The influence of different LocataNet configurations on positioning accuracy

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Abstract

GNSS has limitations or cannot be applied in specific environments with poor geometry like city streets, tunnels, bridges, quarries, mines, ports or in indoor environment in general. In 2003 Locata Corporation from Australia began with the development of a new, completely independent technology called Locata, which was designed to overcome the limitations of GNSS. It can be combined with GNSS, or can be used as an independent measuring system, where the GNSS limitations are the biggest. Within the project "Wearable outdoor augmented reality system for enrichment of touristic content" for the first time one Locata system was implemented in Croatia. Established LocataNet consists of six LocataLites and two Locata receivers. Before establishing LocataNet it was necessary to simulate different network configurations to get insight into geometry influence on positioning accuracy, i.e. the dilution of precision (DOP) values inside LocataNet. The most demanding task was to achieve reasonable VDOP values (i.e. to get largest possible area with VDOP values below 3). In the simplest way, we could have made configuration of all LocataLites set on the ground and with approximately same height which would lead up to high VDOP values inside LocataNet. Because of that, we decided to do optimal configuration with rectangular shape 100 meters long and 50 meters wide with two LocataLites in the middle of longer rectangular lines set up higher than the others (12 meters above ground, compared to others that are set to 4 meters above ground). This LocataNet was established in the field with permanent installation of antennas on stable concrete-steel pillars. In this paper, the basic theory behind calculating DOP values will be given as well as results of simulating different LocataNet configurations and comparisons of simulation results with gathered data in the field.

Key words: Locata, LocataNet, simulation, DOP

1 INTRODUCTION

Although the Global Navigation Satellite System (GNSS) is widely used in many areas of positioning and navigation, it is well known that this technology, in unfavourable observing environments, has its limitations or cannot be applied (indoors or underground). To overcome these limitations many researchers complemented GNSS with other, mainly terrestrial technologies. One of the solutions was the application of pseudolites (pseudo-satellites), ground-based generators and transmitters of GPS-like signals, for use in the local area (e.g. Wang, J. 2002, Novaković, G. et al. 2009, Novaković, G. et al. 2015). However, the technology based on pseudolites has also its limitations. Extensive research and testing has concluded that pseudolites have fundamental technical problems that are very difficult to overcome in the real world: e. g. controlling transmission power levels, near/far problems, configuring special antennas, designing the “field of operations” such that GNSS and pseudolites can work together (Rizos, C. et al. 2011, Rizos, C. 2013) and the basic problem - time synchronization. Also, one of the biggest problem of pseudolites is that they are restricted by law in many countries, due to transmitting on restricted GPS frequency. In 2003 Locata Corporation (Canberra, Australia) began with the development of a new terrestrial radio frequency (RF)-based positioning technology, known as Locata, which was designed to overcome the limitations of GNSS and other pseudolite-based positioning systems. Locata positioning system is designed to enhance GNSS with additional positioning signals, but also can work completely independent where tracking of GNSS signals is not possible. Quality of Locata positioning solution is highly depended on Locata network configuration, hence when forming a new Locata network, it is very important to get insight how network geometry influences final solutions. Dilution of precision (DOP) values are used as indicator of how geometry of network influence on final positioning solution. Least square solution of Locata measurement model are coordinates and receiver’s clock error together with corresponding covariance matrix, which contains information about DOP values.

This paper present theory behind calculating different DOP values in Locata network and results of DOP values in different simulated network configurations. Also, comparison of simulation results with Locata positioning solutions in established Locata network is shown.

2 LOCATA POSITIONING TECHNOLOGY

In 2003 Locata Corporation began with the development of new terrestrial radio frequency based positioning technology called *Locata*. It consists of time-synchronized transceivers called *LocataLites*. Four or more LocataLite transceivers forms *LocataNet* which transmits signals that allow carrier-phase point positioning of mobile rovers. Main invention of Locata positioning technology is patented, wireless technology of time synchronization between LocataLites called *TimeLoc*. Therefore, there is no need for base station, the connection for data transfer from the base to the mobile receiver, and no requirement for measurement double differencing. Unlike pseudolites, which mostly transmit signals at the GPS frequency bands which causes many difficulties (Rizos, C. et al. 2011), Locata incorporates proprietary signal transmission structure that operates on the 2.4 GHz Industrial Scientific Medical (ISM) licence free frequency band (Rizos, C. 2013). This allows high power of transmitted signals so that Locata can work both indoor and outdoor environments.

2.1 CORE COMPONENTS OF LOCATA SYSTEM

Locata system consists of two core components:

1. LocataLite – transmitter,
2. Locata – receiver (rover).

The *LocataLite transmitter* generates a carrier-phase signal modulated with a proprietary ranging code in the 2.4 GHz (ISM) band. A LocataLite currently transmits four PRN-style signals on two frequencies and from two spatially separated antennas, producing four usable ranging signals. The receiver and the transmitter share the same clock which is a cheap temperature-compensated crystal oscillator (TCXO).

Locata receiver (rover) utilizes signals broadcast by LocataLites to position itself, using either code or carrier-based techniques. Figure 2.1 (left) shows LocataLite transceiver and Locata receiver.

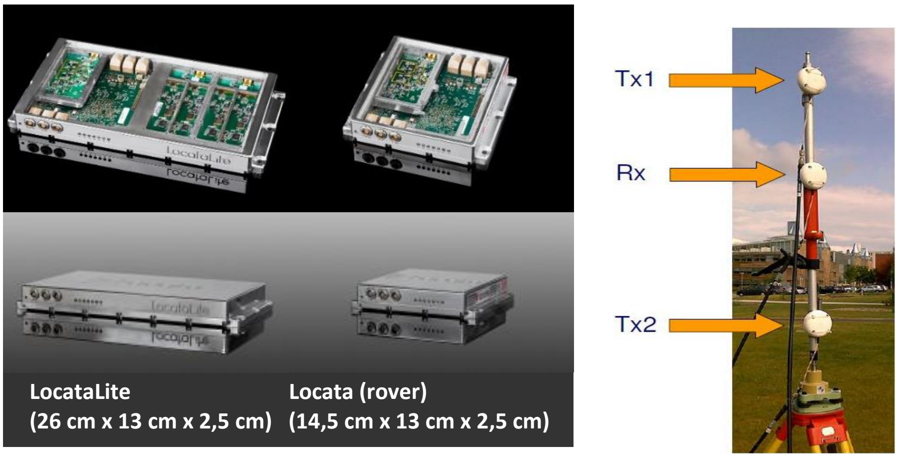

Figure 1 Locata's new G4 LocataLite transceiver and LRx8 Locata rover (left) (URL 1), LocataLite antennas (right) (Bonenberg L. K. et al. 2011)

2.2 TIME SYNCHRONIZATION OF LOCATA SYSTEM

The synchronization of transmitters that are broadcasting a positioning signal is the fundamental requirement for radio-positioning systems. The required level of synchronisation is extremely high, considering a one nanosecond error in time equates to a range error of approximately thirty centimetres (Barnes, J. et al. 2003a). A patented wireless time synchronisation procedure of one or more LocataLite devices is a key innovation of the Locata technology and is known as TimeLoc. The TimeLoc procedure to synchronise one LocataLite (B) to another LocataLite (A) can be described in the following steps (Barnes, J. et al. 2003b):

1. LocataLite A transmits a C/A code and carrier signal on a particular PRN code.
2. The receiver section of LocataLite B acquires, tracks and measures the signal (C/A code and carrier-phase measurements) generated by LocataLite A.
3. LocataLite B generates its own C/A code and carrier signal on a different PRN code to A.
4. LocataLite B calculates the difference between the code and carrier of the signal received from LocataLite A and its own locally generated signal. Ignoring propagation errors, the differences between the two signals are due to the difference in the clocks between the two devices, and the geometric separation between them.
5. LocataLite B adjusts its local oscillator (using Direct Digital Synthesis (DDS) technology) to bring the code and carrier differences between its own signal and LocataLite A to zero. The signal differences between LocataLite A and B are continually monitored and adjusted so that they remain zero. In other words, the local oscillator of B follows precisely that of A.
6. The final stage is to correct for the geometrical offset (range) between LocataLite A and B, using the known coordinates of the LocataLites, and after this TimeLoc is achieved.

In theory, there is no limit to the number of LocataLites that can be synchronised together using TimeLoc.

2.3 LOCATA POSITIONING NETWORK

When four or more LocataLites are deployed, they form a positioning network called a LocataNet. This positioning network is time-synchronous, so that Locata receiver can compute its position without any correctional data. When forming a LocataNet there are two basic considerations for the position of the LocataLites. First, the LocataLites must be able to receive the signal from at least one other LocataLite. The other basic consideration is that the geometry of the network (DOP) is suitable for the positioning precision requirements. A LocataNet is a typical Master-Slave structure. A Master is first selected among the LocataLites and then all the others are synchronized to its clock during a TimeLoc process (Roberts, G. W. et al. 2007).

3 DOP CALCULATION

Like GNSS Locata uses code pseudorange and carrier phase measurements for determining position of receiver where carrier phase measurements are more precise than pseudorange measurements. Basic Locata carrier phase measurement model between LocataLite *i* and receiver *r* is (Rizos, C. et al. 2003):

$$\varphi_r^i = \rho_r^i + \tau_{trop} + c \cdot \delta T_A - \frac{c}{f} N_r^i + \varepsilon, \quad (1)$$

where φ_r^i is carrier phase measurement, ρ_r^i is geometrical distance between LocataLite *i* and receiver r, τ_{trop} is tropospheric delay (which can be modelled), δT_A is receiver's clock error, N_r^i is ambiguity (the unknown number of cycles between LocataLite and receiver), *c* is speed of light in vacuum *f* is frequency of carrier phase measurement and ε is remaining unmodeled errors in measurement. Once the float ambiguities are estimated with certain level of accuracy, they can be treated as known parameters (Jiang, W. et al. 2013). Remaining unknown parameters (position of receiver in ρ_r^i and receiver's clock error δT_A) can be solved by least square estimation. Linearizing measurement model of *n* carrier phase measurements gives geometry matrix G:

$$G = \begin{bmatrix} \frac{\partial \varphi_r^1}{\partial E} & \frac{\partial \varphi_r^1}{\partial N} & \frac{\partial \varphi_r^1}{\partial H} & 1 \\ \frac{\partial \varphi_r^2}{\partial E} & \frac{\partial \varphi_r^2}{\partial N} & \frac{\partial \varphi_r^2}{\partial H} & 1 \\ \vdots & \vdots & \vdots & \vdots \\ \frac{\partial \varphi_r^n}{\partial E} & \frac{\partial \varphi_r^n}{\partial N} & \frac{\partial \varphi_r^n}{\partial N} & 1 \end{bmatrix}. \quad (2)$$

Assuming carrier phase measurements are uncorrelated, covariance matrix of least square estimation will be:

$$\Sigma = \sigma^2 (G^T G)^{-1}, \quad (3)$$

where σ^2 is reference variance. Diagonal elements of matrix $(G^T G)^{-1}$ are squared dilution of precision (DOP) values for solution estimates of position (East, North and Height coordinates) and time (receiver's clock error), which describes how geometry configuration of LocataLites affects solution accuracy:

$$EDOP = \sqrt{\Sigma_{11}}, NDOP = \sqrt{\Sigma_{22}}, VDOP = \sqrt{\Sigma_{33}}, TDOP = \sqrt{\Sigma_{44}}. \quad (4)$$

Further, horizontal DOP value can be calculated as:

$$HDOP = \sqrt{\Sigma_{11} + \Sigma_{22}} = \sqrt{EDOP^2 + NDOP^2}, \quad (5)$$

and positioning DOP value can be calculated as:

$$PDOP = \sqrt{\Sigma_{11} + \Sigma_{22} + \Sigma_{33}} = \sqrt{EDOP^2 + NDOP^2 + VDOP^2}. \quad (6)$$

4 SIMULATION OF DIFFERENT LOCATANET CONFIGURATION

For the first time in Croatia Locata equipment was acquired and applied within project “Wearable outdoor augmented reality system for enrichment of touristic content” and consists of six LocataLite transceivers and two Locata receivers.

Before establishing LocataNet in the field, it is crucial to choose appropriate LocataNet configuration (Grgac, I. et al. 2016). To express influence of LocataNet geometry to positioning accuracy, dilution of precision (DOP) values for different simulated LocataNet configurations was calculated. Main task in LocataNet configuration simulation was to get acceptable VDOP values, where threshold value for VDOP was set to 3. Before simulation lower bound for LocataLite height was set to 4 meters and upper bound was set to 12 meters.

First idea for LocataNet configuration was to arrange five LocataLites in regular pentagonal shape 4 meters above ground, and one LocataLite in the centre 12 meters above ground. Described configuration gives good horizontal positioning quality across network (HDOP ≈ 1), and rounds area with radius approximately 30 meters with VDOP less than 3 (Fig 2). Considering antenna radiation pattern, it is not possible to cover 360° view with one antenna, which lead to significant reduction of area with reasonable VDOP values (Fig 3).

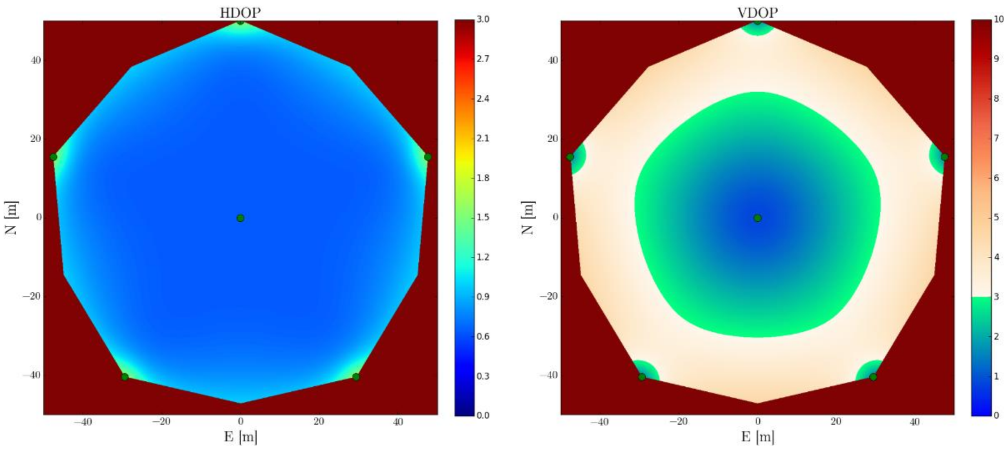

Fig. 2 HDOP (left) and VDOP (right) values for pentagonal LocataNet configuration

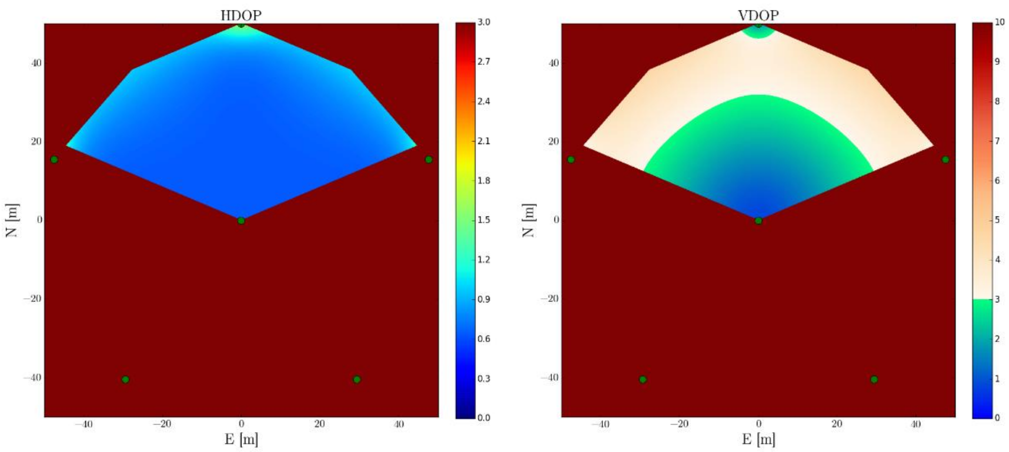

Fig. 3 HDOP (left) and VDOP (right) values for pentagonal LocataNet configuration considering antenna radiation pattern

Next configuration was regular hexagonal shape with two antennas set 12 meters above ground. This configuration gives poor solution in terms of vertical precision (VDOP greater than 3) across whole network (Fig 4).

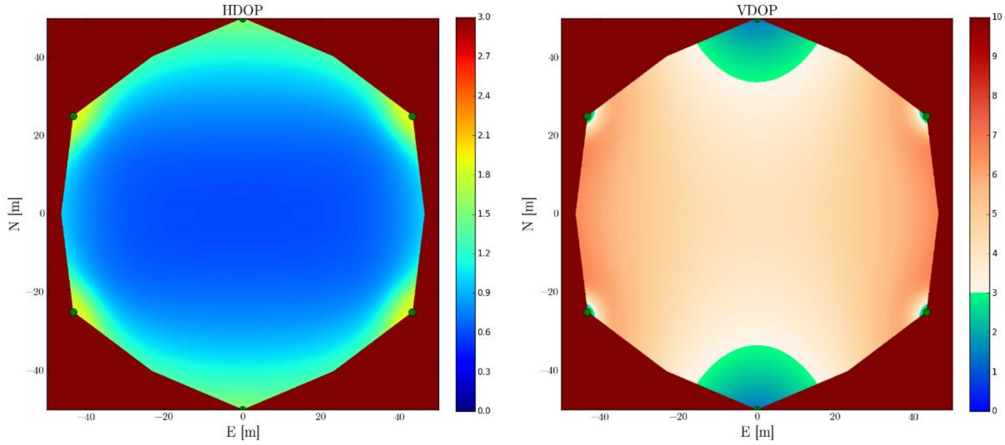

Fig. 4 HDOP (left) and VDOP (right) values for hexagonal LocataNet configuration

Final simulated configuration was with two higher LocataLites put closer to each other which lead to rectangular shape of LocataNet. This configuration yields area approximately 50 x 50 meters with reasonable VDOP values, and was chosen as optimal LocataNet configuration for 3D positioning.

4.1 ESTABLISHED LOCATANET

Established LocataNet slightly differs from optimal rectangular configuration, as existing infrastructure on the field was used for antenna installation, which has minor influence on DOP values within network (Fig. 5).

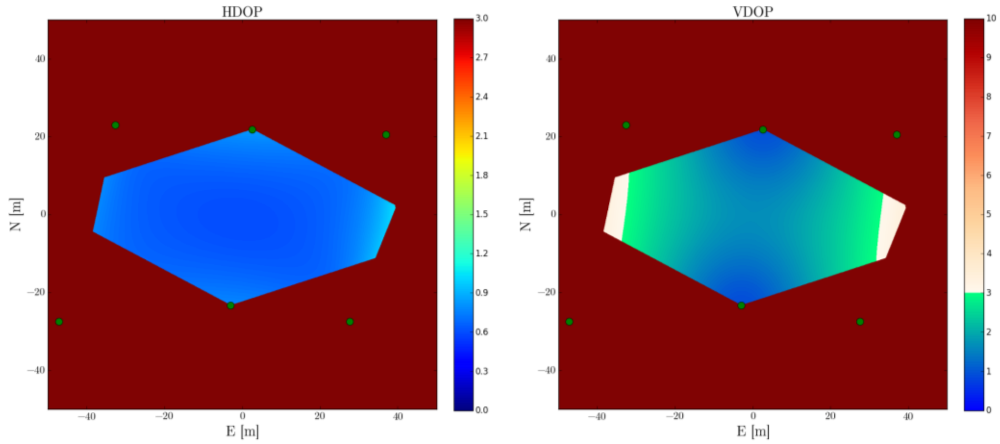

Fig. 5 HDOP (left) and VDOP (right) values for established LocataNet configuration

Within established network Locata measurements were conducted on test points distributed across LocataNet. Measurements were conducted using two receivers simultaneously with registration rate 10 Hz. Points across LocataNet were occupied for different periods of time (from 1 minute to 30 minutes). Analysis of conducted Locata measurements shows weaker achieved precision in direction of higher LocataLites (LL3 and LL6) while a priori simulated error ellipses shows equal precision in all directions (Fig 6). This difference in shape between a priori and achieved error ellipses are caused by instability of 12 meters high poles where two LocataLite antennas are mounted.

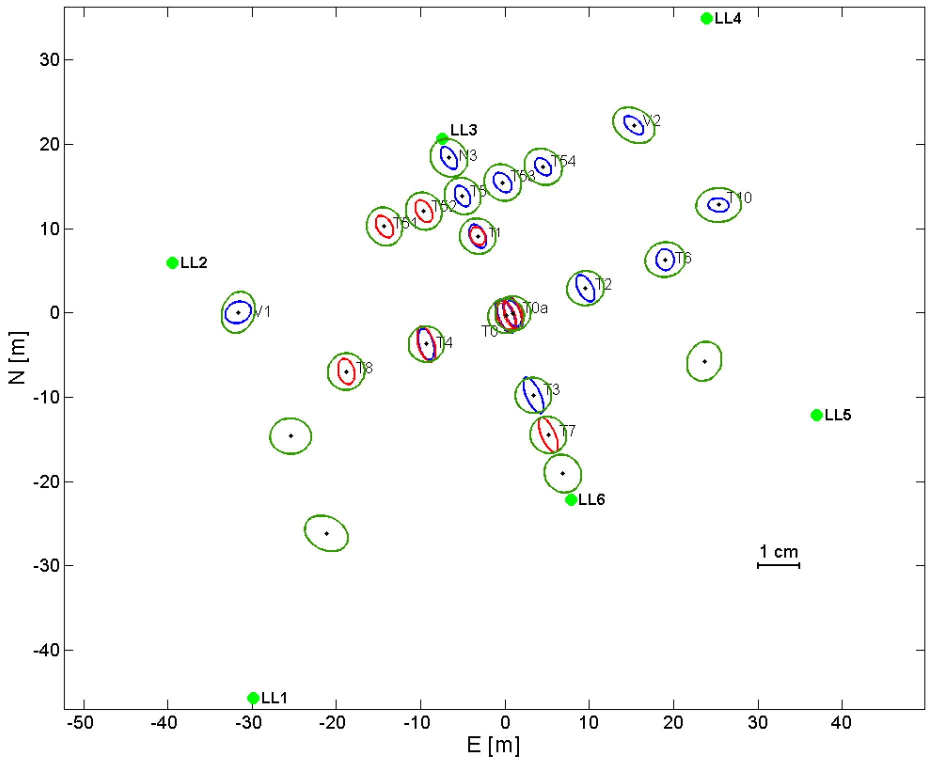

Fig. 6 Comparison of a priori simulated (green) and achieved (red and blue) error ellipses in established LocataNet

5 CONCLUSION

Locata is radio frequency based positioning system, characterized by the biggest technical achievement in wireless technology of time synchronization between signal transmitters called TimeLoc. Locata is designed to enhance GNSS with additional positioning signal in areas with poor signal coverage (e.g. urban canyons, ports, mines), but also can work completely independent where tracking GNSS signals is not possible (indoor environments).

Geometry configuration have substantial influence in potential positioning accuracy of Locata network. Project "Wearable outdoor augmented reality system for enrichment of touristic content" requested centimetre level accuracy of 3D positioning solution from Locata positioning system. To meet this condition different LocataNet configurations, consists of six LocataLites, were simulated. From simulation of different LocataNet configurations, elaborated in this paper, we can conclude that rectangular configuration gives optimal solution in terms of vertical accuracy (VDOP values), which was the biggest concern. This optimal configuration yields area approximately 50 x 50 meters with VDOP values below 3.

Established LocataNet slightly differs from simulated configuration, as existing infrastructure on the field was used for antenna installation. Within established LocataNet, measurements were conducted on test points distributed across network. The analysis of conducted Locata measurements showed differences in terms of shape of horizontal error ellipses determined from measurements and simulations because of instability of high antennas in LocataNet.

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