

State University of Campinas (UNICAMP)
Campinas, SP – Brasil



Lifetime Maximization With Multiple Battery Levels in Irregularly Distributed Wireless Sensor Networks

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- q Introduction
- q Analysis
- q Validation
- q Experiments
- q Conclusions

Introduction

• **Wireless Sensor Networks**

n **Wide Use**

n **Civilian Applications**

n **Meteorology, Surveillance, Environmental Studies**

n **Military Applications**

n **Surveillance, Battlefield Vigilance**

Introduction

- .. **Wireless Sensor Networks**
 - n Cooperative operation of many *motes*.



Introduction

.. **Wireless Sensor Networks**

- n **Fast evolution of electronics devices was not followed by batteries and other energy sources.**

- n **Computational Problems: Temporary **C****

- n **Processors, Memory, Sensors etc.**

- n **Energy Problems: Constant **D****

- n **Low-capacity Batteries, short network *lifetime* etc.**

Irregular Energy Consumption

n *Energy Hole / Doughnut Effect*

- *Circular Networks*

- **Nodes close to Base Station die faster than others.**



Problem

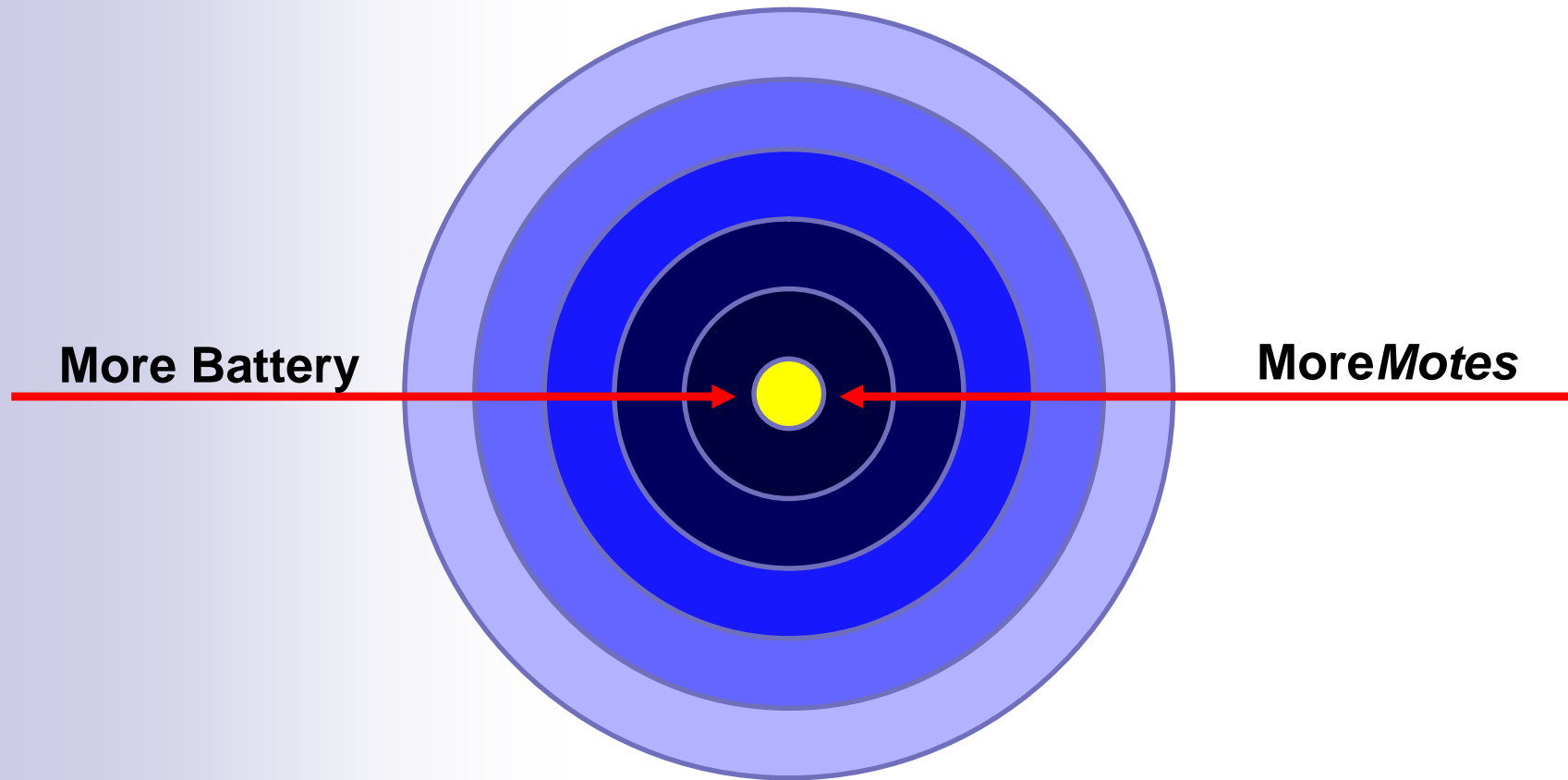
- **High Energy Waste**
 - n **More than 90%**
- **Network lifetime was very short even with large energy budgets**

Problem

- **High Energy Waste**
 - n More than 90%
- **Network lifetime was very short even with large energy budgets**

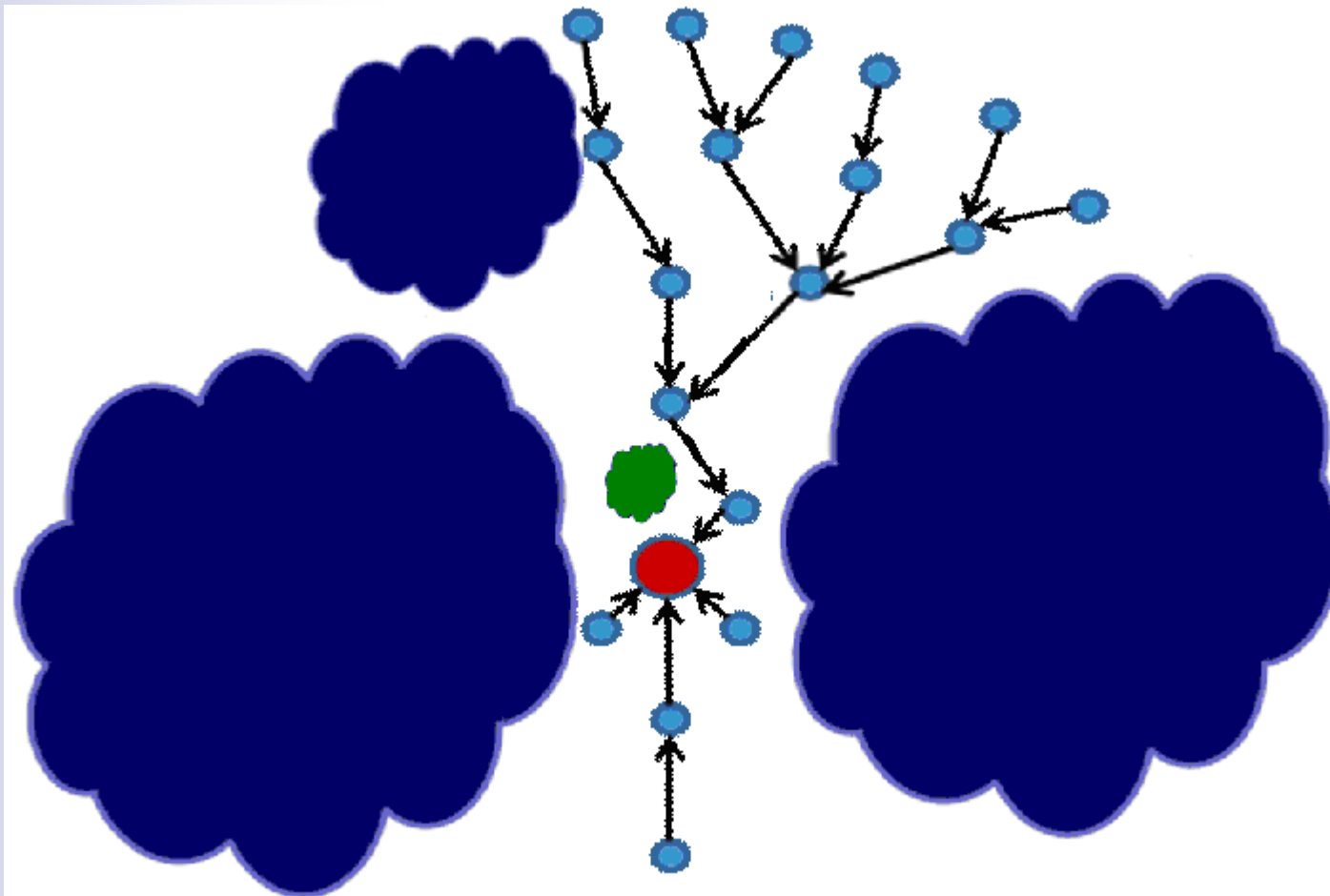
***Wireless Sensor
Networks Inherent
Problems***

Available Strategies

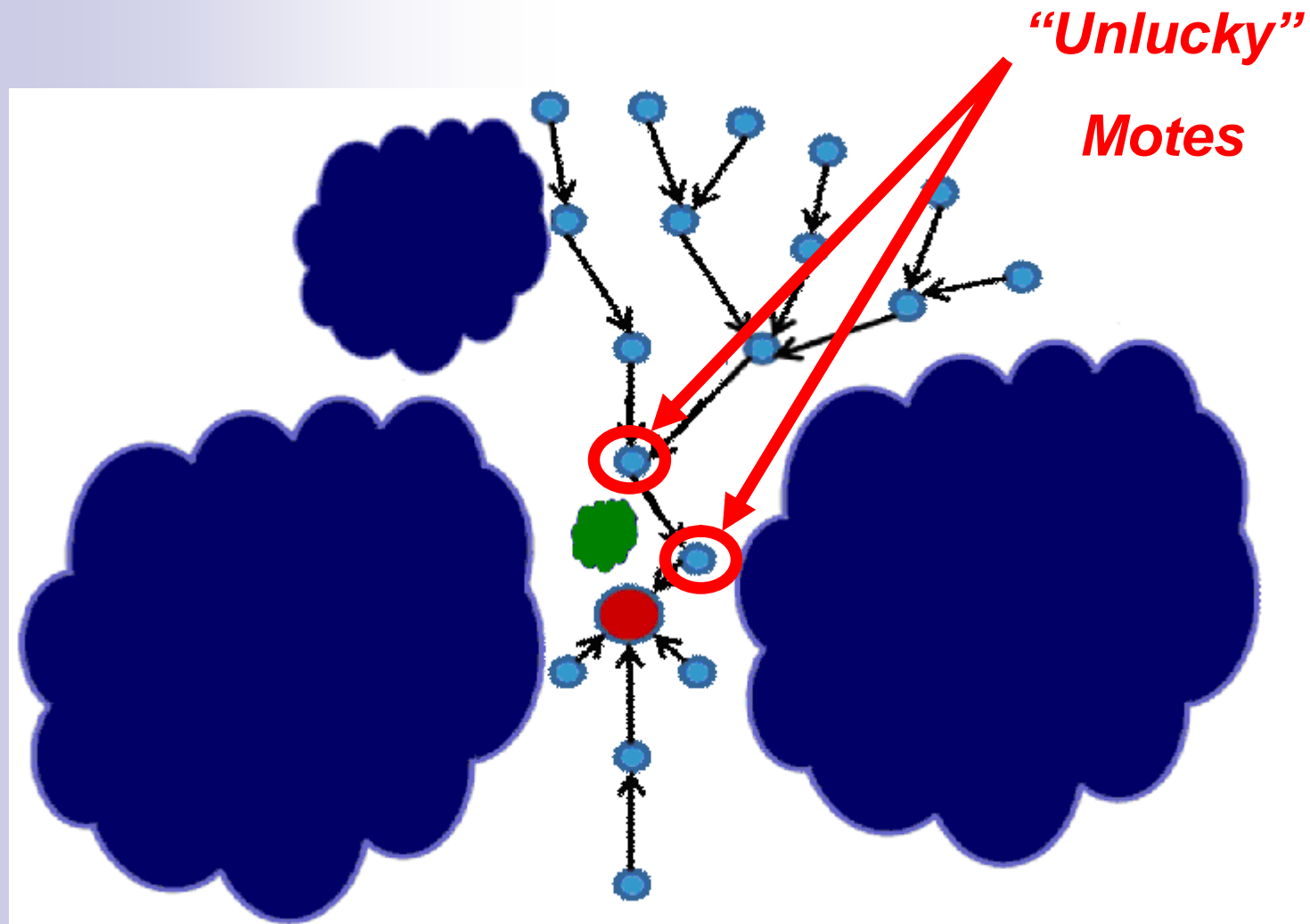


Real Networks

Obstacles forbids a perfect physical organization



Real Networks



Proposal

- .. **Estimate each the consumption of each mote**
 - n **Assign different batteries according to how much energy a mote needs**
 - n **Reduce energy waste**
 - n **Increase *Network Lifetime***

Estimating Energy Consumption on Irregularly Distributed WSN

- **Based on *Time-Driven Networks***
 - ***Defined Network Cycles***
 - ***Repetitive Tasks***
 - ***Predictive Actions***

Estimating Energy Consumption on Irregularly Distributed WSN

- Inclusion of many energy related actions on the energy consumption model
 - *Sent Messages*
 - *Received Messages*
 - *Overheard messages*
 - *Other tasks*
 - *Sensors Reading, Message Rerouting etc.*

Estimating Energy Consumption on Irregularly Distributed WSN

$$Ql_{msg_x} = P_{orl_x} \times f_m$$

Ql_{msg} Quantity of generated-message flows sent through a link.

P_{orl} Portion of message flows that will be routed through a link.

f Generation frequency of new messages.

Estimating Energy Consumption on Irregularly Distributed WSN

$$Ql_{Rrmsg_x} = P_{orl_x} \times F_{Rx_m}$$

- Ql_{Rrmsg} Quantity of rerouted-message flows forwarded through a link.
- P_{orl} Portion of message flows that will be routed through a link.
- F_{Rx} Quantity of received message flows.

Estimating Energy Consumption on Irregularly Distributed WSN

$$B_{abs}_m = M_{Rr}_m + f_m$$

B_{abs} Absolute burden of a mote.

M_{Rr} Number of messages **rerouted** by a mote.

f Generation frequency of new messages.

Estimating Energy Consumption on Irregularly Distributed WSN

$$M_{Rx_m} = \sum_{i=1}^w B_{abs_i} \quad , \text{ where } B_{abs_m} = 0 \quad \forall i \notin N_m$$

M_{Rx} Number of messages **received** by a mote.

B_{abs} Absolute burden of a mote.

N_m Set containing all neighbors of mote m .

Mapa de Fluxos de Mensagens

$$Ec_m = f_m (E_{sens_m}) + B_{abs_m} (E_{Tx_m}) + M_{Rx_m} (E_{Rx_m})$$

E_c Energy consumption of a mote.

E_{sens} Energy required to a mote read all its sensors.

E_{Tx} Energy required to transmit a message.

E_{Rx} Energy required to receive a message.

Energy Assign

- **Planned Energy Assignment**
 - *Each mote/sector can receive an appropriated energy amount*
 - *Energy consumption of each mote is know*
 - *Network lifetime increment*
 - *Less energy waste*

Validation

Simulations

The screenshot displays the 'Wireless Sensor Network Simulator - [wsn01.wsn*]' interface. It is divided into several panels:

- Simulator Control:** A table showing simulation parameters and a 'Standard Logger' window below it.
- Simulator Board:** A central panel with a network diagram and various configuration options.

Simulator Control Panel:

Simulation Time Limit:	00:00:00.000
Active Time Limit:	00y00m00d00:00:00.000
Active Time Pause:	00y00m00d00:00:00.000
Simulation Random Seed:	0
Start Time:	05-Nov-2010 10:26:01
Finish Time:	NOT FINISHED
State:	RUNNING
Simulation Time	Active Time
00:00:05.124	00:02:10.623

Standard Logger:

```
[102][00:02:10.517][Medium] → EOT[35]@00:02:02:10.517
[103][00:02:10.517][Medium] → SOT[36]@00:02:02:10.517
[104][00:02:10.518][Medium] → EOT[36]@00:02:02:10.518
[105][00:02:10.518][Medium] → EOT[36]@00:02:02:10.518
[106][00:02:10.622][Medium] → SOT[37]@00:02:02:10.622
[107][00:02:10.622][Medium] → SOT[38]@00:02:02:10.622
[108][00:02:10.622][Medium] → EOT[37]@00:02:02:10.622
[109][00:02:10.623][Medium] → EOT[38]@00:02:02:10.623
[110][00:02:10.623][Medium] → EOT[38]@00:02:02:10.623
```

Simulator Board Panel:

- Select & Add Elements:** Select, Obstacle, Generic Base Station, Generic Sensor Node.
- Selected Element Attributes:** NOTHING SELECTED.
- Board Information:** Generic Base Station (1), Generic Sensor Node (13).
- Network Analysis:** Distance Graph, Link Graph (checked), Minimum Distance Path, Energy Distribution, Radio Reach.
- Medium Variables:** Gaussian Noise, Humidity, Temperature.
- Tools:** AUTO RENAME NETWORK NODES, BACKGROUND COLOR.

Network Diagram: A 2D plot showing a network of nodes (BS1, SN1-SN13) and links. A green circle highlights a specific area around nodes SN7, SN4, and SN3.

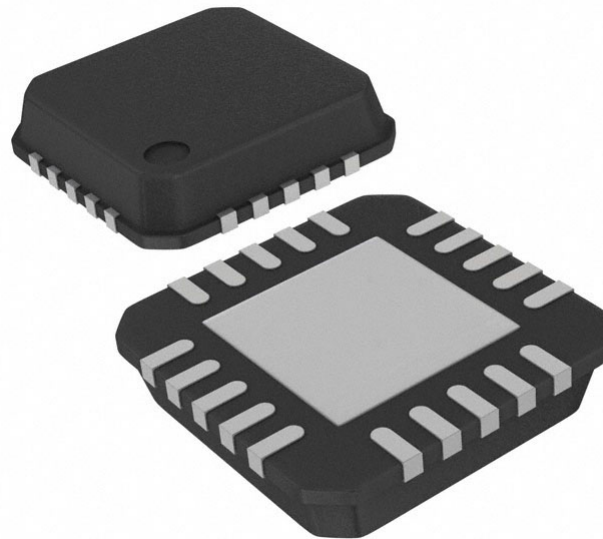
Validation

n **Some models of well-accepted commercial devices**

- .. **Radio Transceiver**
 - n **CC2500 (Texas Instruments)**
- .. **Microcontroller**
 - n **ATMEGA8 (Atmel)**
- .. **Sensor**
 - n **SHT11 (Sensirion)**
- .. **Antenna**
 - n **W1030 (Pulse)**
- .. **Battery**
 - n **Phillips models**

Validation

- n **CC2500 (Texas Instruments)**
 - .. **Clear Channel Assessment (CCA)**
 - n **Used on CSMA/CA and IEEE 802.11**



Validation

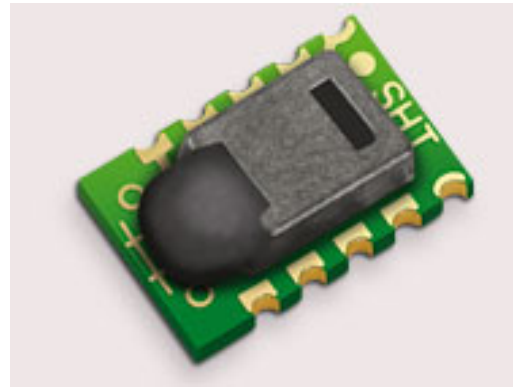
n Atmega8 (Atmel)



Atmega8			
SPI	ADC	Timers	Sleep
Yes	Yes	Yes	7 States

Validation

n SHT11 (Sensirion)



- Temperature and Humidity
- 3V
- Digital Output

Validation

n Antenna (Pulse)

- Omnidirectional
- 2,4 – 2,5 GHz



Validation

n Batteries

- Coin Model
- Phillips



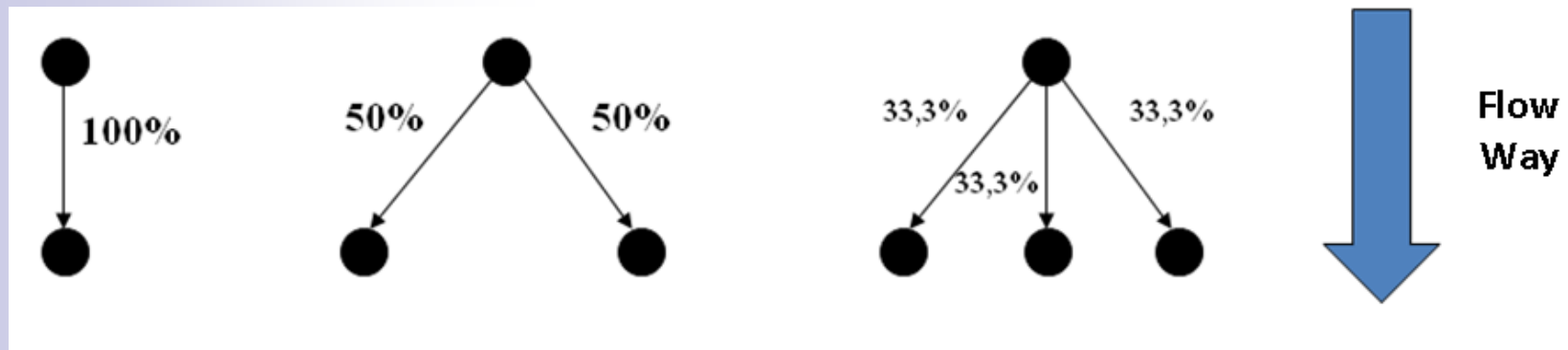
Experiments

Experiments

- **Three Different Networks**
 - n **Normal Distribution (same energy) x Energy Reallocation**
 - Same energy budget
 - n **Base Station Displacement**
 - Irregular distribution scenarios
 - n **Simulations using pure CSMA/CA**
 - n **Simulations using IEEE 802.11 RTS/CTS**

Experiments

.. Sending and Rerouting Policy:

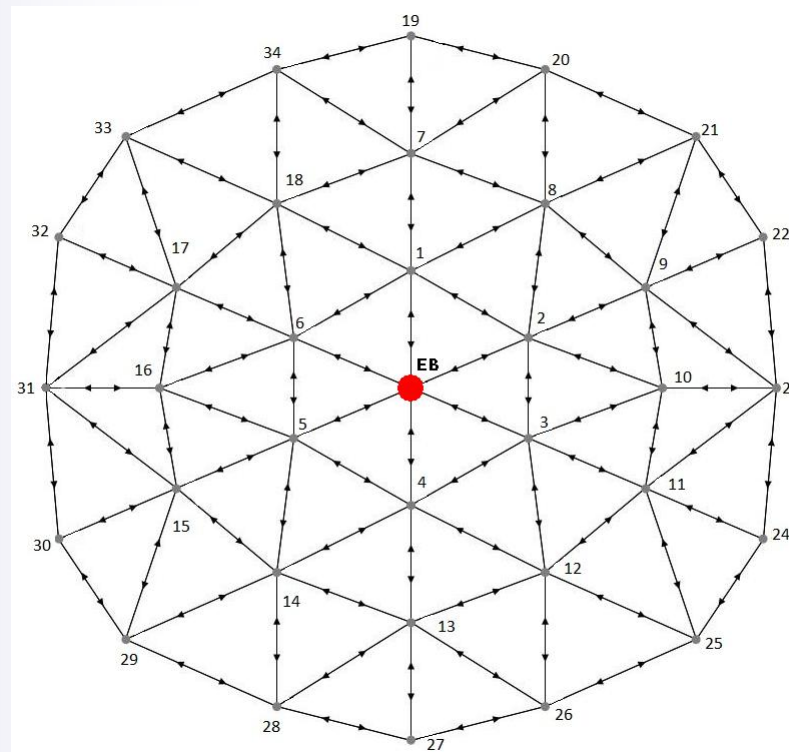




Simulations using pure CSMA/CA

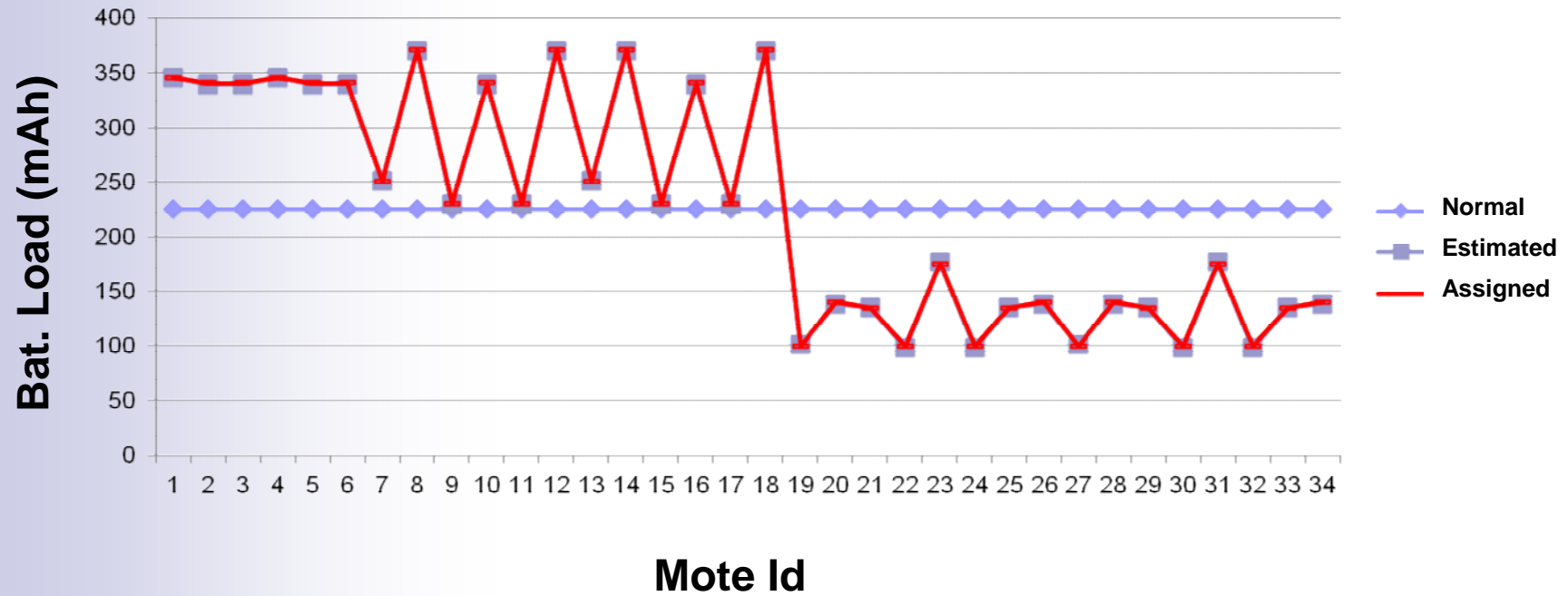
Validation

- Base Station put in the middle
- Perfect organized scenario



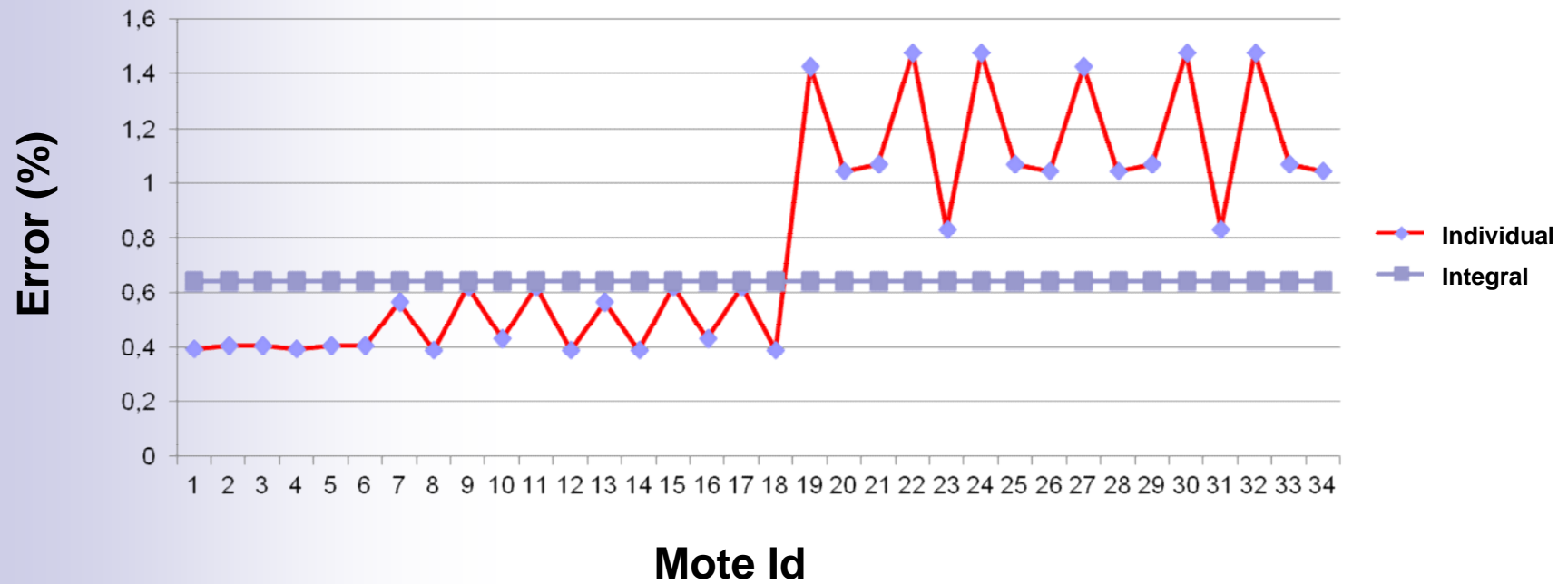
Validation

Energy Assignment

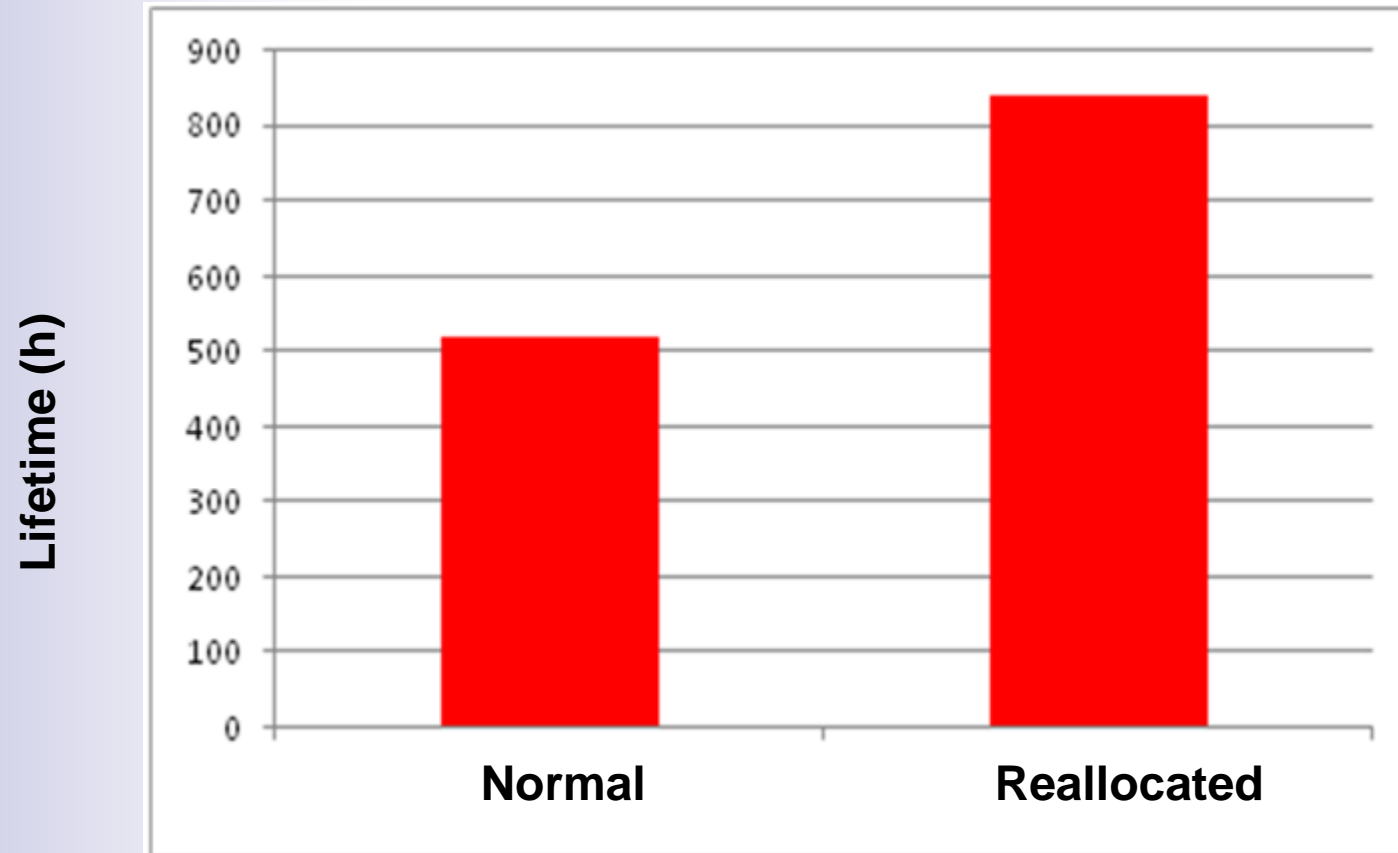


Validation

Estimation Error

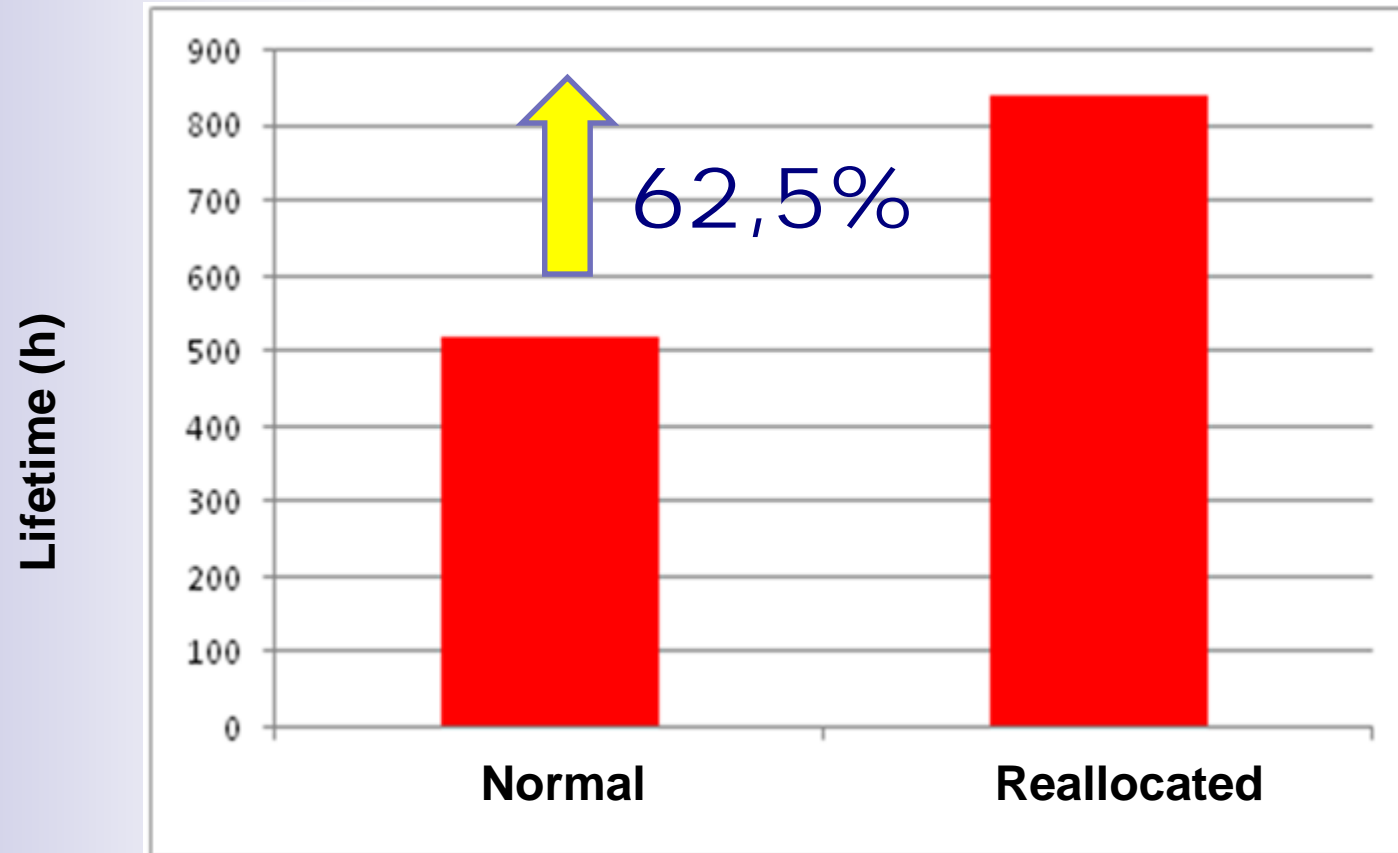


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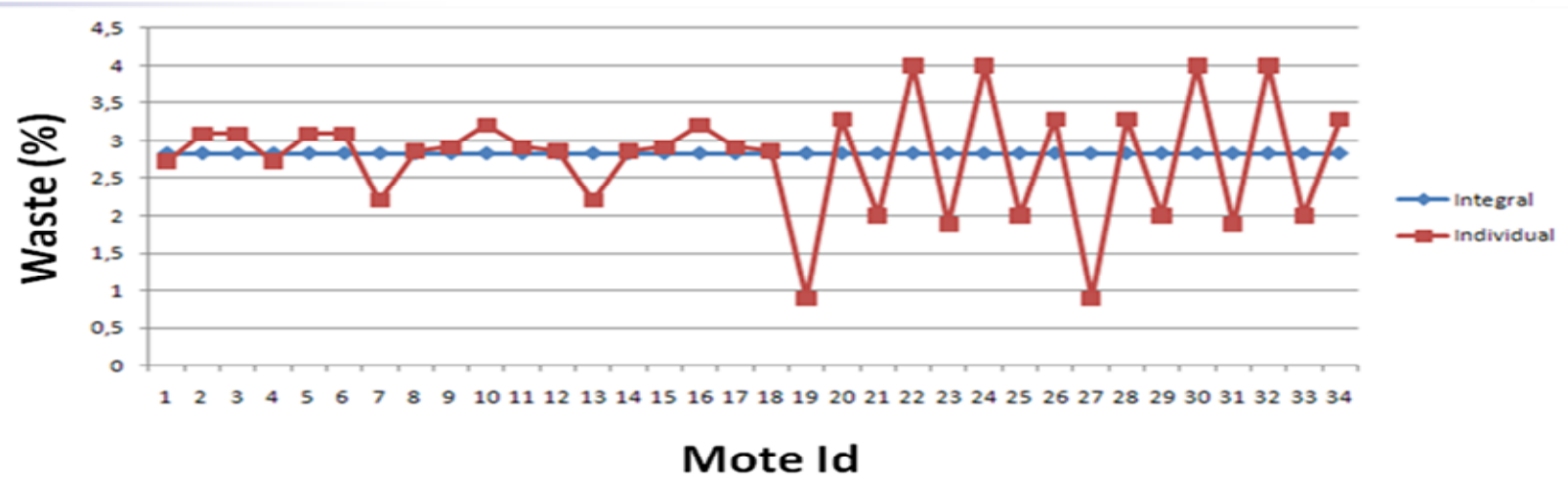
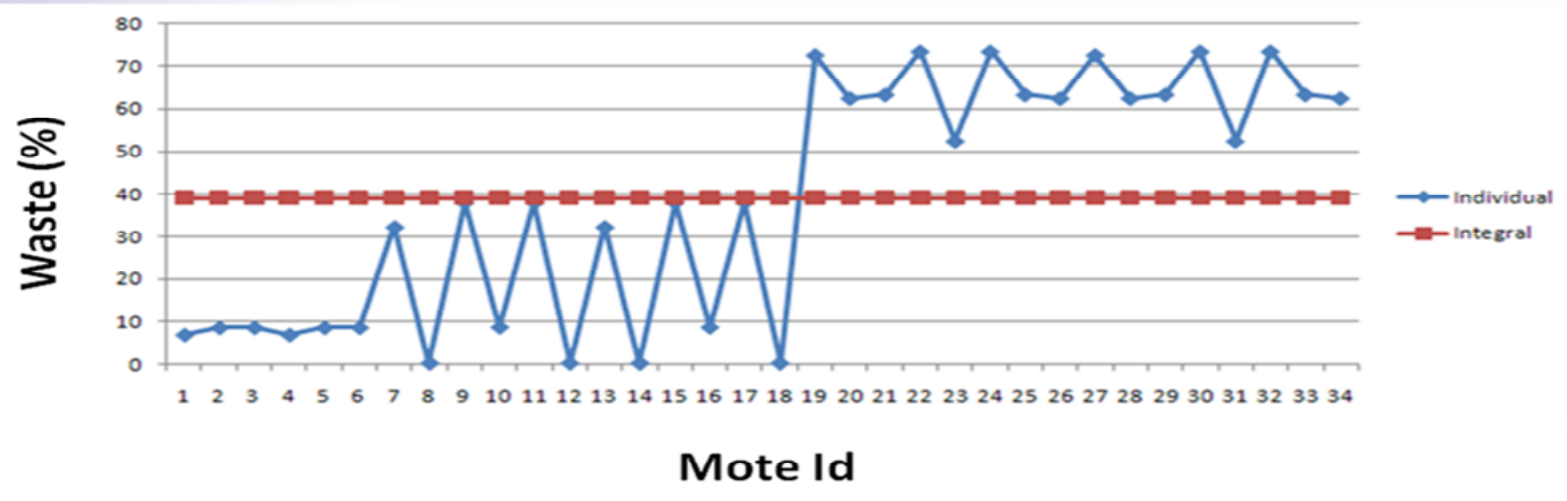
520 h x 840 h

Validation



520 h x 840 h

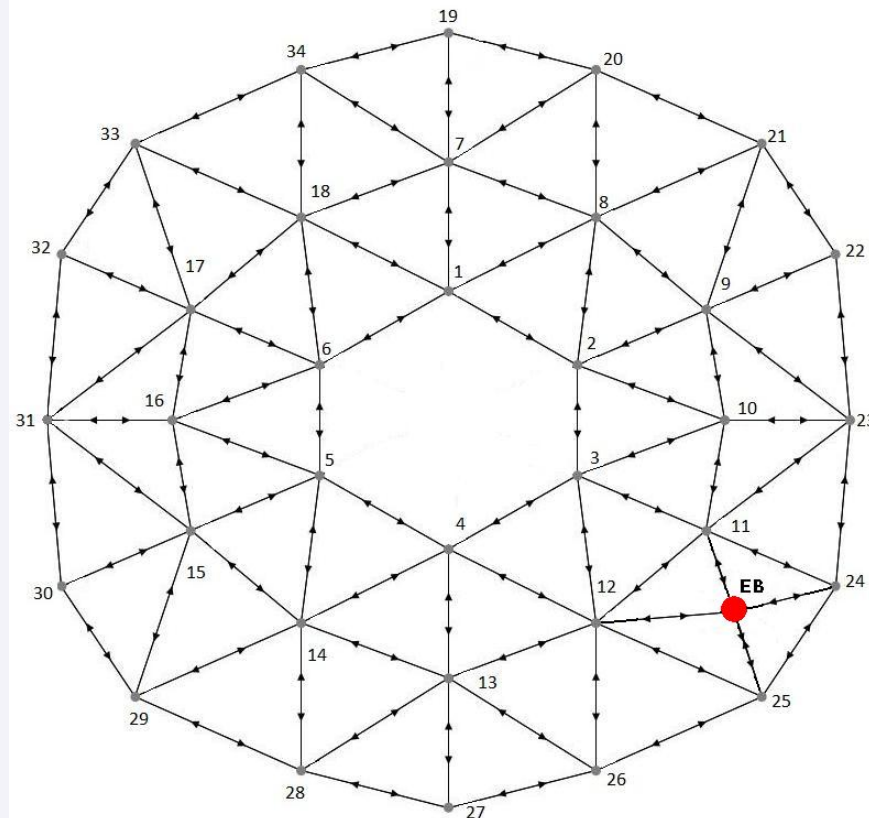
Validation Energy Waste



Validation

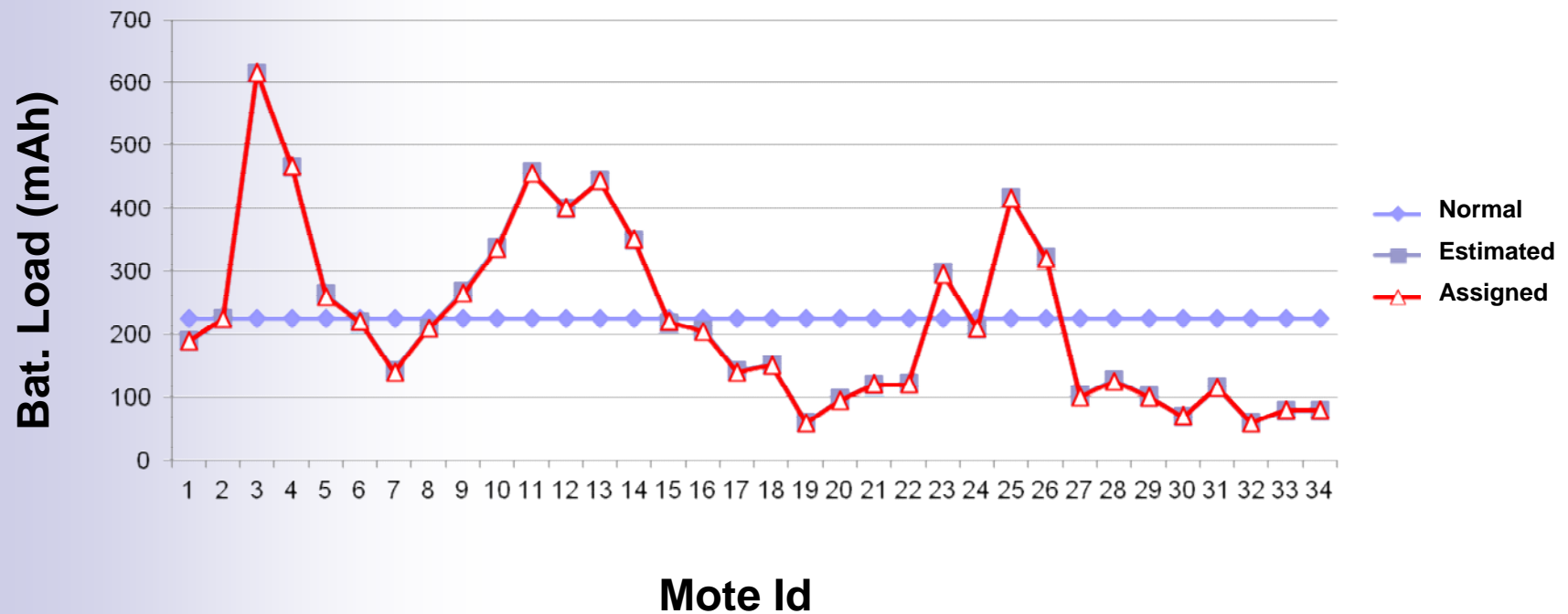
Displaced Base Station

n “Light case” of an irregular topology



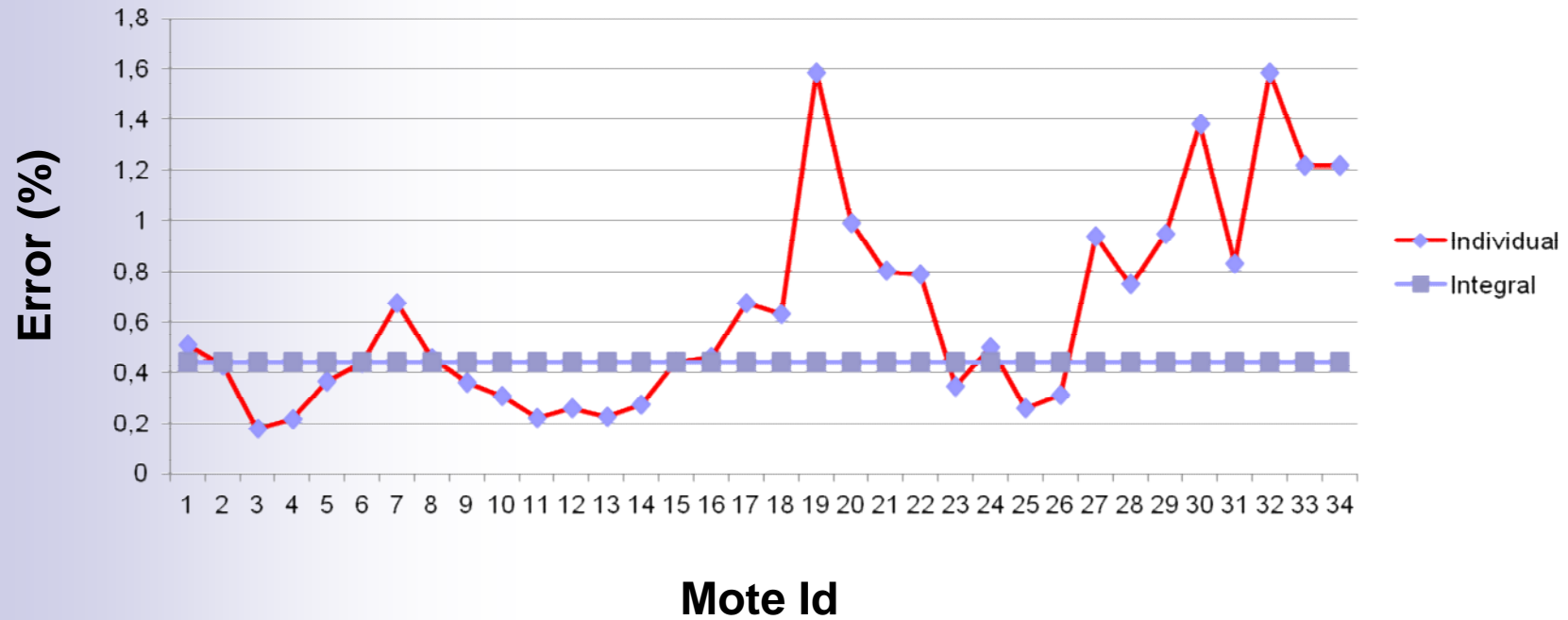
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Energy Assignment

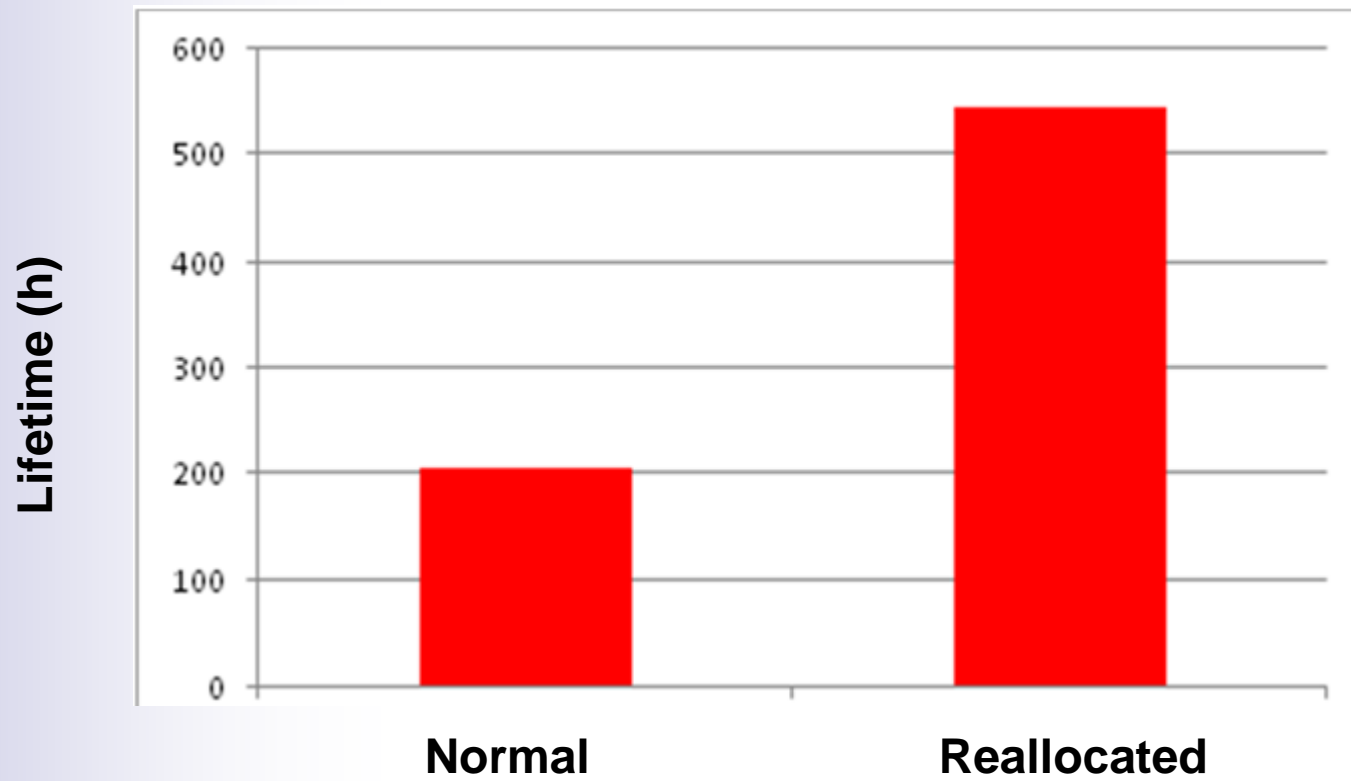


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Estimation Error

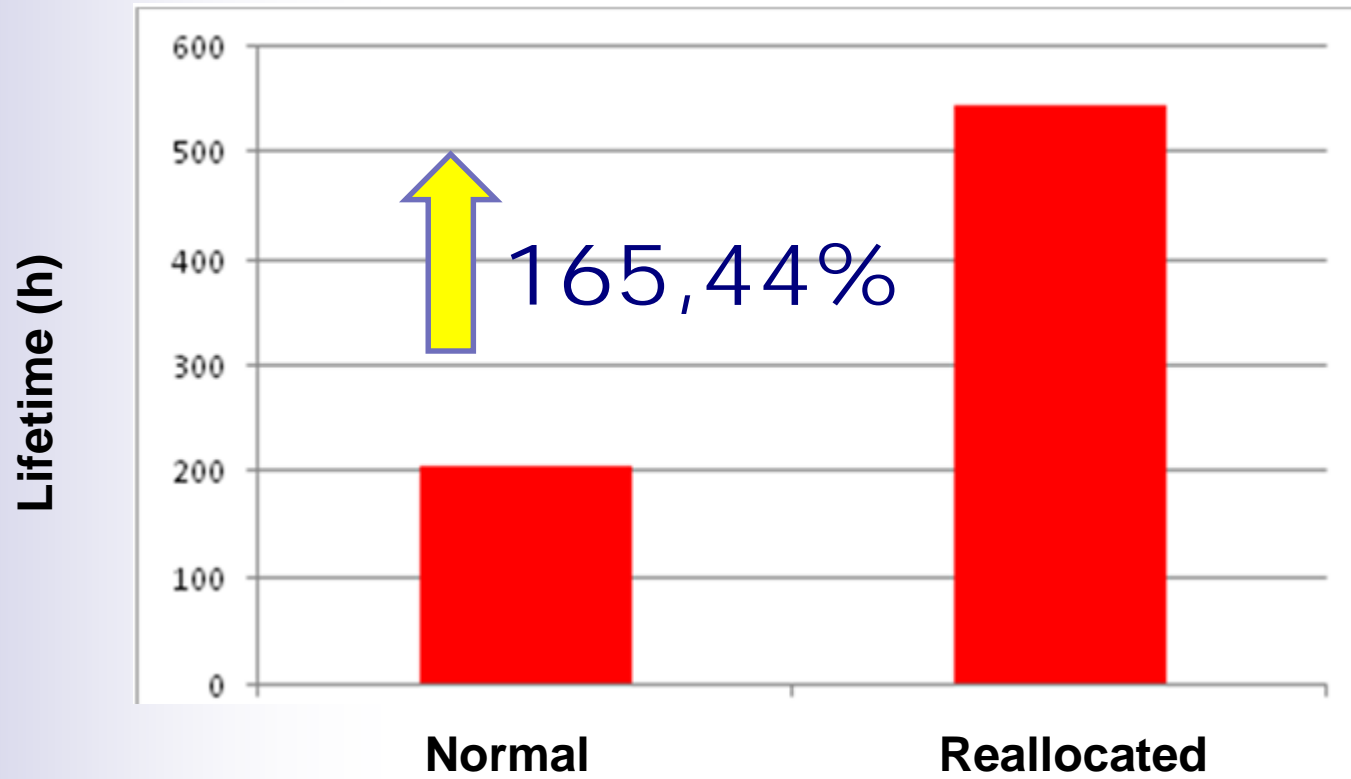


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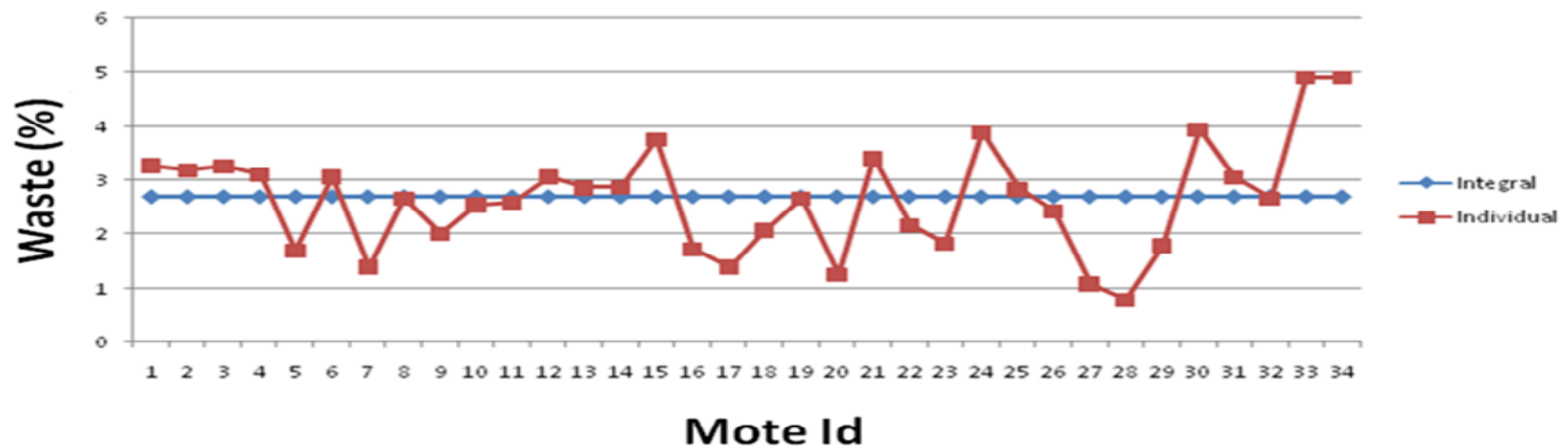
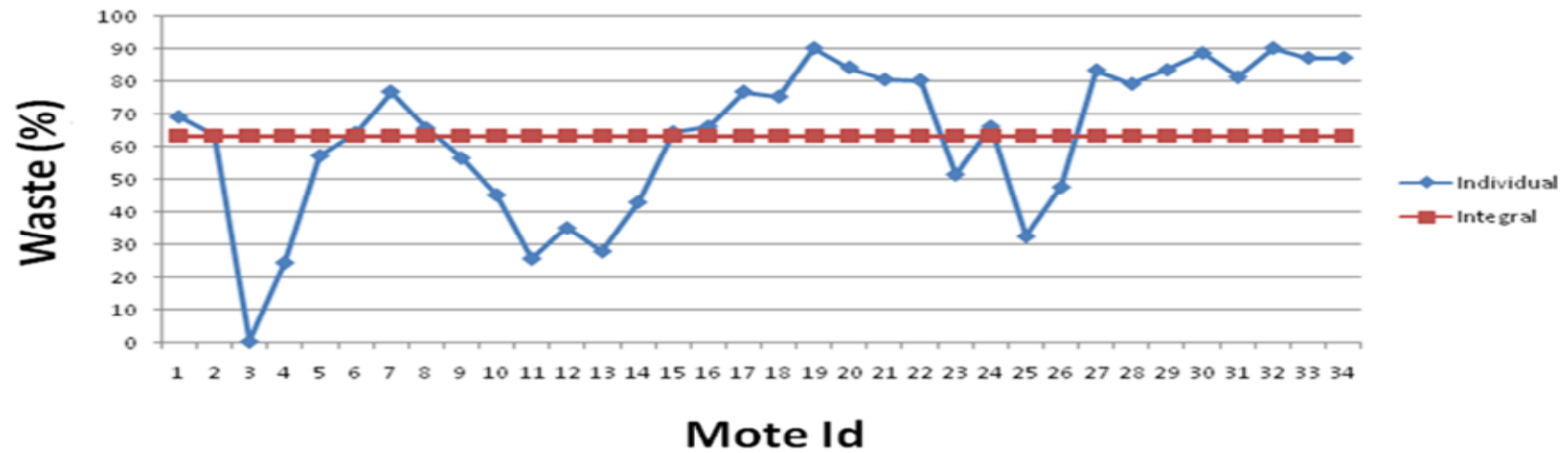
205,6 h x 545,75 h

Validation



205,6 h x 545,75 h

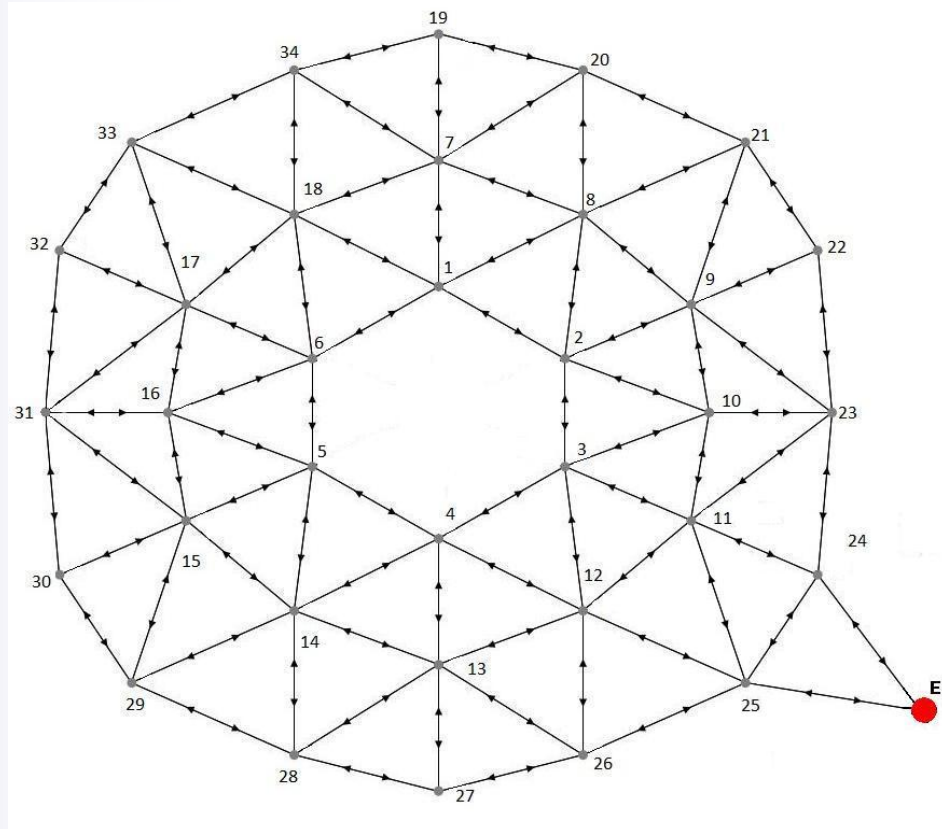
Validation Energy Waste



Validation

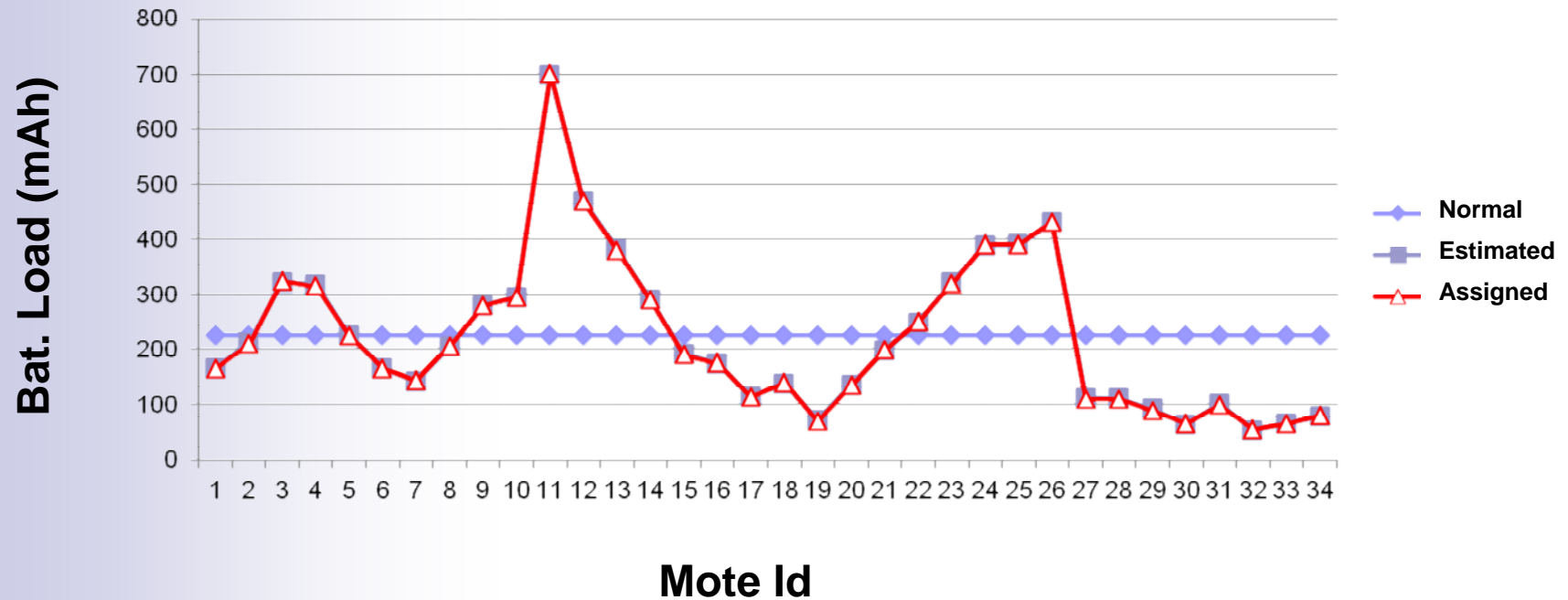
Displaced Base Station

n “Heavy case” of an irregular topology



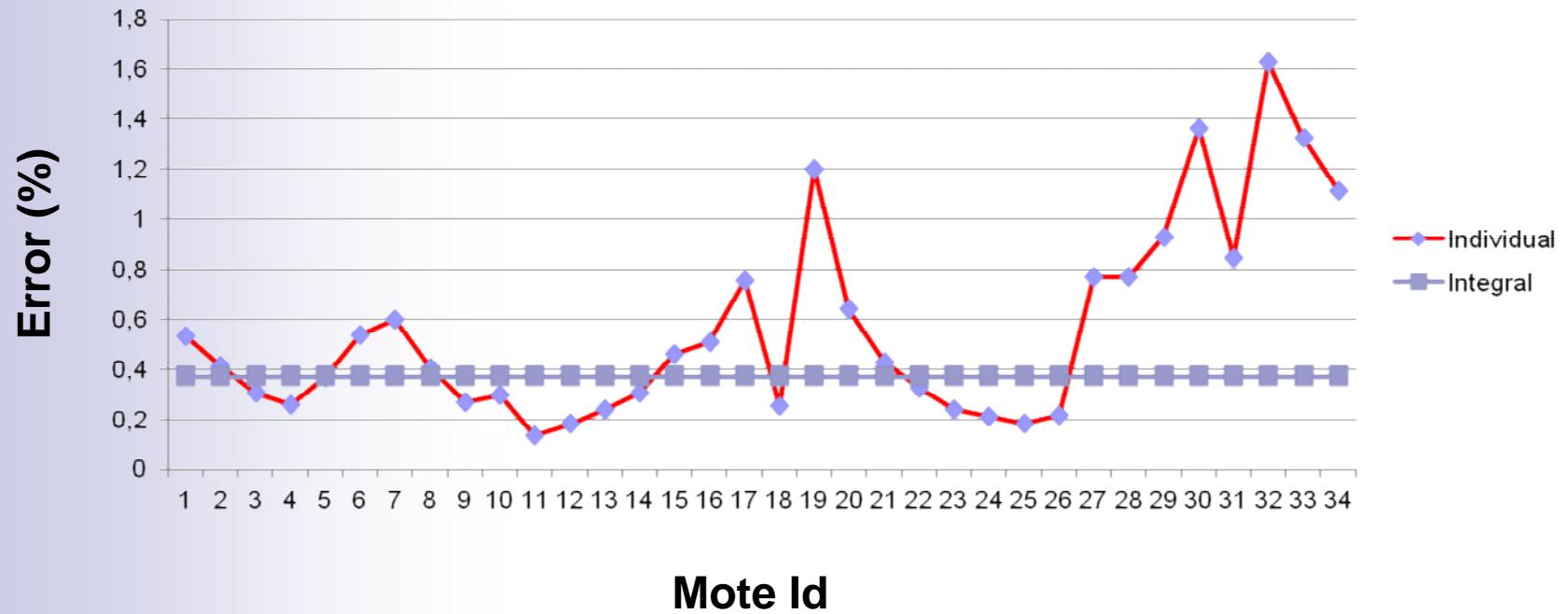
Validation

Energy Assignment

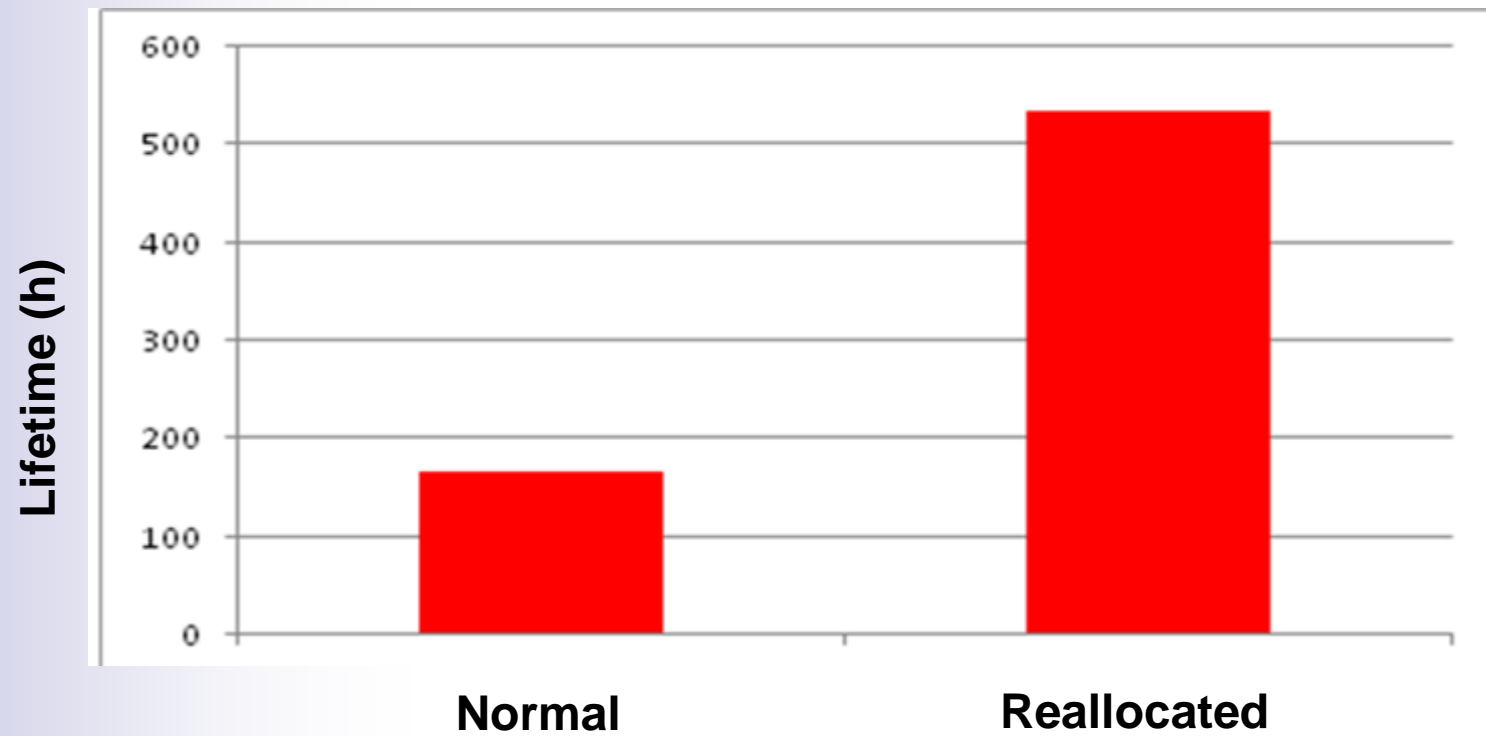


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Estimation Error

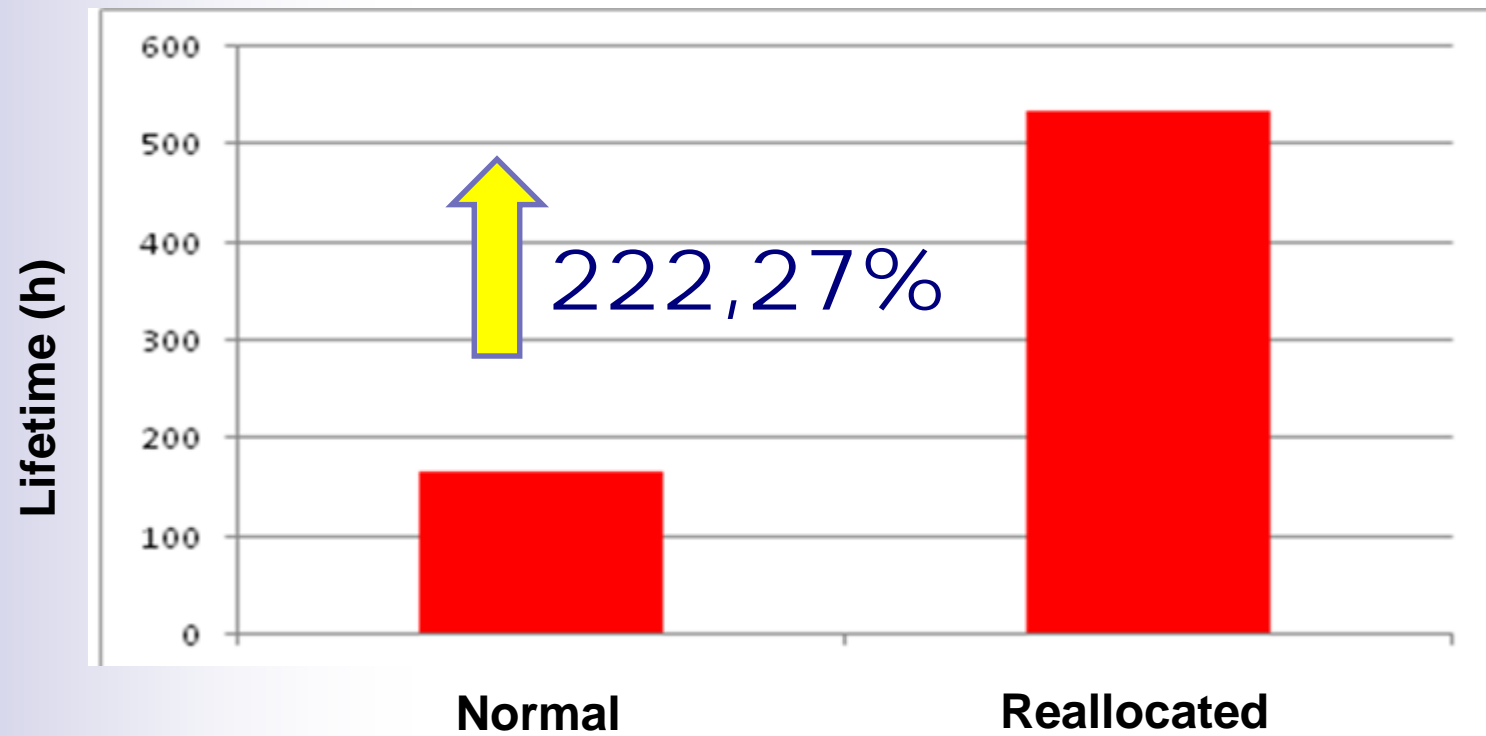


Validation



165,93 h x 534,75 h

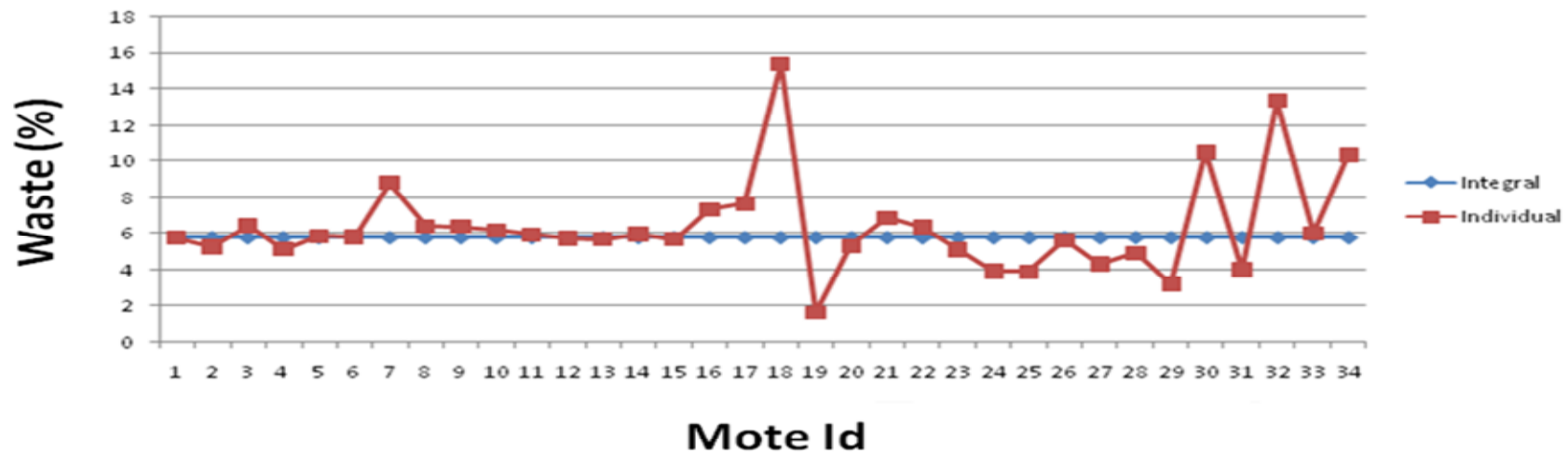
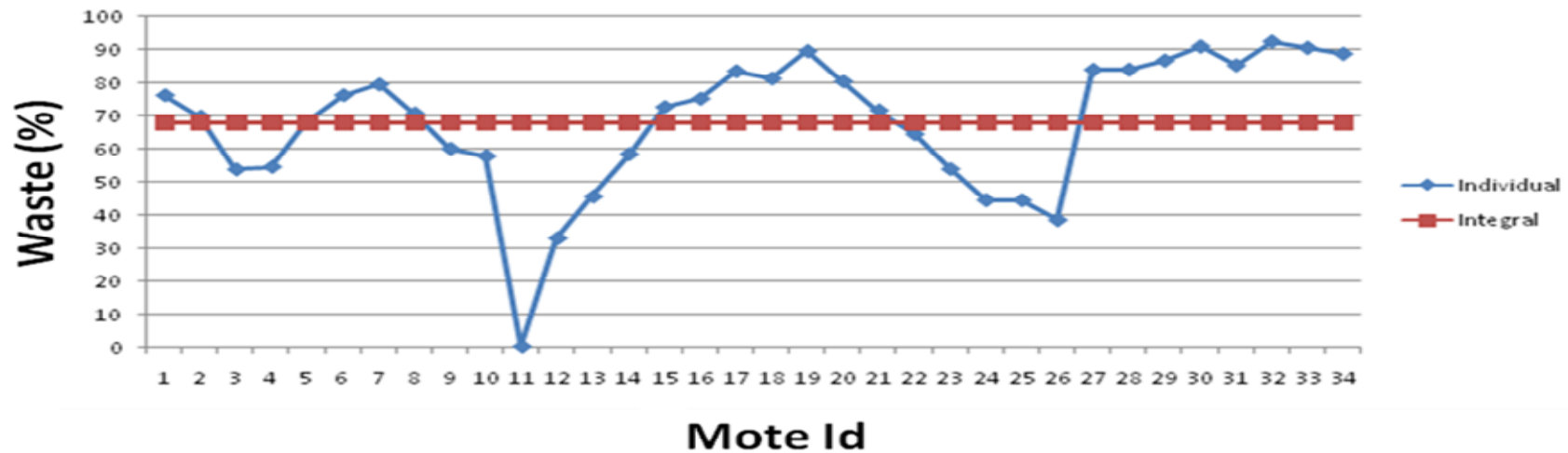
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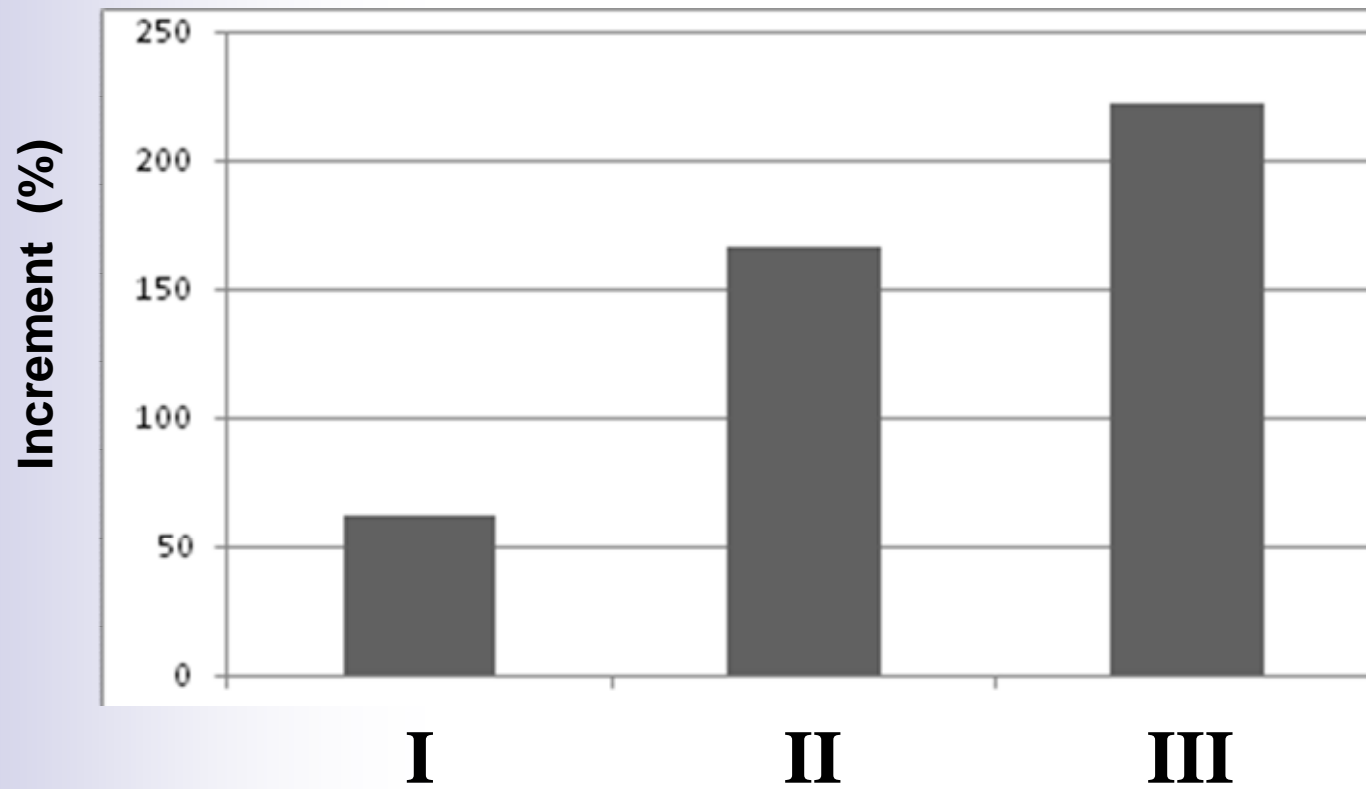
165,93 h x 534,75 h

Validation

Energy Waste



Validation Lifetime Increment

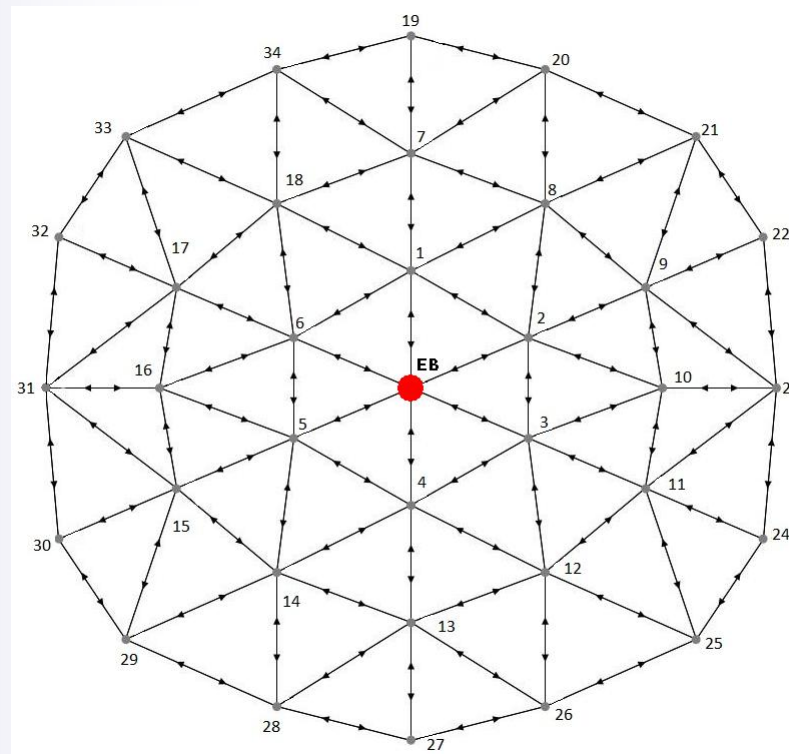




Simulations using IEEE 802.11 RTS/CTS

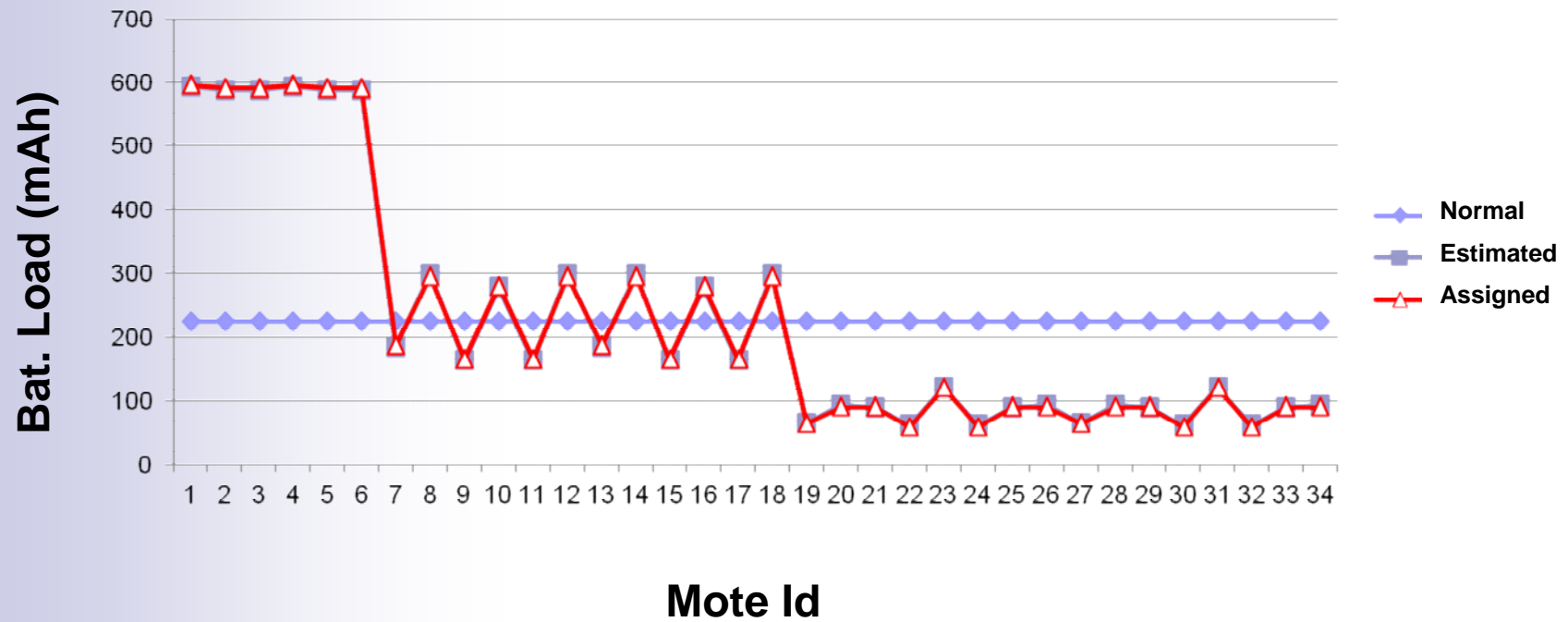
Validation

- **Base Station put in the middle**
 - **Perfect organized scenario**



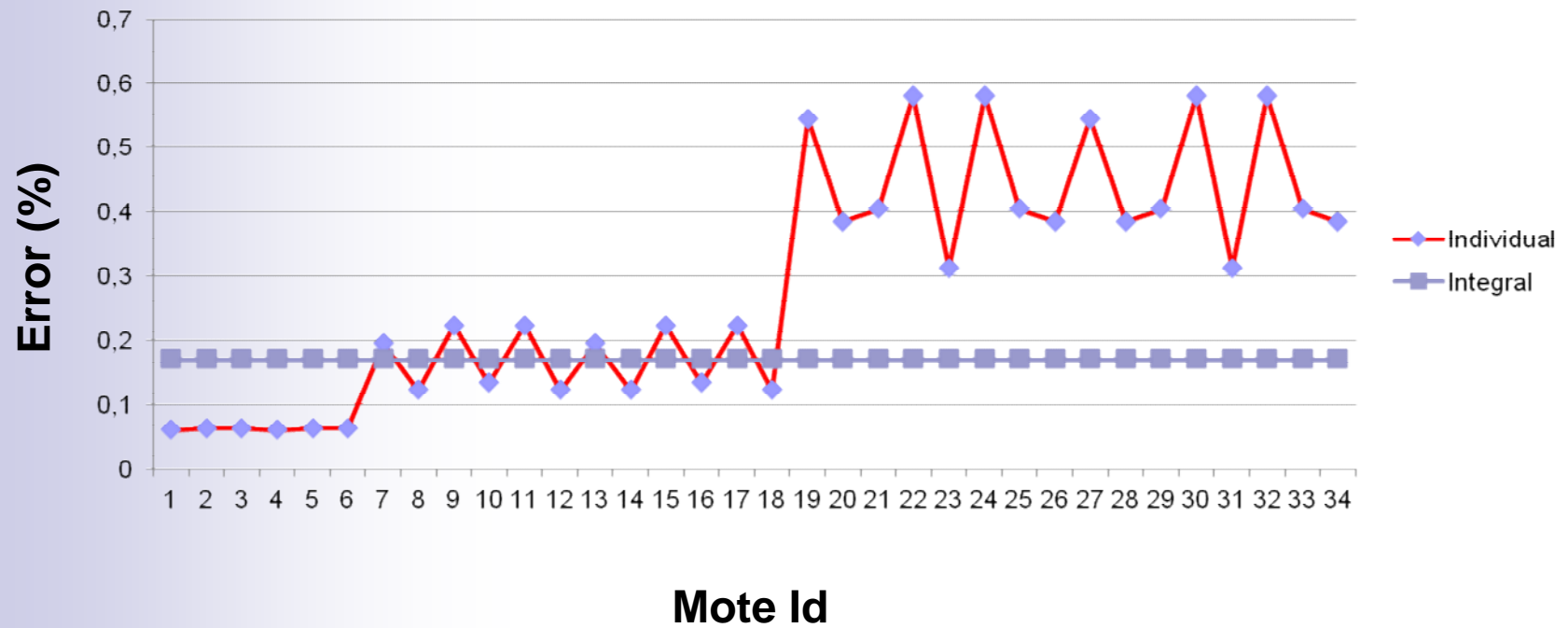
Validation

Energy Assignment



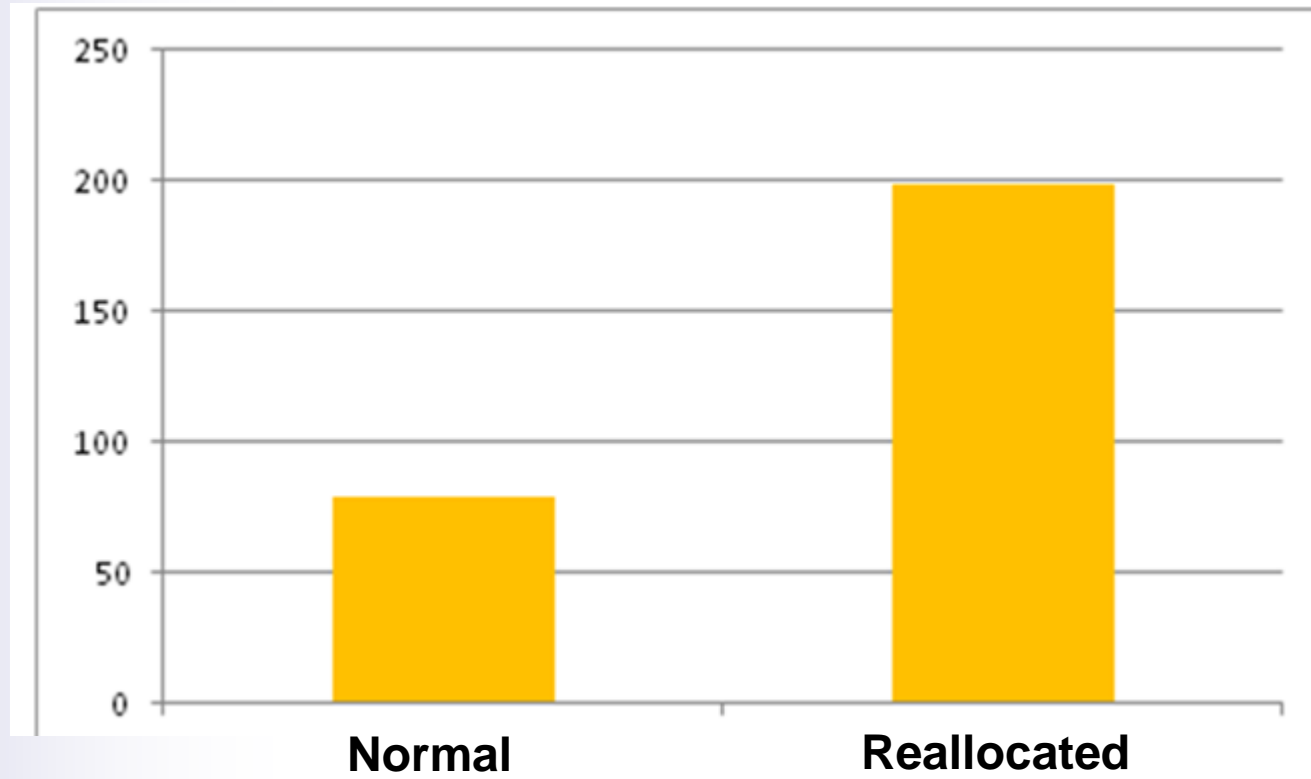
Validation

Estimation Error



Validation

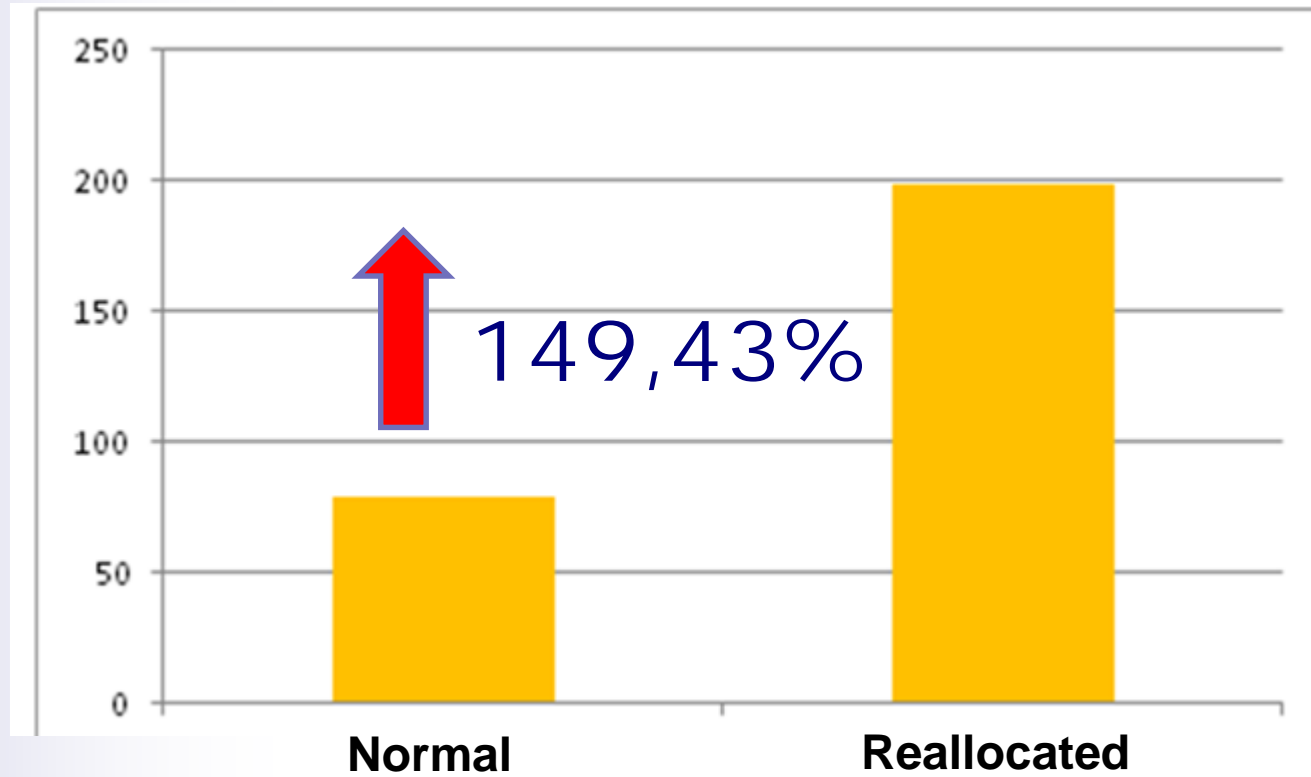
Lifetime (h)



79,41 h x 198,08 h

Validation

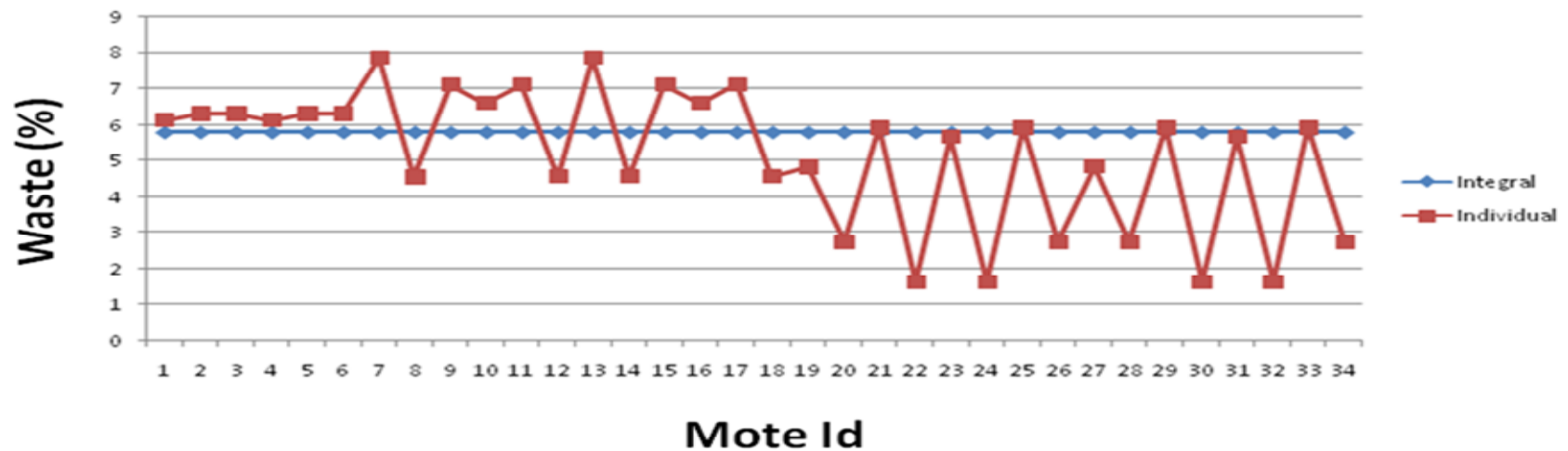
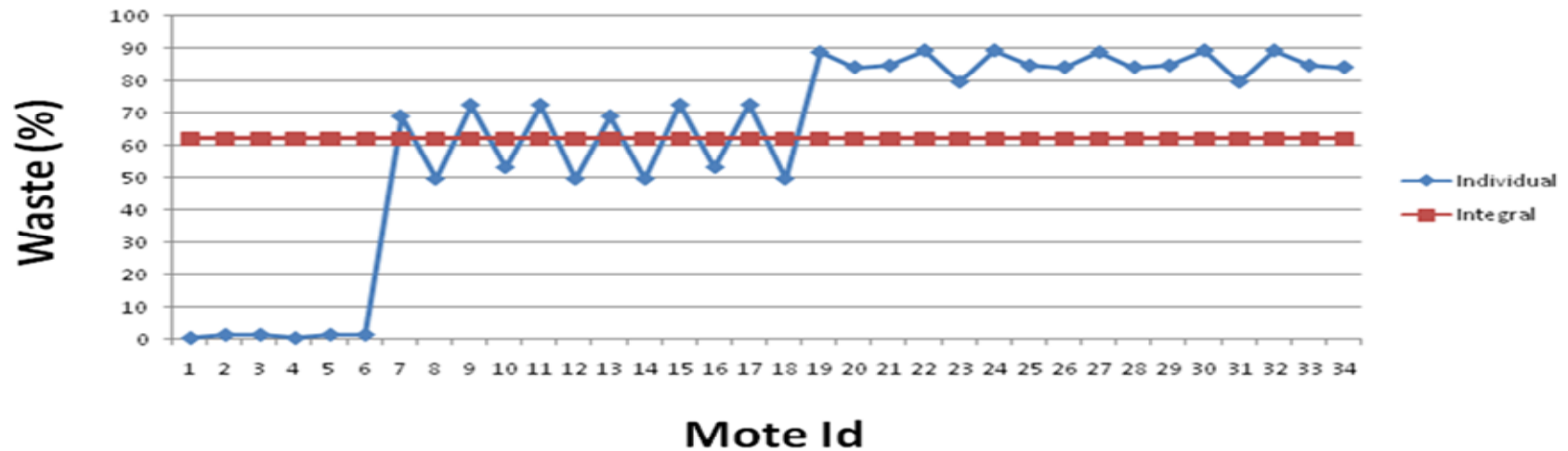
Lifetime (h)



79,41 h x 198,08 h

Validation

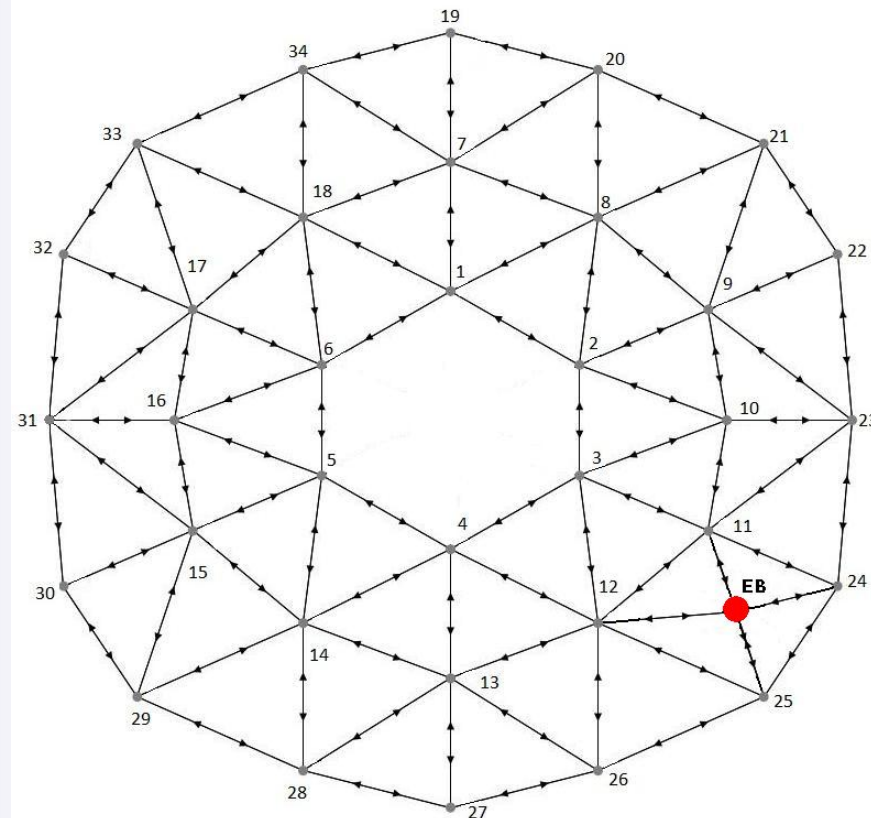
Energy Waste



Validation

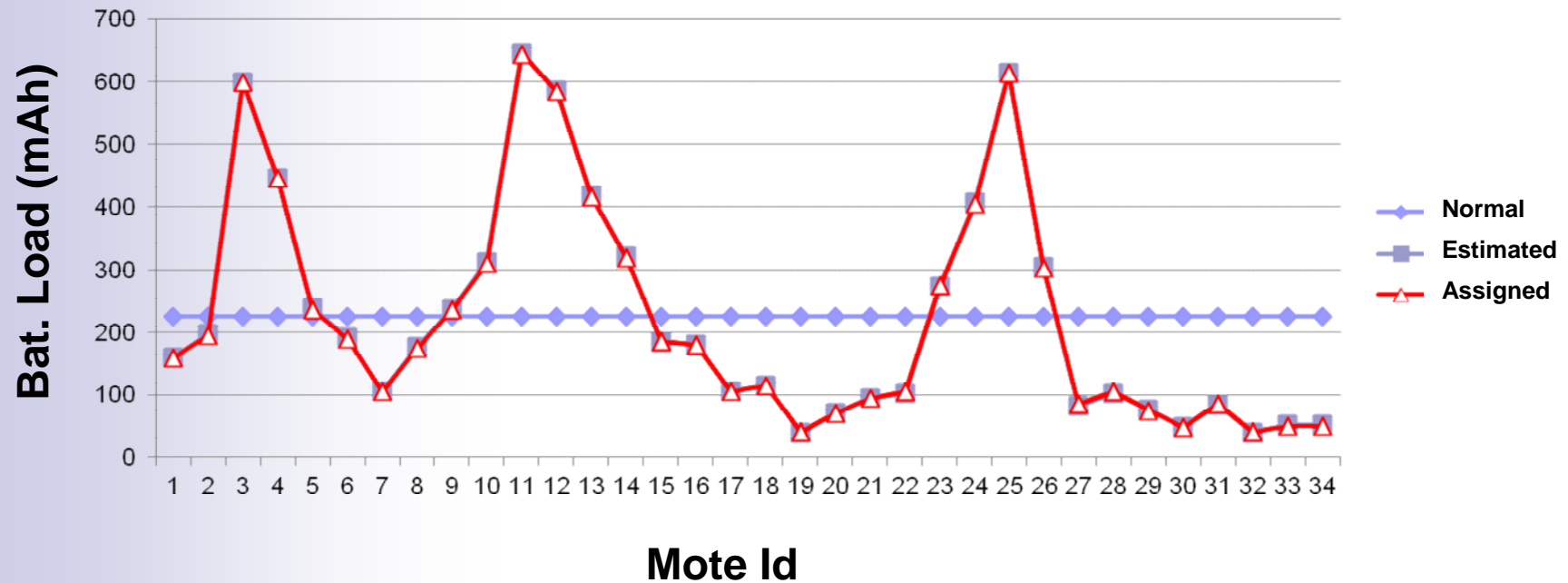
Displaced Base Station

n “Light case” of an irregular topology



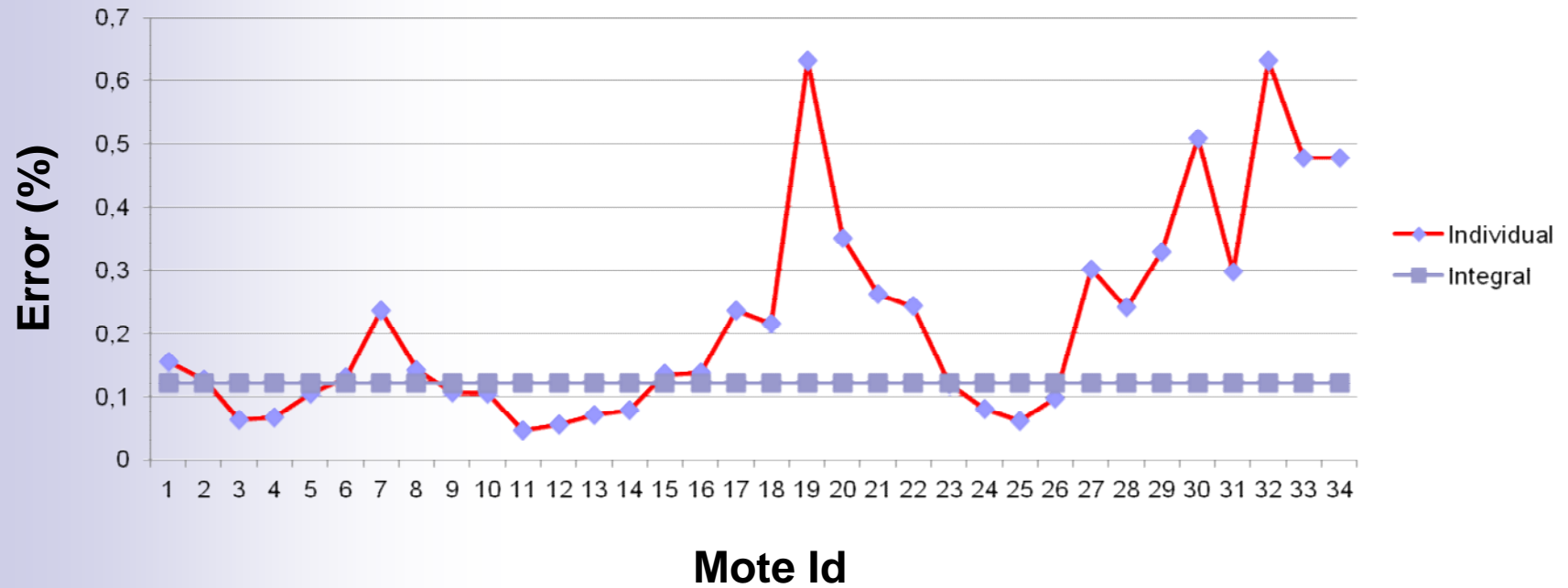
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Energy Assignment

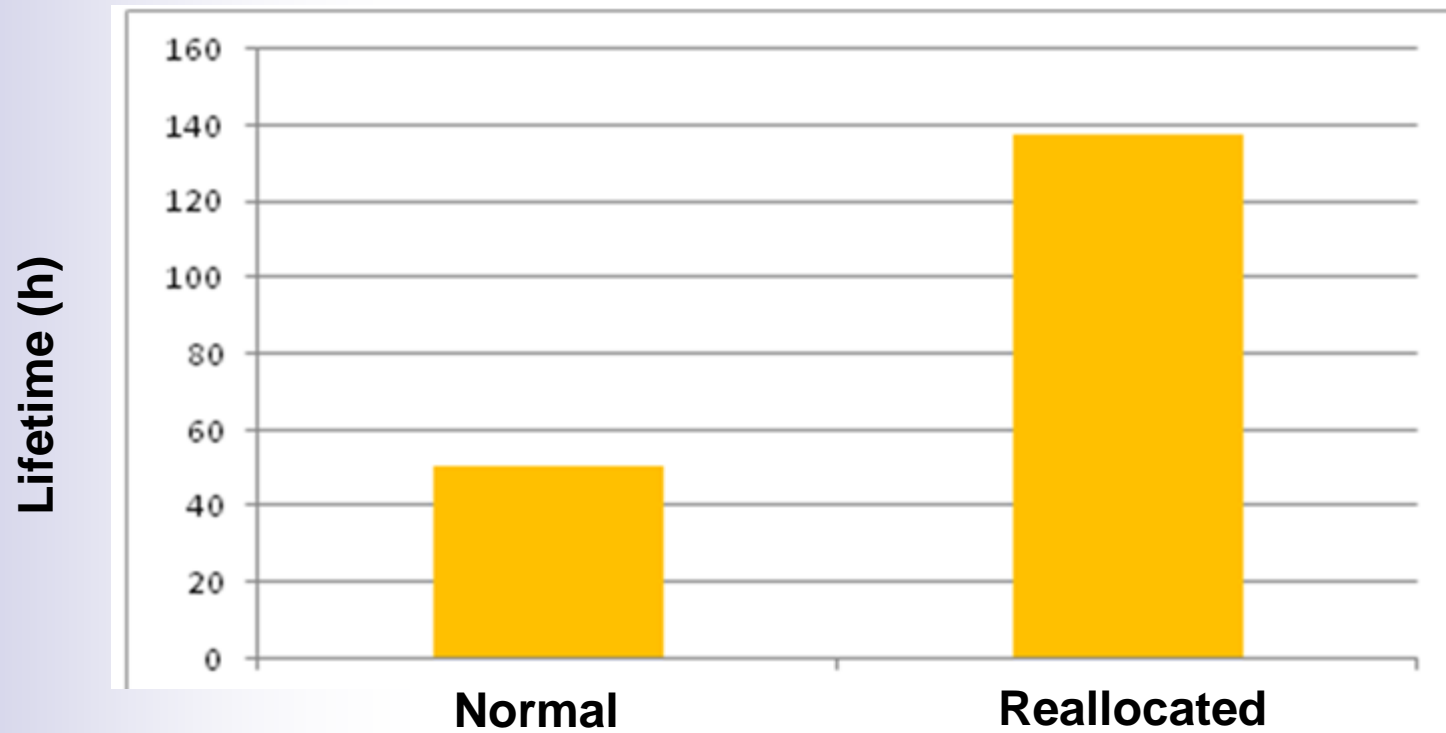


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Estimation Error

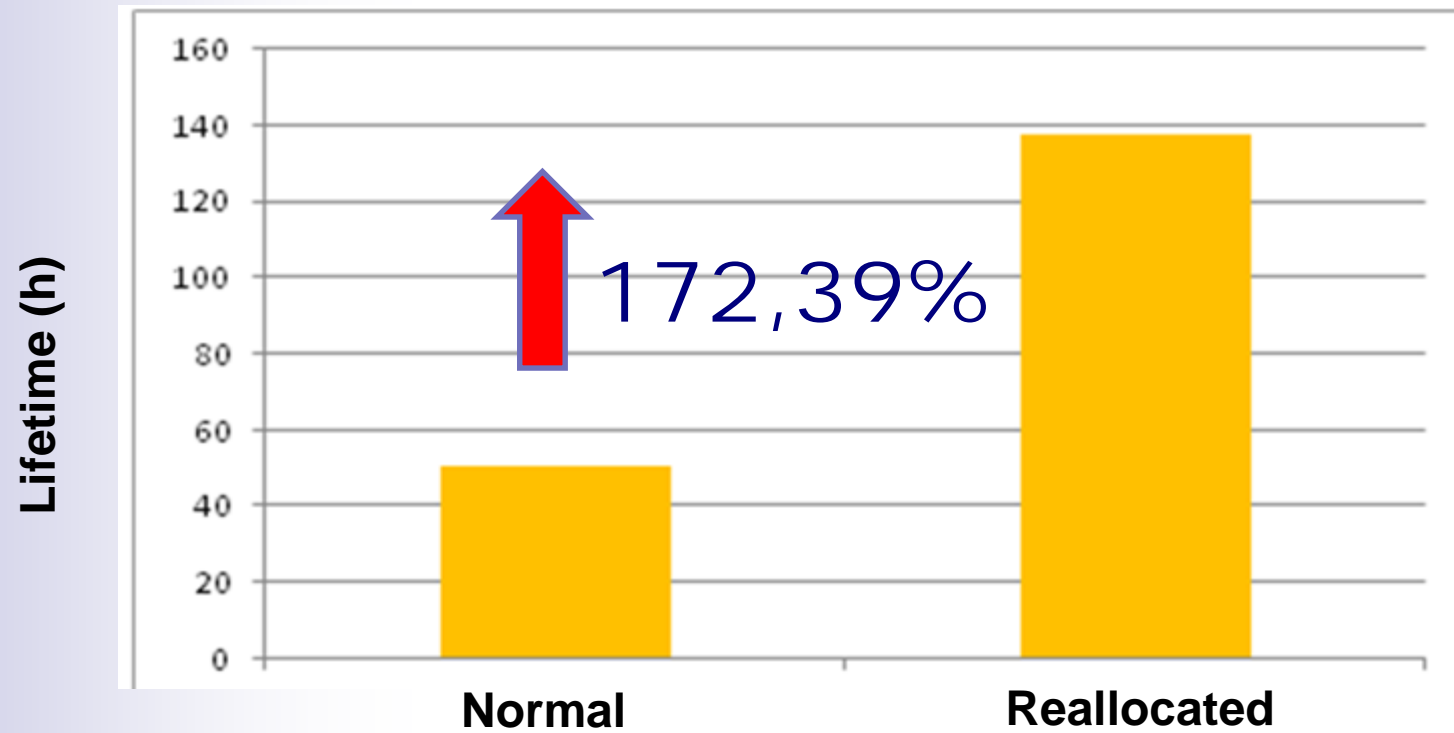


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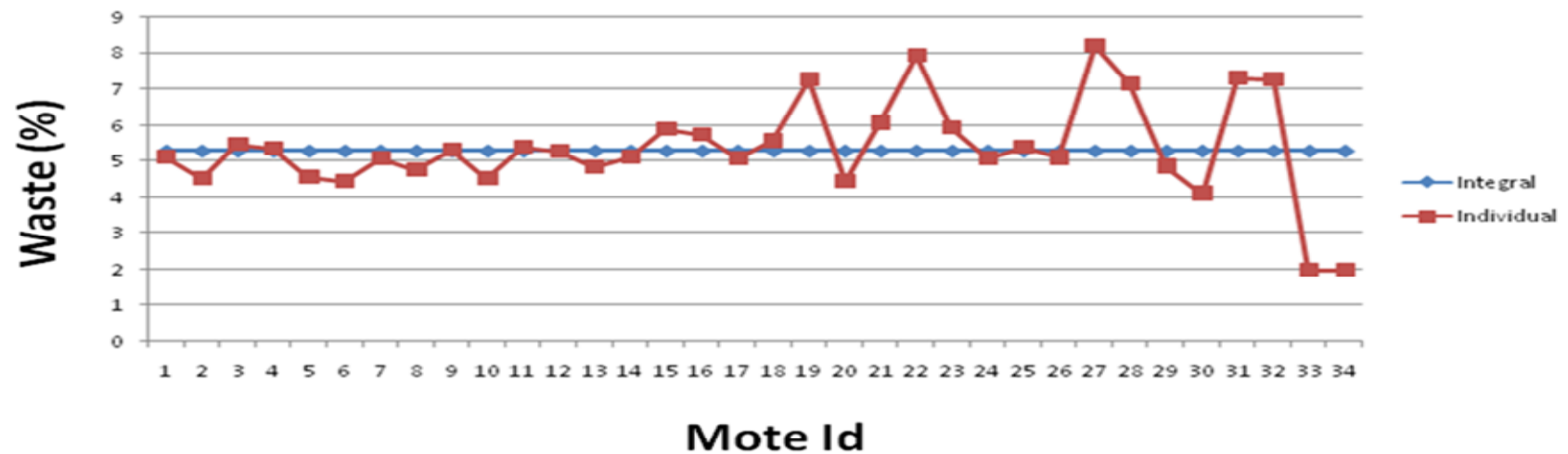
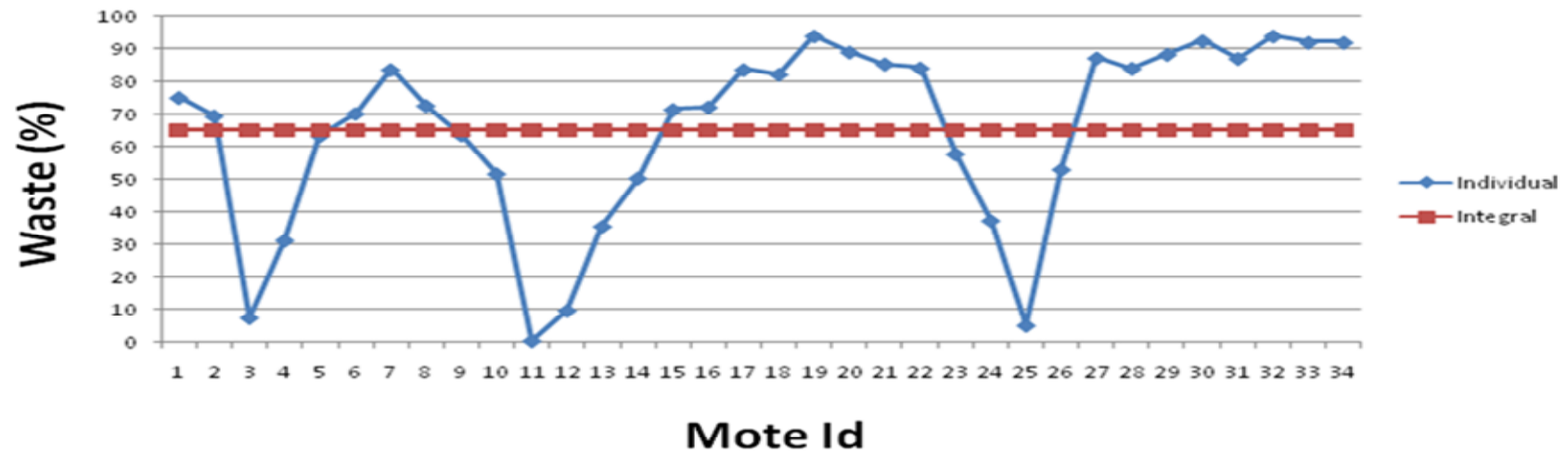
50,6 h x 137,83 h

Validation



50,6 h x 137,83 h

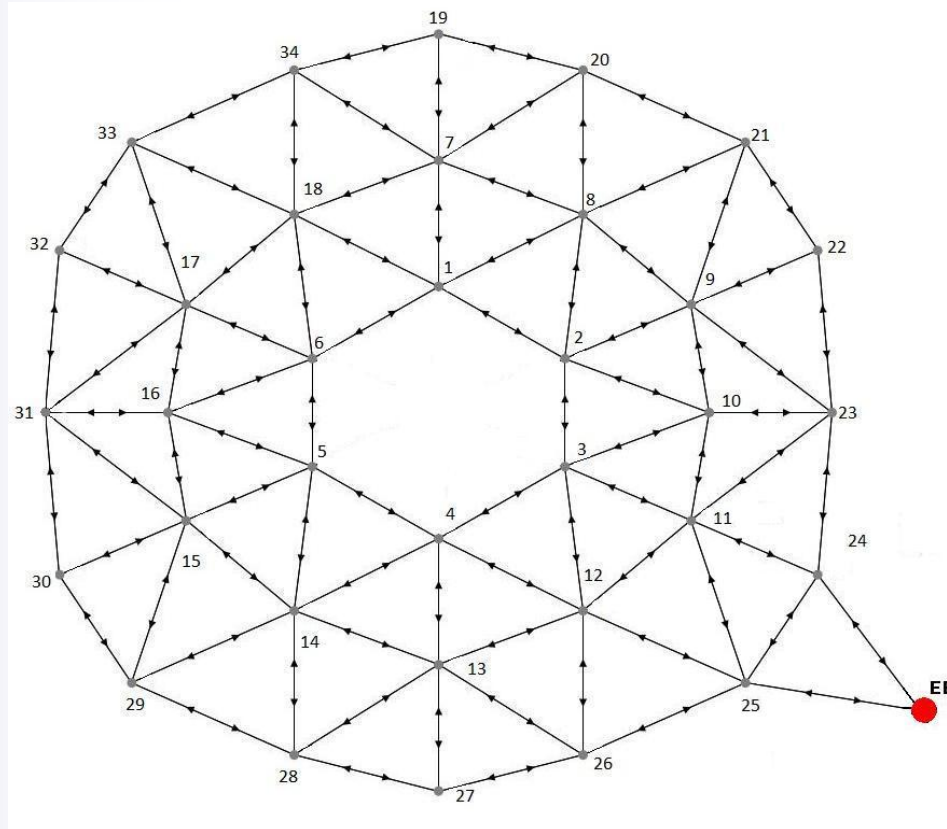
Validation Energy Waste



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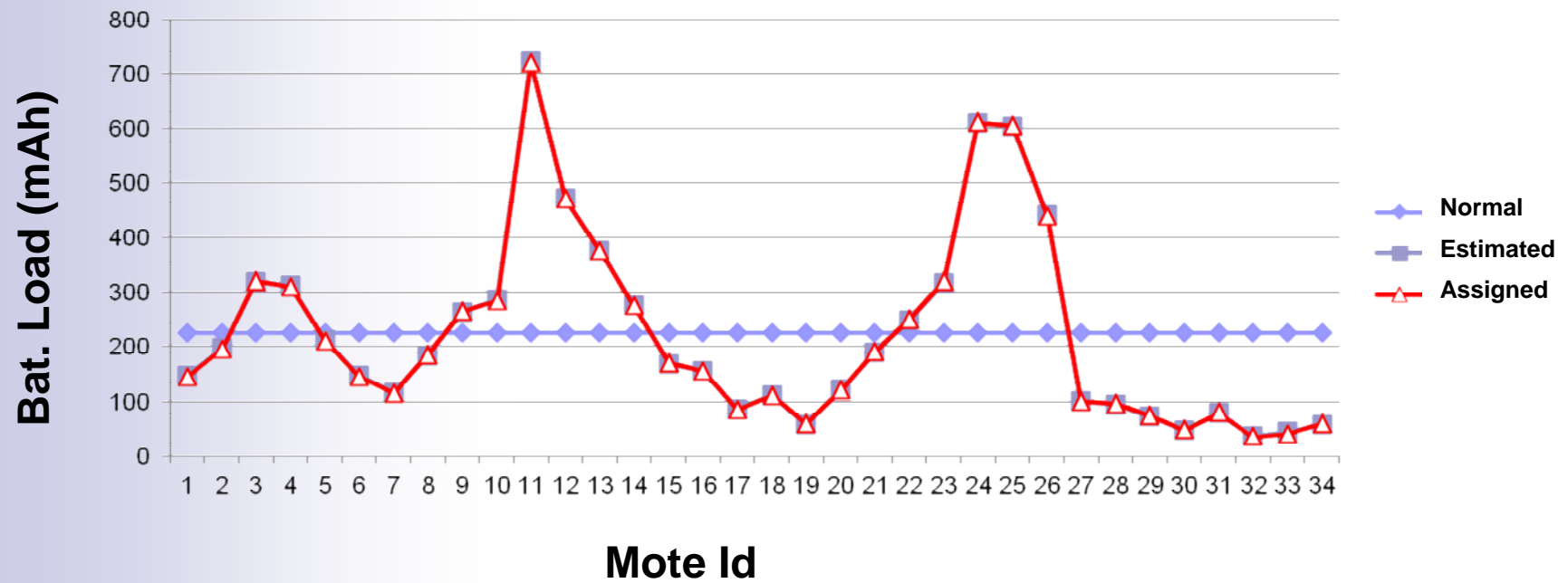
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n “Heavy case” of an irregular topology



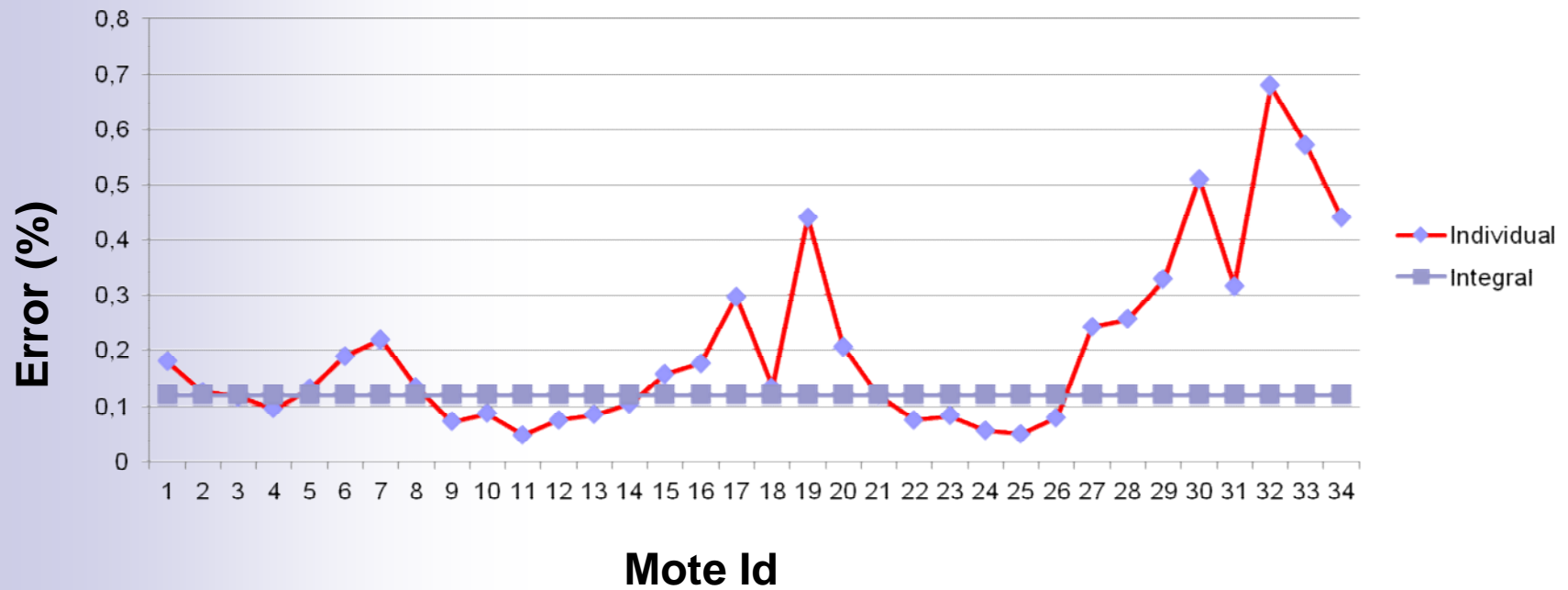
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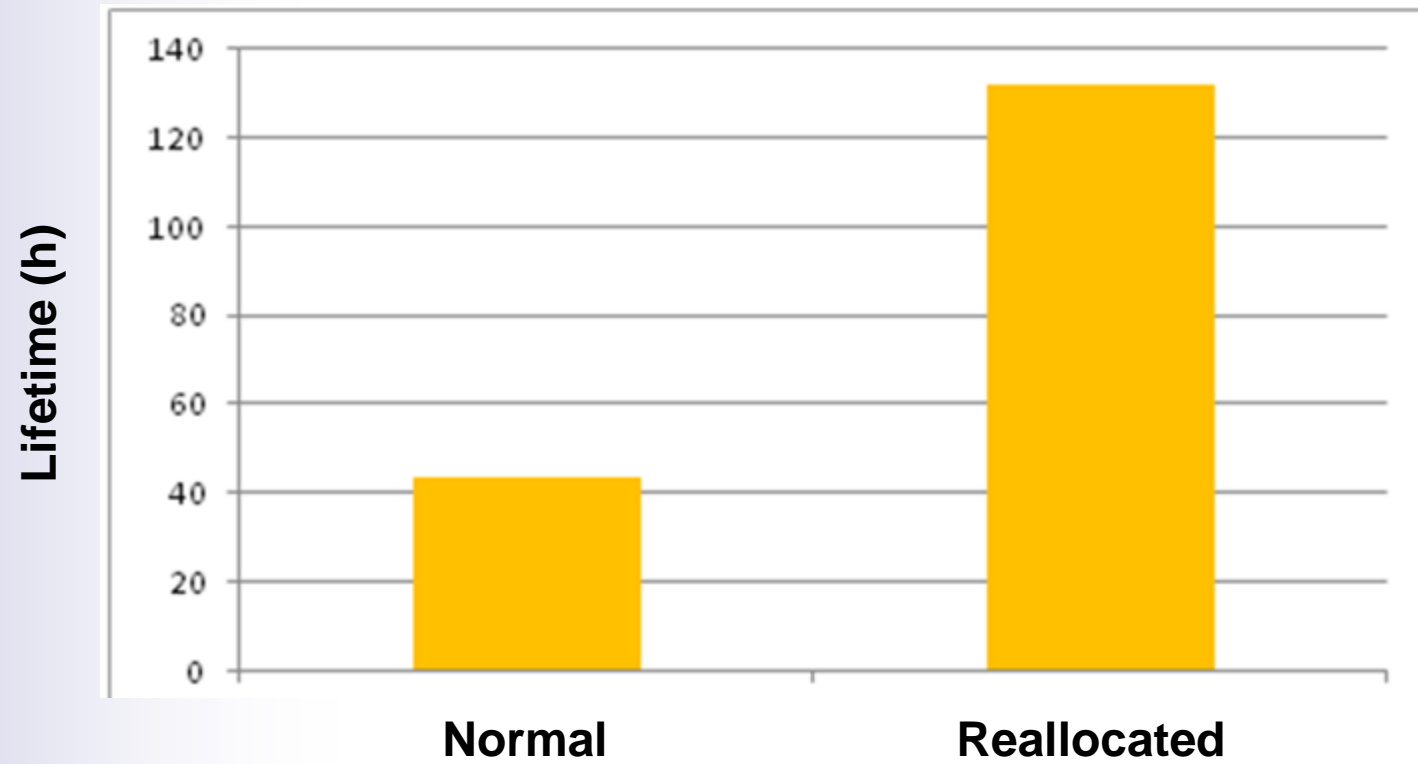


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Estimation Error

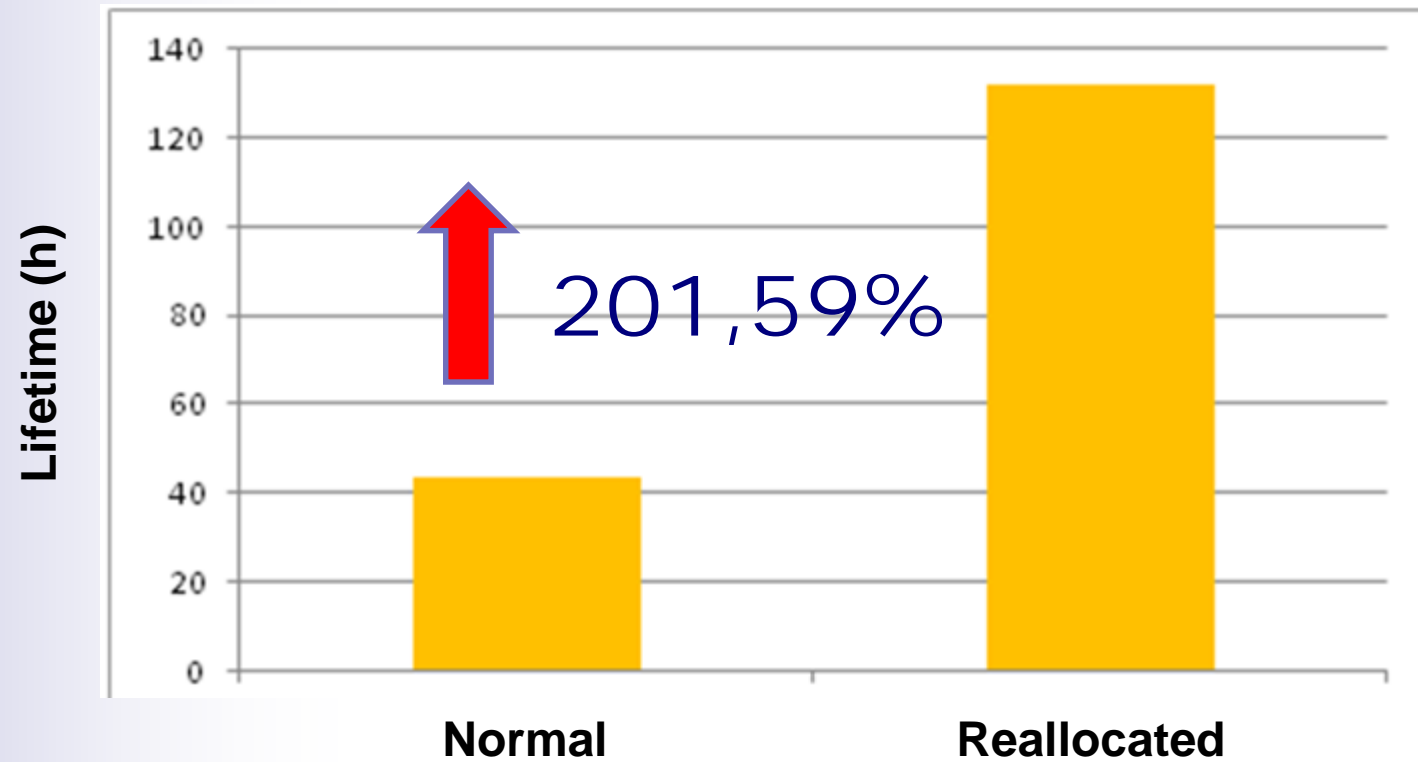


Validation



43,85 h x 132,25 h

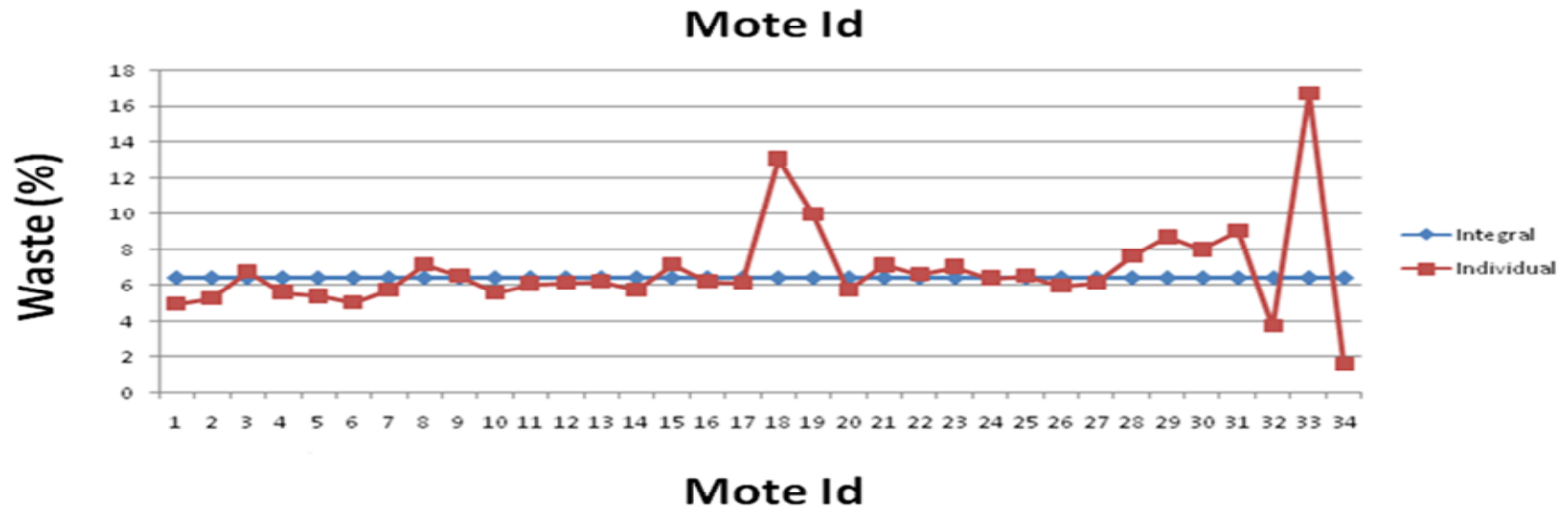
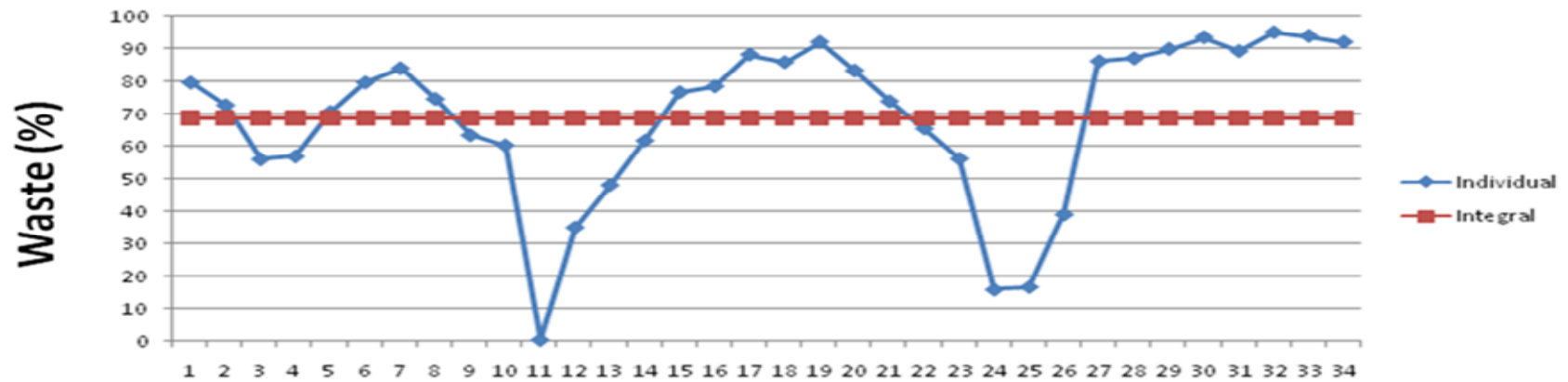
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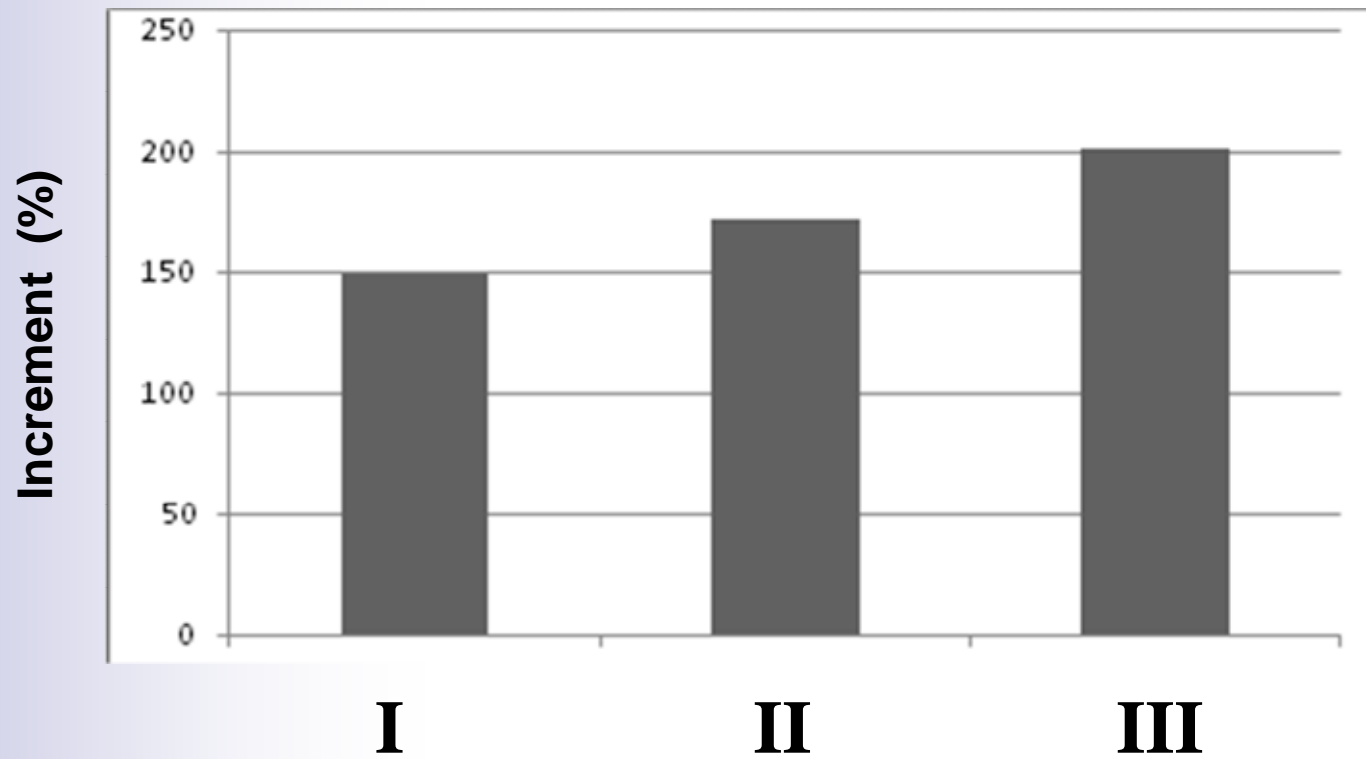
43,85 h x 132,25 h

Validation

Energy Waste



Validation Lifetime Increment



Conclusions

- **Very low estimation error**
 - n **There was no case above 2%**

- **Long lifetime increment**
 - n **Lifetime increment on all scenarios**
 - **Some with more than 200%**

- **Better energy use**
 - n **Less energy waste**

OBRIIGADO

!

THANKS!

Ευχαριστίες!