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A Study on Propagation Path Characteristics of GPS Potential Jamming Signal Based on Spherical Ground Diffraction Loss

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Abstract : *This paper is to investigate propagation path characteristics of GPS potential jamming signal. To do this, the spherical ground diffraction model is applied to the potential jamming scenario referred to the GPS jamming events occurred in recent years. The fundamental theory on the propagation path loss is discussed and a specific model is applied to several vehicles types which have own heights of antennas in order to compare their propagation path loss values at same 2-D location. The transmitting powers are appropriately given as the ordinary GPS jamming events. And then the received powers in dBW are obtained with given transmitting powers and the estimated total loss. The result of received jamming power at various locations due to the given scenario was distinct. For example, propagation loss values were estimated as -147～-142dBW and -167～-162dBW in 10^6W and 10^4W, respectively. This computation result of the loss can be seriously considered with the tolerable jammer power against L1- C/A GPS receiver under any real jamming situations.*

Key Words : *Propagation path loss, Spherical ground diffraction, Potential jamming , Tolerable jammer power, GPS jamming*

1. Introduction

It has known that the vulnerability of GPS jamming may lead to the serious damage in the infrastructure of the civil and the military. The potential interference can cause not only the limited denial of GPS but also the denial of GPS over the large geographic area. The more GPS is applied to various fields in civilian and military areas, the more threat of such a jamming may increase in military operations. The intentional interference against GPS signal, named GPS jamming, was really performed to misguide GPS guided weapons during the Iraq-war in 2003(KNWC, 2003) and the navigation warfare was also introduced as a military operation(DOT, 2001; DOD & DOT, 2001).

One of the serious intentional interferences might be the North Korea's jamming attack against South Korea during the military exercise between U.S. and South Korea over the last two years. Such a jamming attack is similar to the ordinary electronic warfare which has been well known to military persons. There have been previously several studies on characteristics of the jamming against GNSS receivers(Chung, 2004; David, 2009; Ko, 2010). However, no work may exist on GPS Jamming characteristics occurred in the Korean Peninsula. This paper is mainly focused on jamming signal loss due to propagation path. And then the receiving powers of various vehicles installed GPS receivers from the potential jammer are analyzed. Additionally, the values are compared to ones of the potential GPS receivers. The GNSS vulnerability and Navigation Warfare are described, and then the propagation path model and its loss are investigated. To do this, the specific propagation mode, the spherical ground diffraction model is applied to a scenario of GPS jamming to analyze its characteristics. As a result, the additional propagation loss due to diffraction phenomenon between transmitter and receiver points is computed and analyzed with respect to the receiving height of various vehicles. Additionally, the received power of the potential jammer is computed with respect to the total propagation loss. And then the potential jamming area of the given scenario is evaluated over the tolerable power referred to the previous work(Kaplan and Hegarty, 2006). This work is also extended with respect to our fundamental study(Ko, 2013). Finally, we discuss and evaluate the effective jamming range and managing the receiver's location under the jamming circumstance.

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2. The Vulnerability Issue and GNSS Jamming

2.1 The consideration NAVWAR based on EW

EW (Electronic Warfare) refers to any action involving the use of electromagnetic devices to control the electromagnetic spectrum or to attack the enemy(USN, 2006). The purpose of EW is to deny the opponent advantage and ensure freedom of action for friendly forces in EM environment. EW includes three major subdivisions: electronic attack (EA), electronic protection (EP), and electronic warfare support (ES). Specially, EP, which may be deeply related to the GPS users under jamming, is protecting friendly combat capabilities against the undesirable effects of enemy electronic attack. It *assures* that the victims to jam and equipments to be protected are mainly related to military's works and operations.

On the other hand, even if the Department of Defense of the USA began to initiate a Navigation Warfare program as a GPS security program to ensure the United States retains a military advantage, the characteristics on NAVWAR have not been clearly written in military documents, especially even in well known references(Joint Chief of Staff, 2007). It might be reasonable that NAVWAR is dealt with a specific EW with respect to GNSS.

2.2 Denial jamming in EW and NAVWAR

One of the serious threats from the noise jamming occurs to prevent from using GPS navigation signals or other GNSSs. The noise jamming is separated into two categories, the denial jamming and the deception jamming. The GPS jamming is defined to be the intentional radio frequency interference to cause a GPS receiver to fail to acquire or break lock, and then the useful solutions of navigation can not be obtained. It is referred to the denial jamming as mentioned.

The denial jamming methods are the spot jamming, the barrage jamming and the sweep jamming.

Although the terminology used in the jamming of radars and GNSS is slightly different, it has been recognized that the fundamental techniques of the denial jamming are very similar to ones applied to GNSS in process(Joint Chief of Staff, 2007). To perform the jamming, it is essential that the sufficient intentional interference signal must be induced to the receiver, then jammer to receiver signal power ratio power (J/S) should exceed the tracking threshold.

The issue of vulnerability was publicly warned by civilian side. IALA has specially studied GNSS vulnerability since early 2000. The association also published the recent version "IALA Recommendation R-129" on GNSS vulnerability and mitigation measures on December 2008(IALA, 2008). Several distinct conclusions are obviously noted through its study. On the other hand, the worldwide use of GNSS for military applications has driven the development of GNSS disruption called "jamming", which is similar to EW in ordinary operation mentioned previously. In Fig. 1, the concept of GNSS jamming is shown.

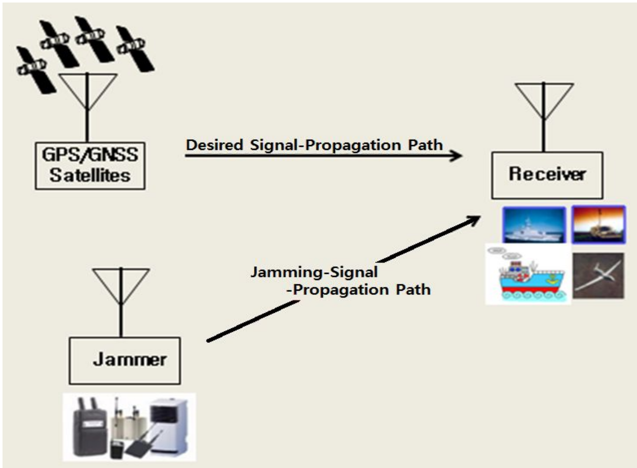

Fig. 1. The concept of GNSS Jamming.

There are several distinct reasons why jamming and anti-jamming like an ordinary EW have been issued in our previous investigation as follows(Ko and Shin, 2012). 1) GNSS jamming techniques are not secrets to protect the theory and design skill against uncertain bad nations. There are various jammers from low power less than 100W to MW for worldwide to not only to sell to ordinary people but also to make easily by technicians. One example is that 18 commercially available GPS jammer based on experimental test was conducted by researchers. 2) The GNSS receiver basically has very low receiving power around -160dBw because of long distance propagation from satellites which is approximately 20,000km far away, and then only order of Pico watt is required to jam GNSS receivers. 3) The GNSS jamming device has an advantage to play the military weapon system as an asymmetry asset.

3. Propagation Path Loss : Theory and its Application

3.1 Consideration on Propagation Path Loss under GPS Jamming

More than 250 flights around South Korea had experienced North Korea' GPS jamming during the military exercise between U.S and South Korea in 2012. The U.S. RC-7B, U.S. military reconnaissance aircraft, conducted an emergency landing due to the loss of accurate position by jamming signal at 5 - 10 minutes interval from North Korea during annual exercise between two countries in 2011. There have been also disruptions of GPS functions at coastal patrol boats and fishing boats at that time.

Furthermore, it is known that the North already has developed jamming device capable of disrupting the receiver over 100km. In addition to these, according to our investigations, most of victims by such attack have occurred in air and sea instead of land. One can consider why the victims were easily happened in air and sea. Here, there might be several reasons including antenna directivity from the location of the jamming source and propagation path as well.

The scientific investigation should be performed with considering the geographic characteristics, mountainous area occupying 70% of the Korean Peninsula because the loss of GNSS jamming signal due to the propagation path may seriously affect the receivers on or around various geographic sizes and shapes. The test of jamming was conducted without broadcasting harmful radiation in outdoor. The indoor simulation test was conducted using GPS simulator, receiver, various commercial jammers and RF set including attenuators with many assumptions(Mitch et al., 2011). It also showed not only the level of tracking and acquisition, 3-11dB, for 4 different commercial jammers but also the effective distance under jamming against receivers referred to the well known popular formulation. The formulation based on the only free space propagation might not be a proper for applying various propagation paths and noise level in real situation. The effective area and distance from the jammer source can be estimated through the more actual parameters including the loss of propagation- path model in terms of geographic condition in next section.

3.2 The Spherical Ground Diffraction Model and the Loss

The radio propagation between transmitting and receiving points may be considered with various characteristics. This is due to the existing various non-free space factors over the radio wave path. The free space propagation path is mostly considered in an almost ideal propagation path such as satellite to satellite or satellite to earth. There are various types of propagation paths due to the physical classification of propagation waves such as directive wave, reflected waves, refracted waves and diffractive waves. The electromagnetic line of sight is obstructed by various geographical shapes. The diffraction wave among the various types should be considered in case of the radio wave passing over mountains or the earth curvatures because the propagation loss may seriously affect the vulnerable system such as a GPS receiver mentioned previously. It is difficult to determine or calculate the exact amount of loss in any propagation path between the transmitting and receiving points. That is why most of studies for propagation loss might have been performed with its estimated values. The spherical ground diffraction model can be adapted for dealing with the phenomenon of its propagation loss referred to the last jamming in this study. The additional propagation loss should be considered for dealing with the received power at any receivers in the actual situation. The additional propagation loss due to the spherical ground model mentioned above is estimated as follows(Shibuya, 1987);

$$\gamma_\alpha = G(\chi_0) - F(\chi_1) - F(\chi_2) - 20.5(dB) \quad (1)$$

where, $\chi_0 = DB_0, \chi_1 = d_1 B_0, \chi_2 = d_2 B_0$

$$B_0 = 670\left(\frac{f}{K^2 A^2}\right)^{\frac{1}{3}}$$

$G(\chi_0)$: hight of gain factor

$F(\chi_1)$, $F(\chi_2)$:attenuations due to line of sight

f : frequency in MHz

K : effective earth radius factor

A : mean radius earth in km

d_1, d_2: line of sight distance in km for each hight of transmitter / receiver

D : distance between transmitter and receiver

The propagation loss can be defined as

$$\gamma = \gamma_s + \gamma_a \tag{2}$$

where,

γ_s : free space propagation loss(dB)

γ_a : additional propagation loss(dB)

4. The Potential GPS Jamming, Fundamental Computation Result, and Analysis

4.1 The Given Scenario for the Propagation Path Loss Based on GPS Jamming

It is necessary that the additional propagation loss due to the spherical ground model can be applied to obtain the received power at the various vehicles installed GPS receivers, which have the heights of the antennas. The received powers may be considered to be the received jamming power at the receivers. The jammer height and the whole distance between the transmitter and the receivers are given to 100m and 100km, respectively. The transmitting powers are appropriately given as the ordinary GPS jamming events. The vehicles are classified to four types, S (small boats or small ships : 5-10m), M (medium size ships : 20-30m), L (large ships : 50-100m) and A (air vehicles : higher than 200m) which have the own heights of antennas over sea level. This assumptions and adaptations may be investigated based on the GPS jamming events occurred around the Korean peninsula in recent years. In addition to these, the gains of antennas are considered as a unity under assumption that the transmitting and receiving antennas are perfect, lossless, isotropic radiation for calculating the well-known free space propagation loss.

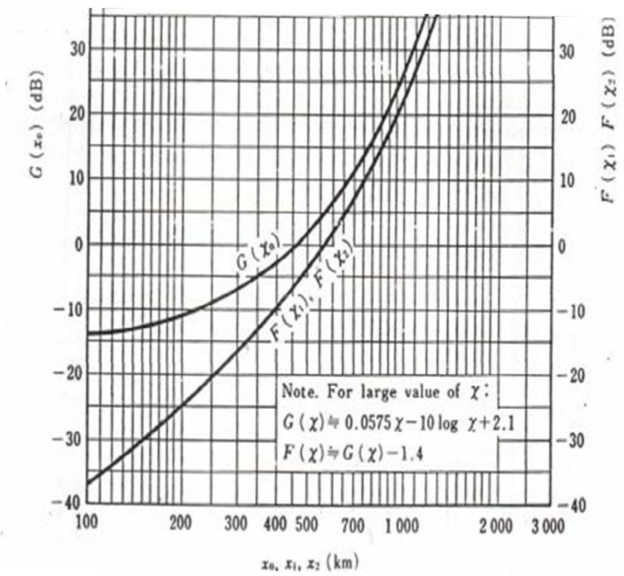

Fig. 2. The Alternative Solution Sheet for Additional Loss(Shibuya, 1987).

The total propagation loss including the free space loss and the diffraction loss can be estimated using the data sheet for diffraction loss model shown in Fig. 2. And then the received power in dBW is obtained with given transmitting powers and the estimated total loss.

4.2 Results and Analysis

The computed diffraction and total propagation loss are shown in table 1. The received jamming powers also shown, which are computed based on the total propagation path loss and transmitting powers from the potential jamming location in table 2.

Table 1. Result of Propagation Loss based on the Potential Jamming Scenario

Vehicles Class	Diffraction Loss (dB)	Total Loss (dB)
S	71-66	207-202
M	58-52	194-188
L	45-32	181-168
A	23	159

The diffraction loss of the class S, small ships, and its total loss are estimated as 71~66dB and 207~202dB, respectively. The received powers of the jamming signal at the GPS receiver due to these propagation loss are estimated as -147~-142dBW and -167~-162dBW in 10^6W and 10^4W, respectively. The received powers are also estimated as -134~-128dBW and -154~ -148dBW in the class M, medium size ship. On the other hand, the received powers are -121~-108dBW and -141~ -128dBW for class L, large ships.

Table 2. Result of the Received Jammer Power at Various Vehicles due to the Scenario

Vehicles Class		Transmitting Power in Watt			
		10^6	5×10^5	10^5	10^4
Received Power in dBW	S	-147 ~ -142	-150 ~ -145	-157 ~ -152	-167 ~ -162
	M	-134 ~ -128	-137 ~ -131	-144 ~ -138	-154 ~ -148
	L	**-121** ~ **-108**	**-124** ~ **-111**	**-131** ~ **-118**	-141 ~ -128
	A	**-99**	**-102**	**-109**	-141 ~ -128

Recalling -118 ~ 125dBW of the tolerable jammer power against L1- C/A GPS receiver from our previous work. We may recognize the distinct results on the effective jamming vehicles. According to the tolerable jammer power and the received jamming power, we can recognize that class S and class M may not be damaged due to the potential jamming in 10KW ~ MW of transmitting power. However, it seems that class L and A may be jammed in the transmitting power. The potential jamming range for class L and class A is underlined inside the table 2.

5. Conclusion and Discussion

The spherical ground diffraction model was applied to the potential jamming scenario. The fundamental simulation for the propagation path loss under the jamming circumstance was conducted and then the effective GPS jamming signal characteristics were analyzed based on the four classified vehicles types. Through the investigations, we recognized that some vehicles at same location over sea level may reduce the jamming damage with the proper managing the height of receivers location. Additionally, one should recognize that the main purpose of this study is not to investigate GPS jamming signal characteristics due to different vehicles heights, but to figure out the propagation path characteristics of GPS potential jamming signal based on spherical ground diffraction loss. There were also several limitations such as the outdoor test and the obtaining real data for propagation path loss during this study.

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