Non-Intrusive Load Monitoring of Smart Meter Data using Ant Colony Optimization Algorithm

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Outline

- Introduction
- Problem Statement
- Methodology
- Results
- Conclusions
- References

Introduction

Non-Intrusive Load Monitoring:

- ❑ Invented by **George W. Hart**, Ed Kern and Fred Schweppe of MIT in the early 1980s
- ❑ Disaggregate a house-level smart meter data into its device levels
- ❑ Time series classification problem

Introduction cont.

Applications of NILM:

- ❑ Detailed bill information
- ❑ Demand response application
- ❑ Occupancy detection
- ❑ Illegal load detections

NILM

I. Data acquisition:

- ❑ Voltage
- ❑ Current
- ❑ Apparent power
- ❑ Real power
- ❑ Reactive power

- ➢ High sampling rate
- ➢ Low sampling rate

NILM cont.

II. Event detection and Feature extraction:

- Steady state features
- Transient state features

NILM cont.

III. Methods:

- Supervised methods
  - Pattern recognition approaches
  - Optimization approaches
- Semi-supervised and unsupervised methods

NILM cont.

IV. Appliance classification and Load disaggregation:

- ❑ Detailed information about the amount of consumption contributed by each device of a household consumption will be provided to the user

Ant Colony Optimization

Ant Colony Optimization:

- ❑ Population based meta-heuristic optimization methods
- ❑ Derived from the behaviour of natural ants. They identify the shortest possible path between their nest and the food source with the help of pheromone depositions.
- ❑ The shortest path will have a stronger pheromone concentration than the other paths.
- ❑ Features
  - Parallel search
  - Adaptability to changes in search space
  - Long term memory
  - Information sharing

Work Conducted

Two Parts:

1. Identification of conforming loads

2. Load disaggregation

Part-1
Identification of Conforming Loads using Ant Colony Optimization Algorithm

Problem Statement

$$\text{Diversity Factor}, DvF_k = \frac{\text{Maximum non-coincident demand}}{\text{Maximum coincident demand}}$$

Objective function:

Minimize $$DvF_k = \frac{P_{ncpeak,k}}{P_{peak,k}}$$

Constraints:

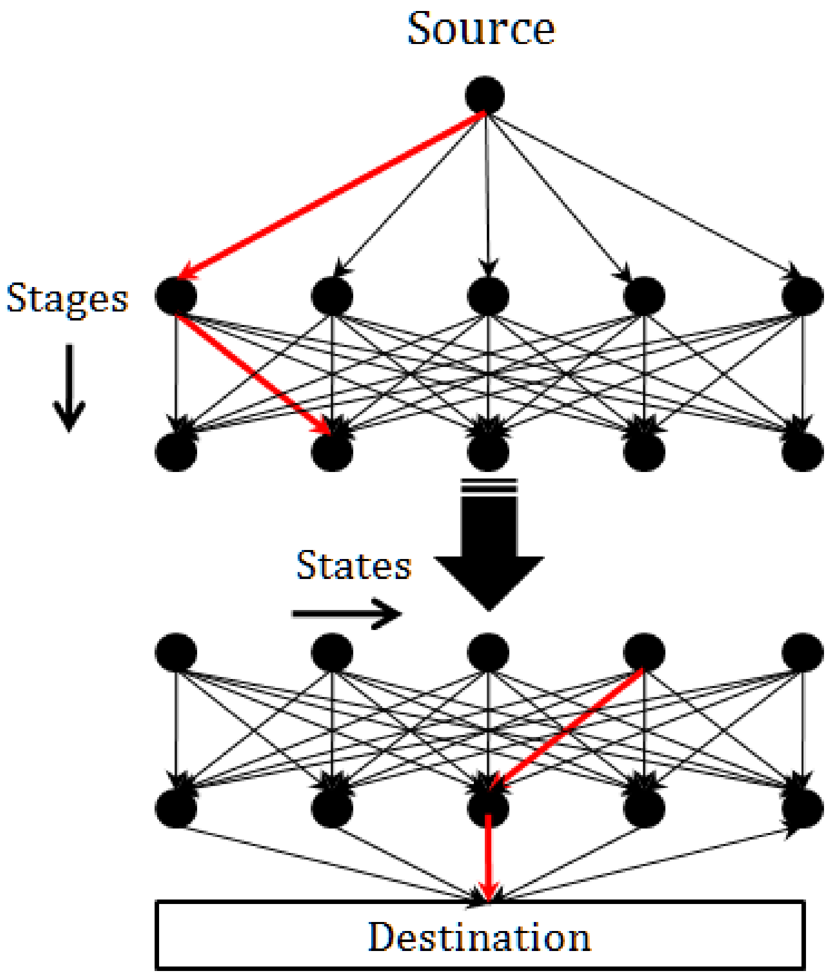
1. Consumers considered should be of similar category.

2. $\Delta DvF_k > 0$

Methodology

- Based on the concept that diversity factor for group of conforming loads is close to 1.

- Conforming Load Identification problems is similar to Travelling Salesman Problem.



Methodology cont.

- Each ant placed on a starting state, will build a full path from the beginning to the end state through repetitive application of state transition rule (probability) which is given by:

$$p_k(i,j) = \begin{cases} \dfrac{[\tau(i,j)]^{\alpha}[\eta(i,j)]^{\beta}}{\sum\limits_{m \in J_k(i)} [\tau(i,m)]^{\alpha}[\eta(i,m)]^{\beta}}, & if\ \ j \in J_k(i) \\ 0\ , & otherwise \end{cases}$$

- Pheromone content of the path from the element- i of previous stage to element-j of the present stage: $\tau(i,j)$
- Inverse of distance of the corresponding path: $\eta(i,j)$
- Set of elements that remain to be visited in the present stage by ant-k positioned at device-i: $J_k(i)$
- Parameters signifying the importance of trail intensity and visibility: α *and* β

Methodology cont.

- Once an ant completes its tour, the pheromone content of the complete path travelled by it is updated using the following equations:

$$\Delta\tau(i, j) = \Delta\tau(i, j) + q \sum_{Stage-1}^{Stage-n} d(k)$$

$$\tau(i, j) = (1 - \rho)\,\tau(i, j) + \Delta\tau(i, j)$$

- incremental change in pheromone for a path from device-*i* of previous stage to device-*j* of the next stage: $\Delta\tau(i, j)$
- heuristic parameter: *q*
- distance of the completed path from stage-*1* to stage-*n:* $\sum d(k)$
- pheromone trail decay co-efficient: *ρ*

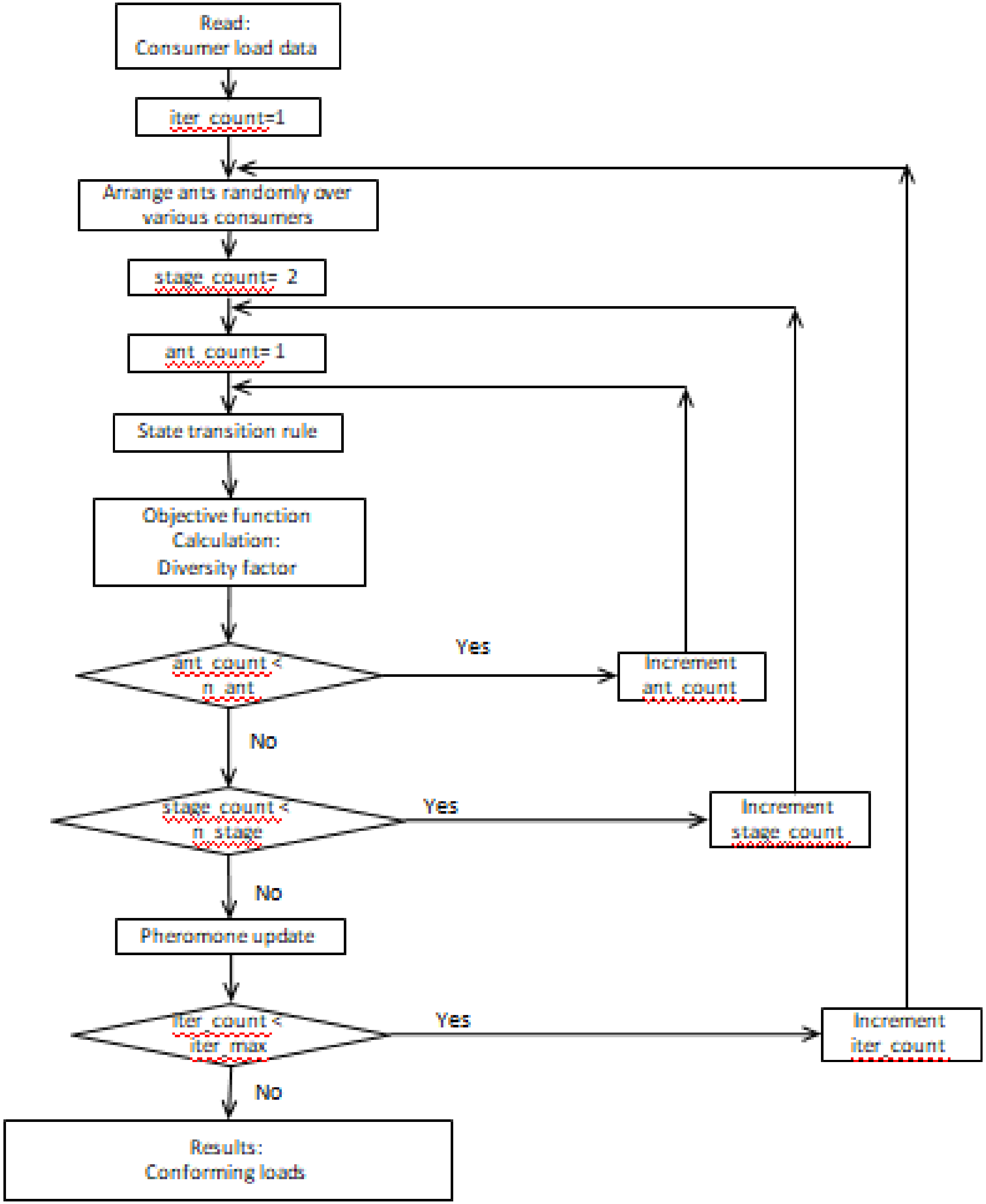
Development of MATLAB Program

- Matrices defined in the code:
  - Pheromone
  - Eta
  - Probability
  - Tabu_list
  - Best

Steps for ACO Algorithm

- Main program consists of the ACO algorithm:

1. Initialization step during which the problem variables are defined and initial ant population is generated and distributed.
2. Evaluations of the objective function for all the ants – diversity factor between combination of two customer loads.
3. Calculation of the probabilities for all available choices based on values obtained in step-2 – which customer to be selected next.
4. Updating of the pheromone intensity for the step considering the evaporation factor.
5. Ants proceed to the next customer.
6. The steps are repeated until the chosen criterion for stopping the calculation is achieved.

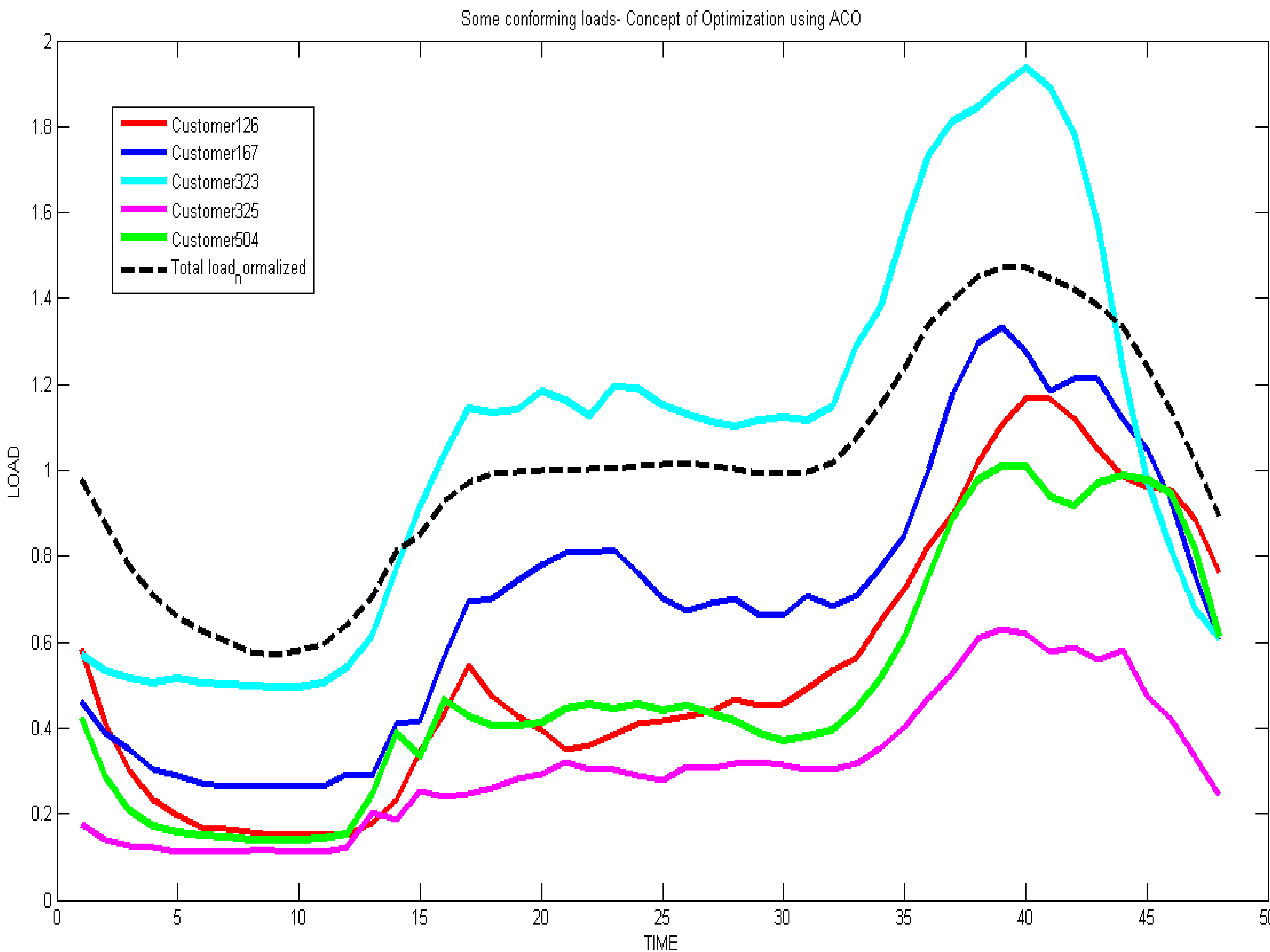


Flow chart for conforming load identification problem

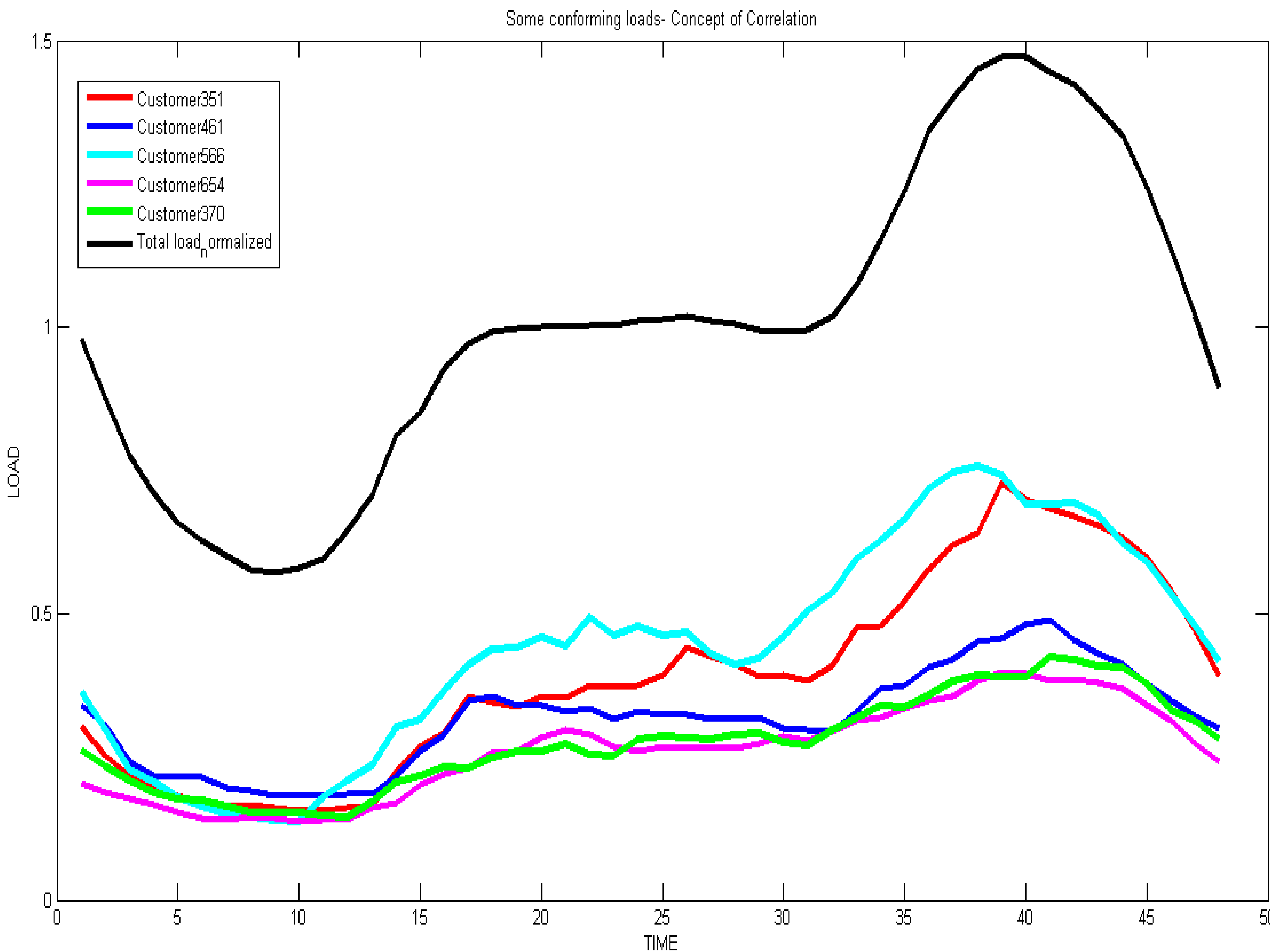
Results

Input: smart meter energy-use-data in London households

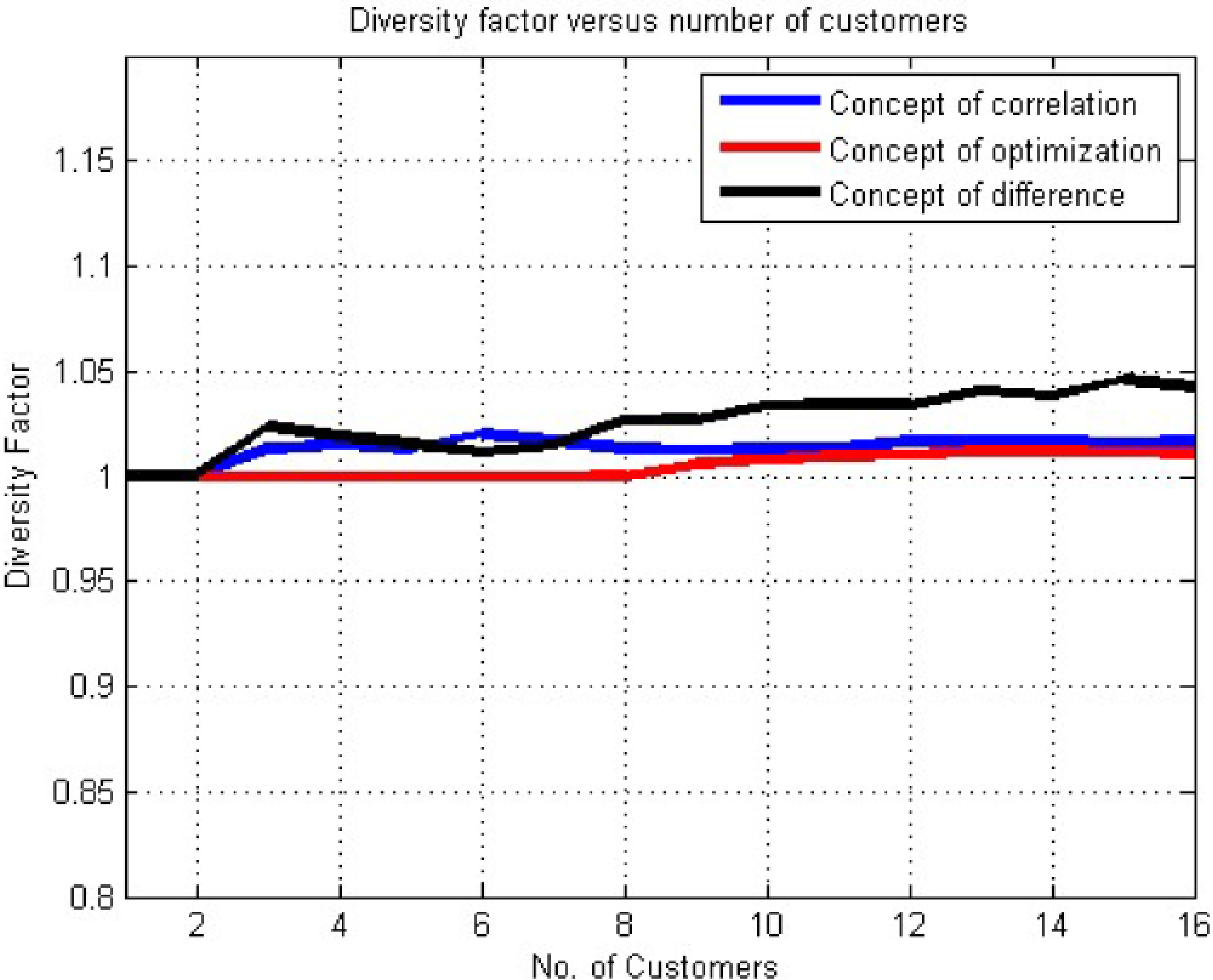
- ❑ Conforming loads based on ACO
- ❑ Conforming loads based on Correlation method
- ❑ Comparison of number of customer versus diversity factor for ACO, Correlation and Difference methods



Some conforming loads- Concept of Optimization using ACO
Customer126
Customer167
Customer323
Customer325
Customer504
Total load_normalized
LOAD
TIME
0
0.2
0.4
0.6
0.8
1
1.2
1.4
1.6
1.8
2
0
5
10
15
20
25
30
35
40
45
50



Some conforming loads- Concept of Correlation
Customer351
Customer461
Customer566
Customer654
Customer370
Total load_normalized
LOAD
TIME
0
0.5
1
1.5
0
5
10
15
20
25
30
35
40
45
50



Diversity factor versus number of customers
Concept of correlation
Concept of optimization
Concept of difference
Diversity Factor
No. of Customers
1.15
1.1
1.05
1
0.95
0.9
0.85
0.8
2
4
6
8
10
12
14
16

Part-2
Non-Intrusive Load Monitoring using Ant Colony Optimization Algorithm

Problem Statement

Constraint Satisfaction Problem : $\langle X, D, C \rangle$

$X = \{X_1, X_2, ..., X_n\}$, set of variables

$D = \{D_1, D_2, ..., D_n\}$, set of their domain values

$C = \{C_1, C_2, ..., C_m\}$, set of constraints

NILM :

X = set of appliances in the house

D = times of the day

C = maximum consumption at a specific time
cannot exceed power consumption registered by a smart meter

Methodology

Ant Colony Optimization

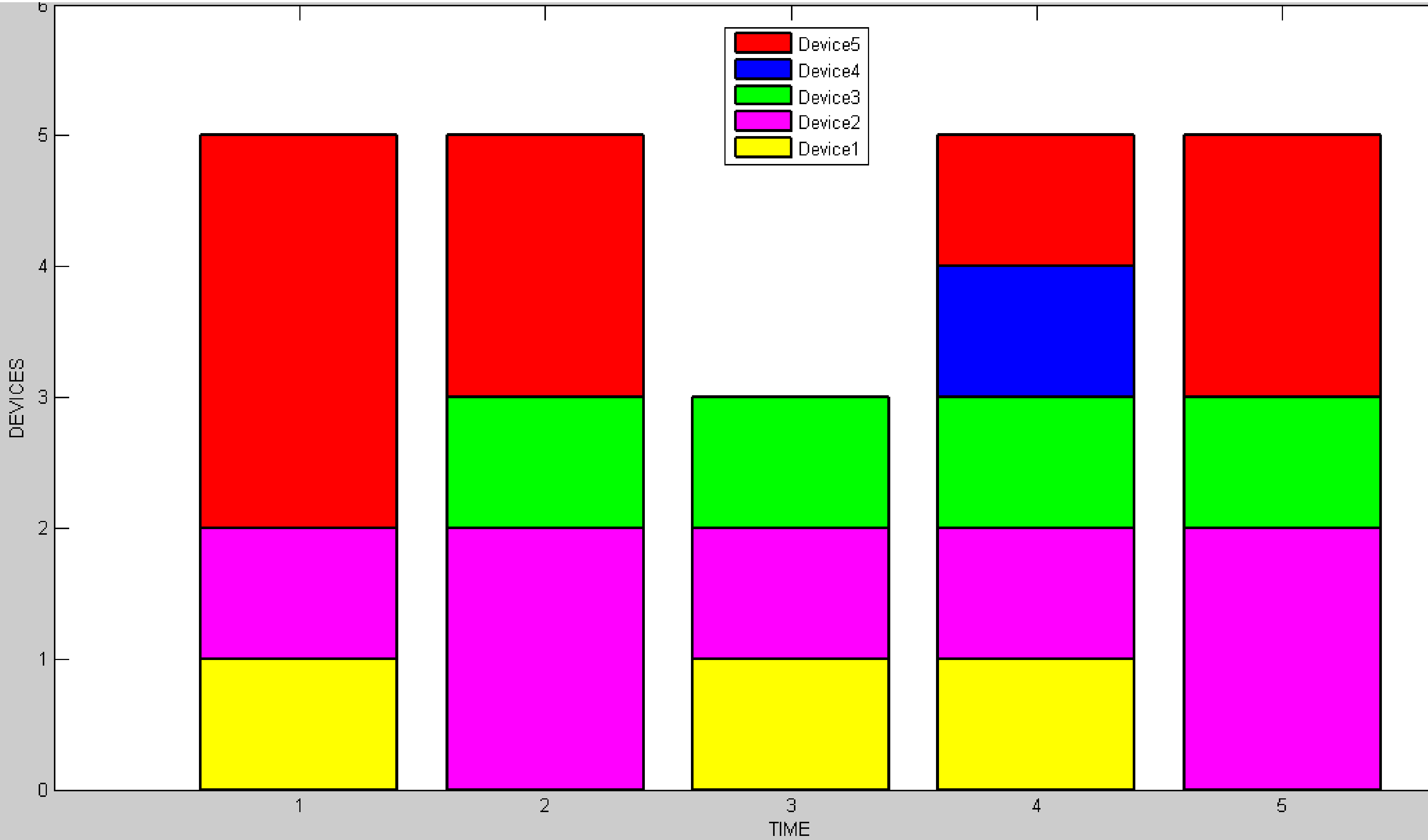
- All devices need not be visited at every instant of time
- Eta which is a factor giving importance to visibility needs to be updated for each selection of devices at each instant
- Many solutions may exist

Results

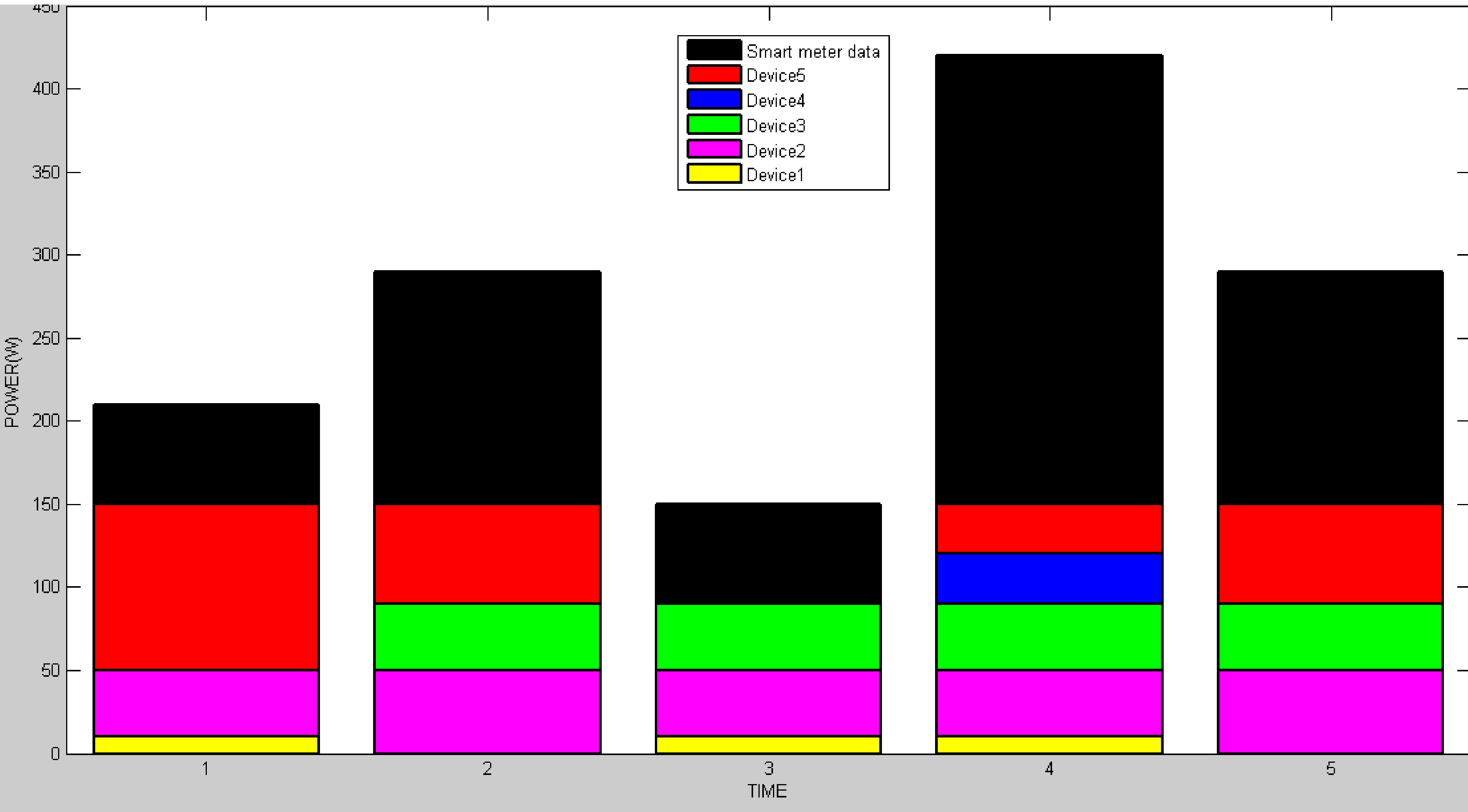
Sample data:

Device no.	Real power (W)	Time instants				
		t1	t2	t3	t4	t5
1	10	X		X	X	
2	50	X	X	X	X	X
3	90		X	X	X	X
4	120				X	
5	150	X	X		X	X
Smart meter data (W)		210	290	150	420	290

Disaggregated Devices



Device Power Levels



Conclusions- Identification of Conforming Loads using ACO

- Optimization methods can be implemented for the problem of identification of conforming loads.
- Statistical methods like correlation give same ranks to loads with same shape and different magnitudes.
- Also they give lower ranks to large consumers who partly share peaks and valleys of total load compared to small consumers whose peaks and valleys match with total load.

Conclusions cont.

- The proposed method gives good results by giving appropriate weights to magnitudes and shapes of individual consumer loads.

- To improve the computation speed of the algorithm, conforming loads obtained through any statistical methods can be given as input.

Conclusions- Non-Intrusive Load Monitoring using ACO

- Optimization methods can be implemented for NILM problems
- Easy to implement since they use static data.
- Computation burden can be reduced by properly tuning the algorithm parameters.
- Difficult to implement when unknown devices are included.

Future Scope

- ❑ Devices with different power levels to be included
- ❑ Program to be tested using benchmark data like REDD, UK-DALE, AMPds

References

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