Introduction to System-on-Chip and its Applications

Global Position System

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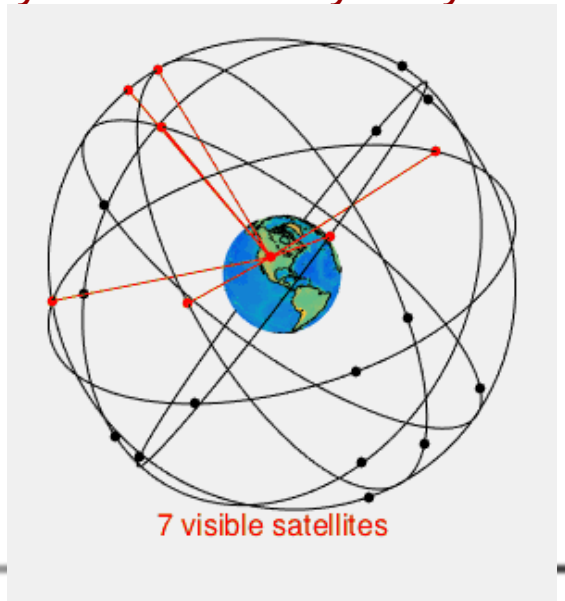
Outline

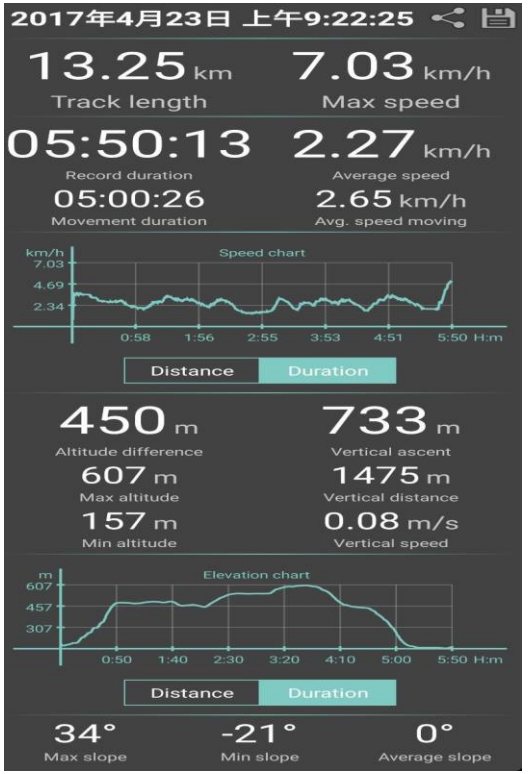
- Introduction
- Technology analysis
- Industry analysis
- Reference

GPS Definition

- GPS (Global Positioning System) is a medium-distance circular orbit satellite navigation/positioning system.
- Navigation Satellite System
  - United States: Global Positioning System, currently the system covering the world.
  - Russia: Global Navigation Satellite System (GLONASS), currently only covers Russia.
  - China: Beidou (北斗) navigation system currently only covers the territory of China.
- Use in Cellphone/Smart watch
  - Precision 10-30m

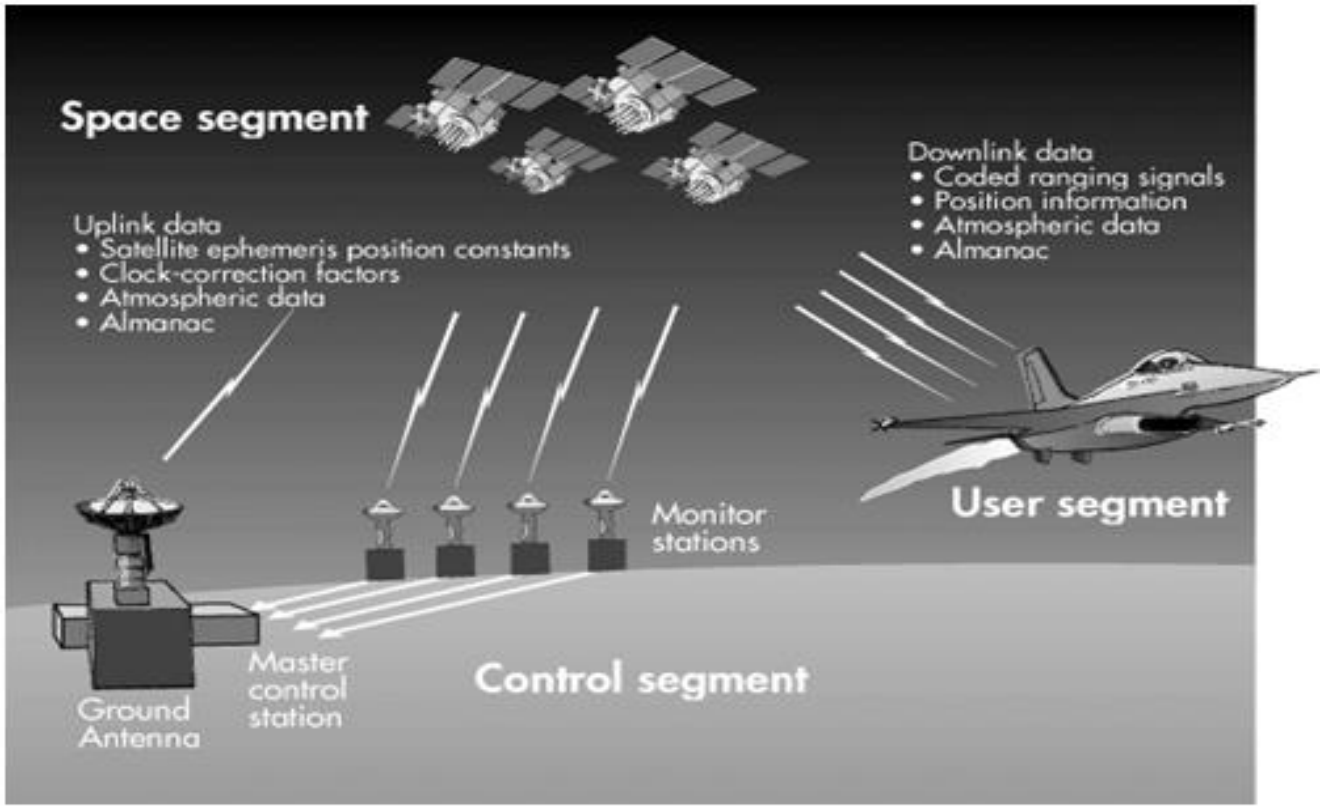


Application



GPS System Architecture

- Space part: 24 satellites distributed in 6 30-degree orbits
- Control part: 1 main control station, 5 monitoring stations, 3 ground antennas
- User part: GPS receiver



Principle of GPS(cont.)

- **Space part:**
  - 24 GPS satellites in space available for positioning.
  - Distributed on 6 orbital surfaces, with 4 on each orbital surface.
  - About 10,900 nautical miles (about 20,000 kilometers) above the ground, orbiting the earth at an angle of 55°.
  - Takes 12 hours to orbit the earth once, it can orbit the earth 2 times a day.
  - At least 4 satellites appear above us regardless of any time and place, including the North Pole and the South Pole,.

Principle of GPS(cont.)

- **Signal part**
  - GPS satellites generate two groups of random codes
    - C/A code –commercial (lower accuracy)
    - P code –defense department (higher accuracy)
  - GPS satellites transmit two frequency carriers,
    - the frequency of the L1 (Link 1) carrier is 1575.42 MHZ,
    - the frequency of the L2 (Link 2) carrier is 1227.60 MHZ.
  - The C/A code is only adjusted on the L1 carrier,
  - The P code is adjusted on the L1 and L2 carriers respectively, and they are distinguished as P1 and P2 codes.
  - U.S. military currently only opens the C/A code for civilian use.

Principle of GPS(cont.)

- **Ground part includes**
  - **master control station (Master Control Station)**,
  - 5 monitoring stations (Monitor Station)-distributed in Hawaii, Yasenxin Island, Diego Garcia, Guagarin Island, Colorado
  - 3 ground control stations (Ground Control Station)
- **The main control station**
  - Extreme accurate time -calculate the satellite ephemeris (星座日曆), timetable correction, and ionospheric(電離層) correction coefficient, almanac(年曆)
  - Convert it into navigation information and normal operation of the satellite system.
  - This part is provided by the United States, the Ministry of National Defense
- **The monitoring station**
  - tracking the operating position, time, meteorological (氣象) data and ionospheric data of all satellites.
  - Observe all data every 15 seconds and calculate a set of smoothed data every 15 minutes (Smoothed Data).

Principle of GPS(cont.)

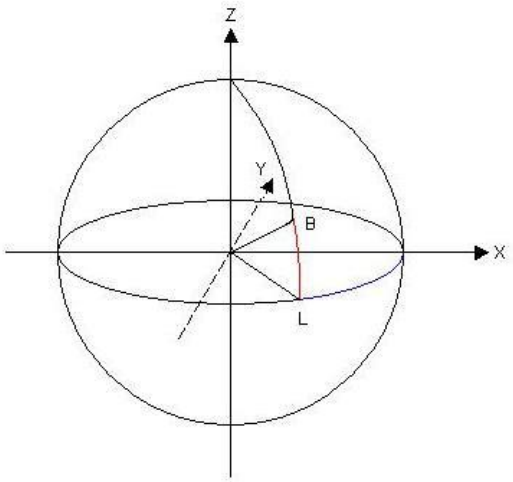
- **User part:**
  - A satellite signal receiver at user's part with different positioning capabilities according to different purposes.
  - The basic function is to
    - receive the L1 carrier,
    - separate the C/A code,
    - perform the simplest virtual distance positioning

Related Technology

- **Structure of GPS signal**
  - Carrier：L1(1575.42MHz)、L2(1227.6MHz)
  - Pseudo Random Noise (PRN)：C/A code、P code
  - Current time and the Satellite position
  - Satellite star
- **GPS uses four satellites for positioning**
  - Three position coordinates
  - clock deviation from satellite time

Principle of GPS

- **The basic positioning principle of GPS**
  - Known satellite position (a, b, c), transmission time t, receiver reception time t'.
  - First calculate the distance between the satellite and the receiver
  - Distance r = speed of light x (t'-t)



$$(X - a_1)^2 + (Y - b_1)^2 + (Z - c_1)^2 = r_1^2 \quad \ldots\ldots (1)$$

$$(X - a_2)^2 + (Y - b_2)^2 + (Z - c_2)^2 = r_2^2 \quad \ldots\ldots (2)$$

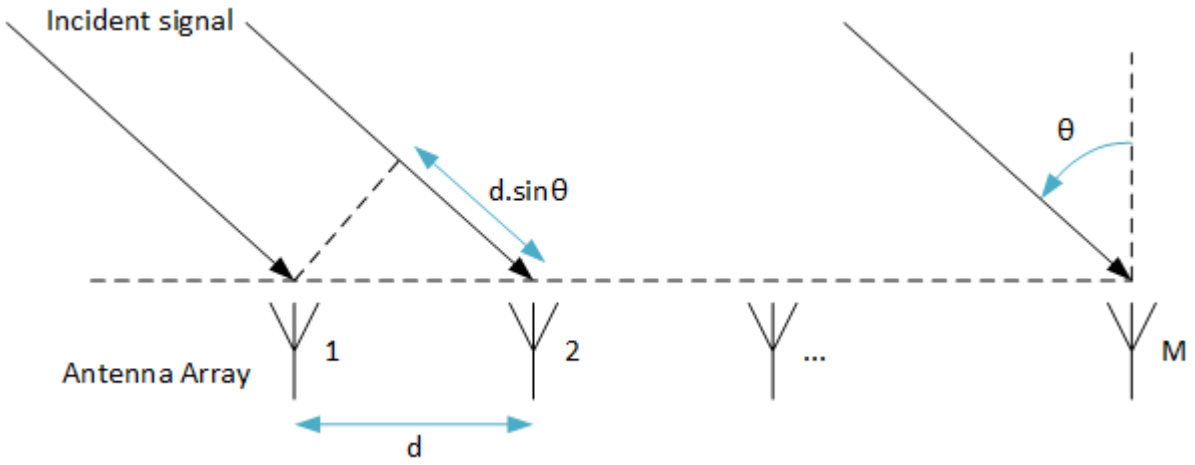
$$(X - a_3)^2 + (Y - b_3)^2 + (Z - c_3)^2 = r_3^2 \quad \ldots\ldots (3)$$

$$(X - a_4)^2 + (Y - b_4)^2 + (Z - c_4)^2 = r_4^2 \quad \ldots\ldots (4)$$

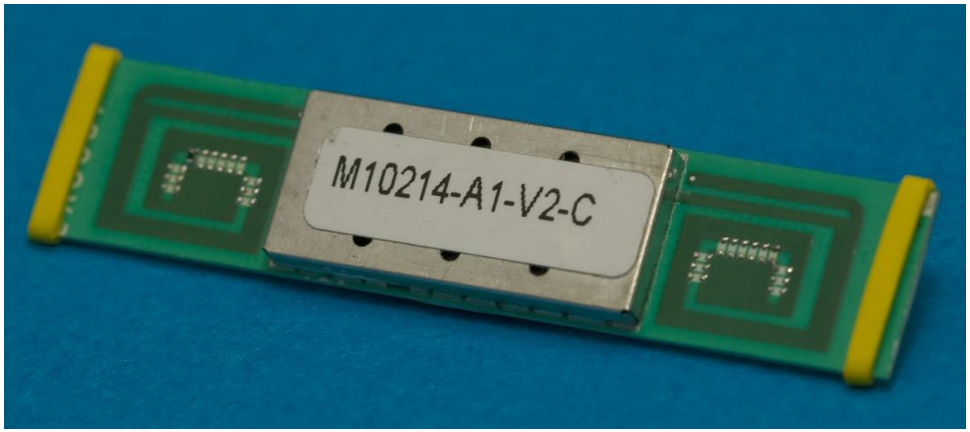
Principle of GPS(cont.)

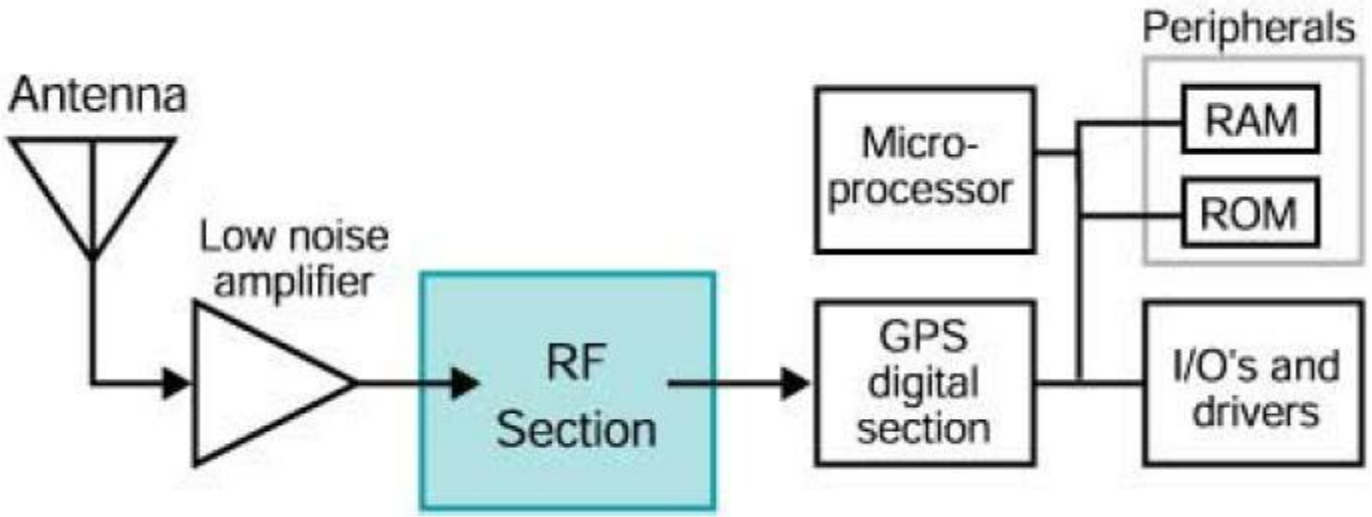
- The process includes three stages:
  - satellite search (Acquisition) and signal download,
  - tracking (Tracking)
  - navigation (Navigation),

the first stage is the most time-consuming.



Chip architecture of GPS





Source : Javad Ashjaee , GPS: The Challenge of a Single Chip , GPS WORLD , May 1, 2001.

Chip architecture of GPS

- **Antenna Element**
  - The main task is to receive signals from GPS satellites.
- **Low Noise Amplifier (LNA)**
  - Used to amplify GPS signals.
- **RF section**
  - Convert the received GPS RF signal (1575.42MHz) into a lower intermediate frequency (20.46MHz), and then into a 4MHz digital signal.

Chip architecture of GPS

- **Digital Section**
  - Deal with GPS signal processing and digital sampling.
- **Microprocessor**
  - Part of the tracking factor is based on the distance measured by the **tracking and the Doppler effect** and control number of the satellite.
  - **Collect navigation data** in GPS signals and orbit and clock data of each GPS satellite.
  - **Calculate position and speed** based on the measured Doppler effect and satellite orbit distance.
  - Use chopping phase measurement to increase the measurement of timely movement time.
  - Handling user application interface.

Chip architecture of GPS

- **Processor peripherals**
  - Provides memory for program and data storage
  - Support application execution
- **I/O port and Drivers**
  - Series, parallel, USB, Internet…

GPS Product Positioning Time

- GPS Product Positioning Time

GPS Product	GPS Positioning speed
ASUS P535	First positioning completed Seconds: 41 seconds
Dopod P800W	First positioning completed Seconds: 38 seconds
GSmart i300	First positioning completed Seconds: 50 seconds
ET X500	First positioning completed Seconds: 34 seconds

Earth Orbit (EO)

- LEO (low earth orbit)- communication
- MEO (Medium earth orbit) –navigation, military
- GEO (Geosynchronous earth orbit) -communication

Parameter	LEO	MEO	GEO
Satellite Height	500-1500 km	5000-12000 km	35,800 km
Orbital Period	10-40 min.	2-8 hours	24 hours
Number of Satellites	40-80	8-20	3
Satellite Life	Short	Long	Long
Number of Handoffs	High	Low	Least(none)
Gateway Cost	Very expensive	Expensive	Cheap
Propagation Loss	Least	High	Highest

Low Earth Orbit (LEO) Satellite

REFERENCE STATUS AND INFORMATION ON KEY LEO AND MEO CONSTELLATIONS

	SES / O3b Networks	OneWeb	LEOSAT	Telesat	SPACEX
Full Constellation Size	27 satellites	648 satellites (900 including spares)	78–108 satellites	117-300 satellites	4,000+ satellites
Total Capacity	210 Gbps (Could reach ~10 Tbps)	~5 Tbps (7.5 Gpbs/satellite)	1.2 to 2.0 Tbps	Multiple Tbps	Up to 90 Tbps
Frequency	Ka-band	Ku-band	Ka-band	Ka- and V-bands	Ku-band
Orbit	MEO (8,062 km)	LEO (1,200 km)	LEO (1,400 km)	LEO (1,000 km)	LEO (1,100 km)
Cost per Satellite	$80 million, after initial eight satellites	< $500,000	$30–$45 million	-	$2.5 million
Mass	~700 kg	< 150 kg/satellite	-	-	-
Satellite Life	12 years	~5 years	10 years	-	-
Latency	< 150 ms	< 50 ms	< 50 ms	< 50 ms	< 50 ms
Vertical Markets	Backhaul/Trunking, Energy, Maritime, Government	Backhaul, Government, Mobility, Broadband	Enterprise, Maritime, Backhaul/Trunking, Energy	Government, Mobility, Rural Connectivity	Broadband

SATELLITE COMMUNICATIONS AND BROADCASTING MARKET SURVEY

Band	Frequency (GHz)
L band	1–2
S band	2–4
C band	4–8
X band	8–12
Ku band	12–18
K band	18–27
Ka band	27–40
V band	40–75
W band	75–110

Mobile phone positioning system

- **GPS positioning**
  - fixed-point positioning based on satellite signals surrounding the earth,
  - **no network connection** is required,
  - Must be outdoors where the sky signal can be received.
- **Base station positioning**
  - Location of **nearby telecommunication base stations** detected by the mobile phone,
  - A larger error range of position due to the long distance between the telecommunication base stations.
- **Wi-Fi positioning**
  - Location of **nearby wireless network base stations** detected by the mobile phone,
  - the positioning is relatively accurate because Wi-Fi base stations are very dense.

Analysis of mobile phone positioning usage

Mobile network	Wi-Fi Detection	GPS	Conclusion
X	X	X	Unable to locate
X	X	O	It can be located, restricted to the outdoors, very accurate, but the map needs to be offline or cached
O	X	X	Can be positioned, may have large errors
O	O	X	Can be positioned to increase accuracy, both indoor and outdoor, to cope with most situations
O	O	O	Can be positioned, the fastest and most accurate

- If you want to save power, there is no need for precise positioning: just open the mobile network and open the map to be able to locate.
- Want to save power, but need precise positioning: turn on the mobile network, Wi-Fi detection, and open the map to accurately locate.
- Need very precise positioning requirements (or satellite navigation when driving): turn on mobile network, turn on Wi-Fi detection, turn on GPS.

Indoor Positioning System (IPS)

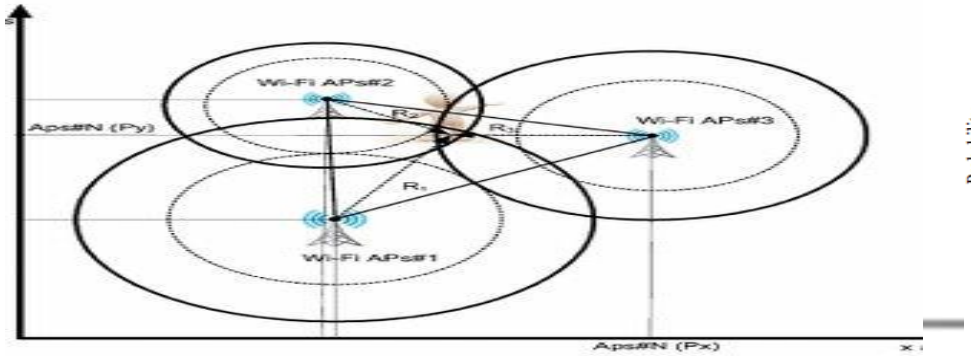
- **Introduction**
  - As indoor positioning is sensitive to interference from buildings
  - mobile phones are used as a medium to solve indoor positioning problems through two wireless sensing technologies
    - Wi-Fi
    - Bluetooth.
- **Principle**
  - Absolute coordinate system---used a benchmark for reference and correction at any time.
  - Positioning algorithm and detection
- **Main applications**
  - In complex stations, shopping malls or department stores, combined with accurately drawn indoor maps
  - routes can be planned through the indoor positioning system
  - the current location

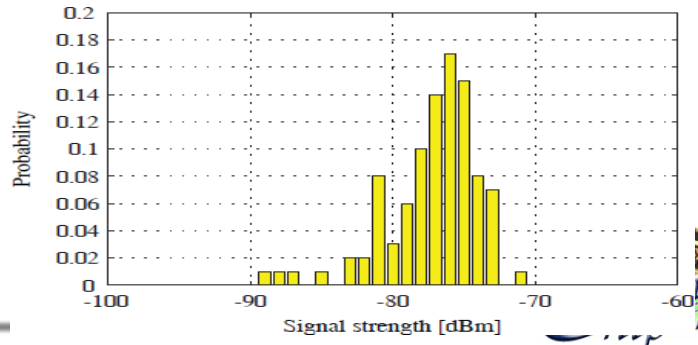
https://www.securityindustry.org/2017/11/21/indoor-positioning-systems/

Wi-Fi indoor position system

- Measuring the intensity of the receive radio wave
- Wi-Fi Fingerprint: During an **offline phase, fingerprints** are collected at known **positions** in the building.
- Radio map: **dataset of locations and associated fingerprint**

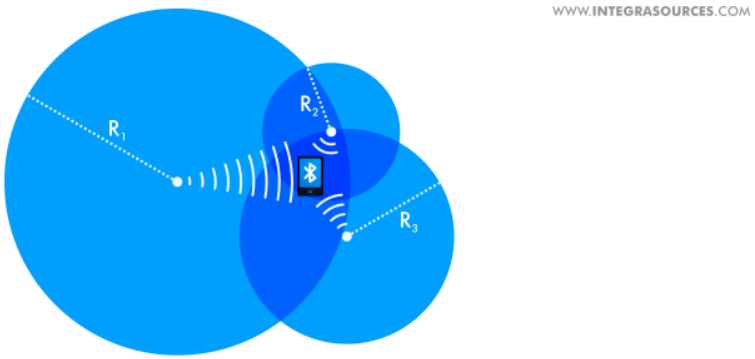
- Online phase: current fingerprint compared with radio map.
- A set of samples is collected at the user location and is used to estimate the signal strength probability distributions Qi(s) of the detected APs.
- User location: calculating a weighted average of the three offline positions that best match the online measurements.





Bluetooth indoor position system

- Beacons to transmit signals
- Smartphone as receivers
- Distance Calculation:
  - RSSI (Received Signal Strength Indicator)
    - Estimating the location of the object by the intensity of the received signal
    - Poor results because the stationary and moving objects surrounding the transmitter can affect the signal
  - Trilateration
    - Network comprises three or more transmitting devices.
    - Once the distances between some reference objects are know, you can measure the distance to the target object.

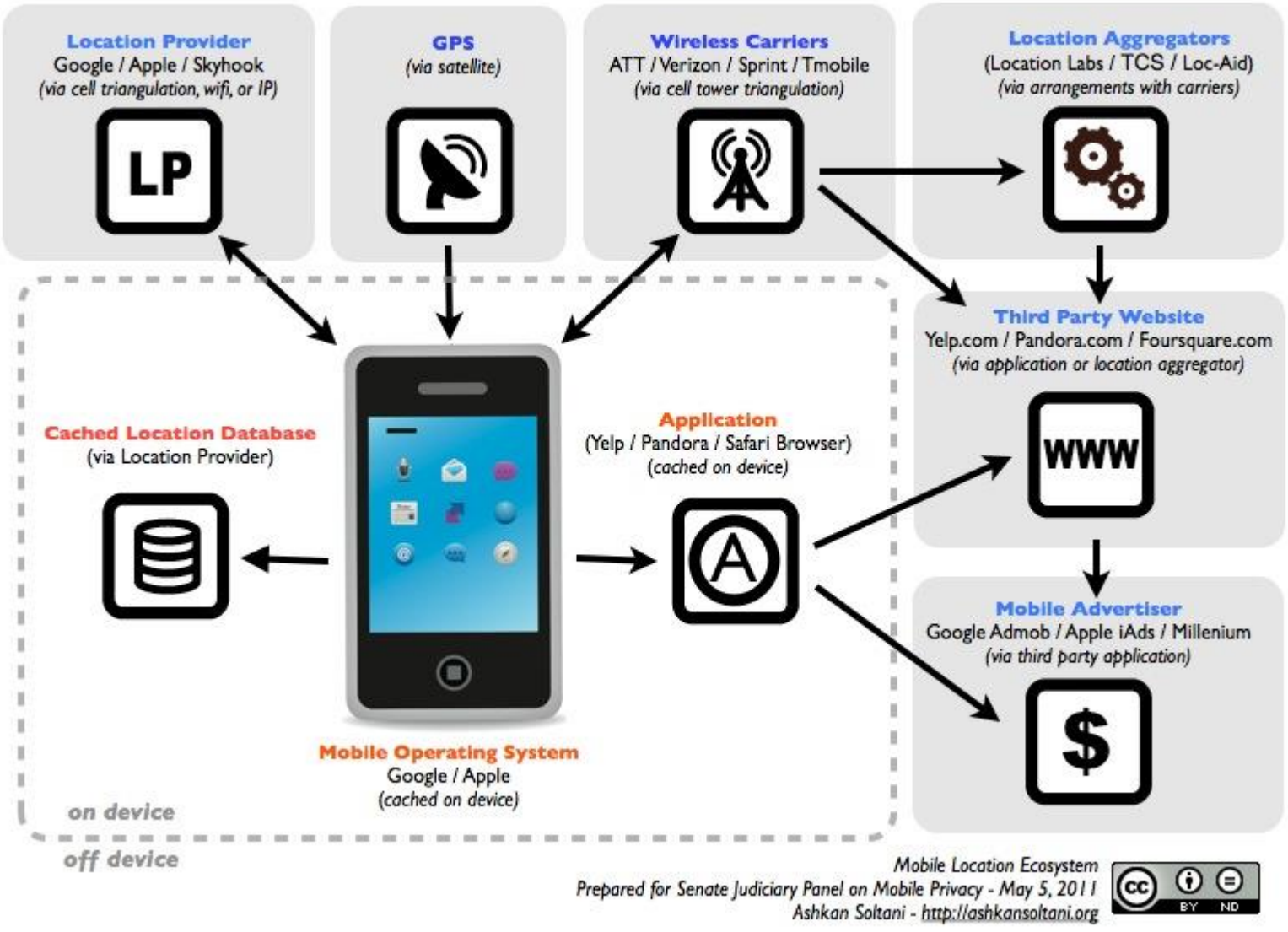


Wi-Fi and Bluetooth Beacons IPS

Wi-Fi indoor position system Comparison

IPS Technology	Accuracy	Complexity	Robustness	Cost	Infrastructure Requirements, Impacts and Notes	Transmitter to Receiver Range
Radio – Bluetooth Low Energy	1-3m	Medium	Performance is affected by obstacles.	Medium	Accuracy is a factor of beacon density; rechargeable battery life is hours to days.	27m
Radio – Wi-Fi	5-15m	Medium	Performance depends on the positioning algorithm and fingerprinting database.	Low	Can use existing Wi-Fi; rechargeable battery life of smart mobile device is hours.	137m

Mobile Location System



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