Project: IEEE P802.15 Working Group for Wireless Personal Area Networks (WPANs)

Submission Title: TDOA Localization Techniques
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Re:

Abstract: This document describes TDOA ranging / localization algorithms

Purpose: In support of TG4a Ranging Subcommittee work.

Where is TDOA (time difference of arrival) used?

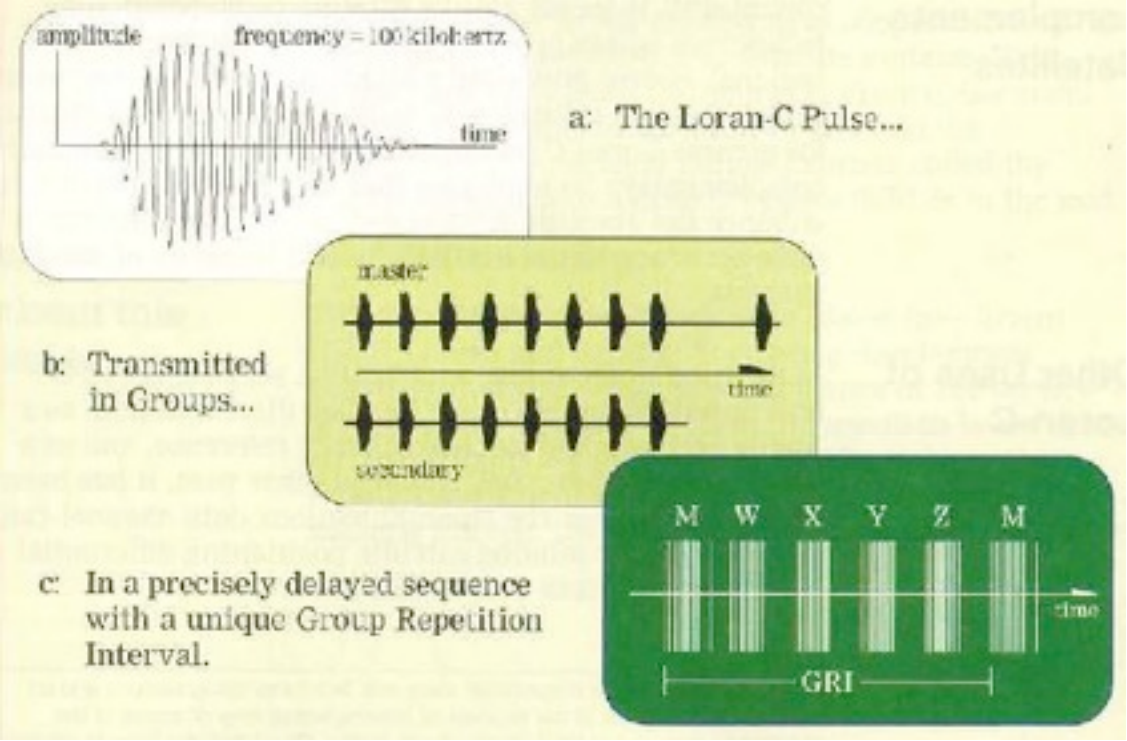
- e911 … cell phone location techniques
- Loran C Navigation System (circ. 1957)

Loran-C … early example of Hyperbolic Location Technique based upon TDOA

- Loran-C transmits wavelets that are used for timing. Both the time of arrival and carrier phase are used to extract information.

- To identify individual Loran-C transmitters, codes are formed by grouping pulses into code words.

- Pulse Position Modulation (PPM) can be used to carry additional information.



Loran-C Basics

The basic “Loran-C like” system consists of three or more reference transmitting stations, each separated by a minimum amount of distance (TBD). Within the transmitting chain, one station is designated as Master while the rest are secondaries. The Master and Secondary stations transmit at precise time intervals. The receiver of interest measures the slight differences in the time that it takes for these signals to reach the receiver.

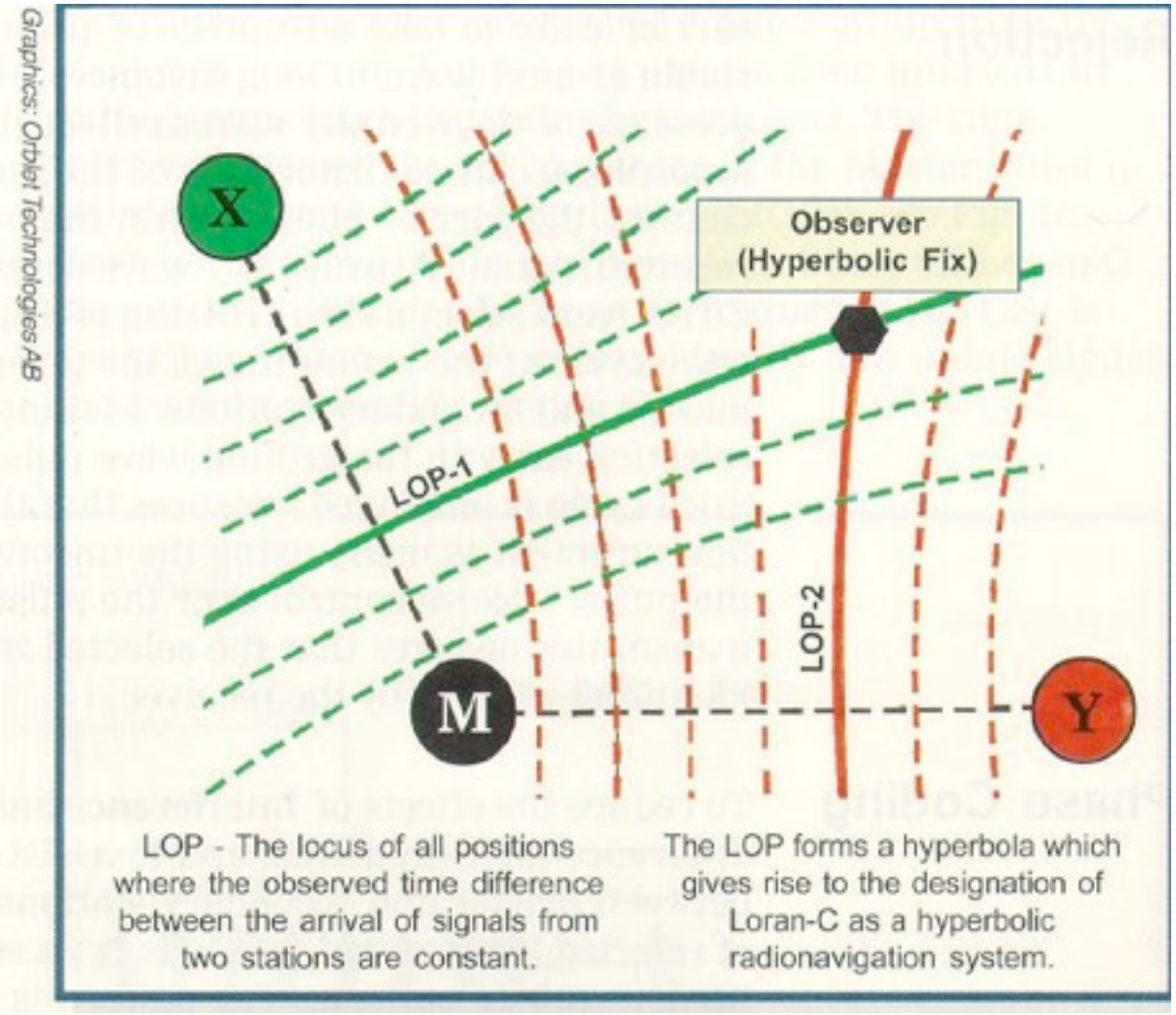
In general, you could say that when the Master signal is received, it is the "Start" of the Stopwatch. When a secondary station is received it is the "Stop" for one TD. Again, the time difference from the receipt of the Master signal to a second secondary is measured[1]. This gives you your second line of the TD. So, when the Master signal is received, it took so many nanoseconds until the receipt of the first secondary signal. It then took another so many nanoseconds until the receipt of the second secondary, and so forth.

The user can now plot their position on charts especially generated for Hyperbolic Location. Obviously, the position would actually be determined via algorithms that will convert the TD's to a more common coordinate system.

Note 1: This important concept will be revisited on page 11 of this contribution.

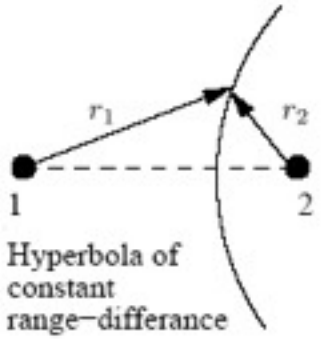
TIME DIFFERENCE MEASUREMENTS

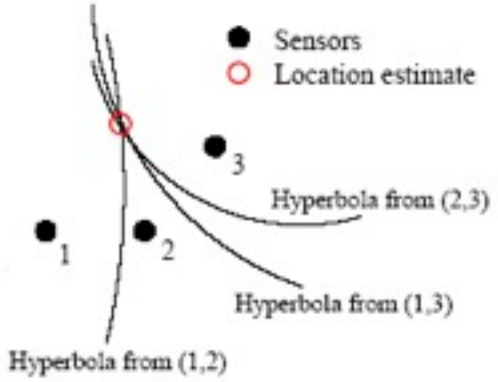
The basic measurements made by Loran-C receivers are to determine the difference in the time-of-arrival (TD) between the master signal and the signals from each of the secondary stations of a chain. In Loran-C, each TD value is measured to a precision of about 100 nanoseconds or better. As a rule of thumb, 100 nanoseconds corresponds to about 30 meters. The principle of time difference measurements in hyperbolic mode is illustrated in the adjacent figure.



Hyperbolic location theory

- The hyperbola is the set of points at a constant *range-difference* ($c_0 \Delta t$) from two foci
- Each sensor pair gives a hyperbola on which the emitter lies
- Location estimation is intersection of all hyperbolas

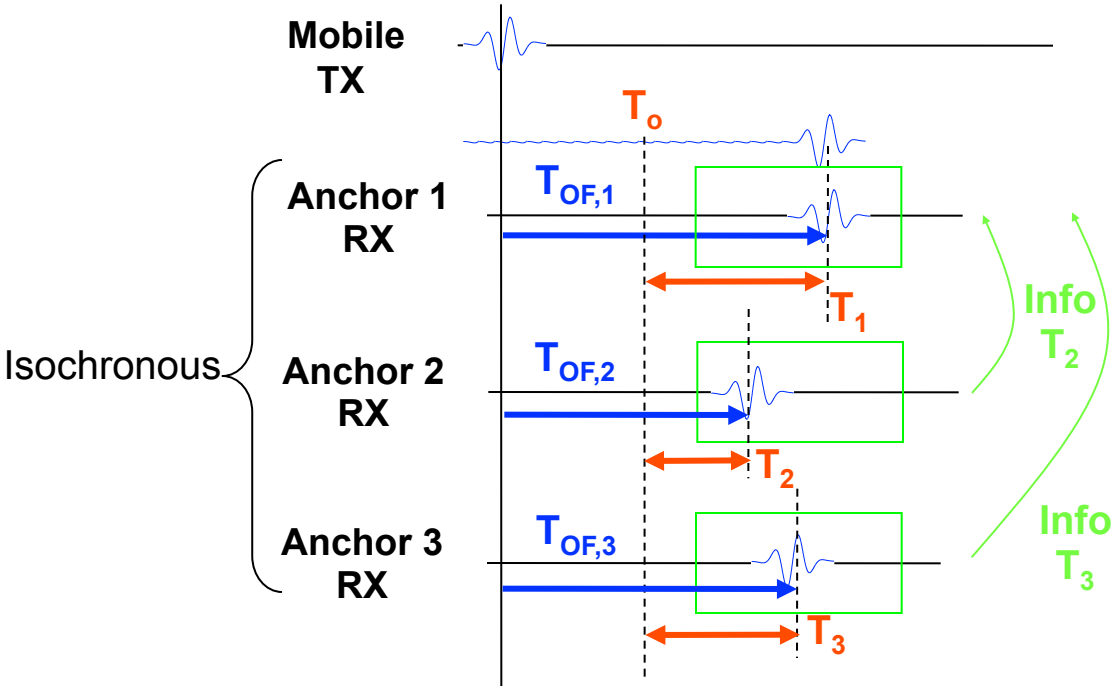


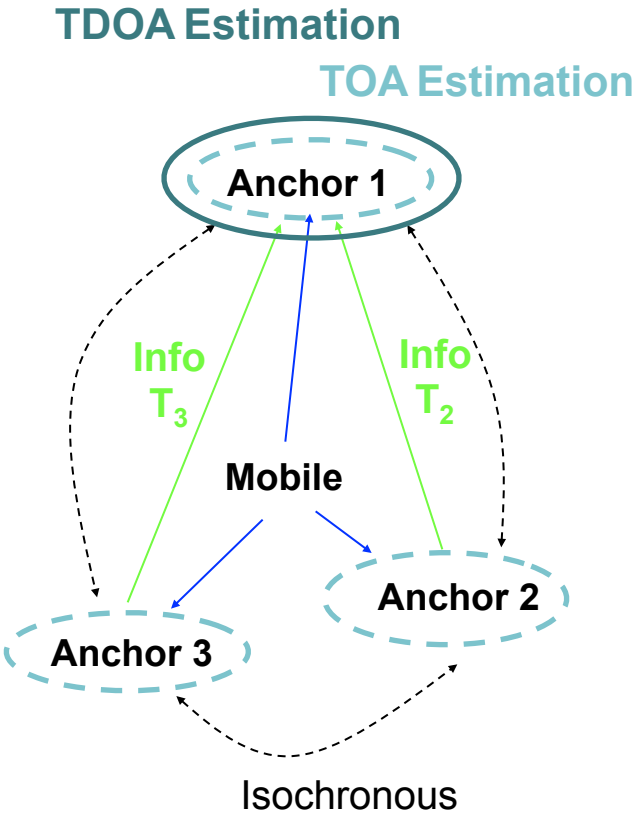


MIT Lincoln Laboratory

TDOA-7
PWB January 16, 2002

Time Difference Of Arrival (TDOA) & One Way Ranging (OWR)





Passive Location

TOA Estimation → TDOA Estimation

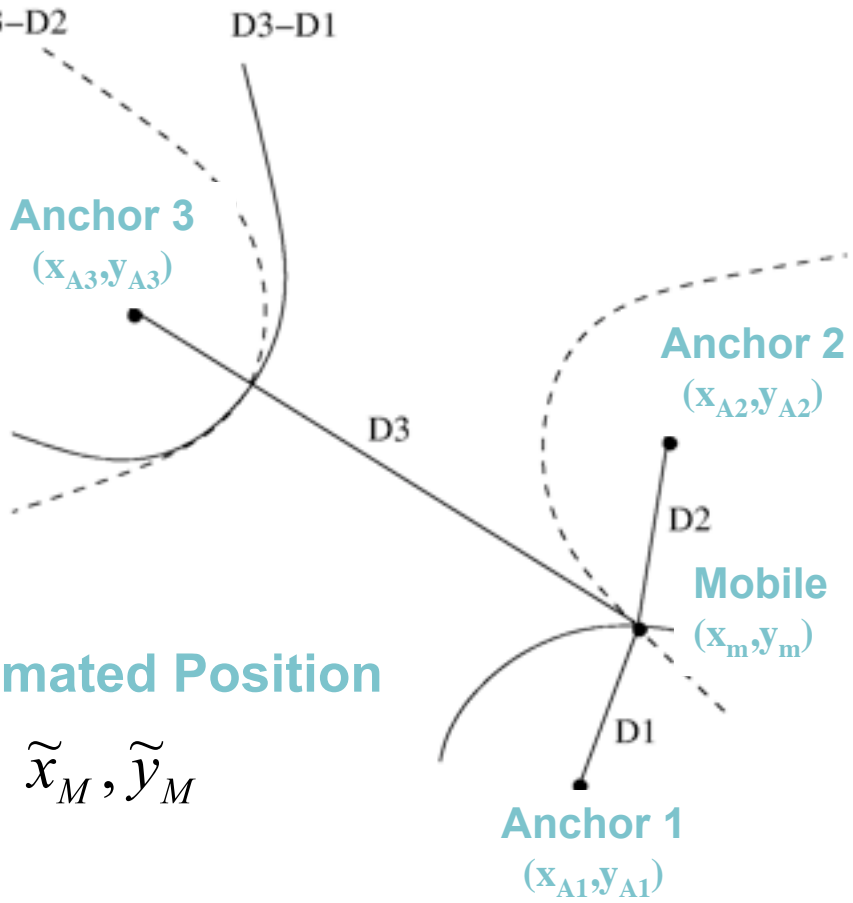
$$T_1, T_2, T_3$$

$$\tilde{T}_{21} = T_1 - T_2 \Rightarrow \tilde{d}_{21} = \tilde{T}_{21}.c$$

$$\tilde{T}_{23} = T_3 - T_2 \Rightarrow \tilde{d}_{23} = \tilde{T}_{23}.c$$

Positioning from TDOA

3 anchors with known positions (at least) are required to find a 2D-position from a couple of TDOAs



Measurements → **Estimated Position**

$\tilde{d}_{32}, \tilde{d}_{31}$ **Specific Positioning Algorithms** $\tilde{x}_M, \tilde{y}_M$

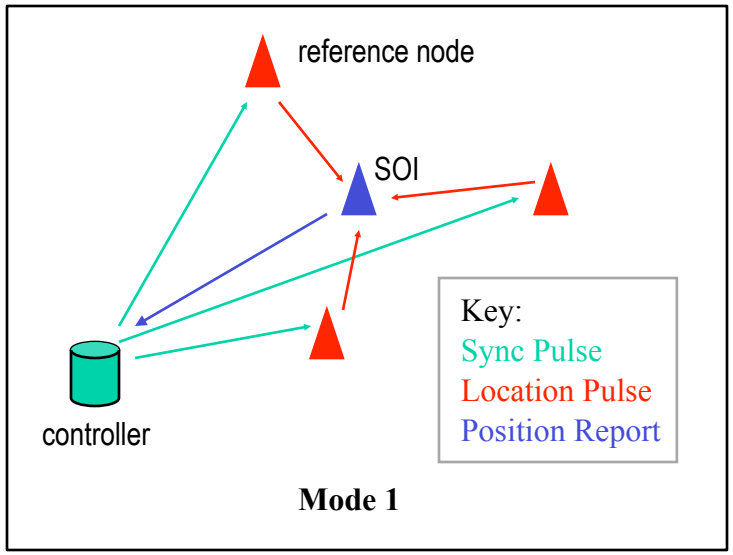
$$d_{32} = \sqrt{\left(x_{A_3} - x_M\right)^2 + \left(y_{A_3} - y_M\right)^2} - \sqrt{\left(x_{A_2} - x_M\right)^2 + \left(y_{A_2} - y_M\right)^2}$$

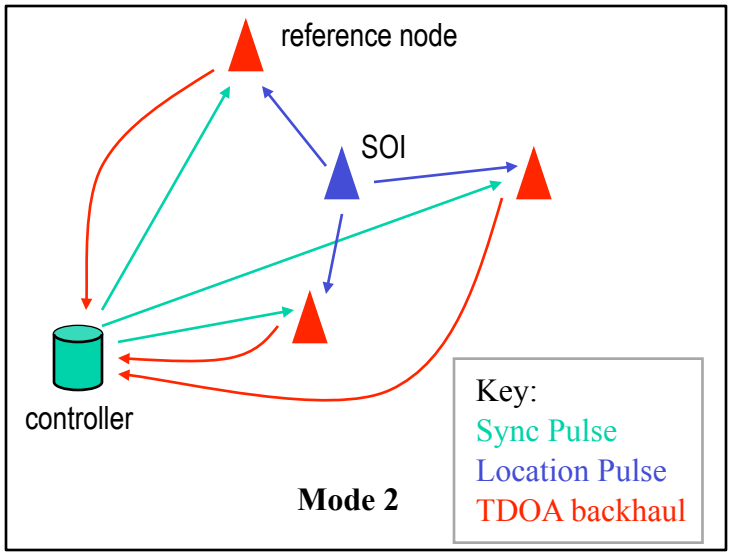
$$d_{31} = \sqrt{\left(x_{A_3} - x_M\right)^2 + \left(y_{A_3} - y_M\right)^2} - \sqrt{\left(x_{A_1} - x_M\right)^2 + \left(y_{A_1} - y_M\right)^2}$$

But TDOA can operate in one of two modes …

- Mode 1 – The station of interest (SOI) receives multiple reference pulses and calculates the TDOA
  LORAN-C type operation and the processing burden is on the receiver to run the hyperbolic location algorithms

- Mode 2 – The station of interest transmits a reference pulse which is received by multiple fixed nodes
  The fixed nodes must forward the TDOA information to a workstation which then runs the hyperbolic location algorithms[2]





Note: The sync pulse accuracy determines the TDOA accuracy and hence the sync pulse requires a wideband transmission

Note 2: The mathematics of mode 2 are discussed in a paper by Gustafsson and Gunnarsson, POSITIONING USING TIME-DIFFERENCE OF ARRIVAL MEASUREMENTS, www.control.isy.liu.se/~fredrik/ reports/03icasspgustafsson.pdf

Impact on PHY SAP and PLME in IEEE802.15.4a

• The PHY is the only layer that has accurate knowledge of pulse arrival and carrier phase; hence, the actual TD calculation should be located in the PHY layer

• As implied on page 5, the PHY will have to have a stop watch that can be used to determine the TD between the master and the slave pulses. This would be in the form of a high speed counter clocked at GHz rates.

• The suggested metrics that are sent to higher layers by the PHY are:
  - Elasped Count (events per unit time – EPUT)
  - Time Resolution (dependent on high rate clock frequency)

• This information would then be collected and used by higher layer applications to calculate hyperbolic location information

• Multiple packet exchanges will have to be used to calculate the TD's as shown in slide 8. The implication here is that a MAC command set will have to be added such that the DME initiates the ranging event and then the MAC autonomously completes the packet exchange.

• It appears at first glance that TDOA is rather similar to TOA at the PHY layer and it is anticipated that the same PHY SAP interface should service both TOA and TDOA ranging/ location techniques.