Duet
Making Localization Work for Smart Homes

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The Smart Home Dream
Problem Statement

Smart homes need continuous tracking of location and identity of occupants

Cannot use camera, privacy-invasive

How about RF?
RF-Based Localization
Problem 1: People Do Not Always Carry Phones
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People don’t carry their phone over 50% of the time
Problem 2: Wireless Signals get Blocked
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Bathroom tiles block wireless signals
RF based location data is:

- **Error-prone**: Users don’t always have their phone
- **Intermittent**: Homes have several blockages for RF signals (TV, bathroom tiles, etc)
Problem Statement

Smart homes need continuous tracking of location and identity of occupants in spite of error-prone and intermittent RF data.
Duet

• Delivers continuous tracking of occupant location and identity with error-prone, intermittent RF data
  • Error-prone data: Combine information from device-free and device-based systems
  • Intermittent data: Use probabilistic logic to encode spatio-temporal constraints

• Evaluated over two weeks in two environments with user devices
Problem 1: People Do Not Always Carry Phones

Idea: Use device-free localization
Device-free Localization

Uses reflections to track people
Doesn’t need a device

But... No Identity
Device-based Localization

- Needs people to carry cellphones [✗]
- Can identify people [✓]

Device-free Localization

- Doesn’t need cellphones [✓]
- Cannot identify people [✗]

Idea: Track both people and devices
Use interactions to match
Idea: Capture interaction between people & devices
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Problem 2: Wireless Signals get Blocked
Observation 1: Logical Spaces have Transition Points
Observation 2: Logical Dependencies in Space-Time
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Logical Dependencies in Space-Time

• Cannot be present in two places at the same time

• Cannot enter places that they already occupy

• Cannot exit from places that they don’t occupy
Step 1: Track Entries and Exits to Spaces

• Duet uses a Hidden Markov Models to identify entry and exits trajectories

Noisy RF-data → HMM → Entry/Exit Trajectories

• Does not need training per region
Step 2: First Order Logic Formulation

\[ S_t = \{ v_j | j = \{1,2, \ldots K\} \} \]

State

\[ v_j = (P, I, R) \]

P: Possible identities for the individual

I: Impossible identities for the individual

R: The location of the individual
Step 2: First Order Logic Formulation

\[ S_i = \{ v_j | j = \{1,2, \ldots K\} \} \]

\[ v_j = (P, I, R) \]

- Can reason about a rich set of constraints
- Provable satisfiability algorithm to prune out invalid states
Experimental Evaluation
Implementation

• 2-week studies in two setups: home and office space

• Occupants used their own cellphones, did not install an app
  • One time registration with the system

• Required no changes to user behavior
Implementation: Home

- 2 occupants, 2 frequent visitors
- Smallest area: couch (1.3 m²)
Implementation: Office

- Office A: 3, Office B: 5, Office C: 1 occupants
Implementation: Office

Office A
Office B
Office C
Conclusion

• Duet: Combine information from multiple modes of RF tracking

• Uses First Order Logic based reasoning to overcome intermittent, partially correct information

• User study over two weeks and two different environments