Test and Evaluation of Localization and Tracking Systems

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Presented at 3rd Invitational Workshop on
Opportunistic RF Localization for Next Generation Wireless Devices
May 7, 2012

Introduction

- Lack of standardized Test and Evaluation (T&E) procedures has been an impediment to market growth for Localization and Tracking Systems (LTSs), as users are unable to verify whether a system meets their requirements.
  - T&E using different criteria and procedures is wasteful and may lead to inconsistent results.
- Use of disparate minimum performance requirements by various buyers / jurisdictions forces manufacturers to develop jurisdiction-specific products, thereby raising product costs.
- Many stakeholders and user communities have expressed a strong desire for development of T&E standards.

Taxonomies

- There are different types of LTS:
  - Operating Environment
    - indoor / outdoor / both
    - above ground / underwater
  - Networking / Sensor Infrastructure
    - available / unavailable
  - Site-Specific Training
    - allowed / not allowed
  - Platform Capabilities (computation / storage / radio communications)
    - RFID tags / smart phones / devices with higher capabilities
  - Person / Object Speed
    - stationary / pedestrian speeds / ground vehicular speeds / higher speeds
- T&E procedures may have to be specialized to the type of LTS under consideration.

Sensors for Localization

- In contrast with purely RF-based localization, there is a trend towards development of LTSs that use a variety of sensors and data fusion. This is particularly true in LTSs for mission-critical applications.
- Representative list of localization sensors:

WiFi/RF Receivers	Clock	Azimuth Rate Sensor	Temperature Sensor
1-/2-/3-Axis AOA/LOB/TDOA Sensors	Accelerometer	Pedometer	Star Tracker
Range/Pseudo-Range Finder	Gyroscope	Inclinometer	2D/3D Imager
GPS	GyroCompass	Barometer	LiDAR
MMWR and Other Radars	Magnetometer	Acoustic Sensor	Infrared Sensor

LTS T&E Approaches

- Test Types
  - System (Black Box) Testing
  - Component Testing
- Repeatability
  - One-Time Site-Specific Testing
  - Repeatable Laboratory Testing
- Repeatable laboratory testing for full-fledged systems is the *holy grail* in LTS T&E.
- It is plausible to design repeatable tests for the components of an LTS in a laboratory setting.
- Network modeling and simulation is an established approach for performance evaluation of communication networks, but there is no counterpart to that for LTS. Fidelity of the modeling and hence reliability of the simulation results is always an issue.

Scope of Proposed T&E Standard

- Develop appropriate performance metrics and T&E scenarios for LTSs with the following caveats:
  - Primarily, localization and tracking in buildings, but also consider transitions between indoors and outdoors.
  - Black box testing, but need to be cognizant of failure modes of various LTS sensors in order to design comprehensive T&E scenarios.
  - One-time site-specific testing
  - Need to test in different types of buildings, because these systems typically need radio communications/networking capability to function properly.
  - Need to consider various modes of mobility (walking, crawling, etc).
- LTS T&E for other application domains, such as miners trapped in an underground mine, submersible vehicles, or very small medical devices moving around inside a human body, may be the subject of future extensions to this “base” standard.

LTS Performance Metrics (I)

- Circular Error x% (CEx): Radius *R* of smallest circle centered at origin that contains x% of the horizontal error vectors.
- Horizontal Error Magnitude Mean and Variance
- Vertical Error x% (VEx): Smallest value *V* such that x% of vertical errors have magnitude not exceeding *V*.
- Vertical Error Magnitude Mean and Variance
- Predictable Accuracy *: Error magnitude mean for several "independent" tests of an LTS <u>at a given location</u>
- Repeatable Accuracy *: Error magnitude standard deviation for several "independent" tests of an LTS <u>at a given location</u>
- Confidence Radius: Like CEx, but for a general (horizontal, vertical, 3D) error vector for several "independent" tests of an LTS <u>at a given location</u>

* Not sure if this is the best possible name for this metric

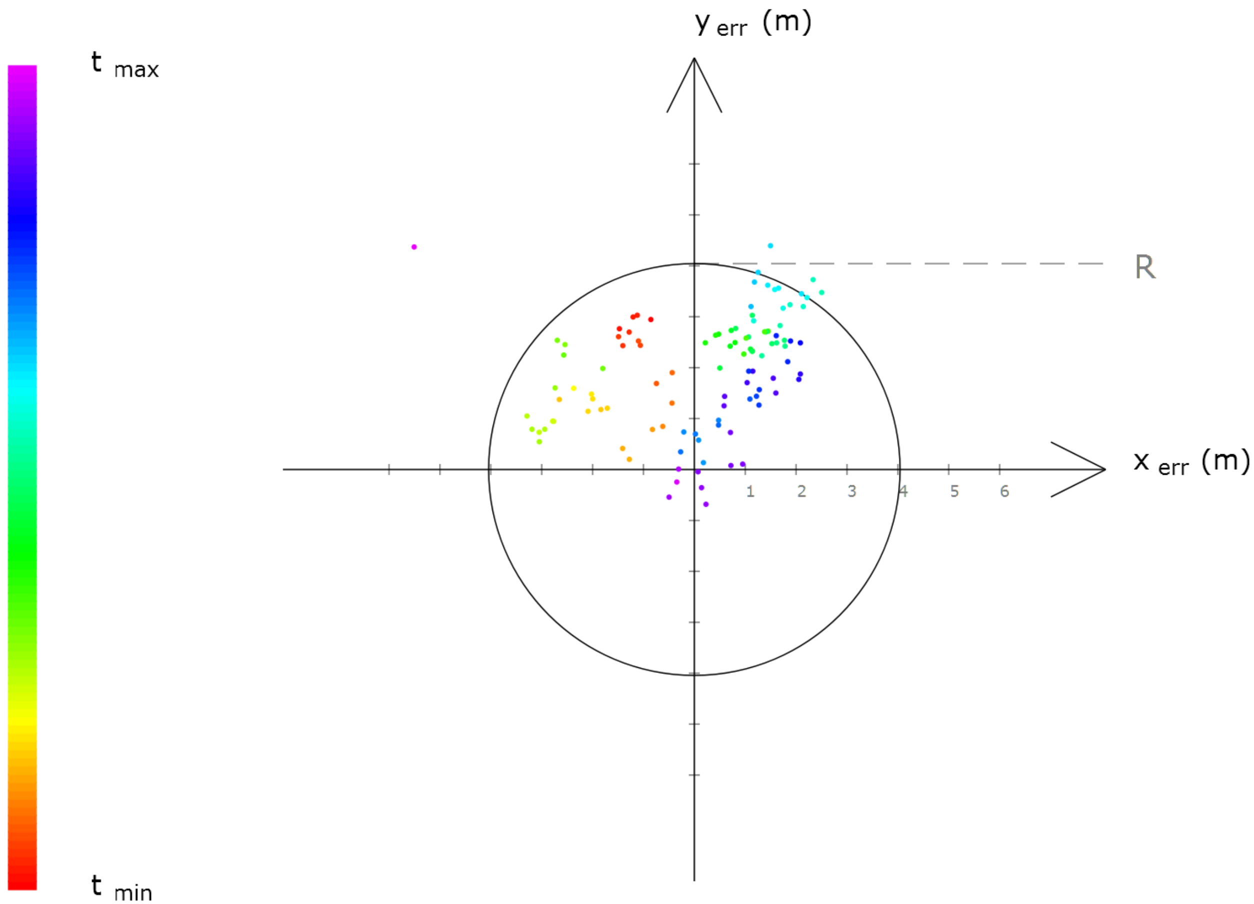
LTS Performance Metrics (II)

- Relative Accuracy: Absolute difference between the actual distance between two mobile users and the LTS estimate of that distance
- Latency *: Time lapsed from when a mobile user has moved by a pre-determined amount until that change in location is detected by the LTS (at the device the user is carrying or by someone else tracking the user)
- Availability **: Percentage of time over a defined operation an LTS meets its “minimum performance requirements”
- Coverage: Regions within evaluation area where the LTS meets its “minimum performance requirements”

* Alternative definition: Time LTS takes to generate a location estimate

** Pitfalls: Depends on the percentage of time the mobile user spends at various locations. Also, it makes a difference whether only the mobile user needs to know where he is or someone else is tracking him. The latter requires availability of a radio link to the entity doing the tracking.

Sample LTS T&E Results (I)



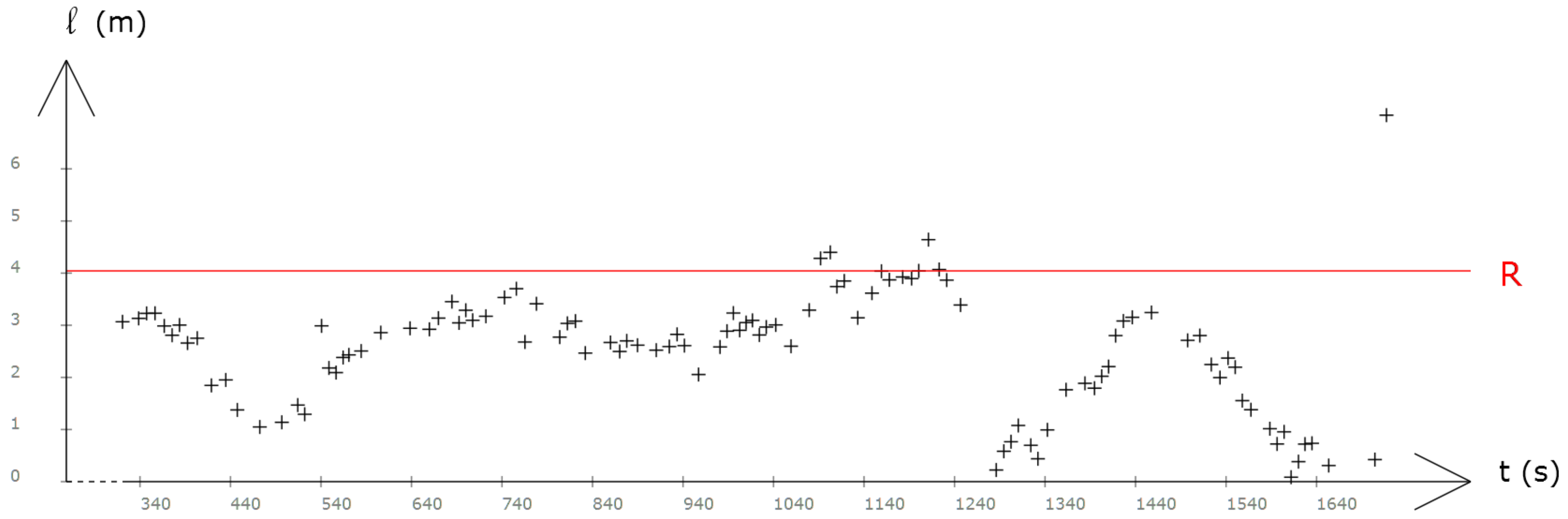
CE95 = R = 4.043 m

Mean = 2.545 m

σ = 1.129 m

Spatial distribution of horizontal error with color-coding to show evolution with test time

Sample LTS T&E Results (II)



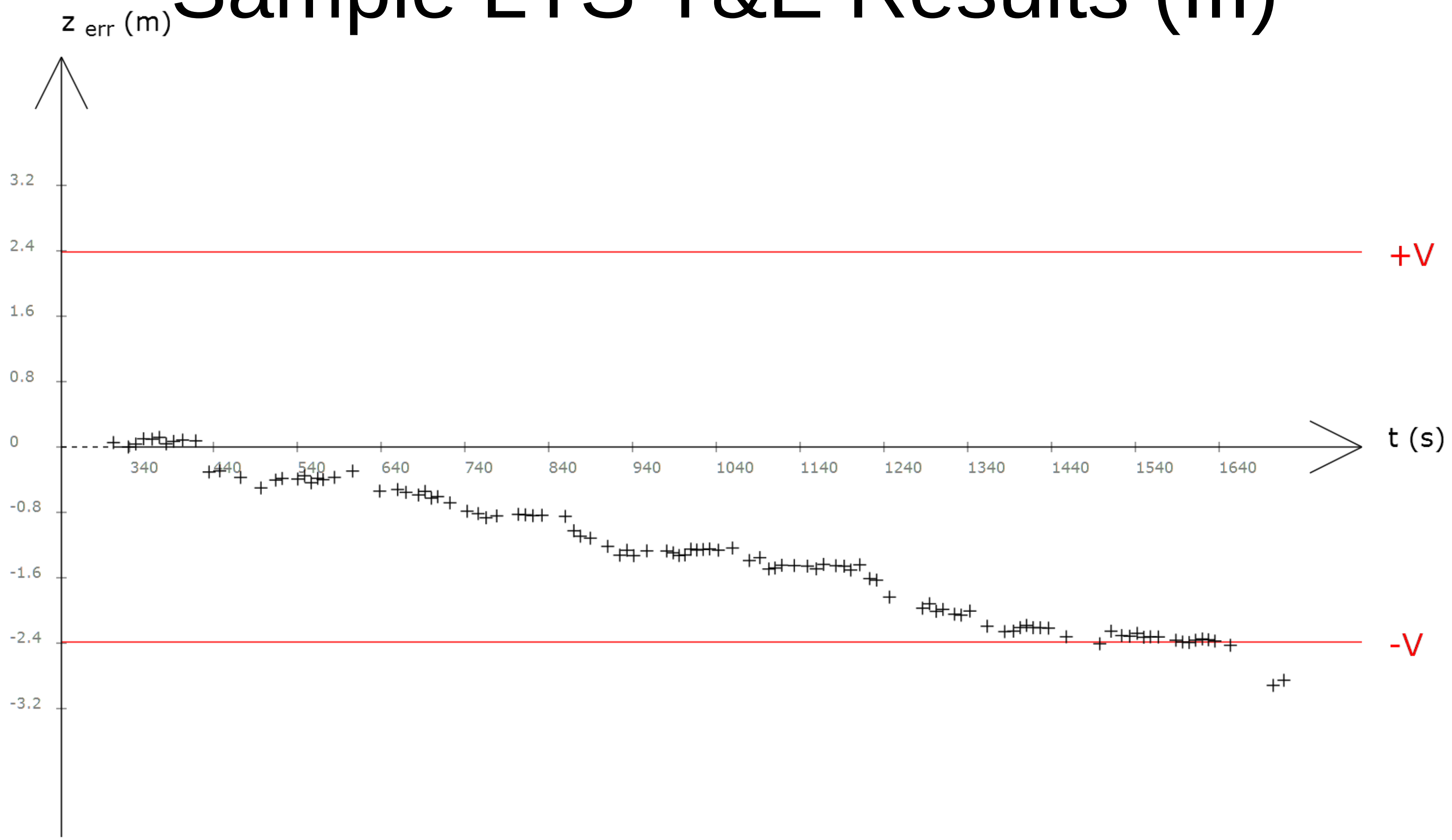
Horizontal error vs. test time

CE95 = R = 4.043 m

Mean = 2.545 m

σ = 1.129 m

Sample LTS T&E Results (III)



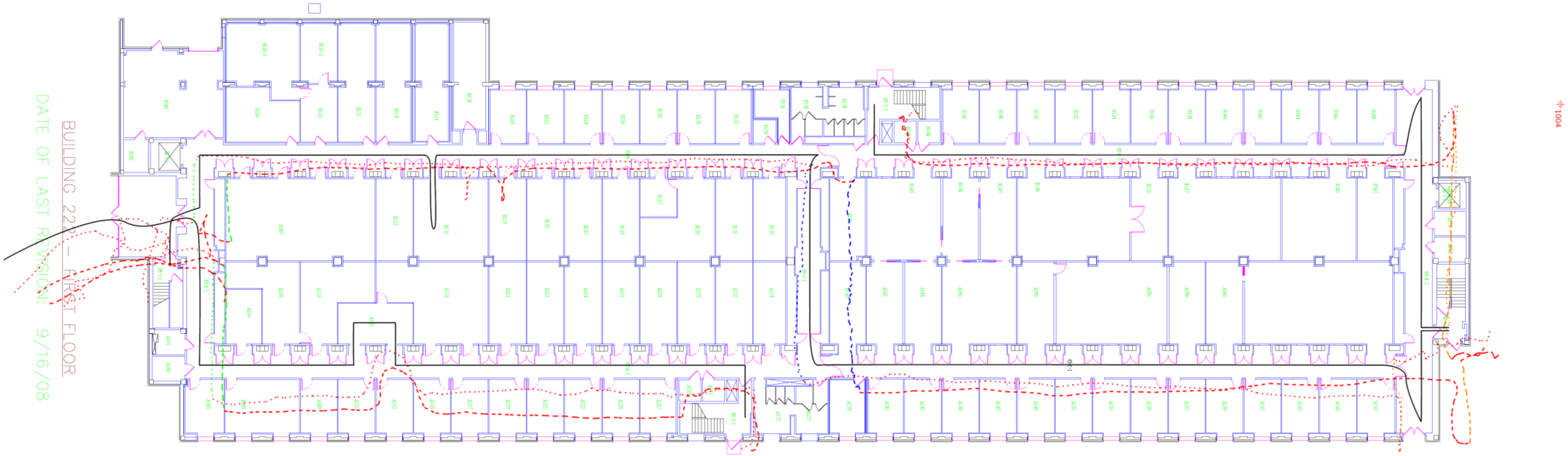
Vertical error vs. test time

VE95 = V = 2.386 m

Mean = 1.309 m

σ = 0.789 m

Sample LTS T&E Results (IV)



Conclusions

- LTS T&E needs careful planning.
- There is a clear need for standardized T&E procedures for LTS in various application domains to make sure the systems will meet user requirements and hence to foster market growth for localization and tracking products.

Backup Slides

Example Hybrid Systems

- DHS S&T Directorate is developing a LTS under its GLANSER (Geospatial Location Accountability and Navigation System for Emergency Responders) Program that uses the following sensors:
  - GPS
  - Inertial Measurement Unit (IMU)
  - RF Ranging
  - Doppler Velocimeter
  - Altimeter
- DARPA is developing systems under its ASPN (All Source Positioning and Navigation) Program that work with a large array of sensors in a plug-and-play fashion and provide positioning and navigation on different platforms and environments.

Additional Performance Metrics

- The requirements for LTS in mission-critical applications is more stringent. Here are two more metrics that may apply in such applications:
  - Susceptibility: Measure of variation in “system performance” due to events that may happen during normal operations at the evaluation site
  - Robustness *: Measure of degradation in “system performance” due to incidents / catastrophic events in the evaluation site

* The scope / extent of incidents needs to be defined, so that we would know the LTS will meet its post-incident performance requirements for certain types of incidents.

T&E Scenario Considerations

- Need to be fully aware of what causes various LTS sensors to perform poorly or outright fail, so that T&E scenarios would have snippets that stress all potential sensors, even for black box testing where we may not know exactly what sensors the LTS is using.
  - The ending point of the evaluation route should not be the same as the starting point, so that IMU errors do not cancel each other. In case of humans moving on their own, one should consider various modes of mobility (running, walking normally/backwards/sideways, and crawling).
  - Magnetometers perform poorly in areas where there is a lot of metal.
  - RF-based TOA rangers fail when presence of too much material on the direct path between the two ranging transceivers causes excessive signal attenuation.
  - Altimeters may be affected by sudden change in air pressure.
- When testing an LTS inside buildings
  - Are building floor plans available? Are accurate GDS-84 coordinates of building corners available?
- Set-up time of an LTS outside a building / structure is another important consideration / metric.

Issues Related to GIS

- Some LTSs need the GDS-84 coordinates of corners of the building in which they are supposed to provide location information.
- (?) Having access to building floor plan(s) makes visualization and presentation of location information much more user-friendly.
- For self-localization of flying objects, where GNSS services may not be available (for example due to jamming) but real-time aerial imaging capability is available, it helps to be able to correlate aerial images with a database of aerial imagery or elevation information.