Application of Array Antenna For a High-speed ISDB-T Reception

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Abstract

Array antenna is an attractive method to improve the performance of mobile communication. In our application targeted here, four antenna elements are set in an automobile to improve the reception quality of mobile ISDB-T receiver. With regard to the directional characteristics of each antenna, we propose and implement a joint Pre-FFT adaptive array antenna and Post-FFT space diversity combining (AAA-SDC) scheme for mobile ISDB-T receiver. Simulation results show that the AAA-SDC scheme drastically improves the performance of mobile ISDB-T receiver, especially in high-speed moving condition. The experimental results conducted in the field also confirm that the proposed AAA-SDC scheme successfully achieves an outstanding reception rate up to 100% while moving at the speed of 80km/h in a highway.

Keyword: OFDM, ISDB-T, array antenna, beamforming

1 Introduction

Orthogonal Frequency Division Multiplexing (OFDM) is adopted as a modulation method of terrestrial Integrated Services Digital Broadcasting (ISDB-T) standard in Japan. OFDM is well-known as a high-spectral efficiency transmission method in the multipath environment [1].

In a circumstance that OFDM receiver is set on the automobile, orthogonality among OFDM subcarrier is destroyed due to Doppler shift as the automobile is moving. Therefore, it is a severe challenge to maintain the reception quality of mobile ISDB-T receiver at a certain level that is acceptable for human vision.

One well-known way to improve the performance of OFDM receiver is to exploit a spatial diversity by utilizing multiple antenna elements. In this paper, we implement a joint Pre-FFT adaptive array antenna and Post-FFT space diversity combining scheme, hereto referred to as AAA-SDC, as a trade-off approach to improve the performance of mobile ISDB-T receiver with reasonable computation complexity. Additionally, directional antenna elements are utilized to mitigate the Doppler shift. The performance of the proposed scheme is evaluated by simulation and the prototype is validated in field experiments.

The rest of the paper is organized as follows. In the next section, the proposed joint AAA-SDC is given. In Sect. 3, the utilization of directional antennas to cope with Doppler shift in high-speed application is discussed. The implementation and experimental results are provided in Sect. 4. Finally, conclusions are given in Sect. 5.

2 Joint Adaptive Array Antenna and Space Diversity Combining

There are two approaches to utilize the array antenna for multi-carrier transmission method, which are Pre-FFT adaptive array antenna and Post-FFT space diversity combining scheme.

The Pre-FFT scheme is a conventional method to employ the array antenna in which inputs from the array antenna are combined before OFDM demodulation. Since this approach only relates to processes prior to FFT, it is an attractive solution in term of low computation requirement. Several approaches based on adaptive array antenna and Pre-FFT scheme, namely as Pre-FFT adaptive array antenna (Pre-FFT AAA) scheme, have been proposed to improve the performance of mobile OFDM receiver in multipath condition. In our previous works [3] and [4], we proposed and implemented the Pre-FFT AAA scheme, in which several DBF algorithms have been adopted, such as Maximum Ratio Combing (MRC), Adaptively Main Beam Forming (AMBF) as the improvement algorithm of MRC, and Sample Matrix Inversion (SMI).

On the other hand, Post-FFT scheme is an advance method to utilize the array antenna for multi-carrier system. Instead of combining before OFDM demodulation, inputs are demodulated using multiple OFDM demodulations. Subcarriers are then combined ac-

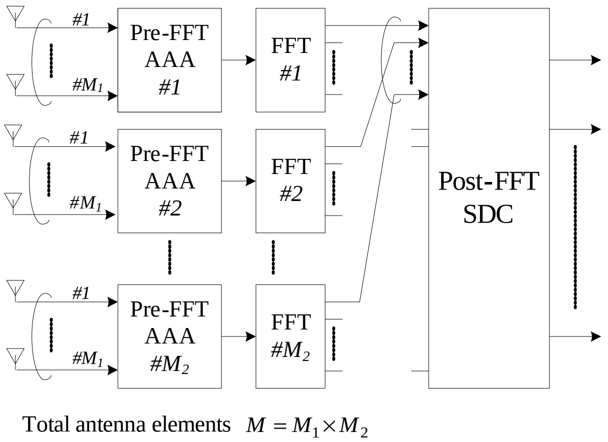

Figure 1: The proposed joint Pre-FFT Adaptive Array Antenna and Post-FFT Space Diversity Combining of OFDM receiver.

cordingly in frequency domain using diversity combining method. Post-FFT scheme therefore is an optimum approach in term of maximizing signal-to-noise ratio (SNR) for each OFDM subcarriers. However, its computation complexity grows drastically as more antenna elements associated with equivalent OFDM demodulations are used.

2.1 The Proposed AAA-SDC Scheme

In this paper, we propose a joint Pre-FFT adaptive array antenna and Post-FFT space diversity combining scheme for OFDM receiver, named as the AAA-SDC scheme. Hence, the AAA-SDC scheme can be considered as a trade-off solution to achieve a reasonable diversity gain with a relatively low computation complexity.

Figure 1 illustrates the principle of the proposed AAA-SDC scheme. The proposed AAA-SDC scheme is comprised of M_2 Pre-FFT AAA schemes corresponding to M_2 OFDM demodulations of the Post-FFT SDC scheme. Each Pre-FFT AAA scheme is comprised of M_1 antenna elements. It is worthwhile to note that the total number of antenna elements is kept unchanged, i.e. $M = M_1 \times M_2$. Several digital beam-forming (DBF) algorithms, e.g. MRC, AMBF and SMI, are performed in the Pre-FFT AAA scheme. Outputs of them are fed to the Post-FFT SDC scheme to perform diversity combining for each subcarrier of OFDM symbols.

2.2 Computation Complexity

In this subsection, the cost versus performance of Pre-FFT AAA, Post-FFT SDC and joint AAA-SDC

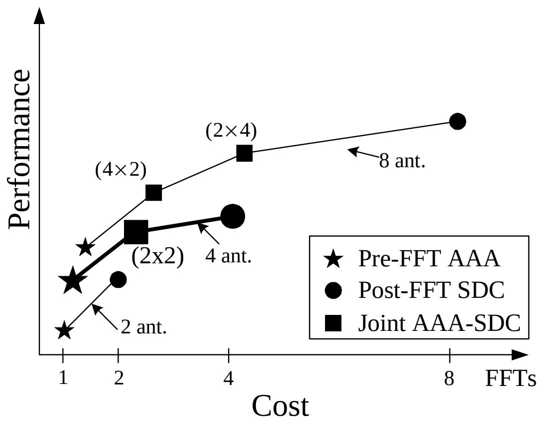

Figure 2: Comparison of Cost vs. Performance of Pre-FFT AAA, Post-FFT SDC and the joint AAA-SDC.

scheme are evaluated. Figure 2 depicts the cost versus performance of them. The cost of the mentioned scheme are measured by a number of FFTs, which also roughly demonstrates its computation complexity. The Pre-FFT AAA scheme is able to achieve some performance enhancement with the identical computation complexity. The Post-FFT SDC is able to achieve best performance, however, with a lot of computation. The proposed AAA-SDC comes in as a trade-off solution. More interestingly, it is the optimum solution in term of cost versus performance.

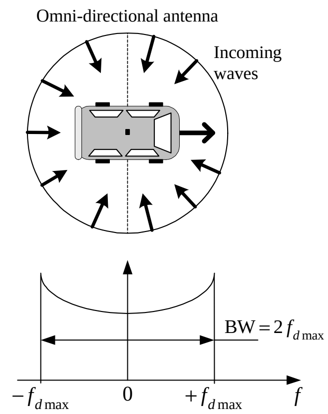

Figure 3: Illustration of Doppler spectrum of an omni-directional antenna.

3 Directional Antennas to Mitigate Doppler Shift

In the previous section, we propose the joint AAA-SDC scheme for mobile ISDB-T reception. In addition to that, we also employ the directional characteristics

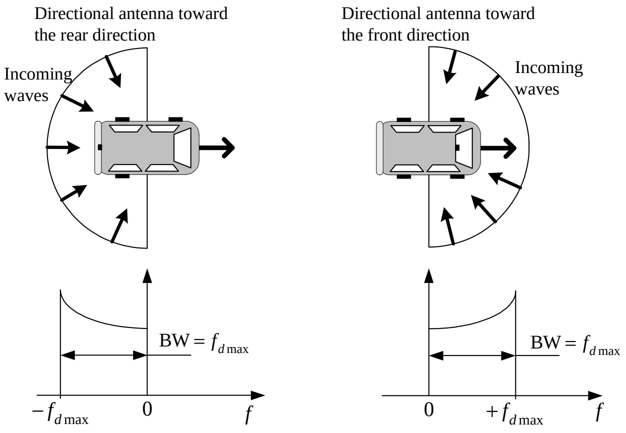

Figure 4: Illustration of Doppler spectrum of the front and rear directional antennas.

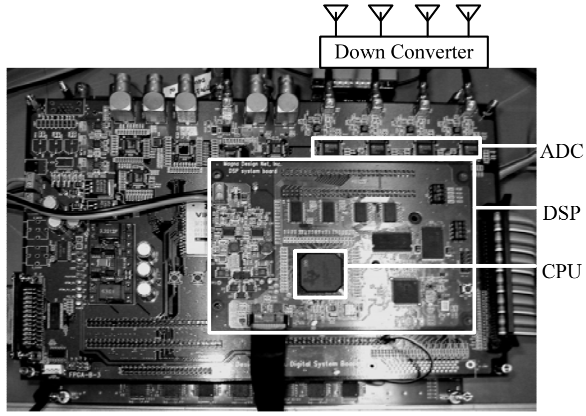

Figure 5: Prototype of the AAA-SDC scheme.

of antenna elements set in the body of vehicle. In this section, we discuss the application of directional antennas and their unique feature to improve the quality of reception in high-speed mobile ISDB-T reception.

In a circumstance that antenna is set on top roof of the vehicle. Since the height of antenna is relatively low, about several meters, the received signal by top roof antenna experiences severe multipath condition; incoming waves are intense and their AOAs are uniformly distributed within $[0,\ 2\pi]$.

In our application, directional antennas are utilized to mitigate the Doppler shift. Figure 4 illustrates the application of directional antennas in automobile. Because the front antenna acts as a directionally spatial filter, incoming waves from the front direction are picked up, meanwhile incoming waves from the rear direction are neglected. A received signal of front antenna element therefore mostly experiences a *positive* Doppler shift randomly distributed within $[0, +f_{d\max}]$. Doppler spectrum of the front antenna are reduced a half as utilizing the directional antenna.

Similarly, the rear directional antenna mostly experiences a *negative* Doppler shift randomly distributed within $[-f_{d\max}, 0]$, associated Doppler spectrum of the rear antenna are also reduced a half comparing with that of omni-directional antenna.

4 Experimental results

The prototype of the AAA-SDC scheme is successfully implemented. Table 1 and Figure 5 show the specification and photograph of a prototype of the proposed AAA-SDC scheme.

The prototype is capable of altering the combination of antenna elements, i.e. four antenna elements can be used as one array antenna or as two array antenna, of which one is set in the front and the other is set in the rear of automobile. In addition, the operation of the Post-FFT SDC scheme can also be switched to a conventional equalizer by using only one OFDM demodulation. As a result, the prototype can be utilized as the proposed AAA-SDC scheme or as the Pre-FFT AAA scheme. Nevertheless, since DBF algorithms are embedded in DSP, beam-forming capability of the array antenna can also be reconfigurable on the fly.

The prototype of the AAA-SDC scheme is the subject of several experiments. The experiments have been conducted in City center loop expressway, which is about 20km far from the SETO tower, Nagoya City, as the digital TV station. The course length is about 10km, in which the speed of the experimental vehicle is 80kmph during the test. The experimental conditions are summarized in Table 2 in detail.

In the vehicle, four directional antennas which are

Adaptive Array Antenna	ADC	Channel	4
		Resolusion	10bit
		Sampling rate	32MHz
	FPGA	Xilinx Virtex-II Pro VP70, VP20	
	DSP	TI DSP C6713 TMS320C6713 225MHz	
Space Diversity Combining	FPGA	Xilinx Virtex-II 4000x2, V3000 (OFDM Demod. and SDC)	

Table 1: Specification of the prototype.

Table 2: Experimental Conditions.

Test Course	City Center Loop Expressway (NLOS enviroment)	
	Course length	10km
	Distance to ISDB-T tower	approx. 20km
Eval. Cond.	4 directional antenna elements	
	Evaluation signal	12SEG HDTV
	Moving speed	80kmph
	Evaluation period	approx. 8 mins

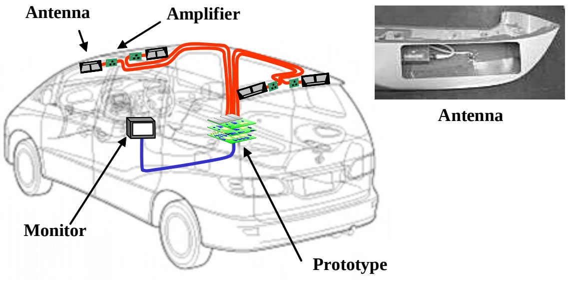

Figure 6: Illustration of the experiment vehicle.

customarily designed are set in the vehicle. The positions of antenna elements and the experimental equipments are illustrated in Figure 6.

In the test course, the prototype experiences no co-channel interference, however non-line-of-sight (NLOS) multipath condition with relatively long delay paths is mostly observed during the experiments.

In the test course, the joint AAA-SDC scheme scheme that utilizes MRC, AMBF and SMI, can achieve the average reception rate of 100%; whereas the average reception rate of the Pre-FFT AAA utilizing MRC, AMBF and SMI can only reaches up to 65%. Obviously, the performance of mobile ISDB-T receiver set in the high-speed automobile are drastically improved by using the proposed AAA-SDC scheme.

5 Conclusions

In this paper, the AAA-SDC scheme is proposed and implemented to improve the performance of mobile ISDB-T receiver. It has been shown that the proposed AAA-SDC scheme is optimum solution in term of cost vs. performance. Moreover, the directional antennas are employed to cope with Dopper shift in high-speed condition. Experiments are conducted to verify the performance of the proposed AAA-SDC scheme. The results show that a performance of mobile ISDB-T receiver is drastically improved as the specific directional characteristics of antenna elements are taken into account. The experiment results show that the proposed AAA-SDC scheme achieves the outstanding reception rate up to 100%, meanwhile the reception rate of the Pre-FFT AAA scheme only reaches up to 65%.

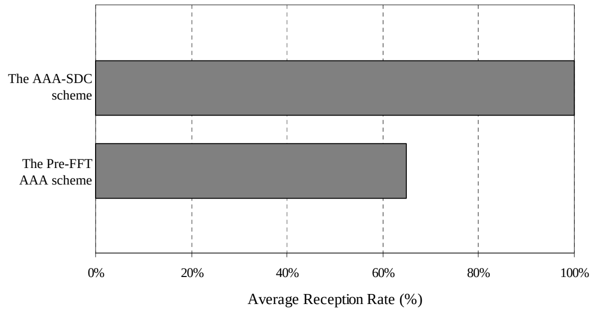

Figure 7: Performances of Pre-FFT AAA and joint AAA-SDC scheme.

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