POLYTECHNIQUE MONTRÉAL
WORLD-CLASS ENGINEERING

Collaborative tracking of devices in historical architecture

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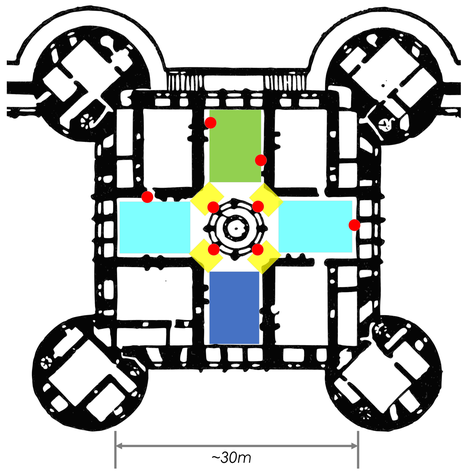
MIST

- *Motivation:*
  - *Localization of hundreds of devices in unstructured environments*
  - *48 rooms => Expensive fixed infrastructure*
  - *Requires access and can damage historical buildings*
- *Goal:*
  - *localization with minimal setup*
- *Proposal:*
  - *use Ultra-wideband (UWB) receivers and Collaborative Localization*
- *Challenges:*
  - *Network sharing*
    - *UWB sensor limitation(delay, collision)*
    - *Large number of devices*
    - *Changing topology of network*
  - *Collaborative localization*
    - *Dynamic nature of devices*

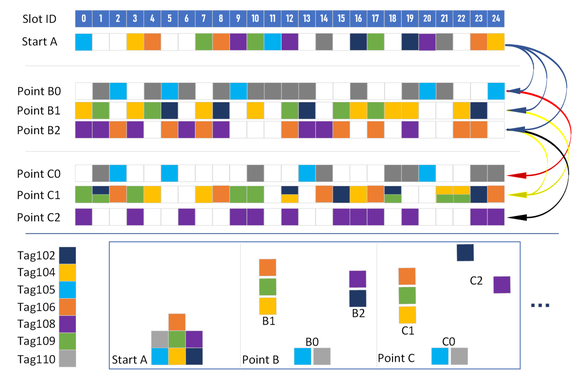


Chambord Castle, France

Results:

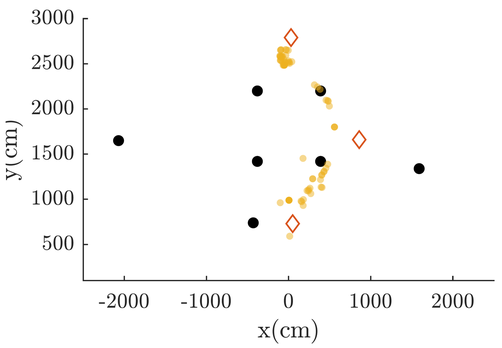
Experiments with 15 devices in Chambord Castle, France.
Tags topology splits into 3 groups.
Time slot usage adapts to dynamic network topology.
Tag located with decimeter accuracy.

- *Usage of UWB network:*



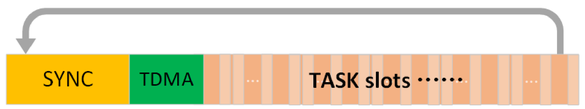
Dynamic network sharing result

- *Collaborative Localization*



Tracking of single tag

How we solve these challenges?



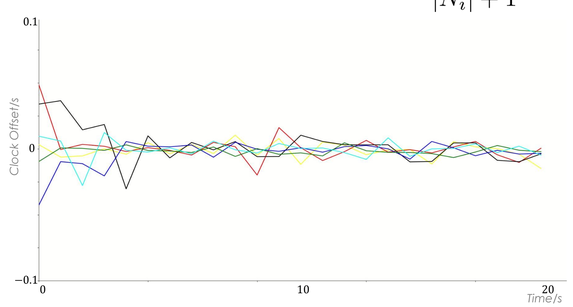
System Workflow

- *Synchronization:*
  - *A Gradient clock synchronization*

Hardware clock $H_i(t) = \int_{t_0}^{t} h_i(\alpha)d\alpha + \phi_i(t_0)$

Logical clock $L_i(t) = \int_{t_0}^{t} h_i(\alpha)l_i(\alpha)d\alpha + \theta_i(t_0)$

Average offset $\theta_i(t_{k+1}) = \frac{\sum_{j\in N_i}(L_j(t_k) - L_i(t_k) + \delta)}{|N_i| + 1}$



- *Time-Division Multiple Access*

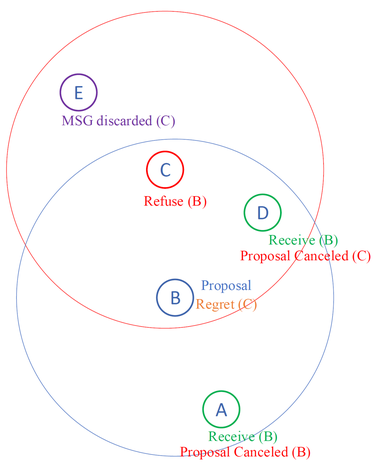
An adapted Unifying Dynamic Distributed Slot Assignment Protocol (USAP) to schedule slots in distributed manner.

  - *Simplified packet format: SlotID+ActionCode*
  - *Two lists are maintained: SendList and ReceiveList*
  - *Three Actions included Proposal, Refuse, Regret*

Example of solving conflict

Situation:
E has slot i to broadcast,
C is to listen E at slot i,
A/B/D's slot i are free.

1. *B → A/C/D (Proposal)*
2. *C → B/D (Refuse)*
3. *B → A/C/D (Regret)*



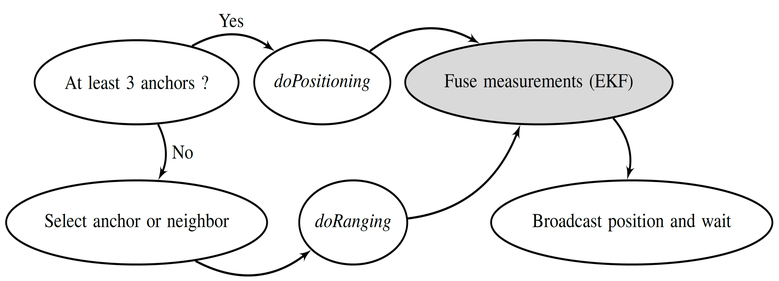
Time slot negotiation

- *Collaborative EKF*
  - *Sensor fusion of UWB and IMU*
  - *Collaborative localization with neighbors*

State Definition: $(x, \dot{x}, y, \dot{y}, z, \dot{z})$
State transition matrix:

$$\mathbf{F} = \begin{bmatrix} \mathbf{D}_F & \mathbf{0} & \mathbf{0} \\ \mathbf{0} & \mathbf{D}_F & \mathbf{0} \\ \mathbf{0} & \mathbf{0} & \mathbf{D}_F \end{bmatrix} \text{ with } \mathbf{D}_F = \begin{bmatrix} 1 & \delta t \\ 0 & 1 \end{bmatrix}$$

Measurement:
doPositioning (trilateration with 3 anchors)
doRanging(with neighbors broadcasting)
IMU measurement



Decision flow for each device

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