An Improved Joint Detection of Frame, Integer Frequency Offset, and Spectral Inversion for Digital Radio Mondiale Plus

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Received December 9, 2013; accepted January 21, 2014; published Febuary 28, 2014

Abstract

In digital radio broadcasting systems, long delays are incurred in service start time when tuning to a particular frequency because several synchronization steps, such as symbol timing synchronization, frame synchronization, and carrier frequency offset and sampling frequency offset compensation are necessary. Therefore, the operation of the synchronization blocks causes delays ranging from several hundred milliseconds to a few seconds until the start of the radio service after frequency tuning. Furthermore, if spectrum inversed signals are transmitted in digital radio broadcasting systems, the receivers are unable to decode them, even though most receivers can demodulate the spectral inversed signals in analog radio broadcasting systems. Accordingly, fast synchronization techniques and a method for spectral inversion detection are required in digital radio broadcasting systems that are to replace the analog radio systems. This paper presents a joint detection method of frame, integer carrier frequency offset, and spectrum inversion for DRM Plus digital broadcasting systems. The proposed scheme can detect the frame and determine whether the signal is normal or spectral inversed without any carrier frequency offset and sampling frequency offset compensation, enabling fast frame synchronization. The proposed method shows outstanding performance in environments where symbol timing offsets and sampling frequency offsets exist.

Keywords: Digital Radio Mondiale Plus, fast frequency tuning, frame detection, joint detection, spectral inversion detection.

This research was supported by the IT R&D program of MSIP/KEIT. [10039196, Smart Platform Development for Integrating Worldwide Radio Technology to Smart Devices]
A preliminary version of this paper was presented at APIC-IST 2013 and was selected as an outstanding paper.

http://dx.doi.org/10.3837/tiis.2014.02.016

1. Introduction

Orthogonal frequency division multiplexing (OFDM) has become a popular technique for digital broadcasting systems. OFDM based Digital Radio Mondiale (DRM) is a digital radio system standard for all frequency bands of Analog Modulation (AM) and Very High Frequency (VHF) [1]. Its Robustness Mode E, known as DRM Plus, has been standardized in September 2009 by European Broadcasting Union (EBU) to cover Band I and Band II (47 to 174 MHz). DRM Plus can offer better sound quality compared to analog FM radio broadcasting systems with maximum data transmission rate of 185 kbit/s in 100 kHz of bandwidth [2]. In addition, DRM Plus provides the ability to transmit multiple data services such as surround sound, Journaline text information, slideshow, electronic program guide (EPG), etc [3,4]. Several countries carried out DRM Plus trial field tests in cooperation with the DRM Consortium [5-7].

In conventional digital radio broadcasting receivers, delays are associated with frequency tuning due to several synchronization steps, such as signal detection, symbol timing synchronization, frame synchronization, and carrier frequency offset and sampling frequency offset compensation [8]. The service start time delay after frequency tuning ranges from several hundred milliseconds to a few seconds. Therefore, a fast synchronization technique is required in digital radio broadcasting receivers to reduce the delay time. Furthermore, if spectral inversed signals are transmitted in digital broadcasting systems, the receivers are unable to decode them, even though most receivers can demodulate the spectral inversed signal in analog radio broadcasting systems. Accordingly, a spectral inversion detection technique is also required in digital radio broadcasting systems that are to replace the analog radio broadcasting systems.

Many literatures show the performance of various synchronization techniques for OFDM systems in various channel environments. They assume perfect sampling frequency synchronization [9-11]. However, in a real environment where sampling frequency offset exists between a transmitter and a receiver, the sampling frequency offset yields a symbol timing offset.

In [12], the authors proposed a joint detection method for the transmission frame and the inversed spectrum signal in DRM Plus, and focused on the detection performance with the assumption of less symbol timing offset. They examined the effect of sampling frequency offset on the frequency-domain frame detection performance under the assumption of a fixed initial symbol timing offset (< the sampling period). However, in a real case, the performance of the frequency-domain frame detection could be degraded by the large symbol timing offset (> the sampling period) which can be caused by the imperfect synchronization depending on the channel impulse response, and/or the sampling frequency offset. In order to consider the real environment, analyzing is necessary under real conditions.

In this paper, we propose a joint method for fast initial synchronization – transmission frame detection and integer carrier frequency offset estimation – and spectrum inversion detection in DRM Plus systems. This paper also shows the relationship between symbol timing offset in finding FFT window point within sampling frequency offset and detection performance, suggests the receiver's structure with the proposed method. We also show that the proposed method is robust to initial (residual) symbol timing offsets and sampling frequency offset. This enables fast frequency tuning of the DRM Plus receiver since the time consuming compensation techniques for symbol timing offsets and sampling frequency offsets are not needed.

The paper is organized as follows. Section 2 describes the OFDM based DRM Plus parameters and the received OFDM signal with oscillator differences between the transmitter and receiver. Section 3 identifies the problems of the conventional frame detection when the symbol timing and sampling frequency offset exist. The proposed joint detection method of frame synchronization, integer carrier frequency offset, and spectrum inversion is described in Section 4. The performance of the proposed method is verified through simulations in Section 5. Concluding remarks are given in Section 6.

2. DRM Plus System Models

2.1 DRM Plus System Description

DRM systems haves three logical channels in the multiplex, that is, the Main Service Channel (MSC), the Service Description Channel (SDC), and the Fast Access Channel (FAC). The FAC provides the information on the channel parameters and services parameters. It also provides service selection information to allow fast scanning per frame. The SDC gives information on how to decode the MSC, the attributes of the services within the multiplex, and may include links to simulcast services. The SDC is transmitted per a transmission super frame. The MSC contains the data for all the services. For the DRM Plus system, the duration of one transmission super frame is 400 ms, which consists of four 100 ms frames. **Fig. 1** shows the transmission frame structure of the DRM Plus system.

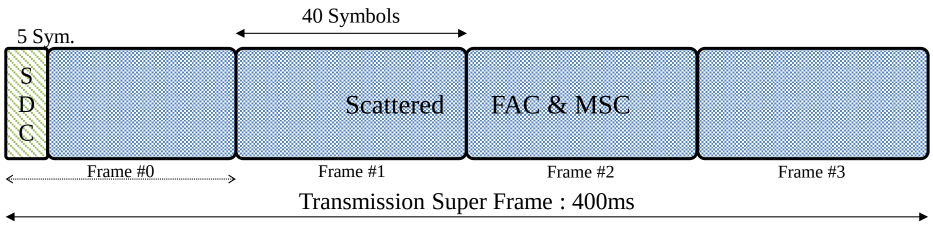

Fig. 1. Transmission frame structure

The DRM Plus system distinguishes three kinds of reference cells for channel estimation and synchronization: Time Reference Cell (TRC), Gain Reference Cell (GRC), and AFS reference cell. TRCs are located in the first OFDM symbol of each transmission frame. GRCs are spread equally in time and frequency direction. GRCs are used mainly to get a proper estimate of the channel transfer function. AFS reference cells are mainly used to improve the channel estimation in the AFS case and to make “snooping” at another frequency reliable.

Table 1 shows OFDM symbol parameters for DRM Plus transmission. The subcarrier spacing is 444 $^4/_9$ Hz, and there are 213 subcarriers. Since there is T_g/T_u = 1/9 relationship, a prime factor FFT, which is composed of DFT and 2^nFFT, is used for the DRM Plus system [13, 14]. The FFT size must be larger than the number of subcarriers and must be a multiple of 9. If we choose 216 (27 x 8) as FFT size N, the on time sampling rate (f_s) and OFDM symbol length including guard interval N_s (=N+N_u) become 96 kHz and 240, respectively.

$$f_s\big|_{N=216} = 216 / 2.25\,ms = 96\,kHz \tag{1}$$

Table 1. DRM Plus system parameters

Parameter	Value
Narrow Bandwidth	100 kHz
Number of Subcarriers (N_{sc})	213
Subcarrier spacing (Δf)	444 $^4/_9$ Hz
Duration of the useful part of symbol (T_u=1/Δf)	2.25 ms
Duration of the guard interval (T_g)	0.25 ms
Duration of an OFDM symbol ($T_s = T_u + T_g$)	2.5 ms
T_g / T_u	1 / 9
Duration of the transmission frame (T_f)	100 ms
Number of symbol per frame	40

2.2 Received Signal Modeling

Carrier frequency offset and sampling frequency offset are introduced by small differences in the oscillator frequency between the transmitter and receiver. The carrier frequency offset causes an ongoing phase rotation of all subcarriers over time. The sampling frequency offset derives various phase drifts such as the inter-carrier interference and the OFDM symbol timing drift that can cause timing error and FFT window shift.

The carrier and sampling frequency offsets will appear as a phase shift ϕ_k. The phase shift is comprised of two parts: a normalized carrier frequency offset ε and a sampling frequency offset ξ. The carrier frequency offset is the same for all subcarriers, while the sampling frequency offset contributes linearly with the subcarrier index k, i.e., $\phi_k \approx \varepsilon + k \cdot \xi$.

The l-th OFDM symbol received in frequency domain can be represented as [9].

$$Y_l[k]_{nor} = sinc(\pi\phi_k) \cdot e^{j2\pi((l \cdot N_s + N_g)/N)\phi_k} \cdot e^{j\pi((N-1)/N)\phi_k} \cdot e^{j2\pi(\tau + \xi \cdot N_s \cdot l)k/N} \cdot X_l[k] \cdot H_l[k] + I_l[k] + N_l[k] \tag{2}$$

where τ is the symbol timing offset, and $I_l[k]$ is the additional inter-symbol interference and the inter-carrier interference caused by the offset. $H_l[k]$ and $N_l[k]$ are the frequency response for the channel and the noise, respectively.

If an inversed OFDM symbol is received, it can be represented as;

(That is, if a spectrum inversed OFDM signal is transmitted, the OFDM signal with the carrier index inversed is decoded in the frequency domain at the receiver side.)

$$Y_l[k]_{inv} = sinc(\pi\phi_k) \cdot e^{j2\pi((l \cdot N_s + N_g)/N)\phi_k} \cdot e^{j\pi((N-1)/N)\phi_k} \cdot e^{j2\pi(\tau + \xi \cdot N_s \cdot l)k/N} \cdot X_l[-k] \cdot H_l[k] + I_l[k] + N_l[k] \tag{3}$$

3. Joint Detection Methods

There are 21 time reference cells and 13 gain reference cells in the first DRM Plus symbol. These 34 reference cells of the first OFDM symbol in the trasmission frame are used for synchronization in frequency domain.

3.1 Conventional Detection Method for DRM Plus

Generally, the start of a frame can be detected by the cross-correlation value between the reference cells and the received symbols [15]. In order to consider time varying channels, the correlation value should be normalized by the instantaneous power of the signals as shown in (8) because the variance is large in the time varying channels.

$$R_{conv}(f,s)=\left|\sum_{n=0}^{N_{rc}-1}\frac{Y_{l+s}\left[P_0(n)+f\right]\cdot X_0^*\left[P_0(n)\right]}{\left(\left|Y_{l+s}\left[P_0(n)\right]+f\right|^2+\left|X_0\left[P_0(n)\right]\right|^2\right)/2}\right| \tag{5}$$

$$\left[\hat{f}_{\text{int}},\hat{s}\right]_{conv}=\max_{\substack{f\in\{-M,\cdots,M\}\\ s\in\{0,\cdots,S-1\}}}\arg R_{conv}(f,s) \tag{6}$$

where $\hat{f}_{\text{int}}$ and $\hat{s}$ are the estimated integer frequency offset and the first OFDM symbol in the frame, $X_0[k]$ is the transmitted data assigned to the k-th subcarrier of the first OFDM symbol in the frame, $R_l[k]$ is the received data of the l-th OFDM symbol, N_{rc} (=34) is the number of reference cells in the first symbol, and $P_0(n)$ is the subcarrier index of the n-th reference cell in the first symbol. M is the maximum integer frequency offset for searching, and S is the number of OFDM symbols in the frame (S = 40).

In order to analyze the characteristic of (5), we assume that N is sufficiently large and there are no integer frequency offsets (f = 0), interferences, and noise effects. In addition, a frequency non-selective and static channel is assumed, where there are no channel changes within an OFDM symbol. If the received OFDM symbol is the first symbol of the frame, $X_l[k] = X_0[k]$, (5) becomes

$$R_{conv}\left(\hat{f}_{\text{int}},\hat{s}\right)=\sum_{n=0}^{N_{rc}-1}sinc\left(\pi\phi_{P_0(n)}\right)\cdot e^{j2\pi\left(\left(l\cdot N_s+N_g\right)/N\right)\phi_{P_0(n)}}\cdot e^{j\pi\phi_{P_0(n)}}\cdot e^{j2\pi\left(\tau+\xi\cdot N_s\cdot l\right)P_0(n)/N} \tag{7}$$

In (7), we can see that the conventional frame detection method is affected by the OFDM symbol index l, whereas the phase shift is affected more by the normalized carrier frequency offset ε. This is because the sampling frequency offset is very small (ξ <<<1 and $\phi_{P_0(n)}\approx\varepsilon$) during the OFDM symbol duration. Therefore, (7) can be expressed as follows:

$$R_{conv}\left(\hat{f}_{\text{int}},\hat{s}\right)=sinc(\pi\varepsilon)e^{j2\pi\left(\left(l\cdot N_s+N_g\right)/N\right)\varepsilon}e^{j\pi\varepsilon}\cdot\alpha \tag{8}$$

$$\alpha=\sum_{n=0}^{N_{rc}-1}e^{j2\pi\left(\tau+\xi\cdot N_s\cdot l\right)P_0(n)/N} \tag{9}$$

From (8), the angle velocities of α is proportional to the fixed subcarrier index of the reference cell $P_0(n)$ and the terms of the symbol timing offset τ and sampling frequency offset ξ. If $\tau \neq 0$ and/or $\xi \neq 0$, there would be signal degradation of α, even though the offsets are small because the subcarrier indexes of the 34 reference cell are scattered from -94 to 98. Therefore, offsets cause signal degradation of α, resulting in frame detection performance loss. On the other hand, if $\tau = \xi = 0$, then the value of α would be N_{rc}=34 and the detection performance would be good because there is no signal loss. This means that the sampling frequency offset and symbol timing offset needs to be accurately compensated before the frame detection to have good detection performance by avoiding the signal degradation of α. However, the high-precision compensation (fine symbol timing offset and sampling frequency offset compensation) causes delay in synchronization and decoding. Furthermore, if spectral inversed signals are transmitted in digital broadcasting systems, the receivers are unable to detect or decode them.

3.2 Proposed Joint Method

In this paper, we propose a joint detection method for frame, integer carrier frequency offset, and spectrum inversion for DRM Plus digital broadcasting systems using the difference among reference cells of the first OFDM symbol in the transmission frame.

The auto-correlation is taken by using the received reference cells and their phase differences. For the inversion case, the correlation is taken simultaneously by using the inverse indexed pilot symbols.

$$R_{\underset{nor}{prop}}(f,s)=\left|\sum_{n=0}^{N_{rc}-2}\frac{Y_{l+s}^{*}\left[P_0(n)+f\right]\cdot Y_{l+s}\left[P_0(n+1)+f\right]\cdot e^{-j2\pi\theta_{diff}(n)}}{\left(\left|Y_{l+s}\left[P_0(n)\right]+f\right|^2+\left|Y_{l+s}\left[P_0(n+1)+f\right]\right|^2\right)/2}\right| \tag{10}$$

$$R_{\underset{inv}{prop}}(f,s)=\left|\sum_{n=0}^{N_{rc}-2}\frac{Y_{l+s}^{*}\left[-P_0(n)+f\right]\cdot Y_{l+s}\left[-P_0(n+1)+f\right]\cdot e^{j2\pi\theta_{diff}(n)}}{\left(\left|Y_{l+s}\left[-P_0(n)+f\right]\right|^2+\left|Y_{l+s}\left[-P_0(n+1)+f\right]\right|^2\right)/2}\right| \tag{11}$$

$$\left[\hat{f}_{\text{int}},\hat{s}\right]_{prop}=\max_{\substack{f\in\{-M,\cdots,M\}\\ s\in\{0,\cdots,S-1\}}}\arg\left\{R_{\underset{nor}{prop}}(f,s),R_{\underset{inv}{prop}}(f,s)\right\} \tag{12}$$

where $\theta_{diff}(n)$ is the phase difference of the consecutive reference cells of the first symbol in the frame and is defined as

$$\theta_{diff}(n)=\angle\left\{X_0^{*}\left[P_0(n)\right]\cdot X_0\left[P_0(n+1)\right]\right\} \tag{13}$$

In order to analyze the characteristic of the proposed method, we assume that the received OFDM symbol is the frame's first symbol ($X_l[k] = X_0[k]$), that there are no interferences and noise effects, that the sampling frequency offset is sufficiently small (ξ<<<1), and that the channel is frequency non-selective and static channel. The equation (10) of the normal case can be expressed as follows:

$$R_{\underset{nor}{prop}}\left(\hat{f}_{\text{int}},\hat{s}\right)=sinc^2(\pi\varepsilon)\cdot\beta \tag{14}$$

$$\beta=\sum_{n=0}^{N_{rc}-2}e^{j2\pi(\tau+\xi\cdot N_s\cdot l)(P_0(n+1)-P_0(n))/N} \tag{15}$$

The angle velocities of β is proportional to the subcarrier index difference between adjacent reference cells $P_0(n+1)$-$P_0(n)$ and the terms of the symbol timing offset τ and sampling frequency offset ξ. If $\tau \neq 0$ and/or $\xi \neq 0$, there would be signal degradation of

β. However, the signal degradation would be small because the subcarrier index difference between adjacent references are conversed. Therefore, the signal degradation of β is smaller than the signal degradation of α even if the symbol timing offset and the sampling frequency offset exist. **Table 2** shows the characteristics of the reference cells' subcarrier index term. The reference cells' subcarrier index term of α is more diffused than that of β. Therefore, the performance of the proposed method is relatively better than that of the conventional method, and fast detection without high-precision compensation is possible.

Table 2. Simulation parameters for signal loss comparison

Reference Cells' subcarrier index term	Average Value	Standard Deviation
"$P_0(n)$" of α	2.735	56.09
"$P_0(n+1)$-$P_0(n)$" of β	5.818	5.908

3.3 Signal Loss Comparison

In order to compare the conventional method of (8) with the proposed method of (14), the relative signal loss comparison is necessary after finishing OFDM symbol detection (finding the FFT windowing point) as follows:

$$Sig\ Loss_{conv.} = \frac{\alpha \cdot sinc(\pi\varepsilon)}{34} = \frac{sinc(\pi\varepsilon)}{34} \sum_{n=0}^{N_{rc}-1} e^{j2\pi(\tau+\xi\cdot N_s\cdot l)P_0(n)/N} \quad (16)$$

$$Sig\ Loss_{prop.} = \frac{\beta \cdot sinc^2(\pi\varepsilon)}{33} = \frac{sinc^2(\pi\varepsilon)}{33} \sum_{n=0}^{N_{rc}-2} e^{j2\pi(\tau+\xi\cdot N_s\cdot l)(P_0(n+1)-P_0(n))/N} \quad (17)$$

We assume the environment for the signal loss comparison to be as shown in **Table 3**;

Table 3. Simulation parameters for signal loss comparison

Parameter	Value
Normalized Carrier Frequency Offset ε	0.01
Normalized Symbol Timing Offset τ	0.1 (10%)
Considered Sampling Frequency Offset ξ (< 10 ppm)	0, 4, 8 ppm
Considered Sampling Frequency Offset ξ (< 50 ppm)	10, 30, 50 ppm

Fig. 2 and **Fig. 3** illustrate the signal losses when the received signal is the OFDM symbol of the frame with the sampling frequency offset and the frequency offset for the DRM Plus system according to the symbol index after the signal detection. The solid lines express the signal loss of the proposed method, and the dotted lines express the signal loss of the conventional method when there is no sampling frequency offset compensation blocks.

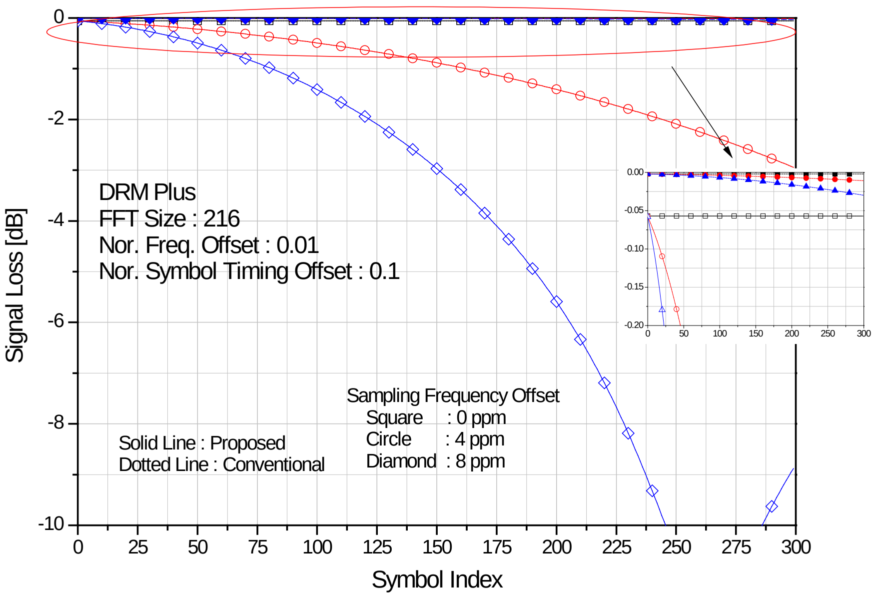

Fig. 2. Signal loss comparison (< 10 ppm)

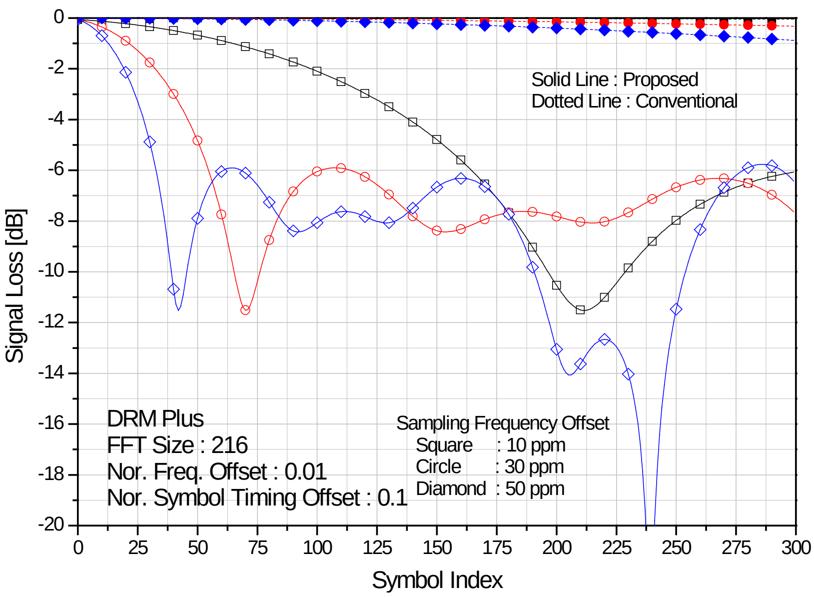

Fig. 3. Signal loss comparison (< 50 ppm)

In the figures, we can see that if there are no sampling frequency offset estimation and sampling rate correction block, then there is a larger signal loss due to the initial timing error and the accumulated sampling frequency offset in the conventional detection method than the proposed method. In the zoom-out figure of **Fig. 2,** we can also see that if there is small sampling frequency offset, then there is small signal loss in the conventional method. This means that the high-precision compensation of the sampling offset is necessary in the conventional method resulting in large delay time. However, there is a small signal loss in the proposed detection method. Therefore, fast detection without high-precision compensation is possible through the proposed technique.

4. Performance Comparison through Simulation

In this section, we performed a computer simulation to compare the performances of the conventional method and the proposed joint method.

4.1 Simulation Parameters

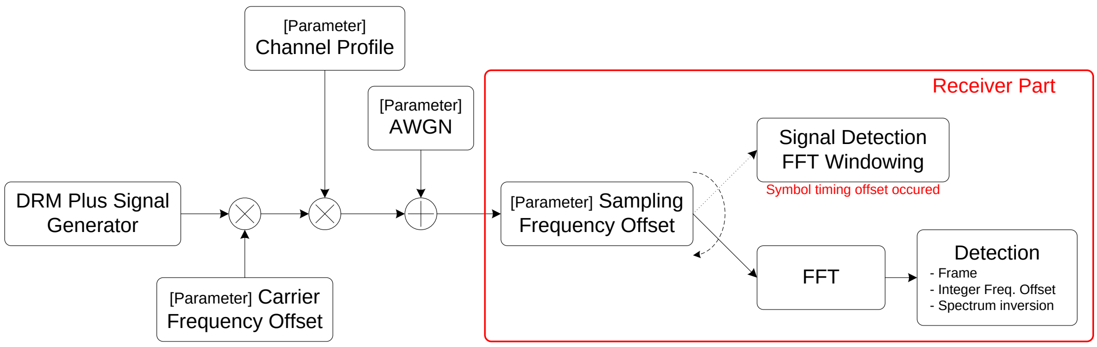

Fig. 4. Simulation block diagram

Fig. 4 shows the block diagram for the computer simulation that evaluates detection performances. The DRM Plus signal generator is used as a transmitter. The reference signals and random data, such as FAC, SDC, and MSC are generated in the DRM Plus signal generator. The transmitted signals are distorted by a carrier frequency offset, multipath channels, noise, and a sampling frequency offset. **Table 4** shows the simulation parameters.

Table 4. Simulation parameters for the comparision of detection performances

Parameter	Value
Spectrum Mode	Normal Spectrum
Normalized Carrier Frequency Offset	0.98
Channel Profile	Urban, Rural, Terrain
SNR of Main Service Channel	-2 dB ~ 7dB
Sampling Frequency Offset	10, 30, 50 ppm

To evaluate the detection performances, 10 ppm, 30 ppm, and 50 ppm sampling frequency offsets are considered. We used the arbitrary sampling rate conversion filter with time registers for the sampling frequency offset effect [16, 17]. The time register method provides signal evaluation at an arbitrary time, where time is specified as an unsigned binary fixed-point number in units of arbitrary sampling period. The normalized carrier frequency offset is set to 0.98. So, the ideal estimated integer and fractional carrier frequency offsets are 1 and -0.02, respectively.

Also, we considered the urban, rural, and terrain channel profiles that were proposed by the DRM Consortium for Bands I and II characteristics [1]. Each channel is defined by a delay profile and a velocity as shown in **Table 5**. The root mean square delay spreads for the urban, rural, and terrain channels are 0.782 μs, 0.429 μs, and 2.17 μs, respectively. Each path has the Jakes Doppler power spectral density characteristic. The carrier frequency is 91.9 MHz.

Table 5. Channel profiles

Channel Velocity	8:Urban 60km/h		9:Rural 150km/h		10:Terrain 60km/h	
Path #	Delay(μs)	Power(dB)	Delay(μs)	Power(dB)	Delay(μs)	Power(dB)
1	0	-2.0	0.0	-4.0	0.0	-4.0
2	0.2	0.0	0.3	-8.0	1.0	-8.0
3	0.5	-3.0	0.5	0.0	2.5	0.0
4	0.9	-4.0	0.9	-5.0	3.5	-5.0
5	1.2	-2.0	1.2	-16.0	5.0	-16.0
6	1.4	0.0	1.9	-18.0	8.0	-18.0
7	2.0	-3.0	2.1	-14.0	12.0	-14.0
8	2.4	-5.0	2.5	-20.0	14.0	-20.0
9	3.0	-10.0	3.0	-25.0	16.0	-25.0

DRM Plus receivers have to find OFDM symbol timing for FFT windowing first. The guard-interval correlation method is used to find the FFT windowing point [9]. To find the OFDM symbol timing, 80 OFDM symbols (200 ms) are used. Note that there are some symbol timing offsets when the first path of the multipath channel does not have the largest power in the correlation based symbol timing offset estimation method. Also, the sampling frequency offset can cause another symbol timing offset. **Fig. 5** shows the probability density function of the symbol timing errors for different sampling offsets in the urban channel. In the test, 0 dB SNR for the main service channel data and 16 over-sampling are considered. In the figure, the solid line expresses the probability density function of the symbol timing offset at 10 ppm of sampling frequency offset and the dotted lines express the one at 50 ppm. One can see that as the sampling frequency offsets increase, the symbol timing offsets also increase in the same conditions. **Table 6** shows the variances of the sampling timing offsets according to the sampling frequency offsets and SNRs briefly.

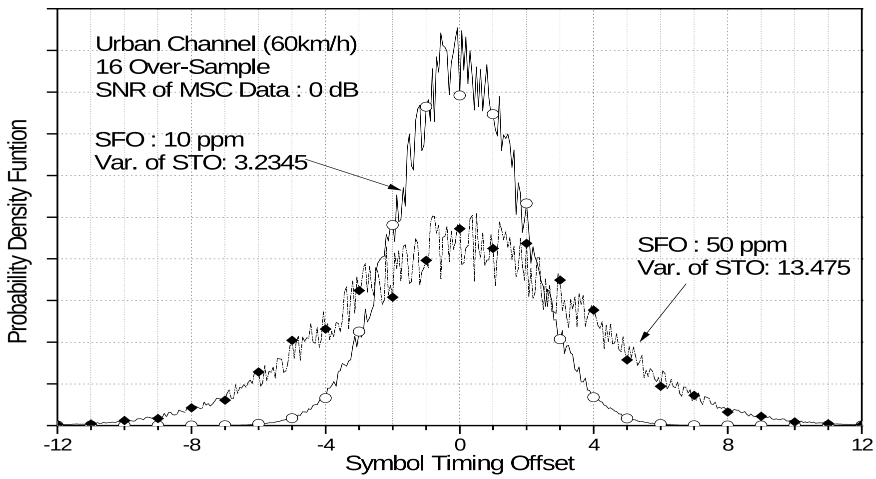

Fig. 5. Probability density function of the symbol timing error

Table 6. Variance of the symbol timing offset

Parameter	SNR : 0 dB	SNR : 7 dB
10 ppm	3.2345	2.851
30 ppm	7.8391	5.234
50 ppm	13.475	10.163

4.2 Performance Comparison

Fig. 6, **Fig. 7**, and **Fig. 8** show the performances of the conventional and proposed detection methods depending on the sampling frequency offset in the urban, rural, and terrain channel environments, respectively. The number of observed symbols is 40 (the number of symbols for one frame). In these simulations, the starting point of the FFT window is estimated by using the guard interval based OFDM symbol timing synchronization, which means that there are some symbol timing offsets in the FFT process depending on the path values of the multipath channel. The solid lines show the performances of the proposed method, and the dotted lines represent the performances of the conventional method.

In the figures, the conventional method shows poor detection performance even though the SNR increases. This is because $\tau \neq 0$ and/or $\xi \neq 0$, and $P_0(n)$ increases with n in (9), resulting in large signal loss. Therefore, a compensation technique for sampling frequency offset and symbol timing offset is required to achieve better frame detection performance. However, in the proposed method, there is small performance degradation in the higher SNR region even if sampling frequency and symbol timing offsets exist. This is because the subcarrier index differences between adjacent reference cells are not scattered and the reference's index term has good characteristic in (15). When the SRN is 5 dB, the conventional method yields 18%, 23.6%, and 13.6% detection probabilities at 10ppm sampling frequency offset in urban, rural and terrain, respectively. However, the proposed method yields 95%, 97%, and 91.2% detection probabilities in the same environments.

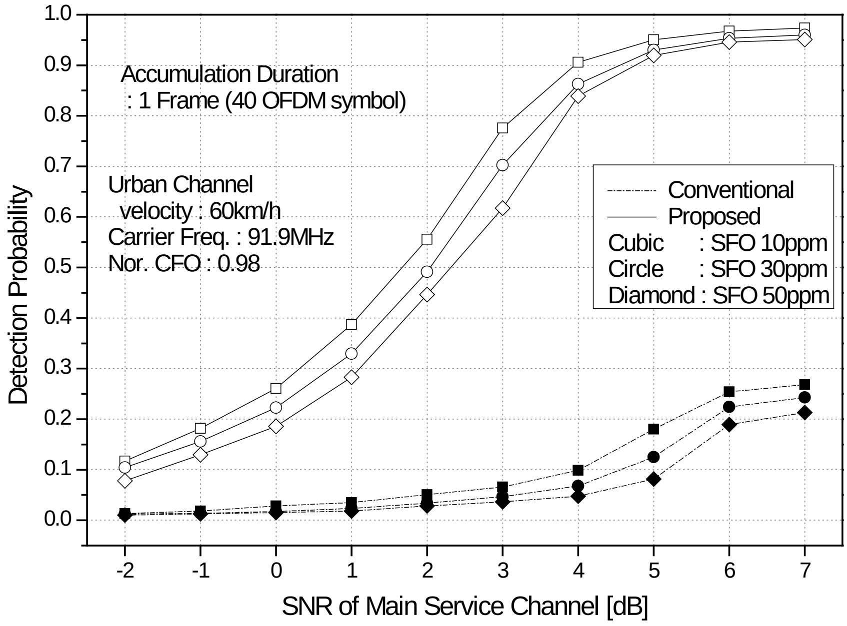

Fig. 6. Detection performances in the urban channel

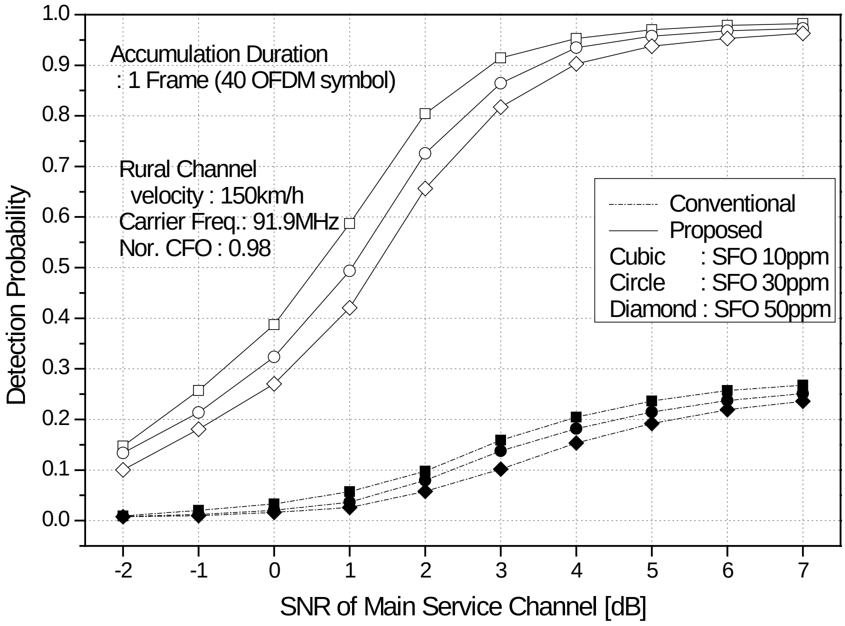

Fig. 7. Detection performances in the rural channel

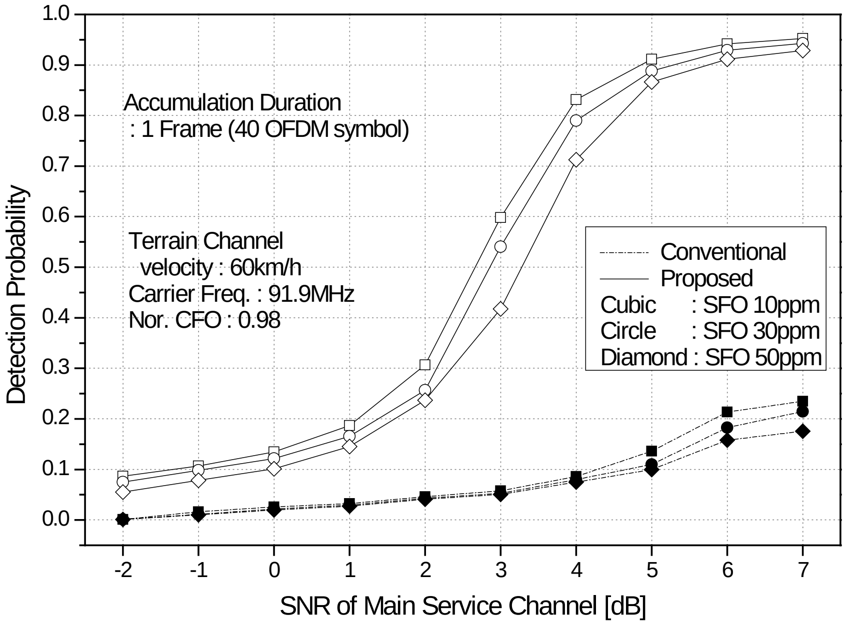

Fig. 8. Detection performances in the terrain channel

5. DRM Plus Receiver Structures with Detection Methods

5.1 Conventional DRM Plus Receiver Structure

There are many literatures that show the synchronization performance for OFDM based systems in various channel environments. These works often ignore sampling frequency offset synchronization under the assumption that enough scanning is performed. However, in a real environment where the number of samples for synchronization is limited, sampling frequency offset exists, resulting in symbol timing offset.

Fig. 9 shows the block diagram of the conventional OFDM based DRM Plus receiver. The received signals from the wireless channel are input to the A/D converter through the local oscillator. In order to estimate and compensate the sampling frequency offset, several symbols are necessary after robustness mode detection. For more accurate sampling frequency offset estimation, more symbols are necessary. This process consumes synchronization time.

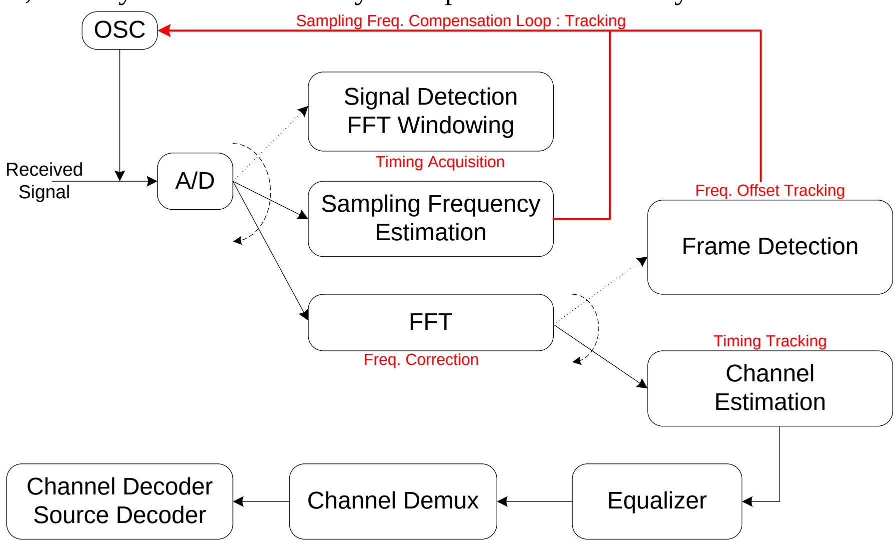

Fig. 9. Conventional DRM plus receiver's block diagram

Fig. 10 shows the residual sampling frequency offsets in the compensation loop as a function of the number of OFDM symbols for 10, 30, and 50 ppm as initial sampling frequency offsets. The number of required symbols for estimation and compensation for stability increases as the sampling frequency offset increases. Therefore, the receiver requires more time to decode the signal after OFDM symbol synchronization. This means that listeners must wait for several seconds after frequency setting to enjoy the radio services in the digital radio system.

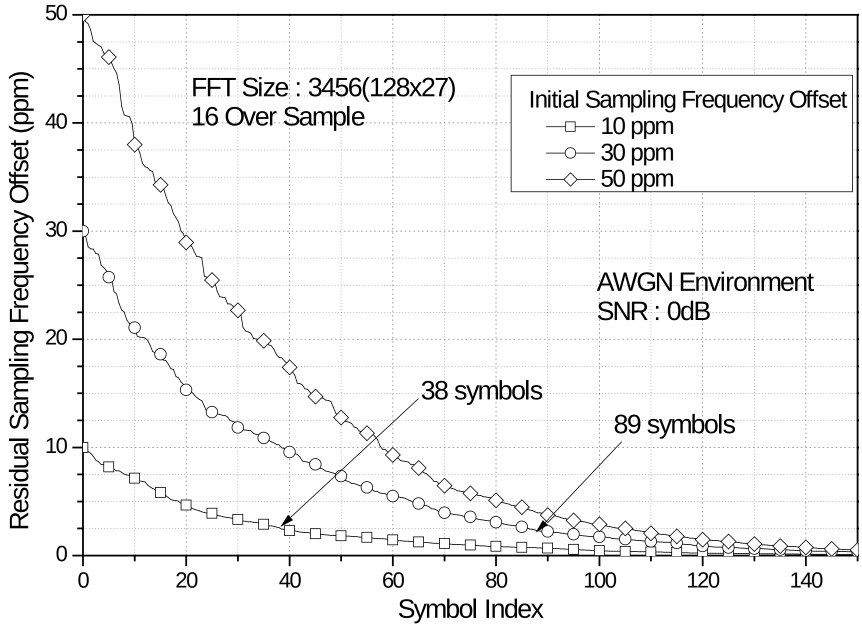

Fig. 10. Residual Sampling Frequency Offset vs. Symbol Index

5.2 Proposed DRM Plus Receiver Structure

Fig. 11 shows the block diagram of the DRM Plus receiver with the proposed joint detection block. Unlike conventional DRM receivers, the sampling frequency offset compensation block is not necessary in the proposed receiver structure because the performance of the proposed method is relatively better than the conventional method, and fast detection without high-precision compensation is possible. Therefore, faster decoding is possible.

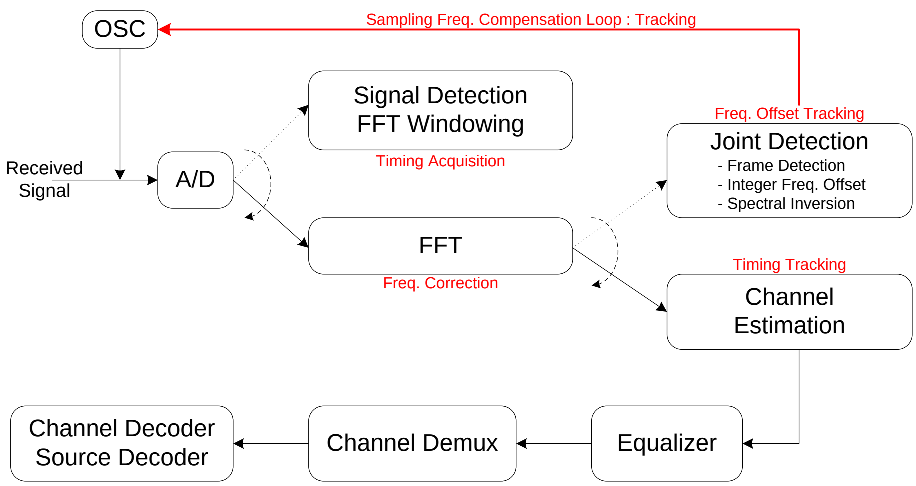

Fig. 11. DRM plus receiver's block diagram with the proposed joint detection method

6. Conclusions

After radio service tuning, digital radio systems have more delays than their analog counterparts because several synchronization steps and signal decoding time are necessary. Furthermore, digital radio receivers are unable to decode digital radio signals when the transmitted signal is inversed, even though most analog radio broadcasting system receivers can demodulate the spectral inversed signal. Therefore, fast and efficient synchronization techniques and a spectral inversion detection method are required.

In this paper, a joint method for fast initial synchronization – transmission frame detection and integer carrier frequency offset estimation – and spectrum inversion detection in DRM Plus systems was suggested. Simulation of the proposed method showed outstanding detection performance due to robustness to the initial (residual) symbol timing offset and the sampling frequency offset. The receiver structure for the proposed method was also presented. The proposed method enables fast frequency tuning of the DRM Plus receiver since the time consuming compensation techniques for symbol timing offset and sampling frequency offsets are not needed. This means that the receiver can offer faster audio service through the proposed joint detection method in a real environment because the estimation and compensation for the sampling frequency offset is not needed in the initial synchronization but only in the tracking stage.

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