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Lifespan and energy-oriented load balancing algorithms across sets of nodes in Green Edge Computing

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Outline

1. Introduction
2. Models and Metrics
3. Proposed Algorithms
4. Experimental Results
5. Conclusions

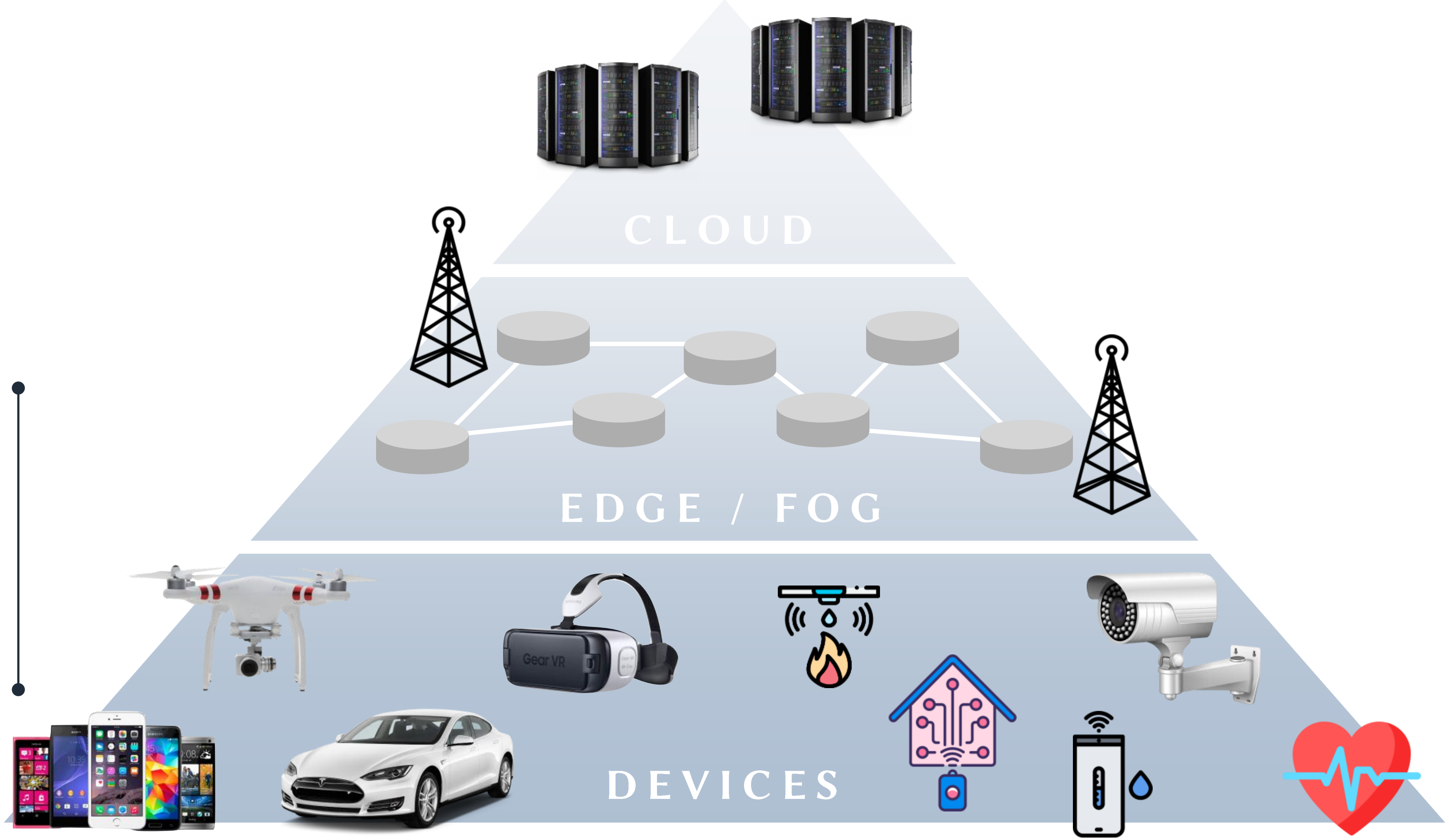
1 Introduction

Context

Fog and Edge Computing

<10ms*

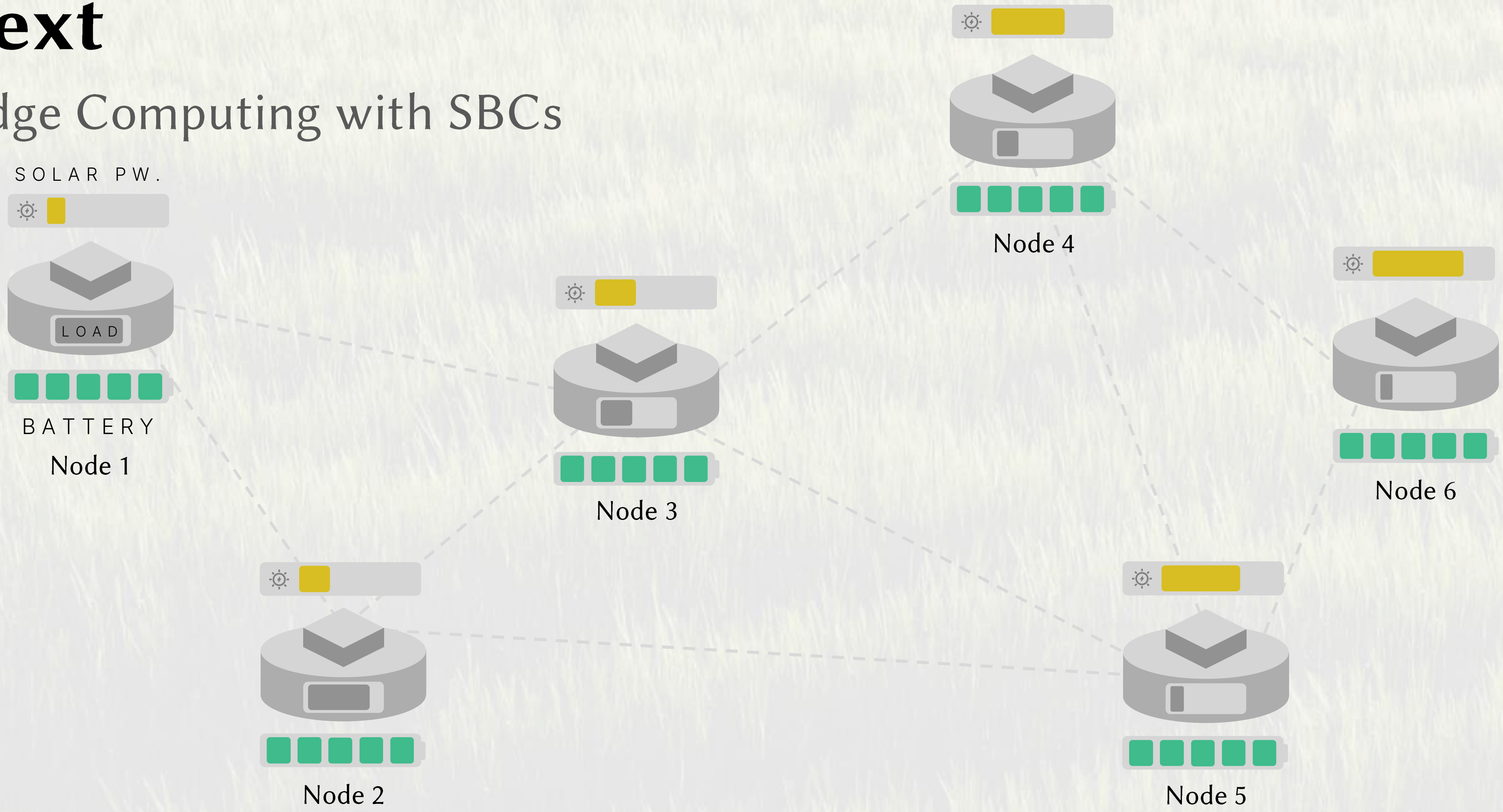
Average
round-trip-time
fog/edge-to-device



*https://geekflare.com/google-cloud-latency/

Context

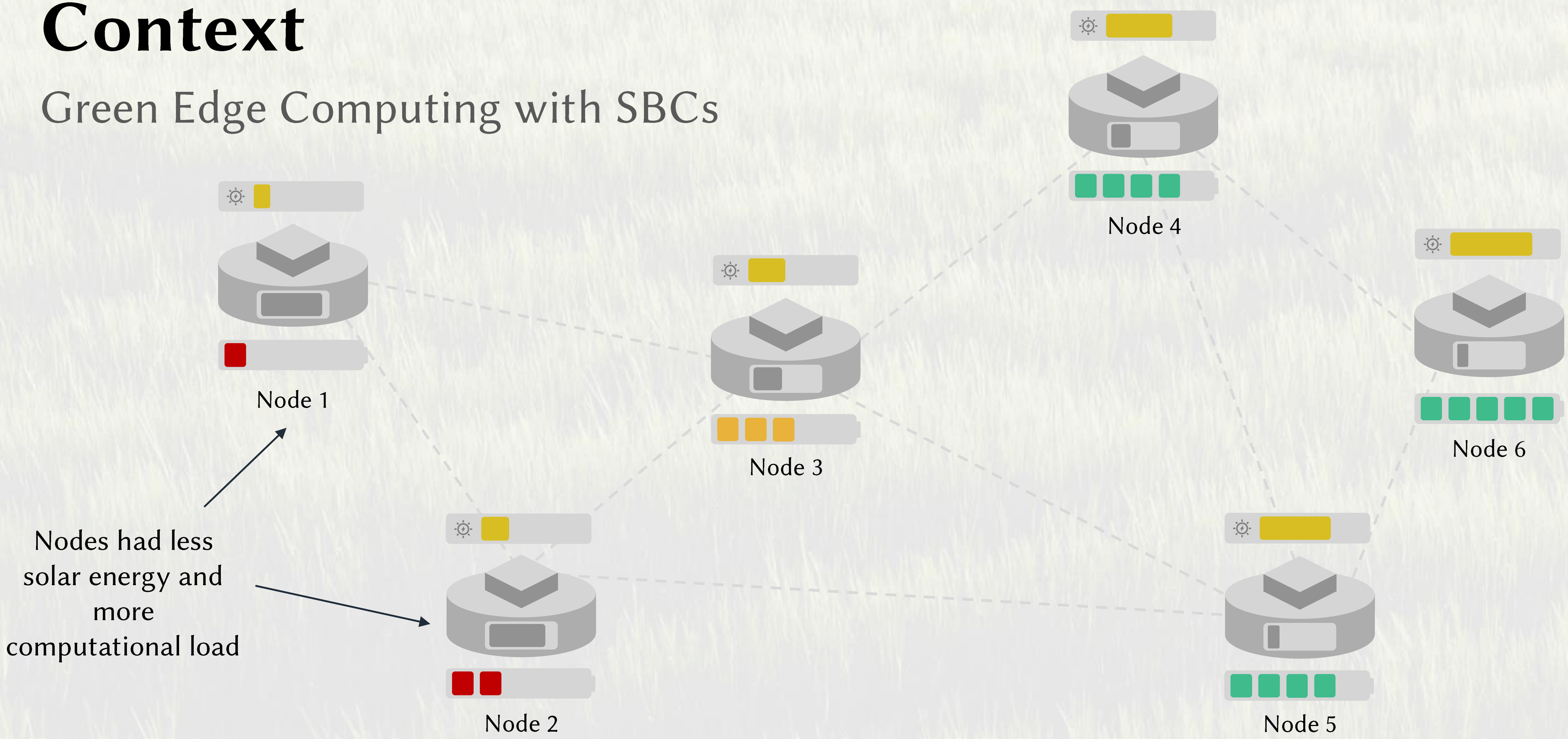
Green Edge Computing with SBCs



We suppose that each node **processes** tasks and can **cooperate** with each other
Nodes can act both as schedulers () and workers (), we assume they have a **battery** a **solar recharge**

Context

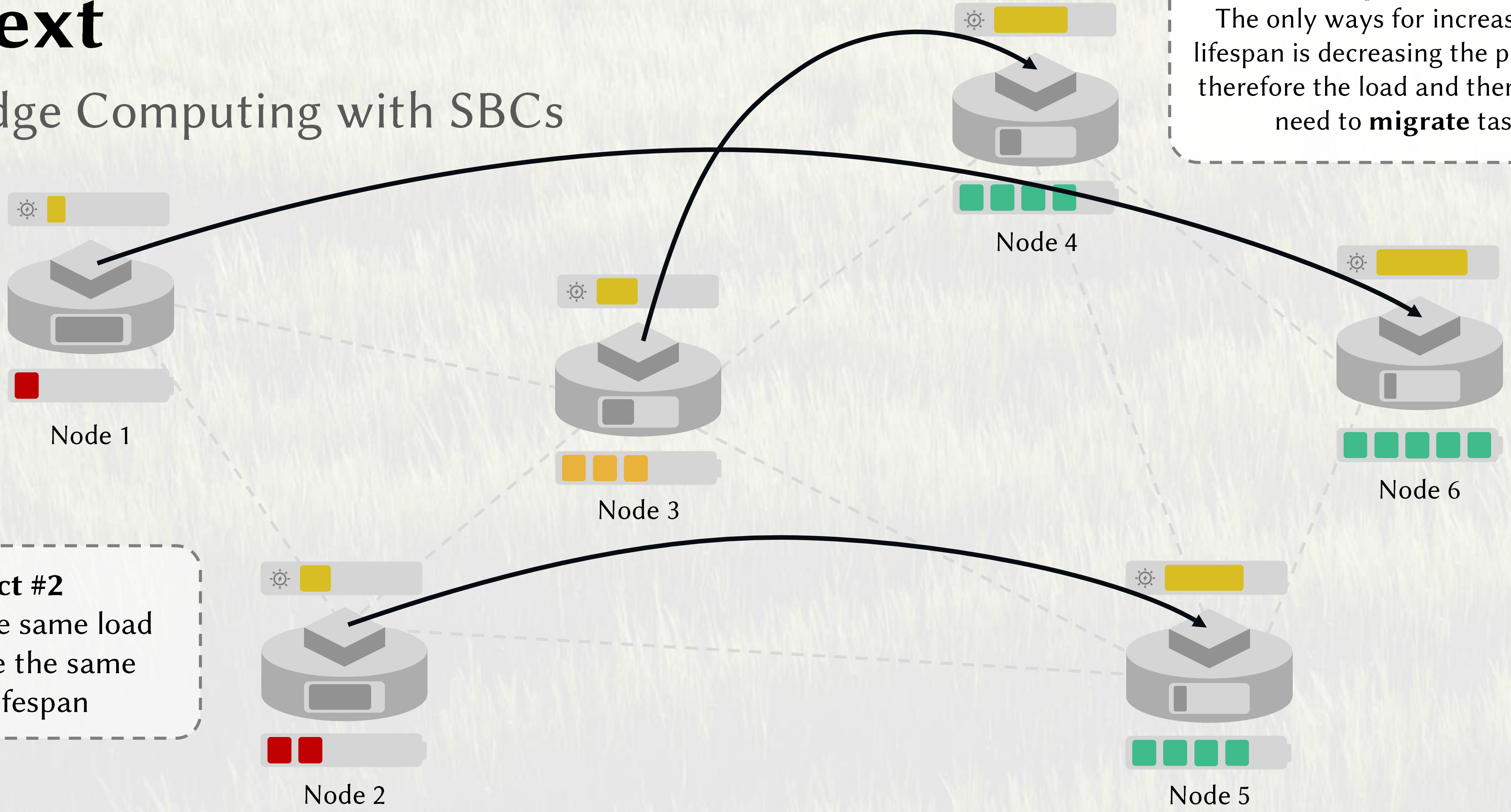
Green Edge Computing with SBCs



Different computational loads and solar patterns make the nodes **discharge** differently

Context

Green Edge Computing with SBCs



Key Fact #1
The only ways for increasing the lifespan is decreasing the power and therefore the load and therefore we need to **migrate** tasks

Key Fact #2
Nodes with the same load may not have the same residual lifespan

If we want to maximize the lifespan of the service an **energy-oriented** load **balancing** strategy is needed

Challenge

The main challenge of the work is finding a **load balancing algorithm** which is able to **maximize the lifespan across all the nodes**, considering that:

- the algorithm must be **fully distributed**, no central node or entity;
- the algorithm should be **adaptive**;
- nodes can potentially be heterogeneous and they can be arranged in different **topologies**;
- nodes' battery recharge **differently** according to solar activity in the area in which it is placed;

In this work, we **three different algorithms** and **experimental results** which shows the performance of the proposed methods in a cluster of 11 Raspberry Pi 4.

Related Work

- Adil et al. in "*An efficient load balancing scheme of energy gauge nodes to maximize the lifespan of constraint oriented networks*" (2020) focus on Wireless Sensor Networks (WSNs) which are networks characterized by nodes that are usually powered by **batteries** and therefore they must efficiently communicate over the network to maximize the lifespan;
- Sampayo et al. in "*Elobaps: Towards energy load balancing with wake-up radios for IoT*" (2019) follow a similar approach which explores the usage of **wake-up radio** which has ultra-low power consumption.

The authors of these works are not specifically targeting Edge and Fog Computing, in which the **nodes are** not only **sensors** but can actively execute the whole or part of the computation, moreover, we also consider the **green energy sources**.

- Lyu et al. in "Selective offloading in mobile edge computing for the greeninternet of things" (2018) propose an architecture that integrates the Cloud, the MEC layer and the IoT for a selective **offloading** algorithm which minimize the energy consumption of devices. However, the approach is tested only in **simulation** and it is not considering the energy contribution that is harvested from the **solar panels**

Our work provide three **fully decentralized algorithms** targeting Green Edge Computing nodes powered by batteries, that perform an **online scheduling** also addressing the solar recharge and we provide results from an **experimental setting**.

2 Model and Metrics

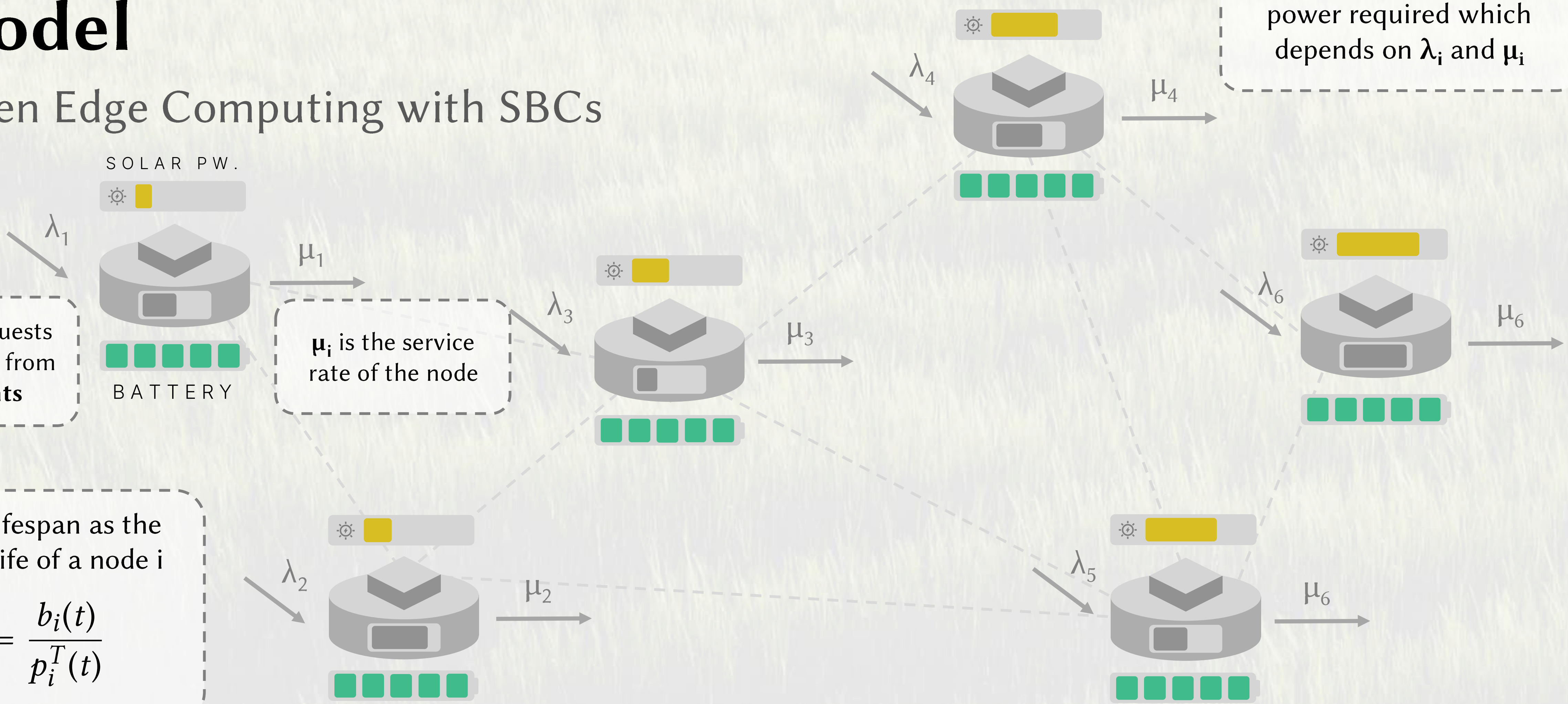
Model

Green Edge Computing with SBCs

We define $p_i^T(t)$ as the power required which depends on λ_i and μ_i

λ_i is the requests rate coming from the **clients**

μ_i is the service rate of the node



We the lifespan as the residual life of a node i

$$l_i(t) = \frac{b_i(t)}{p_i^T(t)}$$

We suppose that each node $\boldsymbol{i}$ receives a flow of tasks λ_i tasks/s to be processed and it is able to process μ_i tasks/s and consumes at time t $\boldsymbol{p_i^T(t)}$ (W), residual lifespan of node i is $l_i(t)$

Metrics

Evaluating the performances of the algorithms

$$\sigma$$

Long-run Variance

The variance of the residual battery energy among all the nodes during the entire experiment

$$d_g$$

Full Discharge Gap Time

The time between the first and the last node that goes down due lack of energy

$$r$$

Drop Rate

Percentage of dropped task that could not be executed

$$d_f$$

First Discharge Time

The lifespan of the first node that goes down due to lack of energy

$$e_i^m(t)$$

Residual Battery wrt min

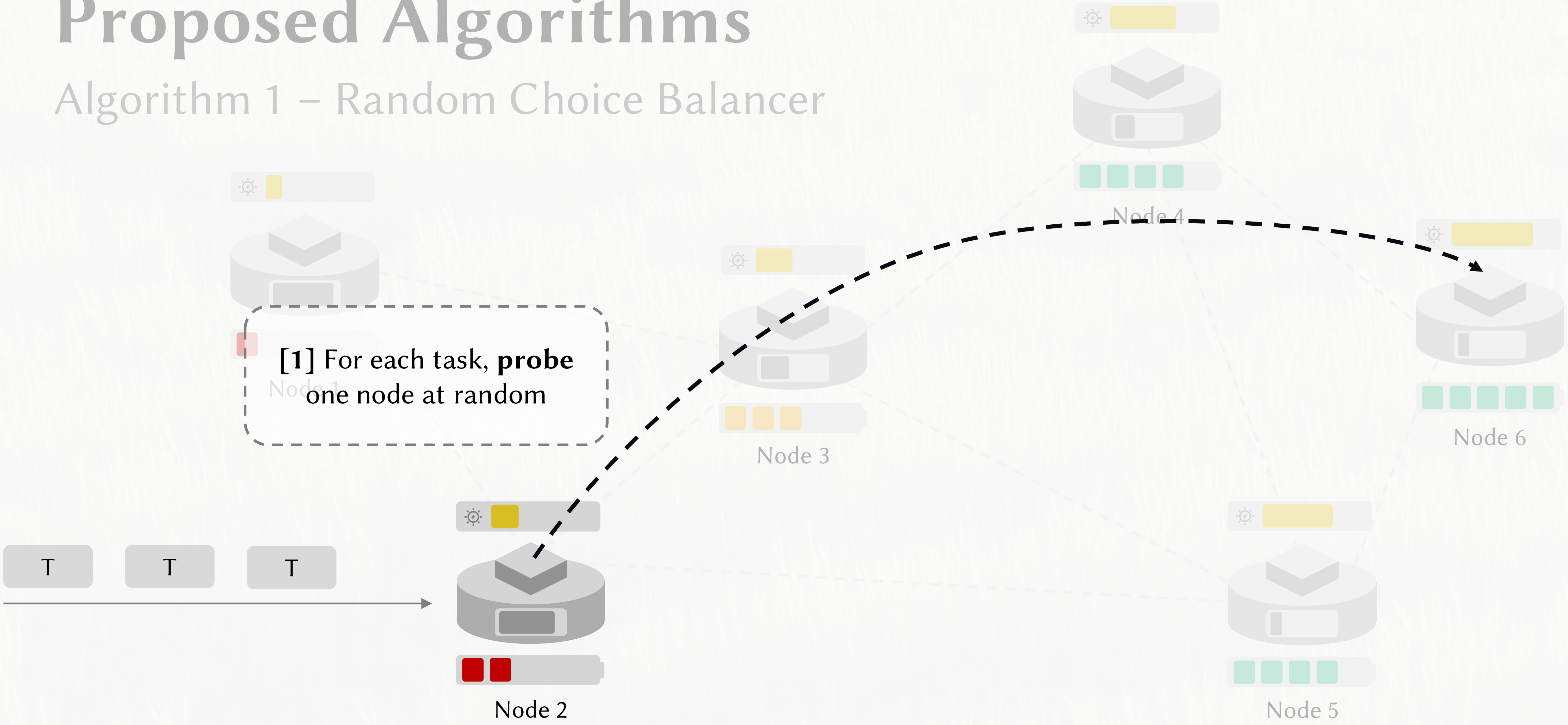
The residual battery energy of node i minus the the minimum residual battery energy among all the nodes

3

Proposed Algorithms

Proposed Algorithms

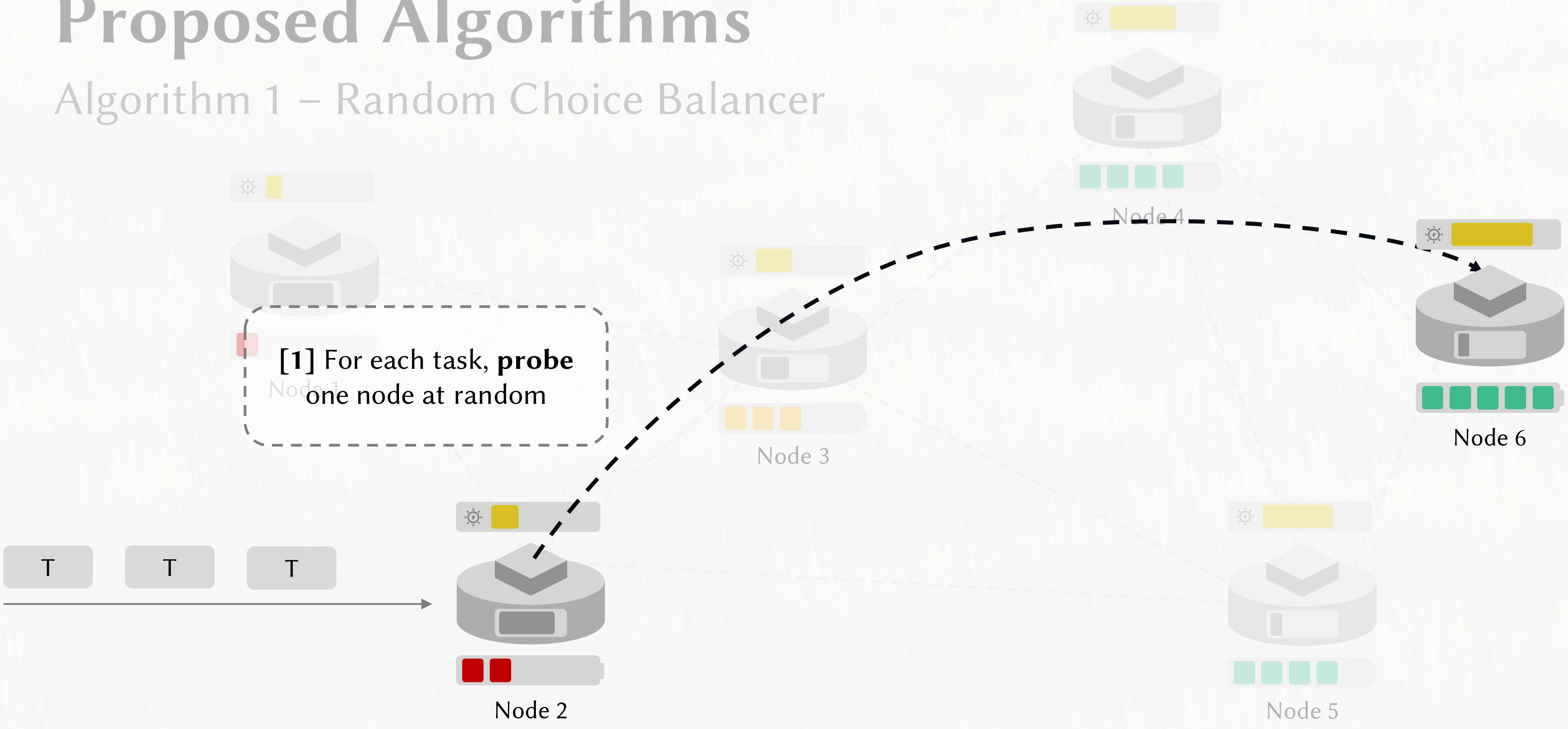
Algorithm 1 – Random Choice Balancer



Different computational loads and solar patterns make the nodes **discharge** differently

Proposed Algorithms

Algorithm 1 – Random Choice Balancer



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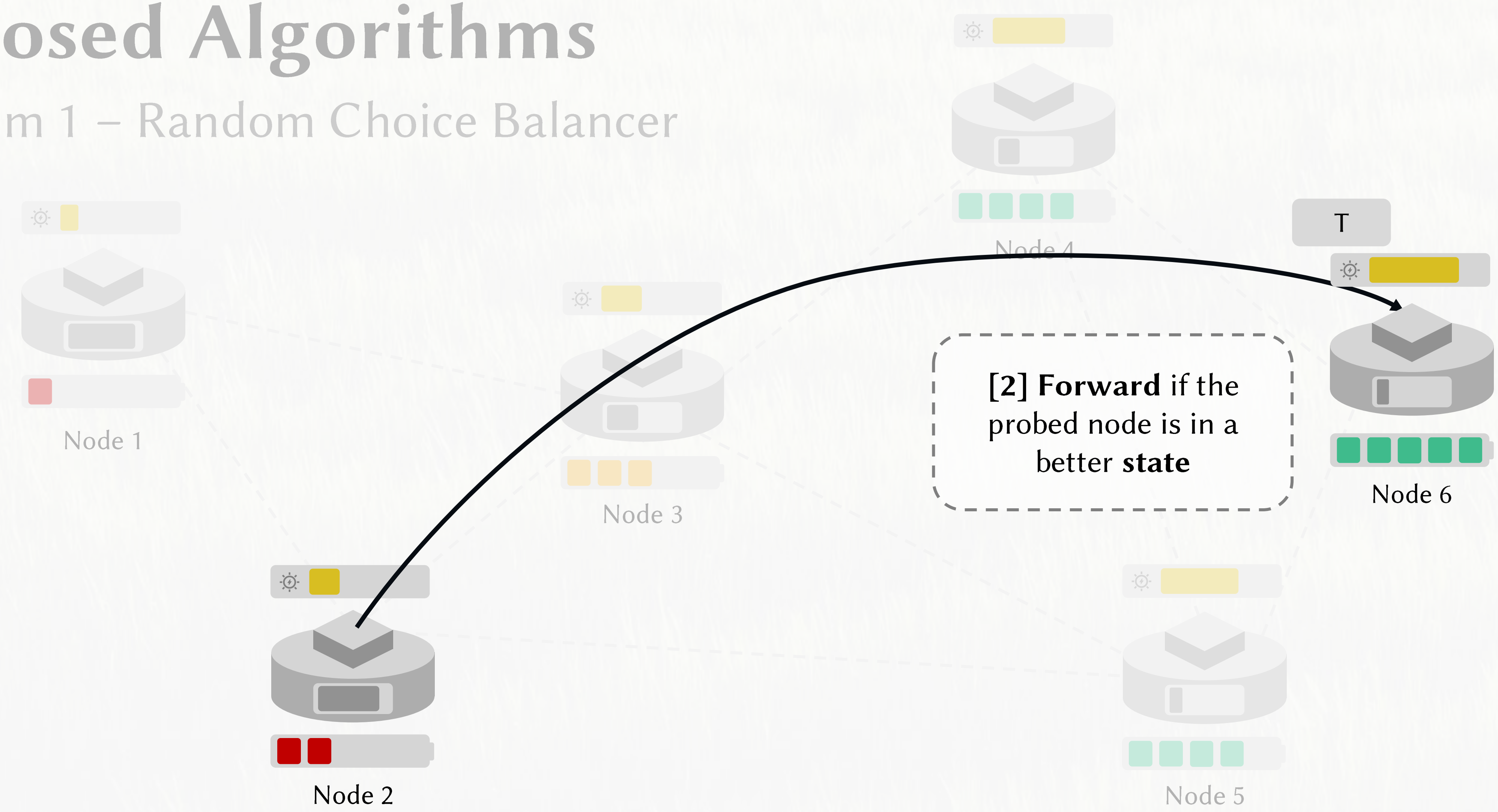
Proposed Algorithms

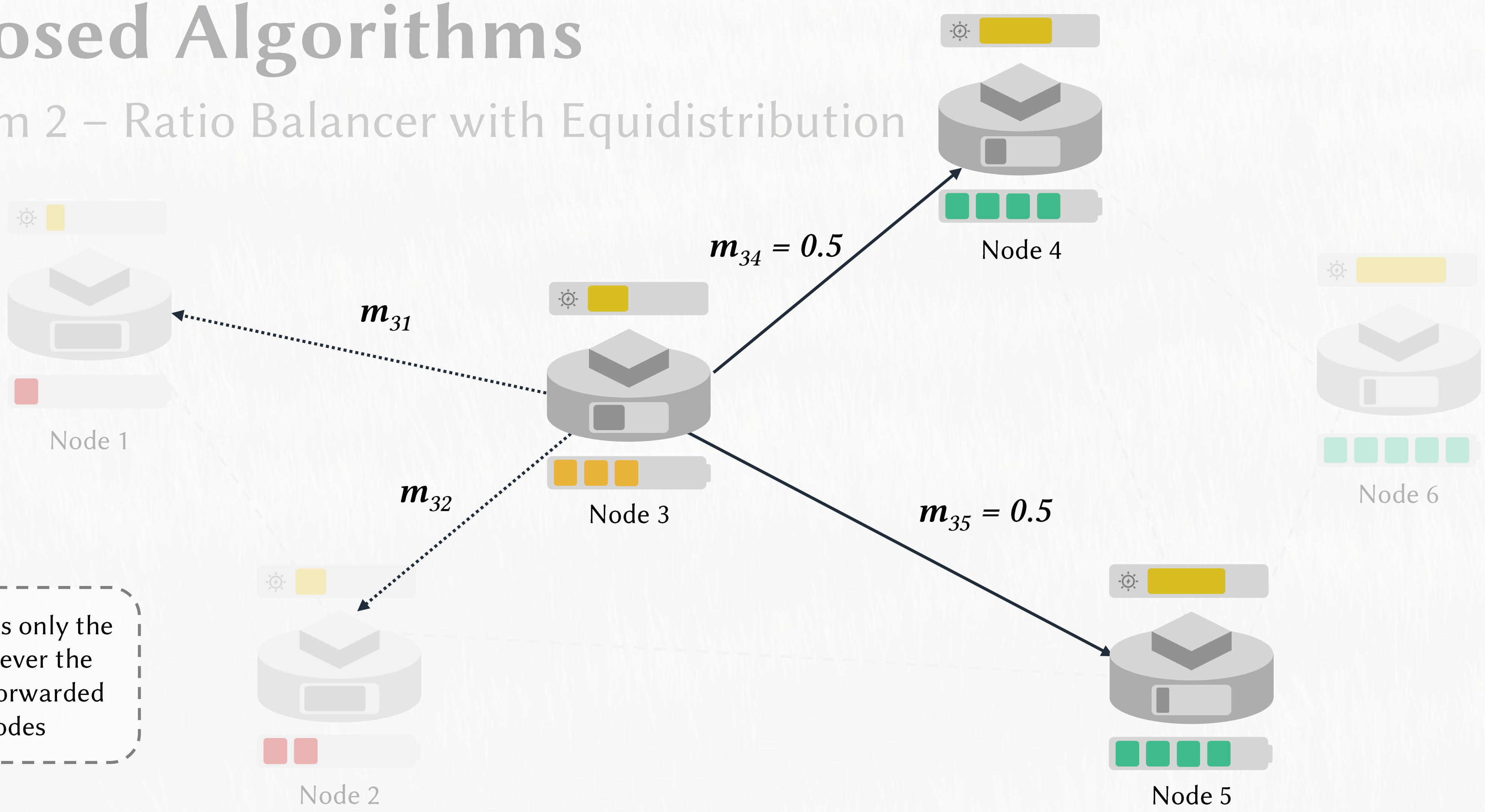
Algorithm 1 – Random Choice Balancer



Different computational loads and solar patterns make the nodes **discharge** differently

Proposed Algorithms

Algorithm 2 – Ratio Balancer with Equidistribution

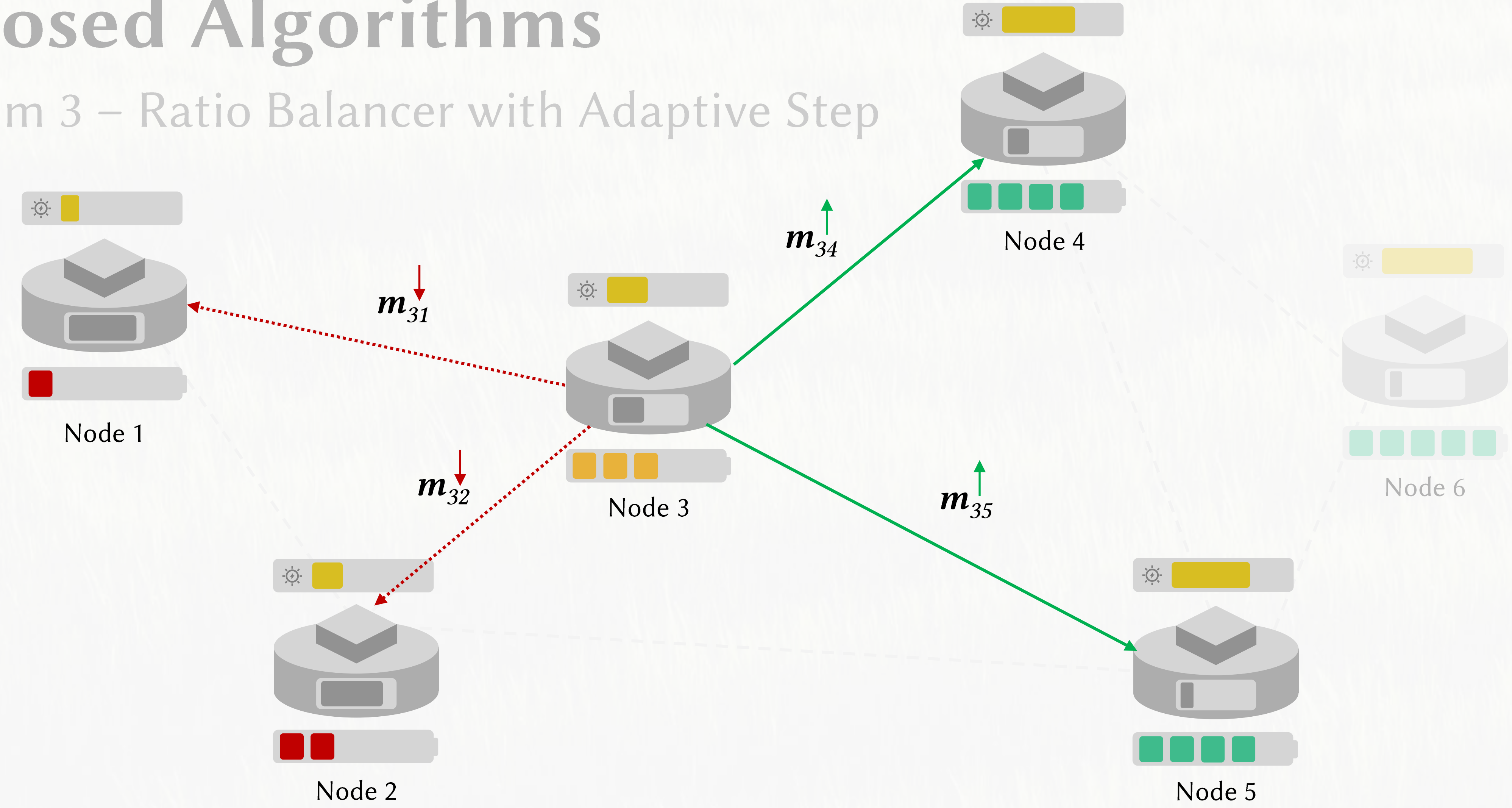


A node i forwards only the traffic λ_i and never the traffic already forwarded by other nodes

In the ratio based balancers we tune the **migration ratios** following a specific policy
In this case, we equidistribute **all the load** to nodes which are in a **better state**, for Node 3, Nodes 4 and 5

Proposed Algorithms

Algorithm 3 – Ratio Balancer with Adaptive Step



In this case, we progressively increase of a step size α the migration ratios to nodes which are in a **better state**, for Node 3, again Nodes 4 and 5 and decrease the ones towards a worse state until a **balanced state**

4 Experimental Results

Experimental Results

The proposed algorithms has been tested in two different experiments in which we used the P2PFaaS framework[1] for implementing the load balancing algorithms and we **simulated** the **energy** model for every node. The experiments are:

1. a **discharge only** test, in which we consider no recharge by the energy harvested by the solar panels;
2. a **discharge and recharge** test, in which we added the solar panels' energy from real traces.

In both the experiments the algorithms took as a reference **both** the battery **percentage** and the **lifespan** and have been compared to the no-scheduler baseline, so we have a total of 3x2x2+2 = 14 experiments of 4 hours.

1. https://p2p-faas.gitlab.io

Experimental Results

Table 4.1 Comparison of the proposed energy balancing algorithms during discharge until the shutdown of all the nodes with **no recharge** during the experiment

Balancers	Based on	$\sigma \downarrow$	$d_g \downarrow$	$r \downarrow$	$d_f \uparrow$
No Balancing	-	140	00:30:40	**13.2%**	02:14:17
Random	battery	1.47	00:02:02	15.7%	02:20:22
Random	lifespan	0.16	00:00:29	19.5%	02:20:44
Ratio E.	battery	0.25	00:00:44	34%	02:14:52
Ratio E.	lifespan	**0.04**	**00:00:03**	16.5%	**02:27:22**
Ratio A.	battery	2.75	00:01:55	16.5%	02:10:10
Ratio A.	lifespan	4.81	00:00:19	15.3%	02:10:53

Best tradeoff

Table 4.2 Comparison of the proposed energy balancing algorithms during discharge until the shutdown of all the nodes with **simulated recharge** during the experiment following the same curves.

Balancers	Based on	$\sigma \downarrow$	$d_g \downarrow$	$r \downarrow$	$d_f \uparrow$
NoScheduler	-	1.57	01:29:44	**11.6** %	03:21:50
Random	battery	1.03	00:42:14	14.7 %	03:46:01
Random	lifespan	**1.02**	00:39:49	16.2 %	**03:46:38**
Ratio E.	battery	1.08	**00:38:00**	38.6 %	03:22:46
Ratio E.	lifespan	1.15	00:43:14	18.2 %	03:25:36
Ratio A.	battery	1.17	00:51:51	26.3 %	03:18:02
Ratio A.	lifespan	1.06	00:47:12	23.2 %	03:20:23

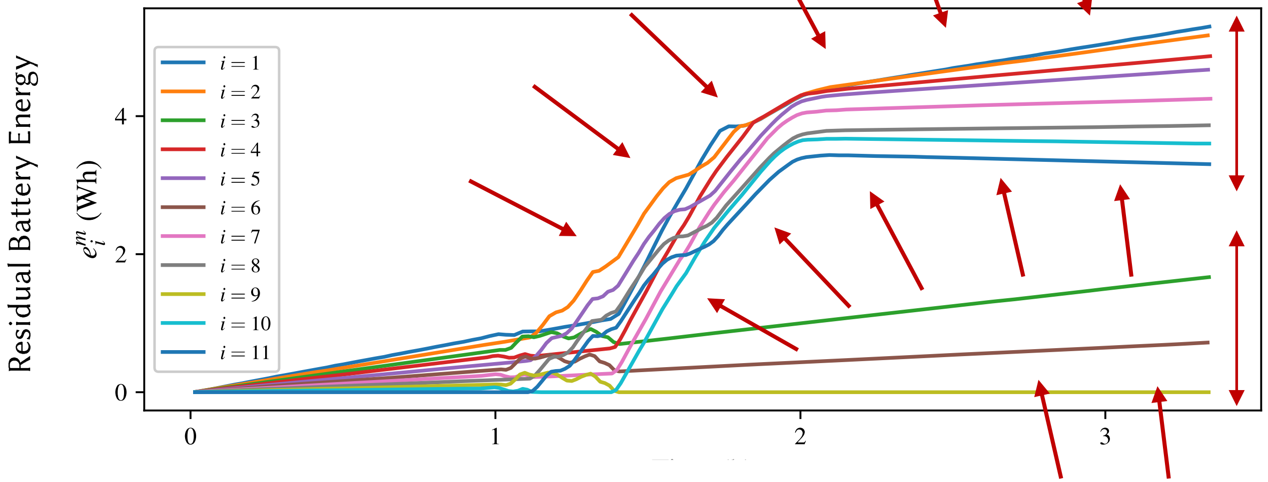
Best tradeoff

Too slow to react to changes

Experimental Results

Discharge with Solar Recharge

High variance (σ) in battery levels



Divergence of residual battery energy

Figure 4.1 Residual battery energy over time with solar recharge and **no balancing algorithm**

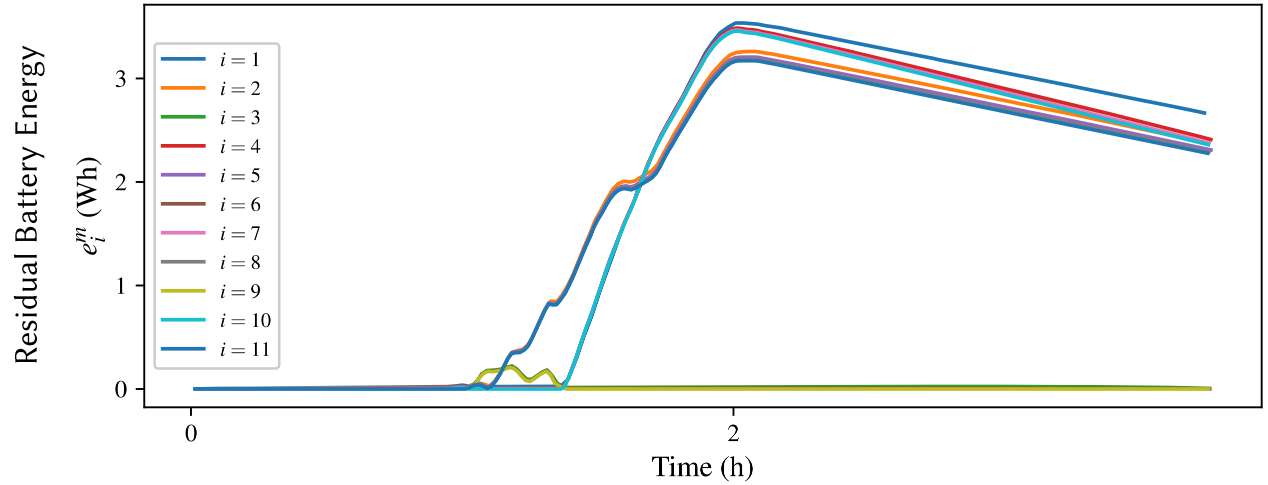


Figure 4.2 Residual battery energy over time with solar recharge and random **balancing algorithm based** on lifespan

5

Conclusions

Conclusions

In this work we proposed:

- the **design** of **three decentralized** algorithms which balance the energy consumption of the nodes by relying on cooperative tasks offloading;
- the **benchmark** of the algorithms in a cluster of **11 Raspberry Pi 4 SBCs** by using the FaaS as task model and the P2PFaaS framework for the implementation;
- the **definition** of a **set of performance metrics** targeting the behavior of the algorithms with respect to service availability, lifespan and lifespan variance;
- the **comparison** of the algorithm both in a **standalone** scenario and in a **solar panel assisted scenario** which solar energy traces from real panels

The results showed that different algorithms a more suitable depending on the particular situations. However, some points need further study:

- design a **mathematical model** which describes the behavior of the node
- find an **optimal solution** to the problem or at least the lower/upper bounds

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talk & presentation

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