



Wireless Positioning System

FIELD OF THE INVENTION

The present invention relates to a wireless positioning system, particularly
5 though not solely to an indoor positioning system using Bluetooth.

BACKGROUND

The Global Positioning System (GPS) provides a system for positioning
using multiple satellites. However, due to the attenuation of satellite signals,
10 GPS does not generally work indoors. Various other techniques exist for
positioning indoors. For example, the prevalence of Bluetooth devices (almost all
mobile phones and notebook PCs are Bluetooth enabled) may allow indoor
positioning using Bluetooth wireless communication.

Most existing Bluetooth positioning systems are based on received signal
15 strengths. This is because of the readily accessible Received Signal Strength
Indicator (RSSI) information. Time of Arrival (TOA) or Time Difference of Arrival
(TDOA) based methods are rarely proposed because these methods require fast
and accurate clocks. With a 1 μ S time offset over 100 meter ranging error may
result. Because the Bluetooth standard (Bluetooth SIG. Specification of the
20 Bluetooth System: Core, version 1.1.) does not rigidly specify the timing, it is
impractical, if not impossible, for TOA or TDOA to reach reasonable accuracy for
general Bluetooth devices. For example, using a TOA based method, (Le Thanh
Son and Pal Orten. Enhancing Accuracy Performance of Bluetooth Positioning,



Proceedings of WCNC 2007, pp 2726 – 2731) with a 80MHz sampling clock, the best achievable ranging accuracy is about 3 meters.

Other prior art systems, (F. J. Gonzalez-Castano, J. Garcia-Reinoso. Bluetooth Location Networks. Proceedings of GLOBECOM 2002, pp. 233 - 237, vol. 1) (ZONITH Indoor Positioning, www.zonith.com), are based on a Cell Identity method. This determines the Bluetooth device's position as the cell in which the highest signal strength is received.

Other methods use the signal strength from several base stations, e.g. RSS to triangulate the location (Tiago M. Fernandez, Javier Rodas, Carlos J. Escudero and Daniel I. Iglesia. Bluetooth Sensor Network Positioning System with Dynamic Calibration. Proceedings of the 4th International Symposium on Wireless Communication Systems 2007 ISWCS2007, pp. 45 - 49).

All these solutions may suffer from a requirement of pre-built infrastructure and low accuracy (several meters).

Another location method uses Angle at Arrival (AOA) detection in the cellular frequency band (I Jami, M Ali and R F Ormondroyd. Comparison of Methods of Locating and Tracking Cellular Mobiles. IEE Colloquium Novel Methods of Location and Tracking of Cellular Mobiles and their System Applications 1999). The AOA at the base station may be determined by electronically steering the main lobe of an adaptive phased-array antenna in the direction of the arriving mobile signal (Soren Anderson, Mille Millnert, Mats Viberg and Bo Wahlberg. An Adaptive Array for Mobile Communication Systems. IEEE Transactions on Vehicular Technology, Vol. 40, No. 1. February 1991).

However, the Cellular AOA method requires several antennas forming an array with a spatial displacement pattern, a sampling circuit for the waveform, and complex array signal processing to generate the estimation result. It is mainly realized in base stations for mobile phones. The method is impractical to
5 be applied indoors due to size and cost limitations.

SUMMARY OF THE INVENTION

In general terms, the invention proposes that a mono-pulse based system is used for AOA detection with Bluetooth devices. With an array made up of
10 several directional antennas and a switch, a normal Bluetooth receiver may be modified into a "radar" receiver based on the mono-pulse system. The RSSI information in Bluetooth devices can be accessed through an HCI (Host Controller Interface). The signal strength from the RSSI can be converted using a simple lookup-table to determine the AOA. This may have the advantage that a
15 1-2 degree accuracy may be able to be achieved.

In a first particular expression of the invention there is provided a method of determining the Angle of Arrival (AOA) of a first Bluetooth device relative to a second Bluetooth device according to claim 1.

In a second particular expression of the invention there is provided a base
20 station for determining the Angle of Arrival (AOA) of a portable Bluetooth device comprising according to claim 8.

In a third particular expression of the invention there is provided a system according to claim 15.

BRIEF DESCRIPTION OF THE DRAWINGS

One or more example embodiments of the invention will now be described, with reference to the following figures, in which:

5 Figure 1 is a block diagram of a system for AOA estimation according to the exemplary embodiment,

Figure 2 is an illustration of a mono-pulse method for AOA estimation,

Figure 3 is a flow diagram of AOA estimation,

Figure 4 is a block diagram for a "following me" TV application, and

10 Figure 5 is a block diagram of a system for 2D position estimation according to the exemplary embodiment.

DETAILED DESCRIPTION

It is believed that no research has been conducted for AOA (angle of
15 arrival) based positioning for Bluetooth. Possible reasons include: 1) difficulty in building very high directivity antennas if a single antenna is used; and 2) complex array signal processing for AOA estimation based on a phased array.

Figure 1 illustrates the setup of a system 100 according to the exemplary embodiment. Its basic elements include a fixed Bluetooth base station 102 and
20 several mobile devices 104, 106, 108, 110 to be tracked. The mobile devices can be any commercial devices with Bluetooth functionality. The total number that one base station 102 can track is only limited by the Bluetooth protocol (at least 7 within one pico-net). The base station 102 includes a Bluetooth receiver 118 connected to a directional antenna array 114 through a switch 116. The switch

116 is controlled by a signal processing unit 120, which may include application software. By comparing the RSSI readings for one mobile device with different receiving antennas, the AOA of the mobile device may be determined using a mono-pulse method.

5 The mobile Bluetooth devices (to be located) 104, 106, 108, 100 may be any standard Bluetooth device. The Bluetooth device 102 working as a base station may include:

- 1) a directional antenna array 114 (at least two antennas) connected to a RF switch 116, with the common port of the switch connected to the antenna input port of the Bluetooth receiver 118. Alternatively a single
10 antenna may be used with multiple positions. In such case, a rotation, repositioning or beam steering mechanism can be included to adjust the orientation or and/or location of the antenna as a sequential lobbing setup. without the need for an RF switch;
- 15 2) digital control signals transmitted in the baseband to control the RF switch 116; and
- 3) application software in the signal processing unit 120 for generating the switch control and calculation of the AOA.

 The Mono-pulse method according to the exemplary embodiment may also
20 be described as simultaneous lobe comparison that measures the direction of arrival of radiation. Its working principle is illustrated in Figure 2. The beacon 200 from position (R, θ) is received by two identical beam patterns 202, 204 (this can be realised by real simultaneous beams with two receivers or sequential lobing

with only one receiver 206) with a “squint angle” α (angle between the beam patterns). The angle estimation is based on comparison of the amplitudes of these two signals. The common estimator is Δ/Σ , which denotes the difference of their amplitudes divided by the sum of them. If the beam patterns are f_1 and f_2 respectively, the estimator can be formulated as seen in Equation (1):

$$\Delta/\Sigma = \frac{f_1(\theta) - f_2(\theta)}{f_1(\theta) + f_2(\theta)} \quad (1)$$

If the antenna patterns can be approximated by the Gaussians as shown in Equation (2):

$$f_{1,2}(\theta) = \exp[-(\theta \mp \frac{1}{2}\alpha)^2 / \theta_0^2] \quad (2)$$

where θ_0 is the beamwidth. Substituting for the angle estimator of Equation 1 gives $\Delta/\Sigma \approx \alpha\theta / \theta_0^2$, for angles near boresight (z-direction). That is, the Δ/Σ estimator may be linearly proportional to the off-boresight angle (θ).

The mono-pulse method can operate as a simultaneous lobe comparison or, alternatively, sequential lobing by antenna switching can be used to avoid the RF mixer. Therefore only one receiver channel may be required.

The mono-pulse concept according to the exemplary embodiment can be applied to indoor AOA applications for Bluetooth devices. The system needs to be adapted to work for short distances (indoor, around 10m compared to kilometres in radar applications) and wide squint angle (tens of degrees compared to few degrees in radar applications).

The directional antenna array 114 may for example have a 3dB beamwidth of about 60 degrees working at a 2.4GHz central frequency with a bandwidth of about 100MHz. A mono-pulse antenna array may achieve its best performance when the squint angle (angle between two antennas' positioning direction) is 0.936 times the antenna's 3dB beamwidth. The antennas may be placed with no separation from each other (unlike a phased array), which may allow a more compact implementation. The number of antennas within an array may be determined by the beamwidth, squint angle and coverage directions. For example, if antennas of 60 degree beamwidth are used, with a squint angle of 60 degree, six antennas may be used to form an array to cover a 360 degree angle of arrival.

The angle estimation may not be restricted to the near-boresight region as in radar applications. Accordingly, the relationship between the estimator and the AOA may no longer be linear. This relationship may be determined from the beam pattern, or a lookup table method may be used.

The amplitude of the signal received at each directional antenna element is measured with the RSSI (received signal strength indicator) for each ACL (Asynchronous Connection-Less) connection and can be read through the HCI (host controller interface). Although the RSSI may only be a rough measurement of the signal power (8-bit signed integer in dBs), the mono-pulse method can still achieve a relatively good accuracy due to its working principle (e.g. the range effect is automatically corrected). The round-off effect may lead to an angle error of less than 1 degree.

Figure 3 shows a flow diagram of a method 300 of determining the AOA of one mobile device based on the RSSI readings with different receiving antennas 302. At 304 the RSSI values are transformed into the absolute RX power P_i ($i=1,2, \dots N$, where N is number of antennas within the antenna array). The method described in Antti Kotanen, Marko Hannikainen, Helena Leppakoski and Timo D. Hamalainen. Experiments on Local Positioning with Bluetooth. *Proceedings of the International Conference on Information Technology: Computer and Communications 2003*) may be used for this step. At 306 the pair of antennas that have a maximum combined RX power (e.g. by simple addition of the RX power of any two adjacent antennas) may be selected as the working antenna pair (i.e. the mobile device is within the coverage of this pair of antennas). At 308 the RX power values on the two antennas may be transformed into amplitude values A_1 and A_2 respectively. At 310 the estimator value is calculated as $\frac{A_1 - A_2}{A_1 + A_2}$ and compared to a pre-determined lookup table to estimate the AOA value θ .

For each mobile device to be located, the base station may switch between each antenna in the antenna array and read the RSSI value received from each antenna (this may imply that at least one ALC connection needs to be made during the "on" time for each antenna). The RSSI values may then be transformed in the absolute received (RX) power P using the method introduced in Kotamen et al. The absolute received power may be converted into signal amplitude as $A = 10^{\frac{P}{20}}$.

The S value (the estimator) is calculated as $\frac{A_1 - A_2}{A_1 + A_2}$ and compared to the pre-determined look-up table to estimate the angle of arrival with regard to this pair of antennas. This output may then be transferred into a bearing reading with reference to a desired coordinate system.

5 With the proposed system, AOA of any Bluetooth device may be accurately detected from a single base station. There's no need to make any hardware modification on the devices to be tracked, and the alterations to the base station device are also minimised. Due to the working principle of mono-pulse concept, directional antennas with a moderate beamwidth (e.g. about 60 degree) can be
10 used and a relatively simple processing can generate high accuracy AOA estimation (estimated to be about 1-2 degrees in 10 m working distance of Bluetooth).

 Either the AOA or 2D position information may be useful for context-aware applications. One domestic example is automatic tuning of "sweet spot" of an
15 audio visual system by monitoring the users' current position (either in terms of angle of arrival, e.g. viewing angle or 2D position).

 Figure 4 illustrates such a domestic application utilising the AOA information. A video display 400 with an embedded base station 402 proposed in this invention is on a rotational platform 404 driven by a motorized system. The
20 user carries a mobile Bluetooth device 406 (any commercial Bluetooth device, e.g. mobile phone) when they are moving within the room. Based on the real-time detected AOA, the motorised platform 404 is controlled in such a way

that the TV 400 is always facing towards the user so that the user enjoys the best viewing angle no matters where they move.

With at least two base stations, the 2D position of the mobile device can be determined using triangulation. With more base stations, the accuracy can be
5 future increased using additional information and processing.

Figure 5 illustrates a system 500 of determining 2D position of a mobile device 502 with two base stations 504, 506. The 2D position may uniquely determined by the bearing readings θ_1 and θ_2 from these two base stations 506, 501 and the pre-known 2D position (x_1, y_1) and (x_2, y_2) of the two base stations
10 504, 506.

Whilst exemplary embodiments of the invention have been described in detail, many variations are possible within the scope of the invention as will be clear to a skilled reader.

CLAIMS

1. A method of determining the Angle of Arrival (AOA) of a first Bluetooth device relative to a second Bluetooth device comprising
5 receiving the Bluetooth signal strength of the first device at at least two different antenna positions relative to the second device,
determining a common estimator based on the two or more signal strengths, and
determining the AOA based on the common estimator.
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2. The method as claimed in claim 1 wherein the AOA is determined from a look up table based on the common estimator.
3. The method as claimed in any one of the preceding claims wherein the first
15 device is portable and the second device is a base station.
4. The method as claimed in claim 3 wherein there are at least two base stations and further comprising determining the relative position of the first device, based on the AOAs determined from each of the at least two base stations and
20 the relative position of the base stations.
5. The method as claimed in any one of the preceding claims further comprising providing at least two antennas angled at a squint angle of approximately 0.936 times the 3dB bandwidth of each antenna.

6. The method as claimed in any one of claims 1 to 4 further comprising an antenna and an antenna rotation, repositioning or beam steering mechanism to sequentially position the antenna at the at least two different antenna positions.

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7. The method as claimed in any one of the preceding claims wherein the common estimator is determined based on

$$\frac{A_1 - A_2}{A_1 + A_2}$$

where $A = 10^{\frac{P}{20}}$, and P is the absolute received power derived from an RSSI value read from a host controller interface HCI associated with the second device.

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8. A base station for determining the Angle of Arrival (AOA) of a portable Bluetooth device comprising:

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at least two different antenna positions,

a Bluetooth receiver to receive a Bluetooth signal from the mobile Bluetooth device at the at least two different antenna positions,

a processor to determine the AOA of the mobile Bluetooth device based on the received Bluetooth signals.

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9. The base station as claimed in claim 8 further comprising at least two antennas angled at a squint angle of approximately 0.936 times the 3dB

bandwidth of each antenna.

10. The base station as claimed in claim 8 further comprising an antenna and an antenna rotation, repositioning or beam steering mechanism to sequentially position the antenna at the at least two different antenna positions.

11. The base station as claimed in claim 9 further comprising an RF switch to connect between the at least two antennas and the Bluetooth receiver, the RF switch configured to be controlled by the processor.

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12. The base station as claimed in any one of the claims 8 to 12 further comprising Received Signal Strength Indicator (RSSI) module to determine the signal strength of the Bluetooth signals.

13. The base station as claimed in claim 12 further comprising a Host Control Interface (HCI) to provide the RSSI values to the processor.

14. The base station as claimed in claim 13 wherein the processor is configured to determine a common estimator based on

$$\frac{A_1 - A_2}{A_1 + A_2}$$

where $A = 10^{\frac{P}{20}}$ where P_X is derived from the RSSI values from the HCI.

15. A system comprising:
- at least one portable Bluetooth device, and
 - a base station as claimed in any one of claims 8 to 14 for determining the Angle of Arrival (AOA) of the at least one portable Bluetooth device.