ALBERT-LUDWIGS-UNIVERSITÄT FREIBURG

Algorithms for Radio Networks

Localization

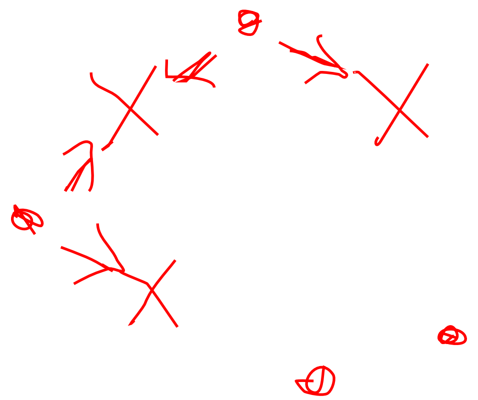
University of FreiburgTechnical Faculty
Computer Networks and Telematics
Prof. Christian Schindelhauer

CoNe Freiburg

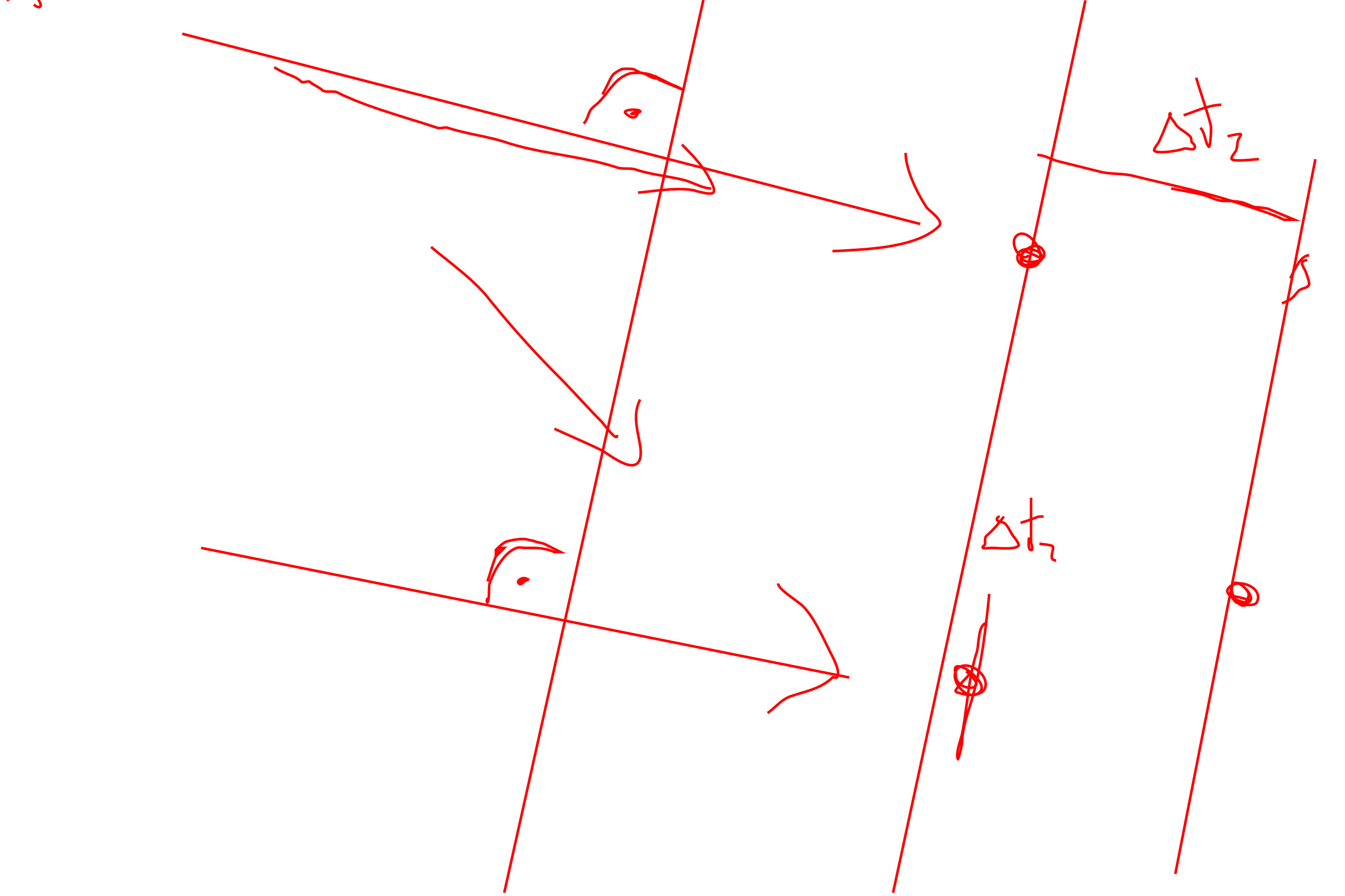
IIF INSTITUT FÜR INFORMATIK FREIBURG

Anchor-free localization

- **Strategies:**
  - **(1.) Estimate receiver topology from known information**
  - **(2.) Assume large number of emitters and receivers**
  - **(3.) Assume specific distribution of emitters and receivers**
  - **(4.) Heat the CPU: Optimization, branch-and-bound search, ...**



Far-field assumption



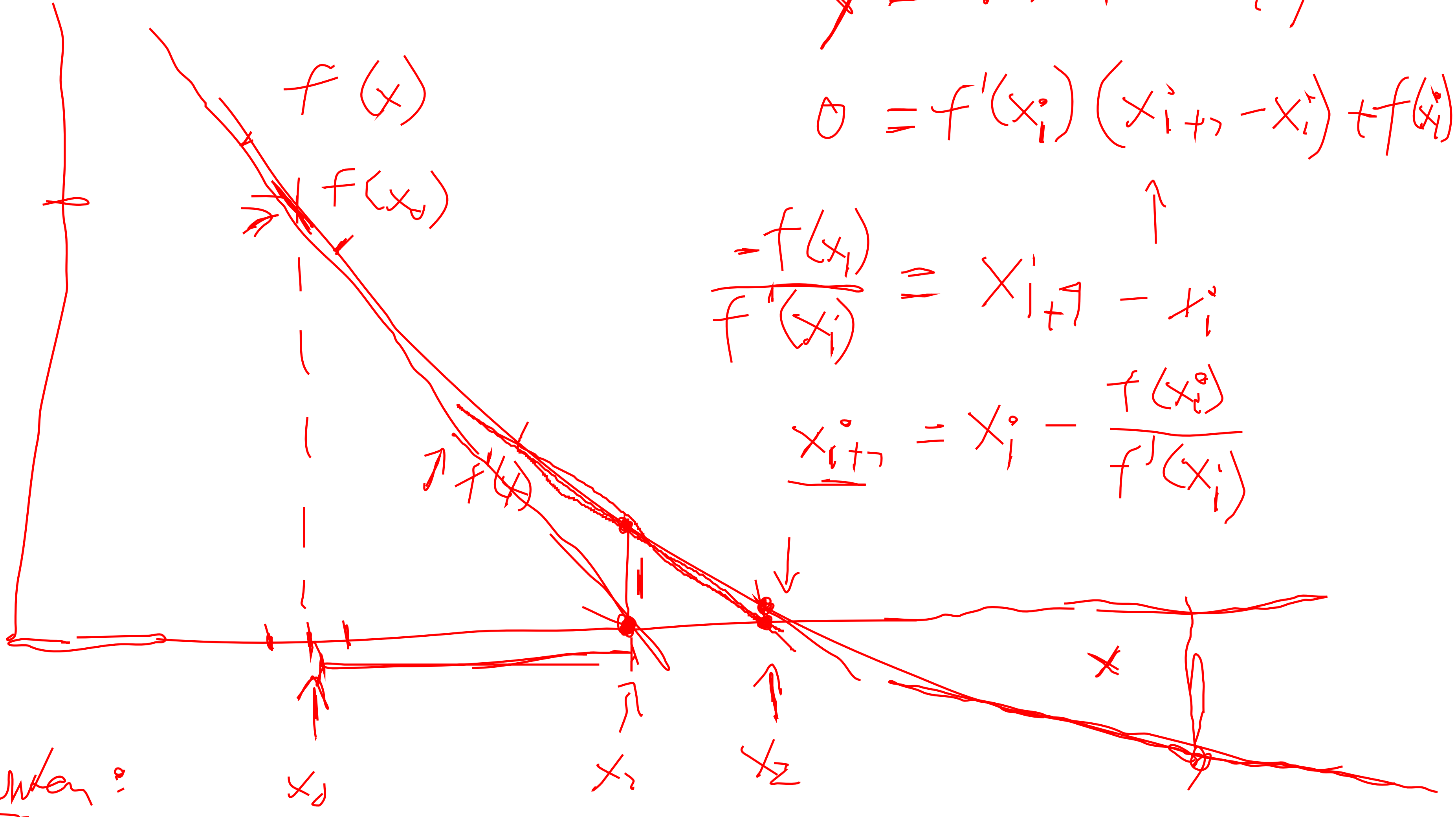
Newton's method

$y = mx + c \quad | \; y = 0$

$0 = f'(x_i)(x_{i+1} - x_i) + f(x_i)$

$\frac{-f(x_i)}{f'(x_i)} = x_{i+1} - x_i$

$x_{i+1} = x_i - \frac{f(x_i)}{f'(x_i)}$

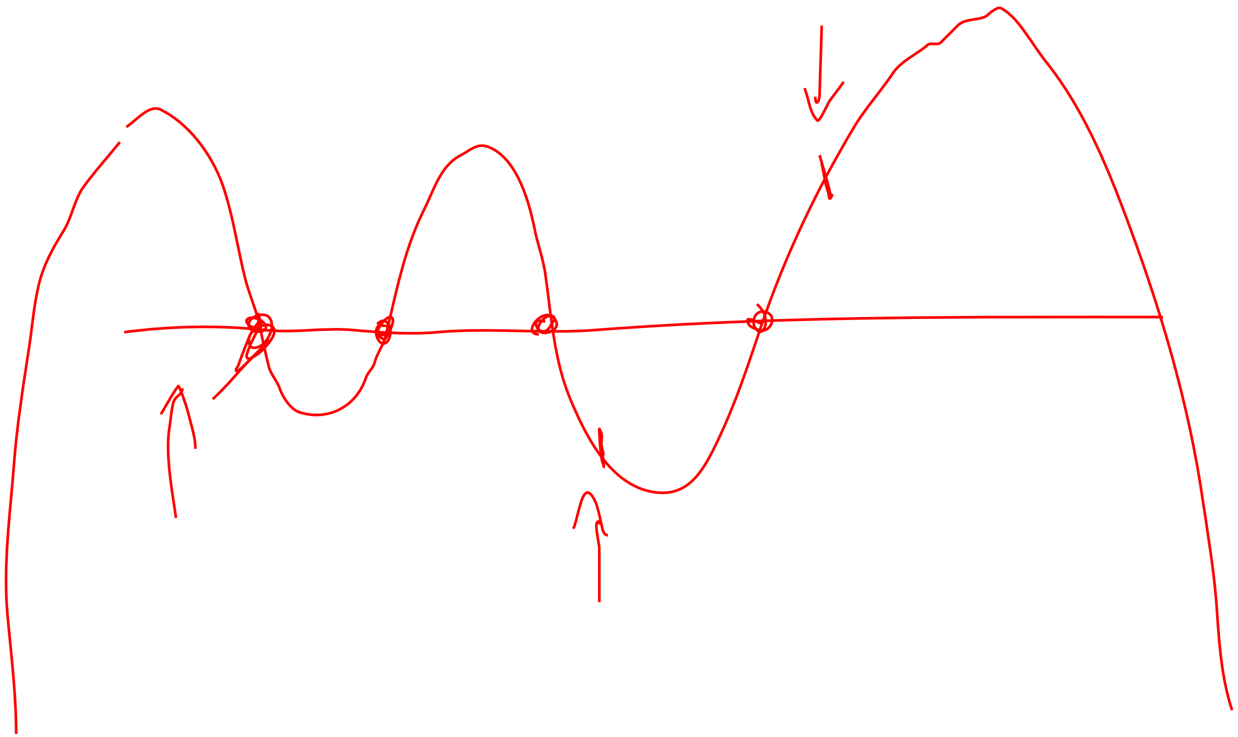


$x_1 \rightarrow x_{i+1}$

$|f(x_i)| < \varepsilon$

$|x_{i+1} - x_i| < \delta$

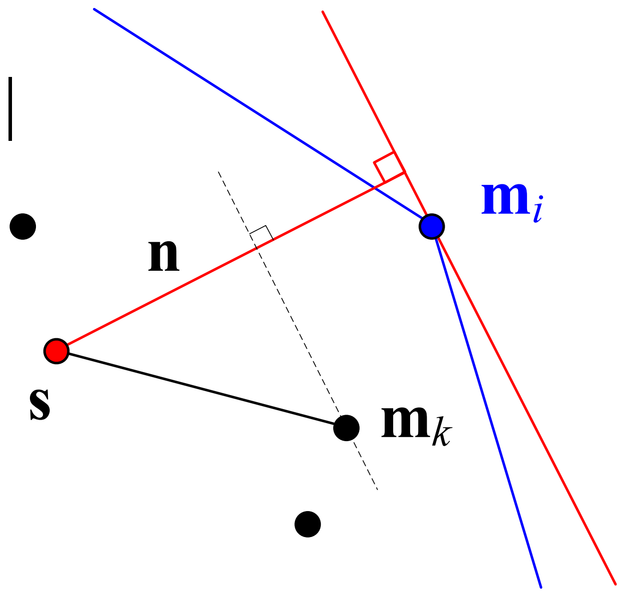
Gauss-Newton:

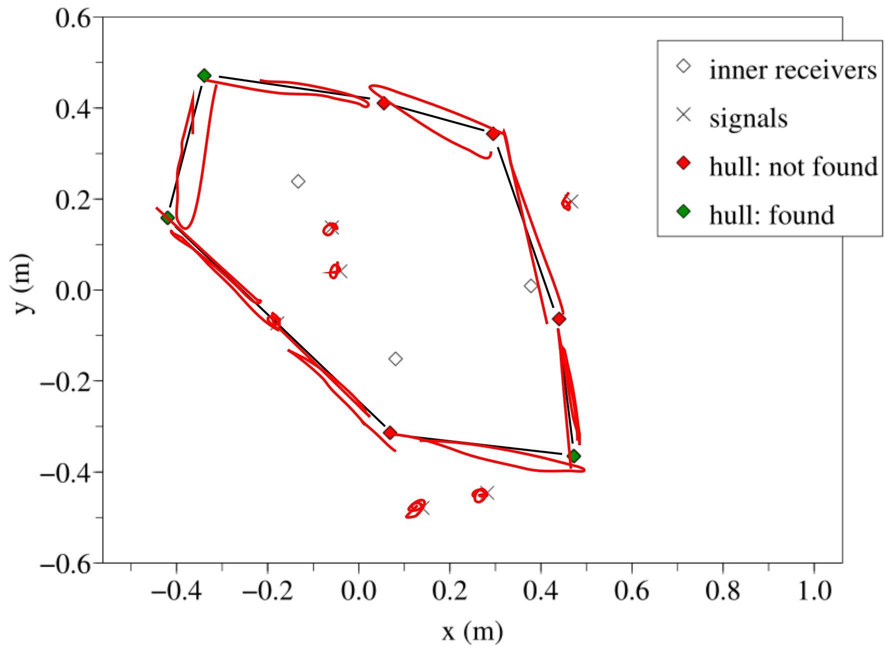


Anchor-free localization

- **(1.) Topology: Hull element**
  - **"The receiver which receives the last timestamp is an element of the convex hull"**

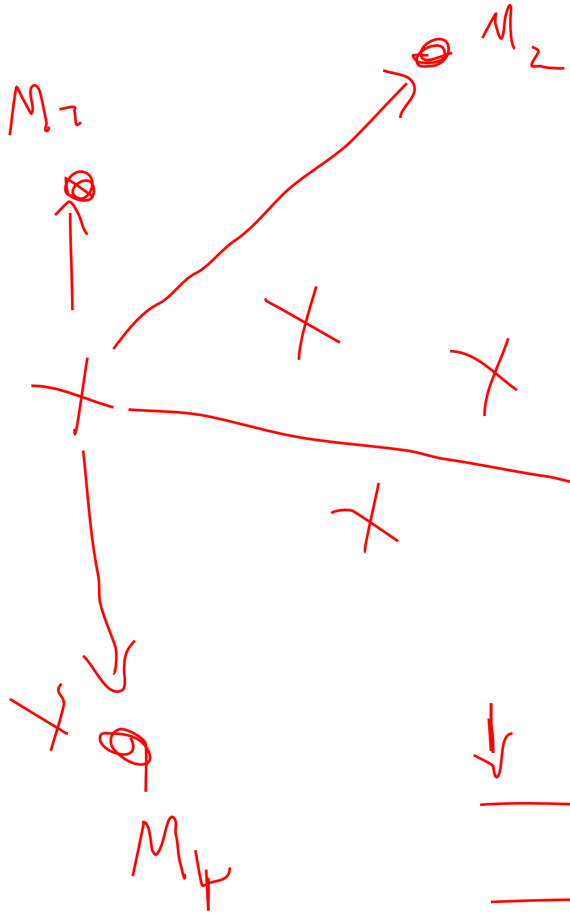
$$\mathbf{n}_0 = \mathbf{n} \,/\, \|\mathbf{n}\|$$

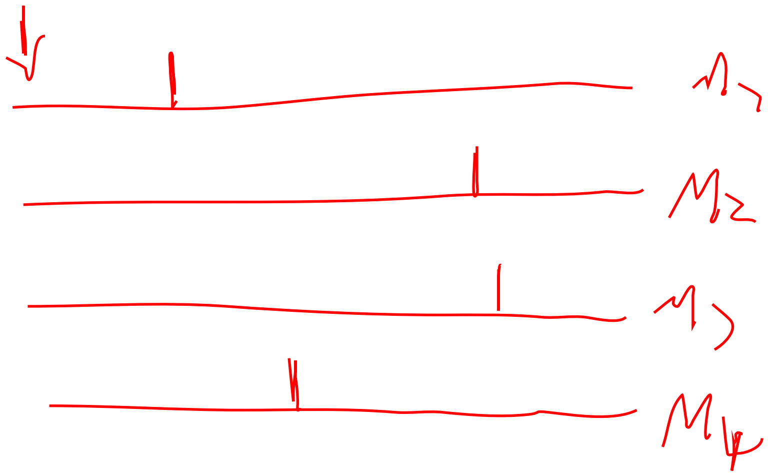




If exists i such that for all k: $T_i \geq T_k$, then holds:

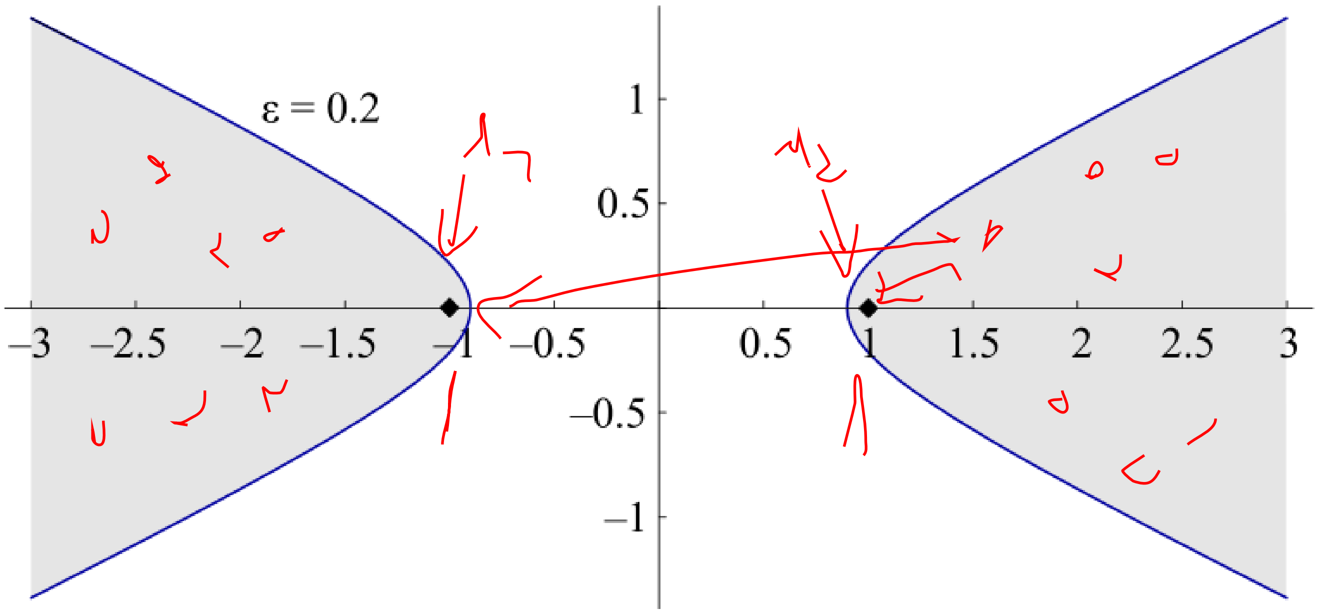
$$(\mathbf{m}_i - \mathbf{s})^T\, \mathbf{n}_0 = \|\mathbf{m}_i - \mathbf{s}\| \geq \|\mathbf{m}_k - \mathbf{s}\| \geq (\mathbf{m}_i - \mathbf{s})^T\, \mathbf{n}_0$$


M1
M2
M3
M4


M1
M2
M3
M4

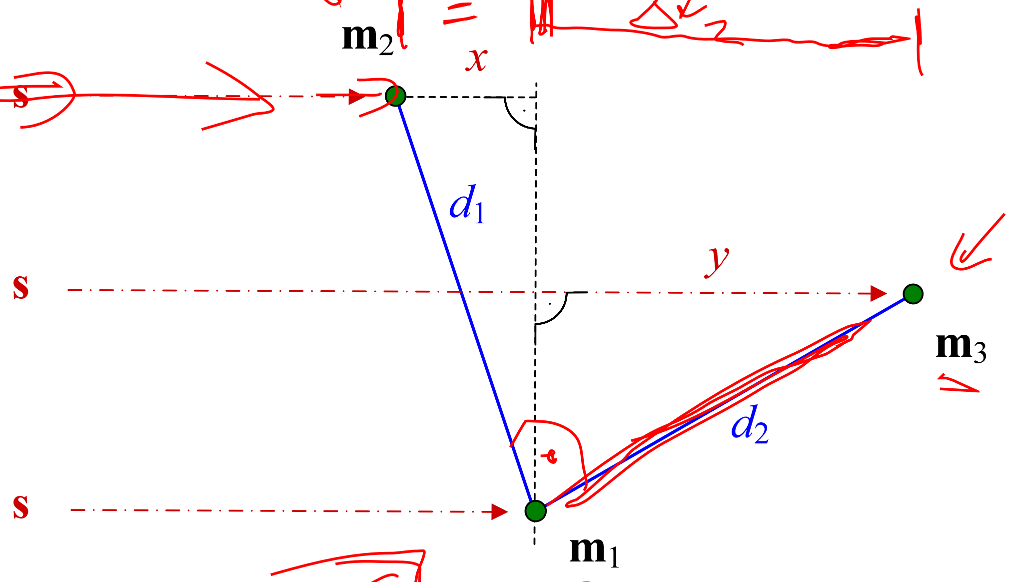
Anchor-free localization

- **(2.) Large number of signals: Statistical assumptions**
  [Schindelhauer, et al., SIROCCO 2011]
  - **Lemma: Many signals occur from the long side of any two receivers.**
  - **Estimate the distance:** $d \sim c/2\,(\Delta t_{max} - \Delta t_{min})$

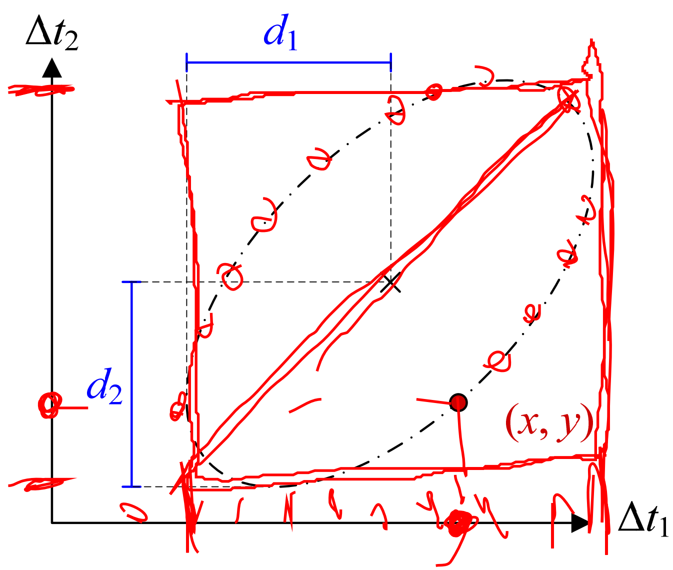


Anchor-free localization

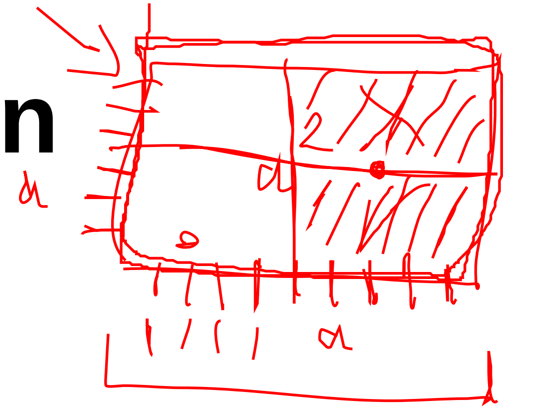
- **(3.) Assume that signals occur from far away:**
  - **"far-field assumption", linear frontier of signal propagation**
- **The Ellipsoid TDoA Method** [Wendeberg, et al., TCS, 2012]
  - **Time differences of *three* receivers form an ellipse**



top-down view



time differences



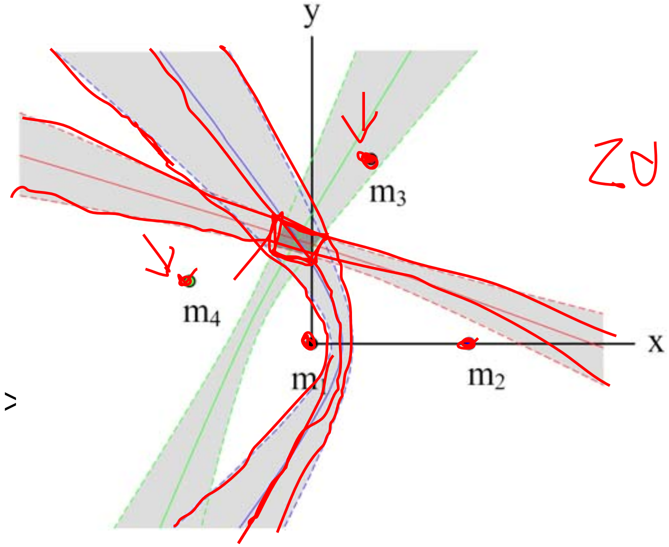
Anchor-free localization

- **(4.) Two-phased *branch-and-bound* algorithm in 2D**
  [Wendeberg and Schindelhauer, ALGOSENSORS 2012]

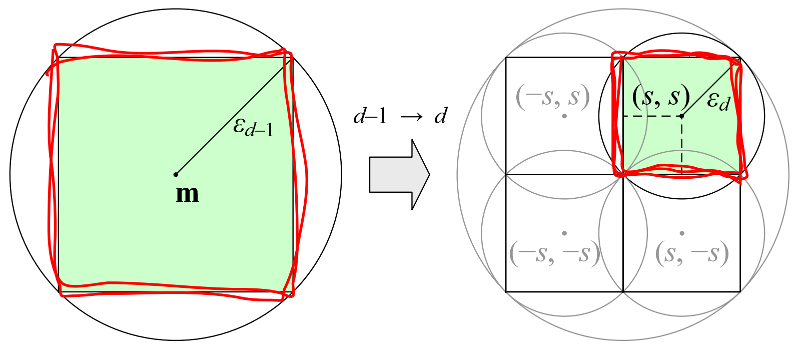
1. **"Bound": Test sub-problems if feasible up to error $\varepsilon \sim s$ with regard to measurements Δt_{ij}. Satisfy**

   $$| \, \| m_i - s_j \| - \| m_1 - s_j \| - \Delta t_{ij} \, | \le \varepsilon$$ (*i* >

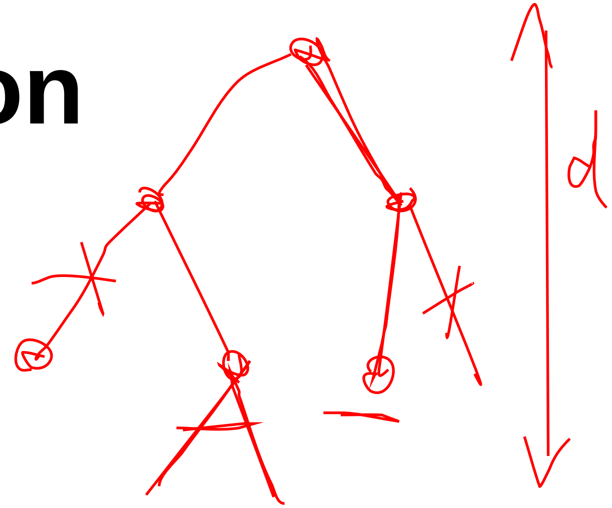
   or discard sub-problem



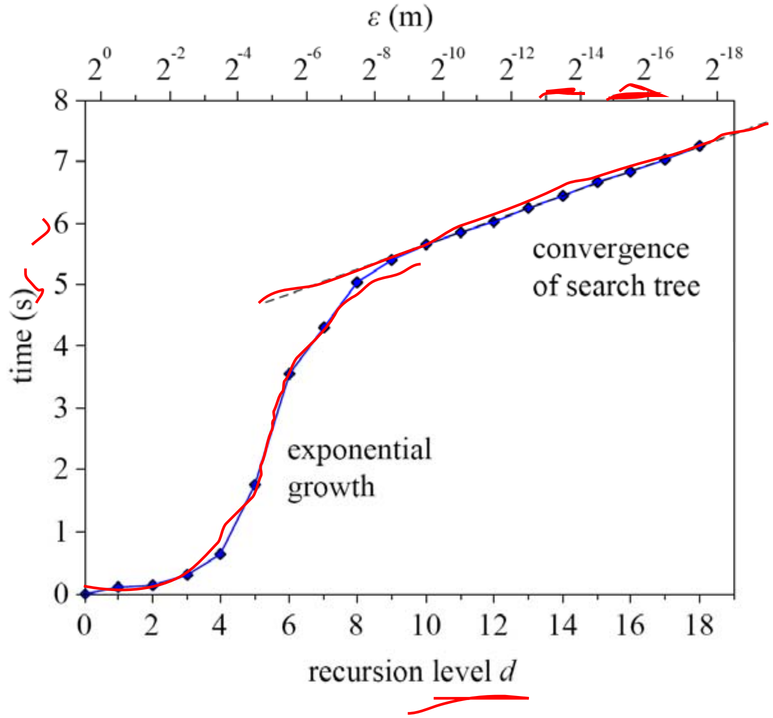
2. **"Branch": Divide feasible problems of size s^n into sub-problems of size $(s/2)^n$**



Anchor-free localization



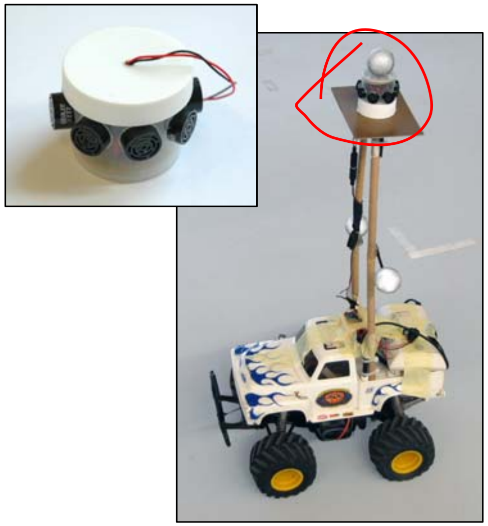
- Numeric simulation
  - Solution always found up to bound ε
  - In case of measurement errors: Solution up to $\varepsilon_{\mathrm{tdoa}}$
- Behavior of search tree
  - Breadth-first search
  - Exponential growth / convergence of search tree
  - Runtime: $\mathcal{O}((\sqrt{2}/\epsilon)^{2n-3}mn^2)$



- ➔ Minimum case FPTAS to Calibration-free TDoA

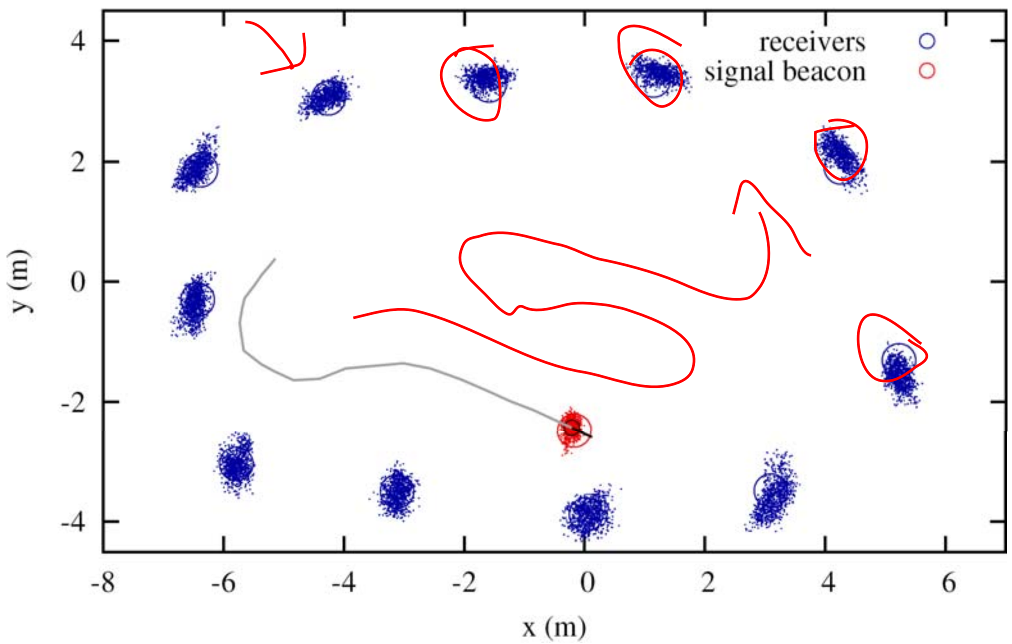
“Calibration-Free Tracking System”

- **Anchor-free TDoA Ultrasound Tracking System**
  [Wendeberg, Höflinger, Schindelhauer, and Reindl, LBS, 2013]
  - **In collaboration with IMTEK / Lab. for Electrical Instrumentation (EMP)**
  - **40 kHz ultrasound moving transmitter and fixed receivers**
  - **Receivers synchronized in a Wi-Fi network**

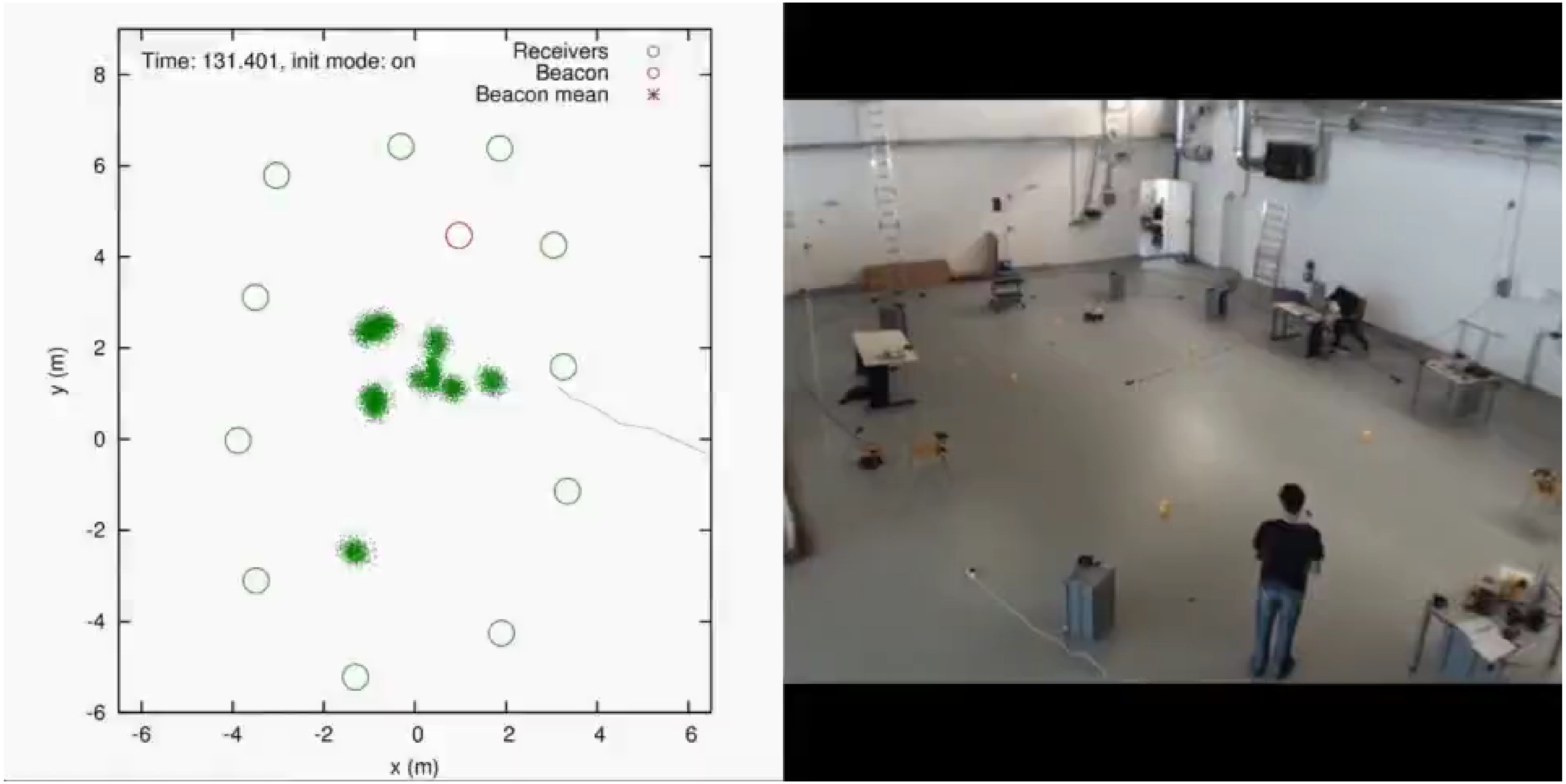


“Calibration-Free Tracking System”

- Tracking system is “calibration-free”
  - Arbitrary placement of ultrasound receivers
  - Compute positions of receivers by TDoA measures
  - Precision of ~ 5 cm



“Calibration-Free Tracking System”



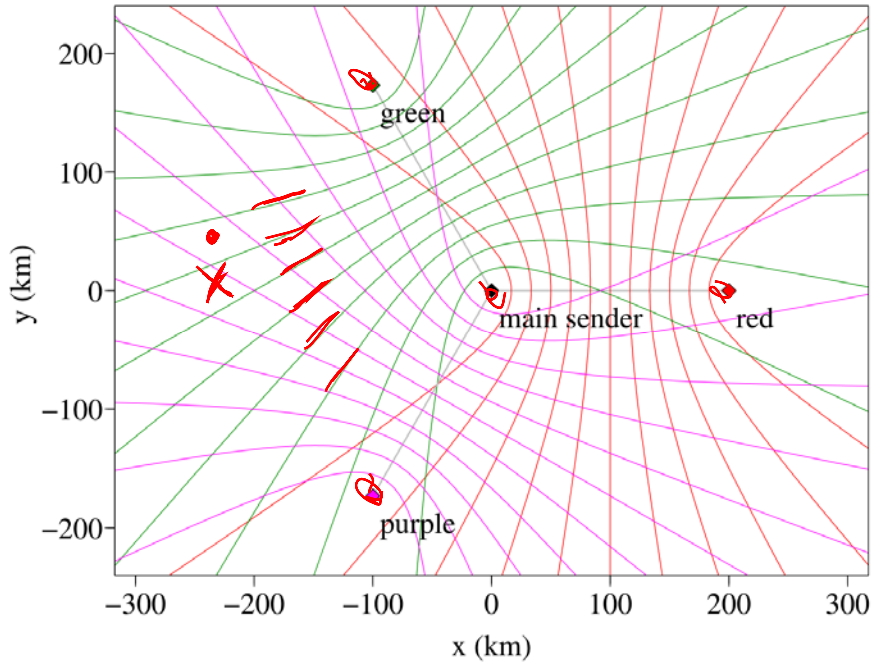
http://www.youtube.com/watch?v=V85wejcYyXs

Some More Available Localization Systems

- **Land stations**
  - **Decca**
  - **LORAN-C**
  - **Mobile cells**
  - **WLAN identification**
- **Satellite-based**
  - **NAVSTAR-GPS**
  - **GLONASS**
  - **Galileo**

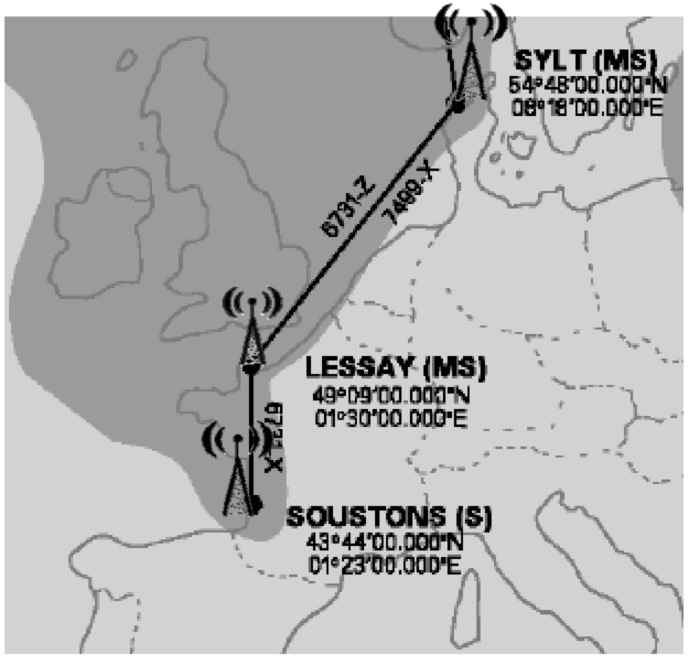
Decca

- W. O'Brien, Decca navigation system, ca. 1942 – 2000
- Hyperbolic multilateration
  - One main sender
  - Three slave senders (distance 100 – 200 km)
  - Senders synchronized
- TDoA by phase difference of continuous harmonics, e.g. $\{6f, 5f, 8f, 9f\}$, f = 14.167 kHz
- Point of departure must be known! (periodic phases)
- Range ca. 400 – 700 km, precision ca. 0.05 – 1 km



LORAN-C

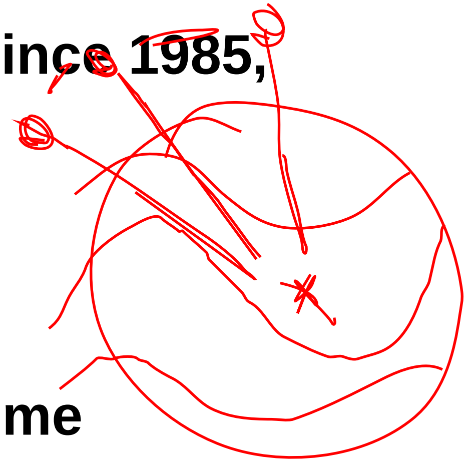
- LOng RANge navigation system, 1957 – now
- Hyperbolic multilateration
  - Chains of senders (distance 100+ km)
- TDoA of discrete pulses of 100 kHz, identification of senders by CDMA (no overlap)
- Range up to 1,000 km, precision 0.01 – 0.1 km



[Wikipedia]

GNSS: GPS (I)

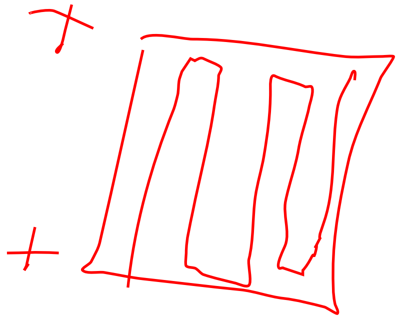
- Global Positioning System (GPS), US Dpt. of Defense, since 1985, no “selective availability” since 2000

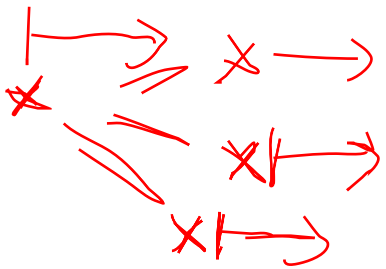


- 24+ GPS satellites
  - earth orbit 20,000 km
  - send ephemerides (trajectory data) and atomic clock time
  - Frequency: 1.228 / 1.575 GHz
- GPS receiver
  - measures TDoA of satellite messages (by correlation)
  - has no precise clock!
  - calculates “pseudoranges”, 3D coordinates and time
  - requires at least 4 satellites (more is better)

GNSS: GPS (II)

- GPS requires line-of-sight: No signal in forest, dense urban areas, indoors
- Precision: 5 – 15 m (good signal)
- Differential GPS
  - Reference receiver, compensating for atmospheric disturbances, precision up to 0.1 m
  - Modern geodetic systems: Even millimeters!





GNSS: GLONASS

- GLONASS, russian GNSS, since 1993 (25 satellites)
- Technology similar to NAVSTAR-GPS
- Limited operation: in 2001 only 7 satellites alive, in 2011 available again (ca. 24 satellites)
- Loss of 3 satellites each in Dec. 2010 and in July 2013
- Supported by modern smart phones (Nokia Lumia series, Samsung Galaxy series, Apple iPhone 4S and later, and others)

GNSS: Galileo

- **Galileo, european GNSS, adopted in 2008**
- **Technology similar to NAVSTAR-GPS**
- **Up to 30 satellites planned**
- **Availability expected for 2014 with 18 satellites**

Possible Improvements

- Combination of different methods
  - magnetic field
  - air pressure
  - sonar
- Kalman filter
  - Extension of Markov filters
- Motion sensors
  - gyroscopes
  - acceleration sensors

Sensor data fusion

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