AN INTEGRATED NETWORK & TERMINAL CENTRIC APPROACH FOR LOCATING / POSITIONING 3G MOBILE TERMINALS

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Abstract - *Localization as a primary factor for service differentiation and personalisation, has boosted the activities of many Telcos and institutions to develop or integrate positioning systems. The integration of satellite-based positioning sub-systems in the user terminal, although a logical evolution to today's devices, introduces (among others) volume/weight overhead and increases power consumption in wireless terminals. An alternative is to estimate users' position based on network resources external to the terminal, without raising network costs. Although equipment manufacturers have already tested some positioning methods, none has been widely deployed in a cellular networking environment. This paper presents critical issues for the deployment of both network- and satellite-based positioning methods for providing location services in emerging 3G networks. In the sequel, the above approaches are evaluated and discussed in terms of both qualitative and quantitative parameters. Based on the above analysis, the authors investigate the synergy between the aforementioned methods in varying environments, and propose a flexible solution, that may be tailored to fulfill diverse constraints.*

I. INTRODUCTION

In today's fast evolving telecommunication world, mobile network operators and service providers continuously seek innovative ways to create service differentiation and revenue opportunities through the delivery of highly personalised services. On the other hand, customers increasingly require more value. Localisation is one of the most powerful ways to personalise services and provide added value for the end-user [1]. Locating a mobile terminal may be extremely useful in cases of emergency, while location may be used by the network operator to provide differentiated billing. Information services may be also offered on a cost-free basis, as a means of attracting subscribers. Examples include location-specific advertising and traffic / navigation assistance, that can be seen as a great asset to drivers, tourists and travelers. Tracking of mobile terminals is considered a valuable alternative to other fleet or asset management systems or even stolen-vehicle service.

On-going research is aiming at improving current GSM-based positioning architectures, focusing on features such as scalability, awareness of location in different contexts, flexibility, etc. Locating a terminal however is a challenging engineering task. It is obvious that the integration of available positioning subsystems (like the popular satellite-based GPS) in the user terminal, although a logical evolution to today's devices, impacts the power consumption and the volume/weight overhead in wireless terminals, while GPS receivers' costs are not yet reduced to a potential minimum. On the other hand, industrials might reason that mass production of terminals will eventually succeed in doing so. A viable alternative seems to be the estimation of users' position based on network resources external to the terminal. The research community worldwide is trying to conclude on positioning techniques, that comply to FCC and ETSI user positioning (UP) recommendations, without raising network costs. Although equipment manufacturers have already tested some positioning methods, none has been widely deployed in a cellular networking environment.

This paper is organised as follows: Section II presents the principles and critical issues regarding the deployment of network-based location services and a brief overview of satellite-based positioning systems, including GPS / GNSS-2 (with the advent of GALILEO) methods and their differential variants (DGPS). In the sequel (section III), these approaches are evaluated and discussed in terms of both qualitative and quantitative parameters including implementation complexity, accuracy, guaranteed availability, power consumption, network load, etc. Based on the above analysis, the authors investigate the synergy between the aforementioned methods (satellite/handset and network centric) in varying (indoor & outdoor) environments, and propose (section IV) a hybrid flexible solution that targets very accurate positioning, requiring only scaled and generally restricted implementation costs. The hybrid approach is then mapped to existing 3GPP positioning architecture, thus demonstrating its compliance to emerging standards.

II. LOCALIZATION TECHNOLOGIES

According to the US FCC requirements for the E911 service[2], positioning techniques are classified in network-based and handset (satellite)-based. Network-based methods must be accurate to within 100 m for 67% of all calls and 300 m for 95% of all calls. Handset-based methods must be accurate to within 50 m for 67% of calls and 150 m for 95% of all calls. Similarly in Europe, since October 1998, ETSI is working on standardizing the provision of location services in 2G (GSM) [3] and 3G (UTRAN) [4] networks. An on-going initiative relevant to the FCC E911 is proposed for adoption in Europe (E112).

Both the network- and the handset-based approaches enable a large number of services, albeit with different properties in terms of positioning parameters such as availability (time-to-fix), accuracy and reliability. Each positioning method has different values associated with these attributes and will be better suited for certain classes of service than others. Network-based solutions may deliver less precise accuracy, with sparse deployment of base stations in rural environments where satellite visibility is at its best. However, satellite-based location can be less reliable in deep canyons, mountain regions and indoors / urban environments where cellular coverage may be denser. From a market aspect, the ability of the network-based solutions to support existing handsets is an advantage in the roll-out of location-based services. The current trend is towards the possibility of exploiting network resources for the provision of support information (in the form of 'ephemeris' data updating, time references or differential corrections) to satellite-based positioning – thus leading to "handset-based / network-assisted" techniques. In the following, some of the major topics in both approaches are elaborated.

Network infrastructure based approaches

The techniques applying in 3G networks share generally the same principles with their GSM counterparts. However, given the fact that in UMTS signal bandwidth (in WCDMA, following its "spreading" by a spreading sequence, is of the order of 5 MHz) is typically larger than in 2G systems (200 kHz for GSM), more accurate location estimates (high self-correlation accuracy [5]) may be achieved in distance measurements. Further advantages in 3G systems relate to the efficiency in providing a communication path for data originating from the MT targeting the network nodes, given the packet based nature of the data bearers. This enables flexible and cost-effective transmission of the messages and commands related to the location procedure contrary to GSM, where the SMS service used is inadequate for many applications and allows only a limited amount of information to be transferred. An expected disadvantage is that the Base Stations (BSs) are not synchronized in the FDD operating mode, which seems to be the technique to be used at least in the first phase of the 3G networks. Networks based on the synchronized TDD mode are foreseen to evolve later. In the FDD mode a method for measuring the relative time differences of the BSs will be required as in the case of GSM, which increases implementation costs.

1. Propagation Delay based (TA, TDoA, E-OTD)

In the majority of network-based techniques, location determination is based on time-delay measurements between the Mobile Terminal (MT) and several BSs. Assuming 2-dimensional geometry and line-of-sight propagation, each time delay measurement defines a circle around a BS and three such circles are needed for unique location determination. In 2G systems, *Timing Advance* (TA) is the mechanism used for synchronization on the radio channel in the mobile-to-BS direction, ensuring that the transmissions of the MTs arrive in the correct TDMA time slots. TA measures the propagation time between the MT and the serving BS, but only in units of a bit period, which corresponds to 554 m in distance. A more accurate measurement would be highly desirable, but would also require modifications to the network. UMTS, uses Round-Trip-Time, which measures the time between the transmission of the frame (by Node B) and the reception of the corresponding frame (again at Node B). The synchronization mechanism is based on the Direct Sequence (DS) that WCDMA uses for spreading, which responds to a chip rate of 3.84 Mchips/s (or Nx1.2288 Mchips/s in the case of US Cdma2000). This allows an increase in the signal self-correlation accuracy used in the calculation of the propagation delay allowing theoretical accuracy of 80m in the distance BS-MT measurement [5].

In the *Time Difference of Arrival* (TDoA) technique, propagation time differences instead of absolute propagation delay times are observed. The MT measures the time differences between signals from several synchronized BSs or alternatively the BSs measure the *Times Of Arrival* (ToAs) of a burst from the MT. The ToAs do not measure the absolute propagation times since the MT is not synchronized with the BSs, but propagation time differences can be calculated from the ToAs of several BSs. The former alternative (MT measures) is chosen in the *Enhanced-Observed Time Difference* (E-OTD) technique while the latter (BSs measure) has been referred to as the TDoA technique. Regardless of the measurement technique, each time-difference measurement defines a hyperbola and 3 such hyperbolas have a unique intersection point. 4 BSs must be received to obtain 3 independent TDOA measurements. However, in many cases 2 hyperbolas have a unique intersection and then 3 BSs are sufficient (see Figure 1).

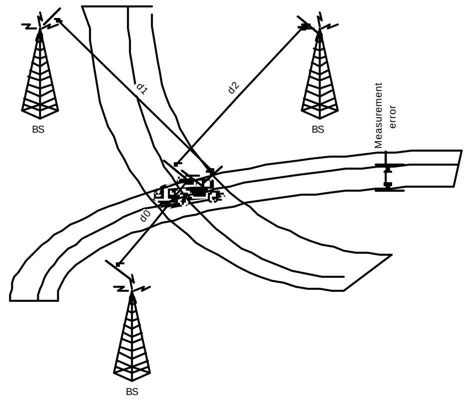

Figure 1: *TDoA / E-OTD configuration*

In TDoA, synchronization of the BSs is achieved by installing similar to the MT receivers in known locations, typically at the BS sites, to measure the timing differences between BSs. These Real Time Differences (RTDs) as well as the OTD's from the MT are sent to the mobile location center (MLC), which then has sufficient information for location calculation. Disadvantages of this technique include the need for software modifications to the handsets and the need for additional receivers. Also multi-path propagation and especially the fact that no line-of-sight to all BSs exist in an urban environment is a problem for all time-based techniques. Current implementations (2G) of the system use the reverse control channel - used for call setup - for time measurements. To enhance time measurements, GPS-timing receivers are employed at each cell site to provide time synchronization accuracy within 100 nanoseconds, or better, between cell sites. A signal collection unit – the LMU is also installed at each cell site to receive the wireless phone signals and to transmit data to the TDoA Location Processor (TLP), which is generally located at the Serving

Mobile Location Center (SMLC). The SMLC lies hierarchically at the same level with the MSC / SGSN. The TLP determines which MTs are to be located and computes their locations, speed and direction of travel.

2. Angle Of Arrival (AoA)

Signal *Angle Of Arrival* (AoA) information, measured at multiple BSs, can be used for locating a MT. Since an AoA measurement requires an antenna array, this is only feasible at the BS. Assuming two-dimensional geometry, the angle of arrival at two BSs is sufficient for unique location determination. A major drawback of this technique is the need for new hardware in 2G systems (antenna arrays at BSs). Due to the continuing growth of mobile applications and as additional capacity is required, special antenna systems have emerged that promise to allow narrow-beam steering (or switching). The most interesting approach, the steered beam approach, utilizes phased array antennas to create a narrower beam directed only to the mobile addressed in the forward link [6]. As the caller moves from cell to cell, the system must follow each voice channel assignment as the call is handed off from channel to channel. This can be difficult if the AoA antennae are not positioned to interpret the in-band voice channel signaling. A further restriction of AoA is the need for line-of-sight propagation conditions to obtain correct location estimates. Consequently, this technique is not the preffered method in dense urban areas, but could be used in rural and suburban areas (macrocells), where the achievable accuracy is better (scaterring models by [7] and [8] prove the expected narrow AOA spread). A further advantage in AoA is that only two BSs are required for the location fix.

3. Cell Global ID (CGI / CGI++)

The simplest example of a "network-centric" approach is the *Cell Global ID* (CGI) method. Cellular networks have a built-in capability to identify the cell where a specific mobile terminal is located with an appropriate level of accuracy – which is significant especially in the case of urban cells, or in cases where sectoring is applied. This capability is an inherent part of mobility management. Clearly, the positional accuracy increases with decreasing cell size. 3G systems, with their hierarchical cell layered structure (macro / micro / pico cells) will offer a coarse location capability which will be sufficient to support many classes of location-based services such as zone-based billing. The combination of the basic CGI capability with the TA/RTT (and neighbouring cells Rx Level measurements) leads to the development of a very effective technique termed CGI++ already tested in live networks [9]. Difficulties include the imprecisions introduced in the prediction of each cell's geographic coverage. However, such method guarantees implementation for the whole population of mobile users since no special modifications of the MT is required and, of course, the lowest implementation costs than any other alternative.

Satellite (terminal) based approaches

In GPS (GPS-t) the only autonomous large-scale satellite navigation system currently operational, a constellation of 24 satellites launched by the USA, transmits information, enabling a GPS receiver to determine its position [12]. The European Galileo system will eventually provide a similar capability only after 2005 according to initial planning by ESA. In GPS, location determination uses the TDoA of satellite signals and is performed either entirely within the mobile unit or within the network. In the latter scenario, the necessary satellite signal attributes are detected by the terminal and reported to the network for location computation, map matching, etc. If the range from the receiver to four satellites is calculated, the receiver can accurately determine its position anywhere on earth. The current level of accuracy is 10 meters (true for 95% of the location estimates). Considerations include the system's availability (planned to exceed 98% guaranteed) and the minimum signal levels required for the calculation of a position fix which respond to a Line-Of-Sight requirement.

Enhancements to the basic GPS service are offered by "*Assisted GPS*" (GPS-n) schemes. These assist the receiver in such ways that the time-to-first-fix is minimised, by automatically updating the GPS ephemeris information kept at the receiver at regular time intervals. When a position fix is needed in an emergency, users of GPS-enabled handsets can push a button, contact an assistance server and have location information available for transmission in less than two seconds (a 10-fold improvement in the expected performance of regular receivers). Other approaches allow indoor positioning (by lowering the minimum required, satellite signal power threshold) [11].

A further evolution to the plain civilian GPS service is the "*relative GPS positioning*" technique which tends to cancel out most errors at least for practical purposes. Also called *Differential* or DGPS, can be accurate to the meter or even sub-meter level depending on the receivers, the mode used for processing and the distance of the roaming receiver to the stationary GPS. The cause for these accuracy improvements is the availability of co-observing reference receivers, which share very much the same GPS error sources. A stationary reference receiver (also called reference or even DGPS "base" station) measures the estimated pseudo-ranges to the satellites and compares them to the expected pseudo-range (stationary receivers have known coordinates) thus deducing timing errors. The corrections vector can be thus applied to the pseudo-range vector as it was measured by the receiver, to produce a highly accurate position estimate. The DGPS method is very much suited to the needs of mobile terminals, given the availability of the communications' link through which the corrections can be broadcast. A variation of the method is the *Inverse DGPS* (I-DGPS), where the raw measurements (pseudoranges) of the distance to each of the four satellites, are transmitted to the reference station (again via the cellular network) which processes them to calculate a very accurate location estimate.

III. HIGH LEVEL EVALUATION

It is worth noting that current 2G/2G+ cellular networks do not use any of the above positioning techniques in large scale and only pilots have been tested [11]. The main impairments in the deployment of such services include the high installation costs, the achieved accuracy and the terminal modifications required for the implementation of each method. The only technique providing basic info on the user's general location, with no modification to the existing network, or the terminals, is the CGI / CGI++ [9].

The idea of TDOA is based on mathematical fundamentals that ensure the success of the method, however there are technical difficulties for its implementation related to the synchronization of the network (achieved through the addition of LMUs at BSs). TDOA is ideal for sub-urban environments where the multi-path effect is limited, LOS reception of the cellular signal is possible and the minimum of 3 BSs (Nodes-B) required is always possible.

AoA requires only 2 BS (possible most of the time), but also an "intelligent"-type antenna at the BS to detect the area of arrival. However the angular error in the detection of a user's observed position angle by the antenna leads to a linear increase of the error by distance from the BS.

Satellite-based methods are the most promising alternatives for location. Among the main disadvantages are cost and degree of integration of satellite receivers into MTs, leading to size and power-consumption overheads. Non-accurate results in (dense) urban areas due to the multi-path and the pure geometry of visible satellites are expected. Indoor satellite positioning is almost impossible, although some technologies may help overcome this problem, by allowing positioning with significantly lower power thresholds [11]. In all other cases a quite good accuracy is provided (errors are generally in the order of 5-10 meters).

In Table 1, a comparative evaluation of the most significant techniques is attempted relating to major system performance and implementation aspects. GPS-n, is not included, as it represents a family of mechanisms rather than an individual technique. Figure 2 compares implementation compexity (and respective costs) and expected accuracy by different techniques.

Table 1 - *Terminal location methods parameters*

	GPS	***DGPS/I-DGPS***	***TDOA***	***AOA***	***CGI ++***
Implementation	Terminal Based	Terminal based - Network assisted	Network based	Terminal / Network based	Network based
Accuracy 2G (GSM, GPRS)	10m (95%)	3m (95%)	60m. rural 200m. urban	N/A	Mean: max 550m, less for sectored cells
Accuracy 3G (UMTS)	10m (95%)	<3m (95%)	<60m. rural <200m. urban	200m (for a 1km radius cell)	Pico-cell
Availability	Low (only outdoors, no US DoD guarantee)	As for GPS	3 BS required	2 BS required	Always (based on serving BS signal)
Speed of response (Time-to-First-Fix)	1-2 min (worst-case "cold start")	Less than GPS	Near real-time	Near real-time	Near real-time
Implementation complexity	Terminal Upgrade	Terminal Upgrade / Ref. Station	LMU modules added to each BS	Later phase of UMTS	IN services (2G) - None (3G)
Terminal power consumption	High	High	Not Affected	Not Affected	Not Affected

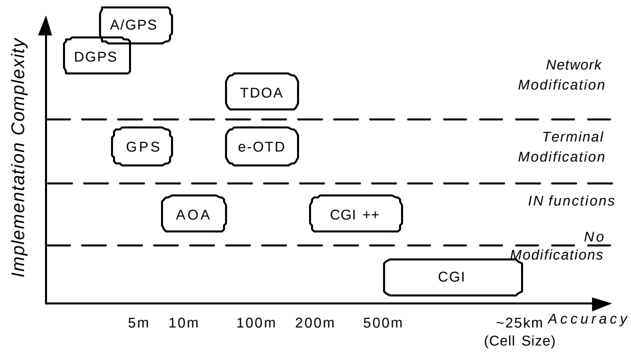

Figure 2: *Accuracy vs complexity for UP techniques*

IV. HYBRID APPROACH

What may be deduced from the previous examination of the expected performance and shortcomings of existing methods, is that no single approach may be considered for providing the performance levels with reasonable cost, ease of installation, and minimum cost overheads. Therefore, hybrid methods are worth investigating. In the following, we propose the evaluation of a hybrid location estimation scheme, in the 3G context. The adopted scheme is based on current industry trends, where estimation is based both on the available terminal resources (generally some type of a GPS receiver, an assisted GPS receiver, or a differentially corrected DGPS enabled device) and on network resources (combined TDoA and AoA along with the CGI++ baseline measurements). The synergy of the components is realised on a weighted least-squares estimation (WLS) of position as it is approximated by the different techniques. However the weights used for the calculation shall be dynamically altered by the central processing entity according to the specific conditions. In satellite positioning we consider GPS to be the only alternative for satellite based positioning, until the arrival of the GALILEO system. Thus given the existence of GPS resources on-board the mobile terminal, the decision on the use of GPS position solution in the calculations will be based on the following parameters:

- The *RAIM (Receiver Autonomous Integrity Monitoring)* index –a direct measure of the reliability of GPS estimates. The implementation of the index itself lies to the receivers' manufacturers based on existing performance metrics delivered by the space segment. Surpassing a pre-defined RAIM threshold will immediately lead to the exclusion of GPS from the calculations.
- The *hand-over word (HOW)* information field of a decoded navigation message. The HOW contains an alert flag that informs civilian ("unauthorized") users user range error may be worse than indicated in the navigation message subframe 1. The setting of this flag to "1" leads to immediate exclusion of GPS from calculations.

Two more parameters will determine the accuracy and thus the weight applied to the GPS estimate:

- The *Dillution-Of-Precision* (DoP) factor, a parameter related to the geometry of the satellites selected for the calculation of the position estimate. High DoP factors are expected to lead to largely inaccurate estimates –thus the algorithm should lessen the weight of the GPS estimate linearly with DoP. The calculated value of the Horizontal-DoP coefficient is actually a multiplication factor to the basic errors introduced by other sources.
- The number of "visible" satellites. Current GPS receiver systems have the ability to track a number of satellites additionally to the 3 / 4 satellites used in the position calculation. This allows for the rapid re-acquisition of a satellite signal from other satellites when the signal from one or more satellites used in the calculations is lost. This allows the definition of one additional metric, that is the number of satellites in view and tracked. A decrease in this measurement (that is to be observed in urban or suburban environments) shall not directly influence the weight of the calculations but will warn the algorithm that satellite reception loss may be imminent.

It is important to note that these parameters are directly measured by the reports issued by GPS receivers (they are included in the GPRMC, GGA messages formatted according to the NMEA-0183 message standard in existing civilian receivers). The network-based co-efficients used by the method are TDoA, AoA and CGI++ estimates. Both TDoA and AoA estimates will be considered for calculation provided that the minimum number of BS (3 and 2 respectively) are received. The relative weight with which the AoA estimate participates in the measurements relates to the distance from the measuring *steered-beam*-type antenna, which may be accurately measured by the value of the *RTT* parameter (or the TA in GSM) value. In TDoA on the other hand, the main error source is the absence of LOS reception and the multi-path effect. In this case a knowledge of the problem will be gained by measuring its symptoms; the authors propose the Least-Squares Estimation of the individual TDoA estimates by the 4 best received BS – however this can only be achieved when at least 4 BS are received. In all cases the minimum network-based estimation will be available at all times by way of the CGI++ method which is based on UTRAN resources requiring no further modification of the terminal (the service may be implemented using strictly resources of the existing Network Subsystem). The relative weight of the CGI++ method will be based on Round-Trip (or similarly TA in 2G systems) time that will determine the distance from the BS (distance results in lower accuracy). Figure 3 depicts the implementation of the hybrid locations scheme. The method is scalable to allow the fusion of a number of different techniques. The location estimation vectors will include the position coordinates and laso the expected accuracy.

A further application of the WLS scheme used lies in its use as an assisted GPS method. The resulting "fused" position estimate may be used to assist the GPS in achieving a more rapid satellite acquisition thus assisting the GPS initialisation time.

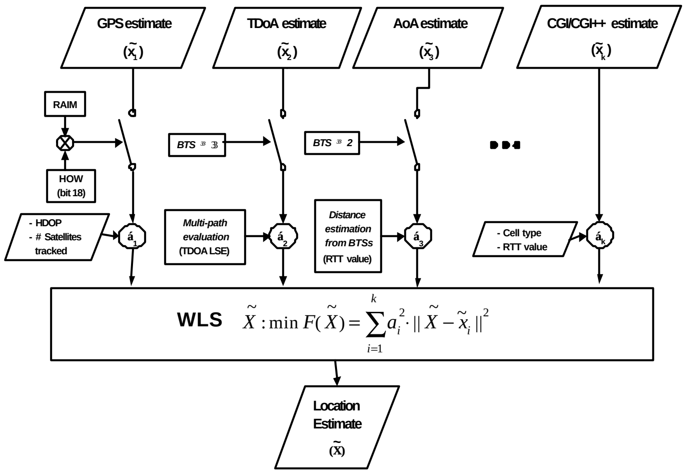

Figure 3: *Hybrid location estimation scheme*

Integrating Location Subsystems in 3G Systems

The general arrangement for the LCS feature in 3G networks (UTRAN R99), illustrating the relation of LCS clients and servers in the core and access network, is depicted in Figure 4.

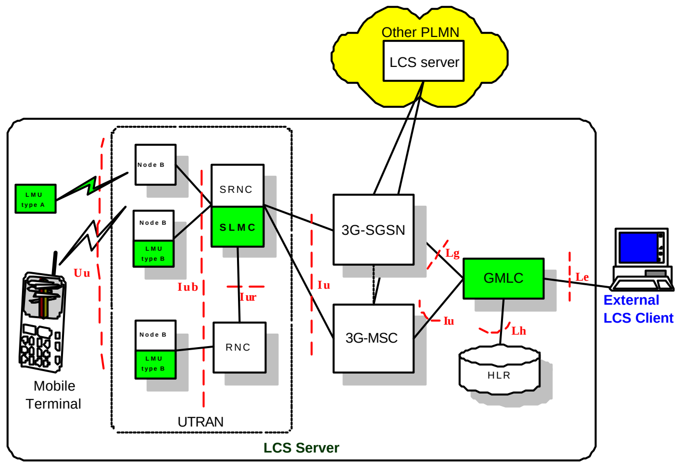

Figure 4: *General arrangement of UP in UTRAN*

The *Gateway Mobile Location Center* (GMLC) is responsible for interfacing with external networks. GMLC will receive external LCS client requests, authenticate them, and verify their authority in requesting a service. The GMLC will handle other aspects related to the QoS requested, the transformation to other coordinate / geodetic datum systems, etc. The *Serving Mobile Location Center* (SMLC) is either co-located with the serving RNC (SRNC) or otherwise a stand-alone component of the UTRAN and determines the MT position (actually co-ordinates and expected accuracy). The SMLC will choose the technique required for the QoS levels requested by the GMLC. Some manufacturers enhance the ETSI-3GPP recommendations [9] and propose the reception by the SMLC of information about expected geographical coverage and cells' planning, should such knowledge be required by location techniques. The RNC must be modified to control the functions of the SMLC (or even incorporate the SMLC functions) and Node Bs will have to incorporate the LMU required for calculations (or communicate with a standalone LMU over the Uu I/F). The MSC (or the SGSN, depending on the core network type) will be required to determine the subscriber profile of the target MT and the rights of the LCS client based on the information contained within the HLR. In some cases the service provision may be based on stand-alone servers that hold the LCS info per each user, integrated within an elaborate IN service mechanism.

The 3GPP specifications for UTRAN R.99 [14] assume that calculations relating to the CGI, UE-assisted OTDoA, and UE-assisted GPS-n methods, are all performed in the SMLC (SRNC). In the UE-based OTDoA and GPS-n methods the calculation of the location fix is performed in the MT. However UE-based methods require additional information to be communicated to the MT (such as position of the measured Node Bs in OTDoA, or DGPS corrections in DGPS), or additional complexity for the MT (incorporating full GPS-receiver functionality in GPS-n). To avoid extra signalling on the radio i/f and reduce power consumption in the MT, it seems appropriate to allocate the functionality required for accumulating available data and calculating the location estimate of the proposed hybrid method in the SRNC (SLMC). This bears additional advantages as the SRNC may request relative information from other RNCs (through the RNSAP protocol), which implies extra UTRAN signalling for the UE-based methods.

V. CONCLUSIONS

Wireless location technologies will become a crucial tool for providing the right service, at the right time, in the right location for mobile customers. Cellular operators must be able to deliver pertinent and accessible information appropriately adapted to different environments to meet diverse customers needs. To achieve such requirements over constantly evolving network infrastructures, flexible methods are required, that combine performance merits with feasible implementation costs. The method proposed in this paper, efficiently combines existing and forthcoming positioning methods, in a scheme that can be adapted to a number of different environments and related requirements. It provides a minimum "always on" location fix (CGI/++ will always provide a result) that is scalable to enhanced accuracy via existing (GPS, TDoA & derivatives) and forthcoming (AoA) techniques. It is an actual improvement of the abstract positioning method selection feature of the current UTRAN specification.

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