Topical Issues: Location Tracking

Part II

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Background

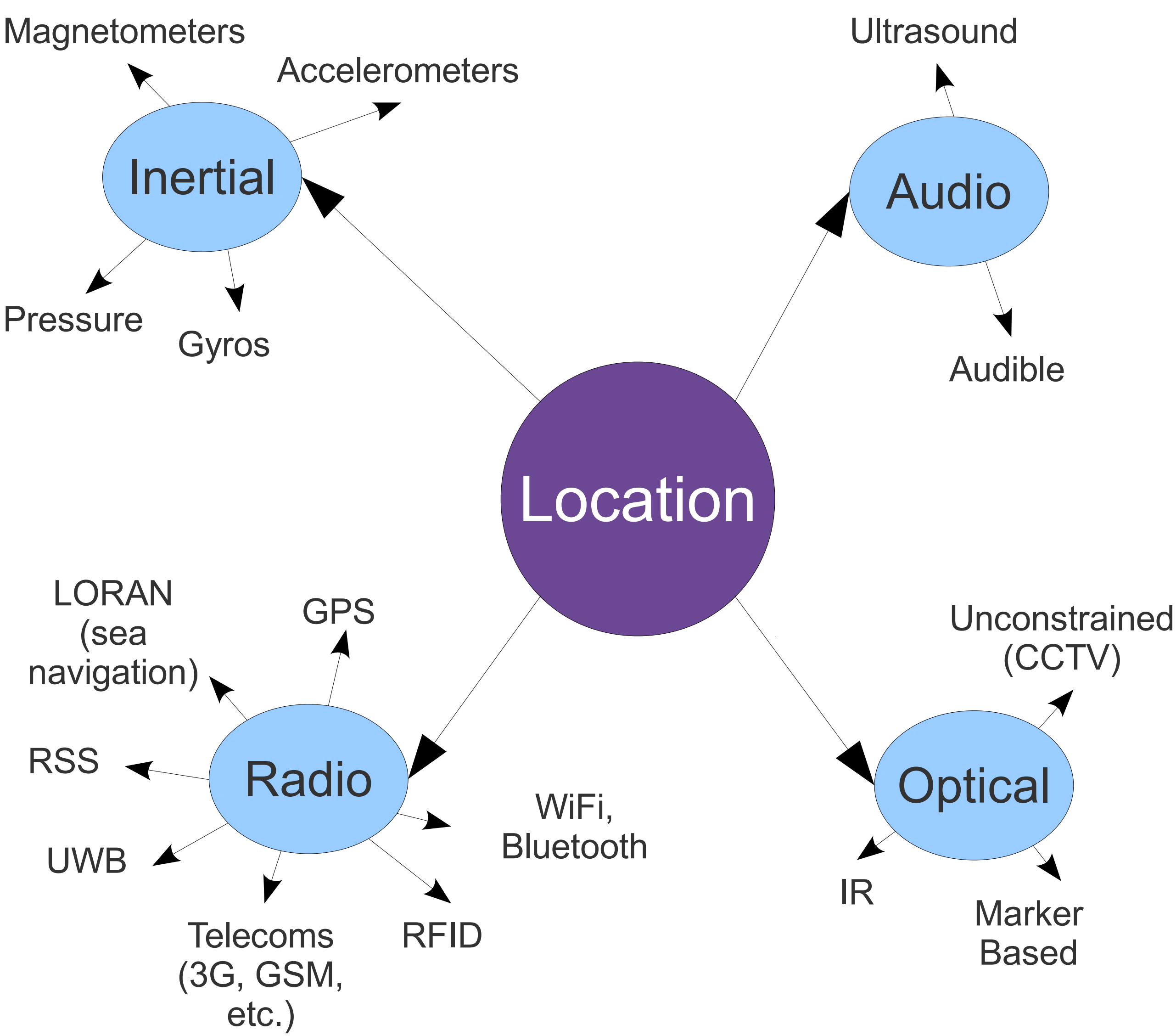
- Many computing eras
  - Mainframe, desktop, networked

- Today the **mobility** era is important
  - Devices more portable but also more *personal.* We carry them around with us and us them to run our lives.
  - They get used in many different *contexts* (communications, camera, navigation, diary, alarm, business...)
  - Adding mobility adds to the context a device must have to respond appropriately: *location* is one of the “next big things” and you'll need to appreciate the location capabilities of devices in the future.
  - But location determination is a hard problem. In this course we'll spend a few lectures looking at the technologies and principles behind today's location systems.

What Accuracy Do We Need?

- Everyone knows about GPS. An amazing piece of engineering that gives us ~10m accuracy outdoors. And completely fails indoors!
- But: even if it worked indoors, 10m is too large to be useful
- Why? Because the scale is different. 10m outdoors is pretty unambiguous – landmarks are separated by much more. Indoors, however, landmarks are much closer. We usually work with:
  - Room-level accuracies
  - sub-metre level accuracies

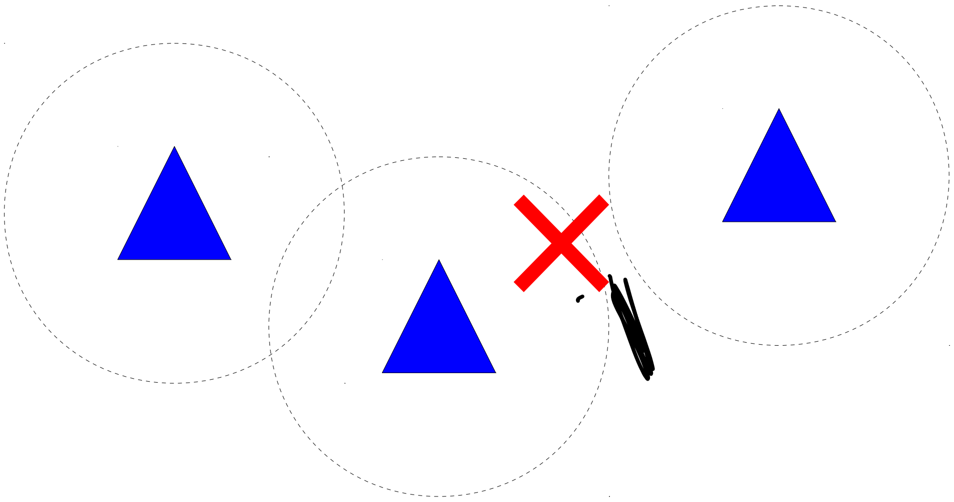
What Do We Measure?



Proximity Systems

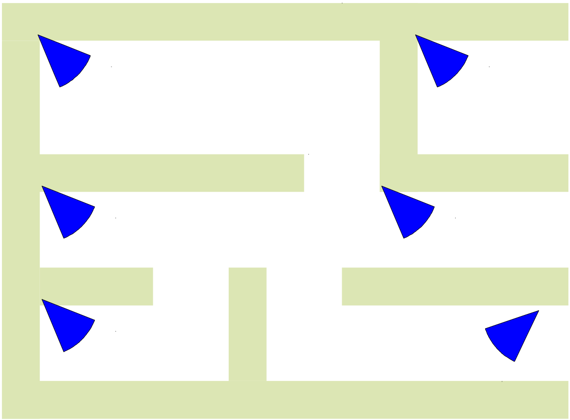
Proximity

- Really simple – if a limited-range base station can see you then you must be within the range of that base station



+ Reliable in the sense of no false positives
+ Easy to set up
- False negatives are possible
- Dead zones are likely
- No precise location

Example 1: Active Badge



- Install 1+ infrared receivers in each room
- People carry active badges that periodically emit IR pulses (encoding a simple ID)
- IR reflected by walls and eventually picked up by receivers
- Room-level location inferred

- Developed and deployed here, primarily for automatic telephone call routing
- Also used at Xerox parc and many other places

Active Badge Display (1990)

ORL/STL Active Badge Project

Name	Location	Prob.	Name	Location	Prob.
P Ainsworth	X343 Accs	100%	J Martin	X310 Mc Rm	100%
T Blackie	X222 DVI Rm.	80%	O Mason	X307 Lab	77%
M Chopping	X410 R302	TUE.	D Milway	X307 Drill	AWAY
D Clarke	X316 R321	10:30	B Miners	X202 DVI Rm.	10:40
V Falcao	X218 R435	AWAY	P Mital	X213 PM	11:20
D Garnett	X232 R310	100%	J Porter	X398 Lib.	100%
J Gibbons	X0 Rec.	AWAY	B Robertson	X307 Lab	100%
D Greaves	X304 F3	MON.	C Turner	X307 Lab.	MON.
A Hopper	X434 AH	100%	R Want	X309 Meet. Rm.	77%
A Jackson	X308 AJ	90%	M Wilkes	X300 MW	100%
A Jones	X210 Coffee	100%	I Wilson	X307 Lab.	100%
T King	X309 Meet. Rm.	11:20	S Wray	X204 SW	11:20
D Lioupis	X304 R311	100%	K Zielinski	X402 Coffee	100%

12.00 1st January 1990

Active Badge Results

- Generally reliable room location, but strong sunlight could swamp the IR signal
- IR nicely contained to room, but signals also stopped by clothing. e.g. jumper or coat falling over the tag.
- False negatives really irritating and meant people didn't rely on the system. This, in turn, meant they didn't value it as much. Which meant they didn't feel motivated to wear their badges...
- Chicken-and-egg situation with usage. If a significant proportion opt out, it degrades the utility for others!

Example 2: Bluetooth

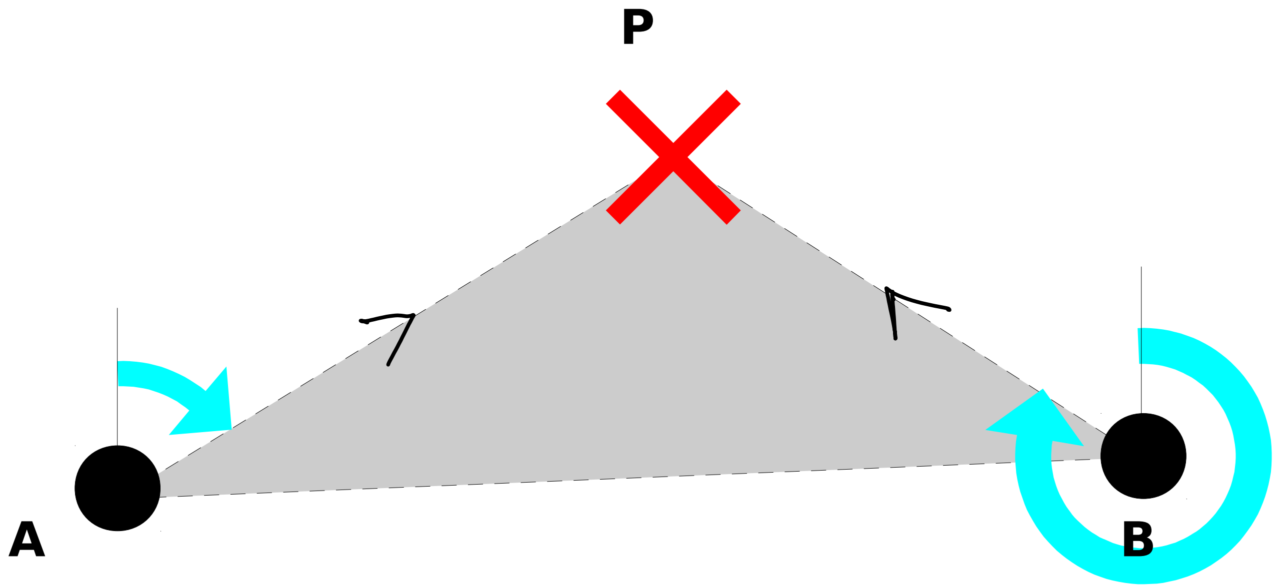
- Bluetooth commonly used as a proximity location system.
  - Different classes of device with different nominal ranges (<1m, 10m, 100m)
  - Device scans for discoverable Bluetooth base stations (or vice versa). If it sees any, it must be near them.
  - Not perfect though – scanning can take 10.24s if you're not careful and constant scanning at the mobile end eats your battery fast. It also causes interference to other applications of Bluetooth.
  - Often not used for tracking so much as presence around a specific object. E.g. automatic locking and unlocking as you approach your machine.
  - Not contained by walls, so can't give reliable room location. E.g. unlock your machine accidentally because you are in the next office!

Example 3: WiFi

- Google etc will use WiFi access points as proximity detectors for mapping. Having first created a database of SSIDs matched to GPS positions (wardriving), they look up the strongest SSID you can see and infer a location to 50m or so.
- Outdoors this works well because the transmitter range is small on the scale of the typical location app.
- Indoors, 50m is waaaay too big. Instead you can look at the signals from multiple WiFi base stations and carry out a more complicated fingerprinting approach – see next lecture!

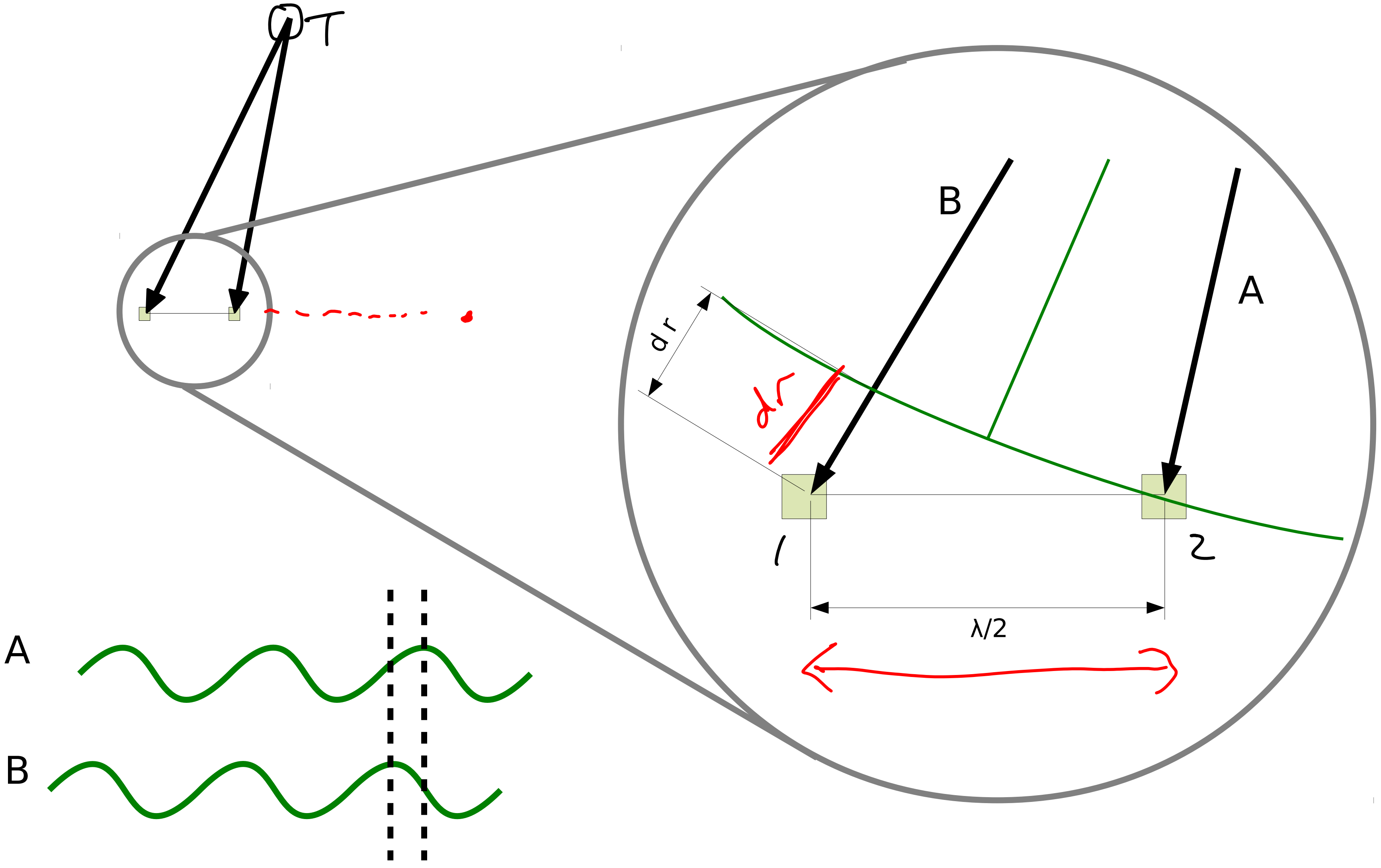
Angle of Arrival Systems

AoA

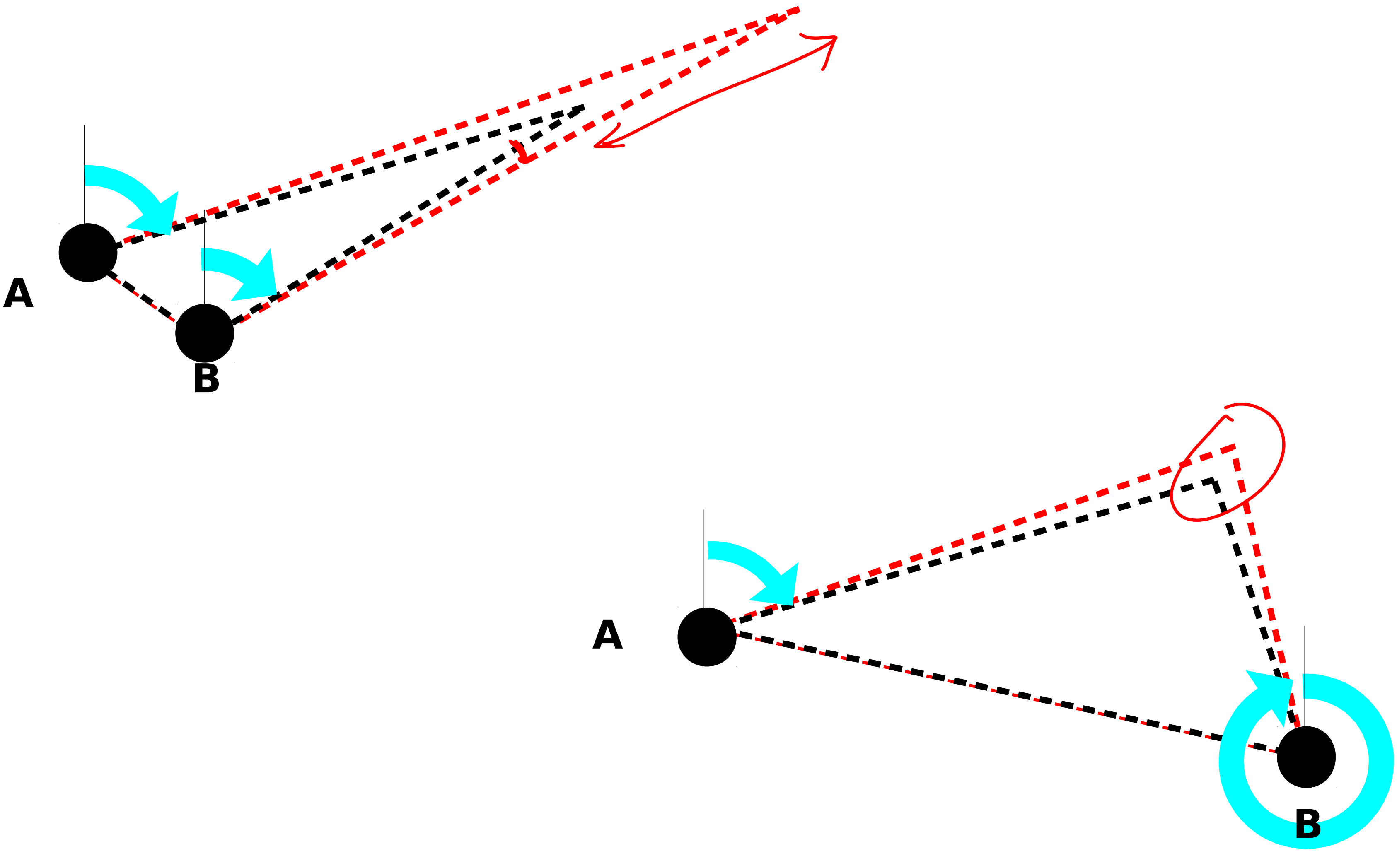


Measuring AoA

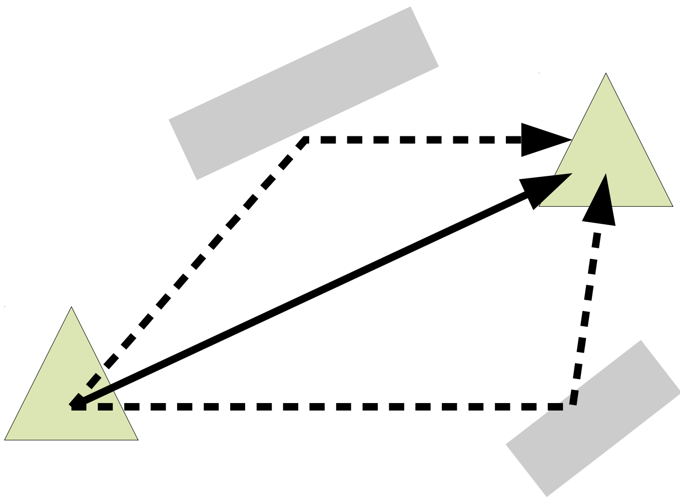
- Phased array of elements

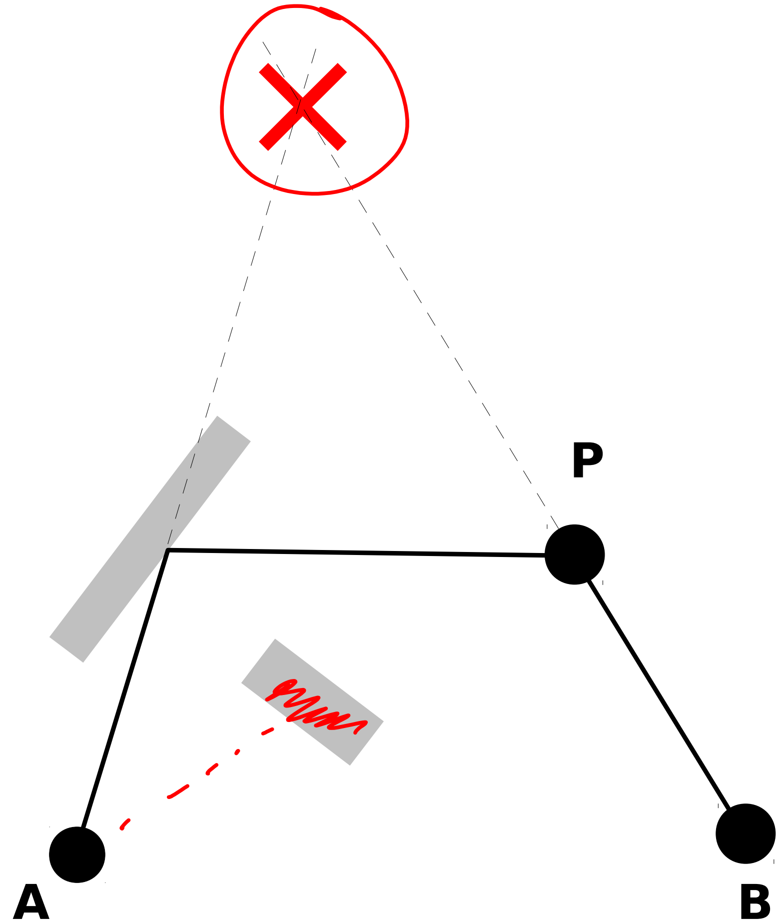


AoA Geometry



Multipath



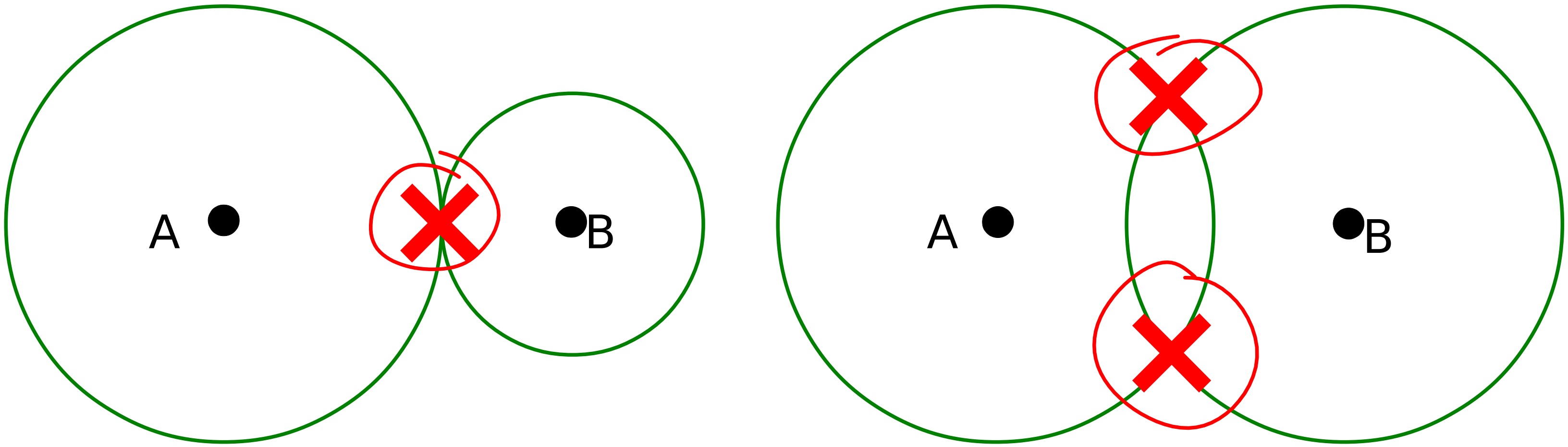


Time of Arrival Systems

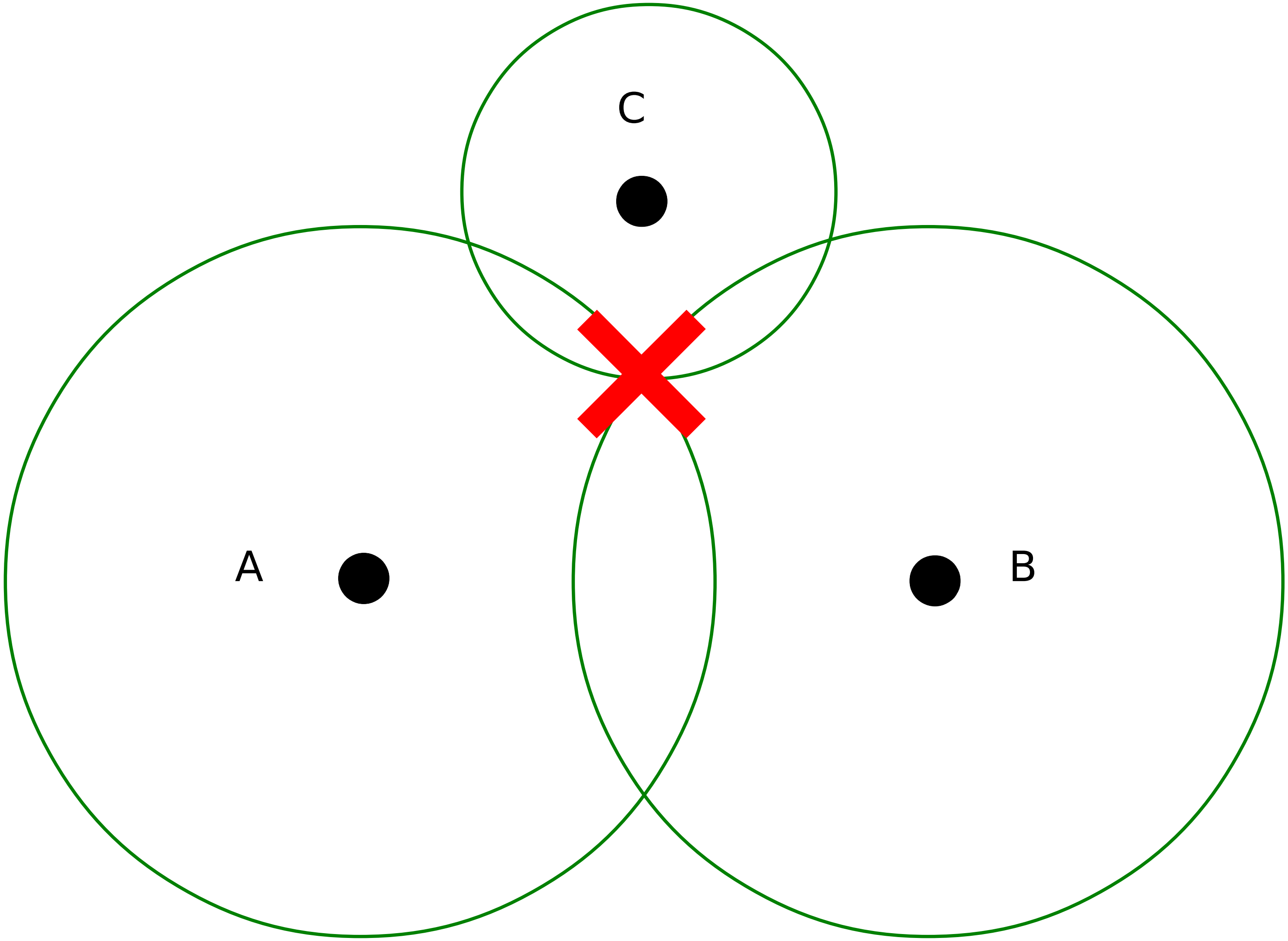
ToA Systems

- Measure how long it takes for a signal to propagate from some know place (a base station) to the target
- Convert the time difference to a lateration (distance) measure using its known speed
  - This defines a radius about each base station, on which the device must lie

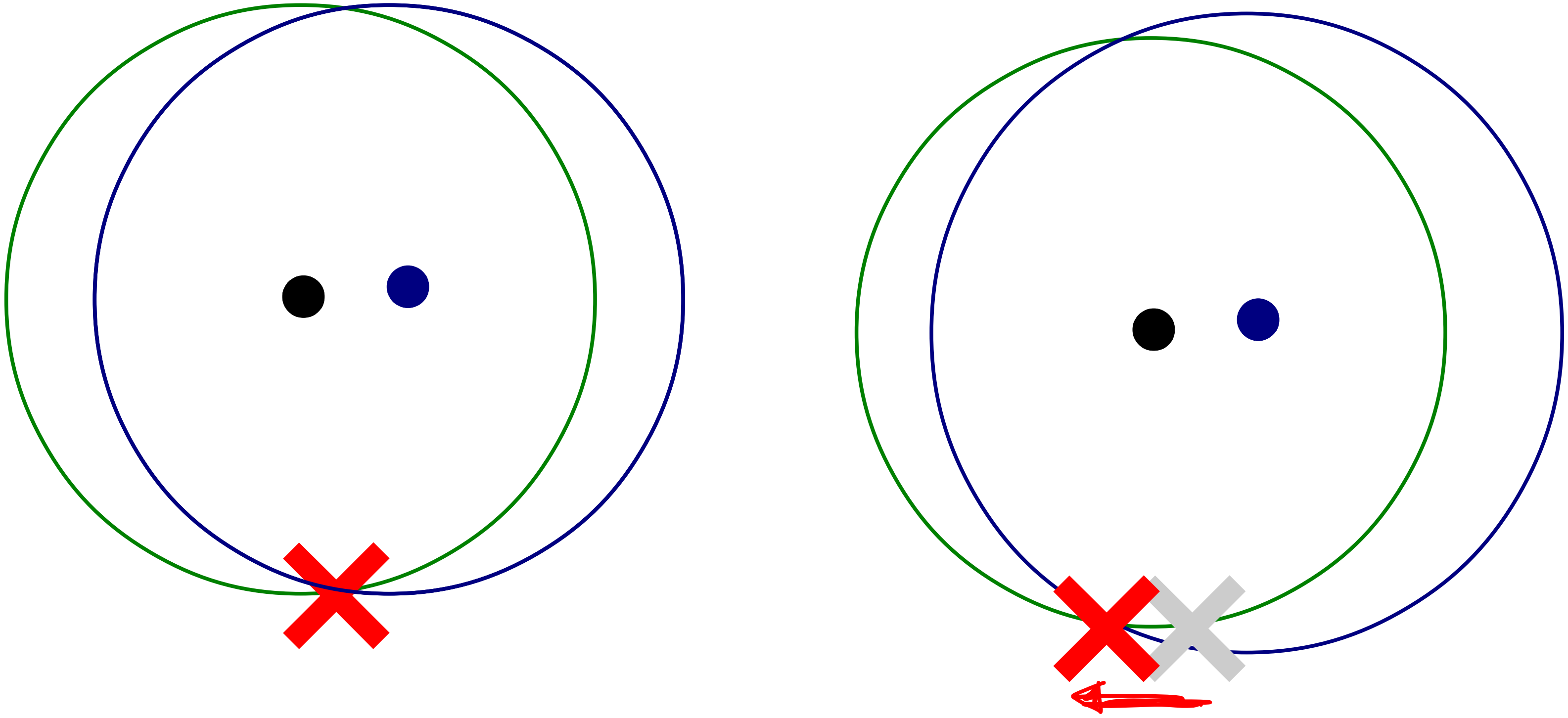
ToA Ambiguity I



ToA Ambiguity II



ToA Errors

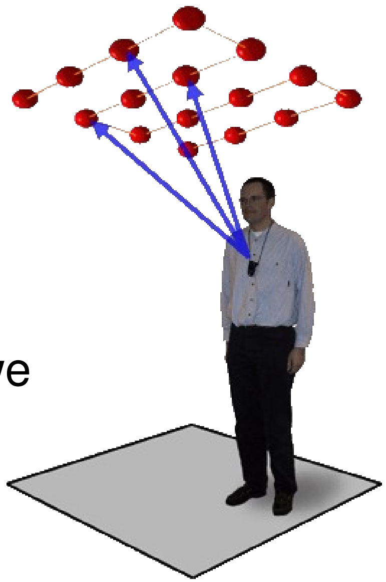


ToA Implementation

- ToA systems are hard to implement because:
  - The base station and target must be synchronised
  - We often want to use radio, but that means our clocks have to be very precise

ToA Example: The Bat System

- Bats are wireless radio devices with ultrasonic transmitters built in
- Install ultrasonic receivers in ceiling
- Bats squeak when told to over radio
- Key advantage of u/s is that it moves a million times slower than radio so we can tolerate much larger timing errors. So we can treat the radio propagation as instantaneous and form a ToA system



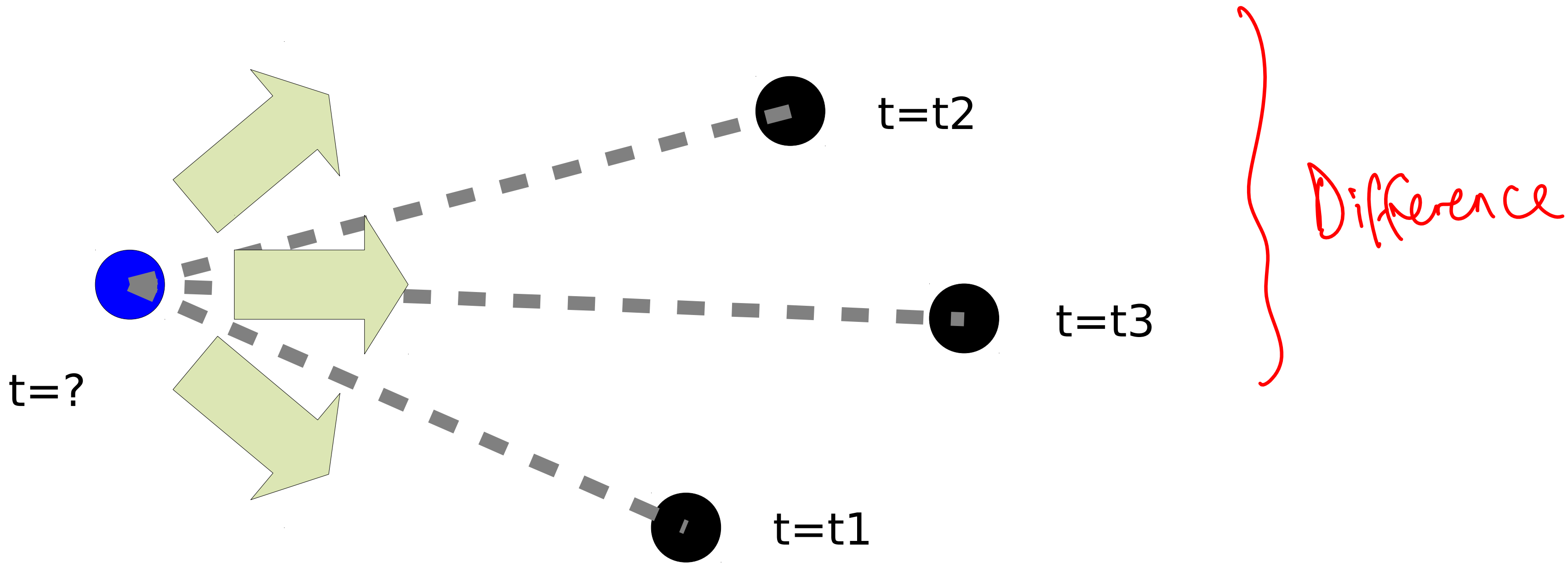
+ 3cm accuracy 95% of the time in 3D!
+ ultrasound contained by room like IR
- Need LoS to ceiling
- Need lots of ceiling receivers in known locations!
- Clothing etc impedes signal
- Some animals can hear the squeaks...
- Can be easily jammed purposefully or accidentally

- Still the benchmark for wide-area indoor tracking since 2002
- Designed and built here

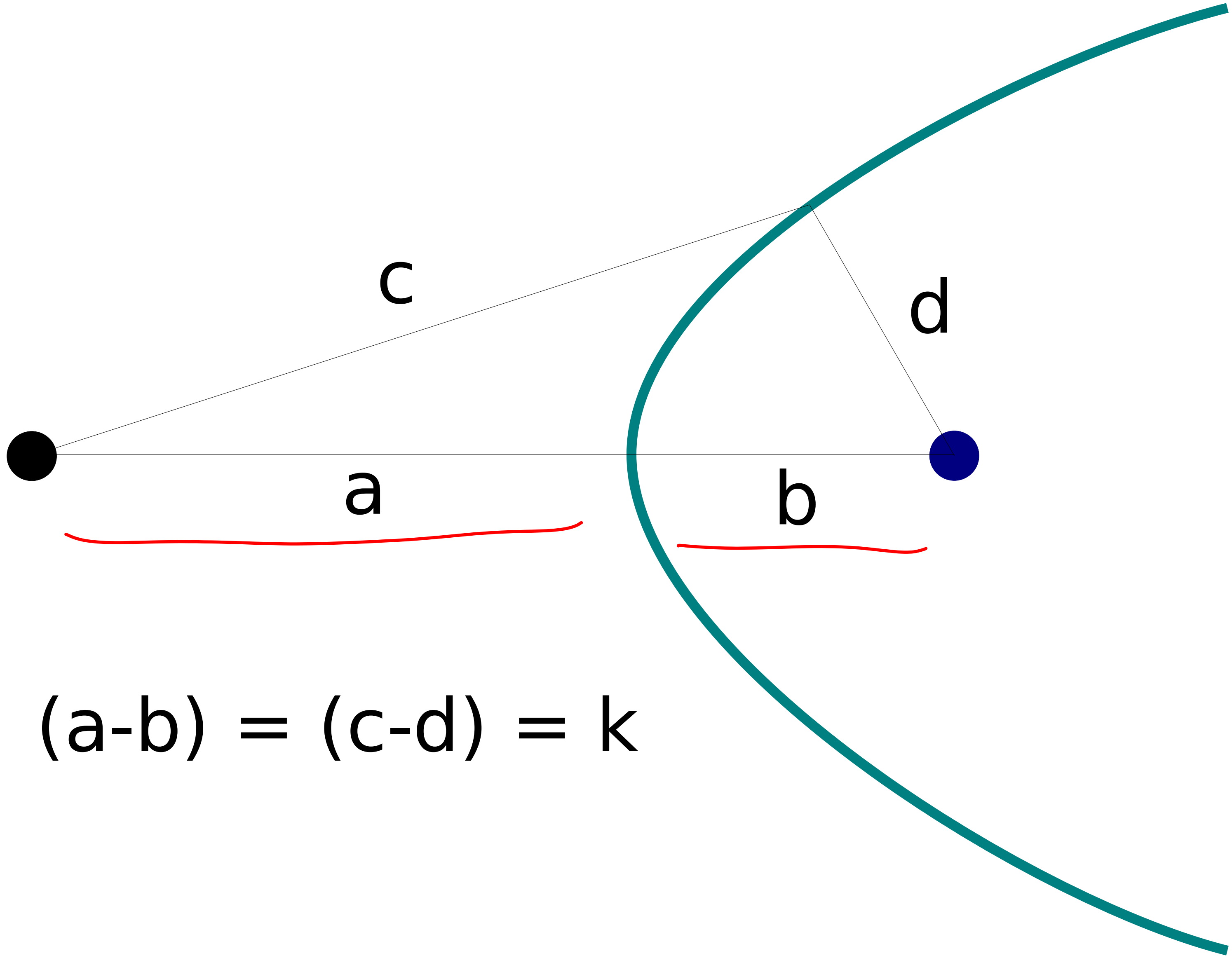
Time-Difference of Arrival Systems

TDoA

- Base stations synchronised together
- Mobile transmitter <u>not synced</u>

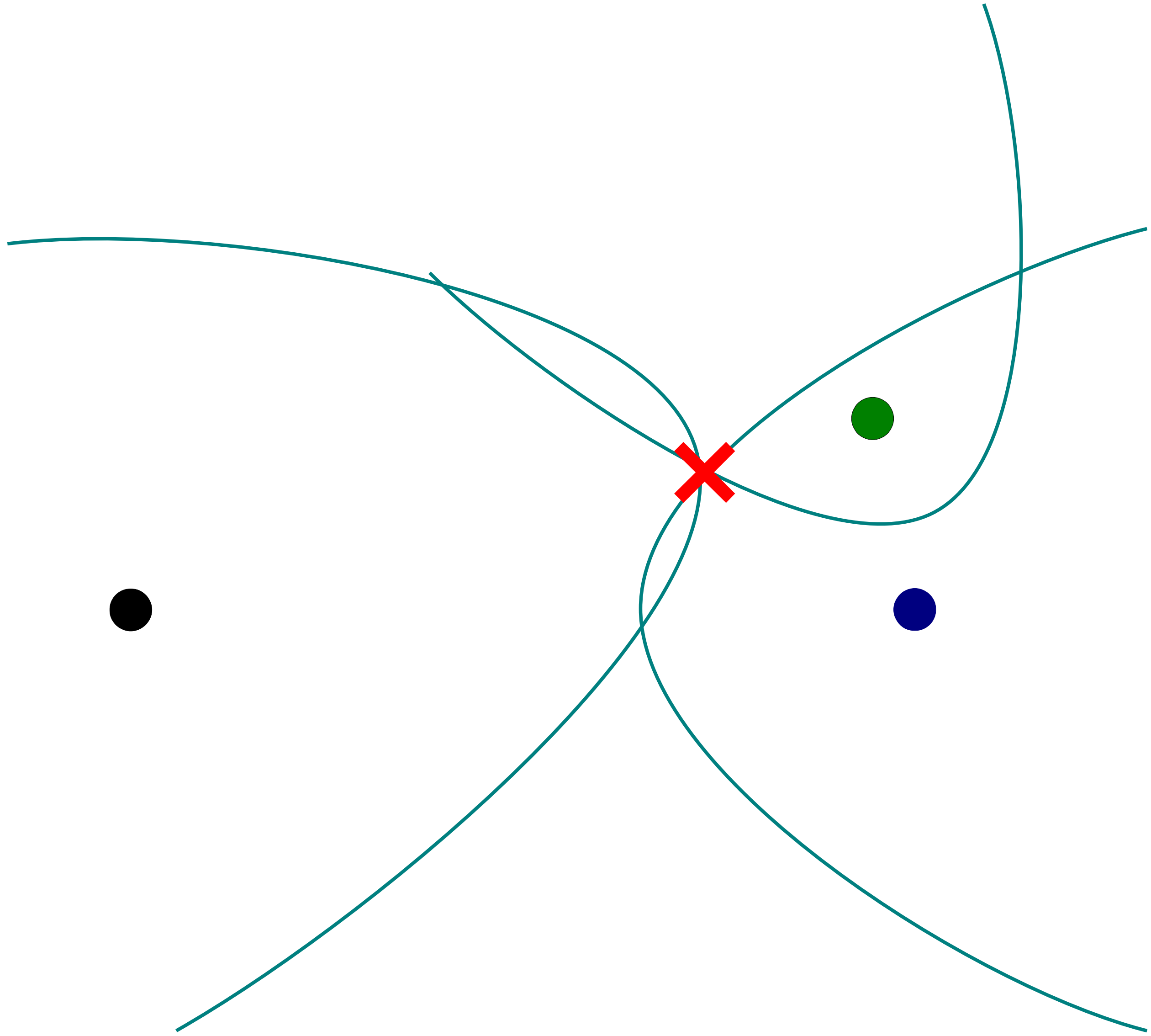


TDoA Hyperbola



(a-b) = (c-d) = k

TDoA Location



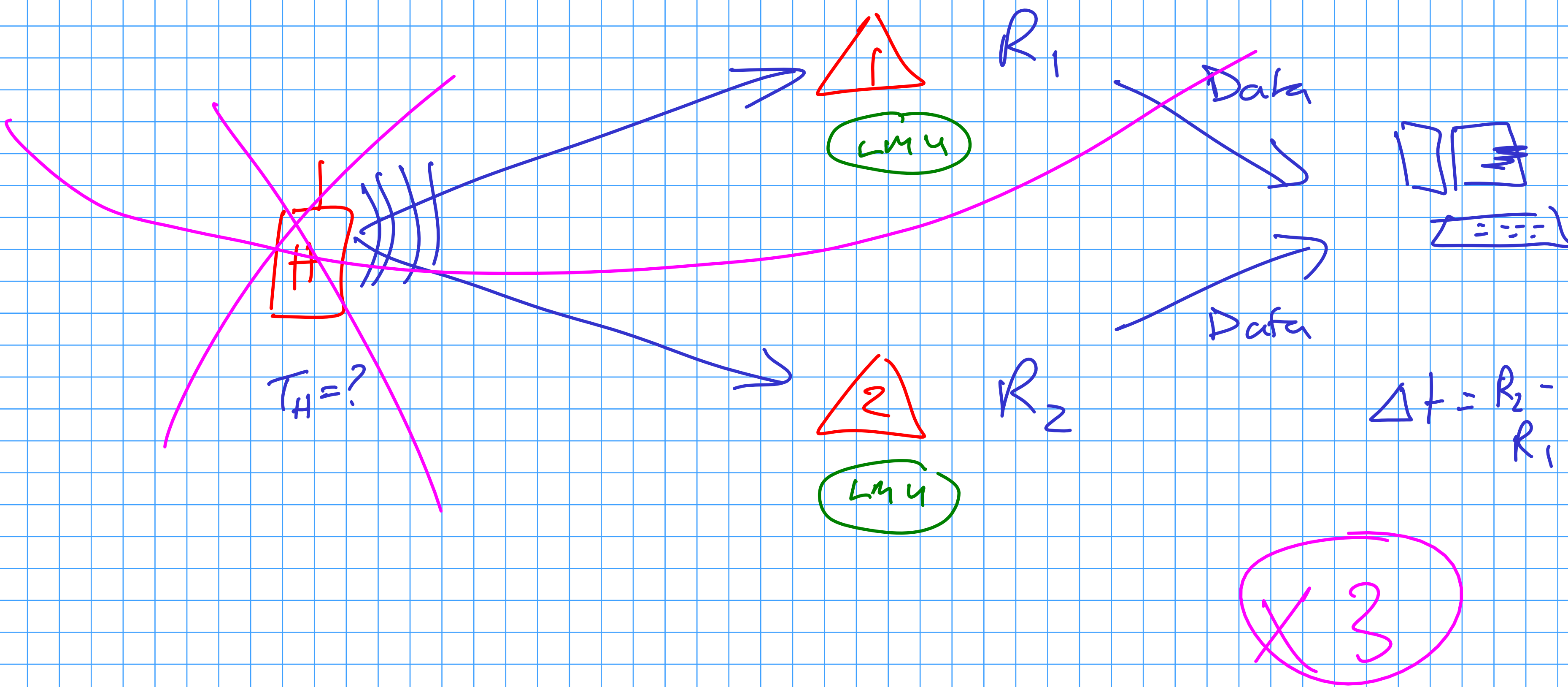
TDoA Example: Phone Tracking

- Radio masts are known as Base Transmitting Stations (BTSs) and they are **NOT** synced together
- **U-TDoA** ($\rightarrow$ normal TDoA)
  - Phone transmits a signal heard by different BTSs
  - They record when in their local clock frame
  - Have to deploy special GPS devices called Location Measurement Units (LMUs) at the BTSs in order to get a common time reference
  - Then we can compute the time difference between arrival at BTS1 and BTS2, etc.
  - Intersect hyperbolae $\rightarrow$ position

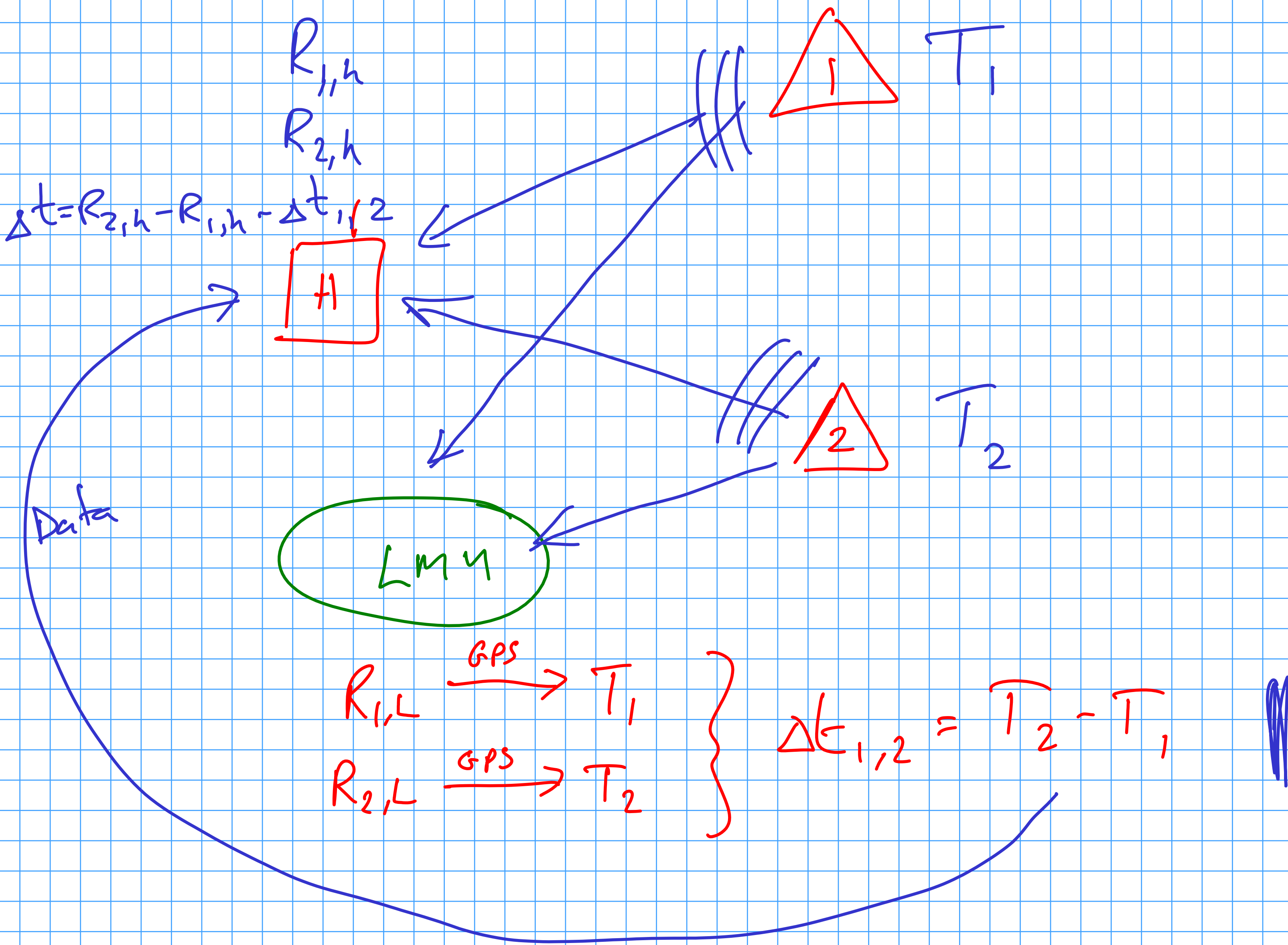
TDoA Example: Phone Tracking II

- **E-OTD** (Estimated Observed Time Diff)
  - The phone measures differences between the corresponding arrivals in its own timeframe
  - This gives us a TDoA value. Collect enough and we can position as usual
  - BUT we can also make the processing easier by ensuring that every pair we derive a TDoA from contains the same BTS. Then we have a load of time differences (=distance differences) from one specific BTS. This means only one unknown in the system...

U-TDOA

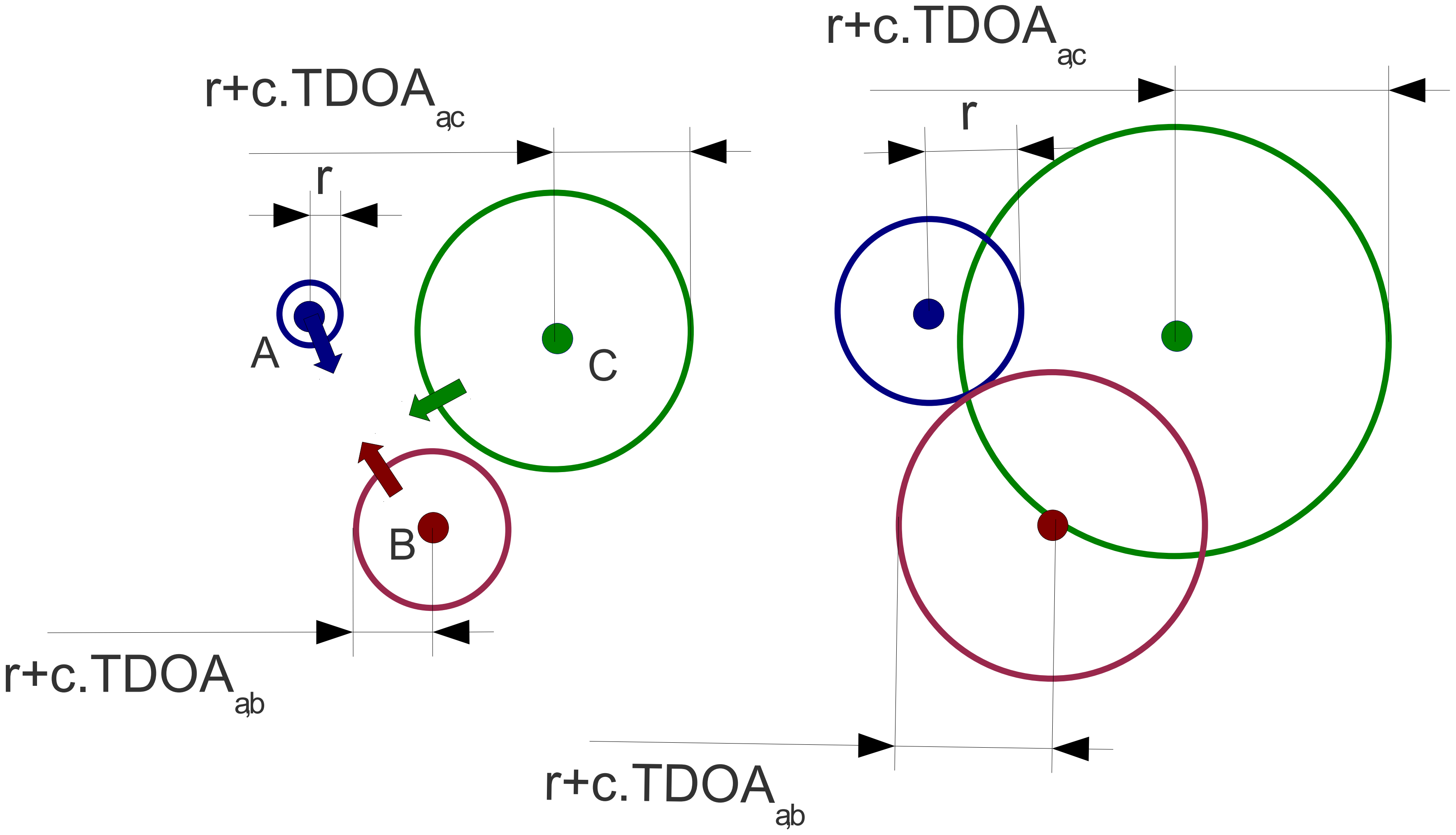


E-OTD



$R_{1,h}$
$R_{2,h}$
$\Delta t = R_{2,h} - R_{1,h} - \Delta t_{1,2}$
H
1
T_1
2
T_2
Data
LMU
$R_{1,L} \xrightarrow{GPS} T_1$
$R_{2,L} \xrightarrow{GPS} T_2$
$\Delta t_{1,2} = T_2 - T_1$

Case Study: Phone Tracking II



U-TDoA vs E-OTD

- U-TDoA
  - Positioning at the server $\rightarrow$ bad for privacy but more attractive to operators
  - Works on all handsets without modification
  - Can increase accuracy by deploying more LMUs
  - Needs lots of LMUs $\rightarrow$ expensive
- E-OTD
  - Positioning at the handset $\rightarrow$ privacy
  - Requires software on the phone
  - Fewer LMUs

Which won?

- U-TDoA is the operators choice. Strong backwards compatibility and the ability to track any active phone without consent – who wouldn't want that..!

Conclusion

- We've only just scratched the surface of location determination
- Next time we'll look at a non-deterministic location technique that is becoming very popular...