Method for Determining Broadcaster Advised Emergency Wake-up Signal for ISDB-T Digital Television Receivers

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Abstract—There is a way to automatically wake up television receivers when a broadcaster sends out an emergency alert. In the Integrated Services Digital Broadcasting-Terrestrial (ISDB-T) digital television standard, the emergency wake-up procedure is called an Emergency Warning System (EWS). In ISDB-T, the special signal is embedded in a control message known as transmission and modulation configuration control (TMCC). However, improper identification of the wake-up signal, often encountered in mobile reception, leads to unnecessary wake ups. In this paper, a method of reliably determining a wake-up signal is proposed by assuming that broadcasters will not change the TMCC message except for the wake-up signal when the broadcaster sends out an emergency alert. A change in the wake-up bit leads to variation parity, and the proposed method also relies on such variations. Mutual information to be obtained by the wake-up receiver is evaluated using the memoryless binary asymmetric channel model. Results showed that the proposed method provided mutual information even at a E_b/N_0 being lower than 10 dB. Mutual information of the proposed method with intermittent reception is also analyzed as a function of the duty ratio of the intermittent receiver.

Keywords—binary asymmetric channel, emergency warning system (EWS), intermittent reception, transmission and modulation coding configuration (TMCC).

1. Introduction

When tremors are felt on the ground, we may turn on television sets or radios to listen to alert messages about earthquakes, tsunami alerts, etc. Prompt audio-and-visual alerts during emergencies have been important, as the requirement to place fire sensors inside houses in the United States significantly reduces the number of people who have died while sleeping.

One could easily come up with ideas to provide automatic wake-up television receivers with a broadcaster assigned emergency signal. This idea has been implemented by broadcasters who send special signals to advise of emergencies. Some components of a television receiver, such as the tuner and the power supply controller, are still active and the receiver continues to receive signals from the broadcaster when it is idle, until special messages are sent. Emergency alerts are sent out based on requests from local governments or meteorological agencies.

Emergency alerts provided by means of broadcasting signals are now available. An Emergency Alert System (EAS) is in operation in the United States. The wake-up signal in EAS is encoded into the main audio channel using frequency shift keying (FSK) modulation, and therefore the EAS wake-up signal is mainly available on analog television sets and radios [1]. Digital television sets in the United States employed the Advanced Television Standard Committee (ATSC) standard after analog television broadcasting ended. ATSC-class television receivers had to be woken up by EAS, by decoding the transport stream (TS), the audio channel and the alert message during the idle state. One possible way of designing ATSC wake-up receivers is to use a guard band between broadcasting channels [2]. ATSC 3.0, a successor of ATSC, plans to implement a new EAS wake-up method [3]. The wake-up signal in the Digital Video Broadcasting-Terrestrial (DVB-T) television standard is also encoded into the main audio channel, just as it was the case with FSK modulation in TS, and is delivered by an optional Announcement Service [4]. This procedure is also called EWS. A method of displaying an emergency pop-up message on the screen has been proposed [5].

The emergency wake-up procedure of ISDB-T is defined as EWS. The wake-up signal bit is embedded in a control signal named TMCC, while detailed emergency content is included in the Program Map Table (PMT) in Transport Stream (TS) [6]. Therefore, accurate determination of the specific bit in a TMCC message may serve as a substitute to improve the effectiveness of the wake-up procedure. An emergency wake-up will also be available in the Terrestrial Digital Multimedia Broadcasting (T-DMB) standard [1]. In T-DMB, both the wake-up signal and the detailed information are embedded in the Fast Information Channel (FIC) that also carries multiplexing, service, and conditional access-related information.

It is important for mobile receivers to decrease their power consumption. Separation of transmissions of the wake-up
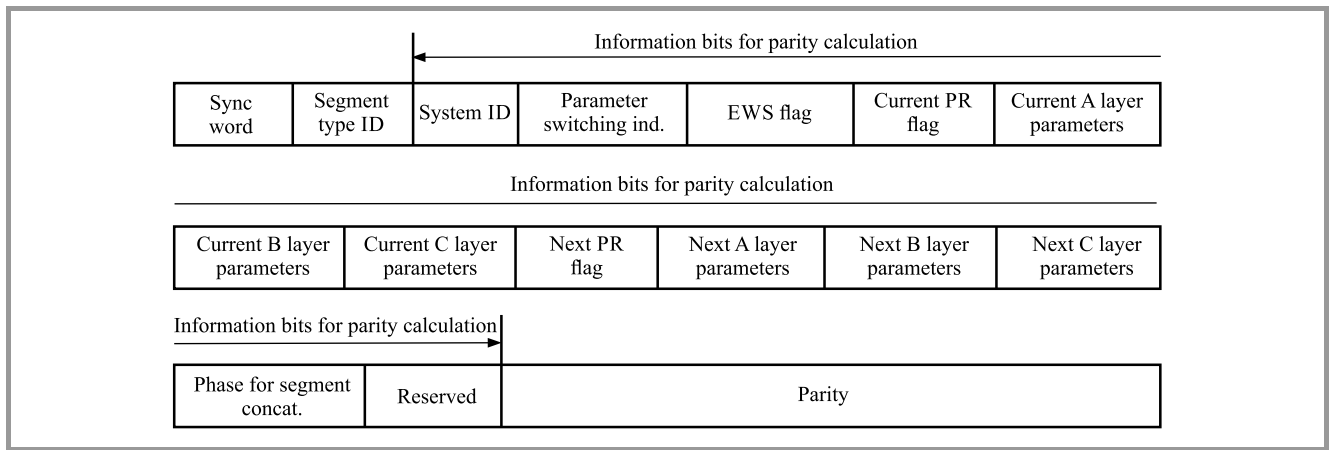
			Information bits for parity calculation				
Sync word	Segment type ID	System ID	Parameter switching ind.	EWS flag		Current PR flag	Current A layer parameters

		Information bits for parity calculation			
Current B layer parameters	Current C layer parameters	Next PR flag	Next A layer parameters	Next B layer parameters	Next C layer parameters

		Information bits for parity calculation	
Phase for segment concat.	Reserved	Parity	

Fig. 1. The TMCC message structure.

signal and the signal containing detailed information decreases, in ISDB-T, power consumption of television receivers remaining at an idle state, because all the idle receiver has to do is only to receive the control signal. A way of potentially decreasing power consumption further is to employ intermittent reception. It enables the receiver to sleep periodically, for a certain time, in order to reduce mean power consumption. Because the frequency of disasters is extremely low, the use of intermittently-active receivers could be possible, but on the other hand, intermittent reception may also lead to misdetection of emergency alerts.

In this paper, a method of determining the wake-up signal in ISDB-T is proposed. Performance evaluation is carried out using the probability of misdetection, the probability of a false alarm and mutual information. Mutual information is also analyzed in intermittent reception to determine the trade-off between performance and power consumption.

2. Emergency Wake-up Procedure for ISDB-T Television Receivers

2.1. ISDB-T Signals

ISDB-T employs band segment transmission-orthogonal frequency division multiplexing (BST-OFDM) with 5616 subcarriers and a phase reference subcarrier. It segments a 5.7 MHz channel band into 13 bands. Each segment consists of two control signals (TMCC and AC[1]) and the payload.

ISDB-T digital television is capable of layering the payload into A, B and C layers. Each layer employs mutually different modulations and coding rates. For example, a broadcaster would choose one-segment QPSK modulation in the A layer for mobile receivers, and 12-segment 64 QAM

[1] Auxiliary channel (AC) is used for broadcasters and for the early earthquake warning in ISDB-T.

modulation in the B layer for fixed receivers. Some important messages, such as the network information table (NIT) and conditional access table (CAT) are sent in the A layer. The arrangement, as well as the wake-up signal, are described in the TMCC message.

The TMCC signal is periodically sent in 0.2 s cycles by differential bi-phase shift keying (DBPSK) modulation. ISDB-T broadcasters in Japan use a subcarrier bandwidth called mode 3, and there are four TMCC subcarriers in a segment. Each TMCC signal contains a 204-bit message and the message is periodically sent at 992 bps.

The TMCC message structure is shown in Fig. 1. It consists of a 1-bit length phase reference to demodulate the DBPSK signal (not shown in Fig. 1), a 16-bit length synchronization word (alternation of fixed patterns 0x39EE and 0xCA11 in a hexagonal expression), a 3-bit length segment type identifier, a 2-bit length system identifier, a 4-bit length indication of parameter change and a 1-bit length emergency wake-up signal (denoted by the EWS flag). There is also a 1-bit length current partial reception flag, a 39-bit length current modulation, coding rate, and segment number, a 1-bit length next partial reception flag, a 39-bit length next modulation, coding rate, and segment number, a 3-bit length phase compensation for segment concatenation, a 12-bit length reserved space and an 82-bit length parity.

2.2. Bit Error Rate in Receiving TMCC Messages

The radio signal in stationary reception arriving at the receiver is represented by additive white Gaussian noise (AWGN). The bit error rate, P_e, for DBPSK modulation is

$$P_e = \frac{1}{2}\mathrm{e}^{-\gamma},$$

where γ is the signal energy per bit above the noise power density, which is usually denoted by E_b/N_0. γ is also proportional to signal strength. An increase in γ monotonically decreases P_e.

Signal strength observed by a moving receiver varies from time to time due to the multipath phenomenon. Signal fluctuation due to Rayleigh fading is caused by both scattered waves in mobile reception. The P_e is [7]:

$$P_e = \frac{1}{2} \frac{1 + \gamma(1 - \rho_C)}{1 + \gamma} , \tag{1}$$

where ρ_C is the correlation coefficient of signals between the symbol duration of T_s. The ρ_C of the uniformly spread scatterers model becomes:

$$\rho_C = J_0(2\pi f_D T_s) , \tag{2}$$

where $J_0(\cdot)$ is the first-kind Bessel function of the zero-th order, and f_D is the maximum Doppler frequency. f_D is obtained from $f_D = v/\lambda$, and v is the velocity and λ is the wavelength. Because the error is the source of the multipath and the Doppler effect, the P_e in mobile reception depends on v and T_s. Various ρ_C are found in reference [7].
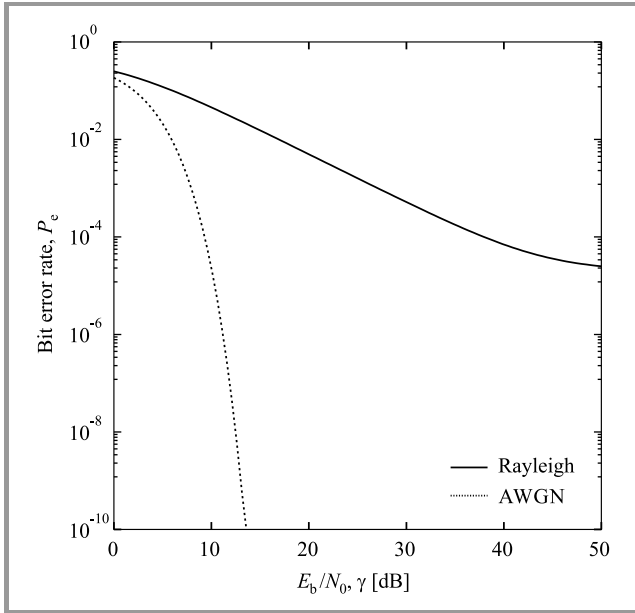

Fig. 2. P_e vs. γ in stationary reception (AWGN) and mobile reception (Rayleigh fading) environments.

P_e in AWGN and Rayleigh fading environments are compared in Fig. 2. In the Rayleigh fading environment, an increase in γ leads to the exhibition of P_e floor, and it is often referred to as an irreducible error. The error floor in Rayleigh fading is calculated by taking the limit of $\gamma \to \infty$ in Eq. (1),

$$P_e = \frac{1}{2}(1 - \rho_C) . \tag{3}$$

2.3. Error Correction Code Employed in TMCC Message

Parity in a TMCC message is generated by the polynomial of $x^{82} + x^{77} + x^{76} + x^{71} + x^{67} + x^{66} + x^{56} + x^{52} + x^{48} + x^{40} + x^{36} + x^{34} + x^{24} + x^{22} + x^{18} + x^{10} + x^4 + 1$. The $(273, 191)$

difference set cyclic code is a type of the BCH code that is capable of correcting 8 error bits[2]. In general, decoding a BCH code requires cumbersome polynomial factorization. But the code may be decoded by majority determination of the summarized syndromes [8]. The code originally proposed by Weldon is shortened to fit the 102-bit TMCC information. A method of efficiently correcting errors with the $(184, 102)$ shortened code is also proposed, relying on majority determination of the syndrome summary [9].

At the receiver, the TMCC message is divided by the generating polynomial to obtain the 82 syndrome bits $S_0 - S_{81}$. They are further summarized into following 18 work bits:

$$A_1 = S_{71} + S_{76}$$
$$A_2 = S_{17}$$
$$A_3 = S_5 + S_{23}$$
$$A_4 = S_{21} + S_{27} + S_{45}$$
$$A_5 = S_3 + S_{25} + S_{31} + S_{49}$$
$$A_6 = S_{16} + S_{40} + S_{42} + S_{66}$$
$$A_7 = S_{35} + S_{52} + S_{56} + S_{78}$$
$$A_8 = S_8 + S_{44} + S_{61} + S_{65}$$
$$A_9 = S_2 + S_{11} + S_{47} + S_{64} + S_{68}$$
$$A_{10} = S_{10} + S_{13} + S_{22} + S_{58} + S_{75} + S_{79}$$
$$A_{11} = S_1 + S_{12} + S_{15} + S_{24} + S_{60} + S_{77} + S_{81}$$
$$A_{12} = S_{30} + S_{32} + S_{43} + S_{46} + S_{55}$$
$$A_{13} = S_6 + S_{37} + S_{39} + S_{50} + S_{53} + S_{62}$$
$$A_{14} = S_0 + S_7 + S_{38} + S_{40} + S_{51} + S_{54} + S_{63}$$
$$A_{15} = S_{18} + S_{19} + S_{26} + S_{57} + S_{59} + S_{70} + S_{73}$$
$$A_{16} = S_9 + S_{28} + S_{29} + S_{36} + S_{67} + S_{69} + S_{80}$$
$$A_{17} = S_4 + S_{14} + S_{33} + S_{34} + S_{41} + S_{72} + S_{74}$$

If more than 8 bits out of $A_1 - A_{17}$ are active, the first bit is determined to be wrong and should be inverted. The procedure of the cyclic shift of the syndrome $S_0 - S_{81}$, the calculation of $A_1 - A_{17}$, and the majority determination are repeated to correct errors in the TMCC message. We could correct an error in the wake-up signal by repeating the procedure by 25 times.

3. Proposed Method of Determining Emergency Wake-Up Signal

3.1. Observation of Broadcaster Advised TMCC Message under Normal Conditions

Broadcaster-sent TMCC messages were observed in the Hiroshima area in Japan to determine actual TMCC messages. An ISDB-T front-end decoder by EIDEN 6500A-001 was

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[2]Because the Hamming weight is 18, this code can correct up to 8 bits through an erroneous channel.

Table 1

Results of observations of broadcaster-sent TMCC messages in the area of Hiroshima city in Japan

System identification	Terrestrial digital television
Parameter switching	Normal
Wake-up signal (EWS flag)	Inactive
Current information	Partial reception on
A layer	QPSK, coding rate of 2/3 inter-leave length of 4, one segment
B layer	64QAM, coding rate of 3/4 inter-leave length of 2, 12 segments
C layer	Unused
Next information	Same as current ones
Concatenate transmission	Unused
Reserved	Unused

used in this observation. Except for the original channel of a cable television (CATV) broadcaster, all six broadcasters sent the same TMCC message listed in Table 1.

Table 2

Parity bit changes according to a change in the wake-up signal

Bit	Change	Coefficient	Bit	Change	Coefficient
122	$0 \rightarrow 1$	x^{81}	160	$1 \rightarrow 0$	x^{43}
124	$1 \rightarrow 0$	x^{79}	163	$1 \rightarrow 0$	x^{40}
127	$0 \rightarrow 1$	x^{76}	164	$1 \rightarrow 0$	x^{39}
128	$1 \rightarrow 0$	x^{75}	165	$1 \rightarrow 0$	x^{38}
130	$1 \rightarrow 0$	x^{73}	169	$0 \rightarrow 1$	x^{34}
132	$1 \rightarrow 0$	x^{71}	170	$1 \rightarrow 0$	x^{33}
133	$0 \rightarrow 1$	x^{70}	171	$1 \rightarrow 0$	x^{32}
135	$0 \rightarrow 1$	x^{68}	173	$1 \rightarrow 0$	x^{30}
138	$0 \rightarrow 1$	x^{65}	177	$1 \rightarrow 0$	x^{26}
139	$0 \rightarrow 1$	x^{64}	178	$1 \rightarrow 0$	x^{25}
140	$0 \rightarrow 1$	x^{63}	182	$1 \rightarrow 0$	x^{21}
142	$1 \rightarrow 0$	x^{61}	183	$0 \rightarrow 1$	x^{20}
144	$0 \rightarrow 1$	x^{59}	187	$1 \rightarrow 0$	x^{16}
148	$0 \rightarrow 1$	x^{55}	194	$1 \rightarrow 0$	x^{9}
149	$0 \rightarrow 1$	x^{54}	200	$0 \rightarrow 1$	x^{3}
150	$1 \rightarrow 0$	x^{53}	201	$1 \rightarrow 0$	x^{2}
156	$1 \rightarrow 0$	x^{47}	202	$1 \rightarrow 0$	x^{1}
158	$1 \rightarrow 0$	x^{45}			

The TMCC message shown in Table 1 is 3D 25 8B 4B 3F FF 25 8B 4B 3F FF FF FC in a hexagonal representation. The 82-bit length parity summarizes the 102-bit TMCC message. Dividing the polynomial representing the TMCC message by the generating polynomial, we obtain the parity of 2B E8 19 CF AE 72 DB A8 F8 A5 80. If the wake-up signal is sent, the parity becomes 8D 5C F3 F7 84 03 0A 24 B8 26 00.

3.2. Determination Method Proposed

We assume that the broadcasters would not change the TMCC message when sending out an emergency signal, except for the wake-up signal. A change in the wake-up signal varies the parity bits listed in Table 2 in a scenario in which the broadcaster sends the TMCC message listed in Table 2 where the broadcaster sends the TMCC message listed in Table 1.

Therefore, the proposed method of determining the wake-up signal is described by the majority of the corresponding bits matched as the 26-th bit (the wake-up signal) being one, the 122-nd bit being one, the 124-th bit being zero and so on, while the synchronization word exactly matches the definition [10]. It is unlucky that the total number of them is an even number of 36. Here, the receiver determines the wake-up signal by agreeing to more than 18 matching bits.
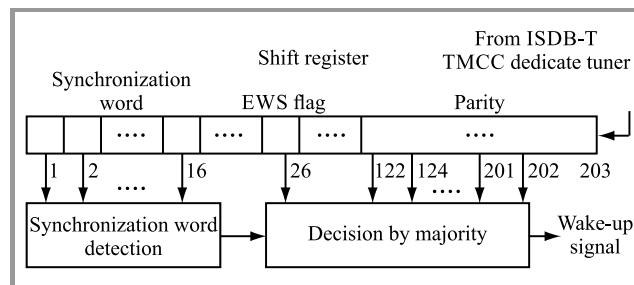

Fig. 3. Schematic block diagram of the proposed method.

It should be noted that parity bit positions to be alternated by change in the wake-up signal state are fixed, regardless of what type of TMCC message is provided, though their values are changed according to the TMCC message kind, as such is the characteristics of linear codes. The schematic block diagram is shown in Fig. 3.

3.3. Misdetection and False Alarm Probabilities

Performance is evaluated in terms of misdetection probability P_{md}, and the false alarm probability, P_{fa}. Misdetection means the receiver has missed the wake-up signal, and a false alarm means the receiver has wrongly been activated when the wake-up signal was not present.

First of all, we obtain P_{md} and P_{fa} when the receiver determines the wake-up signal only. Such determination is defined, hereinafter, as single-bit determination. The receiver decodes a TMCC message after the frame synchronization that matches the reception bit sequence with the synchronization word. P_{md} for the single-bit determination is the complement probability that all 16-bit synchronization words agrees and that the wake-up signal is correctly detected:

$$P_{md}^{single} = 1 - (1 - P_e)^{17} . \qquad (4)$$

On the other hand, P_{fa} is the probability that the synchronization word matches and the wake-up signal is wrongly detected:

$$P_{\text{fa}}^{\text{single}} = (1 - P_e)^{16} P_e \ . \tag{5}$$

P_{md} for the proposed method is the complement probability that the synchronization word will agree and that more than 18 bits of the 36 corresponding bits will agree, and is [3]:

$$P_{\text{md}}^{\text{prop}} = 1 - (1 - P_e)^{16} \cdot \left\{ \sum_{k=0}^{18} {}_{36}C_k \, (1 - P_e)^{36-k} P_e^k \right\} \ . \tag{6}$$

The proposed P_{fa} is also obtained where the 16 synchronization bits are correctly received and more than 18 bits of the 36 bits are wrong:

$$P_{\text{fa}}^{\text{prop}} = (1 - P_e)^{16} \cdot \left\{ \sum_{k=18}^{36} {}_{36}C_k \, (1 - P_e)^{36-k} P_e^k \right\} \ . \tag{7}$$

P_{fa} is a decreasing function for a sufficiently small P_e, but it is also an increasing function where P_e is near to 0.5, which is the highest value. Therefore, the P_{fa} is a convex function of P_e.

The receiver's error correction of the wake-up signal is expressed as "ec" It seems possible to obtain P_{md} for an ec of the receiver as:

$$\tilde{P}_{\text{md}}^{\text{ec}} = 1 - (1 - P_e)^{16} \cdot \left\{ \sum_{k=0}^{8} {}_{184}C_k \, (1 - P_e)^{184-k} P_e^k \right\} \ , \tag{8}$$

but it is virtually impossible to solve the equation, since the number of combinations becomes huge, while the exponent of P_e rapidly approaches zero. Therefore, transmission performance has been evaluated by the Monte Carlo method that uses computer-generated random numbers [11]. But an analytical evaluation using the summarized syndrome in Subsection 3.2 is proposed [12]. P_{md} is the complement probability that the synchronization word is correctly received and that 8 or fewer bits out of the 17 work bits are active:

$$P_{\text{md}}^{\text{ec}} = 1 - (1 - P_e)^{16} \cdot \left\{ \sum_{k=0}^{8} {}_{17}C_k \, (1 - P_e)^{17-k} \cdot P_e^k \right\} \ . \tag{9}$$

Because a single syndrome is obtained with exclusive-or operations of the received sequence, the active ratio of the single syndrome is P_e and the work bit active ratio is also P_e. Therefore, P_{fa} is also obtained when the synchronization word is correctly received and 9 or more work bits are active,

$$P_{\text{fa}}^{\text{ec}} = (1 - P_e)^{16} \cdot \left\{ \sum_{k=9}^{17} {}_{17}C_k \, (1 - P_e)^{17-k} P_e^k \right\} \ . \tag{10}$$

[3]The combinations number of k out of n, $_nC_k$ for a large n can be calculated using the gamma function as $n! = \Gamma(n+1)$ and $_nC_k = \dfrac{n!}{k!(n-k)!}$.

The frequency of 600 MHz, the moving velocity of 10 m/s, and Rayleigh fading were also assumed. Substituting Eqs. (1) and (2) into Eqs. (4), (6) and (9), we obtain P_{md}. They are compared in Fig. 4a. All P_{md} were monotonically decreased as γ increased, and were almost the same, because the probability that the synchronization word would agree was dominant over the probability of agreeing corresponding bits. P_{md} also indicated a floor value, and the high P_{md}, even for a higher γ, was the remaining problem for the all methods.
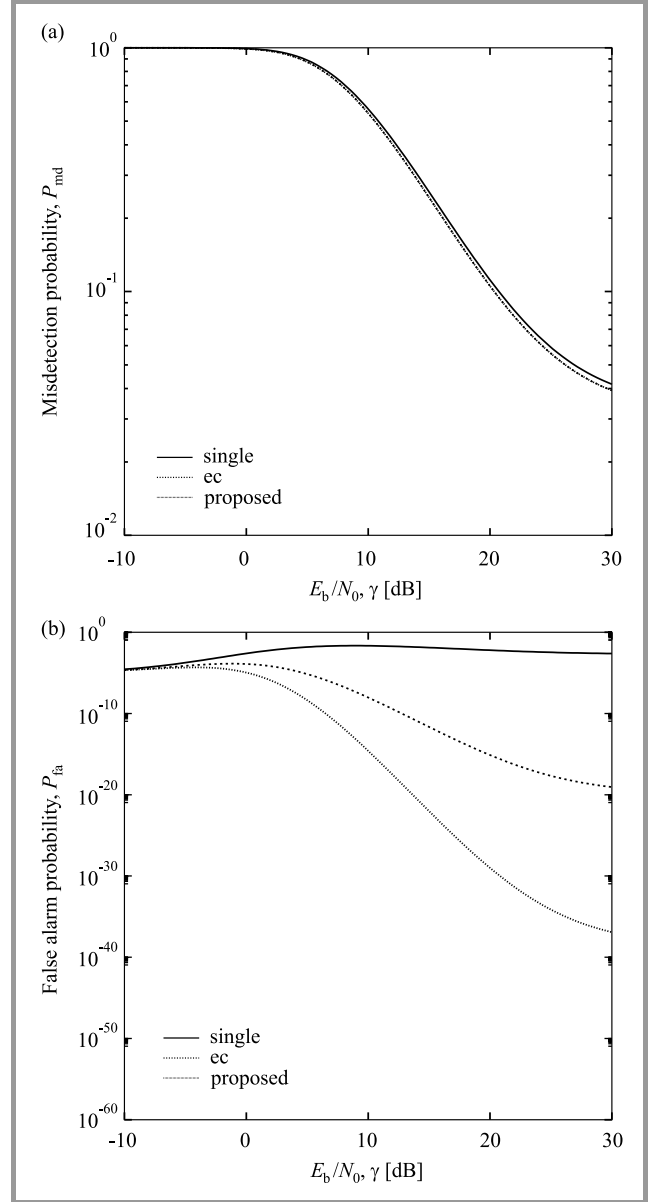
Fig. 4. P_{md} and P_{fa} comparisons in a Rayleigh fading environment: (a) P_{md} and (b) P_{fa}.

P_{fa} are also derived by substituting Eqs. (1) and (2) into Eqs. (5), (7) and (10). They are shown in Fig. 4b. For a higher γ, P_{fa} decreased as γ increased. But for a lower γ, P_{fa} decreased as γ decreased, because synchronization tended to be lost and the receiver did not received any

alerts. Therefore, P_{fa} were a convex in shape. The proposed method provided the lowest P_{fa}. The proposed method uses the parity capability only for correcting the wake-up signal, while the ec receiver uses that capability for correcting all information bits. Focusing on the said capability in the proposed method reduced P_{fa}.
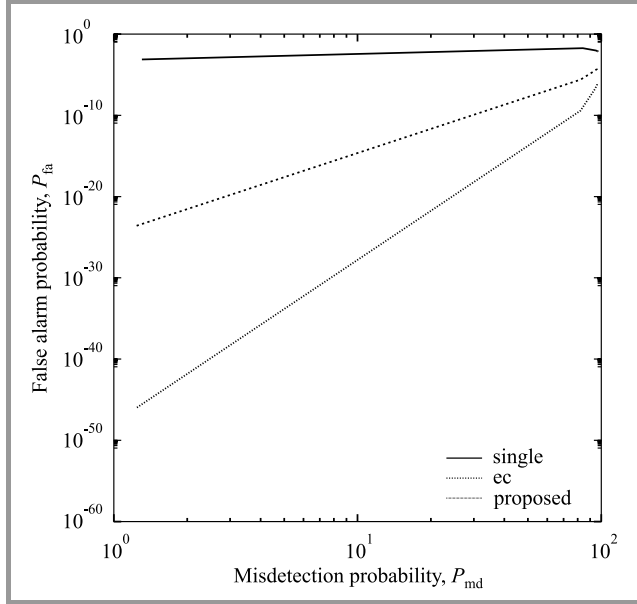

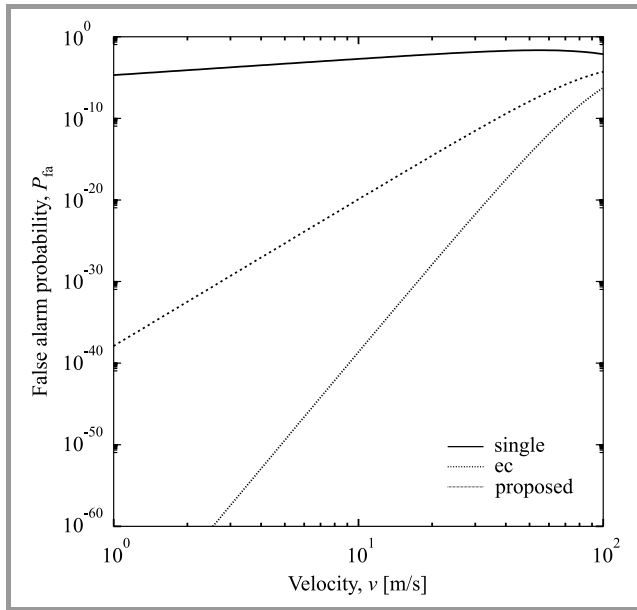**Fig. 5.** P_{fa} vs. P_{md} at $v = 10$ m/s.

Fig. 6. P_{fa} as a function of v for various methods at $\gamma \rightarrow \infty$.

Both P_{md} and P_{fa} depended on P_e. A strict determination would decrease P_{fa} but would increase P_{md}, while a looser determination may decrease P_{md} but increases P_{fa}. For comparing the trade-off, P_{fa} as a function of P_{md} is plotted in Fig. 5. According to the figure, the proposed method indicated the lowest P_{fa} among all other methods. If we assume that power consumption in the television receiver portion

was more dominant than in in portion related to wake-up signal determination, power consumption during the idle state could also be decreased by the same rate as in false alarms.

P_{fa} for a sufficiently high γ is obtained to evaluate the P_e floor effect on P_{fa}. The P_{fa} is obtained using Eqs. (2), (3), (5), (7), and (10) and the results are shown in Fig. 6 as a function of v. A decrease in v also decreased P_{fa}, and the proposed method decreased P_{fa} significantly more than other methods did.

4. Mutual Information Obtained from Wake-up Receiver

Performance can also be compared using the mutual information, instead of using P_{md} and P_{fa}. For evaluating mutual information, we use the line diagram shown in Fig. 7, in
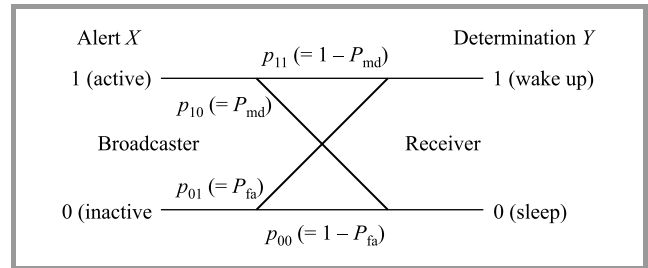

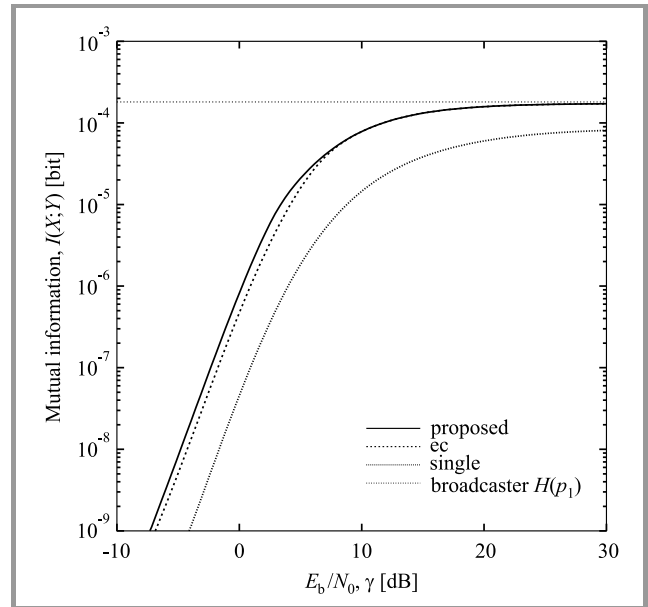**Fig. 7.** Line diagram between the broadcaster's alert X and receiver's determination Y.

Fig. 8. $I(X;Y)$ as a function of γ at $p_1 = 10^{-5}$.

which the broadcaster sends an wake-up signal X. We use 0 for expressing the situation in which the broadcaster does not send the wake-up signal and 1 is used for sending out the wake-up signal. Then, P_{md} and P_{fa} can be expressed as p_{10} and p_{01}, respectively. Because the curve shapes of P_{fa}

and P_{md} as a function of γ were different, the line diagram is asymmetric. Because we can also assume that the current determination does not affect future determination, the channel is memoryless. Mutual information $I(X;Y)$ is:

$$I(X;Y) = (1-p_1)\left\{(1-P_{fa})\log_2\frac{1-P_{fa}}{q_0}+P_{fa}\log_2\frac{P_{fa}}{q_1}\right\}$$
$$+ p_1\left\{P_{md}\log_2\frac{P_{md}}{q_0}+(1-P_{md})\log_2\frac{1-P_{md}}{q_1}\right\},$$
$$q_0 = (1-p_1)(1-P_{fa})+p_1 P_{md}\,,$$
$$q_1 = (1-p_1)P_{fa}+p_1(1-P_{md})\,, \qquad (11)$$

where p_1 is the probability of an emergency alert.

$I(X;Y)$ are plotted in Fig. 8 where we assume $p_1 = 10^{-5}$. p_1 corresponds to the probability of an emergency alert being issued for 26 min over a one year period. The entropy of the broadcaster-issued emergency alerts:

$$H(p_1) = -p_1\log_2(p_1)-(1-p_1)\log_2(1-p_1)\,, \qquad (12)$$

was also shown in the figure. For a lower region of γ, $I(X;Y)$ increased along with the increase in γ. On the other hand, $I(X;Y)$ saturated to $H(p_1)$ for the higher γ. Saturation means that we cannot extract more information from the receiver. The γ that $I(X;Y)$ saturated are about 5 dB for the proposed method and the error correction method, and γ is about 10 dB for the single-bit determination.
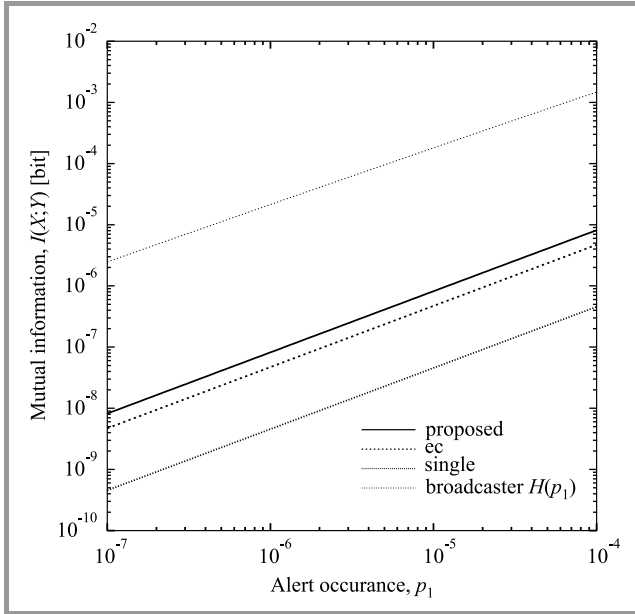

Fig. 9. $I(X;Y)$ as a function of p_1 at $\gamma = 0$ dB.

$I(X;Y)$ as a function of p_1 is calculated and shown in Fig. 9 at $\gamma = 0$ dB. $I(X;Y)$ increased linearly along with the increase in p_1. $I(X;Y)$ for the proposed method and the error correction method were almost the same, and $I(X;Y)$ for the single-bit determination was lower than the above mentioned values.

The dependence of $I(X;Y)$ on v is shown in Fig. 10. In the figure, $I(X;Y)$ was obtained assuming a sufficiently high γ.
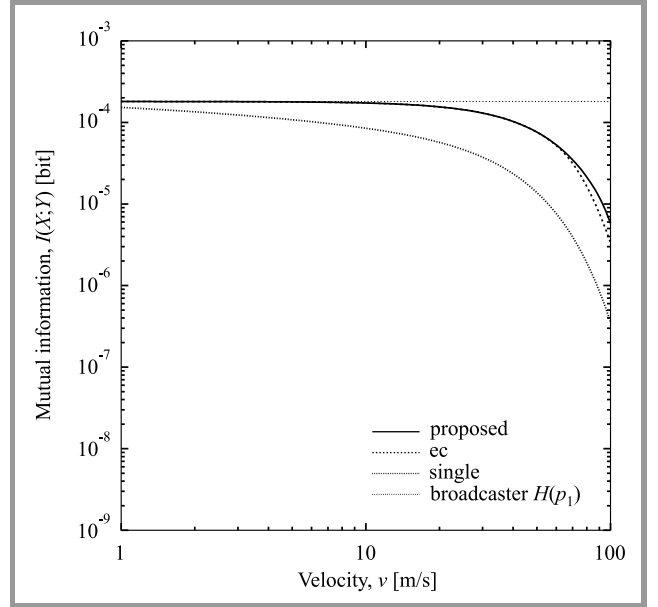

Fig. 10. $I(X;Y)$ as a function of v at $p_1 = 10^{-5}$ and $\gamma \to \infty$.

Therefore, $I(X;Y)$ at v of 30 m/s or less are the same in both the methods, but $I(X;Y)$ for the single-bit determination decreased at the higher v because of the higher P_e.

5. Change in False Alarm and Misdetection Probabilities due to Intermittent Reception

Here, we introduce the intermittent reception of the wake-up signal for the proposed method. The following analysis of intermittent reception will indicate that both false alarm
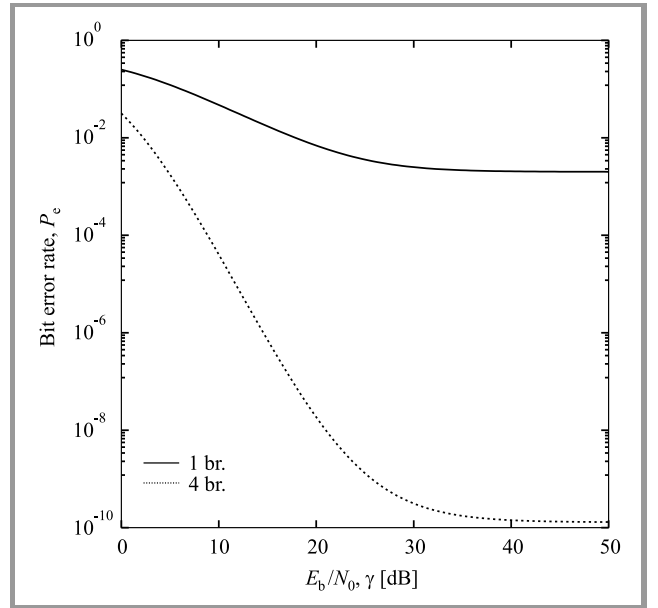

Fig. 11. P_e for TMCC with 1-subcarrier branch (1 br.) and 4-subcarrier branch (4 br.) diversity in a Rayleigh fading environment.

and misdetection rates are increased significantly. Therefore, we employ the subcarrier frequency diversity of 4 TMCC signals. P_e with a 4-branch maximum ratio combining the TMCC signals is also derived [7]:

$$P_e = \frac{1}{2} \left\{ \frac{1 + \gamma(1 - \rho_C)}{1 + \gamma} \right\}^4 . \qquad (13)$$

The comparison of P_e for a 1-subcarrier branch and a 4-subcarrier branch diversity in a Rayleigh fading environment is plotted in Fig. 11.

P_{md} and P_{fa} in TMCC with a 1-subcarrier branch and a 4-subcarrier branch diversity are compared in Fig. 12. Subcarrier diversity has significantly reduced both P_{md} and P_{fa}.
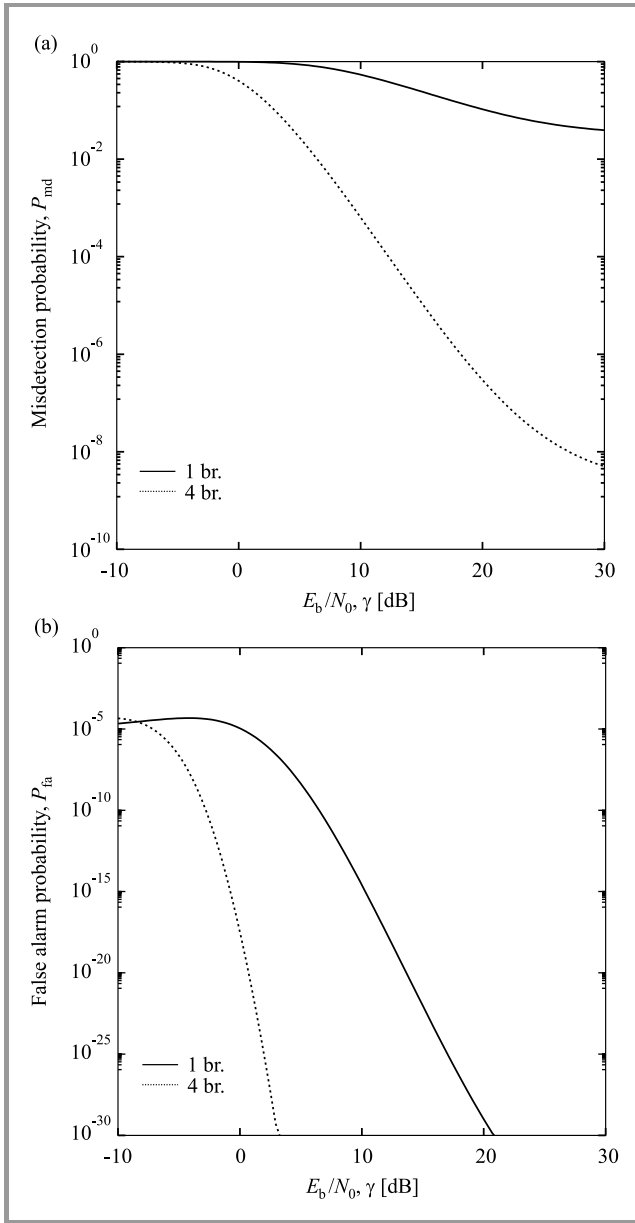
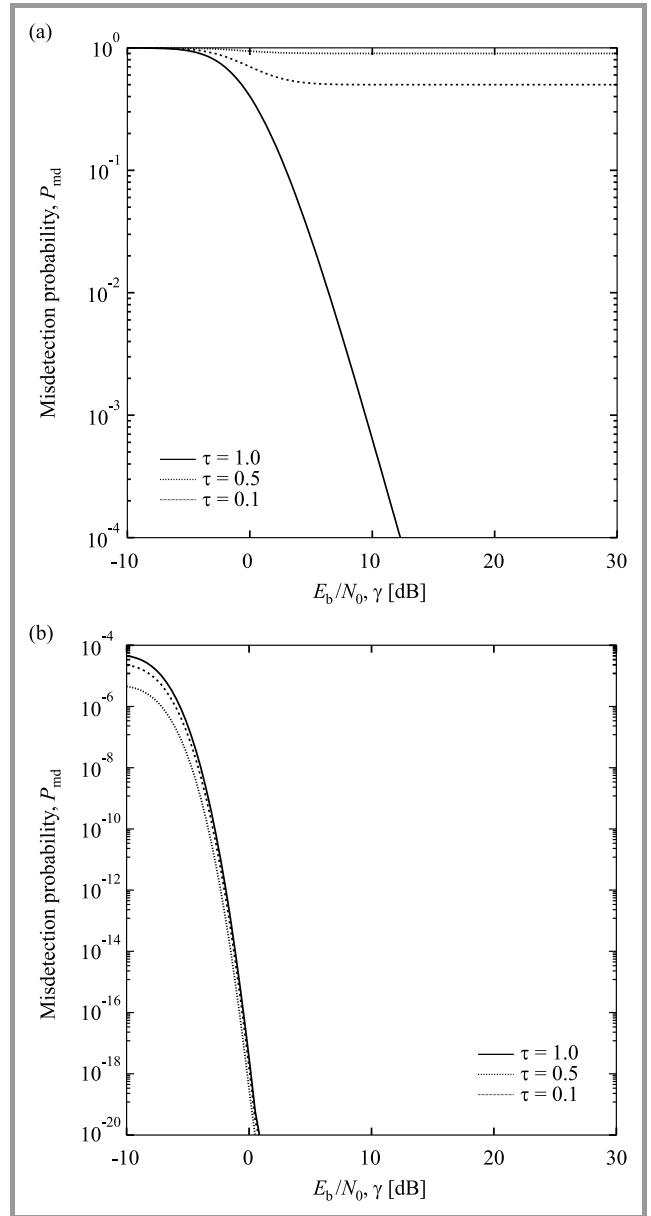*Fig. 12.* P_{md} and P_{fa} of the proposed method with and without subcarrier diversity: (a) P_{md} and (b) P_{fa}.

Fig. 13. P_{md} and P_{fa} for various τ: (a) P_{md} and (b) P_{fa}.

While the receiver is in the sleep mode, it does not misdetect wake-up signals, nor does it produce false alarms. For the actual duty ratio $\tau, (0 < \tau \le 1)$, the false alarm probability $\tilde{P_{fa}}$ is:

$$\tilde{P_{fa}} = \tau P_{fa}. \qquad (14)$$

On the other hand, the complementary event of misdetection probability (i.e. detection probability) is increased by τ times over the complementary event of P_{md}. The misdetection probability, $\tilde{P_{md}}$, becomes:

$$\tilde{P_{md}} = 1 - \tau(1 - P_{md}). \qquad (15)$$

Substituting Eq. (13) into Eqs. (6), (7), (15), and (14), we obtain $\tilde{P_{md}}$ and $\tilde{P_{fa}}$ as in Fig. 13. This figure indicated that an increase in both γ and τ decreased P_{md}, and that τ significantly impacted P_{md}. On the other hand, an increase in τ increased P_{fa}.

$I(X;Y)$ is also calculated and plotted in Fig. 14, where $\tau = 0.1$, 0.5, and 1.0. $I(X;Y)$ decreased as along with the decrease in τ, and $I(X;Y)$ is almost proportional to τ. A receiver with a smaller τ produces a smaller $I(X;Y)$. The saturation value of $I(X;Y)$ also decreased with a decrease in τ. The intermittent reception reduced the mutual information that could not be compensated by increasing γ.
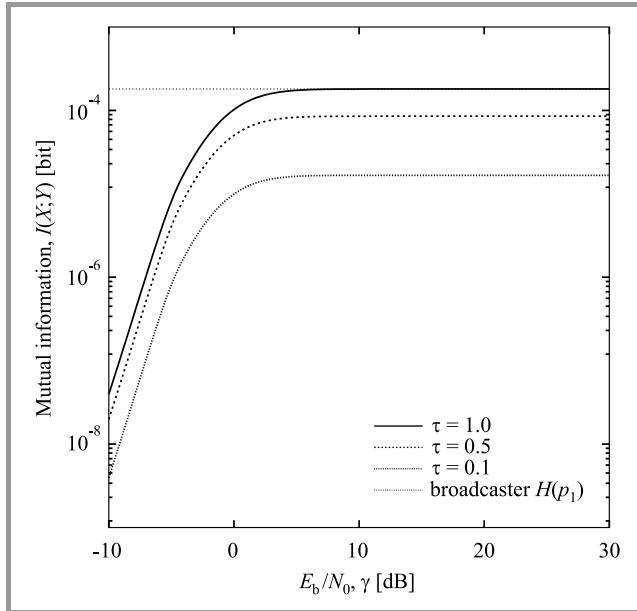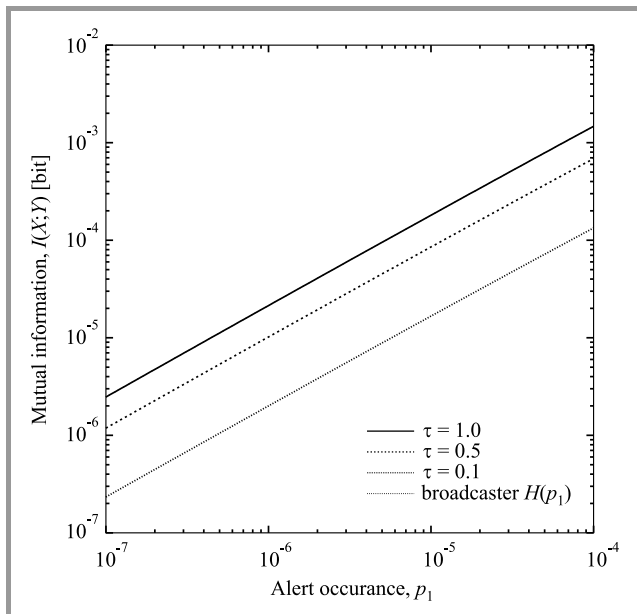

Fig. 14. $I(X;Y)$ as a function of γ for various τ.

Fig. 15. $I(X;Y)$ as a function of p_1 for various τ.

For obtaining the highest $I(X;Y)$ for various p_1 and τ, the P_e floor value is calculated. $I(X;Y)$ is plotted in Fig. 15 by taking the limit of $\gamma \to \infty$. $I(X;Y)$ increased along with the increase in p_1, and $I(X;Y)$ decreased along with a decrease in τ. $I(X;Y)$ approached $H(p_1)$ at $\tau = 1$.
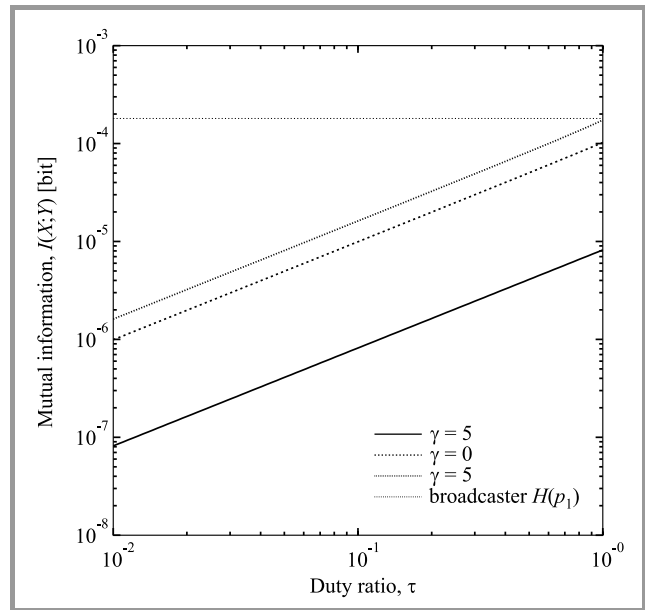

Fig. 16. $I(X;Y)$ as a function of τ for $\gamma = -5$, 0, and 5 dB.

For obtaining $I(X;Y)$ in a weak signal reception environment, $I(X;Y)$ is calculated and plotted in Fig. 16 as a function of τ at $\gamma = 0$ dB. According to the figure, $I(X;Y)$ increased along with the increase in τ at a constant rate, and no significant change was observed.

6. Conclusion

A method of identifying wake-up signals was proposed to reduce the number of false alarms in ISDB-T digital television receivers during idle state. It has been assumed, in this research, that broadcasters did not change the TMCC message except for a situation in which a wake-up signal is sent out. This paper proposed the majority decision method concerning the wake-up signal and corresponding parity bits. The proposed method decreased the number of false alarms, especially for low-mobility users. Mutual information on intermittent reception was also analyzed using the memoryless binary asymmetrical channel model. Intermittent reception always decreased the mutual information that could not be compensated with a higher E_b/N_0. The mutual information exhibited full saturation in a high E_b/N_0 region.

Acknowledgments

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