The Belfast, Northern Ireland, Titanic Trail is an example of the tourism guide category of location-based services. The system uses GPS-based technology, the Node Explorer, to lead visitors on a tour of city sites associated with the Titanic story, from the grounds of City Hall to Queen`s Island.

Photo Credit: Belfast City Council

Hope beyond the Hype

GNSS and Location-Based Services

Like the Galileo system itself perhaps, location-based services have proven to be an elusive, even vexing proposition — at least in the realm of GNSS mass market applications. From the outset, Galileo market analyses have identified GNSS-driven LBS as the primary opportunity for turning European consumers into customers. These early market studies considered the LBS market as ready for take-off, but experience and more recent analyses have shown that a number of technical and legal obstacles still prevent the LBS market from growing as rapidly as once assumed. This article outlines some basics of LBS, elaborates the reasons for its slow take-off, and finally provides some technical insights into how to remove these obstacles and enable a successful launch of LBS.

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A large body of research recognizes personal mobility as the primary future market for global navigation satellite systems in terms of the number of users and potential revenue. This expectation is especially strong for the upcoming European satellite navigation system Galileo, for which location-based service (LBS) applications have a prominent place in market research.

However, the past decade has seen many GNSS manufacturers and would-be service providers disappointed by the persistent failure of a profitable LBS mass market to emerge and grow rapidly. With the notable exception of a few national markets, particularly in Asia, this failure to thrive has stemmed from a combination of technical, legal, business, and market conditions that have thwarted development of widespread consumer LBS applications.

Previous GNSS activities in the field of LBS have primarily succeeded in commercial and professional applications (such as vehicle tracking and fleet management or remote monitoring of former prisoners out on probation or parole) or for safety and security purposes, such as emergency services. These are applications for which requirements can more easily be pinned down and where revenue streams are easier to estimate and project.

Moreover, regulatory activities and legal mandates have stimulated some large-scale uptake of GNSS technology— such as the U.S. Federal Communications Commission's E-911 mandate, which requires automatic location identification capability be made available to aid emergency callers using mobile phones.

Despite this slow start, the LBS mass market definitely holds the potential for providing substantial revenue streams. However, its development remains rather difficult to predict. This article will present some of the leading prospective consumer application markets for LBS, examine the leading causes of the still sporadic adoption of LBS in these mass markets, and describe efforts to mitigate the current technical limitations constraining the growth of consumer-driven LBS.

In particular, on this latter point we will consider assisted-GNSS (A-GNSS) technology that uses information — typically, satellite ephemerides and constellation almanac — provided through the communications network infrastructure. We also address the possibility of combining various non-satellite-based positioning technologies with GNSS to provide the quality of service needed to support large-scale development and adoption of LBSs.

Looking for LBS Winner Apps

As the term suggests, LBS covers all services which are based on the location of the user. Starting from this straightforward definition, it becomes more difficult to categorize LBS applications into groups. One may apply user requirements, the legal constraints, or technological criteria to differentiate location-based services.

Concentrating on the mass market, LBS can most appropriately be grouped by application domain, for example, mobility applications, entertainment applications, e-commerce applications, or emergency applications. Figure 1 shows a representative — not exhaustive — clustering of LBS applications that provide an overview of the potential LBS marketplace. Note that most of these applications can be delivered via mobile phones and, thus, suggest the possibility of a combined positioning solution using GNSS and cellular techniques.

The more important LBS applications, for mass-market deployment from a business perspective, have been identified as emergency service, people tracking, tourism guides, and location-

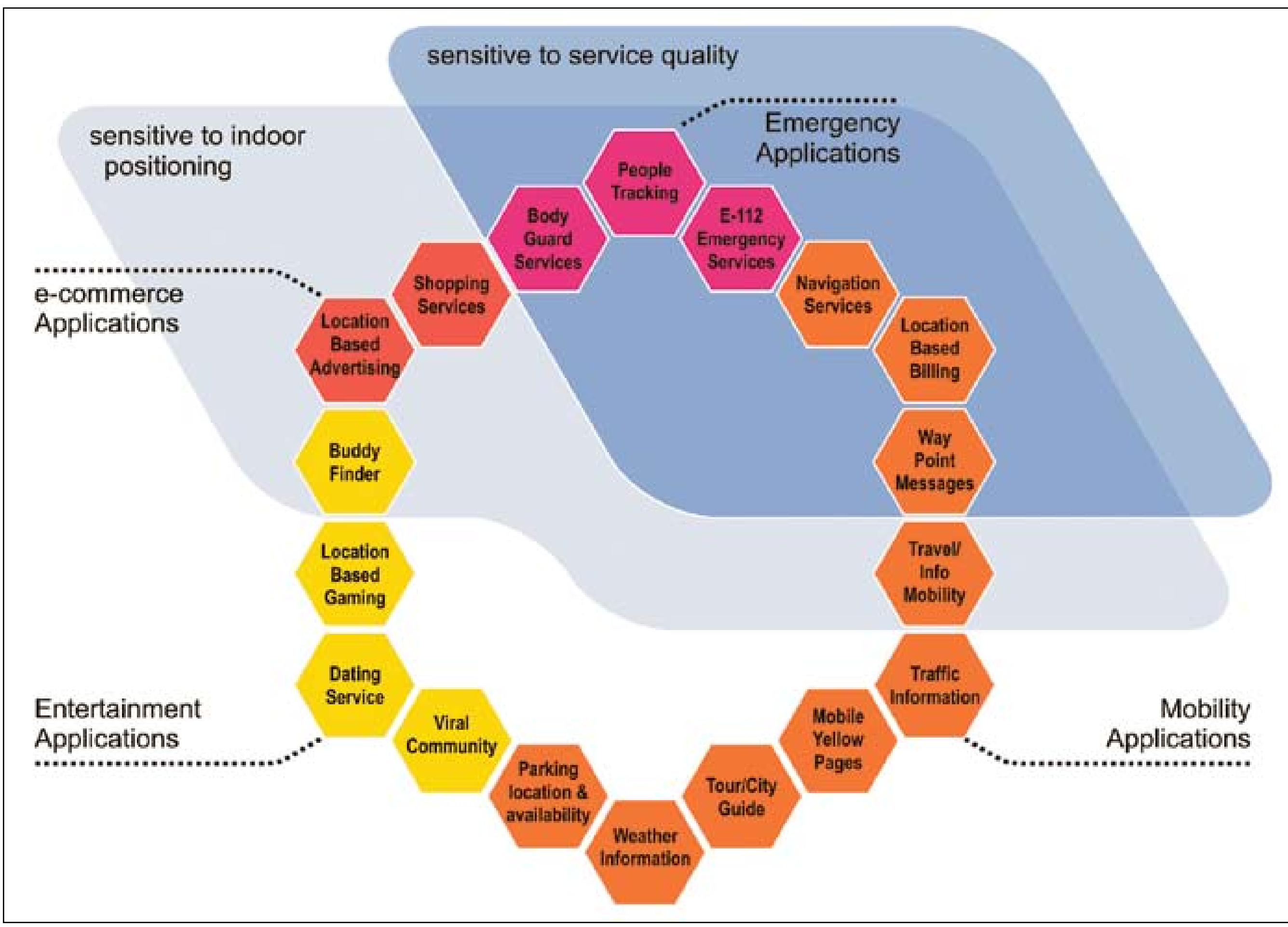

FIGURE 1 LBS application grouping

The Georgia Institute of Technology's Sonification Lab is developing its SWAN Architecture, a voice-guided navigation system that operates on a small computer – either a lightweight laptop or an even smaller handheld device – with a variety of location and orientation tracking technologies including GPS, inertial sensors, pedometer, RFID tags, RF sensors, compass, and others. Sophisticated sensor fusion is used to determine the best estimate of the user's location and which way she is facing.

Photo credit: Georgia Tech

based billing. Let's look at these a little more closely.

Emergency Services. In the United States, this usually refers to the E-911 mandate mentioned earlier and, in Europe, E-112 (for mobile phones) and eCall (for personal vehicles). Emergency situations require first responders (firefighter, ambulance personnel, police) to render assistance as quickly and efficiently as possible. Today, when they receive an emergency call by mobile phone, emergency dispatchers often lack the means to determine the caller's location accurately. Moreover, emergency callers typically are under considerable strain and may not know their whereabouts, be disoriented, or not even speak the native language of the country they are in.

All of these factors lead to delays that not only tie up valuable public safety resources while trying to identify a caller's whereabouts but also often hinder an effective response in dire situations. This application places stringent requirements on position accuracy, availability, and response time.

People Tracking. This application identifies locations of people who need to be located by their caregivers. It is a valuable tool for those responsible for children, the elderly, or persons suffering from such conditions as Alzheimer's disease. A related functionality is "geofencing" — the defining of virtual geographical boundaries that will generate an automatic alert when crossed by someone under supervision.

Again, crucial performance requirements include high positioning accuracy and availability of the service indoors. Continuity of coverage throughout the service area is also indispensable. Apart from that, such LBS user devices must also be robust to survive rough handling.

Such passive tracking systems are technically easy to design and assemble — except for the challenge of meeting indoor positioning requirements. But the legal aspect may prevent market entry for these applications. For example, passive tracking of individuals might not be permitted in several countries, although there usually exist exceptional rules for voluntary use and other cases.

Tourism Guides. The virtual city or tour guide is an attractive LBS application. In this scenario, tourists arriving at a city download text information and multimedia files (videos and sounds) about points of interest (POIs) to their handsets (mobile phones, personal digital assistants or PDAs, or other suitable portable platforms with positioning capability). Then, they can obtain routing information on how to travel to those POIs — information that could be accompanied by location-based advertisements from restaurants or stores near to their destinations or along the route.

This application requires a bi-directional data transfer channel and up-to-date information services accessible to a mobile user. Required position accuracy is similar to that of common navigation services (around 10 meters). These systems may well benefit from indoor positioning capability, too, making the hybridization of GNSS and cellular positioning techniques advisable. Such applications may not need continuous positioning computation, having instead an intermittent "push-to-fix" requirement that helps save battery power.

Location-Based (or –Sensitive) Billing. This service allows companies to customize calling/rate zones to accommodate individual subscribers. Mobile phone operators can charge users a low flat rate for home and office use, and another for use outside of those areas. The prospect of having only one combined landline and mobile phone bill is very attractive for users.

Location-based billing can also be used in connection with location-based advertisements or coupons, similar to the tourism application. These kinds of applications demand a high quality of service (QoS), including short time to fix and indoor availability, because service fees are based on user location information. High accuracy and robustness of positioning service is also important to the service providers to ensure that customers do not receive erroneously reduced tariffs over large regions.

Obstacles to Growth

Location-based services have been implemented since the late 1990s. At that time, network operators and wireless service providers considered subscriber location as the "next big thing" to hit the market. Although the near-term expectations have diminished, LBSs still are considered as a promising way to generate new revenues and drive up wireless carriers' average revenue per user (ARPU).

Much has been written about this delayed LBS market development and many technical and business explanations have been given to justify the slower than expected take-off. Let's take a quick look at some of the reasons why the LBS market did not fulfill its early expectations.

Technical Issues. The technology is not yet ready to provide sufficient quality of service (QoS) for many LBS applications. QoS issues include such factors as unavailability of reliable indoor positioning, equipment size and cost, and the additional power demands on portable devices. In this context, QoS basically means a guarantee given by the service provider that the positioning service is available within specified performance limits.

Today's available positioning technologies, including GNSS, demonstrate the potential for LBS applications. In a real-world market-based environment, however, they have yet to satisfy many users' expectations about the services for which they will pay.

From a QoS and market perspective, the main technical obstacle that positioning technologies must overcome is the provision of seamless positioning as users move from outdoors to indoors or from open rural environments into dense urban areas – the most important environments for LBS users. Furthermore, currently available handsets show deficiencies in terms of screen size, graphics displays, storage memory, power consumption, or user interface mechanisms.

Customers' Perception of the Available Services. Offering high quality content is a prime concern for LBS application providers and represents an important enabler for the creation of successful services. In the past years, customers' experience of the LBS services was that the content was unsatisfactory — incomplete, inaccurate, or out of date — or even not available at all.

To achieve a satisfactory level of content quality, information service providers often need to combine more than one source of data and increase depth of data, such as restaurant type, "star" ratings, and opening hours. Putting all these data together in a coherent way is far from being a trivial exercise: it requires a high degree of automation as well as time-consuming and, thus, cost-intensive manual intervention to maintain complete and accurate LBS-oriented databases.

Operators' Attitudes towards the LBS Domain. In the past, mobile communications network operators have approached the LBS market very tentatively, even skeptically, investing limited resources in the development and marketing of LBS applications. Among the reasons for this hesitant behavior are the following:

- **The perceived high costs for deploying LBS technology.** The investment that U.S. operators faced to meet the

FCC's E911 mandate led to a more conservative attitude towards LBS applications among European operators. This resulted in the implementation of cheaper but less accurate and more variable network-based position technology, such as cell identity (cell-ID). Services built on these technologies produced limited revenues and, in turn, reduced operator enthusiasm for investing further.

- **The need to recoup from third-generation (3G) mobile network investments.** Operators gave priority to mobile data applications requiring 3G, such as multimedia message service (MMS), video streaming,and so forth, as a means for increasing ARPU. Since then, LBS have not been a priority in their business development strategies. This disinterest may stem, in part, from a simplistic perception of the small data throughputs required for position reports and, therefore, of the associated revenue potential. Liability and privacy concerns may also have added to carriers' reluctance to invest. However, LBS applications can benefit from the 3G capabilities and, reciprocally, can certainly enhance existing services, increasing the use and "stickiness" of these.
- **Lack of a "killer application."** Unlike text messaging (using short message service or SMS) and ring tones, which have become the killer applications in the European data services market, LBS has not yet shown compelling applications offering a significant return on investment (ROI) for operators. Yet, in other markets with different system parameters (for example, in Japan or South Korea due to the availability of CDMA networks), it has been possible to generate considerable revenues.

Standardization Issues. The LBS domain has a strong need for interoperability, mainly because of the large number of different kinds of players involved — carriers, positioning device manufacturers, digital mapping software and map server providers, information providers, and others. Several issues need to be addressed to ensure interoperable LBS solutions: Standardized interfaces that enable the different service components to scale and work together; commonly agreed data exchange formats that facilitate data handling and the integration of information in a transparent and manageable way; interoperable GNSSs, navigation systems, and positioning equipment operating under common well-defined standards to support hybridization and encourage market entrance of service providers.

Which Comes First?

The successful take-off of LBS seems to suffer from a classic "chicken-and-egg" dilemma: wireless carriers are waiting for users to express their strong interest and preferences in LBS before the system operators decide to make investments; meanwhile, users are waiting for the business and technical obstacles to be overcome before they can imagine using LBS and paying for the services.

Nevertheless, we can identify a number of ongoing activities that may be seen as precursors for a successful launch of the LBS mass market.

To solve the standardization issues, a number of international bodies have been established. Table 1 lists those of major importance for the LBS sector.

Standardization Organization	Subject	Comment
Open Mobile Alliance (OMA)	Mobile services, including location-sensitive services.	A diverse group formed by companies comprising mobile operators, device and infrastructure suppliers, and content and service providers. Primary interest to LBS because of the Secure User Plane Location (SUPL) protocol and Mobile Location Protocol (MLP), which are maintained within OMA. These protocols are used to handle GNSS and cellular location and assistance information through mobile telecommunication networks.
Open Geospatial Consortium (OGC)	Geospatial and location-based services	A consortium bringing together private industry, governmental organizations, and research institutes that is leading the development of standards for geospatial and location based services. For example, the consortium has developed the OpenLS, an open platform for location-based applications. Examples include a geo-coder service (transforms a description of locations into street address and postal code into coordinates) and a navigation service (determines travel routes and navigation information between two or more points)
Third Generation Partnership Project (3GPP)	Mobile communication evolution based on second-generation communication networks, e.g., GSM	The original scope of 3GPP was to produce globally applicable technical specifications and technical reports for a 3G mobile system based on evolving 2G radio access technologies that they support. The 3GPP has developed specifications for interfaces and performance of assisted satellite navigation and position hybridization between GNSS- and network-based positioning technologies.

TABLE 1. Standardization bodies relevant for LBS

In the past, LBS market development experienced a lack of assisted-GPS–enabled handsets with which users could access location services more pervasively and reliably. Such products have been under development for years and now are beginning to reach the marketplace.

Worthy of note are recent product launches of A-GPS enabled handsets, including some products from Nokia, one of the leading global mobile phone manufacturers. Several GPS technology suppliers have also announced the availability of A-GPS technology for mobile handsets at a unit cost of a very few U.S. dollars.

Availability of A-GPS–enabled handsets underlines the importance of satellite-based localization technology in the LBS area. Especially in view of the upcoming European satellite navigation system Galileo and ongoing modernization efforts of the American GPS and the Russian GLONASS systems, technical issues surrounding GNSS and LBS need a closer look.

GNSS and LBS

Today, mass market receivers mainly use the GPS coarse/acquisition (C/A) code for positioning. Given the ongoing development programs, within the next six years GPS satellites will be emitting 11 signals (counting pilot and data channels and carriers) on three different frequencies, GLONASS will probably transmit at least 6 signals on three frequencies.

Finally, Galileo will broadcast another 10 navigation signals on three frequencies, where the frequency bands and the ranging codes have partly been chosen in common with GPS to increase interoperability and compatibility. Not all signals will be available for civil use, but the user will be able to choose from a wide range of frequencies and signal designs.

Nevertheless, all GNSS systems rely on certain commonalities. In particular, they use travel-time measurements of the satellite signal to derive range information and, thus, position fixes. Any reflected signal (multipath) not traveling along the direct line-of-sight adds a bias to the range measurement and, consequently, decreases position accuracy. Thus, even when it is possible to receive GNSS signals indoors, sufficiently high positioning accuracy is not guaranteed.

That is the misfortune of using GNSS in the field of LBS: the excellent potential of GNSS ends at the entrance to buildings, inside which a large majority of their location requests originate, according to cellular network operators.

Among other objectives, a European project co-financed by the Galileo Joint Undertaking and now the European GNSS Supervisory Authority (GSA), the “Application of Galileo in the LBS Environment” or (AGILE), seeks to show how positioning performance could be improved in dense urban and indoor environments by using modernized GNSS signals, particularly the addition of Galileo. This component of AGILE is also looking into the hybridization of GNSS with cellular location technology.

To address the first item, the French Space Agency (Centre National d’Etudes Spatiales orCNES), which is a member of the AGILE project team, has conducted a number of simulations of GNSS signal availability. The analyses concentrated on showing the potential benefit of assisted A-GNSS for weak signal environments.

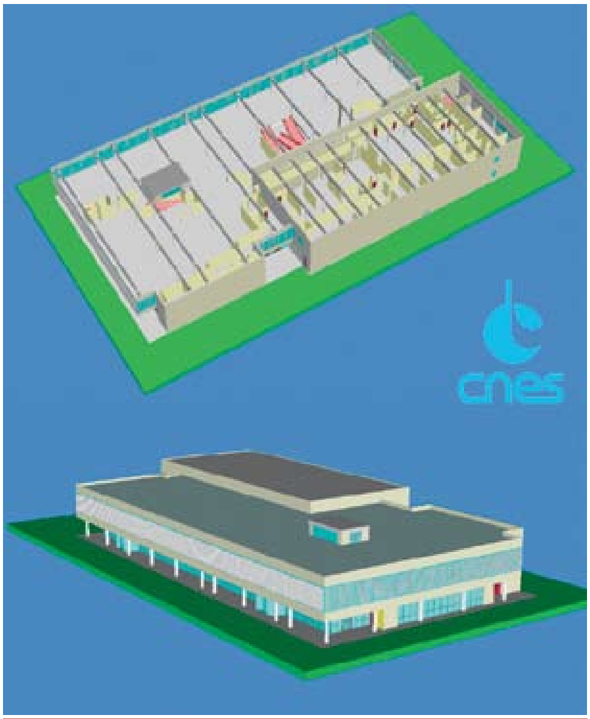

FIGURE 2 Model of the restaurant: indoor view of ground floor (top); exterior view (bottom)

In discussing these results, we must stress that they only calculate signal availability in terms of whether the signal power is higher than a predefined threshold at a given epoch. So, the results do not provide a definitive statement about whether the GNSS signals can be acquired and actually tracked, or that a position solution, if it can be computed, would be accurate or continuously available.

The simulations have been carried out with the aid of an analytical tool that simulates electromagnetic signal propagation using a 3D model of the environment. Applying a deterministic method of ray-tracing on geometrical optics, the software determines all the possible signal paths (direct path and reflections) coming from a GNSS satellite constellation.

For each channel (i.e., each satellite signal), generally made up of several paths, a composite signal power is computed, taking into account interactions provided by transmission, reflection, and/or diffraction effects.

The indoor simulations concentrated on a restaurant building on the ground floor inside the CNES premises in Toulouse. Results of the simulations conducted for the AGILE project show the average signal availability of a two-hour simulation (900-second sample interval) as determined for every point on the map (map resolution 0.5 m). Although only the average signal power over the sample duration was computed, CNES’ detailed analysis showed that the values changed little during this time.

The building, represented in **Figure 2**, is constructed with a glass front on three sides at the ground floor, and a combined glass and metal front on the first floor. Thus, this building provides a favorable environment for indoor GNSS positioning, because low-power GNSS spread spectrum signals are able to penetrate glass more readily than denser materials such as brick, concrete, or metal. The floors are connected by two stairwells. The following discussion and accompanying figures will present the results of signal-availability simulations of the ground floor.

The simulations are based on an assumption of minimum acceptable power levels at the receiver’ antenna as given in **Table 2**.

GPS receiver	Acquisition	Tracking
Autonomous Mode	-147 dBm	-160 dBm
Assisted Mode (A-GPS)	-155 dBm	-160 dBm

TABLE 2. Minimum acceptable power levels

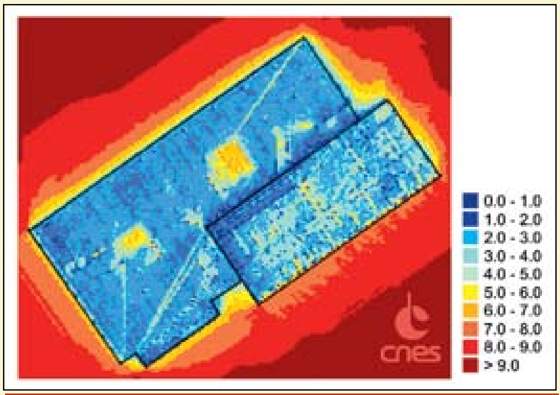

FIGURE 3 Average number of available GPS signals in acquisition mode

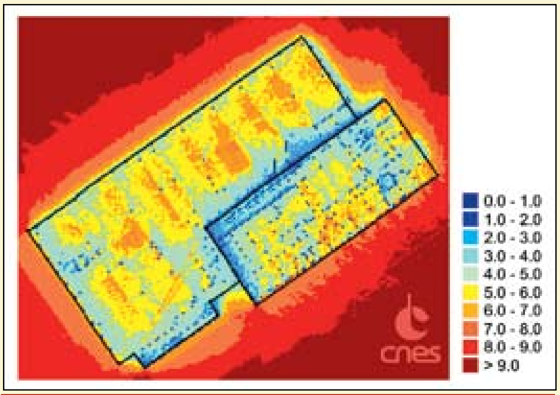

FIGURE 4 Average number of available A-GPS signals in acquisition mode

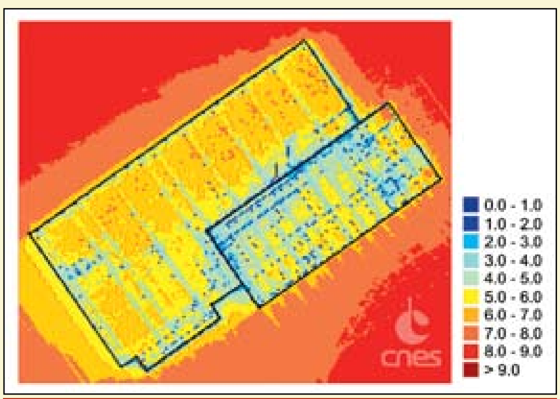

FIGURE 5 Average number of available A-Galileo signals in acquisition mode

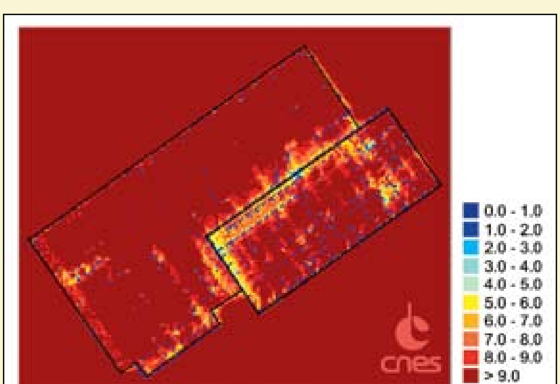

FIGURE 6 Average number of available AGNSS signals in acquisition mode

Simulation Results

The Galileo satellites power level at the receiver input has been assumed to be 8 dB higher than GPS, based on the specifications of the Galileo Signal-in-Space Interface Control Document. The simulations have been developed using a satellite constellation of 27 nominal Galileo satellites and 29 "real" GPS satellites. ("Real" refers to the fact that YUMA almanac data has been fed into the simulation for generating GPS orbits.)

GPS acquistion. Figure 3 shows the average number of GPS satellite signals received by a virtual receiver in acquisition mode (-147 dBm level) during the two-hour period. The two stairwells (yellow rectangles) in the building are clearly visible as locations where position determination might be possible, in contrast to the other areas inside the building. In the stairwells, the receiver 'sees' signals coming from the ground floor as well as from the first floor.

A-GPS Acquisition. The power level required for a GPS receiver to demodulate data during the acquisition of a satellite signal is higher than that needed to simply track a signal once acquired. Consequently, one may expect higher signal availability in A-GPS mode, where aiding information is provided through the separate communication link.

The A-GPS assistance data link not only replaces the navigation message, but this information can also be used for a first estimate of time and Doppler shift in the acquisition search space. This further improves the sensitivity of the receiver; hence, weaker signals can be acquired. This is expressed by the lower power level threshold compared to GPS-only mode (thus the 8 dB reduction assumed for the A-GPS acquisition power threshold in Table 2).

Figure 4 shows the average A-GPS signal availability assuming a signal strength of -155 dBm. The acquisition threshold is now sufficiently low to receive more than three satellite signals nearly throughout the whole building. As one might expect, the simulation result of A-GPS in tracking mode is better than the one of A-GPS in acquisition mode, due to the lower power level needed for tracking in contrast to acquisition. However, certain locations still offer fewer than the four satellite signals required for a 3-D position fix.

A-Galileo – Acquisition. The 8 dB higher transmitted power level and the improved signal structure of Galileo, plus the availability of a "pilot tone", leads to a higher availability in assisted Galileo (A-Galileo) mode. The previous A-GPS result should be compared with the scenario shown in Figure 5. The different configuration of the Galileo satellite constellation (three planes with 9 satellites in each compared to six planes with 4–5 GPS satellites in each) results in a lower number of average satellites available outside the building, but availability inside the building is significantly better than in the A-GPS case as a result of the other factors described just mentioned. Consequently, as expected, the simulation result of A-Galileo in tracking mode is also superior to that of A-GPS.

A-GNSS – Acquisition. More interesting for LBS applications is a combined use of GPS and Galileo in an assisted mode. The simulation results as shown in Figure 6 confirmed these expectations. Across almost the entire building, the number of "visible" satellite signals is higher than 4. The high redundancy of signals would favor a reliable position solution that achieves acceptable position accuracy when implementing addi-

Technology	Description	Features
Cellular network-based positioning technologies	Positioning capabilities offered by communication networks. Position determination may work through cell-ID, measurement of time differences, or measurement of angles to the nearby base stations.	Absolute position determination Need for regional infrastructure No need for local infrastructure (e.g., within buildings)
UWB-based positioning technologies	Ultra-wideband (UWB) transmits information through signals with very high bandwidth (> 500 MHz) over short distances. UWB can therefore be used for indoor positioning by applying techniques similar to the cellular network-based case.	Absolute position determination (often in a local coordinate frame) Need for regional infrastructure Need for local infrastructure (e.g., within buildings)
WLAN-based positioning technologies	Similar to UWB, wireless local area network (WLAN) is a standardized technology used for transmitting information over short distances. Position determination in WLAN networks often relies on signal strength measurements, which are converted to distances or used in symbolic approaches as demonstrated in the research described in the article by N. Samama cited in Additional Resources.	Absolute position determination (often in a local coordinate frame) Need for regional infrastructure Need for local infrastructure (e.g., within buildings)
Transponder/RFID-based positioning technologies	These technologies require pre-installed transponders that provide direct position updates to the mobile device within a range of a few meters; they are also used for indoor positioning.	Absolute position determination (usually in a local coordinate frame) Need for regional infrastructure Need for local infrastructure (e.g., within buildings)
Dead reckoning	Typically use autonomous sensors (gyros, accelerometers) for computing position displacements. In hybridized systems they are usually applied during outages of other, absolute positioning technologies to maintain position availability.	Relative position determination No need for regional infrastructure No need for local infrastructure (e.g., within buildings)
Digital maps, map matching, map aiding	Digital maps also provide a source of information for supporting GNSS-based positioning technologies. Either GNSS positions are matched to predefined areas (roads, buildings), or distance and angle measurements are taken from maps and integrated within GNSS position algorithms (map aiding)	No position determination No need for additional infrastructure

TABLE 3. Candidate technologies for integration with GNSS technology

tional filtering techniques such as those described in the article by T. Pany listed in the Additional Resources section near the end of this article.

Compared to autonomous positioning using satellite navigation systems already in operation, combining Galileo with these will bring improved accuracy and availability performance in indoor environment.

Integrated Positioning

Without a doubt, GNSS-based technology is the most important positioning technology being used today, which is also confirmed by the the favorable results suggested by the previous simulations. However, in certain deep indoor and other extreme GNSS-hostile environments, even assisted-GNSS alone is still not ready to deliver seamless service. Therefore, at least for the near future, GNSS shall be combined with other technologies to create robust positioning solutions.

Much has been written about hybridization of positioning technologies, and research activities are still ongoing with systems incorporating various combinations of these. Table 3 gives a brief overview of candidate technologies for integration with satellite-based positioning systems.

In the AGILE project, a combination of satellite and cellular network positioning has been investigated, to demonstrate the benefits of this combination of technologies for the mass-market deployment of LBS.

The following section presents the proprietary cellular network-based positioning method investigated in the AGILE project and outlines measurement results from a field trial. Note that the A-GNSS data exchange was implemented according to the secure user plane location (SUPL) protocol, version 2.0. This is the first realization of this protocol version in an operative system.

Network-Based Positioning. The network-based location technology under consideration is based on observed time difference (OTD) measurements. The technology measures the arrival times at the mobile telephone of the signals transmitted from the cellular network's base stations, which is equivalent to GPS pseudorange measurements made on satellites.

Time measurements are made in the handset using software, then passed to a server in the network (the SMLC) where the network timing model is constructed. The data may then be used to provide precise GPS Time to mobile handsets, even in an unsynchronized cellular network.

Network timing measurements — obtained either from the handsets, as was the case in the AGILE system trials, or extracted directly from the radio network infrastructure itself — are used to compute a network timing model in the Serving Mobile Location Center (SMLC). This results in a very precise (typically fewer than 200 nanoseconds) knowledge of relative base station times and time offsets across the whole network. Thus, on asynchronous GSM and W-CDMA networks, the system in effect "synchronizes" the network using a software process in the server.

When a position request is made for a specified target terminal, the terminal responds with its timing measurements. This information is used by the positioning server in conjunction with the corresponding base station data extracted from the network timing model to calculate the target mobile terminal's position. A more detailed description of the technology can be found in the

Typical test locations in central Turin (Italy)

2005 article by P.J. Duffett-Smith and P. Hansen cited in Additional Resources.

The commercial developer of this OTD positioning system has also developed, a method to tightly integrate it with A-GPS techniques. In this combination, the best features of both are combined into a single, complementary positioning solution. is able to provide fast, widely available positioning, especially in indoor and challenging urban environments, whilst the GPS component is able to provide high accuracy positioning and navigation whenever the GPS signal is available.

In the course of the AGILE project, we carried out tests in Turin, Italy, using a version of this integrated positioning system. Note that this solution only used the OTD network-based solution as the fall-back positioning method through a dedicated "switching" algorithm.

As well as operating in this "alternative position' mode as demonstrated in the AGILE project, the system is also able to provide very precise aiding data to a GPS receiver. This consists of the starting position — the OTD network-based position, which for is computed in the terminal itself, rather than in the SMLC – and GPS time, with an accuracy of better than five microseconds.

The augmenting technology is also able to provide the GPS receiver with precise frequency information to help narrow down the search area in this domain as well. Together, these elements enable GPS signal acquisition that is faster, available in more environments, and uses less battery power, with the cellular alternative position always being available — in less than one second — to provide a location in all environments.

Measurement Results. Trials of the OTD positioning technology were conducted in Turin, Italy, on the Telecom Italia cellular network during March 2007 using both A-GPS and the OTD network-based position technology in the alternative position mode. It was not possible to perform the tight coupling described earlier in this series of tests. Figure 7 shows the location of the test points in the central Turin area, at a mixture of outdoor and indoor sites in a dense urban environmentt, with different test teams' locations indicated by the various colors of the points in Figure 7.

Typical test point locations are in the accompanying photos with the exact location being the position of the test engineer seen in them.

An initial comparison was made between the performance achieved by the OTD networked-based system and a cell-ID plus timing advance (TA) system as well as with a simple cell-ID solution. The relative accuracies for each method showed that the OTD system provides 100 percent availability of positioning and is also the most accurate method — by a factor of two with respect to a system using cell-ID/TA and by a factor of more than four compared to a simple cell-ID system.

Overall, the typical OTD accuracy for the tests performed in the least GNSS-friendly environments of central Turin was 86 meters across all test environments, including indoor and dense urban locations. Position determination typically was achieved in less than three seconds, providing comparable performance with that of GNSS in these challenging environments with heavy multipath and little or no line-of-sight reception.

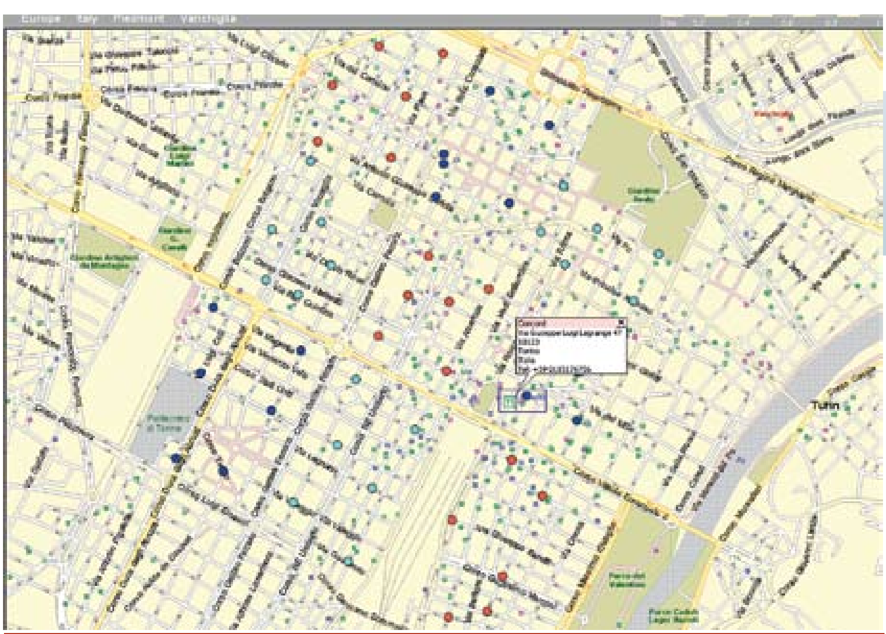

FIGURE 7 Central Turin test point locations. The colors of the dots indicates test locations that were visited by the various test teams during the trial.

Conclusions

The LBS market has the potential to provide huge benefits to consumers. However, LBS needs to overcome technical and market obstacles before it can achieve the growth rates long predicted by market analyses. The AGILE project seeks to overcome these limitations by defining market drivers for LBS applications and, as detailed in this paper, to mitigate current technical limitations by combining various positioning technologies that can provide the quality of service needed to enable LBS.

Acknowledgments

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The authors want to express their gratitude to Marco Boschetti (CNES, France) for the generation of the simulation results, and to Clive Flynn and Dr. Stuart Strickland (Cambridge Silicon Radio Limited, UK).

Manufacturers

Ergospace, a simulation tool for measuring the propagation of radio waves in 3d environments, is a product of **Ergospace**, Toulouse, France. The Matrix network-based positioning system and Enhanced GPS (EGPS) technology that combines Matrix and A-GPS into unified positioning system were developed by **Cambridge Silicon Radio Limited (CSR)**, of Cambridge, United Kingdom. The Matrix positioning software was implemented in test handsets supplied by **ZTE Corporation,** Shenzhen, China and an SMLC provided by CSR. The A-GPS device and A-GPS server were provided by **Thales Alenia Space** of Paris, France.

Additional Resources

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