GPS

Slides borrowed from Richard Y. Yang @ Yale
Motivations

• The ancient question: Where am I?

• Localization is the process of determining the positions of the network nodes

• This is as fundamental a primitive as the ability to communicate
Localization: Many Applications

• Location aware information services
  – e.g., E911, location-based search, advertisement, inventory management, traffic monitoring, emergency crew coordination, intrusion detection, air/water quality monitoring, environmental studies, biodiversity, military applications, resource selection (server, printer, etc.)

• “Sensing data without knowing the location is meaningless.” [IEEE Computer, Vol. 33, 2000]
The Localization Process

- Applications Using Location
- Location Computation
- Localizability (opt)
- Measurements
Classification of Localization based on Measurement Modality

• Coarse-grained measurements, e.g.,
  – signal signature
    • a database of signal signature (e.g. pattern of received signal, visible set of APs (http://www.wigle.net/)) at different locations
    • match to the signature
  – connectivity

• Usage
  – e.g., Microsoft “Locate Me”
  – Place lab: http://data.placelab.org/

• Advantages
  – low cost; measurements do not need line-of-sight

• Disadvantages
  – low precision

For a detailed study, see “Accuracy Characterization for Metropolitan-scale Wi-Fi Localization,” in Mobisys 2005.
Classification of Localization based on Measurement Modality (cont’)

• Fine-grained localization
  – distance
  – angle (esp. with MIMO)

• Usage
  – GPS, sensor networks

• Advantages
  – high precision

• Disadvantages
  – measurements need line-of-sight for good performance
Global Position Systems

• US Department of Defense: need for 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

http://www.colorado.edu/geography/gcraft/notes/gps/gps_f.html
GPS Operational Capabilities

Initial Operational Capability - December 8, 1993

Full Operational Capability declared by the Secretary of Defense at 00:01 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?
  - When is sunrise and sunset?
  - What is the distance between two points?
  - What is my estimated time arrival?
GPS Basics

Simply stated: The GPS satellites are nothing more than a set of wireless base stations in the sky

- The satellites simultaneously broadcast beacon messages (called navigation messages)

- A GPS receiver measures time of arrival to the satellites, and then uses “trilateration” to determine its position
GPS Basics: Triangulation

• Measurement:

\[ t^{R1} = t^S + \frac{\|p - p_1\|}{c} \]

Computes distance

\[ \|p - p_1\| = c(t^{R1} - t^S) \]
GPS Basics: Triangulation

- In reality, receiver clock is not sync’d with satellites
- Thus need to estimate clock

\[ t^{R1} = t^S + \frac{d_1}{c} + \delta_{\text{clock-drift}} \rightarrow \| p - p_1 \| = c(t^{R1} - t^S - \delta_{\text{clock-drift}}) \]

\[ = c(t^{R1} - t^S) - c\delta_{\text{clock-drift}} \]

called pseudo range
Why Do I Need To See 4 Satellites?

The GPS Navigation Solution
The estimated ranges to each satellite intersect within a small region when the receiver clock bias is correctly estimated and added to each measured relative range.
GPS Design/Operation

• Segments (components)
  – user segment: users with receivers
  – control segment: control the satellites
  – space segment:
    • the constellation of satellites
    • transmission scheme
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)
Space Segment: Constellation
Space Segment: Constellation

- System consists of 24 satellites in the operational mode: 21 in use and 3 spares
  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

Peter H. Dana 9/22/98
GPS Satellite Transmission Scheme: Navigation Message

• To compute position one must know the positions of the satellites

• Navigation message consists of:
  - satellite status to allow calculating pos
  - clock info

• Navigation Message at 50 bps
  – each frame is 1500 bits

More detail: see http://home.tiscali.nl/~samsvl/nav2eu.htm
GPS Satellite Transmission Scheme:
Requirements

• All 24 GPS satellites transmit Navigation Messages on the same frequencies

• Resistant to jamming

• Resistant to spoofing

• Allows military control of access (selected availability)
GPS As a Communication Infrastructure

- All 24 GPS satellites transmit on the same frequencies BUT use different codes
  - i.e., Direct Sequence Spread Spectrum (DSSS), and
  - Code Division Multiple Access (CDMA)
  - Using BPSK to encode bits
GPS PHY and MAC Layers

L1 CARRIER 1575.42 MHz

C/A CODE 1.023MHz

NAV/SYSTEM DATA 50 Hz

P-CODE 10.23 MHz

L2 CARRIER 1227.6 MHz

L1 SIGNAL

Mixer

Modulo 2 Sum

L2 SIGNAL

GPS SATELLITE SIGNALS
GPS Identifying Codes

• Two types of codes
  – C/A Code - Coarse/Acquisition Code available for civilian use on L1
  – P Code - Precise Code on L1 and L2 used by the military
    • encrypted P code (called Y code) provides selected availability and anti-spoofing
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

- Selective availability (SA)
  - noise is added to the clock signal and
  - the navigation message has “lies” in it
  - SA is turned off permanently in 2000

- Anti-Spoofing (AS) - P-code is encrypted
Extensions to GPS

• Differential GPS
  – ground stations with known positions calculate positions using GPS
  – the difference (fix) transmitted using FM radio
  – used to improve accuracy

• Assisted GPS
  – put a server on the ground to help a GPS receivers
  – reduces GPS search time from minutes to seconds
iPhone GPS

• Hammerhead™ II
GPS: Summary

• GPS is among the “simplest” localization technique (in terms topology): one-step trilateration

• Russia has a system known as GLONASS

• The EU is deploying GALLIOS
GPS Limitations

• Hardware requirements vs. small devices

• GPS jammed by sophisticated adversaries

• Obstructions to GPS satellites common
  • each node needs LOS to 4 satellites
  • GPS satellites not necessarily overhead, e.g., urban canyon, indoors, and underground
Extending GPS: Multilateration

- A subset of nodes (called anchors) know their positions
  - through GPS, e.g., nodes close to windows, at the entrance of a cave, at an open field inside a forest, etc
  - manual configuration
- Nodes measure relative distance among each other