ToA: Requirements

- We aim to time how long a signal takes to travel from transmitter to receiver
- We need to start and stop a virtual stopwatch
  - **Start**: sync the clocks
  - **Stop**: cross-correlate the signal with what we believe was sent
Signal speed $c$:

\[
\text{St} = \frac{10}{3 \times 10^8} = 30 \text{ns}
\]
ToA: Cross Correlation

\[ [f \ast g]_i = \int_{j=-\infty}^{\infty} f_j g_{i+j} \]
Multipath

- Multipath (signals bouncing around) can get us in two ways:

1) If we **don't** get the direct signal, we will mistakenly use the first bounce

2) If we **do** get the direct signal, we might lose it in the reflections
ToA: The Bat System

- Put lots of ultrasonic receivers in the ceiling (avoid multipath)
- Add a radio channel
- Radio polls each Bat, causing it to emit ultrasound
Key Points

- Got around the sync problem by using ultrasound, which moves so much slower that relatively big timing errors correspond to quite small distances
- Needs to see at least 3 receivers to get a position
  - WGB deployment uses over 400 for one corridor!
  - Each one has to be carefully surveyed...
- 3cm accuracy 95% of the time (in 3D!)
ToA: Realities

- To be commercially realistic, we usually need radio so we don't need lots of receivers in each room.
- In practice, the **sync** is then a real problem.
  - Wireless sync to nanoseconds is **hard** and **expensive**.
- And **multipath** is a major issue too as we saw.
TDoA Systems

- Time Difference of Arrival
  - Base stations synced together
  - But mobile unit **not** synced

\[ \Delta t = \frac{d_2 - d_1}{c} \]

(a-b) = (c-d) = k
Not good enough indoors

Not bad for outdoors: 150m 95%

and apply standard TDoA

Capture the same signal at multiple BTSs

can't the serving cell for

Modify BTSs to listen for phones that they

U-TDoA

TDoa: Mobile Phones
TDoA: Ubisense

- The guys who made the Bat system (here!) went on to found Ubisense
  - Same basic system but dispensing with the ultrasound and using ultra wideband radio (UWB)
    - This is radio with a really big range of frequencies
    - 1GHz-10GHz (all of it!)
    - Huge data bandwidth (obviously) so it's being pushed as a way to wirelessly connect monitors etc.
    - But it has another advantage for location...
The key is that wide ranges in the frequency domain mean narrow ranges in the time domain (remember Fourier Transforms?)...
Ubisense: UWB

- ...and this is better for indoor multipath!

  - Pulses thinner ~ ns
  - Discard reflection
So now we can discard multipathed signals and apply TDoA to get positions using a radio system (note that we can't do ToA because everything's at light speed).

- Average of 1 sensor per room
- Accuracy around 15cm 95% (3D)
- Commercially viable! But bloody expensive just now! ;-)
Fingerprinting

- UWB is rather too pricey for most just now, so can we get sub-metre accuracies using 'normal' radio? Perhaps...

- Option 1: Radio Propagation Models
Option 2: Fingerprinting
- Positioning becomes pattern matching

(8,8,7)
Fingerprinting: Does it work?

- Outdoors/large scale
  - Definitely: Skyhook, iPhone, Google (?)
Fingerprinting: Does it work?

- Indoors/small scale
  - Possibly: Lots of research reports accuracies of a few metres
    - But some suspect methodologies
  - And you do need to increase the density of wifi points (not so free!)
  - No long term studies
Inertial (Dead Reckoning)

- *Relative positioning rather than absolute*
- Any sensor that can be used to give us changes in position
- E.g. Accelerometers
MEMS

- Micro Electro-Mechanical Systems

Don't measure in global frame

[Diagram of MEMS device]
Common IMU sensors

- 3D Accelerometers (accelerations)
- Rate-gyros (angular velocity)
- Magnetometer (bearing)
Common IMU sensors

1) Resolve the accelerations into a global frame (magnetometer may help here)
2) Integrate angular vel. To get heading change.
3) Subtract gravity from $a_z$
4) Integrate accel. To get velocity
5) Integrate velocity to get change in position
Overview

- Proximity
  - Bluetooth, WiFi, RFID

- Angle of Arrival
  - Pirate radio, seek and destroy

- Time of Arrival
  - Bat system

- Time Difference of Arrival
  - Mobile phones, Ubisense

- Fingerprinting
  - WiFi, GSM

- Inertial