Resource Allocation Using Virtual Objects in the Internet of Things: a QoI Oriented Consensus Algorithm

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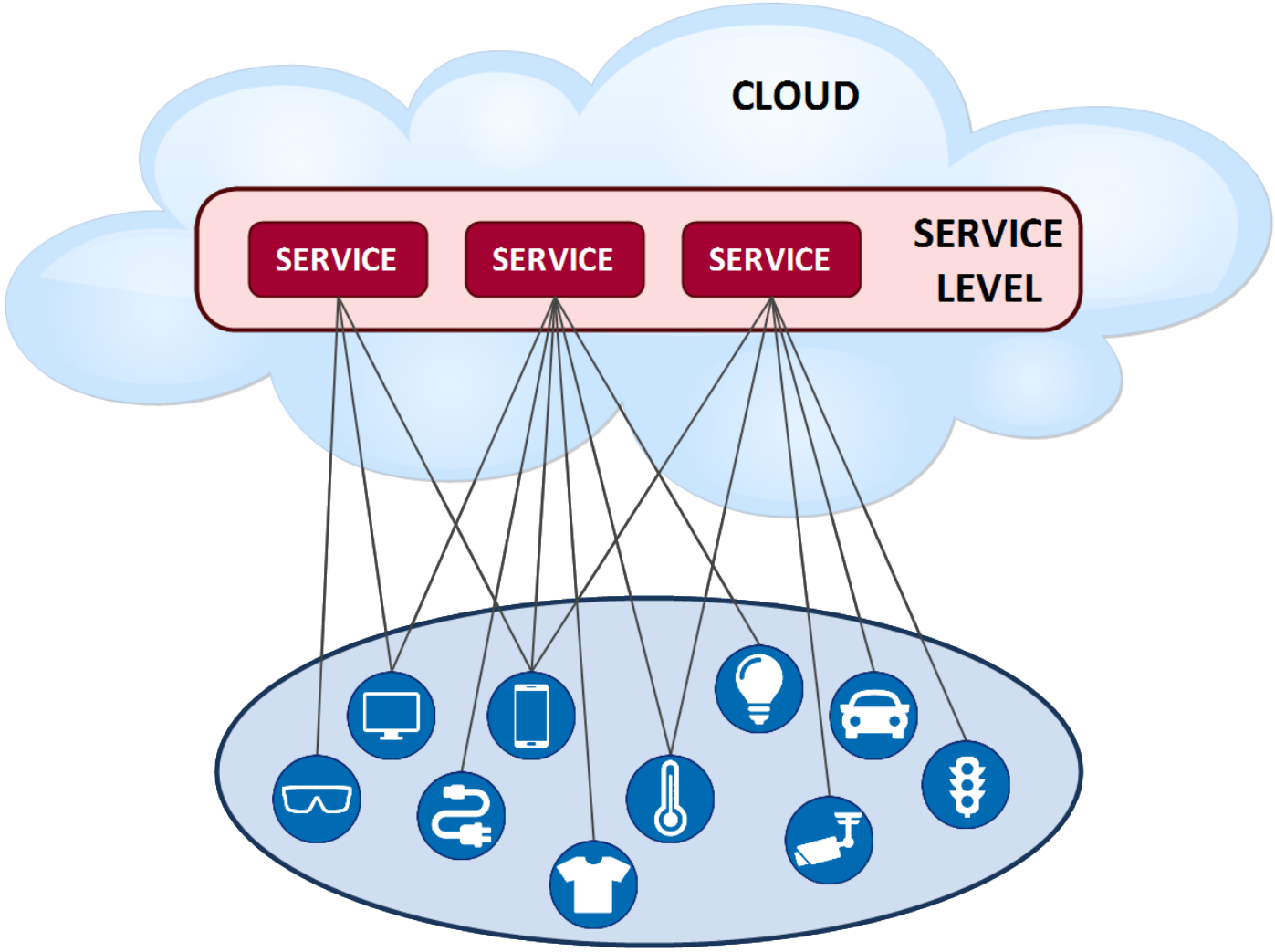
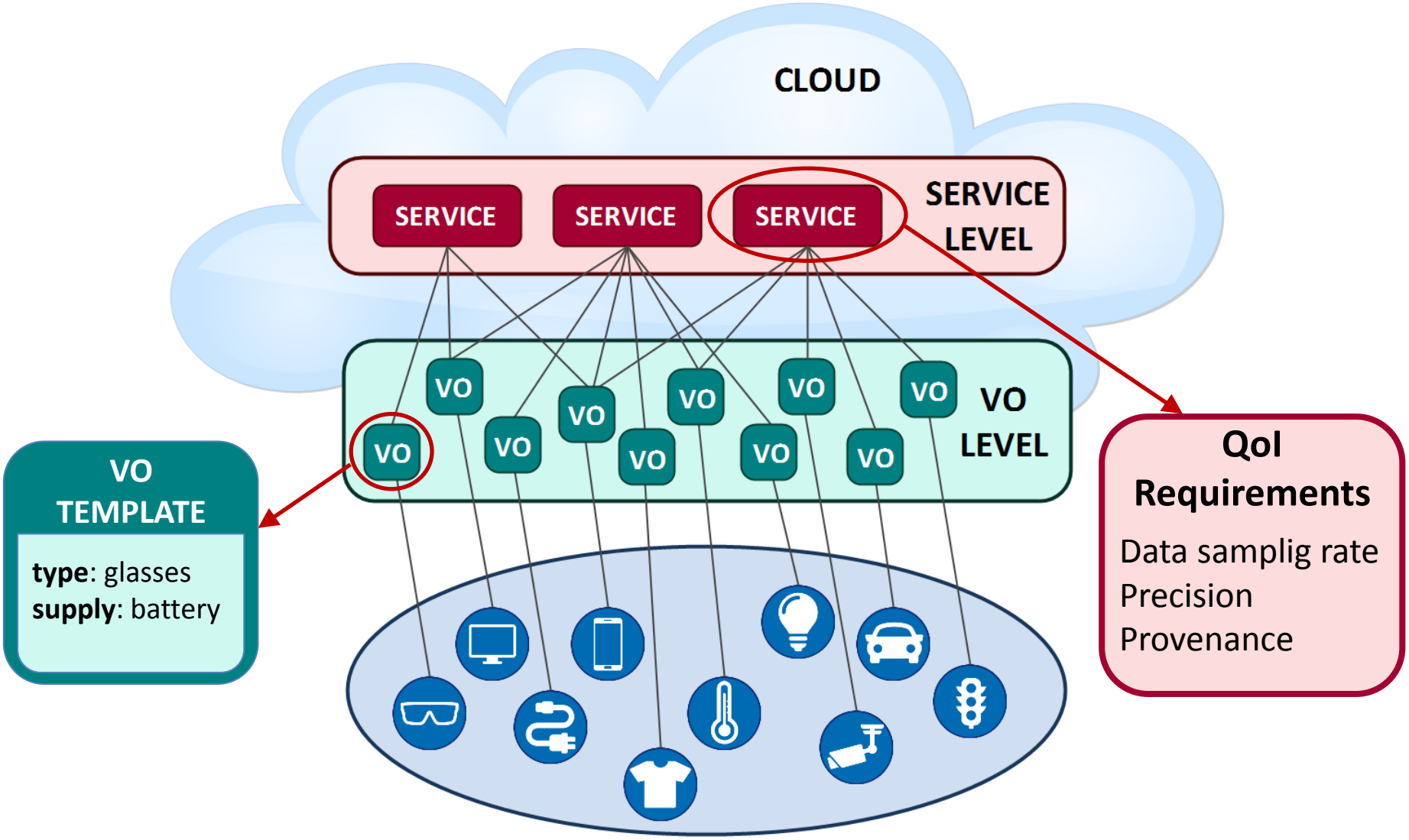
Introduction

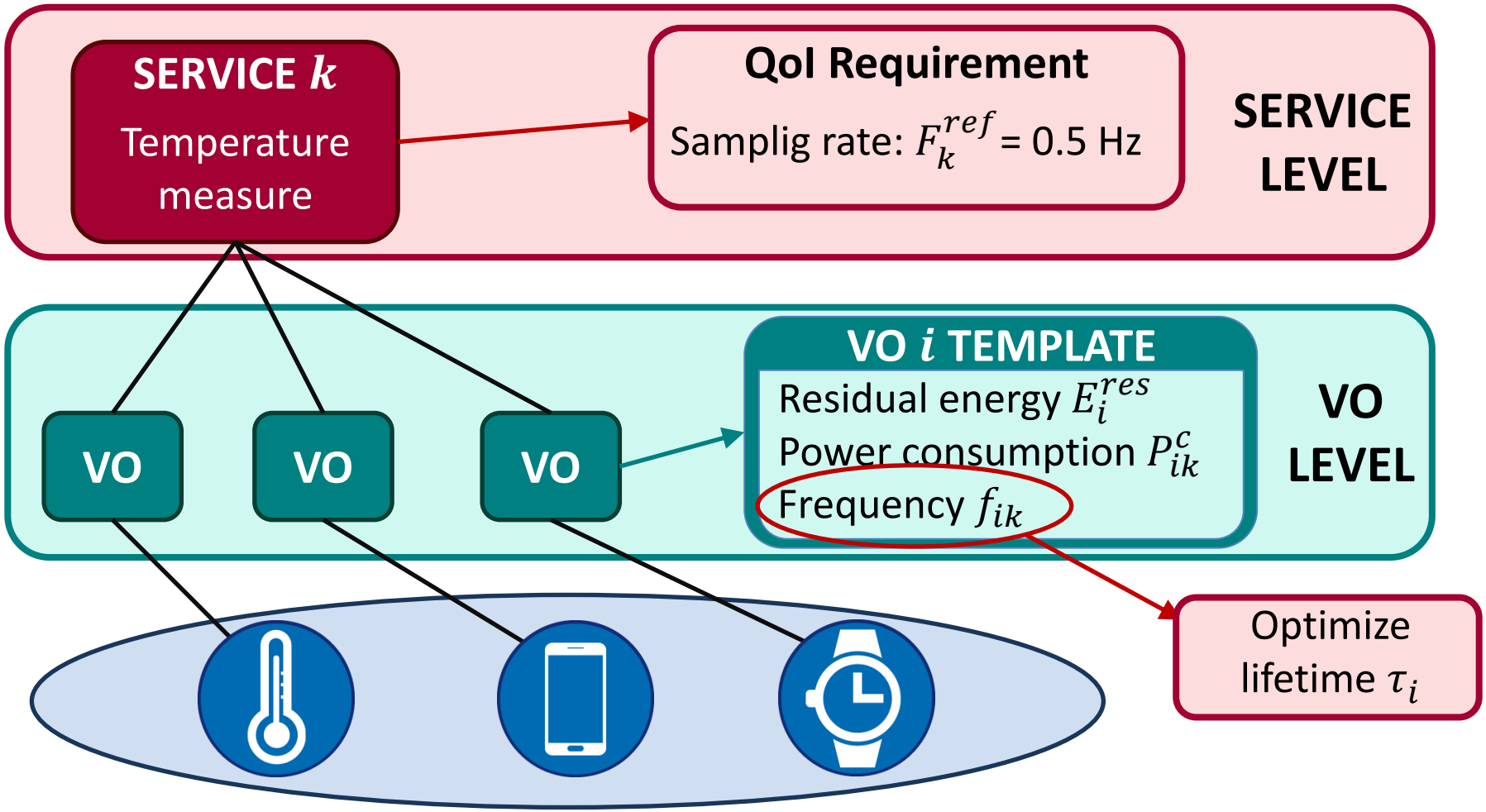


Reference Scenario



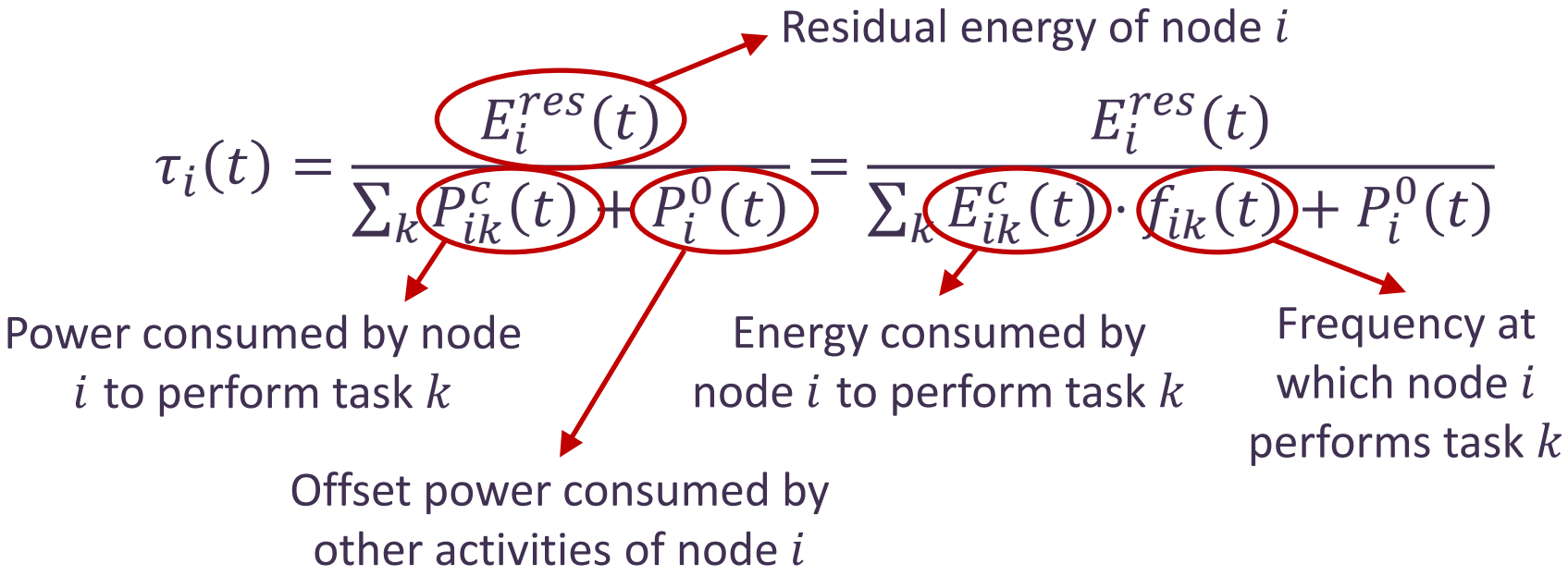
Reference Scenario

- Example: measure of the temperature of a room every 2 sec



Resource Allocation Model

- The lifetime $\tau_i(t)$ of a network at time t is defined as the time until the first node depletes its battery



- Based on this definition, optimising the network lifetime is equivalent to make nodes reach the **same lifetime**

Resource Allocation Model

$$\alpha_{ik}(t) = \frac{E_{ik}^{c}}{E_i^{res}(t)}$$

Contribution of energy consumption due to task k

$$\delta_{ik}(t) = \sum_{l \neq k} \alpha_{il}(t) \cdot f_{il}(t) + \frac{P_i^0(t)}{E_i^{res}(t)}$$

Contribution of energy consumption due to the other assigned tasks and activities of node i

$$\tau_i(t_c) = \tau_j(t_c)$$

$$\alpha_{ik}(t_c) \cdot f_{ik}(t_c) + \delta_{ik}(t_c) = \alpha_{jk}(t_c) \cdot f_{jk}(t_c) + \delta_{jk}(t_c)$$

$$F_k^{ref} = \sum_j f_{jk}(t_c) = \alpha_{ik}(t_c) \cdot f_{ik}(t_c) \sum_j \left(\frac{1}{\alpha_{jk}(t_c)} + \frac{\delta_{ik}(t_c) - \delta_{jk}(t_c)}{\alpha_{jk}(t_c)} \right)$$

Resource Allocation Model

$$\alpha_{ik}(t_c) \cdot f_{ik}(t_c) = \frac{\bar{\varphi}_k}{\bar{\beta}_k(t_c)} + \frac{\bar{\gamma}_k(t_c)}{\bar{\beta}_k(t_c)} - \delta_{ik}(t_c)$$

$$\begin{cases} \bar{\varphi}_k = \dfrac{F_k^{ref}}{N_k} \\ \bar{\beta}_k(t_c) = \dfrac{1}{N_k} \cdot \displaystyle\sum_j \frac{1}{\alpha_{jk}(t_c)} \\ \bar{\gamma}_k(t_c) = \dfrac{1}{N_k} \cdot \displaystyle\sum_j \frac{\delta_{jk}(t_c)}{\alpha_{jk}(t_c)} \end{cases}$$

Number of VOs involved in task k

- They are all mean values evaluated over all the VOs that can perform $k \Rightarrow$ a **consensus algorithm** can be used

Lifetime Optimisation Algorithm

1. VO i receives from the VO level an activation request for task k, with an average frequency requirement of $\bar{\varphi}_k = F_k^{ref} / N_k$
2. VO i initialises its local values $\beta_{ik} = 1/\alpha_{ik}$ and $\gamma_{ik} = \delta_{ik}/\alpha_{ik}$ and sends them to its neighbours
3. Whenever VO i receives an update from its neighbours, it computes the following updates:

$$\beta_{ik}^{+} = \beta_{ik} - \lambda_1 \sum_{j \in \{neighbours\}} \left(\beta_{ik} - \beta_{jk}\right)$$

$$\gamma_{ik}^{+} = \gamma_{ik} - \lambda_2 \sum_{j \in \{neighbours\}} \left(\gamma_{ik} - \gamma_{jk}\right)$$

$$\tau_i^{+} = \frac{\beta_{ik}^{+}}{\bar{\varphi}_k + \gamma_{ik}^{+}} \qquad f_{ik}^{+} = \frac{1}{\alpha_{ik}} \cdot \left(\frac{1}{\tau_i^{+}} - \delta_{ik}\right)$$

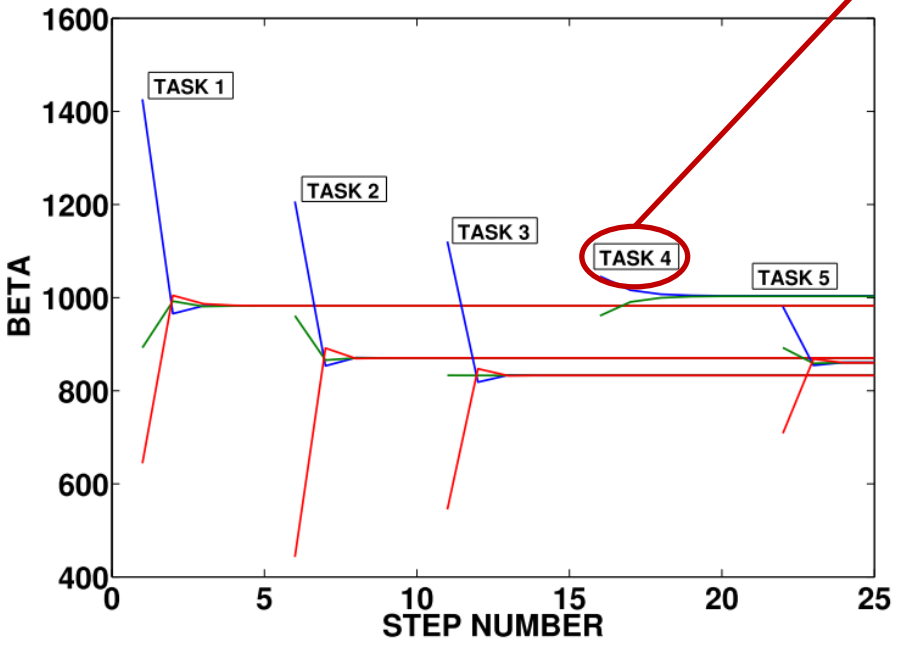
Lifetime Optimisation Algorithm

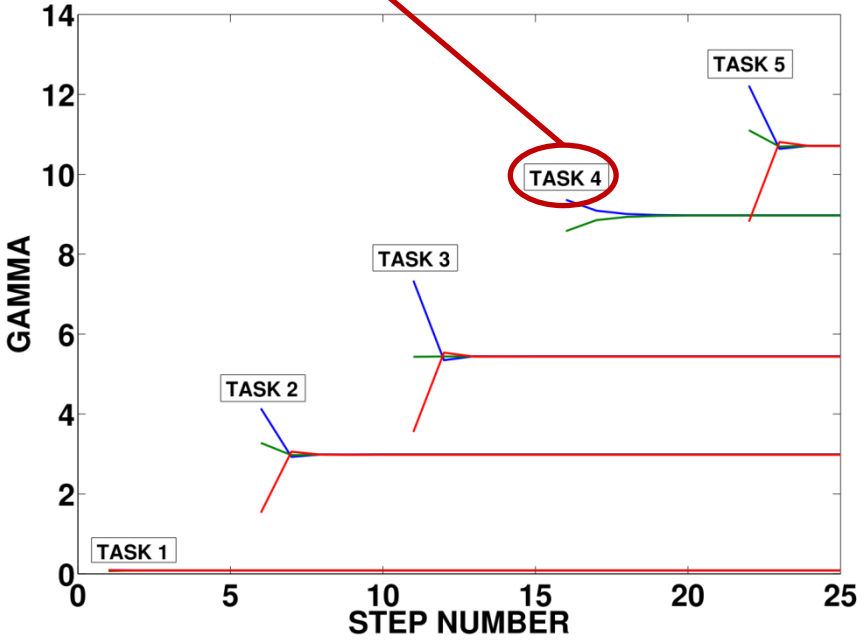
4. If $f_{ik}^{+} > 0$ and if its value has changed after the update, the VO sends β_{ik}^{+} and γ_{ik}^{+} to its neighbours and repeats step 3
5. If $f_{ik}^{+} \leq 0$, the node's workload δ_{ik} is already too high and cannot take charge of other tasks
   - The VO sets f_{ik} to 0 and informs the VO level, which updates its $\bar{\varphi}_k$ value
   - The consensus algorithm starts again without considering VO i
6. If f_{ik}^{+} values has not changed after the update, VO i has reached convergence

Convergence Example

Example of 3 devices and 5 different tasks: convergence of β_{ik} and γ_{ik} for each node and task

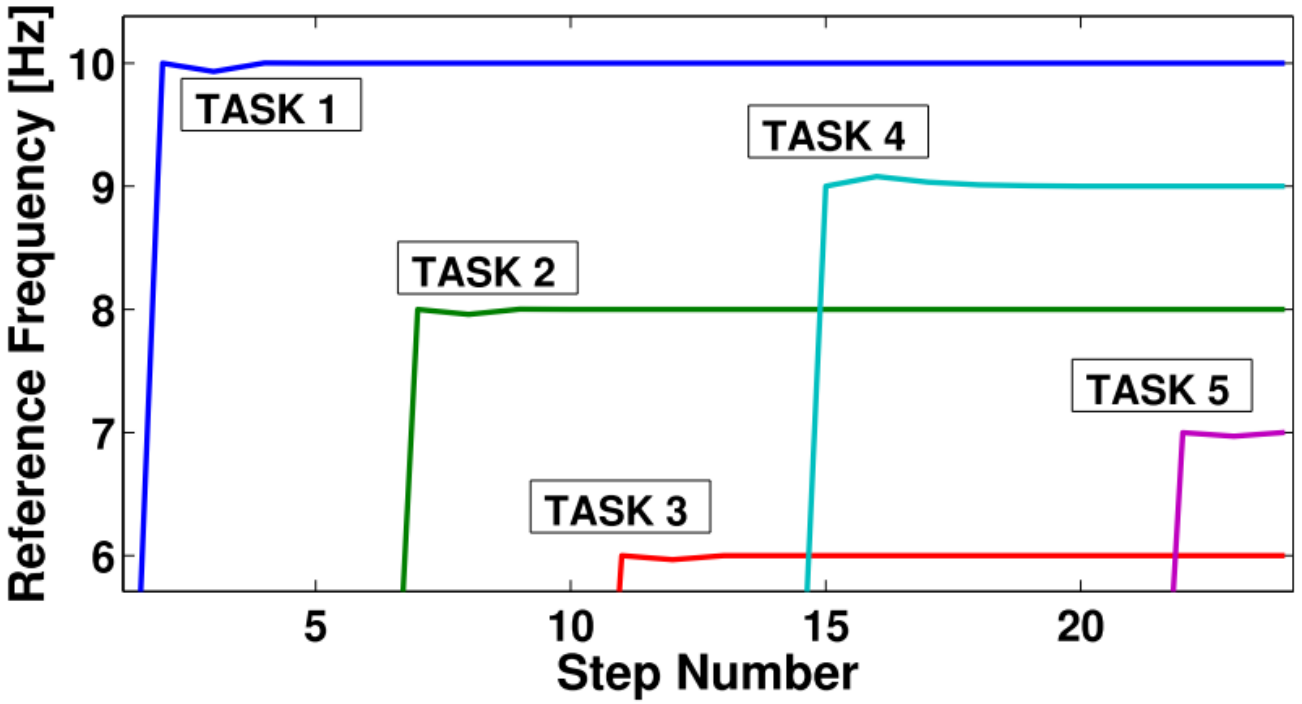
Task 4 can be performed by only 2 nodes out of 3





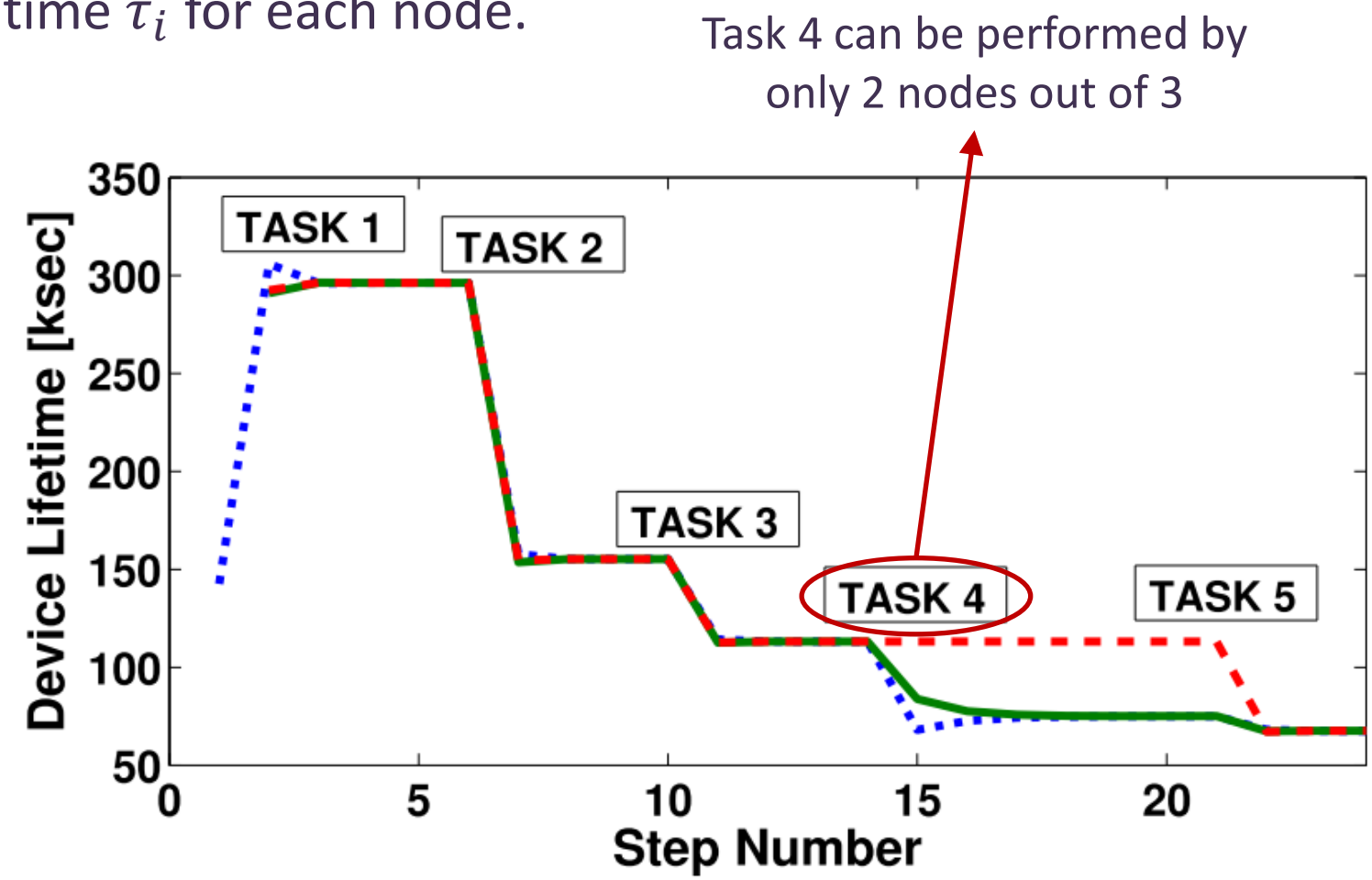
Convergence Example

Example of 3 devices and 5 different tasks: convergence of the reference frequency F_k^{ref} for each task



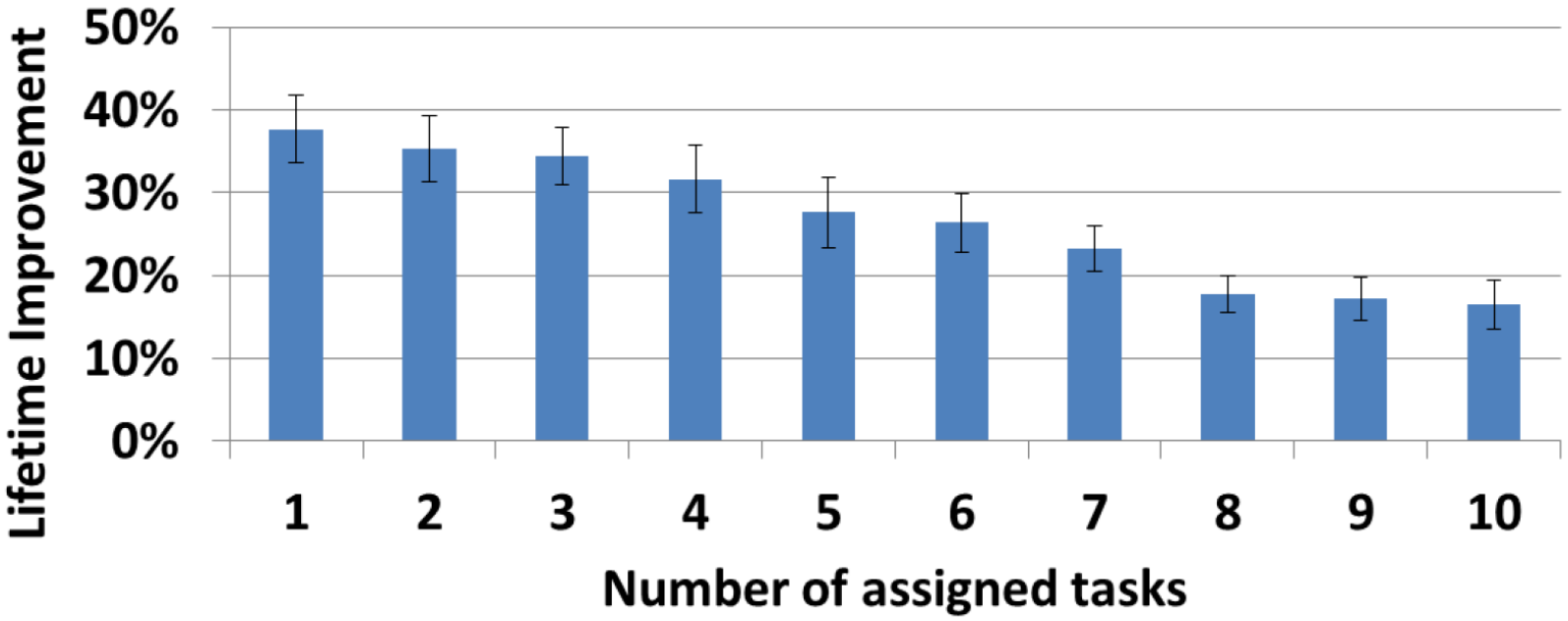
Convergence Example

Example of 3 devices and 5 different tasks: convergence of the lifetime τ_i for each node.



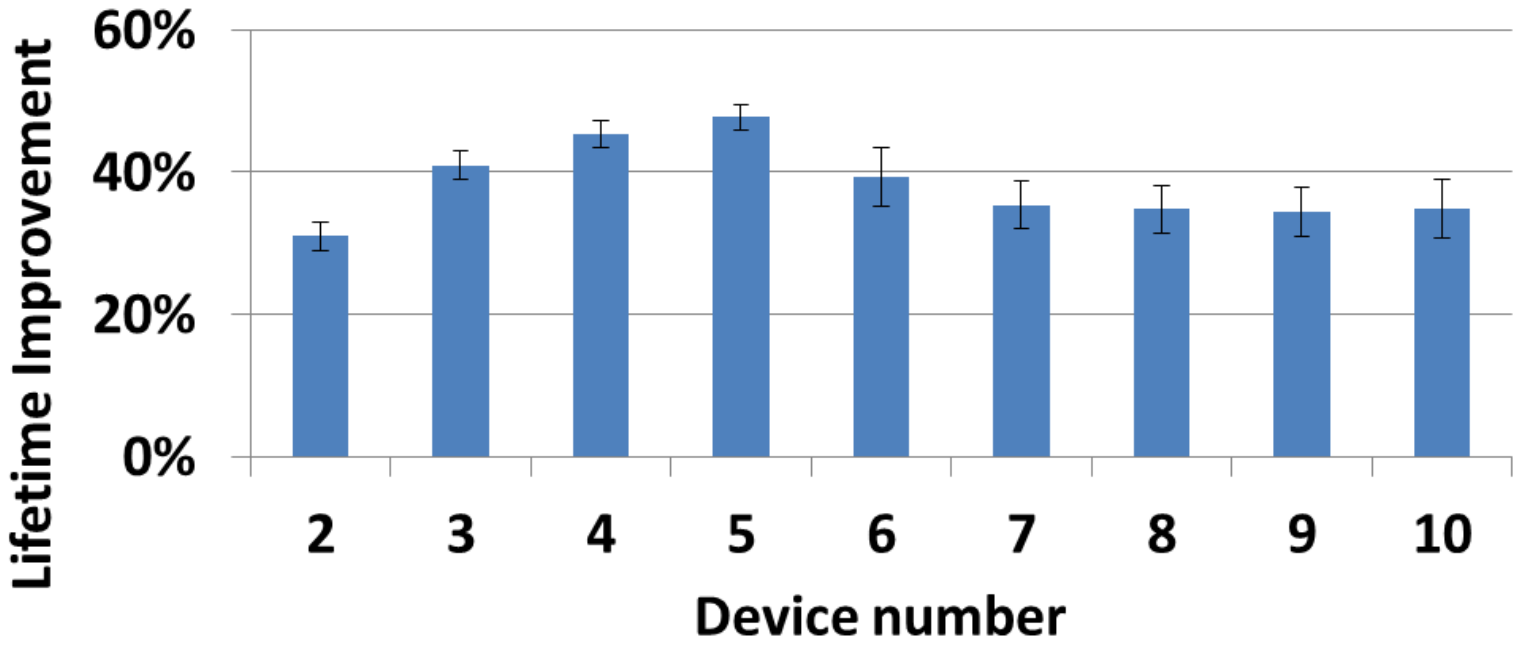
Performance Analysis

- Simulations run with 5 devices reaching consensus on 1 to 10 tasks
- Comparison with the case where F_k^{ref} is equally devided among nodes



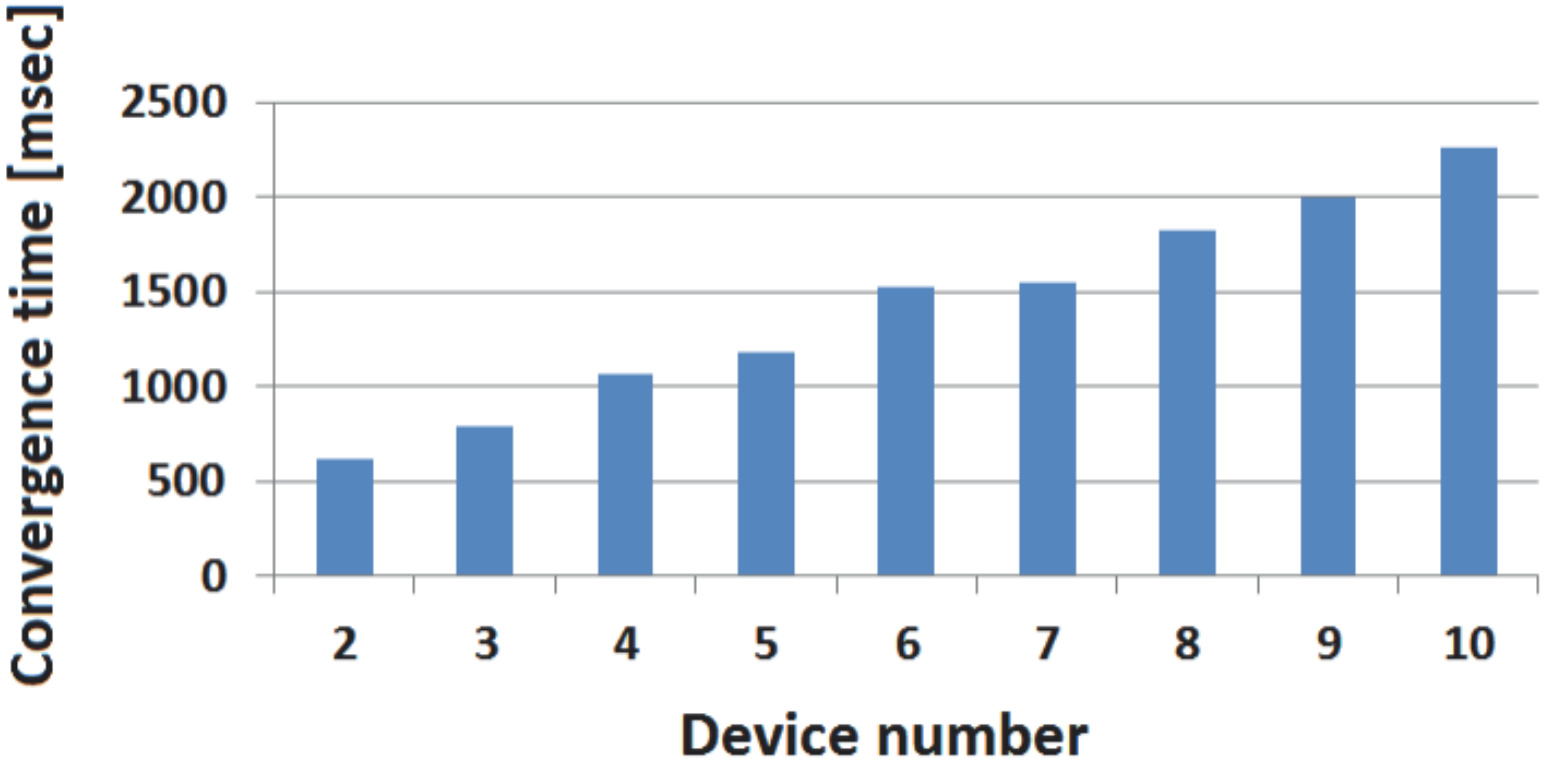
Performance Analysis

- Simulations run with 1 to 10 devices reaching consensus on 5 tasks
- Comparison with the case where F_k^{ref} is equally devided among nodes



Performance Analysis

- Simulations run with 1 to 10 devices reaching consensus on 1 to 10 tasks



Conclusions & Future Works

- We proposed a framework to control and manage IoT heterogeneous resource-constrained objects, so as to assign tasks while
  - Improving resource usage (particularly lifetime)
  - Ensuring the required QoI (particularly data sample frequency)
- Future works focused on
  - Definition of a multi-objective algorithm to
    - Improve other resources (e.g. storage capacity, processing speed)
    - Consider other QoI requirements (e.g. task execution time)
  - Disruptive networks and networks that quickly change topology
    - Particular attention on mobility

Thank you!

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