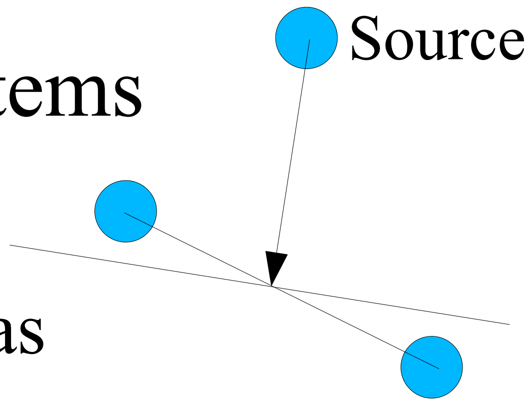
Location for 802.15.4a UWB Phy radio systems

Presented to the
IEEE 802.15 TG4a
by Ivan Reede

Location methods

- There are two basic data acquisition methods
  - Direction Finding
  - Ranging

Direction Finding



- Conventionally performed by CW systems
  - CW time difference of arrival
  - Results phase difference between antennas
  - Phase difference may be converted to bearing
  - Requires relatively narrowband CW
- Ill suited for single antenna “UWB” receivers

Ranging

- Difficult for low bandwidth CW systems
- Well suited for high bandwidth impluse systems
  - UWB
  - 802.15.4 proposed phy

Ranging Based Location Methods

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

Ranging Based Location Method Requirements

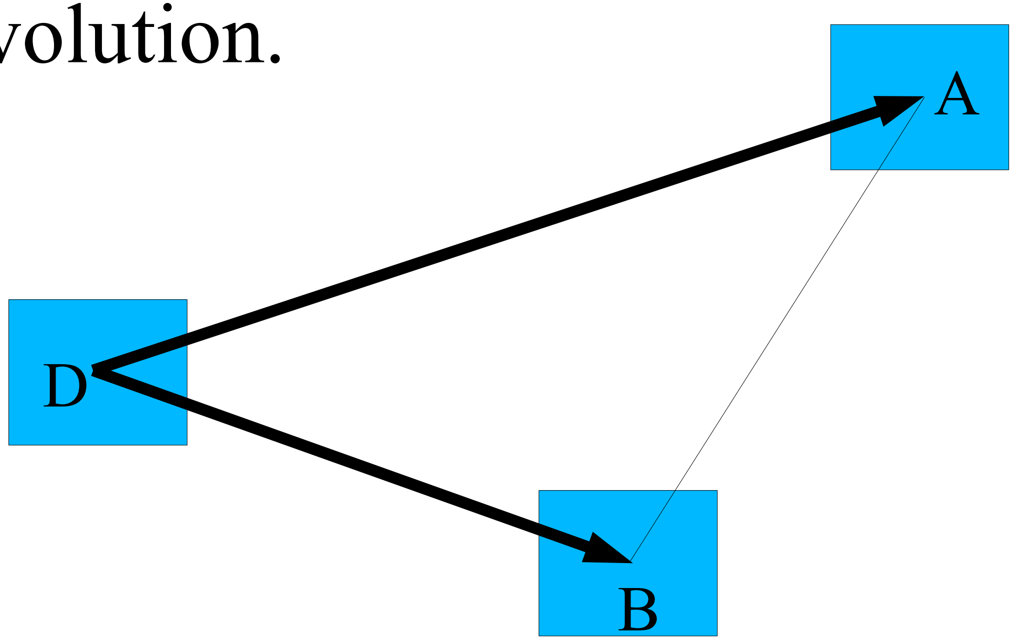
- TDOA
  - Requires minimal if any ranging abilities in RFDs and FFDs
  - Requires at least two FFDs in cooperation to get some resolution
  - Well suited for moving objects, a TDOA array can take many readings at once
- TSOA
  - Requires more ranging abilities in RFDs and full ranging abilites in FFDs
  - Requires at least two FFDs in cooperation to get some resolution
  - Well suited for moving objects, a TSOA array can take many readings at once
- Absolute
  - Requires more ranging abilities in RFDs and full ranging abilites in FFDs
  - Requires only one FFD to get some resolution

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
- Some ranges may be replaced by geometrical factors

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 suface of an elipsoid of revolution.

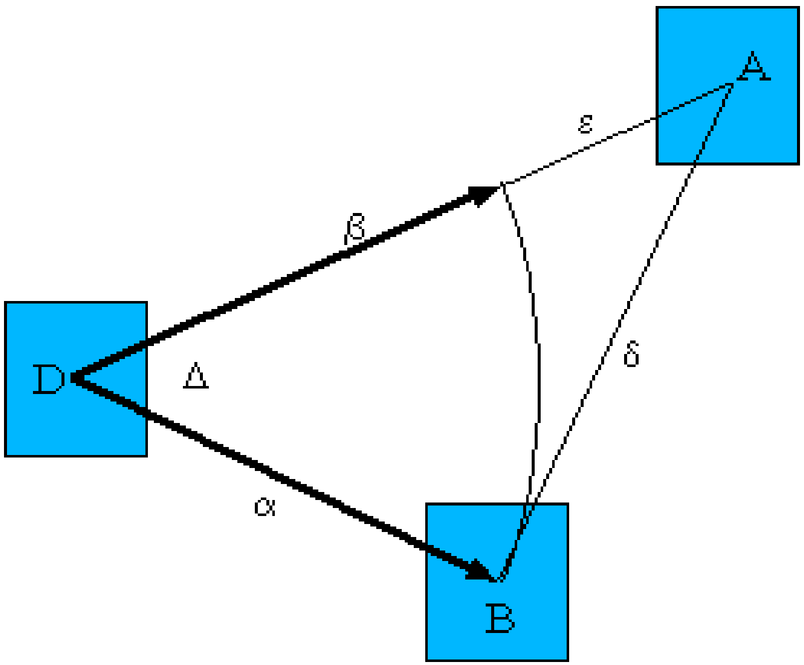


TSOA - II

- 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

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.

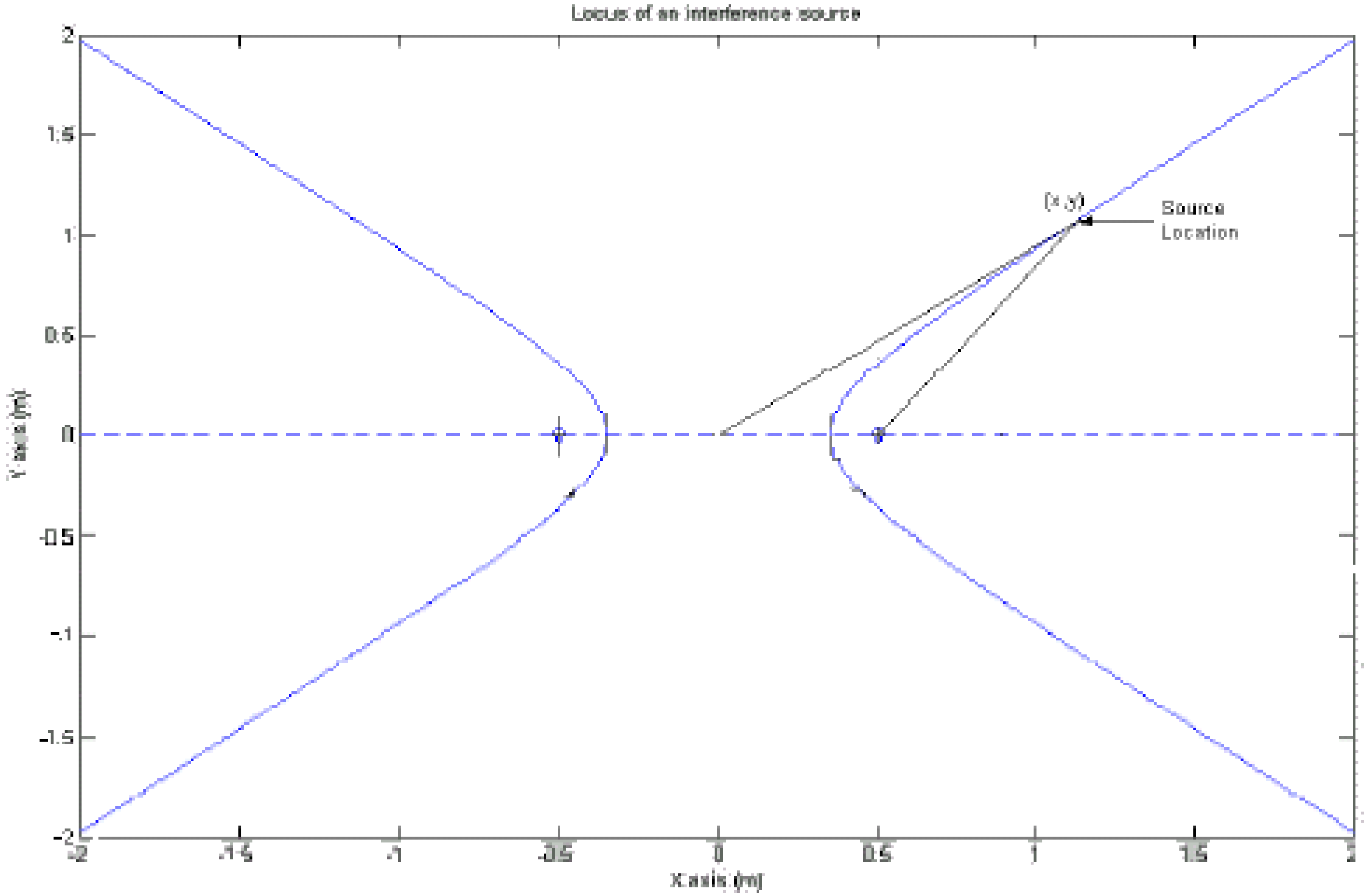


TDOA - II

- 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

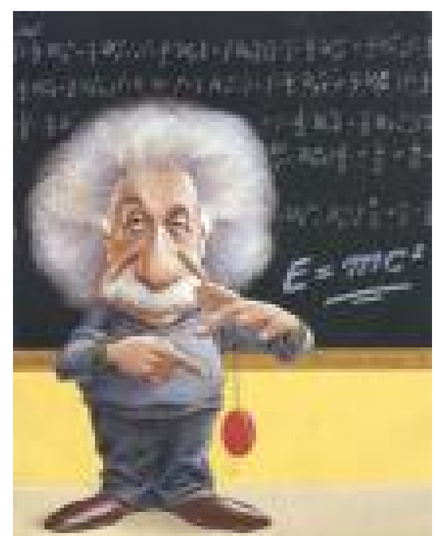
TDOA Location - III

- Graphically, the solution looks like:



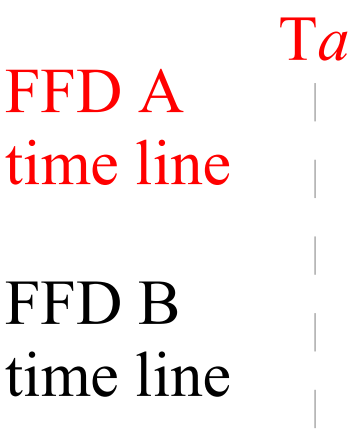
Building a sensor array on the fly

- Let's look at what's needed for a heterogenic FFD sensor array to self-construct in a plug & play model **without** the need for clock distribution or in a clock independent way
- To achieve this, we need to entertain the concept of FFD time referential
- Space has 4 dimensions
  - X,Y,Z,Time



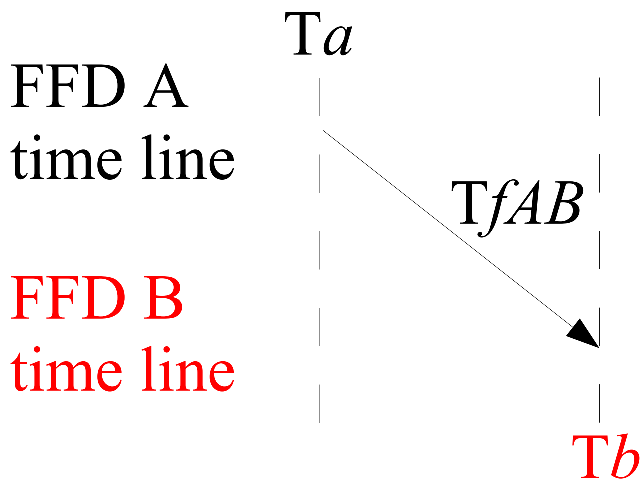
Clock Independent FFD Ranging - I

- At time T*a*, FFD A sends a range probing signal stamped with value T*a*



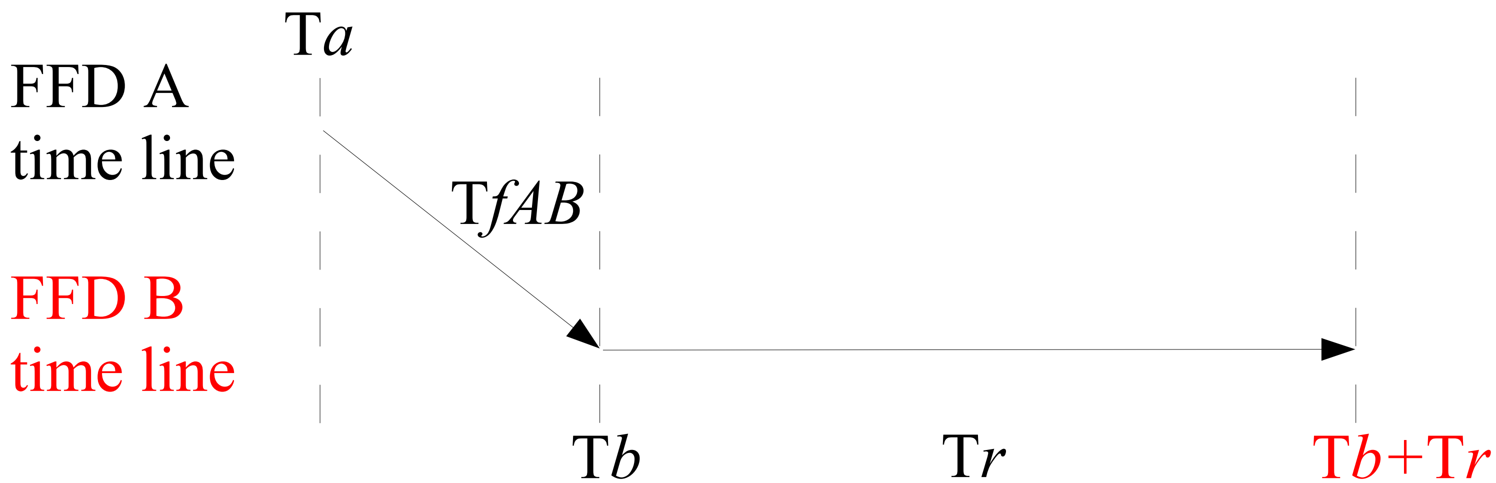
Clock Independent FFD Ranging - II

- At time T*b* FFD B recieves the signal
- FFD B records value T*a* and its own time T*b*



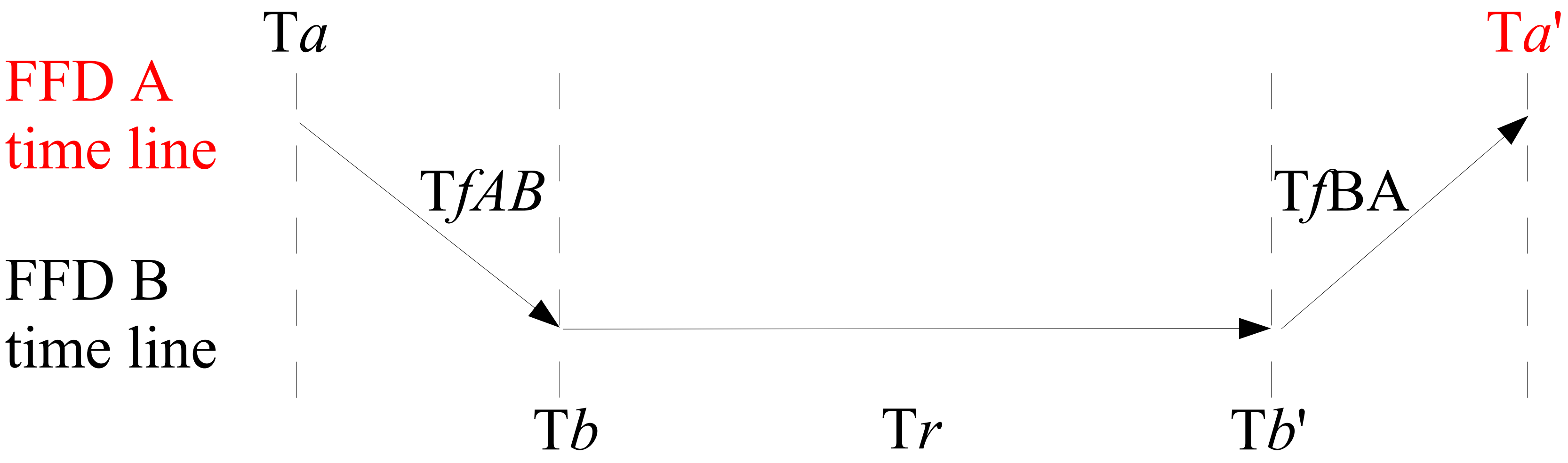
Clock Independent FFD Ranging - III

- At time T*b*+T*r*, FFD B responds
  - with values T*a*,T*b* and T*r*



Clock Independent FFD Ranging - IV

- At T*a*' FFD A receives the response
- It records times T*a*, T*a*', T*b*, T*r*



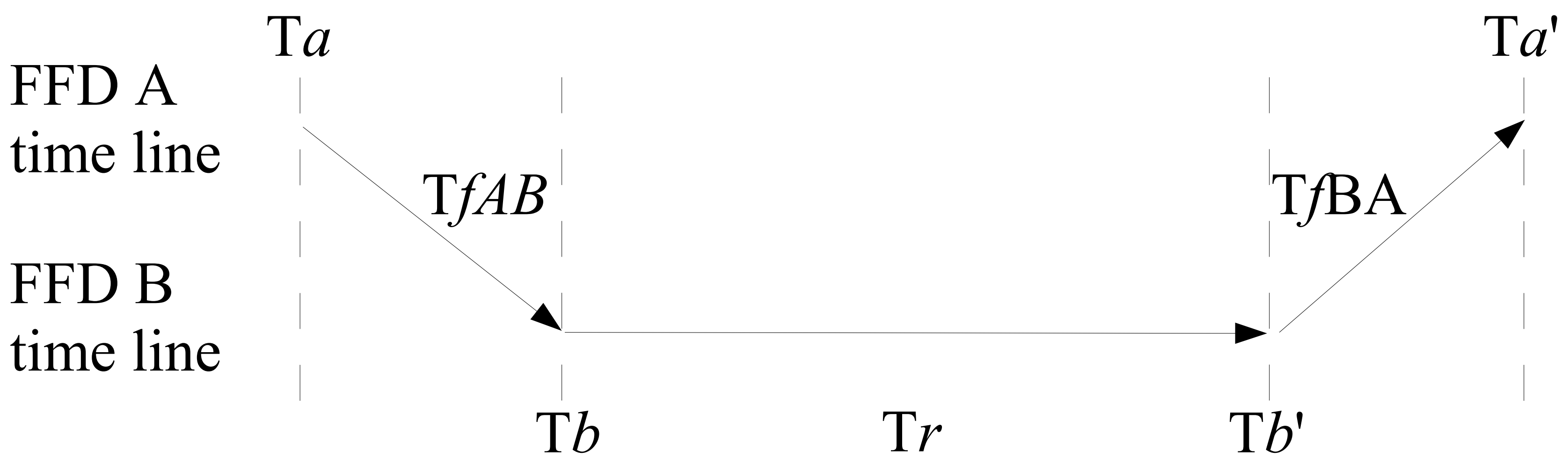
Clock Independent FFD Ranging - V

- FFD Device A can now compute T*f* and T*b*(T*a*)

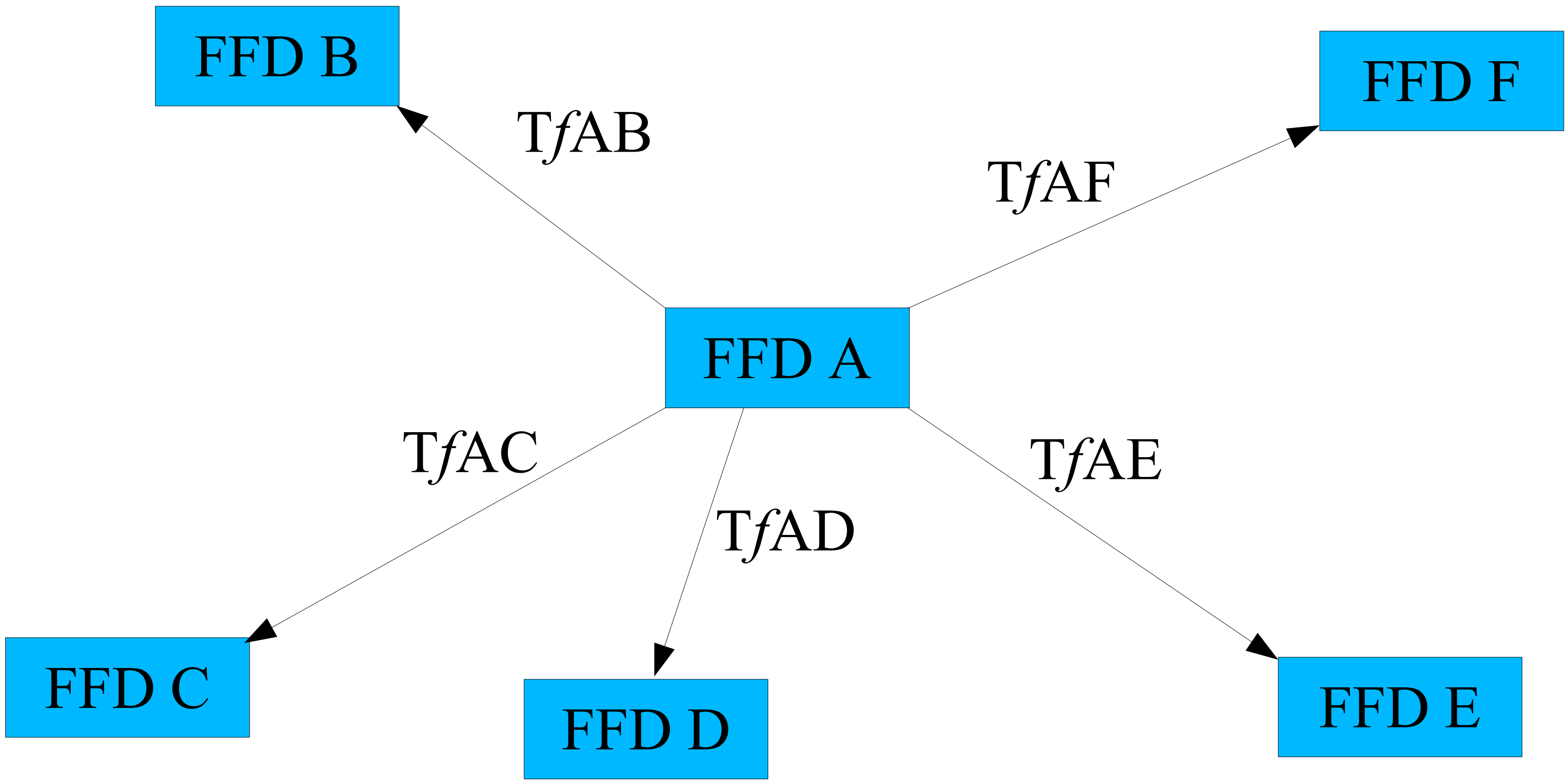
$$TfAB=(Ta'-Ta-Tr)/2$$

$$Tb\{Ta\}=Ta+TfAB$$

$$Tb\{\text{in } Ta \text{ referential}\}$$



Clockless FFD Ranging - VI



Clock Independent RFD Location - I

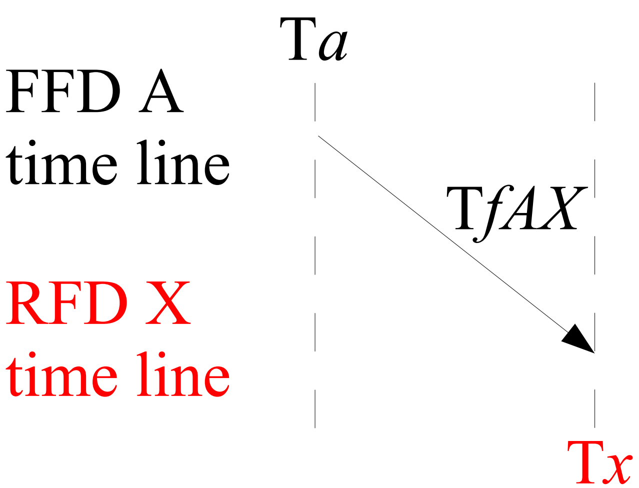
- Now that the FFD sensor array can dynamically auto configure itself and auto discover the location of neighbours, lets look at how the array can locate the simplest possible form of RFD

Clock Independent RFD Location - I

- FFD Transmits Ranging Querry

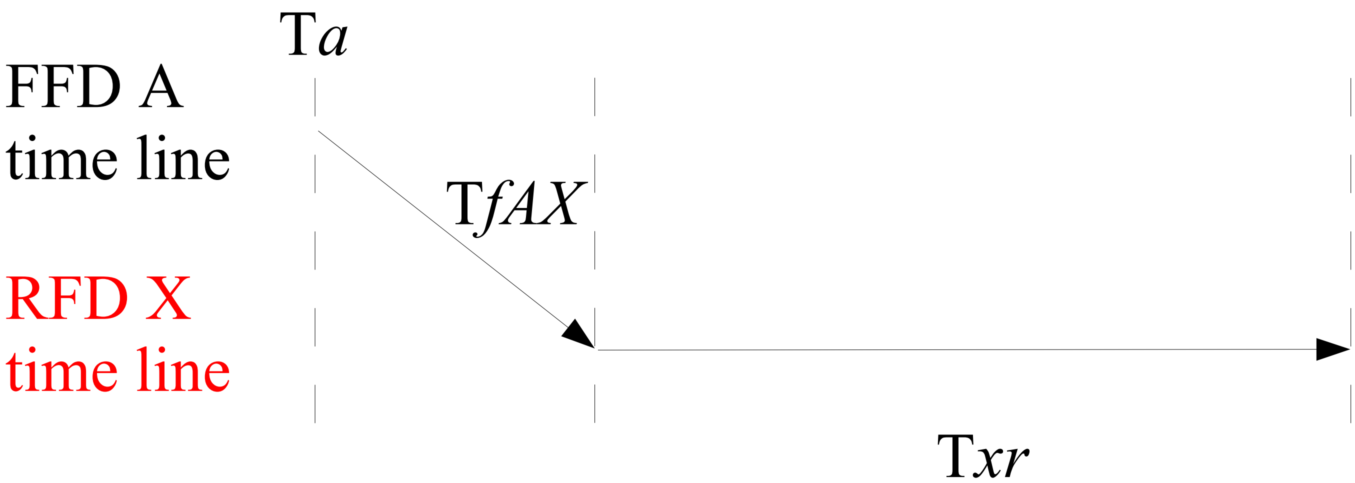
Clock Independent RFD Location - II

- RFD Receives Ranging Querry



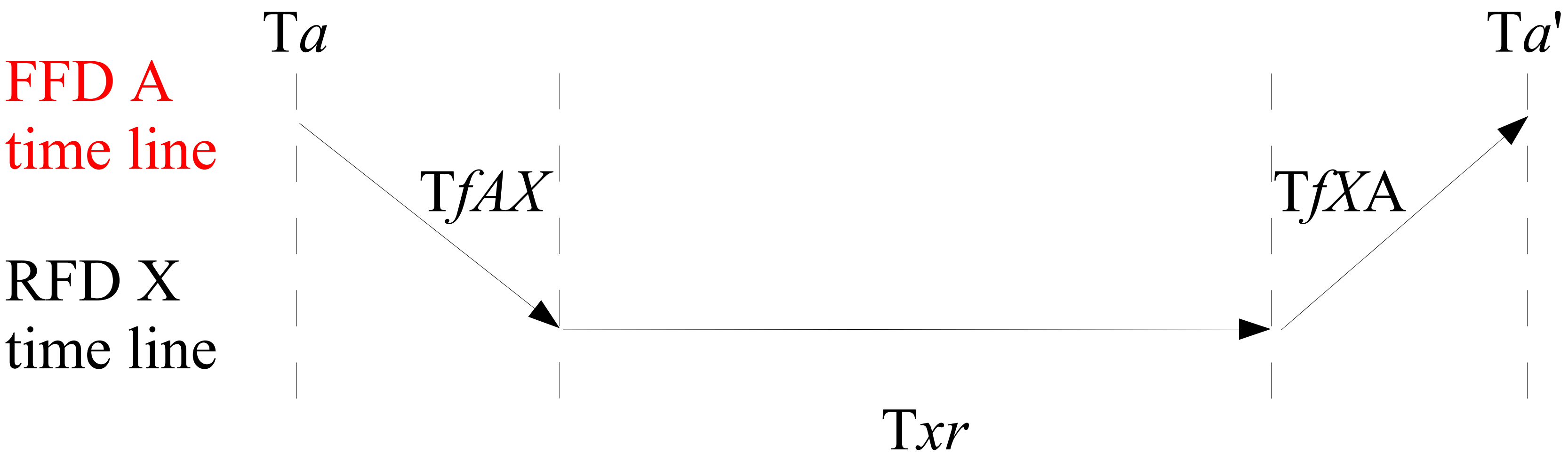
Clock Independent RFD Location - III

- RFD Responds to Querry with value T*xr*



Clock Independent RFD Location - IV

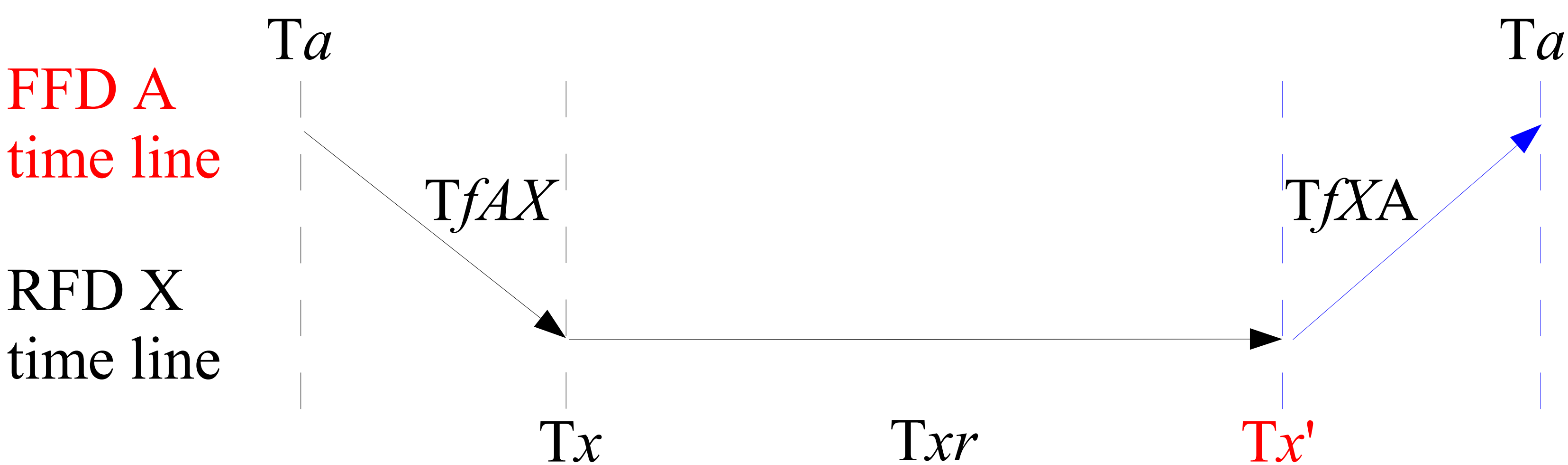
- FFD Receives response to Querry
- It records times T*a*, T*a*', T*xr*



Clock Independent RFD Location - V

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

$$TfAX=(Ta'-Ta-Txr)/2$$



Proposal Conclusion

- It may be very usefull to include protocol
  - To allow for time independent readings
  - To allow for TDOA and TSOA readings
  - To allow for simplified, rangeless RFDs

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

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

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

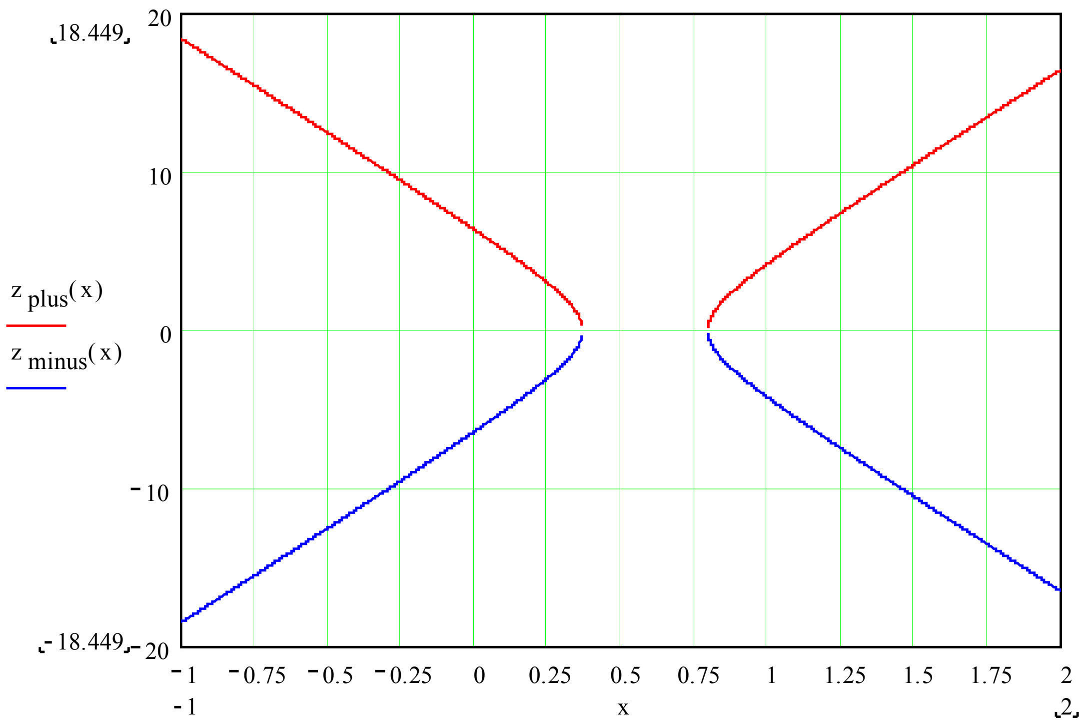
$$f := \left(\frac{R_{12}{}^2}{4}\right) \cdot \left[1 - \left(\frac{x_2}{R_{12}}\right)^2\right]^2 - v^2$$

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:

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