

Hybridised GPS and GSM positioning technology for high performance Location Based Services

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ABSTRACT

This paper presents the results of the specification phase of the EC project named EMILY (European Mobile Integrated Location sYstem).

In the context of high business potential for Location Based Services, providing increased positioning accuracy and availability is a strong market differentiator and opens new horizons for services requiring high performance.

The EMILY concept investigates the coupling of terrestrial positioning named E-OTD in TDMA telecommunication networks with the satellite-based positioning named GNSS in the context of handset-based solutions. This innovative hybridisation aims at taking advantage of the accuracy capability of Assisted-GPS technique, while the tight coupling of the two positioning technologies dramatically increases availability by reducing the minimum number of sources to generate a position to one Satellite and two BTS' or two satellites and one BTS.

I. Market analysis

The variety of Location Based Services is wide and each service has its own requirements.

Following is a summary of a full marketing study realised by Bouygues Telecom in summer 2001 and based on a set of interviews of a wide variety of population (for full study, see reference [1])

A. Service typology

The following classification has been proposed :

- Emergency Services:
Automatic or manual warning to safety forces (PSAP) in case of danger
 - Reassuring service
 - Exceptional use
- Assistance Services:
Roadside assistance, car theft assistance and pedestrian assistance
 - Practical and useful services
 - Occasional use
- Push Services:
Subscriber receives (push) personalised real-time information filtered on his/her location and preferences (previously expressed) (traffic, weather, commercial information)
 - Filtering profile needed
 - Personalised value added
- Pull Services:
Subscriber requests (pull) real-time information filtered on his/her location (traffic, weather, commercial information)
 - No filtering profile needed
 - Personalised value added
- In-vehicle Guidance:
Guidance information to motorist to drive from current location to his/her destination
 - Subscriber's dependence
 - Great personalised value added
 - Control over the environment
 - Frequent use
- Pedestrian Guidance:
Guidance information to pedestrian user to move from current location to his/her destination
 - Subscriber's dependence
 - Great personalised value added
 - Control over the environment, frequent use

- Community Services:
User is kept in contact with “home” (known environment) and with his/her community (friends, family, colleagues) to ensure sociability (people finding, chat, games)
 - Individual or collective use
 - Subscriber located by a third party
 - Feeling of proximity with friends and family
- Asset Tracking:
User (often professional) can track and manage a fleet of assets (cars, trucks, trailers, containers)
 - Professional service
 - No mass market

B. Primary user and systems requirements

Requirements were analysed by service typology to better reflect specificity of each category :

General

- Content updated in real-time
- Access personalisation by use of short-cuts
- Feedback to user’s action
- Information about waiting time for delivery of requested service

Emergency Service

- Minimum QoS to all subscribers for Emergency Services
- Network operator informs PSAP of user preferred language
- Standardised Operator-PSAP interface and cross-border call routing
- Time for location <10sec. Accuracy >100 m

Assistance Service

- Time for location <45 sec. Accuracy >100 m
- First choice in service menu
- Pull Service Requirements
- Objective / impartial information
- Exhaustive information (choice)
- Configurable search perimeter
- Interactivity (for demand refinement)

Push Service

- User chooses precisely what information to receive
- Possibility to unsubscribe easily and quickly
- Objective / impartial information
- Exhaustive information (choice)

In-vehicle and Pedestrian Guidance Service

- Adaptable to user’s means of transport with related relevant information (waiting time, traffic...)
- Accuracy depending on environment, but >10 m for dense urban areas
- Capacity to perform at least 1 fix per minute

Community Service

- User keeps control over who can locate him/her and when
- No personal information transferred to third parties without user consent
- User can activate / deactivate location
- User must be informed when located

- Time for location <45 sec. Accuracy > 50m

C. Conclusion

The performance requirements for the various services clearly show that there is a need for a positioning technology with accuracy and availability not yet achieved by existing standardised technologies.

II. EMILY Architecture

This section describes the architecture proposal to implement the hybridisation concept.

The major architectural topics are :

- overall information flow for the service request
- the required adaptations to the GSM network
- the MS that hosts the GPS chain, the E-OTD computation and the hybridisation algorithm
- the calculated position sent back to the network, to be used by service providers

A. Service scenarios

The EMILY system architecture supports all the standardized service scenarios:

Mobile Terminated – Location Request (MT-LR)

The LCS client is the service provider and it contains the location based application. It makes a LCS Service Request to the network indicating the target MS.

Based on the performance required by the service, the network may send back simple Cell-ID position or transmit the request to the EMILY handset that will switch-on its positioning capabilities and compute its position based on the pseudo-distances it will get from the satellites and from the E-OTD and A-GPS assistance data sent by the network.

The position is sent back to the network, cross-checked with Cell-ID data and sent back to the Service Provider. Thus, the Service Provider will be able to build a service to the user associated to its location.

This scenario enables community services, location-based pull services, location-based push services, guidance services and assets tracking.

Network Initiated – Location Request (NI-LR)

The LCS service request is originated in the network (e.g. automatically after an Emergency Call Origination or to support hand-over). As previously, the network sends assistance data to the target MS, which computes its own location. After cross-checking with Cell-Info, the network sends the result to a LCS client, which can be an external service provider or the initiating LCS client.

Mobile Originated – Location Request (MO-LR)

The location based application is in the MS. The MS sends to the network a service supplementary request and can request to receive its own location or to send it to an other LCS client (such as a service provider). As

response, the network sends only assistance data to the MS without waiting for the response in the case where the location is not sent to an external LCS client. Services which are involved are typically navigation service.

In the other case, as previously, the network initiates the positioning procedure with the assistance data and cross-checks the received location with the Cell-Info: the result is sent to an external LCS client.

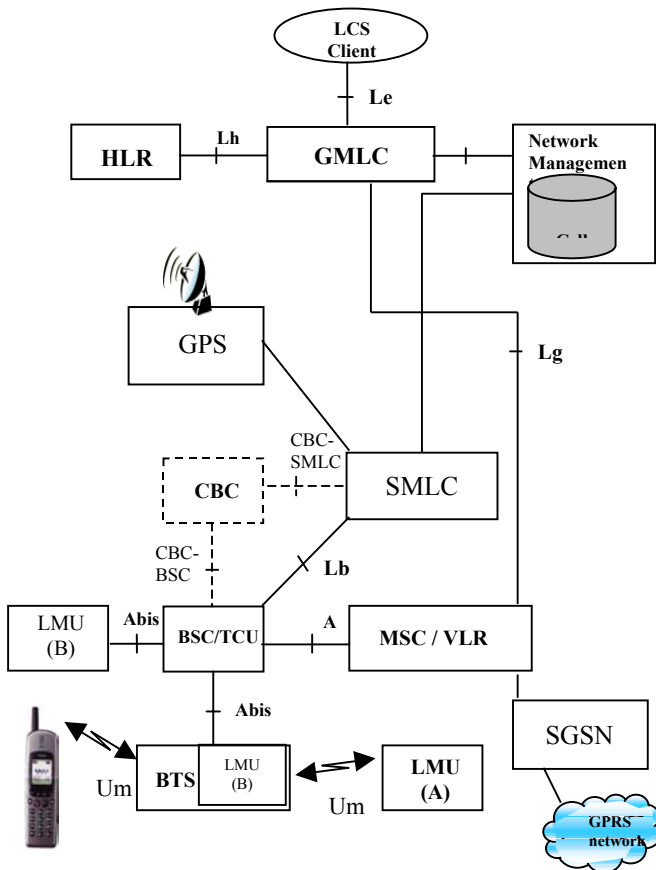
B. Network architecture

In order to support these 3 scenarios, the network will be comparable to a standard GSM network, with the addition of elements necessary for Location Services. These include the LMU (Location Measurement Unit), SMLC (Serving Mobile Location Center) and GMLC (Gateway Mobile Location Center).

The EMILY LMU may include the capability of computing Real Time Differences (RTDs) between the GSM and GPS frames, as well as the habitual RTDs between different GSM base station.

The SMLC is must provide this additional RTD information to the handset. In addition, it will provide Cell-ID/TA based positioning for non-EMILY handsets. The GMLC is completely standard.

The appropriate fields in the standardised assistance message will be enabled to provide all necessary information to the MS.



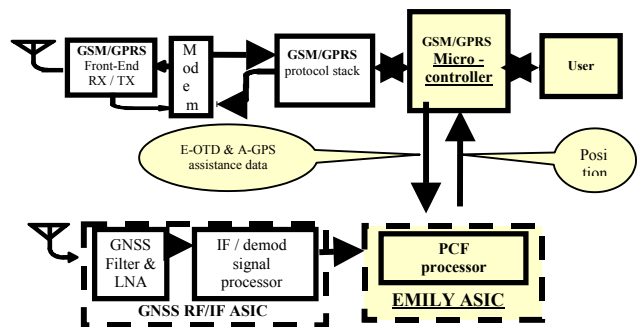
On the GSM side, the MS receives both the bursts from BTS's and the BTS de-synchronisation information (RTD) and, after having performed Observed Time Difference (OTD) measurements, is able to compute the user position by triangulation.

At the same time the MS receives GPS assistance data from the network.

Finally, the MS has GPS capability, performs satellites pseudorange measurements, and compute user position by tight coupling of OTD and GPS measurements.

C. Handset architecture

The handset hosts two separate chains, one for GPS and one for E-OTD.



All measurements (OTD and GPS pseudo-distances) are sent to the EMILY ASIC, that can then compute hybridisation of all available measurements.

It should be noted that in future development of the EMILY concept, there could be a common RF/digital chain to perform both the GSM and GPS measurements and have the Position/Velocity/Time computation in a common GSM/GNSS baseband ASIC. This configuration would enable even better response time and lower consumption.

III. Hybridisation

The EMILY hybridization strategy includes two steps, as illustrated in the following figure:

- GSM/GPRS
 - GPS/GNSS
 - Cell-Id + TA
- } EMILY ASIC step
- } EMILY Network step

In a first step, a preliminary position of the MS is computed using GSM/GNSS and GPS/GNSS measurements, that is, Observed-Time-Differences (OTD) and Pseudo Ranges (PR), respectively. This preliminary position estimate can be further hybridized with Inertial Navigation Systems (INS) in the case of using EMILY in-vehicle. In a second step, the computed position is further hybridized with the cell-id information, and, if available, with the Time Advance (TA) information. While the second step (performed by

the network) simply offers a compatibility with other available location techniques, the first step (performed by the MS) constitutes the main innovation offered by the concept, and the only one focused here.

The most simple first-step hybridization strategy is the so-called *loose coupling* between two positions computed independently using the standard E-OTD and GPS methods respectively. On the contrary, the so-called *tight coupling* is envisaged in EMILY, motivated by its higher performances in terms of accuracy and, mainly, availability. With the *tight coupling* strategy, both OTD and PR measurements are used jointly to deliver a unique positioning estimate. The proposal is to use a global hyperbolic location technique based on time differences.

The conception of this global hybridization leads to the definition of three different kinds of time differences:

- 1) A total of $[N_{SAT}-1]$ OTDs among signals from N_{SAT} satellites under visibility ($OTD_{SAT-SAT}$). These can be easily computed as differences between the pseudo-range of a given satellite (used as reference) and the remaining satellites. As the satellites are synchronized, the Geometrical Time Differences (GTDs) can be inferred directly from the OTDs:
 $GTD_{SAT-SAT}=OTD_{SAT-SAT}$.
- 2) A total of $[N_{BTS}-1]$ OTDs among signals from N_{BTS} base-stations under visibility ($OTD_{BTS-BTS}$). These are the classical ones used by the standard E-OTD positioning method. They are computed using the serving BTS as reference. As the base-stations are unsynchronized, the GTDs need to be computed as in the case of the E-OTD technique:
 $GTD_{BTS-SAT}=OTD_{BTS-SAT}-RTD_{BTS-SAT}$.
- 3) A **single** OTD between the serving BTS and the reference satellite ($OTD_{BTS-SAT}$). The computation of this OTD requires a special hardware, because it involves the joint processing of two signals of different nature. As the reference base-station and satellite are not synchronous, the GTD should be computed as:
 $GTD_{BTS-SAT} = OTD_{BTS-SAT} - RTD_{BTS-SAT}$.

According to this classification, two different kinds of *tight coupling* strategies can be envisaged within the EMILY framework:

- *Tight/partial*. Only the $OTD_{BTS-BTS}$ and $OTD_{SAT-SAT}$ measurements are used. The number of equations available for positioning calculation is then:

$$\begin{aligned} \text{Num. Eq.} &= [N_{BTS} - 1] + [N_{SAT} - 1] \\ &= [N_{BTS} + N_{SAT}] - 2 \end{aligned}$$

- *Tight/full*. The $OTD_{BTS-SAT}$ measurement is used along with the $OTD_{BTS-BTS}$ and $OTD_{SAT-SAT}$ ones. The number of equations available for positioning calculation is then:

$$\begin{aligned} \text{Num. Eq.} &= [N_{BTS} - 1] + [N_{SAT} - 1] + 1 \\ &= [N_{BTS} + N_{SAT}] - 1 \end{aligned}$$

Next table summarizes the difference in terms of availability of the different kinds of the hybridization strategies described above, considering the case of a 3D positioning.

Hybridization Strategy		Minimum availability scenario			
		EMILY		GSM alone	GPS alone
Loose coupling		4 BTS + 4 SAT			
Tight coupling	Partial	2 BTS + 3 SAT	3 BTS + 2 SAT	4 BTS	4 SAT
	Full	3 BTS + 1 SAT	2 BTS + 2 SAT		

It can be seen that *loose coupling* requires either four satellites or four base-stations under visibility. This necessity is avoided with the *tight coupling* strategy. In particular, using *tight/partial*, a total of five mixed references are needed, and if only one satellite or one base-station is under visibility (which may happen in some environments), then this single signal cannot be exploited for positioning. This means that in the cases of 4BTS&1SAT and 1BTS&4SAT, this single SAT and single BTS cannot be used, respectively. Instead, using *tight/full*, a total of four mixed references are needed, no matter them being either base-stations or satellites.

A. $OTD_{BTS-SAT}$ concept definition

As explained above, the computation of the $OTD_{BTS-SAT}$ is required to achieve the full capability of EMILY. The $OTD_{BTS-SAT}$ is defined as the difference between the starting time of the received GSM/GNSS signal frame, and the starting time of the received GPS/GNSS signal frame. The main critical aspect to take into account is that both frame intervals are different. The case of the existing GSM and GPS systems is illustrated in the following table:

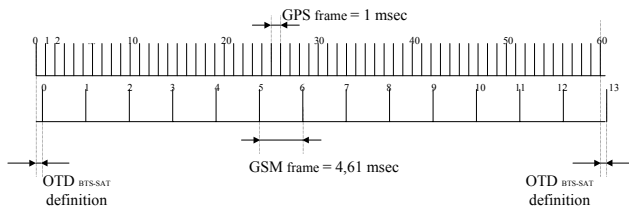
System	Frame duration (milliseconds)
GSM	$GSM_{frame} = 8 \times 15 = 4 + 8 = 4.61$
GPS	$GPS_{frame} = 1$

Nevertheless, the EMILY solution exploits the fact that frame ratio is rational:

$$\frac{GSM_{frame}}{GPS_{frame}} = \frac{60}{12}$$

The implication of this fact is that the time difference between the time of arrival of both frames becomes a constant if the measurement is performed at intervals of

13 GSM frames. The following figure illustrates this concept:



A specific hardware is then to be designed to perform this task, in order to allow the maximum availability performance offered by the *tight/full* hybridization strategy.

B. LMU updated functionality

In the case of *tight/partial*, the LMU does not require any updated functionality with respect the one required by the E-OTD technique. Only in the case of *tight/full* hybridization, the LMU needs to be updated with the same hardware required inside the MS to compute the $OTD_{BTS-SAT}$. For this task, the LMU needs to use the same frame number module 13 used by the MS, to be consistent. The new RTD is then computed as:

$$RTD_{BTS-SAT} = OTD_{BTS-SAT} - GTD_{BTS-SAT}$$

The $GTD_{BTS-SAT}$ in that case is computed, not only from the known position of the BTS, but also from the position of the satellite computed either from the received ephemeris or from the assistance data received from the network in the case of A-GPS.

It is noted that, due to the rational ratio between both system frames, the $RTD_{BTS-SAT}$ computed by the LMU is a very stable quantity. This means that no additional updating rates are foreseen for the LMU to transmit this information to the network. The new RTD is sent to the SMLC along with the remaining $RTD_{BTS-BTS}$, using the same updating rate.

Finally, it is noted that the *tight/partial* strategy can be considered as an intermediate step to achieve the full capability of EMILY. The MS can use this strategy when the RTDs received are computed by standard LMUs. Progressive deployment of updated LMUs may allow the MS to switch to a *tight/full* strategy when it detects that the complete set of RTDs is received from the network.

IV. Performance expectation

The key performance parameters of this new technology are the high accuracy of the GPS performance (when available), combined with high availability resulting from the tight full hybridisation.

Following is a list of the most important performance parameters, to be validated during the trial phase :

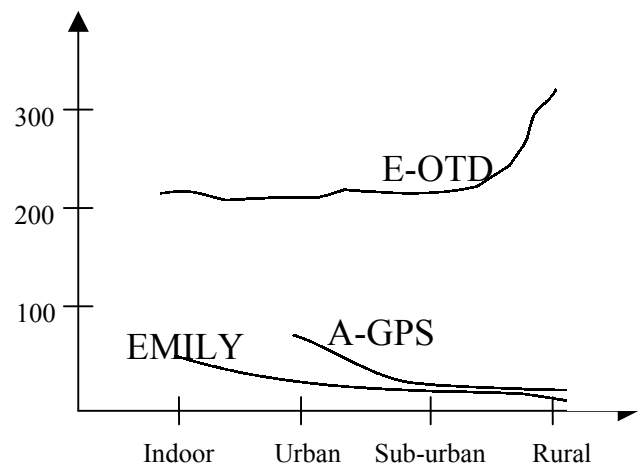
Accuracy	→ 5-50m
Availability	→ ~95%
Response time	→ 30s (3-5s if E-OTD alone)
Legacy handsets	→ non-EMILY phones OK
Service area	→ Everywhere
Network upgrade cost	→ Medium (LMU cost)
System set-up time	→ LMU=slow/SMLC=fast
Standards compliance	→ ETSI (3GPP)
Service scenario	→ MO-LR/NI-LR/MT-LR
User controlled privacy	→ Yes

The only limitation is the response time inherent to the GPS acquisition. However, in case of explicit need for fast positioning (Emergency services, see section I), the system is able to provide a first position with E-OTD performance and update the network with a full EMILY position once available.

The EMILY selected architecture foresees both MS based capability (i.e. E-OTD plus A-GPS) and MS-assisted capability (i.e. Cell-ID plus TA).

Compared to the existing standardised technologies such as Cell-ID, or E-OTD and A-GPS alone, the EMILY system represents a significant step forward in providing enhanced location quality for Location Based Services.

The following graph illustrates the expected accuracy of the EMILY system, compared with E-OTD and A-GPS.



V. Development and Trials definition

This section briefly describes the characteristics of the prototype, and the strategy for the validation phase that will be conducted to assess the expected performances.

The progress can be followed on the EMILY web site www.emilypgm.com where all project deliverables will be posted.

A. EMILY prototype

Using the best industry expertise and best achievable technology, a new generation of “positioning” modules will be developed to provide an economical and technical answer to the need of European mobile manufacturers for the next generation of handsets.

For this purpose, two ASIC’s will be developed: one to host the GPS RF chain, and the other for the GPS baseband processing and the core EMILY algorithm for GSM/GPS hybridisation.

For simplicity, the EMILY prototype will not be a fully integrated handset, but the combination of two terminals. This will not alter the performance of the final systems.



B. Simulation phase

A full system simulation will be performed, utilising a trajectory generator, a complex satellite constellation simulator, and a GSM base station simulator.

This first phase will confirm the performance of the hybridisation with the new ASIC’s in simple line-of-sight environments.

C. Outdoor trials

The network of Bouygues telecom (French operator in the EMILY consortium) will be used to test in a real environment :

- the proper implementation of the network elements and the delivery of the assistance messages,
- the true performance of position computation in the various environments with non-line-of-sight and multipath.

VI. Conclusion

Hybridisation is the key to the performance improvements of the EMILY system. It utilises the best accuracy available from E-OTD or GNSS technologies, while the “tight full” hybridisation concept will ensure maximum availability.

Full standardisation will provide a clear upgrade path to GPRS and UMTS networks, and make the EMILY concept the foundation for future high performance Location Based Services development.

REFERENCES

- [1] M. Gibeaux (Bouygues Telecom), User and System Requirements Report, D5 from EMILY project, www.emilypgm.com