Positioning & Localisation in Cooperative Networks

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This white paper introduces the principles of collaborative positioning and localisation of objects within wireless sensor networks and compares them to more traditional approaches.

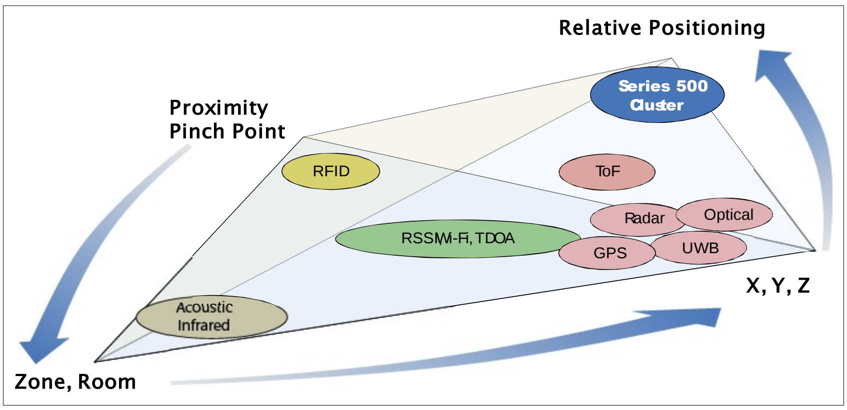
Introduction

Traditionally the location of an object is determined by reference to a number of fixed objects at known locations by observing or measuring the physical relationship: distance, angle, proximity, with one or more of them and from this inferring information about the object's position or location.

Examples of these everyday systems and techniques include:

- RFID systems in which a reader at a known position interrogates and identifies a tag near to the reader (centimetres to metres distant). The position of the tag is inferred through knowledge of the position of the reader. Typically readers are located at pinch-points through which tags must pass and the application tracks the whereabouts of the tags as they move from one zone to another.
- Zone-based systems in which a zone, for example a room, is illuminated using an infra-red or acoustic signal. Any tag (or receiver) within the illuminated zone responds and is identified thereby placing it in the zone.
- GPS and other GNSS systems. The navigation satellites, which are at known positions, transmit navigation signals. Any receiver capable of receiving signals from multiple satellites (typically four or more required) is able to use these signals to compute its position using techniques based on measuring the observed time difference of arrival of the signals (OTDOA).
- UWB (ultrawideband), and a number of other terrestrial positioning system use a network of fixed installed receivers (also sometimes called anchors or access points) to measure the observed time of arrival of radio signals (often called blinks or chirps) transmitted periodically by tags. By comparing the times of arrival at multiple receivers the position of the tag is determined.
- Some indoor positioning systems, such as those based on Wi-Fi and BlueTooth, and basic mobile cellular positioning systems use signal strength (RSSI) to indicate approximate distance from base stations, access points or location beacons. Although coarse and of variable reliability, RSSI is ubiquitous and easy to use.
- Radar systems measure the range and angle to an object and hence determine the position of the target object relative to the observer. Optical systems use a similar principle although usually combine observations from two or more fixed points using the intersecting observation vectors to determine position of the target,
- Observation of physical parameters of the environment can be used to infer position. A magnetic compass gives an orientation relative to the earth's magnetic poles, and gravity can be used to determine orientation relative to vertical. Combined with acceleration, rotation and other motion parameters, relative movement and/or positions can be inferred.

All of these everyday systems share two common attributes: a) they require an infrastructure of devices whose positions are known and which have special knowledge of the signals being used, for example clock synchronisation or transmission time; and b) the mobile devices being positioned have no knowledge of, or interaction with, one another.



The essence here is that each mobile device is positioned alone and independently using the fixed infrastructure devices. For many applications this is a desirable, or at least satisfactory, mode of operation, but for many other applications the real interest is in the relationships between mobile devices.

Collaborative Positioning

Consider a system in which objects exchange information with their neighbours and peers; information that can be used to infer their positions, or at least their relative positions. Therefore instead of you computing your position and me mine independently, using the same or different infrastructure, and then comparing these to find out how far apart we are, isn't it far easier if I can simply exchange a few measurements with you and from these determine directly how far apart we are?

Localisation systems based on peer-to-peer relative positioning are beginning to emerge into mainstream applications now. They are referred to in several different ways: relative positioning; collaborative positioning, peer-2-peer positioning, cluster positioning, or even as swarm systems.

Freeing mobile devices from the restriction that they may only use fixed infrastructure equipment for positioning can lead to improved flexibility and performance. In collaborative systems mobile devices can use signals and information from other (neighbouring) mobiles to position themselves. They also share information about their own position with neighbours to assist them. When combined with signals from (or to) fixed infrastructure devices this approach can lead to much better performance, such as extending coverage into tough areas and increasing confidence in position relative to neighbours.

A number of different techniques for obtaining measurements from neighbours are emerging:

- RSSI based distance estimates;
- Time-of-Flight (ToF) range measurement;
- Optical observations, distance and angle;
- Observed Time of Arrival of radio signals from neighbours.

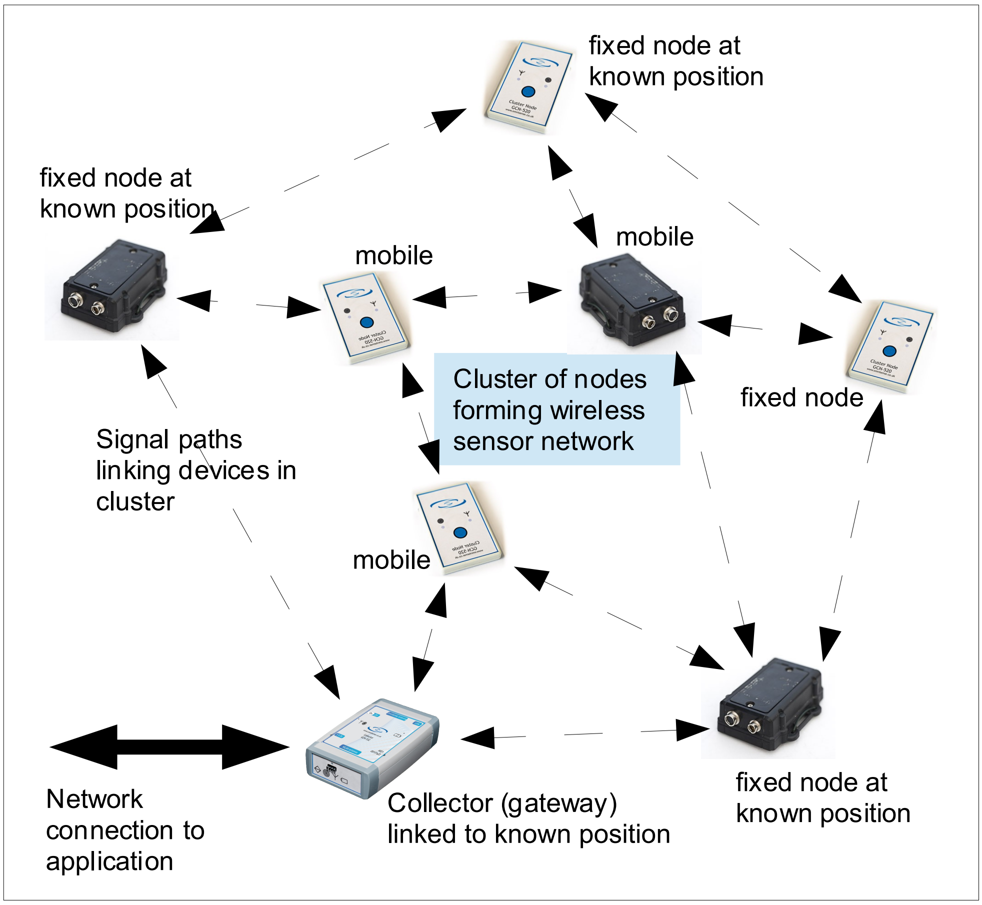
Omnisense Cluster System

Omnisense has developed its Series 500 Cluster System based on the principles of collaborative relative positioning. In essence the Series 500 System is a WSN (wireless sensor network) that has been enhanced through the addition of positioning capability that uses measurements exchanged with neighbours in the mesh to determine position relative to those neighbours.

Every device in a Series 500 system is an active participant in the network, both for positioning and data communications. Each device can both send and receive radio signals; to either a particular neighbour or broadcast to all neighbours within radio range.

The core principle behind operation of the Series 500 system is the broadcast of periodic messages by each device in the network. Any device within radio range may receive and measure the time of arrival of the message. A data payload contains essential information about the transmitting device such as identity, estimated position and other useful items. The receiving device can use measurements made of one or more neighbours (four are required for full 3D positioning) to compute its own position. Alternatively these measurements can be relayed to a dedicated position processor which will compute the position.

Collaborative Measurement techniques



The Omnisense Series 500 system uses one-to-many broadcast messages containing payload data from the transmitting node. This is a similar principle to that used in GNSS systems in which the satellite signals contain information that helps the GPS receiver with essential information needed to compute its position (such as satellite position and trajectory).

By measuring the precise time of arrival (TOA) of neighbour signals being broadcast, a receiving device is able to use the principle of Observed Time of Arrival to compute its position (and clock offset). As a result the Series 500 system exhibits excellent performance characteristics (good accuracy, high update rate and scalability) in comparison with other techniques:

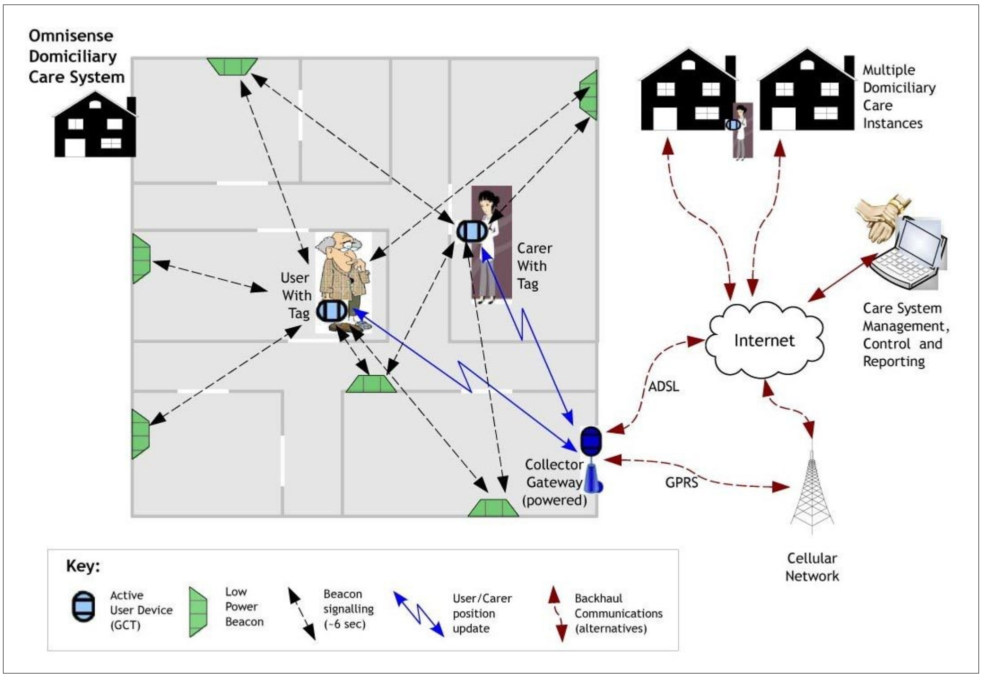
- RSSI provides an approximate measure of range, but is seriously affected by the operating environment and the effects of path obscuration, such as by the body of the person wearing the sensor device. RSSI is a useful metric for contextualising a position, but it is not suitable for high-reliability or high-accuracy positioning. Just like the TOA approach used by Omnisense it scales well since RSSI can be measured for broadcast and one-to-many transmissions.
- Time-of-Flight (ToF) is most often implemented as a two-way measurement between a pair of devices. By exchanging messages back and forth clock offset cancellation occurs and the problem of solving for position is greatly simplified. However, each range linking each pair of devices has to be measured through the pair-wise exchange of measurements. This impacts scalability making systems based on ToF measurements slow and only suitable for smaller networks (tens of devices).

The one-to-many approach used in the Series 500 leads to highly effective scaling. Each broadcast message is short – one to a few milliseconds – and each time a device sends its broadcast all neighbours in the vicinity may receive it. Therefore the system scales linearly with N, where N is the number of devices. The ToF approach on the other hand requires successive point-to-point measurements each requiring several messages - typically 5 to 30 milliseconds. Scaling follows an N^2 characteristic, which makes it infeasible for large networks.

Architecture of Omnisense Cluster System

In its simplest form a system comprises 2 or more devices which are all notionally the same (in terms of their hardware and radio) and which, when operating, are within radio range of at least one or more other devices. Each device in the network periodically broadcasts a positioning message to all neighbours within range, and also receives and measures messages transmitted by neighbours. By using payload information contained in neighbour broadcasts along with accurately measured TOA for the signal the device computes its position relative to its neighbours in the network.

Most systems include an additional device: a network gateway, which provides interconnection between conventional TCP/IP networks and the wireless sensor network. The gateway provides an application interface with structured APIs so that third party and user applications can access the data in the Series 500 System.



One of the devices assumes the role of network coordinator. Membership of the network can be managed or controlled and all devices operating as part of the network are coordinated; the network operates on a TDM (time division multiplex) basis to ensure high efficiency of spectrum utilisation and deterministic behaviour.

Although the Series 500 System uses the IEEE802.15.4a PHY (ZigBee and 6LoPan networks are generally based on IEEE802.15.4 PHY and MAC), higher level protocols are Omnisense proprietary and have been optimised to achieve two major goals:

- Seamless and effective mobility; roaming and movement around and within the network;
- “Any-node routing” capability: any device can be allowed to act as router or parent for any other(s).

Series 500 System in practice

Whilst for many application the positioning interest is that of relative placement between objects, there are other applications that require positions to be computed in the context of the environment. The Omnisense Series 500 System provides the ultimate flexibility when it comes to solving real-world positioning problems: simply by associating some of the sensor devices with the environment in which the system is operating.

These fixed devices have a role similar to base stations, access point, anchor nodes or readers in conventional systems, except that they are the same low-cost devices as used for mobile objects just that they are fixed to a stationary non-moving element of the operating environment. Whether a device operates in a fixed mode, or as a fully-fledged mobile is purely one of configuration: assigning it the appropriate personality within the deployed system. When devices are fixed they can be constrained within the system configuration to be located at a known coordinate. Alternatively if the precise coordinates are not known they can be allocated an approximate location and a fixed personality – in which case the system determines a best estimate for their position.

This flexibility gives the Series 500 System significant advantages for many conventional applications, and the ability to address new emerging opportunities not suited to inflexible traditional systems.

In addition to positioning capability the Series 500 sensor nodes incorporate a comprehensive suite of motion sensors that can be used to aid navigation or behaviour profiling (for example fall detection), including the ability to deliver full orientation information about the device. They are also capable of carrying auxiliary telemetry data for those applications requiring it.

About Omnisense

Omnisense Limited is a Cambridge UK based high technology business specialising in positioning assets: people, animals and other objects.

Omnisense owns IPR relating to its Cluster positioning systems and technology, including patents, designs and know-how.

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