Cluster Positioning with S500 = Flexible Solutions

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Introduction

In WP001 we introduced the concept of relative positioning using collaborative techniques as used in the Series 500 Cluster location system.

In a Series 500 wireless mesh sensor network, devices (nodes) broadcast radio signals (referred to as chirps) to neighbours within radio range. By measuring the precise Time of Arrival (TOA) of chirps received a node is able, with the help of the data included in the chirp, to compute its position relative to its neighbours.

Computation of positions may be carried out by the node itself, or it could transmit measurements to a separate position processor within the network.

In its most general form every node listens to every other and uses this information to compute its position.

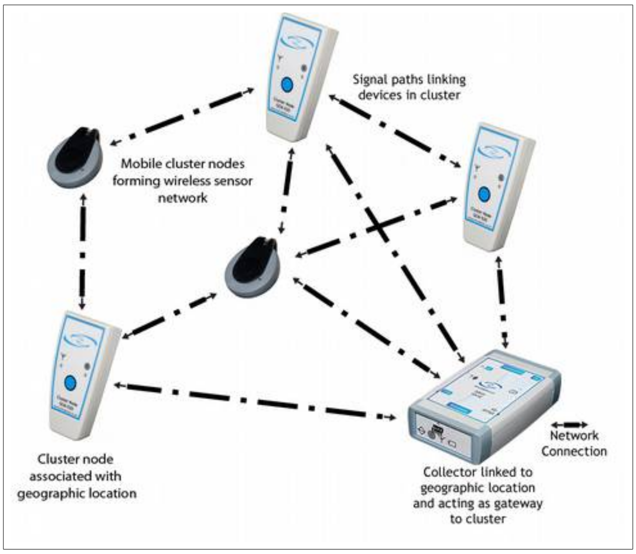
The system can be operated in a completely relative mode, in which case the output positions are not absolute. However, it is more usual to add context of the environment in which the system is operating by associating some of the nodes with features of the environment itself. For example, some of the nodes might be attached to the physical buildings making up the region into which the system is deployed. These “fixed” nodes are no different from normal mobile ones, the difference is achieved by assigning each node a “personality” which in the case of fixed ones might be a known position.

In the Series 500 System all nodes are the same (although different physical variants of the product are made for different applications) with behaviour determined by the way they are configured. However, there are two special functions included in most networks: a) the coordinator role - standard node - and b) the gateway function – standard node with added TCP/IP functionality.

The coordinator manages overall coordination of the network, which is based on a TDM (time division multiplex) structure that ensures efficient use of radio spectrum, power and results in more deterministic operation of the system.

The gateway provides high level TCP/IP connectivity to the external networks allowing applications to interface to the sensors using straightforward APIs.

This paper shows how the Series 500 system can be easily configured to satisfy a wide range of applications.



Sufficiency, Limitations and Constraints

When configuring a system there are a number of factors that need to be taken into account:

- Number of visible neighbours: whilst at least 4 neighbours are required to compute a full 3D position, there are big advantages in having more: 8 to 16 being a good target.
- Geometry of neighbours: the best positions are obtained with good neighbour geometry. Often the minimum number and geometry of neighbours arises when only the permanent (fixed) devices are present, so it may be a good idea to ensure they are well distributed and in sufficient numbers.
- Every position update requires radio signals to be transmitted and received; this is the most power demanding task. Reducing the frequency and quantity of position updates increases battery life.
- Having fewer position updates reduces accuracy: the ability to average or filter results decreases with less frequent measurements. It also becomes increasingly difficult to track clock drift. Therefore fewer position updates leads to less accurate results.

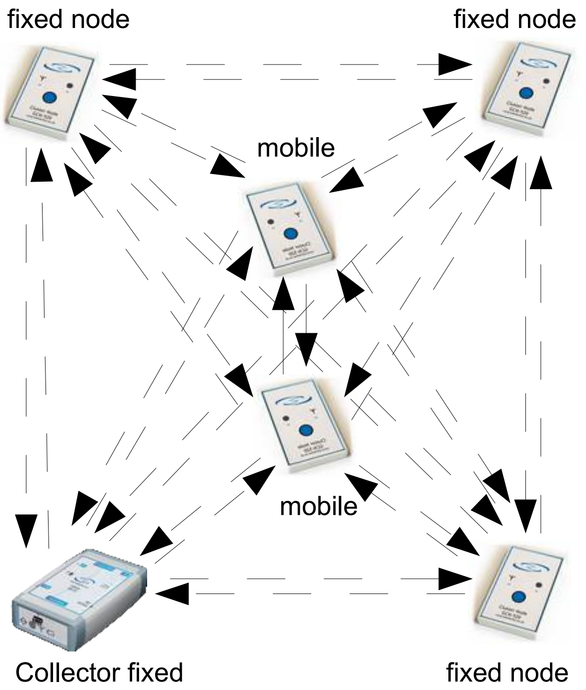
So the key parameters to trade off are: update rate, battery life and accuracy. Higher update rate gives better accuracy but shorter battery life.

Flexibility is one's friend

Every Series 500 node has both transmitter and receiver plus intelligence that allows it to fulfil different roles in a network. This inbuilt flexibility can be used to optimise performance under different conditions.

Fully meshed positioning

This is the highest performance mode in which every node transmits regular chirps and receives chirps from as many neighbours as possible (all of them).



and depicted as an interconnection matrix:

m2	X	X	X	X	X	
m1	X	X	X	X		X
f3	X	X	X		X	X
f2	X	X		X	X	X
f1	X		X	X	X	X
c		X	X	X	X	X
	c	**f1**	**f2**	**f3**	**m1**	**m2**

Each row represents transmit and each column receive.

Selective meshing

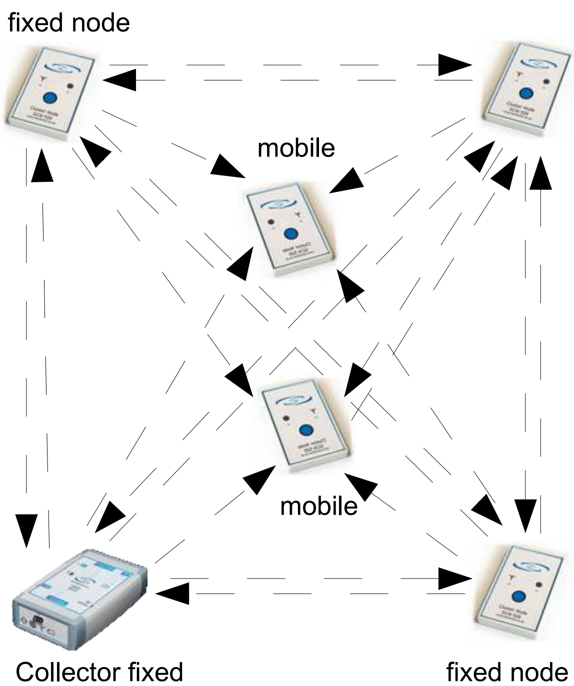
Instead of receiving and processing chirps from all neighbours, each device can be selective and only use a subset of neighbours within range. There are different ways in which this can be managed: for example mobile device may give priority to fixed nodes over neighbouring mobiles. Alternatively it could select neighbours based on geometry, distance or zone. Reducing the amount of time a node spends receiving neighbouring chirps increases the battery life – almost in proportion. In the example shown mobiles that listen only to fixed nodes would need to receive four neighbour measurements instead of five.

The mode in which mobiles only listen to fixed nodes, but fixed nodes listen to all others is shown in tabular format below:

m2	X	X	X	X		
m1	X	X	X	X		
f3	X	X	X		X	X
f2	X	X		X	X	X
f1	X		X	X	X	X
c		X	X	X	X	X
	c	**f1**	**f2**	**f3**	**m1**	**m2**

Receive only modes

An alternative approach is to operate some nodes in receive-only mode. In this case they do not broadcast their own chirps and only listen to broadcasts from neighbours. Whilst this reduces power consumption a little, one of the main reasons for choosing this mode may be to implement covert operation in which a node does not transmit (m)any signals. A diagrammatic representation of this mode is shown below:



In this example the fixed nodes operate fully meshed with one another, but the mobiles only receive chirps and don't transmit.

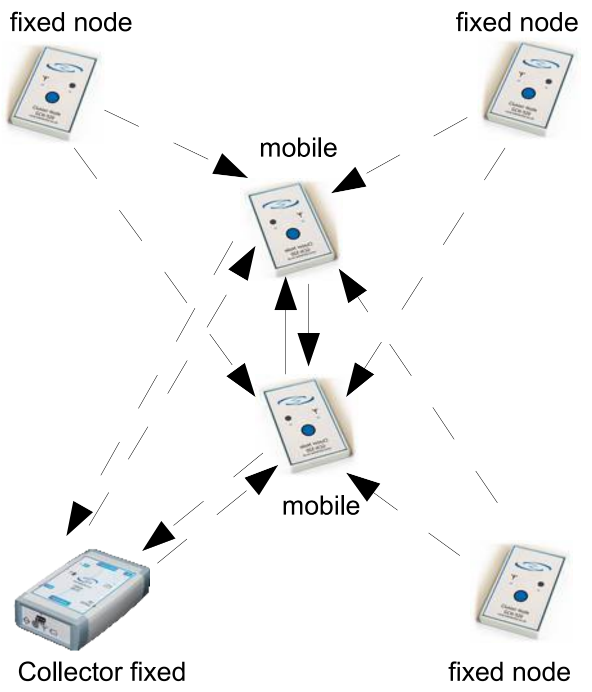
As an interconnection matrix, this is shown as:

m2						
m1						
f3	X	X	X		X	X
f2	X	X		X	X	X
f1	X		X	X	X	X
c		X	X	X	X	X
	c	**f1**	**f2**	**f3**	**m1**	**m2**

Transmit only mode – lowest power

In the lowest power operating mode (nodes can also be dormant – sleep) a node only transmits its regular chirps and does not receive and measure chirps from neighbours. (Similar to many conventional RTLS tag systems.) However, it does still receive network control messages which enable it to maintain network synchronisation and to receive management updates from the network.

This mode is depicted diagrammatically below:



m2					X	X
m1					X	X
f3	X	X	X		X	X
f2	X	X			X	X
f1	X				X	X
c					X	X
	c	**f1**	**f2**	**f3**	**m1**	**m2**

In the example shown it is the fixed nodes that are configured for minimum power (do not listen to neighbour chirps), however, the roles can be reversed with the mobile nodes in a transmit only operating mode, or indeed on a node-by-node basis irrespective of whether they are fixed or mobile.

Dynamic mode selection

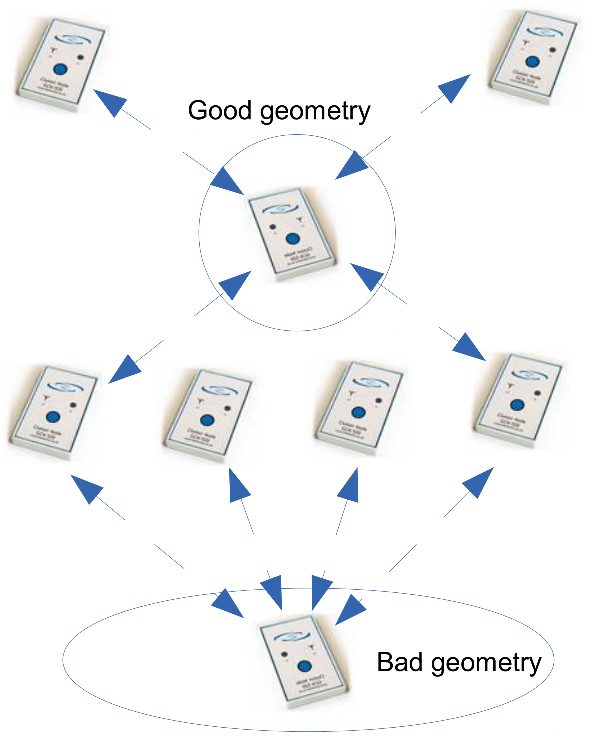
Since the operating mode of a node or system is dependent only on how it is configured, one can set up use profiles during which nodes shift from one operating mode to another dynamically based on the requirements of the system, sensory inputs, or under direct control of the application. In summary the four main operating modes are:

- Fully meshed (with all or some neighbours);
- Receive only (all or subset of neighbours);
- Transmit only;
- Dormant (playing no role in the network).

Geometry

At the beginning of this paper we introduced concepts of sufficiency, limitations and constraints noting that whilst a minimum of four neighbours is required for 3D positioning, having more neighbours is better and one should always strive to achieve good geometry of neighbours.

Geometry is a term used to describe the way the neighbours are placed around the node whose position we're computing. In general if they are separated in all directions one has a good geometry, but if they are towards one side, we have a poor geometry. The diagram below illustrates this point.



The issue of geometry is particularly important to consider when configuring fixed devices and for situations in which operation at or near the edges of the network is required. It is good practice, where possible, to ensure that there are enough fixed devices installed around the periphery of the operating area so that mobiles are always surrounded by fixed nodes.

This is not a limitation of the system, but it is useful to bear in mind that the best performance will be achieved with good geometry and more than the minimum required number of neighbours.

Fixed Nodes

In order to operate the Series 500 system does not require any nodes to be fixed. However, it is helpful for most applications to link some nodes to the operating environment. The system operates in full 3D positioning mode by default, and to provide a proper unambiguous key to the 3D space in which it is operated a minimum of four fixed nodes is required.

If the application is pure 2D (planar), operation can be constrained to a plane rather than in three dimensions and this can lead to a small improvement in performance (accuracy). This is simply done as a system configuration option.

When configuring a device as "fixed" there are two elements to this: a) a constraint limiting its freedom to move around; and b) a position in space.

If its position is well known, the constraint is generally small (though never zero), but for those fixed nodes with estimated or unknown positions the constraint can be large. The system will compute its best estimate for the positions of all nodes, including the fixed ones.

The "smoothest" behaviour is often achieved by allowing fixed nodes freedom to move around a little. For most accurate absolute positioning, the positions of fixed nodes should be accurately known and they should be configured with a small constraint allowing only a little movement.

Mobile nodes will continue to be located even when they cannot see any fixed nodes, provided they can see sufficient (mobile) neighbours, and given a viable data route to the network coordinator. However, errors are compounded as they propagate across the network, so one should expect a degradation in absolute accuracy when positioning mobiles using only other mobile neighbours. However, relative positions with respect to their immediate mobile neighbours may be very good.

Auxiliary Sensors

In addition to wireless positioning capability, the nodes also include a rich suite a motion sensors. These can be used to monitor and detect movement and can, therefore, also be used to select the best operating mode according to the application use case and requirements. For example, it is relatively easy to distinguish, for human tracking, between when the sensor is worn or not worn, and it is also easy to distinguish between stationary (standing or sitting) and walking or running. Knowing the behaviour mode can be used to manage the operating mode of the node. Specifically it could go to a dormant state when it is not worn; it could revert to a low update rate when sitting or standing and be triggered to a higher update rate when walking or running.

In addition to simple behaviour mode detection, the motion sensors measure orientation of the sensor, and for high performance applications full strap-down inertial navigation modes can be engaged to enhance the quality of the output obtained.

Conclusions

The Series 500 system provides a rich set of operating modes that can be adapted according to the requirements of the application. Choice of mode involves trade-offs between update rates, accuracy and battery life.

Choice of operating mode can be preconfigured, can be triggered by motion sensor inputs, or can be linked to situational status such as presence in a particular zone.

Overall bi-directional radio links combined with flexible positioning modes and integrated motion sensors give the Series 500 system uniquely flexible capabilities in many applications.

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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