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GNSS interference reduction method for CORS site planning

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Abstract

Precision, Navigation, and Timing (PNT) system based on Global Navigation Satellite System (GNSS) becomes significant in the air, land, and sea traffic management. Integrity of GNSS is significant to provide a reliable real time PNT system such as CORS (Continuously Operating Reference Stations). GNSS Interference due to intentional or unintentional surrounding signal source may decrease the integrity of GNSS signal. Monitoring and identification of potential GNSS interference sources in the surrounding environment of CORS is significant. This paper proposed a methodology to reduce potential GNSS interference in a planned CORS site by first simulating the radiation pattern of potential source of interference to GNSS signal in the planned CORS sites. Thereafter ambient noise levels in the location of CORS may be measured to provide a reference point for analyzing the other potential sources of interferences. Based on these results, optimal location of CORS is chosen with the lowest possible unintentional interference signal from their surrounding. Measurement has been conducted in the location of CORS owned by BIG (Indonesian Agency for Geospatial Information), which is located in the rooftop of a building neara telecommunication tower.This method is necessary for CORS site planning to reduce potential GNSS interference sources in the environment of alternative sites.

Keywords: *CORS network, GNSS, unintentional interference, radio disturbance characteristics*

1. Introduction

Indonesian Agency for Geospatial Information (BIG) has already137 Continuously Operating Reference Stations (CORS) across Indonesian archilepago until 2017 [1]. Data from this CORS network is accessible in inacors.big.go.id. Indonesian Agency for Assessment and Application Technology (BPPT) and BIG have added 2 location reference stakes' in the area of Puspiptek Serpong for research and development (R&D) purposes especially related to Electronics Navigation System R&D activities. These 2 location reference stakes are bounded to BIG InaCORS station with approximately 10km distance, namely CTGR CORS Station as shown in Figure 1.

The integrity of signals from Global Navigation Satellite System (GNSS) are significant to ensure the availability and reliability of navigation data and information for air, land and sea traffic management. Previous work has used analysis software of GAMIT [2] and GLOBIT [3] to evaluate the integrity of GPS L1 and L2 signals in Merapi region [4]. The integrity of signals from GNSS are potentially distorted by interference signal from the surrounding Radio Frequency (RF) sources either intentionally or unintentionally interference signal. According ITU Radio Regulations Section IV Radio Stations and Systems-Article 1.166 electromagnetic Interference (EMI) or Radio Frequency Interference (RFI) is the effect of unwanted energy due to one or a combination of emissions, radiations, or inductions upon reception in a radio communication system, manifested by any performance degradation, misinterpretation, or loss of information which could be extracted in the absence of such unwanted energy [5].

GNSS receivers receive both direct signal from GNSS satellites and reflected signal from the surrounding environments. In additions there are possible interference signal from other sources. Since GNSS signals are very weak (-132 dBW/m2) in the user equipment receivers, this GNSS signals are vulnerable to RFI/EMI. The received signal of surrounding RF interference source is potentially much higher than the received signal from GNSS satellites in

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the user's GNSS receiver. GPS L1 C/A data acquisition with interference-free and in the presence of a in-band continuous wave interference of -159.6, -162.6 and -165.2 dBW is shown in [6]. Furthermore GNSS potential interference signals in the form of in-band narrowband signal at 1240.5 MHz is shown in [7]. This explain the vulnerability of GNSS signals due to EMI or RFI from the surrounding environment of GNSS receiver location. EMI/RFI may cause distortion in the GNSS receivers such as:

- Loss of Receiver tracking: the EMI/RFI is strong enough that may disturb the tracking process of all satellite signals.
- Signal to Noise/Carrier to Noise (SNR/CNO) decreasing.
- EMI/RFI increase the noise value at the Pseudo Range and Phase measurement.

This paper is mainly discussed unintentionally interference signal which may cause disturbance in receiving GNSS signals. This paper proposes a method to reduce potential GNSS interference signal by simulating and measuring a potential interference source to GNSS receiver.

Figure 1. Distance of 2 reference stakes in Puspiptek from CTGR InaCORS of BIG

2. Research Method

There is a need to investigate the surrounding unwanted energy from any RF sources in the environment of InaCORS CTGR in order to evaluate or plan the site allocation of GNSS receiver of InaCORS CTGR. In this paper a proposed method for CORS Site Planning with consideration of GNSS Interference Reduction is given in the following steps:

- Identification of potential RF emission sources in the surrounding area of planned CORS GNSS receivers, especially in the frequency ranges and interference types as given in Tables 1 and 2.
- Conduct coverage simulation of the potential RF emission sources in order to have the radiation direction and strength of the potential RF emission sources.
- Conduct scanning of the potential RF emission signals in the site location GNSS receivers in order to have the frequency spectrum of potential RF interferences sources.
- Conduct recording of GNSS data and analysis in order to investigate any possible distortion in GNSS data especially for signals from satellite in the direction of potential RFI sources.

3. Results and Analysis

In order to find a better site for the allocation of GNSS receiver, a GNSS receiver site allocation planning which evaluate the potential RF interference to GNSS signals is significant. In this paragraph a detaild proposed method for GNSS receiver site allocation planning is discussed step by step. The method starts with a step to identify the potential RF interference sources until the last step is to analyse the recorded GNSS data in the alternative site location of CORS.

3.1. Identification of Potential RF Interference Sources

GNSS interference sources may not have in-band operational frequency but yet may potentially disturb GNSS signal with their harmonics. Recommendation for the use of frequency in respect to GNSS signal is given in [8]. EMI is classified as intentional interference (jammers) and unintentional interference (other RF sources in the surrounding area of GNSS receivers) as given in Tables 1 and 2. In this table the characteristics of received EMI signals by the GNSS receivers are different for various EMI sources.

Table 1. EMI Types and the Caracteristics of Various EMI Sources [9]

Type of EMI	Typical source	Characteristic of EMI
intentional	noise jammers	Wideband Gaussian
	Spread sprectrum jammers	Wideband spread spectrum
	Continuous Wave (CW) jammers	Narrowband swept Continuous Wave
		Narrowband Continuous Wave
unintentional	TV transmitter harmonics, near band microwave link transmitters	Wideband phase frequency modulation
	Near field of pseudolites	Wideband spread spectrum
	Radar transmitters	Wideband pulse
	AM Stations/CB transmitter harmonics	Narrowband Phase/ Frequency Modulation
	FM Station transmitter harmonics	Narrowband swept Continuous Wave
	Near band unmodulated transmitter's carriers	Narrowband Continuous Wave

Table 2. EMI Types and Potential Interfence in GPS Frequency [9]

GNSS signal	EMI sources	Frequency (MHz)	Interfere with GNSS signal
GPS L1 (1575.42 MHz)	Harmonics of VHF Communication for Air Traffic Control (ATC)	118-137.5	12th and 13th harmonics
	UHF TV and GSM700	782-788	2nd and 3rd harmonics
	Amateur radio	220-225	7th harmonic
	Personal pivacy devices	Swept frequency car jammers (L1 and Galileo E5/1215 MHz)	Effective at a range of 1km to 8km depending on power of jammer
GPS L2 (1227.60 MHz)	Radio Navigation on Earth	1215-1240	In band

Algorithm to reduce the complexity of tracking a weak GPS signal is discussed in [10] by tracking the deviation of Carrier Noise Ratio (CNR) and the frequency. The CNR and frequency track deviation, the gain coefficient and noise level of the discriminator at certain condition can be reflected by statis the averge value and variance of the discriminator's output. In the surrounding of CORS CTGR there are potential EMI/RFI sources namely:

1) In Frequency band of GSM900 and GSM 1800: The potential EMI/RFI sources are mainly GSM700 signals (700 MHz-800 MHz), namely the 2nd harmonics will have potential interference with L1 signal from GNSS satellites. Since Indonesia has only GSM-900 with transmitted power of 40Watt and GSM-1800 with transmitted power of 20Watt then GSM RFI source in Indonesia is probably very limited (this need to be confirmed whether frequency 788MHz is not used by GSM operator or other licenses in Indonesia). In case that it is confirmed that there is no GSM operator in Indonesia is licensed by Indonesian telco operator, then this EMI/RFI source is eliminated. Table 3 shows some GSM bands according to ITU spectrum allocation. Eventhough there is no GSM700 in Indonesia, two nearby GSM towers are identified as shown in Figure 2, namely 1 tower is in a distance of approximately 10m from the CORS CTGR in southly direction of CORS CTGR and another tower is in a distance of approximately 500m from the CORS CTGR in easterly direction of CORS CTGR.

Table 3. GSM Band According to ITU

GSM band	Center Frequency (MHz)	Uplink (MHz) (Mobile to Base)	Downlink (MHz) (Base to Mobile)
GSM-710	710	698.2 – 716.2	728.2 – 746.2
GSM-750	750	777.2 – 792.2	747.2 – 762.2
P-GSM-900	900	890.0 – 915.0	935.0 – 960.0
DCS-1800	1800	1710.2 – 1784.8	1805.2 – 1879.8
PCS-1900	1900	1850.2 – 1909.8	1930.2 – 1989.8

Figure 2.CORS CTGR location and GSM towers

2) In frequency band of TV transmitters: the potential RFI sources from TV transmitters in the surrounding of CORS CTGR are as shown in Figure 3:
   - 3^{rd} harmonics RF sources: TV Transmitters has frequency range between 500-550 MHz (some TV transmitter has 395 meter high tower and transmitted power of 180 kilowatt)
   - 2^{nd} harmonics RF sources: TV Transmitters has frequency range between 750–800 MHz

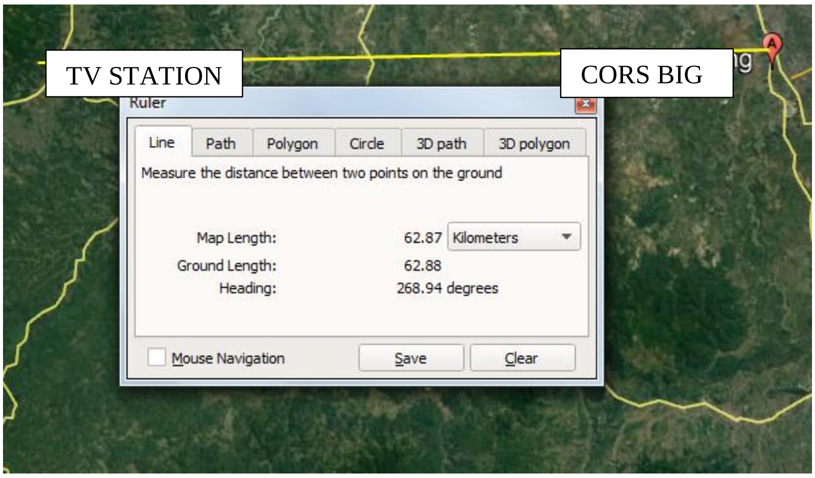

Figure 3.CORS CTGR location and TV transmitter

If a CORS will be allocated in a specific area, it is necessary to identify the TV stations locations near the sites planned in order to reduce the GNSS interference. In [11] TV stations digital MUX infrastructure network of one TV station operator is given and may be used as reference for potential GNSS interference sources. The RF interference may occur as a Line of Sight (LOS) signal or as a multipath signals from various path [12]. In [13] an analogue TV channel which has a carrier frequency of fc=527.25 MHz has 3^{rd} harmonic at 1581.80 MHz. This 3^{rd} harmonic is only 1 MHz distance from L1 central frequency (1581.80–5.25–1575.42 MHz).

3.2. Conduct Coverage Simulation of the Potential RF Emission Sources

After identification of the potential EMI/RFI sources in the surrounding of CORS CTGR, a coverage simulation of the potential EMI/RFI sources is conducted. The simulation is currently to identify whether the nearby GSM tower has potential interference signal to the GNSS receiver in CORS CTGR. As mentioned in the previous paragraph that only GSM 700 has a potential EMI/RFI to GNSS receiver. However a coverage simulation of both GSM900 and GSM1800 are conducted in order to analyse the signal level received in the location of GNSS receiver in CORS GNSS, in case that there are some signals transmitted in the frequency range of 788 MHz from the GSM tower in approximately 10m distance and height difference is approximately 40m.

The simulation is conducted for 3 frequency ranges namely: 788 MHz, 900 MHz and 1800 MHz. The resuls is given in Figures 4. In these figures a parabol antenna model of ITU R-465 with K value of 27 with an azimuth of 10 degrees is used. The simulation shows the signal strength (-38 dBm to -89 dBm) received in the surrounding area of parabol antenna. Figure 4 shows that if there is a GSM signal tower with a distance of 10m from CORS CTGR at transmitted frequency of 788MHz and power of 50 Watt then the GNSS receiver receive a signal approximately -89dBm. Since the potential EMI/RFI is in the 2nd harmonics the received signal is approximately -100 dBm. Received GNSS signal is approximately -135dBm, therefore the 788 MHz signal may interfere and disturb the received GNSS signal. The other GSM frequencies (900 MHz and 1800 MHz) will be received in higher power (approximately -38 dBm) in the GNSS receiver. But has no potential interference with the GNSS signals.

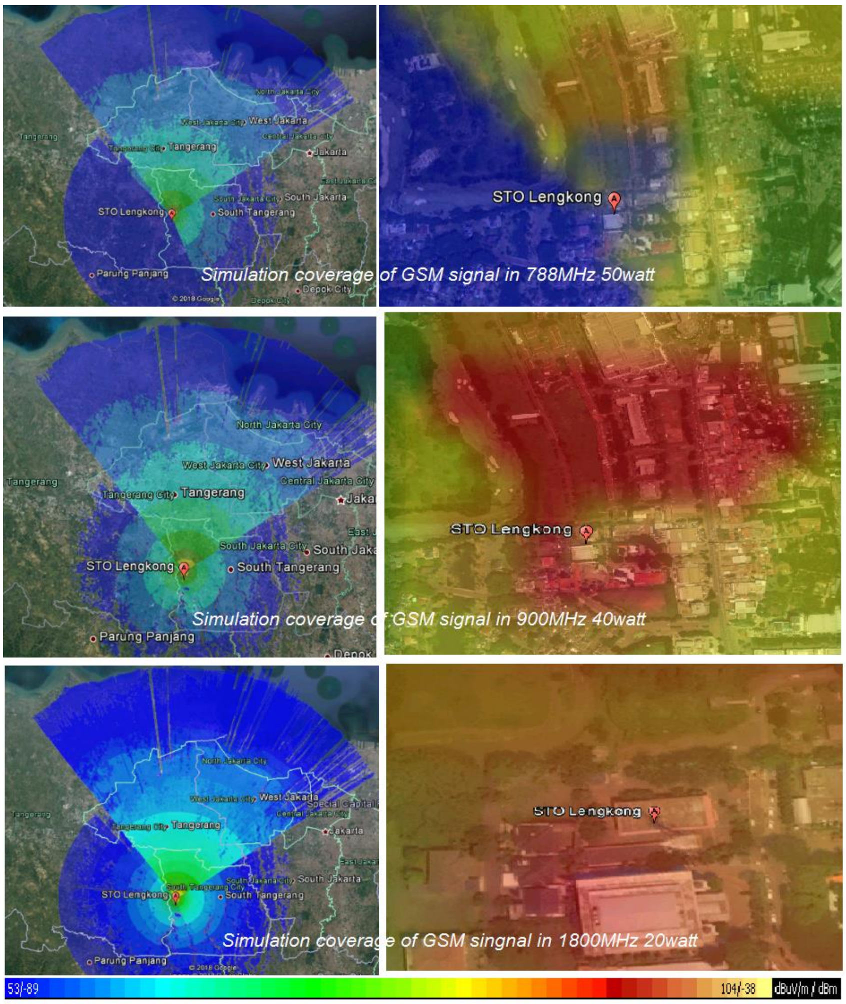

Figure 4. Simulation coverage of GSM signal in 788 MHz 50 watt, 900 MHz 40 watt and 1800 MHz 20 watt

3.3. Conduct Scanning of the Potential RF Emission Signals

After conducting a coverage simulation of the potential EMI/RFI sources, a scanning in the rooftop nearby CORS CTGR GNSS receiver is conducted to measure the real potential EMI/RFI sources in the surrounding of GNSS receiver. The scanning has been conducted for three days with a timeframe of 15 minutes. The scanning as shown in Figure 5 has strong signals in the frequency range between 450 MHz to 790 MHz and between 900 MHz to 1800 MHz. There is no inband interference signal for GPS L1 (1575.42MHz) and L2 (1227.60 MHz), but there are a potential EMI/RFI outband of GPS L1 in the 2nd and 3rd harmonics.The received power is approximately -35 dBm. Since in Indonesia there is no GSM700 type of signals and since the 2nd and 3rd harmonics EMI/RFI signals are wideband signals, may receive from TV transmitters in the surrounding area of CORS CTGR.

Eventhough there is no inband interference signal for GPS L1 (1575.42 MHz), but the 2nd (2*787.71MHz) and 3rd harmonics signal (3*525.14 MHz) may potentially disturb the GNSS receiver to receive GPS L1 signals. The 2ndharmonics of received signal at 615 MHz may potentially disturb the receiving of GPS L2 signals. Identification of the direction of arrival of the potential interference sources is shown in Figure 6. The potential interference frequencies are: in the range of 527.5 MHz (potential 3rd harmonics interference for GPS L1), in the range of 743.5MHz (potential 2nd harmonics interference for GPS L1) and in the range of 942.5 MHz in the southerly direction of GNSS receiver.

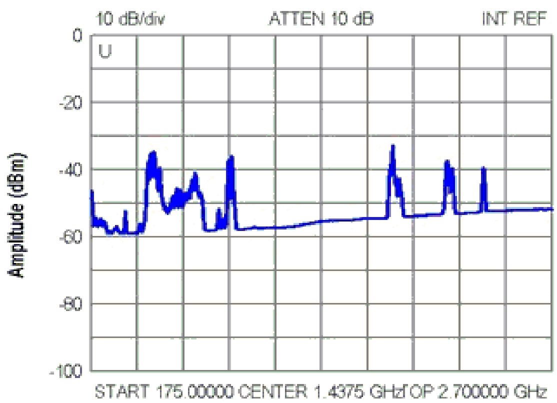

Figure 5. Scanning results of the potential EMI/RFI sources in the surrounding of CORS CTGR

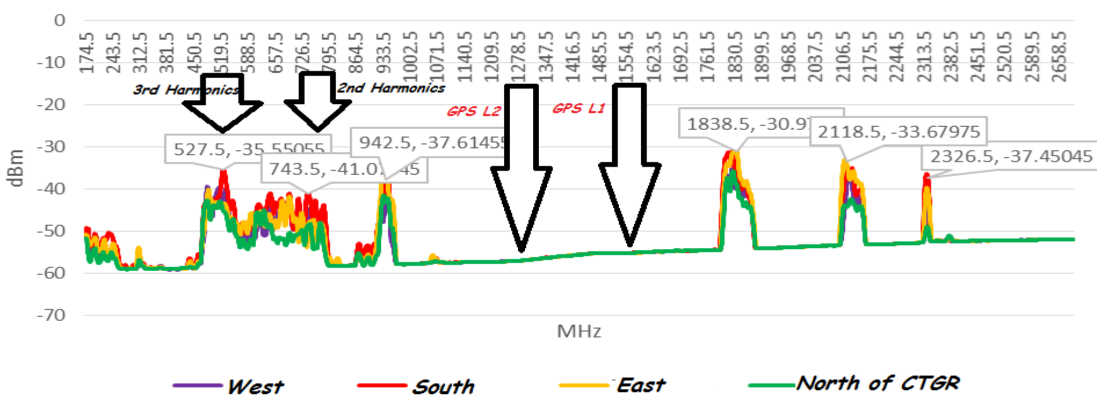

Figure 6. Potential Sources of EMI/RFI for GPS L1 received in the surrounding of CORS CTGR (no in band, 2nd and 3rd harmonics outband)

Table 4 shows the direction of EMI/RFI potential source in the surrounding area of CORS CTGR. The south and east direction of CORS CTGR has the highest average and maximum values. This direction shows the approximate direction of EMI/RFI sources.

Table 4. EMI/RFI Potential Source Direction in Horizontal and Vertical Polarization

EMI/RFI azimuth	Horizontal Polarisation			Vertical Polarisation		
	Minimum (dBm)	Average (dBm)	Maximum (dBm)	Minimum (dBm)	Average (dBm)	Maximu m (dBm)
North	-59.0891	-53.14775073	-34.0767	-59.2062	-54.28864091	-36.8617
South	-59.0107	-52.28181299	-28.7867	-59.0567	-52.66719525	-32.1074
West	-59.1554	-53.30808059	-34.1424	-59.1202	-53.28001596	-35.0596
East	-59.1316	-52.83834992	-31.2813	-59.1787	-52.69843489	-29.3692

3.4. Conduct Recording of GNSS Data and Analysis

After conducting a scanning in the rooftop nearby CORS CTGR GNSS receiver, a recording of GNSS data is conducted in three days from CORS CTGR and analyse with rtklib application. Potential Sources of EMI/RFI for GPS L1 received in the southern direction of CORS CTGR (no in band, 2nd and 3rd harmonics outband) in maximum values recorded from 30th of January 2018 till 2nd of February 2018. Figure 7 shows the location of CORS CTGR related to the GSM tower. The red dots are the scattered coordinates of GNSS receiver during the observation period. The GSM tower has an azimuth of approximately 210^0 relative to CORS CTGR, since there is no GSM700 in Indonesia then EMI/RFI from GSM tower is eliminated. Figure 8 shows the location of CORS CTGR related to the TV tower with a distance of approximately 15 Kilometers with heading of approximately 48 degrees. Eventhough there is no remarkable potential RFI sources in the surrounding of CORS CTGR but a longer observations is necessary to have a more accurate data analysis. As stated in [14] that the potential of RFI for GNSS varies between sites and may vary from 5 potential RFI with low power to more than 100 potential RFI. Therefore a thorough and longer observation time is important.

Figure 7. Eliminated source of EMI/RFI for GPS L1 in CORS CTGR from GSM tower

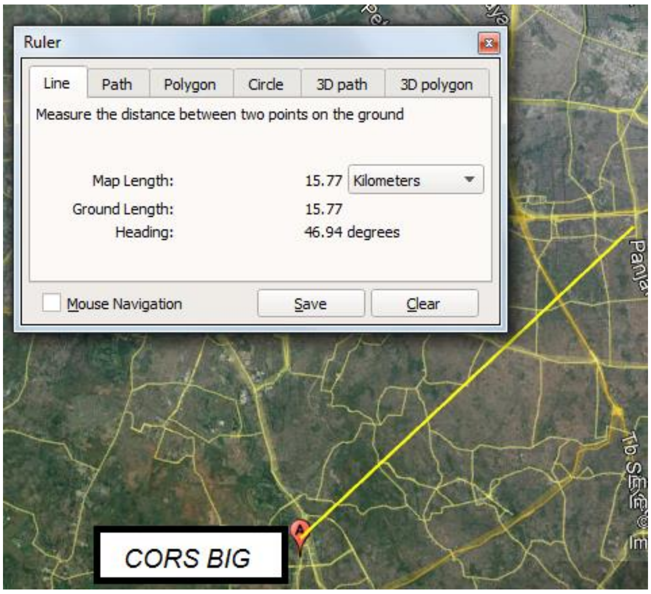

Figure 8. Potential source of EMI/RFI for GPS L1 in CORS CTGR from 3rd harmonics of TV Transmitters

4. Conclusion

In this paper a method for GNSS receiver site allocation planning is proposed, in order to reduce the potential RF interference to the GNSS receiver (CORS) from the surrounding areas. This proposed method will increase the integrity of received GNSS signals in CORS and at the same time will reduce the probability of removing CORS from a location with high RF interference sources to a location with low RF interference sources. Measurements following this proposed method has been performed in BIG CORS station CTGR and the result is analysed. The recorded signal spectrum in the location of CORS CTGR has not shown any potential inband EMI/RFI sources to GPS L1 or L2 signals as shown in Figure 7. The recorded GNSS data shows that there is no significant 2nd harmonics outband EMI/RFI impacts of the GSM tower nearby the CORS CTGR. This is mainly due to no GSM700 transmitted from the GSM tower. This assumption needs to be confirmed by the operator of GSM tower whether the GSM tower transmit any other signal in the frequency range of 650 MHz-800 MHz as shown in Figures 5 and 6. Furthermore, a further study is necessary to investigate the impact of 3rd harmonics outband EMI/RFI from TV transmitter in the surrounding area of CORS CTGR since the high gain transmitted power of the TV transmitters in the frequency range of 500 MHz-600 MHz. The method for 'Planning of GNSS receiver site location' reduces the impact of EMI/RFI from the surrounding alternative CORS site location and therefore will mitigate the potential RFI at GNSS frequency spectrum. This proposed method may be used as additional guidelines for site allocation of CORS is necessary to compliment the standard in [15]. A similar method may be used to identify potential source of unintentional interference of GNSS receivers in a critical application of GNSS (use of GNSS within safety, security, governmental and regulated applications) such air-land-sea navigation. STRIKE3 (Standardizsation of GNSS Threat reporting and Receiver testing through International Knowledge Exchange, Experimentation and Exploitation) project is a European initiative that specifically developed to address GNSS interference treats [16-19]. In addition, the calculation to detect GNSS interference by both stand alone sensor or by network of sensors, and also algorithm to calculate the interference between the GNSS is discussed in [20-25].

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