UWB COEXISTENCE WITH GPS AND AGGREGATE UWB NOISE RISE IN THE SELECTED RADIO BANDS

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ABSTRACT

This paper presents results of coexistence measurement studies between multiple ultra wideband (UWB) transmitters and a global positioning system (GPS). In addition, mathematical models for UWB aggregate noise rise in the GPS, universal mobile telecommunications system (UMTS) and wireless local area network (WLAN) 802.11a/g bands are illustrated. In GPS coexistence measurements, a realistic satellite constellation and outward circumstances were created using a commercial GPS simulator and receiver. Each measurement was carried out using Federal Communications Commission (FCC) compatible prototype singleband UWB transmitters. The measurements took place in an anechoic chamber to minimize any radio interference. The results clearly show that GPS can survive even under a large number of interfering UWB devices which are operating using realistic transmission parameters. Still, if a large number of interfering UWB devices or high UWB activity factor and pulse repetition frequency is used UWB can be regarded as a threat to GPS usage.

INTRODUCTION

UWB requires access to very wide spectrum that is typically occupied also by some other radio transmission. Hence, the spectrum overlapping with those existing systems is often unavoidable. UWB interference can degrade the performance of the victim system, and therefore coexistence plays important role in wireless UWB communications. The broadband nature of the UWB transmission yields to excellent multipath immunity [1]. Thus, UWB technology has potential in a variety of applications including communication and ranging, and it is expected to increase in military, civil and commercial use in the near future.

Coexistence studies between GPS and UWB are usually based on simulations, like partly in [2] and completely in [3]-[4]. In [2], the impact of UWB pulse length and modulation on GPS inband interference are shown. In [3], a framework for UWB and GPS coexistence simulator is given. In addition in [3], impact of UWB interference on GPS acquisition is studied. In [4], methods to reduce UWB interference power in the GPS band are presented. Those includes, e.g., system architecture, power control and selection of UWB activity factor. Impulse jamming against GPS receiver is presented in [5]. The results show that the impact of UWB jamming on GPS positioning accuracy is proportional to the used duty cycle. In addition, it was found that the influence of the pulse repetition frequency is less distinct. Still, real coexistence measurement results are hard to find from literature.

In this study, even though the coexistence measurements between GPS and UWB were carried out using a GPS hardware simulator, results can be compared to a real life because of realistic measurement setup and devices.

Though UWB coexistence with different radio systems is widely studied, an aggregate noise rise in these frequency bands is not commonly covered. In [6], noise rise is defined to be an increase of UMTS power level that ensures the determined bit error ratio (BER) while the amount of UWB interference is changed. Whereas in this study, an aggregate UWB noise rise is the difference between inband powers in interfered and reference measurements. In [7], UWB interference models for WLAN 802.11a, GPS and cellular systems that are based on code division multiple access (CDMA) are presented. The impact of UWB aggregate effect on the victim system is discussed by analytical modelling and simulations in [8].

This paper is organized as follows: The first Chapter introduces UWB hardware that consists of a control board, a pulse generator and an antenna. These are followed by GPS devices, i.e., a GPS simulator and a receiver. In the Measurement setups Chapter, the GPS measurements and aggregate UWB noise rise setups are introduced. Results are presented in the same order as the measurement setups. In Conclusions, the results are summarized.

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MEASUREMENT DEVICES

The prototype singleband UWB devices consist of a power unit, a pulse generator, a control board and an antenna. The power unit is a typical personal computer power unit, and it ensures power for two control boards and four pulse generators. The control board, the pulse generator, and the antenna are introduced more specific in own paragraphs. The prototype singleband UWB system is shown in Figure 1. The devices are made by PJ Microwave, Oulu, Finland.[1]

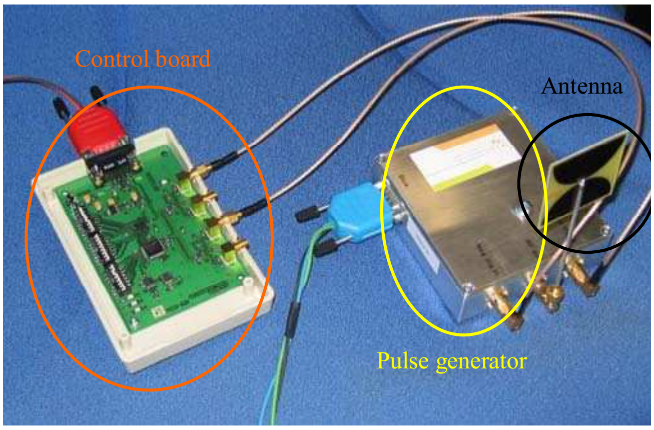

Figure 1. Prototype singleband UWB control board, pulse generator and antenna.

Control board

The control board creates a triggering signal, which is series of pulses for the pulse generator, and is based on m-sequence. That sequence is sampled with the chip clock of the control board, and it is divided into positive and negative pulse triggering parts, i.e., bits "1" and bits "0", respectively. These square-wave triggering signals are sent to the pulse generator. The use of m-sequence causes direct sequence (DS) spectrum scrambling approach. Different alterable parameters are length of the m-sequence, pulse repetition frequency (PRF), duty length (DL) and activity factor (AF).

When the positive and negative triggering signals are created, PRF defines how fast the pulses are emitted. With these UWB devices, PRF can be set either to 100 MHz or to 200 MHz. The transmission is divided continuously into the time frames, and the duty length can be set to 10 µs, 100 µs or 1000 µs. Using the different AF values, the active period of the UWB transmission within one frame can be set. AF is defined as

$$AF = (t_1 - t_0)/(t_2 - t_0) = \Delta h / \Delta t \, , \tag{1}$$

where t_0, t_1, t_2, Δh and Δt are starting time of the UWB frame, ending time of the active transmission period, ending time of the UWB frame, duty length and duration of one active period, respectively. In Figure 2, burst like UWB transmission and the parameters needed to calculate AF are illustrated.

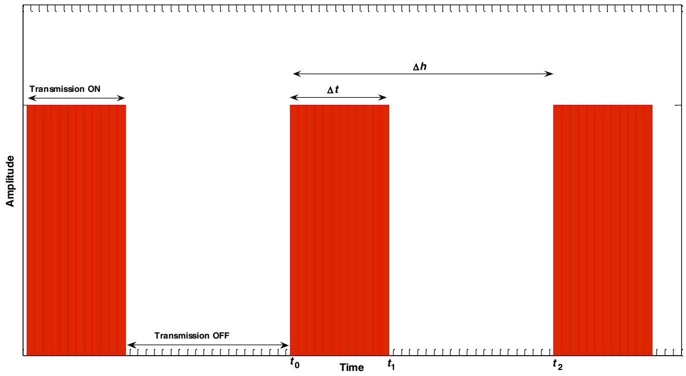

Figure 2. Burst like UWB transmission and parameters to calculate AF.

Pulse generator

The pulse generator creates a positive or a negative monocycle depending on the polarity of a triggering pulse that is coming from the control board. One monocycle is merged from two Gaussian pulses having different polarities. Thus the transmission follows the ideas of binary pulse amplitude modulation (BPAM) and binary phase shift keying (BPSK). A positive Gaussian pulse is generated at every raising edge of the positive triggering signal, whereas a negative Gaussian pulse is created at every falling edge of the negative triggering signal. In that way, the charge times of the capacitors used in the pulse generator stay as constant as possible.

Even though the UWB devices are using the same parameters, the lack of common clock at the control boards causes asynchronous transmission. Thus, the active periods of the devices are likely to be in different time instants.

Antenna

Antennas used in the experiments were bowtie antennas that were designed and build by PJ Microwave[1]. In Figure 3, the conducted and radiated spectra for one UWB device using PRF = 200 MHz, AF = 100% and DL 1 ms are depicted. In addition, noise floor and FCC limits for indoor and outdoor UWB devices [9] are presented. As can be

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[1] Currently Elektrobit Microwave, Oulu, Finland http://www.elektrobit.com/static/en/index.html

seen, the radiated UWB spectrum fulfils the FCC's radiation requirements from [9].

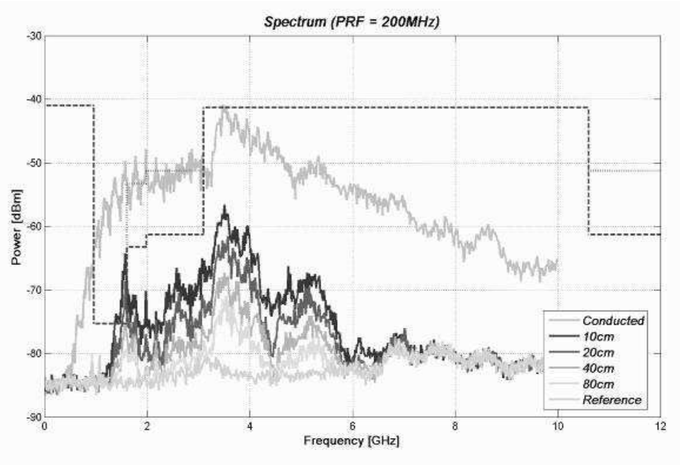

Figure 3. Spectra of the prototype UWB device.

Devices used in the GPS measurements

All GPS coexistence measurements were carried out using Spirent Communication's STR4760 Series GPS simulator [10], interference combiner and Fastrax Inc iTrax02 Receiver [11].

The STR4760 simulator is creating a realistic satellite constellation that is fully comparable with a real life situation with user-specified time and place. In addition, STR4760 can model constellations for receiver's motion patterns with six degrees of freedom and different kind of weather conditions. After the user has specified dominant conditions, the simulator took into account effects, such as, satellite errors, atmospheric signal degradation and Doppler shift. [10]

The simulator is using GPS L1 band with a centre frequency of 1575.42 MHz. L1 band is used to transmit the navigation message, coarse-acquisition code and unencrypted precision code. In addition, up to 16 simultaneously online signal channels, i.e., different satellites were supported. Power of the individual channel can be set from -166 dBm to -110 dBm with 0.1 dB resolution. [10] The GPS signal is radiated using a conical log spiral transmitter antenna ETS-Lindgren 3102 [12].

The GPS receiver iTrax02 is based on two-chip GPS solution, uN8031 baseband chip and uN8021 RF chip [11]. The GPS receiver is equipped with a commercial SM-66 antenna, which is an active GPS antenna having typically absolute gain (zenith) of +5 dBi and +30 dB low noise amplifier [13]. The overall gain of the device is 27 dB. Mini-Circuits bias-tee ZFBT-6G+ is providing DC-component for the receiver antenna's low noise amplifier [14].

MEASUREMENT SETUPS

GPS setup

UWB coexistence measurements with GPS were carried out in co-operation with the Finnish Defence Force's Technical Research Centre[2] at Riihimäki. Different kind of measurement setups were applied, however, the same GPS simulator and receiver were used in all configurations.

The measurements were carried out in an anechoic chamber and the distances between the GPS receiver and the UWB interference sources were fixed. The positioning error is calculated by comparing the GPS receiver's positioning information to the simulator's positioning information. The positioning error reported is averaged over 120 individual measurement points.

In Figure 4, the coexistence measurement setup between UWB and GPS is illustrated. Measurements were carried out in two phases. Both stationary and in motion simulation setups were used. Measurements with a stationary receiver made use of an external GPS transmitter antenna, whereas in motion measurements were carried out using a power combiner to sum GPS signal and UWB interference.

During the measurements, the GPS receiver was accommodated at the latitude and longitude coordinates of Riihimäki, Finland (lat/lon 60.75°/24.78°). In addition, the simulator was set to use May 1, 2003 0:00 o'clock as a starting time. Each measurement was started at the same fictitious time, and the simulator calculates the received power individually from each satellite based on a real satellite constellation. Thus, the GPS receiver could not communicate with every possible satellite.

At the stationary measurements, totally seven GPS satellite were used for navigation. Their received power varied from -95.6 dBm to -94.0 dBm, having an average of -94.817 dBm. In motion measurements, the receiver flew around the circle that had a central point above Riihimäki, and a diameter of 100 meters. Simulations were carried out using 70 km/h velocity. Again, seven GPS satellites were exploited, and their received power varied from -113.7 dBm to -112.1 dBm, having an average of -113.0 dBm.

[2] http://www.mil.fi/laitokset/pvtt/index_en.dsp

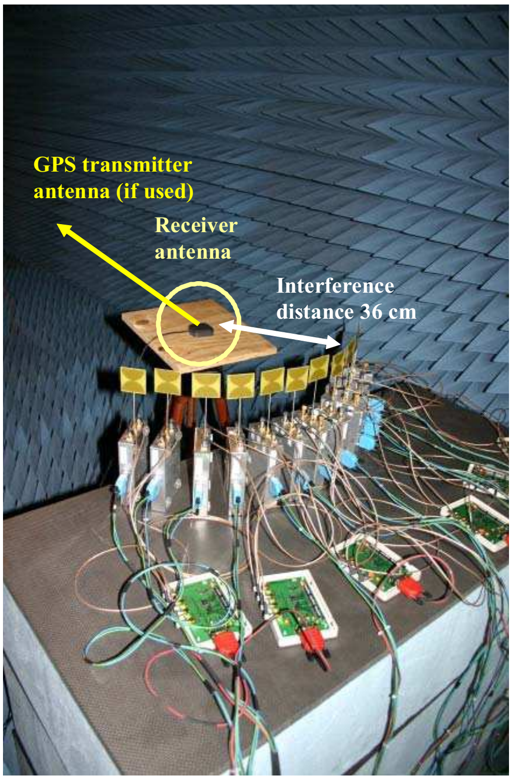

Figure 4. GPS measurement setup.

Aggregate noise rise setup

Aggregate noise measurements were carried out in an anechoic chamber at the University of Oulu. Measurement hardware was composed of Agilent PSA series spectrum analyzer and CWC's[3] prototype singleband UWB interference sources. The PSA was connected to a wideband antenna (CMA-118/A by Antenna Research [15]) via coaxial cable. In Figure 5, the aggregate noise rise measurement setup is presented.

An aggregate noise rise was measured using 1 to 12 UWB devices with interference distances of 15, 36, 50 and 60 cm. UWB devices were set to use AF = 100% and whichever PRF value 100 or 200 MHz. In addition, reference data were collected when UWB devices were completely disabled. The measurements were repeated 100 times to improve the statistical reliability.

PSA was set to span one gigahertz bandwidth using 1, 2 or 5 GHz as a starting frequency. At the measurements, the resolution bandwidth and sweep time were fixed to 100 kHz and 0.12 s, respectively.

[3] http://www.cwc.oulu.fi/home/

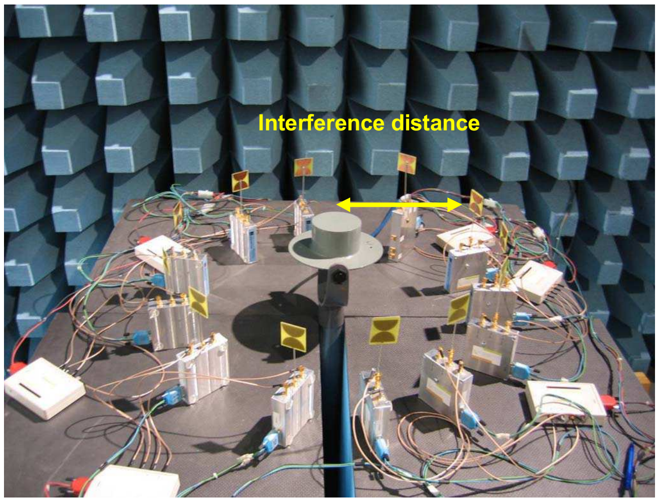

Figure 5. Aggregate noise measurement setup.

During the aggregate noise rise calculations, a formula for free space attenuation is needed to widen the results also for arbitrary distances. The free space attenuation is [16]

$$PL_{\mathrm{free}} = 10\log_{10}\left(\frac{4\pi d}{\lambda}\right)^2, \qquad (2)$$

where d and λ are desired distance and wavelength of the selected band's centre frequency, respectively.

RESULTS

GPS results

In Figure 6, the average GPS positioning errors for stationary receiver are presented. These measurements were carried out with continuous UWB interference, i.e., the interference was present also when the receiver was in an acquisition phase. As seen from Figure 6, either PRF of 100 or 200 MHz is used, interference from 12 UWB devices cannot decrease the GPS position accuracy if AF is less than 10%.

When focusing on the case of PRF = 100 MHz, one can see from Figure 6 that AF = 25%, 50% and 100% cause acquisition failure when 10, 5 and 2 UWB devices were simultaneously active, respectively. In addition, one should notice that four UWB devices using PRF = 100 MHz and AF = 50% inflicts the positioning error to rise near 20 meter. One interesting point is also that when using a low number of UWB devices, the difference to achieve a successful or a failure acquisition between the cases PRF = 100 MHz and 200 MHz is remarkable small, only one interfering UWB device.

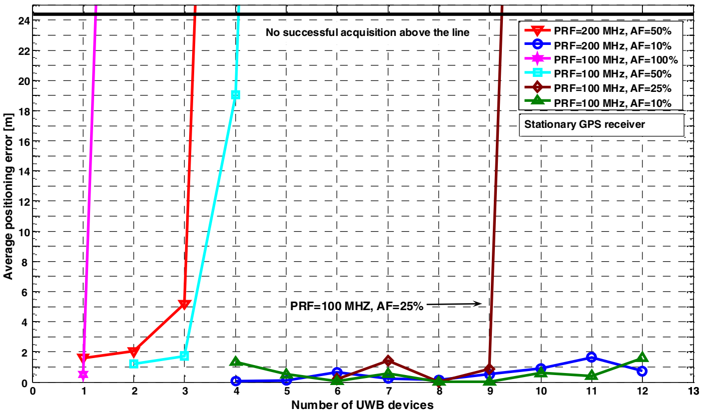

Figure 6. Stationary GPS receiver with continuous UWB interference.

Results from the measurements where the receiver was in motion and PRF was set to 100 or 200 MHz are presented in Figure 7 and Figure 8, respectively. In the figures, black and grey circles illustrate percentually for how long time the positioning information had not been available during the measurement. Thus, if data point is marked with a black or a grey circle, the receiver did not update its coordinates for 5-10% or over 10% of time when UWB interference was present, respectively. If data point is not marked with any kind of circle, the receiver updated its positioning information more than 95% of the measurement time. In addition, the measured UWB power in the 2 MHz band at GPS L1 centre frequency is depicted with dashed lines using the right y-axis of the figures.

12 interfering UWB devices can be simultaneously active with both PRFs if AF = 10%, and still the positioning error is less than three meters if compared to the reference measurements. Thus, the positioning error is less than required in GPS performance standard [17], i.e., 13 and 22 meters in horizontal and vertical directions, respectively. In these interfered cases, the inband UWB power is from -87.5 to -82 dBm. If AF is increased to 25%, and either PRF = 100 or 200 MHz is used, the interfering UWB power in the GPS band is from -84 to -79.5 dBm when the latest positioning information was available, respectively. One should notice that in these measurements, 5-10% or more than 10% of time there were no positioning data available. This is depicted with grey and black circles in Figure 7 and Figure 8, respectively. Thus, the positioning information was badly corrupted.

If comparing successful measurements presented in Figure 7 and Figure 8, it can be seen that the maximum GPS inband interference, when GPS was still capable to navigate, is achieved with low number of UWB devices (less than five) and high AF. Thus, with continuous UWB transmission, i.e., AF = 100% and PRF = 100 MHz or 200 MHz, the inband power is -81 or -82 dBm, respectively. On the other hand, if more than five UWB devices with lower AF's is used, the inband interference power limits for successful positioning are -84 and -81 dBm for PRF = 100 MHz and 200 MHz, respectively. One should notice that these limits were measured with nine interfering UWB devices using PRF = 100 MHz or eight devices using PRF = 200 MHz.

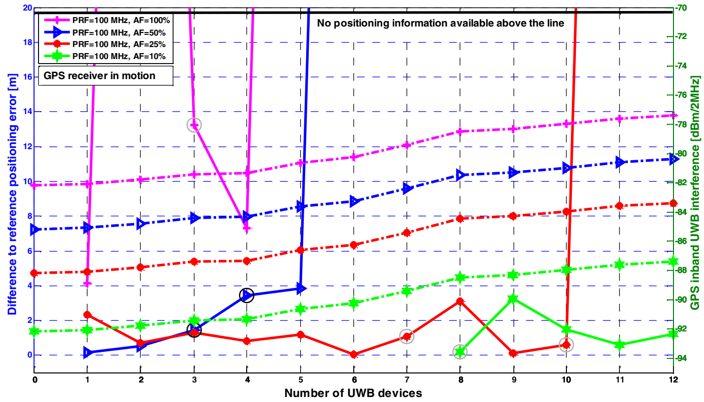

Figure 7. Difference to the reference positioning error, PRF = 100 MHz.

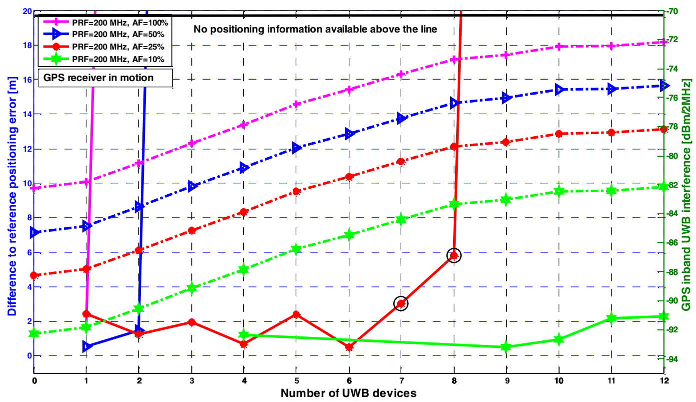

Figure 8. Difference to the reference positioning error, PRF = 200 MHz.

Aggregate results

In Figure 9-10, the aggregate UWB noise rises are presented for selected radio bands: GPS, UMTS, IEEE802.11a and IEEE802.11g. Fixed 15 cm measurement distance and PRF values 100 and 200 MHz were used, respectively. In addition, fitting curves using two interpolation coefficients and their formulas are depicted. These formulas are later called as aggregate noise formulas. Coefficients were interpolated from the absolute values of the UWB inband interference powers.

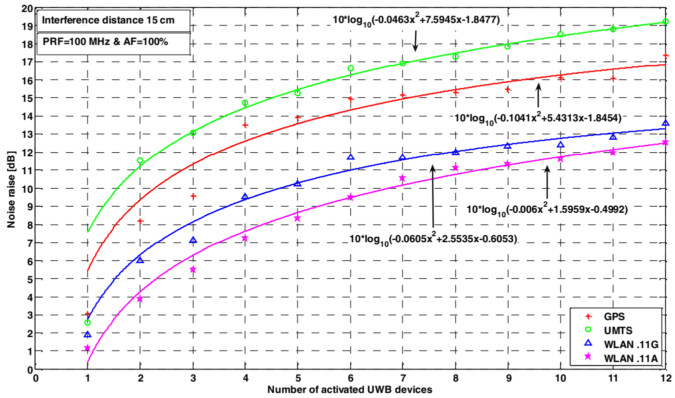

Figure 9. Aggregate noise raise as a function of the number of active UWB devices. PRF = 100 MHz and interference distance 15 cm.

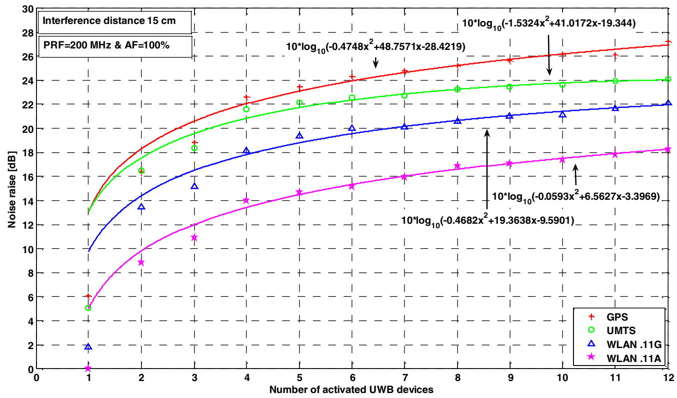

Figure 10. Aggregate noise raise as a function of the number of active UWB devices. PRF = 200 MHz and interference distance 15 cm.

For the interpolated results between 15, 36, 50 and 60 cm interference distances, the factors were calculated using (2). Thus, the total aggregate noise raise can be calculated by summing the free space attenuation to the aggregate noise formulas and factors, which are presented in Tables 1 and 2.

The factors for the free space attenuation depend strongly on the number of the interfering UWB devices. Thus the factors are calculated using 1 to 6 or 7 to 12 interfering UWB devices. These factors are presented in Tables 1 and 2, respectively. In addition, standard deviations σ were calculated and presented in the tables. One should notice that if 1 to 6 interfering UWB devices were used, the factors form linear regression formulas, where *x* illustrates the exact number of active UWB devices. On the contrary, if more than six UWB devices were used, the factors become constants. In the tables, the factors are given in decibels.

Table 1. Factors if 1 to 6 UWB devices are used.

	Selected radio band			
PRF [MHz]	GPS	UMTS	802.11g	802.11a
100 (σ)	1.1x-26.7 (-74.8dB)	1.2x-29.1 (-68.4dB)	0.9x-30.6 (-82.7dB)	0.8x-37.8 (-103.5dB)
200 (σ)	2.5x-25.7 (-53.1dB)	2.1x-28.8 (-61.4dB)	2.4x-29.9 (-60.0dB)	1.9x-38.2 (-85.2dB)

Table 2. Factors if 7 to 12 UWB devices are used.

	Selected radio band			
PRF [MHz]	GPS	UMTS	802.11g	802.11a
100 (σ)	-20.9 (-54.3dB)	-22.8 (-62.5dB)	-25.3 (-62.6dB)	-33.0 (-79.7dB)
200 (σ)	-14.1 (-38.7dB)	-19.3 (-54.7dB)	-18.8 (-48.9dB)	-29.1 (-71.1dB)

Because the factors are constituted based on four measurements using different interference distances, the factors cannot be taken very reliable in statistical means. Hence, the future work will continue the measurements to verify and specify the UWB aggregate noise rise formulas in the frequency bands of interests.

CONCLUSIONS

The measurement results presented in this paper show that GPS can survive and maintain its position accuracy under realistic UWB interference. The measured results discussed here include cases where high number of interfering UWB devices was not able to degrade position accuracy below GPS standard positioning service performance standard. For example, if 12 UWB devices were using parameters AF = 10% and PRF = 200 MHz, the positioning accuracy was better than 13 and 22 meters in horizontal and vertical directions, respectively. On the other hand, if UWB interference power in the GPS band exceeded -84 dBm@2 MHz, GPS receiver was not be able to update its positioning information any further.

This paper presents also the preliminary factors that can be summed to the free space attenuation and to measured aggregate UWB noise rise formulas to predict UWB noise rise in the selected radio bands with arbitrary number of interfering UWB devices.

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