Performance of Wireless LAN System Based on IEEE 802.11g Standard under Man-Made Noise Environment

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SUMMARY 2.4 GHz-band wireless LAN system based on a new standard, IEEE 802.11g, has been taking a great attention as it provides the attractive features such as low cost, unlicensed spectrum use, and high speed transmission rate up to 54 Mbps. However, 2.4 GHz radio frequency band is also used for Industrial, Scientific and Medical (ISM) devices such as microwave ovens, and the man-made noise leaked from ISM devices is known to be one of the major causes of the degradation in the performance of wireless communications systems using 2.4 GHz radio frequency band. In this paper, we evaluate the bit error rate (BER) and the throughput performances of WLAN system based on IEEE 802.11g standard (IEEE 802.11g WLAN system) under man-made noise environment, and discuss the effect of man-made noise on the performance of IEEE 802.11g WLAN system. Numerical results show that the BER and the throughput performances of IEEE 802.11g WLAN system are much degraded by the influence of man-made noise.

key words: IEEE 802.11g, wireless LAN system, 2.4 GHz-band, ISM devices, man-made noise, OFDM

1. Introduction

Due to the wide-spread use of computer-based terminals such as personal computers and digital audio-visual equipments, indoor Local Area Network (LAN) systems, which interconnect these terminals and equipments have been getting a great deal of attention. Although the wireless LAN (WLAN) systems are inferior to wired LAN systems in transmission rate, quality and reliability, WLAN systems are appropriate for mutual connection between terminals because of their freedom from cumbersome wired cable, and many kinds of wireless LAN systems operating at various frequency bands have been developed. Among several WLAN systems, 2.4 GHz-band WLAN system based on IEEE 802.11g standard (IEEE 802.11g WLAN system) is spreading rapidly as it provides the attractive features such as low cost, unlicensed spectrum use, and high speed transmission rate up to 54 Mbps in physical (PHY) layer using Orthogonal Frequency Division Multiplexing (OFDM) as a transmission scheme [1], [2].

IEEE 802.11g WLAN system is operated at a part of radio frequency band prepared for Industrial, Scientific and Medical (ISM) devices like microwave ovens. ISM devices are originally designed so as not to radiate unnecessary electromagnetic wave in free space, and the emission of unnecessary electromagnetic wave is severely regulated in order to guarantee the electromagnetic compatibility. Nevertheless, it has been reported that the electromagnetic wave can be observed near from ISM devices, and it will cause the degradation in the performances of 2.4 GHz-band wireless communications systems including 802.11, 802.11b and 802.11g WLAN systems. As for the effect of man-made noise emitted from ISM devices on the performance of legacy 2.4 GHz-band WLAN systems based on 802.11 and 802.11b standards, we have already investigated the performance of WLAN systems and reported that the performances of IEEE 802.11 and IEEE 802.11b WLAN systems are much degraded by the effect of man-made noise [3]–[5]. However, compared to the legacy IEEE 802.11 and 802.11b WLAN systems, IEEE 802.11g WLAN system has different transmission scheme and transmission rate up to 54 Mbps, and then, the effect of man-made noise on the performance of IEEE 802.11g WLAN system is one of the major interests in the design of 2.4 GHz-band WLAN system.

In this paper, we investigate the performance of IEEE 802.11g WLAN system under man-made noise environment and discuss the effect of man-made noise on the performance of IEEE 802.11g WLAN system [6], [7]. Especially, because the IEEE 802.11 standard originally defines the specifications of PHY layer and the Medium Access Control (MAC) layer protocols, in this paper, we focus on the effect of man-made noise to the Bit Error Rate (BER) and the throughput performances. This paper is organized as follows. In the succeeding section, we briefly describe the characteristics of man-made noise and show the statistical model employed in this paper. In Sect. 3, we explain the MAC layer protocol employed in IEEE 802.11g WLAN system and give the preliminary considerations about the effect of man-made noise on the performance of 802.11g WLAN systems. In Sect. 4, we evaluate the performance of IEEE 802.11g WLAN system under man-made noise environment in various cases. Conclusions of this paper are finally offered in Sect. 5.

2. Statistical Model of Man-Made Noise

As a tractable way of studying the effect of man-made noise emitted from ISM devices on the performance of wireless communications systems, we employ a statistical model to
represent the man-made noise. Although there are many kinds of ISM devices, microwave ovens have been widely used in home and office, and then IEEE 802.11g WLAN system most likely to be interfered by the man-made noise emitted from microwave ovens. Consequently, in this paper, we investigate the effect of man-made noise emitted from microwave oven on the performance of IEEE 802.11g WLAN system. In this section, we describe the brief overview of statistical characteristics of man-made noise emitted from microwave oven and show the statistical model of man-made noise employed in this paper.

Extensive measurements and analyses of the man-made noise emitted from microwave ovens are well documented in [8], [9], and it is reported that the high amplitude man-made noise is periodically and continuously (bursty) emitted from microwave ovens. Microwave ovens are divided into two types by the difference of the methods to generate high voltage for driving the magnetron. One is a trans-type, the other is an inverter- or a switching- type [4]. In this paper, we assume that the source of man-made noise is a trans-type microwave oven, and, we employ a statistical model of man-made noise shown in Fig. 1. The effect of man-made noise emitted from inverter- or switching-type microwave ovens on the performance of IEEE 802.11g WLAN system will be discussed in Sect. 4. For this kind of microwave oven, since a radiation period of high amplitude man-made noise, $t_1$, is generally equal to the frequency of power source, we set $t_1$ to be 20 msec on the assumption that 50Hz of AC power is used [4], [9]. And also, according to the previous studies about the performance of legacy IEEE 802.11 and 802.11b WLAN systems [5], a duration period of high amplitude man-made noise, $t_2$, is set to be 8 msec. In addition, the background noise (BGN) and the man-made noise are assumed to be additive white gaussian noise (AWGN) whose power is N and I, respectively. Therefore, IEEE 802.11g WLAN system is influenced by AWGN whose power is $N + I$ during $t_2$ [4], [5]. The frequency band width of background noise and man-made noise is 20 MHz that is the same as that of one wireless channel of IEEE 802.11g WLAN system. In the references about the actual measurements of man-made noise emitted from microwave ovens like [9], it is reported that the power spectrum density of man-made noise emitted from microwave oven is not uniform (colored noise). Nevertheless, in order to make evaluations easier, in this paper, we assume that the man-made noise emitted from microwave oven is an AWGN. Discussions about the colored microwave oven noise on the performance of IEEE 802.11g WLAN system will be given in Sect. 4. In this paper, we define $I/N$ as the Interference-to-Noise power Ratio (INR), and it represents the power of man-made noise relative to that of BGN.

3. MAC Layer Protocol in WLAN System

IEEE 802.11 standard originally defines the specifications of the PHY layer and the MAC layer protocols of wireless LAN systems. In this section, we simply describe the MAC layer protocol of WLAN system employed in this paper and give the preliminary considerations about the effect of man-made noise on the packet transmission in WLAN systems. The details of PHY and MAC layers specifications are described in the following performance evaluations.

Figure 2 shows a outline of Carrier Sense Multiple Access with Collision Avoidance (CSMA/CA) scheme employed in IEEE 802.11 WLAN system [1], [2], [10]. In this figure, WLAN terminal which wants to transmit a data packet is represented as $T_x$, and also the destination terminal of data packet is represented as $R_x$. If the transmitter ($T_x$ in Fig. 2) wants to transmit a data packet to the receiver ($R_x$ in Fig. 2), the $T_x$ observes the channel (carrier sense) during the period of DIFS (Distributed coordination function Inter Frame Space) and backoff time. While DIFS is constant in any WLAN terminal, the length of backoff time is dependent on the random variable between zero to the value of contention window size ($CW$) in order to avoid the collisions of data packet. The value of $CW$ is given by

$$ CW = (CW_{\text{min}} + 1) \times 2^n - 1. $$

In Eq. (1), the minimum value of $CW$ is represented as $CW_{\text{min}}$, and the number of retransmissions of the data packet is represented as $n$. In the case where $CW$ reaches the maximum value of $CW$ ($CW_{\text{max}}$), $CW$ remains $CW_{\text{max}}$ until $n$ reaches the maximum number of retransmissions of the data packet and is reset. If the $T_x$ detects other carrier signals during this period, $T_x$ decides the wireless channel to be busy and waits to transmit the data packet. On the other hand, if the $T_x$ detects no carrier signals during this period, the $T_x$ decides the wireless channel to be idle and starts transmitting the data packet after random backoff time. At the
receiver Rx, in the case that the data packet successfully received, the Rx replies an Acknowledgement (ACK) packet to the Tx. In order to solve the hidden terminal problem, IEEE 802.11 standard optionally defines a Request-to-Send (RTS) packet and a Clear-to-Send (CTS) packet. However, because the exchange of RTS and CTS packets generally causes the degradation in the throughput performance, RTS and CTS packets are not introduced in the following performance evaluations.

Here, let us preliminary discuss the effect of man-made noise emitted from microwave oven on the performance of IEEE 802.11g WLAN systems. As shown in previous section, periodic and bursty high amplitude man-made noise is emitted from microwave oven. If the microwave oven exists close to the transmitter Tx,
- the transmitter Tx misidentifies the high amplitude man-made noise as carrier signals transmitted from other WLAN terminals and decide the wireless channel to be busy, therefore, the Tx will wait to transmit the data packet until the wireless channel becomes idle.
- the ACK packet is corrupted by the high amplitude man-made noise, therefore, the transmitter Tx will not confirm that the data packet is transmitted to the receiver Rx correctly or not and will retransmit it.

These lead the degradation in the throughput performance. On the other hand, if the microwave oven exists close to the receiver Rx,
- the data packet is corrupted by the high amplitude man-made noise, therefore, the error of data packet will be occurred.

This also leads the degradation in the throughput performance of WLAN system. From the above preliminary discussion, although the man-made noise causes the degradation of throughput performance in both cases, the causes of performance degradation are much different. In the following section, we distinguish the above two cases, that is,
1. the source of man-made noise (microwave oven) is operated close to the transmitter Tx,
2. the source of man-made noise (microwave oven) is operated close to the receiver Rx,

and evaluate the effect of man-made noise on the performance of IEEE 802.11g WLAN system in each case.

4. Performance Evaluations

We evaluate the performance of IEEE 802.11g WLAN system under man-made noise environment by computer simulations and discuss the effect of man-made noise. From the preliminary considerations in previous section, we evaluate the performance in the case where the source of man-made noise is operated close to the transmitter Tx. And next, we evaluate the performance in the case where the source of man-made noise is operated close to the receiver Rx. In order to avoid the degradation caused by multiple access, we assume that both the Tx and the Rx are WLAN terminals based on IEEE 802.11g standard and no WLAN terminal except these two exists. Table 1 shows the parameters of PHY layer and MAC layer protocols employed in this paper [1], [11]. And also, frame formats of a data packet and an ACK packet are shown in Fig. 3 and Fig. 4, respectively. Note that, in IEEE 802.11g standard, multiple transmission rates of data packet are supported, and the part in a data packet is transmitted at an appropriate transmission rate among 8 kinds of “data rates” (6–54 Mbps) shown in Table 1.

![Fig. 3 Frame format of data packet.](image1)

![Fig. 4 Frame format of ACK packet.](image2)

<table>
<thead>
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<th>Table 1 Parameters employed in computer simulations.</th>
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<td>Slot Time</td>
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<td>Maximum Number of Retransmissions</td>
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<td>Optional Data Rate</td>
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4.1 Effect of Man-Made Noise on the Transmitter Side

Here, we assume that the microwave oven is operated close to the transmitter $T_x$ and evaluate the throughput performance of 802.11g WLAN system. Figure 5 shows the throughput versus Carrier-to-Noise power Ratio (CNR) under man-made noise environment. For comparison, the throughput performance under BGN environment is also shown in this figure. In this performance evaluation, the threshold level of carrier sense is set to be 10 dB upper from the level of BGN, and INR is set to be 20 dB. And the data rate is fixed at 6 Mbps, 12 Mbps, 24 Mbps and 54 Mbps. As shown in Fig. 5, the throughput performance under man-made noise environment is about 40% down from that under BGN environment. For example, at the CNR $\sim 30$ dB and the data rate $= 54$ Mbps, while the maximum throughput without man-made noise (under BGN) is almost 29 Mbps, that with man-made noise is decreased to about 17.5 Mbps. As discussed in previous section, in this case, the transmitter $T_x$ misidentifies high amplitude man-made noise as carrier signals, and the transmitter $T_x$ waits to transmit the data packet until the wireless channel becomes idle. Actually, in the result shown in Fig. 5, the ratio of decrease (40%) is equal to $t_2/t_1 = 8$ msec/20 msec. Figure 6 shows the throughput performance of IEEE 802.11 and IEEE 802.11b WLAN systems versus CNR under man-made noise environment. For comparison, the throughput performance under BGN environment is also shown in this figure. In this performance evaluation, the frequency band width of background noise and man-made noise is 22 MHz. The threshold level of carrier sense is set to be 10 dB upper from the level of BGN, and INR is set to be 20 dB. And the data rate is fixed at 2 Mbps and 11 Mbps. The data length is 1,500 byte, and the ACK packet is transmitted at 1 Mbps. Parameters and long frame format of a packet employed in this evaluation are based on IEEE 802.11 and IEEE 802.11b (see [10], [12]). As shown in Fig. 5 and Fig. 6, regardless of a transmission scheme, each throughput performance under man-made noise environment is also about 40% down from that under BGN environment. Therefore, these degradations are caused by $T_x$ waiting to transmit the data packet. In addition, as shown in Fig. 5 and Fig. 6, we can also find that the throughput performance does not improve after the first improvement in spite of an increase of CNR, therefore, we can describe that the throughput performance is hardly degraded by the error of the ACK packet. This is because the transmitter $T_x$ waits to transmit the data packet and the ACK packet rarely arrives at the $T_x$ while man-made noise is emitted. From these result, we can confirm that the degradation of throughput performance is caused by the misidentification of the channel state (busy or idle). In addition, we can also find that, even though high CNR can be obtained in a wireless channel, the throughput performance cannot be improved. This is also due to the fact that the degradation of throughput is caused by the misidentification of the channel state in the CSMA/CA, and it does not depend on the success or failure of transmission of data packet. As mentioned in Sect. 2, although the actual man-made noise emitted from microwave oven is a colored noise, the man-made noise emitted from microwave oven is assumed to be an AWGN in this performance evaluation. However, the misidentification of the channel state is due to only the fact that the received man-made noise power exceeds the threshold level of carrier sense, and it does not depend on whether the man-made noise is white or colored. Therefore, under actual colored man-made noise environment, it can be expected that the degradation of throughput performance will be found.

4.2 Effect of Man-Made Noise on the Receiver Side

In this subsection, we assume that the microwave oven is operated close to the receiver $R_x$ and discuss the effect of man-
made noise on the performance of IEEE 802.11g WLAN system. As shown previously, in this case, the data packet transmitted from the transmitter is corrupted by high amplitude man-made noise, and the error of data packet causes the degradation in the throughput performance of WLAN system. At first, we evaluate the BER and the throughput performances of IEEE 802.11g WLAN system under man-made noise environment. And next, with the consideration of multiple transmission rates control scheme defined in IEEE 802.11g standard, we evaluate the throughput performance of IEEE 802.11g WLAN system.

4.2.1 BER and Throughput Performances

Figure 7 shows the BER performance of IEEE 802.11g WLAN system versus CNR. For comparison, the BER performance under BGN environment is also shown in this figure. In the performance evaluation, the data rate is fixed at 6 Mbps, and INR \( (I/N) \) is set to be 10 dB, 15 dB and 20 dB. As shown in Fig. 7, the BER performance is much degraded by the effect of man-made noise. In addition, we can also find that, there is the area where each BER performance under man-made noise environment does not improve in spite of an increase of CNR. This is because, in this area, the power of carrier signal is not as high as bit errors do not occur while high amplitude man-made noise is emitted.

Figure 8 shows the throughput performance versus CNR, in the case where the microwave oven is operated close to the Rx. For comparison, we also show the throughput performance under BGN environment. In the performance evaluation, the data rate is fixed at 6 Mbps, 12 Mbps, 24 Mbps and 54 Mbps, and INR is set to be 20 dB. As shown in Fig. 8, the throughput performances are much degraded by the effect of man-made noise. In addition, in this figure, each throughput performance has improved twice as CNR becomes larger. For example, in case that the data rate is 54 Mbps, throughput performance is improved at the points about CNR=20 dB and CNR=37 dB. The cause of first improvement (CNR=20 dB) is that the receiver Rx receives a data packet without error only while man-made noise is not emitted. On the other hand, the cause of second improvement (CNR=37 dB) is that the high CNR can be obtained and the receiver Rx receives a data packet without error anytime, that is to say, whether man-made noise is emitted or not. As shown in Fig. 5, in case where the microwave oven is operated close to the transmitter Tx, even though the high CNR can be obtained in a wireless channel, throughput performance is degraded by the effect of man-made noise. On the contrary, as shown in Fig. 8, in case where the microwave oven is operated close to the receiver Rx, if high CNR can be obtained in a wireless channel, throughput performance of IEEE 802.11g WLAN system is not degraded by the effect of man-made noise. As same in the previous performance evaluation, although the actual man-made noise emitted from microwave oven is a colored noise, we assume that the man-made noise emitted from microwave oven as an AWGN in this performance evaluation. For the case of AWGN, since the power spectrum density of man-made noise is uniform, the bit or symbol error probability of each subcarrier signal is same. On the other hand, actual man-made noise emitted from microwave oven is not uniform, and then the bit error probabilities of each subcarrier signal will be different. Consequently, under actual man-made noise environment, the throughput performance of IEEE 802.11g WLAN system will be somewhat different from that shown in Fig. 8. However, whether the man-made noise emitted from microwave oven is white or colored, the periodic high amplitude man-made noise are emitted from microwave ovens and then, we can expect that the qualitative property of IEEE 802.11g WLAN system under man-made noise (e.g., throughput performance has improved twice as CNR becomes larger) will not be changed. Further discussion about the performance of IEEE 802.11g WLAN system under colored man-made noise environment.
is one of future works.

### 4.2.2 Throughput Performance with Multiple Transmission Rate Control

IEEE 802.11 standard supports multiple rates transmission, and the control of transmission rates (multi-rate control) according to the condition of wireless channel enables WLAN system to keep good quality communication. Here, with the consideration of multi-rate control, we evaluate the throughput performance of IEEE 802.11g WLAN system under man-made noise environment. Because a method for multi-rate control is not clearly specified in IEEE 802.11 standard [2], in this paper, we use a typical method of the multi-rate control [13]. In this method, the data rate goes up to 1-level higher than the current rate if the transmission of the data packet is successful \(U\) times continuously, and fall back to 1-level lower rate if the transmission is failed \(D\) times continuously. Referring to [13], we set \(U\) and \(D\) to be 8 and 3 respectively, and the data rate is chosen from 6 Mbps, 12 Mbps, 24 Mbps and 54 Mbps.

Figure 9 shows the throughput performance of WLAN system with multi-rate control versus CNR. For comparison, the throughput performances of WLAN system with fixed data rate, that is to say, the results in Fig. 8 are also shown in this figure. From Fig. 9, we can find that, in some cases, the throughput with multi-rate control is inferior to that with fixed data rate. For example, at CNR=27 dB, the throughput with multi-rate control is inferior to that with fixed transmission rate. In order to investigate this phenomenon more in detail, we evaluate the selected data rates versus time at CNR=27 dB, and its result is shown in Fig. 10. In this figure, “time” expresses the time when the transmitter \(T_3\) starts the transmission of a data packet. In this case, because the CNR=27 dB and the INR=20 dB, to achieve the best throughput performance, appropriate transmission rate of data packet is 12 Mbps while man-made noise is emitted and 54 Mbps while man-made noise is not emitted. However, as shown in Fig. 10, even though the multi-rate control scheme is introduced, this multi-rate control cannot keep up with the rapid variation of the channel condition caused by man-made noise. Because of this insufficient multi-rate control, IEEE 802.11g WLAN system cannot achieve an enough throughput performance. Discussions about the method to select an appropriate data rate suited for man-made noise environment are one of our future works.

As described in Sect. 2, we assume that the source of man-made noise is a trans-type microwave oven in this paper. Here, we discuss the effect of man-made noise whose source is an inverter-type microwave oven on the performance of IEEE 802.11g WLAN system. One of the critical differences of statistical characteristics of man-made noise emitted from inverter-type microwave oven from those of trans-type microwave oven is that there are many minute bursts caused by the switching process of the switching transistor circuit in the microwave oven within \(t_2\) shown in Fig. 1 and known that its switching frequency is about 30 kHz. Because of these, man-made noise is bursty emitted from an inverter-type microwave oven every 30 \(\mu\)sec (a radiation period coinciding with the switching frequency) during \(t_2\) [4]. This may cause the major differences in the performance of IEEE 802.11g WLAN system under trans-type microwave oven and under inverter-type microwave oven environments. However, the time length of the data packet of IEEE 802.11g WLAN system is much longer than 30 \(\mu\)sec, and the period of carrier sense of IEEE 802.11g WLAN system is mostly longer than 30 \(\mu\)sec. And, the degradation of the performance of IEEE 802.11g WLAN system may not be related with a radiation period caused by the switching process of an inverter-type microwave oven. Therefore, in the case that the source of man-made noise is an inverter-type microwave oven, we can discuss the performance of IEEE 802.11g WLAN system considering the only radiation period caused by AC power and employing the same statistical model of man-made noise as that of a trans-type microwave oven shown in Fig. 1.
In this paper, we assume that the IEEE 802.11g wireless LAN system transmits the IP packet and then the size of one data packet is set to be 1,500 byte. However, wireless LAN system is not only used in wireless computer networking and it is applied to several kinds of wireless system including wireless audio-visual transmission system. In this case, the size of one data packet is not always to be 1,500 byte. As shown in the performance evaluation, because the periodic and bursty high amplitude man-made noise is emitted from microwave oven, it can be expected that the performance of wireless LAN system is much related to the length of data packet (size of data packet) and the period of high amplitude man-made noise. Further discussions about the relationship between the size of data packet and the throughput performance of wireless LAN system under man-made noise environment is one of our future works.

5. Conclusion

In this paper, we have investigated the influence of man-made noise emitted from microwave oven on the performance of IEEE 802.11g WLAN system. At first, we have briefly described the characteristics of man-made noise and shown the statistical model employed in this paper. And next, we have explained the MAC layer protocol of WLAN system and evaluated the performance of IEEE 802.11g WLAN system under man-made noise environment in several cases. Numerical results have shown that, in case where the microwave oven is operated close to the transmitter, the degradation in the throughput performance is caused by the misidentification of the channel state, and, even though the high CNR can be obtained in a wireless channel, the throughput performance cannot be improved. On the other hand, in the case where the microwave oven is operated close to the receiver, man-made noise causes a packet error and this also leads the degradation in the performance of WLAN system. In addition, we also have investigated the performance of 802.11g WLAN system with multiple rate control scheme and shown that the conventional multiple rate control scheme cannot achieve a sufficient performance under man-made noise environment.

References


Appendix: Simulation Method

For the throughput performance evaluation, we employ the MAC model shown in Fig. 2. And Fig. A-1 shows the block diagram of the packet transmission in our evaluation. The MAC layer protocol has been described in Sect. 3, therefore, we describe the simulation method of the packet trans-
mission for the throughput performance evaluation of IEEE 802.11g WLAN system.

Firstly, to transmit the packet, the data bits are randomly generated and encoded with a convolutional encoder of punctured coding. These encoded bits are interleaved. Next, these encoded and interleaved bits are divided into the number of the data subcarriers (48) and each data subcarrier is modulated by using BPSK, QPSK, 16QAM or 64QAM (mapping). The coding rate and the modulation method are depended on the data rate. The power of subcarrier is obtained from the defined value of CNR where the power of BGN ($N$) is normalized. These modulated subcarriers and pilot subcarriers are overlapped by Inverse Fast Fourier Transform (IFFT) and OFDM symbols are generated. These OFDM symbols are transmitted after added Guard Interval (GI). During OFDM symbols transmitted, BGN or man-made noise is added to OFDM symbols. The power of man-made noise ($I$) is obtained from the defined value of INR. Received OFDM symbols are removed GI and divided into each subcarrier by Fast Fourier Transform (FFT). After demapping and deinterleaving, transmitted encoded bits are decoded with a viterbi decoder. Decoded bits are compared with transmitted data bits for counting the error and correct bits. If the number of error bits is equal to zero, the transmission of the packet is successful, and if not, the transmission is failed.

Described in Sect. 3, if both the data packet and the ACK packet are transmitted without error, data bits are transmitted completely. And if so, transmitted data bits are counted for the throughput performance evaluation. This routine of transmitting the data packet shown in Fig. 2 is repeated with the large number of routine. The number of the counted transmitted data bits is divided by the required time for the transmission. Finally, the throughput is derived, for a value of CNR or INR.

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