Location-Based Services

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Questions

- How location-based services (LBS) operate and what kind of services there are currently available?
- What are the main challenges for LBS?
- What is an inference attack and what kind of countermeasures are available against it?
- What are duty cycling and sensor management?

Location-Based Services (LBS)

- *Computer applications that deliver information depending on the location of the device and user*
  - Local or global: works in a specific environment (e.g., campus) vs. everywhere (e.g., GPS navigation)
  - Personal or collaborative: designed for single user (e.g., mobile maps) or multiple persons (e.g., participatory sensing)
- Typically require network access and infrastructure for measuring location information
  - Location determination topic later during the course

Architecture of LBS - Stakeholders

- **Mobile client**
  - Runs the application/service on a mobile device
- **Location system**
  - Responsible for determining the location of the device
  - Position can be determined on the client or by infrastructure
- **Service provider**
  - Provides the application/service
  - E.g., advertising service
- **Content provider**
  - Provides content within the application/service
  - E.g., company that provides advertisements

Lifecycle of LBS

1. Client requests the service for location sensitive information
2. Location system determines the location of the client (or uses latest estimate)
3. Request for information and current location sent to service provider that returns relevant information
   - Typically data connectivity needed
   - Optionally some information could be cached/stored on the client directly

Categories of LBS - Emergency Services

- E911 (Enhanced 9-1-1)
  - Locate where a call to an emergency number originates
  - Strict guidelines regarding positioning accuracy and consistency:
    - 50/100 meters 67% of times (handset/network-based)
    - 150/300 meters 90% of times (handset/network-based)
- E112
  - European equivalent of E911
  - No strict positioning requirements
    - "best effort" with respect to technological possibilities of infrastructure

Categories of LBS - Mobile Advertising

- Mobile marketing/advertising
  - One of the most popular domains for LBS currently
  - Push-based: advertisements delivered to the client terminal automatically
    – Permission-based: require user’s consent
  - Pull-based: client requests for advertisements
- Different location-sensitive advertising approaches:
  - Proximity-based: user’s within close proximity pushed advertisement
  - Profile-based: Routines detected by mining user’s location history
  - Coupons: discount vouchers delivered on the mobile device based on locations/shops visited (and profile)

Categories of LBS - Mobile Advertising

Foursquare (video 2010):
https://youtu.be/QYGYmJpwbLo

Categories of LBS - Location-Based Games

- Game where the game play varies or evolves according to user's location
- **Geocaching**
  - User searches for boxes that other users have hidden
  - Treasure-hunt kind of game
  - Boxes specified by coordinates
- **Serious games**
  - Games that aim to achieve some desirable objective
  - E.g., learning or achieving behavior change
  - Example: Savannah, a location-based game that teaches children behavior of lions

Categories of LBS - Location-Based Games

- **Mixed reality games**
  - Games that consists of a virtual and physical reality
  - Actions in the physical world affect the state of the game in virtual reality
  - Example: PacLan / Pac-Manhattan: real-world versions of Pacman
  - Example: Pokémon GO: catching pokemons in the wild
- **Urban games**
  - Games that use the urban environment for gameplay

Categories of LBS - Location-Based Games

Real-world Pacman (2006):
https://youtu.be/KJqxC9FbSCY

Pokémon GO (2016):
https://youtu.be/3kVy5KYfHTs

Categories of LBS - Mobile Augmented Reality

- Live, direct or indirect view of a physical real-world environment that is augmented with virtual content
- Common example: see-through lens + virtual content
- Location needed for two purposes:
  - Tracking the orientation and pose of the device (viewport that is being augmented)
  - Tracking the location of the client for delivering suitable information
- Wide range of examples especially for outdoors:
  - Tourist guides
  - Interactions at a distance (e.g., architecture)

Categories of LBS - Mobile Augmented Reality

Augmented museum app (2013):
https://youtu.be/nWGffYtmODo

Simple architecture example (2014):
https://youtu.be/whUg6ozdGlY

Categories of LBS - Navigation Systems

- System that assists people in the movement from one place to another
  - Indoors: supermarkets, malls, airports, campus or office environments
  - Outdoors: pedestrian navigation in cities or within large tourist sights
- Various ways to present route instructions
  - Mobile maps (2D or 3D)
  - Landmarks (verbal, auditory, visual, multimodal)
    - Generally considered most effective way to present navigation instructions for pedestrian purposes

Categories of LBS - Navigation Systems

Hyondai navigator and driving guide (2015): https://youtu.be/iZg89ov75QQ

Categories of LBS - Mobile Tourist Guides

- Mobile systems that provide assistance to tourists visiting a particular city or other location
  - Cyberguide and Guide are examples of early prototypes of these systems
- Common functionalities include
  - Map with information about interesting locations
  - Navigation support
  - Location-sensitive recommendations
- Also other variations:
  - E.g., restaurant or other point-of-interest (POI) finders

Categories of LBS - Mobile Tourist Guides

Florance travel guide (2012):
https://youtu.be/a90DDQZmGj4

Categories of LBS - Participatory Sensing

- The concept of communities contributing sensory information to form a body of knowledge
  - Mapping prices at different gas stations
  - Nericell: mapping road conditions in India
- Active research area currently, examples of topics:
  - Providing suitable incentives to participate in data collection
  - Security and privacy
  - Determining which users to ask to contribute to data collection

Categories of LBS - Participatory Sensing

GasBuddy (2016):
https://youtu.be/yCRoZ0eq78E

Challenges in LBS

- **Lack of standards**
  - Phone manufacturers have different APIs
  - Location-sensitive databases have different formats
- **Positioning**
  - Tradeoff between power consumption and accuracy
  - Lack of widely available indoor positioning solution
- **Power consumption**
  - Sensing (including positioning), camera and Internet connectivity have high power consumption
- **Privacy**
  - Possibility to deduce sensitive personal information

Location Privacy

Ability to prevent other parties from learning one's current or past location

Beresford & Stajano, 2003

Special type of information privacy which concerns the claim of individuals to determine for themselves when, how and to what extent location information about them is communicated to others

Duckham & Kulik, 2006

Location Privacy – Inference Attack

- An approach that aims to discover sensitive private information from location data
  - Detect patterns in location data
  - Cross-correlate patterns with other data sources
- Home and workplace detection
  - Place detection (discussed later on the course) can be used to identify places where person stays regularly
  - Correlations with time can be used to determine home and workplace for over 80% of individuals
  - Home address detection also examined in the context of GPS traces from drivers

Location Privacy – Inference Attack

- Gruteser and Hoh: completely anonymized GPS data from multiple (3 and later 5) users
  - Clustering can be used to reconstruct original traces of each user with high accuracy despite anonymization
- Wilson and Atkeson: Presence sensors within a smart home (motion detectors, pressure mats, …)
  - Observations from any single sensor not sufficient for detecting identity
  - Patterns in sensor triggering sequences could be used to determine who in the house was where (around 85% accuracy)

Location Privacy – Countermeasures

1. *Regulatory strategies*: governmental rules on the use of personal information
2. *Privacy policies*: trust-based agreements between individuals
3. *Anonymity*: use a pseudonym or create ambiguity by grouping people together
4. *Obfuscation*: reduce the quality of location information

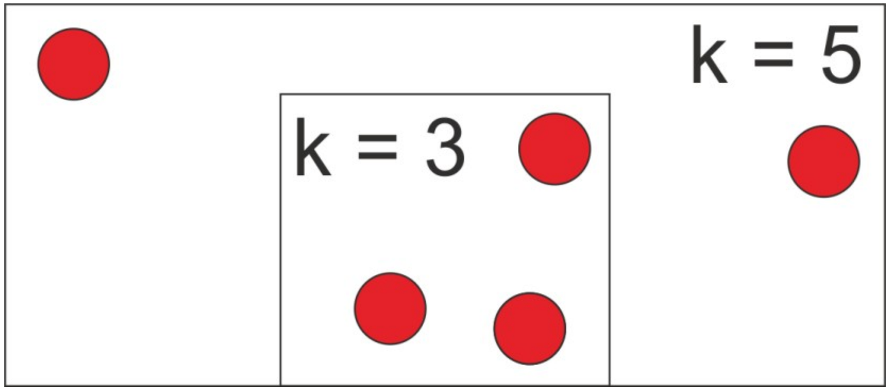
- First two are manual enforcement techniques
- Last two are **computational privacy measures**

Location Privacy – Anonymity

- Basic idea to replace associated name with a pseudonym or other untraceable identifier
  - Naïve approach: change pseudonyms regularly to reduce risk of learning about habits
  - Clustering can be used to detect which pseudonyms belong together, at least when data from only few individuals
- K-Anonymity: instead of reporting the location of a person, report a region containing k-1 people
  - Additional information, such as patterns in service requests, could be used to break k-anonymity
  - “Historical k-anonymity”: inject ambiguity into additional information as well

Location Privacy – K-Anonymity

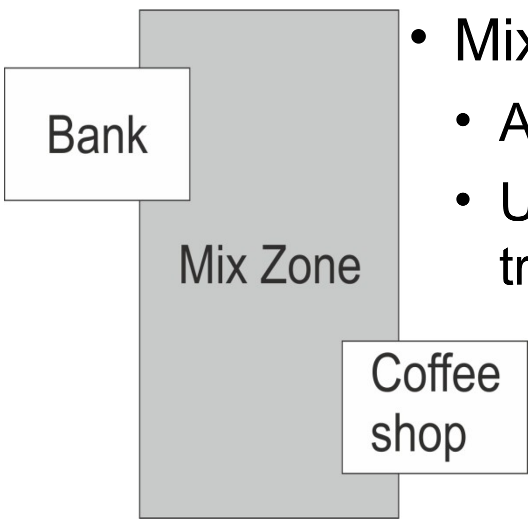
- The protection provided by k-anonymity sensitive to
  - Choice of the value of k
  - The positions of the entities



- K-anonymity can be extended to protect the identify of the person who initiated location request

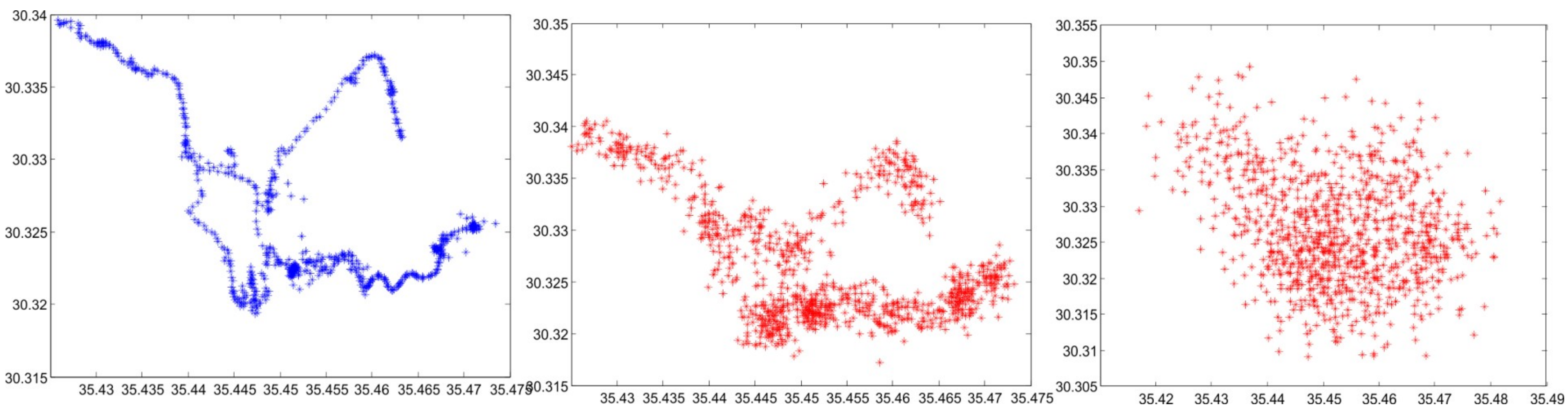
Location Privacy – Mix Zones

- Application zones:
  - Areas where location-based services are used
  - User's location reported
- Mix zones
  - Areas between the application zones
  - User given a new, unused pseudonym when transferring from application zone to mix zone



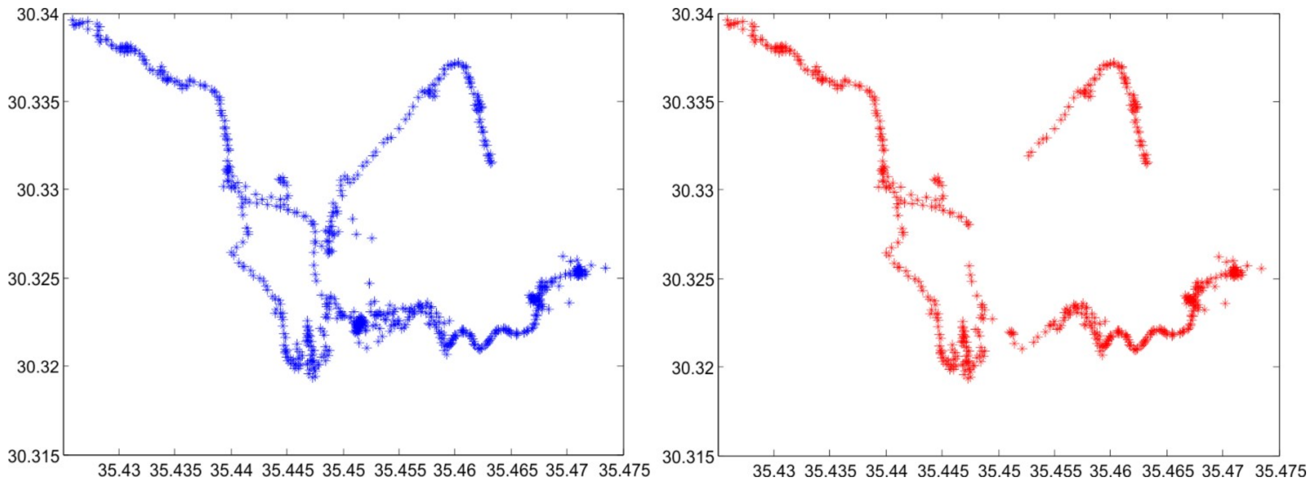
Location Privacy – Spatial and Temporal Degradation

- Alternative countermeasure is to degrade the quality of location measurements
- Adding white noise to measurements
  - Random samples from a zero-mean Gaussian
  - Standard deviation determines extent of noise



Location Privacy – Spatial and Temporal Degradation

- Temporal degradation:
  - Increasing time between location reports
- Cloaking
  - Removing data from certain locations (spatial) and/or from certain times (temporal)



Location Sensing

- Nowadays most location-based services (apps) operate in a continuous (and sustained) mode
  - I.e., location data continually collected and analyzed
- Resource-efficiency a critical constraint
  - High CPU or I/O load can hinder other applications
  - Location sensing drain battery, forcing users to charge the phone more often
- Usability concerns
  - Consistency of the application performance
  - Accuracy, particularly when the user interface is adapted based on them

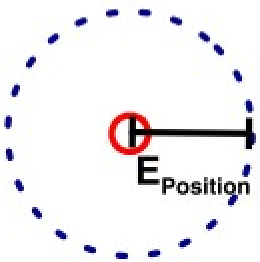
Energy-Efficiency

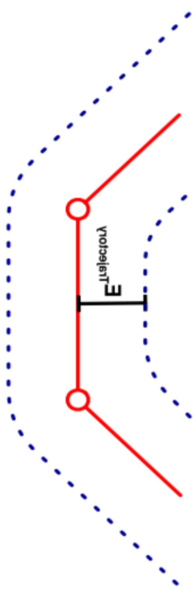
- Continuous location sensing and reporting consumes significant amounts of energy
- Approaches for location sensing vary significantly in terms of power consumption
  - Typically: GPS > WiFi > Inertial > Accelerometer > GSM
- Main ways to reduce power consumption:
  - *Duty cycling*: reduce sensing frequency
  - *Sensor management:* use low-power sensors whenever possible
  - *Intelligent uploading:* reducing reporting (data connectivity) frequency
  - *Offloading:* perform (parts of) computations elsewhere

Energy-Efficiency for Location Sensing

- Savings in power consumption often come at the expense of location accuracy
- Potential solution is to optimize energy consumption for a given error threshold E
  - Reduce power consumption as much as possible
  - Guarantee that location accuracy never (or seldom) exceeds the error threshold E
- Monitoring of location related information referred to as *tracking*

Energy-Efficiency – Location Tracking





- Position tracking:
  - Estimate and report new position only when position error cannot guaranteed to be within error threshold
  - Can be understood as a circle of uncertainty around the last reported location
- Trajectory tracking:
  - Report information about the user's trajectory when error of the trajectory exceeds a threshold
  - Error corridor around actual trajectory
- Buddy tracking:
  - Report entrance/departure of a friend from close proximity

Duty Cycling

- Duty cycling reduces sampling by alternating between idle and active states of the sensor
  - *Duty cycle* = percentage of period where a signal is active
  - $D = T / P * 100\%$ where T is active time and P is the period of the signal
  - Sampling sensor for one minute each five minutes thus corresponds to a 20% duty cycle
- Need to be carefully designed
  - Going from lower sampling state to higher typically has an additional “activation” cost
  - Moving from a high state to a lower state often has delay - need sufficiently long inactive states to save energy

Duty Cycling Example – Motion Tracking

- Duty cycling schemes can be rather sophisticated
- Example: GPS duty cycling for location reporting
  - Assume location needs to be reported every 100m
  - Given current speed of user *v* m/s (from last GPS), the next time GPS needs to be sampled (latest) is 100 / *v*
  - Can also incorporate errors, e.g., if GPS error is *E* m, the next sample should be within (100 – *E*) / *v*

Error threshold

Estimated error since last position update

$$\Delta t = \frac{min(E_{Position}, E_{Trajectory}) - e_{model}}{V_{est}}$$

Estimated speed of the user

Sensor Substitution / Replacement

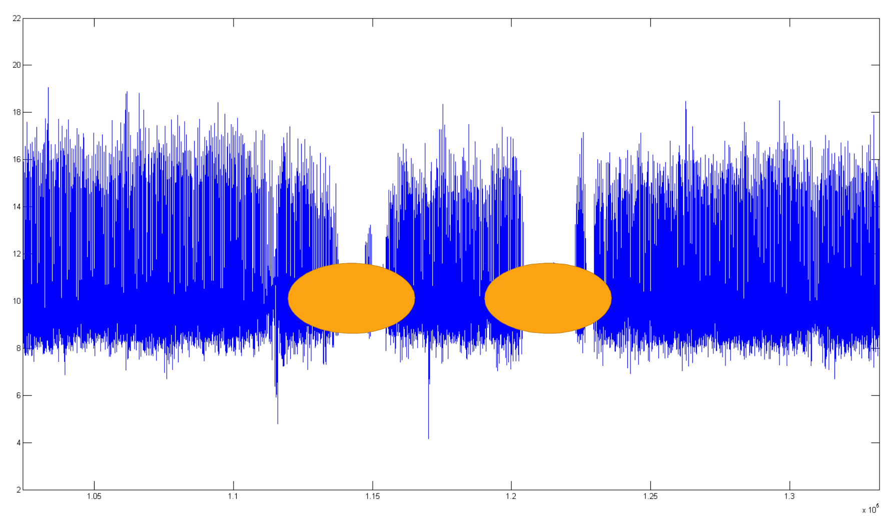
- Often multiple sensors can be used to measure the same phenomena
  - WiFi/GPS/GSM all provide location information
  - Accelerometer and GPS can be used to estimate speed
- *Energy-accuracy trade-off*
  - The more accurate information is required, the more energy heavy sensor (usually) needs to be used
- Sensor substitution/replacement a generic technique whereby a sensor is replaced with another (less power hungry) one

Active / Inactive State Detection

- Users tend to spend the majority of times within few locations (≈ 50+% of time at either home or work)
  - During these periods users mainly stationary - can let sensors sleep until “something” happens
- Activity spotting: determine if any activity (of interest) is taking place
  - Most common strategy is to consider the variance of accelerometer magnitude
  - Another example is monitoring the stability of WiFi / audio environment
- Special case of sensor substitution

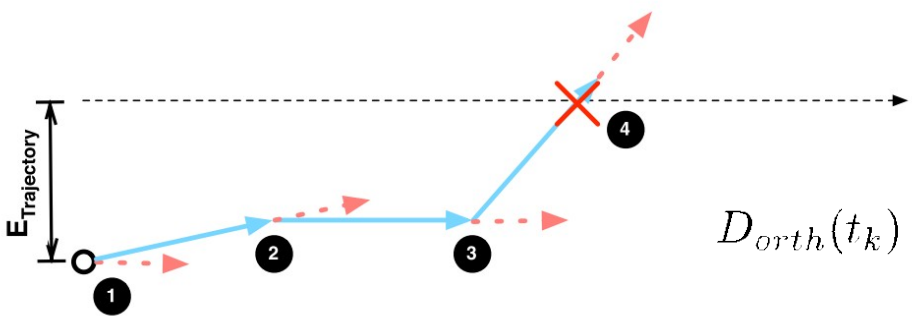
Active / Inactive State Detection: Example

- Example data from a walking segment
- Blue line: accelerometer magnitude, i.e., $\sum_i |x_i|$
- Stationary periods clearly distinguishable as periods of low variance



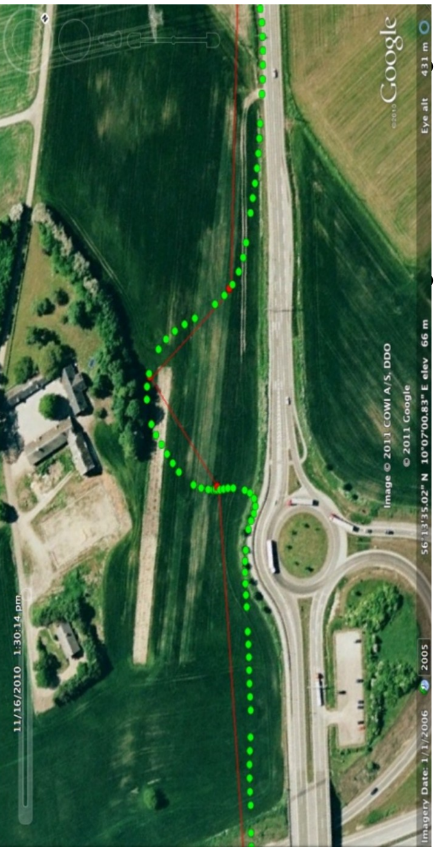
Sensor Substitution Example – Heading-Aware Tracking

- Compass heading can be used to reduce need for GPS when user is moving along a straight line
  - Assume constant velocity
  - Position estimated using accumulated orthogonal distance (discussed later during the course)
  - Position update triggered when error estimate exceeds the tracking threshold



$$D_{orth}(t_k) = \sum_{i=1}^{k} (t_i - t_{i-1}) S_{gps} sin(||\theta_{start} - \theta_i||)(1 + \sigma)$$

Intelligent Uploading

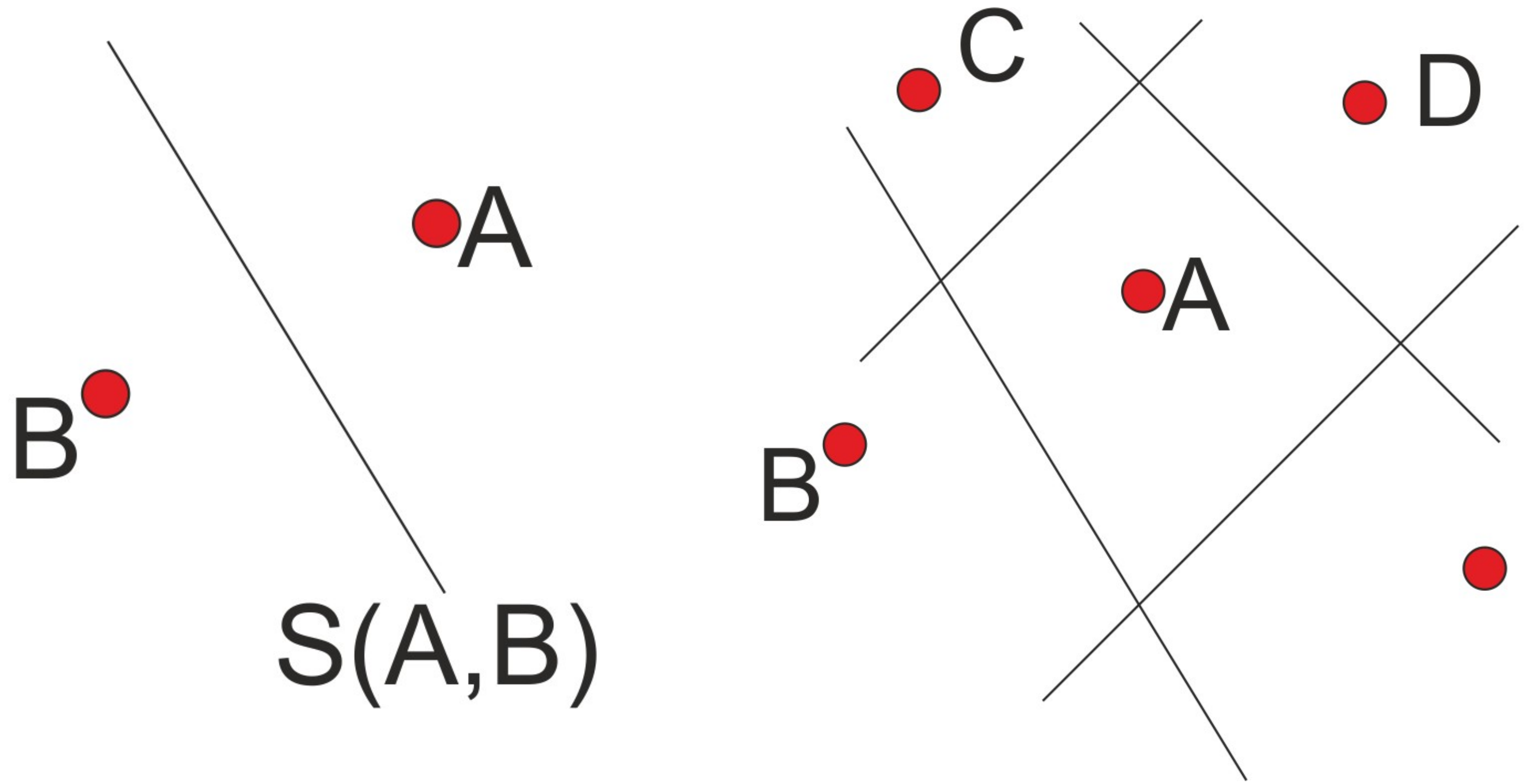


- “Duty cycling” network transmissions
  - Reduce frequency of data transmissions from the mobile client
- Basic uploading strategies
  - Continuous: send data all the time (only realistic for on-demand sensing with low sampling rates)
  - Periodic: schedule uploads at regular intervals
    - Interval determines sampling frequency of reporting
  - Event-based: upload when a given event occurs
  - Error-based: upload when an error threshold exceeded
    - Position tracking: use position error as measure
    - Trajectory tracking: use trajectory reconstruction error

Energy-Efficiency for Buddy Tracking

- Trigger update (or alert) whenever another user (or friend) comes (or leaves) the vicinity of an user
- Strips algorithm
  1. Exchange location messages between devices
  2. For each pair of devices (a,b), determine a strip S(a,b) along which all points are equally far from a and b
  3. If a or b violate the strip S(a,b), they exchange location information
     – If within close vicinity, trigger entrance
     – If not within close vicinity, redefine the strip S(a,b)

Energy-Efficiency – Buddy Tracking



Summary

- **Location-based services**
  - Computer applications that deliver information depending on the location of the user and/or device
  - Require access and to network and location information
  - Client, location system, service provider, content provider
- **Location privacy**
  - Privacy that concerns ability to determine when, how, and to which extent location information is communicated
- **Location Inference attack**
  - Computational approach that attempts to discover sensitive personal data from location traces

Summary

- **Computational countermeasures**
  - Anonymity: k-anonymity, mixed zones
  - Obfuscation: cloaking, noising, temporal degradation
- **Energy-efficiency**
  - Duty cycling: reducing sampling rate
  - Sensor management: using low power sensors when possible
  - Uploading policies: reduce time span when location reported
- **Tracking**: position, trajectory and buddy tracking

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