High Precision Indoor and Outdoor Positioning using *LocataNet*

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BIOGRAPHY

Joel Barnes is a senior researcher within the Satellite Navigation and Positioning (SNAP) group, at the School of Surveying & Spatial Information Systems, the University of New South Wales (UNSW), Sydney, Australia. He obtained a Doctor of Philosophy in satellite geodesy from the University of Newcastle upon Tyne, UK. Joel has assisted in the development of the *Locata* receiver (the mobile positioning device), and testing of the Locata technology. Other current research interests include pseudolites, GPS receiver firmware customisation and high precision kinematic GPS positioning.

Chris Rizos is a graduate of the School of Surveying, UNSW, Sydney, Australia; obtaining a Bachelor of Surveying in 1975, and a Doctor of Philosophy in 1980 in satellite geodesy. Chris has been researching the technology and high precision applications of GPS since 1985, and is currently leader of the SNAP group at UNSW. Chris is a Fellow of the Australian Institute of Navigation, a Fellow of the International Association of Geodesy (IAG), and is currently president of the IAG's Commission 4 "Positioning and Applications".

Jinling Wang is a Lecturer in the School of Surveying & Spatial Information Systems at UNSW. He is Editor-in-Chief of the Journal of Global Positioning Systems and Chairman of the international working Group on pseudolite applications with the International Association of Geodesy.

David Small is director of research and development at Locata Corporation, and is also president. He founded Locata Corporation (formerly QX Corporation) with his partner Nunzio Gambale in 1995. He has invented almost all the technical aspects of the Locata enabling technology. Currently he is the holder of 11 patents granted in 8 countries, with many more in the process.

Gavin Voigt is principal design engineer for Locata Corporation. He is responsible for the development of the Locata technology and is involved at all levels of the design process. He was directly responsible for the design and implementation in all aspects of the hardware and low level software of the Locata technology. He has a B.Eng. in Electronics and Communications from the University of Canberra, Australia.

Nunzio Gambale is chief executive officer of Locata Corporation. He founded Locata Corporation (formerly QX Corporation) with his partner David Small in 1995. He has conceived the business, patent, trademark and marketing concepts, and consumer devices embodied within the Locata technology.

ABSTRACT

Today, GPS is the most popular and widely used three-dimensional positioning technology in the world. However, in many everyday environments such as indoors or in urban areas, GPS signals are not available for positioning (due to the very weak signals). Even with high sensitivity GPS receivers, positioning for urban and indoor environments cannot be guaranteed in all situations, and accuracies are typically of the order of tens to hundreds of meters at best. Other emerging technologies obtain positions from systems that are not designed for positioning, such as mobile phones or television. As a result, the accuracy, reliability and simplicity of the position solution is typically very poor in comparison to GPS with a clear view of the sky.

Locata is a new positioning technology, developed to address the failure of current technologies for reliable ubiquitous (outdoor and indoor) positioning. In this paper key aspects of the new technology are discussed, with particular emphasis on the positioning network (*LocataNet*). An innovative characteristic of the *LocataNet* is its ability to propagate (autonomously) into difficult environments and over wide areas. Through an experimental *LocataNet* installation, a key mechanism for achieving this is tested, and real-time stand-alone positioning (without a base station and additional data link) with sub-centimetre precision is demonstrated.

INTRODUCTION

Accurate spatial information is becoming increasingly important in today's society, and location aware applications cover a broad range, from mobile phones to machine control. Today, GPS is the most popular and widely used three-dimensional positioning technology in the world. However, the GPS signals received on the Earth are extremely weak, and not reliably available in many everyday environments such as indoors, or in urban areas where buildings block the line-of-sight to GPS satellites (Figure 1). This failure in the GPS technology, and a huge market for location aware applications, has led to a large number of new positioning technologies. Currently, the basic approaches of these emerging technologies have been:

1. Use GPS signals, but build special high sensitivity GPS receivers that try to detect and use very weak attenuated signals.
2. Use signals from systems not designed for positioning, including mobile phone networks and television.
3. Use a combination of 1 and 2.

These solutions are attractive because they make use of existing infrastructure. However, they often perform poorly in comparison to that achievable with GPS in a benign environment (with a clear view of the sky), in terms of accuracy, reliability and simplicity. An alternative approach to extending the capability of GPS into urban environments and indoors is to increase the number of GPS signals through ground-based transmitters of GPS-like signals, called pseudolites (short for pseudo-satellites). Although the pseudolite technology has been around since the 1970s, for GPS receiver equipment testing before the launch of GPS satellites (Harrington & Dolloff, 1976), their use has not been widely adopted. There are several reasons for this:

Hardware – Pseudolites (PLs) are available from a very small number of companies, and their price tends to be high (at least US$10,000). The majority of off-the-shelf (OTS) GPS receivers do not have the capability to use pseudolite signals. The few OTS GPS receivers that are able to track pseudolites, can only record pseudolite data for post-processing, and cannot use the signals in real-time.

Near constellation – There are some challenging operational and modelling issues due to the comparatively small separation between PLs and user receivers, including near-far signal strength, PL location errors, tropospheric delays, multipath and non-linearity. These issues have been discussed in a series of papers by SNAP researchers (Barnes *et al.*, 2002; Wang *et al.*, 2001, 2002; Dai *et al.*, 2001).

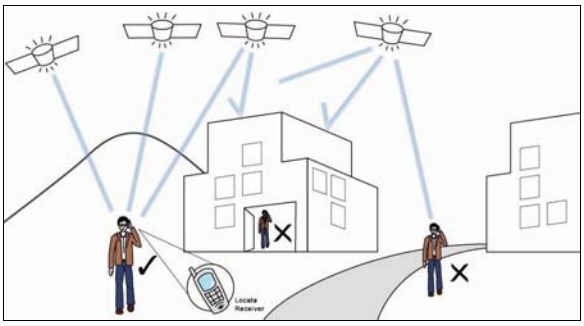


Figure 1. Positioning limitations of the GPS technology.

Unsynchronised – Standard pseudolites are not synchronised to GPS time or to one another. Therefore, single-point positioning is not possible, and differential operation is necessary, similar to DGPS or RTK. Differential operation requires another GPS receiver at a known point to provide data to the user GPS receiver. A wireless communication link must therefore be used between the base station and user receiver, for example radio modem or GSM. This requirement significantly adds to the cost and complexity of a system for widespread use. Until now, attempts to synchronise pseudolites have resulted in position solutions that are up to six times worse in comparison to an unsynchronised approach using double-differencing (Yun and Kee, 2002).

Despite the problems associated with pseudolites, the technology has been applied to niche applications such as the precision approach and landing of aircraft (Soon *et al.*, 2003, Hein *et al.*, 1997, Bartone, 1996, Barltrop *et al.*, 1996, Cobb *et al.*, 1995, Galijan *et al.*, 1993). Integrated GPS and pseudolite systems developed for this purpose are expensive (US$100,000s) and custom built for a particular installation.

Locata is a new positioning technology, developed to address the failure of current technologies for reliable ubiquitous (outdoor and indoor) positioning. In the following sections important aspects of the new technology are discussed, with particular emphasis on the positioning network (*LocataNet*). One innovative characteristic of the *LocataNet* is its ability to propagate (autonomously) into difficult environments or over wide areas. Through an experimental *LocataNet* installation, a key mechanism for achieving this is tested, and real-time stand-alone positioning (without a base station and additional data link) with sub-centimetre precision is demonstrated.

2.0 The Locata technology

The Locata technology was designed with four key objectives (Locata, 2003):

1. Available in all environments.

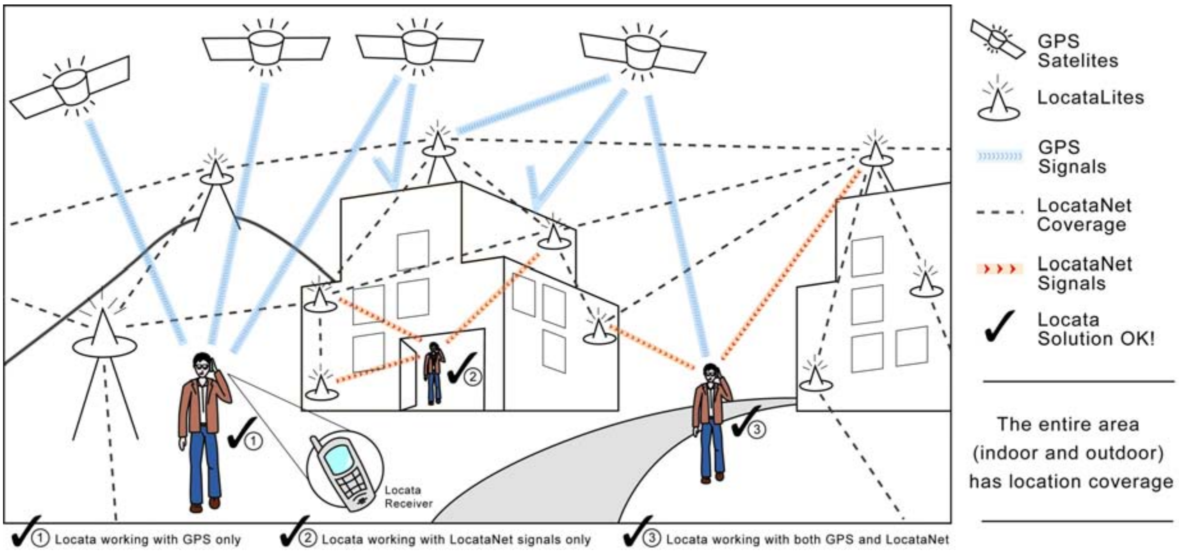


Figure 2. The Locata technology positioning concept.

2. High reliability.
3. High accuracy.
4. Cost effective.

In *Locata* these objectives are achieved through a network of ground-based transmitters that cover a chosen area with strong signals, suitable for accurate positioning in all environments. A *Locata* receiver can track both GPS and *Locata* signals, thereby providing a seamless transition between environments where a user can utilise *Locata* signals, GPS signals, or both. Figure 2 illustrates the positioning concept behind the Locata technology.

Locata is designed to enhance and improve GPS, extending its positioning capability into difficult urban environments and indoors. Therefore, Locata can seamlessly work with GPS or entirely independently of it, and is not designed to replace GPS entirely.

2.1 Core components

At the heart of the Locata technology are two core components (see Barnes, 2003a *et al*. for further details):

1. *LocataLite* – A transceiver which generates a GPS-like signal. The prototype device shown in Figure 3 transmits a GPS L1 signal and C/A code pseudorange, and incorporates the same receiver hardware as the *Locata*.

2. *Locata* – A stand-alone low cost GPS-like receiver that can track both GPS and *LocataLite* signals. The prototype hardware, shown in Figure 4, is based on an existing GPS chipset. When four or more *LocataLite* signals are tracked the *Locata* receiver is capable of 3-dimensional positioning with sub-centimetre precision.

2.2 The positioning network - *LocataNet*

When four or more *LocataLites* are deployed they cooperate to form a positioning Network called a *LocataNet*. This positioning network is time-synchronous, which means a stand-alone *Locata* receiver can compute its position without any additional information or correctional data. The time synchronisation procedure is called *Time-Loc*, and is a key innovation of the Locata technology (see section 2.3).

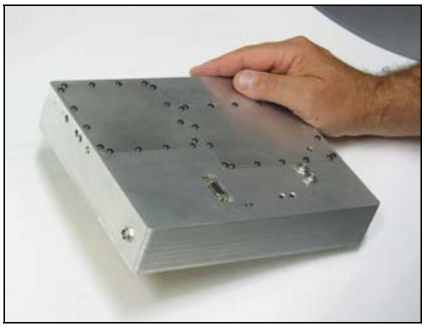


Figure 3. Prototype *LocataLite* (transceiver) hardware.

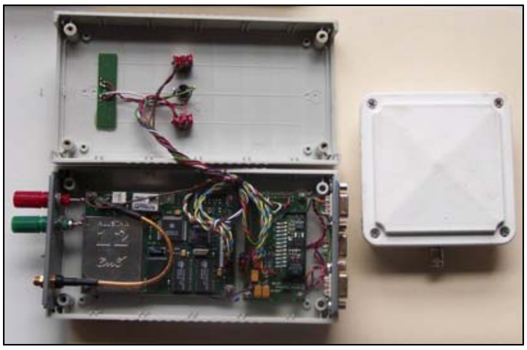


Figure 4. Prototype *Locata* (receiver) hardware.

When building 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 (dilution of precision, DOP) is suitable for the positioning precision requirements.

The establishment of a *LocataNet* is designed to be a simple autonomous process, which is best explained through the following steps:

1. A *LocataLite* self-surveys using the GPS constellation and begins transmission of its own unique ranging signal (Figure 5).
2. A second *LocataLite*, placed within range of the first *LocataLite* self-surveys from the GPS constellation and the first *LocataLite*. It time-synchronises to the first *LocataLite* signal, and then begins transmission of its own unique ranging signal (Figure 6).
3. To allow three-dimensional positioning from a *LocataNet* alone, two additional *LocataLites* are deployed (Figures 7 and 8). The process described in step 2 is repeated for each additional *LocataLite* that is deployed, using all the available signals from the *LocataLites* and GPS.
4. Figure 9 illustrates a basic *LocataNet* with the four time-synchronised *LocataLites*. Each *LocataLite* knows its precise position, and the four transmitted ranging signals are all time-synchronised. The established *LocataNet* can operate independently of GPS.
5. Once the *LocataNet* is established, additional *LocataLites* can be added, even indoors (Figure 10). A fifth *LocataLite* placed inside a building can self-survey using only the *LocataNet* and then begin transmission of its own unique ranging signal.
6. Figure 11 shows an example of a *Locata* receiver outside using both GPS and *LocataLite* signals for positioning.
7. Figure 12 shows a *Locata* receiver inside a building using only *LocataLite* signals for positioning, since GPS signals are blocked.

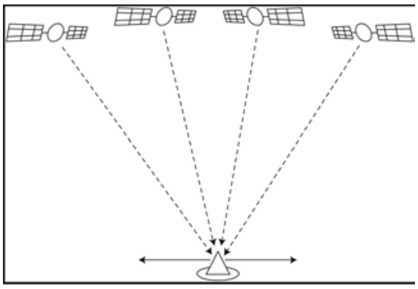


Figure 5. Establishing a *LocataNet*, step 1.

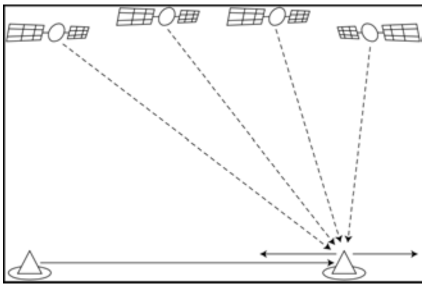


Figure 6. Establishing a *LocataNet*, step 2.

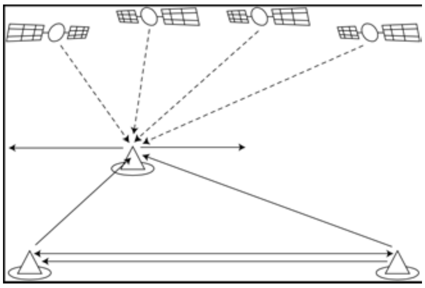


Figure 7. Establishing a *LocataNet*, step 3.

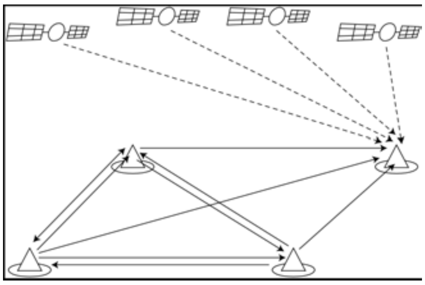


Figure 8. Establishing a *LocataNet*, step 4.

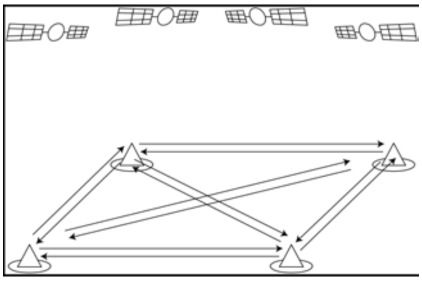


Figure 9. Establishing a *LocataNet*, step 5.

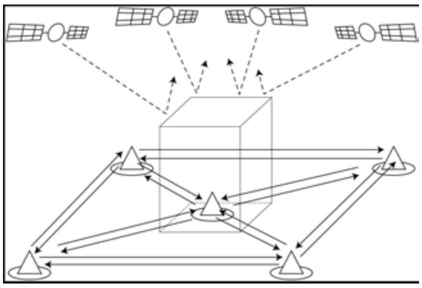


Figure 10. Propagating the *LocataNet* indoors.

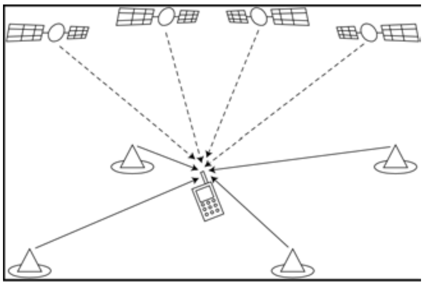


Figure 11. Positioning outside using *LocataNet* and GPS.

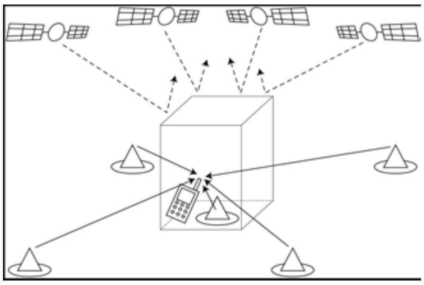


Figure 12. Positioning indoors using *LocataNet* alone.

The *LocataNet* concept is powerful and has some important characteristics including:

Autonomous installation – *LocataLites* can autonomously survey and negotiate themselves into a positioning network. The self-survey can be from GPS or from an existing *LocataNet*. This capability makes *LocataNet* easily expandable to increase signal coverage where necessary, with *LocataLites* autonomously joining or departing.

Ad hoc capability – As well as permanent installation of *LocataNets*, the autonomous installation and built in networking capability allows for ad hoc networks to be created when required. This is very useful for emergency response type applications or civil engineering projects.

Signal penetration – In comparison to GPS signals, *LocataLite* signals are orders of magnitude stronger. Because of this, signals from a *LocataNet* can provide significant building penetration. In situations where "deeper" coverage is required, additional *LocataLites* can be added to the *LocataNet* inside the building.

Seamless positioning with GPS – *LocataNet* uses the same WGS-84 coordinate system as GPS, allowing a *Locata* receiver to seamlessly transition from outdoors to indoors, maintaining consistent coordinates.

Expansion and coupling – In addition to autonomously adding *LocataLites* to expand a network, the unique *Locata* technology provides the capability for *LocataNets* to join together to form a single continuous network from two or more individual *LocataNets*.

Scalability - *LocataNets* can be large or small, ranging in size from a room to a large city. Networks could have as few as four *LocataLites* to thousands of devices.

Time-synchronised – *LocataNet* positioning signals are time-synchronised, which allows single-point positioning in the same manner as GPS. However, unlike GPS the level of synchronisation between *LocataLites* allows single-point positioning with sub-centimetre precision. The time synchronisation is achieved through an autonomous process known as *Time-Loc*.

2.3 *Time-Loc*

The time synchronisation accuracy requirements for *LocataLites* is very high if sub-centimetre positioning precision is desired for a *Locata* receiver, since a one nanosecond error in time equates to an error of approximately thirty centimetres (due to the speed of light). *LocataLites* achieve high levels of synchronisation without atomic clocks, external cables, or a master reference receiver. *Time-Loc* provides an autonomously synchronised network. The *Time-Loc* procedure is best described in the following steps for two *LocataLites* A and B (Figure 13):

1. *LocataLite* A transmits a unique signal (code and carrier).

2. The receiver section of *LocataLite* B acquires, tracks and measures the signal generated by *LocataLite* A.

3. *LocataLite* B generates its own unique signal (code and carrier).

4. *LocataLite* B calculates the difference between the received signal 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 differences between its signal and *LocataLite* A to zero. The signal differences are continually monitored 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 between *LocataLite* A and B, using the known coordinates of the *LocataLites*, and after this *Time-Loc* is achieved.

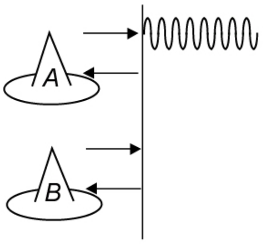
In theory, there is no limit to the number of *LocataLites* that can be synchronised together using the *Time-Loc* procedure described previously. Importantly, the *Time-Loc* procedure allows a *LocataNet* to propagate into difficult environments or over wide areas. For example, if a third *LocataLite* C can only receive the signals from B (and not A) then it can use these signals for time-synchronisation instead. Moreover, the only requirement for establishing a *LocataNet* using *Time-Loc* is that *LocataLites* must receive signals from one other *LocataLite*. This does not have to be the same 'central' or 'master' *LocataLite*, since this is not possible in difficult environments or when propagating the *LocataNet* over wide areas. The proof-of-concept of *LocataNet* propagation, and its influence on signal quality, is investigated in section 3.

2.4 *Locata* receiver positioning accuracy

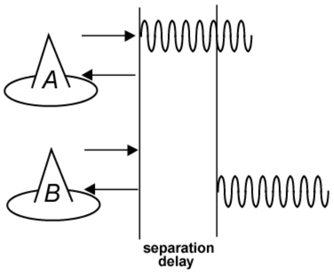
The positioning accuracy of a *Locata* receiver using only *LocataLite* signals has been assessed through two experimental *LocataNet* installations, comprised of five *LocataLites*. One of the installations is designed for positioning ouside while the other is for indoors. At the outdoor test network (approximately 200x60 metres) with direct line-of-sight signals between the *LocataLites* and the *Locata* receiver, static and kinematic point positioning with sub-centimetre and centimetre level precision can be achieved respectively (Barnes *et al.*, 2003a). For the indoor test network (approximately 65x35 metres), the *LocataLites* are located outside a two-story office building, and the signals penetrate the building (brick walls and a metal roof). Using this *LocataNet*, indoor static and kinematic real-time positioning can be achieved with sub-centimetre and sub-metre precision respectively (Barnes *et al.*, 2003b). For indoor kinematic positioning with line-of-sight signals, centimetre level positioning is possible. A *Locata* receiver using a *LocataNet* has several major advantages in comparison to other currently available positioning technologies (including GPS) which include:

Reduced latency – In a differential-based navigation system, the highest positioning accuracies are achieved when a user waits for time-matched base station data (with no interpolation). There is therefore latency associated with base station data transmitted on the communication link. The *Locata* receiver does not have to wait for any additional data in order to compute a position and therefore has less latency.

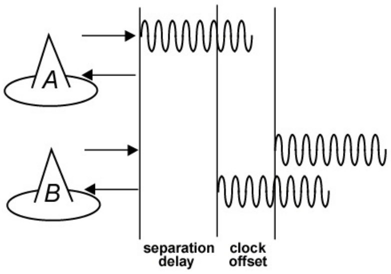
Theoretically greater precision – In differential GPS the double-differenced observable is formed from four carrier-phase measurements. Assuming all measurements have equal precision and are uncorrelated, the precision of the double-differenced measurement is two times worse than a single carrier-phase measurement (the basic measurement used by the *Locata* receiver).



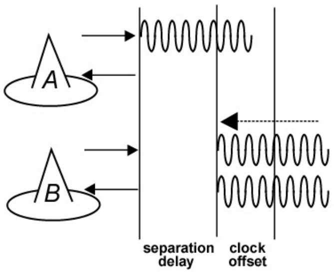
Step 1. *LocataLite* A transmits a unique signal.



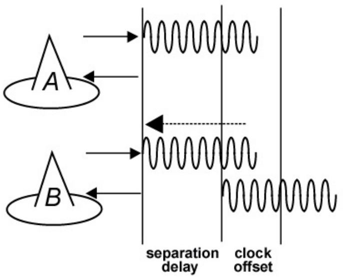
Step 2. *LocataLite* B receives signal from A.



Step 3. *LocataLite* B transmits a unique signal.
Step 4. *LocataLite* B computes difference between transmitted and received signals.



Step 5. *LocataLite* B makes difference (in step 4) zero.



Step 6. *LocataLite* B corects for A & B seperation.

Figure 13. *Time-Loc* procedure.

Time solution – In differential GPS the double-differencing procedure eliminates the clock biases and hence time information is lost. For certain applications precise time is important, and the *LocataNet* approach allows time to be estimated along with position (as is the case of standard GPS single-point positioning).

No data-links – Centimetre level positioning precision can only be achieved with GPS in a differential operating mode. A base station is used along with a wireless link (radio modem or GSM) to communicate data to the user receiver. The base station concept is meaningless in the *LocataNet* approach, and no radio modem is required at the *Locata*. Additionally there are no radio modems or hard-wires connecting any of the *LocataLite* devices.

3. *LocataNet* propagation and signal quality

As discussed in section 2.3 the *Time-Loc* methodology allows a *LocataNet* to autonomously propagate into difficult environments and over wide areas, such as an entire city. To demonstrate the proof-of-concept of *LocataNet* propagation, and its influence on signal quality, an investigation was conducted at an experimental outdoor *LocataNet* (Figure 14), near Canberra in October 2003. The approach for this investigation was to establish the *LocataNet* using the *Time-Loc* procedure in two different ways:

1. Master *Time-Loc*: The *LocataNet* was established through all *LocataLites* time synchronising to a central 'master' *LocataLite* (32), as illustrated in Figure 15.

2. Cascaded *Time-Loc*: To simulate the propagation of a *LocataNet*, time synchronisation was established in four steps: 14 to 32, 29 to 14, 12 to 29, and 21 to 12, as illustrated in Figure 16.

In both *Time-Loc* configurations pairs of *LocataLites* were time-synchronised in less than ten minutes. It is important to note that the *Locata* receiver uses the five *LocataLite* signals from the two *LocataNet* configurations in exactly the same manner for positioning, as illustrated in Figure 15.

For each *LocataNet* configuration, the *Locata* receiver antenna was mounted on a static pole (with known coordinates), at the centre of the *LocataNet*. The geometric configuration of the *LocataLites* is such that the dilution of precision (DOP) values at the *Locata* receiver antenna, in East North and Up are 0.97, 0.70 and 4.25 respectively. The poor DOP in the Up component is due to the fact that the greatest elevation angle from the *Locata* receiver pole to any *LocataLite* is 24.5 degrees (32).

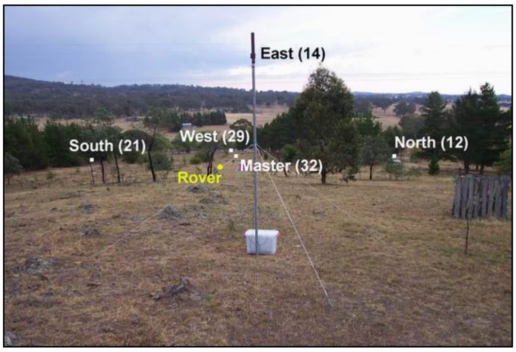


Figure 14. Outdoor experimental *LocataNet* comprised of five *LocataLites.*

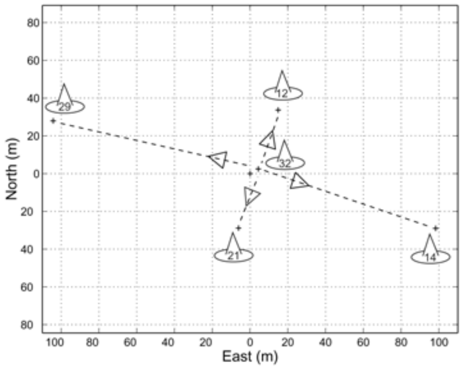


Figure 15. Master *Time-Loc* procedure using 'master' *LocataLite* 32.

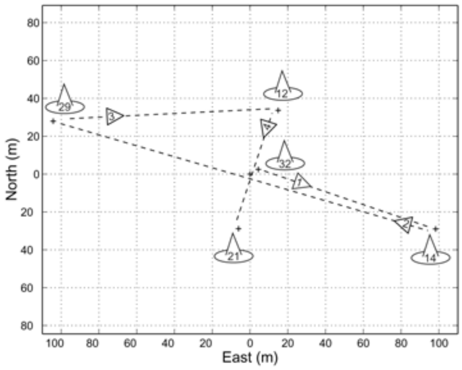


Figure 16. Cascaded *Time-Loc* procedure, simulating network propagation.

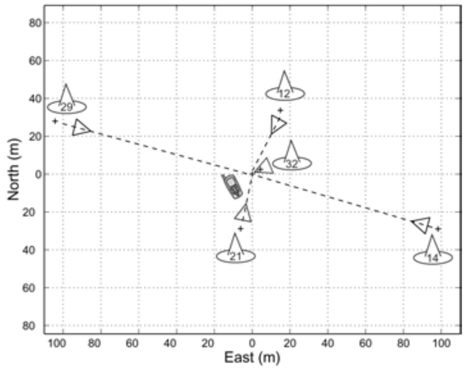


Figure 17. *Locata* receiver positioning using *LocataNet* signals from either Master or Cascaded Time-Loc.

Before a *Locata* receiver (in the prototype system) can compute its position using the *LocataNet* signals, it must first determine carrier-phase biases using the known coordinates of the initial receiver position and the *LocataNet* (see Barnes *et al.*, 2003a). For each *LocataNet* configuration these were determined, and then for approximately twenty-three minutes the *Locata* receiver independently computed real-time position and time solutions once a second. The real-time positions together with the raw measurement data were logged using a laptop computer via a serial interface.

3.1 *LocataLite* signal precision

A good way to assess the quality of the signals from the *LocataLites* and how well the *LocataNet* is time-synchronised is to compute single-difference measurements between the *LocataLites*. This eliminates the *Locata* receiver clock error, and shows any time synchronisation errors, and also multipath error. Using the logged measurement data for both *Time-Loc* procedures, single-difference measurements were computed between *LocataLite* 32 and all the other *LocataLites*. The ambiguities of the single-differences were resolved using the known coordinates of the *LocataLites* and the *Locata* receiver pole.

Figures 18 and 19 show the four single-differences between 32 and the other *LocataLites* for the Master and Cascaded *Time-Loc LocataNets* respectively. Most importantly, visually all the single-difference time series on average fit a horizontal line, and do not have any long-term drifts during the twenty-three minute test. The single-difference standard deviations (Table 1) for the Master *Time-Loc LocataNet* range from 3.9 to 10.4 mm. Interestingly, the standard deviations of *LocataLites* 12 and 21 are at least 40% smaller than 29 and 14. These *LocataLites* are approximately 30 m from 32, as opposed to approximately 100 m for 29 and 14. However, in a previous experiment using the same *LocataNet* (Barnes *et al.*, 2003b), the standard deviation of 12 was slightly greater than 14, 29 and 21, all with similar values (difference of less than 20%). Therefore, the size of the values do not appear to be correlated with the distance over which *Time-Loc* is conducted, and requires further investigation.

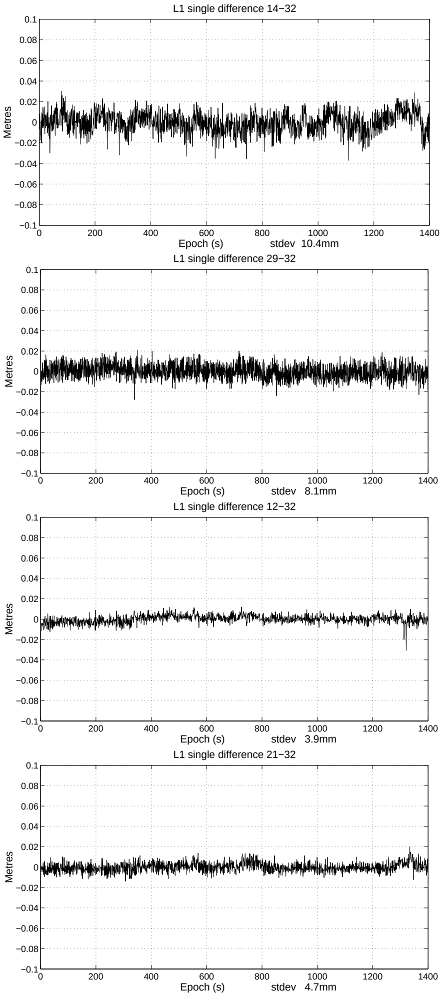


Figure 18. Master *Time-Loc: LocataLite* single-differences using 32 as reference (14, 29, 12, 21, top to bottom).

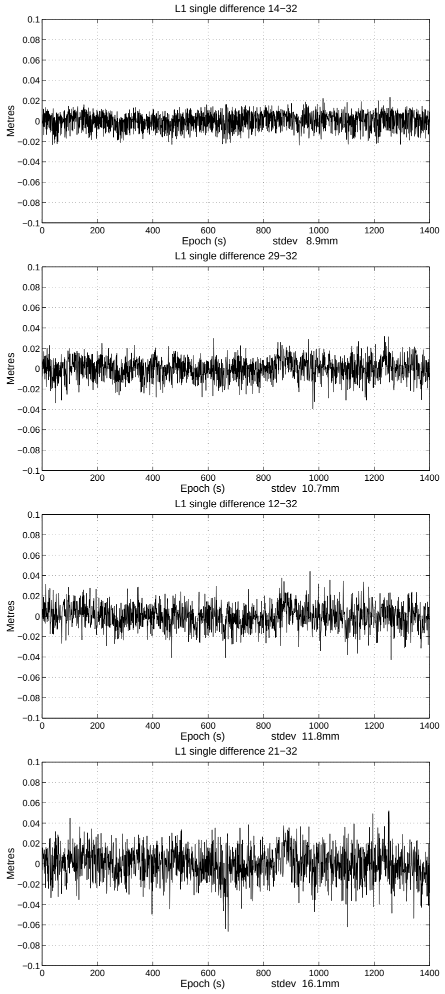


Figure 19. Cascaded *Time-Loc: LocataLite* single-differences using 32 as reference (14, 29, 12, 21, top to bottom).

The single-difference standard deviations (Table 1) for the Cascaded *Time-Loc LocataNet* range from 8.9 to 16.1 mm. In both *Time-Loc* procedures *LocataLite* 14 time synchronises to 32, and therefore the standard deviations are expected to be almost the same. However, the standard deviation of *LocataLite* 14 single-difference time series is 14% smaller (1.5 mm), and visually appears more random in the Cascaded *Time-Loc LocataNet*. The reason for this requires further investigation. As expected, for the other *LocataLites* the single-difference standard deviations of the Cascaded Time-Loc are greater than the Master *Time-Loc LocataNet*. It is difficult to quantify exactly the increase in measurement noise due to the Cascaded *Time-Loc* procedure, given that the single difference standard deviation of *LocataLite* 14 is not the same for both procedures. However, comparing the *LocataLite* standard deviations for each step in the Cascaded *Time-Loc* shows the values increase by 1.8mm (29-14), 1.1 mm (29-12) and 4.3 mm (21-12). The size of the increases requires further investigation, however they do not appear to be correlated with the distance over which *Time-Loc* is carried out. For example, the greatest standard deviation increase (4.3 mm) is over the shortest distance (60m) in the Cascaded *Time-Loc* procedure (Figure 15). A possible cause for the variation in the standard deviations is multipath error.

LocataLite	Single difference stdev (mm)	
	Master *Time-Loc*	Cascaded *Time-Loc*
East (14)	10.4	8.9
West (29)	8.1	10.7
North (12)	3.9	11.8
South (21)	4.7	16.1

Table 1. *LocataLite* standard deviations.

3.2 *Locata* positioning accuracy

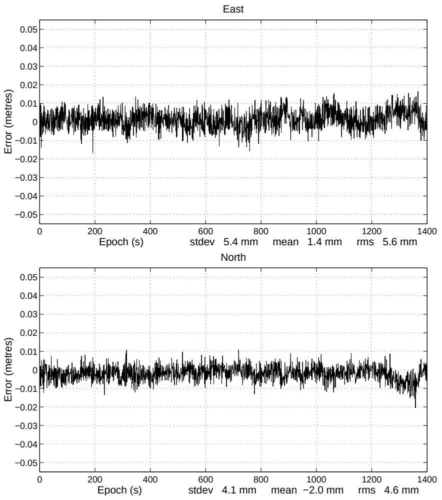


Figure 20. Master *Time-Loc: Locata* receiver East and North static positioning error.

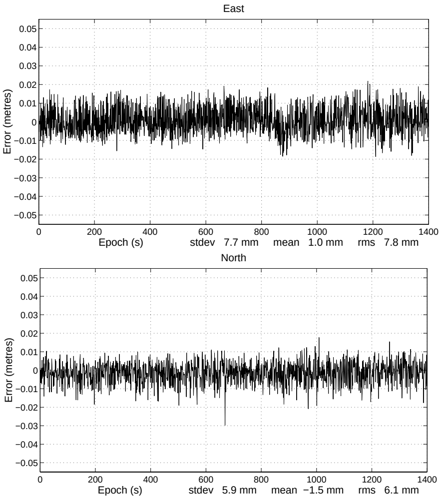


Figure 21. Cascaded *Time-Loc*: *Locata* East and North static positioning error.

To assess the accuracy of the real-time positioning results, the known (sub-centimetre) coordinate of the *Locata* receiver pole was used to compute the positioning error for each epoch in the two different *Time-Loc LocataNets*. Because of the poor DOP in the Up component, the following discussion will concentrate on horizontal components only. Figures 20 and 21 show the East and North errors for Master and Cascaded *Time-Loc LocataNets* respectively. For all the time series the mean error is 2mm or less, with standard deviations all less than 8 mm. Clearly sub-centimetre positioning precision has been achieved for both *LocataNets*. The standard deviations of East and North positioning results in the Cascaded *Time-Loc LocataNet* are approximately 30% greater than the Master *Time-Loc LocataNet*. This increase is expected since the *LocataLite* single-difference measurement time series have greater standard deviations (see section 3.1). However, importantly there are no biases or long term trends introduced as a result of the Cascaded *Time-Loc* procedure. As expected, the North position standard deviation for both *LocataNets* is smaller than the East, because the network geometry is slightly better in the North (smaller DOP value, see section 3).

4. CONCLUDING REMARKS

In this paper important aspects of the *Locata* technology have been described, with particular focus on the positioning network (*LocataNet*). Through an outdoor experimental *LocataNet* installation, proof-of-concept for a propagating positioning network has been demonstrated. In two different *LocataNet* configurations, one propagating (Cascaded *Time-Loc*) and the other non-propagating (Master *Time-Loc*), stand-alone positioning with sub-centimetre level precision was achieved. This level of precision is very pleasing for a prototype system, and is as good as (if not better than) GPS RTK using a base station, radio modem and double differencing. Moreover, the propagating mechanism of *LocataNet* is a significant innovation, because it allows the positioning network to extend into difficult environments and expand over wide areas. The *Locata* technology has the potential to deliver high-precision, ubiquitous (outside and inside) positioning for an enormous range of location aware applications, and research and development continues to realise this potential.

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