GPS: Applications to Distributed Systems and Networks

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- Principles of operation
- Current applications
- Potential applications
- Obstacles
- Current products and manufacturers

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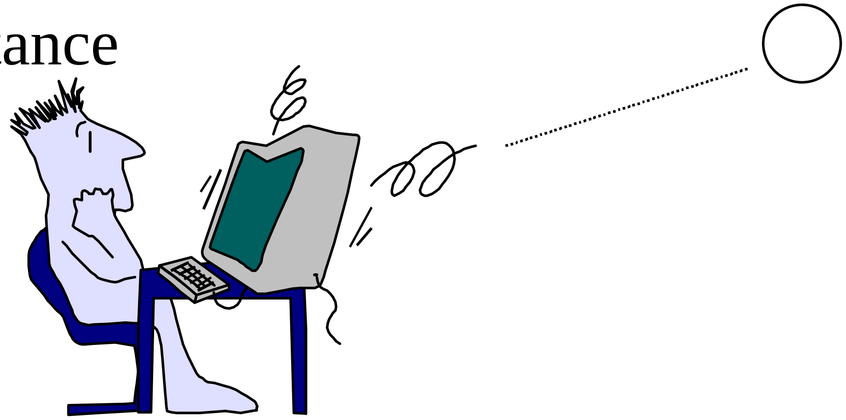
Executive Summary

- Precise determination of location, velocity, direction, and time.
- Price is falling rapidly and applications are growing
- Goal was to survey current applications
- Most efforts are in providing navigational guidance to drivers
- Only two non-navigational applications
- Identified many new applications of GPS for distributed computing and networking
- A few obstacles to GPS deployment
- Detailed lists of GPS products, addresses of manufacturers
- Sources for further information

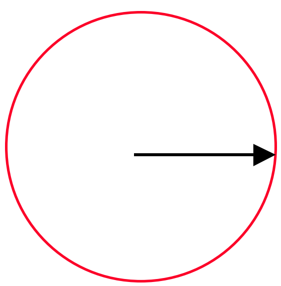
Introduction

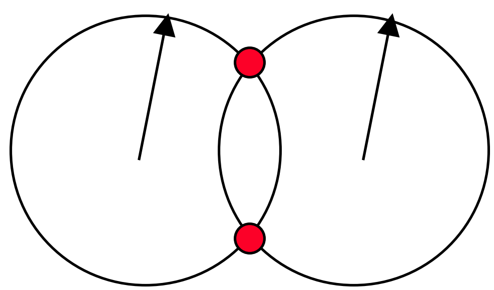
- Space-based radio positioning system
- Provide
  - time
  - three-dimensional position
  - velocity
- First conceived after the launch of Sputnik 1 in 1957
  - Measuring the frequency shifts in the small bleeps
    ⇒ Distance

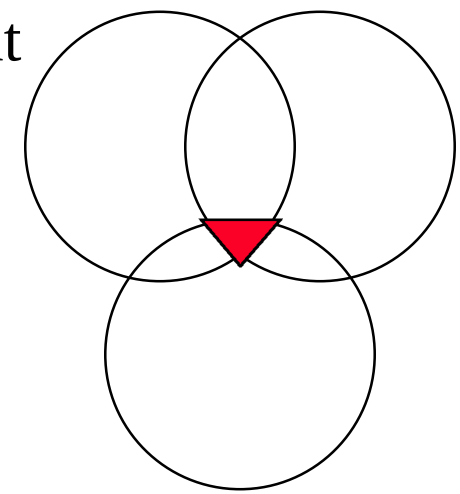


Principles of Location Determination

- Broadcast signals allow computing the distance from the satellite
- Distance from one satellite ⇒ Any point on the circle (sphere)
- Distance from two satellites ⇒ Two points (circle)
  Ridiculous answer can be eliminated
- Distance from three satellites ⇒ One point (two points)
- Distance from four satellites ⇒ One point







NAVSTAR

- Constellation of 24 satellites (Three are spare)
- Orbiting at a height of 10,900 nautical miles
- Orbital period of 12 hours
- Planned life span of 7.5 years
- Orbits inclined 55 degrees to the equatorial plane
- Provide a minimum of four satellites in good geometric positions
- Up to 10 GPS satellites are usually seen
- Each satellites carries several cesium clocks
- Positional accuracy of 100 m, Timing accuracy of 300 ns
- Frequency accuracies of a few parts in 10^{12}

NAVSTAR (Cont)

- Two L band frequencies, L1 (1575.42 MHz) and L2 (1227.6 MHz)
- L1 carries a precise (P) code and a coarse/acquisition (C/A) code
- L2 carries the P code
- The P code is encrypted (also known as Y code)
- Only the C/A code is available to civilian users
- Space vehicle (SV) number: Assigned in order of launch
- Two services: SPS and PPS

Standard Positioning Service (SPS)

- Sandard level of positioning and timing accuracy
- Available to any user on a continuous worldwide basis
  - 100 m horizontal accuracy
  - 156 meter vertical accuracy
  - 167 ns time accuracy

Precise Positioning Service (PPS)

- Can only be accessed by authorized users with cryptographic equipment and keys
- US and Allied military and approved civil users
- Accuracy:
  - 17.8 meter horizontal
  - 27.7 m vertical
  - 100 ns time

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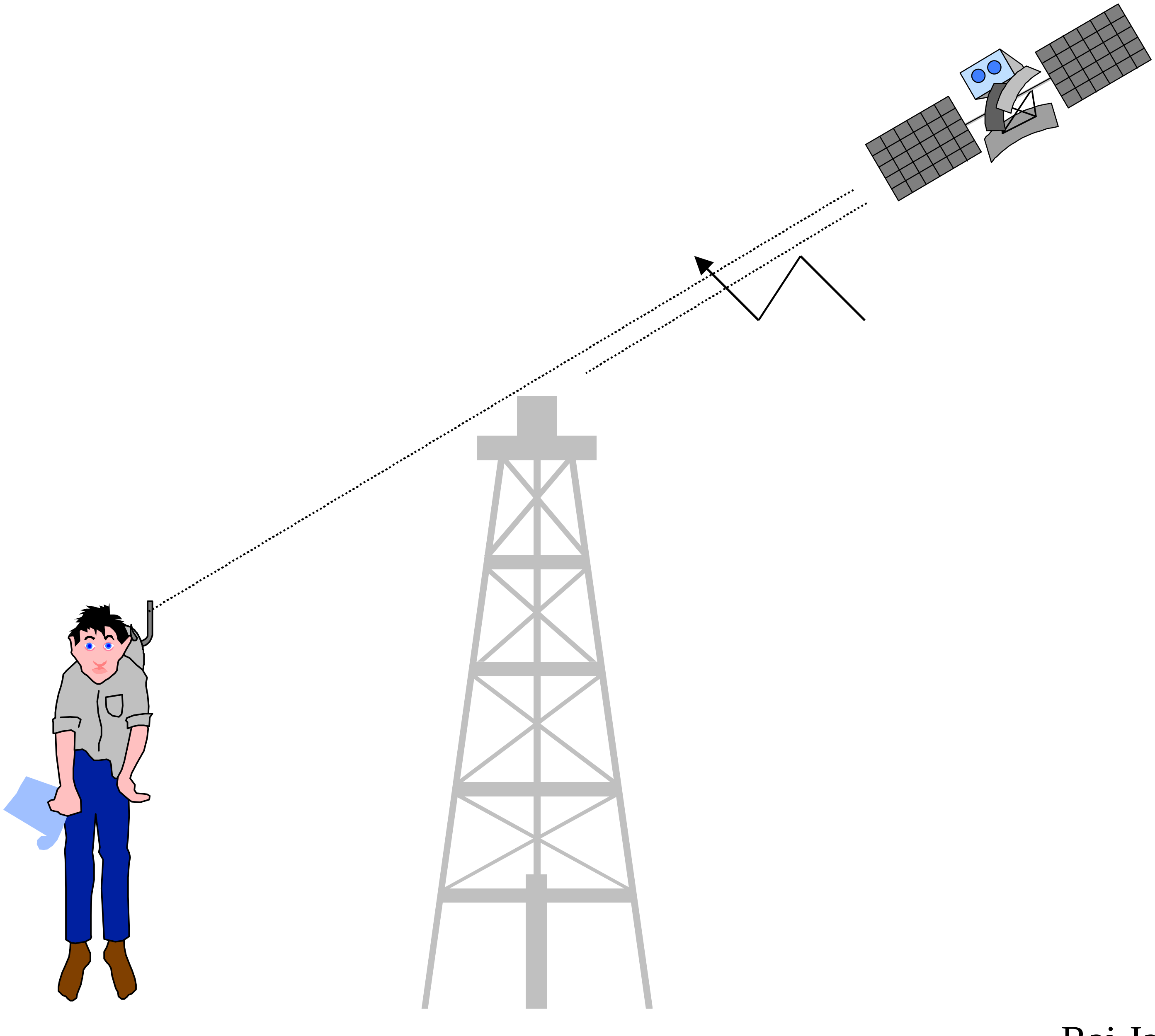
Selective Availability (SA)

- Intentional degradation by DOD to limit accuracy
- For non-US military and government users
- Accuracy of C/A code reduced from 30 m to 100 m



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Differential GPS (DGPS)

- Method of eliminating errors in a GPS receiver
- Assumes most of the errors seen by GPS receivers are common errors
- Caused by clock deviation, selective availability, drift from predicted orbits, multipath error, internal receiver noise and changing radio propagation conditions in the ionosphere
- Use a base station with known location to determine error
- Use the error to correct the location of rovers
- Continuous broadcast $\Rightarrow$ real-time DGPS
- Post-processing correction (Used in surveying)
- Offers accuracies of few m

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Accurate Time using GPS

- Time accuracy from GPS signals:
  - Better than 340 ns (95% probability) using SPS
  - 100 ns using PPS
- Inexpensive GPS receivers operating at known positions $\Rightarrow$ accuracy of about 0.1 μs with only one satellite in view
- With more sophisticated techniques, one ns is possible (globally)
- Requires advanced preparation, coordination of the two sites and tracking of specific satellites during specific time periods

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Current Applications of GPS

- Frequency Counters
- Intelligent Vehicle Highway Systems (IVHS)
- Car Navigation Systems
- Geographic Information Systems (GIS)
- Emergency Systems: Backpacking
- Aviation
- GPS Aides for the Blind
- Astronomical Telescope Pointing
- Atmospheric Sounding using GPS Signals
- Tracking of Wild Animals
- Recorded Position Information
- Airborne Gravimetry

Commercial Efforts

- Trimble & Bell Atlantic, Trimble & IBM, PacTel Cellular Wireless & Wireless Solutions Inc:
  - Vehicle tracking and location devices
- Ford:
  - GPS based car alarms to locate stolen cars,
  - Traffic control, Vehicle tracking, Vehicle recovery, Navigation, Mapping
- Avis: Testing GPS in rental cars in NYC area
  - As a navigational aid
- DeTeMobil:
  - GPS receivers in all cars in Germany
  - Pay tolls using smart cards and GSM digital phone

Current Distributed Systems and Networking Applications

- Network delays in DA-30
- SONET Synchronization

Network Delays

- Wandel & Goltermann Inc.
- DA-30 Internetwork Analyzer uses GPS to make latency measurements between Ethernet LANs linked by a WAN
- GPS boards lock into the GPS time signal broadcasts
- S/W conducts latency trials
- Accurate to within 150 μs
- Requires two kits priced at $6,750 each

Ref: Government Computer News,
March 21, 1994, vol. 13, no. 6, p.64.

SONET Clock Distribution

- Multiple bit streams to a single network element
  $\Rightarrow$ Need synchronized clocks
- CCITT Recommendation G.811
  $\Rightarrow$ Long term frequency departure $\leq 10^{-11}$.
- Building Integrated Timing Supply (BITS) is Bellcore's clock-system specification $\Rightarrow$ Multi-level hierarchy
- Stratum 1 (ST-1) is the highest quality clock
- BITS allows LORAN/Rubidium ST1 clock systems
- AT&T's primary reference clock (PRC) uses GPS signals for long term timing accuracy
- Rubidium oscillators provide short-term stability

Ref: Telephony, August 24, 1992, pp. 50-54.

Potential Applications to Distributed Systems and Networks

- Time applications
- Position Applications

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Time Applications

- Circuit Switching Using Synchronized Clocks
- Synchronous Slotted Systems
- Clock Synchronization in Distributed System
- Database Synchronization
- Connectionless Real-time Communication
- Real-Time Communications
- One-Way Delay
- Delay based routing
- Time to Live

Circuit Switching Using Synchronized Clocks

- Synchronized clocks $\Rightarrow$ circuit switching easy
- Precompute switching schedule
- Similar to synchronized lights on roads

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Synchronous Slotted Systems

- Slotted systems are less sensitive to distance bandwidth product
- More suitable for high speed or long distance networks
- Slotted architectures for all-optical, multi-gigabit networks
- Need clock synchronization
- GPS clocks an all-optical ARPA research project

Clock Synchronization in Distributed System

- Clock difference $\leq \Delta$, Smaller $\Delta \Rightarrow$ Better system
- Currently: NTP, OSF-DTS, DECdts, Fuzzbal, timed
- Future: GPS clocks (1 ns) at least in timeservers
- Ordering of events (e.g., FCFS scheduling)
- Consistent update of replicated data
- At most once receipt of messages
- Authentication tickets in some systems (e.g., Kerberos)
- Ensuring atomicity
- Expiration of privileges
- Prearranged synchronization
- Ordering multi-version objects

Database Synchronization

- Synchronization after a failure or a disconnected operation
- Use logs with timestamp to decide the order of actions
- More precise clocks $\Rightarrow$ less conflicts

Connectionless Real-time Communication

- Delay guarantees on IP-like networks $\Rightarrow$ Need deadline scheduling
- GPS $\Rightarrow$ Deadline timestamp on the packet
- Similarly, scheduling subtasks of real-time tasks

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One-Way Delay

- Currently, clock differences ≥ one-way delays
  ⇒ Can't measure one-way delay
- Round-trip delays used instead
- Example: ATM networks ABR parameters are fn(delay)
- GPS synchronized clocks at source and destination
  ⇒ exact one-way delay between source and destination and to every switch can be measured with a single timestamp.

Delay based routing

- Internet uses link delays for routing
- Accurate measurement is difficult
  $\Rightarrow$ approximate or round-trip delay used
- GPS provided exact one-way delay can be used

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Time to Live

- Helps remove old packets from the networks
- Currently, the time-to-live field is decremented by 500 ms regardless of actual delay
- With GPS synchronized clock, exact time-to-live possible

Diagnostics/Maintenance of system clocks

- A GPS frequency calibrator can be used to periodically check crystals in various equipment

Time and Frequency Alternatives

- National Institute of Standards and Technology (NIST)
  - WWV and WWVH radio broadcasts (accurate to 1 ms)
  - WWWVB broadcasts (2 to 3 parts in 10^{11})
- US Naval Observatory (USNO)
  - Loran-C (LOng RAnge Navigation)
  - Land based radio navigation system
  - Frequency accuracies of 1 part in 10^{12}, Time better than 1 μs
- Both USNO and NIST provide
  - Telephone voice messages (accuracy 30 ms)
  - Computer modem time transfer (several ms)
  - Remote synchronization of time bases (10^{-9}).

Position Applications

- Resource Location
- Location Adaptive Protocols
- Handoffs in Wireless Networks
- Prescheduled Hand-overs Based on Velocity and Direction
- Adaptive Transmission Power Control Algorithm
- Directional Antennas
- Temporary Cell Partitioning for Congestion Avoidance
- Peer-to-peer Routing with Limited Range Receivers
- Email Delivery Based on Geographic Location
- Distributed Robot Control and Navigation
- Equipment Location Marking for Maintenance Crew

Resource Location

- Digitized maps and GPS locations
- Find the nearest printer or fileserver
- Prescheduling possible

Location Adaptive Protocols

- Currently, networking is location transparent
- Service decisions do not use location
- In many applications, knowing location helps
- Examples: Home vs Office vs Car. Electronic Fence.

Home vs Office vs Car

- Different physical medium: wire, ISDN, modem, cellular, or radio
- Different bandwidth bandwidth, cost, and error characteristics
- Mobile computing decisions = fn(GPS location)
  Example: Which files to fetch for home vs other town

Electronic Fence

- Company confidential papers stay within physical walls
- GPS provides electronic fence for electronic information
- Information usable only if computer is within the corporate boundary

Handoffs in Wireless Networks

- Inter-cell (change base) or intra-cell (change channel)
- Decision by base or by mobile unit
- Currently use signal strength
  Better to use position
- Avoids passive listening to beacons
- Simplifies handoff

Prescheduled Uninterrupted Handoffs

- Signal strength ⇒ Difficult to predict future
- GPS location, velocity, and direction ⇒ Future predictable
- Handoff ⇒ Interruption in service as the packets sent to the previous base have to be forwarded to the new base
- Prediction ⇒ Prenegotiate the hand-over with all parties

Adaptive Transmission Power Control Algorithm

- Battery lifetime is important for mobile computing
- Little hope for exponential increase in lifetime
- Need to save battery usage
- Optimize transmission power
- Nearby base ⇒ transmit less power
- Also allow frequency reuse in the same cell

Directional Antennas

- Transmission in all directions ⇒ most of the energy wasted
- GPS ⇒ less power
- Particularly helpful for satellite communication
- Also allow better packing density - more users for the same space
- Provides the minimum radiated RF pattern for covert communications.
- Can talk to the least busy base unit even if it is not closest unit

Temporary Cell Partitioning for Congestion Avoidance

- Cell splitting: Dividing a cell to form new cells
- Allows reuse of spectrum and helps in reducing congestion
- Requires prior preparation and usually a permanent change
- GPS $\Rightarrow$ dynamic, quick, temporary splitting feasible
- Can also be used in case of base station failures

Peer-to-peer Routing with Limited Range Receivers

- Civilian wireless communication uses base units
- Military communication $\Rightarrow$ no pre-existing infrastructure
  $\Rightarrow$ Better to use peer-to-peer communication
- Position, heading, velocity, as well as, digital terrain topology information can be used for optimum routing

Email Delivery Based on Geographic Location

- Name, addresses, route, and physical position are not related
- Multicast/anycast to a particular geographic location
- For example, "to all police cars near Stanford university on route 101"

Distributed Robot Control and Navigation

- Intelligent robots can use position and environment information
- Unmanned vehicles can navigate effectively.

Equipment Location Marking for Maintenance Crew

- Service requesters (mobile or stationary) provide GPS location
- Maintenance crew carry GPS to locate the equipment

Current Limitations of GPS

- Selective Availability: degrades achievable accuracies
- Temporary outage of the receiver as the receiver passes under obstructions
  $\Rightarrow$ GPS for performance not for operation
- Systems should continue to work without the GPS
- Like cache memories

Details of Selected Products

- Trimble's Mobile GPS Card: Type II PCMCIA GPS sensor by Trimble ($995). 3 channels tracking up to 8 satellites. 100 m accuracy. Acquisition time of less than 30 s and re-acquisition rate of 2-3 s.
- Trimble's Mobile GPS Gold Card: Differential-ready ($1,595). Provides 2-5 m accuracy in real-time.
- Trimble's Mobile GPS Intelligent Sensor 100: Low-end sensor $395
- Rockwell's NavCard PCMCIA GPS sensor
- Mobile Computing Kit: Includes pen-based TelePad, Proxim's RangeLAN, cellular phone, Trimble GPS, FotoMan Plus camera, ScanMan, AudioMan ($7,299).

GPS Software Applications

- GPS for windows ($1,995): By Peacock Systems
- City Streets for Windows: $99.95 by Road Scholar software
- Streets on a Disk: By Kylnas Engineering ($225+$95/county)
- Map'n'GO: ($50) 3CS Software.
- NCompass 3.0 for Windows: - real time GPS
- Zagat-Axxis CityGuide: by Axxis Software.
- MapInfo for Windows 3.0: MapInfo Corp.
- Atlas GIS for Windows 2.0: By Strategic Mapping Inc.
- GISPlus for PC: By Caliper Corp.
- Maptech Professional Marine Chart S/W: ($1,290) by Resolution Mapping Inc.

Summary

- Cheap PCMCIA receivers for \$300-400 ⇒ Growing applications
- Currently mostly for navigational guidance to drivers
- SONET and Wolter and Golderman's DA-30 network analyzer
- Many many potential applications
- Main obstacles: Antennas must point to open sky

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