Design of an Emergency Wake-up Alert System Utilizing Digital Television Guard Band

Kwanwoong Ryu, You-Seok Lee, Jae-Hyun Seo, and Heung Mook Kim

In this paper, we propose an emergency wake-up alert system (EWAS) for providing accurate and rapid emergency information. The proposed system can provide an emergency wake-up alert service without an additional frequency allotment by utilizing the guard band of the Advanced Television Systems Committee (ATSC) Terrestrial Digital Television (DTV) system. The design target of the proposed system is to match the indoor reception coverage of EWAS with the outdoor reception coverage of the ATSC DTV system. To achieve this, the proposed system should be about 35.65 dB more robust than the ATSC DTV system. The simulation results show that the proposed system offers an emergency wake-up alert service supporting a data rate of up to 23 bps.

Keywords: Emergency alert service, wake-up, DTV.

I. Introduction

Considering that natural and manmade disasters such as earthquakes, tsunamis, and floods usually occur unexpectedly and often result in significant damage, an accurate and rapid emergency alert service is crucial for minimizing the impact of such a disaster. As an emergency alert service, broadcasting systems have been considered reliable delivery systems because they are relatively robust to the destruction of network infrastructure from a natural disaster. Other advantages of such systems are the "real-time" aspect of broadcasting and a larger coverage area.

Several different emergency alert systems (EASs) including terrestrial digital multimedia broadcasting and one segment systems have been researched for mobile broadcasting [1]–[3]. In addition, an EAS using a transmitter identification watermark signal for use in the Advanced Television Systems Committee (ATSC) Terrestrial Digital Television (DTV) system has been proposed [4].

However, these systems make it difficult for emergency information to promptly propagate to the general public when the receiver is turned off.

This paper proposes an emergency wake-up alert system (EWAS) for providing accurate and rapid emergency information even when the receiver is turned off. The proposed system can connect with various digital television systems such as satellite, cable, terrestrial, IPTV, and mobile TV systems, and provide an emergency alert service. However, in this paper, we only consider the proposed EWAS for the ATSC DTV system.

The remainder of this paper is organized as follows. In Section II, the proposed system model is described. Section III investigates the interference of ATSC DTV reception from an EWA signal and vice versa. In Section IV, we calculate the

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minimum CNR for an EWA signal. In Section V, the simulation results of the proposed system are presented. Finally, some concluding remarks are given in Section VI.

II. System Model

Figure 1 shows a scenario of the EWAS for emergency broadcasting in an ATSC DTV system. The ATSC DTV signal is received from a 9-m high outdoor antenna, and an EWA signal is received from a 1.5-m high indoor antenna. To provide emergency information, the service coverage of the EWA signal should be the same as that of the ATSC DTV signal.

A block diagram of the proposed EWAS is shown in Fig. 2. The payload marks the start or stop sequence of the EWA signal for an emergency alert. The preamble is multiplexed with the spread payload. The multiplexed signals are modulated using an FSK modulator. At the receiver, the preamble is detected, and it is then determined whether the payload is the start or stop sequence of the EWA signal.

When a start or stop sequence is detected, the EWA receiver sends a control signal to the set-top box (STB). When the start sequence is detected and the STB is in an off state, the STB is turned on. If the STB is in an on state, the STB maintains its current state. The STB then monitors the TV status using an HDMI-CEC protocol. The STB will turn on the TV and change the channel to a specific station. When the stop sequence is detected, the STB and TV revert to their previous state before the time of the disaster.

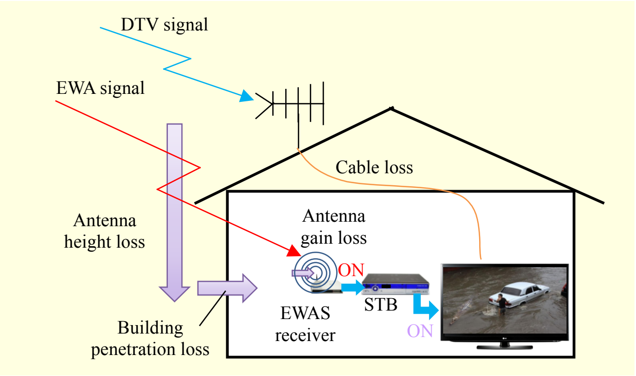

Fig. 1. Scenario of EWA signal for emergency alert service.

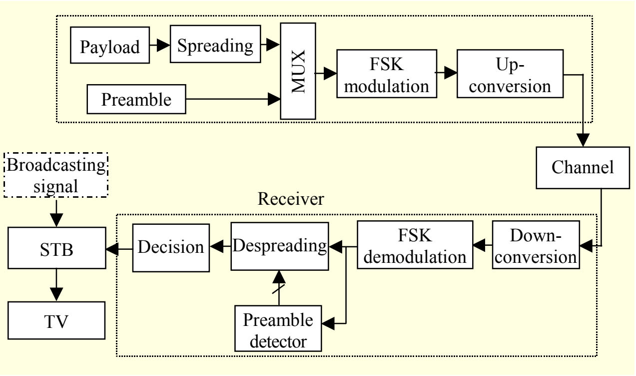

Fig. 2. Block diagram of EWAS.

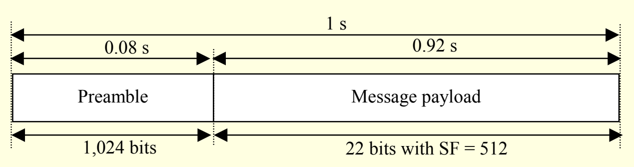

Fig. 3. Frame structure of EWAS.

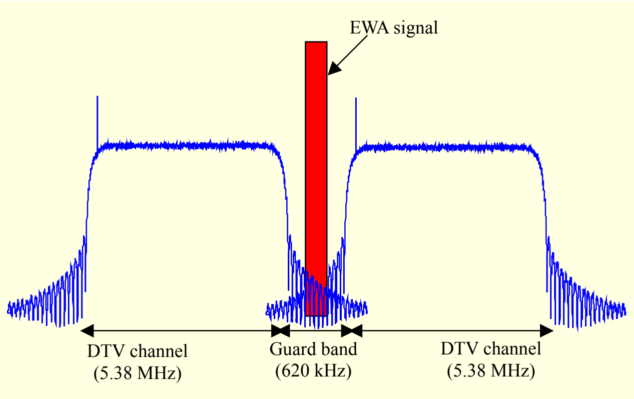

Fig. 4. Power spectrum density of the EWA signal.

Figure 3 shows a frame structure for the EWAS. The fame structure of the EWAS is determined by assuming that the service coverage of the EWA signal should be the same as that of an ATSC DTV signal. The frame length for the EWAS has a short length of 1 s, which enables low-latency support.

The frame is divided into a 0.08-s preamble and 0.92-s message payload. The preamble consists of 1 FSK bit with a spreading factor (SF) of 1,024, and detects a start or stop signal of the EWAS. The message payload consists of 22 FSK bits with SF 512 and provides emergency information, which includes the emergency level and area information of the EWAS.

Figure 4 shows the power spectrum density of the EWA signal. The ATSC DTV signal is transmitted through the ATSC DTV channel bandwidth, and the EWA signal is transmitted through the ATSC DTV guard band.

The guard band is defined as the additional bandwidth required for a data transmission beyond the “ideal” minimal Nyquist bandwidth [5]. The EWA signal utilizes a 620-kHz DTV guard band between two adjacent ATSC DTV channels.

III. Interference Test between EWA and ATSC DTV Signals

In this section, we investigate the interference of the ATSC DTV reception from an EWA signal and vice versa.

To investigate the interference of the ATSC DTV reception from an EWA signal, we tested the transmit power level of the EWA signal according to the EWAS bandwidth. In addition, we investigated the interference of the EWAS reception from a residual ATSC DTV signal according to the filter bandwidth of the EWAS receiver. Based on the results, we investigated the effect of the filter according to the bandwidth of the EWAS receiver.

1. Interference of DTV Reception from EWA Signal

An EWA signal interferes with the performance of the ATSC DTV reception based on the transmit power level. Therefore, we tested the effect on the ATSC DTV reception by inserting an EWA signal on the left and right sides of the ATSC DTV channel. Next, according to the bandwidth of the EWA signal, we investigated the maximum power level of the EWA signal. Figure 5 shows the results of a laboratory test indicating the maximum power level of the EWA signal that does not interfere with the performance of the ATSC DTV reception at the threshold of visibility (ToV). From the laboratory test, we were able to obtain the maximum power level of the EWA signal by increasing the power level of the EWA signal until some errors occurred on the display video at the ToV. The results show that the receiver of the EWAS has a better gain under a narrower bandwidth than under a wider bandwidth. This means that the wider bandwidth of the EWA signals increases the interference at the receiver of the ATSC DTV.

For convenience and simplicity, we assume that the transmit power of the EWAS is the same as that of the ATSC DTV. In this case, the EWA signal to DTV signal power is 0 dB, and the bandwidth of the EWA signal should be less than 50 kHz. As shown in Fig. 5(a), when the bandwidth of the EWA signal is 50 kHz on the left side, DTV #1, DTV #2, and DTV #3 have a gain of about 8 dB, 14 dB, and 5 dB, respectively. In addition, when the bandwidth of the EWA signal is 50 KHz the right side, DTV #1, DTV #2, and DTV #3 have a gain of about 6 dB, 10 dB, and 2 dB, respectively.

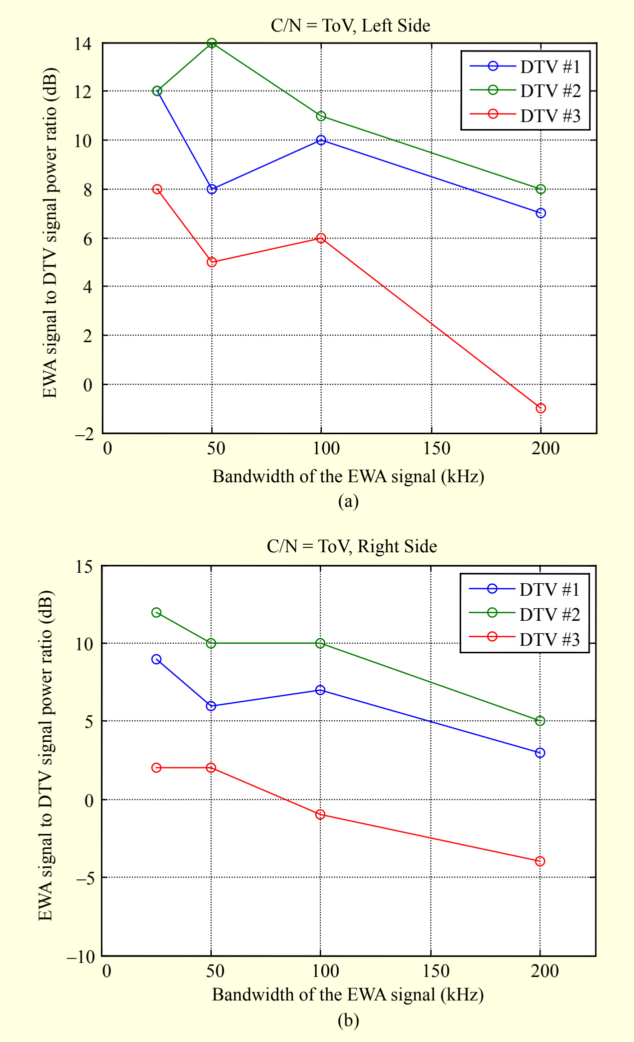

Fig. 5. Laboratory test results: (a) left and (b) right sides.

2. Interference of EWAS Reception from Residual ATSC DTV Signal

Figure 6 shows a block diagram of an equivalent model for calculating the effect of interference of the EWAS reception from a residual ATSC DTV signal. As shown in Fig. 6, the ATSC DTV channel is combined with an adjacent channel in a combiner, and then fed to the EWAS LPF filter in the receiver. The EWA signal is modulated by a FSK modulator, and then fed to the LPF filter of the EWAS receiver.

Both signals are combined and then demodulated and detected in the EWAS receiver.

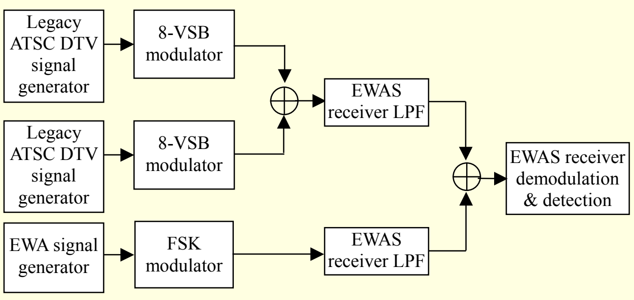

Fig. 6. Equivalent model for calculating interference of the EWAS reception from ATSC DTV signal.

Figure 7 shows the spectrum of two adjacent ATSC DTV signals after going through a combiner.

Figure 8 shows the frequency response of an LPF for an EWA signal with a 200 kHz bandwidth and 1,024 filter taps as an example.

The time and frequency domains of the residual ATSC DTV

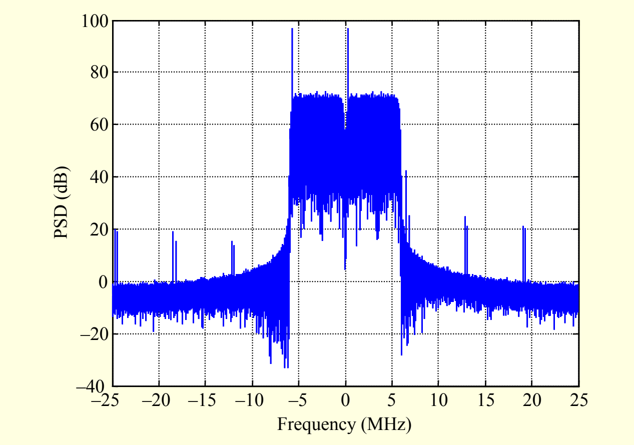

Fig. 7. Spectrum of adjacent ATSC DTV channel signals.

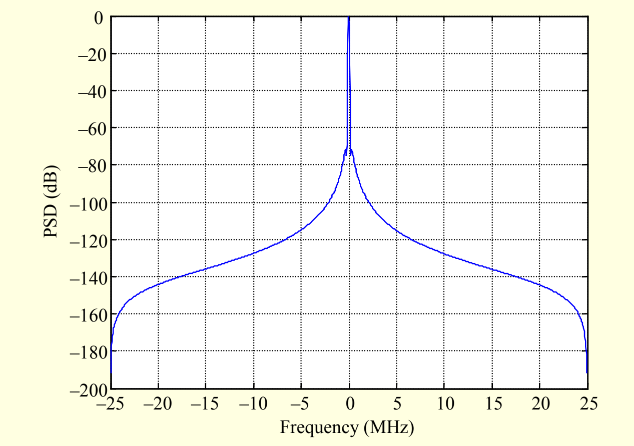

Fig. 8. LPF response for EWA signal (bandwidth, 200 kHz).

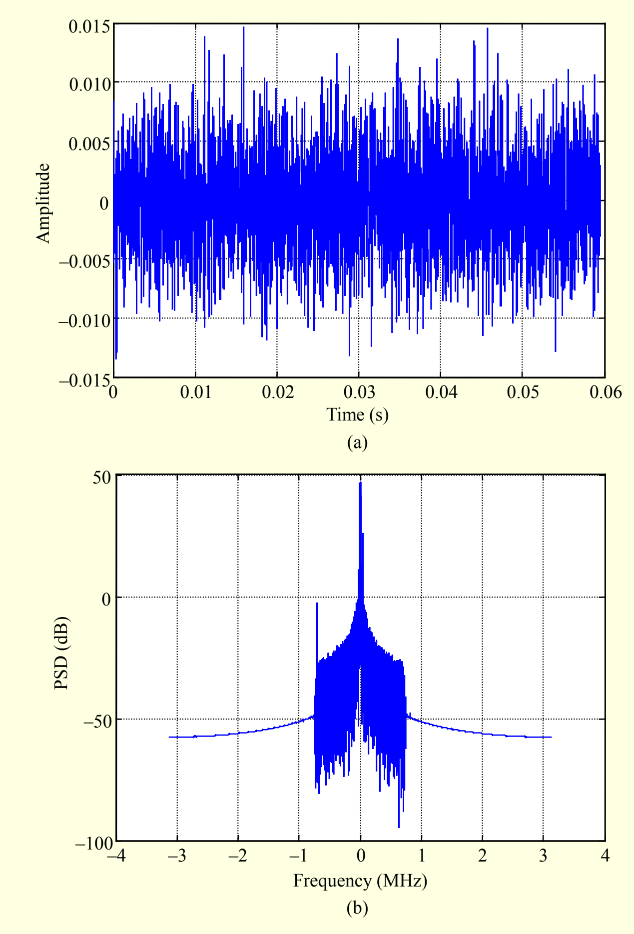

Fig. 9. Residual ATSC DTV signal after the EWA IF filter in the (a) time and (b) frequency domains (bandwidth, 200 kHz).

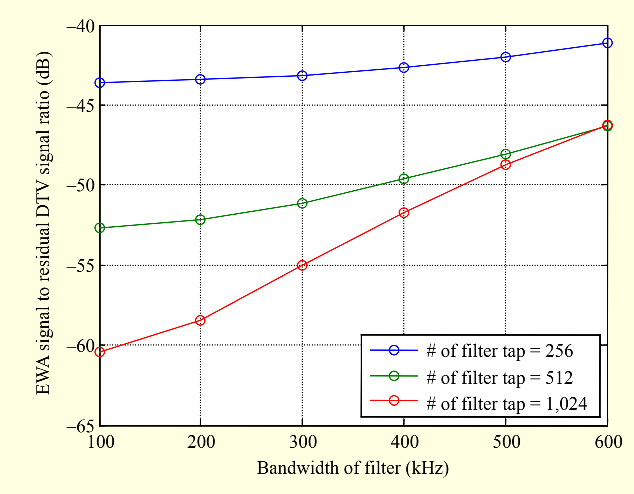

Fig. 10. EWA signal to residual DTV signal ratio according to the bandwidth of the filter.

signal through an LPF EWA signal with a 200-kHz bandwidth are shown in Fig. 9. Next, the residual ATSC DTV signal is combined with an EWA signal, as shown in Fig. 6.

Figure 10 shows the EWA signal to residual ATSC DTV signal power ratio according to the bandwidth of the filter. The performance of the EWA signal is degraded because the residual ATSC DTV signal interferes with the EWA signal.

As the results in Fig. 10 show, the EWA signal to residual ATSC DTV signal power ratio increases as the bandwidth of the filter increases and the number of filter taps decreases. However, because the EWA signal to residual ATSC DTV signal power ratio is less than –40 dB, the effects of the filter can be ignored.

IV. Minimum CNR of the EWAS

In this section, we calculate the minimum CNR of the EWAS under the following two conditions.

1) The transmit power of the EWAS is the same as that of ATSC DTV.

2) The receiver of the EWAS is located indoors and has the same coverage as the ATSC DTV system.

The coverage of the ATSC DTV and EWA signals in the

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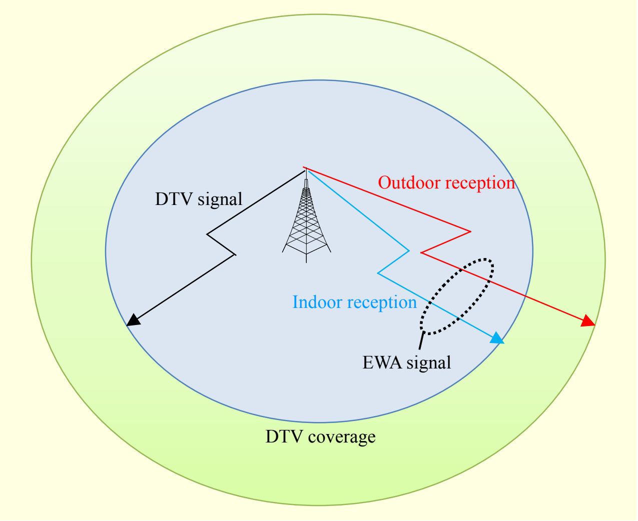

Fig. 11. Service coverage of ATSC DTV and EWAS.

design of the EWAS is shown in Fig. 11.

The EWA signal has the same coverage as the ATSC DTV signal in an indoor environment, and a larger coverage in an outdoor environment. The coverage of an ATSC DTV signal is defined such that an ATSC DTV receiver with a noise figure of 7 dB will be able to decode the signal when the received signal power is –84 dBm and the minimum field strength is 40.8 dBuV/m [6]. Assuming the same coverage as an ATSC DTV for outdoor reception, there are several considerations when designing the EWAS, such as the antenna height loss, building penetration loss, and antenna gain loss [7]. First, the loss according to differences in height of both systems can be considered. The height loss of the EWAS compared with that of the ATSC DTV system is about 16.5 dB [7], [8]. Second, the antenna gain loss of the EWAS compared with that of the ATSC DTV system can be significantly attenuated. The gain of the UHF DTV antenna in an outdoor environment is usually about 10 dBd. The gain of the UHF DTV antenna in an indoor environment is usually about 0 dBi. Therefore, the loss of the EWAS indoor antenna is about 12.15 dB.

Third, the building penetration loss of an EWAS when located indoors can be considered. In comparison with an ATSC DTV system used outdoors, such loss will be attenuated significantly depending on the materials and construction of the building. The building penetration loss of a UHF signal is usually about 11 dB [7], [8]. Finally, the EWAS has a 4-dB gain over the ATSC DTV system because there is no cable loss in the EWAS. Therefore, the EWAS should be designed to be about 35.65 dB more robust than the ATSC DTV system. The receiver sensitivity of the EWA signal is as follows.

$$P_{r,\min}(\text{dBm}) = -114 + CNR_{\min}(\text{dB}) + 10\log_{10}(W_{\text{MHz}}) + N_F(\text{dB}), \tag{1}$$

where W_{MHz} is the signal bandwidth (MHz), and N_F (dB) is the noise figure of the receiver [9].

The relation between the receiver sensitivity, $P_{r,\min}$ (dBm), from the receiving antenna and the minimum field strength of the EWA signal, $E_{\min}(\text{dB}\mu\text{V/m})$, can be expressed as

$$\begin{aligned} E_{\min}(\text{dB}\mu\text{V/m}) = P_{r,\min}(\text{dBm}) + 77.22 + 20\log_{10} f_{\text{MHz}} \\ - G_{\text{r,dBi}}(\text{dB}) + L, \end{aligned} \tag{2}$$

where G_r (dB) is the gain of the receiver antenna, f_{MHz} is the center frequency, and L is the loss, such as the building penetration loss or height loss [6], [8]. Substituting (2) into (1), the minimum field strength can be obtained as

$$\begin{aligned} CNR_{\min}(\text{dB}) = E_{\min}(\text{dB}\mu\text{V/m}) + G_{r,\text{dBi}}(\text{dB}) - N_F(\text{dB}) \\ - 20\log_{10} f_{\text{MHz}} - 10\log_{10}(W_{\text{MHz}}) + 36.78 - L. \end{aligned} \tag{3}$$

The minimum CNR of the EWAS is 0.36 dB when the bandwidth is 50 kHz and receiving antenna gain of the EWA signal is 0 dBi at a center frequency of 615 kHz.

V. Simulation Results

In this section, we show the simulation results when determining the preamble length (PL) and message payload, as shown in Fig. 3. Figure 12 shows a false alarm and missing probability of the preamble according to the PL in an AWGN channel. In addition, because of a cost limitation, we consider an EWAS receiver with a frequency stability tolerance (FST) of 10 ppm and 20 ppm. Usually, the cost of the local oscillator decreases as the FST of the EWA signal increases. The FST refers to the oscillator's specified tolerance range under the specified temperature conditions and with the operating voltage range. Therefore, we should design an EWAS receiver with an acceptable performance until total offsets of 10 ppm and 20 ppm are reached. Figures 12(a) and 12(b) show a false alarm and the missing probability of the preamble when the FST is 10 ppm and 20 ppm, respectively.

It can be seen in Fig.12(a) that a false alarm probability of 10^{-5} is achieved with about a normalized threshold of 0.5, and that a missing probability of 10^{-5} is achieved with about a normalized threshold of 0.85 when the EWAS receiver PL is 1,024 and the FST is 10 ppm. This means that the frame can be acquired when the range of a given normalized threshold is from 0.5 to 0.85.

It can be seen in Fig. 12(b) that a false alarm probability of 10^{-5} is achieved with about a normalized threshold of 0.5, and that the missing probability of 10^{-5} is achieved with about a normalized threshold of 0.58 in an EWAS receiver with a PL of 1,024 and FST of 20 ppm. This means that the frame can be acquired when the range of the given normalized threshold is

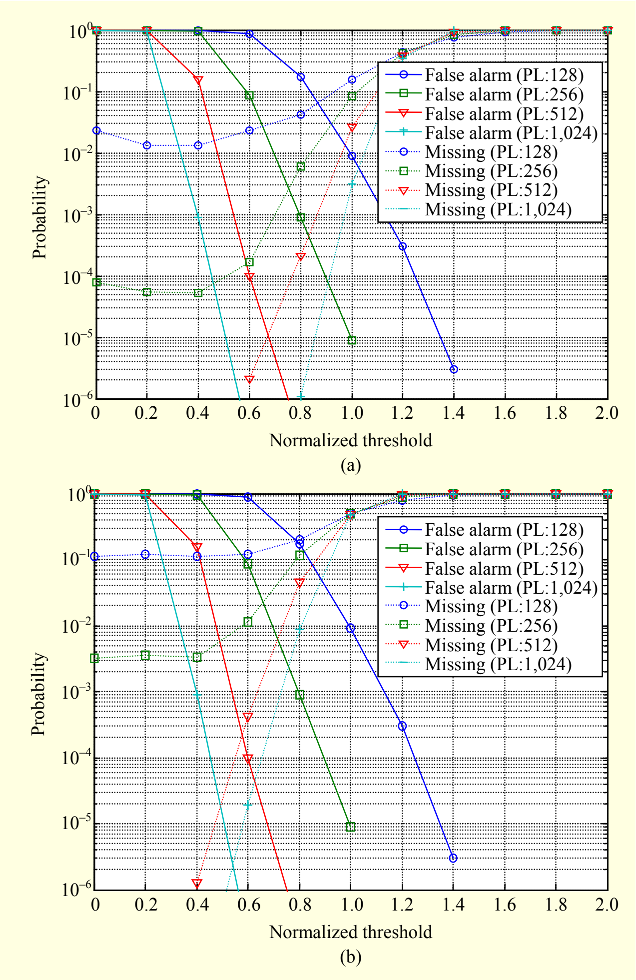

Fig. 12. PL according to FST at a bandwidth of 50 kHz: FST of (a) 10 ppm and (b) 20 ppm.

Table 1. Brazil type-D channel.

Delay (μs)	Amplitude (dB)
–5.71	–0.1
–5.23	–3.9
–3.64	–2.6
–2.81	–1.3
0.0	0
0.07	–2.8

from 0.5 to 0.58.

From Figs. 12(a) and 12(b), we can conclude that the preamble of the EWAS with an FST of 10 ppm has a better acquisition performance than that of the EWAS with an FST of 20 ppm. The false alarm and missing probability with an FST of 10 ppm under a given normalized threshold is better than with an FST of 20 ppm when the whole PL is considered.

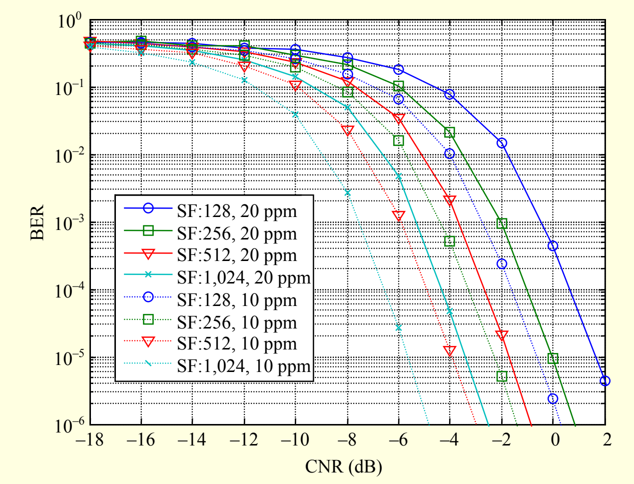

Fig. 13. Performance of EWA signal in AWGN (bandwidth, 50 kHz).

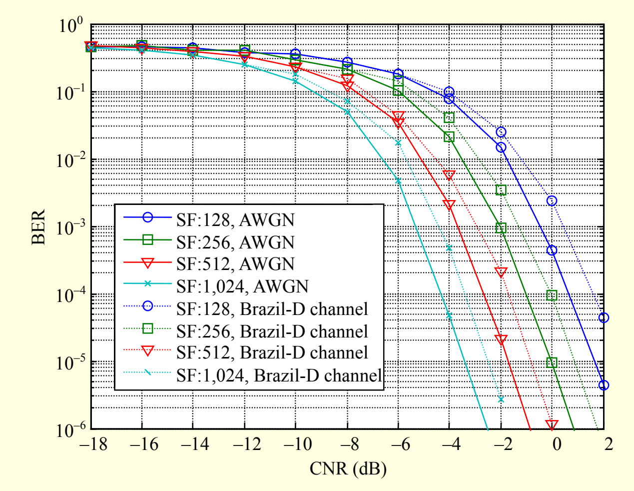

Fig. 14. Performance of EWA signal in Brazil type-D channel (bandwidth, 50 kHz).

From the simulation results, the PL of the EWAS should be over 1,024 to achieve the false alarm and missing probabilities concurrently under a target probability of 10^{-5}.

Furthermore, we determined the SF of the message payload of the EWA signal through a simulation based on the required CNR of 0.36 dB. For the simulation, a Brazil type-D channel modeled for indoor channel conditions was used [10]. The channel information is given in Table 1.

Figure 13 shows the BER performance of the EWAS as a function of the CNR in dB with the SF as a parameter in an AWGN. In the AWGN, an EWAS with an FST of 10 ppm can be achieved under a target BER of 10^{-5} when the SF is over 128, as shown in Fig. 13. In addition, an EWAS with an FST of 20 ppm can achieve a target BER of 10^{-5} when the SF is over 256.

Figure 14 shows the BER performance of the EWAS as a function of the CNR in dB with the SF as a parameter in a

Brazil type-D channel. In the Brazil type-D channel, an EWAS of 20 ppm can achieve a target BER of 10^{-5} when the SF is over 512, as shown in Fig. 14.

From the results, we can conclude that the length of the SF is over 512 for transmitting a 1-bit message payload. Assuming that the length of a frame is 1 s, we can calculate the number of bits of the message payload in the EWAS.

We concluded that the frame of the EWAS is as follows. Based on the results in Fig. 12, we determined that the PL of the EWAS is 1,024, and its time period is 0.08 s. Based on the results in Fig. 14, we determined that the SF of a 1-bit message payload is 512, and thus 22 bits are available with a 0.92-s time period.

VI. Conclusion

In this paper, a novel EWAS utilizing a DTV guard band was proposed to provide accurate and rapid emergency information. The EWAS was designed to be about 35.65 dB more robust than the ATSC DTV system because the indoor reception coverage of the EWAS should be similar with the outdoor reception coverage of the ATSC DTV system. Based on laboratory test results, the appropriate bandwidth and maximum available power level of the EWAS were determined. In addition, through a simulation, we selected the preamble length and SF of an emergency message payload in the EWAS under a frame length of 1 s. Based on the results, we concluded that the EWAS offers an emergency wake-up alert service supporting a data rate of up to 23 bps.

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