The Implementation of Channel Diversity in Mobile Software Radio Receivers

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***Abstract*—A novel channel diversity concept is proposed and demonstrated, which avoids receiving signal deterioration due to multipath fading in mobile receivers. The system is based on coherent superposition of the signals received from several transmitters supplying the same information at different frequencies.**

Based on a software radio architecture this concept may increase the quality of mobile reception in modern car receivers considerably. Compared with multiantenna-receivers which overcome the multipath fading problem by simultaneously receiving the same program with several antennas, the proposed solution is advantageous, since it requires only a single antenna.

***Index Terms*—Diversity, MIMO systems, mobile reception, multipath propagation, receiver, software defined radio.**

I. Introduction

Several concepts to improve FM radio receiving conditions have been presented in literature. A major cause for low receiving quality in mobile receivers is multipath fading, which yields strong attenuation of the received signal. Methods based on the constant modulus algorithm (CMA) can avoid some of the distortion introduced by multipath effects [1]. Unfortunately these algorithms yield problems in the case of fast fading conditions, since they cannot track fast variations of the channel parameters [2]. In the case of multipath fading, antenna diversity allows to increase the signal quality at the expense of the use of several antennas [3], [4].

The proposed channel diversity concept utilizes the fact, that the same radio information is supplied by various transmitters at different frequencies as depicted in Fig. 1 [5]. This approach implements a coherent superposition of these multiple information to increase the reception quality. Its main advantage is the capability to compensate fast multipath fading, since it is unlikely that the multipath fading signal minima of two channels will occur at the same location. This paper presents the channel diversity concept based on a direct digitizing software radio architecture.

II. Channel Diversity in a Software Radio Architecture

In our mobile software radio architecture, the whole FM band will be directly digitized after a low noise amplifier and an antialiasing filter. Sampling with 56 MHz is sufficient for direct digitizing the whole FM band via subsampling [6], [7].

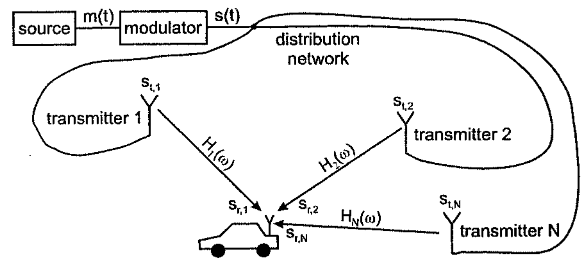

Fig. 1. Typical receiving situation for channel diversity.

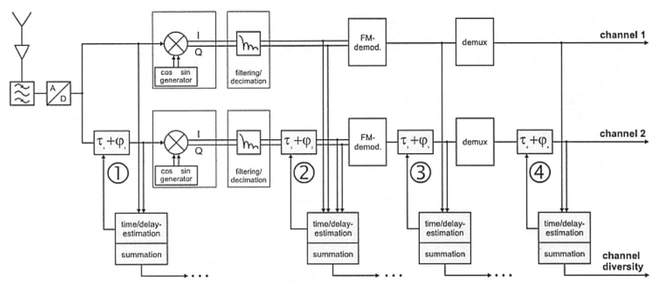

Fig. 2. Schematic overview of channel diversity in a software radio receiver.

By filtering and downsampling the broadband signal, the different channels can be extracted from the same source. Fig. 2 depicts an overview of the building blocks of our software radio implementation for the two channel FM case. This viewgraph shows the different positions in the signal path, where channel diversity can be implemented. Due to the software radio architecture this concept can be easily extended to more channels or other transmission standards.

Signals bearing the same information, being broadcasted by various transmitters at different frequencies, are substantially for channel diversity. The main task in a channel diversity system is to extract an exact estimation of the time respective phase delay between the different channels allowing a coherent superposition of the signals. A weighting of the incoming signals by an individual quality factor will lead to a maximum improvement in the resulting SNR of $P_{\mathrm{SNR,comb}} = \sum_{i=1}^{N} P_{\mathrm{SNR},i}$ in the steady case [8], [9]. N denotes the number of used channels. Fig. 3 schematically shows the area between two transmitters, where channel diversity will improve the performance of a standard radio receiver.

Especially for moving vehicles multipath propagation has to be considered. Even with a high average receiving field strength present, deep fading conditions may occur. Due to the transmission of the same information from different locations with dif-

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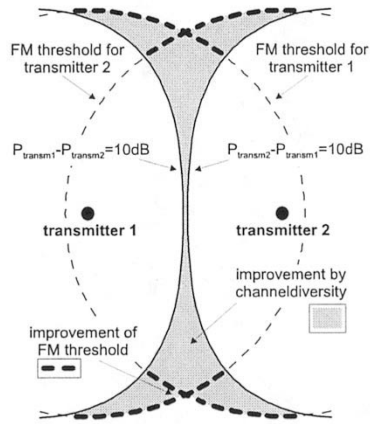

Fig. 3. Area of improvement for channel diversity.

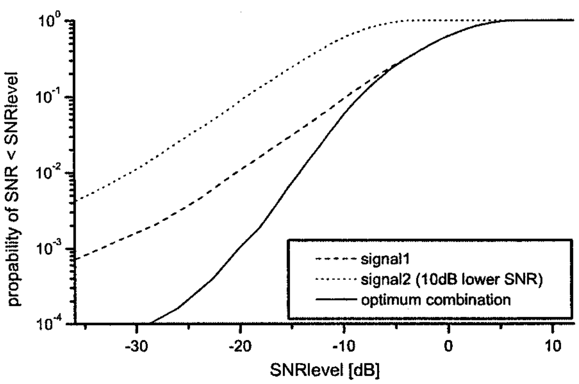

Fig. 4. Improvement of signal quality in multipath conditions.

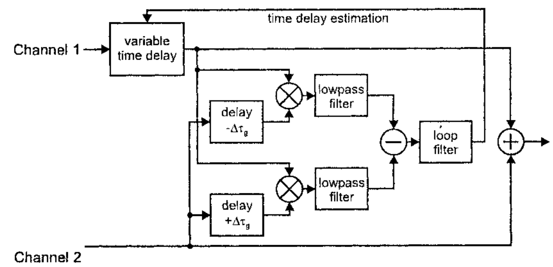

Fig. 5. Tau-dither time delay tracking loop.

ferent frequencies, the probability of another channel having a deep fade at the same time is not very likely [9]. Therefore even a signal with lower average amplitude may help to improve the SNR of a strong signal under multipath conditions. Fig. 4 depicts the improvement by applying channel diversity on two signals with the same multipath statistics but different average field strength respective SNR.

III. Tracking of the Channel Parameters

For mobile reception tracking has to be used to achieve a good performance for channel diversity. This is needed to follow the changes in the time delay between the channels as well as for the acquisition of the signal quality and compensating carrier frequency errors introduced by Doppler effects in the different channels. Different concepts for time delay, frequency and signal quality tracking will be discussed in the following sections.

A. Time Delay Tracking

Opposed to switching antenna diversity system as in the phase tracking of the different signals is essential for the coherent superposition of the signals. The system has to cope with long time displacements between the different channels due to the distances between their transmitters of up to 50 km and more. Additionally delays originating from signal buffering in the distribution network have to be taken into account. Measurements show that time delays up to 10 ms and more can be possible as well as nearly no time delay, depending on the position of the receiver and the type of distribution network. Certain measured delay values were presented in [9].

Therefore a digital delay in this order of magnitude has to be implemented in the system. The estimation of the time delay may be done by calculating the correlation of a pair of channels to be considered. The resulting correlation peak marks the time delay. As the computation of a correlation needs very much computational resources, this is only suitable for an initial guess of the time delay. For tracking the time delay once it is detected, other structures should be used.

Tau-dither loops [10] as depicted in Fig. 5 are to be considered as a good solution especially for tracking the time delay after the demodulation, covering tracking capabilities as well as using low computational resources.

The family of the constant modulus algorithms is not applicable, as the given large time delays lead to very long filter lengths of the equalizers, but modified variants with an additional time delay are under investigation.

B. Frequency Tracking

Constant doppler shifts in the received frequencies do not lead to harmonic distortions in the demodulated signal for FM modulated signals, as far as the frequency shift is significantly smaller than the channel bandwidth. Normal travelling speeds of up to 50 m/s lead to doppler shifts below 20 Hz, which is much smaller than the channel bandwidth for the considered FM broadcasting.

Changes in the doppler frequency due to accelerating or changing the heading of the mobile receiver leads to distortions at low frequencies in the demodulated signal, which are lower than the lowest frequency component of the transmitted signal for mobile reception. These distortions can therefore easily be filtered out. However different additional doppler frequencies arising from different transmitter locations lead to fading effects in the superposed signal, requiring frequency tracking.

Small errors in the tuning frequency might be absorbed by the aforementioned phase tracking loop, but for larger values and for long time stability of the system some means of frequency correction scheme has to be implemented. This may be done by utilizing the fact that frequency offsets before demodulation are transferred to DC offsets after demodulation. Slowly changing frequencies therefore lead to very low frequencies next to DC, which can be used as an error signal in a feedback loop.

C. Identification of Identical Channels

If the signal quality of a single channel is high enough to receive RDS (Radio Data System) data, the identification of iden-

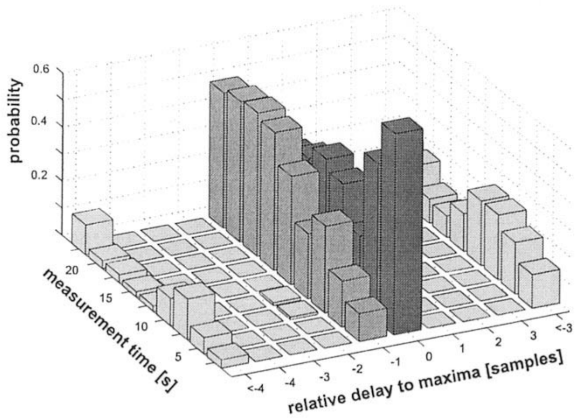

Fig. 6. Histogram over time for correlation peak position in urban area.

tical channels can be done by using the program name in the RDS information. In the important case, when the signal quality lowers the RDS information is likely to be distorted, while the audio signal may still be at good quality. This is an effect of the FM modulation, which introduces more noise in the higher frequency part of the multiplex signal, where the RDS information is located.

Therefore the correlation of the signals or a previously obtained program name has to be considered for low quality signals in order to determine identical channels.

D. Signal Quality Tracking

A scheme for signal quality tracking may consist of an averaging detector for signals in a small bandwidth (16 kHz to 18 kHz) in the multiplex signal where normally no signal is transmitted. So the system detects all errors like noise and harmonic distortions that fall into this bandwidth leading to good estimation of the signal quality. By comparison with the fixed amplitude of the pilot tone a quality factor can be derived. By changing the averaging filter the time sensitivity of the system can be adapted.

IV. Experimental Setup and Measurement Results

The measurement setup is built for a two channel system by two linked signal processing cards implemented in a PC. These cards are both linked to an external analog-to-digital converter, which is driven by a very low jitter PLL clock source. The setup is built in a way, that it can be used in our test car for mobile measurements. Fig. 6 shows the histogram of the correlation peak position gained from measurements conducted in an urban area. The number of false peaks emerging show that the tracking algorithm has to cope with a certain amount of distortion.

V. Conclusion

Channel diversity may become an alternative or addition to antenna diversity, which may result in a reduction of the number of antennas. The presented concept therefore has the potential to replace several "hardware" antennas by software techniques. An advantage of the channel diversity will be its easy integration into currently emerging multichannel software radio designs.

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References

[1] J. R. Treichler and B. G. Agee, "A new approach to multipath echo cancellation in FM transmission," *IEEE Trans. Acoust., Speech, Signal Processing*, vol. ASSP-31, pp. 459–472, 1983.

[2] K.-D. Kammeyer, R. Mann, and W. Togberte, "A modified adaptive FIR equalizer for multipath echo cancellation in FM transmission," *IEEE J. Select. Areas Commun.*, vol. 5, no. 2, pp. 226–237, 1987.

[3] R. Kronberger, H. Lindenmeier, L. Reiter, and J. Hopf, "Array antenna principle applied to modern car antennas for mobile communication," in *Proc. IEEE Int. Symp. Antennas and Propagat. Soc.*, Atlanta, GA, June 1998, pp. 2224–2227.

[4] H. Lindenmeier, J. Hopf, L. Reiter, and R. Kronberger, "Optimization of the antenna-diversity-effectiveness of complex FM-car-antenna systems," in *Proc. IEEE Int. Symp. Antennas and Propagat. Soc.*, Orlando, FL, July 1999, pp. 2058–2061.

[5] H. Schnepp, T. Müller, and J.-F. Luy, "Channel-diversity in a software autoradio," *Proc. IEEE 53rd Veh. Technol. Conf.*, Mai 2001.

[6] T. Müller, H. Schnepp, and J.-F. Luy, "A software autoradio," in *Proc. 1st Karlsruhe Workshop on Software Radios*, Karlsruhe, Germany, Mar. 2000, pp. 85–89.

[7] J.-F. Luy, "Software configurable receivers," in *Proc. 32nd Eur. Microwave Conf.*, Milano, Italy, Sept. 2002.

[8] D. G. Brennan, "Linear diversity combining techniques," *Proc. IRE*, vol. 47, pp. 1075–1102, June 1959.

[9] H. Schnepp, T. Müller, J.-F. Luy, and P. Russer, "Channel diversity in a mobile software radio," in *Proc. 2nd Karlsruhe Workshop on Software Radios*, Karlsruhe, Germany, Mar. 2002, pp. 7–12.

[10] M. K. Simon, "Noncoherent pseudonoise code tracking performance of spread spectrum receivers," *IEEE Trans. Commun.*, vol. 25, pp. 327–345, Mar. 1977.