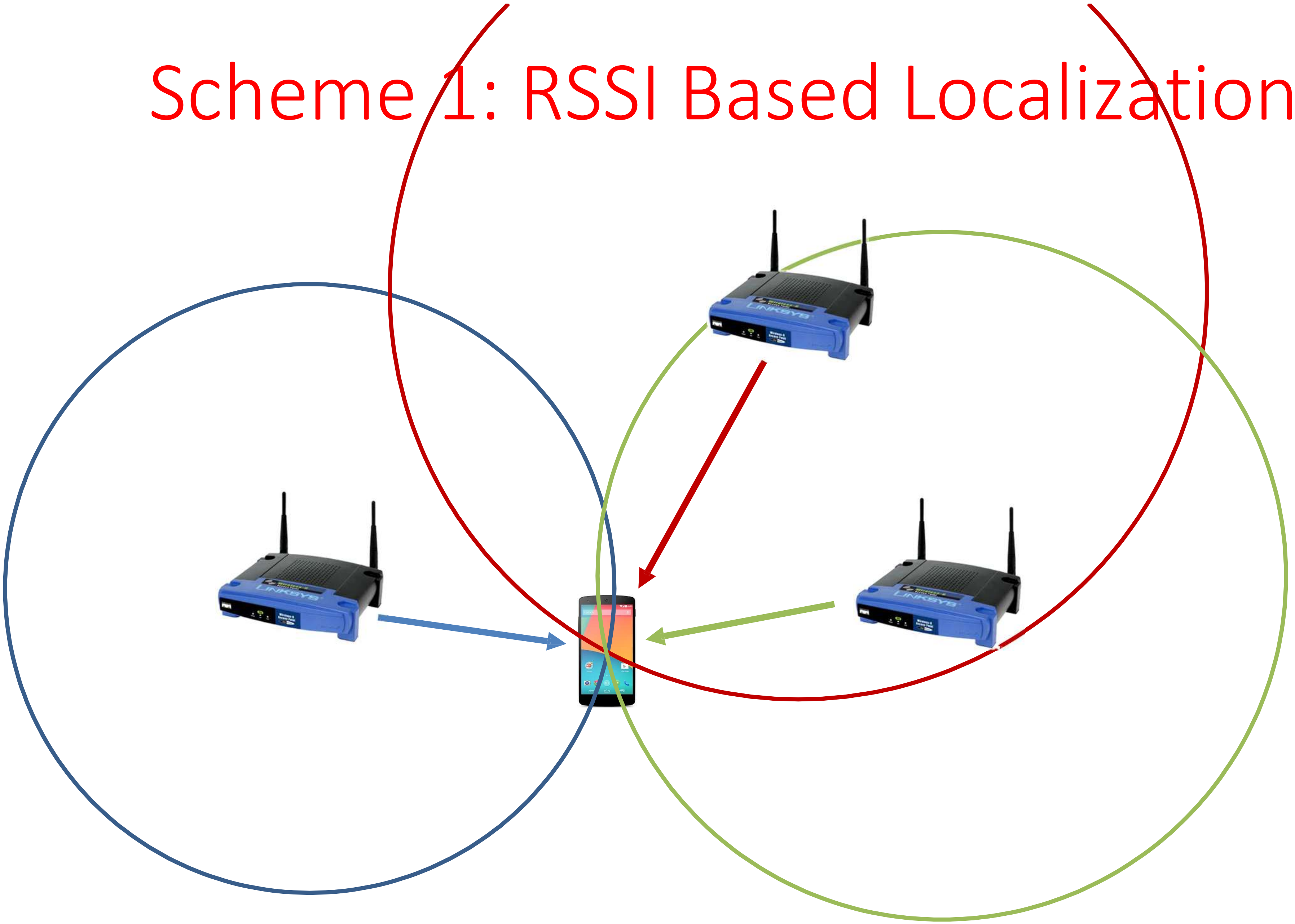
Localization

Wireless Localization

- Navigation: outdoors (GPS) and indoors (e.g., museum)
- Location based services: Tagging, Reminder, Ads
- Virtual Reality and Motion Capture
- Gestures, writing in the air
- Behavioral Analytics (Health, activities, etc.)
- Locating misplaced items (keys)
- Location based security
- Delivery drones

Scheme 1: RSSI Based Localization

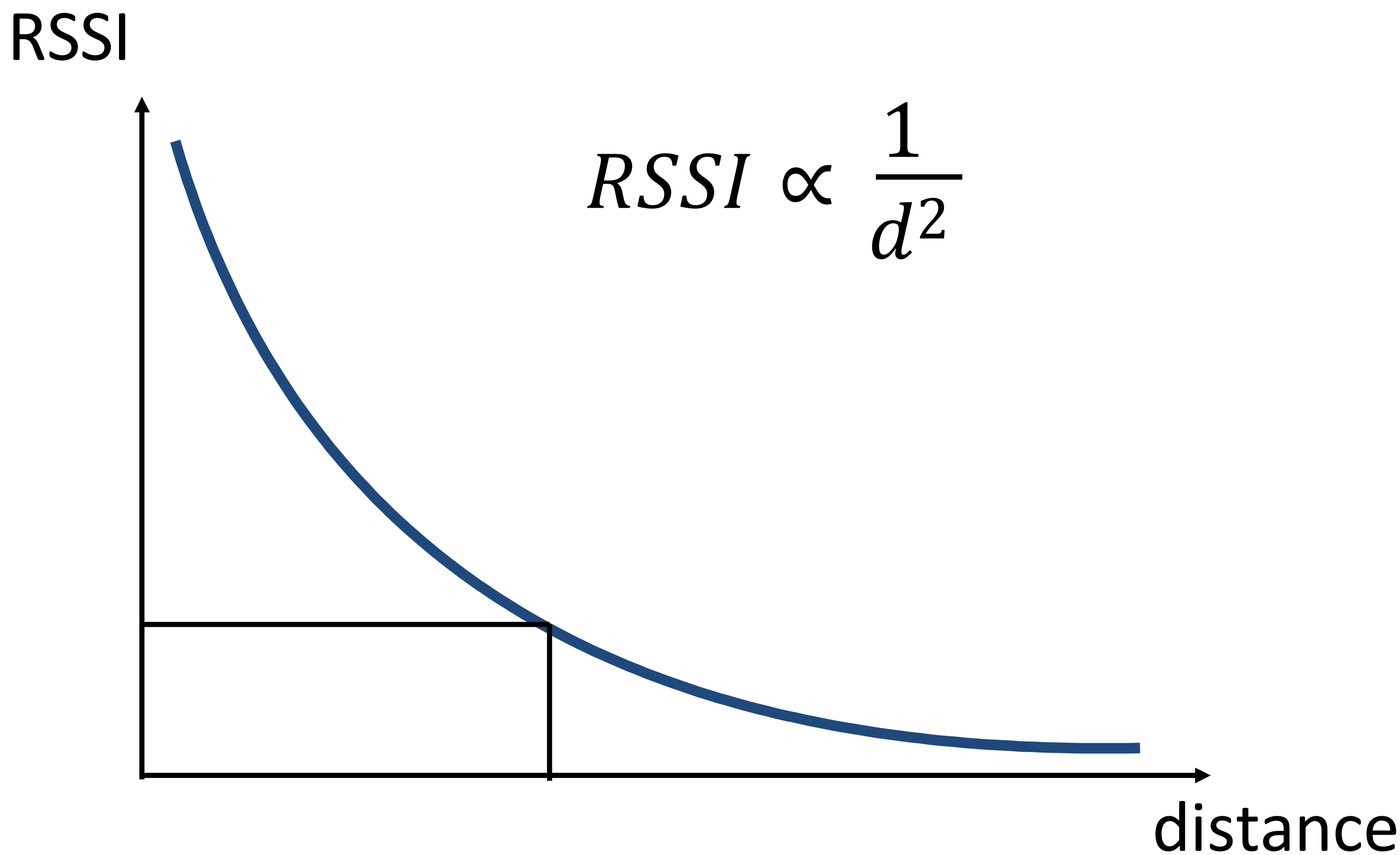


Trilateration

Scheme 1: RSSI Based Localization

$$P_{Rx} = \frac{G_{Tx}\, G_{Rx}\, \lambda^2}{(4\pi d)^2}\, P_{Tx} \quad \Rightarrow \quad RSSI \propto \frac{1}{d^2}$$

Scheme 1: RSSI Based Localization



$$RSSI \propto \frac{1}{d^2}$$

Scheme 1: RSSI Based Localization

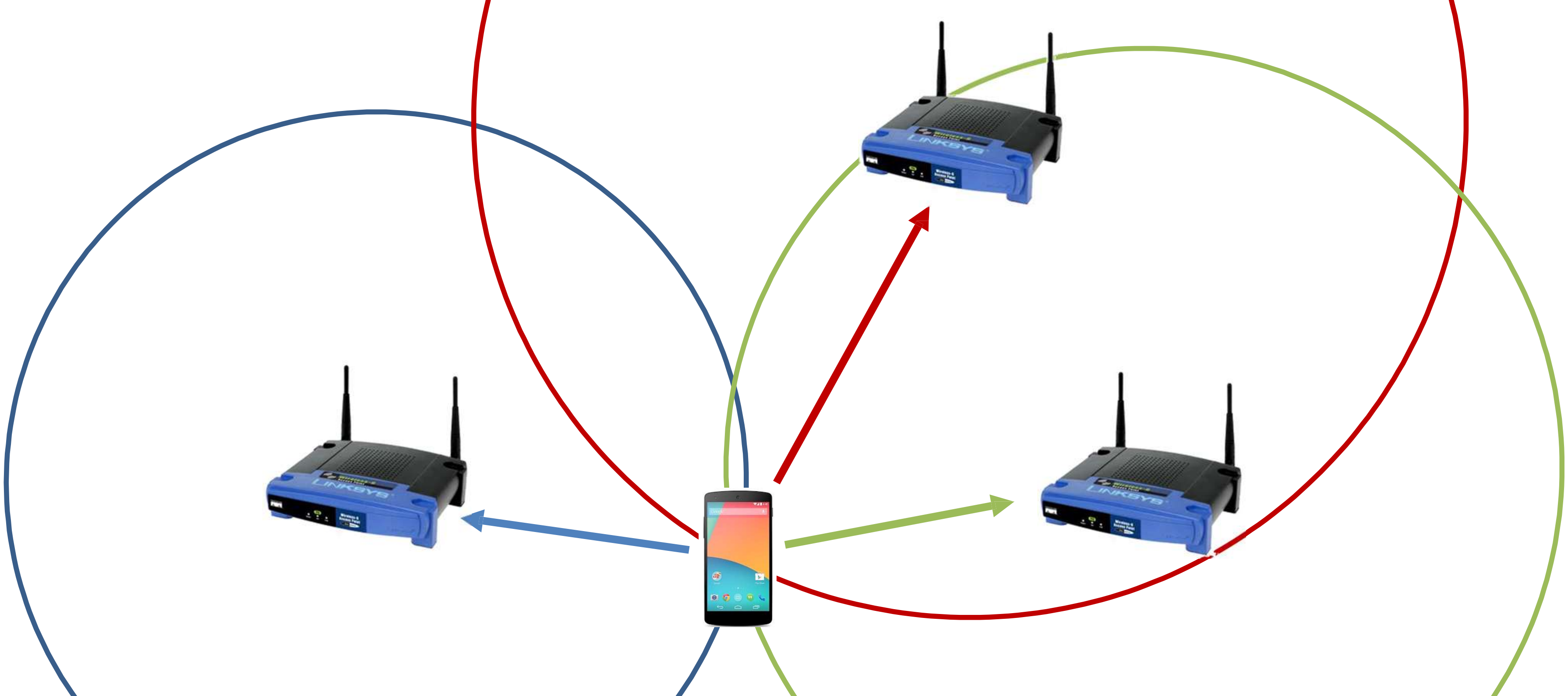
Pros: Very simple, no hardware modifications!

Cons: Highly inaccurate!

Does not work with blockage or multipath!

Scheme 2: ToF Based Localization

Measure Time of Flight (ToF) from device to each AP



Distance = Time of flight × speed of travel

Measure ToF → Get distance → Trilateration

Scheme 2: ToF Based Localization

Measure Time of Flight (ToF) from device to each AP

Challenges:

- How do you know when signal was transmitted?

Measure Round Trip

- Long distance like GPS
- Short distance: acoustic signals

Scheme 3: Doppler shift

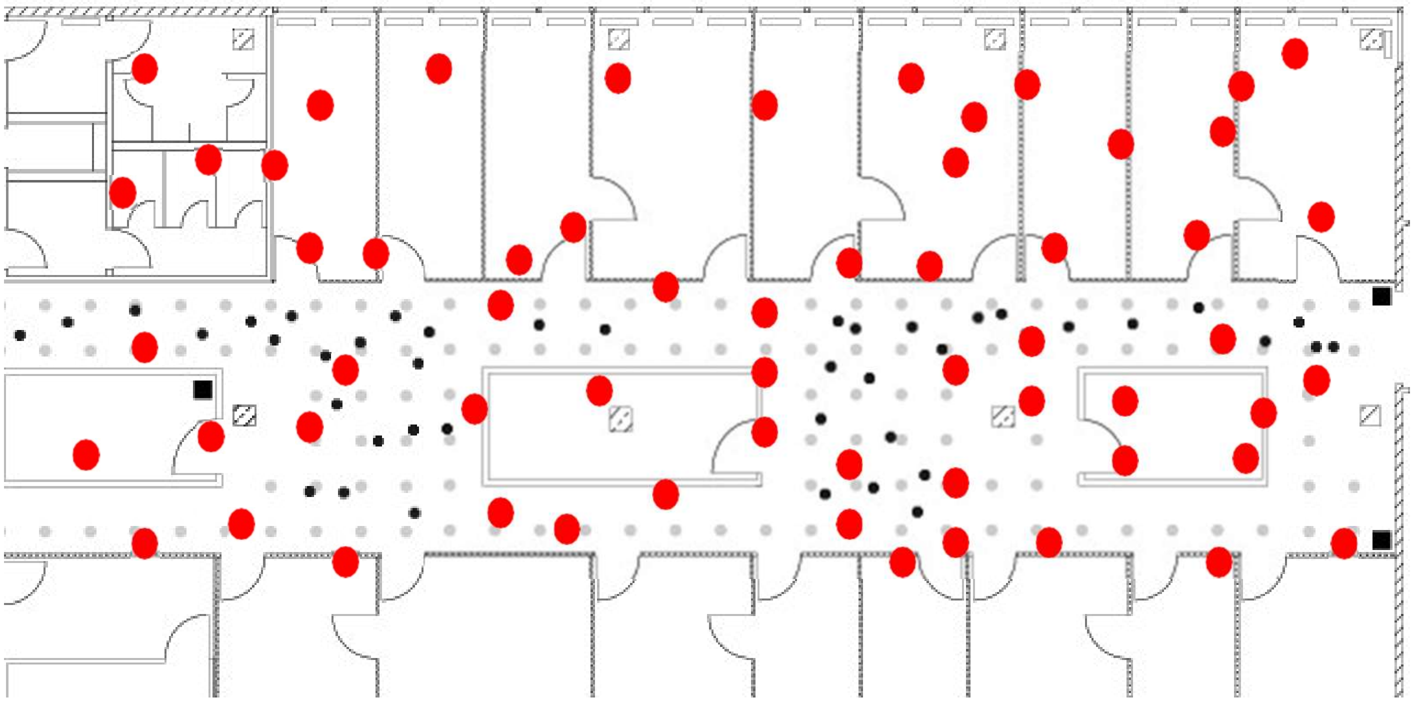
Change of the frequency due to the movement

$$F^s = \frac{v}{V_s} F$$

F^s: Doppler shift
V_s: propagation speed of the medium
F : frequency of the wave

Scheme 4: RSSI Based Fingerprinting

Measure and records RSSI fingerprints at each location

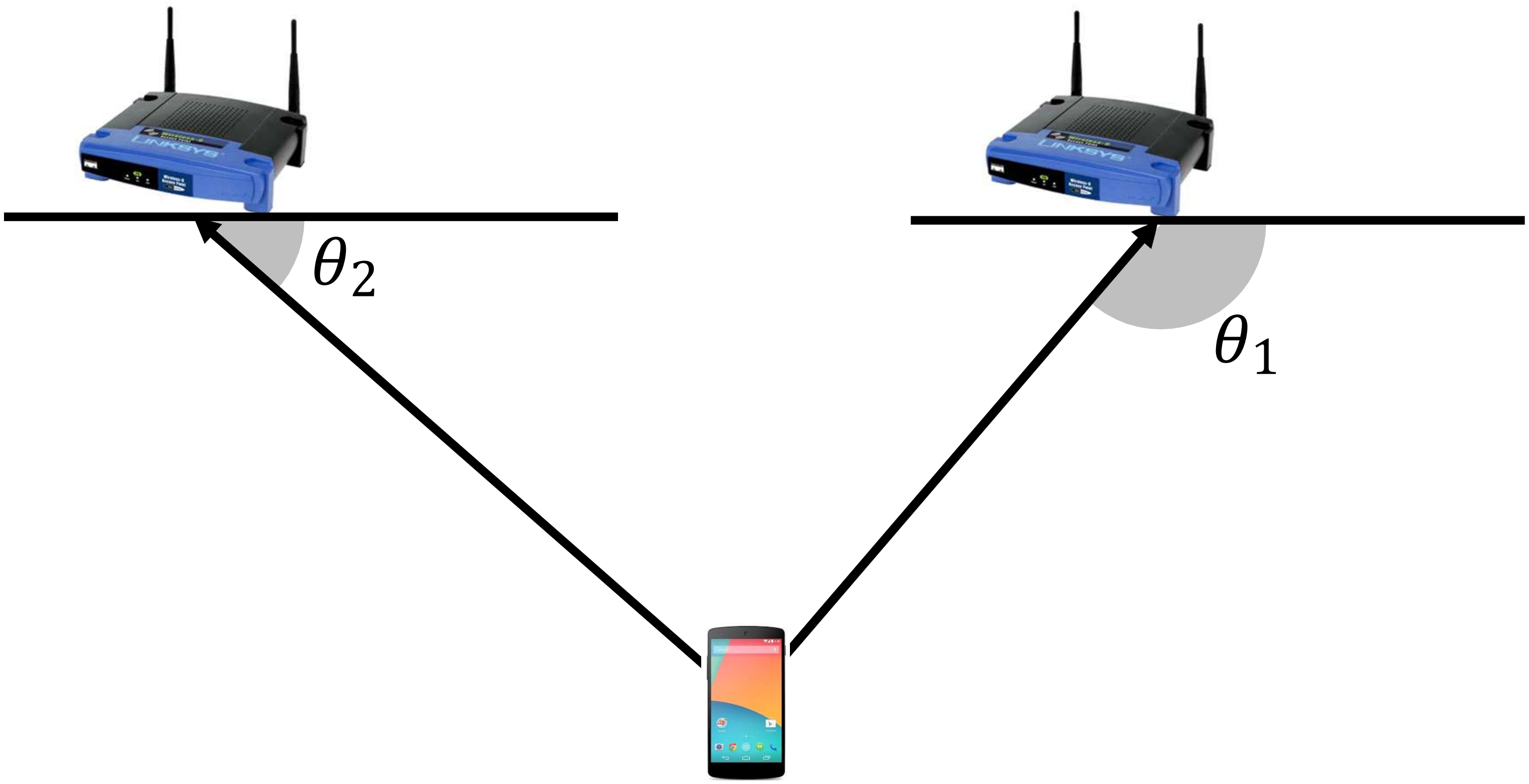


Pros: Works with multipath, No need to know AP locations!

Cons: Changes in environment/movement ➔ change RSSI!
Continuous training is needed. Lots of effort!

Scheme 5: AoA Based Localization

Measure Angle of Arrival (AoA) from device to each AP

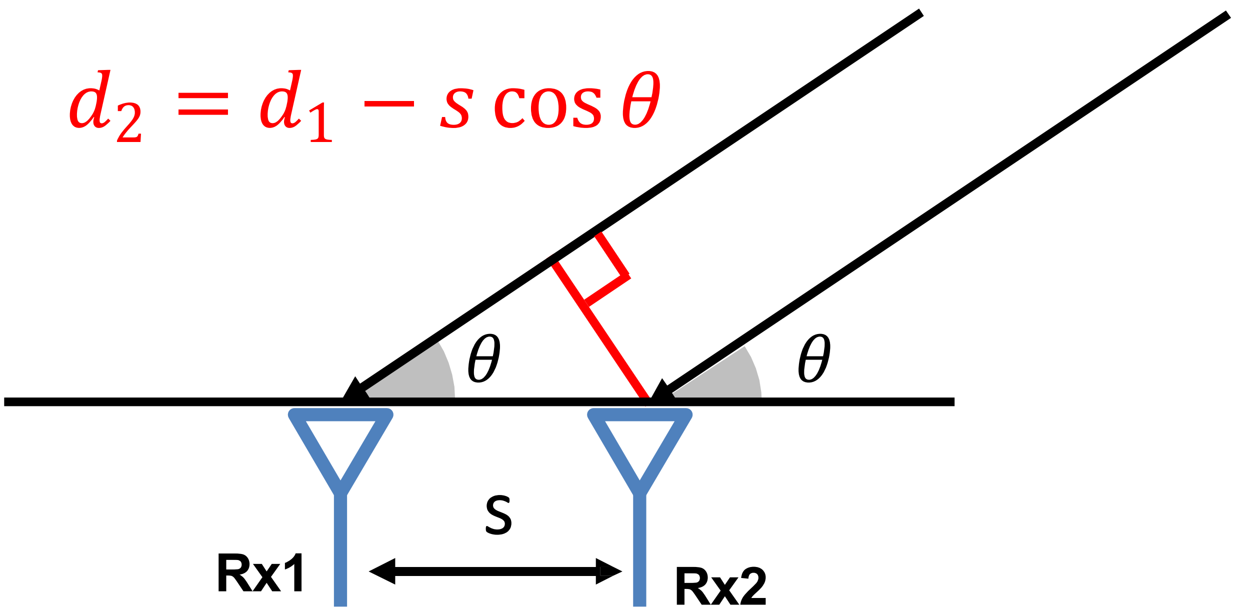


Triangulation

Method 5: AoA Based Localization

Measure Angle of Arrival (AoA) from device to each AP

$d_2 = d_1 - s\cos\theta$

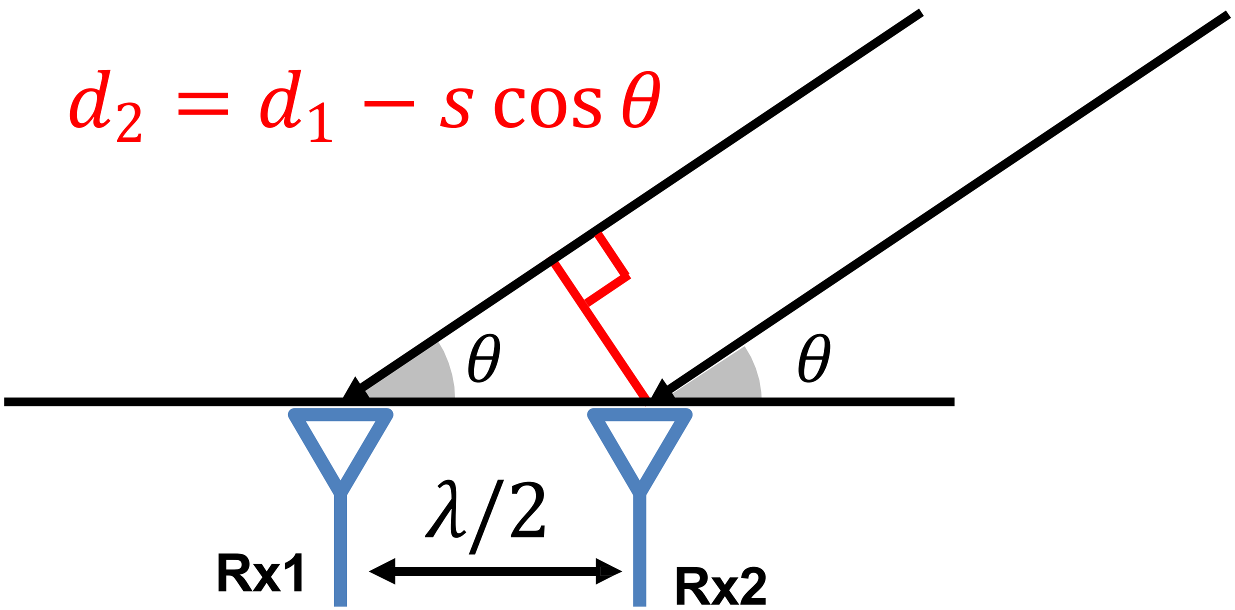


$$h_1 \propto e^{-j2\pi\frac{d_1}{\lambda}} \qquad h_2 \propto e^{-j2\pi\frac{d_2}{\lambda}} = e^{-j2\pi\frac{d_1 - s\cos\theta}{\lambda}}$$

$$\Delta\Phi = \angle h_2 - \angle h_1 = 2\pi\, s\cos\theta\,/\lambda \mod 2\pi$$

Method 5: AoA Based Localization

Measure Angle of Arrival (AoA) from device to each AP



Pros: More accurate than RSSI, Simple!

Cons: Ambiguity: $\cos\theta = \cos\ (-\theta)$

Error not linear with θ due to $\cos\theta$

Requires 2 Antennas separated $\lambda/2$

Does not work with multipath!

Localization Systems

Xbox Kinect

https://www.youtube.com/watch?v=pzfpXAbQ61U

Audio based tracking

https://www.youtube.com/watch?v=2z8AKrJzUVw

https://youtu.be/awO5wSVvn5A

https://www.youtube.com/watch?v=awO5wSVvn5A&feature=youtu.be

https://www.youtube.com/watch?v=AcAteT2Ts5s

WiFi based tracking

https://youtu.be/VZ7Nz942yAY

http://people.csail.mit.edu/fadel/wivi/

http://witrack.csail.mit.edu/

Light based tracking

https://www.youtube.com/watch?v=7wK-zo66GdY&feature=youtu.be

Google Soli 60 GHz based tracking

https://www.youtube.com/watch?v=hwEDIya5bx0

Health sensing

https://youtu.be/CzAWndQh6xE

GPS

Global Position Systems

US Department of Defense wants very precise navigation

In 1973, the US Air Force proposed a new system for navigation using satellites

The system is known as Navigation System with Timing and Ranging: Global Positioning System or NAVSTAR GPS

GPS Operational Capabilities

Initial Operational Capability - December 8, 1993

Full Operational Capability declared by the Secretary of Defense at 00:01 hours on July 17, 1995

NAVSTAR GPS Goals

What time is it?

What is my position (including attitude)?

What is my velocity?

Other Goals:

- What is the local time?
- What is the distance between two points?
- What is my estimated time arrival?

GPS System: Overview

GPS satellites are essentially a set of wireless base stations in the sky

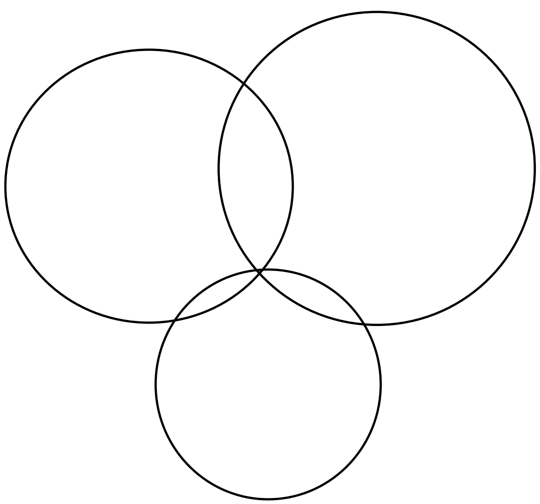
The satellites simultaneously broadcast beacon messages

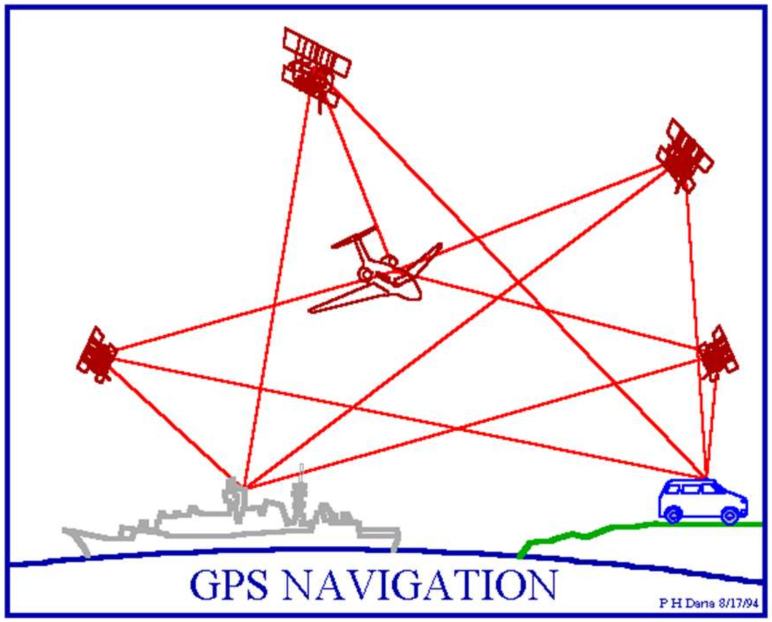
A GPS receiver measures time of arrival to the satellites, and then uses “triangulation” to determine its position

GPS System: Overview

Assume receiver clock is sync'd with satellites
"Triangulation" determines position

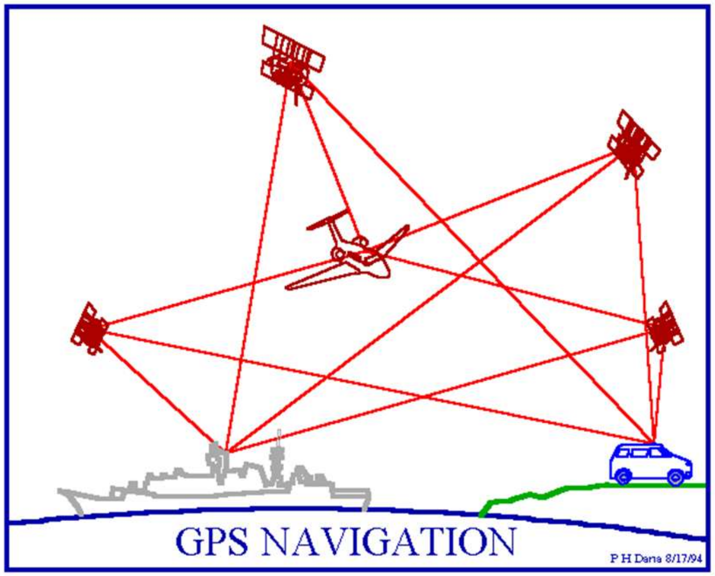
$$t^{R1} = t^S + \frac{\|p - p_1\|}{c} \longrightarrow \|p - p_1\| = c(t^{R1} - t^S)$$





Why we need 4 satellites?

GPS System: Overview



In reality, receiver clock
is not sync'd with satellites

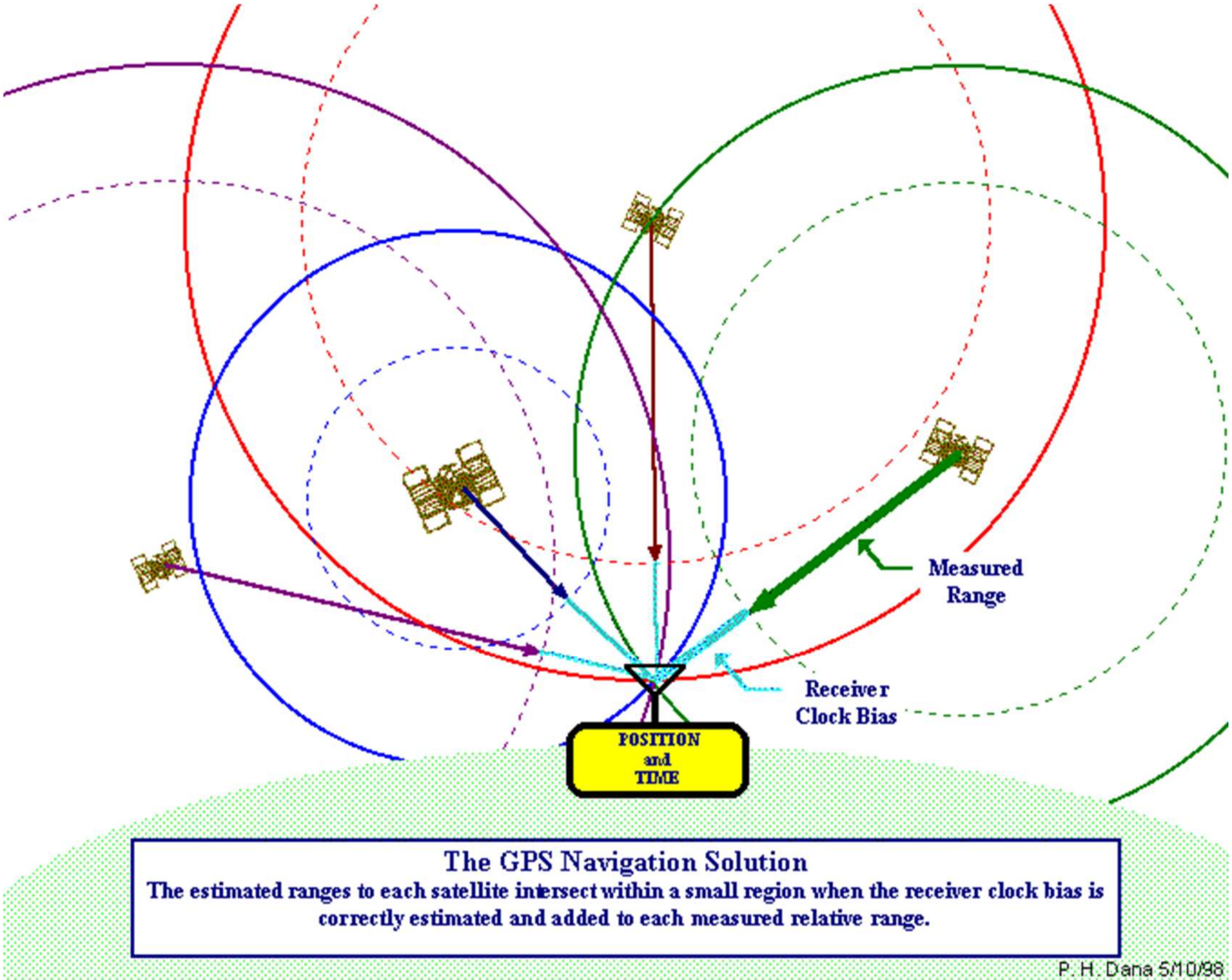
Thus need one more satellite
to have the right number of
equations to estimate clock

$$t^{R1} = t^S + \frac{d_1}{c} + \delta_{clock-drift} \longrightarrow \|p - p_1\| = c(t^{R1} - t^S - \delta_{clock-drift})$$

$$= c(t^{R1} - t^S) - c\delta_{clock-drift}$$

called pseudo range

We need to see 4 satellites in GPS



Each satellite timestamp transmission and receivers measure received time

Time of transmission
Correct satellite location
Speed of radio wave
Time of arrival

GPS Satellite Transmissions

Requirements

all 24 GPS satellites transmit on the same frequencies
resistant to jamming
resistant to spoofing
allows military control of access (selected availability)
satellites provide their positions

GPS Multiple Access and Identifying Codes

All 24 GPS satellites transmit on the same two frequencies BUT use different codes

- i.e., Modulation used is
  - Direct Sequence Spread Spectrum (DSSS) and
  - Code Division Multiple Access (CDMA)

Navigation Message

To compute position one must know the positions of the satellites

Navigation Message (37,500 bits) - transmitted on both L1 and L2 at 50 bps

Navigation message consists of:

- satellite status to allow calculating position
- clock information

GPS Identifying Codes

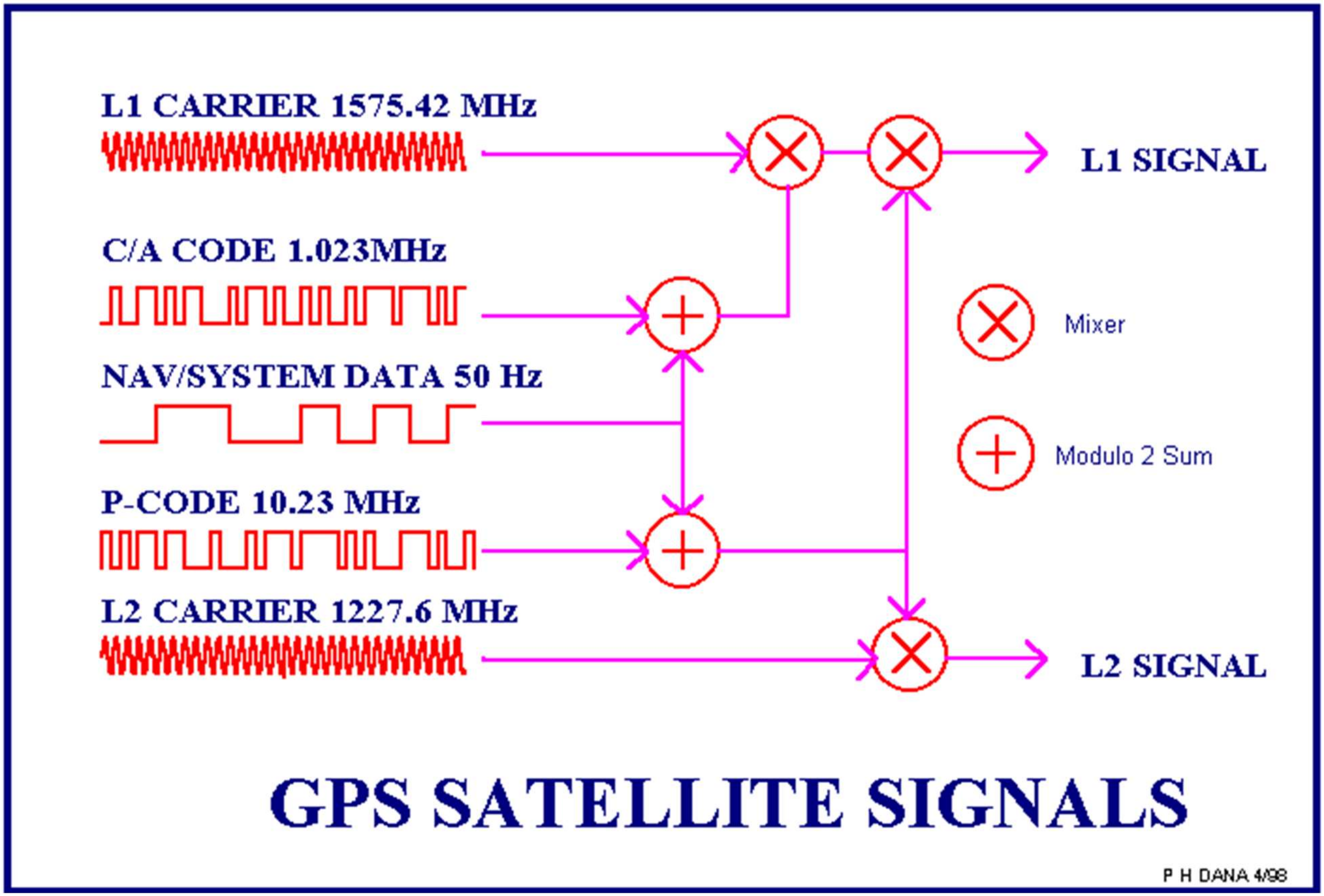
Two types of clock signals

C/A Code - Coarse/Acquisition Code available for civilian use on L1 provides 300 m resolution

P Code - Precise Code on L1 and L2 used by the military provides 3 m resolution

Encrypted P Code provides selected availability and anti-spoofing

GPS Messages



GPS Receiver

Typical receiver: C/A code on L1

During the “acquisition” time you are receiving the navigation message also on L1

The receiver then reads the timing information and computes the “pseudo-ranges”

Denial of Accuracy (DOA)

The US military uses two approaches to prohibit use of the full resolution of the system

- Anti-Spoofing (AS) - P-code is encrypted
- Selective availability (SA)
  - noise is added to the clock signal
  - the navigation message has “lies” in it

GPS Operation

Segments (components)

space segment: the constellation of satellites
control segment: control the satellites
user segment: users with receivers

Space Segment

Space Segment

System consists of 24 satellites in the operational mode

- 21 in use
- 3 other satellites are used for testing

Altitude: 20,200 Km with periods of 12 hr.

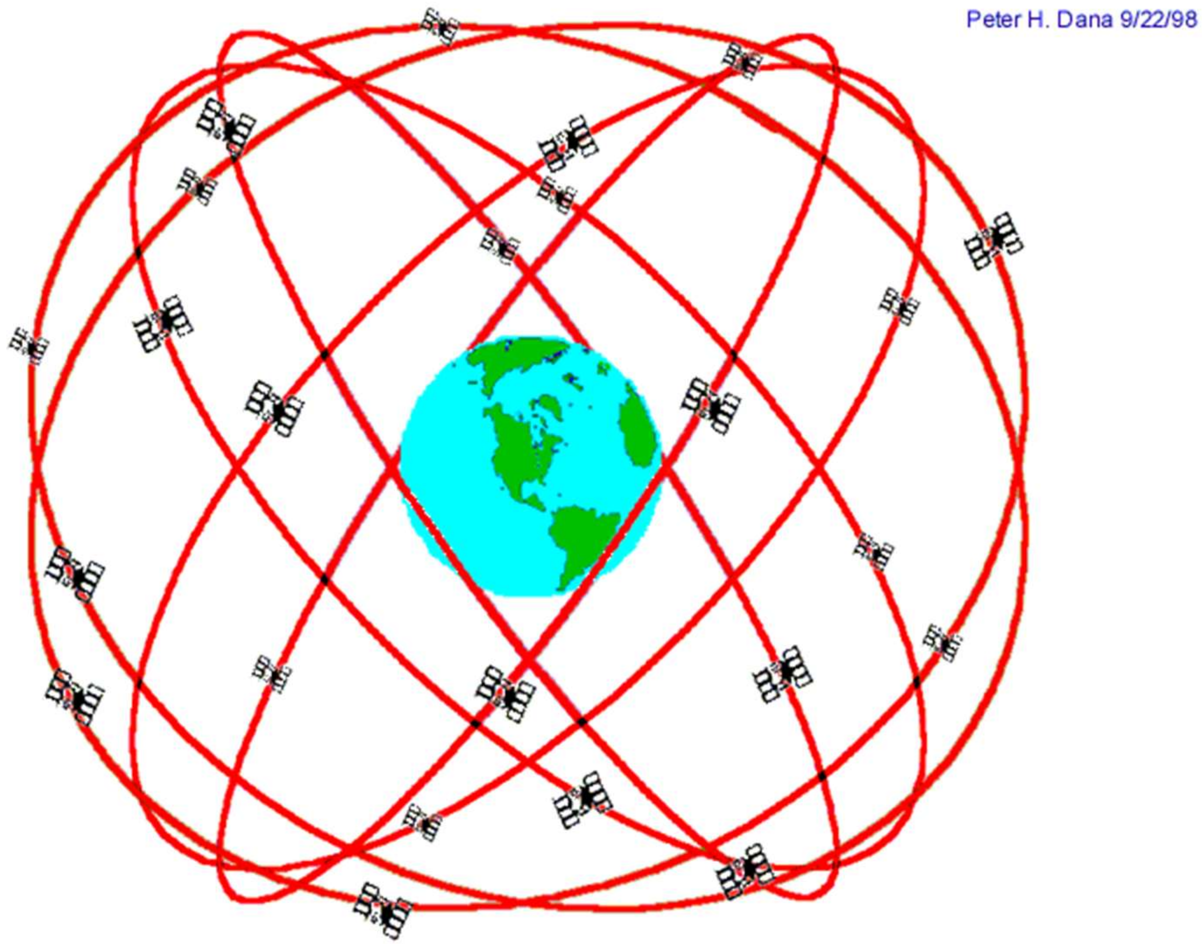
Current Satellites: Block IIR- 25,000,000

2000 KG

Hydrogen maser atomic clocks

- these clocks lose one second every 2,739,000 million years

GPS Orbits



GPS Nominal Constellation
24 Satellites in 6 Orbital Planes
4 Satellites in each Plane
20,200 km Altitudes, 55 Degree Inclination

Control Segment

Master Control Station is located at the Consolidated Space Operations Center (CSOC) at Flacon Air Force Station near Colorado Springs

CSOC

Track the satellites for orbit and clock determination

Time synchronization

Upload the Navigation Message

Manage Denial Of Availability (DOA)

GPS: Summary

- GPS is among the simplest localization system in terms of topology
- Limitations of GPS
  - Hardware requirements vs. small devices
  - Obstructions to GPS satellites common
    - Each node needs LOS to 4 satellites
    - LOS hard to achieve in many environments, e.g., urban canyon, indoors, and underground
  - GPS jammed by adversaries
  - GPS spoofing

GPS Spoofing

Proof of concept: Luxury yacht “White Rose” misdirected from Monaco to the island of Rhodes

Suggested it caused capture of a Lockheed RQ-170 drone aircraft in northeastern Iran

Geneva Motor Show in Switzerland, an attack affected the GPS systems of Audi, Peugeot, Renault, Rolls-Royce, Volkswagen, Daimler-Benz and BMW cars. The cars were reporting that they were in Buckingham, England, in the year 2036.

10,000 instances where Russia interfered navigation of > 1300 civilian vessels in 10 locations

Uber drivers create fake trips

Cheat at Pokemon Go

Devices: software defined radio <$300