Cellular Systems[1]

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Abstract: Wireless communication is experiencing a proliferation in technologies and standards worldwide. This is expected to continue in the future. In addition to existing second generation cellular networks, third generation cellular systems and WLAN technologies are currently being deployed, allowing higher data rate communications. The concept of a multimode transceiver which can simultaneously operate within cellular and WLAN environments becomes increasingly significant as these technologies become more popular. Software radio is a potential solution for the implementation of reconfigurable transceivers, thus allowing the provision of services using different access technologies. This paper considers a multimode receiver architecture, based on bandpass sampling, suitable for operation in cellular and WLAN systems.

1. Introduction

The future of wireless communications can be considered as a plethora of heterogeneous systems operating together with current and legacy technologies. One view point of fourth generation wireless communications is the seamless integration of a wide variety of systems for efficient service provision. It is envisaged that reconfigurable radio will be an important feature in the solution of providing interoperability of transceivers in a number of different wireless systems [1].

Software radio or reconfigurable radio systems may be an efficient solution for the provision of multimode, multiband reconfigurable transceivers. The transceiver can be programmed to operate in different systems by changing software modules which define the radio functionality. The ideal software radio transceiver essentially consists of a wideband RF stage, wideband linear digitisation stage, which is as close to the antenna as possible in the transceiver chain, followed by programmable hardware [2]. Sampling close to the antenna can be enabled by employing bandpass sampling. Digitisation can be implemented efficiently, allowing the frequency downconversion of the received signal from RF or IF without the use of mixers.

This paper presents a receiver architecture capable of simultaneously receiving signals from a WLAN and cellular system which can be implemented as a software radio. An OFDM signal, and a single carrier - QPSK modulated signal are used to represent the signals from WLAN and cellular systems respectively. The paper begins by introducing the bandpass sampling concept which is used to digitise and downconvert the received signal. This is followed by a brief description of OFDM and then a discussion of the multimode receiver architecture. Finally, the simulation model and results are presented for various investigations regarding IF filtering, signal spacing, and sampling frequency.

2. Bandpass Sampling

Bandpass sampling is a variation on the sampling theorem where the sampling rate is significantly less than the Nyquist rate, thus resulting in intentional aliasing. However, if the sampling rate is chosen carefully, and is greater than twice the signal bandwidth, spectrum overlap will not occur and the signal can be recovered with little distortion. The range of allowable sampling rates for first order uniform bandpass sampling is given in [3]. The inherent aliasing property of bandpass sampling allows for signal translation from an RF or IF, down to a lower IF. The relationship between the carrier frequency, sampling rate and IF is discussed in [4]. The translated signal is in fact a copy of the signal spectrum resulting from the sampling process. Care must be taken to ensure that the low-IF signal has correct orientation since inverse spectral placement can occur, and the conjugate of the signal is obtained [5].

A number of technical challenges are associated with bandpass sampling which must be addressed in order to achieve high performance. The analogue-to-digital converter has a limited analogue input bandwidth and thus any signal which is to be digitised must fall within this bandwidth. High performance ADCs suitable for use in wireless communications receivers have an analogue input bandwidth of the order of a few hundred Megahertz, thus preventing digitisation of RF signals for cellular and WLAN systems at present. At least one stage of heterodyning is necessary before analogue-to-digital conversion.

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[1] This paper is based, in part, on our paper "Investigation of the Performance of a Multimode, Multiband Receiver for OFDM and Cellular Systems" which will be presented at the IEEE Vehicular Technology Conference – VTC2003-Fall 2003, 6–9 October 2003, Orlando, USA.

During the sampling process, all energy from DC to the bandwidth of the ADC is aliased in to the passband resulting from sampling (equivalent to half the sampling rate). Therefore it is very important to attenuate all out-of-band noise and interference. A bandpass filter with steep roll-off and high stopband attenuation is necessary to achieve this desired suppression of noise and interference. This can be difficult to achieve at higher frequencies, especially if the signal to be sampled is narrowband.

Another problem associated with the analogue-to-digital conversion is the effect of aperture jitter, which becomes more significant as sampling occurs at higher carrier frequencies [6].

3. OFDM

OFDM (orthogonal frequency division multiplexing) is a spectrum efficient multi-carrier transmission scheme [7]. OFDM is used in many broadcast and WLAN schemes and is also considered to be a prospective modulation scheme for future wireless systems. One of its most important characteristics is mitigation of the effects of multi-path fading since the symbol period is made to be longer than the delay spread by multiplexing a high data rate signal on to a number of equally spaced carriers.

The IFFT provides a computationally efficient method of multiplexing the complex data symbols on to sub-carriers while preserving the modulated sub-carriers' orthogonality. This is important in order to minimise inter-carrier interference. One of the criteria for preserving orthogonality is that the sub-carrier spacing must be 1/T where T is the time interval of the OFDM symbol.

In practical OFDM systems, in order to alleviate ISI (inter-symbol interference) and ICI (inter-carrier interference) caused by frequency selective fading, each OFDM symbol is cyclically extended, such that the cyclic prefix duration exceeds that of the channel delay spread [7].

4. Simulation Model and Results

For software radio implementation of a multimode receiver capable of simultaneously receiving a WLAN and cellular system, the most efficient arrangement is such that a wideband front-end RF stage is realised, heterodyning the two signals to two distinct intermediate frequencies. Once the WLAN and cellular signals are downconverted to different IFs, a single ADC can be used to sample, and digitise the signals. Using bandpass sampling results in the translation of these signals to two distinct low-IF positions. This arrangement has been investigated previously by Akos et al. in [4] where signals from two satellite navigation broadcast systems are directly digitised at RF. Digitising at RF is currently impractical to realise for WLAN and cellular receiver purposes, therefore the heterodyning of the received RF signals to IF is preferred. Reference [4] provides useful expressions to ensure that signals do not overlap or alias during the sampling process.

The model used for the investigations in this paper is shown in Figure 1. An OFDM signal is generated and transmitted, centred on a carrier f_{c1}. A single carrier QPSK signal is generated and transmitted, centred on f_{c2}. To simplify the modelling process, such carrier frequencies were not taken as the nominal radio frequencies used by WLAN and cellular systems, but are "intermediate frequencies," therefore ideal RF stage can be assumed and then omitted from both transmitters and the receiver.

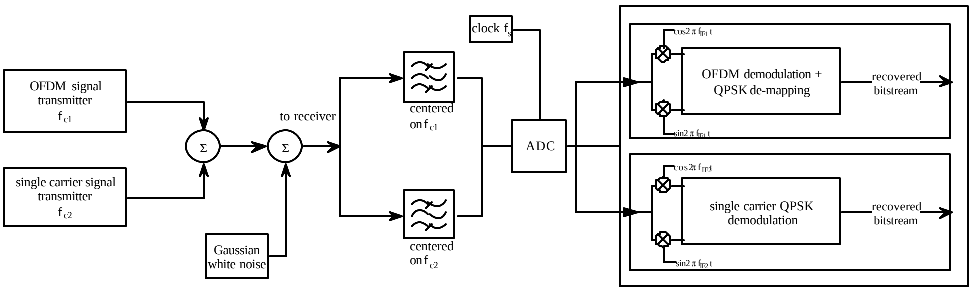

Figure 1. Architecture of multimode, multiband receiver model

Before the model described above was used, a slight variation was investigated. Instead of using a two IF filter solution, a single wideband filter was implemented and the performance investigated. The advantage of this arrangement is the use of a single wideband filter instead of two IF filters. However, there is considerable potential for adjacent channel interference between the two types of signal. In the model, the transmit powers of the two signals are adjusted such that they have equal E_b/N_o after passing through the AWGN channel. The sampling rate is set to 104MHz, achievable using high performance ADCs suitable for basestation use in wireless networks [8]. Results of the performance of this receiver architecture are presented in Figure 2. It can be seen that the BER performance of the OFDM signal in the presence of the single carrier signal, and the BER performance of the single carrier signal in the presence of the OFDM signal are severely degraded when compared to theoretical QPSK performance. This performance degradation is due to the adjacent channel interference between the two signals. Performance is improved when only one of the signals are transmitted and received, and can be improved further by using narrowband IF filters with increased stopband attenuation.

Filtering the two signals separately, as shown in Figure 1**,** results in an improvement in performance as illustrated by Figure 3, showing the transmitter and IF filtering of a single signal (either single carrier or OFDM), where each filter bandwidth is narrower than that of the single IF filter case above. Figure 4 presents the performance when the two signals are transmitted simultaneously and the distance between their carriers is changed from 7.5MHz to 12.5MHz. An improvement in performance can be seen when comp ared to the single wideband IF filter case. The difference in performance can be attributed to the interference associated with spectrum copies due to sampling. The position of the signals must be taken in to account in order to minimise signal distortion due to spectral overlap since the position of the IF signals with respect to the sampling rate (f_s) and in particular with respect to multiples of the folding frequency ($f_s/2$) is important.

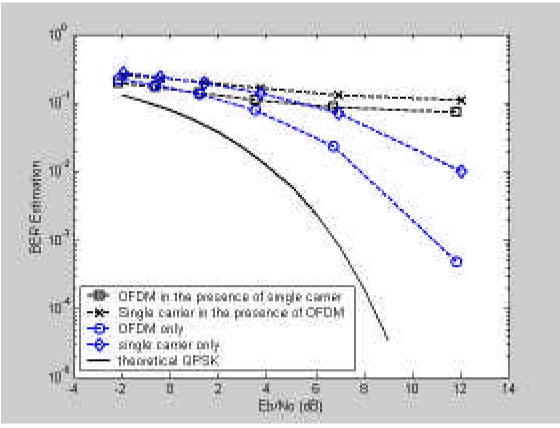

Figure 2. Performance in AWGN for a single IF filter solution

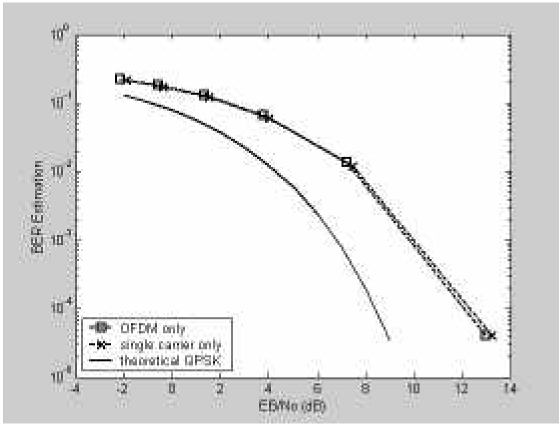

Figure 3. Performance in AWGN of OFDM and single carrier signal with a two IF filter solution

Increasing the sampling rate with respect to the signal bandwidth, (but keeping such rates less than the Nyquist rate) results in further spaced out spectrum copies subsequent to the sampling process. This implies that it is less likely for aliasing to occur, but once again, this is also dependent on IF position with respect to the sampling rate, and signal bandwidth. Figure 5 illustrates the performance of the multimode receiver when the sampling is changed from 104MHz, down to 57.78MHz. The spacing between the carriers of the two signals remains constant at 12.5MHz. It is observed that performance of the single carrier signal in the presence of the OFDM signal degrades when the sampling rate is reduced from 104MHz to 57.78MHz. This is due to the increase in noise in the sampled passband due to the intentional aliasing process when the sampling rate is decreased i.e. more aliasing of noise occurs with lower sampling rates.

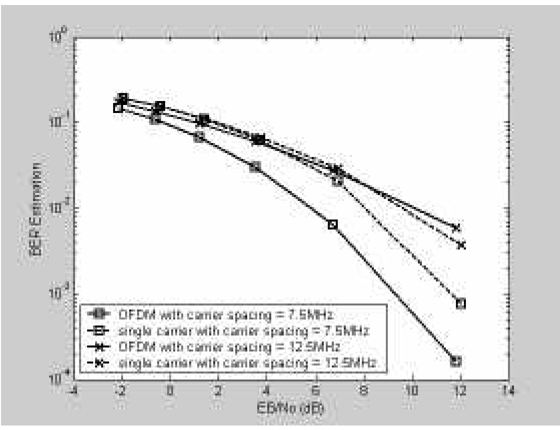

Figure 4. Performance in AWGN with different carrier spacing between the OFDM signal and the single carrier signal

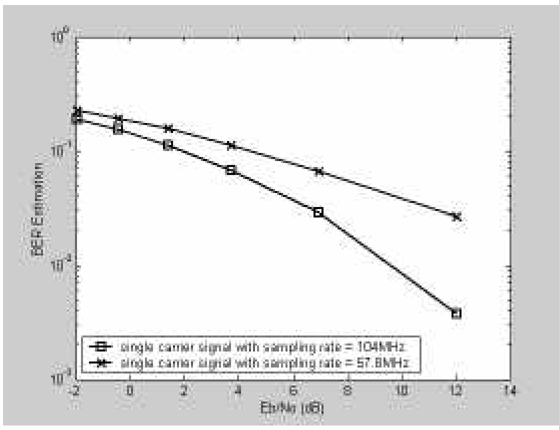

Figure 5. Performance in AWGN with different sampling rates

Finally the effect of spacing the two signals such that the distance between carrier frequencies is greater than the folding frequency is investigated. This implies that the two signals experience different amounts of intentional aliasing and are translated to low-IF positions which can be closer to each other when compared to the original IF positions. For this investigation the sampling rate is set to 60MHz. Figure 6 shows the results obtained from simulation for the performance of the OFDM and single carrier signals in AWGN. It can be seen that the performance of the OFDM signal remains constant, since its position was kept constant at 135MHz. However the performance of the single carrier signal varies as it is changed from a carrier at 85MHz to a carrier at 65MHz. The positions of the signal spectra and spectrum copies due to sampling are shown in Figure 7. The attenuation with frequency is the result of the sample-and-hold operation.

The above investigations highlight a number of points which need to be considered when implementing a multimode, multiband receiver. Filtering of the signals at IF, prior to sampling ensures that interference between the signals is reduced. Filtering the signals individually, rather than using a single wideband filter results in reduced adjacent channel interference, and improves performance. The samp ling rate must be chosen such that no spectral overlap of the signal occurs during the sampling process. The two (or more) signals must not overlap before or after the sampling process, and nor should any of their spectra copies due to sampling overlap with each other. Reference [4] presents expressions to avoid these aliasing situations. The positions of the IF signals with respect to the sampling rate and folding frequency may affect the performance of the receiver due to interactions of the signals with spectrum copies.

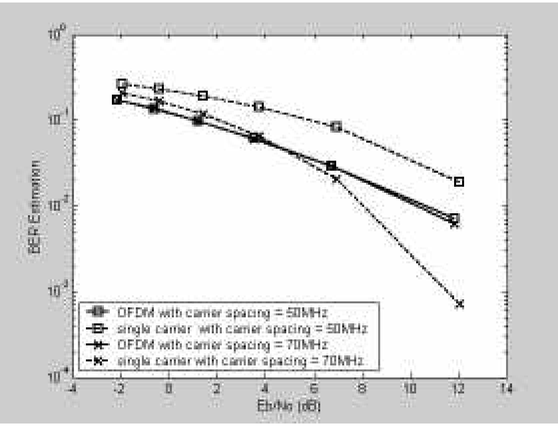

Figure 6. Performance in AWGN with large carrier spacing between the OFDM signal and the single carrier signal

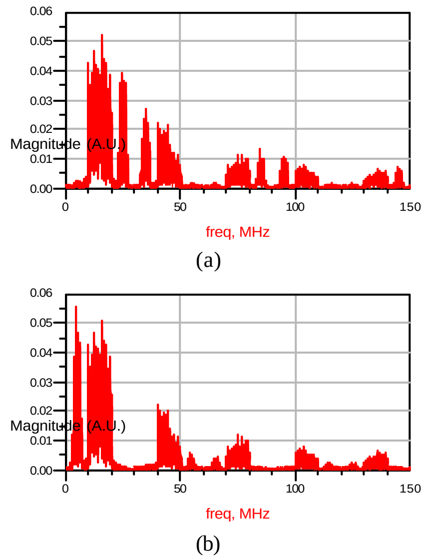

Figure 7. Frequency domain representation of sampled signals using sampling rate = 60MHz. The carrier frequencies of the OFDM and the single carrier signals are 135MHz and 85MHz (a) , 135MHz and 65MHz (b), respectively.

6. Conclusions

This paper describes a multimode, multiband receiver architecture suitable for software radio implementation. The receiver is capable of simultaneously receiving and demodulating an OFDM signal as used by WLAN systems, and a single carrier signal as used in cellular systems. The simulation model used is described and results are presented for various investigations regarding the carrier positions of the signals and variation in sampling rate. The use of a single wideband IF filter was investigated and the receiver performance compared to the use of two IF filters to individually filter each signal. Significant improvement in performance is seen when two IF filters are used. An investigation of the signal position with respect to multiples of the folding frequency would be most helpful to analyse the interaction between the spectrum copies produced due to the sampling process.

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