EBS-RTTB: ENERGY BALANCING SYSTEM FOR IOT NETWORK REAL-TIME TASK BALANCING

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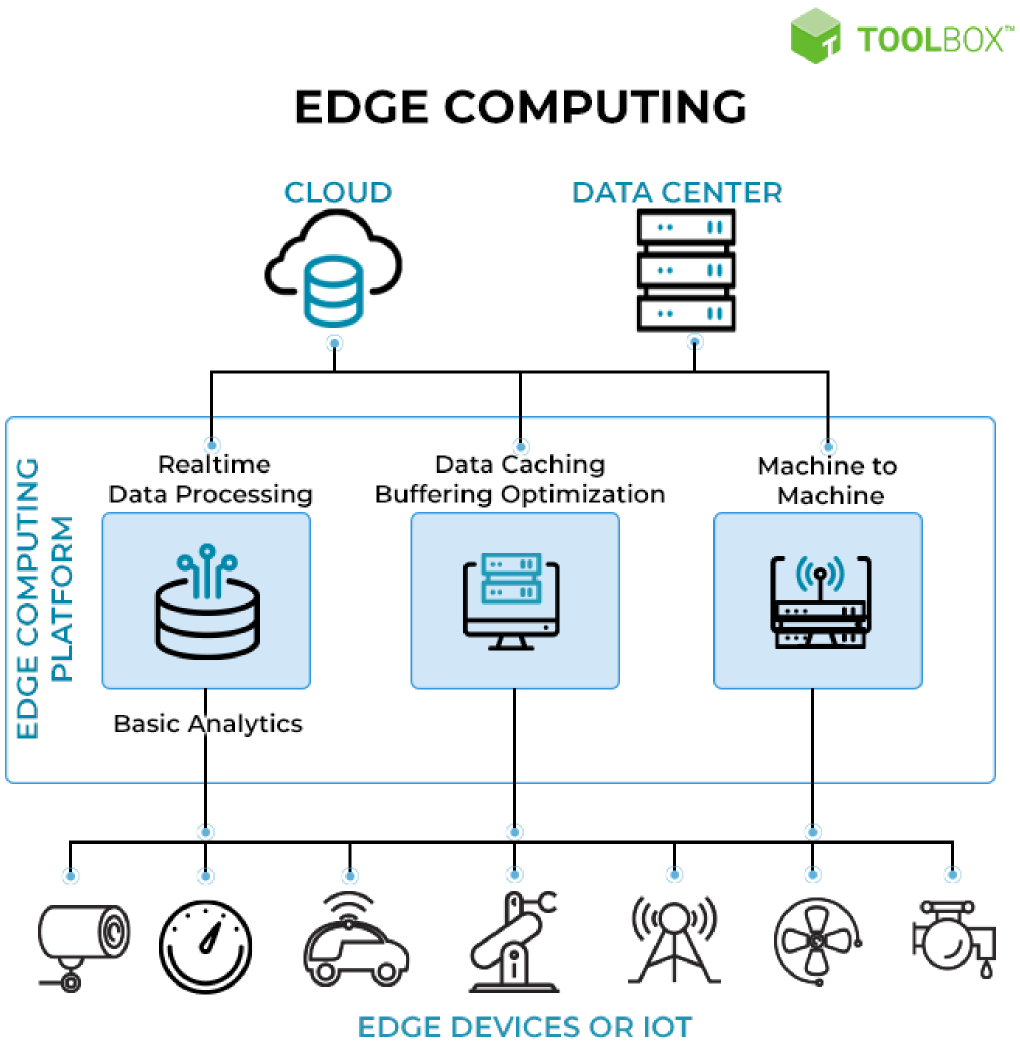
BACKGROUND

Cloud vs. Edge Processing:

Traditional IoT systems rely on cloud servers, which may introduce significant latency. For example, delays in a smart traffic system could delay emergency response.



[1]

[1] "Edge Computing vs. Cloud Computing: 10 Key Comparisons," Spiceworks. https://www.spiceworks.com/tech/cloud/articles/edge-vs-cloud-computing/

BACKGROUND (PI-RTTB)

ACO-Based Pheromone-inspired Real-time Task Balancing (pi-RTTB) [2]:

- Recent research has used Ant Colony Optimization (ACO), in which each node behaves as a "collaborative ant" by leaving pheromone trails.
- Pheromone indicates each node's processing capability (attractiveness).
- This decentralized, serverless strategy reduces latency and reliability by minimizing relying on cloud infrastructure.
- However, this strategy focuses on reducing latency without concern about balancing energy consumption among IoT nodes, resulting in faster battery depletion in certain devices and a shorter network lifespan.

[2] M. Wilson, H. Nunoo-Mensah, K. O. Boateng, and F. A. Acheampong, "A Real-Time Task Balancing Strategy for IoT Networks Using Ant Colony Optimization," Jun. 23, 2024, doi: https://doi.org/10.21203/rs.3.rs-4625359/v1.

MOTIVATION

Negative impacts of node depletion:

- Loss of critical sensing coverage → hazardous, can lead to critical failures.
  - Relay node monitoring a key pipeline section dies.
- Reduced network capacity → higher latency.
- Unacceptable for safety-critical systems.

[3]

[4]

[3] S. Liu, "21yo's horror death a warning to 'all Aussies,'" *news*, Feb. 18, 2025. https://www.news.com.au/technology/gadgets/sad-warning-to-all-aussies-after-21yos-death/news-story/a9f65f260c1db17f7968fda965ece849 (accessed Mar. 26, 2025).
[4] T. Symonds, "National Grid boss says Heathrow had 'enough power' after substation fire," Mar. 24, 2025. Available: https://www.bbc.com/news/articles/cdjy4m0n1ex0

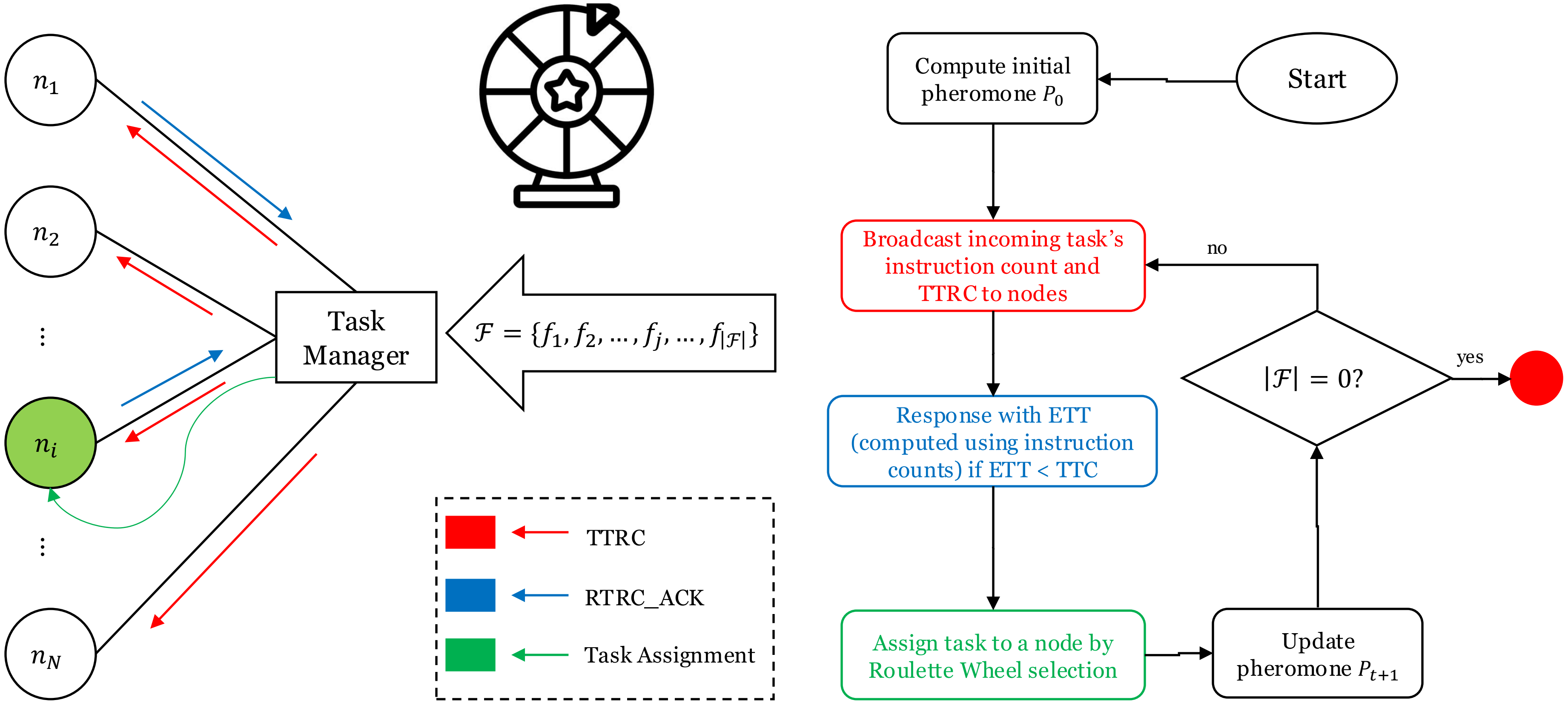
EBS-RTTB

- 1. Integrating an energy balancing mechanism into the task assignment process to increase the lifespan of the IoT system.
- 2. Maintains the efficacy of the real-time task distribution system.
- 3. Preventing single-node energy depletion by adding state-of-charge (SoC) measurements into the decision-making process.
- 4. Conduct a simulation experiments to validate the improvement of system durability while maintaining efficiency.

EBS-RTTB ARCHITECTURE

- Mesh topology
- 3-way handshake
- Decentralized (task manager can be any node in $\{n_1, \ldots, n_N\}$)
- Roulette Wheel selection (ETT – estimated completion time of task)

$$p_{select,i,j} = \frac{(P_{i,t(j)})^{\alpha}(ETT_{i,j})^{-\beta}(SoC_{i,t(j)})^{\gamma}}{\sum_{i=1}^{N}(P_{i,t(j)})^{\alpha}(ETT_{i,j})^{-\beta}(SoC_{i,t(j)})^{\gamma}}$$



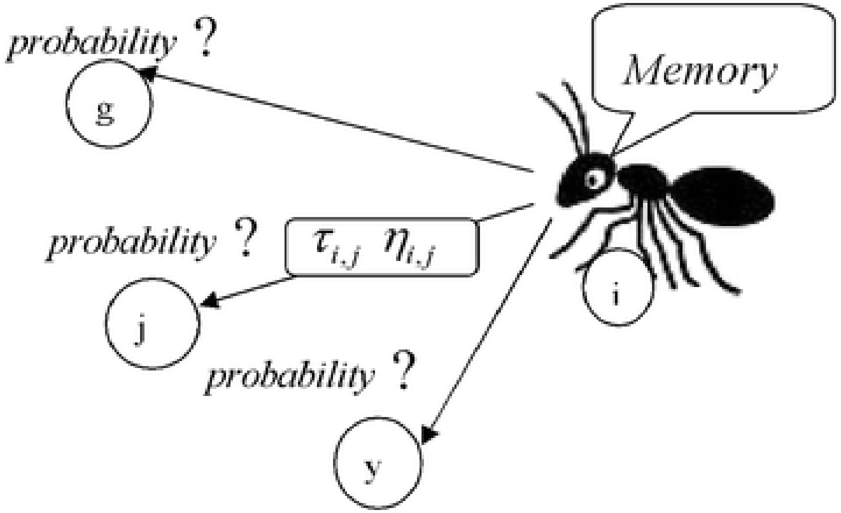
PHEROMONE COMPUTATION

- Inspired by Ant-colony Optimization (ACO)
- Model the attractive level of an IoT node to a Task:

$$P_0 = \frac{K_\alpha \times PC}{T_{benchmark}}$$

Nodes with more process cores (PC) and less execution time on benchmark programs ($T_{benchmark}$) are more attractive because they have more computational power.

K_α captures other factors that will affect the execution time.



[5]

- Integrate energy balancing:

$$P_0' = P_0 \times SoC_0$$

If a node has a low battery percentage when adding to the network (SoC_0), then it becomes less attractive.

[5] M. A. El-Hawary and A. A. El-Hawary, "A review on the applications of bio-inspired algorithms to electrical power systems problems," *SpringerPlus*, vol. 5, no. 1, p. 1530, Sep. 2016. [Online]. Available: https://doi.org/10.1186/s40064-016-2040-9

PHEROMONE COMPUTATION (CONT'D)

- Pheromone update after completing a task:

$$P'_{t+1} = \frac{P'_0}{\omega_1 \max(R_a - R_e, 0) + \omega_2(1 - SoC(t+1)) + 1}$$

If the actual completion time is more than expected ($R_a - R_e > 0$), this node will be less attractive.

If the battery is low (large $1 - SoC(t+1)$), this node will be less attractive.

If $\omega_2 = 0$, then it is pi-RTTB. EBS-RTTB use $\omega_2 = 50$.

- Jeong [6] developed an SoC Indicator chip to extract SoC with minimum energy cost. Coulomb Counting is used for simulation:

$$SoC(t) = SoC(t_0) - \int_{t_0}^{t} \frac{\eta(\tau) I(\tau)}{C} \mathrm{d}\tau$$

A linear version: $SoC(t) = \max(SoC_0 - At, 0)$ $A = \frac{\eta I}{C}$

[6] D. Jeong, K. Y. Lee, S. Bang, D. Sylvester, and D. Blaauw, "A 42 nJ/Conversion On-Demand SoC Indication Circuit for Small IoT Batteries," in Proceedings of the IEEE International Solid-State Circuits Conference (ISSCC), pp. 1–3, 2015.

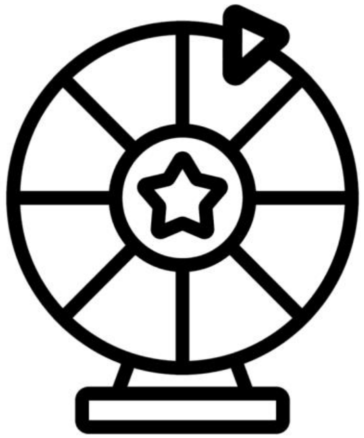
ROULETTE WHEEL SELECTION

- Probability of a node i being selected:

$$p_{select,i,j} = \frac{(P_{i,t(j)})^{\alpha}(ETT_{i,j})^{-\beta}(SoC_{i,t(j)})^{\gamma}}{\sum_{i=1}^{N}(P_{i,t(j)})^{\alpha}(ETT_{i,j})^{-\beta}(SoC_{i,t(j)})^{\gamma}}$$

Nodes with faster expected runtime for task j ($ETT_{i,j}^{-1}$), more battery at time when task j arrives ($SoC_{i,t(j)}$), and more attractive ($P_{i,t(j)}$) are more likely to get selected for executing task j.

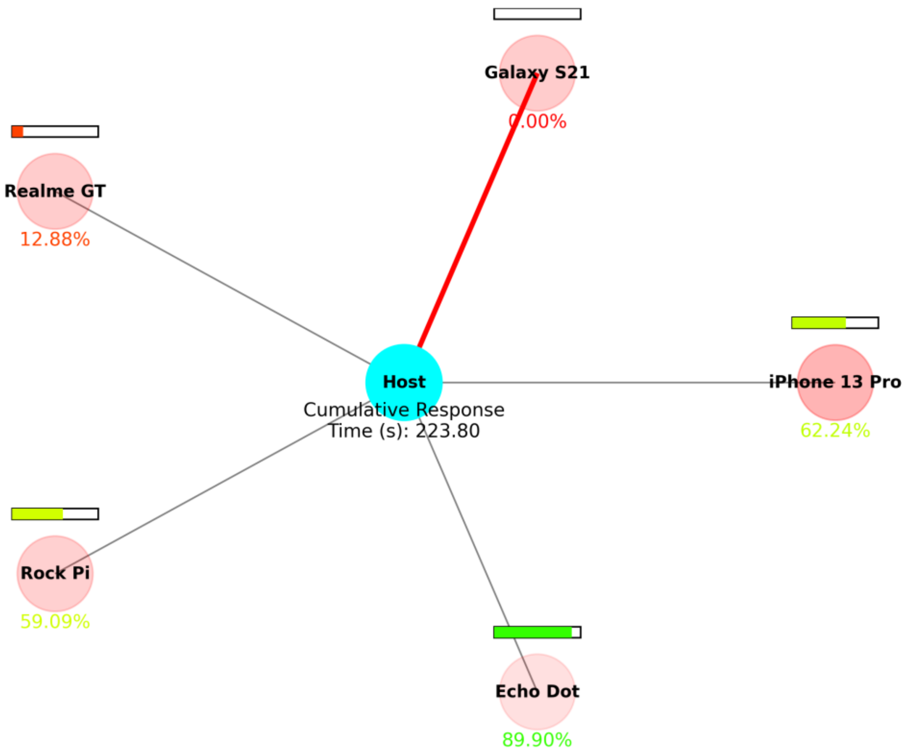
If $\gamma = 0$, then it is pi-RTTB. EBS-RTTB use $\gamma = 1$.



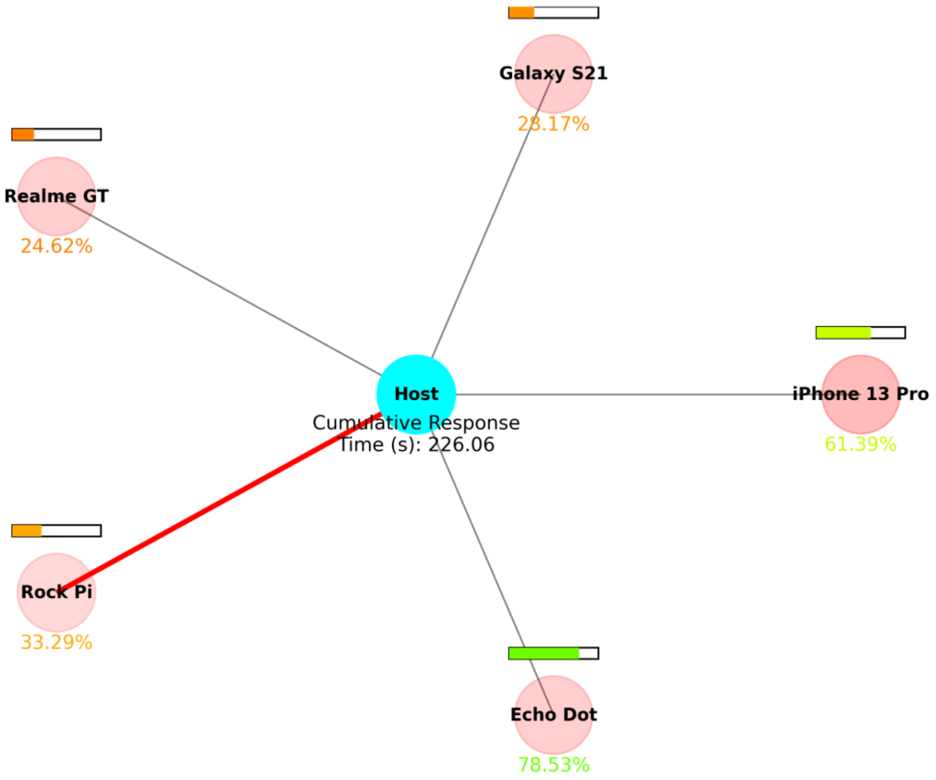
- For simulation, ETT is computed using linear regression based on executing a dummy function with known instruction counts:

$$ETT = \frac{T_{avg,f_{dummy}} \times IC + e}{PC}$$

DEMO OF SIMULATION (PYTHON)

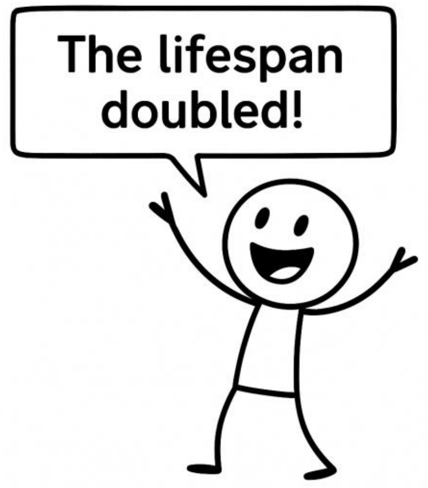


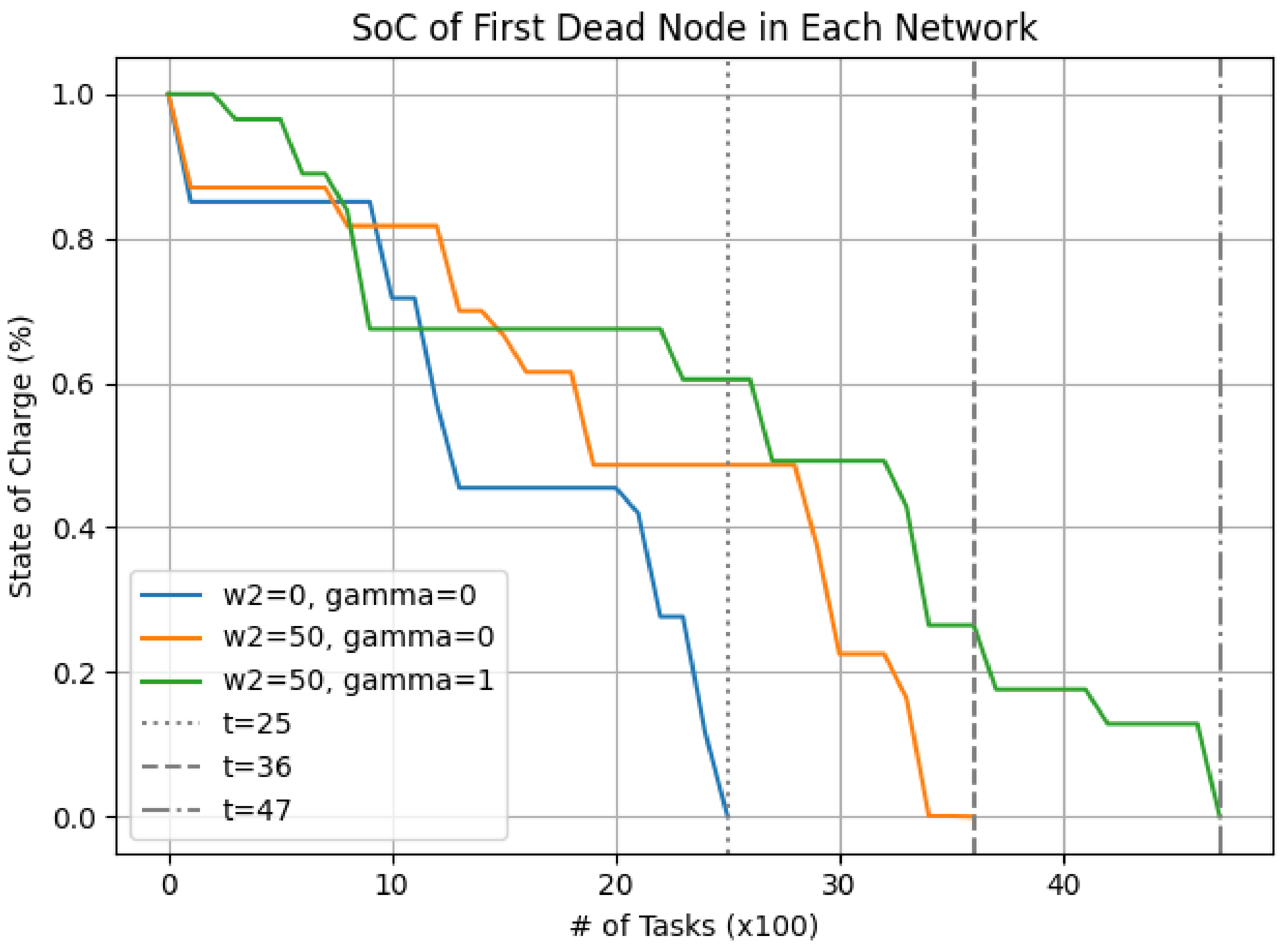
Pi-RTTB ($\omega_2 = 0, \gamma = 0$);
30 tasks;
CRT = 223.8s



EBS-RTTB ($\omega_2 = 50, \gamma = 1$);
30 tasks;
CRT = 226.06s

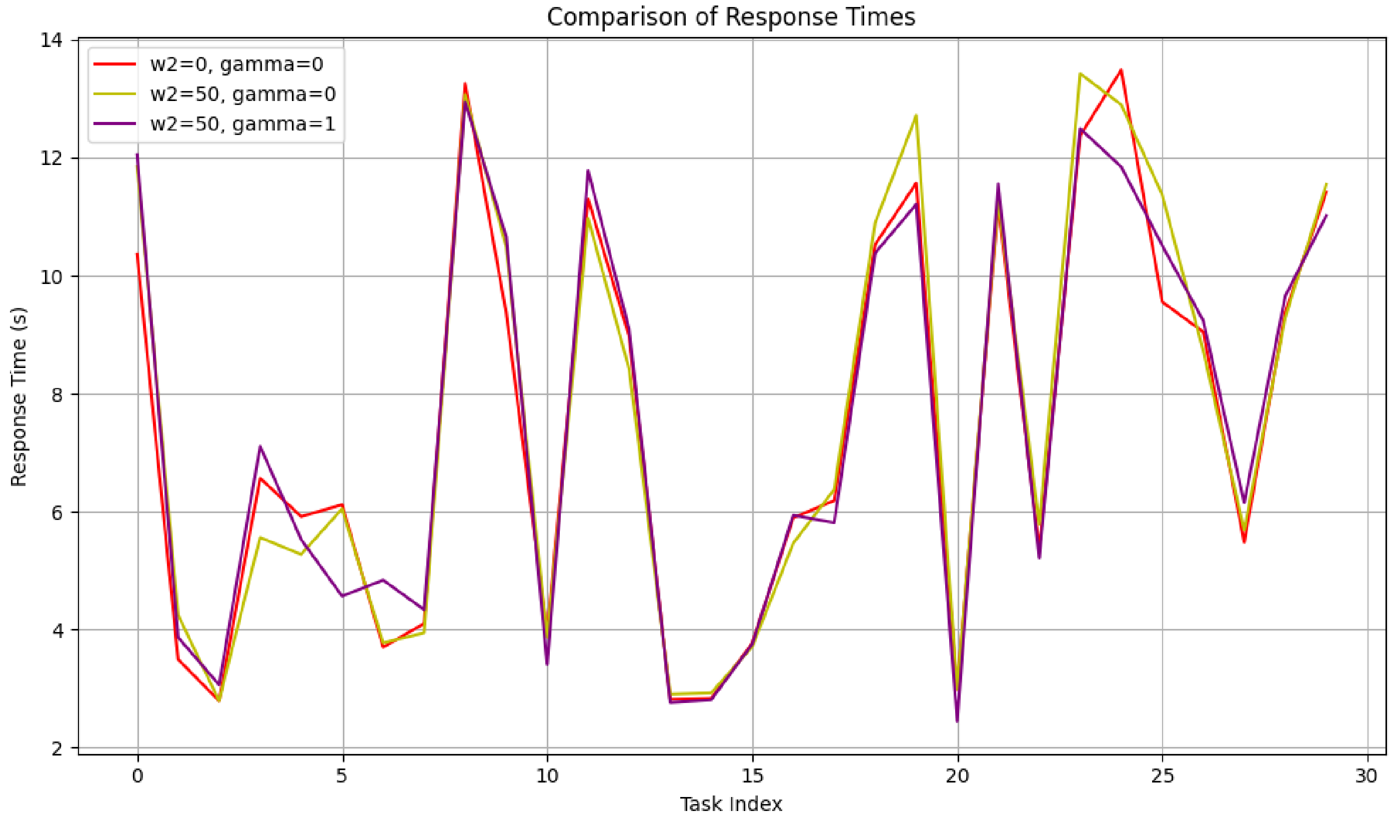
RESULTS: SYSTEM LIFESPAN

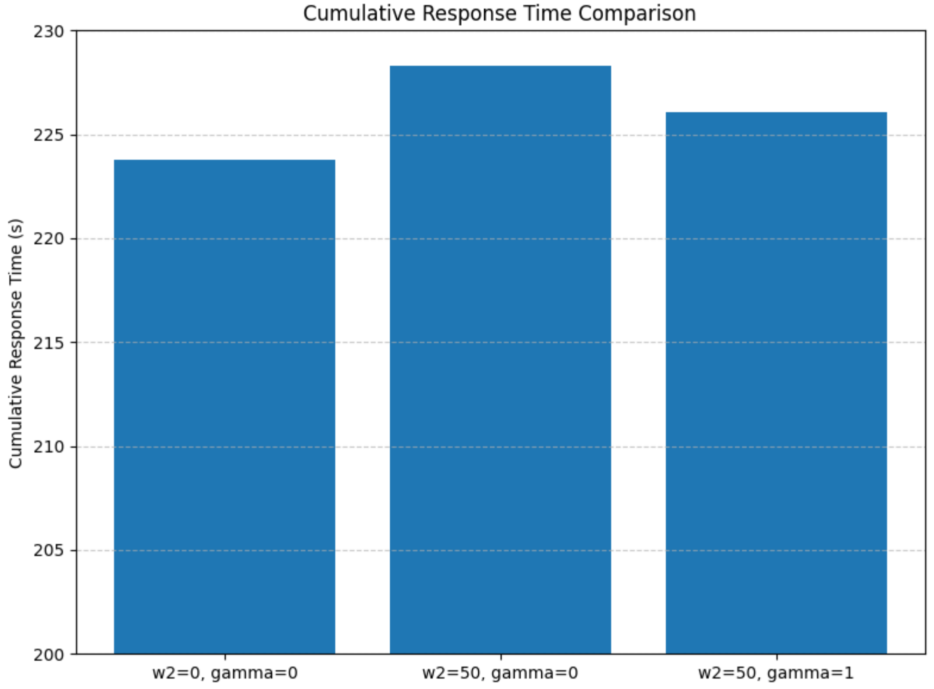




The lifespan of the system is significantly improved!!!!

RESULTS: RESPONSE TIME





POTENTIAL IMPROVEMENTS

- This is just a simulation experiment, physical implementation required for real-world justification.
  - Consider the energy cost for computing SoC (with the use of Jeong et al [6]'s chip).
  - Propagation delay not included in simulation of response time.
  - Replace dummy tasks with real-world tasks.
- Adapt multi-hop architectures (currently only support MESH).
- Require a matured ETT computation method.

[6] D. Jeong, K. Y. Lee, S. Bang, D. Sylvester, and D. Blaauw, "A 42 nJ/Conversion On-Demand SoC Indication Circuit for Small IoT Batteries," in Proceedings of the IEEE International Solid-State Circuits Conference (ISSCC), pp. 1–3, 2015.

QUESTIONS

- Q1: What will a node do after receiving TTRC (task assignment request) from Task Manager?
- Q2: When will the pheromone value goes down (node become less attractive)?
- Q3: [True/False?] If the battery level of device A is higher than B's when the task manager is assigning a task, we can determine that the probability of assigning this task to device A is greater than of B?

Thank You!