Mutual Information Analysis of Broadcaster Advised Emergency Automatic Wake-Up Signals with Intermittent Reception

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***Abstract*—A television broadcaster would send a special signal to automatically wake up their receivers when in emergency. Such wake-up receivers are available around the world. In a mobile television receiver, however, the activation signal would be wrongly determined due to the reception errors. In addition, because a disaster rarely occurs, one would think the receiver does not provide useful information at all and it is better to make it sleep. In this paper, quantitative information to be obtained by the wake-up receiver is evaluated approximating the transmission channel of the activation signal from the broadcast station to the receiver to the asymmetric memoryless binary communication channel. On the other hand, battery capacity in a mobile receiver is limited and the intermittent reception would be used. Therefore this paper also analyses the mutual information as a function of the duty ratio of an intermittent receiver.**

***Index Terms*—ISDB-T, emergency warning broadcasting, automatic wake-up signal, intermittent reception, asymmetric memoryless binary channel**

I. INTRODUCTION

A television broadcaster would perform “emergency warning broadcasting” by the request of local governments or meteorological agency when an earthquake or tsunami is likely to occur. In the terrestrial digital television system, ISDB-T (Integrated Services Digital Broadcasting-Terrestrial), there is a procedure the receiver turns on its own power and switches to a news channel when an emergency warning broadcasting is advised. In ISDB-T, this procedure is defined as EWS (Emergency Warning System).

The ISDB-T broadcasting signal is based on OFDM (Orthogonal Frequency Division Multiplexing) that consists of 5,617 subcarriers. There is an emergency activation signal on the ISDB-T control signal, specifically, TMCC (Transmission and Modulation Configuration Control). Subcarriers of 432 are assigned for mobile reception and 4 subcarriers of them are used for TMCC signal transmission. Differential bi-phase shift keying (DBPSK) modulation is used for TMCC signal. The TMCC information contains data of 204 bits in length, and the transmission rate in Mode 3, which is generally used is 992 bit/s. The message is cyclically sent every about 0.2 seconds, and the activation signal is present at the 26th bit of this message [1].

If the activation signal can be received at a lower consumption power, it is possible that emergency information can be caught reliably from a mobile television receiver attached to a smartphone or car navigation. However, in such a receiver, a false alarm (the receiver wrongly determines an emergency in spite of ordinary) or a misdetection (the receiver misses an activation signal) occurs due to a receiver bit error. A part of the TMCC signal is digitized by signal processing and extracted the activation signal. The rather strict determination criterion of the activation signal reduces the false alarm, but the activation signal tends to be misdetected.

On the other hand, battery capacity of a mobile receiver is limited and the receiver would sleep for a certain period of time after reception for a certain period to extend the battery life. The intermittent reception also increases the misdetection.

A dedicated wake-up television receiver has been proposed[1]. The receiver determines the activation signal by listening the 26th bit of the TMCC information. For reliably determining the activation signal, the author proposed using several parts of the parity bits on TMCC information [2]. A change in the activation signal results in variations of 35 parity bits and the majority determination could reduce the false alarm significantly. In this method, it is assumed that only the activation signal changes in the TMCC information before and after the emergency alert is advised.

False alarms and misdetections of the activation signal lead to reduction in information to be obtained from the receiver. Because a disaster rarely occurs and the information the activation signal provides itself is extremely low, one would think the receiver does not provide useful information at all and it is better to make it sleep. Therefore, in this paper, the mutual information that provides the wake-up receiver is analyzed. the communication channel between the broadcaster and the receiver is approximated to the memoryless asymmetric binary communication channel, and the mutual information is derived. First, we summarize the relationship between false alarm and misdetection probabilities. Next, the mutual information on the memoryless asymmetric binary communication channel is obtained. From this result, the reception characteristic of the activation signal is shown.

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[1] `http://www.dibeg.org/news/2008/0802Philippines_ISDB-T_seminar/Presentation5.pdf`, available on June 15th, 2018.

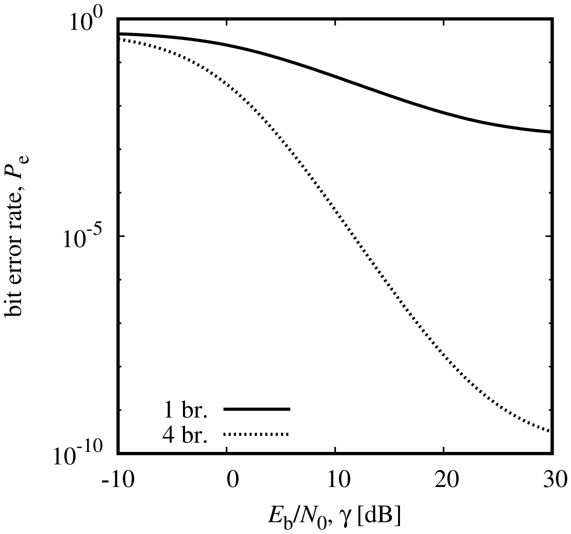

Fig. 1. P_{e} as a function of γ.

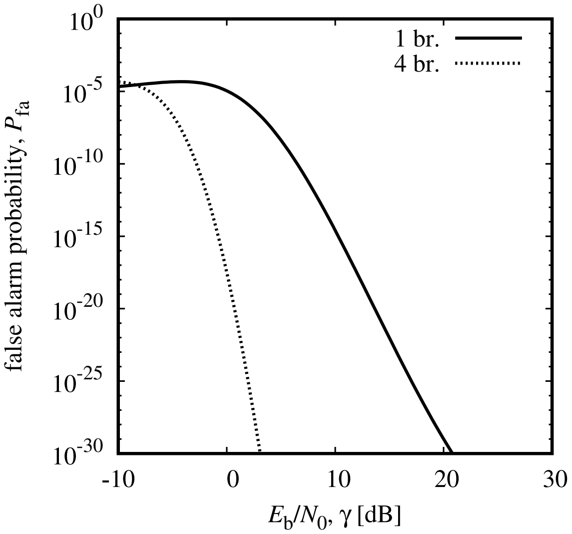

Fig. 2. P_{e} as a function of E_{b}/N_0.

II. FALSE ALARM PROBABILITY AND MISDETECTION PROBABILITY OF ACTIVATION SIGNAL

First of all, we assume that the receiver moves and continuously receives an activation signal on the TMCC signal. The receiver encounters Rayleigh fading caused by the multipath propagation between the broadcaster and the receiver, and it results in bit errors in reception of the TMCC information. The bit error rate of the DPSK-modulated signal, P_{e} is known to be

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

where γ is E_{b}/N_0, $\rho_C = J_0(2\pi f_D T_s)$ is the correlation coefficient of time or frequency where the receiver is surrounded by uniformly distributed scatterers. $J_0(\cdot)$ is the zeroth Bessel function of first order, $f_D = v/\lambda$ [Hz] is the maximum Doppler frequency, v [m/s] is the velocity, λ [m] is the wavelength, and T_s [s] is the symbol duration. P_{e} with the frequency diversity reception with the 4-branch maximal ratio combining is also derived to be [3]

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

A frequency of 600 MHz and a velocity of 10 m/s were assumed and P_{e} as a function of γ is plotted in Fig. 1. As an increase in γ generally decreased P_{e}. The P_{e} with a single TMCC subcarrier (denoted by 1 br.) exhibited the floor as the increase in γ and a higher P_{e} was observed. On the other hand, P_{e} with 4 subcarriers diversity (denoted by 4 br.) decreased P_{e} as an increase in γ.

If we assume that the TMCC information other than the automatic activation signal does not change before and after the broadcaster advises an emergency, values of 35 bits out of 82 bits parity change in accordance with the change in the activation signal [2]. Though the initial values of the 35 bits depend on the TMCC information, these bit positions do not change whatever the TMCC information is set. This is because of the characteristics of the linear code used in TMCC parity.

The majority determination of the 36 bits, the activation signal itself and the 35 bits, are used for evaluating emergency state sent from the broadcaster. Then, the false alarm probability, P_{fa}, is the probability the 16-bit unique word is identified correctly but more than half of the 36 bits are wrongly received,

$$P_{\mathrm{fa}} = (1-P_e)^{16}\left\{\sum_{k=19}^{36} {}_{36}C_k\,(1-P_e)^{36-k}P_e^k\right\}. \tag{3}$$

P_{fa} as a function of γ is plotted in Fig. 2.

On the other hand, the misdetection probability is the complementary probability the unique word and more than half of the 36 bits are received correctly, P_{md}

$$P_{\mathrm{md}} = 1-(1-P_e)^{16}\left\{\sum_{k=0}^{18} {}_{36}C_k\,(1-P_e)^{36-k}\cdot P_e^k\right\}. \tag{4}$$

P_{md} is also plotted in Fig. 3.

III. MUTUAL INFORMATION OF ACTIVATION SIGNAL RECEIVED BY INTERMITTENT RECEIVER

A line diagram between the broadcaster and the receiver can be shown in Fig. 4. In this figure, symbol 0 shows the broadcaster does not send activation signal or receiver is inactive. Symbol 1 shows the broadcaster send the activation signal or the receiver is active. On the other hand, p_{00} indicates the probability the broadcaster does not send the activation signal and the receiver is in inactive state, and so on. Then, p_{00}, p_{01}, p_{10} and p_{11} can be expressed in terms of P_{fa} and P_{md}. Because P_{fa} and P_{md} are mutually different each other

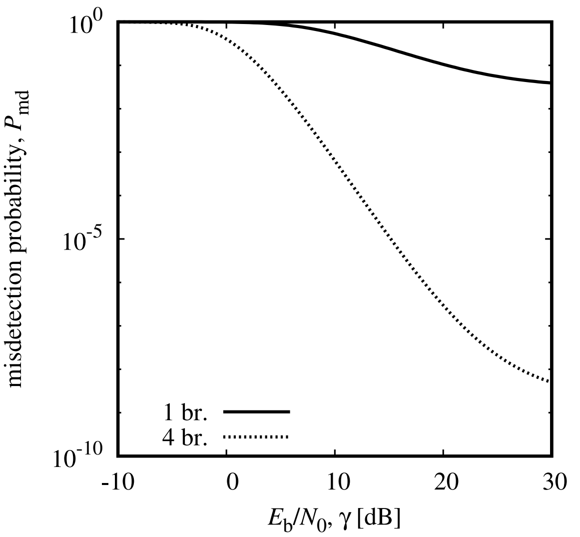

Fig. 3. P_{md} as a function of E_{b}/N_0.

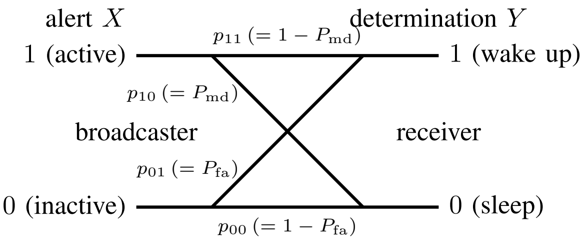

Fig. 4. Line diagram.

as shown in Figs. 2 and 3, the communication channel is asymmetric. Though the activation signal may be sent continuously for a certain period of time, the receiver determines the activation signal not from the previous determination result but from TMCC information reception. Therefore, the line diagram is memoryless.

The entropy with respect to X, $H(X)$, is

$$H(X) = -\sum_{x=0}^{1}\sum_{y=0}^{1} P(x,y)\log_2 P(x). \tag{5}$$

On the other hand, the conditioned entropy with X, $H(X|Y)$ is

$$H(X|Y) = -\sum_{x=0}^{1}\sum_{y=0}^{1} P(x,y)\log_2 \frac{P(x,y)}{P(y)}. \tag{6}$$

We denote the probability the broadcaster sends out the activation signal X as p_1, and we use the complementary probability as p_0. Similarly, we represent the probability the receiver Y detects the activation signal as q_1 and the complementary probability as q_0. Then, the mutual information $I(X;Y)$ is

$$\begin{aligned} I(X;Y) &= H(X) - H(X|Y) \\ &= p_0\left\{p_{00}\log_2\frac{p_{00}}{q_0} + p_{01}\log_2\frac{p_{01}}{q_1}\right\} \\ &+ p_1\left\{p_{10}\log_2\frac{p_{10}}{q_0} + p_{11}\log_2\frac{p_{11}}{q_1}\right\}, \end{aligned} \tag{7}$$

where

$$q_y = \sum_{x=0}^{1} p_x\, p_{xy} = p_0\, p_{0y} + p_1\, p_{1y}. \tag{8}$$

According to Fig. 4,

$$\begin{aligned} p_{00} &= 1 - P_{\mathrm{fa}} \\ p_{01} &= P_{\mathrm{fa}} \\ p_{10} &= P_{\mathrm{md}} \\ p_{11} &= 1 - P_{\mathrm{md}}, \end{aligned} \tag{9}$$

and $p_0 + p_1 = 1$, (7) and (8) can be rearranged to

$$\begin{aligned} &I(X;Y) \\ &\quad= (1-p_1)\left\{(1-P_{\mathrm{fa}})\log_2\frac{1-P_{\mathrm{fa}}}{q_0} + P_{\mathrm{fa}}\log_2\frac{P_{\mathrm{fa}}}{q_1}\right\} \\ &\qquad + p_1\left\{P_{\mathrm{md}}\log_2\frac{P_{\mathrm{md}}}{q_0} + (1-P_{\mathrm{md}})\log_2\frac{1-P_{\mathrm{md}}}{q_1}\right\}, \\ &q_0 = (1-p_1)(1-P_{\mathrm{fa}}) + p_1 P_{\mathrm{md}}, \text{and} \\ &q_1 = (1-p_1)P_{\mathrm{fa}} + p_1(1-P_{\mathrm{md}}). \end{aligned} \tag{10}$$

Because P_{fa} and P_{md} are functions of γ, $I(X;Y)$ is a function of γ and p_1.

IV. CHANGE IN FALSE ALARM AND MISDETECTION PROBABILITIES DUE TO INTERMITTENT RECEPTION

Here, we assume the receiver performs intermittent reception, and represent its duty ratio as τ, $(0 \leq \tau \leq 1)$. While the receiver is in sleep, the receiver misdetects the activation signal, but it never produces false alarms. Therefore, the false alarm probability, $\tilde{P_{\mathrm{fa}}}$, is less than P_{fa} and it is

$$\tilde{P_{\mathrm{fa}}} = \tau\, P_{\mathrm{fa}}. \tag{11}$$

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

$$\tilde{P_{\mathrm{md}}} = 1 - \tau(1 - P_{\mathrm{md}}). \tag{12}$$

Substituting (2) into (3), we obtain P_{fa}. And we substitute P_{fa} into (11) and $\tilde{P_{\mathrm{fa}}}$ is plotted in Fig. 5. An increase in γ reduced P_{e} and also reduced P_{fa}. On the other hand, an increase in τ increased P_{fa}. In the figure, $\tau = 1$ means the receiver does not use intermittent reception. Similarly, substituting (2) into (4) and (12), we obtain $\tilde{P_{\mathrm{md}}}$ as in Fig. 6. An increase in γ decreased P_mrmd and an increase in τ decreased P_{md}. τ effects on P_{md} significantly.

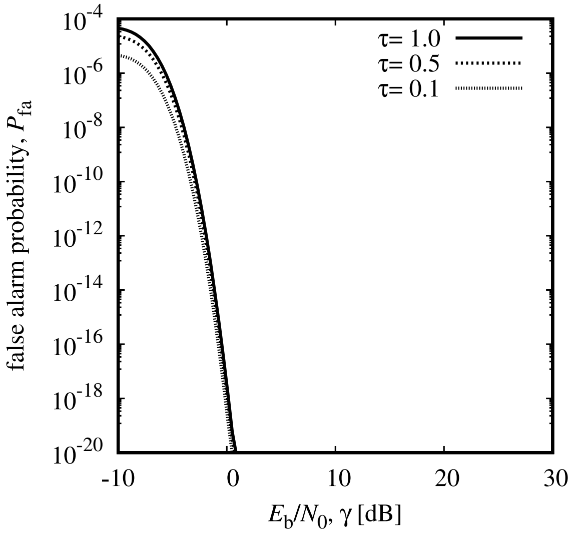

Fig. 5. $P_{\rm fa}$ as a function of γ for various τ.

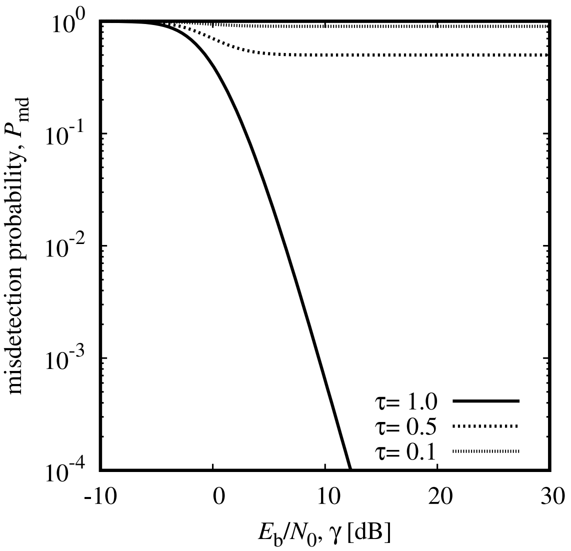

Fig. 6. $P_{\rm md}$ as a function of γ for various τ.

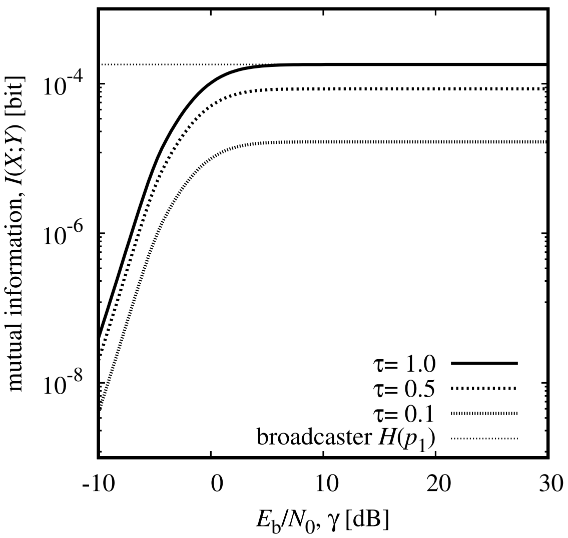

Fig. 7. $I(X;Y)$ as a function of γ for various τ.

TABLE I
EVALUATION PARAMETERS

frequency	600 MHz
symbol duration T_s	$1/992$ s (ISDB-T mode 3)
subcarrier diversity branch number	4
probability of emergency advise p_1	10^{-5} (26 minutes a year)
velocity v	10 m/s

V. NUMERICAL EXAMPLE

The mutual information $I(X;Y)$ the receiver performs intermittent reception is obtained from (10) as a function of γ and is plotted in Fig. 7. In the evaluation, the parameters shown in TABLE I was used. $I(X;Y)$ increased as an increase in γ, but it saturated where γ exceeds about 5 dB. The figure also shows the entropy of the emergency alert from the broadcaster,

$$H(p_1) = -p_1 \log_2(p_1) - (1-p_1)\log_2(1-p_1). \tag{13}$$

When intermittent reception was not performed, $I(X;Y)$ and $H(p_1)$ are almost identical. This indicated we could not extract more information from the receiver even the receiver obtained a higher γ. This is source of the extremely low alert occurrence p_1. Although $I(X;Y)$ decreased as a decrease of τ, the saturation value of $I(X;Y)$ also decreased. The intermittent reception would be necessary to reduce the receiver power consumption, but it also reduces the mutual information that cannot be compensated by increasing γ.

Next, the $P_{\rm e}$ floor is calculated taking the limit $\gamma \to \infty$ of (2). $I(X;Y)$ as a function of τ is obtained and is plotted in Fig. 8. $I(X;Y)$ increased as an increased in p_1, and $I(X;Y)$ decreased as a decreased in τ. $I(X;Y)$ approached $H(p_1)$ at $\tau = 1$. $I(X;Y)$ decreased as a decrease in τ.

$I(X;Y)$ as a function as τ is plotted in Fig. 9 where γ is near 0 dB that $I(X;Y)$ varied significantly with γ. According to the figure, $I(X;Y)$ increased as an increase in τ at a constant rate and significant change was not observed.

VI. CONCLUSION

We analyzed the reception characteristics of the activation signal for emergency warning broadcasting on the ISDB-T digital television signal. The mutual information on the intermittent reception was analyzed using asymmetrical memoryless binary communication channel. The intermittent reception decreased the mutual information that could not be compensated with an increase of $E_{\rm b}/N_0$. The mutual information exhibited

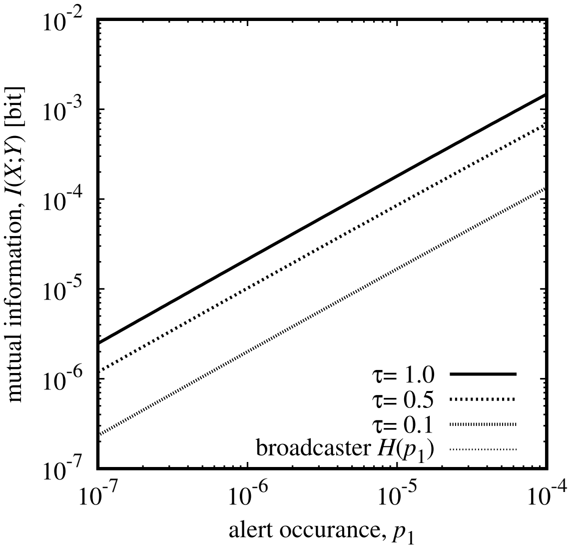

Fig. 8. $I(X;Y)$ as a function of p_1 for various τ.

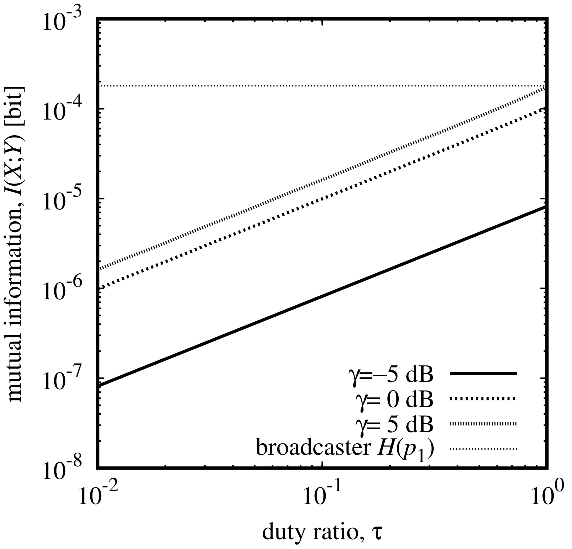

Fig. 9. $I(X;Y)$ as a function of τ around $\gamma = 0$ dB.

saturation and it depended on E_b/N_0 and the duty ratio of intermittent reception.

ACKNOWLEDGMENT

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