無線網路概論
Intro. to Wireless Internet

Lecture 08 – Localization

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YZU CSE

Lecture Material

- 無線網路 - 通訊協定、感測網路、射頻技術與應用服務, 2011.
  - Ch18. GPS定位技術簡介
  - Ch19. 無線感測網路定位技術
- Wireless Networks and Applications
  - Prof. Peter Steenkiste
  - Carnegie Mellon University
- Wireless Internet
  - Prof. You-Chiun Wang
  - National Sun Yat-sen University

Outline

- Location-based services
- Positioning concepts
- Global navigation satellite system
- Positioning technology by wireless networks

Location-based Services

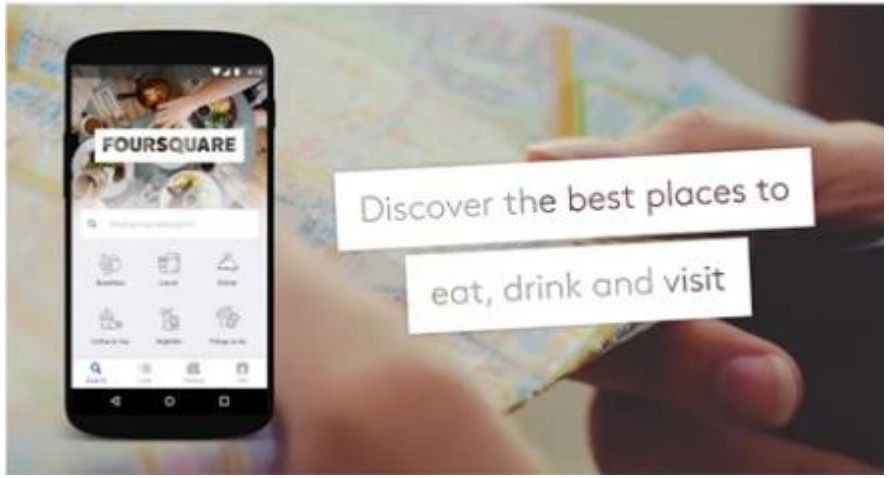
- Think about what services you can provide to make money once you know people's locations?
  - Best Location Aware Apps
  - https://www.tomsguide.com/us/pictures-story/1042-best-location-aware-apps.html

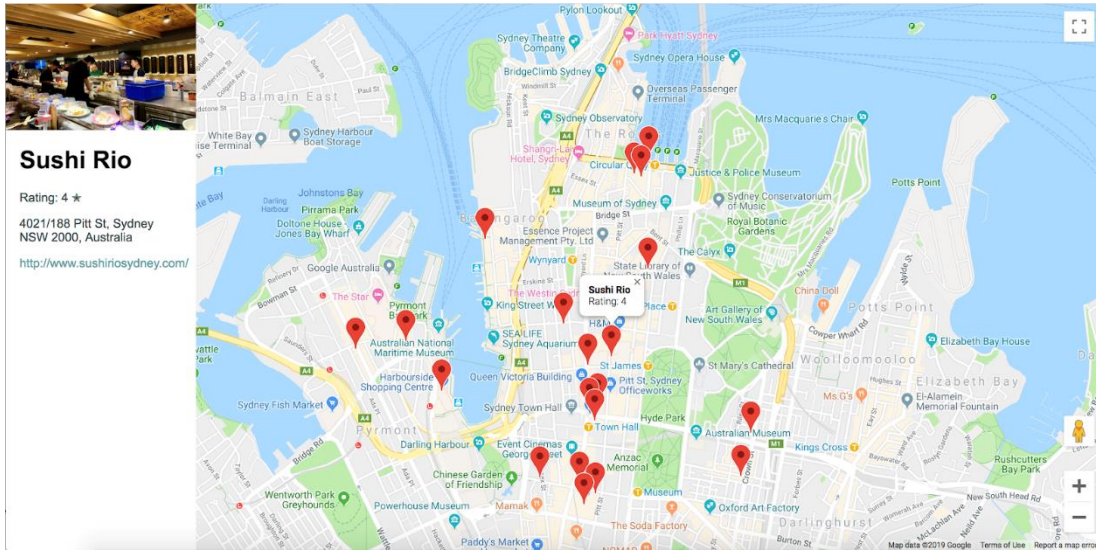
Location-based Services

- Examples of common LBS applications:
  - Where are you?
  - How best to get to a destination?
  - Whether friends are nearby?
  - Local weather forecast
  - Where businesses of interests in this area are located?
  - Companies to track packages, vehicles, buses, etc.
  - US 9-1-1 emergency localization by 2012

Location-based Search

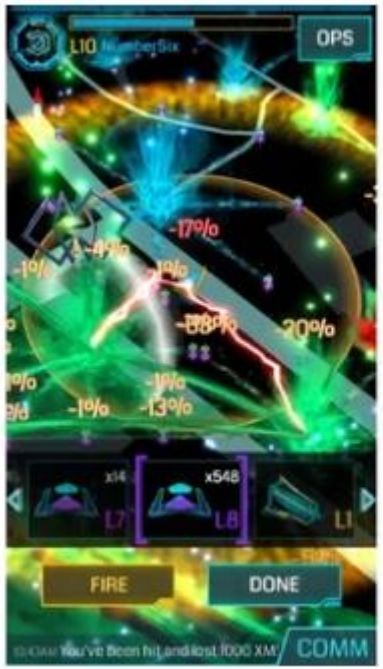
- Foursquare (Android, iOS)
  - Location-aware smart search tool focusing on discovery of nearby locations, events, restaurants and shops
- Google map
  - Digital map for location-aware search





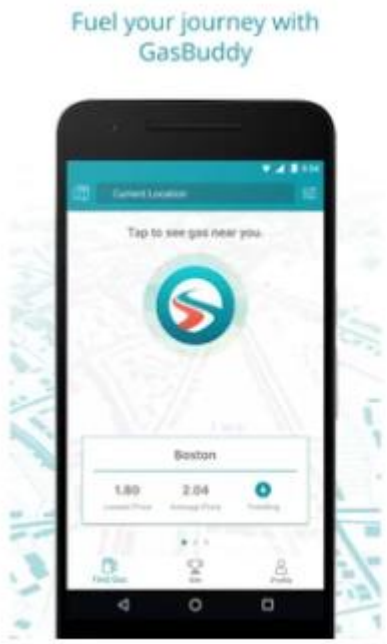
Location-based Games

- Combine the creature collection and monster battling gameplay of Nintendo's Pokémon with Niantic's augmented reality technology.
- Ingress



Location-based Information

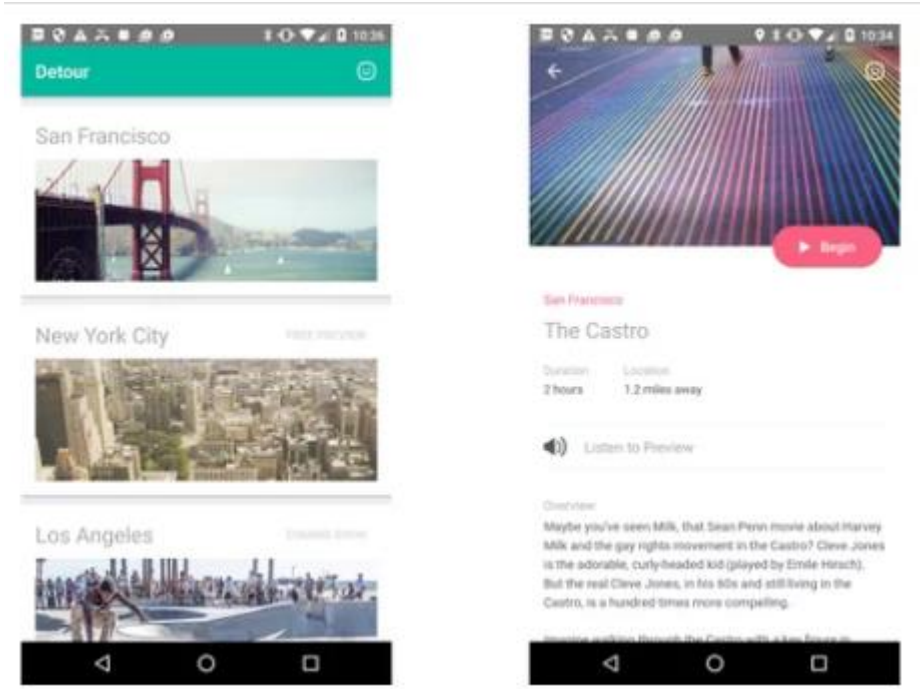
- Gas Buddy
  - A mobile app that helps users track down the cheapest nearby gas station based on their present location.



- Waze
  - A combination of social network and crowd-sourced traffic map, allowing drivers to report traffic conditions and incidents and share them in a living map to the benefit of all.

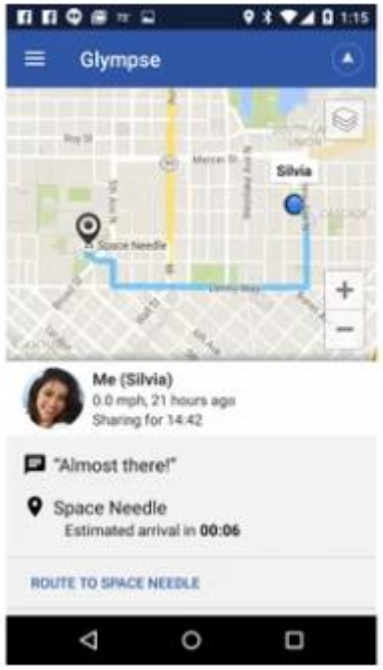
Location-based Tour Guides

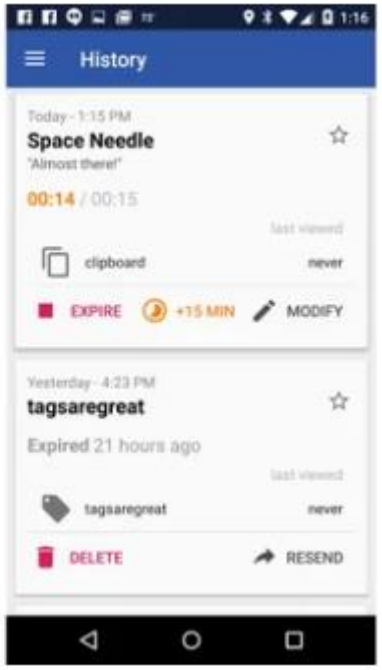
- NPS National Mall
  - Work as an excellent companion app to explore the historical buildings and monuments that surround the nation's capital.
- Detour
  - Provide guided walking tours of famous neighborhoods and landmarks of cities around the world.



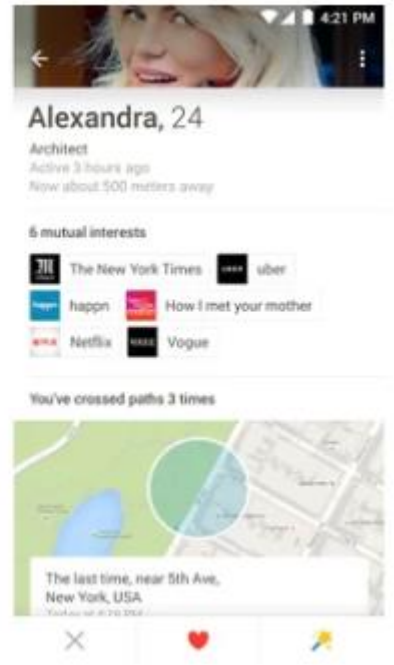
Social Networks

- Glympse
  - A popular location-sharing service that earns praise for its combination of features and ease of use.





- Happn
  - Highlight interesting people that you might have crossed paths with down the jogging path, cafe, or party.



LBS Systems

- Closed systems:
  - They do not have the capability of wireless communication.
  - Global positioning system (GPS) is a representative.
  - [Drawback] When there is something occurring (such as temporary close of roads or sudden car accident), it cannot be immediately reported by the system.
- Mobile location-based service (MLBS) systems:
  - They are based on wireless communications (such as WiFi, LTE-A) to provide positioning services.
  - [Example] You can call 119 via your mobile phone in case of emergency, where your position can be sent back to the nearby fire bureau.

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- Location-based services
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Data Types

- Point locations in terms of coordinates:
  - Physical or geometric locations
  - GPS: latitude and longitude, height
  - Cartesian coordinate system based on three orthogonal planes
- Extended region locations given by names:
  - Symbolic locations
  - YZU, Building I, Room 1102

Approaches

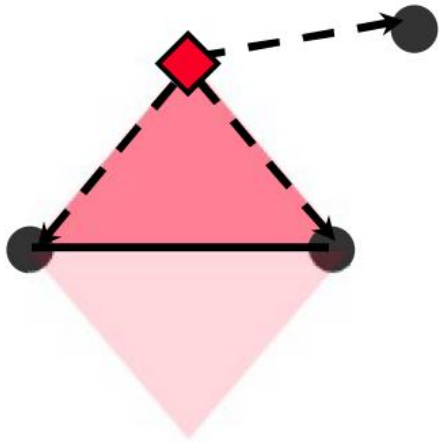
- Proximity: estimate distance between two nodes
- Trilateration and triangulation
  - Using elementary trigonometric properties: a triangle is completely determined,
    - if two angles and a side length are known
    - if the lengths of all three sides are known
  - Infer a 3D position from information about two triangles
- Fingerprinting (scene analysis)
  - Using radio characteristics as fingerprint to identify it
- Hybrid methods: multiple sources of information

Proximity and Distance

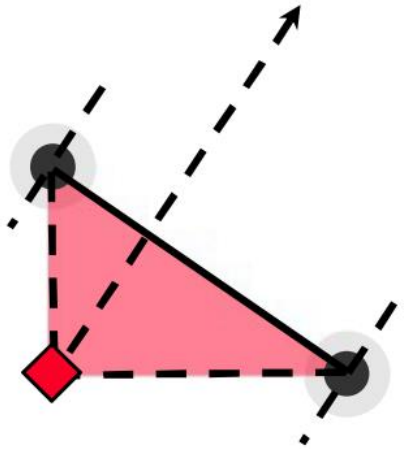
- Binary nearness: using finite range of wireless communication and/or threshold
  - within range of a beacon signal from a source with known position
  - yields region locations, e.g.: cell in cellular network
- Distance measurement (ranging)
  - Received signal strength
  - Time of flight (time of arrival)
  - Time difference of arrival

Measuring Location: Trigonometry Basics

- Triangles in a plane
- Lateration: distance measurement to known reference points
  - A triangle is fully determined by the length of its sides
  - Time of Flight (e.g. GPS, Active Bat)
  - Attenuation (e.g. RSSI)

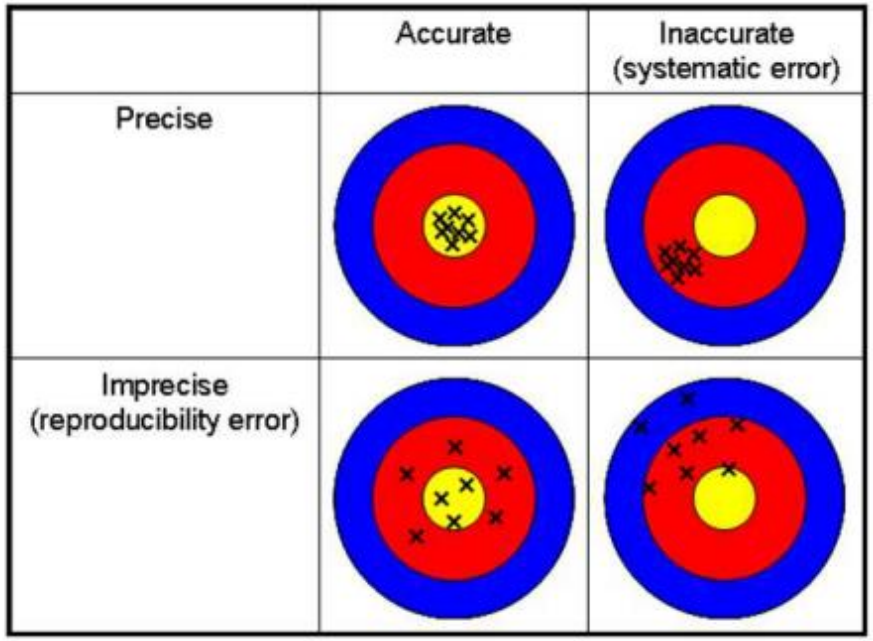


- Angulation: measuring the angle with respect to two known reference points and a reference direction or a third point
  - A triangle is fully determined by two angles and one side as shown
  - Phased antenna arrays
  - Aircraft navigation (VOR)



Quality of Position Information

- Positioning accuracy: largest distance between an estimated position and the true position
- Precision: the ratio with which a given accuracy is reached, averaged over many repeated attempts
  - Example: average error of less than 20cm in 95% of cases.



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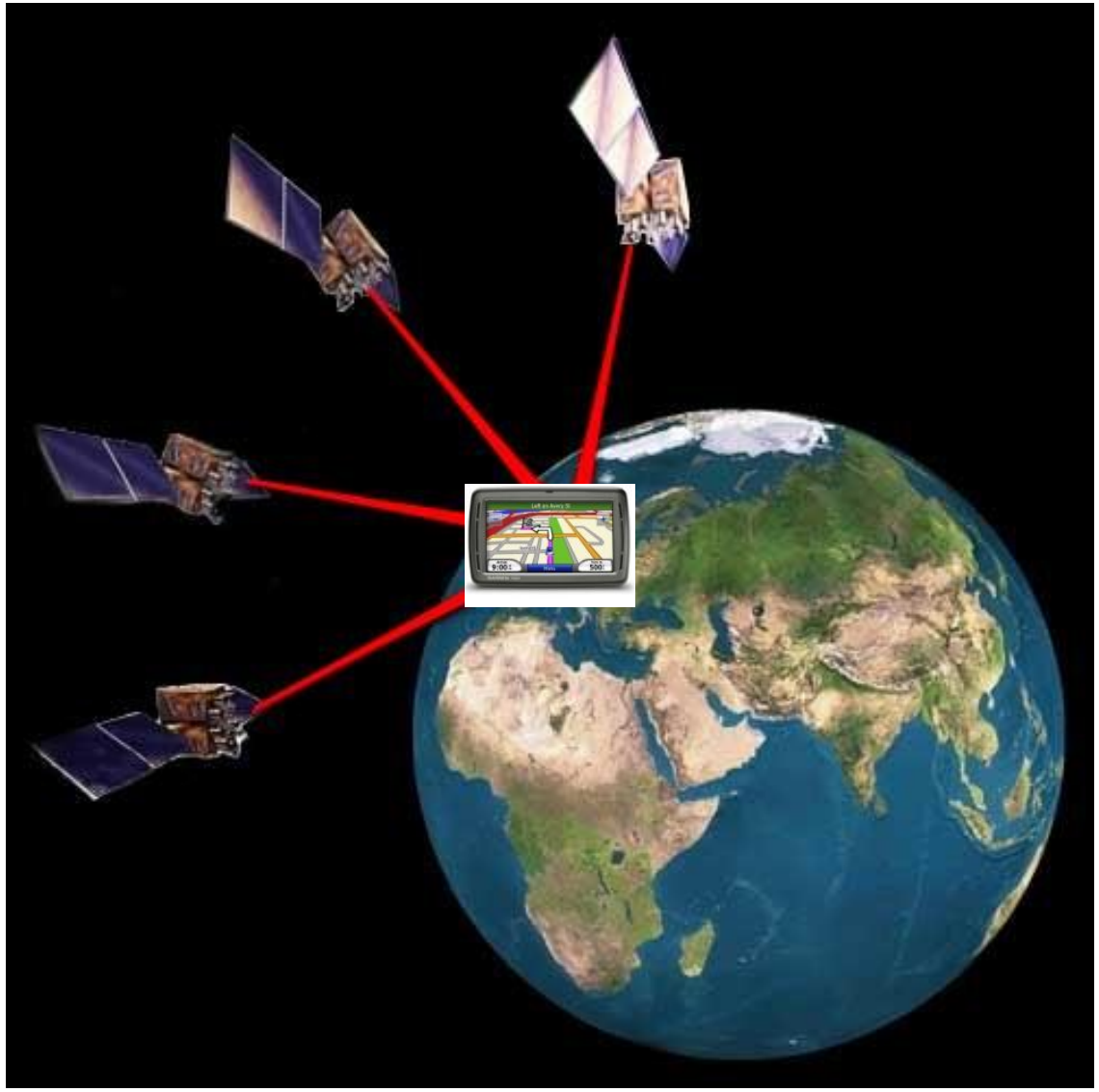
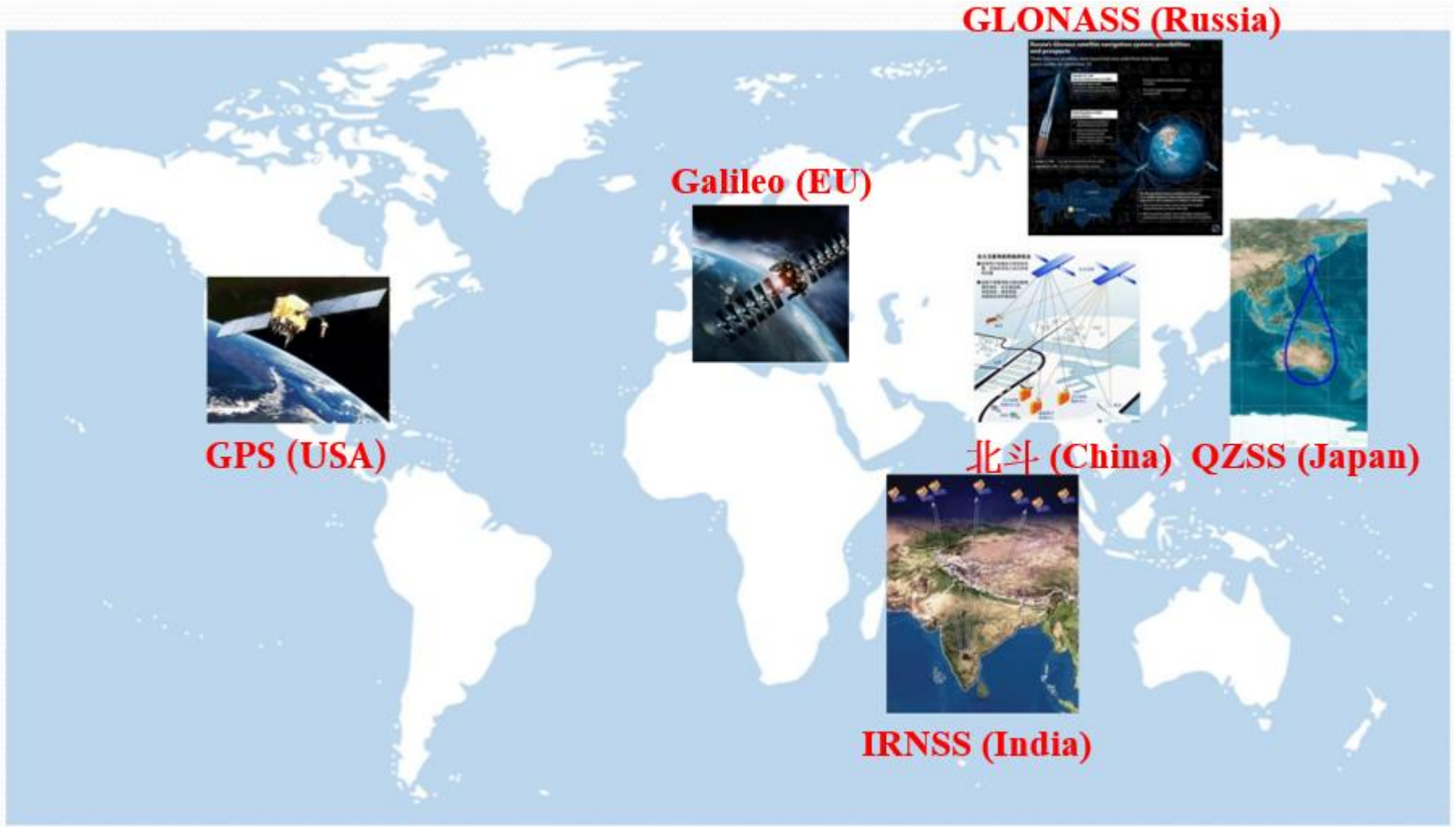
GPS Concept

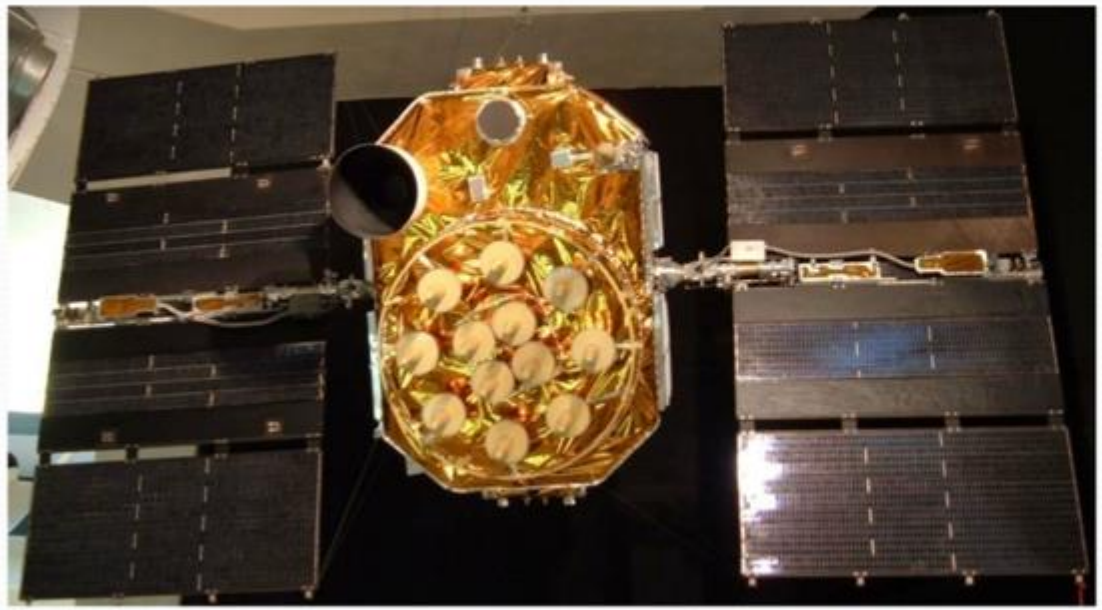


Global Navigation Satellite System



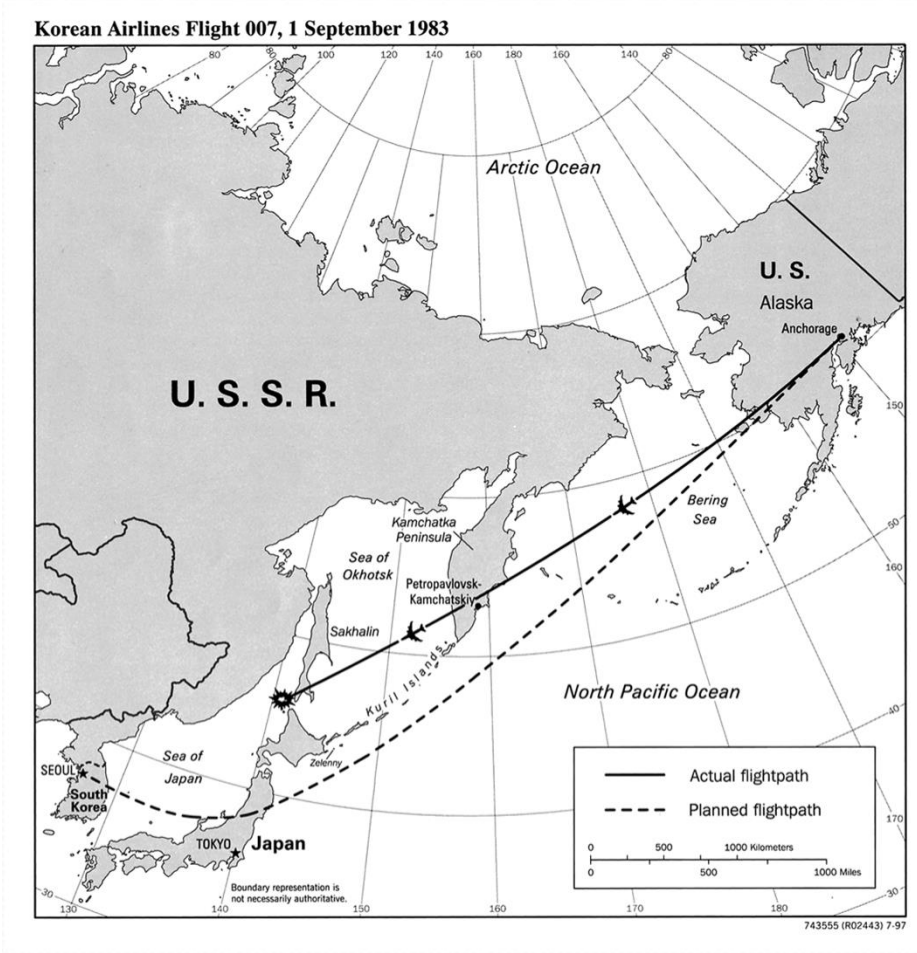
GPS History (1/2)

- GPS was developed by US Department of Defense in 1973 and completed established in 1995.
- GPS can provide 3D positioning service.

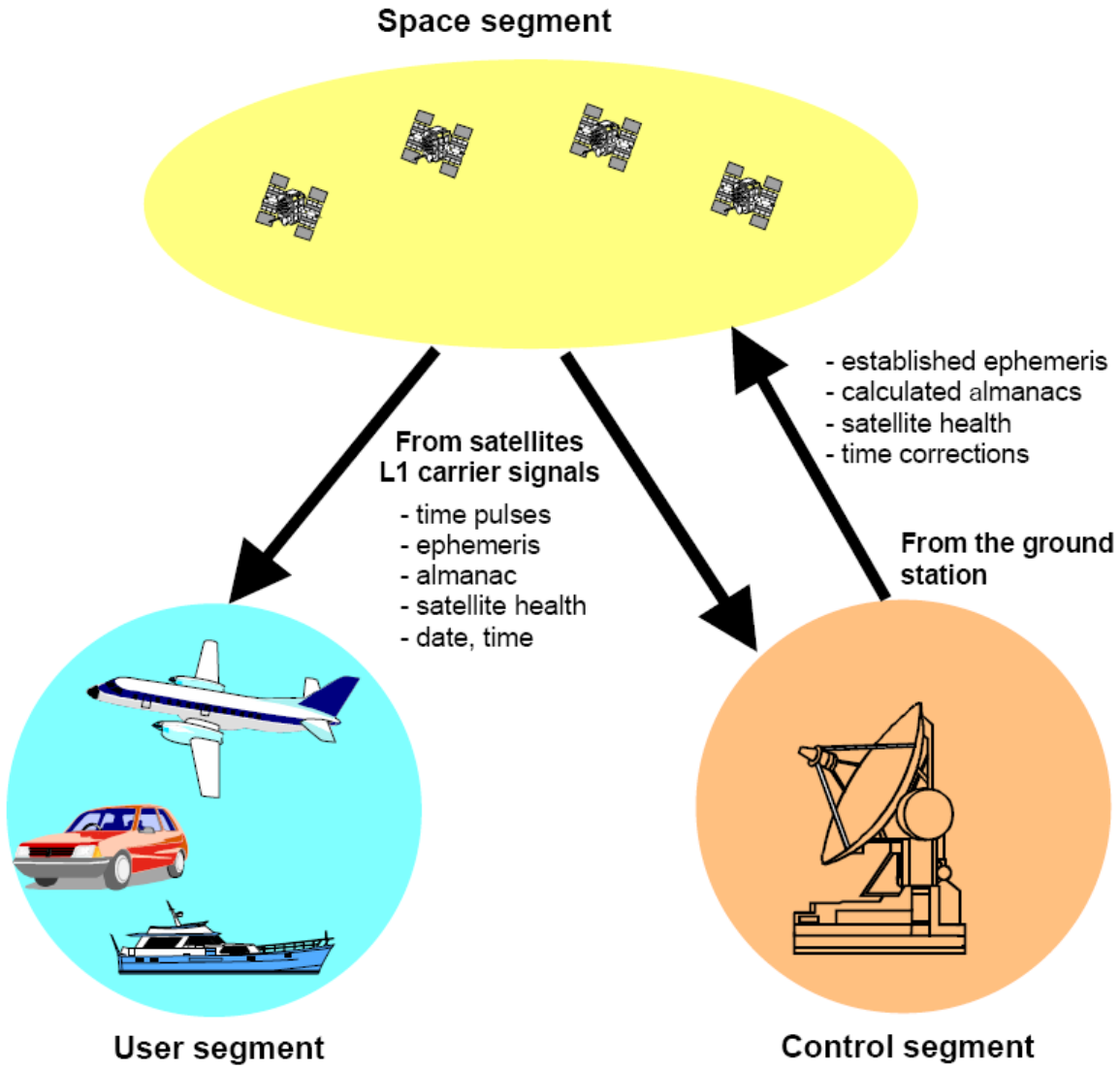


GPS History (2/2)

- In 1983/9/1, Korean Air Lines flight 007 flew to the territorial air space of USSR and was shoot down by USSR air force Su-15.
- Due to that accidence, US government announced to open parts of the GPS service for civil usage.



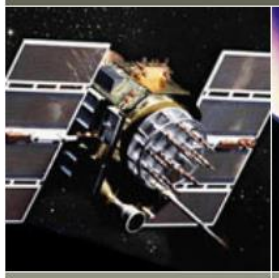
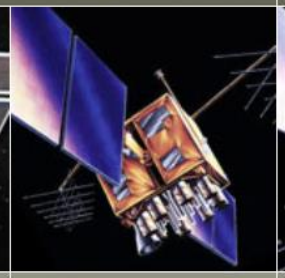
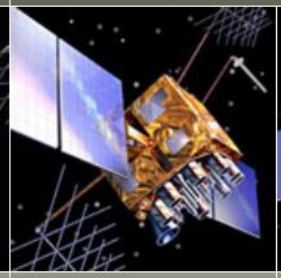
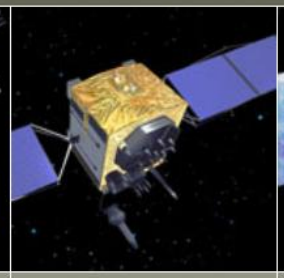
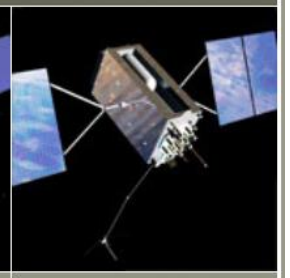
GPS Architecture



GPS Space Segment

- GPS system has 24 satellites (with 3 backup satellites).
  - They fly along 6 orbits, with the altitude of 20,200km.
  - Round-trip time: 11hr & 58min
  - Orbit inclination angle: 55°
  - Coordinate system: WGS 84
  - Each satellite is equipped with an atomic clock to provide precise timing.

GPS Satellites

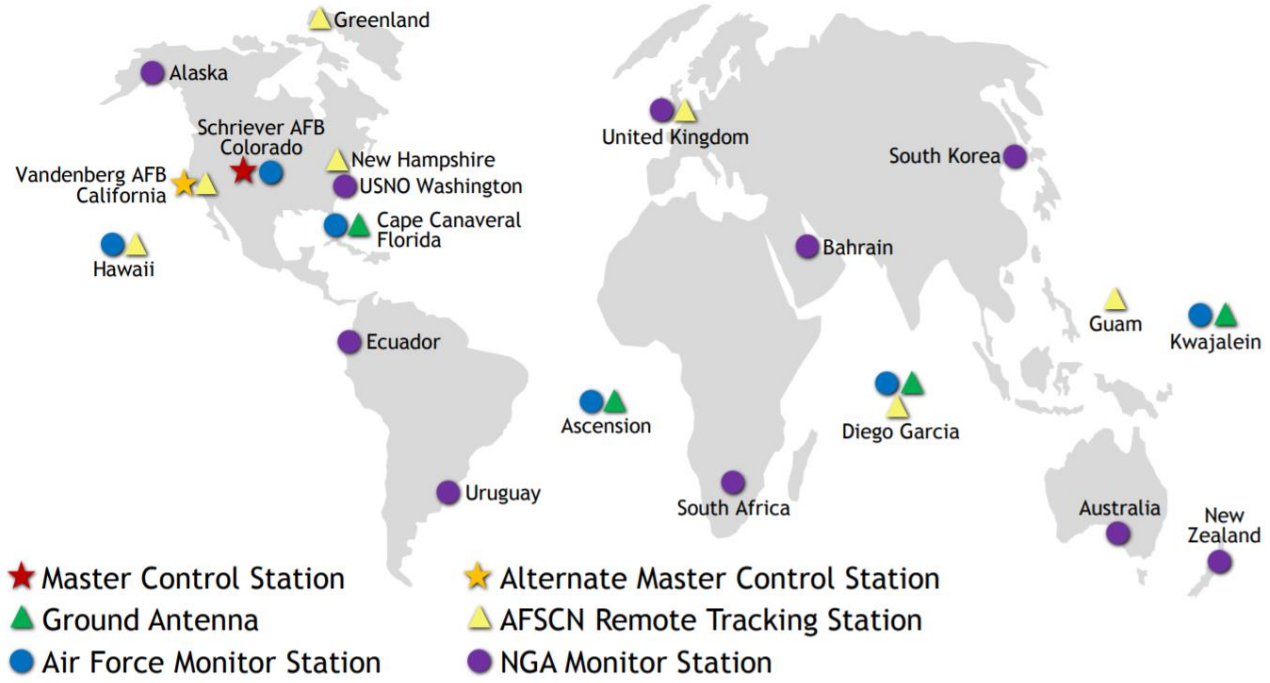
LEGACY SATELLITES		MODERNIZED SATELLITES		
				
BLOCK IIA	**BLOCK IIR**	**BLOCK IIR-M**	**BLOCK IIF**	**GPS III/IIIF**
1 operational	11 operational	7 operational	12 operational	1 in checkout
▪ Coarse Acquisition (C/A) code on L1 frequency for civil users ▪ Precise P(Y) code on L1 & L2 frequencies for military users ▪ 7.5-year design lifespan ▪ Launched in 1990-1997	▪ C/A code on L1 ▪ P(Y) code on L1 & L2 ▪ On-board clock monitoring ▪ 7.5-year design lifespan ▪ Launched in 1997-2004 *LEARN MORE ABOUT GPS IIR AT AF.MIL* ➡	▪ All legacy signals ▪ 2nd civil signal on L2 (L2C) *LEARN MORE* ➡ ▪ New military M code signals for enhanced jam resistance ▪ Flexible power levels for military signals ▪ 7.5-year design lifespan ▪ Launched in 2005-2009 *LEARN MORE ABOUT GPS IIR-M AT AF.MIL* ➡	▪ All Block IIR-M signals ▪ 3rd civil signal on L5 frequency (L5) *LEARN MORE* ➡ ▪ Advanced atomic clocks ▪ Improved accuracy, signal strength, and quality ▪ 12-year design lifespan ▪ Launched in 2010-2016 *LEARN MORE ABOUT GPS IIF AT AF.MIL* ➡	▪ All Block IIF signals ▪ 4th civil signal on L1 (L1C) *LEARN MORE* ➡ ▪ Enhanced signal reliability, accuracy, and integrity ▪ No Selective Availability *LEARN MORE* ➡ ▪ 15-year design lifespan ▪ IIIF: laser reflectors; search & rescue payload ▪ First launch in 2018

Satellite Orbits

- 24 satellites are needed to guarantee that 4 are always visible everywhere
- Extra satellites provide redundancy
  - Deal with maintenance, replacement, …

Control Segment (1/2)

- Master control stations:
  - Located in the Schriever air base, Colorado, USA
  - Collect data from monitoring stations.
  - Calculate the satellite orbits.
  - Regulate timing.



Control Segment (2/2)

- Monitoring stations
  - Track GPS satellites as they pass overhead
  - Collect navigation signals, range/carrier measurements, and atmospheric data.
  - Feed observations to the master control station
- Ground antennas
  - Send commands, navigation data uploads, and processor program loads to the satellites.
  - Collect telemetry.

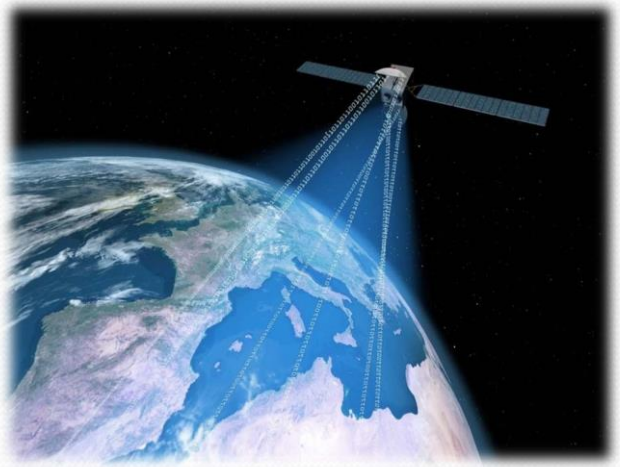
User Segment

GPS Involves 5 Basic Steps

- Satellite Ranging
  - Determining distance from satellite
- Trilateration
  - Intersection of spheres
- Timing
  - Why consistent, accurate clocks are required
- Positioning
  - Knowing where satellite is in space
- Correction of errors
  - Correcting for ionospheric and tropospheric delays

How GPS Works?

- Find a satellite and calculate the distance to that satellite.
  - Distance = time delay * speed of light
- Use trilateration to determine your position or “fix”.
  - Intersection of spheres
- At least 3 satellites required for 2D fix
- Use extra satellites to support 3D positioning.
- Correct the positioning errors due to environment.

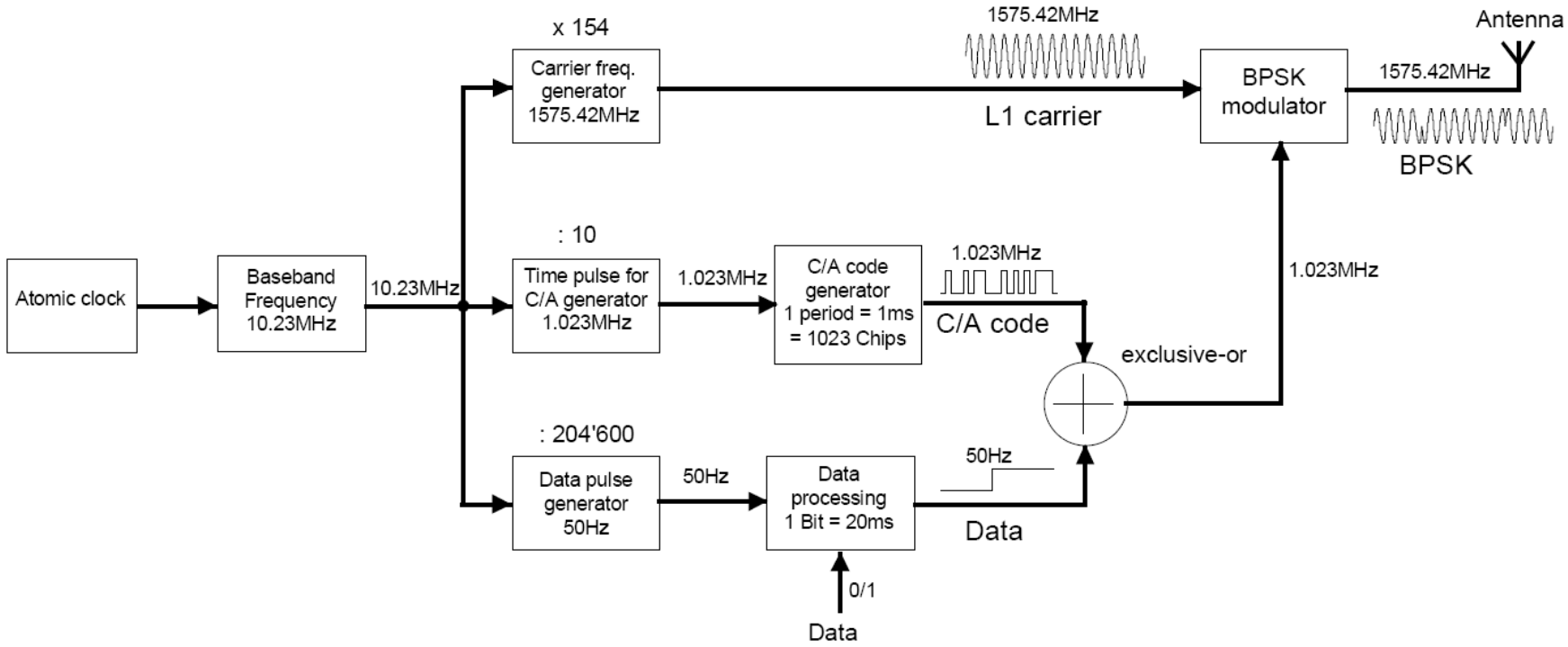


Types of GPS Services

- Standard positioning service (SPS):
  - It operates on GPS L1 frequency, which contains coarse acquisition code (C/A code, for civil usage).
  - Positioning accuracy < 12.8 meters
  - Timing accuracy < 40 nanoseconds
- Precise positioning service (PPS):
  - This service requires the authorization from USA government.
  - It operates on both GPS L1 and L2 frequencies, and also transmits precise code (P(y) code, for military usage).
  - Positioning accuracy < 11.8 meters
  - Timing accuracy < 40 nanoseconds

GPS Signals

- L1 carrier: 1575.42MHz, L2 carrier: 1227.6 MHz
- PRN (pseudo random noise): as satellite identification
  - C/A (coarse acquisition) code, P (precise) code



GPS Operating Bands

- L frequency bands for GPS signals:

L band	Frequency	Purpose
L1	1575.42 MHz	C/A code, P(y) code, L1C code (future)
L2	1227.60 MHz	P(y) code, L2C code (future)
L3	1381.05 MHz	Detection of high-energy activity (nuclear detonation)
L4	1379.91 MHz	Correctness of errors caused by ionosphere
L5	1176.45 MHz	Safety-of-Life (SoL) signals

- GPS uses pseudo-random noise (PRN) to identify satellites.
  - C/A code: Commercial GPS receivers
  - P(y) code: Military purpose

Selective Availability

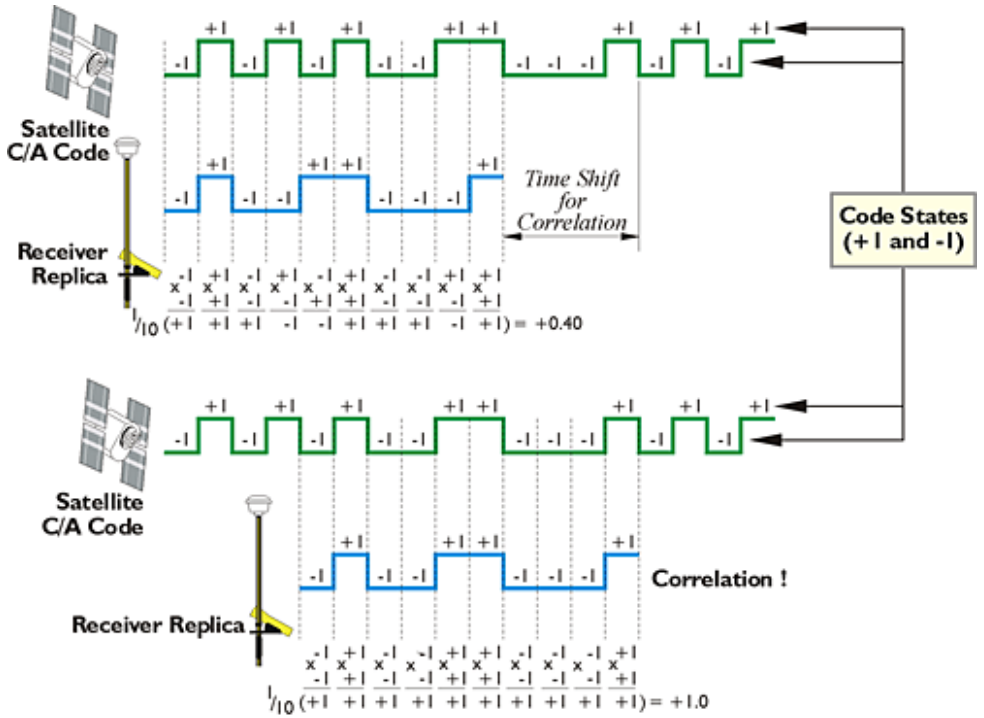
- For military purpose, USA government introduces selective availability (SA) to GPS so as to intentionally add errors to satellite clocks and broadcast inaccurate orbit parameters.
  - The positioning inaccuracy will increase to 100 meters.
  - When turning off SA, the positioning inaccuracy will decrease to 15 meters.
  - In 2000/05/02, President Clinton announced to cancel the SA function.

Satellite Positions

- Each satellite has an atomic clock that keeps time very accurately
  - Satellites synchronize their clocks
  - Also periodically synchronize with the true time maintained on earth
- Satellites also know their location very accurately.

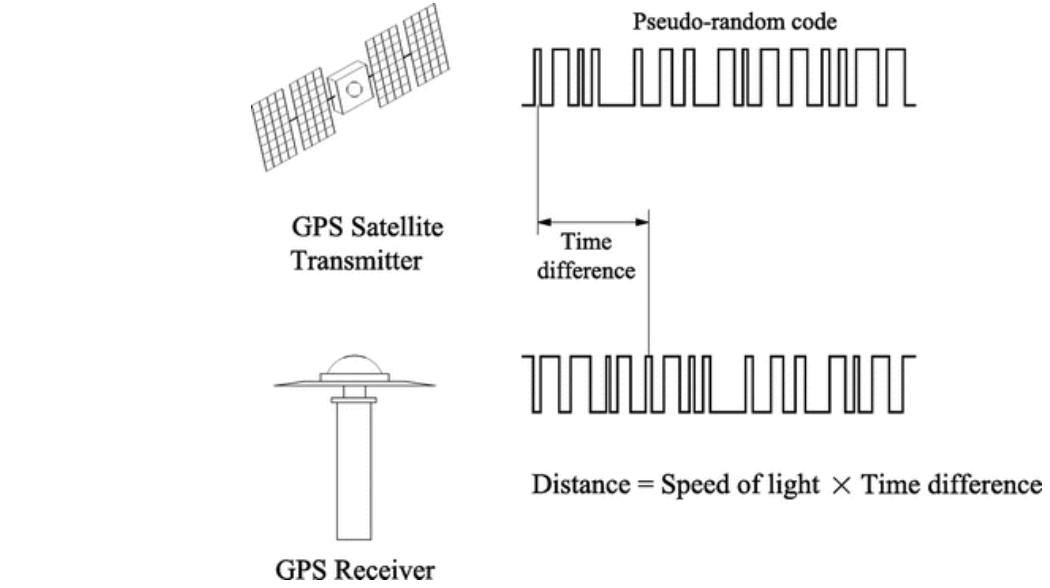
Step 1: Find a Satellite & Ranging

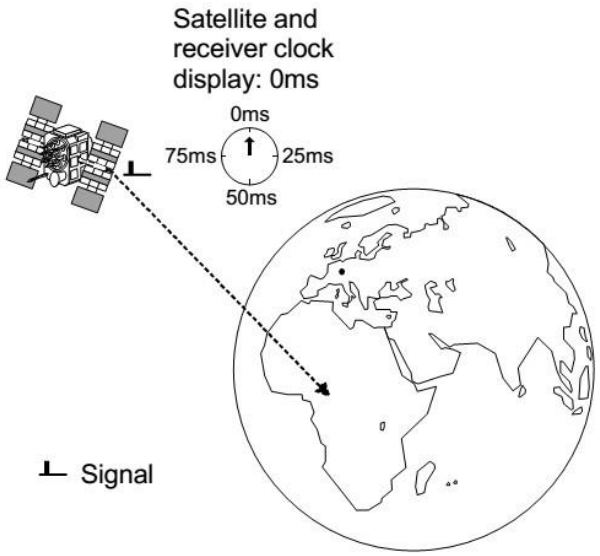
- Once your GPS receiver obtain the signal from a satellite, it can employ the time-to-arrival (ToA) scheme to calculate the distance to that satellite.
  - Distance = velocity × time.
  - Velocity: Light speed (i.e., 299,792,458 meters per second).
- GPS Lock



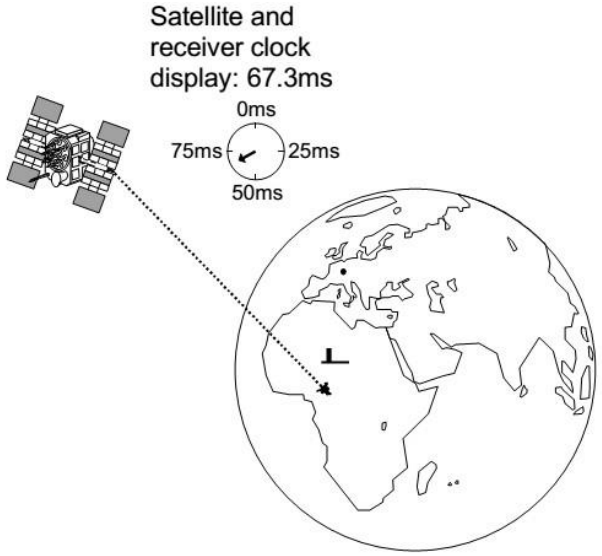
Determining Range

- Each satellite periodically generates a pseudo random code
  - Receivers also locally generate the codes in synchronized fashion
- Receivers measure Time of Arrival (TOA) of codes
- Transmission includes Time of Transmission (TOT) of code and the location of the satellite at that time
  - Allows receiver to calculate Time of Flight and distance





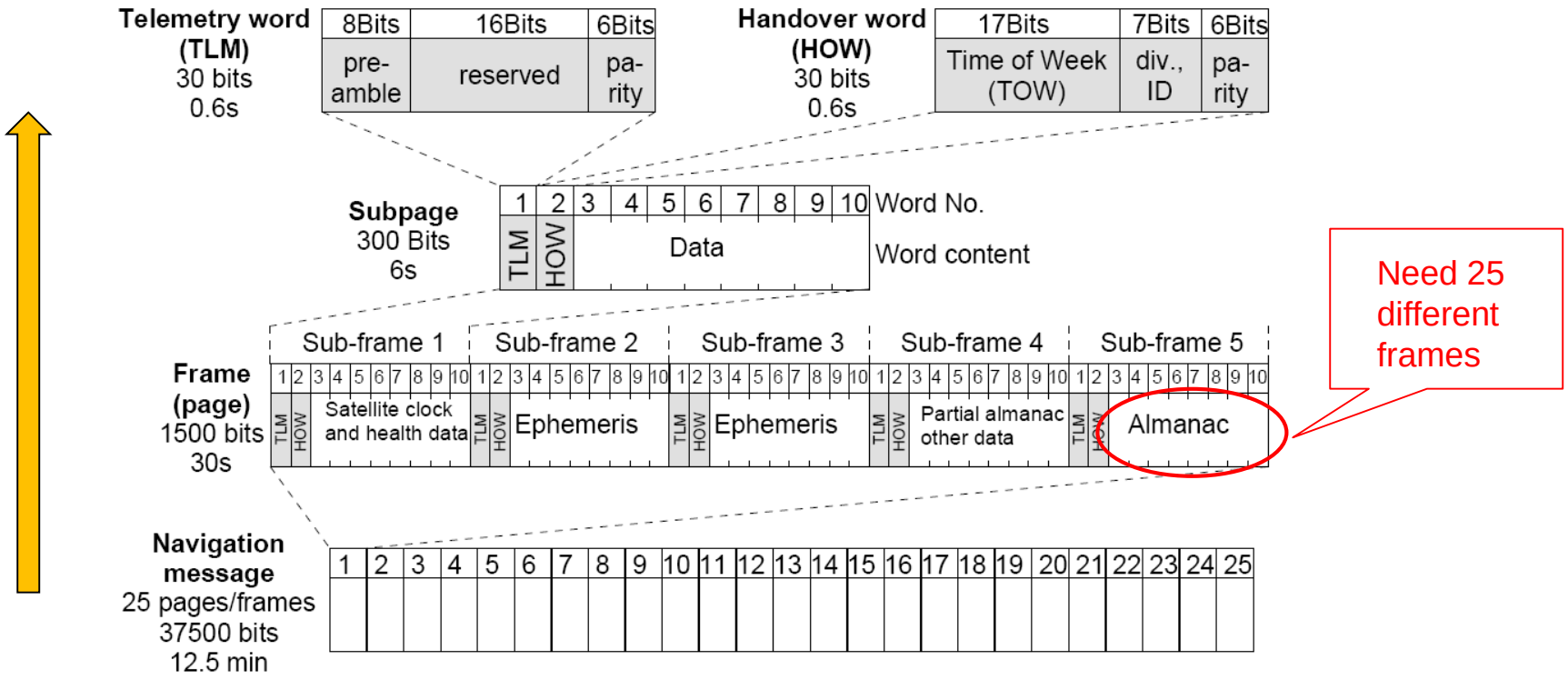
Signal transmission (start time)



Signal reception (stop time)

Navigation Messages

- System time and clock correction values
- Its own highly accurate orbital data (ephemeris)
- Approximate orbital data for all other satellites (almanac)
- System health, etc.



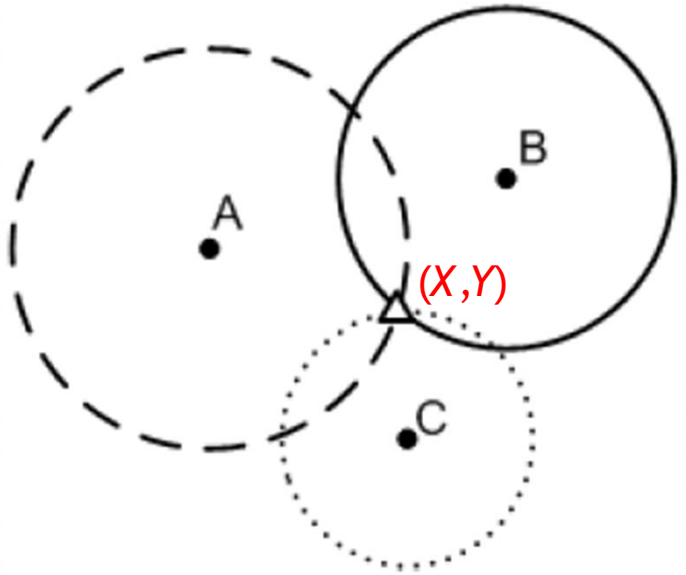
Step 2: Trilateration

- Let (X, Y) be the position of your GPS receiver.
- The positions of satellites A, B, and C are (x1, y1), (x2, y2), and (x3, y3), respectively.
- The distance between your GPS receiver and satellites A, B, and C are r1, r2, r3, respectively.
- Then, we can derive position (X, Y) by

$$r_1^2 = (X - x_1)^2 + (Y - y_1)^2$$

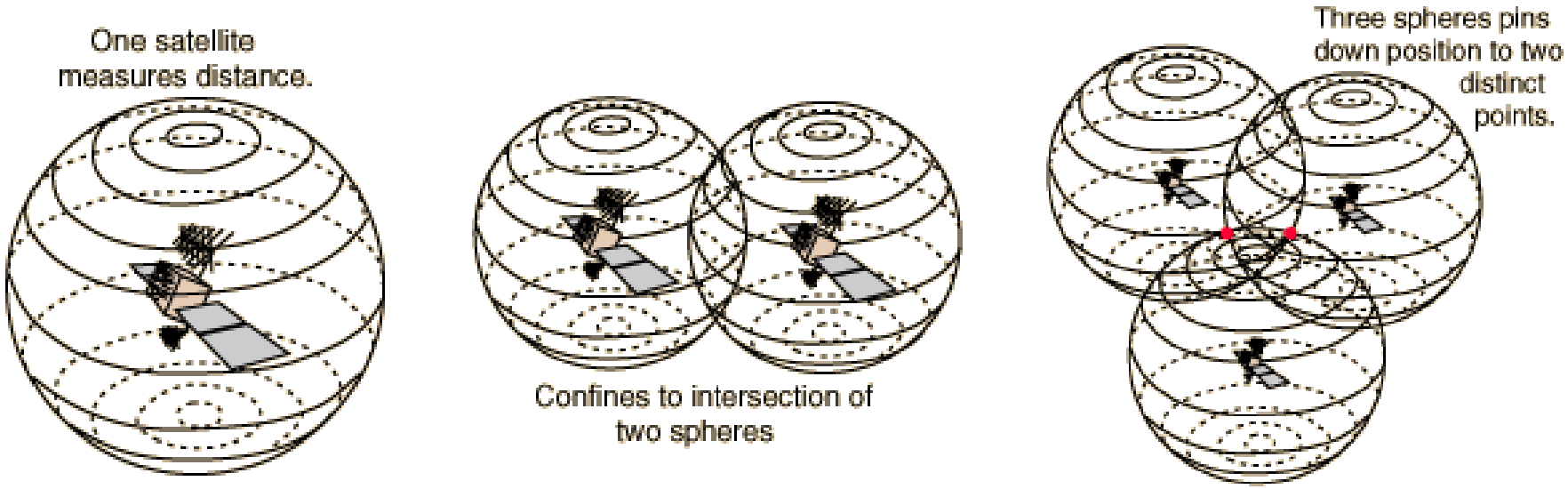
$$r_2^2 = (X - x_2)^2 + (Y - y_2)^2$$

$$r_3^2 = (X - x_3)^2 + (Y - y_3)^2$$



Step 3: Amend the Result

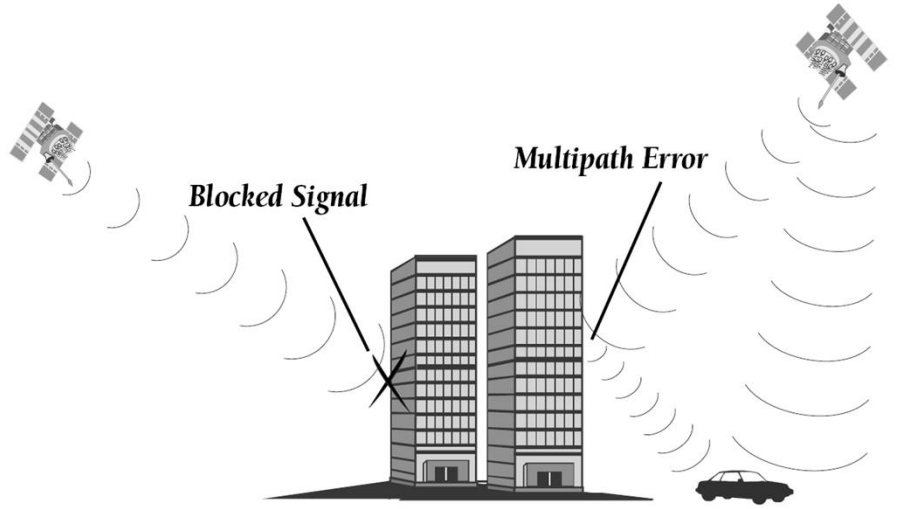
- GPS uses three satellites to localize a receiver but the positioning result can be applied to only the 2D plane.



- Therefore, it requires the fourth satellite to amend the positioning result in the 3D space.

Step 4: Correct Errors

- The final positioning result can be obtained by correcting the following errors:
  - Latency caused by the atmosphere (especially ionosphere and troposphere)
  - Multi-path effect
  - Time difference at the GPS receiver
  - Satellite clock errors
  - Orbit inaccuracy
  - Number of satellites

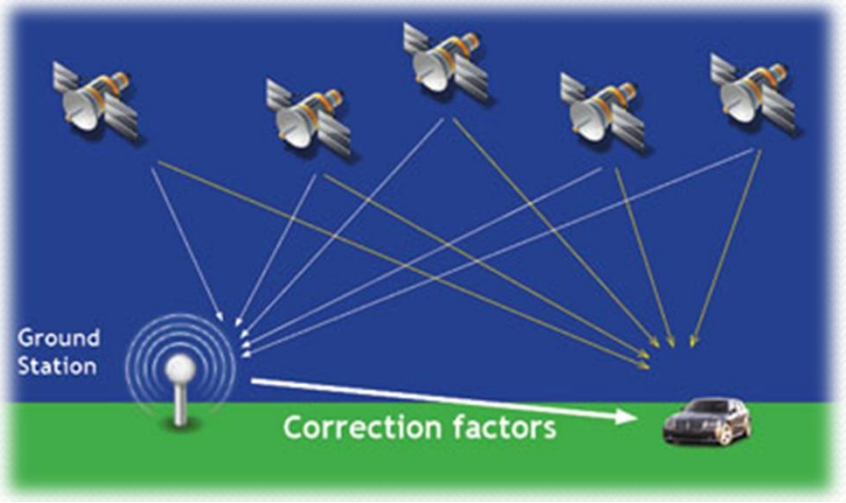


Assisted GPS

- Enhance GPS startup performance
  - Measure by time-to-first-fix (TTFF).
- Obtain navigation messages through mobile networks (control plane) or data networks (user plane)

Differential GPS

- DGPS uses ground-based reference stations to help measure the difference between the actual (or internally computed) pseudo-ranges and the measured satellite pseudo-ranges.
  - It then broadcasts the difference and known position.
  - GPS receivers may correct their pseudo-ranges by the same amount.
  - DGPS can improve positioning accuracy from 15m (nominal GPS) to about 10cm.



NMEA Messages

- NMEA 0183 (or NMEA for short) is a combined electrical and data specification for communication
  - Between marine electronic devices such as echo sounder, sonars, anemometer, gyrocompass, autopilot, GPS receivers and many other types of instruments.
- It has been defined by, and is controlled by, the U.S.-based National Marine Electronics Association.

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$GPGGA,092750.000,5321.6802,N,00630.3372,W,1,8,1.03,61.7,M,55.2,M,,*76
$GPGSA,A,3,10,07,05,02,29,04,08,13,,,,,1.72,1.03,1.38*0A
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$GPGSV,3,2,11,02,39,223,16,13,28,070,17,26,23,252,,04,14,186,15*77
$GPGSV,3,3,11,29,09,301,24,16,09,020,,36,,,*76
$GPRMC,092751.000,A,5321.6802,N,00630.3371,W,0.06,31.66,280511,,,A*45
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Outline

- Location-based services
- Positioning concepts
- Global navigation satellite system
- Positioning technology by wireless networks

How about Indoors?

- We can use received WiFi signal strength (RSS) to measure distance to APs with known location.
- Does not work in practice: too many factors affects RSS: objects, people, …
  - Results of triangulation based on RSS tend to give large, unpredictable errors
- How about using time of arrival?
  - e.g., based on sound, radar-like techniques, …
  - Works better, but it is still hard
  - Can work well but often requires special infrastructure
  - Reflections can also create inaccuracies: longer path.

Positioning Technologies

- Proximity: estimate distance between two nodes
- Trilateration and triangulation
  - Using elementary trigonometric properties: a triangle is completely determined,
    - if two angles and a side length are known
    - if the lengths of all three sides are known
  - Infer a 3D position from information about two triangles
- Fingerprinting (scene analysis)
  - Using radio characteristics as fingerprint to identify it
- Hybrid methods: multiple sources of information

Positioning Technologies

- Positioning technology realized by wireless networks:
  - Cell identification
  - Time of arrival (ToA)
    - Trilateration positioning
  - Time difference of arrival (TDoA)
  - Angle of arrival (AoA)
  - Received signal strength (RSS) localization

Cell Identification

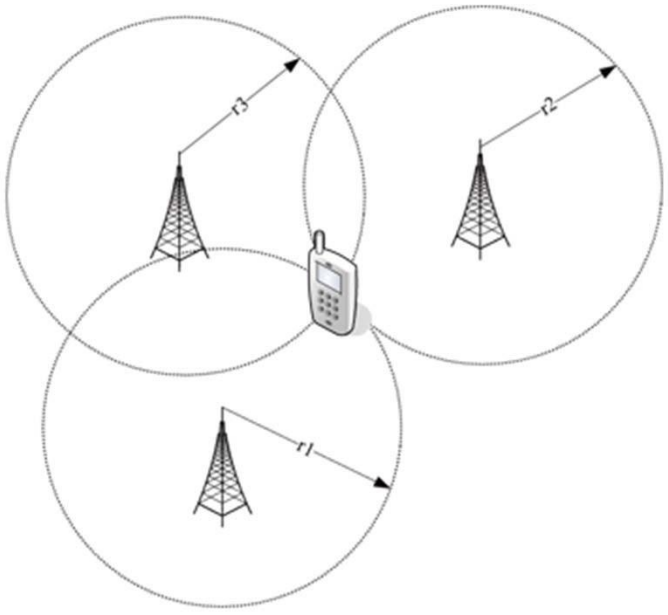
- Cell identification uses the associated cellular base station to localize a mobile phone.
  - It is the simplest positioning technology.
- The accuracy of this scheme depends on the coverage range and density of base stations.
  - In countryside, the error rate is larger.
  - In urban, the error rate can decrease due to high density of base stations.
  - Average inaccuracy: 200m ~ 2km

ToA

- ToA is based on signal transmission time.
  - According to the arrival time of a transmission signal, the base station can estimate the distance between it and the mobile phone.
  - Then, we can localize the mobile phone via trilateration scheme.
- ToA requires strict time synchronization among base stations to monitor the signal emitted from a mobile phone.
  - Even with a small error of just 1 microsecond (10^{-6} seconds), the positioning inaccuracy will increase to 200~300 meters.

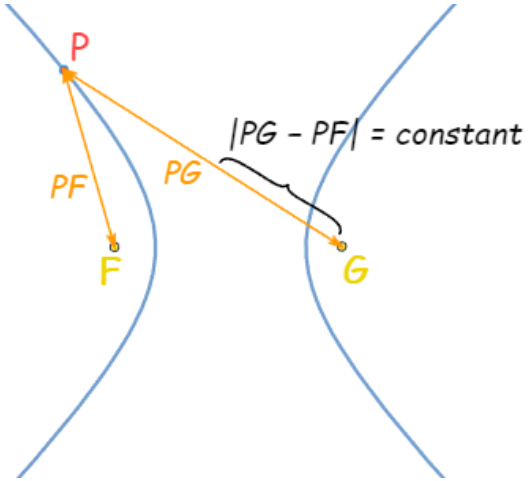
Trilateration

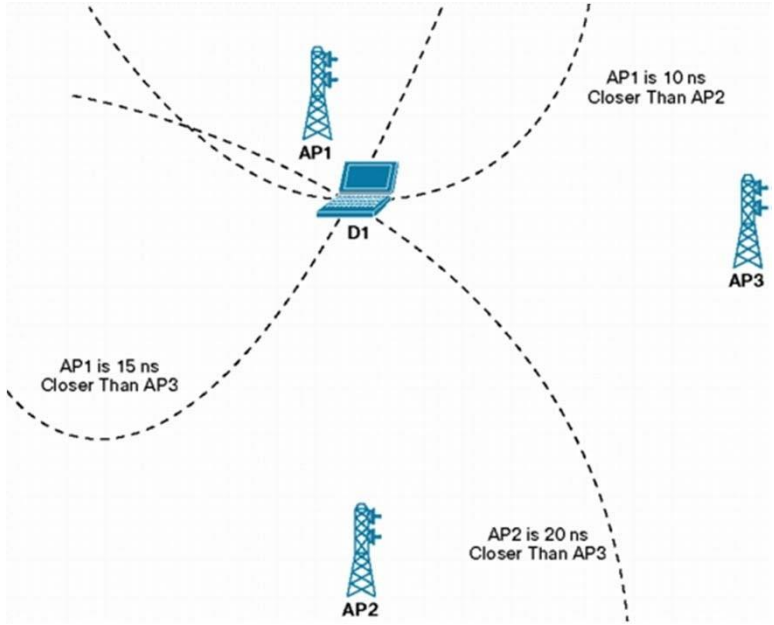
- Trilateration positioning uses the intersection point of cell coverage to identify a mobile phone.
  - When a mobile phone obtains the signal from a base station, it can calculate its distance R to that base station (using signal strength).
  - We can draw a circle centered at the base station with radius R.
  - Then, the position of the mobile phone is the intersection point of three circles.



TDoA (1/2)

- TDoA is an improvement of ToA, which is also based on the transmission time of a signal.
  - It requires a reference base station and multiple auxiliary base stations to calculate the distance, which is realized based on the time difference of their received signals.
  - We can get the position of a mobile phone by using hyperbola formulas.



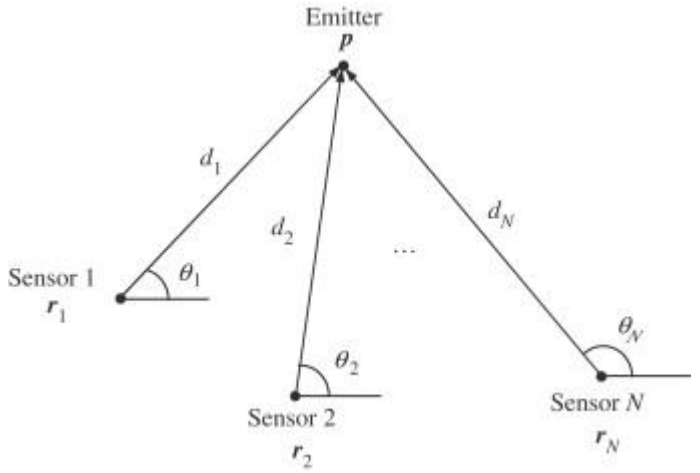


TDoA (2/2)

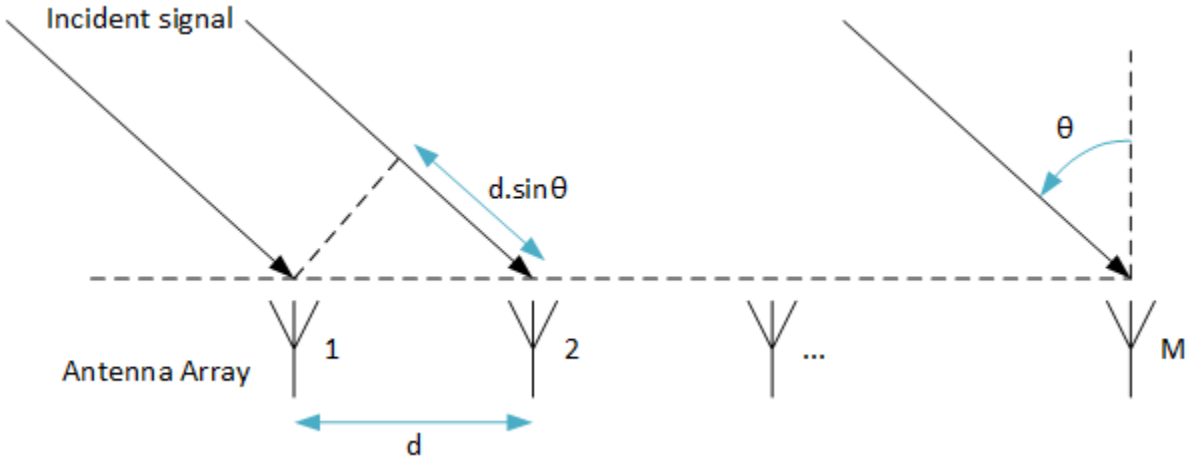
- Comparing with ToA, TDoA is easier to implement.
  - TDoA can work well without time synchronization between the mobile phone and base stations.

AoA

- Estimate the position by received angles.



- MIMO for measuring received angle
  - The phase-shift difference of the received signal arriving at antennas equally separated by a "d" distance

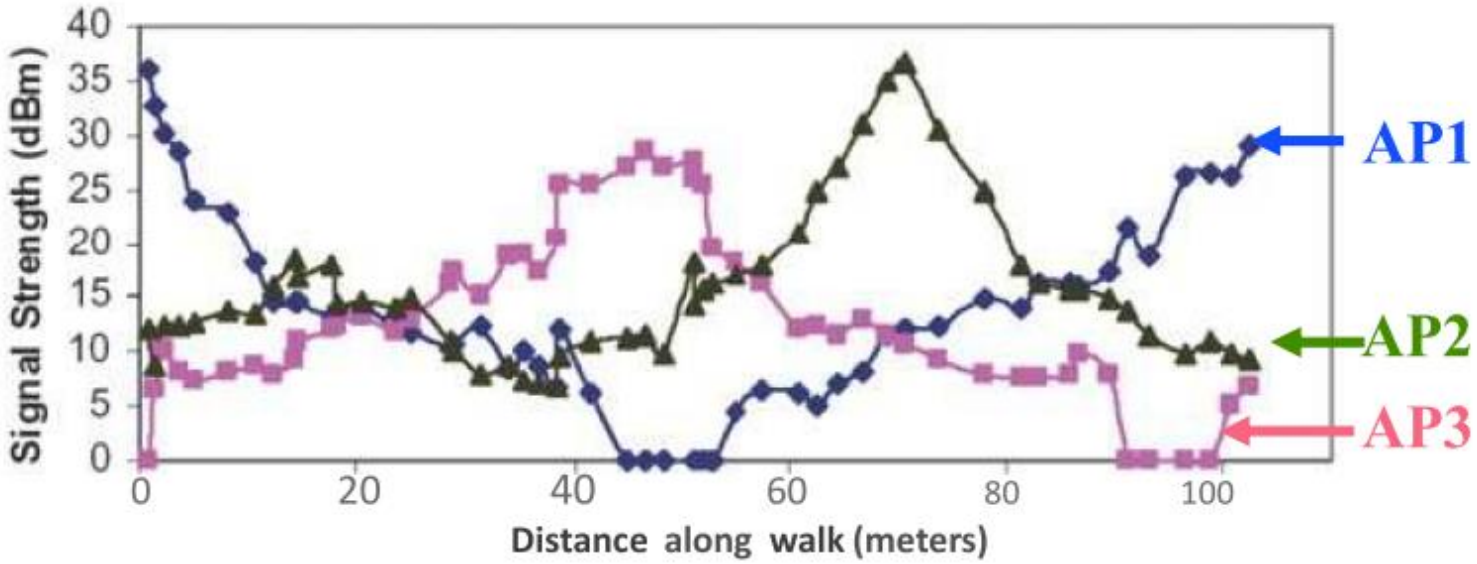


Location Fingerprinting

- Fingerprint methods for recognizing locations
- Examples
  - Visual identification of places from photos
  - Recognition of horizon shapes
  - Measurement of signal strengths of nearby networks (e.g. RADAR)
- Method: computing the difference between a feature set extracted measurements with a feature database
- Advantages: passive observation only (protect privacy, prevent communication overhead)
- Disadvantage: access to feature database needed

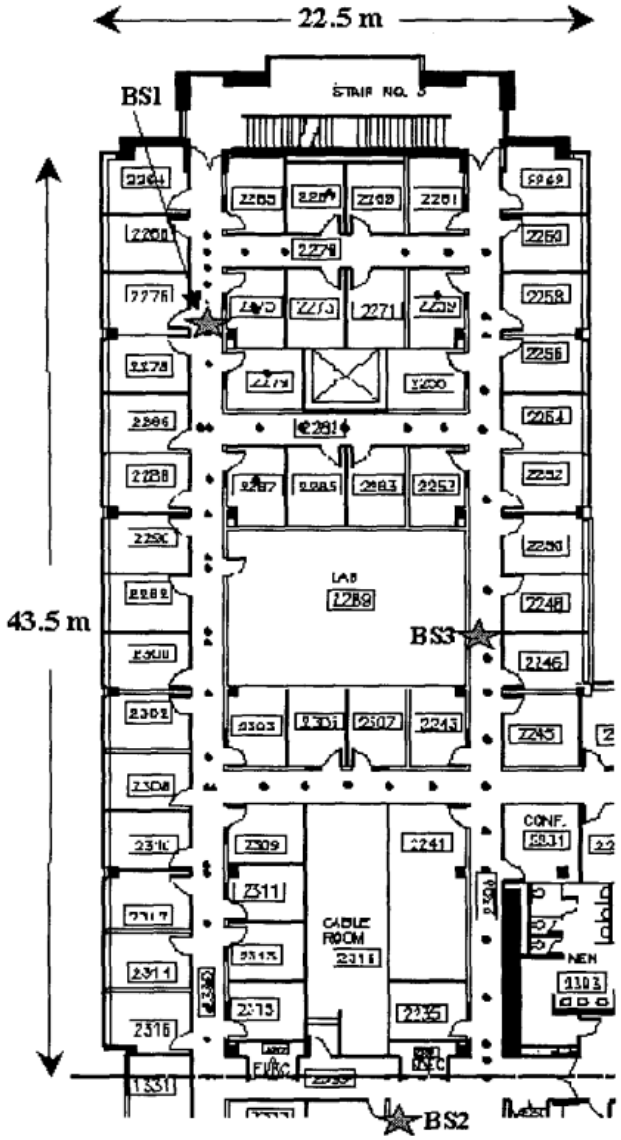
RADAR: Key Idea

- RSS from multiple APs tends to be unique to a location.



RADAR Approach

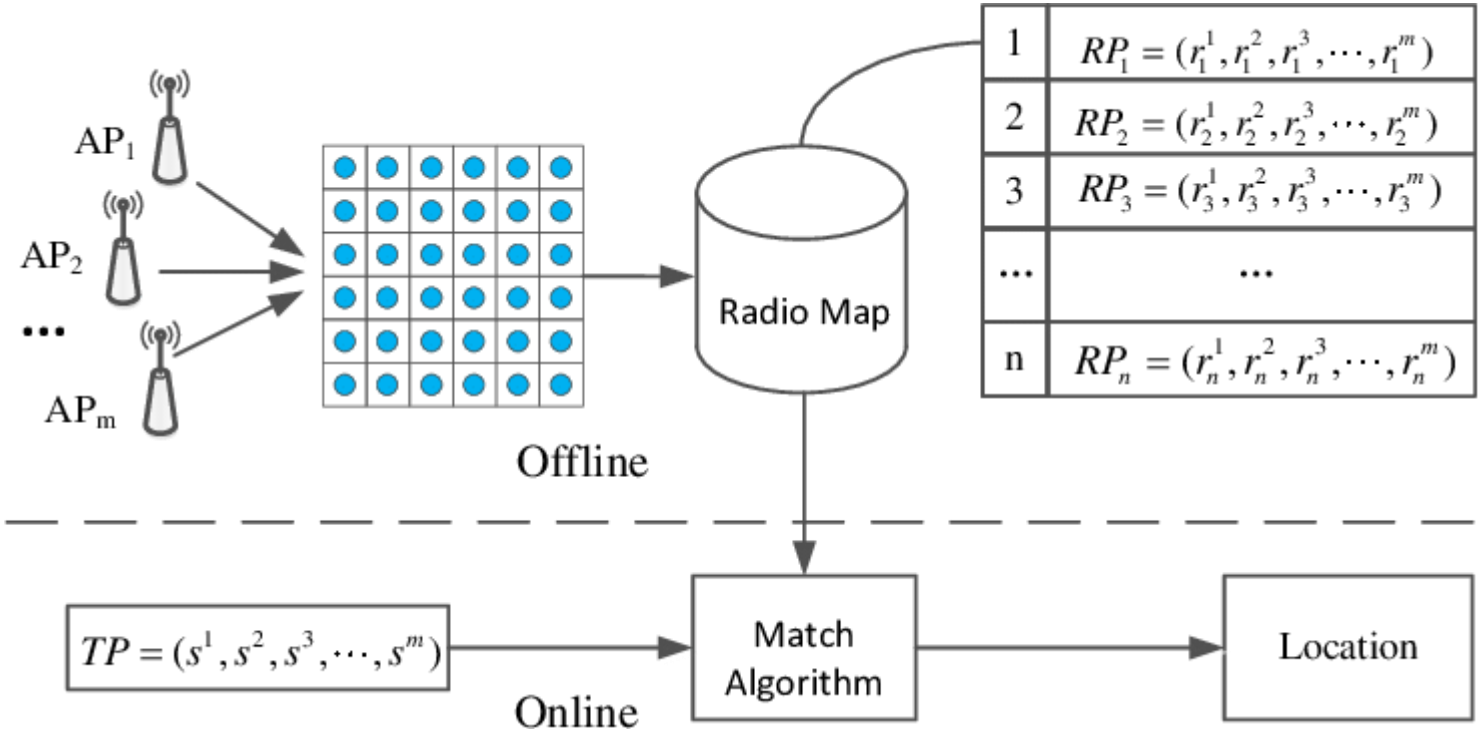
- Scenario: floor layout with three base stations (in the hallways)
- Empirical method
  - offline phase: database is constructed
    - Collect signal strength measurements from all three base stations at 70 distinct locations
    - Store each of the 70 measurement triples together with the spatial location and orientation in a database
  - online phase: position can be determined
    - Measure the current signal strength from all three base stations
  - Find the most similar triple(s) in the database
  - Resolution 2.94m (50 th percentile)



RSS Localization

- RSS localization is a two-phase positioning technology.
- Training phase (offline):
  - This phase uses mobile phones to collect signal strength from different base stations at a set of points P in advance and then constructs radio map in the region of interest.
- Positioning phase (online):
  - By comparing the radio map and the received signal strength, a mobile phone can choose the nearest location in P as its position (or using interpolation method).
- RSS localization can be used in an indoor environment.

RSS Localization (2/3)

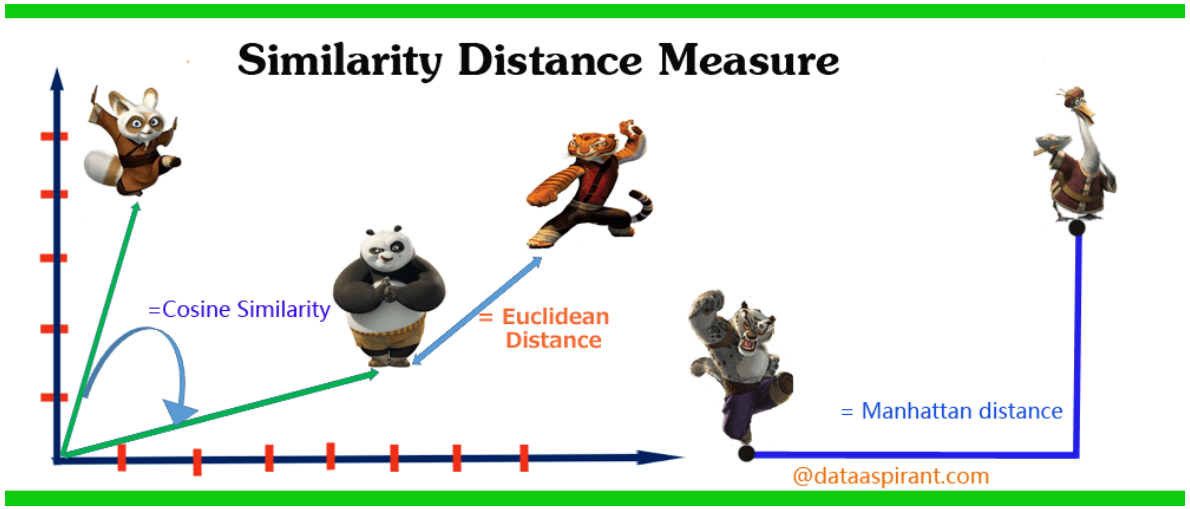


Match Algorithm (1/2)

- Distance (Similarity)
  - Evaluate the difference of a captured fingerprint and a known fingerprint in the radio map database.
  - Ex: Euclidean distance

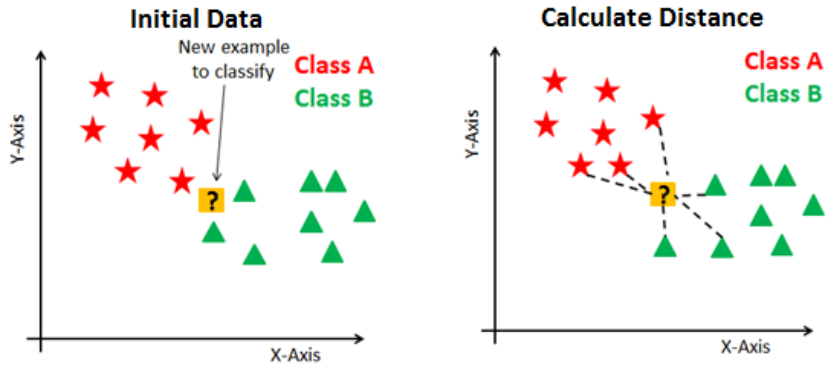
$$d(\mathbf{p},\mathbf{q}) = d(\mathbf{q},\mathbf{p}) = \sqrt{(q_1 - p_1)^2 + (q_2 - p_2)^2 + \cdots + (q_n - p_n)^2}$$

$$= \sqrt{\sum_{i=1}^{n}(q_i - p_i)^2}.$$



Match Algorithm (2/2)

- *K*-nearest neighbor (KNN)
  - Find the k nearest neighbor (with the lowest distance) and use the location of these neighbors for estimating the position.
    - Ex: Average



Model-Based Radio Map

- Model set-up phase incurs high cost.
- Alternative use: radio propagation model and floor plan (instead of measurements)
  - Considered models
    - Rayleigh fading model: small-scale rapid amplitude fluctuation to model multi-path fading
    - Rician distribution model: like Rayleigh but with additional LoS component
    - Floor Attenuation Factor propagation model: large scale path loss with building models
    - Wall Attenuation Factor model: considers effects from walls between transmitter and receiver
  - Resolution 4.3m (50 th percentile)

Limits of Localization Using Signal Strength

- Measuring distance based on signal strength is an attractive idea for wireless networks:
  - RSS does not require additional hardware
  - RSS declines with distance
  - Many different promising methods proposed
- Experimental study:
  - 802.11 technology with a range of methods and environments tested
  - Median localization error of 10ft (3.05m) and 97th percentile of 30ft (9.15m)
- Fundamental limitations that require
  - more complex environment models
  - additional infrastructure

Hybrid Technologies

- Smartphones: have many other sensors
  - Accelerometer, compass, …
- Can be used to estimate the user's walking speed, direction, …
- This information can be combined with finger printing based techniques
- Especially useful if finger printing provides accurate location in specific points
  - When entering a store, escalator, elevators
  - Can use the other sensors starting with these well-known locations

Summary

- Once you know people's locations, you can develop many interesting and practical applications.
- Closed systems (such as GPS) and MLBS are two major categories of LBS.
- GPS was developed by the US Department of Defense, and is now open for commercial usage.
- GPS is based on time of arrival.
- Except for GPS, you can get your positions by some other technologies such as cell identification, trilateration, ToA, TDoA, RSS localization, and so on.