Location Technologies for GSM, GPRS and UMTS Networks

SnapTrack, A QUALCOMM Company

SnapTrack
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White Paper

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1/2003 Location Technologies-WP X2

1 EXECUTIVE SUMMARY

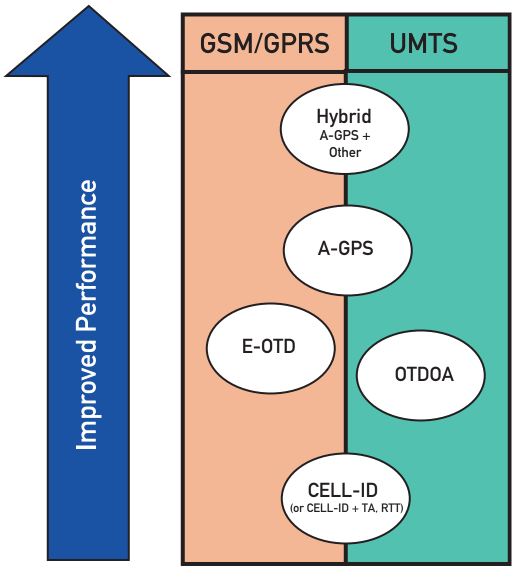
Recent marketing estimates from two market studies [1, 2] conclude that the wireless location services market will generate from $7B to $8B in revenue over the next few years – new revenue that is over and above that generated through services currently offered by wireless operators. This white paper presents the requirements for these services and compares the location technologies available to operators of GSM, GPRS and UMTS networks.

To be successful, location services must provide value and meet the service expectations of the subscriber as well as meeting the implementation and cost requirements of the operator. The location technologies examined in this paper are evaluated from the perspective of these requirements. Technologies considered are Cell-ID, Enhanced Observed Time Difference (E-OTD), Observed Timed Difference of Arrival (OTDOA), Wireless Assisted GPS (A-GPS) and A-GPS-based hybrid technologies (combining A-GPS with other standards-based technologies). From the analysis performed, key trends and the most appropriate solutions for new wireless location services are identified.

Conclusions:

Cell-ID is a cost-effective approach to location technology for GSM/GPRS and UMTS, and may be an excellent way for operators to introduce location services; however, Cell-ID provides inconsistent accuracy and fails to provide the performance necessary for the majority of new, lucrative location services.

FIGURE 1: LOCATION TECHNOLOGY PERFORMANCE TRENDS



E-OTD improves accuracy, but is expensive, operates only on GSM/GPRS and requires major changes to the infrastructure that make its deployment throughout multiple networks with independent operators cumbersome and unlikely, limiting the ability to offer services to roaming subscribers. OTDOA is similar to E-OTD, but may provide lower yield and operates only on UMTS networks.

A-GPS offers very good overall performance, easily supports roaming and network expansion, provides compatibility across 2G, 2.5G and 3G networks, and has a much lower cost than E-OTD or OTDOA when all cost elements are considered. In addition, A-GPS offers a natural extension to Cell-ID for improved performance, suggesting that an effective hybrid deployment can be based on a combination of A-GPS plus Cell-ID for high accuracy and improved yield. A-GPS can also be combined with limited "spot" deployments of E-OTD or OTDOA. These combinations can provide the performance and flexibility of A-GPS and may help improve yield in limited areas of the network, while maintaining the overall cost benefit to the operator.

BottomLine:

The flexibility and performance offered by A-GPS-based solutions, in particular the A-GPS-based hybrid, make them the best choice for addressing the majority of new location services as well as providing the maximum return on investment for the operator. As testimony to this, it is important to note that A-GPS based location services are offered commercially today on millions of phones, producing real revenue and enabling services that are increasing ARPU and subcribership.

2 INTRODUCTION

Wireless operators around the world have identified location services as a excellent opportunity for growth since recent market studies [1, 2] conclude the wireless location services market will generate from $7B to $8B in revenue over the next few years. Some operators have already launched commercial services or are currently evaluating different location technologies. Safety applications, for example, have become popular, evidenced by the April 2001 deployment of location-based security services in Japan by SECOM (Japan's largest private security company), and the North American E9-1-1 mandate.

As Table 1 shows, safety and security services are only a small part of a much larger application space. Beyond the example applications shown are hundreds of location service possibilities. The accuracy requirement for these applications varies, but the majority require accuracy in the 10-to-100 meter range and must support a highly mobile user who will likely roam across wide areas into various networks. It is generally agreed that increased accuracy and broad coverage will enable a larger number of services and increase the subscriber base available to operators. This has been proven in several markets, where today, high accuracy location services are being used vigorously by millions of subscribers that have increased the subscriber count and ARPU for the operator.

TABLE 1: EXAMPLES OF LOCATION SERVICES (CATEGORY GROUPINGS FROM RECENT MARKET STUDY [3])

TRIGGER SERVICES	INFORMATION SERVICES	TRACKING SERVICES	ASSISTANCE SERVICES
Location-sensitive billing	Mobile yellow pages	Commercial fleet management	Emergency notification
Automated advertising	Traffic reports	Find-a-friend, -pet, etc.	Roadside assistance
Special announcements	Weather notifications	Buddy service	Health- and medical-related location ID
Mobile commerce security	Navigation information	Asset tracking	Efficiency enhancement for business applications
Enhanced call routing	Wireless Internet services	Public safety dispatching	
Tolls and ticketing	Tourist services	Agency personnel safety	
	Dating and games		
	Logistics management		

Implementing an effective location solution requires that the operators, infrastructure providers, system integrators, and handset manufacturers work together to reconcile performance, cost, and implementation requirements for existing networks (GSM), networks in progress (GPRS), and planned networks (UMTS). This white paper presents the requirements for location services, summarizes the location technologies, and compares them for GSM, GPRS, and UMTS networks.

2.1 DEFINITIONS

The terminology used in this white paper to describe different aspects of location technology is defined in Appendix A and should be reviewed prior to reading the body of this document.

2.2 SCOPE

To simplify this white paper, we have limited the scope as follows:

- Focus is on standards-based technology – This paper addresses the following standardized location technologies: Cell-ID, E-OTD, OTDOA and A-GPS. Hybrid solutions that combine A-GPS with other standards-based technologies are also addressed, but hybrids without A-GPS are not. Note: While it is quite possible to swiftly introduce standards-based A-GPS messaging on a variety of convenient transport mechanisms, this paper assumes that only fully compliant signalling transport mechanisms are employed.

- Scope of analysis is limited to performance, implementation, and cost – The subject of "the killer app" is not addressed in this white paper. Also, any implementation or cost factors common to all technologies (such as standards-based signaling software) are ignored.

- A business model for location based services is available from SnapTrack as a separate white paper. Therefore, this white paper does not address specific business model issues.

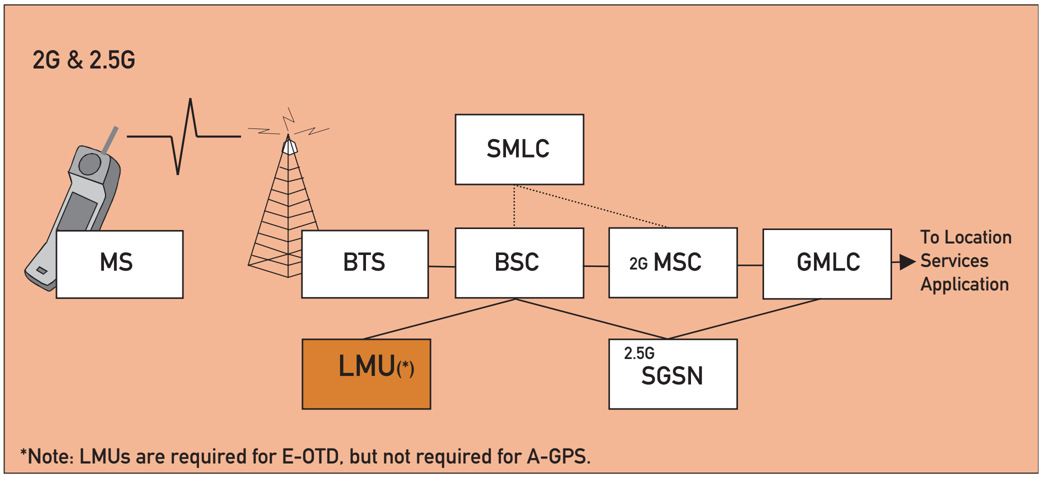
- GSM and GPRS are grouped together – Since GSM and GPRS networks share similar characteristics, they are treated as equivalent for the location service analysis.

- Network discussions are limited to location technology.

3 BASIC LOCATION SYSTEM ELEMENTS

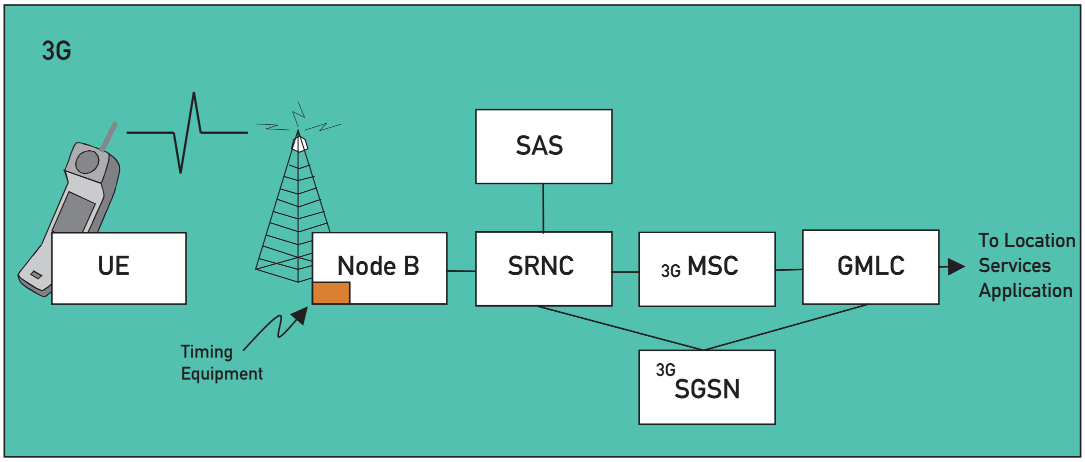
Figures 2 and 3 define the network elements commonly used in providing location information to the location services application. The elements for 2/2.5G systems are similar to the elements for 3G systems, but in some cases have different names and different functions. Definitions of the network element entities are provided in Appendix A.

FIGURE 2: BASIC LOCATION SYSTEM ELEMENTS ON GSM/GPRS NETWORKS



Note: When moving from 2G to 2.5G networks, the 2.5G SGSN is deployed, adding complexity to the BSC design. Various new elements need to be deployed to support voice, data and certain location technologies such as E-OTD (for example, LMUs are required for E-OTD).

FIGURE 3: BASIC LOCATION SYSTEM ELEMENTS ON UMTS NETWORKS



4 REQUIREMENTS

Location services offer an excellent revenue opportunity to the operator, but what does it take for a location service to be successful? Clearly, the service must provide value to the subscriber that creates demand for the service. Beyond this basic requirement there are other criteria that affect success, but at a minimum location services must meet at least three other key requirements:

1. Performance expectations of the subscriber
2. Implementation requirements of the operator
3. Cost and return-on-investment objectives of the operator

These criteria are defined in the following sections and will be used to evaluate each location technology later in this white paper.

4.1 PERFORMANCE REQUIREMENTS

One of the most common measures of performance is location accuracy, since accuracy is easy to measure and traditionally has been considered indicative of the quality of the solution. But accuracy is only one of several important performance parameters. The location technology must also produce the location information reliably, quickly and with consistent performance across a variety of networks and diverse geographies. More important than any individual performance requirement is the broader requirement that these goals all be achieved simultaneously. Only then will performance be adequate for most location services. The key performance requirements are defined in Table 2. For an example of real-world performance requirements, the North American E9-1-1 mandate requirements are provided in Appendix B.

4.2 IMPLEMENTATION REQUIREMENTS

Depending on the technology chosen, the implementation of location services can affect elements across the entire system. Implementation can dramatically affect the quality of service and, ultimately, whether or not the subscriber will consider the application valuable. As operators expand their properties through network development or acquisition, having a common location solution across all properties is beneficial. Solutions that are intrinsically local by their nature do not meet this requirement and limit service. As with the performance parameters, implementation requirements are considered as a simultaneous set of requirements, since all affect the success of the service. The key implementation requirements are defined in Table 3.

4.3 COST REQUIREMENTS AND RETURN ON INVESTMENT

Regardless of how well the technology performs or how easily it can be deployed, the implementation must support an efficient cost model to enable the operator to derive the maximum benefit from the service revenue. The cost analysis should account for costs in all stages of the service and consider the overall user experience for the deployed system – certain solutions may seem inexpensive, but may also limit the availability or quality of the location service to the point where they are counterproductive to the operator's business goals. The key cost requirements are defined in Table 4.

Also, it is important to look beyond cost. Perhaps the greater measure of value to the operator is the return on investment. Since this white paper does not address business models for location services, detailed ROI analyses cannot be performed. However, it is possible to rate the relative value a technology brings in relation to the cost of the technology. This is addressed in Section 7 – Return on Investment.

4.4 PRIVACY REQUIREMENT

The public sometimes expresses concern that location information can be used to invade their privacy, providing information on their whereabouts even if they don't want that information made available. The use and protection of a caller's location is typically managed by the operator, but certain technologies do lend themselves more easily to accommodating privacy, or at least lend themselves to the perception of managed privacy. Privacy is addressed at a summary level in the next section.

TABLE 2: KEY PERFORMANCE REQUIREMENTS

REQUIREMENT	DESCRIPTION
Yield	Solution should produce a high yield of location fixes (75% – 99% depending on the application and the conditions under which the position measurements are made) in difficult environments such as: • Dense urban areas (representing areas of high signal blockage and multipath) • Long straight roads (representing a linear network configuration) • Rural settings (representing sparse base-station coverage)
Consistency	Solution should produce consistent results in different environments and across a variety of networks. For example, a solution that produces 100-meter accuracy in some locations and 2000-meter accuracy in other locations does not perform consistently. Inconsistent performance can create doubt in a user's mind as to the overall reliability of the information and may also make the location service difficult or impossible to deliver.
Accuracy	Accuracy varies by application. Most location services require accuracy in the 10-to-100 meter range to enable a wide range of commercial services. Accuracy is typically measured in error relative to a known point – an accuracy of 50 meters specifies that the position will be within a circle with a radius of 50 meters from the actual point.
Start Time	Solution should produce location data quickly (also known as start time, time-to-first-fix, or TTFF). This parameter is typically measured in seconds and is expected to be in the range of 5-to-20 seconds for most technologies. This parameter can be affected by network latency, so it is important to differentiate between network latency and the time it takes for the technology to actually make a position calculation.

TABLE 3: KEY IMPLEMENTATION REQUIREMENTS

REQUIREMENT	DESCRIPTION
Handset Impact	New circuitry or software should minimize impact to the handset and have negligible incremental drain on battery power (commonly less than 5% of the battery charge).
Roaming Capability	Solution should easily support roaming across wide geographic areas, into other networks (e.g., GSM to GSM), and into different networks (e.g., GSM to UMTS).
Network Efficiency	Solution should use minimum over-the-air and backhaul network bandwidth for individual position reports as well as continuous position reports.
Network Expansion	Solution should easily support network expansion and be scalable. That is, as the operator expands the network, it should be easy to expand the location solution.
Network Compatibility	Solution should be standards compatible, compatible to new networks (e.g., GSM to UMTS), and compatible with existing networks (e.g., UMTS to GSM/GPRS).

TABLE 4: KEY COST REQUIREMENTS

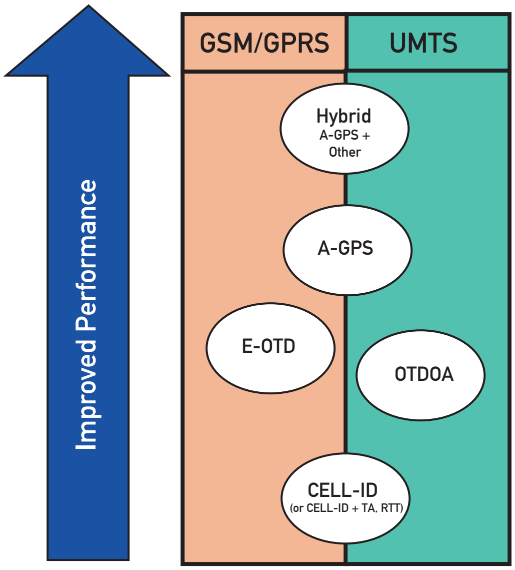
REQUIREMENT	DESCRIPTION
Handset Cost	Solution should not significantly increase the handset cost relative to the payback potential of the service offering.
Infrastructure Cost	Solution should not significantly increase the infrastructure cost relative to the payback potential of the service offering.
Expansion Cost	Solution should not require larger investments to expand the network or expand the service as subscriber demand grows.
Maintenance Costs	Solution should minimize maintenance costs.
Timing of Expenditures	Solution should provide an efficient economic model that minimizes up-front costs to avoid service pricing pressure.
Return on Investment	Solution should maximize the return on investment by providing value to the subscriber that generates service revenue at a low cost to the operator.

5 LOCATION TECHNOLOGIES

This white paper addresses standards-based location technologies only. These are listed below and shown in Figure 4:

- Cell-ID and Cell-ID variants (Cell site IDentification) – standards supported in GSM, GPRS, and UMTS
- E-OTD (Enhanced Observed Time Difference) – standards supported only in GSM/GPRS
- OTDOA (Observed Time Difference of Arrival) – standards supported only in UMTS
- A-GPS (Wireless Assisted GPS; also known as Assisted GPS) – standards supported in GSM, GPRS and UMTS
- Hybrid (combinations of A-GPS and other standards-supported technology) – standards supported in GSM, GPRS, and UMTS

FIGURE 4: SUMMARY OF LOCATION TECHNOLOGIES SHOWING STANDARDS COMPATIBILITY AND RELATIVE PERFORMANCE RATING



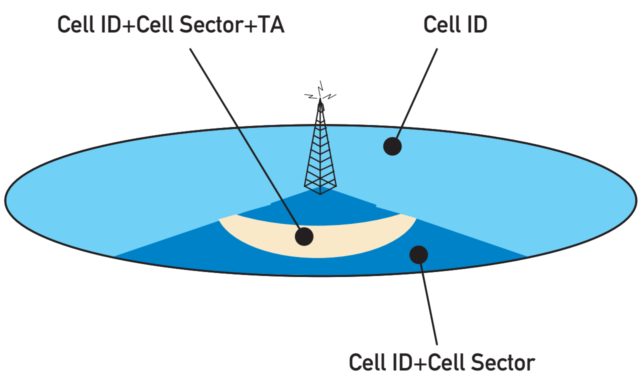
This section identifies the performance and implementation characteristics of these technologies relative to the requirements defined in the previous section. Also included are comments about privacy and the operation of these technologies on synchronous versus asynchronous networks. Cost comparisons for each technology are addressed in the Section 6 (Location Costs) and return on investment is addressed in Section 7 (Return on Investment).

5.1 CELL-ID

Cell-ID operates in GSM, GPRS and UMTS networks. It is the simplest way to describe the general location of a handset. It requires the network to identify the BTS to which the cell phone is communicating and the location of that BTS. If this information is available, the Cell ID LS identifies the MS or UE location as the location of the base station and passes this information on to the location service application.

Since the MS/UE can be anywhere in the cell, the accuracy of this method depends on the cell size, and can be very poor in many cases, since the typical GSM cell is anywhere between 2km to 20km in diameter. Further reducing the cell area by specifying cell sector is a typical strategy used to improve accuracy.

FIGURE 5: CELL-ID WITH CELL SECTOR AND TA



Positioning is generally more accurate in urban areas with a dense network of smaller cells than in rural areas where there are fewer base stations. If micro-cells are utilized, the cell size may be reduced significantly – to the range of several hundred meters. Ultimately, the diversity in cell-site size, density and operational characteristics across a network makes the accuracy of this technology inconsistent.

Cell-ID with TA or RTT. Cell ID accuracy can be further enhanced by including a measure of TA in GSM/GPRS networks or RTT in UMTS networks. TA and RTT use time offset information sent from the BTS/Node B to adjust a mobile handset's relative transmit time to correctly align the time at which its signal arrives at the BTS. These measurements can be used to determine the distance from the MS/UE to the BTS or Node B, further reducing the position error.

Even with the enhancements, however, this technology is one of the most inconsistent and least accurate of the technologies discussed in this paper. It is an inexpensive approach to implementing a very coarse location solution. Generally, the yield and TTFF are very good, but the accuracy is poor and the consistency of the solution varies dramatically, depending on cell site density. It is particularly poor in rural areas where cells are a long distance apart. In terms of implementation, it supports roaming to other networks without major modifications, is easy to maintain, and requires no major cost expenditure to expand the network. Despite these advantages, the basic accuracy performance supports only the minimum of possible services. Cell-ID characteristics are summarized in Table 5.

TABLE 5: SUMMARY OF PERFORMANCE AND IMPLEMENTATION CHARACTERISTICS FOR CELL ID

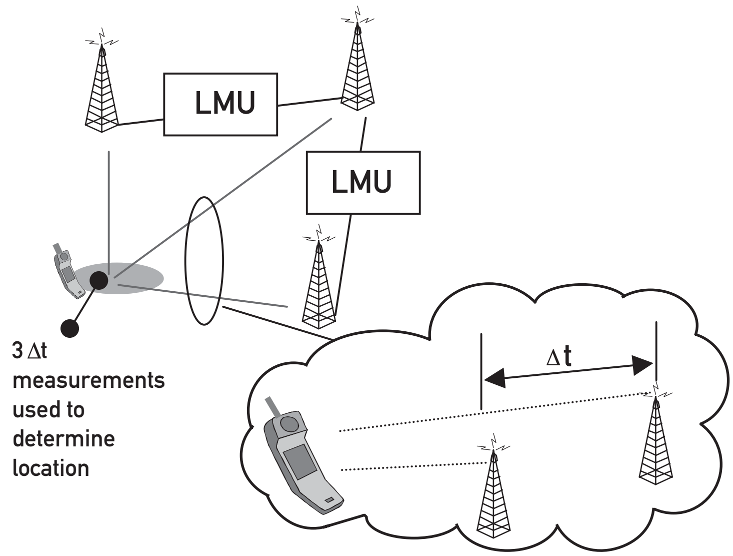
CRITERIA	RATING	COMMENT
Yield	Excellent	Requires only one base station.
Consistency	Poor	Accuracy varies widely depending on cell density and enhancing techniques.
Accuracy	Poor	500m-20km GSM, 100m-5km UMTS, two-dimensions only (no altitude).
TTFF	Excellent	Approx 1 second, depending on network latency.
Handset	Excellent	No changes required and no incremental battery power drain.
Roaming	Excellent	LS support is required in the roamed-to network.
Efficiency	Excellent	Uses minimum network bandwidth and capacity.
Expansion	Excellent	Easily supports network expansion and can be scaled.
Compatibility	Excellent	Cell-ID information is generally available in all networks.

5.2 ENHANCED OBSERVED TIME DIFFERENCE

E-OTD operates only on GSM and GPRS networks. In GSM, the MS monitors transmission bursts from multiple neighboring BTSs and measures the time shifts between the arrivals of the GSM frames from the BTSs to which it is communicating. These observed time differences are the underlying measurement of the E-OTD radio-location method and are used to trilaterate the position of the mobile device.

The accuracy of the E-OTD method is a function of the resolution of the time difference measurements, the geometry of the neighboring base stations, and the signal environment. The mobile handset must measure time differences from at least three base stations to support two-dimensional position determination (no altitude measurement is provided).

FIGURE 6: E-OTD OPERATION



Because time is critical to the location measurement, E-OTD requires precise time information. For GSM and GPRS, this requires the addition of Location Measurement Units (LMUs) everywhere in the network where a location service is offered at an average rate of 1 per every 1.5 BTS sites [5]. This deployment constraint comes from the requirement for each of the BTS in the network to be observed by at least one LMU. Further, special software is required in the MS to support E-OTD. E-OTD does not support legacy handsets without software modifications, at a minimum. This software cannot be downloaded over the air.

The need for LMUs introduces significant infrastructure changes. To provide network-wide coverage could require the installation of thousands of LMUs at existing BTS sites or at new sites near existing BTS sites. This requires significant network planning, an assessment of the RF impact to the network, adherence to local ordinances where new sites are involved, and the expense to plan, install, test and maintain the network of LMUs. As the communications network grows or existing networks are acquired, the same process must occur for the new BTS sites. If a subscriber roams into a partner network, there must be LMU support in the partner network to provide an E-OTD location service. This level of intricacy complicates the operator’s ability to provide roaming support for an E-OTD-based location service and extends the time required to deploy network-wide location service.

E-OTD solutions offer improved performance relative to Cell-ID, but require the use of LMUs. This increases the cost and complexity of implementation, as described above. E-OTD also requires a large number of data messages be exchanged to provide location information, and this information must be updated constantly. This message traffic is much greater than that used for A-GPS or Cell-ID, and E-OTD uses more network bandwidth than these other technologies. Because E-OTD must interact with at least three base stations and utilize terrestrial measurement to derive a position estimate, the technology is vulnerable to accuracy degradation from multipath and signal reflections, and will fail completely in areas where there are too few BTSs, such as rural areas. This situation is worsened by the fact that, although BTSs are placed in specific spots to optimize communication efficiency, these spots may be poor choices for use in deriving position estimates. For example, an MS in a line with several BTSs can produce ambiguous results, so the technology may operate unreliably along linear road networks where this BTS configuration relative to the MS may be common. For roaming, implementation of E-OTD requires major modifications since the roamed-to network must have LMUs. This is true even if only one subscriber wants to roam into a network. Also, expanding the network represents a major planning effort and requires major cost expenditures. E-OTD characteristics are summarized in Table 6.

TABLE 6: SUMMARY OF PERFORMANCE AND IMPLEMENTATION CHARACTERISTICS FOR E-OTD

CRITERIA	RATING	COMMENT
Yield	Average	Requires at least 3 BTS to determine position – poor rural coverage.
Consistency	Average	Accuracy varies depending on BTS density and location.
Accuracy	Average	100m to 500m, two-dimension position (no altitude provided).
TTFF	Very Good	Approx 5 seconds, depending on network latency.
Handset	Good	At minimum, SW changes required to handset; limited incremental power drain.
Roaming	Poor	Must have LS and LMU support in roamed-to network.
Efficiency	Average	Uses network bandwidth and capacity for LMU measurement traffic.
Expansion	Poor	Expansion requires LMU extension.
Compatibility	Poor	GSM/GPRS only – cannot be extended into UMTS networks.

5.3 OBSERVED TIME DIFFERENCE OF ARRIVAL

OTDOA operates only on UMTS networks. The OTDOA LS estimates the position of a handset by referencing the timing of signals as they are received at the UE from a minimum of three Node B stations. The handset's position is at the intersection of at least two hyperbolas defined by the observed time differences of arrival of the UMTS frames from multiple Node Bs.

OTDOA is generally considered a UMTS version of E-OTD. As such, its weaknesses are similar to those of E-OTD (time dependency drives need for timing units, poor yield in areas without at least three Node Bs, poor accuracy along linear networks, multipath degradation, compatibility with only one network, etc.). In addition, OTDOA has a unique characteristic that may result in yield below that of E-OTD. Because the UMTS network is based on CDMA, it is optimized for low power and the efficient use of communications bandwidth. The handset's ability to see and use multiple Node B stations is severely limited. This affects accuracy and, more important, influences yield to the point that overall OTDOA performance may in many cases be worse than E-OTD. A study in Germany [6] showed that a Node B density equivalent to the current GSM base-station deployment supports base-station visibility for 2-D positioning only between 28 percent and 36 percent of the time, a statistic that would suggest OTDOA is not viable as a standalone positioning technology. An approach that uses the idle-period down link (IPDL) to compensate for this problem is being considered, but IPDL isn't likely to work in path-loss-limited cell deployments (large cells in rural areas) since the UE won't be able to detect signals from the neighboring base stations even during IPDL periods. Further, the impacts on communication capacity resulting from periodically power-cycling NodeB transmissions are still unknown.

Since UMTS networks require new infrastructure, many networks will be synchronized to optimize communications [4] or designed so that they can be synchronized at a later date by adding timing equipment to appropriate network elements. For communications synchronization, this can be done using relatively inexpensive timing units throughout the network. To synchronize a network to the degree of precision required to support OTDOA location requires using more expensive timing units, such as LMUs. Because these expenditures can be included in the initial base-station implementation costs, they are not as easy to identify as the costs associated with LMUs on existing GSM/GPRS networks. But the costs are there, and will add up over time in maintenance and expansion costs. OTDOA characteristics are summarized in Table 7.

TABLE 7: SUMMARY OF PERFORMANCE AND IMPLEMENTATION CHARACTERISTICS FOR OTDOA

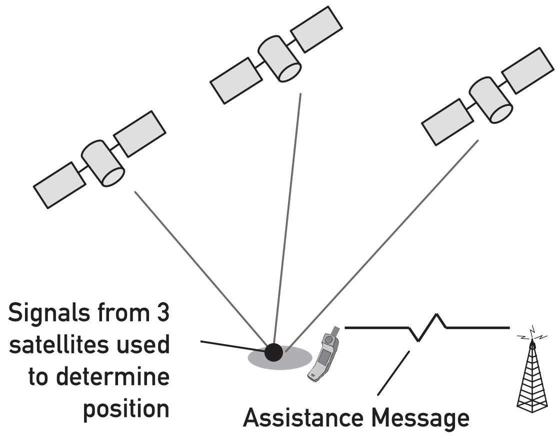
CRITERIA	RATING	COMMENT
Yield	Average	Requires at least 3 BTS to determine position – poor rural coverage.
Consistency	Average	Accuracy varies depending on BTS density and location.
Accuracy	Average	100m to 500m, two-dimension position (no altitude provided).
TTFF	Very Good	Approx 5 seconds, depending on network latency.
Handset	Good	At minimum, SW changes required to handset; limited incremental power drain.
Roaming	Poor	Must have LS and LMU support in roamed-to network.
Efficiency	Average	Uses network bandwidth and capacity for LMU measurement traffic.
Expansion	Poor	Expansion requires LMU extension.
Compatibility	Poor	GSM/GPRS only – cannot be extended into UMTS networks.

5.4 WIRELESS ASSISTED-GPS

Wireless Assisted GPS operates on GSM, GPRS and UMTS networks. A-GPS uses satellites in space as reference points to determine location. By accurately measuring the distance from three satellites, the receiver triangulates its position anywhere on earth. The receiver measures distance by measuring the time required for the signal to travel from the satellite to the receiver. This requires precise time information, so for 3-dimensional positioning, measurements from a fourth satellite are required to help resolve time measurement errors created by the inaccuracies of inexpensive timing circuits typically used in MS/UEs.

Accurate time can be derived from the satellite signals, but this requires demodulating data from the GPS satellites at a relatively slow rate and requires that the satellite signals be relatively strong. To address this limitation, an A-GPS receiver utilizes aiding data from an A-GPS LS that provides the receiver information it would normally have to demodulate as well as other information which increases start-up sensitivity by as much as 25dB (relative to conventional GPS) and reduces start times to approximately five seconds (independent of network latency). This approach eliminates the long start times typical of conventional GPS (one to two minutes) and allows the A-GPS receiver to operate in difficult GPS signal environments, including indoors. A-GPS yield will drop in environments where the satellite signals are severely blocked.

FIGURE 7: A-GPS OPERATION



A-GPS receivers can operate in several modes, but there are two primary modes of assisted operation, MS/UE-based and MS/UE-assisted. In MS/UE-assisted mode, the A-GPS receiver in the handset obtains a small set of aiding data from the A-GPS LS, then calculates only pseudoranges from the satellite signals (distance measurements to the satellites in view), then sends this information back to the A-GPS LS, which calculates the position. In MS/UE-based, the position calculation is made in the receiver, which requires an extended set of assistance data.

A-GPS provides better accuracy than CELL-ID, E-OTD or OTDOA, and operates on asynchronous or synchronous networks without the need for LMUs (although LMU information can be used if it is available). An A-GPS implementation has almost negligible impact on the infrastructure and can easily support roaming, but requires A-GPS circuitry inside the phone, so legacy handsets cannot be supported without modification. A-GPS requires message exchanges with an A-GPS LS in the infrastructure, but there is flexibility in how this is handled, and the messages are small. In contrast to LMU-based technologies, activating an A-GPS-based solution in a new network or roaming into an existing network requires only a connection to an A-GPS-enabled location server for support – no expensive hardware or major network changes are required, although if precise time is available from LMUs, A-GPS TTFF and sensitivity can be further optimized. A-GPS characteristics are summarized in Table 8.

TABLE 8: SUMMARY OF PERFORMANCE AND IMPLEMENTATION CHARACTERISTICS FOR A-GPS

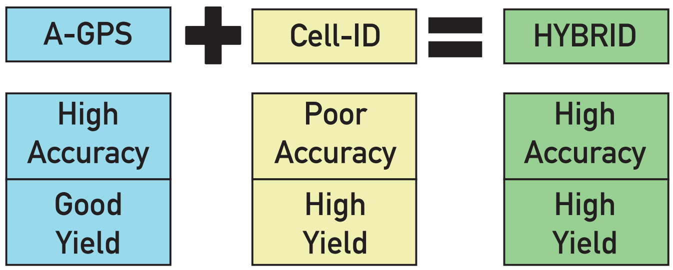
CRITERIA	RATING	COMMENT
Yield	Very Good	Assistance improves sensitivity and therefore yield, significantly.
Consistency	Very Good	Accuracy is consistent across geographies and networks.
Accuracy	Excellent	Typically 5m to 50m, three-dimensional position (includes altitude).
TTFF	Very Good	First fix typically 5-10 seconds plus network latency.
Handset	Average	HW & SW changes required to handset; power drain within criteria.
Roaming	Excellent	Requires only A-GPS LS support in roamed-to network.
Efficiency	Very Good	Uses minimum network bandwidth and capacity.
Expansion	Excellent	Easy expansion.
Compatibility	Excellent	Supports all networks (old and new).

5.5 HYBRID TECHNOLOGY

A-GPS-based hybrids operate on GSM, GPRS and UMTS networks, although compatibility depends on the other location technology used with the A-GPS technology. Hybrid location technology combines A-GPS with other location positioning in a way that allows the strengths of one to compensate for the weaknesses of the other to provide a more reliable and robust location solution. Because A-GPS is air-interface independent, it can be combined with any of the other technologies discussed in this paper to suit the network plan and service offering, rollout plans, and budget restrictions of the operator. Hybrid solutions are typically designed to use the best information available from A-GPS or terrestrial sources, either individually or in combination, to provide accurate and reliable positioning even where independent network solutions and unassisted GPS solutions fail.

The most straight-forward implementation of Hybrid technology for GSM, GPRS and UMTS networks is to combine A-GPS with Cell-ID. This improves yield in areas where A-GPS cannot produce position information and provides the accuracy of A-GPS in all other cases. A-GPS coverage and accuracy is typically excellent just about anywhere a subscriber can go, degrading only deep inside buildings or in dense urban areas where Cell-ID may still be able to produce a position. Typically, these are areas where cell density is high, so Cell-ID will be at the more desirable end of its accuracy range, though it will not be as accurate as A-GPS. The combination of A-GPS and Cell-ID also incorporates the roaming advantages defined for both Cell-ID and A-GPS, and can be used in networks with a high population of legacy handsets – Cell-ID can be used as the location technology for the legacy handsets and as a safety net for environments that degrade A-GPS.

FIGURE 8: HYBRID OPERATION



As an alternative to combining A-GPS and Cell-ID, A-GPS can also be combined with E-OTD or OTDOA. This approach requires only spot deployments of E-OTD or OTDOA, allowing A-GPS to be used in the majority of the network to provide the basis for most location information. The Hybrid approach generally improves yield and allows the location technology performance to gracefully degrade in a way that supports most location services. Hybrid characteristics are summarized in Table 9.

TABLE 9: SUMMARY OF PERFORMANCE AND IMPLEMENTATION CHARACTERISTICS FOR HYBRID

CRITERIA	RATING	COMMENT
Yield	Excellent	Assistance improves sensitivity and therefore yield, significantly.
Consistency	Very Good	Accuracy is consistent across geographies and networks.
Accuracy	Excellent	A-GPS is typically 5m to 50m, three-dimensional position (includes altitude). May degrade depending on the technology combined with A-GPS.
TTFF	Very Good	First fix typically 5-10 seconds. Depends on network latency.
Handset	Average	HW & SW changes required to handset; power drain within criteria.
Roaming	Excellent	Requires only A-GPS LS support in roamed-to network. May be some limitations if combined with E-OTD or OTDOA.
Efficiency	Very Good	Uses minimum network bandwidth and capacity.
Expansion	Excellent	Easy expansion.
Compatibility	Excellent	Hybrid approach can be adapted to different networks.

5.6 SYNCHRONIZED VERSUS ASYNCHRONOUS SYSTEMS

The location solutions for each technology described in this white paper share a common characteristic: the accuracy, speed and yield are affected by the degree of time precision to which each technology has access. In precisely synchronized networks (e.g., existing CDMA systems), precise time is available throughout the system and can be used by the location technology. In asynchronous networks (existing GSM systems and planned GPRS systems), precise time is not available, and must be created by adding timing units (i.e., LMUs) to the existing infrastructure or derived in some other way. For UMTS, networks will be operated in either synchronized or asynchronous modes, but for location capabilities, the time precision required is greater than that used for synchronized wireless mobile management.

For Cell-ID, there are no special timing requirements unless it is supplemented with TA or RTT, in which case the handsets use the coarse time in the network to make approximate position calculations. This is an inexpensive solution but, as mentioned earlier, provides inconsistent accuracy.

For E-OTD, LMUs must be deployed throughout the network to provide precise timing information. This timing equipment enables E-OTD location, but can make the location technology deployment very expensive (see Location Costs section) and, even with the added expense, does not provide optimum performance.

For OTDOA, precise time is needed throughout the network, even if the network is synchronized, because the synchronization required for wireless mobile management on UMTS systems has resolution on the order of tens of microseconds, which is inadequate for the tens-of-nanoseconds resolution required for OTDOA. For mobile management, operators can use relatively inexpensive timing units to optimize communications performance [4] at little incremental cost. The synchronization required to support location using OTDOA uses much more expensive timing equipment, meaning an operator must make a significant investment to enable OTDOA.

A-GPS requires precise time to perform satellite signal processing. It can utilize precise time from a synchronized network (which provides optimized TTFF and sensitivity), or derive it on either a synchronized or an asynchronous network from aiding data received from the Location Server. A-GPS operates on any air interface network, synchronized or not, without requiring any costly equipment to derive time, and will operate with enhanced efficiency and performance on precisely synchronized networks. Table 10 summarizes the synchronization aspect of each technology for each air interface.

TABLE 10: LOCATION TECHNOLOGY TIMING REQUIREMENTS BY AIR INTERFACE

TECHNOLOGY	GSM/GPRS	UMTS-SYNCH	UMTS-ASYNCH	COMMENTS
Cell-ID	Cell-ID + TA uses Coarse Time	Cell-ID + RTT uses Coarse Time	Cell-ID + RTT uses Coarse Time	No special timing requirements
E-OTD	Requires precise timing unit	Not compatible	Not compatible	Use of timing units increases cost and complexity
OTDOA	Not Compatible	Requires precise timing unit	Requires precise timing unit	Use of timing units increases cost and complexity
A-GPS	Uses Assistance Message for time	Uses Assistance Message for time	Uses Assistance Message for time	Can use precise time from LMUs or other sources if available, but not required

5.7 PRIVACY

Cell-ID information is available in GSM networks today as an integral part of call processing. It can also be used to provide coarse position information. For this reason, it may be perceived by the subscriber to be difficult to disable, even though it may be possible through software changes to eliminate this information from use by unauthorized personnel in the network. In contrast, A-GPS requires that circuitry in the MS/UE be used in the position calculation. These circuits can be disabled by a keypad instruction, thereby easily turning off the part of the phone that is responsible for location. Since this gives the user control and disables the position function, A-GPS will likely be viewed as a technology that affords a high degree of privacy. Since E-OTD and OTDOA depend heavily on infrastructure measurements, they are often incorrectly perceived as network-based technologies (they also require special software in the MS/UE), and thus the control of the location calculation is perceived to be in the network, making the user wonder if they can really turn off the feature. E-OTD and OTDOA will likely be viewed as a technology that provides limited privacy.

6 COSTS

The cost of implementing location services depends on a large number of factors, such as handset modifications, infrastructure modifications, new infrastructure deployment, maintenance activity, network expansion plans, etc. These costs are addressed in this section as order of magnitude costs that identify the cost trends in the technologies. Our analysis looks at incremental costs beyond baseline costs that are common to all technologies. To simplify the analysis, we have grouped the technologies into three categories:

1. Cell-ID
2. E-OTD, OTDOA
3. A-GPS

There is often confusion about the costs associated with the last two categories, so a cost comparison between E-OTD and A-GPS is provided at the end of this section.

6.1 CELL-ID

Cell-ID-based technologies can be implemented using the general communications infrastructure as it exists today (or as it may be introduced in 3G networks), with limited changes. As noted in Table 11, this category of solutions offers the lowest implementation cost. Unfortunately, the accuracy of these systems is such that these technologies alone will not support the majority of the location services that subscribers are projected to demand. These technologies offer the opportunity for general services that require limited accuracy, but do not provide a solution that allows the operator to offer a wide suite of location services or the flexibility to quickly address requests for new accuracy-oriented services.

TABLE 11: COST FACTORS FOR CELL-ID-BASED TECHNOLOGIES

COST AREA	COST FACTOR	COMMENTS
Handset Cost	Low	No modifications required to the handset.
Infrastructure Cost	Low	Other than the addition of LS software, no modifications are required in the infrastructure.
Expansion Cost	Low	This cost is low as long as network expansion is done into a network that supports the technology.
Maintenance Cost	Low	No special maintenance required.
Timing of Expenditures	Low	No extraordinary costs associated with any stage of deployment.
Overall Cost Factor	Low	Overall, technologies in this category are relatively low cost.

6.2 E-OTD AND OTDOA

E-OTD can be implemented only by adding significant numbers of LMUs to GSM and GPRS infrastructures. OTDOA can be implemented only by planning precise timing equipment in the baseline equipment for 3G networks or adding precise timing equipment later. For both technologies, there is infrastructure hardware and software that must be added. Also for both, at a minimum, special handset software must be installed. As noted in Table 12, these solutions are the most expensive to implement. And given the huge cost investment required, the performance of these systems is not the best available in the technologies discussed in this paper.

TABLE 12: COST FACTORS FOR E-OTD AND OTDOA TECHNOLOGIES

COST AREA	COST FACTOR	COMMENTS
Handset Cost	Low	Modifications to existing handsets are required for E-OTD. Special software is also required for new E-OTD-based handsets and new OTDOA-based handsets.
Infrastructure Cost	High	Cost depends on the size of the deployment. For these solutions to work on asynchronous networks, LMUs must be deployed at base stations throughout the infrastructure, wherever location coverage is desired. For most operators, this represents a large number of base stations and thus a substantial cost. There is also significant planning and analysis that must be performed to ensure the addition of timing units does not conflict with the RF characteristics of the existing network. This applies for basic infrastructure changes as well as changes related to expansion. In addition, there may be easement issues with modifying existing towers to accommodate new equipment or with erecting new sites for the new equipment.
Expansion Cost	High	Cost is high since the network being expanded must have LMUs at the majority of base stations. If expanding into an existing network, that network must be outfitted with LMUs requiring the same costly planning, deployment, and maintenance support described above.
Maintenance Cost	High	After being deployed, each LMU must be maintained according to a specified maintenance schedule. This requires management time to keep track of the maintenance effort, technician time to perform maintenance, and equipment cost if LMUs need to be replaced.
Timing of Expenditures	High	Upfront investment for LMU deployment can be huge. Even if only a small number of subscribers initially request the service, the entire coverage area must be enabled with LMUs.
Overall Cost Factor	High	The cost factor is high to deploy an initial system, and remains high throughout system deployment for ongoing maintenance, and costs for additional LMU deployment if expansion is made to another network, or if roaming into a partner network requires that the partner deploy LMUs as well.

6.3 A-GPS

The technologies in this category can be implemented with appropriately enabled handsets using the general communications infrastructure as it exists today (or as it may be introduced in 3G networks), with minor changes. As noted in Table 13, the overall cost factor is low to moderate, and provides very good performance in most conditions, enabling the operator to provide the widest range of services possible and the flexibility to quickly address requests for new accuracy-oriented services.

TABLE 13: COST FACTORS FOR A-GPS TECHNOLOGIES

COST AREA	COST FACTOR	COMMENTS
Handset Cost	Medium	A-GPS circuitry must be added to the handset. This circuitry can be deeply integrated into the phone's components, so that its cost is minimal (much lower than perceived relative to using discrete devices or separate boards).
Infrastructure Cost	Low	Other than A-GPS LS software, no infrastructure modifications are required.
Expansion Cost	Low	A handset enabled with A-GPS requires no changes to move to another network. A small infrastructure change in the new network will accommodate expansion.
Maintenance Cost	Low	Negligible maintenance cost in the infrastructure since location-server locations are limited and typically centrally located.
Timing of Expenditures	Low	A-GPS based solution can be supported with very little up-front costs. If a small subscriber base is launched initially, only their handsets require A-GPS circuitry, so the handset cost scales directly with the growth of the subscriber base, linking expenditures directly with revenue growth.
Overall Cost Factor	Low to Medium	High performance and very low infrastructure costs make this an attractive technology. Handset-based solutions are less expensive than perceived, and the cost of the circuitry in the phone will continue to decrease as integration and Moore's law is applied to semiconductor implementations of the GPS circuitry.

6.4 COST COMPARISON – E-OTD VERSUS A-GPS

As mentioned earlier, the debate over location technology cost is often focused on E-OTD technology versus A-GPS technology. Below is a comparison of order-of-magnitude cost estimates. The assumptions and calculations are presented first, and then summarized in Table 14. In this example, the cost for the E-OTD system is nearly twice that of the A-GPS system. Regardless of the size or type of installation, however, for the comprehensive network coverage required to ensure adequate performance, the need for LMUs always makes E-OTD more expensive than A-GPS, yet A-GPS outperforms E-OTD!

General assumptions:

- Network of 20 million subscribers, growing at 2 million subs/year
- 2400 subscribers/base station
- 20% LBS penetration

- Location server costs are capacity-based and are equivalent for E-OTD and A-GPS; server maintenance costs are equivalent for E-OTD and A-GPS
- Costs are calculated using a discounted cash flow (DCF) methodology, which accounts both for the perpetually recurring nature of some of the costs (e.g., new LMUs, annual LMU maintenance, handsets) and the time value of money, to produce a Net Present Value (NPV).
- Discount rate for NPV calculation: 18%

E-OTD assumptions and calculations:

- One LMU for each base station to achieve acceptable accuracy
- Each LMU retrofitted on an existing base station costs $8,000 for hardware, software, planning, installation and validation; NPV for retrofitted LMUs = $56.5 M
- Each LMU included in a new base station costs $4,000 for hardware, software, planning, installation and validation; NPV for new LMUs = $14.8 M
- 5% additional "LMU only" sites, required to address holes in coverage and geometry, at $70,000 per site (including LMU installation) [6,7]; NPV for additional sites = $37.7 M
- 15% annual maintenance assessed on LMU cost basis; NPV for LMU maintenance = $76.4 M
- Total perpetuity-based cost of incremental equipment required solely for E-OTD = $185 M

A-GPS assumptions and calculations:

- 18 month average handset life
- Three-year ramp to achieve full (20%) LBS penetration on existing subscriber base.
- Delta price to operator for A-GPS-enabled handset is $25 in first year, declining to $2 by sixth year; NPV for A-GPS handsets = $95.2 M

TABLE 14: SUMMARY OF COSTS ONE YEAR AFTER INITIAL INSTALLATION

	COST FOR A-GPS	COST FOR E-OTD	COMMENTS
Summary of Perpetuity Costs			
Retrofit LMUs New LMUs LMU-Only Sites Annual Maint. Handsets Items as defined in assumptions above	0 0 0 0 $95.2M -------------- $95.2M	$56.5M $14.8M $37.7M $76.4M 0 -------------- 185.4M	This analysis does not reflect the impact of the performance difference of the two solutions, which favors AGPS; a true economic comparison would need to account for the **incremental revenue generated from services enabled by the additional precision available with A-GPS that would not be possible with an E-OTD solution**
Comparisons of Key Cost Parameters			
Expenditure required for the first year	$26.7M	$95.8M	**A-GPS cost scales as handsets are deployed and revenue can be realized so as to minimize initial expenditures and capital expenses**. E-OTD cost starts high (including a large initial capital expenditure) regardless of LBS subscribers since network-wide LMU coverage is required to offer comparable service to even a single subscriber
NPV of on-going network maintenance cost	$0	$76.4M	E-OTD maintenance cost adds up (and increases) year after year; **there are no network maintenance costs for A-GPS**, outside of the location server maintenance assumed to be the same for both A-GPS and E-OTD

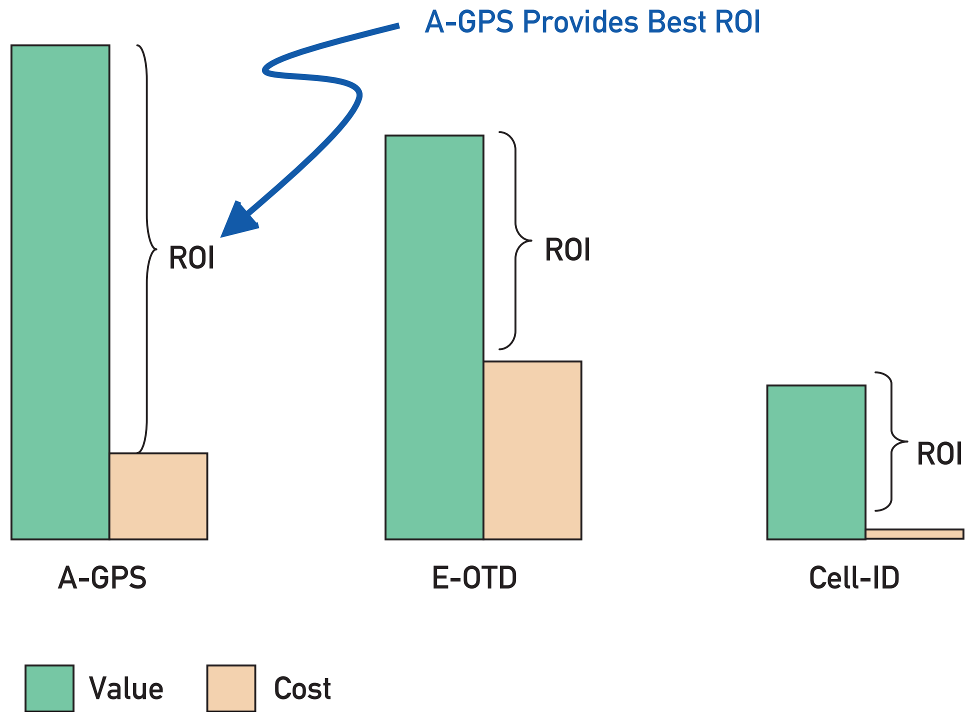
7 RETURN ON INVESTMENT

The costs for location technology can vary widely, and the ultimate cost to the operator will depend on the technology chosen as well as the type and breadth of service offered. A cost analysis alone can be misleading, however, since the true measure of the value to the operator is the return on investment (ROI) rather than cost. A large initial cost may be acceptable if the payback justifies it. In contrast, an inexpensive approach is useless if it bears no service revenue or provides no measurable value to the customer.

This white paper has not attempted to provide a business model or analyze applications, so an extensive ROI analysis is not provided (though a business model for location services is available from SnapTrack as a separate white paper). However, this white paper does address general trends in ROI. Better performance generally enables a broader range of services. Presumably, these services will provide more value to the subscriber than the general services that are enabled by Cell-ID. Cell-ID has been available in networks for a long time, but has not resulted in broad acceptance of location services, so one must conclude that better performance is needed to generate a better return.

Figure 9 shows that A-GPS provides the best return on investment. It has the best performance, which should enable the broadest spectrum of location services and generate the most revenue. And since it has a low cost relative to E-OTD and OTDOA, the ROI for A-GPS is very large. While Cell-ID is the least expensive, history has shown that its performance does not enable location services that subscribers value on a large scale, so it provides a poor return. E-OTD performance does enable a number of location services, but its deployment cost is high for less precision than A-GPS, so its ROI is poorer. Also, since roaming can be restricted with E-OTD, the typical subscriber (whose profile definitely includes roaming among networks) may find lesser value in the application and thus tend to invest subscription dollars in other services.

FIGURE 9: TRENDS IN ROI



8 LOCATION TECHNOLOGY COMPARISON SUMMARY

Each technology should be evaluated in light of its advantages and disadvantages for the application, considering the simultaneous performance, implementation and cost requirements. Table 15 summarizes these characteristics using the data from previous sections.

For additional detail on performance characteristics, an excellent source of independent technology performance comparisons, available to the general public, is the company technology evaluation filings for the North American FCC E9-1-1 mandate. For example, in a recent filing that compared E-OTD, Multipath Fingerprint, and A-GPS, A-GPS was shown to dramatically outperform the other technologies and was the only technology that met the performance mandate. For public information on carrier technology evaluations (test conditions, performance comparisons and conclusions), visit the FCC website [9]. SnapTrack can also help the reader gain access to this public information.

TABLE 15: SUMMARY OF PERFORMANCE, IMPLEMENTATION, AND COST RATINGS FOR EACH TECHNOLOGY

REQUIREMENT	CELL-ID	E-OTD	OTDOA	A-GPS	HYBRID
Yield	Excellent	Average	Poor	Very Good	Excellent
Consistency	Poor	Average	Average	Very Good	Very Good
Accuracy	Poor 100m-20km 2-dimensions	Average 100m-500m 2-dimensions	Average 100m-500m 2-dimensions	Excellent 5m-50m 3-dimensions	Excellent 5m-50m 3-dimensions
TTFF	Excellent 1s	Very Good 5s	Very Good 5s	Very Good 5-10s	Very Good 5-10s
Handset	Excellent	Good	Good	Average	Average
Roaming	Excellent	Poor	Poor	Excellent	Excellent
Efficiency	Excellent	Average	Average	Very Good	Very Good
Expansion	Excellent	Poor	Poor	Excellent	Excellent
Compatibility	Excellent	Poor	Poor	Excellent	Excellent
Overall Cost	Excellent	Poor	Poor	Very Good	Very Good
Summary	**Average**	**Average**	**Poor**	**Very Good**	**Excellent**

9 CONCLUSIONS – PERFORMANCE, IMPLEMENTATION AND COST TRENDS

The majority of location service applications require high performance at a reasonable cost to optimize return on investment. From the general summary in Table 15 and the trends summarized in Table 16, the most appropriate technology for location services is an A-GPS-based solution, since:

- Cell-ID meets cost objectives, supports roaming, but provides generally poor performance and poor ROI,
- E-OTD provides good performance, but has severe roaming limitations, is expensive, is limited to GSM networks and provides poor ROI,
- OTDOA provides average performance, but has severe roaming limitations, is expensive, is limited to UMTS networks and provides poor ROI,
- A-GPS provides very good performance, is relatively inexpensive, supports roaming, can be used on all networks and provides good ROI,
- A-GPS hybrid combinations of A-GPS + Cell-ID provide very good performance, support roaming, optimize yield, minimize the cost of the hybrid implementation and provide ROI on par with A-GPS solutions,
- A-GPS hybrid combinations with spot deployments of E-OTD or OTDOA are also viable, but the complexity and cost of these implementations increases over the A-GPS + Cell-ID hybrid because of the need for LMUs in the network to support E-OTD/OTDOA, which can decrease the ROI.

TABLE 16: SUMMARY OF PERFORMANCE, IMPLEMENTATION AND COST TRENDS

TREND	CELL-ID	E-OTD, OTDOA	A-GPS
Performance Trends	• Cell-ID accuracy varies dramatically and is often very poor • Provides good coverage	• Provides improved accuracy compared to Cell-ID, but is subject to errors from linear BTS configurations and multipath • Has coverage problems where there are limited base stations (tends to be in rural areas)	• Provides optimum accuracy compared to the other location technologies • Has coverage problems deep inside large buildings (tends to be in heavy urban areas)
Implementation Trends	• Easy to implement • Requires no handset changes • Can be supported without major infrastructure changes • Requires BTS almanac development and maintenance • Easy to roam wide areas or other networks, but areas of sparse coverage create severe accuracy degradation	• Difficult to implement • E-OTD requires changes to the handset • Requires the addition of LMUs for asynchronous networks • Requires BTS almanac development and maintenance • Possible BTS easement issues • Does not easily support roaming in wide areas or into other networks	• Easy to implement in the infrastructure • Requires handset changes • Requires no major infrastructure changes • Operates on both synchronized and asynchronous networks • Easy to roam wide areas and into other networks
Standards Support	• Works across all air interface standards including GSM, GPRS, UMTS	• E-OTD = GSM only • OTDOA = UMTS only	• Works across all air interface standards including GSM, GPRS, UMTS
Overall Cost Evaluation	• Low initial cost since Cell-ID is generally available in the network as long as the Cell-ID LS has access to BTS location and ID for BTS communicating to the handset • Cost to maintain is low • Cost to expand is low as long as expansion is into compatible network • Poor ROI	• Initial rollout cost is high – must add extensive equipment to provide subscriber coverage (approx 1 LMU per every BTS) • Cost to maintain is high since must maintain large network of LMUs • Cost to expand is high since must add LMUs as add new BTS to expand coverage • Poor ROI	• Initial cost is driven by the cost of the handset, related to the number of subscribers that need location • Handset cost delta is related to semiconductor costs and will go down with time. There is minimal infrastructure cost for the initial rollout and for expansion. • Cost to maintain A-GPS is negligible • Good ROI

10 DEPLOYMENT RECOMMENDATIONS

Given these conclusions and trends, what is the best location technology deployment plan? The simplicity and low cost of Cell-ID and Cell-ID variants suggests this technology may be the best to begin with. Cell-ID location services have already been deployed in some GSM networks, although the inconsistent and generally poor accuracy can support only a limited number of location services. When increased accuracy is needed to address a much larger subscriber base, more accurate location technology will be required. The following sections address how this might be done for each air interface.

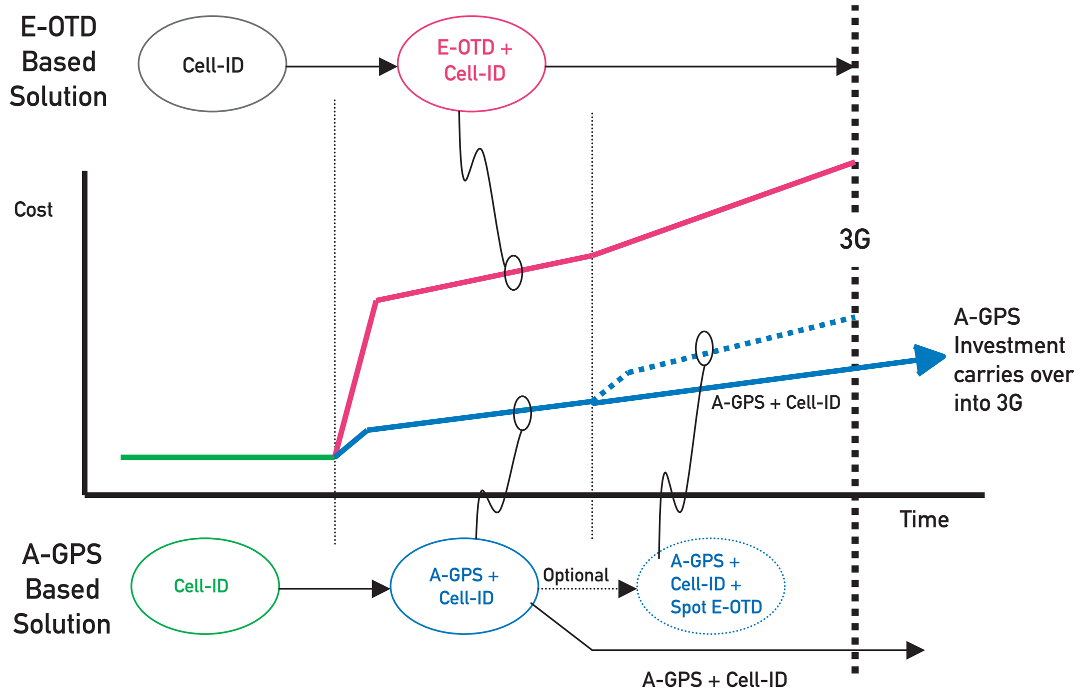
Note: Appendix C contains additional information on deployment beyond that provided below.

10.1 GSM/GPRS DEPLOYMENT

In GSM networks, beginning with Cell-ID allows the operator to test location technology and build a business model and applications infrastructure around feedback from these initial Cell-ID implementations. When faced with improving location performance, the choice is generally between E-OTD and A-GPS-based solutions. With E-OTD, there is a very large up-front investment in LMUs to enable the network. Even after this large investment, it may be necessary to augment an E-OTD deployment with A-GPS to support advanced services across the network in areas where E-OTD performance is poor. As Figure 10 shows, the cost of an E-OTD deployment is large very early in the process and remains larger than an A-GPS-based deployment for the life of the service.

In contrast, A-GPS is much less expensive and simpler to deploy, and is compatible across all air interfaces. Moving to an A-GPS-based implementation from a Cell-ID starting point allows the operator to invest at a rate that is more consistent with incoming revenue, yet immediately provides network-wide high performance capability to the subscriber. If the A-GPS implementation requires augmentation in certain areas, E-OTD can be used in hybrid combination with A-GPS on a spot basis, requiring very limited investment in LMUs and other expenses associated with E-OTD. This provides optimum performance at a much lower cost than network-wide E-OTD systems. In addition, any investment in A-GPS-based handset technology and infrastructure elements is not limited to GSM/GPRS, since A-GPS operates equally well on UMTS networks, unlike E-OTD, which is limited to GSM/GPRS networks.

FIGURE 10: E-OTD DEPLOYMENT COST COMPARISON TO A-GPS ON GSM/GPRS



10.2 UMTS DEPLOYMENT

UMTS deployment reflects different dynamics, since entirely new networks are being deployed and compatibility to old networks is required. For location services, it would benefit operators for 2/2.5G location technology deployments to transition to 3G deployments. Similarly, 3G deployments will need to have compatibility back to 2/2.5G networks. As discussed earlier, E-OTD is not forward compatible to 3G networks and OTDOA is not compatible with existing networks, so with these technologies network expansion and product evolution to support new applications and a growing subscriber base will require significantly more investment over time. With A-GPS-based solutions, this expansion happens easily and the same handset can be used (assuming it supports communication on both networks). An operator may choose to implement Cell-ID for initial location capability, but will likely be motivated to move quickly to a higher performance solution. A move to A-GPS provides significant performance improvements, offers location services compatibility in both GPS/GPRS and UMTS networks, and costs much less than either an E-OTD or OTDOA system.

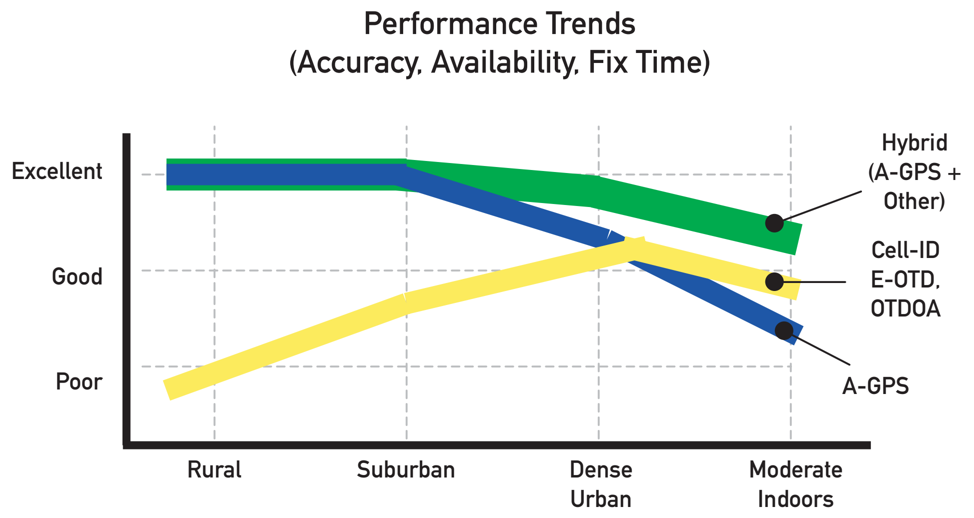
10.3 HYBRID DEPLOYMENT

A-GPS can be augmented with a location technology that provides position information in severely blocked GPS signal environments. This hybrid approach provides an optimum solution that leverages the accuracy of A-GPS and improves yield. A-GPS's flexibility allows it to be combined with almost any other location technology or supplemental technology (Cell-ID, TA, RTT, E-OTD, OTDOA, etc.).

The most cost-effective hybrid approach that maximizes yield is A-GPS + Cell-ID, but A-GPS can also be combined with either E-OTD or OTDOA. Since the cost of deploying E-OTD/OTDOA technologies is much greater than that of A-GPS, however, these deployments should be limited by deploying A-GPS on a network-wide basis and supplementing it with spot deployments of E-OTD, OTDOA or both, depending on what air interface the service supports. Using this approach, A-GPS can be deployed in a network to allow the operator to get started with precision oriented location services. As areas of A-GPS + Cell-ID imperfections are identified, spot deployments of E-OTD or OTDOA can be made to supplement the A-GPS + Cell-ID coverage. In this way, the operator can carefully manage cost growth while improving service for subscribers. This approach works equally well in 2G, 2.5G and 3G networks.

The concept of hybrid technology has been proven on CDMA deployments in Japan and will be used extensively in North America for E9-1-1 deployments. These deployments use A-GPS and AFLT (a ranging technology similar to E-OTD and OTDOA), and their performance translates directly to location service deployments on GSM, GPRS and UMTS. An indication of the performance trends obtained is shown in Figure 11.

FIGURE 11: PERFORMANCE TRENDS



Only the individual operator knows exactly what location technology is best for the services planned, but it's clear that an A-GPS-based solution, and in particular the A-GPS-based hybrid, offers the best performance, provides the best ROI, operates equally well on 2G, 2.5G and 3G networks, and enables the most extensive list of location services.

APPENDIX A — ACRONYMS AND DEFINITIONS

ACRONYM	NAME	DEFINITION
Autonomous	Autonomous	Term typically used in GPS and wireless-assisted GPS implementations. A mode of operation in which the MS calculates a position with no aiding from the location server. This mode is also referred to as "standalone" mode, and is commonly the mode in which conventional GPS receivers operate.
A-GPS	Assisted GPS, Aided GPS, or shortened version of Wireless Assisted GPS	This term is used widely in the industry, but has at least three definitions: 1. Most often used as a shortening of the term Wireless Assisted GPS, a location technology based on GPS to determine a three-dimensional position (includes altitude), but utilizing special assistance information from a location server to reduce start time and improve sensitivity. 2. Sometimes used to describe the combination of conventional GPS with network technology (the network technology is said to assist or aid when GPS is not operating). We do NOT use this definition. Combining different location technologies is considered a hybrid solution (see Hybrid). 3. Sometimes used to abbreviate Autonomous GPS. We do NOT use this definition.
AOA	Angle of Arrival	A location technology that uses special antenna arrays at BTS sites to determine the angle of arrival of handset signals. At least two AOA measurements are then combined to identity the position of the handset.
ARPU	Average Revenue Per User	Used primarily in the context of a network operator's subscriber base, this is a term used to quantify the average revenue per user on a wireless network.
BTS	Base Transceiver Station	A base station transceiver in the wireless communications infrastructure.
CDMA	Code Division Multiple Access	A high-capacity digital wireless communications technology.
Cell-ID	Cell-ID	A location technology that utilizes the location of the BTS to identify caller location. Can be combined with TA in GSM networks and RTT in UMTS networks to improve accuracy.
DGPS	Differential GPS	A technique used to remove errors in GPS calculations to improve GPS accuracy.
E-OTD	Enhanced Observed Time Difference	A technique comparing the time an MS signal arrives at different base stations to determine two-dimensional position (altitude not determined).
GMLC	Gateway Mobile Location Center	The infrastructure element in 2G, 2.5G and 3G systems that makes location information available to the location application.
GPRS	GSM Packet Radio System	The packet radio version of GSM communications.
GPS	Global Positioning System	A technique utilizing distance measurements to GPS satellites to determine three-dimensional location (includes altitude).
GSM	Global System for Mobile Communications	Standard for digital mobile telephony originally developed for pan-European use, but now used worldwide.
Hybrid	Hybrid Location	Any blending of different location technologies. In this white paper, hybrid refers specifically to combining wireless assisted GPS with other location techniques.
IPDL	Idle Period Down Link	A signaling method used with OTDOA positioning technology to mitigate the near-far problem inherent to UMTS systems.
LMU	Location Measurement Unit	A device used with E-OTD to provide precise timing information for asynchronous networks.
LS	Location Server	The software entity used to calculate position or provide assistance data or participate in the positioning process in some other way. Different location technologies require different location server functionality. In this white paper, the LS term will be preceded by a location technology description to indicate the LS supports that type of location technology (e.g., an A-GPS LS is a location server that supports A-GPS technology and therefore provides assistance data and can calculate a final position).

ACRONYMS (CONTINUED)

ACRONYM	NAME	DEFINITION
MS	Mobile station	The term used in GSM and GPRS networks to describe a subscriber's handset or wireless terminal.
MS-Assisted	MS-Assisted	Term typically used in wireless assisted GPS implementations. A mode of operation in which the MS provides data to the location server to enable the location server to calculated a position.
MS-Based	MS-Based	Term typically used in wireless assisted GPS implementations. A mode of operation in which the MS receives aiding data from the location server to enable the MS to calculate a position.
MSC	Mobile Switching Center	A primary switching hub in 2G, 2.5G and 3G wireless network.
Multipath fingerprint	Multipath fingerprint	A location technology that uses a complex database of stored communication signal images, or "fingerprints" that are each unique to locations throughout the user network. Real-time handset signals are then compared to the stored fingerprints to find a match, which produces a location estimate.
Node B	Node B	The term for a base station in a 3G network.
OTDOA	Observed Time Difference of Arrival	A location technology that compares the time a UE signal arrives at different base stations to determine two-dimensional position (altitude not determined).
P-range	Pseudorange	The distance measurement derived from the elapsed travel time of a GPS signal from a GPS satellite to a GPS receiver.
RTT	Round Trip Time	A technique utilizing the total round-trip time from an MS to a base station to determine the approximate distance an MS is from a base station.
SAS	Stand-Alone Assisted GPS SMLC	The UMTS network node that may operate the assisted-GPS location server software.
SGSN	Serving GPRS Support Node	The node required in 2.5G and 3G systems to provide data support in the core network.
SMLC	Serving Mobile Location Center	The GSM/GPRS network node that operates the location server software.
SNRC	Serving Network Radio Controller	The UMTS network node that may operate the location server software.
TA	Timing advance	A technique utilizing the timing advance information applied by the GSM network to determine the approximate distance an MS is from a base station.
TU	Timing Unit	A timing unit required for networks that are not synchronized. Typically uses special GPS receivers to provide absolute timing.
TOA	Time of Arrival	A technique comparing the time an MS signal arrives at different base stations to determine two-dimensional position (altitude not determined).
Trilateration	Trilateration	A technique used to derive location by determining the intersection of hyperbolas derived from the range measurements between a BTS and handset.
TTFF	Time to First Fix	The time elapsed between when a position was requested and when a position was determined. Most commonly applied to GPS and A-GPS technologies, but also applicable for the other location technologies.
UE	User Equipment	The term used in UMTS networks to describe a subscriber's handset or wireless terminal.
UL-TOA	Uplink TOA	A location technology that uses at least three BTS sites to monitor handover access bursts from the mobile, determine time of arrival relationships, then trilaterate the position of the mobile device.
UMTS	Universal Mobile Telecommunications Systems	UMTS is the third generation (3G) evolution from 2G/2.5G networks and since it is based on wideband CDMA radio access technology (WCDMA), it is generally considered synonymous with WCDMA.
WCDMA	Wideband CDMA	IMT-2000 CDMA direct spread standard developed by 3GPP.
Yield	Yield	The ratio of the number of successfully calculated positions (meeting specified quality criteria) to the number of attempts to determine a position. A yield of 100 percent means all position attempts resulted in a position calculation within the boundaries of the specified quality criteria. 50 percent yield means only one of every two attempts resulted in a position calculation.

APPENDIX B – NORTH AMERICAN FCC MANDATE E9-1-1 PERFORMANCE REQUIREMENTS

One well-publicized set of criteria is the performance requirement for North American E9-1-1 Emergency services mandate [8]. The performance requirement for this narrowly defined application varies depending on the type of technology deployed.

For handset-based technology:

- Within 50m for 67 percent of the calls
- Within 150m for 95 percent of the calls
- Consistency is not specified, though it is implied in the above requirements to be within 50m to 150m the majority of the time
- TTFF is 30 seconds to report

For Network-based technology:

- Within 100m for 67 percent of the calls
- Within 300m for 95 percent of the calls
- Consistency is not specified, though it is implied in the above requirements to be within 100m to 300m the majority of the time
- TTFF is less than 30 seconds to report

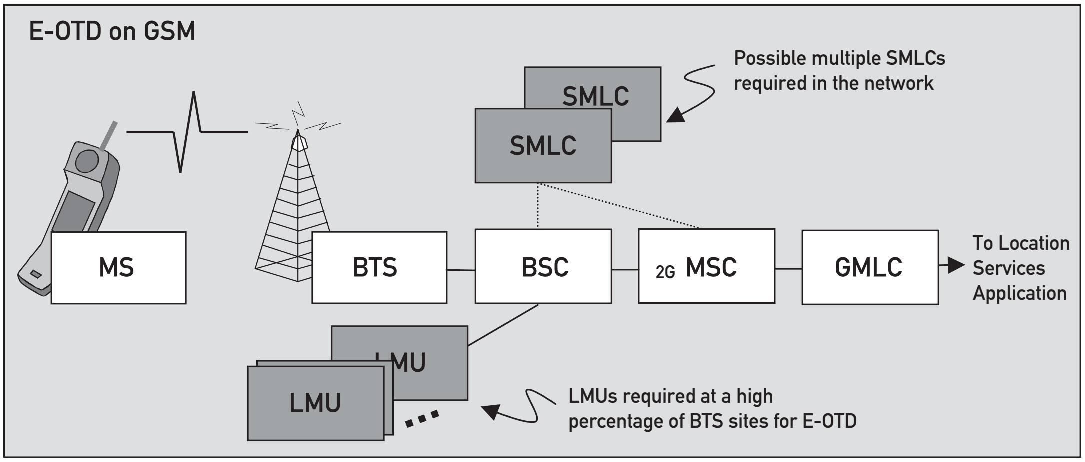
APPENDIX C – TECHNOLOGY DEPLOYMENT AND EXPANSION COMPARISONS

DEPLOYING A-GPS VERSUS E-OTD ON GSM NETWORKS

To deploy A-GPS on an existing GSM network requires only the addition of an SMLC and A-GPS LS software at the SMLC (above and beyond that required for redundancy, etc.). In contrast, to deploy E-OTD on an existing GSM network requires the addition of LMUs to a high percentage of base stations, and the addition of E-OTD LS software at multiple SMLCs (because E-OTD traffic for a position calculation creates a larger load on the SMLC than A-GPS, it is possible that E-OTD will likely require more SMLC resources than A-GPS). From an infrastructure prospective, deploying E-OTD is much more complex than deploying an A-GPS or an A-GPS-based hybrid solution. This is shown in Figure 12.

These conditions are also important when the network is expanded. To expand an A-GPS solution that has been deployed on a GSM network requires only a connection from the existing SMLC to the new MSC/BSC – or – the addition of LS software at a new SMLC in the new network. This means that A-GPS networks can be expanded at little or no extra infrastructure cost or complexity – or – if the operator decides to enter into a roaming agreement with another operator or a sister network, all that is required to offer a location service is an SMLC in the new network. This means roaming support in a new network is simply a matter of implementing SMLC support in that network. To expand an E-OTD system that has been deployed on a GSM network requires an extensive rollout of additional LMUs and additional SMLCs. This is a complex task that requires significant investment in the infrastructure each time a new network is added or the operator desires to offer services in a portion of the network that has no LMUs.

FIGURE 12: RESOURCES REQUIRED TO IMPLEMENT E-OTD ON GSM NETWORKS



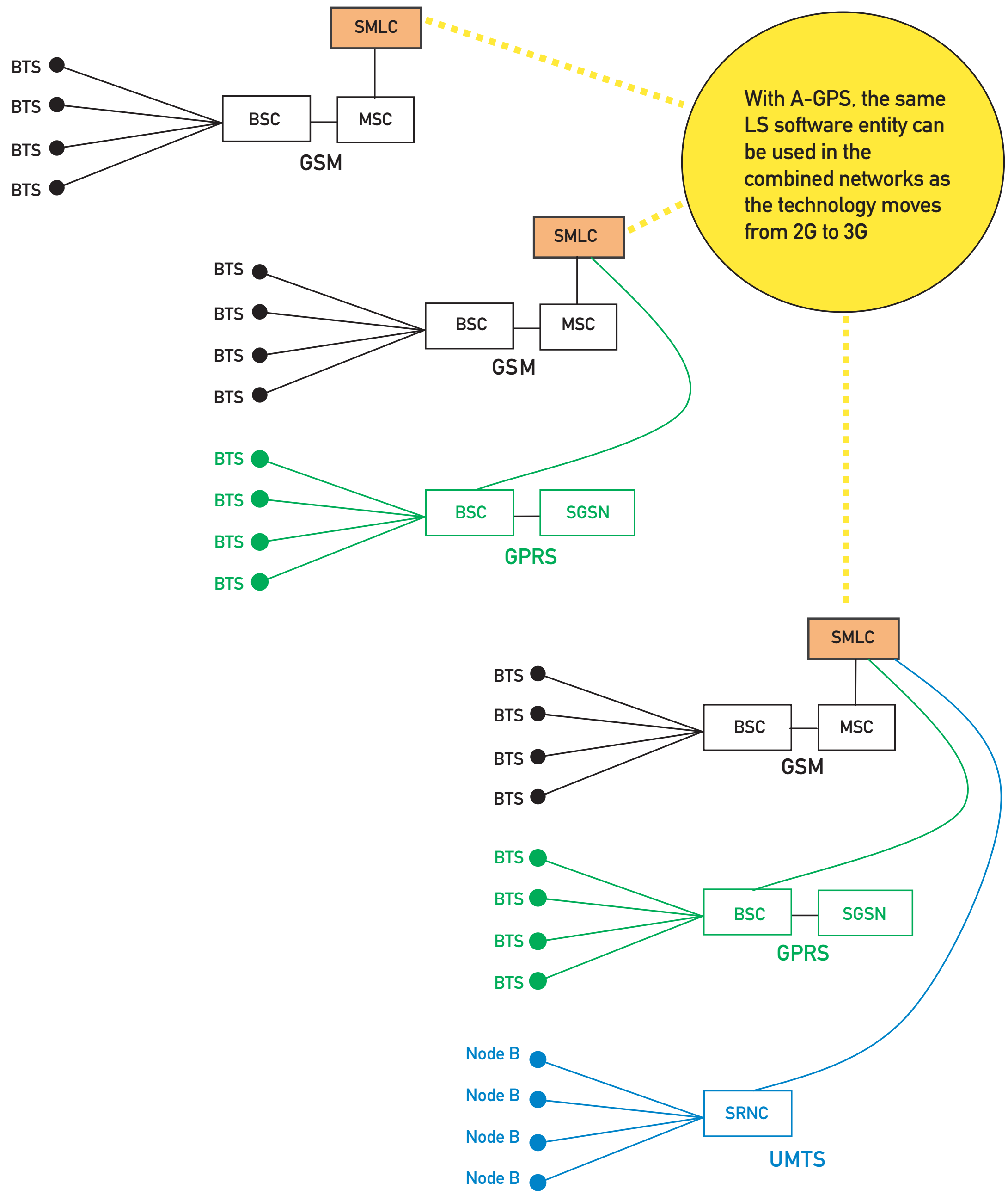
DEPLOYING A-GPS VERSUS OTDOA ON UMTS NETWORKS

The comparison of A-GPS vs. OTDOA for UMTS networks is very similar to A-GPS vs. E-OTD for GSM/GPRS networks with one exception. For UMTS, the Location Server software at the A-GPS SMLC is treated as a separate entity to simplify the migration of A-GPS-based location solutions from GSM to UMTS. For OTDOA, the managing OTDOA LS function remains within the SRNC, and must be duplicated on an SRNC-by-SRNC basis, increasing cost and complexity. As with the GSM implementation, timing elements are required extensively throughout the network. From an infrastructure prospective, deploying and expanding OTDOA is more complex than deploying an A-GPS or A-GPS-based hybrid solution.

MIGRATING A-GPS FROM GSM TO GPRS TO UMTS NETWORKS

To extend A-GPS from a GSM network to a mixed GSM + GPRS + UMTS network is straightforward because of the approach to the infrastructure support that has been developed in the standards bodies. The SMLC in the GSM network utilizes software that operates independently to support A-GPS-based solutions in the GSM network. As the GSM network is expanded to GPRS, this same software entity can be used to support the SGSN/BSC function in GPRS, with compatibility to the GSM A-GPS-based deployment. As the network migrates to UMTS, this same software entity can be used to provide A-GPS and A-GPS-based hybrid support to the SRNC, with compatibility to both the GSM and GPRS A-GPS-based deployment. This support across various network combinations is shown in simplified form in Figure 13 (the UMTS configuration shown reflects work-in-progress in standards bodies).

FIGURE 13: A-GPS MIGRATION FROM GSM TO GPRS TO UMTS



REFERENCES

[1] Location Based Services, A Strategic Analysis of Wireless Technologies, Markets, and Trends; Frank Viquez, AnnaLee Dragon, Tim Archdeacon; Allied Business Intelligence; 1Q, 2001

[2] Ready or Not, Mobile Location Technology is Here!; Allen Nogee; Cahners In-Stat Group; March 2001

[3] European Wireless Location Services; Jake Sanders, Jamie Moss, Stephan Beckert; The Strategis Group; March 2000

[4] Synchronous vs. Asynchronous Deployment of WCDMA – Effect on Communication System Performance; QUALCOMM; publish date September 2001

[5] GSM Mobile Location Systems; Omnipoint Technologies, Inc.; Document #0710009-00B, 1999

[6] Determining Location Using Wireless Networks; Gunter W. Hein, Bernd Eissfeller, Jon O. Winkel, and Veit Oehler; GPS World; March 2001

[7] Synergies Between Satellite Navigation and Location Services of Terrestrial Mobile Communication, Gunter W. Hein, Bernd Eissfeller, Jon O. Winkel, and Veit Oehler; Institute of Navigation; September 2000 Conference Proceedings, September 2000.

[8] http://www.fcc.gov/e911; FCC mandate for Docket 94-102

[9] http://gullfoss2.fcc.gov/cgi-bin/websql/prod/ecfs/comsrch_v2.hts; Carrier Filings on performance relative to FCC mandate 94-102