IBEACON BASED PROXIMITY AND INDOOR LOCALIZATION SYSTEM

THESIS DEFENSE

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AGENDA

- Background
- Problem Statement
- Research Questions
- Hypotheses
- iBeacon-based Proximity Detection System (PDS)
- iBeacon-based Indoor Localization
- Conclusion
- References
- Questions

BACKGROUND

- Wide-scale proliferation of communication devices
    - Poised to reach 50 billions by 2020.
- Devices and ‘Things’ can be leveraged for Location-based Services (*LBS*)
    - Why?
    - Outdoor Localization
    - Indoor Localization

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BACKGROUND

- BLE has emerged one of the candidates for *LBS* due to its energy efficient characteristics.
    - Modifying the BLE stack and optimizing it for LBS is necessary.
        - Apple’s *iBeacons*, Google’s *Eddystone.*
- iBeacons, based on BLE, is the industry standard for proximity-based services.
        - Widely used by different industries.
        - 60 millions to be shipped by the end of 2016.

PROBLEM STATEMENT

- iBeacons suffer from higher localization error due to reliance on Received Signal Strength Indicator (RSSI).
    - RSSI is prone to noise
        - Multipath fading
    - Localization error needs to be limited (<1m)
        - Bayesian Filtering widely used for Indoor Localization
            - Application to iBeacons would improve its performance.
            - Particle Filter is the most accurate of the Bayesian Filters.

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RESEARCH QUESTION

- Will the use of Kalman filter and Extended Kalman filter in cascade with Particle Filter improve the localization accuracy of an iBeacons-based indoor localization system when compared with use of only Particle filter?
- Is it possible to improve the proximity detection accuracy of an iBeacon-based proximity detection system using the proposed Server-side algorithms when compared with the current approach used by Apple?

HYPOTHESES

Proximity

- H_{O1} : The use of our proposed Server-side Running Average (SRA) and Server-side Kalman Filter (SKF) algorithms does not improve the proximity detection accuracy when compared with iBeacon's current proximity detection approach.
- H_{a1} : The use of our proposed Server-side Running Average (SRA) and Server-side Kalman Filter (SKF) algorithms improves the proximity detection accuracy when compared with iBeacon's current proximity detection approach.

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HYPOTHESES

Indoor Localization

- H_{O2} : The use of a Kalman Filter or an Extended Kalman Filter in cascade with Particle Filter does not significantly reduce the average localization error of an iBeacon based indoor localization system when compared with using only Particle Filter.
- H_{a2} : The use of a Kalman Filter or an Extended Kalman Filter in cascade with Particle Filter reduces the average localization error of an iBeacon based indoor localization system by at approximately 25% when compared with using only Particle Filter.

IBEACON BASED PROXIMITY DETECTION SYSTEM

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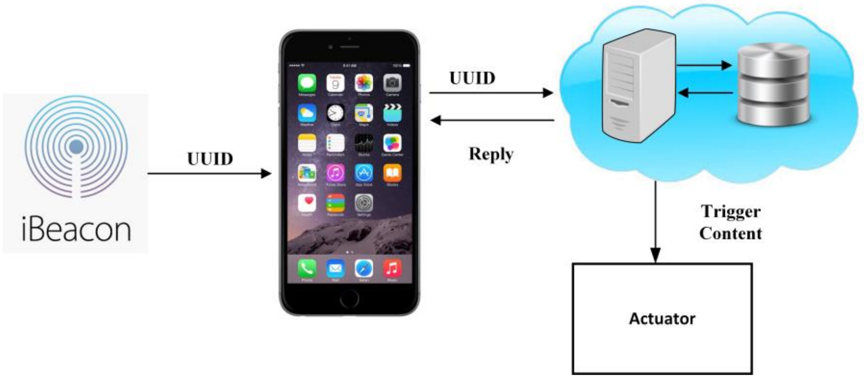
IBEACON-BASED PDS

- Traditional Approach

Proximity Decision based on
Running average of RSSI

Zone	Distance
Immediate	<1 meter
Near	1-3
Far	>3 meters
Unknown	Not in range



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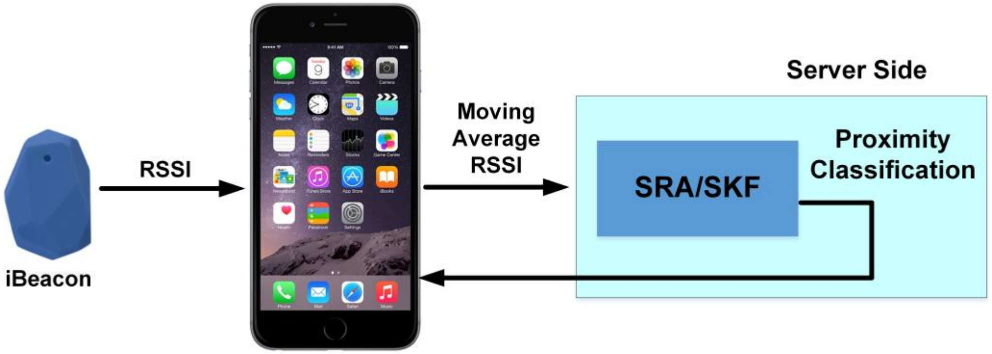
IBEACON-BASED PDS



- Our approach
  - Server side based
  - Do site-survey to obtain path-loss model
  - Use obtained path-loss model to obtain distance from RSSI values.
- Two Algorithms
  - Server-side Running Average (SRA)
  - Server-side Kalman Filter (SKF)

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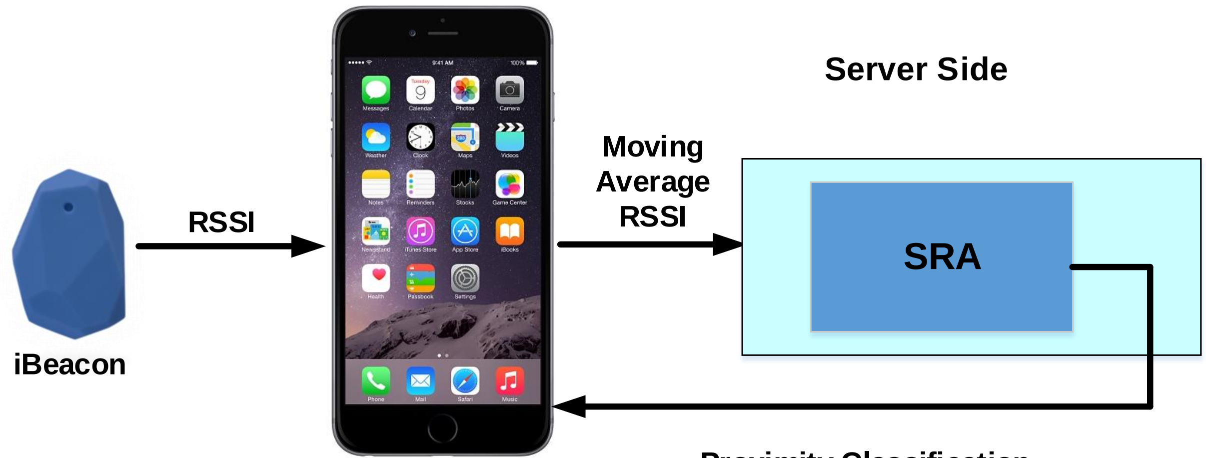
IBEACON-BASED PDS

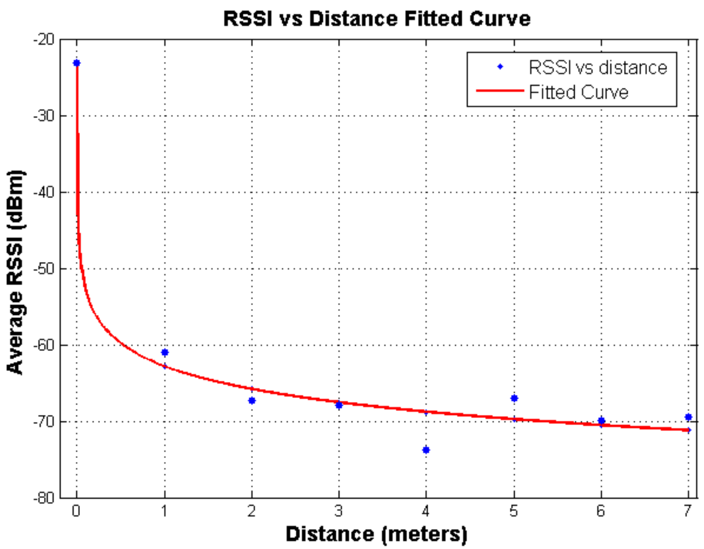
Server-side Running Average (SRA)



Algorithm 1 Server-side Running Average

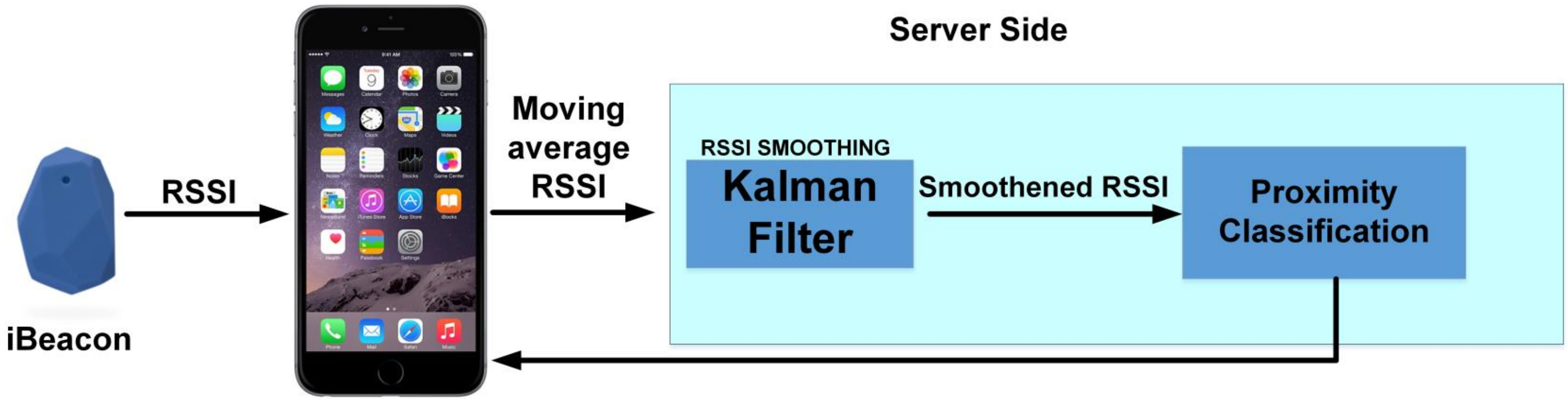
procedure SERVER-SIDE RUNNING AVERAGE
    Obtain a path-loss model using site survey
    while User device receives RSSI from iBeacons **do**
        Report RSSI values from user device to server
        Obtain distance from RSSI values using path loss model.
        Classify proximity zone based on distance
        if The user is classified as being present in the same zone by three consecutive measurements obtained from beacons **then**
            Accept the proximity estimate
        else Reject the proximity estimate

Proximity Classification



IBEACON-BASED PDS

Server-side Kalman Filter (SKF)

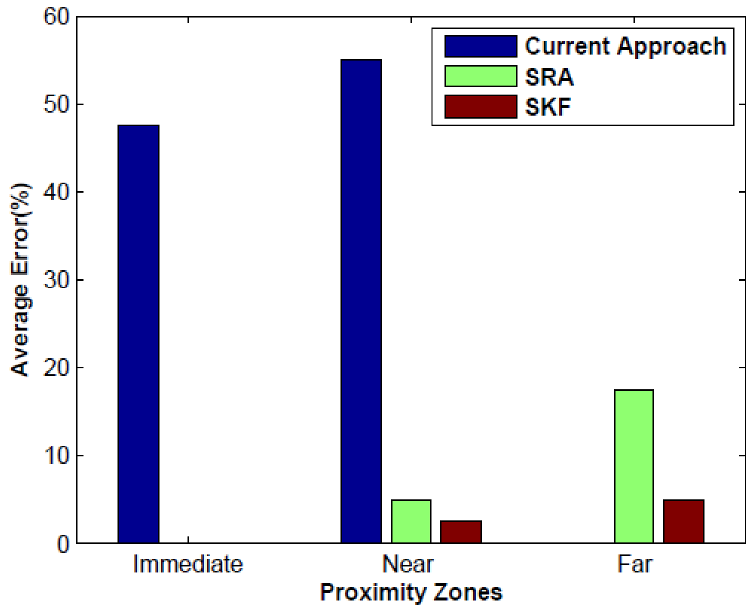


Algorithm 2 Server-side Kalman Filter

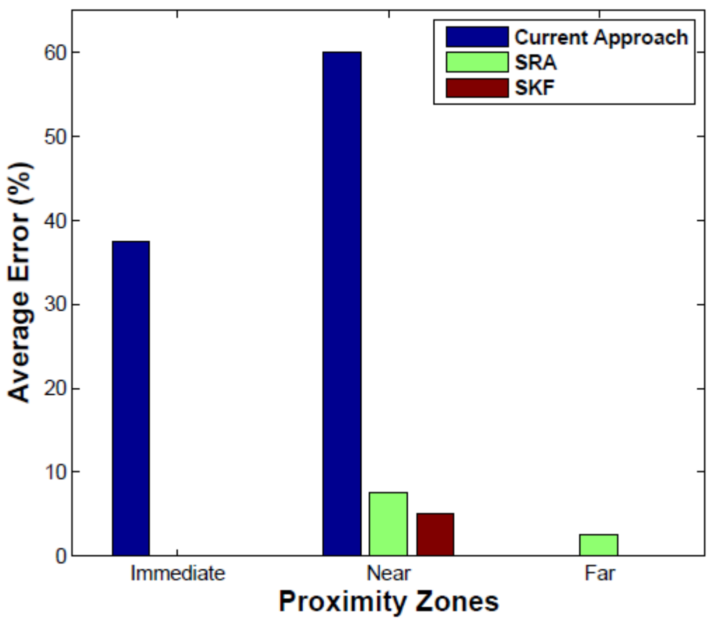
```
procedure SERVER-SIDE KALMAN FILTER
    Obtain a path-loss model using site survey
    while User device receives RSSI from iBeacons do
        Report RSSI values from user device to server
        Pass RSSI through Kalman Filter
        Obtain distance from filtered RSSI values using
          path-loss model.
        Classify proximity zone based on distance
        if The user is classified as being present
          in the same zone by three consecutive
          measurements obtained from beacons then
            Accept the proximity estimate
        else Reject the proximity estimate
```

IBEACON-BASED PDS

- Two different Environments
  - Environment-1 11m x 6m
  - Environment-2 8m x 4m



Environment 1



Environment 2

Results (Submitted to ACM Sensys 2016)

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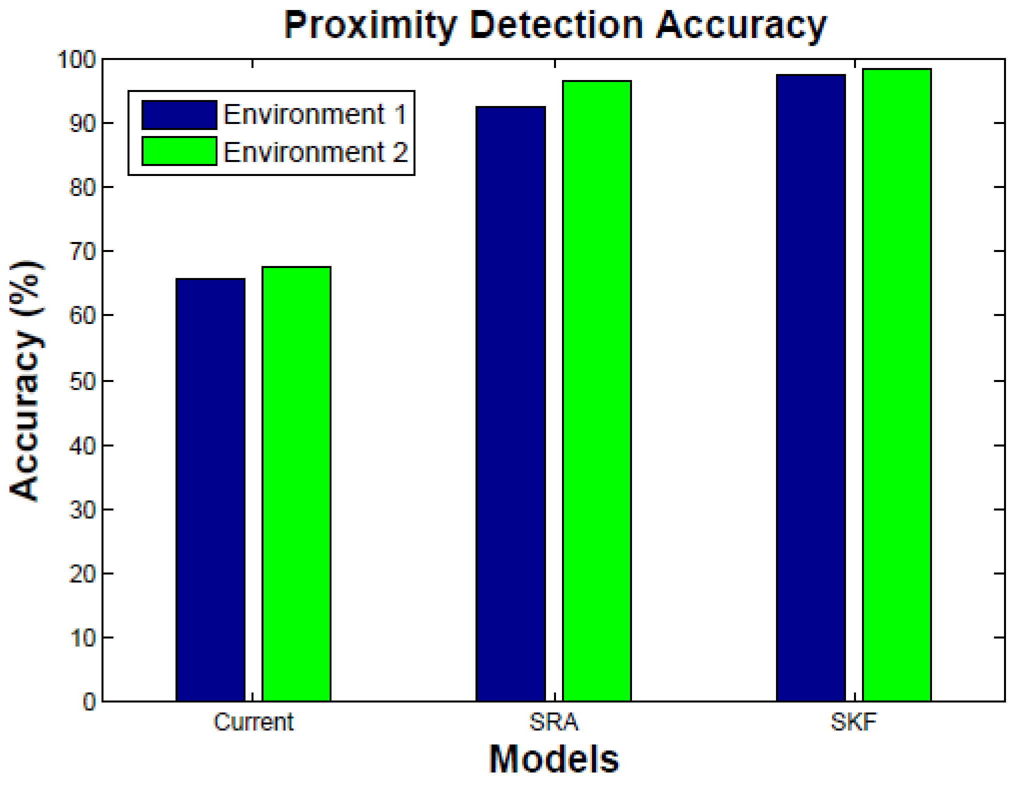

Hence we reject H_{01}

Results (Submitted to ACM Sensys 2016)

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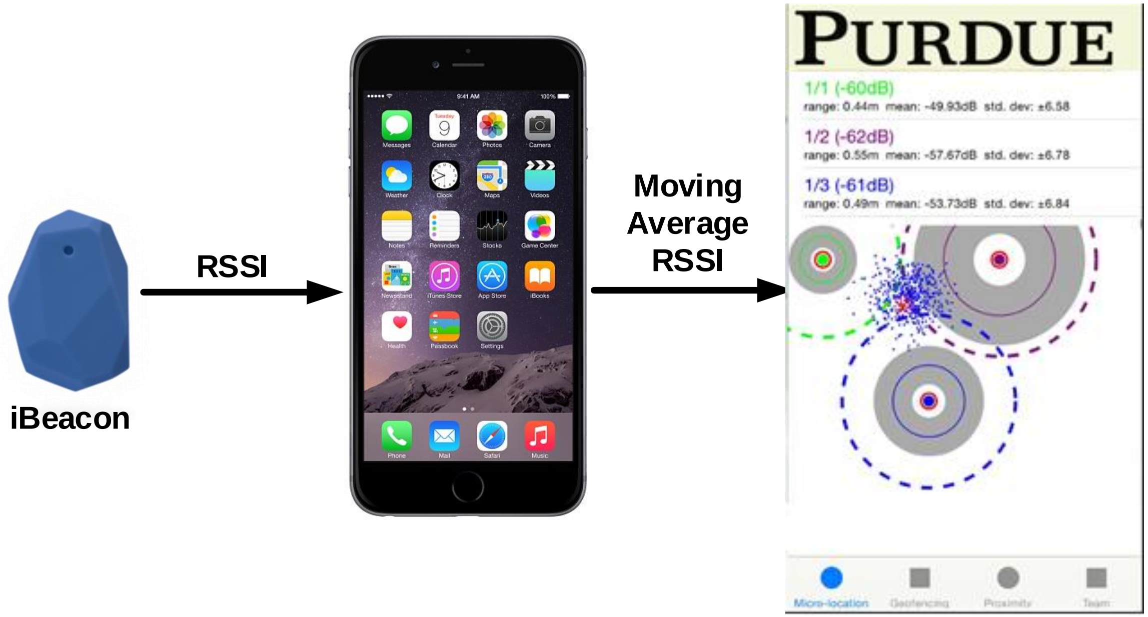
IBEACON BASED INDOOR LOCALIZATION SYSTEM

IBEACON BASED INDOOR LOCALIZATION

- Four different approaches
  - Particle Filter on the user device.



Results (Published in Globecom 2015)

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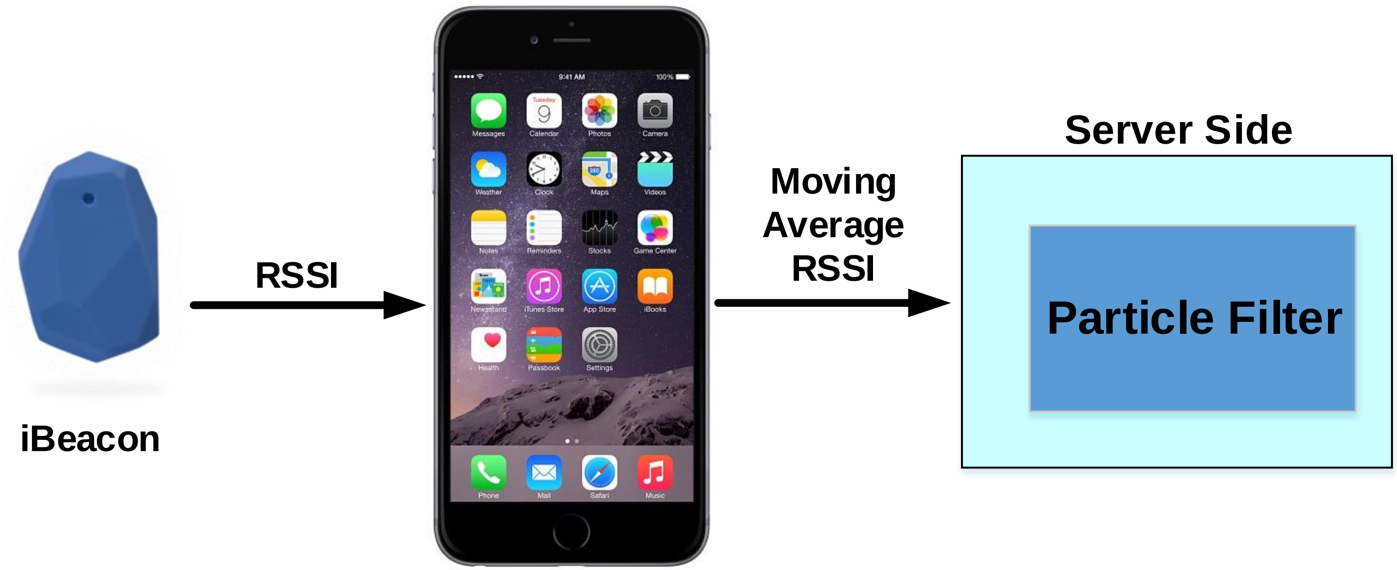
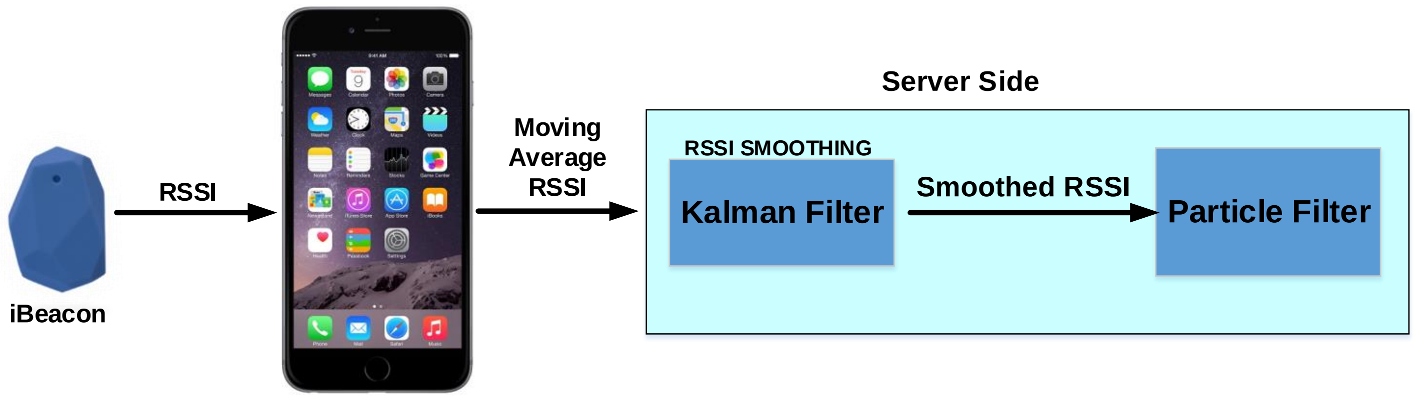
IBEACON BASED INDOOR LOCALIZATION

- Four different approaches
    - Particle Filter on the server side



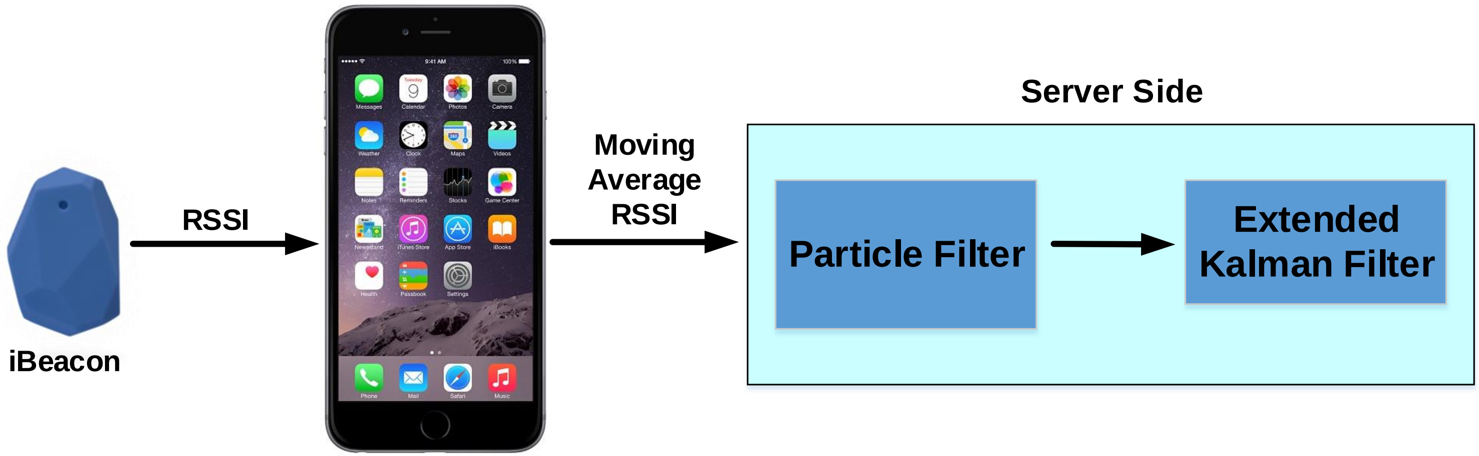
IBEACON BASED INDOOR LOCALIZATION

- Four different approaches
  - Kalman Filter-Particle Filter on the server side (To be submitted)



IBEACON BASED INDOOR LOCALIZATION

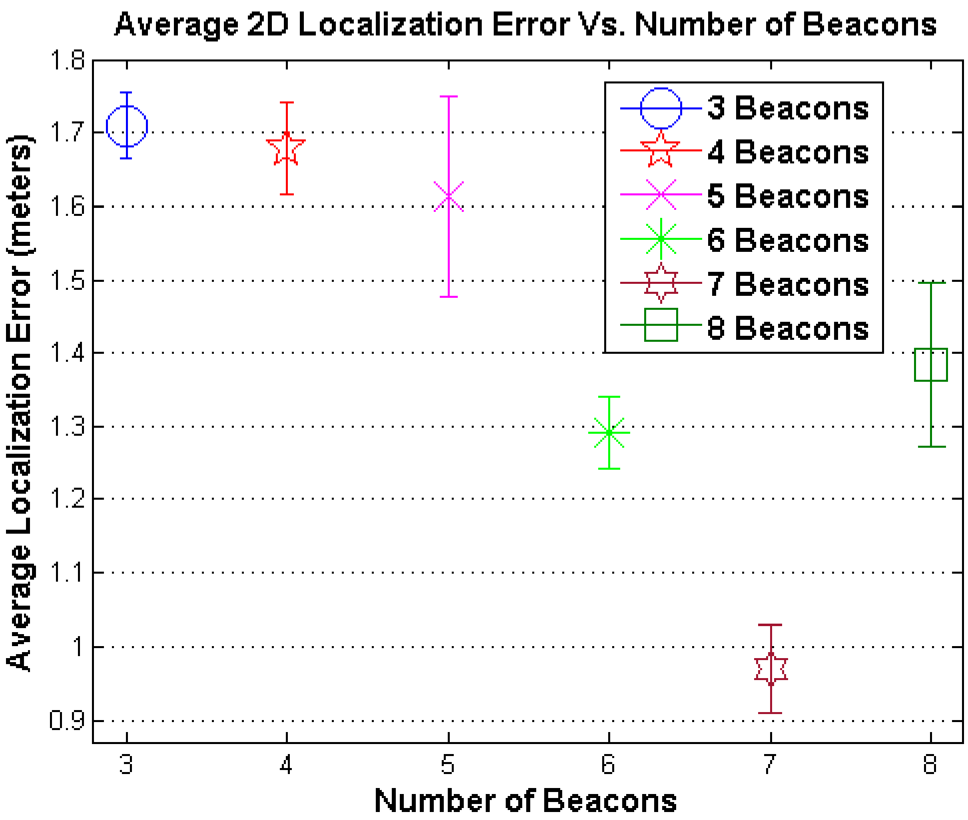
- Four different approaches
  - Particle Filter-Extended Kalman Filter on the server side



IBEACON BASED INDOOR LOCALIZATION

Results: PF on server side

- Locating a user in a 7m x 6m



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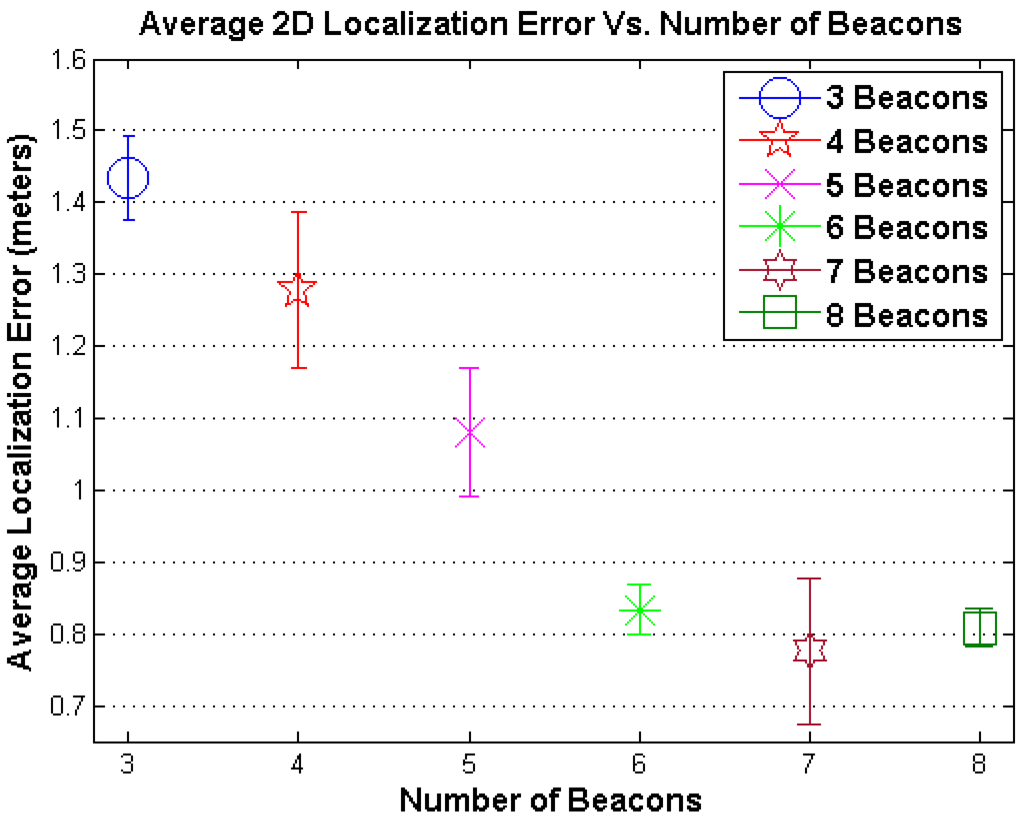
Results: KFPF on server side

- Locating a user in a 7m x 6m



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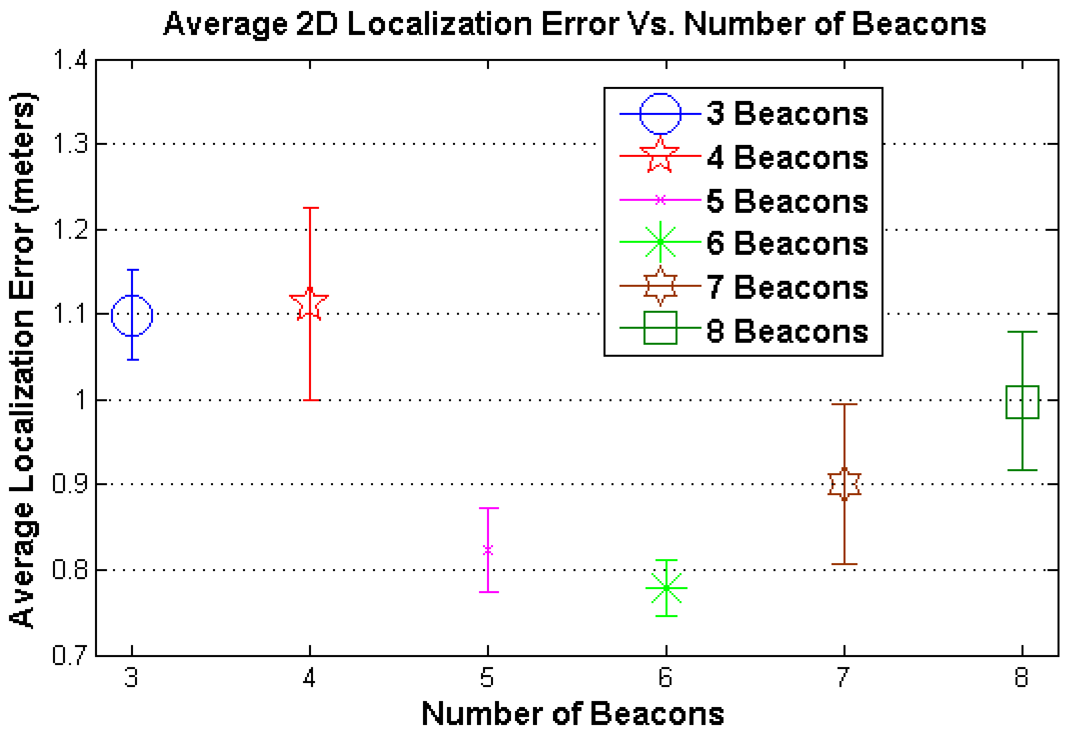
IBEACON BASED INDOOR LOCALIZATION

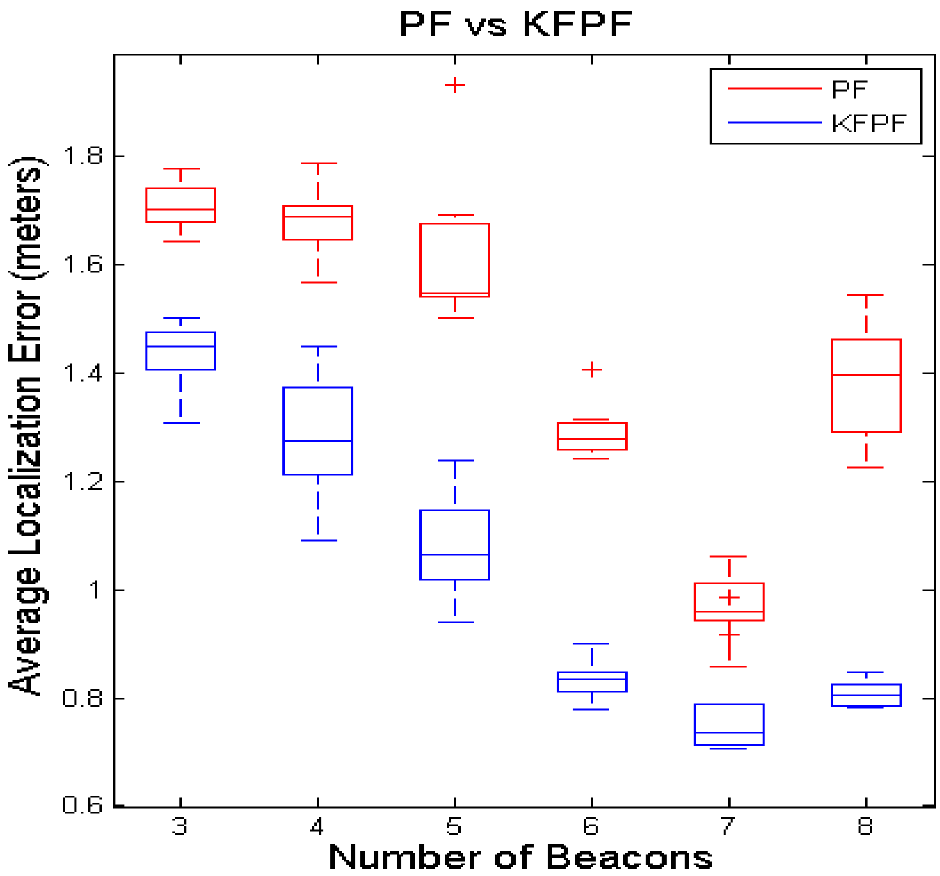
Results: PFEKF on server side

- Locating a user in a 7m x 6m



IBEACON BASED INDOOR LOCALIZATION

Results: Comparison b/w PF and KFPF



- 28% improvement brought by cascaded filters

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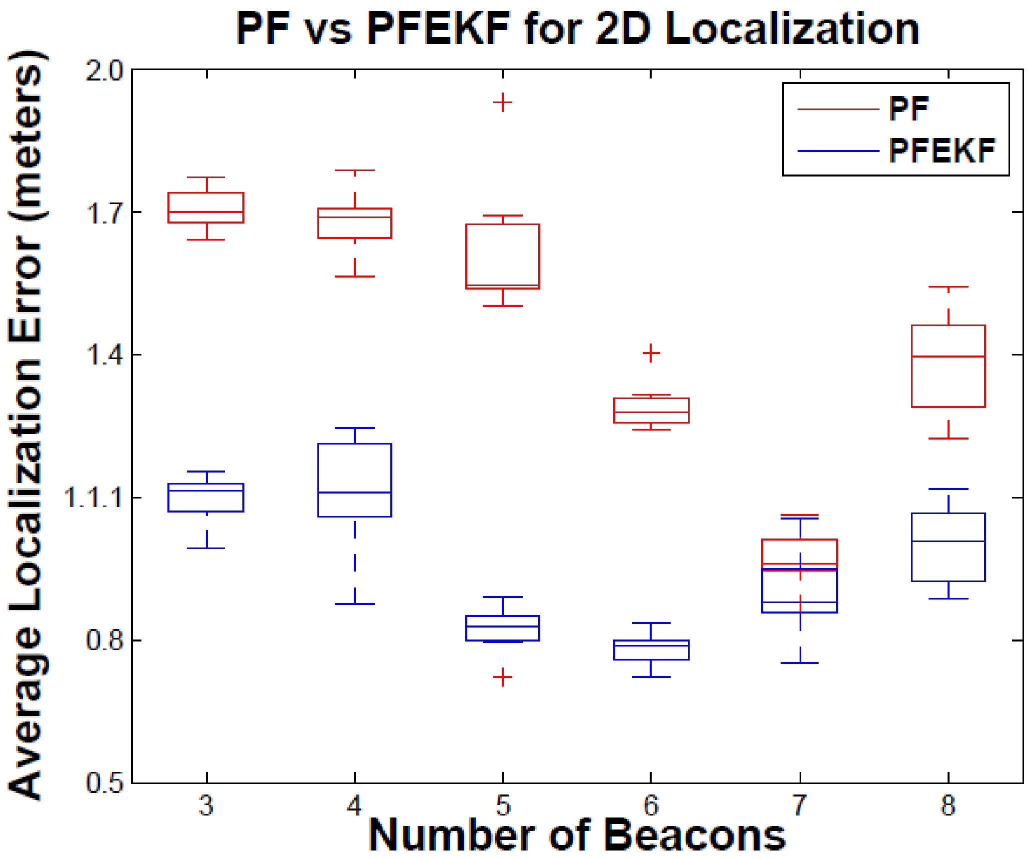
IBEACON BASED INDOOR LOCALIZATION

Results: Comparison b/w PF and PFEKF



- 33.94% improvement brought by cascaded filters

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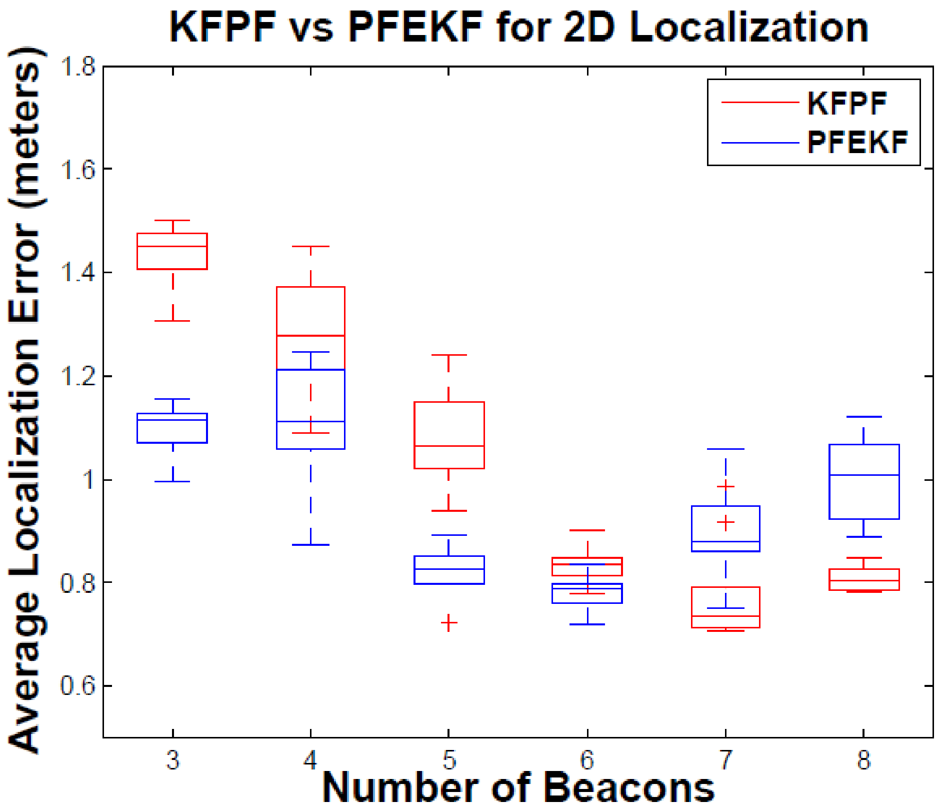
IBEACON BASED INDOOR LOCALIZATION

Results: Comparison b/w KFPF and PFEKF



- 8.04% improvement brought by PFEKF in comparison with KFPF

CONCLUSION

- iBeacon's performance can be improved for a reliable and accurate proximity and indoor localization system.
- The use of our server-side based algorithms, SRA and SKF, can improve the proximity detection accuracy when compared with Apple's current approach.
- The use of cascaded filters can improve the indoor localization accuracy when compared with only using Particle filters.
- iBeacon, being the industrial standard for PBS, is a viable technology for LBS.

PUBLICATIONS

- F. Zafari, I. Papapanagiotou and K. Christidis, "Microlocation for Internet-of-Things-Equipped Smart Buildings," in *IEEE Internet of Things Journal*, vol. 3, no. 1, pp. 96-112, Feb. 2016.
- F. Zafari and I. Papapanagiotou, "Enhancing iBeacon Based Micro-Location with Particle Filtering," *2015 IEEE Global Communications Conference (GLOBECOM)*, San Diego, CA, 2015, pp. 1-7.
- F. Zafari, I. Papapanagiotou, M. Devetsikiotis, T.J. Hacker, "Enhancing the Accuracy of iBeacons for Indoor Proximity-based Services" (*Submitted to ACM Sensys 2016)*
- F. Zafari, I. Papapanagiotou, T.J Hacker, "Cascaded filtering for enhancing the performance of RSSI based indoor localization", (To be submitted)

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- Arulampalam, M. S., Maskell, S., Gordon, N., & Clapp, T. (2002). A tutorial on particle filters for online nonlinear/non-Gaussian Bayesian tracking. *Signal Processing, IEEE Transactions on*, *50*(2), 174-188.
- Gustafsson, F., Gunnarsson, F., Bergman, N., Forssell, U., Jansson, J., Karlsson, R., & Nordlund, P. J. (2002). Particle filters for positioning, navigation, and tracking. *Signal Processing, IEEE Transactions on*, *50*(2), 425-437.
- Guvenc, I., Abdallah, C. T., Jordan, R., & Dedeoglu, O. (2003, March). Enhancements to RSS based indoor tracking systems using Kalman filters. In *GSPx & international signal processing conference* (pp. 91-102).

QUESTIONS

Questions?

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