White Paper

UltraWideBand Indoor Positioning

Indoor positioning to match the best satellite navigation performance

www.thalesgroup.com

THALES

UltraWideBand Indoor Positioning : Indoor positioning to match the best satellite navigation performance

Author	Stuart Ingram
Date	July 2006
Reference	NAV060601
Issue	2

Abstract

UltraWideBand is a new kind of radio signal, now being introduced for very short range and very high data rate links such as wireless USB. However, this is not its only use: UWB can also provide precise positioning over longer ranges or throughout buildings.

This paper describes how UWB makes this kind of positioning system possible, even indoors where radio signals suffer from the very cluttered environment. It takes as its main application the location and tracking of emergency services personnel in a fire or other dangerous area.

Keywords

UltraWideBand, signal resolution, position measurement, electromagnetic interference, frequency allocation

Thales

Thales is a leading international electronics and systems group, addressing Aerospace and Space, Defence and Security markets worldwide. The Group's civil and military businesses develop in parallel and share a common base of technologies to serve a single objective: the security of people, property and nations. Thales's leading-edge technology is supported by 22,500 R&D engineers who offer a capability unmatched in Europe to develop and deploy field-proven mission-critical information systems. The Group builds its growth on its unique multidomestic strategy based on trusted partnerships with national customers and market players, while leveraging its global expertise to support local technology and industrial development. Thales employs 68,000 people in 50 countries with 2008 revenues of £10.2 billion.

Thales Research and Technology (UK) Limited

Thales UK's Reading-based research & technology facility is the UK arm of the Thales corporate research centre. Its activities focus on providing solutions: Security and Communication Systems, Galileo and Position-Based Systems, and Enhanced Digital Environments. These are based on the key technologies of IP Networks and Network Security, Wireless Communications, Sensors and Signal Processing, and Navigation and Positioning. The facility offers a wide range of consultancy and development services to European Government Agencies and to industry throughout the world.

Thales Research and Technology (UK) Limited
Worton Drive, Worton Grange
Reading, Berkshire, RG2 0SB, UK

Company Registration No. 774298

e-mail: navigation.TRTUK@thalesgroup.com
web site: www.thalesresearch.com

Introduction

What is UltraWideBand?

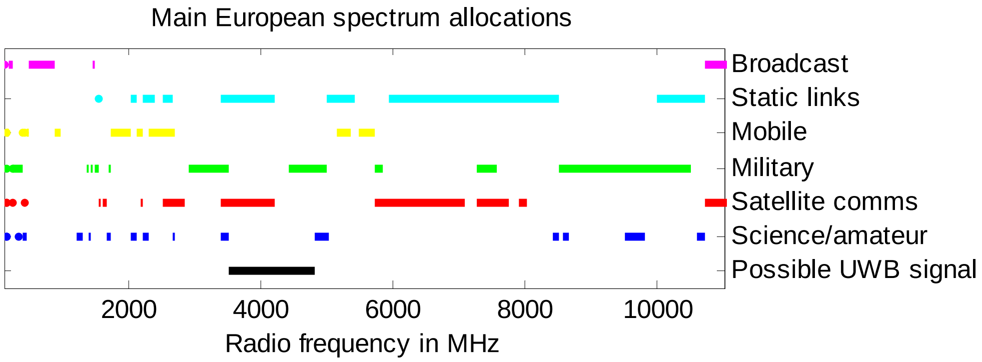
UltraWideBand (UWB) radio (or wireless) signals occupy a very wide bandwidth, typically 1000MHz, which is much wider than other radio signals. UWB will be used in high-speed data links for short ranges, and the first pieces of UWB equipment to be put on the market will be for “wireless USB”. In this paper we will consider a rather different application that also needs UWB signals: determining the position of mobile radio units indoors with an accuracy of 1m or better.

The way UWB is used is closely linked to the allocation of radio frequencies (spectrum) to different uses and users. In discussing this we will need to use the terms “band” and “bandwidth”, so first we need to clear up some confusion surrounding them. In radio, the bandwidth of a signal is its width in the frequency spectrum, but “band” is more often applied to part of the radio spectrum allocated to a use or service (e.g. the analog TV band). In almost all cases this allocation is divided internally into channels, so that transmitters in different channels do not interfere with each other’s signals. A single signal’s bandwidth has to fit inside one of these channels. Further sharing of an allocation is possible if transmitters (and their receivers) are far enough apart – then they do not interfere even if they are in the same channel. Note, however, that outside of the field of radio “bandwidth” (and “broadband”, “wideband” etc.) is used in a variety of other technical meanings, and there is a recent fashion for it to be used even more generally.

The data rate that a digital radio can carry depends on the bandwidth and the signal level (more accurately the signal to noise ratio) at the receiver. The maximum practical rate in Mbit/s is roughly the same as the bandwidth in MHz, provided the signal is above the receiver noise. Computer connections can have data rates of 400 MHz (USB 2) or even higher, so UWB is needed in a wireless link to replace them. However, you can also send a much lower data rate, and in return you get some other advantages, such as increased range (i.e. distance), efficient channel sharing (in CDMA cell-phones), covertness (in military spread spectrum radios), or lower transmitter power (in some radars).

There has been a general trend for new digital radio systems to adopt wider bands to carry data at higher speeds. Recent examples are: mobile phones moving from GSM (0.2 MHz wide) to third generation (5 MHz wide), or the various kinds of wireless LAN (now going up to 40 MHz). These are referred to as broadband or wideband, and it is very hard to find space in the spectrum for signals with a greater bandwidth than this – none of it is unused, at least not at suitable frequencies. Which frequencies are suitable depends on how well they reach into buildings (see later in this section) and on what the latest technology can deliver for an affordable cost.

Around the world, radio regulators (such as Ofcom in Britain) are trying to find more space for a variety of radio data services, but that means sharing a band, or displacing existing users. Sharing is a complicated matter, involving a careful consideration of the two different uses, to make sure they do not interfere with each other. The chart on the next page shows how crowded the spectrum is – most of the spectrum is already shared (and many secondary allocations have been omitted from the chart). The widest bands that have been re-allocated to new services are around 200 MHz wide, and there is no prospect of re-allocating a band wide enough for UWB.



UltraWideBand – as we have said – takes up a lot more of the spectrum than other radio signals. For example, the total amount of bandwidth up to where satellite TV operates is about 10000 MHz. The behaviour of radio waves varies as we move across the spectrum – low frequencies go through walls and round corners much better than high ones, so terrestrial TV uses low frequencies, roughly 400-800 MHz, and mobile phones have a total of 250 MHz in several bands close to 1000 and 2000 MHz. Both of these work (to some extent) inside buildings, while satellite TV at above 10000 MHz does not.

If UltraWideBand is to use such a very wide bandwidth, where in the radio spectrum can we put it? There are no gaps that wide, so it has to operate in bands already in use for other services. In fact, it has to share with many other uses in several allocations, which is more complicated than the usual one-on-one sharing. To allow the existing systems in each band it spreads across to work without interference, UWB has to use very low power levels.

Using such a low power level restricts UWB to certain specific uses. However, first we note that it is the power in a "victim" receiver that would cause interference. Technically, it is the power density per MHz that is limited; and over its very wide band the total power can be rather higher than the very low limit suggests. Regulations for Europe are now being finalised, and the maximum power level proposed is 3 µW in a 40 MHz receiver bandwidth, or 100 µW total over 1300 MHz[1]. For comparison, your mobile phone has a maximum transmitter power of around 1 W.

The first way of using UWB is for high data rate applications, accepting that the range is going to be short (the signal to noise ratio is only high enough at short ranges). Most of the development in UWB is for this kind of application, such as wireless USB, "wireless personal area networks", or other fast data links. Over a distance of 10 m or less, a data rate of hundreds of Mbits/s is possible.

The second way of using UWB is for low data rate applications, which can use much lower received power levels, so that longer-range operation is possible. Alternatively the transmit power can be lowered, reducing local interference levels or making the transmissions covert. Apart from these special cases, reducing the data rate significantly means that UWB is no longer essential for communications links, but competes with other solutions using narrower bandwidths.

There is another reason for wanting a very large bandwidth, and that is "resolution", vitally important in radar and positioning applications (as we will see later on). This is resolution in the sense that measures how fine the definition of an image is, or the equivalent for measuring

---

[1] This is –41.3 dBm/MHz, the maximum mean EIRP permitted in the USA. At the time of writing, CEPT is developing regulations to be adopted by the European Commission, with the same maximum level but different restrictions.

distance. If we want a resolution much finer than 1 m, in most environments, we need a radio signal bandwidth of much more than 300 MHz – and that means UWB.

There are many ways of making a signal that has this very wide bandwidth, and several of these are likely to be used. You may see references to MB-OFDM, DS-UWB, FH-UWB, pulse UWB, or others. The choice of signal is important if you are making a single-chip UWB radio, and also determines the interference between UWB and other equipment, However, it has only a minor impact on the uses we can put UWB to, and the rest of this paper applies to all kinds of UWB.

What is indoor positioning, and why do we want it?

Most of us are now familiar with satellite navigation (GNSS) in the form of GPS. So far we use it mostly when driving or for outdoor recreational activities like sailing or hiking, but a few people already make use of location-based services as pedestrians as well. As the user population grows, and as GNSS receivers start to appear inside other gadgets we carry about, more of these services will appear.

GNSS works well out of doors, but there are times when we need similar positioning coverage inside buildings:

- As pedestrians, we not only walk about out of doors, but also inhabit several kinds in indoor environment. Some of these are really quite large, and we use them just like outdoor spaces – shopping Malls, airports, railway stations, etc.
- In addition to these consumer applications, there are specific users who would benefit from being tracked or knowing their own position. This includes some with disabilities, such as the blind, who would gain guidance in large public indoor spaces. Some jobs that already use location services out of doors will also need them to support their work indoors too.
- Some machines or gadgets – robots in the widest possible sense – need to know where they are.
- There is an important safety-related group of users in the emergency services. They are going into dangerous places, and if they get into trouble a rescue will be mounted. These rescue missions are among the most dangerous things fire-fighters or the police have to do, and a UWB positioning system offers two vital capabilities: notification that they need rescue, and their exact location.
- Finally there are military uses. Actually these are the original users of UWB, though not for positioning purposes. Covert communications and some kinds of through-wall radar were the original UWB applications. Positioning is just as useful for military users, but equipment to meet their requirements has to be rather different. This paper does not consider military applications any further.

Positioning techniques

When we talk about the position or location of something or someone, we usually understand that to be relative to its immediate environment. Several ways of finding positions have been devised, and they vary in the way they obtain position-specific information from their surroundings.

GNSS (satellite navigation)

GNSS (GPS or the European Galileo system) actually finds your position relative to the Earth as a whole, using satellites that are themselves in known positions at any instant. Your receiver needs to have a map, and has to convert the GNSS position into the same co-ordinates as this map to show you where you are.

GNSS is great for outdoor use, as it is truly global. There are some places (such as “urban canyons”) where it gets rather unreliable, because the receiver needs a good view of the sky so it can use many satellites at once. GNSS relies on receiving only signals coming straight from each satellite, and if that’s not true it will give large errors in position.

GPS can be made to work indoors, but with some major limitations. It takes much longer to make a measurement, so you can move only very slowly. It is also much less accurate, since the signals cannot now get to the receiver without going through or round the building structure. Generally, you get an answer to “which building?” rather than “where in this building?”

Wireless LAN

Since wireless networks already exist in many places where positioning is desirable, a number of systems use them to do positioning. WiFi (IEEE 802.11) was never meant for this purpose, so these methods are a bit indirect. One of the main contenders measures the power levels at a mobile terminal, and compares them with a detailed set of calibration measurements. This can work well, given a dense enough set of access points (fixed terminals), but only as long as the calibration is valid. Moving anything – furniture, access points, even people, alters the pattern of power levels. Worse, the mobile user’s body alters the pattern as well, so you can’t put the terminal in your pocket, or even hold it close to you, without affecting the accuracy.

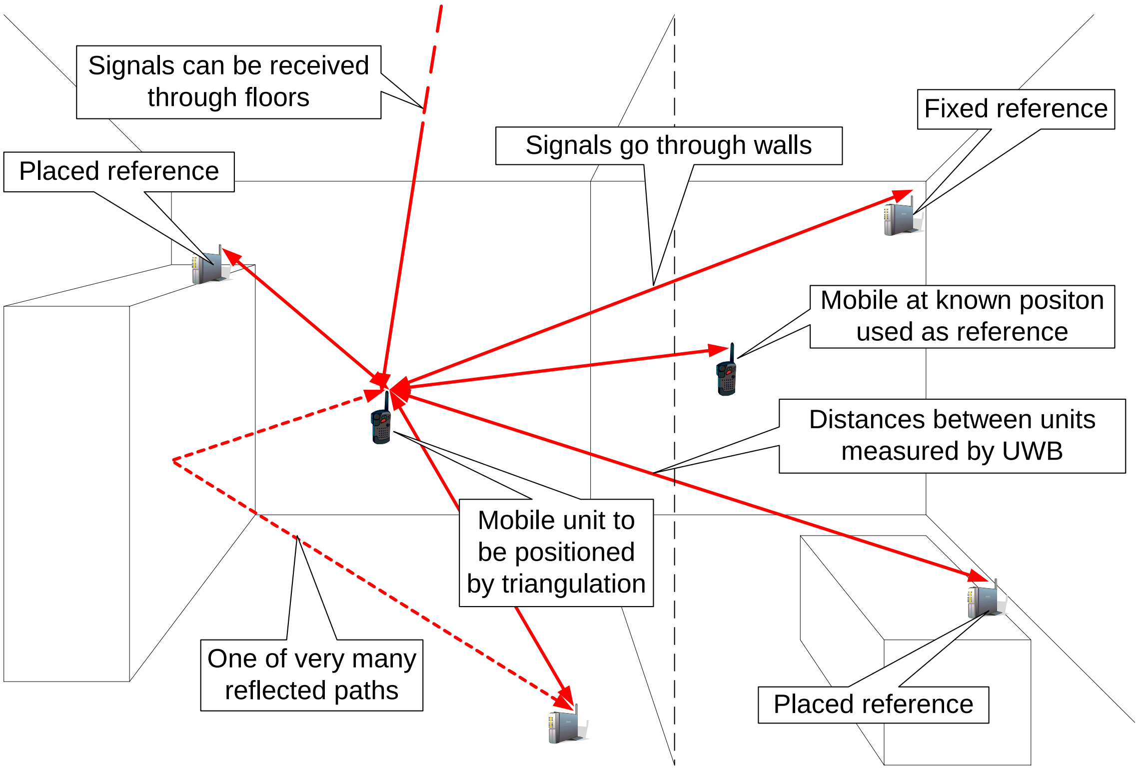
The other main contender uses modified access points that can measure the time of arrival of radio signals very accurately. In this respect is it similar to the UltraWideBand methods we will describe later on. However, the WiFi signals were never designed to do this, so the accuracy is not as good as one would like. The high level of interference in these bands is a problem, and the need to use non-standard access points means this system is not just a software addition to an existing network.

Radio ranging and the importance of bandwidth

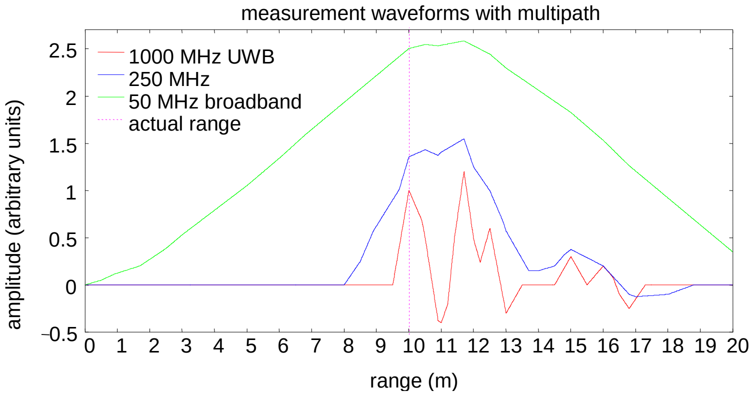
The principle used by GNSS, some WLAN systems, and UWB positioning, is radio ranging: measuring the distance between two terminals by timing radio signals when transmitted and when received. There are several variations on this principle, but all rely on knowing the speed of light to convert times into distances. Fortunately, in air, this speed hardly varies, and is accurately known.

The received signal arrives after a delay that is proportional to the distance it has travelled, so each time a signal goes from one unit to another the distance between them can be measured. Given the distances from one mobile unit to several other “reference” units at known positions, as well as the positions of all the references, the mobile unit can be located by triangulation. The illustration on the next page shows the principles, but does not represent any particular system or application.

Ideally, for each path just one direct signal arrives on its own. However in reality signals can arrive by many paths, involving reflections off surrounding objects (including the ground) and other scattering effects (this is called “multipath”). When we have processed the received signals into a suitable form for measurement of the delay, they have a finite width: this width in essence is the resolution. If the spacing (in delay) of the multiple received signals is closer than the resolution of the signals, they will overlap, and cannot be measured separately.



This is illustrated in the graph below: only UWB can separate these closely spaced components and measure the first on one its own. The narrower bands mix them together, and remember that 250 MHz is still wider than any foreseeable allocation. There is a clear relationship between the resolution of time and range measurements and the bandwidth of the signals.



GNSS only uses a small bandwidth, so its resolution is not really that good (for civil GPS it's 300 m). So how does it get an accuracy of a few metres? Basically, because out of doors the received signal from the satellite comes along a straight-line path, and doesn't bend round anything or reflect off anything. The receiver knows the shape of a clean measurement waveform, and relies on setting a threshold at precisely the right height on the leading edge. However the shallow slope of this edge makes this measurement very sensitive to the way the multipath alters the peak level, so even quite small reflections off surrounding objects, received together with the direct signal, cause a significant loss of accuracy.

The radio environment inside a building is very cluttered. There are lots of things for the signal to reflect off or scatter off, and unobstructed paths are only possible if very short. Unless we provide several fixed terminals in each room, we have to transmit signals through walls, reducing the direct signal power. This reduction gets worse as the frequency goes up, so we would like to operate lower down (below 5000 MHz) if we can. To separate signals from paths with lengths 50 cm apart we need a bandwidth of at least 1000 MHz.

That's why UWB is such a good match to this indoor positioning application. It has an inherent accuracy, due to its resolution, of much better than 1 m, so it can cope with the indoor environment where narrower bandwidths could not. In cases where we can't put fixed terminals all round the mobiles, or where we use mobiles as references to position other mobiles, we need a ranging accuracy much better than the positioning accuracy, and only UWB can do that in such environments.

Active versus passive

In a GNSS only the satellites transmit, and users have receivers, giving the advantage that you can have any number of users without limit – it is very "scaleable". To make that idea work you need to know exactly where the transmitters are at any instant, despite the very high speeds of the satellites, and also need to put a very accurate clock in each of them to synchronise the signals. These clocks are very expensive, though cost-effective for a few satellites that serve the whole world.

The same principle can be used in an indoor positioning system, and would be a good choice for a mass-market application offering GNSS-like coverage in buildings. The transmitters (sometimes called beacons or pseudolites) are fixed, and can be at known positions, and scalability to large user numbers is required. This can be called a "passive" system, because positioning is done in a mobile unit that does not transmit anything. The transmitters still need to be synchronised, either via cables or by receiving each other's signals. It is also possible with this system to broadcast messages, or any kind of data, to the mobile units via the fixed transmitters.

In other circumstances it is better for all the units to both transmit and receive: this can be called an active system. This is particularly the case if we do not have an infrastructure of fixed units, and must rely on mobile (or transportable) units being the references for positioning done by other mobiles. Exchanging messages provides a more direct way of measuring the distance between units than the "pseudoranging" that a passive system has to use.

If we want to use the UWB radio signals to carry two-way user data traffic, as well as for positioning, we really have to use an active system. We've said that carrying data has to be traded off against other aspects of system performance, and the result will depend on the application. An active system is less scaleable than a passive one, with a limit on the number of terminals it can accommodate. Data rate, user capacity, and maximum range (combined with building penetration) all trade off against each other.

In both active and passive systems each mobile unit needs to be given some system data to calculate its position, such as where the references are, just as in a GNSS.

A further possibility has mobiles that only ever transmit, and has the position worked out within the infrastructure. This is best for asset-tracking applications, where the UWB transmissions of the mobile units can also report the status of the asset, for example to be displayed along with its location. In this application there is no need to tell the mobile unit where it is, and battery life and overall size are very important. UWB transmitters do not use much power, especially if (as here) they only need to turn on infrequently for a location report. If the mobile unit had a receiver it would need to be kept on much more of the time, and would use more power from the battery.

Fixed infrastructure versus ad-hoc (dynamic)

We have already said that one of the main reasons for using an active system is to avoid having a fixed infrastructure. This is familiar in communications, where it is called "ad-hoc networking", meaning that there is no fixed arrangement of links and routes. All the units have to work out which other units they have links to (the "network topology"), and where this fits into the overall arrangement. This is a necessary part of the positioning task – we add the accurate measurement of the distance along these links, and that allows the units to work out their positions.

Obviously there do still need to be some units at known positions; otherwise we could never locate any of them. However, we only need a few (four, in general), and they can be outside the coverage area (but within reception range). If there are places where too few fixed units can be received, other mobile units, or similar units placed where they are needed, can be used as references instead.

Application examples

Mass market users

A lot of us already have GPS receivers, either mounted in our cars or to carry with us. Like most things, they are getting smaller and cheaper all the time, and increasingly we will have them built into other electronic devices. An important example is the mobile phone, and integrated GPS is already common in some countries, though not in Europe. It is put there to support the reporting of your position when you make an emergency call, and in most cases is not a complete independent GPS receiver – but these are often available as plug-in extras.

As more of us get these "location aware" gadgets, more services will be set up that make use of them. Some of these are the kind of services we would like to have indoors as well as out of doors, at least in some kinds of indoor spaces – airports, shopping malls, railway systems (including tunnels), hospitals, offices, and the like. Positioning will also have its uses in the home, for example in some kinds of games, and more importantly to support independent living for the disabled – including the ever-increasing number of us living into old age.

Public indoor spaces like these all have a lot of people going to them and (all too often) getting lost. That provides an important justification for providing the positioning service, since it would cost money to set up and could be difficult to charge for (after all, GPS is free, and Galileo will be too). What you get is the same kind of location service in "indoor streets" as GNSS gives you outside – or probably much better, as GNSS does not work very well outside, in narrow streets.

Emergency services

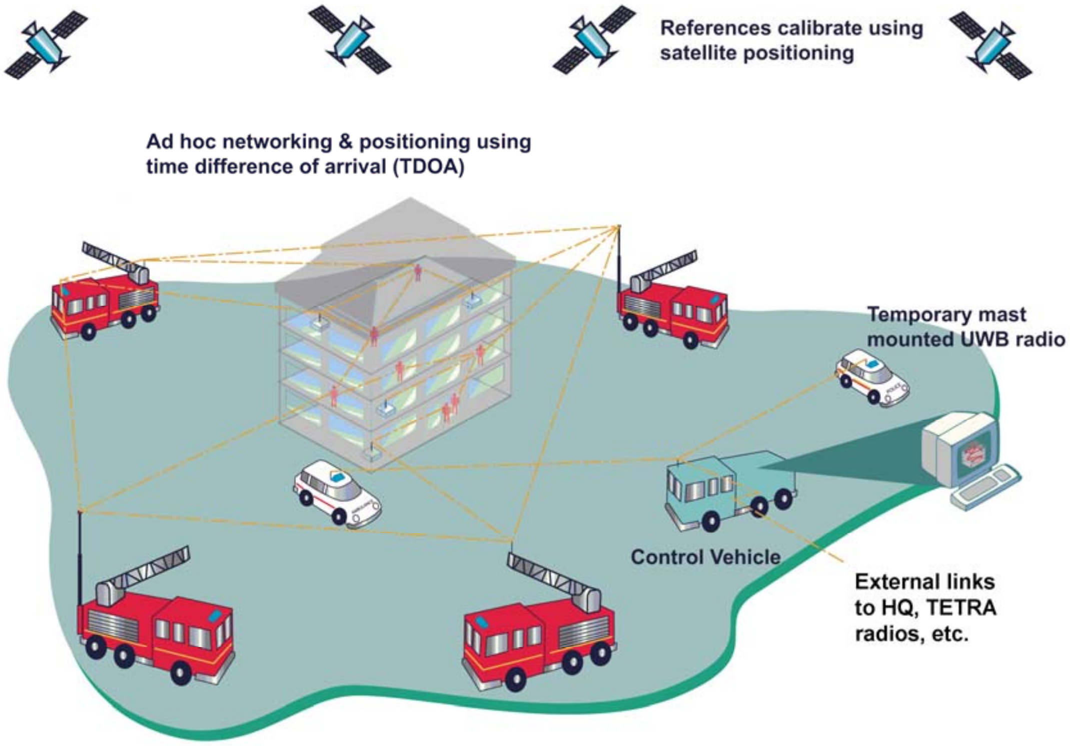
If you ask yourself who would really need positioning information, the answer is probably going to include fire-fighters and the other services that deal with emergencies. Their lives may depend on their colleagues knowing where they are and whether they need help.

The range of emergencies for which this tracking service would be useful is very large. Fires pose the clearest requirement, because fire services have already had to cope with this need to know where fire-fighters are. They have developed procedures (and some equipment) to prevent one fire-fighter being trapped, or injured, in an unknown location.

Fire services also have to manage the response to other emergencies, such as chemical leaks, flooding, some terrorist attacks, or any emergency where access is restricted and their equipment is needed (such as tall buildings or tunnels).

Police services have a wider range of potentially dangerous situations to deal with, and it is difficult to describe a typical case. They are always involved with controlling access to an incident (cordons and evacuations), and with vehicles, criminals, and where anyone is armed.

Because of the unpredictability of such situations, they do not have the same strict procedural methods for controlling the risks of being trapped, and arguably need the tracking service even more. Military or paramilitary forces are also likely to be involved, and the dividing line between them and the police varies widely between different countries.



Other services may also be involved in the kind of emergency where tracking is called for, but usually in a secondary role. Ambulance and medical staff are the obvious example, but other specialists may be called on as well. With no tracking service they often have to be escorted by fire or police personnel, as appropriate, and the tracking service removes to the need for such close escorting simply to keep track of them.

For this application, we cannot assume there will be any infrastructure present and working, so any fixed reference units will have to be deployed on arrival. The emphasis has to be on quick deployment and automation of the set-up tasks, such as using GNSS to locate the reference units. Providing communications capacity is not a priority, because those who need it will already have radios to provide it. The positioning system should be self-contained, i.e. carry the data it needs for its own operation, and otherwise only offer a back-up to make sure vital calls for assistance get through. The picture above gives an idea of such a system.

Integration with GNSS

For most of these applications, the function of the indoor UWB positioning service is the same as GNSS. We can describe the indoor positioning as an extension of accurate GNSS. Even in those cases where the indoor environment drives the requirement for positioning (such as fire-fighting), we do not want a user to vanish from the operator's screen when they come outside. Here, we could see GNSS as extending the UWB system into the surrounding outdoor areas. Integration of the two positioning systems is therefore a must.

This integration should really be "seamless" – any location-based service should work with either system, without the user having to do anything or even being aware of the switch. In the areas where the two systems overlap, we need even closer integration. That's because just outside a building the coverage of both systems is often poor, and combining their range measurements to do a joint position calculation fills in this gap.

Conclusions

UltraWideBand radio offers the unique capability to measure positions to a fraction of a metre in a wide range of indoor environments. It has great potential to assist the emergency services to do their jobs more safely. Given the right business model, it promises to extend the whole range of location-based services to indoor environments.

Thales Work on Indoor Positioning

TRT (UK) has several years of experience with UWB systems for both communications and positioning applications. These are the main areas of work carried out:

- Technology development of frequency-hopping UWB, a form of UWB that is especially well suited to indoor positioning.
- Prototype indoor positioning systems have been built and tested, using TRT's FH-UWB and pulse UWB hardware, with funding from BNSC and ESA.
- Europcom. This project will demonstrate a positioning system for use by the emergency services in 2007, It involves IMST in Germany, two technical universities (Delft and Graz), and user organisations, and is part-funded by the European 6th Framework programme. See http://ist-europcom.org for more details.
- A demonstration of military uses of UWB, including radar detection and tracking of people as well as communications. This was part of the Euclide programme of European defence research,
- Further work is underway into advanced UWB radar techniques and applications, with support from the DTI.
- A study for the GJU into the use of UWB indoor positioning linked to the Galileo GNSS.

Abbreviations

BNSC	British National Space Council
CDMA	Code Division Multiple Access – used in American mobile phones
CEPT	the European organisation where radio regulators discuss common rules
DS-UWB	Direct Sequence UWB
DTI	Department of Trade and Industry
ESA	European Space Agency
FH-UWB	Frequency-Hopping UWB
Galileo	the future European GNSS
GJU	Galileo Joint Undertaking (which has managed development for ESA and the European commission).
GNSS	Global Navigation Satellite System
GPS	the American GNSS
GSM	the main European (and now worldwide) mobile phone standard
LAN	Local Area Network
MO-OFDM	Multi-Band Orthogonal FrequencyDdivision Multiplexing (a kind of UWB)
USB	Unified Serial Bus – the standard link from a PC to a peripheral
UWB	UltraWideBand
WLAN	Wireless Local Area Network