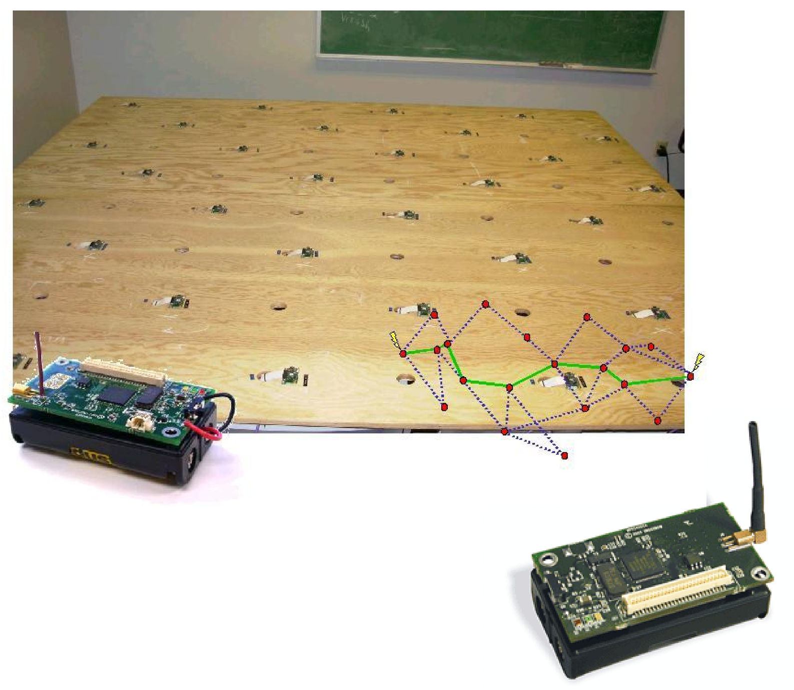

EMULI

Model Driven Sensor Stimuli for Experimentation

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Summary

We describe Emuli — a method of replacing sensor data with a network-wide model of stimuli events. Sensor readings are generated on demand from the modeling data stored at each device. This approach allows for both repeatable and variable experimentation with a network of physical devices for existing and planned sensing modalities. We illustrate the approach with (i) a light sensor and (ii) a hypothetical range sensor used in a tracking application.

Light Sensor Emulation

We demonstrated how a statistical model can be effectively used to emulate environmental sensing. We implemented a simple light-sensor data collection application. To instantiate our model we collected light sensor data from 14 motes mounted on benches in a lab and equipped with MTS300 sensor board. For each node we collected 60 light measurements over an hour (one sample per minute) with the overhead fluorescent lights on. The values and their distribution differed significantly between the motes.

Mote Personality

On basis of experimental data readings we created *personality* for each mote. The probability that Emuli reports a certain value x was made proportional to the number of times x was reported in the actual experiment. The cumulative distribution function was stored in tabular form in the flash memory to be loaded at boot-time.

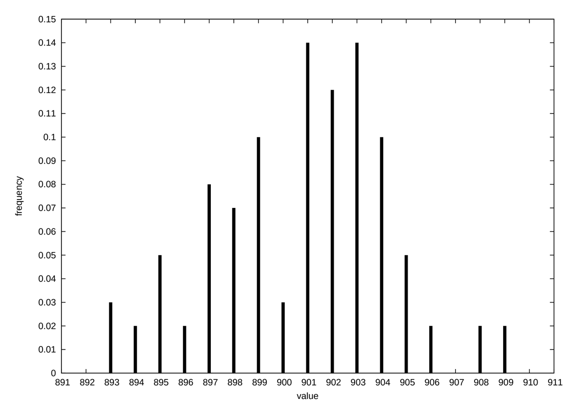
For each individual mote we replaced the light-sensor component in our application with an Emuli component configured with a unique personality and run the experiments with this model for 1000 samples.

Replacing Light Sensor Component with Emuli

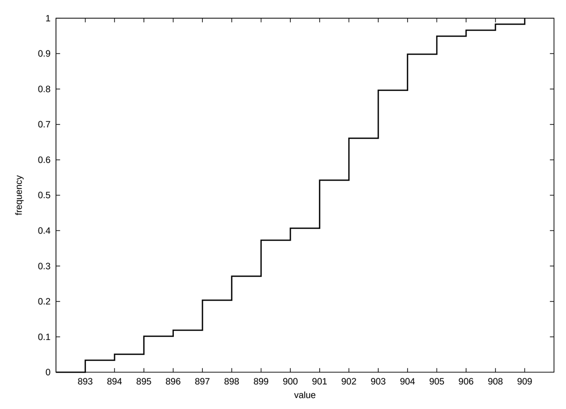
Actual and Emuli sensor data. The results indicate that Emuli data closely matches the experimental data in both average, standard deviation and distribution.

mote	readings	
id	actual	Emuli
1	900.68 ± 0.92	900.69 ± 0.21
2	882.76 ± 1.04	882.76 ± 0.24
3	859.53 ± 1.47	859.55 ± 0.34
4	916.88 ± 0.61	916.87 ± 0.14
5	868.56 ± 1.02	868.57 ± 0.24
6	952.73 ± 0.56	952.73 ± 0.13
7	957.78 ± 0.5	957.78 ± 0.12
8	943.59 ± 0.52	943.61 ± 0.12
9	940.42 ± 0.61	940.44 ± 0.14
10	952.97 ± 0.54	952.96 ± 0.13
11	915.81 ± 0.63	915.77 ± 0.15
12	951.42 ± 0.47	951.36 ± 0.11
13	927.75 ± 0.8	927.73 ± 0.19
14	957.78 ± 0.46	957.78 ± 0.11

Actual and Emuli light sensor data with 95% confidence intervals

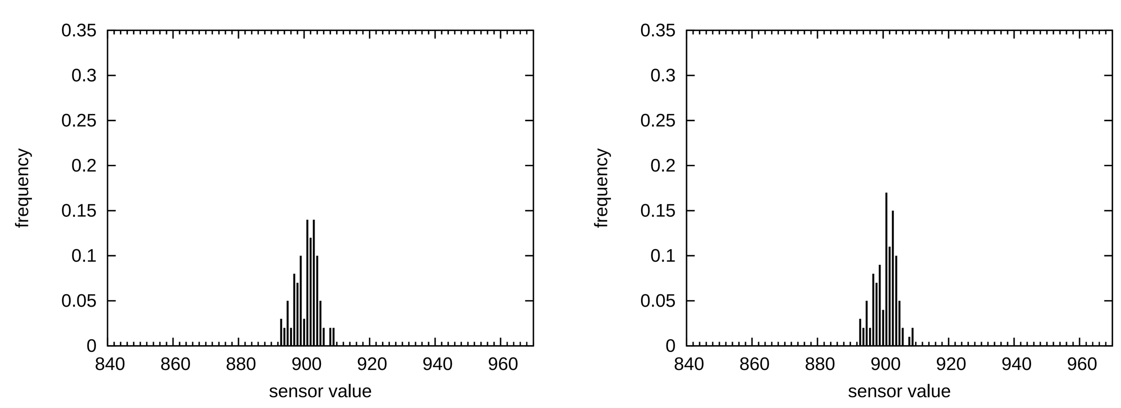


Histogram of light readings for Mote 1

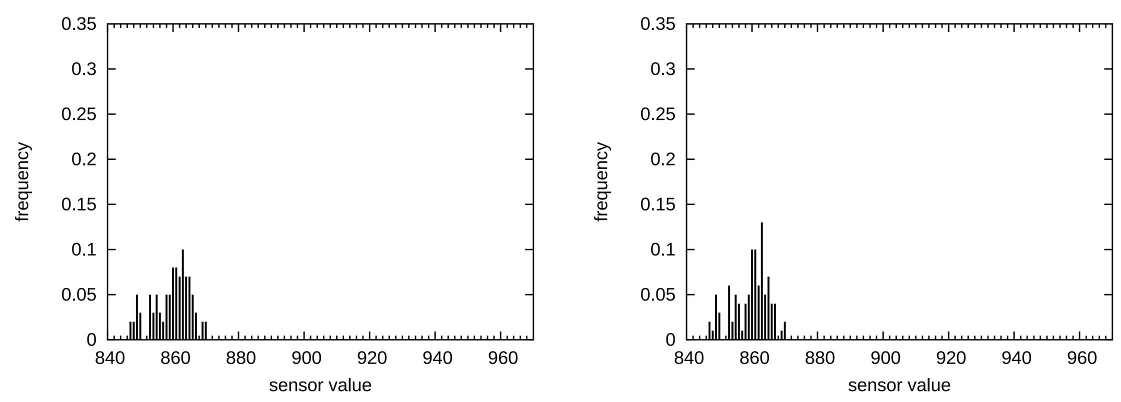


Cumulative distribution function for Mote 1

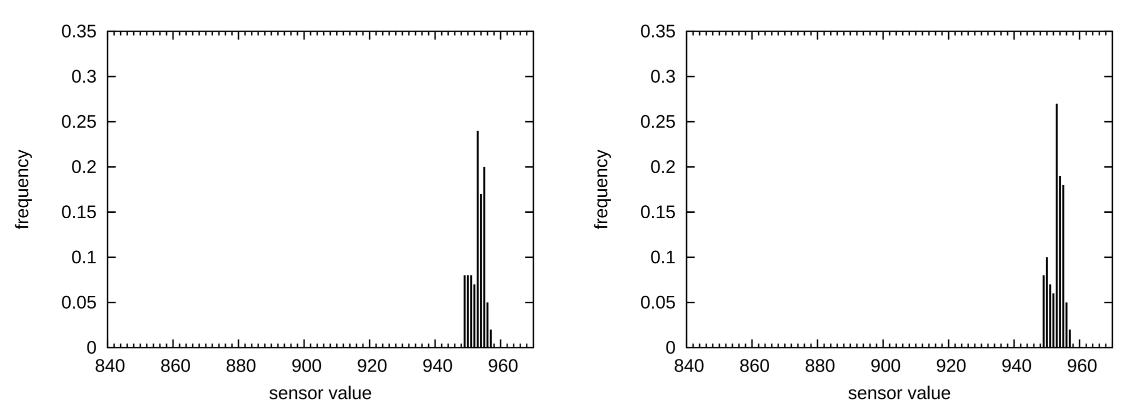
Example Actual and Emuli Histograms



mote 1



mote 3

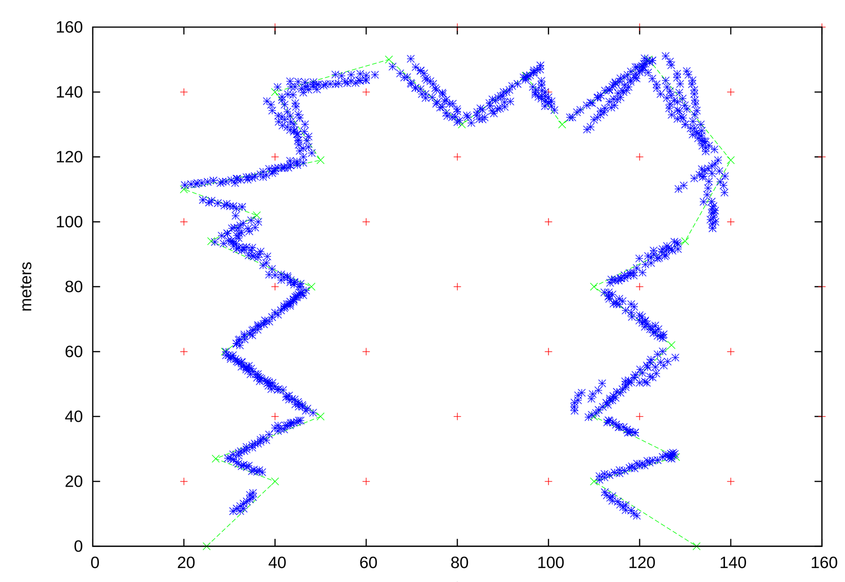


mote 10

Delay Measurement

The amount of time it takes to compute a light measurement is as follows: actual sensor — 556.82 ± 0.5, Emuli — 452.34 ± 1.77. Greater variability of Emuli data is due to linear search of CDT table. This variability can be mitigated by waiting before returning the result. The wait time would depend on the location of the data in the table.

Larger Scale Experiment



32 motes, 8 samples/secs

Hardware Injected Sensor Stimuli

Can use an industrial control board to send electric signals as if they are coming from the individual motes' sensors. There are a number of potential advantages to this method:

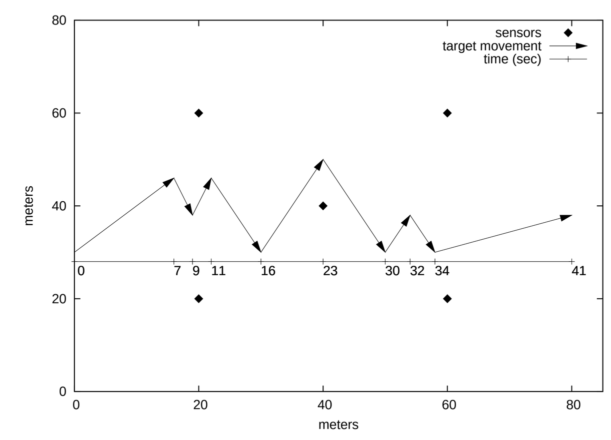
- leaves the motes completely oblivious to the sensor source substitution and requires no mote program modification;
- capable of concurrently emulating sophisticated analog inputs for multiple motes;
- does not require in-situ time synchronization, does not compete with the application for compute cycles.

Range Sensor Emulation and Target Tracking

Simulated Track

Emuli simulates a range sensor reading of target following a pre-defined track. A range sensor determines the distance from the mote to the target within its range. For this experiment the sensor range was set to 32 meters. The target moved in a zigzag pattern with speed of 3 meters per second across a plane surface.

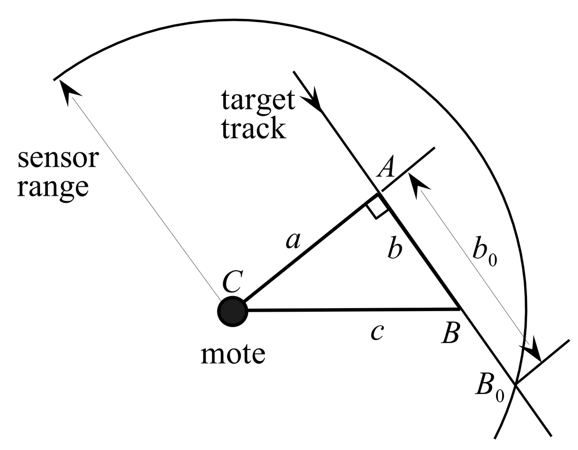
Simulated track presented by Emuli to the tracking application



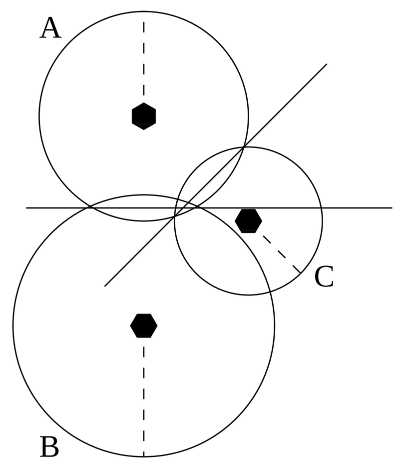
Track Representation

To report the position of the target, each mote stored the information about the segment of the target track that was within the range of its sensor. To optimize the calculations and storage, the segment is always represented by two points: the closest to the mote and the furthest sensed (i.e. the intersection of the track and the sensor range). A track may have to represented by multiple segments.To synchronize the target readings between motes, Emuli runs the FTSP time synchronization protocol.

Target distance computation with Emuli



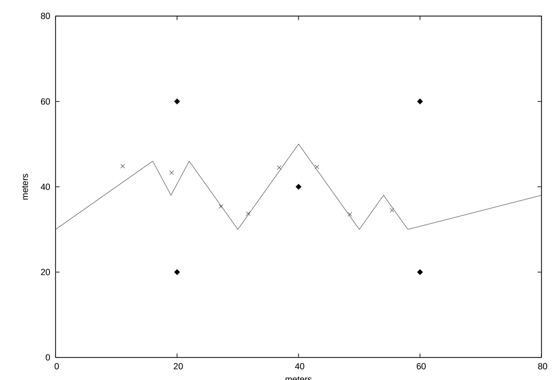
Trilateration with Emuli



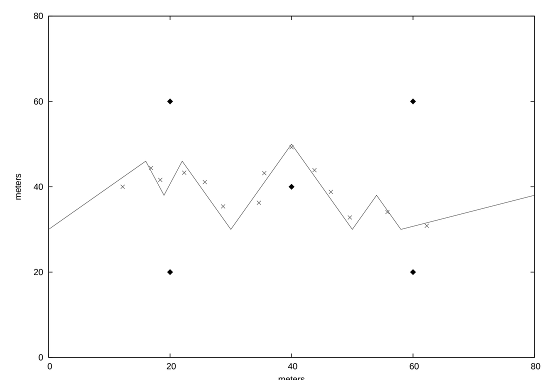
Track Calculation

To demonstrate the operation of range sensing simulation with Emuli, we implemented a simple trilateration application. The trilateration requires target distance measurements from three motes We computed intersection points of the circles whose radius are these measurements. We selected two arbitrary pairs of intersection points and draw lines through them. The target location was at the intersection of these two lines. Offline, for each distance measurements, we selected two other closest in time measurements and computed the target location.

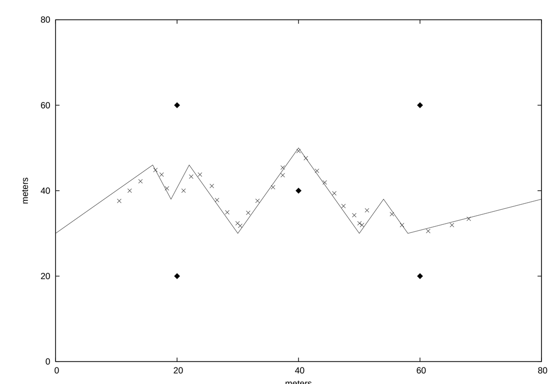
Varying Sampling Rate



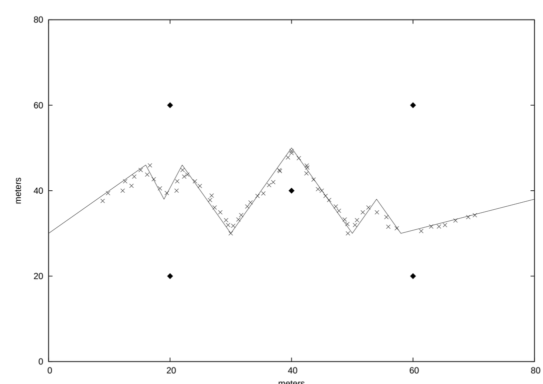
.25 samples/sec



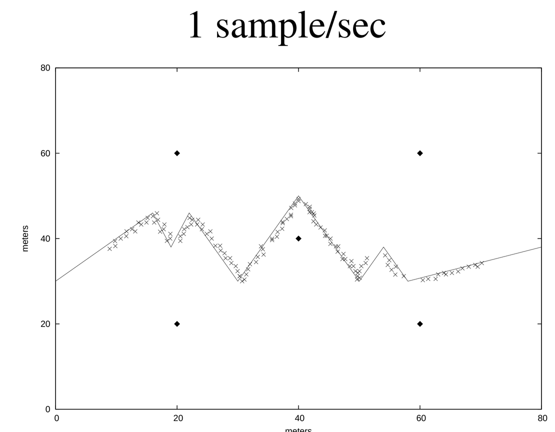
.5 samples/sec



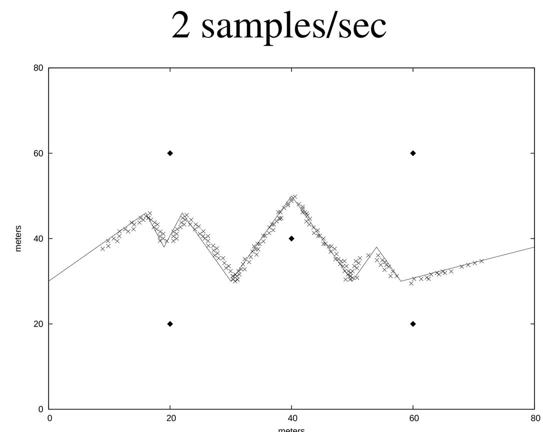
1 sample/sec



2 samples/sec

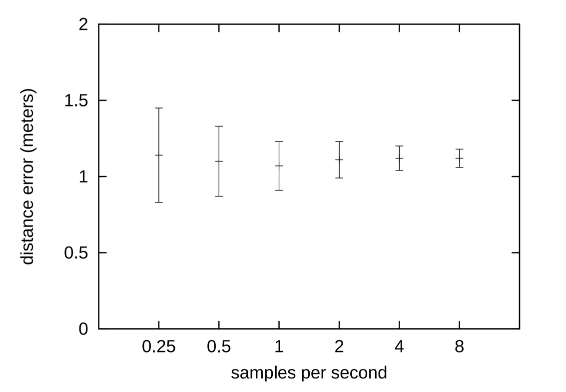


4 samples/sec

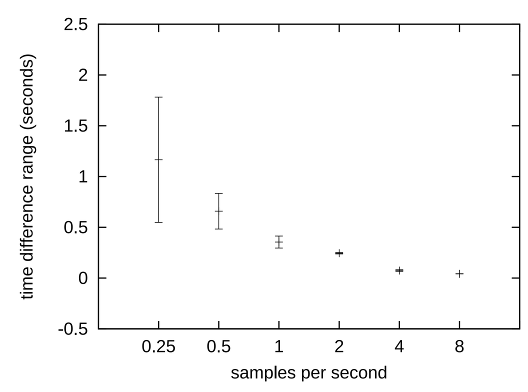


8 samples/sec

Analysis of Tracking Measurements



distance difference between reported by Emuli and simulated



time difference between measurements used for trilateration