Dynamic Model-Based Filtering for Mobile Terminal Location Estimation

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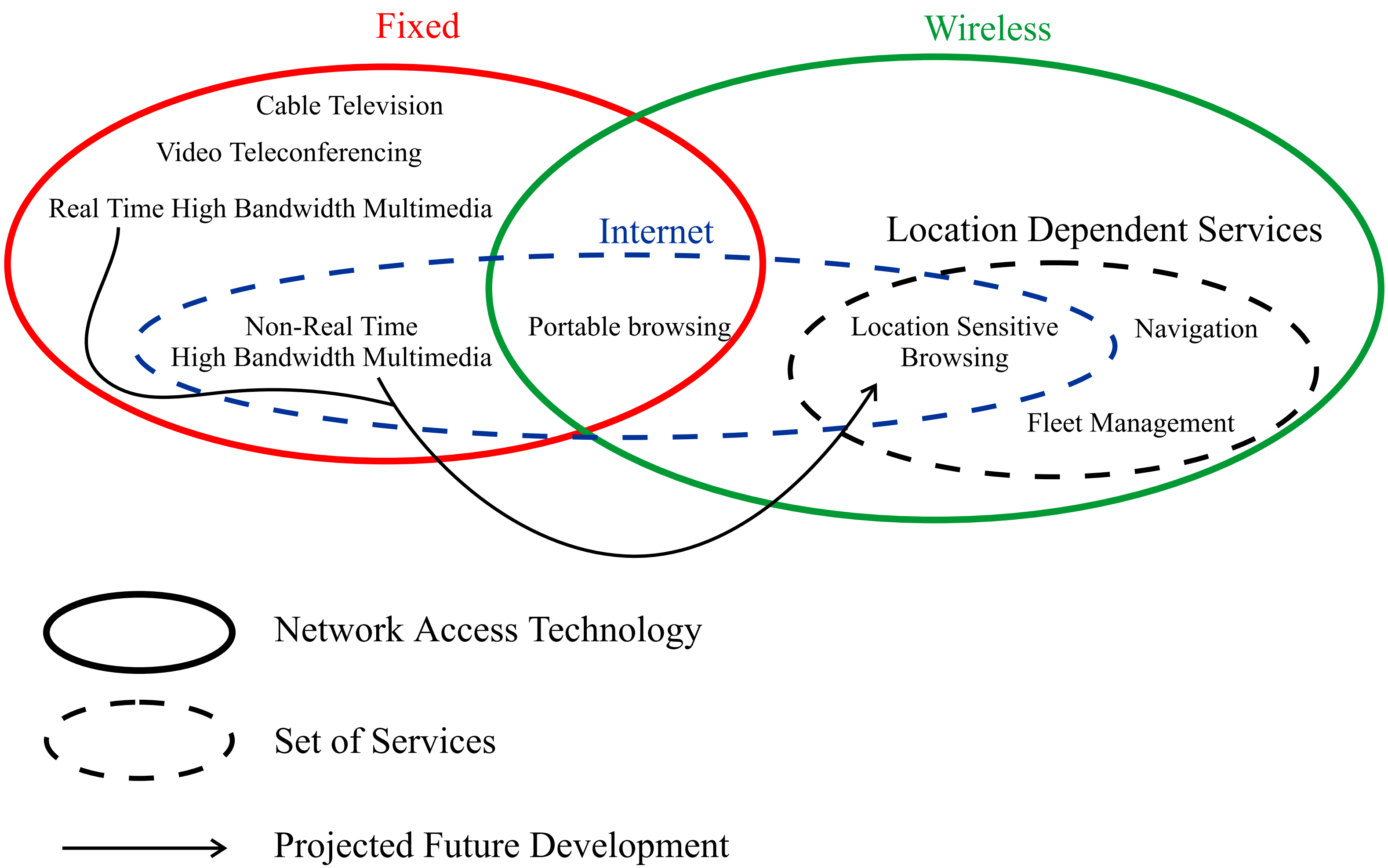
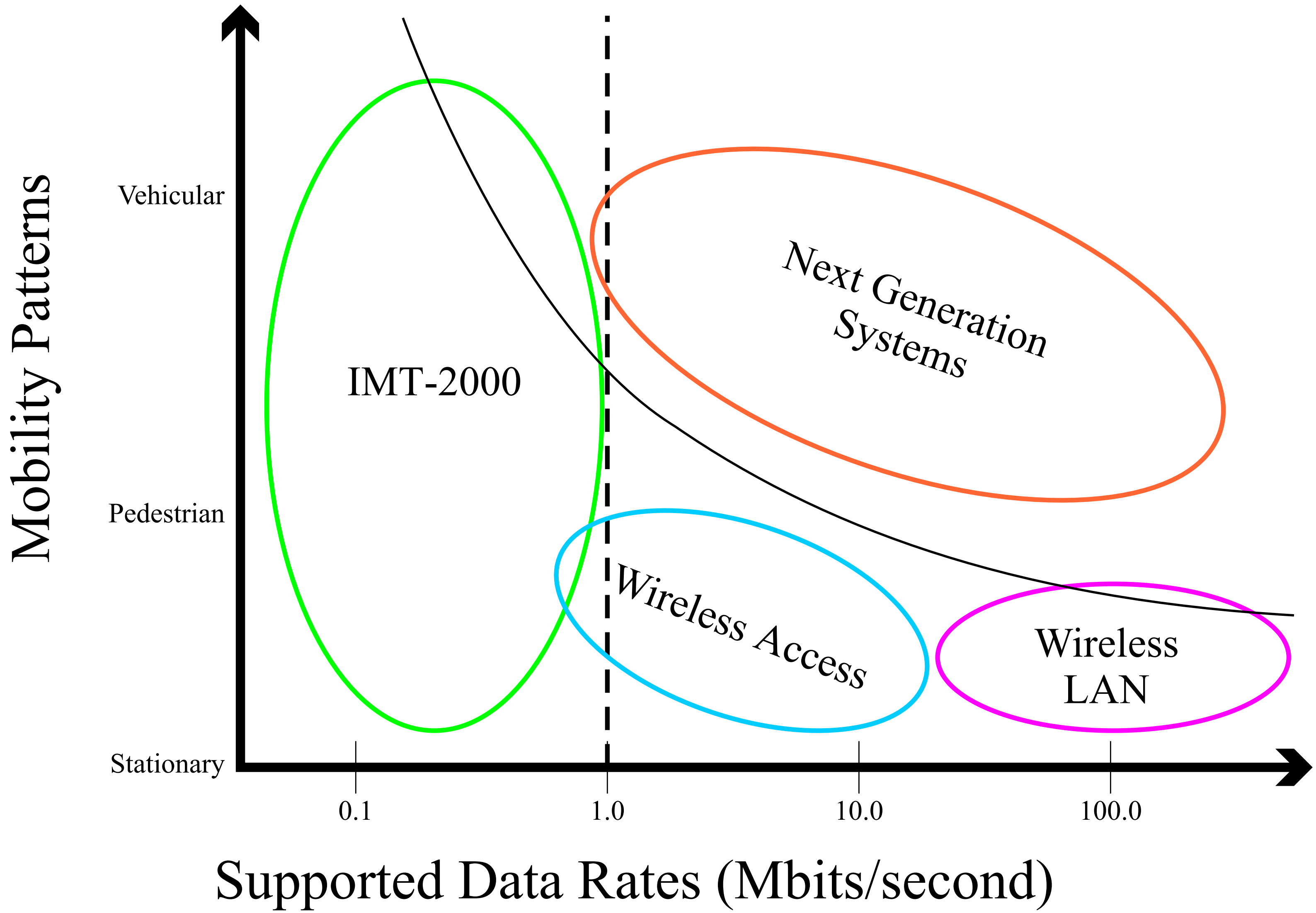
Outline

1. Signal Processing for Future Wireless Communications Systems.
2. Introduction to Mobile Terminal Location.
3. Zero Memory Estimation
4. Dynamic Estimation
5. Conclusions.
6. Future Work.

Evolution of Wireless Services



Mobility & Multimedia



Mobility & Multimedia

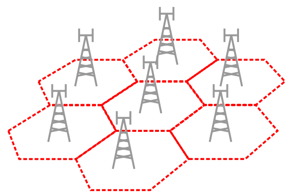
- 3G Systems
  - UMTS (ETSI)
  - IMT-2000 (ITU)
  - Support user bit rates up to 2 Mbps
  - High mobility environment: 144 kbps
- Ad Hoc Systems
  - IEEE 802.11
  - Bluetooth

Signal Processing for Wireless

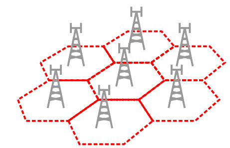
2G → 3G/4G

Cell Radii:

Macro/Microcells



Micro/Picocells

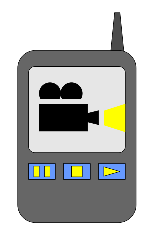


Multihop

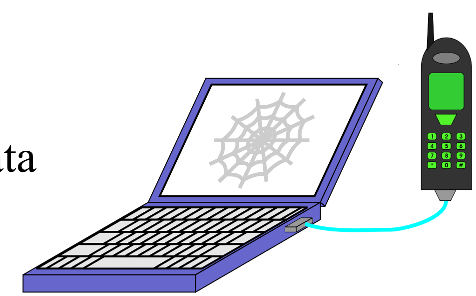
Data types:

Majority Voice

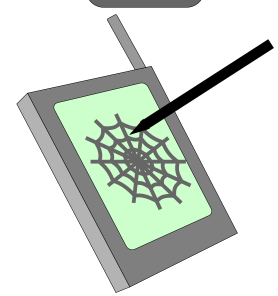
Multimedia Data



Best Effort Data



QoS-aware IP



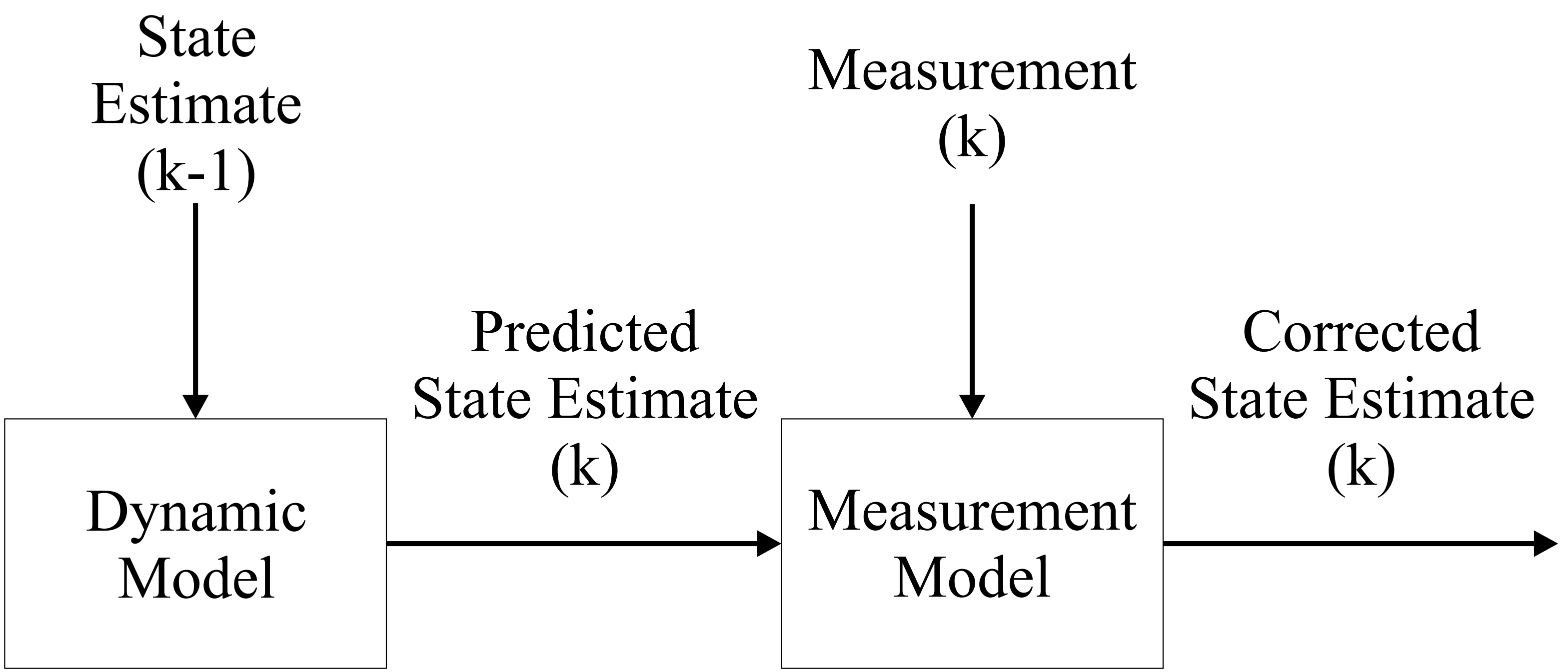
Signal Processing for Wireless

- Key problems:
  - Capacity
  - Resource allocation
  - Connection management
  - Channel management

Signal Processing for Wireless

- Present: Reactive control methods
- Future: Proactive control methods
  - Requires future system state estimation.

State Estimation



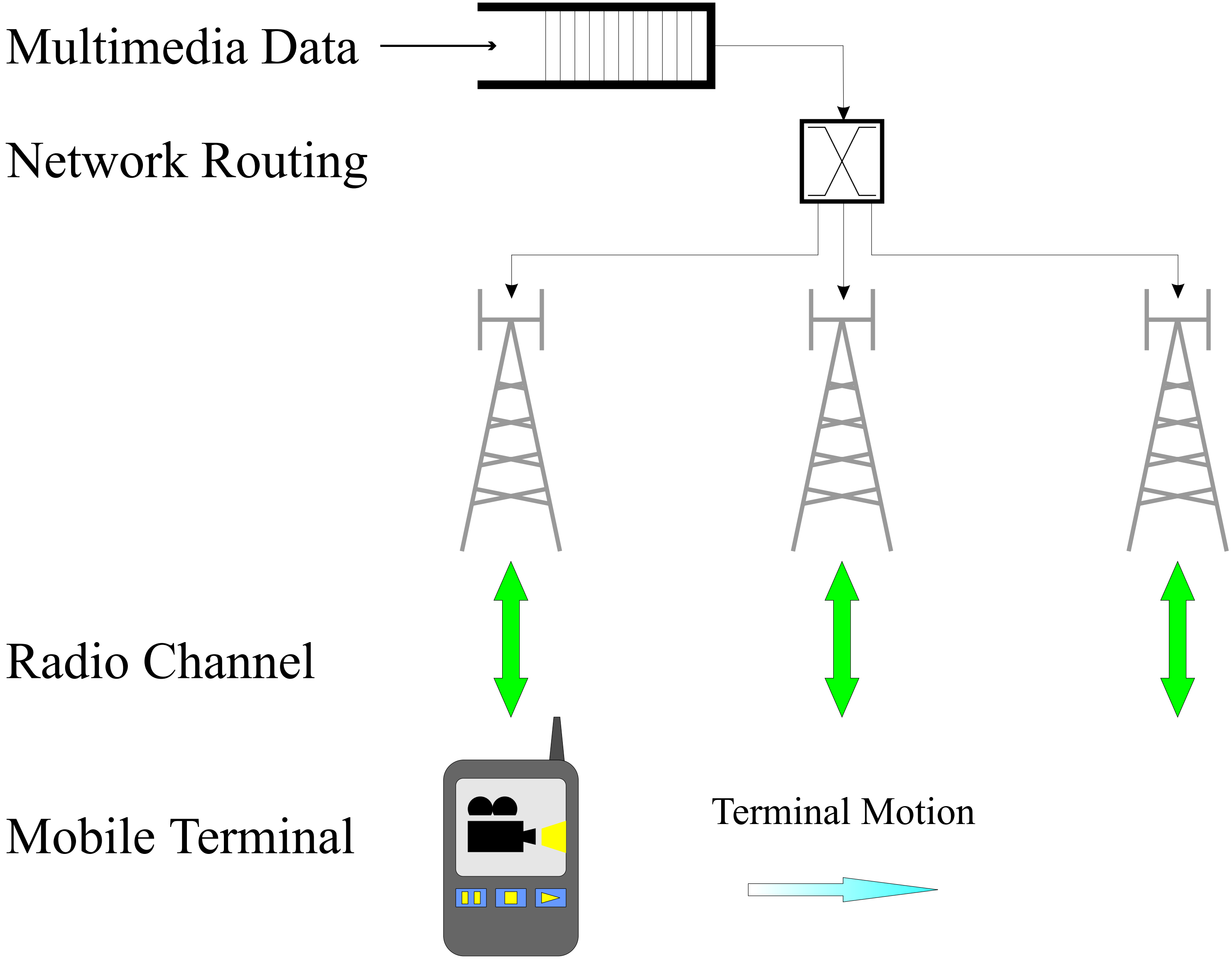
State Estimation

- Adaptive estimation
  - Learning model.
  - Adapting to changing model.
- Estimation techniques
  - Parametric
  - Non-parametric

Mobility Management

- Need to know resources that terminals require in future
  - Prediction of future locations.
- Channels
  - Handoff algorithm
  - Routing
- Power/Bandwidth allocation
  - Power control
  - Code selection (CDMA)

Mobility Management



Mobile Terminal Location

- Locating mobile terminal from radio signal
- Applications
  - Resource allocation
  - Location sensitive information
  - Emergency communications

Terminal Location Methods

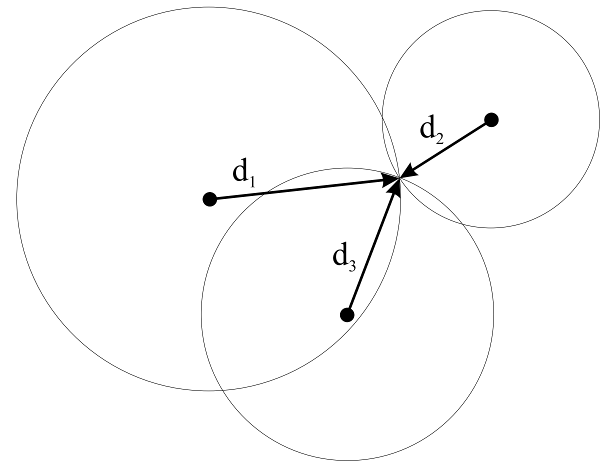
- Handset based
  - Perception of user privacy.
  - Currently greater accuracy.
- Network based
  - Cheaper terminals.
  - Greater potential accuracy

FCC Requirements

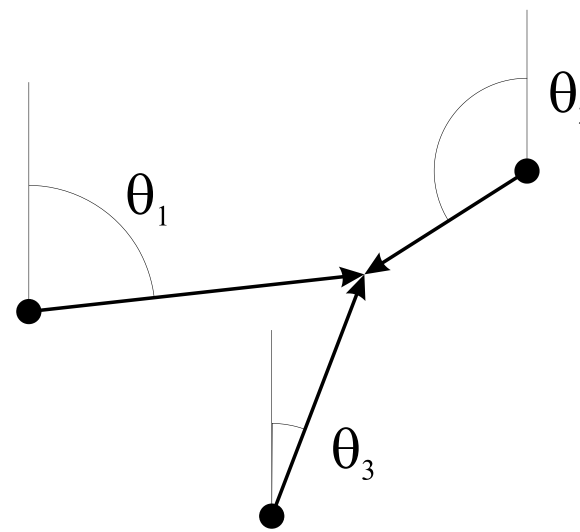
Configuration	Accuracy Requirement	
	$> 67\%$	$> 95\%$
Handset	50 m	150 m
Network	100 m	300 m

Terminal Location Measurements

Received Signal Strength(RSS),
Time of Arrival (ToA),
Time Difference of Arrival (TDoA).



Angle of Arrival (AoA).



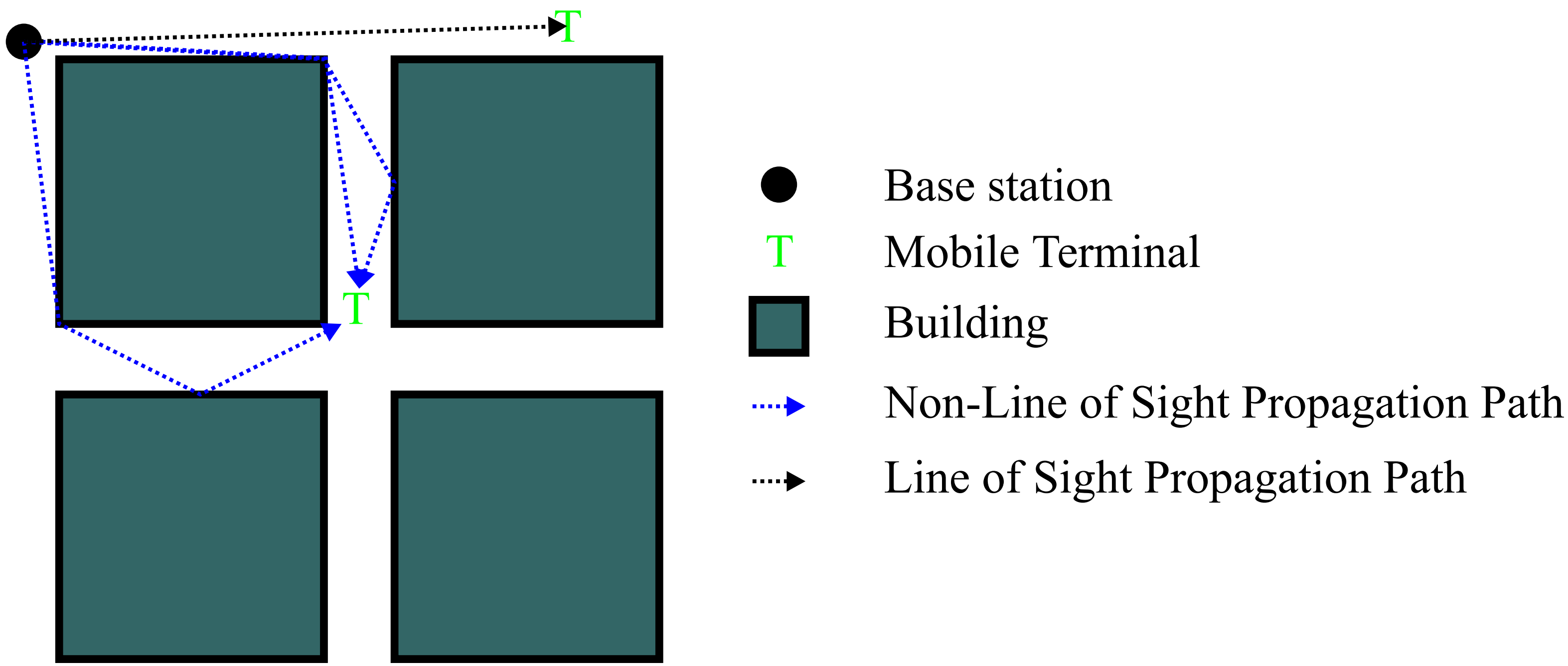
Terminal Location Measurements

Measurement Type	Advantages	Disadvantages
Received Signal Strength (RSS)	• low cost measurements • simple computations	• low accuracy in large cells
Angle of Arrival (AoA)	• simple computations	• specialized antennae • low accuracy in large cells
Time of Arrival (ToA)	• time measurement required for TDMA/CDMA network operation • simple computations	• synchronized network required • receiver must know time of transmission • expensive measurement
Time Difference of Arrival (TDoA)	• time measurement required for TDMA/CDMA network operation • receiver does not need time of transmission	• synchronized network required • expensive measurement • complex calculations

TDMA - Time Division Multiple Access, CDMA - Code Division Multiple Access

Radio Signal Measurements

- Non-linear effects make problem more complex



Radio Signal Measurements

- $\boldsymbol{\tau}(k)$ is the vector of propagation time measurements for sample time k

$$\boldsymbol{\tau}(k) = \mathbf{d}(k) + \boldsymbol{\varepsilon}(k)$$

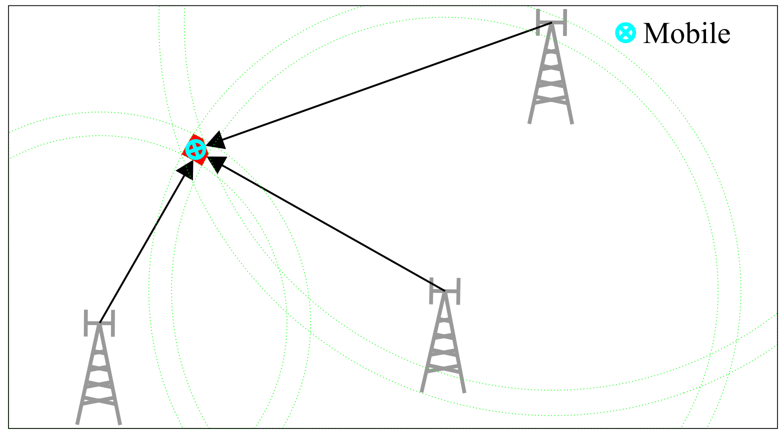
  - $\mathbf{d}(k)$ is the vector of propagation distances.
  - $\boldsymbol{\varepsilon}(k)$ is the vector of measurement noise.
- $\mathbf{z}(k)$ is ToA/TDoA measurement vector:

$$\mathbf{z}(k) = \mathbf{F}\boldsymbol{\tau}(k)$$

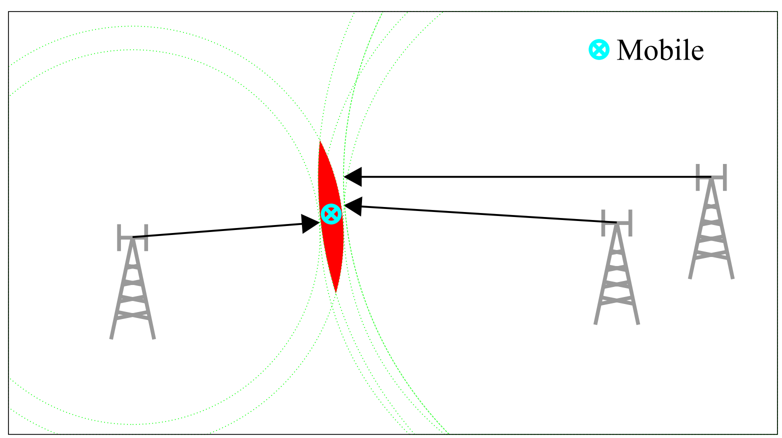
  - $\mathbf{F}$ is the measurement difference matrix.

Geometric Dilution of Precision (GDOP)

- High Precision Geometry



- Low Precision Geometry



My Contribution

1. Improved Zero Memory Estimation
2. Bounds on Zero Memory Estimation Error
3. Model-based Dynamic Estimation
   - New Filter Algorithm Developed
4. Bound on Dynamic Estimation Error

Zero Memory Estimation

- Previously proposed techniques are Maximum Likelihood Estimators(MLE).
- Problems with MLE:
  - Prior knowledge is ignored.
  - Assumed Line of Sight (LOS) propagation model.
    - NLOS is common in urban areas of interest.

Zero Memory Estimation

- Observations:
  - Statistical knowledge of terminal position available from hand off algorithm.
  - Propagation survey made during network configuration.
- $\Longrightarrow$ Network has knowledge that can be used for location.

Zero Memory Estimation

- k is sample interval.
- $\boldsymbol{\theta}(k)$ is location of mobile terminal at k.
- $\hat{\boldsymbol{\theta}}(k)$ is estimated location of mobile terminal at k.
- Survey data: j survey point, $j \in \{1, 2, ..., n\}$.
  - $\boldsymbol{\theta}_j$, location of survey point j.
  - $\mathbf{z_j}$, measurement taken at survey point j.

Zero Memory Estimation

- Estimated location is weighted average of survey point locations:

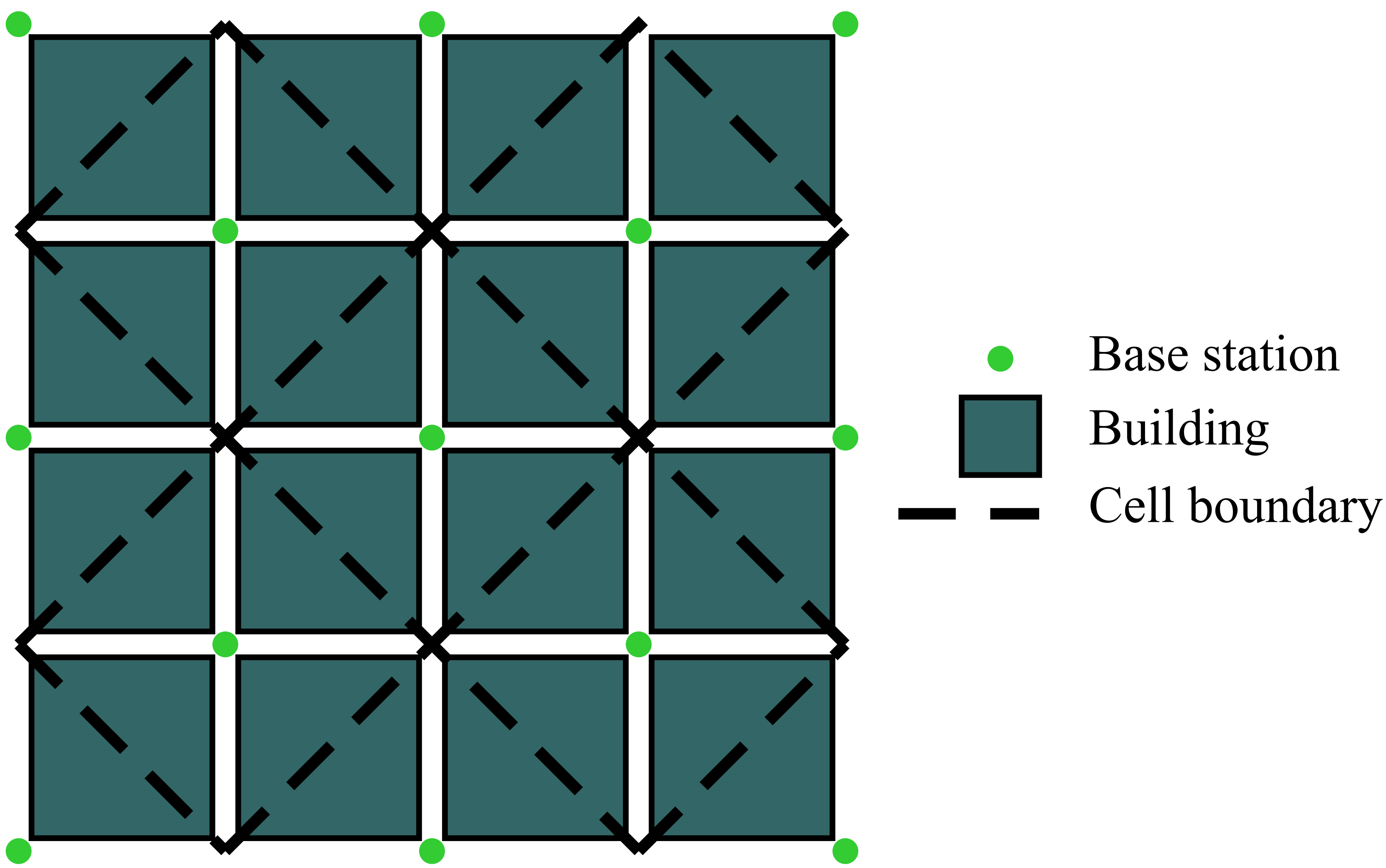
$$\hat{\boldsymbol{\theta}}(k) = \frac{\sum_{j=1}^{n} \boldsymbol{\theta}_j h(\mathbf{z}(k), \mathbf{z_j})}{\sum_{j=1}^{n} h(\mathbf{z}(k), \mathbf{z_j})}$$

  - $h(\cdot)$ is kernel function.
  - Estimated location is weighted average of survey point locations.
  - Weights determined by kernel functions.

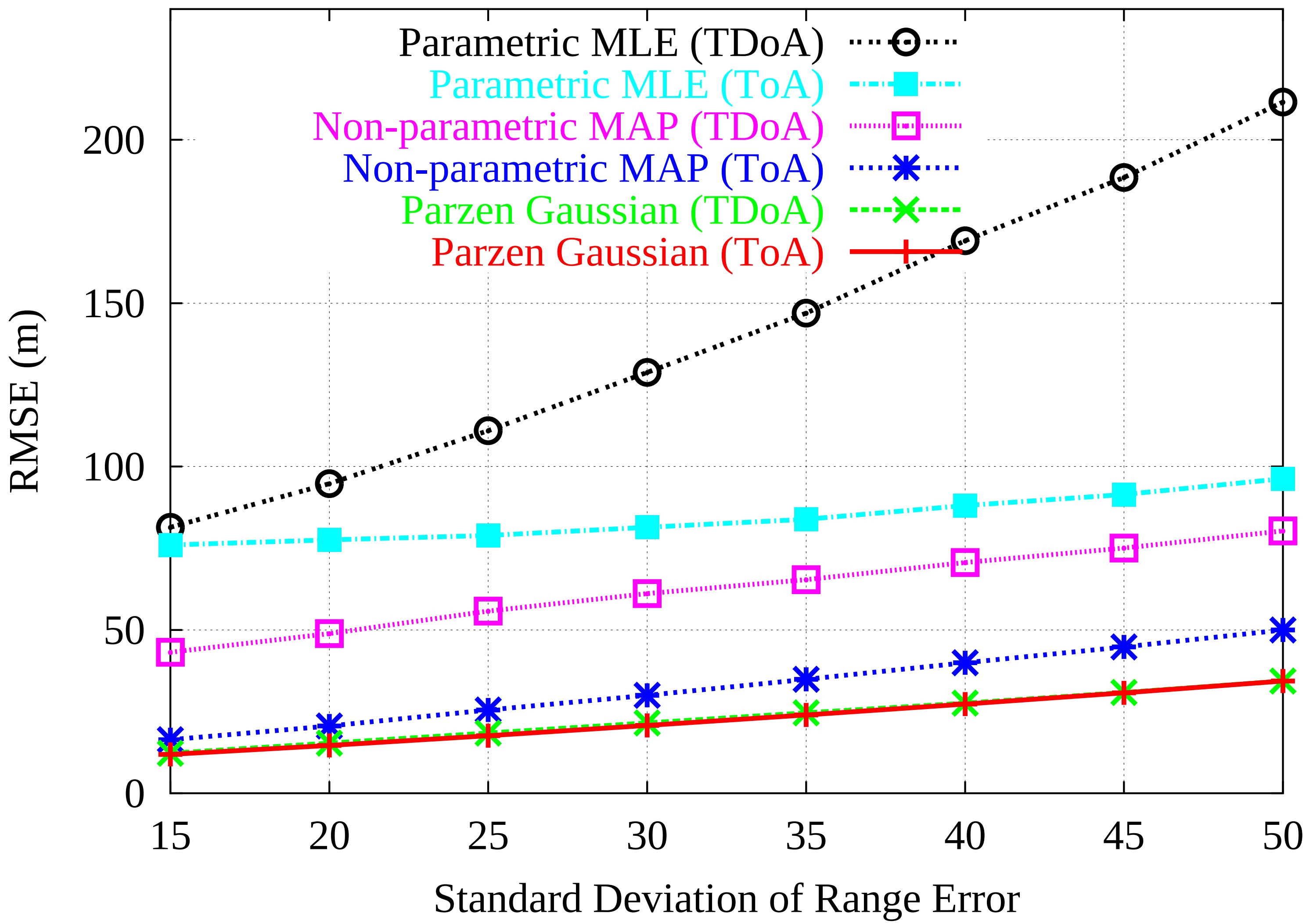
Zero Memory Bounds

- NLOS propagation creates discontinuities in propagation equations.
- Standard bounds (e.g. Cramer-Rao no longer apply).
- Use other bounds
  - Barankin bounds
  - Weinstein-Weiss bounds.

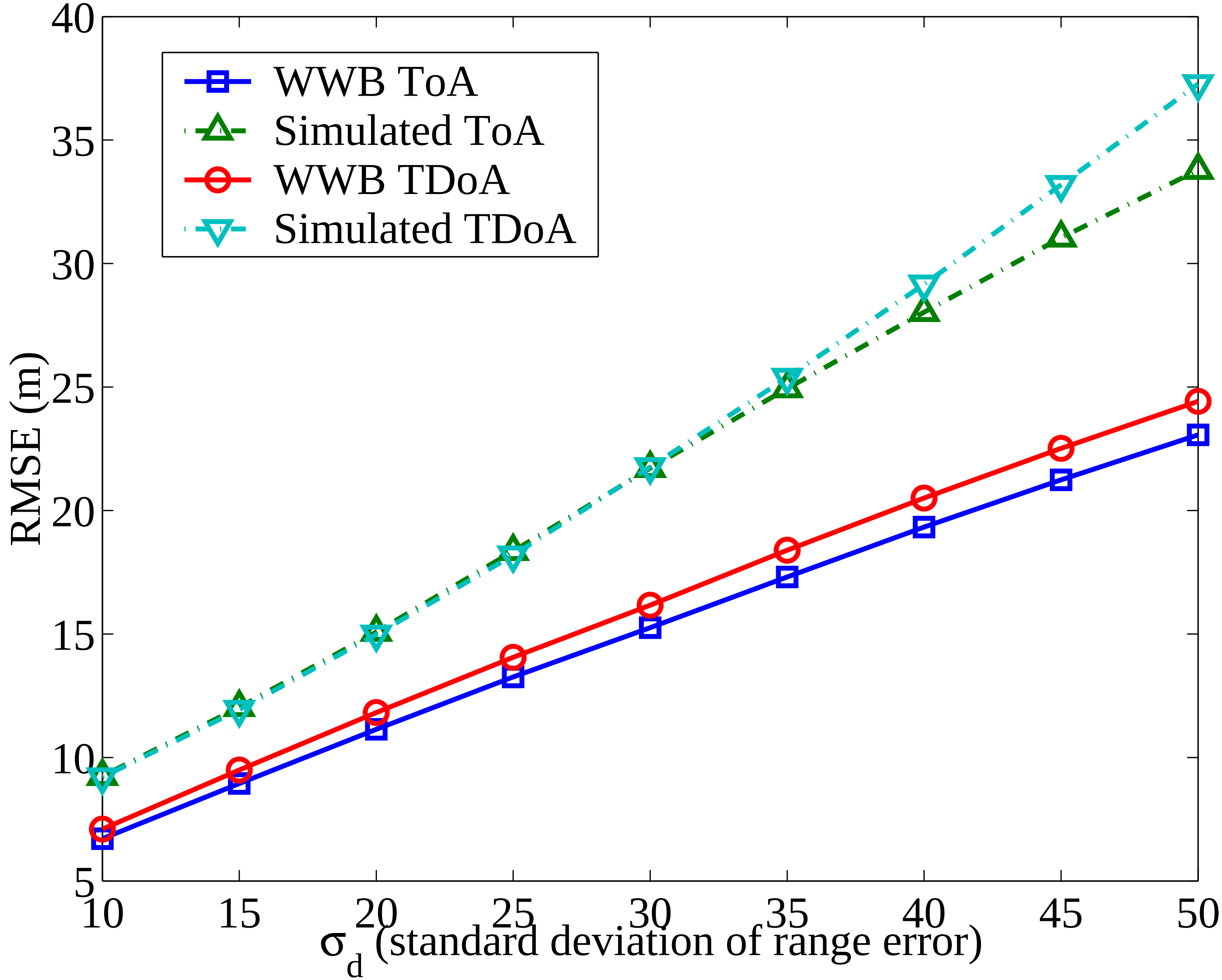
Simulated Environment



Zero Memory Results



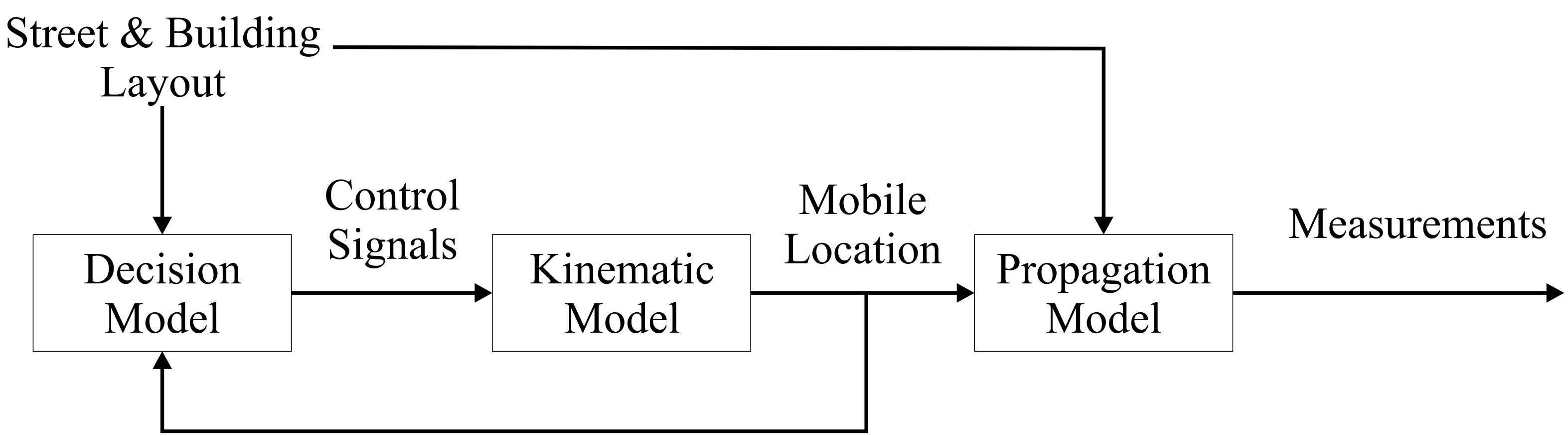
Zero Memory Results



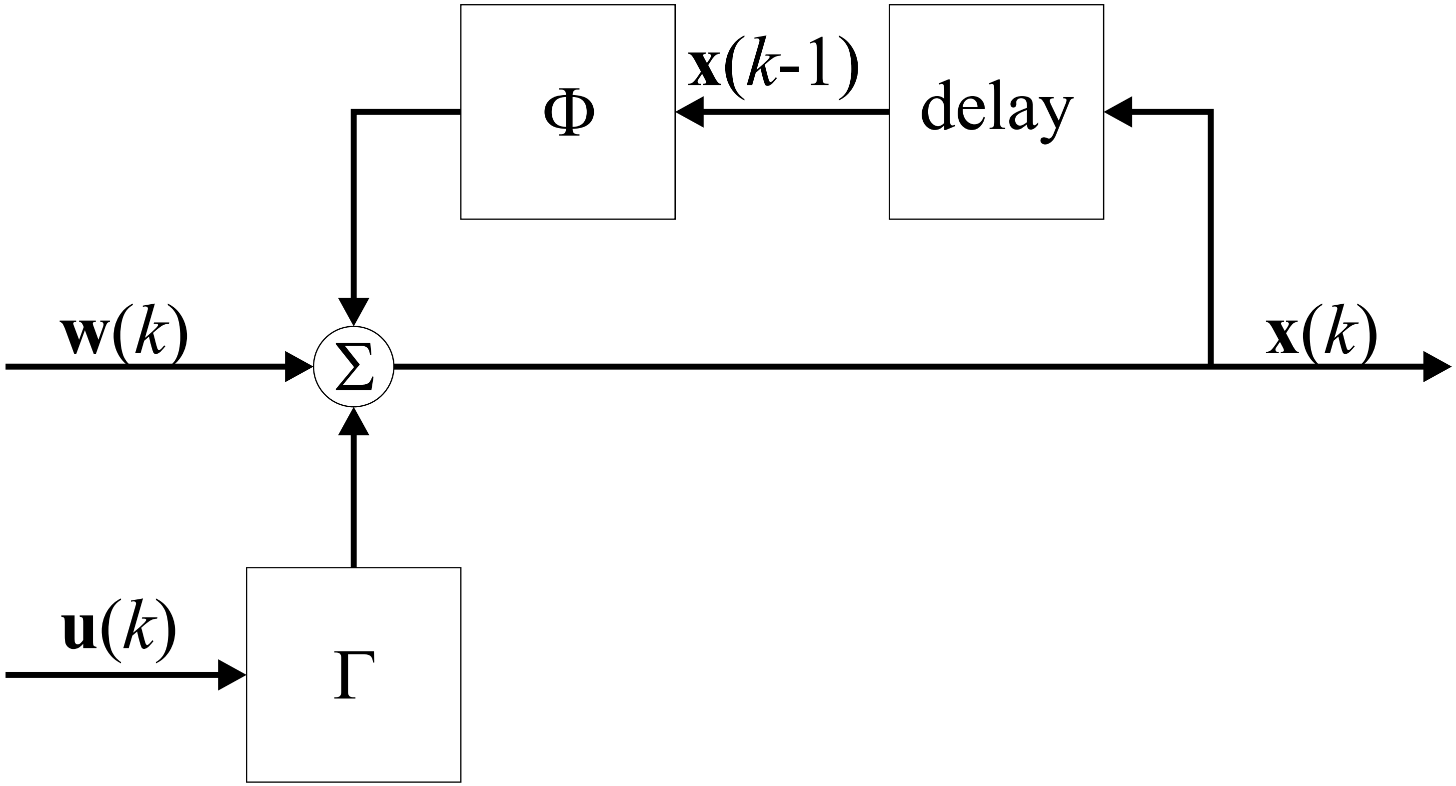
Dynamic Estimation

- Combine measurements from different sampling periods.
- Use dynamic model of mobile terminal motion.
- Dynamic model consists of:
  - Kinematic model.
  - Human Decision model.

Mobile Terminal Motion Model

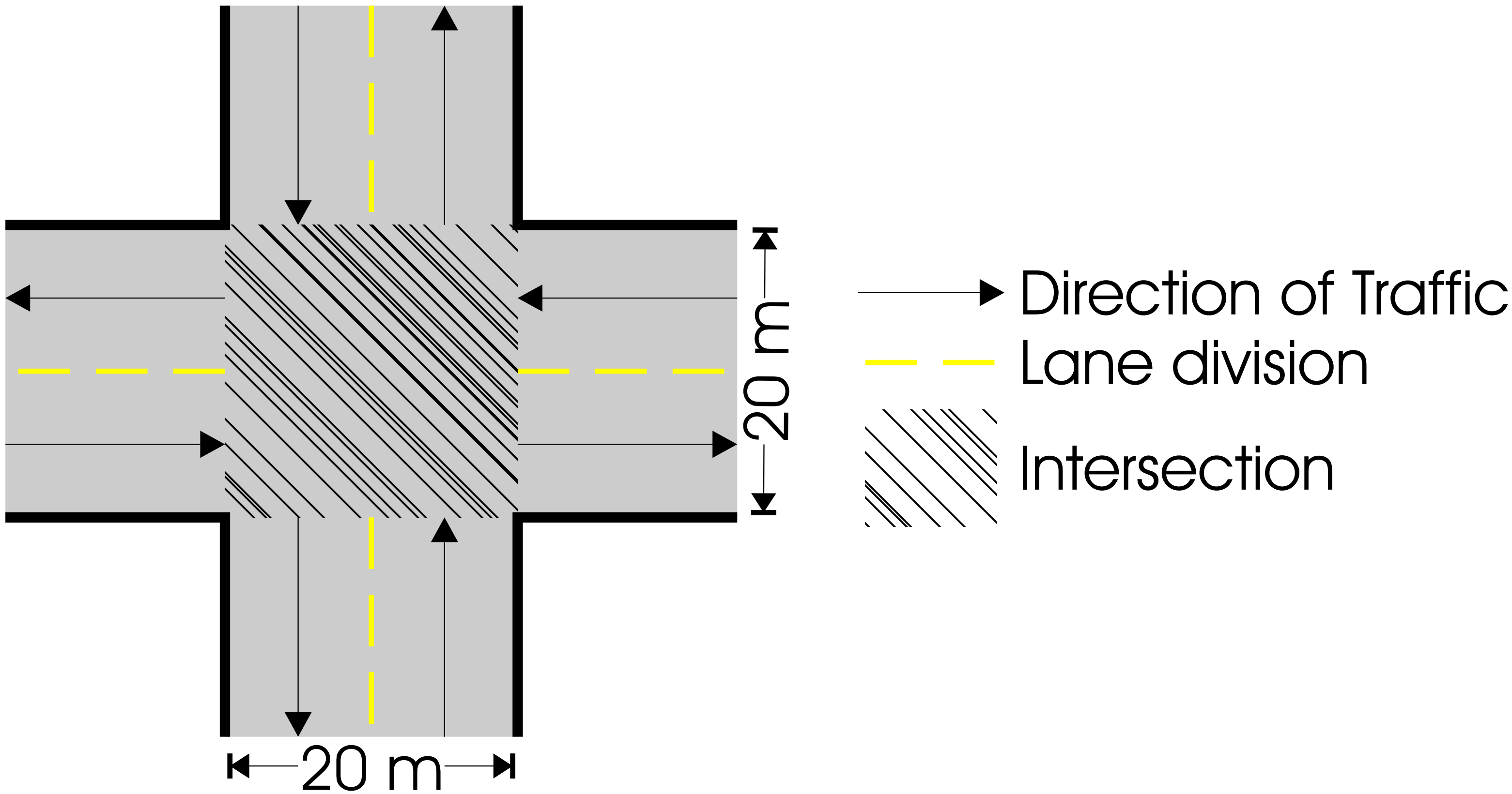


Kinematic Model

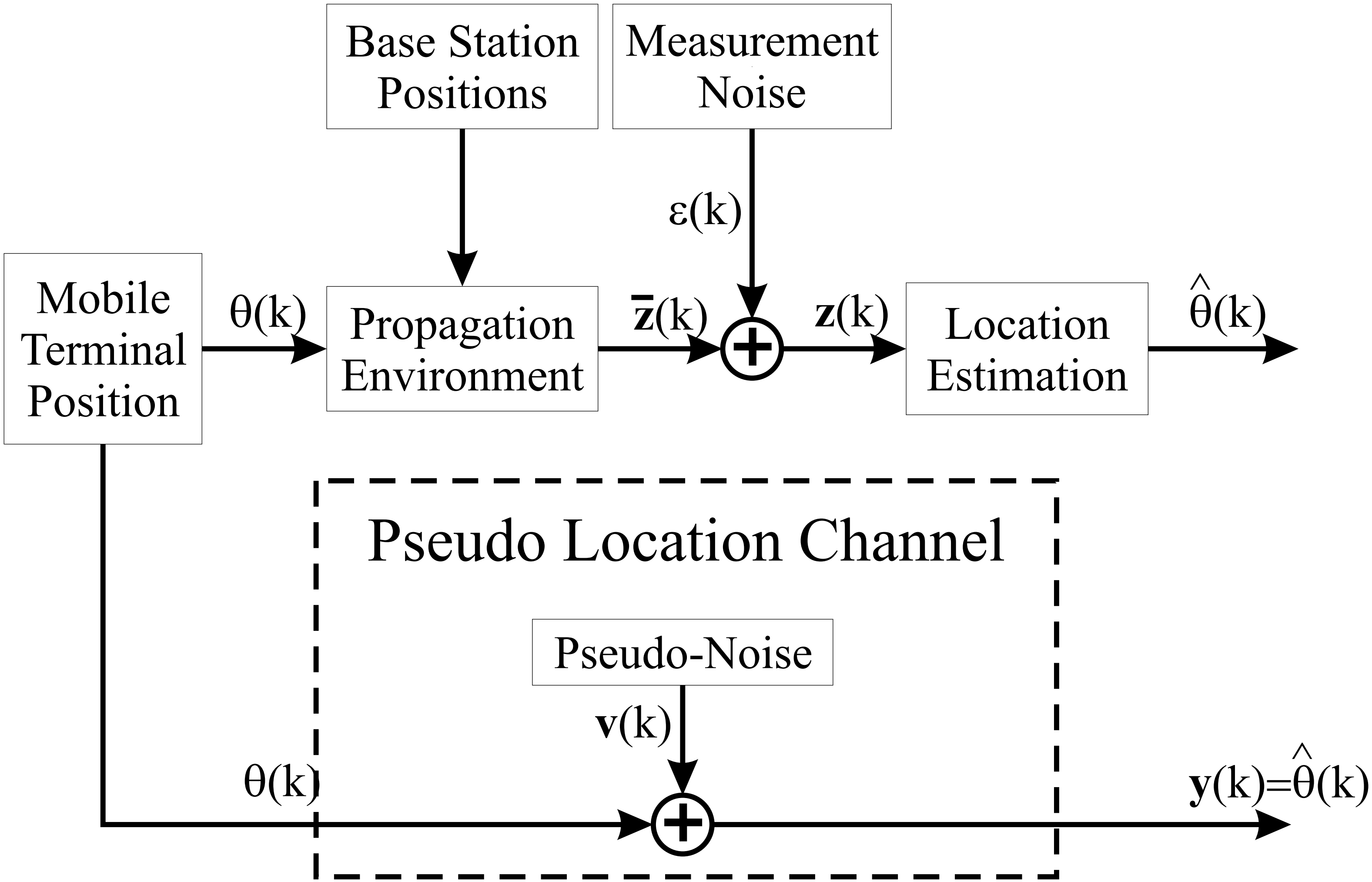


- $\mathbf{x}(k)$ is terminal state.
- $\mathbf{u}(k)$ is control input.
- $\mathbf{w}(k)$ is process noise.

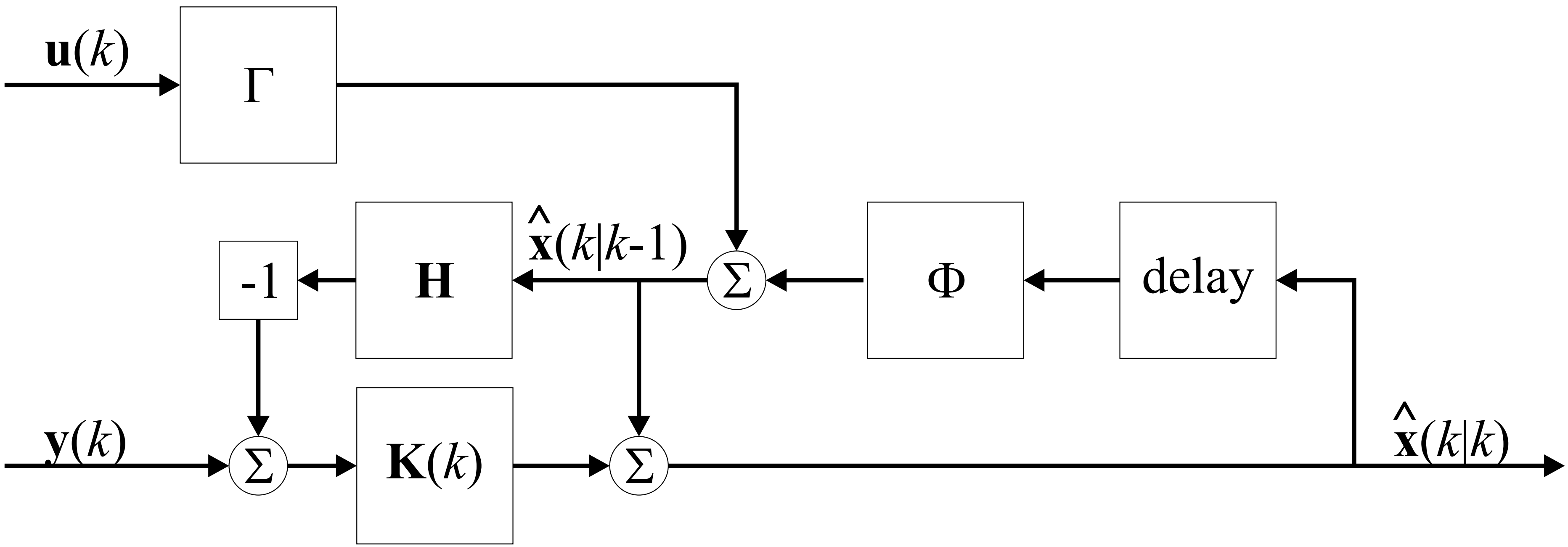
Human Decision Model



Zero Memory Estimator Preprocessor

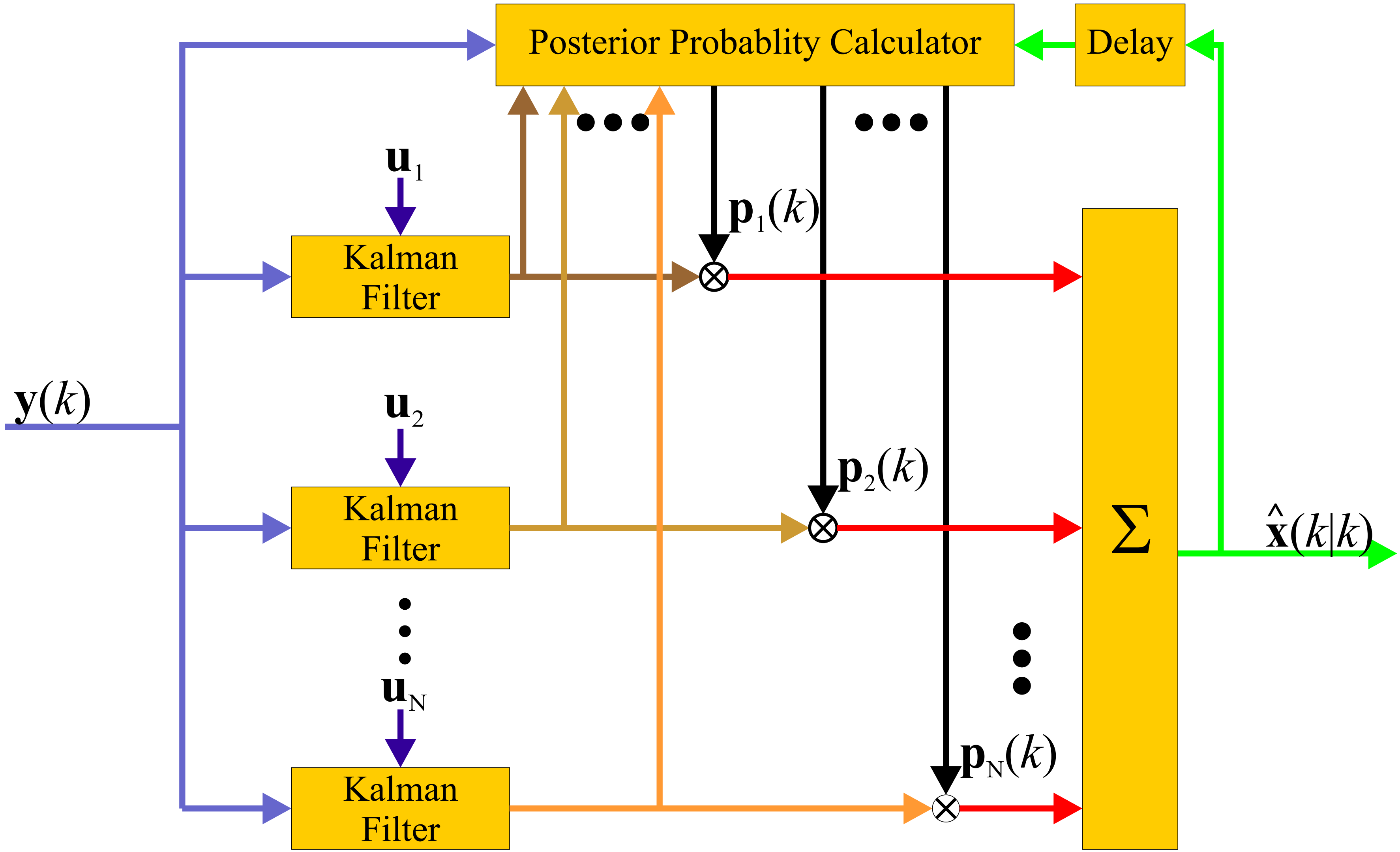


Dynamic Estimation



- Prediction phase
- Correction phase

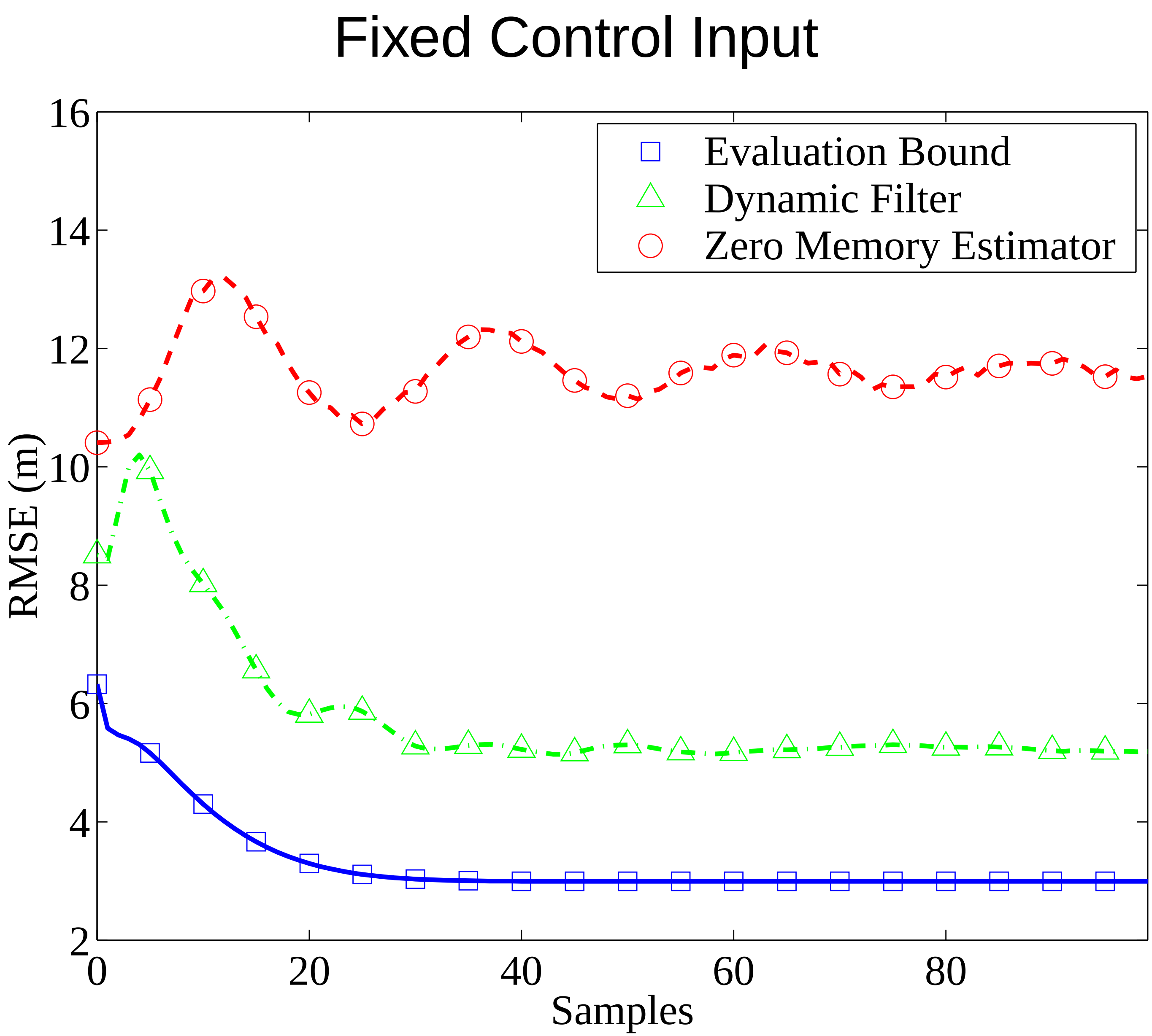
Dynamic Estimation



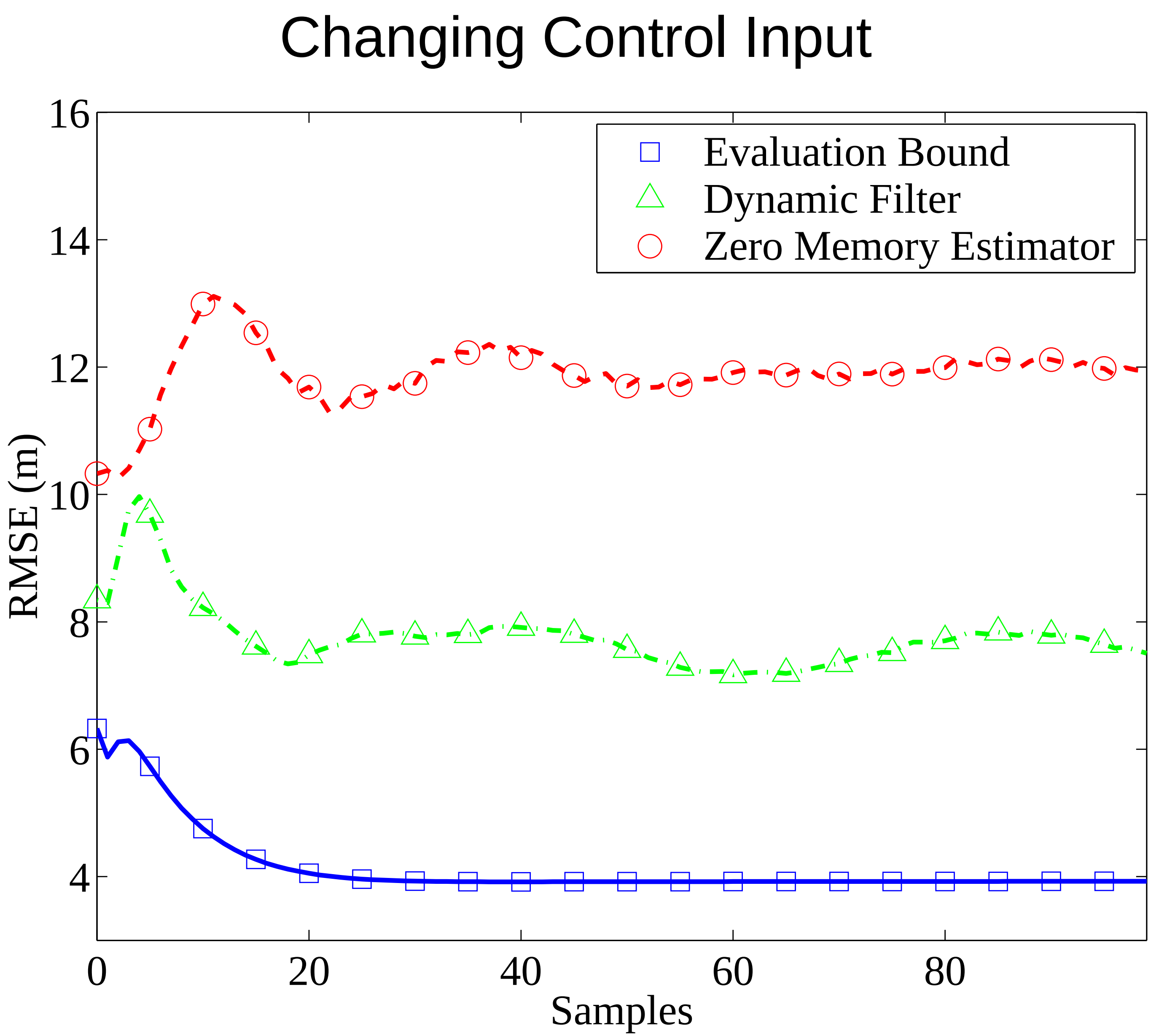
Bounds on Dynamic Estimation

- Combine following information sources:
  - Zero Memory Estimator.
  - Dynamic model for mobile terminal motion.
  - Prior distribution for mobile terminal location.
- Bound calculated on squared error.

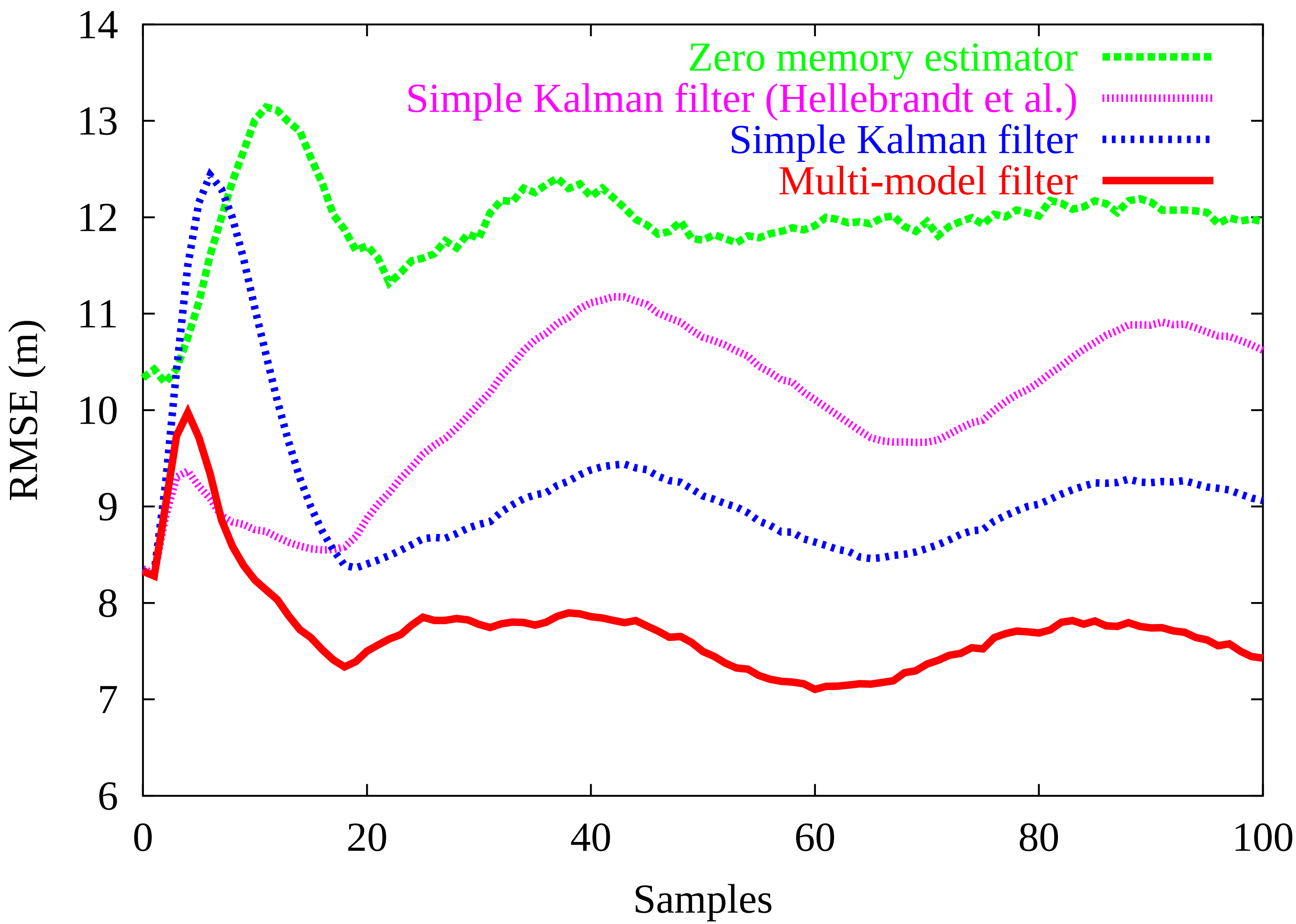
Dynamic Estimation Results



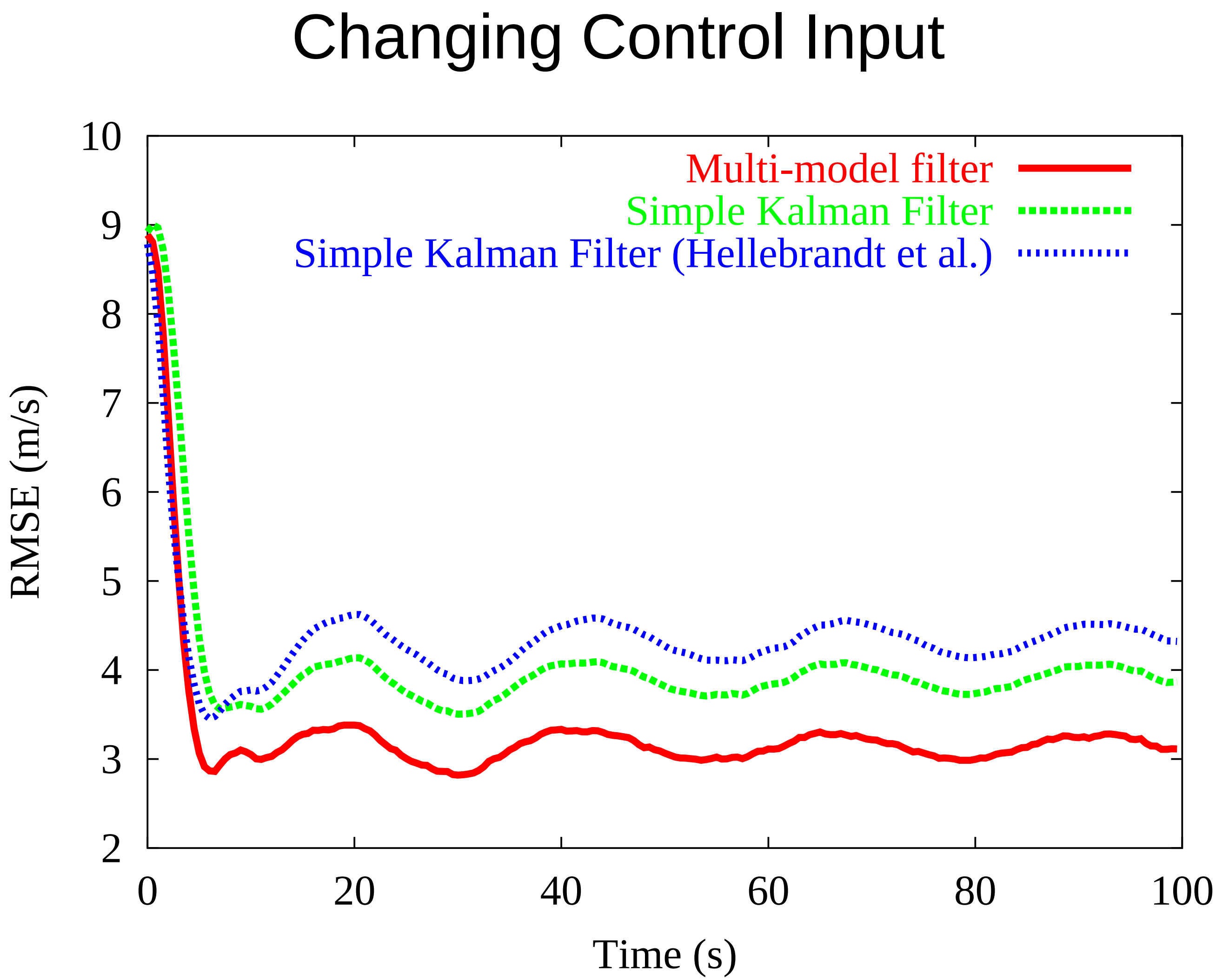
Dynamic Estimation Results



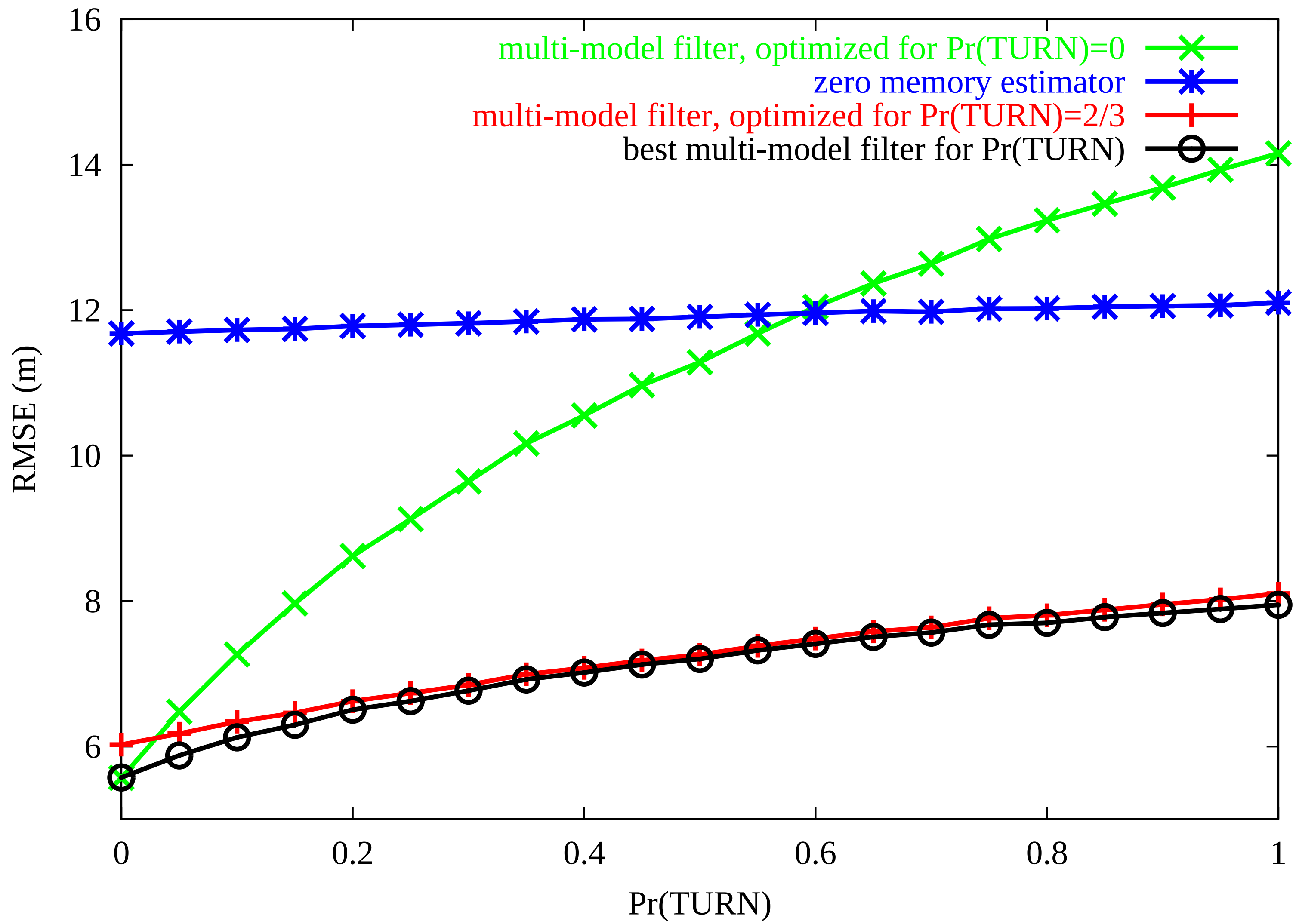
Dynamic Filter Comparison



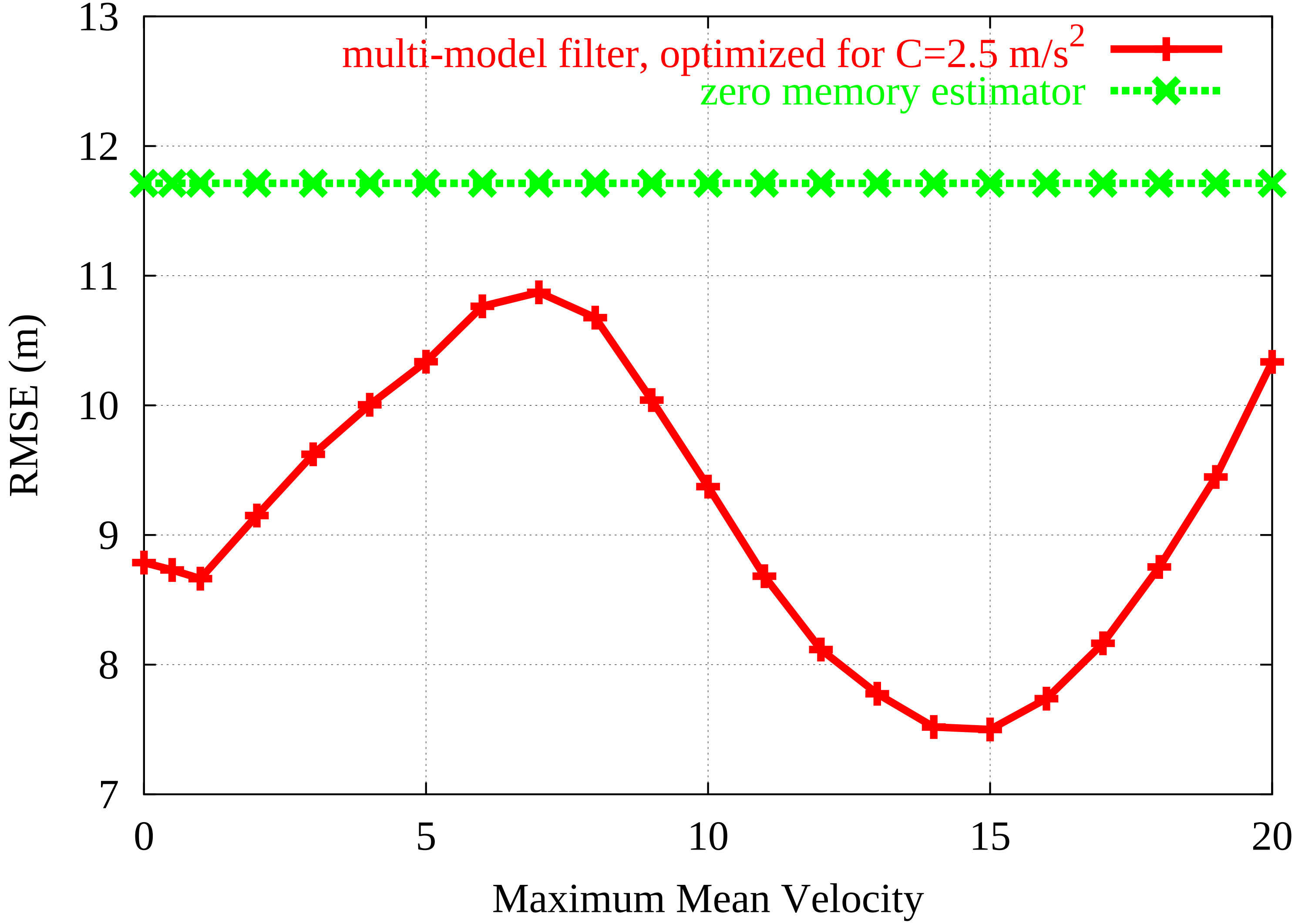
Dynamic Filter Comparison

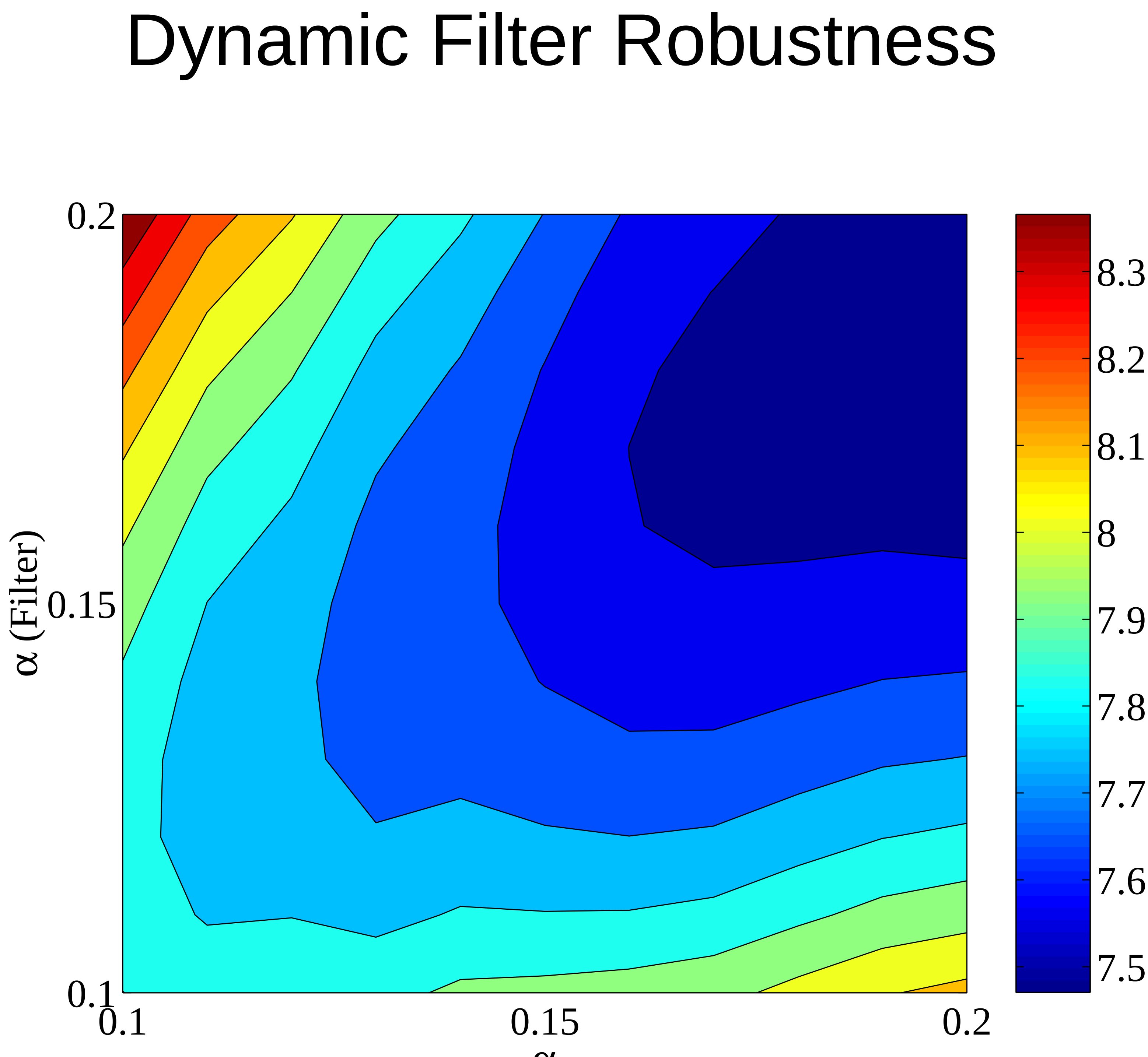


Dynamic Filter Robustness

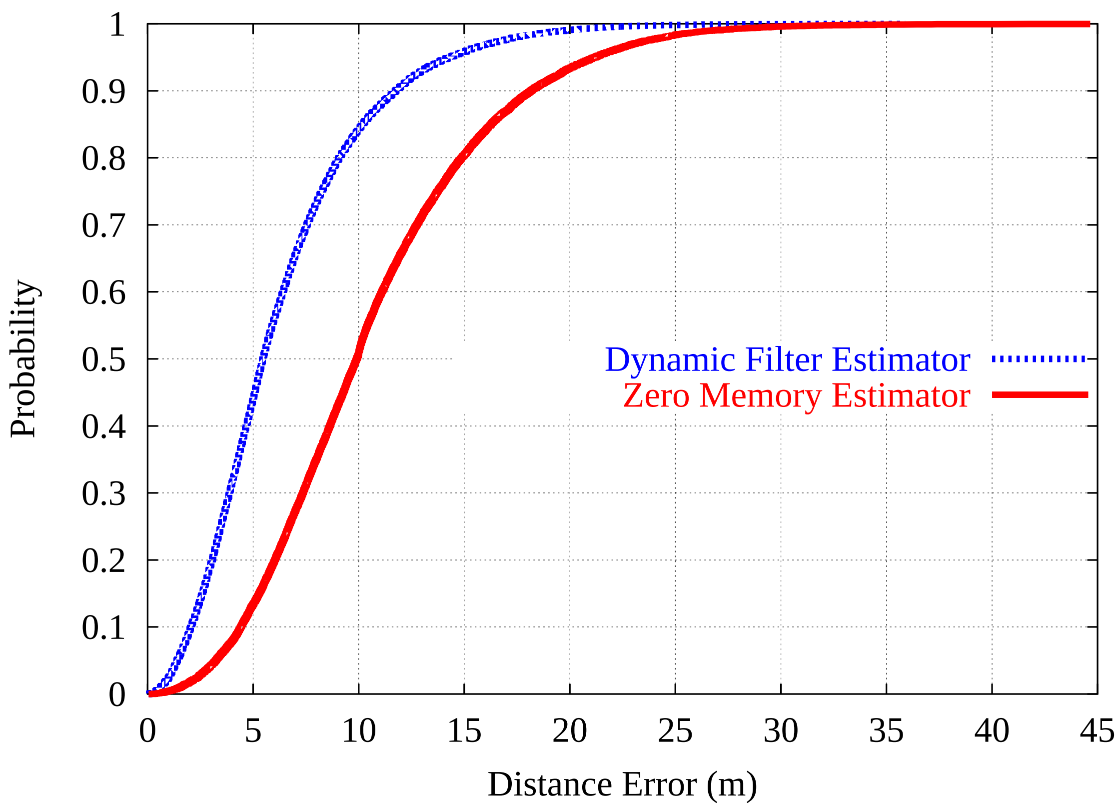


Dynamic Filter Robustness




Dynamic Filter Robustness
0.2
0.15
0.1
α (Filter)
0.1
0.15
0.2
α
8.3
8.2
8.1
8
7.9
7.8
7.7
7.6
7.5

Results



Configuration	Accuracy (ToA $\sigma_d = 15$ m)	
	67%	95%
Zero Memory Estimator	12.17 m	21.16 m
Dynamic Estimator	7.12 m	14.28 m

Conclusions

- Use all information sources.
- Model-based estimation gives accurate location estimates.
  - Efficiently combines information from different time periods.
- Estimation methods are robust.
  - Zero memory estimator robust to changes in noise/propagation model.
  - Dynamic estimator robust to changes in dynamic model.

Future Work

1. Applications of mobile terminal location.
2. Long term motion models.
3. Data fusion.
4. Location of terminals in ad hoc networks.
   - Location of terminals in hybrid networks.

Applications

- Resource allocation
- Hand off algorithms
- Many possibilities for collaboration.

Long Term Motion Models

- Current dynamic filter based on short term motion models.
- Long term motion models will improve estimation.
- Improve motion prediction.

Data Fusion

- Use data from multiple information sources.
  - RSS is cheap with wealth of propagation data but has large uncertainty.
  - ToA/TDoA are expensive with low uncertainties.
  - AoA requires special antennae and provides varying accuracy.

Ad Hoc Networks

- Examples: Bluetooth, IEEE 802.11
- Terminal must be low cost.
- Limited connectivity between terminals.
- Hybrid networks

Final words

- Large amount of work to be done.
- Many applications of results.
- Potential to develop new estimation and filtering algorithms.