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Department of Electrical and Electronic Engineering

Final Year Project Report 2014

Project Title: **Simulator for Decentralised Energy Systems**

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Abstract

In many developing countries the electricity grid network is underdeveloped, causing low levels of rural electrification. However, electricity access in these rural communities are not non-existent. There are a number isolated and independent electricity generators owned by individuals, NGOs and local government institutions. This project explores the feasibility of a Decentralised Community Energy System which utilises these isolated sources of electricity to create a community micro grid. It is planned to conduct the feasibility study with the help of a simulation to be developed using Presage2 and Java. This report outlines the deliverables, planning process, background research, and the design and implementation of the simulation model.

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Introduction 1

In many areas of rural developing countries, there are often no wide-spread access to a continuous and reliable electricity supply such provided by the country's electricity grid.[2] However there exists many isolated sources of electricity generation such as solar panels and standalone diesel generators utilised by relatively wealthy households, shops and buildings belonging to large organisations.

The aim of this project is to explore the idea of using a holonic institution to model a Decentralised Community Energy System which bring together the existing decentralised generation infrastructure to provide an affordable source of reliable electricity for users in rural communities.

Over the course of this project, a multi-agent simulation model was built using Presage 2 with individual households and businesses modelled agents. The agents can be grouped together to form communities such as villages, which in turn can be grouped together to form a larger entity such as a district or a province.

With humans being social creatures who are likely to band together to form communities, the structure of the decentralised energy system model will be designed in a similar way with holonics. The structure of how the simulation is designed is based on the design of holonic systems. In the case of this project, the simulation will be to distribute fairly electrical power between interrelated agents which are in turn composed of interrelated subagents recursively, until reaching lowest level of subagents (households and businesses).

To allow the model to be realistic, candidate rural communities with no access to a source of reliable electricity will be identified using data and research. Additional data on usage habits and potential generation profiles of generators in the candidate areas will be obtained through research to produce a simulation model that is accurate and relevant.

Include:

- Design Choices: Holonics, design of objectives
- difficulties and how they were designed:

  Out of order parallel execution

  Presage

  One action per time step
- Discovery or invetion of something novel?
- What did you learn:

  Java, Presage, Software design

This report outlines the design, implementation and testing of a holonic multiagent simulation of a decentralised energy system.

Background 2

Electricity as a Common Pool Resource

A Common Pool Resource is a depletable resource which can be utilised by a group of people, characterised by a reduction in the availability of this resource as individuals withdraw or utilise this resource.[3] Electricity can be a Common Pool Resource if there exists a finite amount of electricity generation capacity. As users connect demand appliances to the generators, the availability of electricity supply for additional demand diminishes.

In developing communities with significant generation from renewable sources such as wind and solar, the availability of power is subject to variation between periods in time. This inherent volatility in the amount of available resource could increase the likelihood of selfish actions of by individuals in the community.

Ostrom showed that Common Property Regimes can be formed to maintain the Common Pool Resources by controlling the access to the resource.[3]

Decentralised Community Energy Systems as a Holonic System

A holonic system (or holarchy) is a system which is composed of interrelated subsystems or institution, each of which are in turn composed of sub-subsystems or institution and so on, recursively until reaching a lowest level of "elementary" subsystems. Each system, sub-system or institution has a well-defined set of goals or objectives which is achieved through enforcing a set of rules on its members (subsystems, sub-institutions and elementary entities).[4] It is this type of Common Property Regime that will be explored in this project to maintain the Common Pool Resource that is electricity.

In the context of a rural Decentralised Community Energy system, a network between households, communities and even villages to pool and share electricity as a common pool resource can be modelled as a holonic system. The holonic system in this case would be composed of communities such as Districts, Provinces, Sectors which are composed of sub-communities such as Towns and Villages. The sub-communities would be composed of many "elementary" subsystems such as households, businesses and other points of connection for electricity. Each community or institution has the goal of fairly allocating electricity to all members. This goal would be achieved with the assumption that they are provided with the necessary infrastructure and powers for enforcing quotas and contribute to a common pool of electricity.

Distributive Justice

Given that the necessary infrastructure and powers exist for enforcing quotas and contribution to the Common Pool, the allocation needs to be fair. Being fair forms two of the necessary Ostrom's Principles for Enduring Institutions in a Common Property Regime.[3] Rescher

Multi-Agent Simulation

The simulation will be designed as a Multi-Agent System (MAS). MASes are particularly suited for this kind of model as Agents in MASes have three very important characteristics:

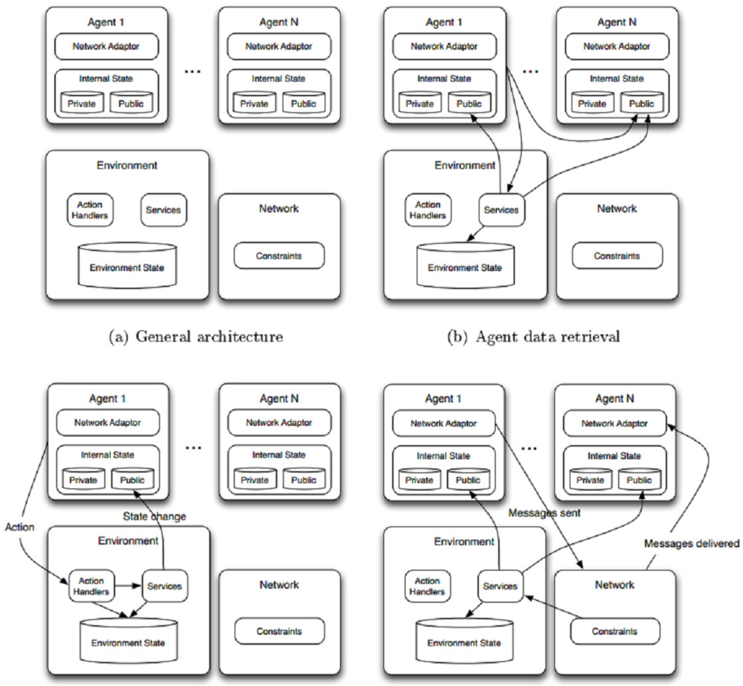
- Autonomous: Agents act independently
- Local view: no Agent can see or manipulate the environment it is in
- Decentralised: There is no Agent which controls the action of all Agents

In reality, individual households which are represented by Agents in the simulator all perform actions according to their individual and unique needs, and not controlled by a third party. This makes Autonomy and Decentralisation a requirement for the Agents in the Simulator. Participants or households connected to the network can't directly control how other participants use or generate electricity for the Common Resource Pool, making it an requirement for the Agent to have a Localised view.

About Presage 2

Presage 2 is a simulation platform for multi-nodal or Agent simulation of societies. The platform was built by Sam Macbeth and is currently maintained by PhD students within Imperial. This platform was chosen for the simulator as it enables the investigation of the impact of agent design (such as household behaviour), network properties (constraints on access) and the physical environment on individual agent behaviour and long-term global network performance.[9] In the context of this Project, each Node/Agent can represent individuals, households, businesses or generators.

Presage 2 was chosen for this project as it is a platform which allows the rapid prototyping of complex Agent societies. Presage 2 Agents are only allowed to act during increments of time steps, which makes the simulation a discrete time driven one. Figures 2.1 and 2.2 illustrates general and simulation archtecture.



(a) General architecture

(b) Agent data retrieval

(c) Agent acting

(d) Agent messaging

FIGURE 2.1: Presage 2 architecture[1]

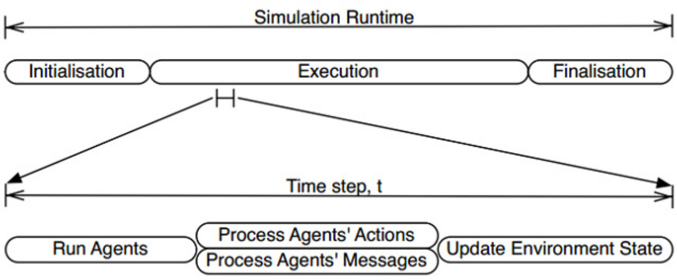


FIGURE 2.2: Presage 2 simulation architecture[1]

Rural Communities in Rwanda

With an estimated 25% rural electrification rate in 2009,[2] rural Africa is one obvious candidate for simulation scenarios. Vast amounts of rural communities remain un-electrified. For a realistic simulation scenario, knowledge of existing infrastructure in place will need to be obtained. With many areas within many countries in Africa, Rwanda in particular has been identified as a good potential simulation scenario to research. Data is difficult to source for rural communities in developing countries, however in the case of Rwanda, some data can be easily from the student society e.quinox. e.quinox is a student-led society which aims to find a scalable solution for rural electrification who mainly operate in Rwanda.[5] The subsections below outline some of the ways remote rural communities are able to access electricity in Rwanda.

Electricity Generation

One of the solutions currently being implemented by e.quinox is the "Energy Kisok" model.[6] The "Energy Kiosk" model features an Energy Kiosk - a building where the generation, storage and distribution of electricity takes place. In e.quinox operated kiosks, electricity is generated from renewable sources. Traditionally, this has been with solar panels. However, hydro-electric generation has been demonstrated to be feasible with the recent construction of a "Hydro Kiosk" at Rugaragara Falls in Southern Rwanda.

Storage and Distribution

Within each kiosk, electricity that is generated is stored in storage batteries placed in the kiosks. The storage batteries regulate power output and allows access to electricity in the kiosk even during periods of no electricity generation.

Battery Box

In the absence of any electricity distribution infrastructure, e.quinox has traditionally provided a number of portable batteries for the purpose of electricity distribution. An example of the portable batteries can be seen in Figure 2.3.

Consumers from local community pay to hire the battery boxes under one of two payment schemes: pay-per-recharge and pay-per-month.[7] The biggest difference between the two schemes are that users can recharge as often as they would like with pay-per-month. Both payment schemes involve the recharge of the boxes at the energy kiosk when they are depleted of energy.

A potential use case of this project can be the simulation of charging of battery boxes at an energy kiosk. This could alleviate congestion and improve asset utilisation of the existing distribution systems by reducing the turn-around time of battery boxes for customers.

Micro Grid

With the recent completion of a hydro-electric kiosk. e.quinox for the first time has a kiosk with access to an always-on generator. With a limited number of battery

FIGURE 2.3: First Generation e.quinox Battery Boxes deployed at Rugaragara Falls Kiosk

boxes in circulation and a constant generation available during the off-peak hours, there is excess capacity for electricity generation.

To improve utilisation of the generator in the kiosk, e.quinox has recently started conducting a feasibility study into constructing a transmission line and a distribution network which will serve a village near the kiosk with a view to make the most of the electricity generated.

Preliminary surveys conducted in the nearest village to the kiosk indicates the demand could exceed the amount of excess power generated by the kiosk.

The result of this project can be used in conjunction with e.quinox to conduct the feasibility study of implementing the Micro-Grid. Should a trading platform for energy also be built, the Micro-Grid could serve as a test-bed for this new system.

Standalone Solution

The Standalone Solution is an independent electrification solution which was recently developed by e.quinox for customers who live far from energy kiosks.

The Stand-alone solution consists of a pay-as-you-go solar electricity generation and storage kit, known as the Izuba.Box.[8] With the Izuba.Box, customers no longer have to travel regularly back to the Energy Kiosk for electricity. Solar panels are installed on the customerâĂŹs roof, and is connected to a sealed box which contains a large battery box. The attached large battery box allows a regulated power output and access to electricity during dark hours.

With the customers not returning to Energy Kiosks, the battery boxes are not hired out like the battery boxes are. The high capital costs of the independent solar system is spread over typically a two year rent-to-own payment plan using a mobile payment system.

It is hoped that the Standalone Solution and additional generation from the Energy Kiosk can be complemented the battery boxes in circulation to provide a continuous access to electricity to all households in the village.

Figure 2.4: First Generation Izuba.Box deplyed in Minazi, Northern Rwanda

In the context of the Project

In developing countries such as Rwanda, poor communities with no access to grid electricity are often in isolated locations. In these areas, fuel for generators are often difficult to obtain. Other available sources of electricity such as solar and wind power are highly dependent other variables such as weather. It is also highly unlikely that they will have access to redundancies to ensure continual access much like the electricity we receive from the national distribution and transmission network in the UK. It is therefore beneficial for systems such as the one being modelled as it has lower barriers to entry than access to grid electricity.

Requirements and Design 3

In this project, a model of a rural electricity network that is disconnected to the grid is expected to be modeled. To allow the network to be scalable, the network is holonic in structure and consist of communities of "smart households" which can generate and utilise electricity depending on their demand and generation profiles. Therefore the simulator was required to have the following features:

- Multiple Forms of Generation: Renewable and Non-renewable generators which can operate continuously or discontinuously
- Realistic Generator Models: Programmable variable generation power output to simulate wind and solar power
- Multiple demand centres: the simulation will be of one or more communities operating with a number of households/businesses requiring electricity
- Self organising by the system to allocate the available power fairly to all users
- Presage 2: The simulation will be programmed in Java using Presage 2.

As this was a simulation implemented in Presage 2, there were no specific requirements which must be adhered to with regards to speed, portability and performance.

The simulation was developed using Presage 2, with the hope that a network of Decentralised Community Energy Systems can be simulated, and an algorithm for fairly allocating available generation to demand will be implemented. It is assumed that no cheating will take place.

Model Design

To allow communities to work as holonic systems, communities will be created and simulated akin to the simplified model in Figure 3.1. The Agents in this case are reprsented by the Circles labeled A-H, with various demand/generation equipment connected to the Agents. The Agents are connected to a Virtual Agent or a Parent Agent represented by the single black dot that all Agents on the periphery are connected to in Figure 3.1.

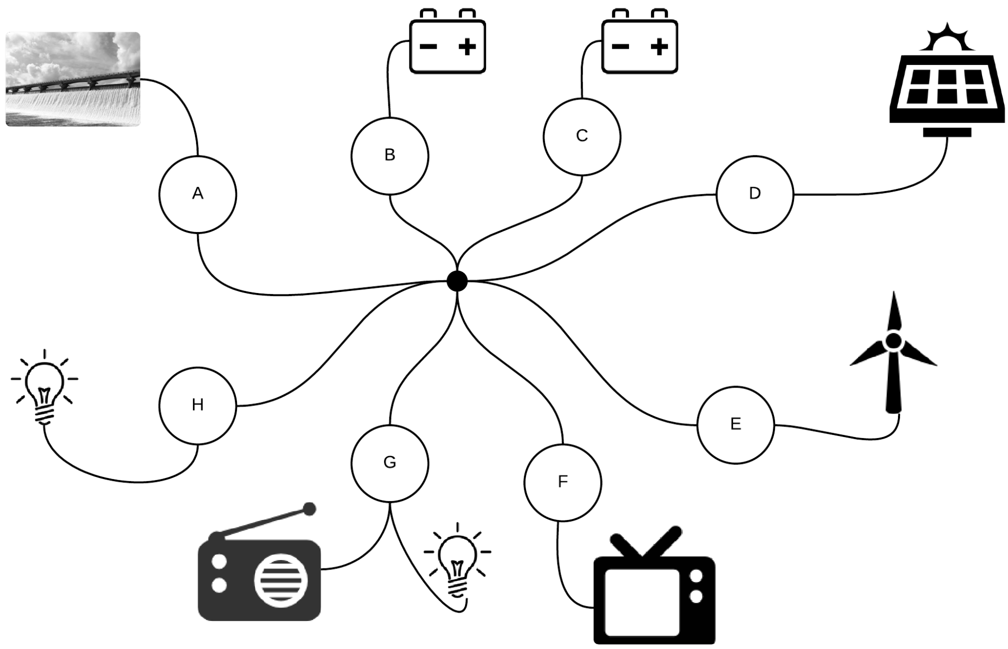


Figure 3.1: A simplified model diagram

Agents that group together are connected to a central virtual agent to allow the agents to form a community. These communities can further connected to another virtual agent to form even larger communities demonstrated in Figure 3.2.

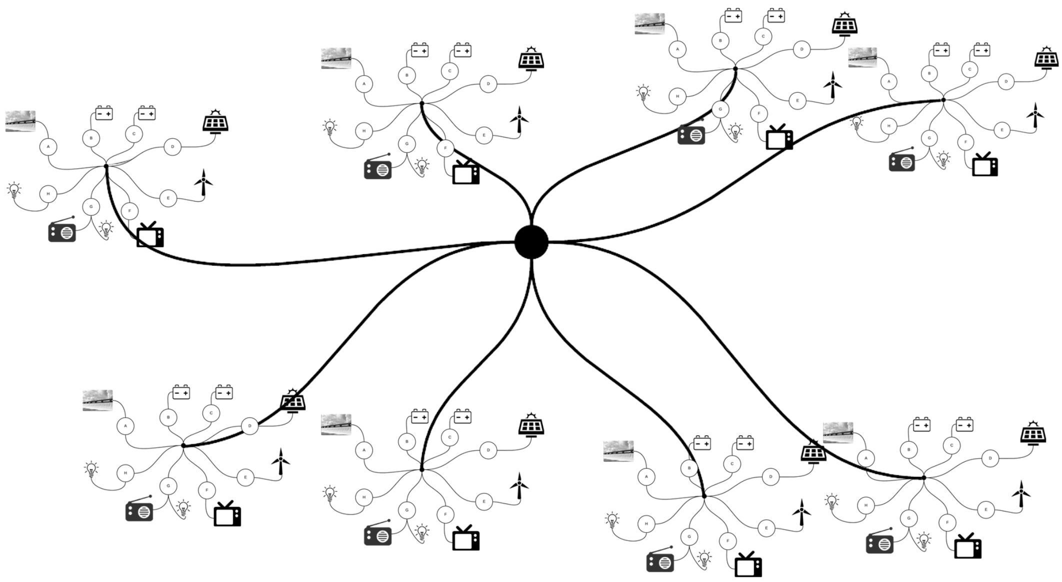


Figure 3.2: A simplified network model diagram

Design and Model Assumptions

To simplify the implementation of the model, a number of assumptions will be made in the design process:

- No losses would be incurred by the network
- All load on the network will be purely resistive
- All generation will act as negative load
- Only basic appliances such as phones, lights and fridges will be connected to the vast majority of households.

Types of Agents

Presage's main components are Agents, which are the actors which can act on the environment.

Virtual Agents

Virtual Agents represents all connected sub-communities or Agents in community of Virtual Agents. These Agents will be responsible for enforcing quotas on connected sub-communities or Agents and collecting Generation for the Common Pool.

Prosumer Agents

Agents represent the most "elementary" system such as generators, households, businesses and other demand centres.

Agent Properties

Agent Properties represent the information that is to be relayed to the Community or Institution that the Agent is part of.

Demand - All Agents will also have the Demand property which represents aggregated electricity consumption at a point of connection. Assumed demand curves will be produced from survey data of potential customers in the area for the initial testing. Should the survey data not be available for the area, a reasonable approximation will be made based a predicted usage habits of the wider local population.

It is anticipated that the final simulation will have a desired demand profile that each agent will aim to have.

For Virtual Agents, this property represents the aggregated Demand of all connected sub-communities or Agents and will not have any associated Demand profiles.

Generation - All Agents will have a Generator property which will allow all agents to generate power. For Virtual Agents, this property represents the aggregated Generation of all connected sub-communities or Agents. Four types of generator properties will be implemented in this simulation model for Prosumer Agents:

- Hydro-electric - a constant source of energy based on a mixture of historical data and projections.
- Solar - a source of energy following the typical output profile of a solar panel connected to households.
- Wind - a source of energy which will be highly variable in output.
- Diesel - a constant source of energy.

With the power output of renewable sources of energy such as wind and solar being non-predictable in nature, one of two approach will need to be undertaken to model these sources:

- A probabilistic generating factor is applied to the generators. This is a constant amount of power each solar panel or wind turbine is assumed to produce during some hours of the day that is to be determined.
  - If this method is to be used, the model needs to be implemented in such a way to allow dynamic load-shedding and load-dumping.
- A probabilistic generation power output curve based on the least sunny / least windy days
  - If this method is to be used, sufficient weather and generation data will need to be obtained to implement this method

Both methods are in use by distribution networks in the UK for assessing network congestion.[10]

Storage - Storage devices will be batteries of various types that can be connected to the network. For the purpose of this project, it will be assumed that all Prosumer Agents will have one of these to allow allocation of electricity on a hourly basis.

The Storage property should be designed have the capability to prioritise the allocation of its stored energy for certain Agents. For example, the energy output of Storage-only agents could be made to always prioritise the households they are attached to. If the battery box is communal or belongs to a centralised entity such as an e.quinox Energy Kiosk, then no priority will be attached.

Simulation with Presage 2

For the initial implementation and testing, the model will only contain two levels of Aggergation (see figure below):

Include figure here.

During a round, Agents are expected to publish their Demand/Generation to their Community or Parent Agent. The Parent Agent aggregates this Demand/-Generation and publishes to the Supervisor. The Supervisor aggregates the total Demand/Generation and appropriates the electricity fairly.

Fair Appropriation of the Common Pool Resource

Implementation 4

In this section, how the design is implemented will be described in detail

Agents

Agents in Presage 2 are created by extending the AbstractParticipant class. As Virtual Agents and Prosumer Agents behave in a similar fashion, the Prosumer Agent is designed to extend the Virtual Agent with additional properties such as ParentID and ability to add Demand/Generation profiles.

Environment Services

All Agents act within Environments, which would contain shared state between Agents. In the context of this simulation shared state would be information such as the amount available in the Common Resource Pool.

Action

To act on the Environment or acess a shared state in the Environment, Agents are expected to perform an Action. In the context of this simulation, Action would be Demand/Generation requests. As Generation can be modelled as a negative Demand, a single Action can be defined to allow the contribution and appropriation of electricity.

Action Handlers

To enable the Environment to be able to process the Action requests, Action Handlers need to be created to tell the simulation how to deal with Actions from Agents.

Simulation

Issues

Out of order parallel execution meant that Agents need to submit their individual Demands to the SharedState, and have that summed at the end of each timestep. It is not possible to sum the Demands on the fly.

Being new to both Java and Presage presented problems of its own. It was difficult to understand how simulations could be run and therefore create our own.

One action per time step meant that it takes 4 time steps to simulate one round of request and appropriation of electricity. It would therefore take 24*4 time steps to simulate a full day of requests and appropriation.

Figure 4.1: Agent UML Diagram

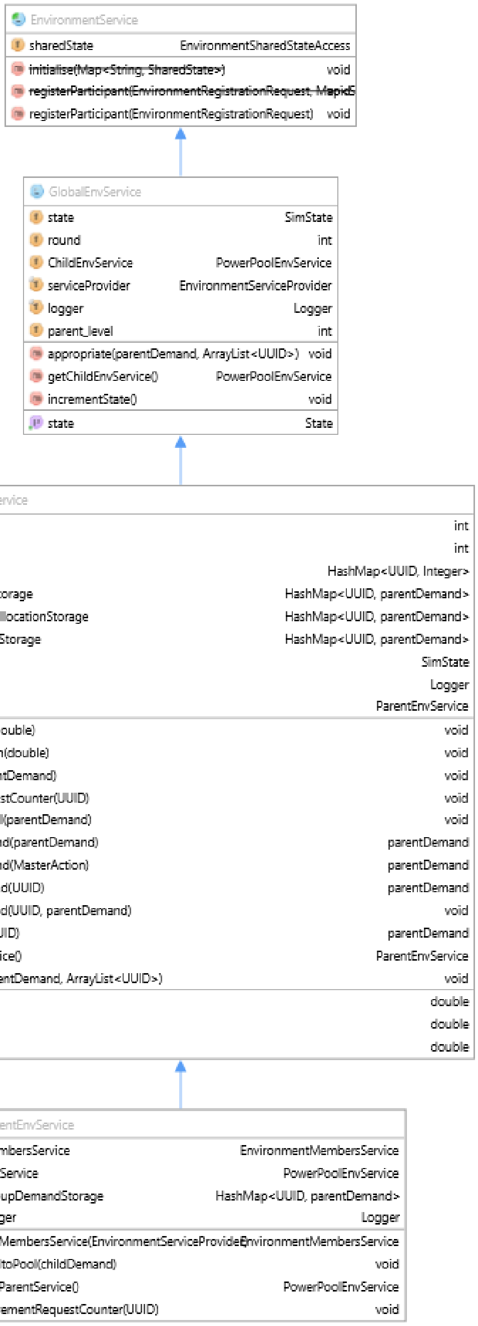


Figure 4.2: Environment Services UML Diagram

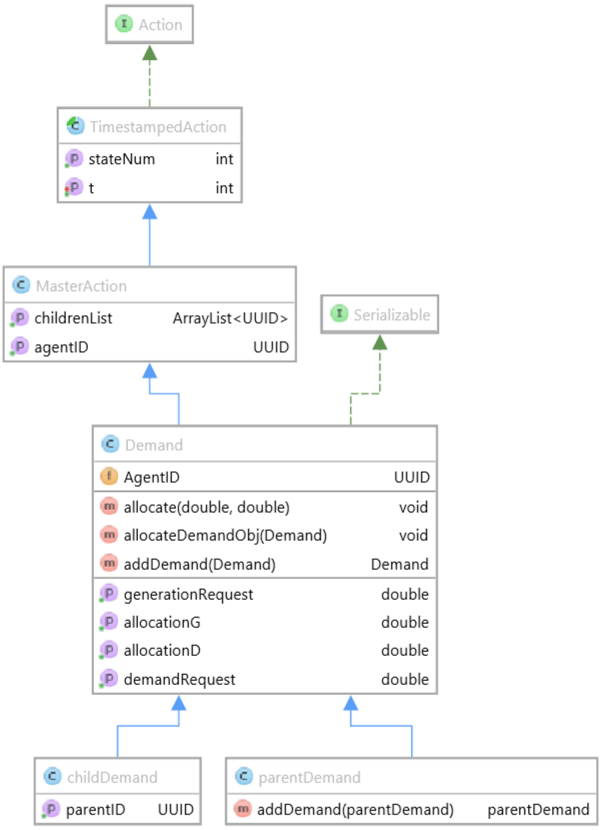


Figure 4.3: Actions UML Diagram

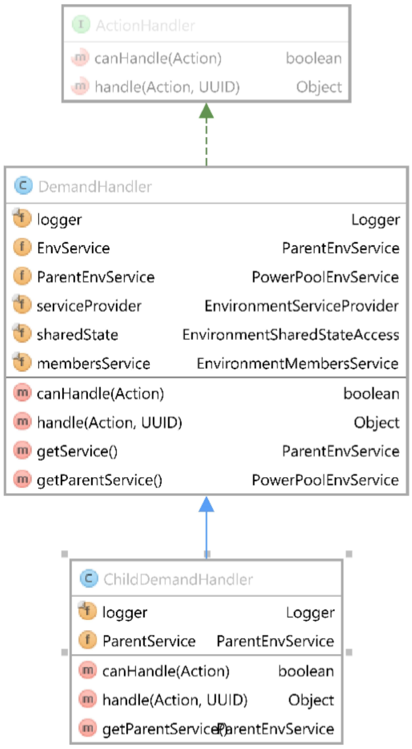


Figure 4.4: Action Handler UML Diagram

5 Testing

The final product of this project should be a realistic simulation of a Decentralised Community Energy System. To produce the simulation, each of the following features will be tested to ensure they work individually and together:

- A network of Agents able to trade electricity with each other.
- Agents are able to utilise energy. The amount of energy utilised can be pre-determined manually by an operator of the simulation or automatically with an algorithm.
- Agents are able to generate an amount of energy corresponding to a pre-allocated fixed output, or an amount based on their assigned Generation Profiles.
- Each Agent is able to utilise and generate electricity at the same time.

5.1 Contribution to Pool

To test the contribution to the Common Pool,

5.2 Correct Appropriation

Results 6

6.1 One Agent (No Participation)

6.2 Multi-Agent Proportional Allocation

6.3 Multi-Agent Fair Allocation

7 Evaluation

Conclusions 8

Since October, an attempt has been made on understanding the properties of Common Pool Resource, and how electricity can be a Common Pool Resource in the context of a Decentralised Community Energy System. An attempt has been made on building a simulator of a Decentralised Community Energy System in developing countries.

The simulator demonstrated that the

The simulation of the Decentralised Community Energy System will be used to explore possible utilisation patterns within rural communities, and also explore controls for regulating the use of electricity. If the study proves to be successful, an attempt at designing and implementing a trading platform for Decentralised Community Energy Systems will be made.

Further Work 9

So far, the works carried out will be only be applicable for one community in rural Rwanda. It is hoped that work will be carried out to make this applicable to other communities by including more generation types such as biogas, and more types of appliances owned by each house.

In the immediate future, it is hoped that this tool could be used to aid the feasibility study of the Micro-Grid to be implemented in Rugaragara Falls. Should there be time, an energy trading platform will be designed and built based on the model created in this project to provide adequate electricity access to all members of the community. However, the energy trading platform would require a different design and implementation scheme which is not included in this report.

The sections below outlines the various properties each Agent must be able to take and how they could be implemented for the simulation scenario of rural communities in Rwanda. All of the properties must be allowed to exist on the same Agent during simulation.

In addition, the e.quinox Micro Grid is currently undergoing feasibility studies. If time allows, a system could be designed and built for the Micro Grid to allow the trading of electricity between households to guarantee electricity supply for when it is needed. This system however will have a completely different set of requirements, which will be drawn up after the completion of this project.

Consider Diesel Generators' costs Consider satisfaction of individual agents for them to partake in this

User Guide 10

The github source code repository for this project can be found at: https://github.com/yuchen-w/DCES-Simulator

The code was developed in IntelliJ Idea 14.1.3 IDE, however will work fine on Eclipse. Detailed instructions can be found on the readme of the repository.

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