Location for 802.22 WRAN radio systems

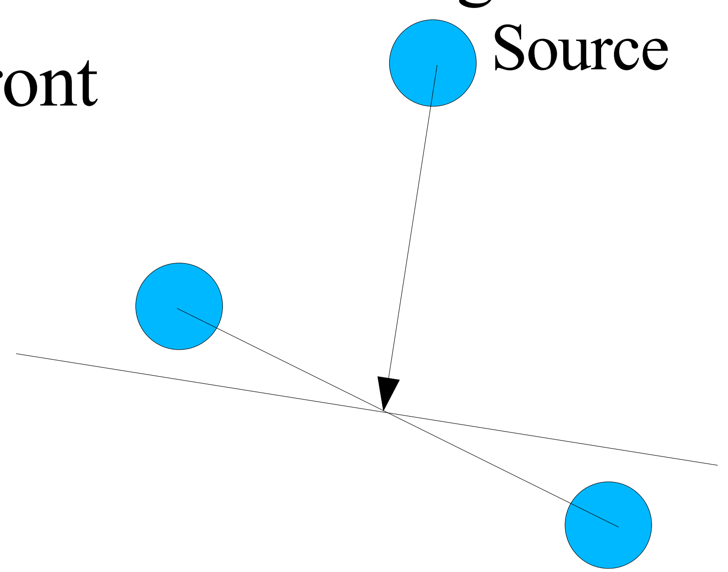
Presented to the
IEEE 802.22
by Ivan Reede

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

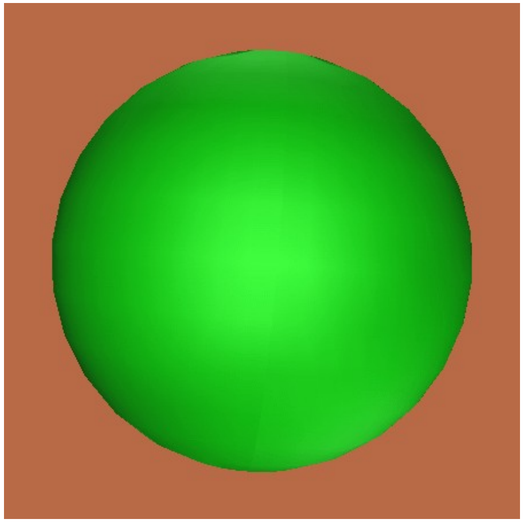
- TSOA
  - Requires more ranging abilities in CPEs and full ranging abilites in BSs
  - Requires at least two BSs in cooperation to work
  - Ill suited for currently single BS deployments

Location Method Requirements

- Absolute
  - Requires more ranging abilities in CPEs
  - Requires full ranging abilites 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

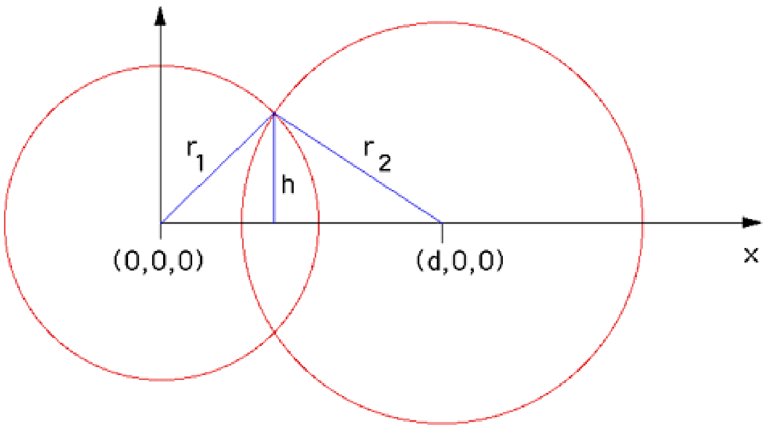


Absolute Ranging Location

- 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

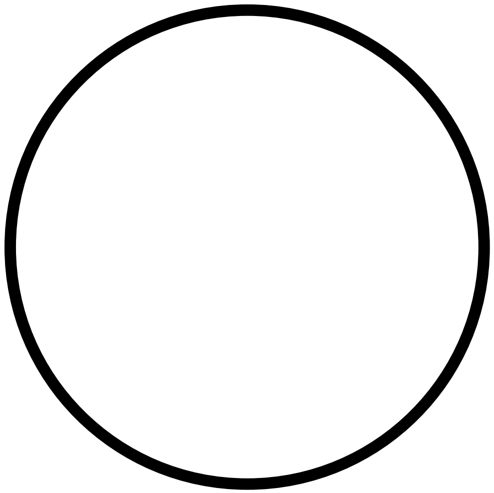
- One range places source on the surface of a sphere
- Two intersecting spheres may place source on an annular ring
- Two intersecting annular rings may place source on two points
- Fourth range places source on a single point

Absolute Ranging Location

- If we assume z=0 (forget altitude information)

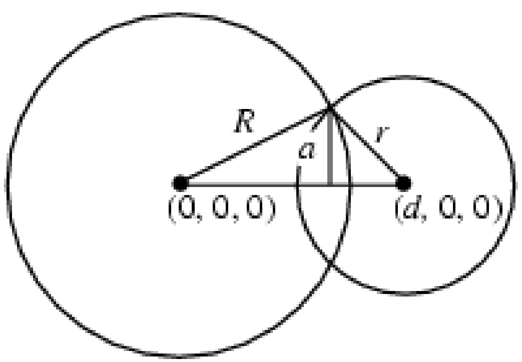
Absolute Ranging Location

- 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

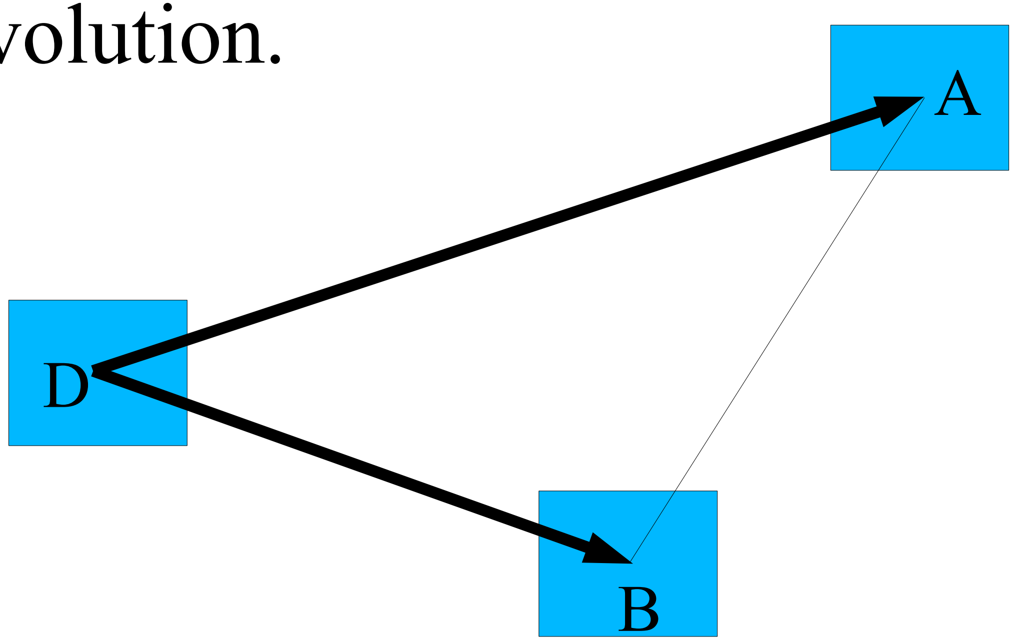


Absolute Ranging Location

- 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 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 elipsoid of revolution.

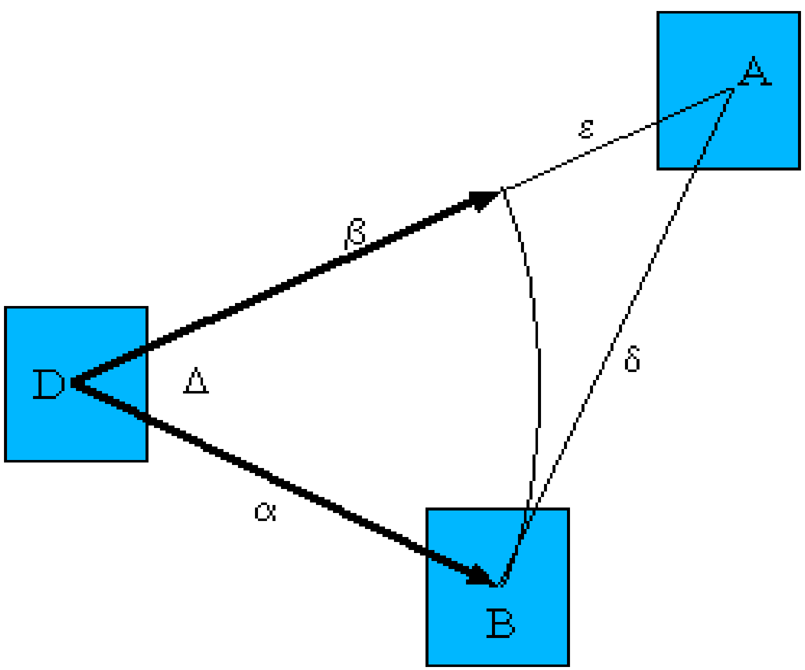


TSOA - II

- 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 - I

- 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.

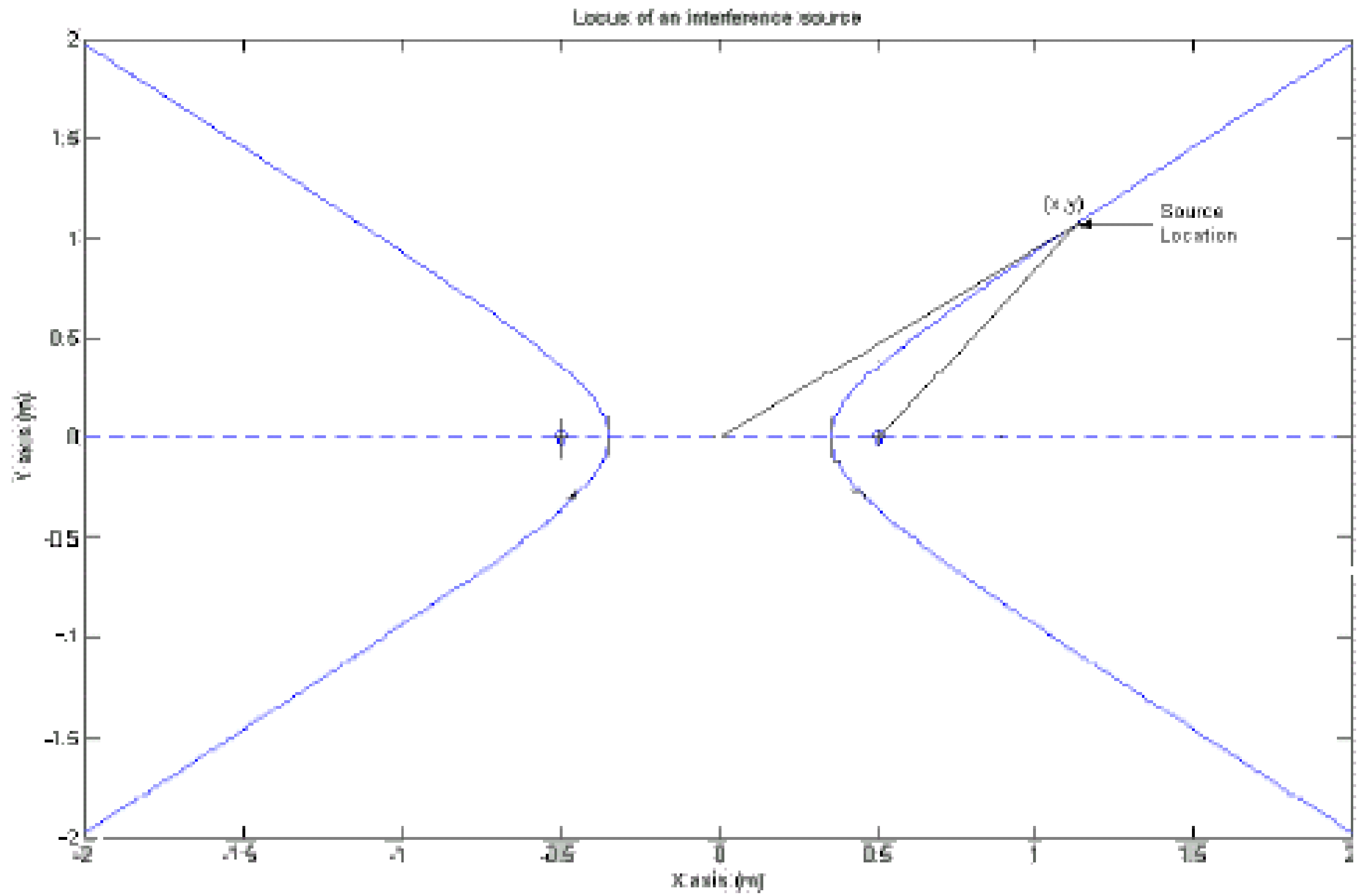


TDOA - II

- 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 $z=0$)

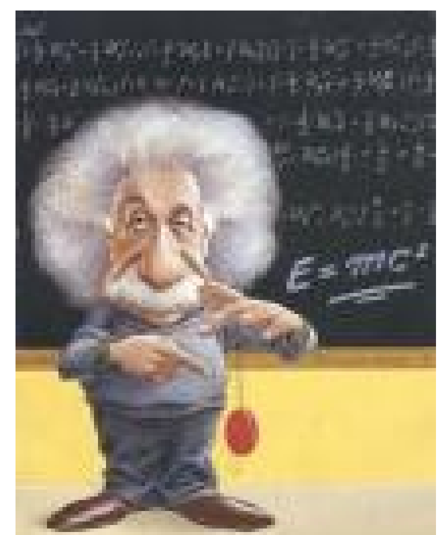
TDOA Location - III

- Graphically, the solution looks like:

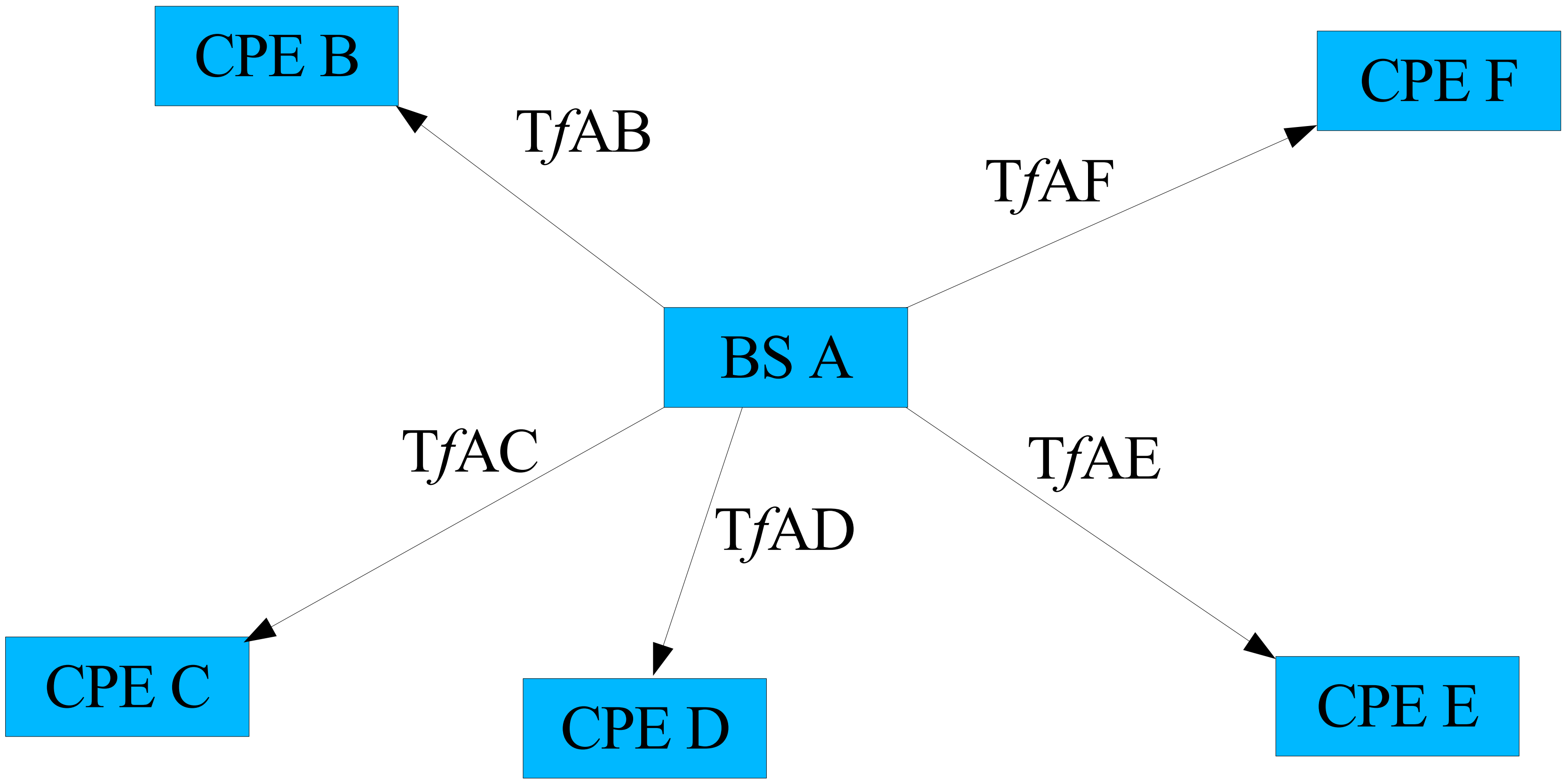


Building a BS sensor array on the fly

- 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

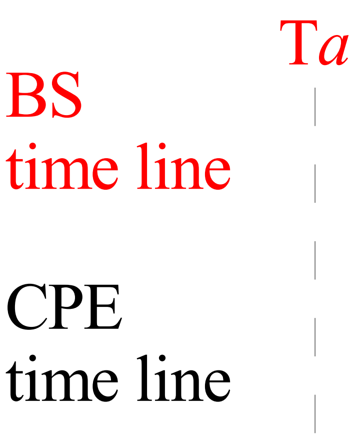


CPE Location - I

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

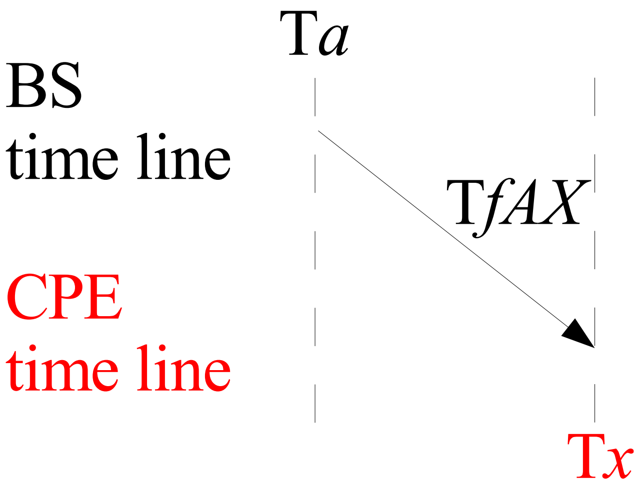
CPE Location - I

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



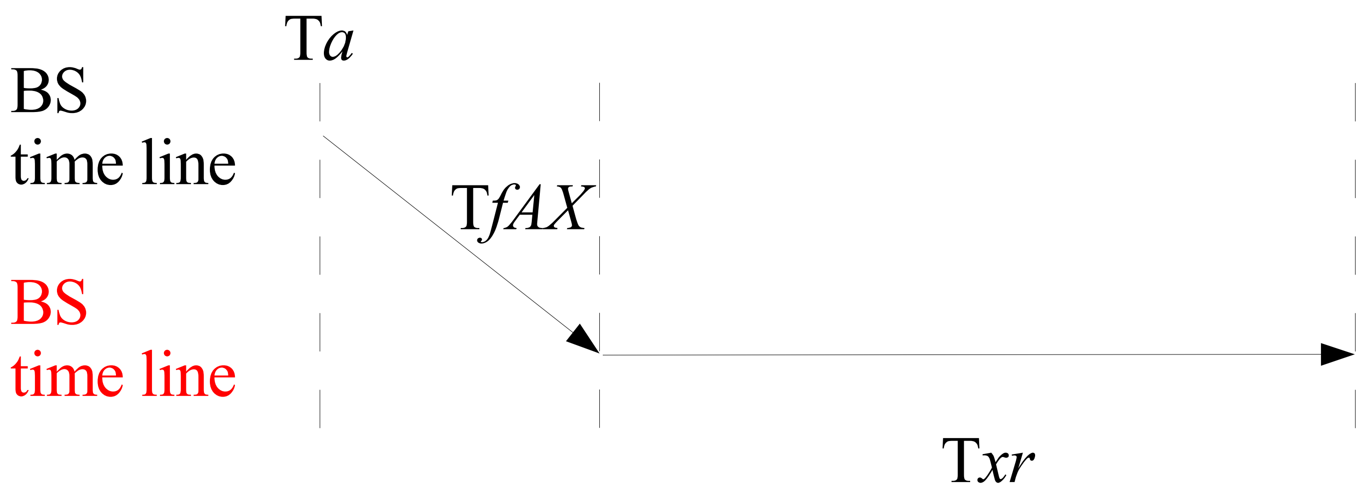
CPE Location - II

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



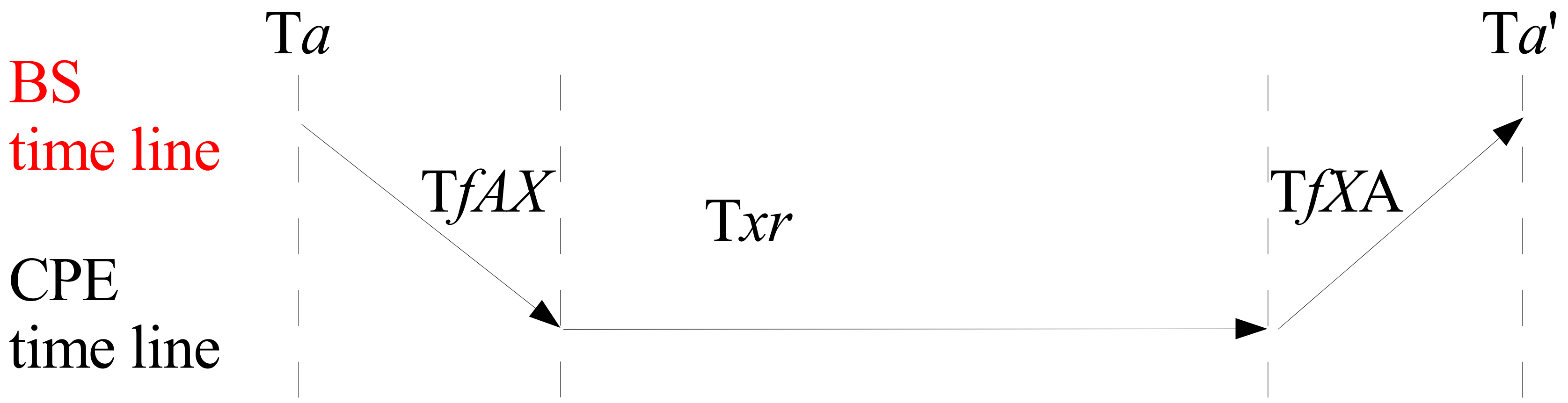
CPE Location - III

- CPE Responds to Query with value T*xr*
  - CPE PHY records second high resolution time stamp



CPE Location - IV

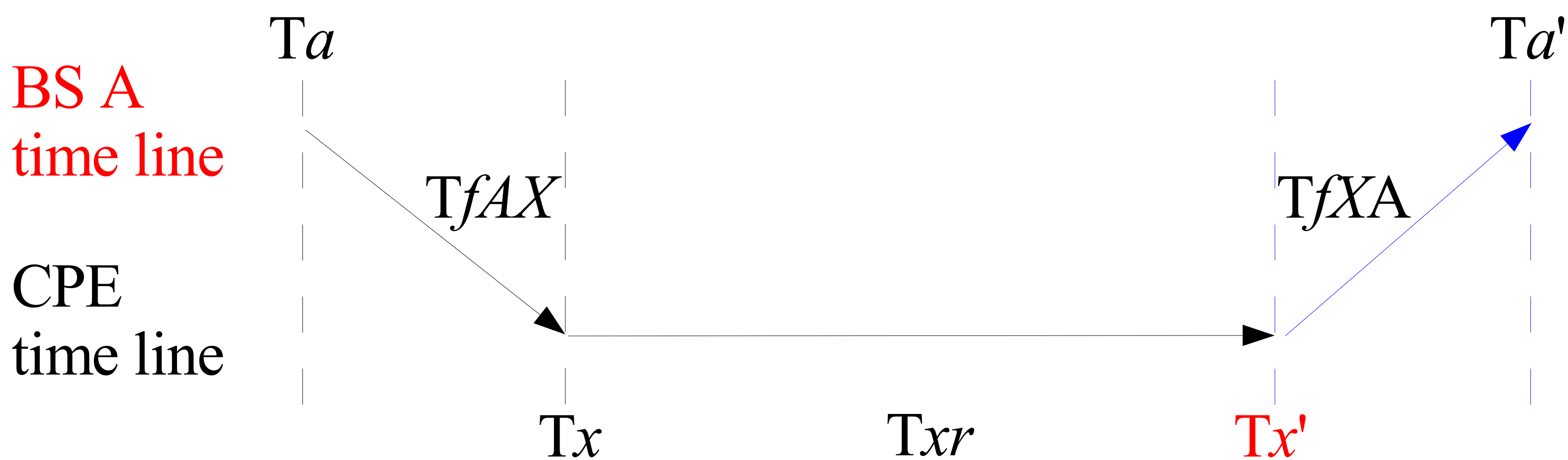
- BS Receives response to Query
  - BS PHY records second high resolution time stamp
- CPE transmits its time stamps to BS



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

$$Tf AX=(Ta'-Ta-Txr)/2$$



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=x2, y_2=0, z_2=0 (somwhere on the x axis)
  - Sensor3, x_3=x3, y_3=y3, 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 = delay from source to Sensor1
  - D_2 = delay from source to Sensor2
  - D_3 = 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

$$\sqrt{x^2 + y^2 + z^2} - \sqrt{\left(x - x_2\right)^2 + y^2 + z^2} := R_{12}$$

$$\sqrt{x^2 + y^2 + z^2} - \sqrt{\left(x - x_3\right)^2 + \left(y - y_3\right)^2 + z^2} := R_{13}$$

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:

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

$$R_{13}^2 - L_3^2 + 2 \cdot x_3 \cdot x + 2 \cdot y_3 \cdot y := 2 \cdot R_{13} \cdot \sqrt{x^2 + y^2 + z^2}$$

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

$$y(x) := u \cdot x + v$$

$$u := \frac{\frac{R_{13}}{R_{12}} \cdot x_2 - x_3}{y_3} \qquad v := \frac{L_3^2 - R_{13}^2 + R_{13} \cdot R_{12} - \frac{R_{13}}{R_{12}} \cdot x_2^2}{2 \cdot y_3}$$

3 Sensor TDOA Math VII

Solution

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

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

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

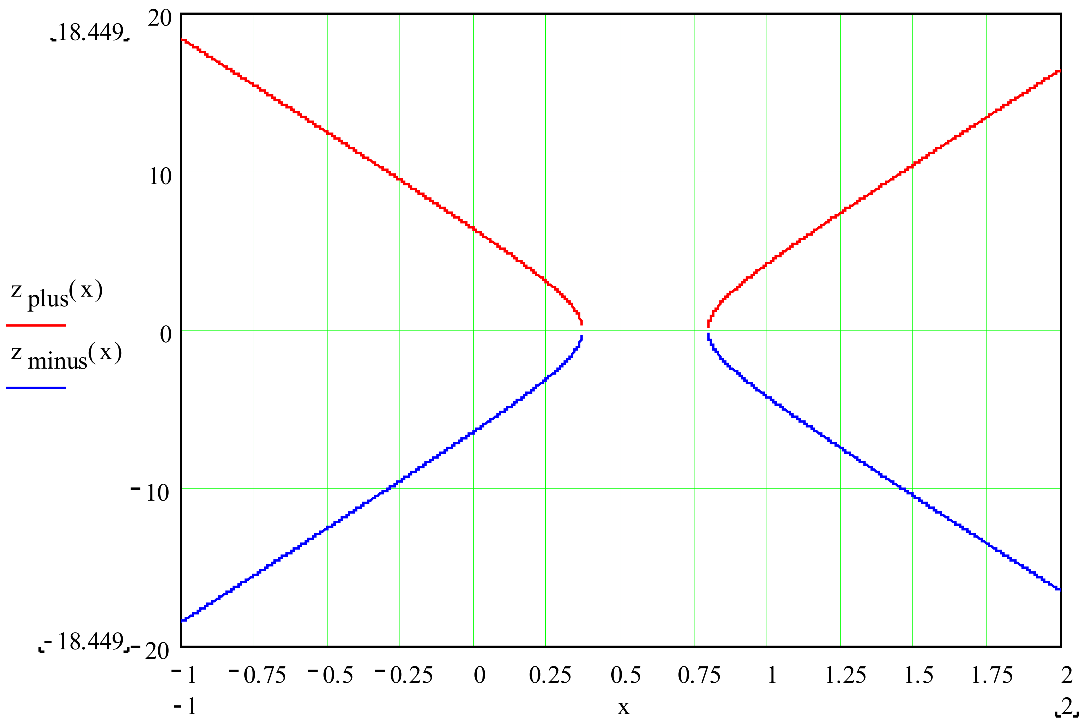
$$f := \left(\frac{R_{12}{}^2}{4}\right) \cdot \left[1 - \left(\frac{x_2}{R_{12}}\right)^2\right]^2 - v^2$$

3 Sensor TDOA Math VIII

Solution

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

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



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:

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