INDOOR LOCATION OF RESCUERS IN A COMPLEX EMERGENCY MANAGEMENT SCENARIO: THE LIAISON ITALIAN FIRE BRIGADE TEST CASE

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Abstract

After three years and half, in May 2008 the EC funded Integrated Project LIAISON has delivered the final results.

The project was focussed on location based services in a number of scenarios representative of potential market segments. Two of them were emergency related: the Incident Management scenario, user-led by the Sussex Police Authority and the Fire Brigade scenario, user-led by the Italian Ministry of Interior, Department of Firemen Corps (CNVVF).

While the former aimed at improving the incident management through a set of outdoor location services implemented over a GIS system; the latter one took benefit from the first and focussed on the indoor location, the result of which this paper will present.

The Fire Brigade scenario was understood since the kick-off of the project as the most demanding one. The interest of the Department of Firemen Corps in the project was justified by the need of drawing a sound technological path to quickly deploy a reliable location service able to perform anywhere, anytime.

Several companies in the past have proposed to the CNVVF state-of-the-art systems able to deliver location services to improve the emergency management under specific conditions. Whenever such systems have been acquired, their practical use in real emergency has been negligible, mainly due to limitations of the operating conditions, performance and/or procedures. From those experiences it was clear the need for reaching a minimum level of performance and operating conditions before deploying any further system. In fact, location systems are deemed necessary only if available everywhere (even indoor) and for all the rescuers operating in the same emergency (high number of devices: high costs for devices and personnel training).

Taking benefit from the project assets it was possible to put in place a location test bed in house, within the Firemen Corps Operative Training Centre near Rome. That test bed has been used to test in near-to-real-life conditions the location technologies that the project industrial partners were able to propose, namely AGPS, WIFI Fingerprinting, MEMS with calibration and UWB positioning. All such techs have been tested over communication bearers which realistically will be broadly and effectively deployed in the near future, namely GPRS, TETRA, WIMAX and UWB.

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Indoor Location Techniques

The Fire Brigade tests have been performed on Montelibretti site in the SFO (Operative Training School) of CNVVF near Rome. The figure below shows the test area map with the Tunnel, the Fire House and the Training Building.

The indoor location techniques used during Liaison project were:

1. WiFi Fingerprinting indoor location;
2. Micro Electro Mechanical Sensors (MEMS) with or without calibration;
3. UltraWideBand (UWB) radio technology.

WiFi Fingerprinting indoor location

The use of WiFi technologies to deploy an indoor location service is well known. There are basically two variants of this approach:

1. measuring the attenuation of the signal strength of each access point (AP) as received by a rover unit and compare it to a previously measured distribution of such signal strengths (WiFi fingerprinting);
2. measuring the time-of-flight of the signal received by a rover from each AP and apply any sort of triangulation technique (triangulation or multilateration).

Since the beginning of the project, it was chosen to explore the potentials of the first one. The baseline assumption which justified the choice, was that the very same infrastructure used for inter-networking inside building could have been used for indoor location as well. If this was true, a large number of buildings would have been ready for the deployment of such location service without the need of imposing any structural fitting.

Although seemingly very promising the use of WiFi fingerprinting for indoor location has been proven disappointing.

The assumption of using the same infrastructure collides with the stringent location accuracy requirement of most indoor applications: if we want to have a meter level accuracy then the density of Aps must exceed one every 50 square meters, which is more than four times the density nominally required for inter-networking.

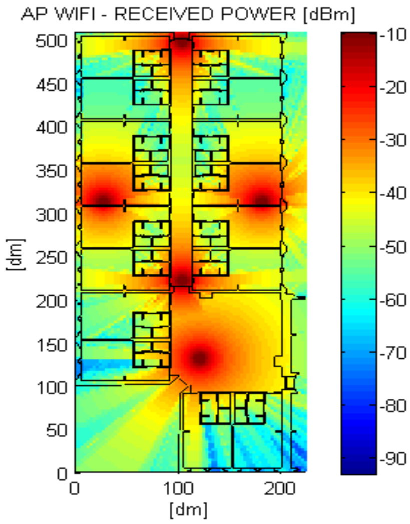

Figure 1: Received Signal Strength Intensity

Figure 1 shows the Received Signal Strength Intensity (RSSI) of a floor measuring about 40x20 meters in a test building with five WiFi APs. As seen the WiFi coverage is good (if not excellent) for inter-networking, but the indoor location quality is just fair (5meter RMS at best).

Some techniques to increase the location accuracy have been scrutinized, among which topology related augmentations like particle filtering or Voronoi diagrams. The net conclusion is that they add little value to the location accuracy (not better than 30%) at the cost of a complex and error-prone preparation of the test site maps and that they are not suitable to adapt to a dynamic scenario (e.g. it is hard to synchronize the particle filter with a scenario where a fireman come in and out any rooms through the windows using a ladder).

Moreover all indoor location technologies that are “infrastructure based” have a severe drawback if used in emergency situations when the resilience of any system is seriously at stake. In fact they can easily became unavailable due to power outage and other effects like smoke and moisture. To satisfy the resilience requirement, it is possible to reinforce the fire resistance of the devices and/or to increase the redundancy. The first measure greatly increase the cost per device, which is critical to assure a good coverage iin a significant number of buildings. Whereas to increase the redundancy we should further increase the number of WiFi APs, which is in contrast again with the baseline assumption to use the very same infrastructure used for inter-networking. Moreover whenever an increased number of APs would be installed, the network should demonstrate to be able to self-adapt to the sudden loss of some of them. Instead, , in the case of WiFi fingerprinting techniques, if we destroy one or more APs, a very likely event in case of fire, the indoor location greatly degrades to the limit that it is quite likely that the indoor location will be wrongly assigned to the wrong room or worse to the wrong floor. Even without such dramatic changes, a seemingly minor change in the furniture is sufficient to greatly tamper the location accuracy (50% or more wrong room discrimination, for example), if a new ‘fingerprinting map’ is not provided. All of these situations have been tested during the trials and clearly indicate that WiFi is not a good solution for emergency location services. On the other hand WiFi, if supplemented by other location technologies like RFID tags, could be an excellent “nominal” location technology and have its role in standard environments, especially for the tracing of goods and possibly people inside buildings.

Calibration, MEMS technology and GPS/AGPS

A further indoor location technique was based on three different modules, which merged Assisted-GPS with MEMS location estimates and a calibration service to supply updated firemen coordinates within buildings.

The module in charge of acquisition and processing MEMS data was developed by Ecole Polytechnique Fédérale de Lausanne (EPFL), Switzerland, providing:

1. dead-reckoning information composed of the distance travelled by the user since the last computation, the direction of travel (2D) and the altitude variation by detection of stairs climbing/descending (3D)
2. posture (standing, lying, etc.) information, which informs about the user's current posture (standing, lying, etc.) and its immobility condition to infer about its safety condition.

These information were supplied from MEMS technology (Micromechanical systems); in particular it was chosen to use 3 MEMS sensor units placed on the user's trunk, thigh and shank of the firemen. Each sensor unit consists of 3 accelerometers, 3 gyroscopes and 3 magnetometers based on MEMS technology.

A further module supplies GPS or assisted GPS position providing longitude, latitude, altitude, direction, velocity and error information.

A last module, developed by Telespazio allows to correct drifts errors due to the MEMS derived positioning, along given trajectories, performing their calibration.

MEMS-based location services present quite good potentialities when compared with some of the stringent requirements of the emergency management domain. Such services are not hindered by the number of walls interposed or their number. Moreover they work without the need of any infrastructure. On the other hand it is well known that their location accuracy rapidly decreases if not 'calibrated' from time to time.

Providing such calibration is not an easy task during a fire intervention. The ideal situation would be to have RFID tags pre-fitted inside the building which provide their location when interrogated, but some tactic was needed to address the most frequent case where a map of the building were accessible, but no calibration tag were available. So that the only tactic which was deemed acceptable foresaw the following: the first fireman entering the building affixes a calibration RFID tag over all the door gone by. This 'door tag' starts transmitting a short message able to identify the location as a 'door' or 'staircase', so that all the device carried by the following firemen can calibrate its location comparing this notice with the nearest 'door' or 'staircase' found on the previously saved map.

The 'door tag' functioning was simulated by the fireman who was pushing an hardware button whenever passed through the predefined reference points (e.g. any doorway, window, stairs etc), whereas the system determined which "simulated" RFID had been detected and retrieved its exact position coordinates from a database.

The calibration module for pre-fitted RFID tags was implemented so as to be able to provide an absolute position from one of these sources:

1. RFID tags by a RFID receiver and a lookup in a table of tag position loaded on terminal;
2. manual indication from the mobile user or the control operator pointing on a map.

<u>MEMS and calibration tests results</u>

Two different kind of indoor location tests were performed:

1. MEMS and AGPS location based technique;
2. MEMS, and AGPS location based technique with calibration.

For all tests, the firemen started outside of the buildings remaining totally still for few seconds to obtain a good GPS/AGPS signal and for the convergence of the MEMS initialization, while during the route, the firemen (equipped with operative devices) walked normally trying to keep a right posture.

The several obtained results showed the absolute need to use calibration points to minimize bearing errors due to the MEMS sensors. Below are reported the most significant tests results (rms values in proximity of all the calibration points, the gap from an assigned path and success percentage of room and floor discrimination) conducted inside the Training Building, Fire House and Tunnel with some screenshots of the results showing the measured trajectories and firemen positions.

Training Building

Post-processing analysis have supplied good location accuracy results: average rms = 4.5 m at the calibration points (rms was obtained as combination of horizontal and vertical error) and average rms= 4.0 m across the trajectory (rms was computed as error distance from the assigned path) Figure 2. During several runs inside the building, this indoor technique has allowed to obtain 70% of success for the floor discrimination (climb stairs from ground floor to first floor and back) and 80% of success for rooms detection. The major or minor success of room calibration depends by calibration point positioning.

Fire House

In the Fire house the results have been better than the tests performed in the Training Building due to the small rooms and short corridors. Anyway the magnetic perturbations caused by the metallic panels have produced minimal drifts, Figure 3.

Tunnel

Also in the tunnel, the presence of trucks (metallic masses) have requested calibration points (one in the entrance and another one on the back), Figure 4.

Figure 2: MEMS, and AGPS location based technique with calibration inside the Main Building

Figure 3: MEMS, and AGPS location based technique with calibration inside the Fire House

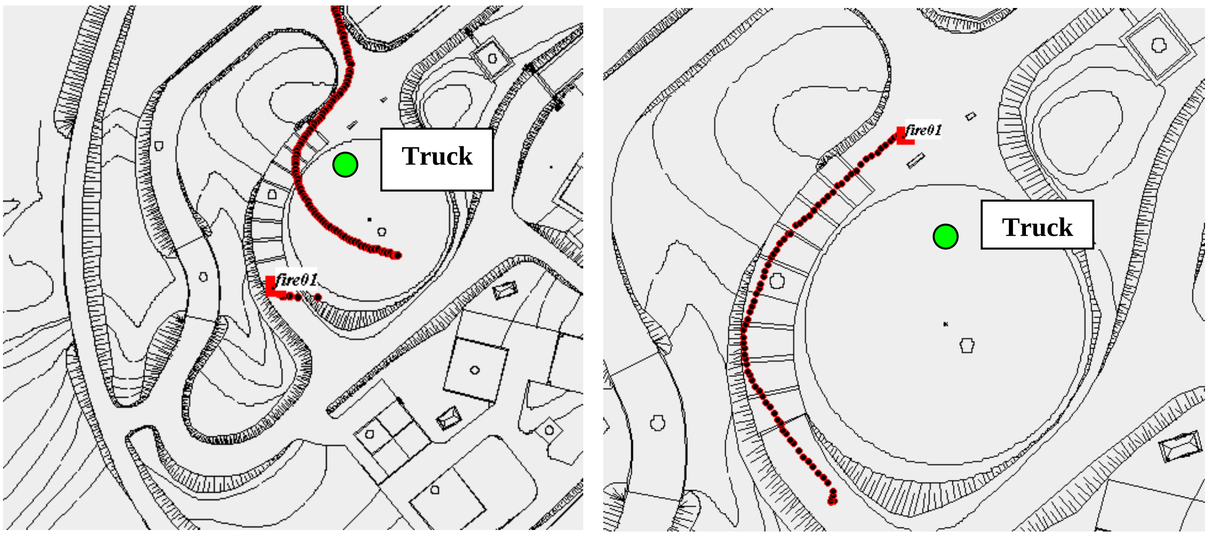

Figure 4: MEMS, and AGPS location based technique with calibration inside the Tunnel

Indoor location enhancements

To enhance the quality of the indoor location it was tried the exploitation of the building topology knowledge.

One relatively easy and rewarding way it was to avoid room crossing at wrong places. Figure 5 shows the concept.

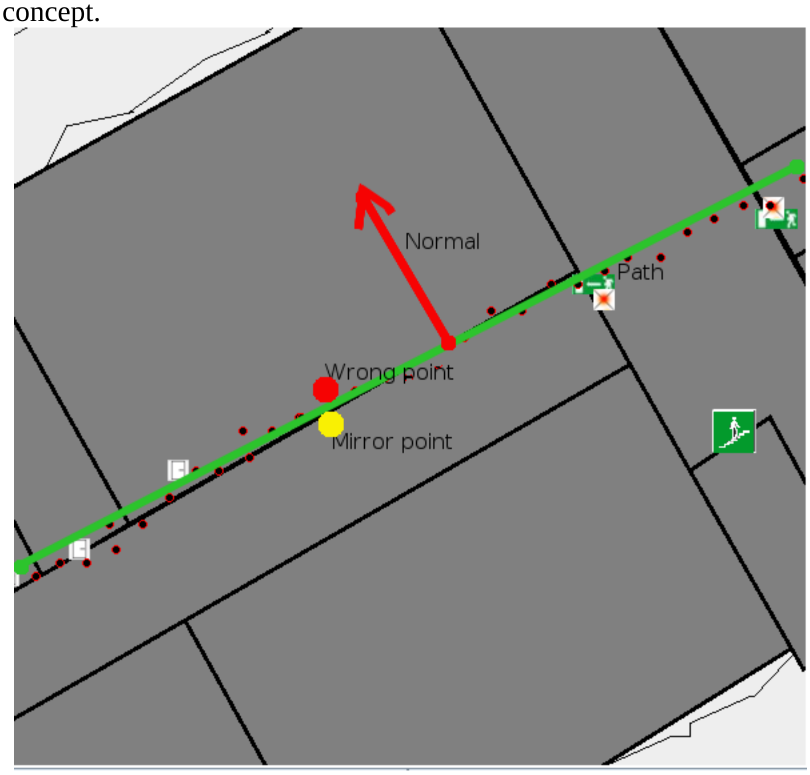

Figure 5: Indoor location enhancements

The terminal is travelling on a long corridor: this is one of the most difficult environments for MEMS. In this case an error of 5° in bearing results in crossing the corridor after not more than 20 meters.

If we have a digital map of the corridor it is relatively easy to detect that the terminal is crossing walls and we can correct the location by mirroring it along the wall. Within the chosen solution wall crossing is accepted only at connecting elements and when the angle of incidence is close to 90°.

Moreover there is an added benefit to this approach in that the mirrored location is fed back into the MEMS hybridization layer and therefore in the Kalman filter to improve the following locations.

Looking at the test results this approach proves effective by reducing the location error (about 30% RMS error decrease). The benefit is observed even in presence of maps with topological errors (like holes between rooms).

Another possible heuristic could be to impose that room crossing happens only at connecting elements (doors, windows, entrances, stairs, elevators). But in this case the benefit is not so easy to obtain, because great care needs to be taken to avoid ambiguous situations, like in the case of one door close enough to another one and connecting a different room. If the wrong door is selected the terminal will be assigned to the wrong room and remain confined there. Topological hinting might be made more complex to solve this ambiguity, but the added complexity does not justify the effort.

UltraWideBand (UWB) radio technology

Another interesting indoor technique tested was the UltraWideBand (UWB) radio technology as provided by Thales Research & Technology (UK) Ltd within the EUROPCOM EC R&D project.

The use of UWB technique was justified by the need to solve the problem of radio propagation inside and around a building, which is severely affected by the walls and other obstacles within it. Signals are attenuated severely and also arrive at receivers by a variety of paths with different propagation times. This limits the accuracy of timing information used for positioning and reduces data throughput. The use of UltraWideBand (UWB) technology claimed to reduce the impact of these problems.

A generally accepted definition of a UWB radio is any device which transmits a signal with a fractional bandwidth greater than 25% or in the case of centre frequencies above 2GHz, any signal with a bandwidth >500MHz. One of the key features of UWB, which makes it of interest for communications, positioning and radar applications, is the very fine time resolution that can be achieved, by virtue of its wide bandwidth. This enables very accurate measurement of 'time of flight', leading to highly accurate positioning. It also enables resolution of the closely spaced multipath propagation components typically found within buildings and provides high-resolution radar at relatively low centre frequencies.

The system foresees the installation of UWB Base Units (BU) over the fire trucks located outside the building subject to the intervention. These UWB BUs are able to accurately calculate their position through GPS RTK and synchronize between themselves wirelessly. The position is then calculated by a UWB Mobile Unit (MU) carried by the fireman through triangulation between the ranges from that unit and a minimum of other four UWB units. To overcome wall penetration problems, each unit become a node of a self-configurable network able to locate itself as soon as 'see' four other 'location-aware' units. The system foresees the use of UWB Droppable Units (DU), devices which can be 'dropped' periodically by the fireman when he enters the building so as to reach the minimum number of 'visible' 'location-aware' units, Figure 6.

Due to the time constraint imposed by the tight schedule of the EUROPCOM project, it was possible to carry out only a limited number of tests. However the results obtained, while more qualitative than quantitative, were undoubtedly interesting. Since it was clear that the main limitation of this solution was linked to the walls penetration provided, the few tests carried out focussed on it.

Each unit was able to estimate cm-accurate range within 100 metres line-of-sight from another unit. Then the system was tested within a standard building with structure in reinforced concrete with 9-cm-thick laterice & plaster walls and it was clearly stated that the units were normally not able to penetrate more than two walls. When the units were able to 'see' the minimum number of other 'location-aware' units, then the accuracy was good (<1m).

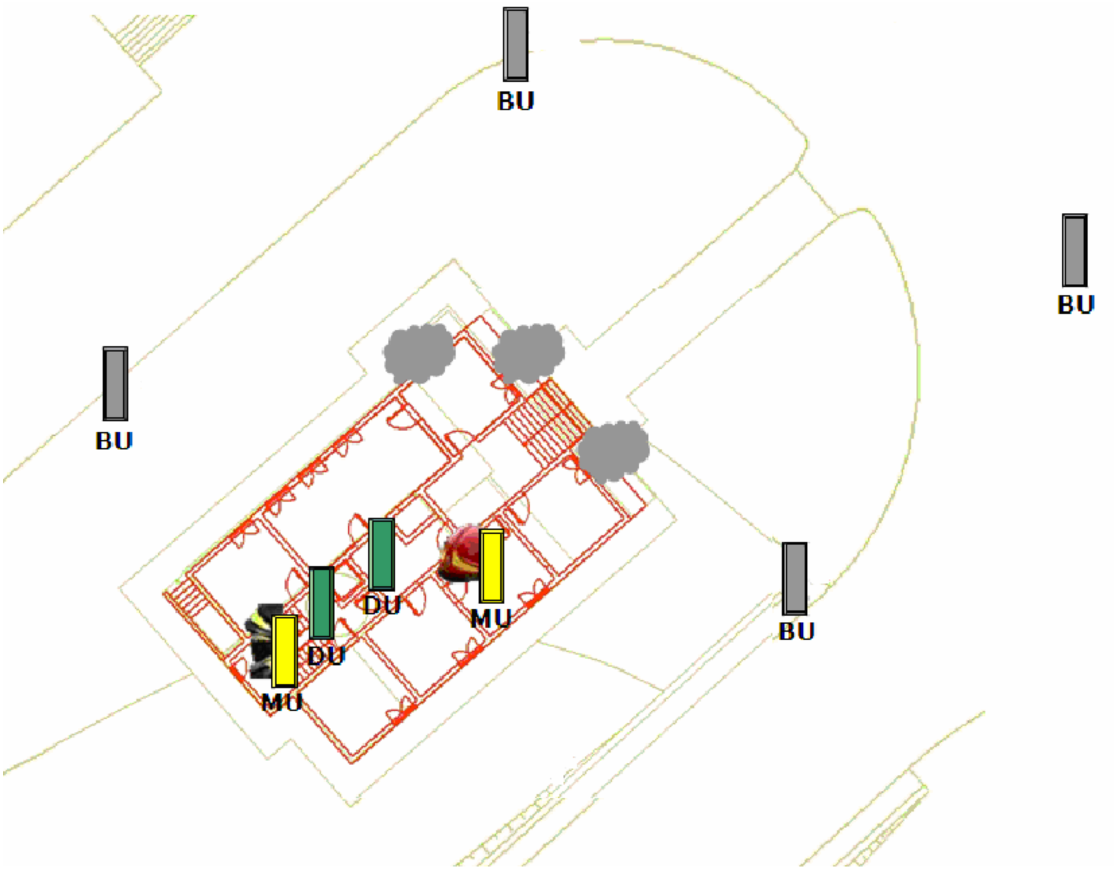

Figure 6: Deployment of the BU (Base unit), MU (Mobile unit) and DU (Droppable unit)

Conclusions

The opportunity to submit the above mentioned techniques to comparable tests has been proven valuable. In fact it was possible to complete an up-to-date state-of-the-art of both presently available and near to be developed indoor location solutions. Some of the tested techniques present limits which do not permit their use in this emergency management domain while others demonstrate noteworthy performance, but none of them appears to be able to satisfy by itself the stringent requirements of fire intervention indoor location service.

On the contrary the adoption of more techs coupled together could possibly solve the dilemma between the opposite requirements of self-sufficiency and coverage. In fact the first requirement asks the availability of a location service everywhere, anytime, basing on devices and material directly deployed by the first responders, without the need of pre-installed systems within the building of interest. On the contrary the previously described test results makes clear that within a large fraction of infrastructure – often the one with the higher risk - will not be possible to obtain any indoor location service, there will be no coverage, wherever an ad-hoc pre-installed indoor location system is not made available for the coming rescuers.

As a result the solution to be adopted will have to be deployable and able to easily extend its coverage - as for the tested UWB solution - but able to provide a ready-to-be-used location service based on specific pre-installed system - as for the tested RFID solution - within those high risk infrastructure where the deployable solution could not suffice.

Therefore, if an "emergency location system" is needed, from now on it will be necessary to agree on the type of system and to the most suitable commercial and regulation roadmap to obtain the largest coverage in the shortest time, beginning from the higher risk infrastructure and in particular avoiding to waste resources with systems unable to cope with the first responders' requirements.