

Throughput Derivation for Analysis of Interference of the System with Interference Avoidance Function in 2.4GHz ISM Band

Seonhui Yun*, Hokyung Son*, Heonjin Hong, Jaemin Ahn**

*Electronics Telecommunications Research Institute, 138 Gajeongno, Yuseong-gu, Daejeon, Korea

**Information and Communications Department, Chungnam National University, 79 Daehangno, Yuseong-gu, Daejeon, Korea
shyun@etri.re.kr, hgson@etri.re.kr, hjhong@etri.re.kr, jmahn@cnu.ac.kr

Abstract—There are various systems using ISM (Industrial Science Medical) band, resulting in a potential for interference. To avoid interference effectively, interference analysis in ISM band is essential. Monte-Carlo method is mainly used for interference analysis among wireless communication systems. In this paper, we suggest a modified Monte-Carlo method which can calculate throughput to provide the effect of interference on data communication system. And we analyze the throughput of the system with interference avoidance function in the presence of other interfering systems in ISM band.

Keywords— Monte-Carlo, throughput, collision avoidance, victim, interference

I. INTRODUCTION

Recently, the usage of data in the 2.4GHz ISM (Industrial Science Medical) band is dramatically increased. There is no strict radio regulation in the ISM band. Therefore, interference frequently occurred in heterogeneous systems. To avoid interference, we need to calculate the influence of interfering systems on victim system first. There are various solutions to measuring the effects of interference. Monte-Carlo simulation is analytical method to enable us to evaluate the level of interference which would be experienced by representative receivers. The level of interference should be expressed in terms of the probability that reception capability of the receiver under consideration is impaired by the presence of an interferer [1]. In data communication systems, throughput variation is more useful than the probability of interference. As mentioned earlier, there is no strict radio regulation in the ISM band. Thus, the systems in 2.4GHz ISM band have algorithm to avoid interference. In this paper, we suggest the method for deriving throughput variation of victim system using modified Monte-Carlo and we analyze the throughput variation of victim system with interference avoidance algorithm.

II. MONTE-CARLO METHOD

A. Monte-Carlo Method

Monte-Carlo method is mainly used for interference analysis among wireless communication systems. To derive

the probability of interference, statistical modeling of interference scenarios will be required [1].

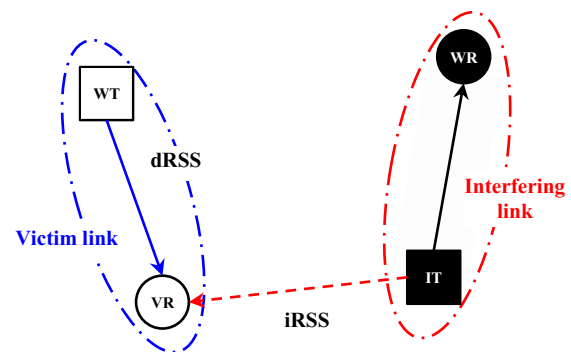


Figure 1. Relation of victim link and interfering link

Fig. 1 presents the occurrence of the interference between antenna systems. Victim link is the target of interference analysis. The link which interferes in victim link is called interfering link. Victim link consists of victim receiver (VR) and wanted transmitter (WT). Interfering link consists of interfering transmitter (IT) and wanted receiver (WR). We define the received signal strength from WT to VR as dRSS (desired Received Signal Strength) and define the received signal strength from IT to VR as iRSS (interfering Received Signal Strength).

The process of Monte-Carlo interference analysis is shown Fig. 2-(a). First, system and path parameters are needed to simulate. The parameters include the characteristics of antenna, frequency, bandwidth, transmit power, spectrum mask, distance, propagation model, and so on. Based on the parameters, victim link and interfering links are generated as given probability distribution. After generating system links, the dRSS and the iRSS may be computed.

The dRSS may be represented as equation (1).

$$dRSS = p_{wt}^{supplied} + g_{wt \rightarrow vr}(f_{vr}) - pl_{wt \leftrightarrow vr}(f_{vr}) + g_{vr \rightarrow wt}(f_{vr}) \quad (1)$$

Where f_{vr} denotes frequency received in the victim receiver, $p_{wt}^{supplied}$ may denote maximum power level

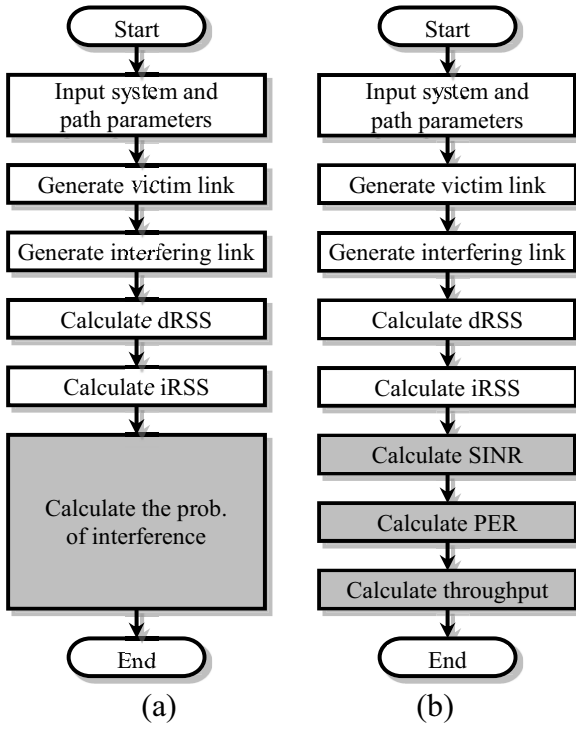


Figure 2. Process of Monte-Carlo interference analysis
(a) Monte-Carlo method, (b) modified Monte-Carlo method

distribution supplied to the wanted transmitter antenna. $pl_{wt \leftrightarrow vr}$ denotes the path loss between the wanted transmitter and the victim receiver, $g_{wt \rightarrow vr}$ and $g_{vr \rightarrow wt}$ may denote wanted transmitter antenna gain in the victim receiver direction and victim receiver antenna gain in the wanted transmitter direction respectively.

In general, an interference mechanism may be divided into unwanted emission, blocking, intermodulation, and the like. The iRSS are expressed as equation (2) to (4)

The iRSS due to unwanted emission may be represented as equation (2).

$$iRSS_{unwanted_j} = emission_{it}(f_{it}, f_{vr}) + g_{it}^{PC} + g_{it \rightarrow vr}(f_{vr}) - pl_{it \leftrightarrow vr}(f_{vr}) + g_{vr \rightarrow it}(f_{vr}) \quad (2)$$

Where $iRSS_{unwanted_j}$ is j-th interferer's interfering received signal strength due to unwanted emissions. f_{it} denotes interferer transmitting frequency, $emission_{it}(f_{it}, f_{vr})$ may denote emission mask by the interfering transmitter. g_{it}^{PC} denotes power control gain for the interfering transmitter and $g_{it \rightarrow vr}$ denotes interfering transmitter antenna gain in the victim receiver direction. $pl_{it \leftrightarrow vr}$ is the path loss between the interfering transmitter and the victim receiver, and $g_{vr \rightarrow it}$ is victim receiver antenna gain in the interfering transmitter direction.

The iRSS due to blocking may be represented as equation (3).

$$iRSS_{block_j} = p_{it}^{supplied} + g_{it}^{PC} + g_{it \rightarrow vr}(f_{it}) - pl_{it \leftrightarrow vr} - a_{vr}(f_{it}, f_{vr}) + g_{vr \rightarrow it}(f_{it}) \quad (3)$$

Where $iRSS_{block_j}$ is j-th interferer's interfering received signal strength due to blocking. $p_{it}^{supplied}$ is maximum power supplied to the interfering transmitter antenna (before power control). $a_{vr}(f_{it}, f_{vr})$ attenuation of the victim receiver.

The iRSS due to intermodulation may be represented as equation (4).

$$i_{i,j}RSS_{intermod} = 2i_iRSS_{int} + i_jRSS_{int} - 3intermod - 3sens_{vr} - 9dB \quad (4)$$

Where $i_{i,j}RSS_{intermod}$ is the d received signal strength due to intermodulation product of third order by i-th and j-th interferer. i_kRSS_{int} is received power in the victim receiver due to interferer $k=i$ at f_{it} or interferer $k=j$ at $f_{it,j}$. $intermod$ denotes receiver intermodulation response for a wanted signal 3dB above the sensitivity. and $sens_{vr}$ is sensitivity of victim receiver.

After calculating dRSS and iRSS, the probability of interference can be derived as equation (5).

$$P = P\left\{\frac{dRSS}{iRSS} > \frac{C}{I} \mid dRSS > sens_{vr}\right\} \quad (5)$$

The overall probability of interference P corresponds $dRSS/iRSS > C/I$ (carrier-to-interference ratio) when the $dRSS > sens_{vr}$ is satisfied.

B. Modified Monte-Carlo Method

Existing Monte-Carlo method can provide the probability of interference among the wireless systems. However, it cannot reflect the actual change of throughput in data communications. Therefore, we suggest a modified Monte-Carlo method shown as Fig. 2-(b)

Most process of the modified Monte-Carlo method is identical to conventional Monte-Carlo method. And calculating SINR (Signal-to-Interference-plus-Noise Ratio), PER (Packet Error Rate) and throughput processes are added instead of calculating the probability of interference process. The added processes are explained (6) to (8)

$$SINR = \frac{dRSS}{iRSS + NoiseLevel} \quad (6)$$

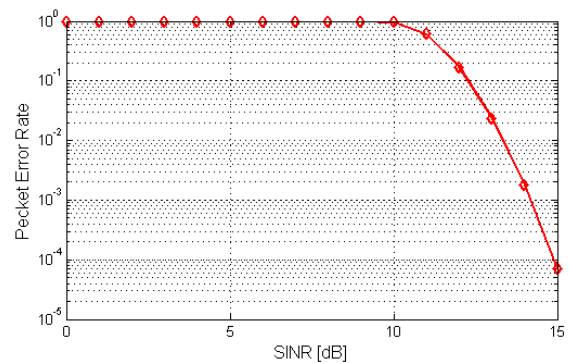


Figure 3. An example of the relation between SINR and PER

$SINR$ is calculated using $dRSS$ and $iRSS$ and noise level. $NoiseLevel$ is included in input parameters. PER can be derived from a given $SINR$ vs. PER table like Fig. 3.

Generally, packet error rate can be changed through the system, environment, and packet length.

In order to assess the throughput, $SINR$ values must be mapped to a quality measure. The packet throughput of a data connection is taken as measure for the link quality. Because of the ARQ mechanism, a packet is not only lost if the forward link is erroneous, but also if the acknowledgement on the backward channel is erroneous. Since a packet and its acknowledgement are transmitted on different frequencies, which are selected independent from each other. The packet error rate depends on the actual $SINR$ [2]. Equation (7) and (8) represents the throughput calculation process

$$Throughput = R \cdot [(1 - P_{timecol}) \cdot 1 + P_{timecol} \{ (1 - PER_{DATA}) (1 - PER_{ACK}) \}] \tag{7}$$

Where, R is maximum data rate, $P_{timecol}$ denotes the probability of time collision, i.e. the probability of the victim and the interfering systems transmit data at the same time. PER_{DATA} is the packet error rate of data packet and PER_{ACK} is the packet error rate of the packet error rate of acknowledge packet.

III. INTERFERENCE AVOIDANCE ALGORITHM

There is no strict radio regulation of the interference in the ISM band. Therefore, some systems operating in 2.4GHz ISM band have their own algorithm for interference avoidance like LBT (Listen Before Transmit), AFH (Adaptive Frequency Hopping), DCS (Dynamic Channel Selection), ED (Energy Detection), and so on. Throughput analysis method that we discussed before, it cannot consider the effect of interference avoidance algorithm. So we suggest a throughput calculation method considering interference avoidance algorithm.

Most of the interference avoidance algorithms use sensing mechanism which measures the strength level of interfering signal power. That is, a system measures the signal strength to the wanted channel before attempting link connection. Depending on the measured signal strength, the system decides whether the channel is usable or not. If the measured signal strength is larger than the level that the system can communicate with other wanted system, the system regards the wanted channel is already occupied by other interfering system. The system doesn't use the channel and attempts to use other channel.

Fig. 4 shows a process of throughput analysis with interference avoidance algorithm. When generating victim link and interfering link, a channel is randomly selected according to stochastic condition of input channel parameter. After calculating $iRSS$ (interfering Received Signal Strength), $iRSS$ value is compared with the arbitrary threshold that is set for victim system. If the $iRSS$ value is less than the victim's threshold ($iRSS < threshold$), victim system assumes that the interfering signal strength is within the acceptable level in that channel and victim system starts transmission without

switching channel. While the $iRSS$ value is more than victim's threshold ($iRSS \geq threshold$), victim system assumes that the interfering signal strength in the channel exceed the acceptable level. And victim system attempts to connect the other channel.

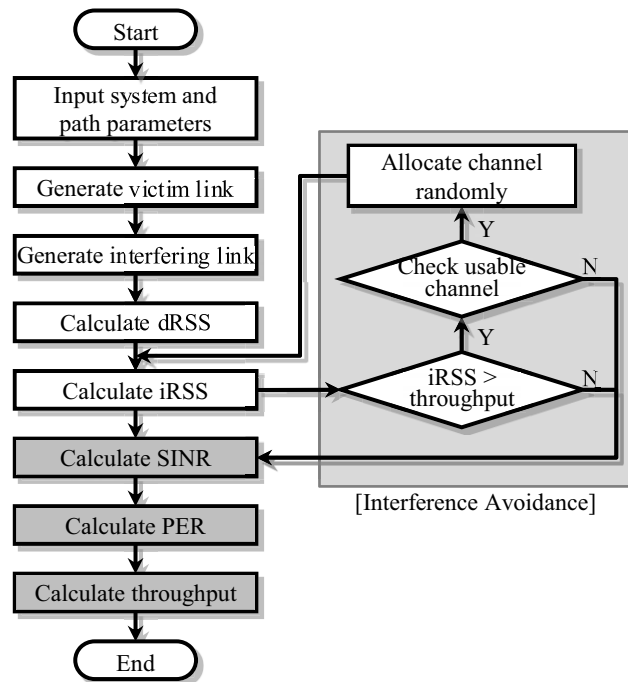


Figure 4. Process of throughput analysis with collision avoidance

To use the other channel, victim system seeks the other available channel. If there is no available channel, victim system uses the previously assigned channel and precedes the throughput calculation. While there are available channels, a new channel is randomly assigned and repeats previous processes.

IV. THROUGHPUT EVALUATION

In this section, we present simulation results to evaluate the throughput variation of Bluetooth system in the presence of WLAN interference using suggested Monte-Carlo method and collision avoidance algorithm.

A. System Parameters

Main parameters of systems for evaluating throughput are as Table 1 to Table 3

TABLE 1. PARAMETERS OF VICTIM LINK (BLUETOOTH)

Transmitter settings	
power	0dBm
frequency	DU* (min:2402, max:2480,step:1)MHz
Receiver settings	
Sensitivity	-70dBm
Bandwidth	1000kHz
Noise floor	-100dBm
Antenna settings	
Height	1.5m

Azimuth	Uniform (0,360)°
Elevation	Constant 0°
Gain	0dBi

*DU: Discrete Uniform distribution

TABLE 2. PARAMETERS OF INTERFERING LINK

Transmitter settings			
power	20dBm		
Frequency	DU (min:2412, max: 2462, step: 5)MHz		
Emission mask	Offset(MHz)	Unw. lv.(dBc)	Ref. BW(kHz)
	-40	-50	100
	-22.001	-50	100
	-22	-30	100
	-11.001	-30	100
	-11	0	100
	11	0	100
	11.001	-30	100
	22	-30	100
	22.001	-50	100
	40	-50	100
Receiver settings			
Bandwidth	22000kHz		
Antenna settings			
Height	1.5m		
Azimuth	Uniform (0,360) °		
Elevation	Constant 0°		
gain	0dBi		

TABLE 3. PARAMETERS OF PATH

Wt-Vr path		
Coverage radius	mode	User defined
Mode	Coverage radius	0.01km
It-Vr path		
Correlated distance	Mode	uniform
	Path azimuth	Uniform (0,360)°
	Path dist. factor	Uniform polar dist. 1
	Coverage radius	0.1km
	# of interferer	1
Propagation model		
(applied Wt-Vr and It-Vr path)	Modified Hata SRD	
	Variations	TRUE
	Median loss	TRUE
	General env.	Urban
	Local env. (Vr)	Outdoor
	Local env. (Wt)	Outdoor
	Propagation env.	Below roof
	Wall loss(in in)	5dB
	Wall loss std(in in)	10dB
	Wall loss(in out)	10dB
	Wall loss std(in out)	5dB
	Loss bet. adjacent floor	18.3dB
	b	0.46

B. Simulation Results

Figure 5 shows the dRSS and iRSS values of the victim Bluetooth system with WLAN interference. The iRSS value is approximately -59dB. If the threshold value is too low or too high, collision avoidance function cannot classify good channel and bad channel. So we set the threshold of interfering signal strength with -50dB. Figure 6 show the

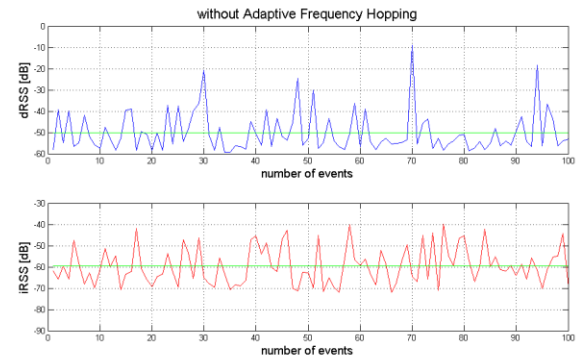


Figure 5. dRSS and iRSS without AFH

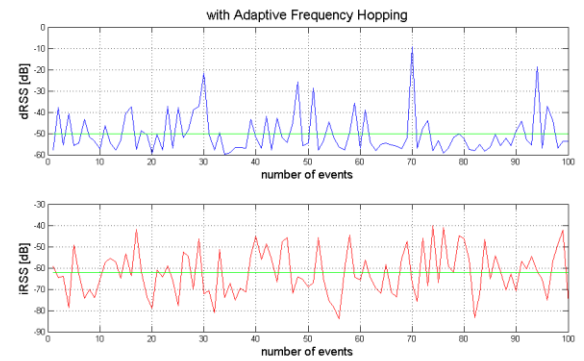


Figure 6. dRSS and iRSS with AFH

dRSS and iRSS values of the victim Bluetooth system which uses collision avoidance algorithm. By using collision avoidance algorithm, the iRSS value is approximately -61dB. It is lower than the iRSS value without collision avoidance algorithm.

Figure 7 and figure 8 shows the throughput variation through the simulation number of events. The blue line is the throughput variation without interference and the red line is the throughput variation with WLAN interference. Throughput loss is calculated from the difference between the throughput with interference and the throughput without interference.

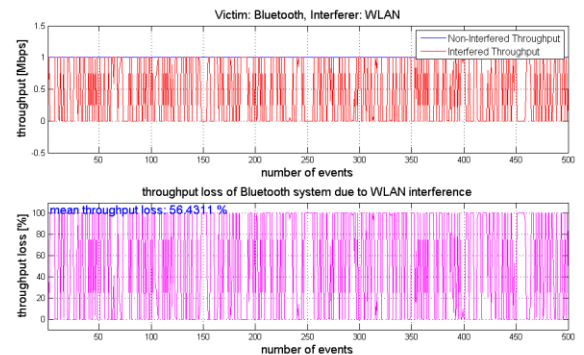


Figure 7. Throughput and throughput loss without AFH

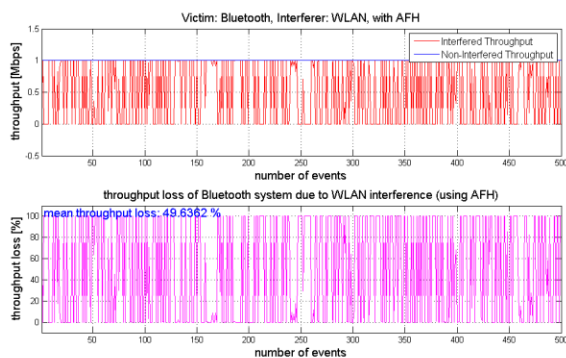


Figure 8. Throughput and throughput loss with AFH

The mean throughput losses of the victim system without collision avoidance algorithm and with collision avoidance algorithm are 56.4311% and 46.6362% respectively. When using collision avoidance algorithm, the performance of victim system becomes better.

V. CONCLUSION

Monte-Carlo method has been used to analyze the effect of interference among various systems. Communication units using ISM band are increased dramatically. But there is no strict radio regulation in ISM band. Thus, we need to analyze interference to avoid other system's interference. To do this, it is useful to analyze interference by Monte-Carlo method. But as the usage of data in the ISM band is increasing, it cannot infer the change of data traffic from the probability of interference. Therefore, we suggest the modified Monte-Carlo interference analysis method that can derive throughput. Some systems operating in ISM band have their own algorithm for interference avoidance. Most of the algorithms use sensing mechanism which measures the strength level of interfering signal power. So we suggest a throughput calculation method considering interference avoidance algorithm.

Using the proposed new Monte-Carlo interference analysis method, we showed the throughput variation of the Bluetooth system under the interference of WLAN system which systems are the representative systems in 2.4GHz ISM band.

To show the effect of applying interference avoidance algorithm with modified Monte-Carlo method, we compared throughput variation of Bluetooth system with collision avoidance algorithm and without collision avoidance algorithm under WLAN interference. The suggested Monte-Carlo method for throughput calculation and the collision avoidance algorithm can evaluate the throughput variation of the victim system in the presence of interfering signal and it can derivate the effect of the collision avoidance algorithms.

ACKNOWLEDGMENT

This work was supported by the IT R&D program of MKE/KEIT. [2008-F-013-1, Development of Spectrum Engineering and Millimeterwave Utilizing Technology].

REFERENCES

- [1] ERC Report 68, "Monte-Carlo simulation methodology for the use in sharing and compatibility studies between different radio services or systems", ERC, June 2002.
- [2] ERC Report 109, "Compatibility of Bluetooth with other existing and proposed radio communication systems in the 2.45 GHz frequency band", ERC, October 2001.
- [3] IEEE 802.15.1, "Wireless medium access control (MAC) and physical layer (PHY) specifications for wireless personal area networks (WPANs)", IEEE, June 2005.
- [4] IEEE 802.11g, "Wireless LAN Medium Access Control (MAC) and Physical Layer (PHY) specifications: Amendment 4: Further Higher Data Rate Extension in the 2.4 GHz Band", IEEE, July 2006.
- [5] IEEE 802.11, "Wireless LAN Medium Access Control (MAC) and Physical Layer (PHY) specifications, Standard", IEEE, Aug.1999.
- [6] IEEE 802.11b, "Wireless LAN Medium Access Control (MAC) and Physical Layer (PHY) specifications: Higher-Speed Physical Layer Extension in the 2.4 GHz Band", IEEE, Sept. 1999.
- [7] IEEE 802.15.4, "Wireless Medium Access Control (MAC) and Physical Layer (PHY) Specifications for Low-Rate Wireless Personal Area Networks (WPANs)", IEEE, Sep. 2006.