SIMULATION OF POWER DISTRIBUTION MANAGEMENT SYSTEM USING OMACS METAMODEL

by

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Abstract

Designing and implementing large, complex and distributed systems using semi-autonomous agents that can reorganize and adapt themselves by cooperating with one another represents the future of software systems. This project concentrates on analyzing, designing and simulating such a system using the Organization Model for Adaptive Computational Systems (OMACS) metamodel. OMACS provides a framework for developing multiagent based systems that can adapt themselves to changes in the environment. Design of OMACS ensures the system will be highly robust and adaptive. In this project, we implement a simulator that models the adaptability of agents in a Power Distribution Management (PDM) system.

The project specifies a top-down approach to break down the goals of the PDM system and to design the functional role of each agent involved in the system. It defines the different roles in the organization and the various capabilities possessed by the agents. All the assignments in PDM system are based on these factors. The project gives two different approaches for assigning the agents to the goals they are capable of achieving. It also analyzes the time complexity and the efficiency of agent assignments in various scenarios to understand the effectiveness of agent reorganization.

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CHAPTER 1 - Introduction

Power Distribution Management (PDM) or Electricity Distribution Management is a system responsible for ensuring that the consumers have undisrupted power supply. Implementing a simulator for PDM system can aid in understanding the behavioral aspects of multiagent approach in distributed applications. This chapter gives an overview of the existing system of Power Distribution Management.

1.1 Problem and Approach

The main purpose of the PDM system is to supply electricity from the generating stations to the consumer locations via transmission stations. To improve transmission efficiency and to comply with consumer needs, the voltage may be stepped-up or stepped-down during transmission. The distribution and supply of electricity uses [3] a whole network of routers, circuit breakers, switches, alarms, load-reading meters and telemetry.

The network of PDM system includes various companies sharing National Grids for power distribution and supply. National Grid is the electricity transmission network that connects the major power stations and substations to distribute the electricity generated elsewhere. The current system makes use of a centralized architecture in which the Control Engineers (CE) with the assistance of Field Engineers (FE) does the management of these power distribution networks. The Control Engineer has to ensure that losses in the electricity transmission is kept minimal and all consumers are supplied an undisrupted power supply by maintaining an optimal power grid configuration [6].

The extent to which the CE controls the operations involved in ensuring the above priorities varies between substations. However, most of the time they have to rely on incomplete information obtained from a variety of sources. The decisions taken by them have to be both timely and secure, which include delegating responsibility to Field Engineers for network switching operations.

In order to make the system more robust and work asynchronously, we introduced a multiagent approach. The project involves analyzing the various components in the PDM system and designing the components as agents that can interact and cooperate with each other to achieve the goals of the system. Following the OMACS metamodel for designing the system ensures robustness and flexibility of the components. In addition, agents that can reorganize themselves divide and distribute the complex tasks between them, according to the changes in environment.

The main purpose of a simulator is to model an application before its real time implementation so that we can test our design and analyze the working of the system without the physical repercussions. This can help developers understand the behavior of current design under various conditions. Simulating the system like this will help in constantly improving the design and in refining the frameworks used for implementing the system.

The first step in this project was to study the existing PDM system. This included the various components that already exist in the system. We needed to understand "what is the main purpose of the system?", "how the tasks are met?", "how the objectives are achieved?" etc. For this, we analyzed the interaction and working of every module in the existing system. This enabled in identifying various system level goals of the system.

The next step was to apply a multiagent approach for the system design. This approach had several advantages over other centralized architectures. Dividing the tasks between various agents reduced the complexity of computation among them. Various tasks in the system were determined and a Goal Model was created to map the hierarchy of these goals. The tasks that require little interaction were divided into separate, fully independent goals so that a single agent could solve them. The subsequent step was to identify the agents in such a way that they can play their roles independently while cooperating with other agents in order to achieve the goal of the system.

All the agents possess a set of different capabilities. This helps to assign agents to roles that it can play the best. This also aid in distinguishing the agents between them. Each agent in the system has a different score for the capabilities they possess. This will help in determining the ability of an agent to play a role better than others do. In addition, this will aid in studying the reorganization patterns within the organization.

The final step was to determine the organizational activities that need to be monitored in the simulation. This was decided based upon the entities involved in the OMACS metamodel. An additional functionality to step through the simulation solves the problem of user not being able to review the assignments during run time.

Thus, the project analyzes the problems associated with the Power Distribution Management system. We have applied a multiagent system based approach with OMACS metamodel as the supporting framework. The project also overlook into the reassignment of agent tasks due to the changes in environment.

1.2 Scope and Objectives

The primary objective of the project was to study the behavior of PDM system implemented using the multiagent approach. OMACS provide a framework to develop complex, distributed systems that can autonomously adapt to their environment [9]. The ability of the agents to reorganize themselves according to their capabilities makes it adaptive to the changes in environment.

A large number of complex systems are conceptualized using multiagent system design. Distributed Vehicle Monitoring, Air Traffic Control, Power Distribution Management, Supply Chains, Network Management and Routing are some of them. We selected Power Distribution Management system for the study because of its complex, distributed nature. In addition, it very well associates into real-world problem domains that require distributed decision-making.

The aim of the project was to design the classic problem of Power Distribution Management using the multiagent systems concept. This project focuses on implementing a PDM simulator that conforms to the OMACS metamodel. The PDM simulator can replicate the system behavior according to various input scenarios. It also allows changes in number of agents available in the system and variations in the capability scores possessed by these agents.

The scope of this project limits to the implementation of a simulator for the PDM system. This simulator will enable us to study the working of PDM system under changing environments. This includes loading a configuration file, which specifies the various agents in the system and their capabilities and capability scores. The simulator will dynamically create the agents with those capabilities and uses two different algorithms for assignment of agents to goals. The simulator also enables us to step through the process and analyze the various assignments and agent reorganizations. Finally, it creates a log file, which records all the organization level activities and reorganizations in the system.

1.2 Document Overview

The structure of this report is as follows: Chapter 2 briefly outlines the background information about the OMACS metamodel. It contains literature review about the various research works on power distribution management system designed with the multiagent approach. Chapter 3 describes the analysis and design of the application including the various models created for system design. It explains the integration of agents into a cooperative problem solving community. Chapter 4 gives the implementation details of the PDM simulator and the two different reorganization algorithms used for organizational assignments. Chapter 5 explains the time and efficiency analysis of the two reorganization algorithms and the running time results of the simulator. It also explains briefly the limitations of the system and future works that can improve the usefulness of simulator.

CHAPTER 2 - Background

Organization Model for Adaptive Computational Systems provides a framework to develop complex, distributed systems that can autonomously adapt to their environment. This chapter explains the metamodel used in this project. It also provides a literature review of related work on power distribution management systems designed with the multiagent system approach.

2.1 Organization Model for Adaptive Computational Systems

In this report, OMACS refers to the Organization Model for Adaptive Computational Systems. The term Organization can be defined in many ways. In a multiagent system context, we can define an Organization as a complex, adaptive and distributed system in which a set of agents playing roles within the structure in order to satisfy a set of goals [8].

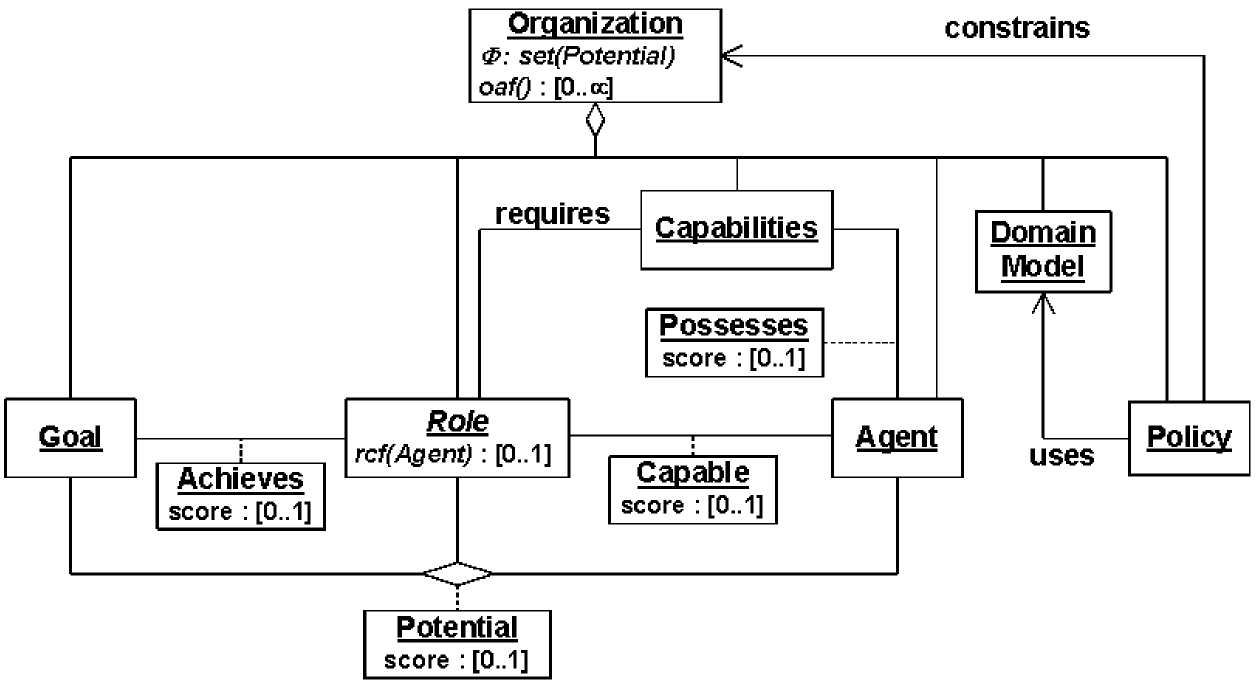
The main objective of the OMACS metamodel is to provide a framework that help in developing a stable multiagent system that is robust and reliable in unpredictable application environments. It makes sure that the configuration and dynamic nature of the application does not restrict the capabilities of the system. This is particularly relevant in complex and distributed applications like PDM as they involve much dynamic reorganization within the system.

Figure 2.1 shows the UML depiction of OMACS model. OMACS defines three standard entities of an organization: goals (G), roles (R) and agents (A). It also defines three additional entities: capabilities (C), assignments (Φ) and policies (P). These entities form the foundation for the OMACS model, and they are encapsulated in an overall entity called Organization.

OMACS defines a set of goals within the system that can be achieved only by playing the roles defined. In addition, there are agents defined within the organization that possess a set of capabilities. For an agent to play a role, it must possess the capabilities required by that role. The capability score measures the ability of an agent to play a role. A tuple of an agent assigned to achieve a goal by playing a role defines an Assignment at organization level. The policies defined can control the assignment of agents within the organization. The policies can also restrict the association of entities within the system.

The relationships between various entities in the organization model are as shown in Figure 2.1. The relationship between goals, roles and capabilities are assumed static. Nevertheless, the set of agents and their assignments are dynamic in nature and may change with the changes in environment. This is the key reason for using the OMACS metamodel for designing PDM system. The components of PDM application are distributed in nature and need to cooperate and communicate dynamically to achieve the system goals.

Figure 2.1 Organization Model [8]



The following section explains the definition of each of the entities in OMACS model and their relationships with each other.

2.1.1 Organization

Organization is a high-level entity that comprises of an aggregation of five other entities: Goals, Roles, Agents, Capabilities and Policies [9]. The organization entity in OMACS consists of a set of goals that the organization is trying to achieve. It also contains a function called oaf or organization assignment function. It calculates an organizational score for every assignment in the organization. This score determines the quality of assignments in an organization. In order to match the requirements of specific application we can override this function.

Another component in the organization entity is the assignment set (Φ). This set contains a set of assignments made within the organization that assigns an agent to achieve a goal playing respective role.

2.1.2 Goals

Every organization has an objective or goal that it wants to achieve. In OMACS metamodel, this root goal is sub-divided into a set of goals. Once all these goals are achieved, the root goal of the organization is achieved. This again depends on whether the goal is AND-refined or OR-refined. The goal refinements are explained in the later part of this section. The ordering of goals gives an opportunity to divide the root task of the application into separate goals, which may or may not dependent on other goals. In other words, the top-level organizational goal is decomposed into sub goals in order to specify the finer details of how the root goal can be achieved.

This is particularly relevant for the power distribution management application as the root goal of the application is to ensure uninterrupted power supply to all the customers. But this include a lot of distributed components in the whole process like electricity generation, transmission, supply, circuit breakers, switches etc. which has to be defined in finer detail in order to achieve the root goal.

The best way to depict the goals in an organization model is by using a goal tree structure called GMoDS or Goal Model for Dynamic Systems [11]. It uses UML class notations to represent the goals. The sub goals will be either conjunctive or disjunctive in nature. This depicts the decomposition of goals based on AND-refinement and OR-refinement. An AND-refined goal can be *achieved* if and only if all of its children are *achieved* while an OR-refined goal is *achieved* if any of its children is *achieved*.

For the goal tree to be compatible with the structure defined in GMoDS, it needs to satisfy three properties [11]: there must be exactly one root goal, all goals except root goal must have exactly one parent goal and there must not be any cycles in the tree. This AND/OR goal tree structure also allows to include attributes within a goal. Any attribute possessed by a goal is visible to all of its children. In addition, the goals in the goal model can have *precedes* and *triggers* relationship which are explained in coming sections.

Thus, the root goal defines the overall function of the organization. It is divided into sub goals in accordance with the definitions specified in GMoDS. This task of transforming the system requirements into goals and/or sub-goals [12] is termed as Model Goals.

2.1.3 Precedes

The *precedes* is a relation between two goals in the goal tree. It specifies a sequence, which has to be followed while achieving the goals. If a goal g1 *precedes* goal g2, then goal g1 has to be *achieved* before goal g2 becomes *active*. If a goal is in active state, then that goal is available to agents for processing. Once the processing of the goal is complete, it moves to the *achieved* state. The precedence relationships make sure that the dependency between the goals is preserved while multiple goals are active. All the sub-goals inherit the *precedes* relationship. For example, if a goal g1 *precedes* goal g2, then all the sub-goals of g1 must be *achieved* before any of the sub-goals of g2 becomes *active*.

In the PDM application, some goals should not be processed before certain goals are *achieved*. For instance, the system is not supposed to coordinate with the Field Engineer before trying to fix the fault by automatic operation of circuit breaker and remote switching operations. In this scenario, the *precedes* relationship will help in defining the sequence of operation while achieving the goals in the organization.

2.1.4 Trigger

During the processing of a goal tree, an *Initial Trigger* is required in order to create the initial set of goal instances. This will create an instance of all goals that do not have a *precede* or *trigger* relationship. These goals are then moved to the set of *active goals*. The organization will then start processing the goals in *active* set. Once a goal in *active* set is achieved, it is moved to the set of *achieved goals*. This will result in creating instances of goals that are *preceded by* that goal. They are added to the set of *active goals*.

If the goals are OR-refined, then achievement of any one of the sub-goals causes that goal to be moved to the set of *achieved* goals. As the parent goal is *achieved*, there is no need to work on its sibling goals. Those sibling goals are moved to a set of *obviated goals*. A set of *obviated* goals contain all the goals than do not need any more processing as their parent goal was *achieved*. This condition arises only in the case of OR-refined goals.

The *trigger* relation prevents the goals to be moved to the set of *active* goals until a specific event occurs. Once the *event* occurs, the triggered goals are moved to the set of *active* goals. The *triggers* relationship is inherited by its sub-goals. If a goal g1 triggers goal g2, all the sub-goals of g2 are moved to the set of *active goals* unless they have separate *triggers* defined. The event that caused the *trigger* to occur may happen anytime during the achievement of the goal, g1. The occurrence of an event allows a goal to pass attributes in the *trigger* to the goal created. Thus, the triggered goals are parameterized based on the attributes and any additional information provided by the event that triggers the goal.

2.1.5 Roles

Role is the entity in OMACS that has an *achieves* relationship with *goal* entity. Every goal in the set of active goals is *achieved* by playing one of the roles defined. An agent achieves a goal by playing the role that can achieve that goal. The role entity has a *requires* relationship with the *capabilities* entity in organization model. In order to play a *role,* there is a set of *capabilities* defined for that *role*, which need to be *possessed*. The *achieves()* function in OMACS returns a score which determines how well the *role* can achieve the *goal*. A role may be capable of achieving more than one goal. However, this function helps to determine which *role* can achieve the *goal* best.

For an agent in OMACS to play a role, it must possess the set of *capabilities* that are required by the role. OMACS defines role capability function or *rcf ()*, which helps to determine the ability of an agent to play a role. If and only if the agent possesses the capabilities required by the role, it can play that role. Calling the *rcf ()* function on a role by passing the agent and goal as parameters will help us to determine if the agent can play that role. The function returns a score between 0.0 and 1.0. The higher the score returned by *rcf ()* function, the better the agent can play that role to achieve the goal.

In the PDM application, each of the leaf goals is *achieved* by a different role. In addition, each of these roles requires a different set of capabilities. This will relate well to the real world application requirements.

2.1.6 Agents

According to Panait and Luke [6], an agent is a "computational mechanism that exhibits high degree of autonomy, performing actions in its environment based on information received from the environment". This is a generic definition for an agent in multiagent based systems. OMACS defines an agent as "computational system instances that inhabit a complex dynamic environment, sense and act autonomously in this environment, and by doing so realize a set of goals" [12].

Agents have a *possesses* relationship with the *capabilities* entity in OMACS. It gives the list of capabilities that an *agent* possesses. We can define a score for each of the capabilities in this set. The value of score typically varies between 0.0 and 1.0. The higher the value, the better the *capability* will be. The role capability function uses this capability score to determine how well the agent can play a role.

The agents in an organization are mostly designed to be heterogeneous. This will result in agents differing in their ability to play the same role. This is mainly due to the difference in capabilities possessed by the agents and the variations in capability scores. The agents in PDM simulator are heterogeneous in nature as there are agents with different set of capabilities. We can also specify the capability scores for each agent by changing the configuration file used for loading the agents in the simulation.

2.1.7 Capabilities

Capabilities is the entity defined in the OMACS model, which helps in assigning agents to play a role defined. They define a set of skills that an agent may possess. These skills will enable the agent to perform various actions in the environment. All the roles in OMACS define a set of capabilities that are *required* in order to play that role. The agents will possess a set of capabilities, which will help them to perceive and perform in the environment [12].

There is a score associated with each of the capabilities that an agent possesses. This will enable the organization to assign an agent to play a role using the role capability function. The agents in PDM application requires various capabilities like connecting to database, accessing network information, receiving weather updates etc. These capabilities will enable the agents to perform various tasks like monitoring network data and finding location of fault.

2.1.8 Policies

OMACS defines a set of policies for every organization. Policies are a set of formally specified rules to restrict the behavior of the organization in a particular situation [8]. They mainly limit the activities within the organization level. These restrictions can be on various levels and are classified as Assignment Policies, Behavioral Policies and Reorganization Policies. Mainly they impose constraints on organizational level entities like goals, roles and agents. They can impose restrictions on assignment of agents to play roles. The Reorganization Policies defines how the reorganizations within the organization must happen. The policies can also aid in managing the dynamic nature of organization.

2.2 Related Work

The multiagent system approach tends to influence a very large number of problem domains like embodied agents, game-theoretic environments and applications to real world problems [6]. Some specific examples are Cooperative Navigation, Cooperative Target Observation, Coordination Games, Distributed Vehicle Monitoring, Electricity Distribution Management, and Models of Social Interaction. Researchers follow different methodologies and metamodels to design these applications. This section reviews some of the interesting works on Power Distribution Management problems.

2.2.1 Cooperating Intelligent Systems for Distribution System Management

Varga, Jennings and Cockburn use a general-purpose framework called ARCHON (Architecture for Cooperative Heterogeneous ON-line systems) in order to design a management system for electricity distribution. They developed the application Cooperating Intelligent systems for Distribution system Management or CIDIM [1] using the ARCHON multiagent framework, to design the whole agent community.

One of the important factors that one will observe while analyzing the power distribution management system is that there are many pre-existing components in the system. So designing the system from scratch does not make a lot of sense. This is where the ARCHON framework has an edge over other frameworks. It allows the developer to incorporate the existing systems along with the newly designed components. This is extremely important for the majority of existing industrial applications. Even though this is an advantage for the ARCHON framework, if we compare it with the OMACS, the ARCHON framework does not aid much in assisting the developers for making the application to be dynamic in changing environments. The organization metamodel that we have used for the PDM system defines agent assignments and reorganizations in any highly adapting environment. Integrating the existing systems to the PDM system designed based on OMACS model concepts like agents, roles, goals and capabilities can deliver a very high order of efficiency for the application.

In CIDIM application, Varga, Jennings and Cockburn use a two-sided approach for integration. They use a hybrid top-down and bottom-up approach to incorporate the existing systems and to analyze the problem from a multiagent perspective. The paper details a specification of the CIDIM application in which the already existing functionalities as well as those newly required were described. In addition, the paper defines the agent instantiation approach and some of the common problem solving activities in electricity distribution management. These works have influenced the design of some of the functionalities and agent entities in the PDM simulator.

2.2.2 Other Works

Researchers have approached the problem of power distribution management from a number of different angles. Other than the CIDIM application, some of the notable works in this area are by Wittig and Mamdani [5] on use of Distributed Artificial Intelligence for industrial applications and by Li, Poulton and James on Agent based optimizations for Electrical Load Management. They mainly focus on the implementation of the system and the difference in performance of the system from the classical approach.

Most of the works on multiagent system design concentrate on simple environments and a restricted number of agents. The PDM simulator project using the OMACS framework tries to focus more on some of the more realistic areas like multiple agents, heterogeneity of agents and different scenarios. The PDM simulator also concentrates on the dynamic behavior of agents in different scenarios.

CHAPTER 3 - PDM System Analysis and Design

This chapter gives the application requirement specification for the power distribution management system. It explains the modeling of the PDM system and the high-level architecture for the simulator. The final section has the UML diagrams depicting the relationship between the various classes created for the implementation of the simulator.

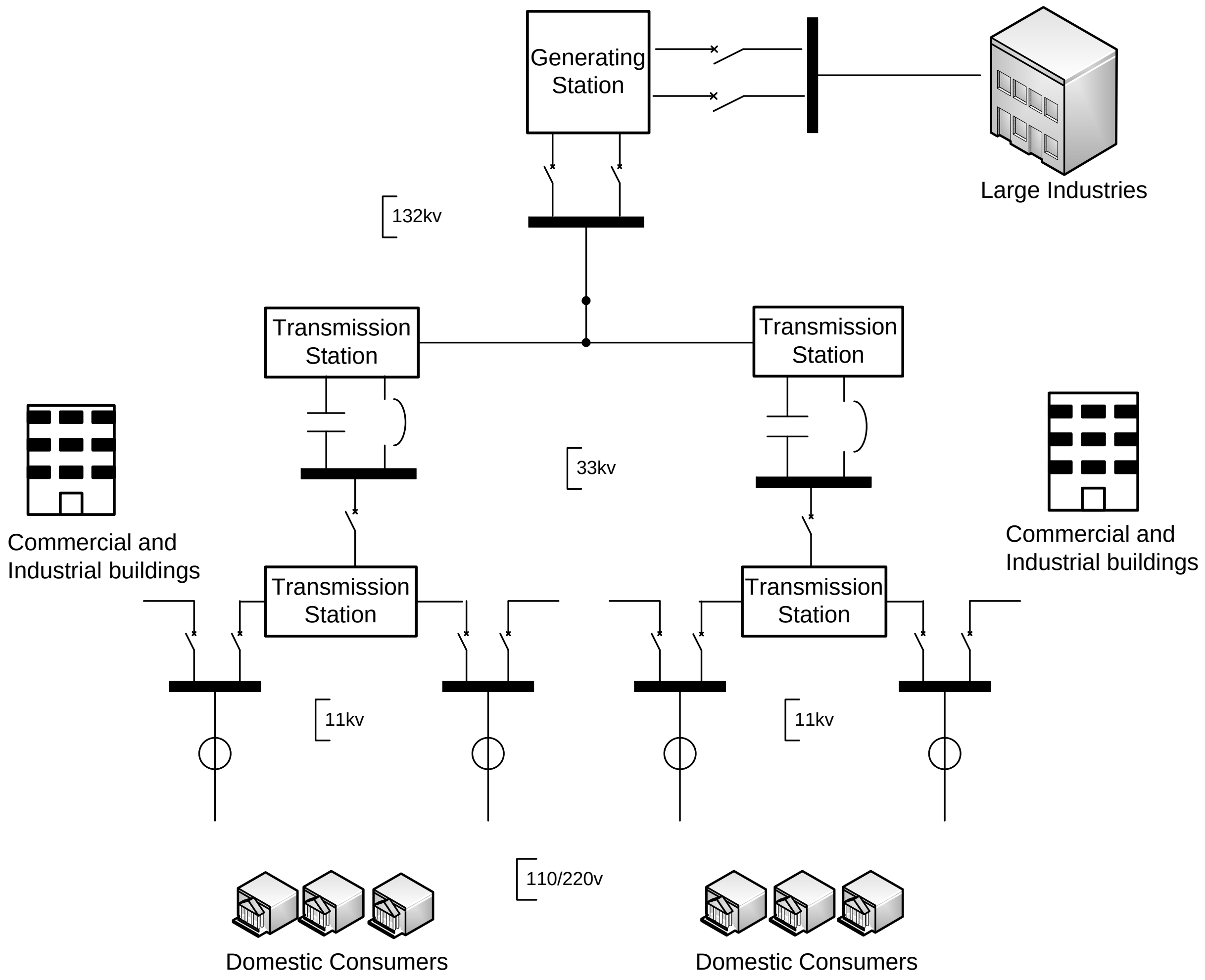
3.1 System Description

Figure 3.1 shows the pictorial representation of a part of Power Distribution Network. The real network will have more number of generating stations interconnected in a similar fashion. Electricity is generated at the generating station and is transmitted to the customers via transmission stations. High voltage network grids are used to transmit electricity from generating station to transmission stations at a range of 132 kV (kilo Volt). Very large industries that may require high voltage for their machinery will be directly connected to these generating stations. The voltage is stepped down at the transmission stations and is transmitted to other sub stations through high voltage lines. The voltage in those lines is typically 33 kV. Commercial and small industrial buildings are directly connected to them. The domestic consumers require power at a range of 110 to 220 volt. The electricity from transmission stations is stepped down to the required voltage using local transformers, from which connections to the domestic and household consumers are made via low voltage lines. This gives a brief overview of power distribution networks.

The Control Engineers (CE) monitoring the network has to ensure minimal losses in the electricity transmission. They make sure that all consumers are supplied an undisrupted power supply by maintaining an optimal power grid configuration [6]. This optimal configuration is maintained by reducing the transmission losses, preventing overloads and by proper switching of networks.

One of the important requirements in order to achieve the above goal is to respond promptly to the emergencies that may arise due to system faults and to carry out the maintenance work in a planned fashion. CE must be able to monitor the whole system and information must be available from all the events, and external systems associated with the network [1]. The customers may be high voltage consumers like industries or low voltage consumers like independent households. Irrespective of the consumer types, PDM must be able to satisfy their needs and should be able to deliver an uninterrupted power supply. The simulation helps CE to achieve this goal by monitoring the network, simulating the electricity transmission and showing the location and type of fault in the network [5]. It will also suggest the fix for the fault occurred in the network.

Figure 3.1 Power Distribution Network



The whole PDM system and the simulation act as an aid to the control engineers to maintain and carry out the electricity distribution system requirements. The system also focuses on improving the effectiveness of power distribution and on suggesting the network fault fixes. This is achieved by applying the multiagent approach for designing the system.

3.2 Requirements Analysis

A simulator for power distribution management must consider all the factors in the transmission network that can make the work of CE easier. This should integrate the existing systems as well as the new systems that may improve the overall system management and information sharing. The important requirements [1, 2, 4] that has to be considered while designing a simulator for PDM are given below:

1. Monitor Network for faults:
   - Monitor data from Telemetry: Telemetry readings contain the following details: Name of substation, Time stamp, Circuit Breaker State (Open/Close), Alarm State (Open/Close), Severity (Nil, Low/Medium/High) and any additional information in String Format.
   - Monitor Customer Calls: It has the following details: - Customer Name, Customer No., Time of Call, Severity (Nil, Low/Medium/High) and any additional information in String format.
   - Monitor Circuit Breaker and Alarms: Circuit Breaker State (NA/Open/Close), Alarm State (NA/Open/Close).
   - Monitor Weather: Weather update messages will contain the severity of lightning/weather condition and affected Location.
2. Identifying faults on network and Find Fix: Faults will be due to following reasons:
   - Overloading: The load connected to a substation grid must not exceed its maximum load capacity. Anything more the specified maximum load will cause overloading.
   - Switching failure: Switch is being operated to restore power to an area by providing an alternate route. Malfunction in this causes switching failure. It is determined by the status of the switch (On/Off).
   - Third party damage: Any Equipment failure or industrial actions cause disruption in power supply. The details are obtained from customer calls/telemetry messages.
   - Disasters or Lightening: Natural calamity and Lightening will cause disruption in power supply in the affected area. The disaster/lightening area obtained from Weather Watch Agent. Information includes name of Substation, Location, Date and Time, Severity (Nil, Low/Medium/High).

3. Analyze faulty network
    - Log load readings and database: It will help to analyze if there was any switching failure or overload in faulty network as described in 2.1 and 2.2.
    - Collect information about lightning strikes and weather conditions by implementing a Weather Watch Agent (WWA)
    - Implement a Network Agent that has static information about connectivity of pieces of plant, and dynamic information like state of circuit breakers, switches and alarms. The states of them will be in the format given in section 2.
    - Implementing a Telemetry Agent (TA) to receive telemetry, convert it to standard format and to send data to different agents on request. Telemetry data is only present at the point where there is a join between low voltage and high voltage network. Substations sent messages to update the status. Message format is as specified in 1.1.
4. Determine the type of fault
    - A Network Voltage Expert System (NVES) and a Network Voltage Diagnosis Agent (NVDA) to diagnose the location, time and type of network fault on the electricity network.
5. Find Fix for the fault
    - Automatic operation of circuit breakers
    - Remote switching operation in response to faults
    - Coordinate with FE in locations where remote operation is not available
6. Simulate the dynamic information obtained through telemetry, customer calls and transmission station information.
7. A control system interface view of the organizational level activities and the results of network monitoring.

3.3 Modeling of PDM Simulator

The requirements specified above were used for the modeling of the Power Distribution Management simulator. It required modeling all the dynamic information necessary for simulating the environment. The first step was to decide what all data are to be monitored. The network details were classified based on a top down perspective. From the specification available for PDM system, the functionalities were refined. This includes monitoring the system and analyzing the monitored data. The analyzed data helps to establish the location and type of fault. From this, a fix for the network fault has to be determined. Finally, the Control Engineers must have a simulation of these processes to analyze them and fix the fault.

The initial task was to design a Goal Model that captures the various tasks in the PDM system. This involved deciding the system level goals, the goal precedence and the events that can occur while achieving a goal. From this, a Role Model was designed to depict which role an agent has to play in order to achieve a leaf goal. It also defines the capabilities required for playing a role. Once this is completed, the agents in the PDM system were decided by analyzing the Role Model and the Goal Model. The Agent Model was created to show the capabilities possessed by the agents and the roles that an agent can play.

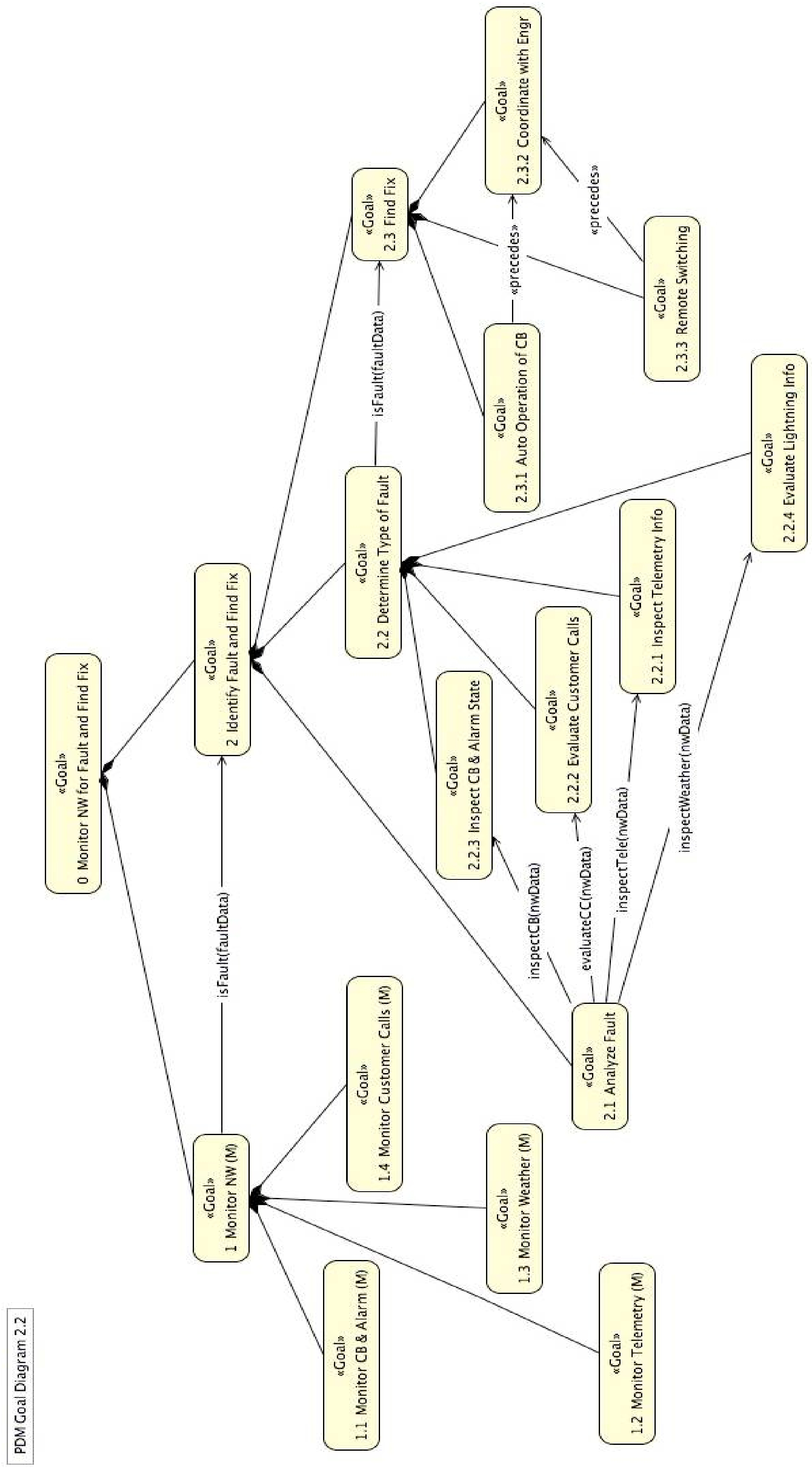
Each of the above models was created using the agentTool. This helped in getting the models in XML format, which was used for directly loading the goal specification tree from the model.

3.3.1 Model Goal

The root goal of the PDM is to *Monitor Network for Fault and Find Fix*. This goal is divided into two sub-goals of *Monitor Network* and *Identify Fault & Find Fix* based on AND-refinement. Figure 3.2 shows the Goal Model for PDM simulator. The *Monitor Network* goal is subdivided into *Monitor Telemetry*, *Monitor Customer Calls, Monitor CB & Alarm* and *Monitor Weather* goals by AND decomposition. They are *maintenance* goals and take care of simulating the dynamic data in the power distribution network by monitoring the telemetry messages from the substations, the failures reported by the telephone calls from consumers and the state of circuit breakers and alarms in transmission stations. The *Monitor Weather* goal monitors any severe weather or lightning reported in substation locations. Once any of these activities occur, a *Fault* event triggers the *Identify Fault & Find Fix* goal.

The Monitor Network goals are maintenance goals and hence they are never *achieved*. They continue to monitor the network for incoming network messages. Whenever there is an update, they trigger the *Identify Fault & Find Fix* goal.

Figure 3.2 Goal Model


PDM Goal Diagram 2.2
«Goal» 0 Monitor NW for Fault and Find Fix
«Goal» 1 Monitor NW (M)
«Goal» 1.1 Monitor CB & Alarm (M)
«Goal» 1.2 Monitor Telemetry (M)
«Goal» 1.3 Monitor Weather (M)
«Goal» 1.4 Monitor Customer Calls (M)
isFault(faultData)
«Goal» 2 Identify Fault and Find Fix
«Goal» 2.1 Analyze Fault
inspectCB(nwData)
evaluateCC(nwData)
inspectTele(nwData)
inspectWeather(nwData)
«Goal» 2.2 Determine Type of Fault
«Goal» 2.2.1 Inspect Telemetry Info
«Goal» 2.2.2 Evaluate Customer Calls
«Goal» 2.2.3 Inspect CB & Alarm State
«Goal» 2.2.4 Evaluate Lightning Info
isFault(faultData)
«Goal» 2.3 Find Fix
«Goal» 2.3.1 Auto Operation of CB
«precedes»
«Goal» 2.3.2 Coordinate with Engr
«precedes»
«Goal» 2.3.3 Remote Switching

The *Identify Fault & Find Fix* goal is *achieved* when all the three sub goals *Analyze Fault*, *Determine Type of Fault* and *Find Fix* goals are *achieved*. On receiving a *Fault* trigger from one of the maintenance goals, an instance of *Analyze Fault* goal is created. This goal analyzes the data received while monitoring the network and determines which child of *Determine Type of Fault* goal is to be instantiated. On analyzing the monitored data, the corresponding leaf goal will be triggered on occurrence of any of the events: *inspectCB (), evaluateCC (), inspectTele ()* and *inspectWeather ()*.

The *Determine Type of Fault* goal is AND-refined into *Inspect CB & Alarm State, Evaluate Customer Calls, Inspect Telemetry Info,* and *Evaluate Lightning Info* goals. The *Inspect Telemetry Info* goal evaluates the data received from substations via the telemetry messages. The *Evaluate Customer Calls* goal investigates the complaint details from the customer telephone calls. Similarly, the *Inspect CB & Alarm State* goal evaluates the *telecontrol* messages received from the transmission stations. They contain information about the state of alarms and circuit breakers located at transmission stations. Any bad weather updates reported is verified by achieving the *Evaluate Lightning Info* goal. These leaf goals play a key role in determining the location and type of fault.

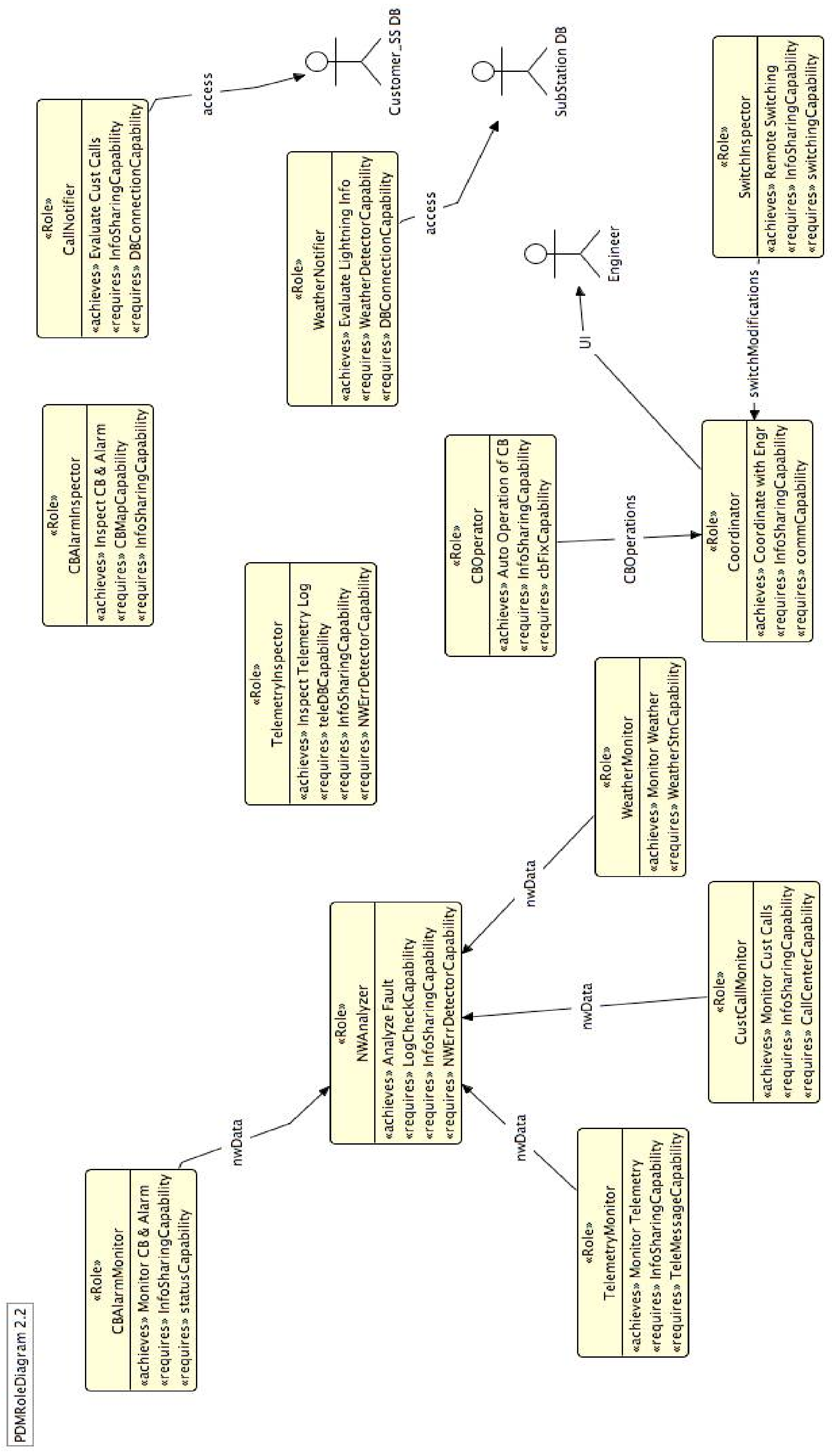
Once the type of fault is determined, the *isFault* event is *triggered* with the fault information. This event will *trigger* only the *Auto Operation of CB* and *Remote Switching* goals. The leaf goal *Coordinate with Engr* is not triggered because the other two goals *precede* this goal. These goals determine if a fix can be obtained by automatic operation of the circuit breaker and by remote switching. Once these goals are *achieved*, an instance of *Coordinate with Engr* is instantiated to determine whether the control engineer should contact the field engineer to fix the fault.

When the maintenance goal finds more data input while monitoring the network, it results in other goals being instantiated in the same fashion as explained above. This will help to determine the location and type of fault, and to find fix for the network problem.

3.3.2 Model Role

The Role Model depicts the various roles in the PDM simulator that an agent can play in order to achieve the goals. Figure 3.3 shows the Role Model for PDM.

Figure 3.3 Role Model


«Role» CallNotifier
«achieves» Evaluate Cust Calls
«requires» InfoSharingCapability
«requires» DBConnectionCapability
access
Customer_SS DB
«Role» WeatherNotifier
«achieves» Evaluate Lightning Info
«requires» WeatherDetectorCapability
«requires» DBConnectionCapability
access
SubStation DB
Engineer
UI
«Role» SwitchInspector
«achieves» Remote Switching
«requires» InfoSharingCapability
«requires» switchingCapability
switchModifications
«Role» CBAlarmInspector
«achieves» Inspect CB & Alarm
«requires» CBMapCapability
«requires» InfoSharingCapability
«Role» CBOperator
«achieves» Auto Operation of CB
«requires» InfoSharingCapability
«requires» cbFixCapability
CBOperations
«Role» Coordinator
«achieves» Coordinate with Engr
«requires» InfoSharingCapability
«requires» commCapability
«Role» TelemetryInspector
«achieves» Inspect Telemetry Log
«requires» teleDBCapability
«requires» InfoSharingCapability
«requires» NWErrDetectorCapability
«Role» WeatherMonitor
«achieves» Monitor Weather
«requires» WeatherStnCapability
nwData
«Role» NWAnalyzer
«achieves» Analyze Fault
«requires» LogCheckCapability
«requires» InfoSharingCapability
«requires» NWErrDetectorCapability
nwData
«Role» CustCallMonitor
«achieves» Monitor Cust Calls
«requires» InfoSharingCapability
«requires» CallCenterCapability
nwData
nwData
«Role» CBAlarmMonitor
«achieves» Monitor CB & Alarm
«requires» InfoSharingCapability
«requires» statusCapability
«Role» TelemetryMonitor
«achieves» Monitor Telemetry
«requires» InfoSharingCapability
«requires» TeleMessageCapability
PDMRoleDiagram 2.2

Every leaf goal in the Goal model is achieved by playing a different role. Role model also depicts the capabilities required for playing the role. The four leaf goals of the *Monitor Network* goal namely *Monitor Telemetry*, *Monitor Customer Calls, CB & Alarm Monitor* and *Monitor Weather* are achieved by playing *TelemetryMonitor*, *CustCallMonitor, CBAlarmMonitor* and *WeatherMonitor* roles respectively. Also for an agent to play any of the first three roles, they must possess the *InfoSharingCapability*. This is a capability equivalent to communication capability, which enables the agents to pass and share the monitored data to other agents in the model. The *TelemetryMonitor* role requires a *TeleMessageCapability* to enable them receive and process telemetry messages. The *CustCallMonitor* role requires *CallCenterCapability* to receive and monitor telephone calls and complaints from the consumers. Similarly, *CB & Alarm Monitor* and *Monitor Weather* roles require *statusCapability* and *WeatherStnCapability* respectively to process and monitor data.

The *Analyze Fault* goal is achieved only by playing the role of *NWAnalyzer*. This role requires *LogCheckCapability*, *InfoSharingCapability* and *NWErrDetectorCapability* in order to achieve the goal. Possessing these capabilities by an agent will enable it to analyze the monitored data for error in network.

The *CBAlarmInspector* role can achieve the leaf goal of *Inspect CB & Alarm*. The role requires the *CBMapCapability* and *InfoSharingCapability* for achieving this goal. Similarly, the *WeatherNotifier* role achieves the *Evaluate lightening Info* goal and this role requires the *DBConnectionCapability*. This capability inspects if there is a substation at the location where severe weather is reported. For checking this, it needs to have the *WeatherDetector* capability, to obtain the location of known substations from the database. The role *TelemetryInspector* can achieve the goal of *Inspect Telemetry Log*. Any issues in the substation are determined by inspecting the telemetry messages from the corresponding station. For an agent to play this role, it must possess the *InfoSharingCapability* and the tele*DBCapability*. The *Evaluate Customer Calls* goal is achieved by playing *CallNotifier* role and requires *InfoSharingCapability* and *DBConnectionCapability* to access the database.

Finally, *CBOperator*, *SwitchInspector* and *Coordinator* roles achieve the leaf goals of the *Find Fix* goal. They achieve *Auto Operation of CB*, *Remote Switching* and *Coordinate with Engr* goals, and require the *InfoSharingCapability* in common to communicate with each other about the actions taken while achieving those goals. In addition, they require *cbFixCapability, switchingCapability* and *commCapability* respectively to achieve the goals.

3.3.3 Model Agents

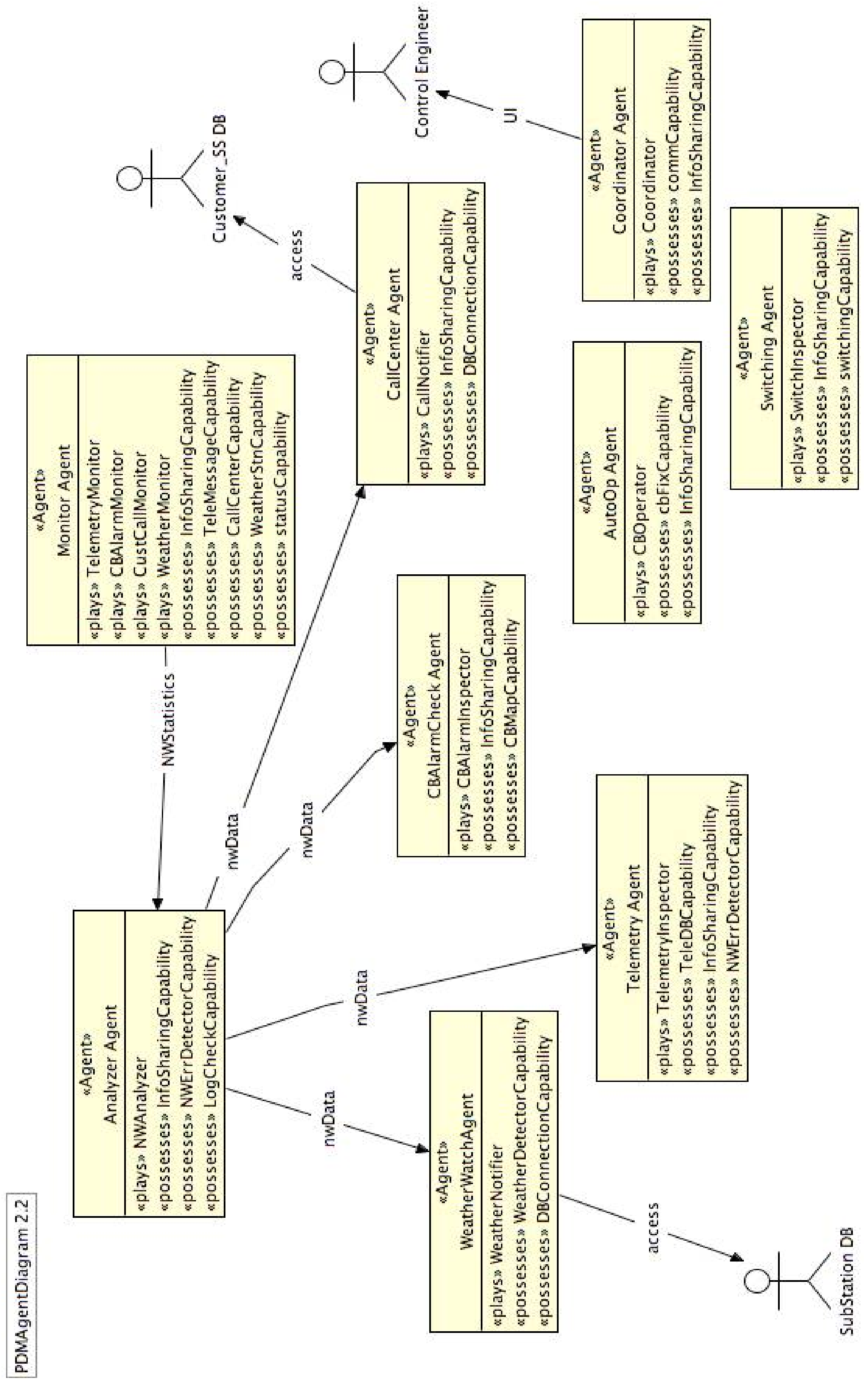
Figure 3.4 models all the agent types in the PDM Simulator. The agent classes capable of performing different roles specified in the Role Model were identified in this model. Initially the *Monitor Agent* plays the role of *TelemetryMonitor*, *CBAlarmMonitor, CustCallMonitor* and *WeatherMonitor*. It monitors the network for analyzing the incoming messages in order to come up with the current network statistics. This agent is designed to *possess* all the *capabilities* required to play the above roles. Therefore, it can play any of those monitoring roles. These network statistics are sent to the *Analyzer Agent*.

The capabilities possessed by *Analyzer Agent* are *InfoSharingCapability, LogCheckCapability* and *NWErrDetectorCapability*. This will enable it to play the role of *NWAnalyzer*. This is the only role that the agent can play. Similarly, the agents *Telemetry Agent, CallCenter Agent, CBAlarmCheck Agent* and *WeatherWatch Agent* can play only one role due to the limited capabilities possessed by them. These agents can achieve the corresponding goals mapped to the roles by playing the role that they are capable of playing. However, it will become interesting if there is more than one of any of these agents. For instance, if there is more than one *Analyzer Agent*, then the ability to play the role best depends on the score of capabilities possessed by each of these *Analyzer* agents.

AutoOp Agent in PDM simulator can achieve the leaf goal *Auto Operation of CB*. This is achieved by playing the role *CBOperator,* as the agent possesses both *cbFixCapability* and *InfoSharingCapability*. *Switching Agent* possesses *switchingCapability* along with *InfoSharingCapability*, which enables it to play the role of *SwitchInspector*. *Coordinator Agent* is responsible for achieving the *Coordinate with Engr* goal. This goal allows the control engineer to coordinate with the field engineer when he fails to fix the fault in the network by automatic operation of circuit breaker and by remote switching.

PDM simulator allows the user to specify the different agents in the system. A configuration file is used for this purpose. Appendix A shows a sample configuration file that specifies the agents in the system along with the capabilities they possess. Configuration file has the specifications for dynamically loading the agents into the PDM system.

Figure 3.4 Agent Model


PDMAgentDiagram 2.2
«Agent» Analyzer Agent
«plays» NWAnalyzer
«possesses» InfoSharingCapability
«possesses» NWErrDetectorCapability
«possesses» LogCheckCapability
«Agent» Monitor Agent
«plays» TelemetryMonitor
«plays» CBAlarmMonitor
«plays» CustCallMonitor
«plays» WeatherMonitor
«possesses» InfoSharingCapability
«possesses» TeleMessageCapability
«possesses» CallCenterCapability
«possesses» WeatherStnCapability
«possesses» statusCapability
NWStatistics
nwData
nwData
nwData
nwData
«Agent» CallCenter Agent
«plays» CallNotifier
«possesses» InfoSharingCapability
«possesses» DBConnectionCapability
access
Customer_SS DB
«Agent» CBAlarmCheck Agent
«plays» CBAlarmInspector
«possesses» InfoSharingCapability
«possesses» CBMapCapability
«Agent» WeatherWatchAgent
«plays» WeatherNotifier
«possesses» WeatherDetectorCapability
«possesses» DBConnectionCapability
access
SubStation DB
«Agent» Telemetry Agent
«plays» TelemetryInspector
«possesses» TeleDBCapability
«possesses» InfoSharingCapability
«possesses» NWErrDetectorCapability
«Agent» AutoOp Agent
«plays» CBOperator
«possesses» cbFixCapability
«possesses» InfoSharingCapability
«Agent» Coordinator Agent
«plays» Coordinator
«possesses» commCapability
«possesses» InfoSharingCapability
UI
Control Engineer
«Agent» Switching Agent
«plays» SwitchInspector
«possesses» InfoSharingCapability
«possesses» switchingCapability

The scenario file in the PDM simulator specifies the network messages that need to be processed by the system. These files will help in testing different scenarios within the PDM application. The implementation also allows the user to specify the capability score possessed by every agent in the system. Appendix B shows the format of scenario file.

3.4 PDM System Architecture

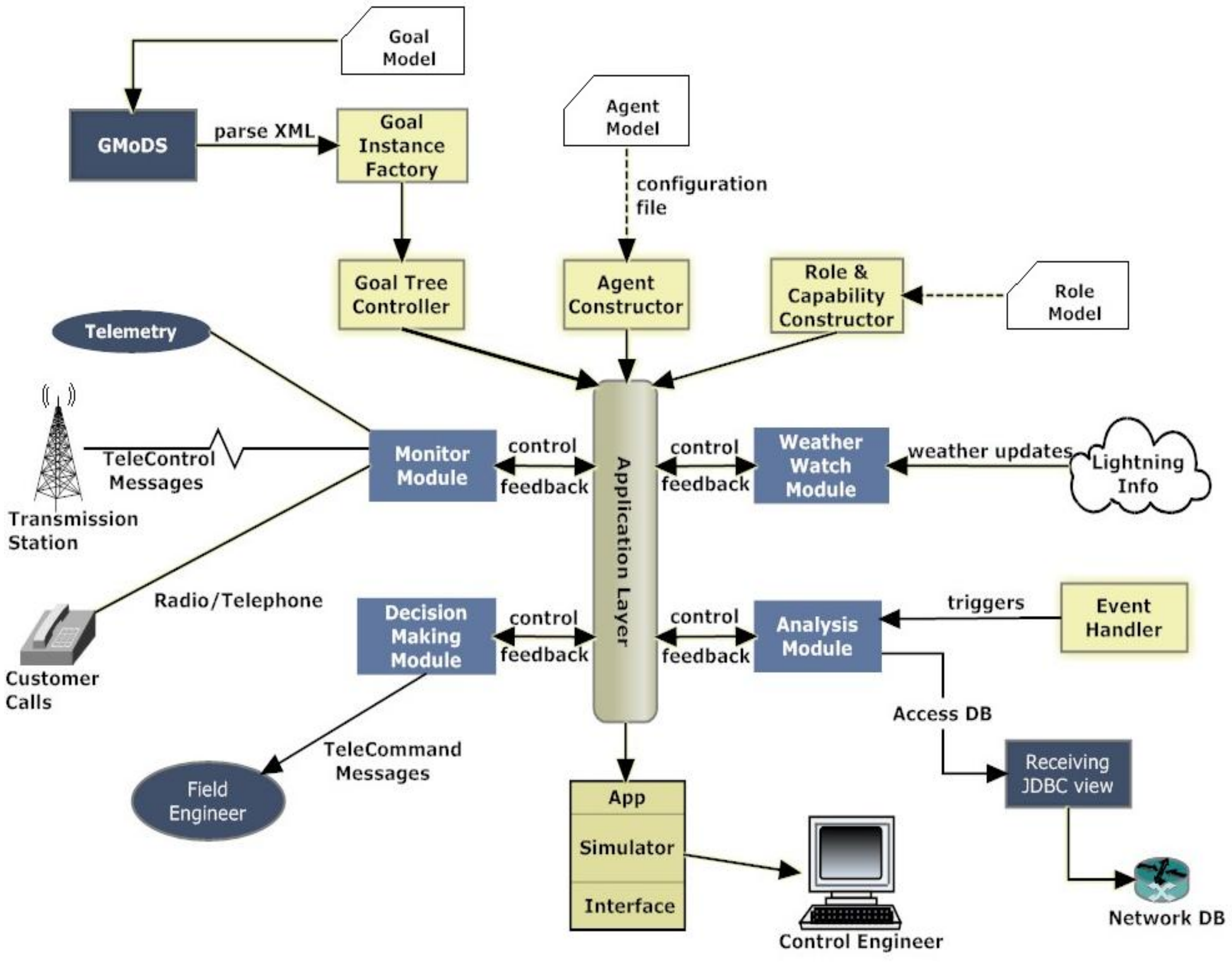
Figure 3.5 shows the high-level architecture of the PDM simulator. The OMACS models for the PDM simulator are created using the agentTool. This gives an xml file for each of the models. The Goal Model created in this way can be directly parsed to generate a goal instance factory in the memory. The GMoDS module is used for this purpose. This module reads the Goal Model file given as input. It parses the xml file to create a goal tree structure in the memory. This goal specification will have all the relationships specified in the model like the *precedes* and the *triggers*. We can make use of the different method calls specified in GMoDS project to instantiate the goal tree instance. These calls also help to keep track of the state of various goals. The Goal Tree Controller handles these functionalities in the PDM application.

The Construct Agent module creates the different agents in the application. It creates agent objects with different capability scores from the specification given in the configuration file. The configuration file is nothing but a file in which we list all the agents that are to be loaded for simulating the system. It also lets the user specify the score of various capabilities possessed by each of these agents. The capabilities possessed by the agents are mapped using the Agent Model. The Role and Capability Controller module creates the different roles, and the capabilities required by them as specified in the Role Model for the PDM system. The Goal Tree Controller, Construct Agent and Role & Capability Controller modules are linked with the application layer of the simulator as shown in Figure 3.5.

The Monitoring Module is where all the interactions with the external entities take place. The telemetry messages sent from the generating stations and the *telecontrol* messages sent from transmission stations are received in this module. It handles the information received from the customers about network complaints and power outages. This module decodes the messages and passes them to the application layer for processing. The application layer is where the processing logic is coded. It also helps in sharing information between different modules. The core functionality of the Weather Watch Module is to receive the messages and updates about severe weather conditions and lightning information.

The Analyzer Module analyzes all the data received about various network updates. The various agents in this module are responsible for carrying out the analysis. The agents in the Analyzer Module access the network database for more information about the location of substations and the default state of circuit breakers and alarms. The Event Handler Module generates the system level events that cause the goals to be *triggered* for continuing network investigation.

Figure 3.5 PDM High Level Architecture



Finally, the Decision Making module in the PDM application evaluates the result of analysis and takes appropriate action to find fix for the issues reported in the network. The agents in this module are *AutoOp Agent, Switching Agent* and *Coordinator Agent*. The Simulator Interface is the UI module for the PDM simulator where all the actions in the organization and the network fault reports are displayed. This module receives this information from the application layer of the simulator.

3.5 Class Diagram

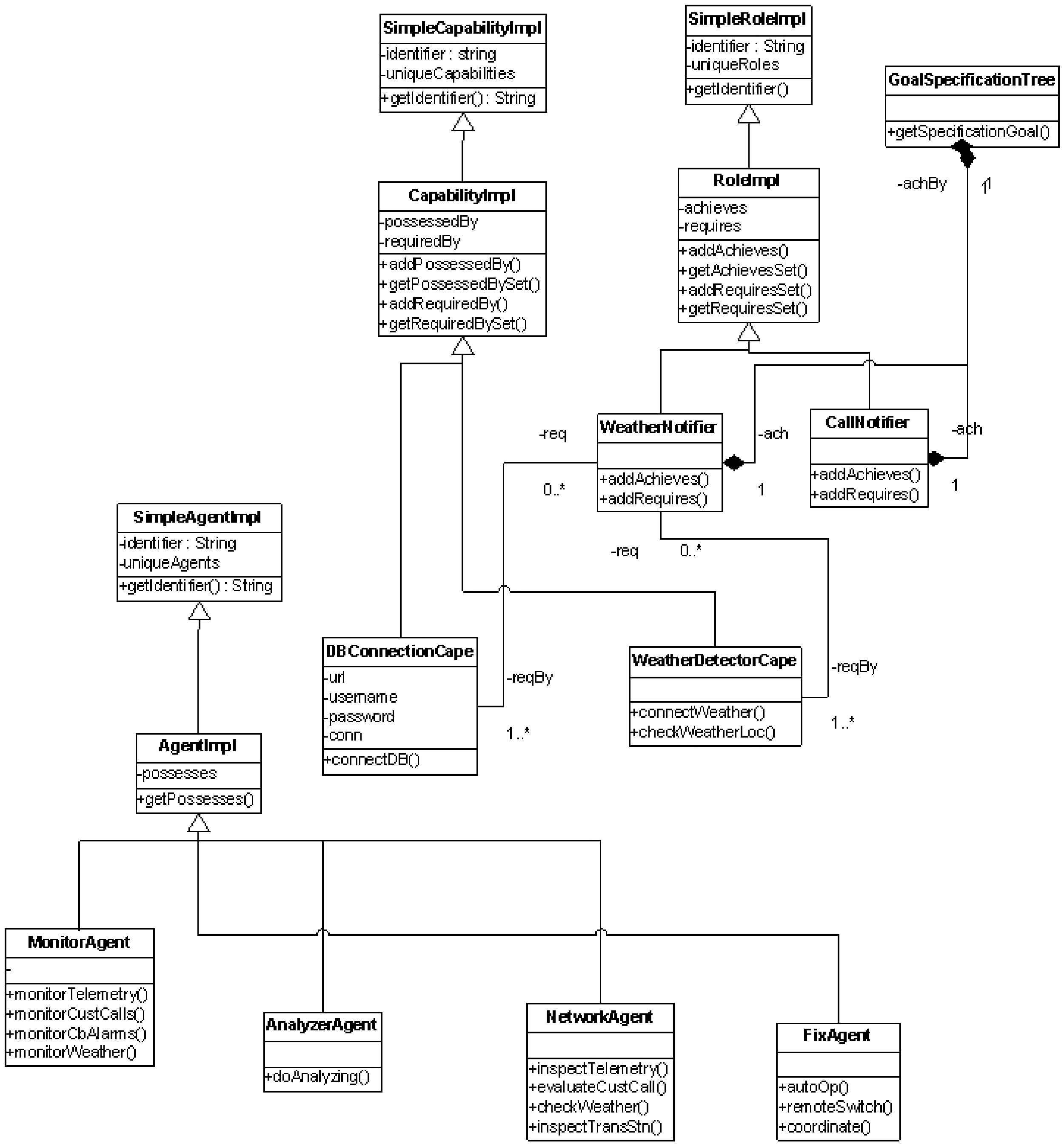
Figure 3.6 shows the class diagram for PDM simulator. It represents the important classes used in the application, their hierarchy and interaction between them. *SimpleAgentImpl* is the base class for all the application specific agent implementations. It contains a unique identifier for representing the agent. It also defines a static list of agents called *uniqueAgents*. Every time an object that extends this class is created, the identifier of that agent is added into this map. It has a method that returns the identifying name of the agent. The *AgentImpl* class extends this class. It mainly contains a map to store the list of capabilities possessed by the agent. The *getPossesses ()* method returns the capabilities possessed by the agent.

All the agents created for the PDM application extends the *AgentImpl* class. The *MonitorAgent* class has methods to observe the incoming network data from various sources like telemetry, customer calls, telecontrol messages and weather station updates. The capabilities possessed by the agent are also defined within this class. The *AnalyzerAgent* has a *doAnalyzing ()* method, which inspects the monitored data and decides which agent, can process it for diagnosing the fault. The class also defines the capabilities possessed by that agent.

The *NetworkAgent* is the abstract representation of the four agent classes in PDM application that mainly determine the type and location of fault in network from the analyzed data. It consists of *TelemetryAgent, CallAgent, CbAlarmAgent* and *WeatherWatchAgent*. Each of them has their own methods implemented to achieve the tasks they are assigned. The *FixAgent* shown in Figure 3.6 represents the three agent classes in PDM application: *AutoOpAgent, RemoteSwitch* and *Coordinator*. They have the capabilities defined within them and the methods that enable them to find a fix for the network fault from the data available.

The structural hierarchy of Role and Capability class implementations is similar to that of the Agent class. *SimpleRoleImpl* and *SimpleCapabilityImpl* are the respective base classes for them. Both these classes have a variable defined to identify the name of the implemented class uniquely. They also have a static list variable to store the object identifiers and a method to return the unique identifying name of the extended class.

Figure 3.6 Class Diagram



WeatherNotifier and *CallNotifier* represent the roles defined for the application. The class diagram in Figure 3.6 shows only two roles in the PDM simulator. The actual application implements all the roles specified in the Role Model. As the hierarchy of other role classes is similar to them, they were omitted from the diagram. The *GoalSpecificationTree* class represents a goal tree in memory, which has a method to return the goals currently active in the organization. It also has the list of active goals in the system. The *WeatherNotifier* and *CallNotifier* roles have a composite relationship with the *GoalSpecificationTree* class. This is because every role achieves one and only one goal in the organization. Similarly, every goal is achieved by one and only one role in the organization.

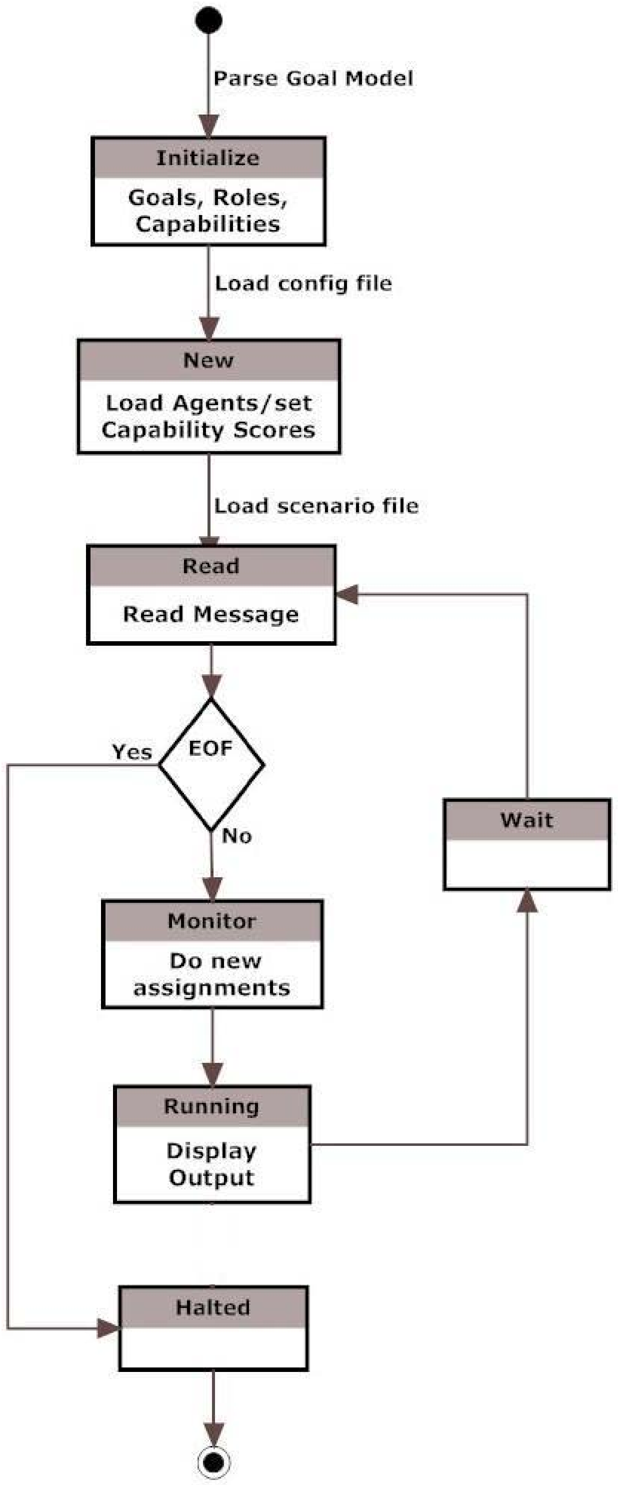
DBConnectionCape and *WeatherDetectorCape* represent the capabilities defined for the application. The class diagram shows only two capabilities in the PDM simulator. The actual application implements all the capabilities specified in the Role Model and Agent Model. As the hierarchy of all capability classes is similar, they were omitted from the diagram. Every role in PDM requires one or more capability while every capability is mapped to zero or more roles.

3.6 State Diagram

Figure 3.7 shows the state diagram for the power distribution management simulator. The state diagram depicts the various states of the system during its execution. The first state for PDM simulator is the initialization phase. It parses the goal model and creates a goal specification tree in system memory. It also initializes the roles and capabilities in the system. Then it reads the configuration file to load the agents and assign the capability scores. In the next state, the scenario file is loaded. The first network message is read. If it is the end of file, then the simulator is halted. Otherwise, it does new assignments and the simulator will be in running state. It displays in the UI the output of organizational activities. Once the processing is done, the simulator goes to the wait state until the next message is read.

Due to the difficulties to create live network messages and weather updates, we use a scenario file to simulate this. This file contains a list of messages from various sources like telemetry, transmission stations, call centers and weather stations. Appendix B shows the format of these messages. The Monitor module processes the messages from this file. There is also an option to specify the wait time between the messages. This helps to simulate the time difference between the messages received.

Figure 3.7 State Diagram



When there is a wait specified in the scenario file, it simulates the state of no network data available. The system goes to the wait state. There it waits for the specified time before processing the succeeding messages. Once it receives a new message, it goes back to monitor state. This loop continues to execute. Once the process is finished, the simulator comes to halt which is the final state. Any exception during the initialization state will also result in halting the simulator. The system undergoes these states when we run the PDM simulator.

3.7 Summary

The modeling done for the PDM system is explained in this chapter, which eventually led to the simulation of the system. The Goal Model shown in Figure 3.2 helps to understand the different tasks within the system. The Agent Model explains the heterogeneous nature of the system. It shows how the nine different agents designed for the PDM application cooperate and communicate with each other to achieve the goals in the organization. Following that, the architecture of the simulator is described. It gives an overview of the functional modules that need to be implemented for simulating the system. The UML diagrams shown in Figure 3.6 and 3.7 support this. The next chapter focuses on the two different approaches for assignments within the organization. In addition, the complexity and running time of the two algorithms are analyzed.

CHAPTER 4 - Implementation

This chapter describes the two different approaches used for assignments in the organization. It also gives a brief overview of the database used in the project. The last section in this chapter explains the different steps involved in implementing the PDM simulator.

4.1 Reorganization Algorithm

The PDM application involves many heterogeneous agents cooperating with each other to achieve the goals in the system. This requires agent assignments and reorganizations to decide which role each agent plays the best to achieve the goal. This PDM simulator implements two different approaches for doing the reorganizations.

Figure 4.1 First Fit Algorithm based Reorganization Pseudo Code

```
function assignFF ($\omega_G$, $\omega_A$)
   for each goal g from $\omega_G$ do
       $\omega_R \leftarrow$ goal.getAchievedSet()
       for each role r from $\omega_R$ do
           for each agent a from $\omega_A$ do
               score $\leftarrow$ r.rcf(a, g)
               if (score > 0) then
                   $\lambda \leftarrow$ <a, r, g>
                   assignments $\leftarrow$ assignments $\cup\ \lambda$
               end if
           end for
       end for
   end for
   return assignments
```

Figure 4.1 gives the pseudo code for first fit algorithm based agent reorganization. In lines 1-3, we iterate through the active goals in the system and makes use of the *getAchievedSet()* method to get the list of all roles that are capable of achieving each goal. Lines 4-6 iterate the list of available agents over the list of roles in order to find out the score returned by the role capability function (rcf). The *rcf ()* function calculates the effectiveness of the given agent to play the role. If the method returns zero as the score, then the agent cannot play that role. As we use a first fit strategy, whenever the score is greater than zero we assign the agent to play that role and adds to the list of assignments. Lines 7-10 do this. This strategy ensures faster assignment processing. However, it does not always assign an agent to the role that it can play the best.

The next step is to analyze the complexity of the algorithm shown in Figure 4.1. The *for* loop in line 3 executes n_g times where n_g is the number of goals in the active set. Similarly, the *for* loop in line 4 and 5 executes n_r and n_a times, where n_r is the number of roles and n_a is the number of agents in the organization. Everything else runs in constant time. The worst-case running time of the first fit algorithm will be $O\ (n_g.n_r.n_a)$. In the PDM application, every leaf goal is achieved by a separate role defined in the organization. Hence the *for* loop in line 4 runs in constant time reducing the overall complexity to $\theta\ (n_g.n_a)$. If we assume the number of active goals to be same as the number of agents in the system, then n_g will be equal to n_a. In that case, the running time of the algorithm will be $\theta\ (n^2)$, which is quadratic time.

The second algorithm used is the best-fit algorithm. Figure 4.2 gives the pseudo code for this. It is a modified version of brute force algorithm. In this, we consider all the possible assignments for an agent, and assigns only the one in which it has the maximum score for role capability function. This will ensure that the agent is always assigned the role that it can play the best.

In lines 3-7, we iterate through the list of active goals and roles in the organization to check if a role can achieve the goal. Whenever we find a role that can achieve the goal, we add it to the power set P. Now set P will consist of all the valid role-goal mappings. The *refine ()* will filter this set in accordance with the testing requirements. The requirement may be that, we do not want a specific role to achieve any of the goals. These filtering are done within this method.

Once this mapping is refined, Lines 8-16 iterates through the refined set and the list of agents available in the organization. It calculates the ability of each agent to play a role by using the role capability function. The next step is to makes sure that this is the best available assignment based on *rcf* score. The *best ()* method call in line 13 takes care of this. This method iterates through the set of assignments to check if the new assignment is better than the assignments in the set. If the new assignment has a better *rcf* value, then the set of assignments is updated. Line 17 returns the set of assignments to the called function.

Figure 4.2 Best-Fit Reorganization Pseudo Code

```
1   function assignBestFit ($\omega_G$, $\omega_A$)
2       for each goal g from $\omega_G$ do
3           for each role r that achieves g do
4               $P \cup$ <r, g>
5           end for
6       end for
7       $P \leftarrow$ refine (P)
8       for each set p from P do
9           for each agent a from $\omega_A$ do
10              score $\leftarrow$ r.rcf(a, g)
11              $\lambda \leftarrow$ <a, p>
12              if (score > 0) then
13                  assignments $\leftarrow$ assignments $\cup$ best($\lambda$, score)
14              end if
15          end for
16      end for
17      return assignments
```

If we analyze the time complexity of best-fit algorithm, we can see that it runs in cubic time. The first two *for* loops given in line 2 - 6 takes quadratic time in the worst case. In our application there is a separate role defined to achieve every goal in the organization. Therefore, the complexity will be reduced to θ (n_g), which is in linear time. The method *refine ()* also runs in linear time as it requires just one loop to iterate through the power set, P. From the above analysis, we can conclude that for PDM application, the nested *for* loop in line 8-9 also run in quadratic time. However, the method *best ()* needs iterating the assignment set to verify the maximum score of assignments. Hence the running time for that function call is θ (n), where n is the number of elements in the *assignments* set. Everything else in the algorithm runs in constant time. From this, we can see that the best-case running time is θ ($n_g + n + n_g.n_a.n$). Whenever we have a polynomial run time for an algorithm, we simplify it by throwing out all but the highest-order term. In the worst case, n_g and n_a will be equal to n and hence the complexity of the algorithm will be θ (n^3), which is in cubic time.

The algorithm ensures that the agents are assigned based on the capabilities possessed by them. As it relies on the brute force algorithm, it has to consider all the possible combinations to delegate the most effective assignment. This is the reason why it has higher running time.

The running time analysis of the two algorithm implementations is provided in the next chapter. The time and efficiency of agent assignments during reorganization was tested for a given scenario. The graphical analysis is shown in the results section of the last chapter.

4.2 Database

The control center in a real world power distribution management system receives various types of messages from different sources. They receive weather update messages from weather stations, network complaints from domestic consumers by telephone etc. If weather station reports a severe weather or lightning info at a certain location, it will not have any detail about the generating stations located at near that place. Therefore, there must be a database where the location of all the generating stations is listed. Similarly, the details about the transmission stations to which consumers at different locations are connected come from the database. These data are required in order to analyze the messages received.

To serve this purpose, we have created a MySQL database. The database mainly contains three tables, which has information about various network details. The first table is Substation_Details table. The structure of the database is shown in table 4.1. It mainly contains the details of generating stations including their name, city where station is located and maximum load allowed. Every generating station has a code name, which is used in the telemetry messages. For example, the generating station at Wichita is known as Murray Gill

Energy Center [13] and the name used in messages is MGEC. When a telemetry message is received with this name, the location and load details are obtained from the Substation_Details table.

Table 4.1 Substation_Details

Column Name	Data Type
Name_of_Substation	varchar
Max_Load	int
Location	varchar

The next table in PDM database is Cust_SS_Mapping table. This table has mapping of substation to customer location. Electricity to customers at a location is supplied from the substation nearest to that location. If a customer complaints about power outage, the only detail they report is their location. In order to know the substation to which the customer is connected, we need to fetch data from this table. Table 4.2 shows the structure of this database.

Table 4.2 Customer_SS_Mapping

Column Name	Data Type
Name_of_Substation	varchar
Customer_Location	varchar

The third table in PDM simulator is called Transmission_Station. This table contains the location of transmission stations and the default status of circuit breaker and alarm in these stations. The structure of Transmission_Station is as shown in Table 4.3.

Table 4.3 Transmission_Station

Column Name	Data Type
Transmission_Station	varchar
CB_Status	int
Alarm_Status	int

The default status of alarm and circuit breaker can be one, two or three. A status value of one represents they are On/Open by default. Similarly, a status value of two denotes they are Off/Close by default. Any value other than these two shows the absence of the respective equipment in the transmission station. The data from this table is required to analyze the messages received from transmission stations through *telecontrol* messages.

The weather update messages will not contain any details of nearby substation location. So the network database is used to find out if severe weather was reported near any of the generating station locations. The main purpose of this database is to support the analysis done during the simulation for determining the location and type of fault. This is not a very important entity in the PDM architecture as we are more interested in the behavior of agents in the organization and their reassignments.

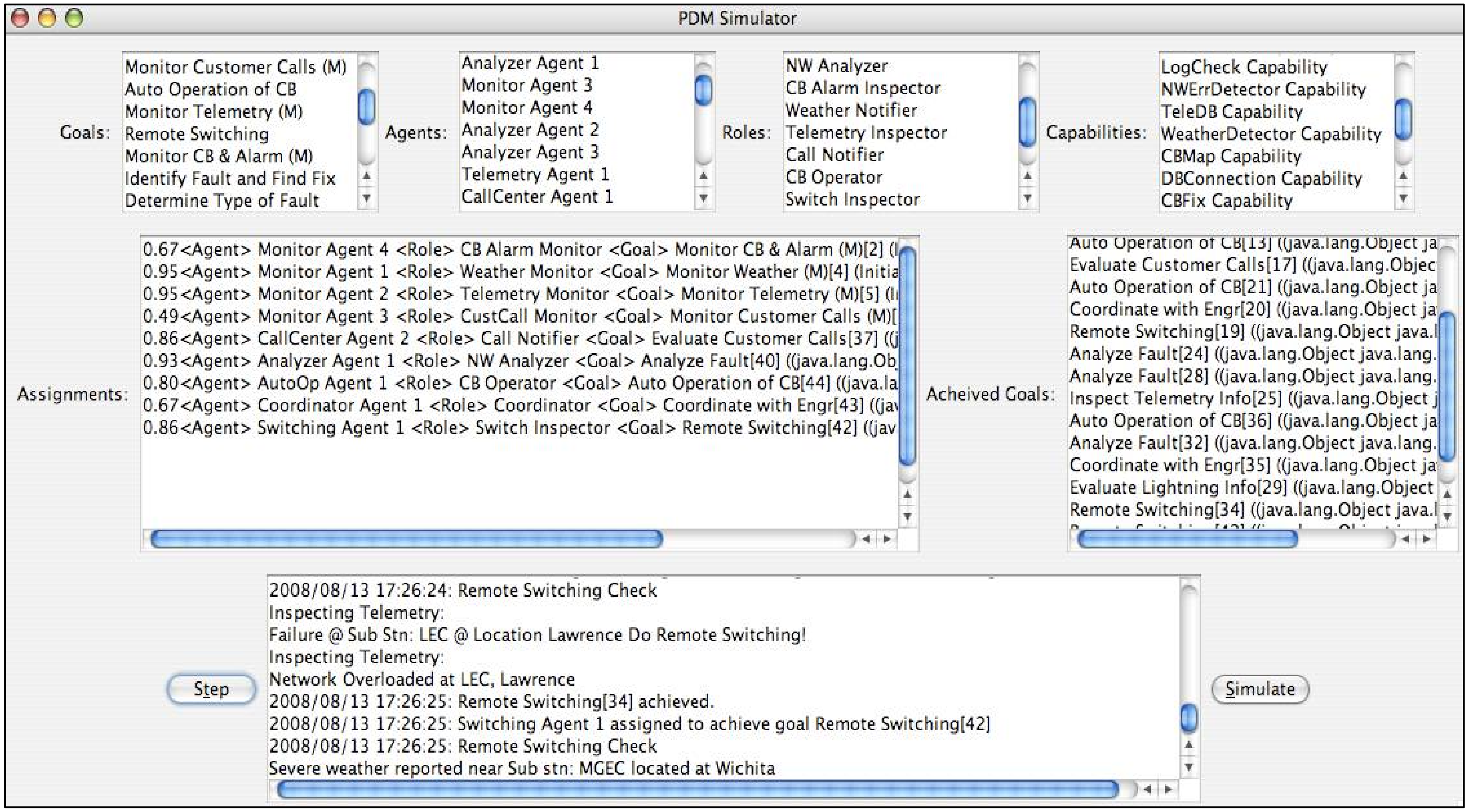
4.3 Implementation Details

The first step in implementing the PDM simulator was to generate the Goal Specification Tree from the Goal Model shown in Figure 3.2. The *GoalModel* project was used to parse the Goal Model and create the specification tree in memory. This also creates all *precedes* and *triggers* relationship specified in the model. In the next step, the roles for achieving goals were created conforming to the Role Model specifications in Figure 3.3. All the roles extend the *RoleImpl* class of the *OrganizationModel* project. The role to goal mappings was made in the application layer of the simulator project.

Once the goal and role structure were developed, the capabilities were implemented. The agents and capabilities extend their base implementation from the *OrganizationModel* project. The capabilities that an agent must possess were defined and added. The *Initial Trigger* creates instances of *Monitor* goals. All the agent assignments are done within the *assignment ()* method.

The main objective of *Monitor* goals is to watch the network for different messages and updates in the power distribution management system. We use static input in order to simulate this. Scenarios file specifying the various incoming messages are used for the PDM simulator. In order to mock a real world application, there is an option to specify wait time between the messages in the scenario file. This will make sure that the simulation runs for a particular amount of time. See Appendix B for the format and specification of scenario file. It can have data from the telemetry messages coming from the substations, details of customer complaints by telephone call, state updates of circuit breakers and alarms in various transmission stations and the weather condition of any location. We can also leave message data empty to simulate corrupted messages.

Figure 4.3 PDM Simulator



PDM Simulator

Goals:
```
Monitor Customer Calls (M)
Auto Operation of CB
Monitor Telemetry (M)
Remote Switching
Monitor CB & Alarm (M)
Identify Fault and Find Fix
Determine Type of Fault
```

Agents:
```
Analyzer Agent 1
Monitor Agent 3
Monitor Agent 4
Analyzer Agent 2
Analyzer Agent 3
Telemetry Agent 1
CallCenter Agent 1
```

Roles:
```
NW Analyzer
CB Alarm Inspector
Weather Notifier
Telemetry Inspector
Call Notifier
CB Operator
Switch Inspector
```

Capabilities:
```
LogCheck Capability
NWErrDetector Capability
TeleDB Capability
WeatherDetector Capability
CBMap Capability
DBConnection Capability
CBFix Capability
```

Assignments:
```
0.67<Agent> Monitor Agent 4 <Role> CB Alarm Monitor <Goal> Monitor CB & Alarm (M)[2] ((
0.95<Agent> Monitor Agent 1 <Role> Weather Monitor <Goal> Monitor Weather (M)[4] (Initia
0.95<Agent> Monitor Agent 2 <Role> Telemetry Monitor <Goal> Monitor Telemetry (M)[5] ((
0.49<Agent> Monitor Agent 3 <Role> CustCall Monitor <Goal> Monitor Customer Calls (M)[
0.86<Agent> CallCenter Agent 2 <Role> Call Notifier <Goal> Evaluate Customer Calls[37] ((j
0.93<Agent> Analyzer Agent 1 <Role> NW Analyzer <Goal> Analyze Fault[40] ((java.lang.Ob
0.80<Agent> AutoOp Agent 1 <Role> CB Operator <Goal> Auto Operation of CB[44] ((java.la
0.67<Agent> Coordinator Agent 1 <Role> Coordinator <Goal> Coordinate with Engr[43] ((ja
0.86<Agent> Switching Agent 1 <Role> Switch Inspector <Goal> Remote Switching[42] ((jav
```

Acheived Goals:
```
Auto Operation of CB[13] ((java.lang.Object ja
Evaluate Customer Calls[17] ((java.lang.Objec
Auto Operation of CB[21] ((java.lang.Object ja
Coordinate with Engr[20] ((java.lang.Object ja
Remote Switching[19] ((java.lang.Object java.l
Analyze Fault[24] ((java.lang.Object java.lang.
Analyze Fault[28] ((java.lang.Object java.lang.
Inspect Telemetry Info[25] ((java.lang.Object j
Auto Operation of CB[36] ((java.lang.Object ja
Analyze Fault[32] ((java.lang.Object java.lang.
Coordinate with Engr[35] ((java.lang.Object ja
Evaluate Lightning Info[29] ((java.lang.Object
Remote Switching[34] ((java.lang.Object java.l
```

```
2008/08/13 17:26:24: Remote Switching Check
Inspecting Telemetry:
Failure @ Sub Stn: LEC @ Location Lawrence Do Remote Switching!
Inspecting Telemetry:
Network Overloaded at LEC, Lawrence
2008/08/13 17:26:25: Remote Switching[34] achieved.
2008/08/13 17:26:25: Switching Agent 1 assigned to achieve goal Remote Switching[42]
2008/08/13 17:26:25: Remote Switching Check
Severe weather reported near Sub stn: MGEC located at Wichita
```

The implementation follows the design and every time an organizational activity happens, the updates are displayed in the simulation screen shown in Figure 4.3. The maintenance goals for monitoring the network are never achieved. They continuously monitor for network data as specified in the scenario file. The *PDMEventHandler* class takes care of the events that occur while achieving goals, thereby triggering new instance of goals.

The top row of the simulator screen shows the list of all the goals in the Goal Specification Tree and all the agents acting in the PDM application as specified in the configuration file. In addition, it shows the list of capabilities the agent can possess and roles that the agent must play in order to achieve the goals. The second row in Figure 4.3 shows the agent-role assignments for the active goals in PDM. It also shows the score of role capability function returned for each of these assignments. This score indicates how effectively an agent can play a role to achieve the goal. The higher the score returned, the better the quality of assignment.

Once a goal is *achieved*, it is moved to the *achieved goals* list shown next to that. The third row in the PDM simulator displays the result of network analysis along with failure location and fix for the network fault. It also displays all the organizational level activities like agent assignments, reorganizations, event occurrence etc.

There are two ways to run the simulation. Clicking the *Simulate* button will do all the analysis continuously without any pause and the results will be displayed. The other method is to step through the process. In this, every time the *Step* button is clicked, it will show the active goals and the agent that achieves it, in the assignments box. It also shows on the simulator screen the roles played by the agent and the *rcf* score for assignment. This will allow stepping through the simulation in order to track the organizational activities. Appendix C gives the procedure for running the simulator.

The PDM simulator also creates a log file in which it logs all the activities taken place in the organization. This will help to compare the reorganizations and activities between various scenarios simulated.

4.4 Summary

This chapter explains the two different algorithms used for the implementation of reorganization within the PDM simulator. In addition, the complexity and running time of algorithm is analyzed. The first-fit algorithm has quadratic running time while the time complexity of the best-fit algorithm is θ (n^3). The next section describes the structure of database used for simulator. The analysis of network messages is highly influenced by the records entered in this database. The next chapter gives the running time of the two different algorithms when implemented in java.

CHAPTER 5 - Results

The first section in this chapter illustrates the results and conclusion of PDM Simulator implementation. The next section contains the time and efficiency analysis of agent assignments when using the two different reorganization algorithms. In the final section, it describes the limitations of the implementation and an outline of future work suggested for improving the usefulness of the application.

5.1 Result Analysis

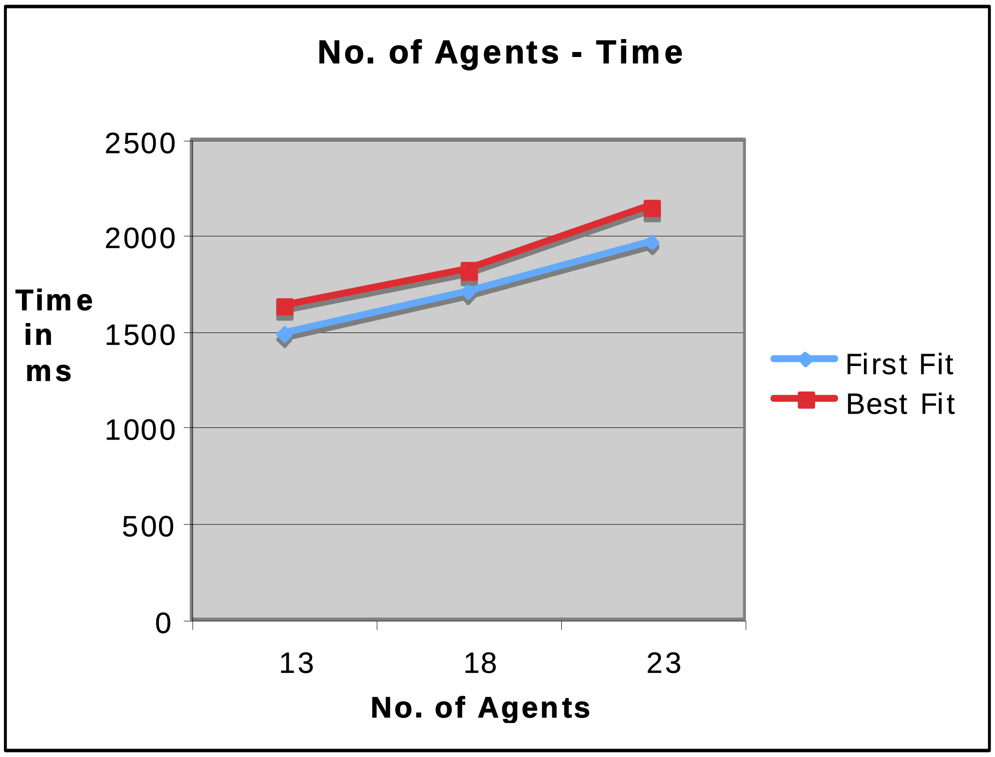
The goal of simulating a power distribution management system for monitoring the network for faults and finding fix was achieved. The design and implementation of PDM simulator conforms to the OMACS methodology.

The simulator was run with both the reorganization algorithms in order to analyze the difference in running time. For the same *scenario* file, the time taken for agent assignments was studied. Figure 5.1 shows the graph plotted for number of agents against time in milliseconds. In the tests, the time was logged just before the algorithm begins and immediately after the algorithm completes. The algorithm was implemented in Java. The system used for testing had a 2 GHz Intel Core 2 Duo processor with 1 GB RAM. The JVM could provide a precision of microseconds.

For the first run, the number of agents in the organization was thirteen. The time taken for the assignment function throughout the simulation was recorded. In addition, there were five runs of the same test so that a better estimate of the runtime could be obtained. It was found that the first fit reorganization took lesser time compared to the best-fit algorithm. The same test was repeated by increasing the number of agents to eighteen and twenty-three. In all cases, the time taken by best-fit algorithm based assignment was slow compared to the other.

Figure 5.1 shows the graphs plotted based on tests. As the number of agents is increased, the time taken for assignments also increases. It is obvious that the difference in time taken by the two methods is not very high. The result looks linear because many operating systems measure time in units of tens of milliseconds. Even though, java returns time in milliseconds, the granularity of the value depends on the underlying operating system implementation. As the time taken for executing the assignment algorithm is in milliseconds, we need to run the test in a system that can give results accurate to the degree of microseconds. In addition, the test included limited number of messages in the scenario file. In the real world application, the system will be running for longer periods and the number of network messages processed will be much higher. In those cases, this difference in time will be much more significant and will play a key role in the performance of the system.

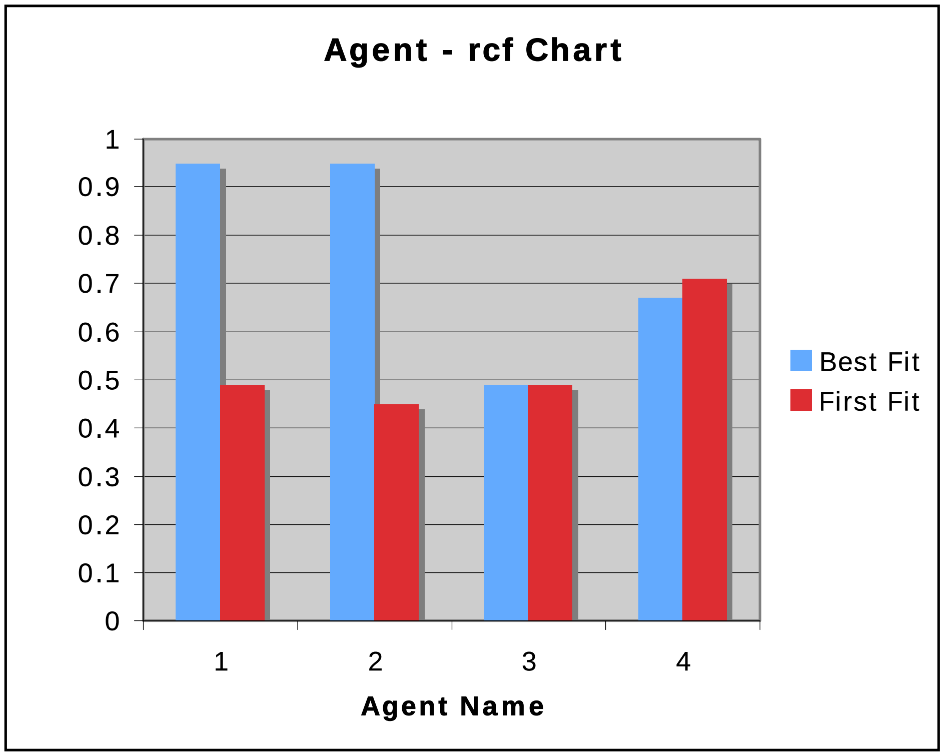
Figure 5.1 Number of Agents – Time Graph



Another important observation in the analysis of simulation result was that the best-fit algorithm made sure that during reorganization, the agent is always assigned to the role that it can play the best from the specified score of capabilities that it possess. This may not be better than the assignments based on organization assignment function (oaf). Considering the fact that we mainly depend on the capability scores for assignment, this approach gives better assignments than first-fit algorithm.

As the first-fit approach always chose the first available match for assignment, agents were not assigned the roles that it can play most effectively. Figure 5.2 shows the chart that compares agents against the rcf scores. The four monitor agents were tested for this. From chart, it is clear that the agents were assigned to play roles, which they can play the best when using the best-fit based assignment. The x-axis shows the four monitor agents and y-axis shows the rcf values of their assignments.

Figure 5.2 Agents - rcf Chart



5.2 Conclusion

The PDM application was able to simulate the process of power distribution management by displaying the goals, roles, agents and assignments in the simulator. It was able to mock the real world application by analyzing and simulating the network messages using the *scenario* file. Two different approaches were put forward for the organization level assignments. An analysis of runtime complexities of reorganization algorithms was done.

This project will be helpful to test and analyze the performance of multiagent systems designed using the OMACS framework. It allows modifying the number of agents in the organization and the score of capabilities possessed by each agent. The *configuration* file makes it easy to achieve this. It also helps in studying the behavior of the organization under various conditions. The system can be used for studying various network conditions by changing the specifications in the *scenario* file. Analyzing the system for different reorganization algorithms is also straightforward. The log files created during the simulation will help in comparing the organization level activities when running the system in different environments. These are the main advantages of using semi-autonomous agents for designing the PDM simulator.

Thus, the PDM simulator will be a useful tool for the analysis of systems designed using the multiagent approach. It will help to study the methodology and performance, on applying multiagent approach for complex and distributed systems.

5.3 Limitations

One limitation of the PDM Simulator is the unavailability of live network messages and updates. In order to overcome this, we specify all the network messages in a *scenario* file. It will enable to test different situations that an electricity distribution network may encounter. The file also allows specifying the wait time between two messages in order to simulate the time difference between the different updates received in the real world scenario.

Another limitation of the simulator is that we do not use xml format for configuration file and scenario file. They are plain text files. Therefore, the simulator expects the user to follow the exact format specified while modifying those files. The format of these files are specified in Appendix A and B.

5.4 Future Work

Incorporating some changes to this simulator will make it more flexible and reusable. One of the features of this simulator is that it can read the Goal Model diagram created using the agentTool and can create a goal specification tree in the memory. If this feature is extended to read Role Model and Agent Model, then it will be able to simulate any application designed using multiagent approach, with very less modification. This will help in developing this into a generic simulator framework. It enables to simulate a system from the design models. It will also let the user easily customize the simulator for specific applications.

Another enhancement suggested for this simulator is to make the configuration file and scenario file into xml format. This will add a lot more flexibility to the application.

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Appendix A - Configuration File

We specify all the agents for running the PDM simulator in this file. The file lets user specify the name and the capability scores for each of the agent. We can specify any number of agents in this file. This is a text file and it expects all the specifications to be in the format given below.

```
<Agent Name 1>
<Capability Name 1>          <Capability Score>
<Capability Name 2>          <Capability Score>
```

Figure A.1 shows a part of the configuration file used for running the PDM simulator.

Figure A.1 Sample Configuration File

```
Monitor Agent 1
infocape                 0.2
teleMessageCape          0.4
callCenterCape           0.3
weatherStnCape           1.0
statusCape               0.3

Monitor Agent 2
infocape                 0.9
teleMessageCape          0.9
callCenterCape           0.3
weatherStnCape           0.2
statusCape               0.1

Analyzer Agent 1
infoCape                 0.7
nwErrCape                1.0
logCheckCape             0.9
```

Appendix B - Scenario File

We specify all the different network messages in this file. It will also allow the user to specify a wait time in seconds between the messages. We can specify any number of network messages in this file. This is also a text file and it expects all the specifications to be in the format given below. The possible values for different messages are given in section 3.2.

Figure B.1 shows a part of the scenario file used for running the PDM simulator.

Figure B.1 Sample Scenario File

```
<wait>                      5

<Name of Substation>        GEEC
<CB Status>                 Open
<Alarm Status>              On
<Severity>                  High
<Load in kV>                890

<Name of Customer>          abc
<City>                      Manhattan
<State>                     KS
<Phone>                     7987986986
<Urgency>                   Medium

<TS CB Status>
<TS Alarm Status>
<TS Location>

<Weather>                   Severe
<W Location>                Wichita

<wait>                      10

<Name of Substation>        WCGC
<CB Status>                 Close
<Alarm Status>              Off
<Severity>                  Low
<Load in kV>                500
```

Appendix C - User Manual

The various steps for running the simulator are given below.

1. Check out the PDMSimulator project from the macr.user.cis.ksu.edu project repository.
2. Create a text file in C:\Desktop with name as config.txt.
3. Specify all the agents and their capability scores in the format given in Appendix A.
4. Create a text file in C:\Desktop with name as scenario.txt.
5. Specify the network messages for testing the scenario in the format given in Appendix B.
6. Open the PDMSimulator project using Eclipse IDE.
7. Add the projects GoalModel and OrganizationModel to its build path.
8. Right Click on the file PDMSimulator.java in edu.ksu.cis.macr.pdm.simu package and click on Run as Java Application.
9. The application displays the simulator screen as shown in Figure 4.3
10. The Step button lets the user run the application one-step at a time. It updates the screen with the organizational activities in each step.
11. The Simulate button will let the simulator run without any pause.
12. Once the simulator is run, a log file is created in location C:\Desktop\logs\
13. The file contains all the organization level activities during the simulation.