Determining Broadcaster Advised Emergency Wake-Up Signal with Switching Two Detection Methods and Observing Several TMCC Frames for Mobile ISDB-T Receivers

Satoshi Takahashi (member)†

Abstract When in an emergency, an ISDB-T (Integrated Services Digital Broadcasting-Terrestrial) broadcaster would send a special signal to wake-up their receivers. However, the mobile receivers would wrongly determine the wake-up signal due to the erroneous radio channel. The mobile receivers also need reducing the power consumption when in idle because they are generally battery-operated. In this paper, a method of reliably determining the wake-up signal while reducing the power consumption is proposed. The method uses switching two detection methods and determining the wake-up signal with a certain time observation. The evaluation is conducted in terms of the mutual information to be obtained from the receiver. The combination of the detection method and the determination method maximizes the mutual information.

Key words: digital television broadcasting, ISDB-T, EWS (Emergency Warning System), wake-up receiver

1. Introduction

Rapid delivery of disaster information is realized in various ways around the world1). In broadcasting systems, a broadcaster would send a special signal to automatically turn on their receivers and to present a news channel when in emergency. Those receivers that the main switch is off still continue to receive a part of the broadcaster signals and wait for the emergency wake-up signals. In digital television standard of ISDB-T, the emergency wake-up procedure is defined as EWS (Emergency Warning System) or EWBS (Emergency Warning Broadcasting System)2).

An ISDB-T broadcaster uses OFDM (Orthogonal Frequency Division Multiplexing) modulation to simultaneously send the control signal as well as audio-and-visual contents for fixed and mobile receivers. This wake-up signal is on one of the control signal named TMCC (Transmission and Modulation Configuration Control). This control signal is sent over 52 different subcarriers out of the total of 5,617 OFDM subcarriers, and they convey the same information. The TMCC signal employs DBPSK (differential bi-phase shift keying) modulation at a rate of 992 bit/s, and it has 203-bit long data. The TMCC signal is sent cyclically and the 26th bit is assigned to the start flag for emergency-alarm broadcasting (hereinafter it is referred to as “wake-up signal”)3). Mobile receivers would be powered with the battery, and a lower power consumption when in standby state leads to a longer operational time of the receiver. Therefore, the subject of rapid notification of disaster information in ISDB-T mobile reception can be substituted into reliably receiving the wake-up signals in lower power consumption.

A possible way of reducing power consumption at a receiver is to perform intermittent reception. It reduces the average power consumption by sleeping the receiver only for a fixed time after there is no wake-up signal detected by receiving for a fixed time. Though some of the parts such as the timer still active while the sleep duration, they consumes a negligibly smaller power. A dedicated intermittent receiver that operates the period from the beginning of the TMCC signal frame to the wake-up signal bit in the 26th bit and that sleeps for another period has been proposed4). On the other hand, an error of receiving the wake-up signal means error in the receiver activation. An alternate method of reliably determined the wake-up signal using the parity bit was proposed5). A state change in the wake-up signal results in variation of the parity bits. The method detects the wake-up signal by the majority determination of these varying bits on the assumption of that the broadcaster do not change TMCC information except for the wake-up signal before and after the wake-up signal is issued.
However, the method does not perform an intermittent reception because one of the needed parity bit is almost at the end of TMCC information.

Because the reception bit error is a decreasing function of the signal strength, one would easily come up with an idea that the receiver performs the intermittent reception for reducing the power consumption when in higher signal strength and that the receiver uses the parity for reliably receiving the wake-up signal when in lower signal strength.

On the other hand, the direct use of these detection results may possibly result in wrong receiver activation. Observing several results of the wake-up signals alleviates the wrong activation and increases the mutual information to be obtained by the receiver. In this paper, switching two detection methods and its determination based on observation of the several detection results are proposed to maximize the mutual information while reducing the average power consumption of the receiver.

2. Detecting Emergency Wake-Up Signal on TMCC

2.1 Detection Method 1: Single-bit

The intermittent receiver operates the period from the beginning of a predetermined 16-bit pattern (unique word) to the wake-up signal as in Fig. 1. Comparing it with the continual reception of TMCC signal, the receiving duration of the intermittent receiver reduced to \(27 \div 204 = 0.132\) times. The average power consumption of the receiver is also reduced by the ratio.

There are multiple radio paths from the broadcaster to this receiver in mobile radio environments, and they cause variation in the reception signal strength. It is often referred to as Rayleigh fading, and it results in wrong detection of the wake-up signal. The probability distribution of the reception power is

\[ p(\gamma) = \frac{1}{\gamma} \exp \left( -\frac{\gamma}{\bar{\gamma}} \right). \]

Here, \( \gamma \) is \( E_b/N_0 \), which represents the power per bit for the noise power density, and is a value proportional to the received signal strength. \( \bar{\gamma} \) is the average \( \gamma \). The bit error rate of DBSK modulation in Rayleigh fading environments, \( P_e \), is also known

\[ P_e = \frac{1}{2} \left( 1 + \frac{\gamma(1 - \rho_C)}{1 + \gamma} \right), \]

where \( \rho_C \) is the spatial correlation function with the maximum Doppler frequency \( f_D \) and the signal duration \( T_s \) assuming there is uniform scatterer around,

\[ \rho_C = J_0(2\pi f_D T_s). \]

\( P_e \) generally decreases as \( \gamma \) increases.

For expressing the wrongly determined the wake-up signal, there are two probabilities, the false alarm probability (\( P_{fa} \)) and the misdetection probability (\( P_{md} \)). \( P_{fa} \) is the probability the receiver correctly receiving the unique word and wrongly receiving the wake-up signal

\[ P_{fa} = (1 - P_e)^{16} P_e. \]

\( P_{md} \) is the probability the receiver wrongly misses the wake-up signal and is the complementary event of “probability of correctly receiving the unique word and correctly receiving the wake-up signal,”

\[ P_{md} = 1 - (1 - P_e)^{17}. \]

2.2 Detection Method 2: Parity

On the other hand, the TMCC information has parity that is for error correction as in Fig. 1. A change in the wake-up signal varies 35 bits out of 82 bits in the parity. The parity method uses the majority determination to detect the wake-up signal. Comparing it with the single-bit detection, the parity detection reliably detects the wake-up signal. However, the parity detection needs continual reception throughout the TMCC signals.

\( P_{fa} \) of the parity detection is the probability of correctly receiving the unique word and having more than half of the 36-bit pattern errors,

\[ P_{fa} = (1 - P_e)^{16} \left\{ \sum_{k=18}^{36} 36C_k (1 - P_e)^{36-k} P_e^k \right\}, \]

and \( P_{md} \) is the complementary event of “probability that the unique word is correctly received and the error
of the bit pattern is less than half, “
\[ P_{\text{md}} = 1 - (1 - P_e)^{16} \left( \sum_{k=0}^{18} C_k (1 - P_e)^{36-k} P_e^k \right) \] (7)

2.3 Mutual Information to Be Obtained from Receiver

The mutual information is obtained with the communication diagram shown in Fig. 2, where the receiver activation Y is realized by the wake-up signal X issued from the broadcaster. In the diagram, \( P_{\text{fa}} \) and \( P_{\text{md}} \) can be represented as \( p_{01} \) and \( p_{10} \), when the state of the wake-up signal is represented by either symbol 0 or symbol 1. Then the mutual information, \( I(X; Y) \) is

\[ I(X; Y) = (1 - p_1) \left\{ (1 - P_{\text{fa}}) \log_2 \left( \frac{1 - P_{\text{fa}}}{q_0} \right) \right. \]
\[ + P_{\text{fa}} \log_2 \left( \frac{P_{\text{fa}}}{q_1} \right) \left. + p_1 \left\{ P_{\text{md}} \log_2 \left( \frac{P_{\text{md}}}{q_0} \right) \right. \right. \]
\[ + (1 - P_{\text{md}}) \log_2 \left( \frac{1 - P_{\text{md}}}{q_1} \right) \left. \right\} \]
\[ q_0 = (1 - p_1) (1 - P_{\text{fa}}) + p_1 P_{\text{md}}, \text{ and} \]
\[ q_1 = (1 - p_1) P_{\text{fa}} + p_1 (1 - P_{\text{md}}), \] (8)

where \( p_1 \) is the probability the broadcaster issues the wake-up signals.

3. Detection Method Switching and Their Determination

In general, the wake-up signal would be continuously sent over several hundreds frames, and the signal continuity helps the receiver to lessen \( P_{\text{fa}} \) and \( P_{\text{md}} \). Therefore, in addition to selection of the single detection and the parity detection, the use of the successive results is proposed. This k-out-of-n determination uses the past \( n \) results of the detection results, and determines a presence of the wake-up signal when there are more than or equal to \( k \) wake-up signals are detected as illustrated in Fig. 3. Assuming the duration of the continual wake-up signal sent from the broadcaster is sufficiently longer than the duration of \( n \) at the receiver and the transient duration is negligibly small, \( P_{\text{fa}} \) applied to the k-out-of-n determination can be expressed without use of \( P_{\text{md}} \) as,

\[ \hat{P}_{\text{fa}} = \sum_{m=0}^{n-k} m C_m (1 - P_{\text{fa}})^m P_{\text{fa}}^{n-m}. \] (9)

The \( P_{\text{md}} \) applied to the k-out-of-n determination is also expressed as

\[ \hat{P}_{\text{md}} = \sum_{m=0}^{k-1} n C_m (1 - P_{\text{md}})^m P_{\text{md}}^{n-m}. \] (10)

Qualitatively, a larger \( k \) reduces \( P_{\text{fa}} \), while a smaller \( k \) results in a lower \( P_{\text{md}} \). A larger \( n \) decreases both \( P_{\text{fa}} \) and \( P_{\text{md}} \), but the reduction rates are diminished as an increase in \( n \).

The \( P_{\text{fa}} \) and \( P_{\text{md}} \) for the single-bit detection and parity detection methods are shown in Figs. 4 and 5. In these figures, \( I(X; Y) \) of the receiver without the k-out-of-n determination (that is, instant determination) is also shown as “instantaneous.” In Fig. 4(a), the \( P_{\text{fa}} \) is convex shaped. A higher \( \gamma \) results in reduction of \( P_{\text{fa}} \), while a lower \( \gamma \) prevents synchronization with the unique word and it results in a lower \( P_{\text{fa}} \). The higher \( k \) reduced \( P_{\text{fa}} \). In Fig. 4(b), the lower \( k \) reduced \( P_{\text{md}} \) to \( 10^{-7} \) order at \( \gamma = 30 \text{ dB} \). Comparing it with the \( P_{\text{fa}} \) in the single-bit detection, \( P_{\text{fa}} \) in the parity detection is smaller. But, \( P_{\text{md}} \) between the single-bit detection and the parity detection are almost the same. In these calculations, an operation frequency of 600 MHz, and a mobile velocity of 10 m/s were assumed.

\[ I(X; Y) \] of the single-bit detection and the parity detection with k-out-of-n determination is obtained using Eqs. (2)–(10) and is plotted in Fig. 6 for \( n = 5 \) (it corresponds to wake-up signal observation of 1 s) and for various \( k \). In the figure, the total duration of issuing the wake-up signal by the broadcaster was set to 5.26 minutes a year (the probability \( p_1 \) is \( 10^{-5} \)). The maximum \( I(X; Y) \) was limited to the entropy the broadcaster issues the wake-up signal. The entropy calculated by

\[ H(p_1) = -p_1 \log(p_1) - (1 - p_1) \log(1 - p_1) \] is a function of \( p_1 \). \( I(X; Y) \) increased as an increase in \( \gamma \), and ap-

![Fig. 2 Communication diagram of emergency wake-up signal flow.](image-url)
proached to $H(p_1)$. In Fig. 6(a), the instantaneous determination in the single detection did not reach $H(p_1)$.

Comparing it with the instantaneous determination, the $k$-out-of-$n$ determination with $k = 1$ provided a higher $I(X;Y)$, but it did not reach $H(p_1)$. The $k$-out-of-$n$ determination with $k = 5$ provided rather higher $I(X;Y)$ than the instantaneous $I(X;Y)$, but it did not reach $H(p_1)$. The $k$-out-of-$n$ determination with $k = 3$ provided the highest $I(X;Y)$ at $\gamma$ of 9 dB and above, and it approached to $H(p_1)$ at $\gamma$ of 20 dB and above. $k$ of the half of $n$ reduced both of the $P_{fa}$ and $P_{md}$ and provided the highest $I(X;Y)$.

On the other hand for the parity detection, the $k$-out-of-$n$ determination with $k = 1$ provided the highest $I(X;Y)$. This is because the $P_{fa}$ is enough lower than $P_{md}$, and the lower $P_{md}$ resulting from $k = 1$ provided the higher $I(X;Y)$.

Therefore, $I(X;Y)$ for the single detection with the 3-out-of-5 determination and the parity detection with the 1-out-of-5 determination are plotted in Fig. 7. Both of $I(X;Y)$ approached to $H(p_1)$ at $\gamma$ higher than 20 dB. $I(X;Y)$ of the single-bit detection diminished at $\gamma$ lower than 20 dB, and $I(X;Y)$ of the parity detection did at $\gamma$ lower than 10 dB. The use of the single detection when $\gamma$ was higher than 20 dB to diminish the power consumption and the parity detection when

---

**Fig. 4** $P_{fa}$ and $P_{md}$ for the single-bit detection with $k$-out-of-$n$ determination.

**Fig. 5** $P_{fa}$ and $P_{md}$ for the parity detection with $k$-out-of-$n$ determination.
The expected power consumption can be evaluated using Eq.(1). The probability $P_{\text{single}}$ the single detection is selected at the average $E_b/N_0$ of $\gamma$ is obtained as

$$P_{\text{single}} = \operatorname{Prob}(\gamma_0 < \gamma) = \int_{\gamma_0}^{\infty} \frac{1}{\gamma} \exp \left( -\frac{\gamma}{\gamma} \right) d\gamma$$

$$= \exp \left( -\frac{\gamma_0}{\gamma} \right).$$

Therefore, the normalized power consumption $C$ is expressed as

$$C = \frac{27}{204} \cdot P_{\text{single}} + \frac{204}{204} (1 - P_{\text{single}}),$$

and is plotted in Fig. 8 at $\gamma_0 = 20$ dB. An increase in $\gamma$ increases the opportunity to select the single-bit determination and decreases $C$, and $C$ is a monotonically decreasing function of $\gamma$. At $\gamma$ higher than 30 dB, the receiver chose the single-bit determination and the power consumption was 1/5 times lower than the power consumption of the continual reception.

The parity detection uses the majority determination
among the predetermined bit pattern, and it can measure $\gamma$. An increase in $P_k$ also increases the number of the disagreement bits. The dependence of $\gamma$ on the mean disagreement bits is expressed as

$$D = \sum_{k=1}^{36} k \cdot 36C_k (1 - P_e)^{36-k} P_e^k,$$

(13)

and is plotted in Fig. 9 using Eqs. (2) and (13). Because an increase in $\gamma$ reduces $P_e$, $D$ is a monotonically decreasing function of $\gamma$. At the threshold of $\gamma$ that the receiver chose the single-bit determination or the parity determination, $D$ was less than 1 bit. This indicates that the receiver should select the parity detection where there is a disagreement bit.

4. Conclusion

In this paper, the switching two detection methods and the $k$-out-of-$n$ determination method were proposed. The single-bit detection method could intermittent reception and the power consumption was reduced by 0.132 times than the power consumption of the continual receiver, but it encountered higher false alarms. The parity detection method could reduce the false alarms, but it needed the continual reception whole the TMCC frame. The single detection with the 3-out-of-5 determination and the parity detection with the 1-out-of-5 determination provided the highest mutual information. The expected power consumption was obtained as a function of the average signal strength. The parity detection is capable of estimating the signal strength through the number of the disagreement bits. The presence of the disagreement bits indicated the mutual information to be obtained from the single-bit detection diminished because of the low reception signal strength.

Acknowledgment

This work was supported by JSPS KAKENHI Grant Number JP17K06436.

References

1) S.J. Choi, “Analysis of emergency alert services and systems,” 2007 International Conference on Convergence Information Technology, pp.657–662 (Nov. 2007)
2) Y. Ito, “Keywords you should know: emergency warning broadcasting system,” The Journal of The Institute of Image Information and Television Engineers, 61, 6, pp.761–763 (June 2007), in Japanese
3) Association of Radio Industries and Business (ARIB) ed., “Transmission system for digital terrestrial television broadcasting,” ARIB STD-B31, Tokyo, 2.2 Ed. (2014)
4) M. Taguchi, H. Hamazumi, and Y. Ito, “An examination of receiver for emergency warning signal in one-seg service,” IEICE General Conference, DS-2-6, (March 2006) in Japanese
5) S. Takahashi, “A method of determining broadcaster advised emergency wake-up signal for ISDB-T digital television receivers,” Journal of Telecommunications and Information Technology (JTIT), 2019, 1, pp.103-112 (March 2019)
6) A. Goldsmith, Wireless Communications, Cambridge University Press, New York (2005)
7) S. Takahashi, “Detecting emergency wake-up signal based on observation of several TMCC frames for ISDB-T television receivers,” The Journal of The Institute of Image Information and Television Engineers, 73, 6, pp.1178–1171 (Nov. 2019) in Japanese
8) S. Takahashi, “A low consumption power reception method with TMCC parity disagreements for determining ISDB-T emergency automatic wake-up signals,” The Journal of The Institute of Image Information and Television Engineers, 72, 6, pp.J94–J97 (June 2018) in Japanese

Satoshi Takahashi received B.E., M.E. and Ph.D. degrees from Tokyo Denki University, Japan, in 1990, 1992, and 2001. In 1992, he joined Hitachi, Ltd., where he engaged in research on radio propagation for indoor wireless systems. In 1996, he was a research engineer at YRP Key Tech Labs, Co., Ltd., where he engaged in research of radio propagation and systems for the future generation mobile radio communication. In 2002, he joined CRL (Communications Research Laboratory, and now NICT, National Institute of Information and Communications Technology), Ministry of Internal Affair, where he engaged in research of intelligent transport systems (ITS) and future radio communication systems. Since 2005, he is an associate professor at Hiroshima City University, Japan. Dr. Takahashi is a member of ITE, IEEE, and IPSJ, and a senior member of IEICE.