Dejavu:An accurate Energy-Efficient Outdoor Localization System

SIGSPATIAL '13

Dejavu

- Outdoor localization system
- Provides accurate and energy-efficient outdoor localization
- Uses only energy-efficient sensors or sensors which are already running
- leverages road landmarks like moving over potholes, bumps, tunnels etc

Introduction

- GPS considered as de facto standard for outdoor localization
  - but it is energy hungry and accuracy limited in areas like tunnels
- Dejavu's approach is based on low-energy sensors (accelerometer,gyroscope,compass)
- Using array of sensors it identifies landmarks (anchors)
- crowdsourcing to build database

System overview

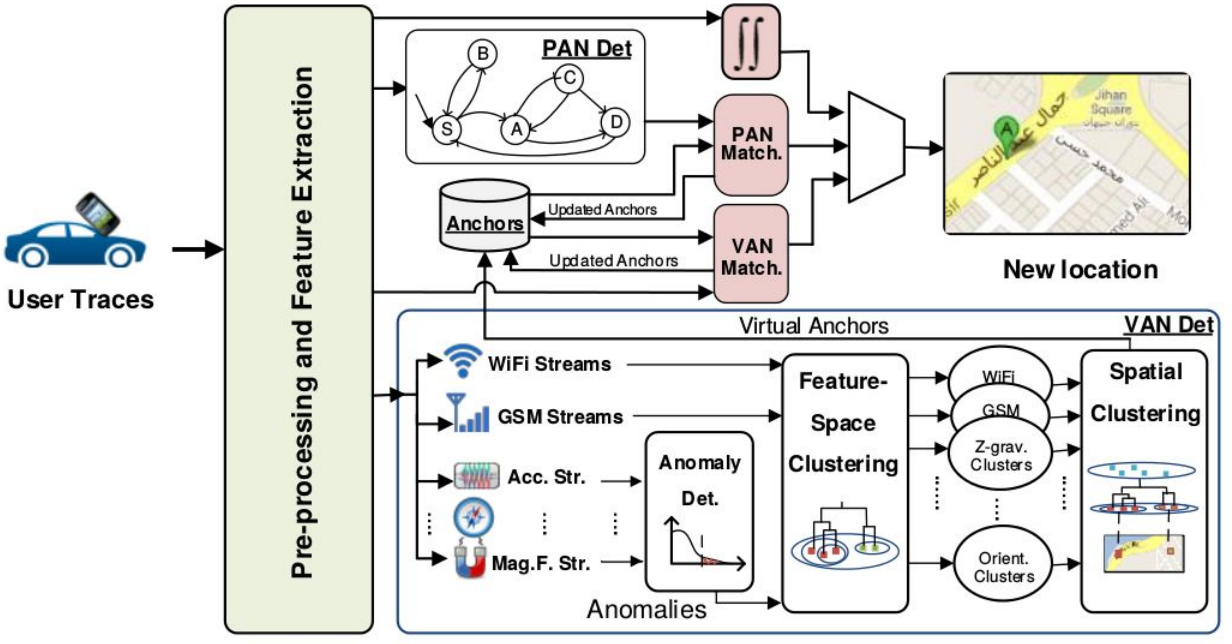


Figure 1: *Dejavu* architecture — The phone location is estimated using dead-reckoning, physical (PAN) and virtual (VAN) anchors are used to reset accumulated error. Sensor traces are also mined to detect new anchors, improving the system accuracy over time.

Raw sensor information

- System collects raw sensor information
- cellular network information (RSS and associated cell tower ID)
- opprtunistically leverags the Wifi chip to collect surrounding Wifi APs

Error Resetting

- uses linear accelaration combined with direction of motion to compute displacement
- uses Vincenty's formula
- to limit accumulated error system uses physical and virtual anchors

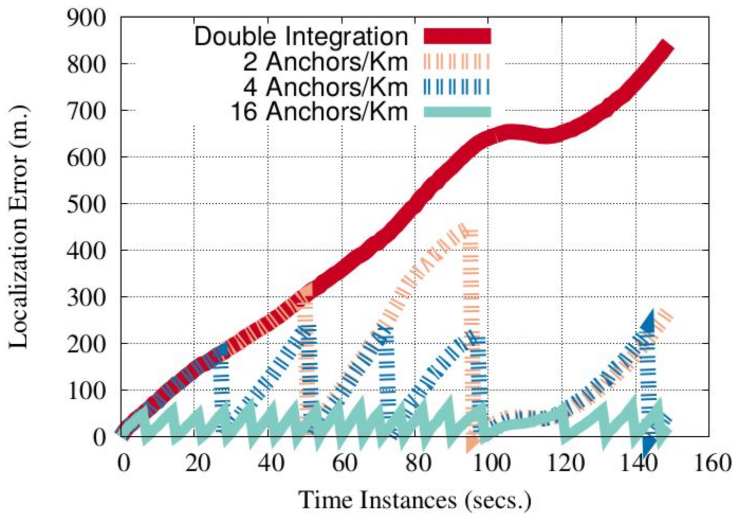


Figure 2: Comparing double integration (dead-reckoning) error to *Dejavu* with different anchor densities per kilo meter—The trip length is 1.5 Km.

Physical and virtual anchors

- Dejavu uses two types of anchors
- physical anchors mapped to road features like bridges, tunnels, speed-bumps
- extracted from map or through pror knowledge
- virtual anchors detected automatically
- includes points with unique GSM or Wifi RSS
- learned through crowd-sourcing

Anchor detection

- large number of road features can be identified on their unique signature

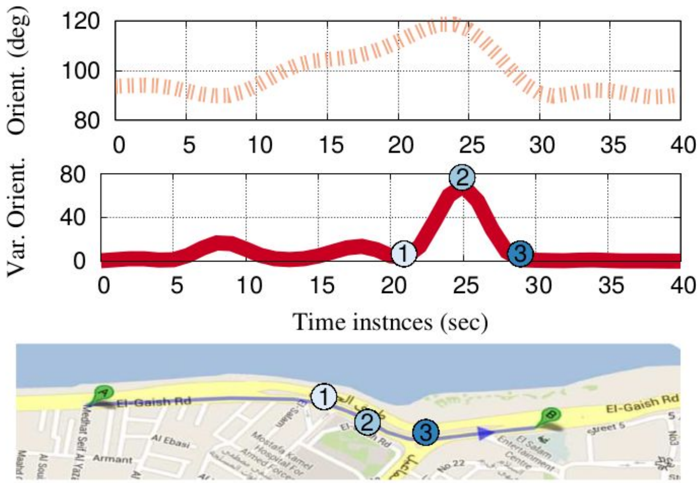
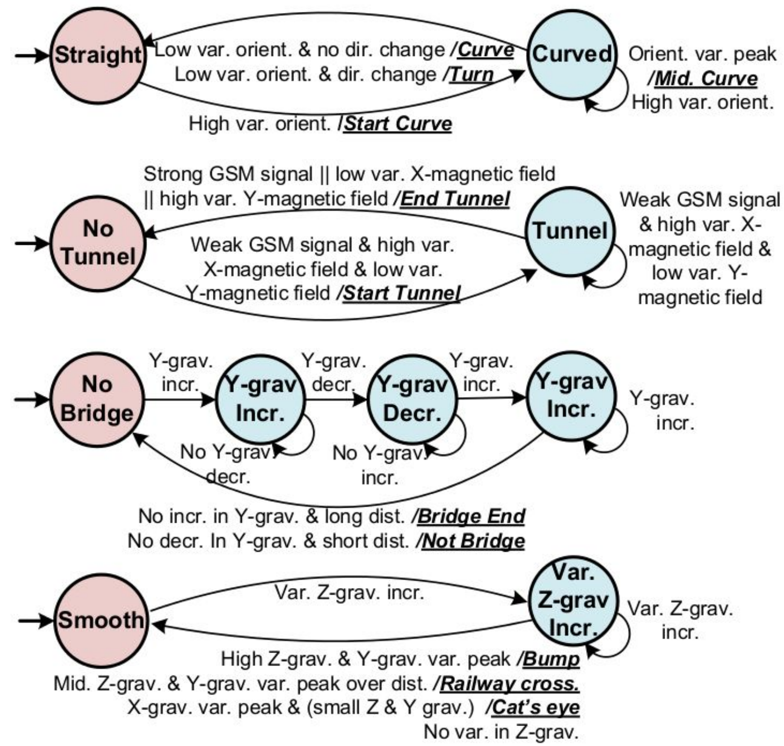


Figure 3: A car moving along a curve affects the orientation angle. The variance of the orientation can be used to detect different numbered landmarks.

Physical anchors

- used to seed the anchor database
- identified from maps or by prior knowledge of the location
- different classes of physical anchors



Physical anchors

- Curves and turns -
  - road curvature forces car to change its direction which results in big variance of phone's orientation
- Tunnels -
  - drop in cellular signal
  - large variance in the ambient magnetic field in x-direction
- Bridges -
  - cars go up at the start of the bridge and go down at the end
  - reflected in x-gravity or y-gravity acceleration
- Road anomalies-
  - cat's eye does not cause high variance in y or z-axis gravity accleration
  - speed bumps usually have highest variance
  - railway crossing leads to medium variance

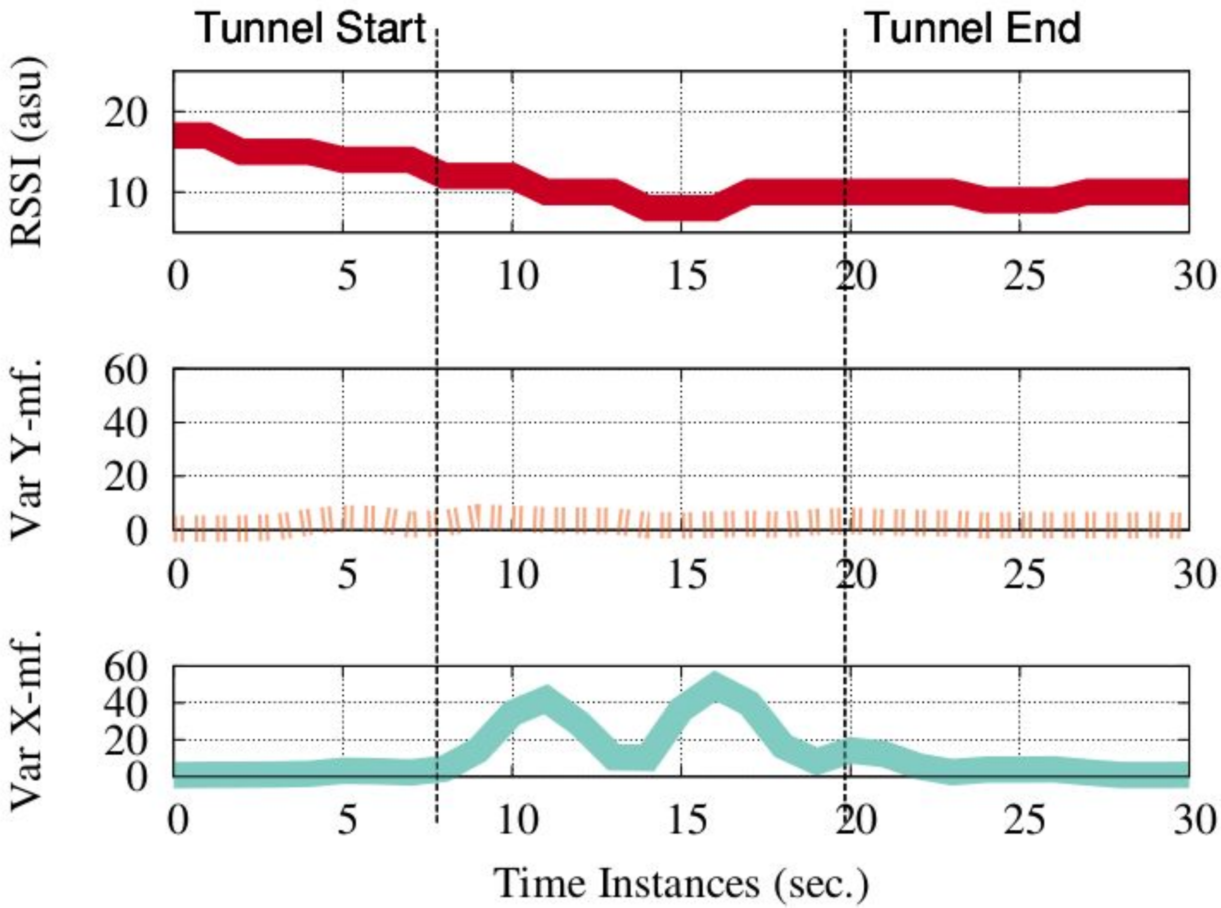
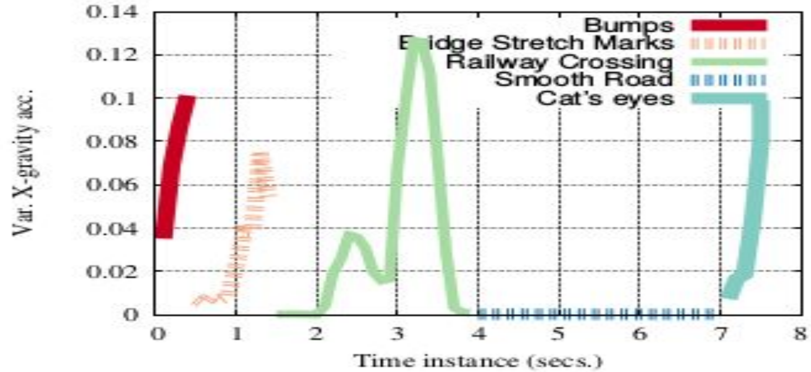
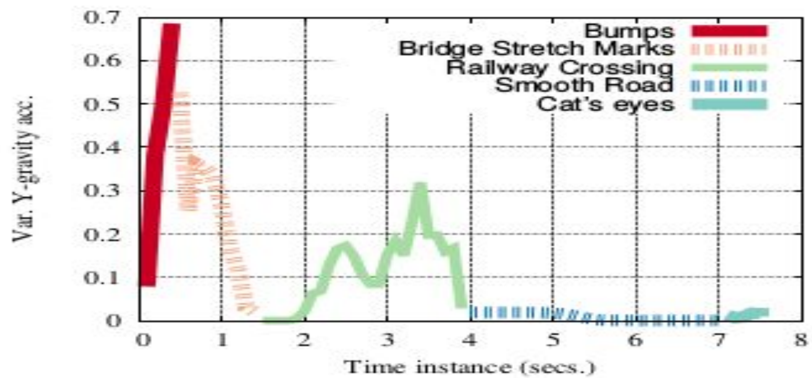


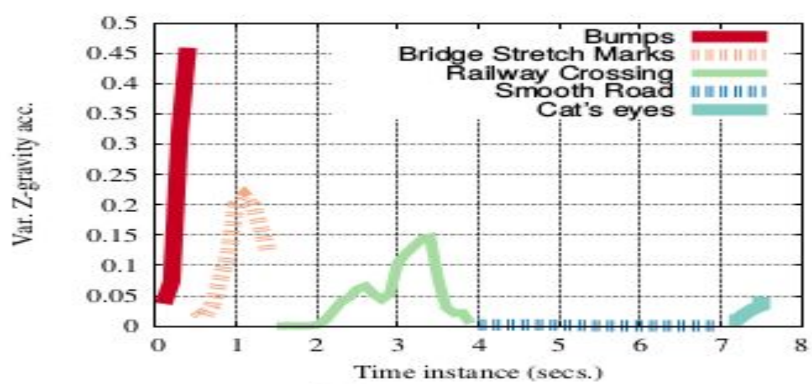
Figure 5: Example of the different sensors behavior that characterize a tunnel: reduction in the cellular RSS, high variance of the ambient magnetic field in the x-direction, and low variance of the ambient magnetic field in the y-direction.



(a) X variance.



(b) Y variance



(c) Z variance

Virtual anchors

- uses un-supervised learning techniques to identify virtual anchors
- anomaly detection techniques are used to identify anomalies in sensor readings.
- they are clustered into sensor space to identify candidate clusters
- points of each cluster are spatially clustered to identify the location of each anchor

Feature selection

Cellular and Wifi anchors correspond to points in RSS signal space with unique signature

$$\frac{1}{|A|}\sum_{\forall a \in A}\frac{min(f_1(a), f_2(a))}{max(f_1(a), f_2(a))}$$

Anomaly detection

$$\hat{f}(v) = \frac{1}{nh}\sum_{i=1}^{n} K(\frac{v - v_i}{h})$$

$$K(q) = \begin{cases} \frac{3}{4}(1 - q^2), & \text{if } |q| \leq 1 \\ 0, & \text{otherwise} \end{cases}$$

optimal bandwidth can be estimated as -

$$h^* = 2.345\hat{\sigma}n^{-0.2}$$

- h - bandwidth
- n - sample size
- K - kernel function

Two stage clustering

- Cluster feature space using hierarchical clustering in vector feature space
- Clustering will group similar anomalies
- spatial clustering of points in clusters obtained previously
- cluster is accepted if the number of points is above a threshold

Computing anchor location

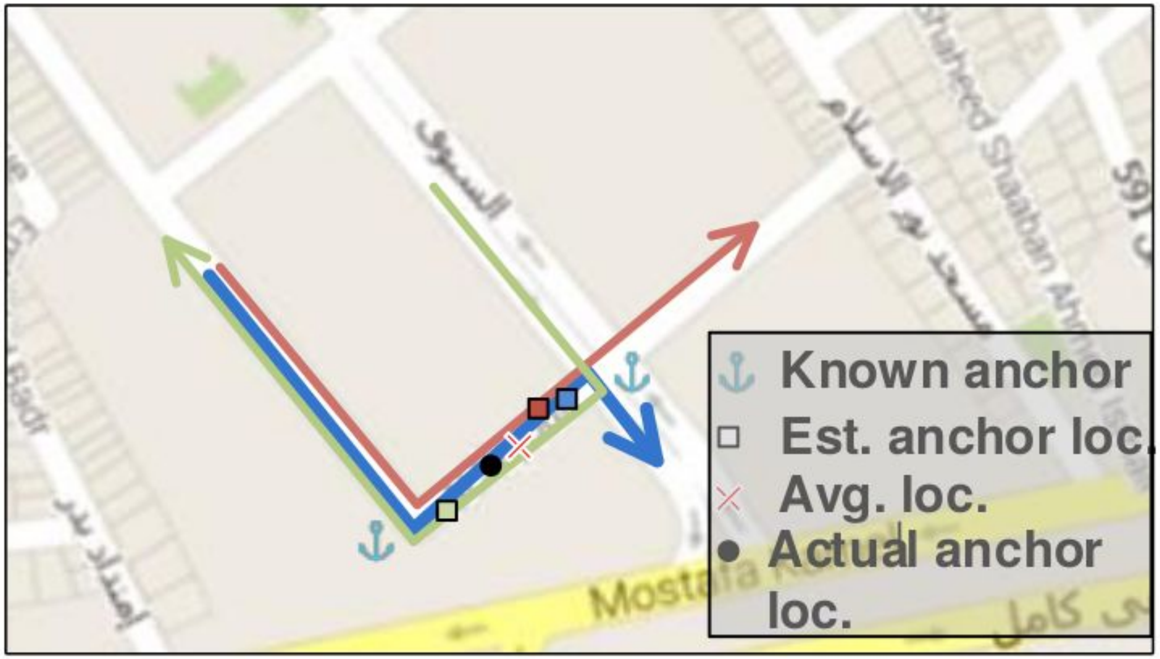


Figure 7: Different car traces passing by the same anchor and the corresponding estimated anchor location. The starting point of each trace is the point of the last error resetting event. Shorter traces have higher accuracy.

Discussion

- Anchors aliasing
  - classes of anchors can be confused with other anchors
  - leverages map context information
- Efficient matching
  - limits search space to small area around the user location
- Processing location
  - can be split into a client-server architecture
- Other sensors
  - other sensors of the phone such as camera, mic could be used
- Handling heterogeneity

Evaluation

Testbed	Distance covered (km)	Speed (km/h)		Average Anchor Density (per km)					
				Phy. anch.	Virt. vect. sens.		Virt. scalar sensors		
		Avg.	Max.		GSM	WiFi	Acc.	Magnet.	Orient.
City	39.5	12.6	55.8	3.3	50	112.2	10	7	9
Highway	50	51.1	100.1	1	33.3	7	2.9	1.7	1.4

Table 1: Summary of the different testbeds used. The high density of anchors, even without WiFi, allows Dejavu to obtain high-accuracy energy-efficient localization in both testbeds.

	Cat's eyes	Bumps	Curves	Rail cross.	Bridges	Tunnels	Turns	unclass.	FP	FN	Total traces
Cat's eyes	**22**	0	0	0	0	0	0	5	0	0.18	27
Bumps	0	**30**	0	3	0	0	0	0	0.03	0.09	33
Curves	0	0	**20**	0	0	0	0	0	0	0	20
Rail cross.	0	1	0	**13**	0	0	0	0	0.21	0.07	14
Bridges	0	0	0	0	**9**	0	0	1	0	0.1	10
Tunnels	0	0	0	0	0	**10**	0	0	0	0	10
Turns	0	0	0	0	0	0	**40**	0	0	0	40
Overall									**0.03**	**0.06**	**154**

Table 2: Confusion matrix for classifying different physical anchors.

Virtual anchor detection accuracy

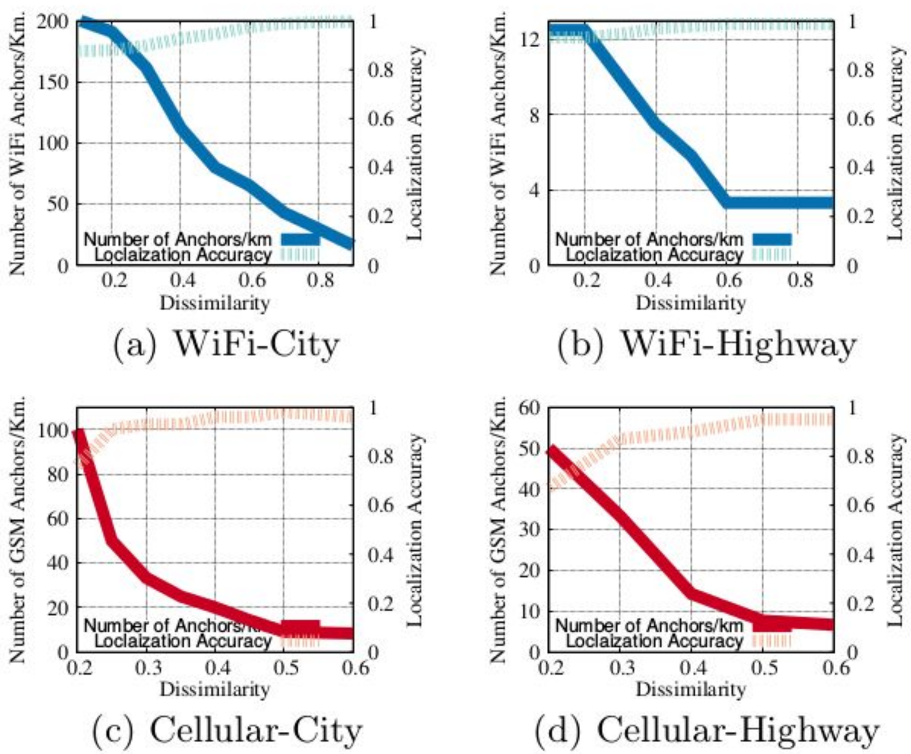


Figure 8: Effect of changing similarity threshold on anchor density and correctly identifying the anchor

Anchor localization accuracy

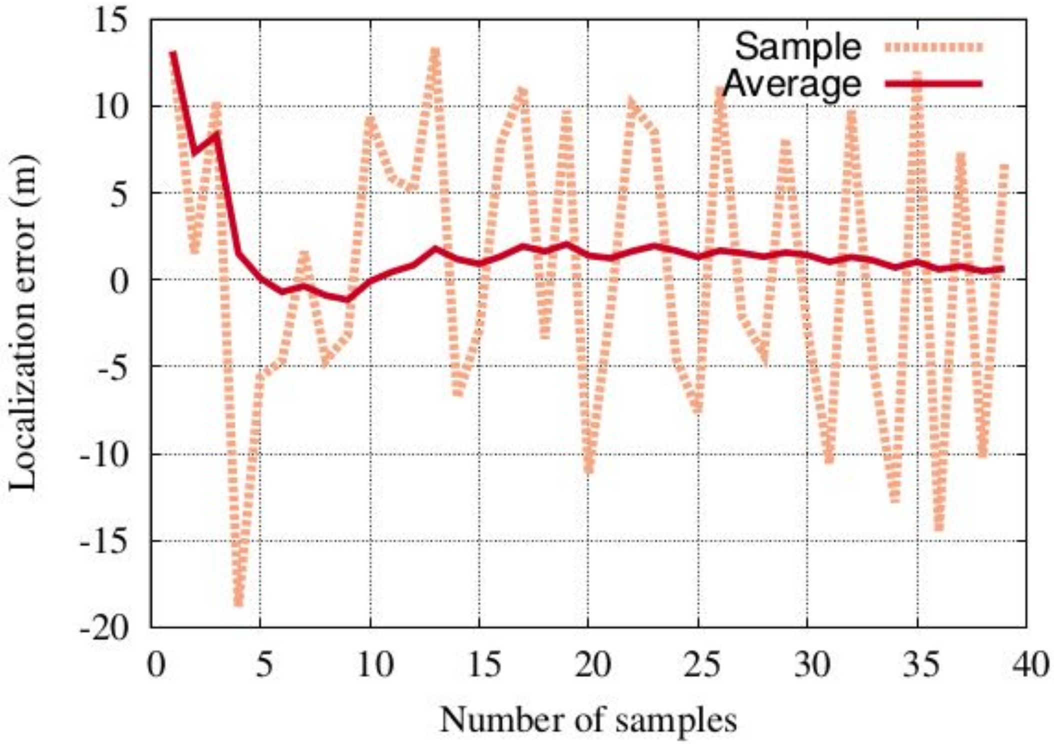


Figure 9: Effect of number of samples on the accuracy of estimating the anchor location.

Effect of anchor density on accuracy

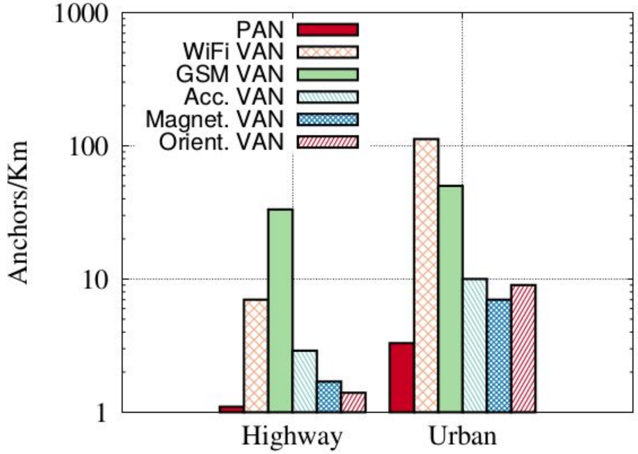


Figure 10: Physical (PAN) and virtual (VAN) anchors density for the different classes in our testbeds.

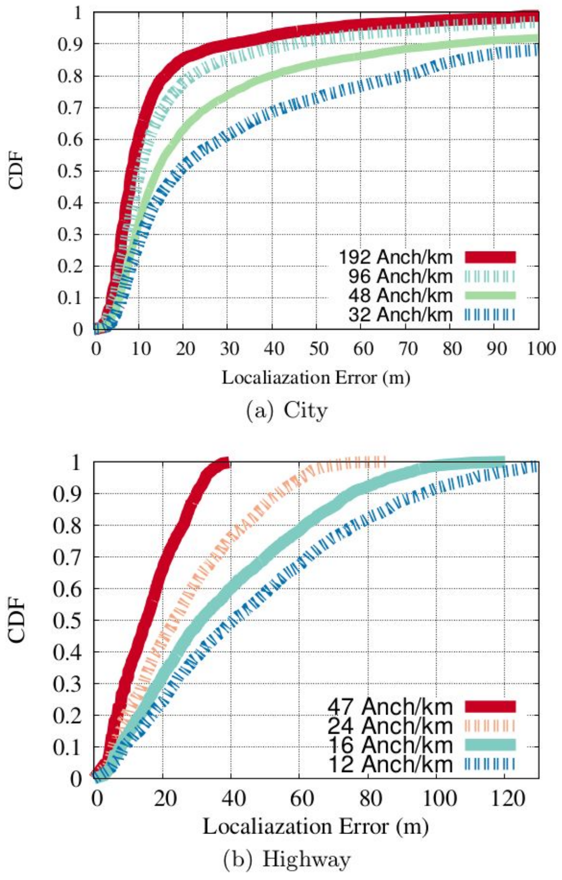


Figure 11: Effect of density of anchors on the localization accuracy.

Dejavu against other systems

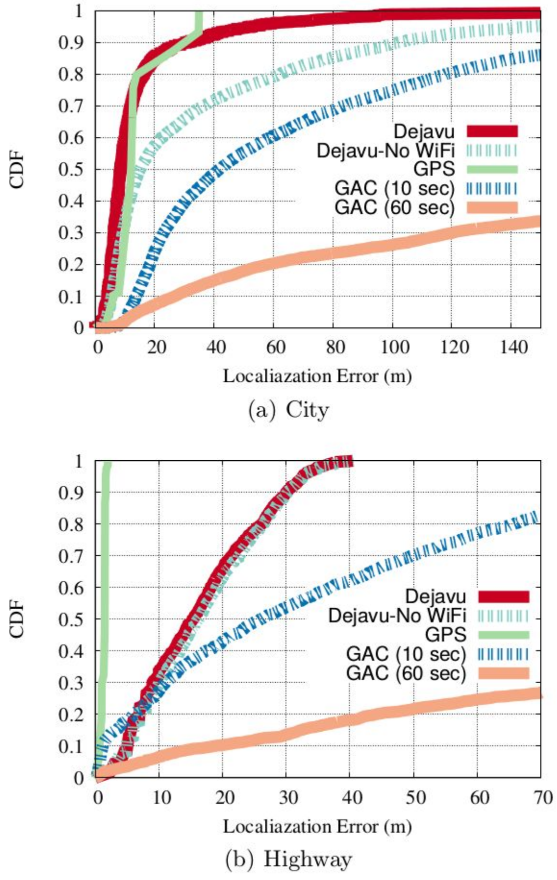


Figure 12: CDF of localization error of *Dejavu* compared to GPS and GAC [27].

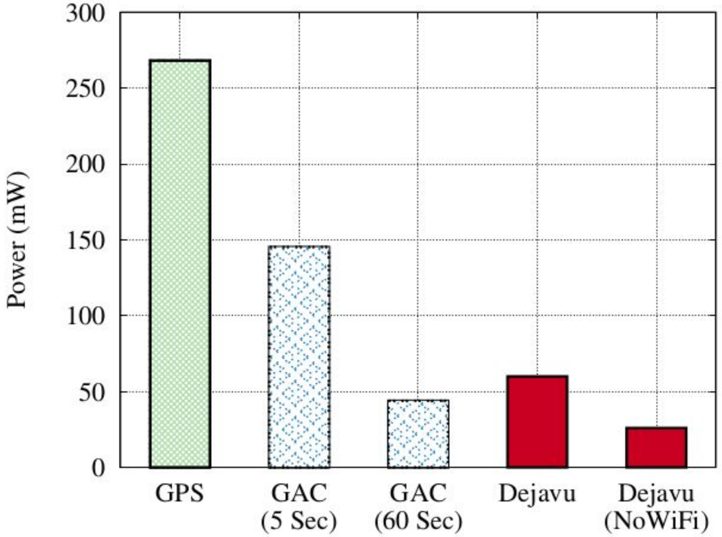


Figure 13: Power consumption for the different systems.