MULTIPATH EFFECT MITIGATION IN SIGNAL PROPAGATION THROUGH AN INDOOR ENVIRONMENT

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ABSTRACT
Highly accurate positioning of an object is a target that requires measurements performed with devices (mainly Global Navigation Satellite System receivers) able to provide a satellite connection towards minimum four satellites. However, GNSS receivers face low accuracy in areas where the satellite signals are obstructed or even non-existent. In order to obtain location estimate in an Indoor environment, a series of Indoor Positioning Systems based on WLAN technology and pseudolites have been developed. Signal propagation in an Indoor environment is affected by several factors, among them the multipath effect, cause by reflective surfaces around the receiver. This paper aims at analyzing different methods for mitigating the multipath interference on signal propagation.

Keywords: GNSS, Pseudolites, WLAN Positioning Systems, Indoor environments, reflection, refraction

INTRODUCTION
For being a Line-of-Sight (LOS) system, a Global Navigation Satellite System is not suitable for navigation in environments where the satellite signals are obstructed, due to the fact that in order to calculate the precise position of an object, the positioning system must be equipped with a device which ensures a satellite link. Or, it is known the fact that in Indoor areas, the satellite signals are blocked and even the most expensive GNSS receivers will not function properly in order to provide high accuracy. In urbanised Indoor environments and beyond, the Line-of-Sight condition towards minimum four satellites can not be accomplished by a GNSS receiver. Satellites are able to sense visible light, infrared radiation and other electromagnetic radiation, therefore the transmitted signals are in the visible spectrum, which means that they will penetrate through clouds, glass, plastic, but they will be easily obstructed by most solid objects such as walls, buildings, mountains, trees etc.

Whereas GNSS works well in many Outdoor scenarios, it suffers from obstacles such as skyscrapers creating shielded street canyons (or urban canyons) or walls blocking the radio signal. Furthermore, Indoor environments causes a series of problems to the propagation of GNSS signals, such as the multipath effect, interference, attenuation, near-far effect, no-line-of-sight (NLOS), Indoor path loss. The same errors occur when deploying a WLAN Positioning System in an Indoor environment, the WLAN signal propagation being highly attenuated in the presence of surrounding objects.

Multipath (or signal reflections) is the effect of transmitted signals who arrive at the receiver’s antenna on different paths in addition to the direct signal, when they encounter a reflective or a separation surface between two environments.

Multipath signals are delayed with respect to the direct signal and the amplitude, phase and polarisation, and it is characterised by the reflective surface and the number of reflections [1].

(Fig. 1) shows a phasor diagram describing the carrier tracking loop operation and demonstrating a relationship between in-phase (I) and quadrature (Q), with the direct ($A_d$) and reflected signal ($A_m$), together with their combined signal ($A_c$) [2].
MATERIALS AND METHODS

1. Multipath effect

The signal propagation, whether transmitted by a WLAN Access Point or by GNSS satellites, is highly affected by the multipath interference to the extent that multipath signals can interfere destructively with the direct signal, which will be faded. The multipath problem severity varies with the environment where the measurements are taken. Therefore, an Indoor environment causes more reflections and diffractions on the signal propagation due to the fact that there is a wide range of reflective objects, such as reinforced concrete, metallic structures, furniture etc. The multipath propagation refers to signal reflection on flat, reflective surfaces close to the MD’s antenna. The radio signal travels over a distance and is either reflected by a nearby surface, arriving at the MD’s antenna by two or more paths in addition to the direct signal, or is absorbed by surrounding objects such as walls and floors, as seen in (fig. 2).

Fig.1. Phasor diagram

The location estimate is influenced by the localization scenario and the radio propagation in Indoor environments would also suffer from multipath fading. The Radio Frequency based
positioning systems performances depend mostly on the electromagnetic characteristics of the environment which can suddenly change due to the some factors existing in the Indoor environment. Thus, the presence of walls and other structures, persons, furniture, open/closed doors will obstruct the direct path of radio signals, producing a decrease in accuracy of estimated location in Indoor environments.

However, the performance from the accuracy point of view is not acceptable for several Indoor location based applications. Phenomena like multipath interference, reflections and refractions can provide different amplitudes and phases on the end receiver. The combination of these replicas of the transmitted signal can be either constructive either destructive through the generation of a random and sudden fluctuation of the received power strength [3].

2. Experiments and discussion

After an analysis of WLAN signal propagation on several Test Points (TP4, TP11) in the experimental test bed, it was concluded that, although the RSSIs have a constant behaviour in time with only ±5 [dBm] variations, the propagation is still affected by the multipath effect, as seen in (fig. 3), (fig. 4). An offset of +10 [dBm] and more is produced by the reflection and refraction from surrounding objects.

Satellite signals propagation inside a building is 20÷30 [dB] weaker than in Outdoor environments. The range between the receiver and the GNSS satellite is dependent on the propagation time needed by the signal to reach the receiver. The receiver’s time scale is not synchronised with the GNSS satellites time scale, due to high implementation costs of atomic clocks in GNSS satellites, which is not feasible for a regular receiver. The distance measured to at least four satellites is obtained by means of multiplying the signal propagation time by the speed of light in order to get 3D position estimation, and it is called pseudorange due to errors that appear in the time measured. Errors in pseudorange measurements of tens of meters results from the multipath effect.
In (fig. 5) a spectrum analyzer of signal propagation transmitted by the pseudolites from an Integrated Pseudolites/GNSS System is presented, with visible multipath signals.

1. Multipath Mitigation methods

There are several approaches to mitigate the multipath propagation such as antenna based methods and signal processing methods.

3.1. Antenna based methods

Sensitivity to RHCP and Axial Ratio: When reflected, the transmitted GNSS signal changes its polarisation into left-hand, unlike a direct signal. The GNSS antenna is designed to have high sensitivity to the right-hand circular polarised signals (RHCP – co-polar signals) and low signals for the left-hand polarised signal (LHCP – cross-polar signals) [4]. A RHCP antenna is small in size,
does not need extra signal processing hardware in the receiver, and suppresses the LHCP signals partially, therefore it is not able to mitigate effectively multiple reflected signals. The quality of a Circular Polarised antenna is measured by the ratio of co-polar to cross-polar components recorded by the antenna, identified by means of the Axial Ratio (AR) parameter. A good performance antenna should have an AR parameter close to 1dB in broadside, increasing with decreases in elevation angles, while a high performance antenna should have an AR parameter ranging between 3 to 6 dB with an elevation angle of 10 degrees.

Choke ring ground plane antenna: The choke ring ground plane antenna is used to mitigate the low elevation angle reflected signals in the antenna by reducing its gain at low elevation angles and creating a high-impedance surface which prevents propagation of surface waves near the antenna. This method is effective in mitigating low elevation reflected signals, by reducing code and carrier phase multipath errors[5]. The use of a choke ring ground plane antenna has limitations concerning big size and weight, and in dynamic applications where the altitude of the antenna is not fixed causes the elimination of low elevation direct signal when the ground plan is not horizontal.

Antenna array: A directional antenna consists of a series of antenna elements combined in an array, in order to be able to have gain in one direction and loss in another direction. An antenna array can distinguish between the multipath signals and the direct one by adding spatial dimension. The combination of applied relative amplitude and phase shift on each antenna elements is referred to as the complex weight [6]. The correct weight is applied to each element of antenna array by means of signal processing techniques. A directional antenna is big in size and needs additional signal processing techniques. However, it provides a good control of the antenna pattern and ensures the mitigation of multipath signals.

3.2. Signal processing methods

Narrow early-late correlator: The Narrow early-late correlator method is effective for long delay secondary path and it is not able to track the signal in low Signal to Noise Ratio situations. A chip difference smaller than 1 (usually 0.1) is used in the code discriminator between the early and the late code. The relative delay of the secondary path must be of at least 300 meters (one chip) for the C/A code. The phase multipath error is similar to the wide correlator due to the fact that it depends on the shape of the signal autocorrelation function which is the same for both wide and narrow correlators.

Double delta correlator family: Within this method two correlator pairs are used in the code discriminator function and includes several code multipath error mitigation techniques, such as the High Resolution Correlator (HRC) and the Early/Late Slope technique. The Double delta correlator family method can mitigate medium delay multipath effect on carrier phase measurements, showing a better performance than the Narrow early-late correlator. This technique does not perform well on short (less than 30 meters) and long delay multipath signals.

Maximum Likelihood based mitigation method: The parameters of the direct signal are determined together with the multipath signals that minimise the mean square error between the received signal and the estimated signal. Even though the computational burden and algorithm implementation costs are high, the Maximum Likelihood estimation is the most efficient method to mitigate the multipath effect, the code and carrier multipath errors being greatly reduced [7].

CONCLUSIONS

When implementing a Pseudolite/GNSS integrated system for location estimate, the Indoor environment is notorious for multipath propagation and noise. In GNSS receivers the signal arrives at a very low or even a negative elevation angle becoming subject to signal fading. They manifest as severe signal power fluctuations, and lead to signal loss. The problem can be solved by using
spatial separation of the antennas and by using pulsed signal and double frequency to overcome any environment generated noise.

The multipath signals are delayed in relation to the direct signal due to the fact that the amplitude, carrier phase and polarization are different, featured by the reflective surface and the number of reflected signals, hence the reflected signal will always be longer than the direct signal. Short delay multipath usually has a greater impact on pseudoranges than long delay multipath, hence its effects are difficult to mitigate due to the fact that reflective objects from close proximity of the antenna corrupts the correlation function peak. If the delay is large enough, the receiver is able to mitigate the multipath effect due to the fact that it does not affect autocorrelation function peak, hence the positioning algorithm is able to track the correlation between the reflected signal and the direct signal.

However, Indoor environments are considered to be the most suitable areas where multipath signals are actually useful for a GNSS receiver or a WNIC, since there is little or no direct GNSS or WLAN signal strength inside buildings. Whereas the variety of signals resulting from the direct signal taking different paths over a range of angles enhances the possibility of the signal to be received by the antenna, the multipath propagation is used in order to increase the capacity of the channel the signal is transmitting in (e.g. Multiple-Input and Multiple-Output (MIMO) technology).

REFERENCES