Scalable Location Protocol

Date: 2017-08-30

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Summary

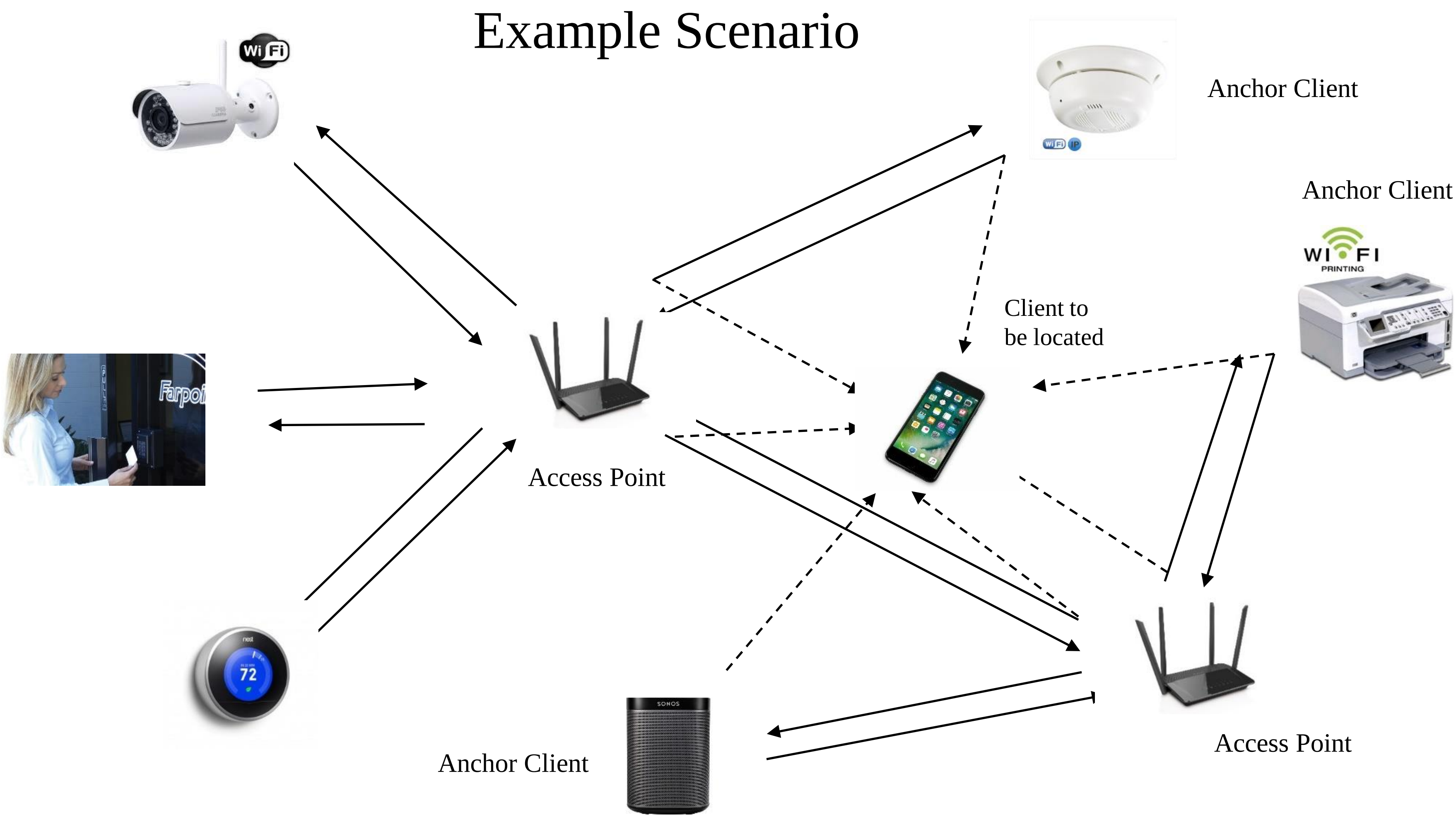
In this presentation we are outlining a practical realization of transmissions between anchor stations such as to enable a client station to calculate its location while only listening to these transmissions.

We realizing this localization method by to the maximum extent reusing ranging functionality anyways being standardized for 802.11az such as to minimize the extra functionality required to realize scalable location.

Fixed Wi-Fi Devices

Any venue is likely to contain a large number of fixed Wi-Fi devices. We can use these devices to facilitate scalable location.

Client Centric Scalable Location

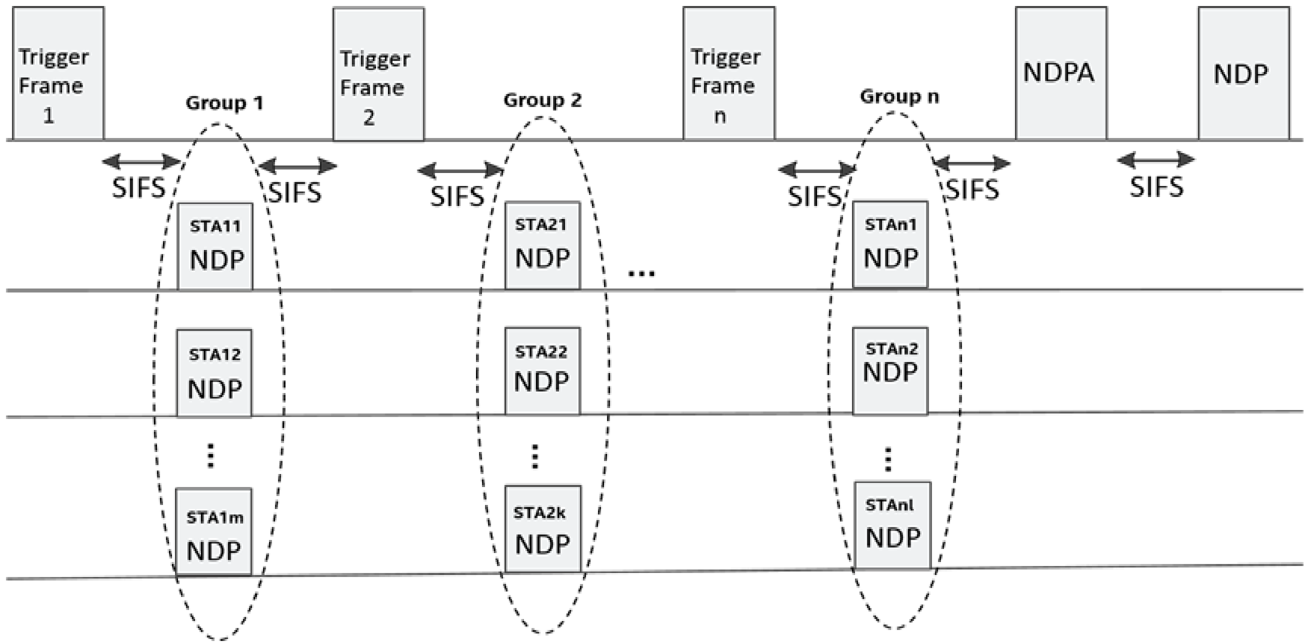


Example Frame Exchange Protocol

Reuse Ranging Protocol

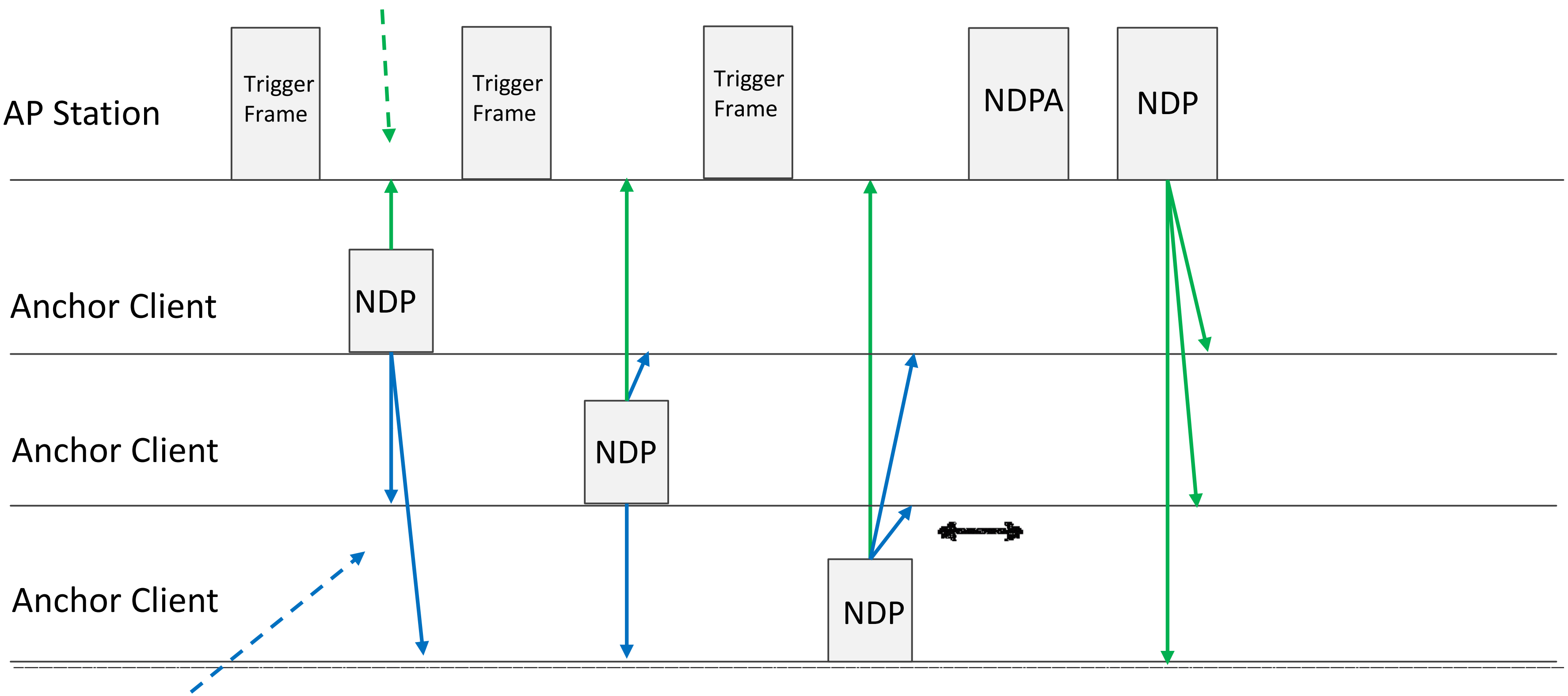
- **Reuse ranging protocol**
- **Can use SU or MU ranging**
- **MU ranging has the inherit benefit of being scheduled**
  - Facilitates clients listening to transmissions
  - No need to add new protocol for the scheduling of the ranging

TGaz SFD UL MU Ranging Sounding



MU ranging with Extra Frame Exchanges

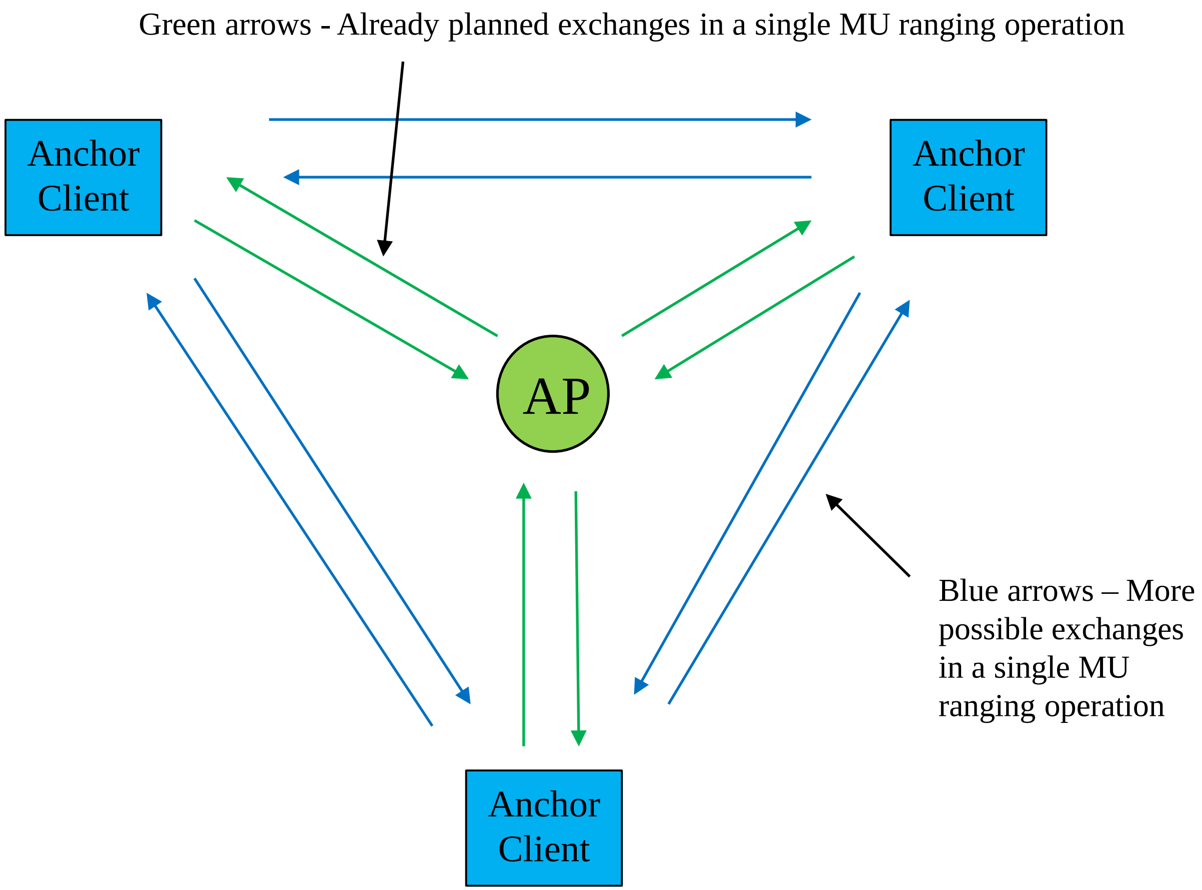
Green arrows – Regular ranging frame exchanges



Blue arrows – Extra ranging exchanges

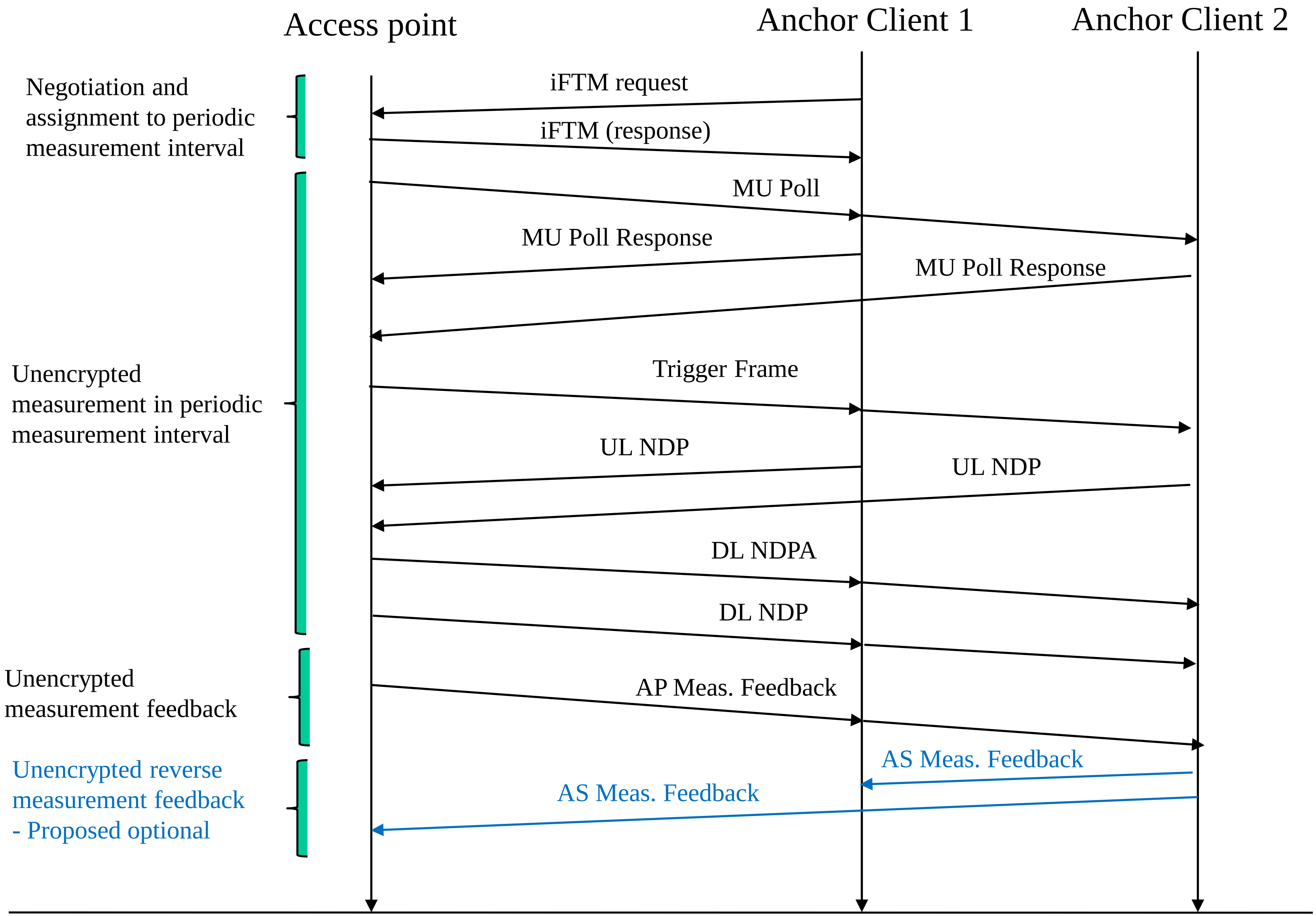
Note: No new transmissions or protocol required. It is simply up the anchor stations to listen to the NDP transmissions, calculate their TOA and report them.

MU Ranging Operation



In one shot we can communicate with all other STAs!

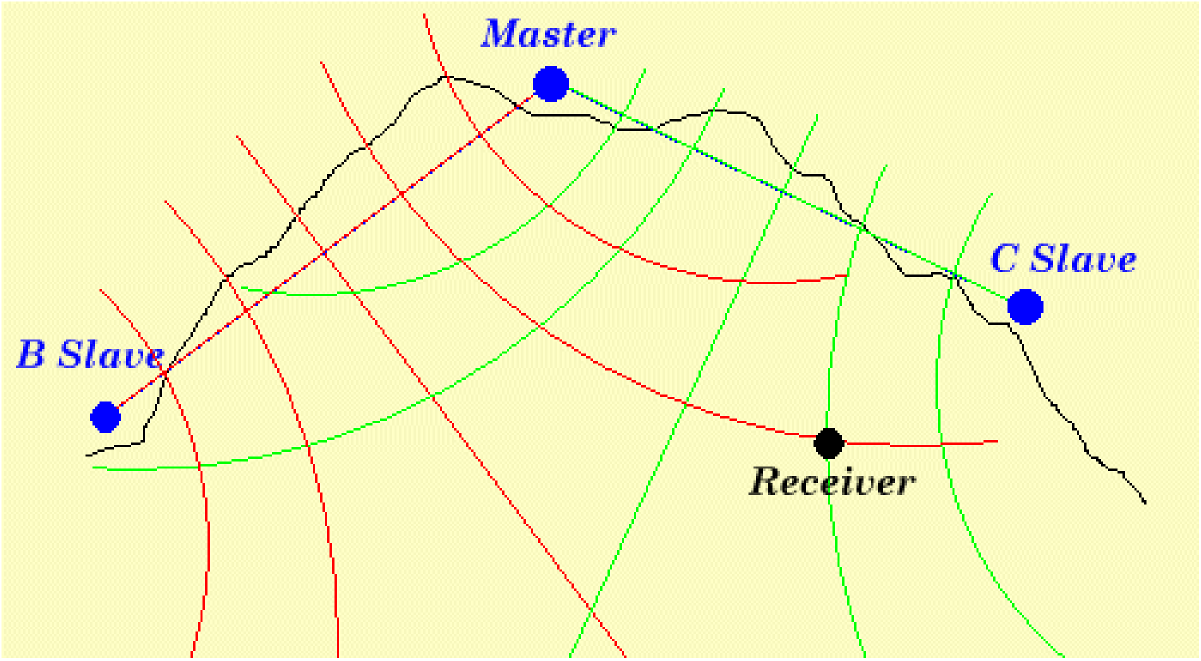
Example Protocol with MU Ranging



Client Location Calculation

TDOA - Hyperbolic Navigation

Recap from [3]:

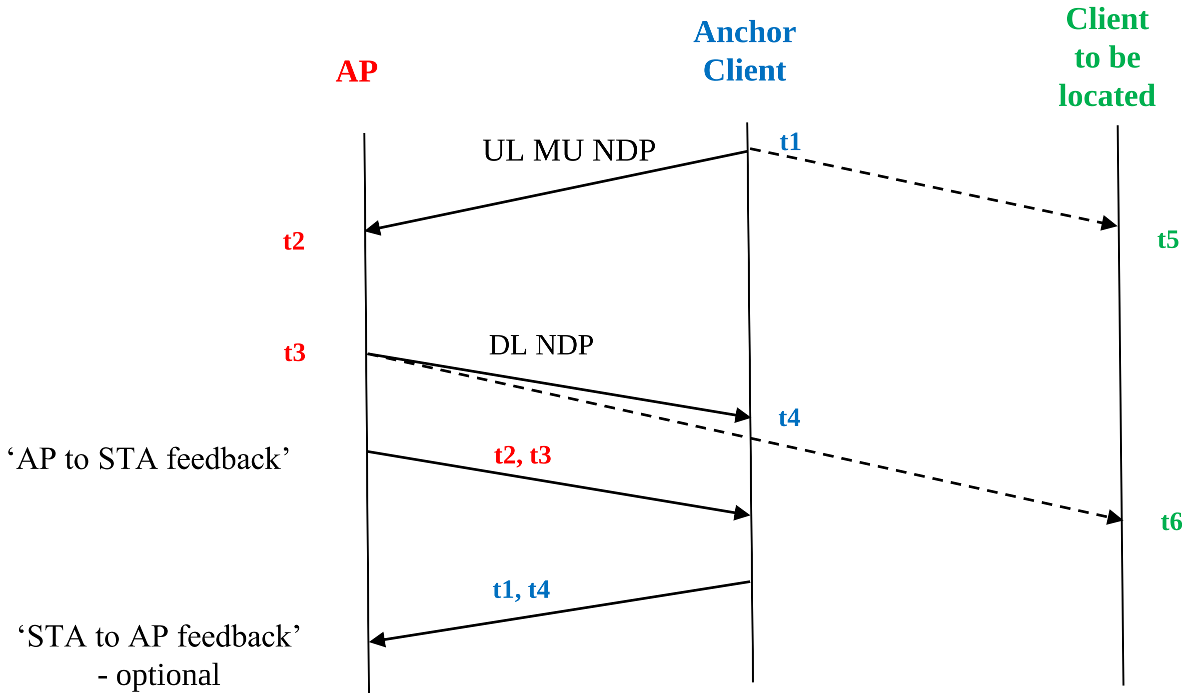


Source: http://asadahmedansari6395.blogspot.ca/2016_04_01_archive.html

Propagation paths and time stamps

Recap from [3]:

Illustrating timing diagram showing double sided feedback of time-stamps:



Double-Sided Differential Distance Calculation

Recap from [3]:

- The client listens to the exchanges between the AP and the anchor client and records the time t5 when it receives the UL MU NDP from the fixed client and the time t6 when it receives the DL NDP from the AP.
- The client also listens to the relayed t2 and t3 from the AP and the relayed t1 and t4 in the feedback from the anchor client.
- The differential distance between the client and the AP vs. the anchor client can now be calculated as follows:
  - D_01 = [t6 – t5 – (t3 – t2 + T_12)] * c
  - Using T_01 = [(t4 – t1) – (t3 – t2)]/2
  - We get D_01 = [t6 – t5 – (t3 – t2 + 0.5*t4 – 0.5*t1 – 0.5*t3 + 0.5*t2)]*c
  - Or finally:

D_12 = [t6 – t5 – 0.5*t3 + 0.5*t2 – 0.5*t4 + 0.5*t1]*c

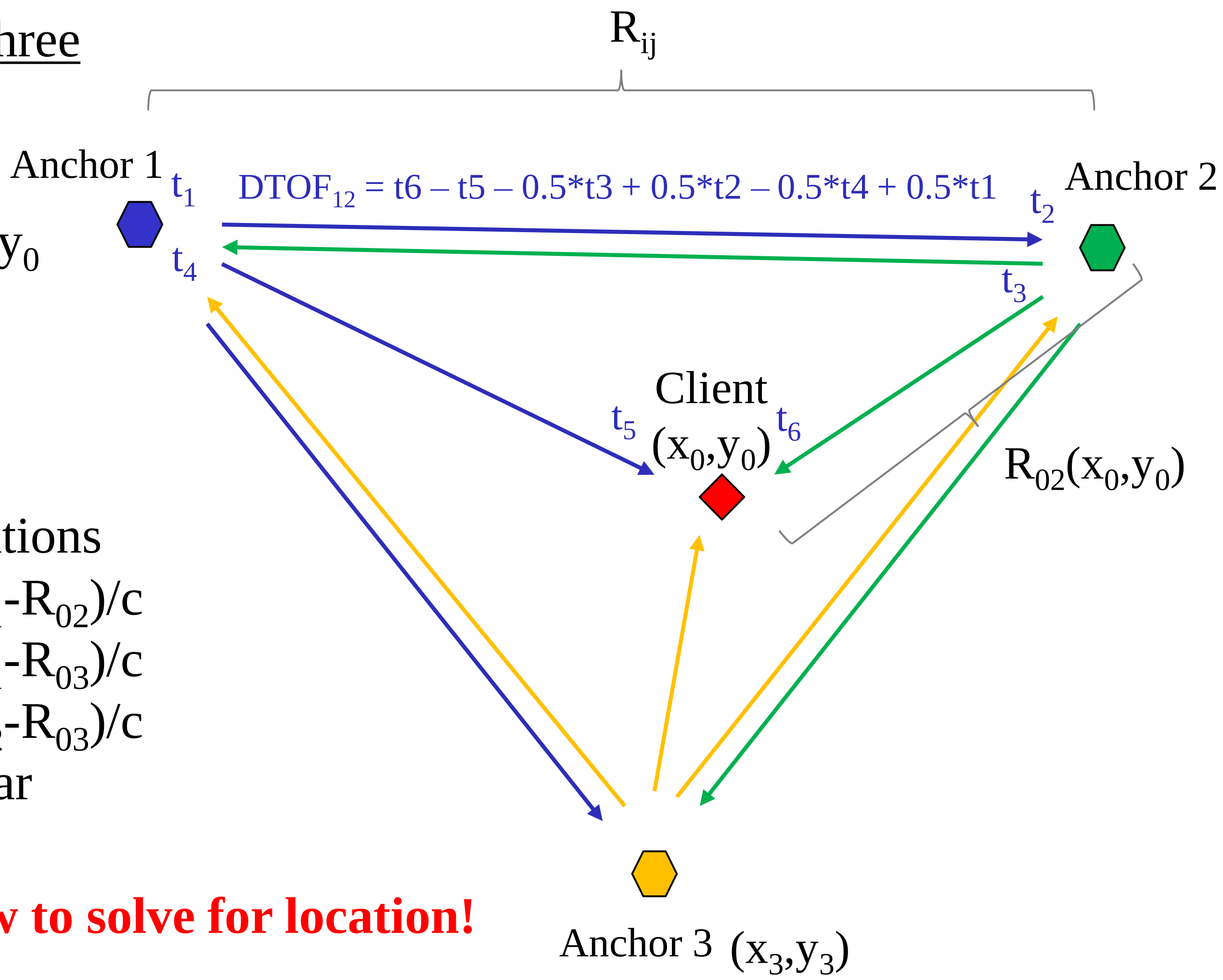
- Note that the above expression for the differential distance D_12 does not depend on the ToF, T_12, between the AP and the anchor client. Thus this method of calculating D_12 is insensitive to LOS obstructions between the AP and the anchor client.

Or just use single sided differential distance calculation [3].

Differential Distance Location Estimation Calculations

<u>In two dimensions with three anchors:</u>

Unknowns:
- Client coordinates x_0,y_0
- 2 unknowns



Equations:
- Differential ToF equations
  - $DToF_{12} = (R_{01}-R_{02})/c$
  - $DToF_{13} = (R_{01}-R_{03})/c$
  - $DToF_{23} = (R_{02}-R_{03})/c$
- 3 equations, non-linear

See Appendix A for how to solve for location!

Client Listening

Client Listening

- **Client listens to ranging exchanges**
- **AP announcement of the ranging schedule can facilitate the clients listening**
    - Knows when and where to listen

Ranging Schedule

Schedule Content

Recap from [3]:

- **Two levels of schedule complexity:**
  - AP conveys scalable ranging operations in its own channel
  - AP conveys scalable ranging operations also for neighboring APs channels
- **Content:**
  - Times of ranging
  - Ranging format parameters (e.g. number of antennas)
  - Anchor Clients LCI information
- **Additional content for neighboring APs operations:**
  - BSS channels and bandwidths
  - Clock mappings

Schedule Conveying

- For example:
  - Periodically broadcast in an APs beacons
  - Counter in every beacon to count down to presence schedule

Protocol to Add

Protocol Aspects to Add

- Bit in iFTM request indicating desire for unencrypted ranging and is willingness to share LCI
- Protocol for periodic announcement of scalable location ranging schedule
- Optional:
  - Protocol for periodic announcement of scalable location ranging schedule
  - Bit in iFTM request indicating desire for double sided ranging measurement feedback
    - And the extra frames for the reverse ranging measurement feedback
    - This double sided feedback also have uses other than for scalable location
  - ToA feedback from extra listening opportunities in MU ranging

Only limited additions needed!

Conclusions

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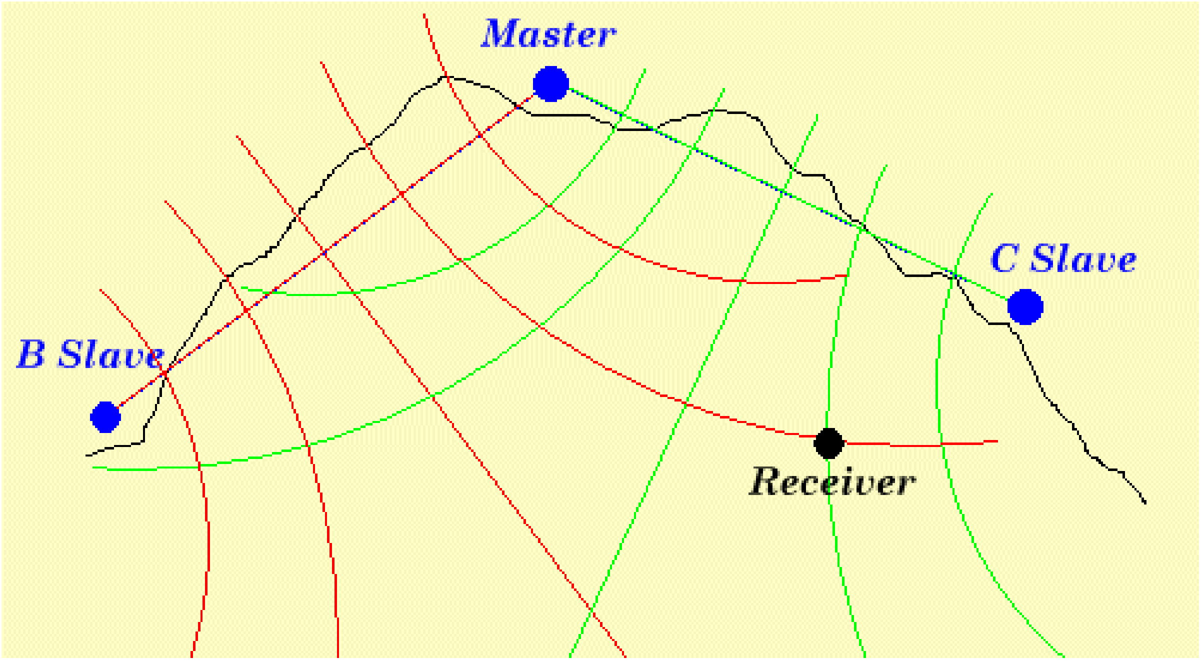
- **Any venue is likely to contain a large number of fixed Wi-Fi clients**
- **Can use such 'Anchor Clients' to enable scalable location**
- **Use regular ranging protocol to provide time-stamped transmissions to use for client location**
- **Minimal additions required to protocol for regular ranging**

Appendix A:
Calculation of Client Location

TDOA - Hyperbolic Navigation



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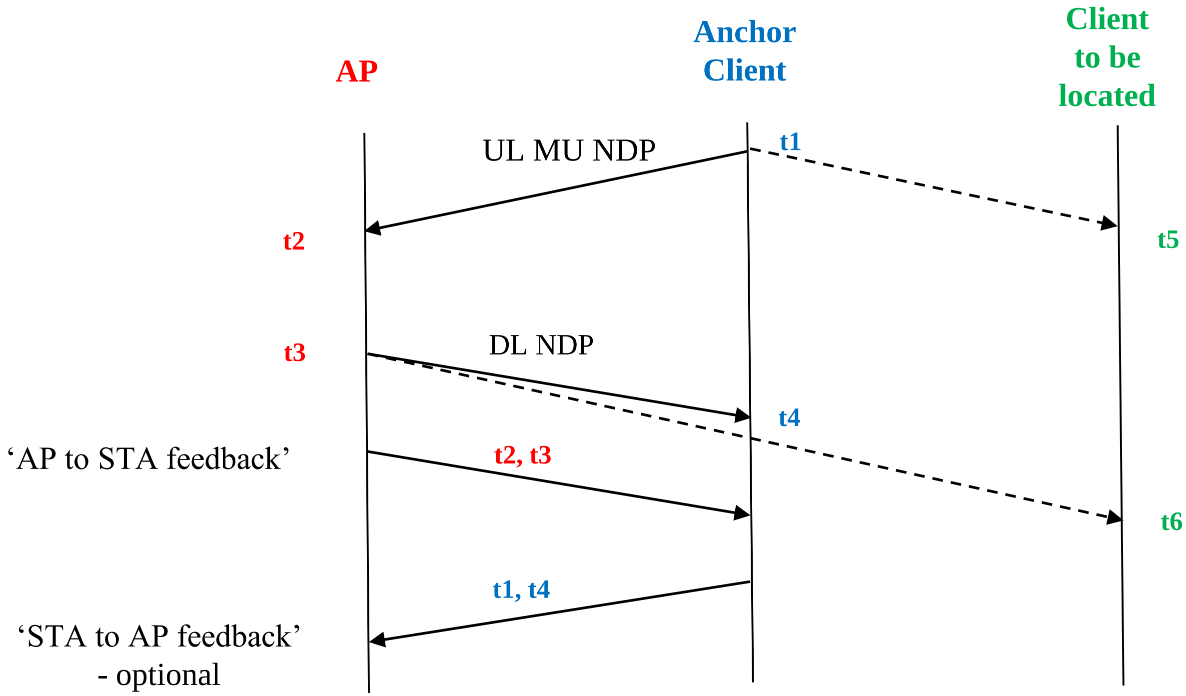
Illustrating timing diagram showing double sided feedback of time-stamps:



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  - $D_{01} = [t6 - t5 - (t3 - t2 + T_{12})] * c$
  - Using $T_{01} = [(t4 - t1) - (t3 - t2)]/2$
  - We get $D_{01} = [t6 - t5 - (t3 - t2 + 0.5*t4 - 0.5*t1 - 0.5*t3 + 0.5*t2)]*c$
  - Or finally:

$$D_{12} = [t6 - t5 - 0.5*t3 + 0.5*t2 - 0.5*t4 + 0.5*t1]*c$$

- Note that the above expression for the differential distance D_12 does not depend on the ToF, T_12, between the AP and the anchor client. Thus this method of calculating D_12 is insensitive to LOS obstructions between the AP and the anchor client.

Or just use single sided differential distance calculation [3].

Differential Distance Location Estimation Calculations

In two dimensions with three anchors:

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Equations:

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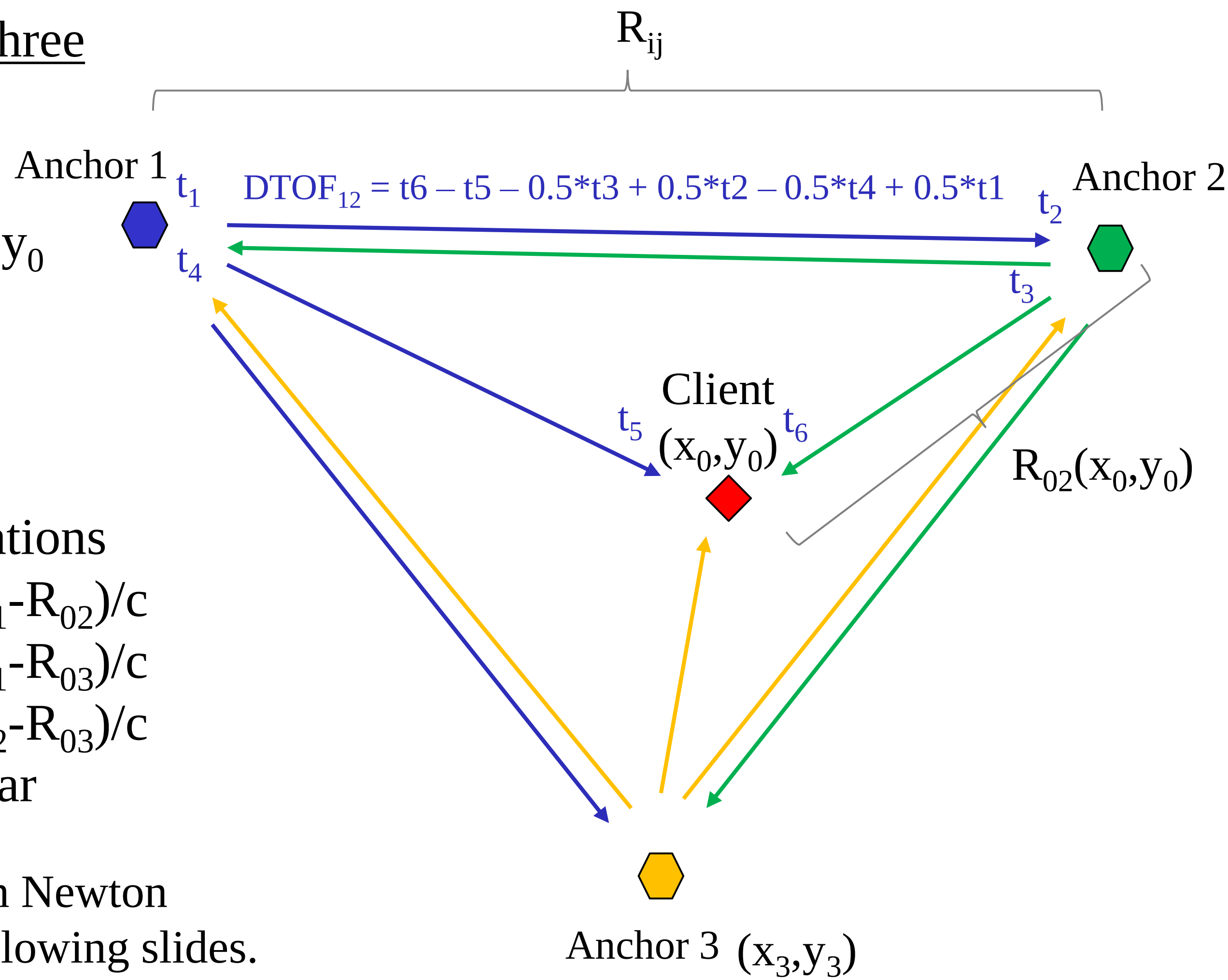
- 3 equations, non-linear

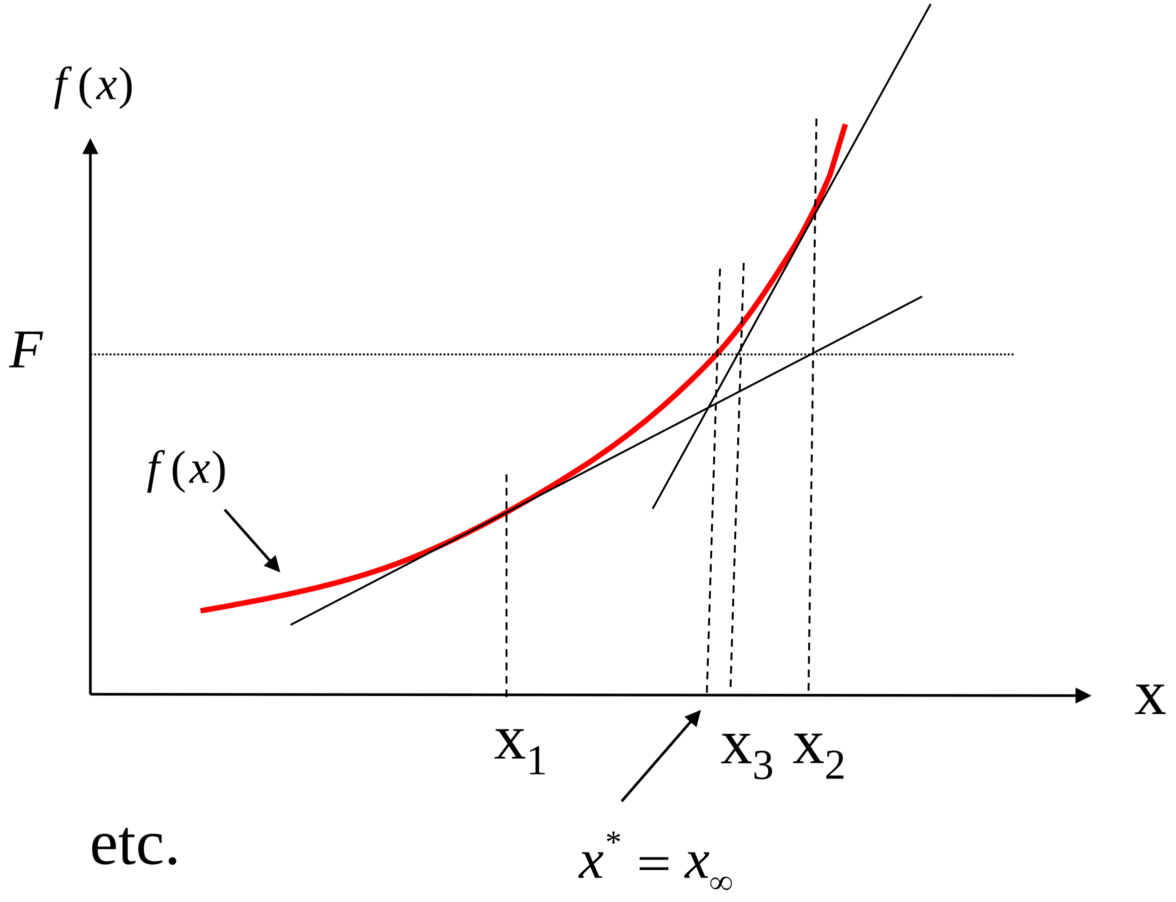
Solve for location, e.g. with Newton iterations – described in following slides.



Newton's method for solving non-linear equation

Solve equation:

$$F = f(x^*)$$



etc.

Solving of non-linear system of equations

Non linear system of equations: $F = f(x^*)$ - solve for x*

Use Newton's method for multiple variables:

Linearization: $F = f(x^*) \approx f(x_k) + \nabla f(x_k)\Delta x$ where $\nabla f(x) = \left[\frac{\delta f_i}{\delta x_j} \right]$

Over-determined non-linear system of equation to solve for Δx:

$$F - f(x_k) \approx +\nabla f(x_k)\Delta x$$

Least squares solution for iterative step:

$$x_{k+1} - x_k = \Delta x = \left(\nabla^T f(x_k)\nabla f(x_k)\right)^{-1}\nabla^T f(x_k)\left[F - f(x_k)\right]$$

Iterate according to:

$$x_{k+1} = x_k + \left(\nabla^T f(x_k)\nabla f(x_k)\right)^{-1}\nabla^T f(x_k)\left[F - f(x_k)\right]$$

Our derivatives

To simplify the equations, measure time in *light seconds* - the distance light travels in one second.

$$DToF_{ij} = f_{ij}(x_0, y_0) = R_i - R_j$$

$$R_i = \sqrt{(x_0 - x_i)^2 + (y_0 - y_i)^2} \qquad R_j = \sqrt{(x_0 - x_j)^2 + (y_0 - y_j)^2}$$

$$\nabla_{x,y} f_{ij}(x_0, y_0) = \left[\frac{\delta\left(R_i(x_0, y_0) - R_j(x_0, y_0)\right)}{\delta x_0} \quad \frac{\delta\left(R_i(x_0, y_0) - R_j(x_0, y_0)\right)}{\delta y_0} \right]$$

$$\nabla_{x,y} f_{ij}(x_0, y_0) = \left[\frac{x_0 - x_i}{R_i(x_0, y_0)} - \frac{x_0 - x_j}{R_j(x_0, y_0)} \quad \frac{y_0 - y_i}{R_i(x_0, y_0)} - \frac{y_0 - y_j}{R_j(x_0, y_0)} \right]$$

Iterative solution for client position (x_0,y_0)

Step calculation. LS solution to:

$$\begin{bmatrix} DTOF_{12} - \left(R_{01} - R_{02}\right) \\ DTOF_{13} - \left(R_{01} - R_{03}\right) \\ DTOF_{23} - \left(R_{02} - R_{03}\right) \end{bmatrix} = \begin{bmatrix} \frac{x_0 - x_1}{R_{01}(x_0, y_0)} - \frac{x_0 - x_2}{R_{02}(x_0, y_0)} & \frac{y_0 - y_1}{R_{01}(x_0, y_0)} - \frac{y_0 - y_2}{R_{02}(x_0, y_0)} \\ \frac{x_0 - x_1}{R_{01}(x_0, y_0)} - \frac{x_0 - x_3}{R_{03}(x_0, y_0)} & \frac{y_0 - y_1}{R_{01}(x_0, y_0)} - \frac{y_0 - y_3}{R_{03}(x_0, y_0)} \\ \frac{x_0 - x_2}{R_{02}(x_0, y_0)} - \frac{x_0 - x_3}{R_{03}(x_0, y_0)} & \frac{y_0 - y_2}{R_{02}(x_0, y_0)} - \frac{y_0 - y_3}{R_{03}(x_0, y_0)} \end{bmatrix} \begin{bmatrix} \Delta x_0 \\ \Delta y_0 \end{bmatrix}$$

Note: Time in units of *light seconds*

Iterations:

$$\begin{bmatrix} x_0(k+1) \\ y_0(k+1) \end{bmatrix} = \begin{bmatrix} x_0(k) \\ y_0(k) \end{bmatrix} + \begin{bmatrix} \Delta x_0 \\ \Delta y_0 \end{bmatrix}$$

References

[1] “Client Positioning using Timing Measurements between Access Points”, Erik Lindskog, Naveen Kakani, Raja Banerjea, Jim Lansford and Jon Rosdahl, IEEE 802.11-13/0072r1.

[2] “A Low Overhead Receive Only Wi-Fi Based Location Mechanism”, Erik Lindskog, Hong Wan, Raja Banerjea, Naveen Kakani and Dave Huntingford, Proceedings of the 27th International Technical Meeting of The Satellite Division of the Institute of Navigation (ION GNSS+ 2014), Tampa, Florida, September 2014, pp. 1661-1668.

[3] “Passive Location”, Erik Lindskog, Naveen Kakani and Ali Raissinia, IEEE 802.11-17/0417r0.

Thank You!