Location for 802.22 WRAN radio systems

Presented to the IEEE 802.22 by Ivan Reede
Location methods

- There are two basic data acquisition methods
  - Direction Finding
  - Ranging
- Both can be used together to determine a location from another location
- Both can be used without the other to determine a location from a group of other locations
Direction Finding

- Conventionally performed by CW systems
  - CW time difference of arrival at the sensors
  - Results obtained from difference in time of arrival
  - Time difference (phase) is converted to bearing
  - Requires known stable wave front
Ranging

- Difficult for low bandwidth (low speed) (MAC)
- Well suited for higher bandwidth (fast) (PHY)
- Requires simple logic addition (detector/counter)
Ranging Based Location Methods

- Time Sum Of Arrival (TSOA)
- Time Difference Of Arrival (TDOA)
- Absolute Range
Location Method Requirements

- TDOA and/or Direction Finding
  - Requires minimal if any ranging abilities in CPEs
  - Requires at least two BS PHYs in cooperation to work
  - TDOA PHY array takes all readings at once – fastest result
Location Method Requirements

• TSOA
  - Requires more ranging abilities in CPEs and full ranging abilities in BSs
  - Requires at least two BSs in cooperation to work
  - Ill suited for currently single BS deployments
Location Method Requirements

• Absolute
  - Requires more ranging abilities in CPEs
  - Requires full ranging abilities in BSs
  - Requires only one BS to get some resolution
  - Works well with multiple BSs
Absolute Ranging Location

- One range places source on the surface of a sphere
Absolute Ranging Location

• One range places source on the surface of a sphere

• Two intersecting spheres may place source on an annular ring
Absolute Ranging Location

- One range places source on the surface of a sphere
- Two intersecting spheres may place source on an annular ring
- Two intersecting annular rings may place source on two points
Absolute Ranging Location

- One range places source on the surface of a sphere
- Two intersecting spheres may place source on an annular ring
- Two intersecting annular rings may place source on two points
- Fourth range places source on a single point
Absolute Ranging Location

• If we assume $z=0$ (forget altitude information)
Absolute Ranging Location

- If we assume $z=0$ (forget altitude information)
- One range places source on the surface of a ring
Absolute Ranging Location

- If we assume $z = 0$ (forget altitude information)
- One range places source on an annular ring
- Two intersecting rings may place source on any of two points
Absolute Ranging Location

- If we assume $z=0$ (forget altitude information)
- One range places source on the surface of a circle
- Two intersecting circles may place source on any of 2 points
- Third reading may place source on a single point
TSOA - I

- TSOA is based on readings from two observers, A and B at known locations. If the sum of the time of arrival at A and B is known, D's position is constrained to be on the surface of an ellipsoid of revolution.
TSOA - II

- Two ranges places source on an ellipsoid of revolution
- Two intersecting ellipsiods of revolution may place source on an annular ring
- Two intersecting annular rings may place source on two points
- Another range may place source on one point
- Some ranges may be replaced by geometrical factors (such as assuming z=0)
• TDOA is based on readings from two observers, A and B at known locations. If the difference in the time of arrival at A and B is known, D's position is constrained to a hyperboloid of revolution.
TDOA - II

- Two ranges places source on an hyperboloid of revolution
- Two intersecting hyperboloids of revolution may place source on an annular ring
- Another reading places source on two points
- Another reading places source on one point
- Some ranges may be replaced by geometrical factors (such as assuming $z=0$)
TDOA Location - III

• Graphically, the solution looks like:
Building a BS sensor array on the fly

• Let's look at what's needed for a heterogenic BS sensor array to self-construct in a plug & play map

• To achieve this, we need to entertain the concept of CPE time referential

• Space has many dimensions
  – X,Y,Z,Time,...
CPE Location and Ranging

- CPE B
  - TfAB
- BS A
- CPE C
  - TfAC
- CPE D
  - TfAD
- CPE E
  - TfAE
- CPE F
  - TfAF
CPE Location - I

- Assume the BS PHYs are at known locations
- CPEs have minimal location abilities
CPE Location - I

- BS Transmits Ranging Query
  - BS PHY records first high resolution time stamp
CPE Location - II

- CPE Receives Ranging Query
  - CPE PHY records first high resolution time stamp
CPE Location - III

- CPE Responds to Query with value $T_{xr}$
  - CPE PHY records second high resolution time stamp
CPE Location - IV

- BS Receives response to Query
  - BS PHY records second high resolution time stamp
- CPE transmits its time stamps to BS
RFD Location - V

- In range BSs can report RFD TDOA data
- Out of range BSs can report RFD TSOA data
- CPE's don't need to keep track of absolute time

\[ T_{fAX} = \frac{(T_a' - T_a - T_{xr})}{2} \]
Proposal Conclusion

• It may be very useful to include protocol
  – To allow for time independent readings
  – To allow for TDOA and TSOA readings
  – To allow for simplified, rangeless CPEs

• It may be useful to mandate a ranging packet data pattern that forces a sharp leading edge pulse (6 Mhz BW) out of the FFT engine

• This would make CPE ranging easier and more precise (interpolating down to 5 meter resolution)
3 Sensor TDOA Math I

Assumptions

- Let $x, y, z$ be the position on the X and Y and Z axis of a flat cartesian space

- Position of sensors
  - Sensor1, $x_1=0, y_1=0, z_1=0$ (at the coordinate system origin)
  - Sensor2, $x_2=x_2, y_2=0, z_2=0$ (somewhere on the x axis)
  - Sensor3, $x_3=x_3, y_3=y_3, z_3=0$ (somewhere on the x-y plane)

- Position of source $x_0=x_s, y_0=y_s, z_0=z_s$

- Distances can be computed from propagation delay
3 Sensor TDOA Math II

Notations

- Let the propagation delay of a signal from the source to a sensor be
  - $D_1 = \text{delay from source to Sensor1}$
  - $D_2 = \text{delay from source to Sensor2}$
  - $D_3 = \text{delay from source to Sensor3}$

- Let the TDOA from one sensor to another be
  - $D_{12} = D_1 - D_2$ (TDOA between Sensor1 and Sensor2)
  - $D_{13} = D_1 - D_3$ (TDOA between Sensor1 and Sensor3)

- Let the corresponding distances be
  - $R_{12} = R_1 - R_2$
  - $R_{13} = R_1 - R_3$
3 Sensor TDOA Math III

Starting Premise

Assuming the source is located at x,y,z, geometry the

\[
\sqrt{x^2 + y^2 + z^2} - \sqrt{(x-x_2)^2 + y^2 + z^2} := R_{12}
\]

\[
\sqrt{x^2 + y^2 + z^2} - \sqrt{(x-x_3)^2 + (y-y_3)^2 + z^2} := R_{13}
\]
3 Sensor TDOA Math IV

Define an antenna baseline

\[ L_3 := \sqrt{x_3^2 + y_3^2} \]
3 Sensor TDOA Math V

After simplification

we obtain after simplification:

\[ R_{12}^2 - x_2^2 + 2 \cdot x \cdot x = 2 \cdot R_{12} \cdot \sqrt{x^2 + y^2 + z^2} \]

\[ R_{13}^2 - L_3^2 + 2 \cdot x \cdot x + 2 \cdot y \cdot y = 2 \cdot R_{13} \cdot \sqrt{x^2 + y^2 + z^2} \]

These equations represent hyperboloids of revolution with foci at Sensors 1 and 2.
3 Sensor TDOA Math VI

Solution

eliminate one degree of freedom by expressing \( y \) as a function of \( x \)

\[
y(x) := u \cdot x + v
\]

\[
u := \frac{R_{13}}{R_{12}} \cdot \frac{L_{3}^{2} - R_{13}^{2} + R_{13} \cdot R_{12} - \frac{R_{13}}{R_{12}} \cdot x_{2}^{2}}{y_{3}} \quad v := \frac{L_{3}^{2} - R_{13}^{2} + R_{13} \cdot R_{12} - \frac{R_{13}}{R_{12}} \cdot x_{2}^{2}}{2 \cdot y_{3}}
\]
3 Sensor TDOA Math VII

Solution

eliminate a second degree of freedom by expressing z as a function of x

\[ z(x)^2 := d \cdot x^2 + e \cdot x + f \]

\[
d := - \left[ 1 - \left( \frac{x_2}{R_{12}} \right)^2 + u^2 \right]
\]

\[
e := x_2 \cdot \left[ 1 - \left( \frac{x_2}{R_{12}} \right)^2 \right] - 2 \cdot u \cdot v
\]

\[
f := \left( \frac{R_{12}^2}{4} \right) \cdot \left[ 1 - \left( \frac{x_2}{R_{12}} \right)^2 \right]^2 - v^2
\]
3 Sensor TDOA Math VIII

Solution

eliminate a second degree of freedom by expressing \( z \) as a function of \( x \)

\[
\begin{align*}
\mathbf{z}(x)^2 & := d \cdot x^2 + e \cdot x + f
\end{align*}
\]
3 Sensor TDOA Math VIX

Solution

If $z$ is known, with the knowledge of the TDOA polarity, $x$ is determined

$$z(x)^2 := d \cdot x^2 + e \cdot x + f$$

For examples, with $z=0$, we have:

$$x_{\text{pos}} := \frac{-e + \sqrt{e^2 - 4 \cdot d \cdot f}}{2 \cdot d}$$

$$x_{\text{neg}} := \frac{-e - \sqrt{e^2 - 4 \cdot d \cdot f}}{2 \cdot d}$$