

EUROPCOM – Emergency Services Location Service using UltraWideBand Radio

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Abstract—This paper starts with an overview of the EUROPCOM EC Framework 6 (FP6) project, which aims to provide accurate positioning within buildings for the emergency services. The current project status and the performance aims are outlined. The UltraWideBand (UWB) technology which will be used in the demonstrator is then discussed, with the reasoning behind the particular choice. The paper concludes with a description of the overall demonstrator system and how it will operate.

Index Terms— Emergency services, Position measurement, Multipath Channels, UltraWideBand (UWB)

I. INTRODUCTION

THIS paper is based on the work being done in the EUROPCOM EC FP6 project. It starts with a description of the targeted application, describes the aims of the project and current progress and finally describes the UltraWideBand (UWB) technology being used and the reasons for its selection.

The emergency services are already making increasing use of satellite positioning to aid their operations outside buildings. Currently once personnel enter a building, they lose this location service, due to loss of the satellite signals which are absorbed and reflected by the building materials. EUROPCOM's main aim is to fill this capability gap.

II. EUROPCOM APPLICATION OVERVIEW

A. The Target Application

In many emergency situations, particularly within large buildings, which may be partially or completely collapsed, safety and co-ordination of the operations is hampered by a lack of knowledge of the whereabouts of emergency staff. The intention of EUROPCOM is to investigate and demonstrate the use of UltraWideBand (UWB) radio technology, to allow the precise location of personnel to be displayed in a central control vehicle and simultaneously provide some level of extra robust communications.

The concept is best illustrated by a typical scenario in

which the system would be used:

A large building has collapsed (perhaps due to fire, terrorist action, earthquake...) and the emergency services have arrived on the scene. Each member of the emergency service team is equipped with a EUROPCOM UWB unit, as is every emergency vehicle. A temporary infrastructure, consisting of the UWB radios on each emergency vehicle, is automatically in place as the vehicles are deployed in the area. In some situations, if there are insufficient vehicle mounted units for example, it may be necessary for the emergency personnel to deploy additional portable UWB units. These 'infrastructure' units (Base units, BUs) automatically calculate their own position using differential Real-time Kinematic (RTK) satellite positioning, which allows them to determine their absolute position to centimetric accuracy in outdoor locations.

As described in more detail later, the EUROPCOM system will allow the real-time 3D positions of every member of the emergency service teams to be determined within and around the building(s). These positions are communicated back to a single control point, enabling easier co-ordination of the search and rescue efforts. The system is activated as the vehicles arrive on site and the data, giving positions of all personnel, will be displayed at the control point as soon as it is activated. In principle, any of the vehicles could contain a computer capable of acting as the control point for the system, so positions could be displayed as the first personnel enter the building.

The main elements of the concept are shown in Fig. 1. As already mentioned, the emergency service personnel are each

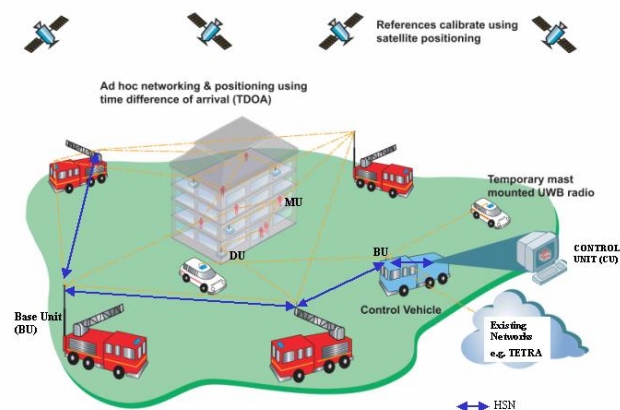


Fig. 1. EUROPCOM Concept

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equipped with a small unit (a mobile unit, MU) which allows transmission and reception of UWB signals (eventually this could be integrated with their existing radio equipment). Each unit determines its range from at least four of the surrounding units and hence its relative position with respect to those units. As personnel go into the building, it is likely that at some stage, depending on the building structure and numbers of other personnel, their MU will lose contact with a sufficient number of other units to maintain their position calculation. Before this happens, the personnel will be advised, by a signal from their MU, to place an extra portable UWB unit (a dropped unit or DU), which will enable positioning continuity. The DUs are essentially the same as the MUs, except that they will need to be activated by some sort of switch when placed. However no further action will be required. In general, the EUROPCOM system will require minimal intervention from the emergency service personnel to operate effectively.

Each UWB unit, whether it is fixed, portable or carried by a user (i.e. BU, DU or MU), is a node in the UWB network. As already mentioned, the relative position of nodes is determined by measuring the ranges between them. Within any network of nodes with known relative positions, fixing the absolute positions of at least four of the nodes allows the absolute positions of all nodes to be fixed unambiguously in three dimensions. See Fig. 2, which illustrates this for two dimensions (in this case a minimum of three nodes must be fixed rather than four.)

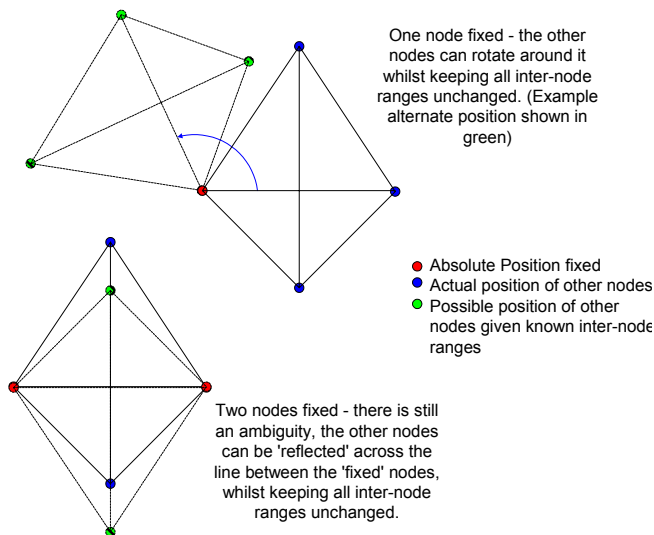


Fig. 2. Illustration of the need, in two dimensions, for at least three nodes to have their absolute position fixed, for unambiguous determination of the absolute position of other nodes

The Base units (BUs), with their GPS determined absolute positions, act as references to allow the absolute positions of all nodes in the UWB network to be determined

Each UWB radio also provides limited data communications capability which allows a control vehicle to

collate information from all of the UWB units and display the real-time positions of all of the rescue personnel on a detailed map/building plan. Accurate representation of the personnel locations is thus enabled. Note that in cases where no detailed plans are available, the facility to create a representation of relative personnel locations is envisaged. This may be shown in the final EUROPCOM demonstrator, but may be left for a future product development.

Personnel who get into difficulties can push an emergency button, which will automatically flag up an urgent message on the control vehicle's display and their exact location will be marked on the plan. Since the system will know the precise location of all personnel, any of them could be directed to where he is trapped. The officer in charge can see at a glance who is in the best position to give assistance. The UWB units, both those with personnel and those deployed as 'infrastructure', will form an 'ad-hoc' network allowing data to be transferred from say a trapped rescue worker, through multiple UWB units, to the control vehicle. Extremely reliable data communication will be provided by the system, even in severe environments, both by virtue of the multipath resistance of UWB and also due to the ad hoc networking, which enables every node to act as relay.

B. User Requirements Overview

Some of the main user requirements are apparent from the description above, so only a limited subset is highlighted here:

- Positions of personnel displayed to an accuracy of $\pm 1\text{m}$ in three dimensions (the important aim being to know which floor and which side of a wall)
- Position Update rate: 1 per second
- The system should have reasonable capacity (up to 1000 users has been suggested as an upper limit)
- Coverage should extend over the site, which could include an area around the buildings as well as multiple buildings on a site
- Reliability and availability are key issues – if a position is not accurate, this needs to be recognised by the system and marked as such on the display
- Information Security – this is very important for a final system, but isn't being demonstrated by EUROPCOM
- Battery life – at least 6 hours (this may not be achieved by the EUROPCOM demonstrator)

III. EUROPCOM PROJECT AIMS AND PROGRESS

The project aims to prove the principle of using UWB to provide emergency personnel positioning by producing a demonstrator capable of meeting the most difficult of the requirements – the main priority being the reliable positioning of personnel with different building structures. Although, we will not be able to cover all types of building within the scope of the project, it is the intention to test the system in multiple locations. In addition, the project looked at the feasibility of using the same UWB units to provide a radar capability to search for victims buried under rubble. This is feasibility study, rather than a part of the demonstration and an initial

report has been published. Further work is continuing, but the initial conclusion is that it looks feasible, albeit with some constraints and would be worth further research.

The system design for the demonstrator has been completed and the hardware build and software implementation are now in progress, with an expectation of integration being carried out in April 2007 and trials of the system starting in June 2007 followed by demonstrations. The exact format and locations of the trials and demonstrations are not yet decided.

IV. WHY UWB AS THE POSITIONING TECHNOLOGY?

The reasons for the choice of UWB as the technology to meet the emergency services requirements will be outlined here. The reasons for the specific choice of UWB technology for the demonstrator will be described in section VI.

There are many different ways to determine location in an indoor environment. The principal challenges are:

- Attenuation by walls/floors of any location signal used
- Multipath – Reflection of the signals from wall, floors, furniture etc.

Of the possible location techniques, the use of radio has the advantage of being able to penetrate the majority of building materials (except metal). Many non-radio technologies, such as ultrasonics, for example, can provide very accurate location, but cannot operate within buildings without a very dense fixed infrastructure. Another non-radio technique is to use dead-reckoning (probably using accelerometers and gyros). This can be a very accurate technique, but suffers from drift – from a known starting point, its accuracy starts high but rapidly degrades with time. This is especially true for units which are suitable for the application - low power, size and cost. However, this technology is potentially valuable in conjunction with other technologies which may provide accurate location, but suffer from areas of poor coverage. There are a wide variety of positioning systems using radio technologies and this paper will discuss a small sample, which illustrate the range of options.

Satellite Navigation systems, such as GPS, offer a range of accuracies, depending on the way the satellite signals are used. In an open area, a standard, low cost GPS, used in conjunction with a satellite based augmentation service, can achieve about 3m accuracy. This can be improved to around a centimetre using differential carrier phase measurement techniques. These accuracies can be significantly degraded in urban areas, due to multipath caused by reflections from objects such as buildings. In fairly open urban areas the different multipath components usually have a significantly longer path length than the direct path from the satellites and the impact of this multipath can be alleviated by the use of special algorithms within the receiver. For shorter path differences, special ‘survey quality’ antennas can alleviate the multipath effects, but these are large and relatively expensive. However, for positioning within a building, the multipath components can have very similar path length to the direct signal and this inevitably causes significant errors. In addition, the attenuation of the satellite signals by the structure is a

major problem, even with the more sensitive receivers which are now available. It is possible to receive the satellite signals even with fairly high attenuation, but the averaging time required to achieve this means that any motion to be tracked must be very slow. In conclusion, satellite navigation can be suited to positioning outside or close to buildings, provided that precautions are taken to reduce the effects of multipath, but once inside buildings, the two problems of attenuation and multipath prevent its use for most applications.

Wireless Local Area Networks (WLANs) are becoming ever more common inside buildings. The signals are not designed specifically with positioning in mind, but they can be used with some success and systems are commercially available. The advantage is that the WLAN network often already exists, and this existing infrastructure can be used, though it may need to be supplemented to get sufficient positioning coverage. The main problems for the EUROPCOM type applications are:

- In buildings with no WLAN infrastructure there is no coverage and it would not be easy to install something quickly in an emergency
- Even if a WLAN infrastructure does exist, most of the existing systems rely on pre-calibration – not something easily done in an emergency situation.
- A pre-calibrated system can be made inaccurate by changes in the radio propagation caused by changes in the environment

RFID tags offer another promising approach to indoor navigation. The advantage is that the tags can be very cheap and small. However the range of the tags is generally limited and the location systems rely on the presence of a pre-installed tag reader infrastructure. In most cases, accuracy will at best locate someone to which room they are in. Their accuracy is achieved by virtue of their short range of operation.

The approach chosen by EUROPCOM is UltraWideBand (UWB) radio, which offers a solution to most of the issues outlined for the other techniques.

The extremely high bandwidth of UWB enables very accurate timing information to be resolved (resolution is directly proportional to bandwidth). This enables highly accurate range measurements and hence highly accurate positioning, using multiple ranges from different sources (similar to the principle on which satellite navigation systems, such as GPS, operate). In addition, the precise timing resolution allows separation of the various components of the

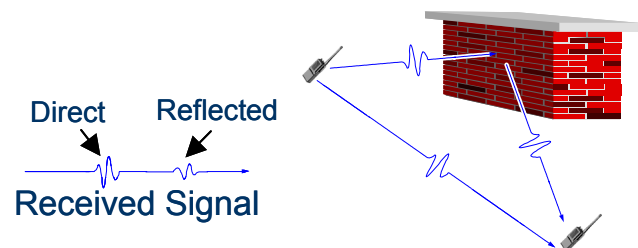


Fig. 3. Illustration of resolution of multipath components

high levels of multipath propagation found within buildings; this permits high accuracy positioning to be maintained within buildings and also offers the potential of robust communications. This is illustrated in Fig. 3 using a UWB signal based on the transmission of narrow pulses, but it applies equally to UWB generated in other ways. The narrower the pulse, the wider the bandwidth and the closer the reflected path distance can be to the direct path distance before the direct and indirect received pulses overlap and become inseparable.

Potential disadvantages of UWB are:

- UWB will always be restricted to low power levels (due to the fact that the very wide bandwidth forces spectrum sharing with other radio systems). This restricts the achievable range/building penetration capability. However the UWB technology chosen by EUROPCOM maximises the range and it may be possible to increase power levels to some degree for this particular application.
- Regulation – UWB is not yet legal in most parts of the world (See next section)

V. REGULATORY ISSUES

The inherent requirement to share radio spectrum with other services makes the licensing of UWB transmissions a contentious issue. UWB has now been legal in the USA for some time, but other countries and the ITU have been slow to follow. This is due to the concerns about interference potential to existing and future planned services, in particular the mobile phone, wireless broadband and some satellite and radar services. The regulator in the USA, the FCC, specifies a maximum transmit power spectral density of -41.3 dBm/MHz over the range from 3.1 GHz to 10.6 GHz. As a rough guide consider the following comparison: the typical power output from a cordless (DECT) phone is around 100mW to 500mW. A typical 1GHz bandwidth UWB transmitter would output about $100\mu\text{W}$ i.e. around 1000 times less power.

At the time of writing, it is looking very likely that European regulations will soon be agreed. Between 6GHz and 8.5GHz, it is likely that the European regulations will allow the same power levels as permitted by the FCC, but the situation at other frequencies seems less favourable to UWB. From 3.1GHz to 4.8GHz, it may be possible to use the FCC power levels, possibly with some techniques to minimise potential interference, but the decision on this is likely to come later. The other frequency ranges within the FCC UWB band look less likely to be available in Europe at realistic power levels.

From the point of view of the EUROPCOM application, it is possible that a special case could be made to operate at the lower frequencies and/or at slightly higher power levels. This really depends on the strength of the case that can be made, for which the EUROPCOM trials will supply much of the background. The FCC does impose some rules on UWB, which favour particular technologies, whilst the rules within

Europe are intended to be technology neutral. This is particularly relevant to the technology chosen for the EUROPCOM demonstrator, which is based on Frequency Hopping technology. This would not be permitted under the current FCC rules, but would be permitted within the proposed European regulations.

See [1] for more details of the regulatory position.

VI. CHOICE OF UWB TECHNOLOGY

This section first summarises the reasons for the technology choice and then gives some details of the chosen technology. See [2] for a comparison between the chosen Frequency Hopping technology and other pulse based technology.

A. Reasons for the choice

The first part of the EUROPCOM project was concerned with studies of particular techniques to tackle the main problems posed by the EUROPCOM application. In particular, this involved choosing a suitable technology for the demonstrator. The main factors in the final choice were:

- Availability of the technology (i.e. could we procure it in time for the demonstrator, within the project budget and timescale)
- Scope to adapt the chosen technology to the specific EUROPCOM requirements
- Range and building penetration – it was clear that in order to maintain sufficient connectivity to allow position to be determined, we needed several tens of metres range within buildings.

Several options were considered, reflecting the wide range of ways in which UWB signals can be generated, including:

- Pulse UWB
- Direct Sequence UWB
- Chaotic Waveforms
- Multi-band Orthogonal Frequency Division Multiplexing (MB-OFDM)
- Frequency Hopping

The technology finally chosen was frequency hopping technology developed for previous indoor positioning demonstrators by TRT – see [2], [3]. This met the first two criteria of availability and scope for adaptation, though the extent of modification required for the application is stretching the EUROPCOM budget. On the final factor, TRT has demonstrated a free space range of 1km. A crude calculation shows why this is required: If one adds in an attenuation of 20dB for a typical outside wall and a further 20dB of attenuation for two typical internal walls, the resulting range would be of the order of 10m. This is right at the edge of acceptability for the system and we will only really know whether it is sufficient after measurements in more buildings. However, of all the available technologies evaluated, the FH-UWB system offered the best range, in many cases by a significant margin.

B. UWB Technology Description

The FH-UWB technology chosen for the EUROPCOM

demonstrator has the following main features:

- The basis is a Direct Sequence Spread Spectrum signal of about 20MHz bandwidth
- Basis signal is hopped at about 80k hops per second over a bandwidth of 1.25GHz

The level of signal integration that can be carried out relatively easily at the receiver is one of the main strengths of the technology, since it allows us to trade data rate for path loss capability. Since the focus of EUROPCOM is on the positioning, rather than data communications aspects, increasing achievable range is more important than data rate. The demonstrator is aiming to achieve a 1 km range (in free space), which will reduce the available data rate to around 15kbps after Forward Error Correction (FEC). This data is not all available for data communications, since much of the transmission time is used for ranging between nodes for positioning. However, it is intended that all of the position information from the nodes will be transmitted via the UWB network to the vehicle mounted base units (BUs). In addition, it is intended that some other sensor data could also be accommodated. In the demonstrator this is intended to include an alarm signal and acknowledgement, temperature sensor data and limited voice messages.

Another factor in favour of the FH-UWB technology is its resistance to interference and the ability to shape the spectrum transmitted to avoid interference to other users. This could be particularly relevant to the European regulations in the lower frequency band between 3.1 and 4.8GHz. It has been shown in simulation that the system can tolerate the loss of up to about 25% of its hops, before significant degradation of its ranging accuracy results.

VII. OVERVIEW OF EUROPCOM ARCHITECTURE/HARDWARE

The basic EUROPCOM system comprises four main components (See Fig. 1.):

- A Control Unit (CU) which is the focus for all of the positioning data and has the control and display facility
- Base Units (BU) which are generally envisaged to be UWB transceivers permanently mounted on emergency vehicles, with absolute positioning determined via differential carrier phase GPS. It is also likely that there will be a need for portable BUs. For the demonstrator we may only equip a sub-set of BUs with the differential carrier phase GPS capability. Other BU positions would be surveyed ‘manually’ (using a shared differential carrier phase GPS unit).
- Dropped Units (DU) – Portable UWB transceivers carried into a building by the emergency service personnel and deposited in useful locations to help with positioning and communications connectivity.
- Mobile Units (MU) – the UWB transceivers worn by the emergency service personnel.

In addition, the system will obviously also require other items such as mounting brackets, portable tripods, power units, battery charging capability etc. The BUs are connected

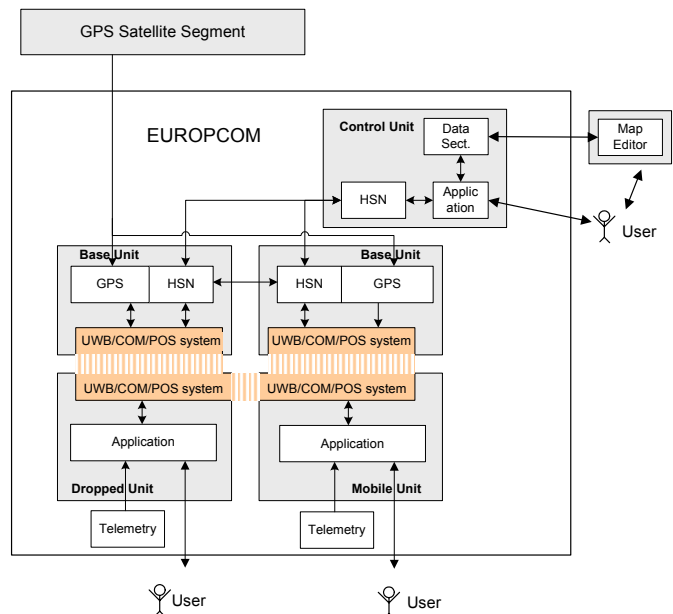


Fig. 4. Overview of the system interconnections

to the CU via a High Speed Network (HSN). In the demonstrator this is intended to be a straightforward WLAN, possibly with one or two extra access points, ‘hard-wired’ together. In a final product we would envisage a completely wireless system.

The connections between the components are summarised schematically in Fig. 4.

The heart of the system is the FH-UWB transceivers. These allow the range to be accurately determined between node pairs. The method of operation is summarised below:

The whole system operates on a single time-sliced channel. One BU node is designated the master, which starts to transmit its position as soon as it has acquired an accurate GPS fix. Once synchronised to the master, the other BU nodes start to transmit their position in free timeslots. DUs and MUs will note which timeslots are in use by other nodes and choose a free slot for their own purposes. They will then listen until they have heard the positions of at least 4 other nodes. They will then select the best 5 candidates for ranging partners from the nodes they have heard and transmit a ranging request to them, in what they perceive to be a free timeslot. When a node receives a ranging request, it triggers a ranging response. The delay between receiving a request and transmitting the response will be known and hence the node originating the range request can determine the round trip delay. An estimate of the range between the two nodes can then be made. The accuracy of the estimate depends mainly on the extra propagation delay due to construction materials and on the ability of the UWB receiver signal processing to determine the leading edge of the impulse response of the channel (i.e. to separate the direct path from multipath components). This is an area which has been subject to considerable research during the project. Once a node has determined its range from at least four other nodes, it estimates its own position, together with an estimate of the quality of that position. Determining

whether or not a position is reliable is very important to the end users and is another area in which the project has concentrated its research efforts. In broad terms, once the position has been calculated, the position data plus any telemetry is forwarded either to a BU node or, if there is no BU in communication range, then to another node which is closer to a BU. The data can be forwarded via multiple nodes in this way until it reaches a BU. From the BU, the data is passed to the CU via the HSN. At the CU, positions of all the nodes are displayed on a map of the building, if this is available. The display will allow the representation of 3D data, at least to the extent of a floor plan plus floor number. The CU display will differentiate between the different node types and also between different emergency services. It will also allow the display of any data associated with nodes (such as name, rank etc) and will log all activity so that it can be saved for later analysis or used for training purposes etc.

The fact that the system only uses one logical channel, whereas several channels could actually be available¹, may seem strange at first, since it will limit the number of users. The reason is essentially due to the fact that each node must be able to receive information from all other nodes, whilst it is not transmitting. Since the current demonstrator hardware is half duplex and can only provide a single channel receiver, it cannot be either monitoring several channels or transmitting at the same time as it is receiving on a different channel. It is anticipated that this will impose an upper limit on the number of users in a given area, but the technique used to allocate channels is designed to allow re-use of the channel over a larger area. Any need for system design changes in this area will be assessed by simulation and informed by the project trials. Some simulation work has already been done, but the interpretation depends very much on deployment details and actual propagation conditions.

VIII. CONCLUSION

The EUROPCOM project aims to provide a demonstrator, for in-building positioning of emergency service personnel using UWB technology, by mid 2007. The project has established a clear architecture and implementation path and believes that its demonstrator implementation will enable a convincing proof of principle, which is likely to lead to a future product for the emergency services.

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¹ by choosing different hop sequences and/or by choosing different spreading codes