GTNOpS, AN AGENT -BASED OPTIMIZATION SOFTWARE FOR GAS TRANSMISSION NETWORK

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Abstract- GTNOpS is an agent-based optimization software for Gas Transmission Network (GTN). Two main software agents have been implemented in this software. The agents are coordinator and search agents with logical and layered structure respectively. The agents have been developed using Unified Modeling Language (UML) and C++ technology. The core of search agent comprise of two components. Each component is a software thread which employs one unique method to optimize the GTN. The first optimization thread is based on dynamic programming (DP) as a mathematical approach and the second one is based on genetic algorithm (GA) as a heuristic and model-free method. The simulation results show that GTNOpS works well.

1 Introduction

The function of a GTN is receiving gas from the sources and delivering to the consumers through the pipeline network. The large dimension of the network results in a considerable reduction of the gas pressure. On the other hand, the minimum required pressure and flow of deliverable gas to the consumers must be guaranteed under all conditions. Therefore, the network must be equipped with some compressor stations to compensate the pressure and flow drop.

The optimization of a GTN means minimizing the compressors running time whilst satisfying the consumers required pressure and flow. Generally about 1-5% of the transported gas is diverted for running the compressors which is so great that a small improvement will result in a huge economic benefit.

More than three decades, researchers are working on the problem of minimization of GTN. Different methods have been developed and applied to this problem [1-6].

Agent-oriented approach is an evolving way to model and control of many different problems. In this paper, this approach has been used for optimization of GTN as a typical large industrial system.

This paper is organized as follows: Section 2 presents a brief description of GTN and its mathematical equations. In section 3 a brief description of agent-oriented approach is given. Optimization of a typical GTN using agent-oriented approach is presented in section 4. The design and implementation of the software agent of GTNOpS is given in section 5. Section 6 presents the simulation results. The conclusions are presented in section 7.

2 Problem Definition

The main components of a typical GTN are pipelines and compressor stations. In addition to these main components, there are one or more gas sources (gas producers or storages), some gas consumers and other devices such as valves and regulators. The compressors are used to compensate the gas pressure losses in the network. Valves and regulators are for cutting off the selected sections of the GTNs, preventing excessive growth of pressure in the network, and preventing the flow of gas in an undesirable direction.

A GTN can be considered as a real large-scale and complex system. The compressor stations are in fact the subsystems which interact together through the pipelines.

a. Mathematical Model of the Gas Pipeline

A common mathematical model of gas pipeline segment under normal operation condition is formulated as a set of partial differential equation of parabolic form [7]:

$$
\begin{aligned}
&\frac{\partial P(x,t)}{\partial t} = -M_0 \frac{\partial Q(x,t)}{\partial x} \\
&\frac{\partial P(x,t)}{\partial x} = -\frac{\lambda L M_0^2}{2D} \frac{Q(x,t)\left|Q(x,t)\right|}{P(x,t)} \qquad (1) \\
&x \in [0, L]
\end{aligned}
$$

where $P(x,t)$ is gas pressure, $Q(x,t)$ is gas flow, and M_0 is a steady-state match number. The other parameters are geometry and physical parameters of the pipeline; l is the friction coefficient, L and D are the length and diameter of the pipeline, respectively.

The flow rate of pipeline k from node i to node j can also be calculated as follows [8]:

$$f_k = f_{kij} = S_{ij} \times 6.4774 \frac{T_0}{p_0} \sqrt{S_{ij} \frac{(p_i^2 - p_j^2) D_k^5}{F_k G L_k T_{ka} Z_a}} \tag{2}$$

where f_{kij} is the pipeline flowrate, S_{ij} is $sign(p_i - p_i)$, T_0 is standard temperature, p_0 is standard pressure, p_i is pressure at node i, p_j is pressure at node j, D_k is internal diameter of pipeline, F_k is pipeline friction factor, G is gas specific gravity, L_k is pipeline length, T_{ka} is average gas temperature, and Z_a is average gas compressibility factor.

b. Mathematical Model of the Gas Compressor

The compressor power consumption is a function of the amount of gas that flows through the compressor and the pressure ratio between the suction and the discharge [8].

$$H_k = H_{kij} = B_k f_k \left[\left(\frac{p_j}{p_i} \right)^{Z_{ki}\left(\frac{a-1}{a}\right)} - 1 \right] \tag{3}$$

where B_k is $\frac{3554.58 T_{ki}}{h_k}\left(\frac{a-1}{a}\right)$, T_{ki} is compressor suction temperature, h_k is compressor efficiency, a is specific heat ratio, p_i is compressor suction pressure, p_j is compressor discharge pressure, and Z_{ki} is gas compressibility factor at compressor inlet.

The main goal of the optimization is minimizing the total compressors consumption,

$$j = \sum_{k=1:N} H_k \tag{4}$$

where N is the number of compressors. This minimization should be performed in accordance with satisfying the boundaries of pressures and flows of the gas delivered to the consumers, i.e. $p_{min} \le p_j \le p_{max}$ and $f_{min} \le f_j \le f_{max}$, where p_{min}, p_{max} are the minimum and the maximum permissible pressures, and f_{min}, f_{max} are the minimum and the maximum permissible flow rates delivered to the consumer j respectively.

3 Agent-Oriented Approach

The agent-oriented view is perhaps the most natural way of characterizing many types of problems. The real world is full of objects that have operations perform on them, and full of active and purposeful agents that interact to achieve their objectives. Indeed, the main perspective of object and agent-oriented approach is: "we view the world as a set of autonomous agents that collaborate to perform some higher level function" [9]. In this view, Agents are encapsulated computer systems that are situated in some environment and can act flexibly and autonomously in that environment to meet their design objectives [10].

Figure 1 shows a canonical view of an agent-based system. According to the figure: i) the key abstraction models of agent-oriented mindset are agents, interactions, and organizations; ii) agent-oriented decomposition is an effective way of portioning the problem space of a complex system; iii) agent-oriented philosophy for modeling and managing organizational relationship is appropriate for dealing with the dependencies and interactions that exist in complex systems [11].

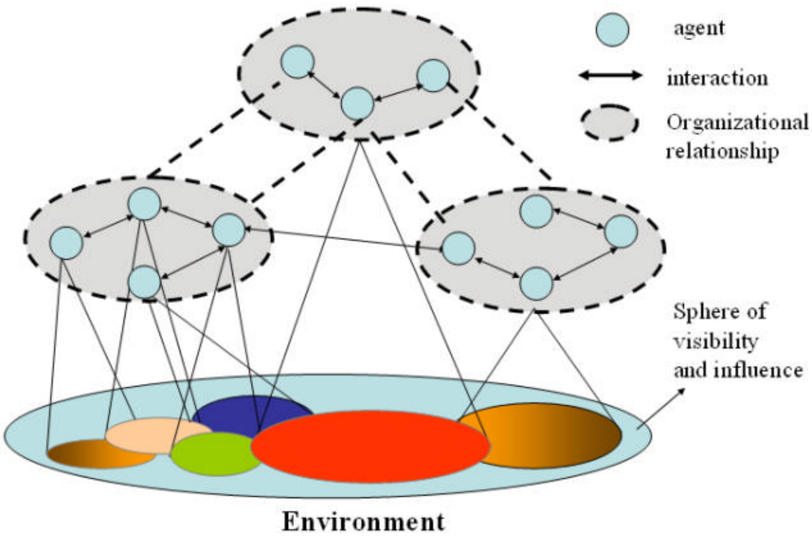

Figure 1. Canonical view of agent-based system

Agent-oriented is a distributed approach, hence it profit all the main advantages of distributed processing method such as efficiency, modularity, distributed control and data, and parallel processing which in turn increase speed and redundancy. In addition, agent-oriented approach has some more advantages such as Robustness, Reliability, Reusability, and Natural representation of the domain [12].

4 Agent-Oriented Optimization of GTN

GTN management is usually performed by expert operators in dispatching control room (DCR). The network is generally equipped with a sophisticated data acquisition system such as SCADA, and some application programs that help the operator or a control engineer to analyze and manage it. Using this data and other additional information such as consumers' requirements, the operator can manage the network based on his/her cognitive knowledge.

The optimization of a GTN in normal operation means determining each compressor working time and power while satisfying the followings:

- The total consumption of the compressors is minimized.
- The minimum pressure and flow delivered to the consumers is guaranteed.

To achieve this goal in a real system, a number of activities must be done. A global search in the problem search space must be carried out to find an optimal or at least a suboptimal solution in a finite time. The set values (pressure and/or flow) for each compressor must be sent to the stations. The compressors must evaluate their tasks and acknowledge the results to the DCR. In case of accept, the compressors should try to perform their tasks and achieve their setpoints, and return the results to the DCR. In case of reject or failure of operation, the DCR must find the next suboptimal solution and send it to the coprocessors as an alternative solution [13].

The development of the first and main part of this scenario is given in this paper. In fact, this part includes two software agents which are designed and implemented to find the optimal/suboptimal solution. The agents are Search Agent (SA) and Coordinator Agent (CoA). The structure of CoA is logical and the SA use layered structure.

Two layers have been considered for SA, where each layer is corresponded to one search algorithm. In first layer, genetic algorithm (GA) is implemented. The second one is dedicated to dynamic programming (DP). In addition, a knowledge base has been considered for the agent to save the optimal solution of the network for each scenario. This feature speeds up the response of the system especially whenever similar conditions are taken place.

GA is a stochastic global search method which can be used to find the global optimal parameters. It operates on a population of potential solutions applying the principle of survival of the fittest solution. GA technique prevents falling into the local minimums, does not require the derivative information and does not need the plant model in control applications. It is quietly appropriated for optimization process of nonlinear and complex systems. The main operations of GA are initialization, fitness evaluation, selection, mutation and crossover [14]. In this application, a chromosome is a solution wherein each real-valued gene is dedicated to one compressor station. The fitness function is simply summation of the compressor stations power consumption.

5 Design and Implementation of GTNOpS

Figure 2 shows a schematic view of the developed GTNOpS. Each software agent runs on one computer. However it is possible to run both agents on one computer, but this scheme preserve the main advantages of agent-based system such as distributed processing, reliability and so on. The agents communicate together based on messages passing using TCP/IP. A number of standard data packets are defined for transferring information between them. Different methodologies and technologies have been used to develop these agents.

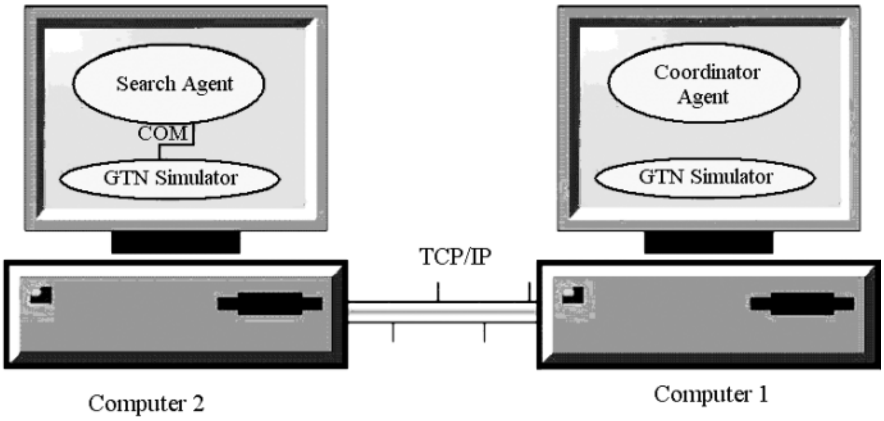

Figure 2. Schematic view of GTNOpS

a. Coordinator Agent

The CoA gets the GTN model and the restriction table from user and sends them to the SA. This information in addition to the initial solution is in fact the beliefs of CoA. This initial solution may provide by the human experts or generated randomly by the system or even come from the system knowledge base. When SA receives this information, it starts its search algorithms to find an optimal solution. The SA sends every optimal valid solution to the CoA. The CoA updates its beliefs whenever it receives an optimal solution with less total power consumption. It also saves the solutions in a solution database and displays them in an appropriate window.

Prometheus methodology has been used for design and implementation of CoA. This methodology has three main phases: system specification, architectural design and detailed design. Figure 3 shows theses phases and their relations [15].

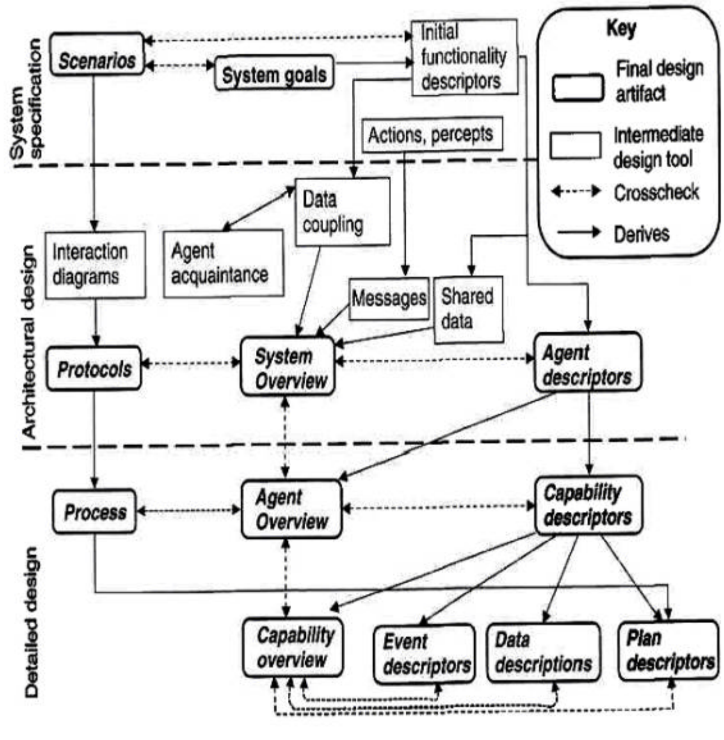

Figure 3. Prometheus methodology phases

The CoA has been developed in JDE (JACK Development Environment)[15]. JACK is an agent platform based on Java. It views agent as a number of plans which are triggered by events and messages as a specific type of event. The design diagram of CoA in JACK environment is shown in figure 4.

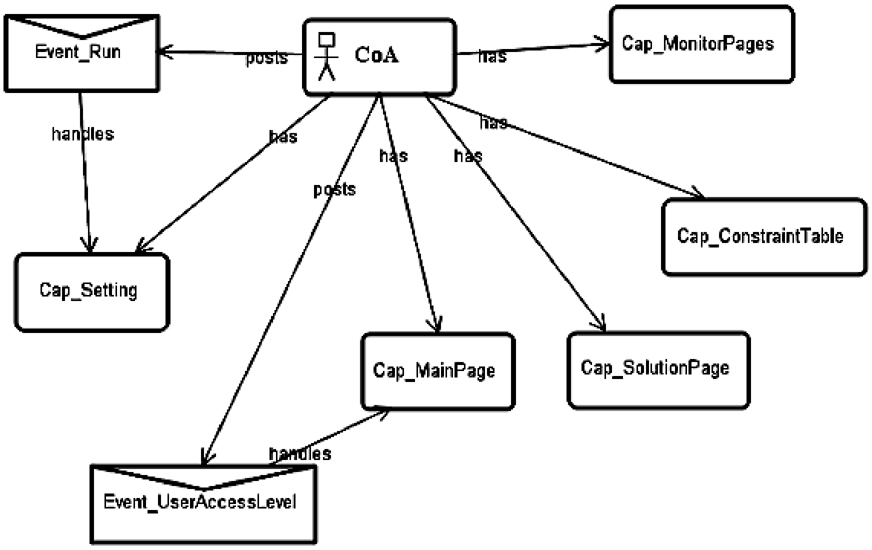

Figure 4. Design diagram of CoA in JACK environment

b. Search Agent

UML has been used for software modeling of SA [16]. The Usecase diagram is shown in figure 5.

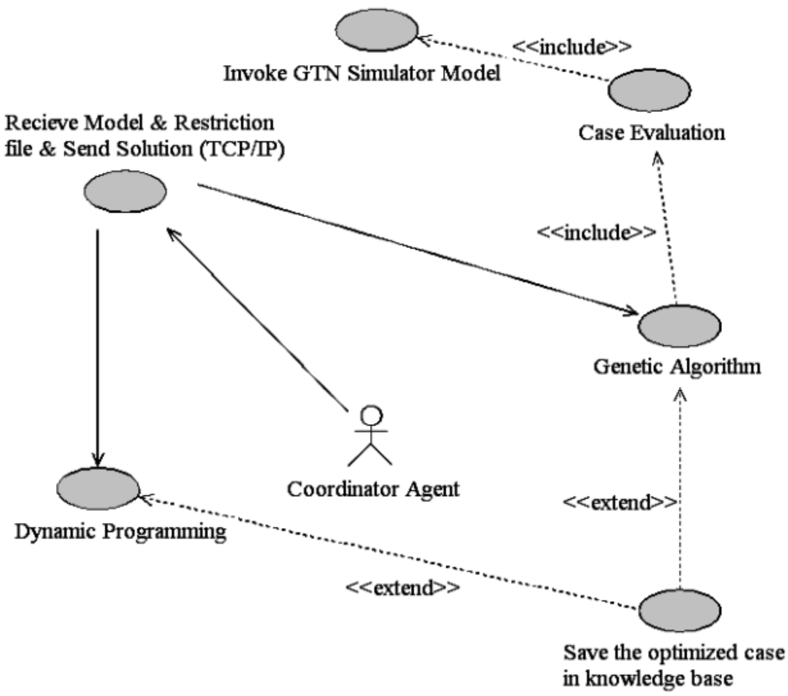

Figure 5. usecase diagram

As it can be shown from figure 5, two search algorithms (GA and DP) have been considered to find the optimal solution of the given scenarios. The flowchart of the GA is given in figure 6. The verified optimal solution will be stored in a knowledge base for future use whenever a similar scenario is happen. It will improve the system speed and performance. It can be imagined as a kind of learning for the GTNOpS. A number of classes have been extracted from Usecase diagram to satisfy the requirements.

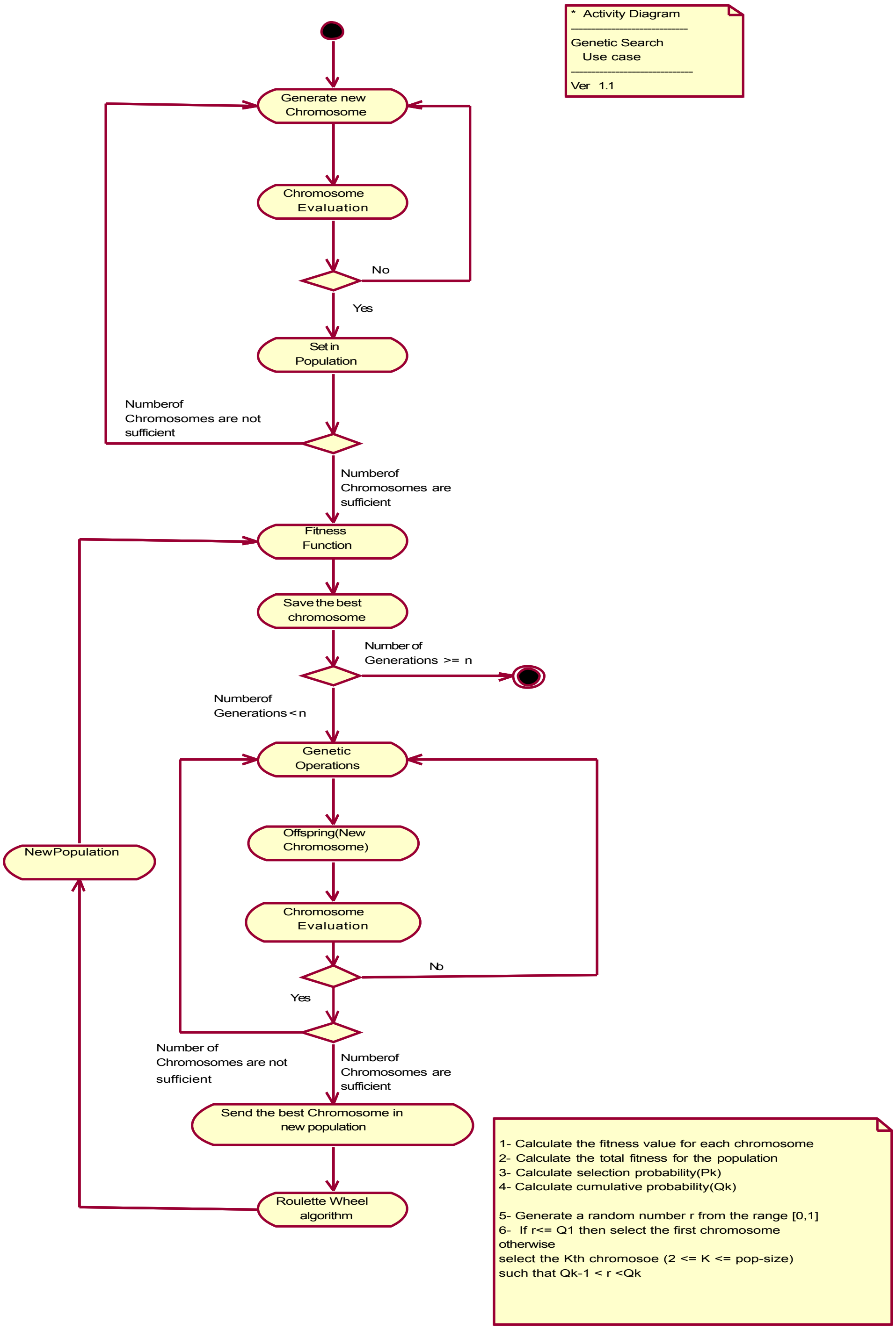

Figure 6. Activity diagram

Every solution of the SA must be satisfied two conditions. The first one is checking whether is it a solution of the GTN, and the second one is that whether the solution pass the consumers mini mum required pressure and flow. If the solution satisfy the above two condition, it will be tagged as a valid solution. Otherwise, it will be rejected. The valid solution with less total power consumption is the optimal solution. A GTN simulator will be used to verify the above conditions. The connection between the SA and the GTN simulator is established using the Microsoft COM tech nology. Figure 7 shows the schematic of this connection. A number of commercial GTN simulator such as Simone[17], Pipephase[18] may be used.

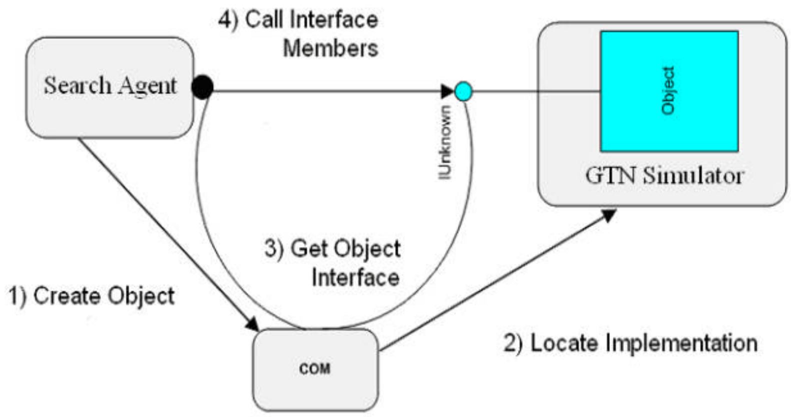

Figure 7. Connection between SA and Pipephase software

6 Numerical Results

Three real GTN samples have been used to verify the developed GTNOpS. The first network (GTN06) has 6 compressor stations with about 1100km pipelines, the second one (GTN22) includes 22 compressor stations with approximately 5000km pipelines, and the last one (GTN32) includes 32 compressor stations with approximately 6500km pipelines.

Table 1 shows the results of the GTN06 when the output pressures of the compressor stations have been set by the human experts where the total consumption of the compressors is equal to 359900KW. Table 2 shows the results of this network when the output pressures of the compressor stations have been proposed by the GTNOpS where the total consumption of the compressors is equal to 274514KW. It is clear that the total power consumption of the GTNOpS is significantly less than of the human expert system. The results of the GTNOpS are mainly produced by the GA component of the SA. Figure 8 depicts the training process of the GA.

TABLE I. THE RESULTS OF SOLVING GTN6 (HUMAN EXPERT)

The results of GTN06 solution (Human Expert)							
No.	Comp. ID	Pin (PSI)	Pout (PSI)	Pdiff (PSI)	Tin (C)	Tout (C)	Power (KW)
1	FRA3	847	1255	408	28.2	67.4	65000
2	FAR2	846	1280	434	29.1	69.5	63928
3	NOU2	937	1050	113	46.4	57.4	14610
4	NRD3	781	1250	469	47.7	97.8	89163
5	PTV2	714	1050	336	39.0	65.9	35247
6	PTV3	648	1050	402	68.0	116.4	91952
Total power consumption						359900 (KW)	

TABLE II. THE RESULTS OF SOLVING GTN6 (GTNOPS)

The results of GTN06 solution (GTNOpS)							
No.	Comp. ID	Pin (PSI)	Pout (PSI)	Pdiff (PSI)	Tin (C)	Tout (C)	Power (KW)
1	FRA3	847	1148	301	28.2	56.4	46174
2	FAR2	846	1265	419	29.1	68.0	61640
3	NOU2	918	1106	188	45.5	63.5	24031
4	NRD3	619	1291	672	40.9	93.5	93257
5	PTV2	785	902	117	42.4	51.9	12331
6	PTV3	731	897	166	65.1	85.5	37081
Total power consumption						274514 (KW)	

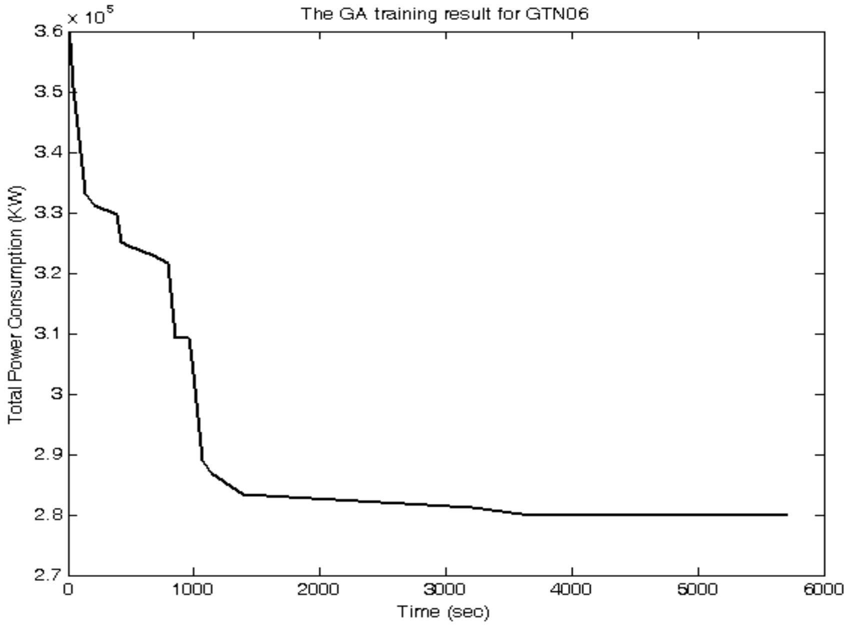

Figure 8. Training process of the GA for GTN06

The proposed GTNOpS is also tested and verified with GTN22. Table 3 shows the results of the human experts where the total consumption of the compressors is equal to 1053467KW. Table 4 shows the results of the GTNOpS where the total consumption of the compressors is equal to 683108KW. The total power consumption of the GTNOpS is about 65% of the human expert system. Figure 9 depicts the training process of the GA componen t for this network.

TABLE III. THE RESULTS OF SOLVIN G GTN22 (HUMAN EXPERT)

The results of GTN22 solution (Human Expert)							
No.	Comp. ID	Pin (PSI)	Pout (PSI)	Pdiff (PSI)	Tin (C)	Tout (C)	Power (KW)
1	ESF1	644	930	286	50.4	86.1	24547
2	ESF2	583	1050	467	89.6	149.6	123307
3	2NR1	874	1050	176	44.4	57.0	23291
4	ESF3	885	1050	165	66.5	83.5	22880
5	DHG2	707	1050	343	108.4	156.6	67423
6	DHG3	811	1050	239	58.4	83.8	34127
7	DHG1	656	930	274	49.5	83.5	20192
8	DRH2	661	1050	389	68.1	114.1	88523
9	DRH1	615	930	315	38.9	78.5	28054
10	DRH3	844	1050	206	77.3	98.3	27583
11	FAR3	709	1200	491	29.3	79.1	69385
12	FAR2	707	1127	420	30.7	73.1	110000
13	KVRN	706	1250	544	23.3	75.4	51081
14	TPZL	800	1050	250	20.0	44.5	14834
15	3NR1	874	1200	326	50.0	72.5	38619
15	PTV2	617	1050	433	33.4	84.0	90052
17	PTV3	603	1050	447	51.4	105.6	70213
18	PTV1	720	930	210	30.5	54.2	18114
19	GOM1	678	930	252	43.9	74.3	18705
20	GOM2	672	1050	378	98.6	152.1	68078
21	RSHT	556	1000	444	20.0	59.2	16127
22	SAVH	797	950	153	97.0	115.0	28332
Total power consumption						1053467 (KW)	

TABLE IV. THE RESULTS OF SOLVING GTN22 (GTNOPS)

The results of GTN22 solution (GTNOps)							
No.	Comp. ID	Pin (PSI)	Pout (PSI)	Pdiff (PSI)	Tin (C)	Tout (C)	Power (KW)
1	ESF1	1001	1092	91	50.5	58.9	6020
2	ESF2	1001	1137	136	61.7	74.3	21179
3	2NR1	849	1251	402	44.4	71.5	50524
4	ESF3	1015	1158	143	63.2	76.3	17186
5	DHG2	923	1057	134	53.0	66.0	16933
6	DHG3	950	970	20	53.7	55.7	2513
7	DHG1	830	1094	264	38.0	64.1	16648
8	DRH2	1017	1258	241	58.4	79.1	35253
9	DRH1	847	1230	383	39.4	75.0	27187
10	DRH3	856	1153	297	64.9	93.3	36206
11	FAR3	709	1158	449	29.3	75.6	61898
12	FAR2	707	1117	410	30.7	72.4	110000
13	KVRN	706	1172	466	23.3	69.4	44921
14	TPZL	800	1114	314	20.0	50.0	18199
15	3NR1	849	1282	433	47.7	76.8	50333
15	PTV2	907	1291	384	38.5	72.1	55074
17	PTV3	743	1054	311	54.2	88.5	43247
18	PTV1	964	1150	186	36.7	53.2	13532
19	GOM1	856	1049	193	35.9	55.0	13117
20	GOM2	851	1041	190	42.0	61.0	21513
21	RSHT	556	981	425	20.0	57.9	15567
22	SAVH	889	934	45	39.2	43.7	6058
Total power consumption						683108	

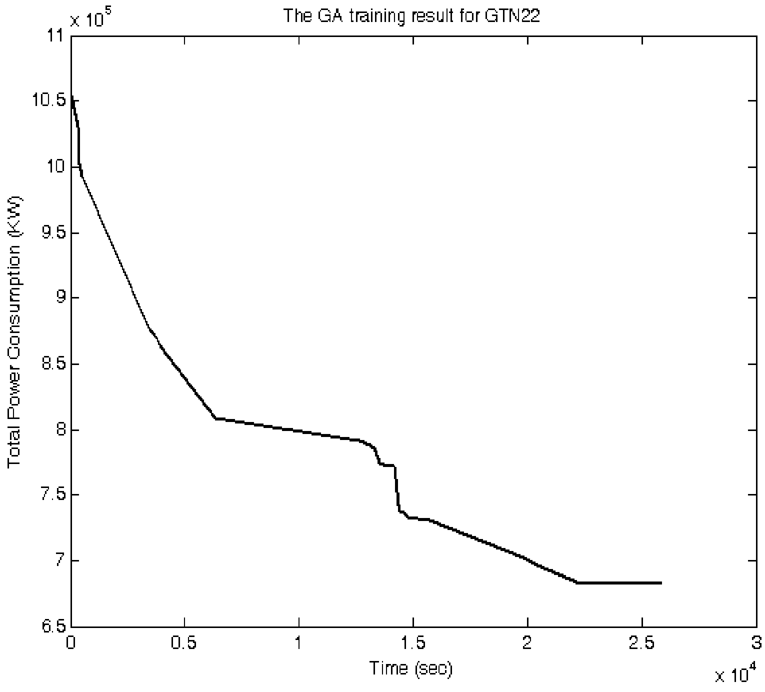

Figure 9. Training process of the GA for GTN22

The proposed GTNOpS is finally tested and verified with GTN32. Table 5 shows the results of the human experts where the total consumption of the compressors is equal to 1142222KW. Table 6 shows the results of the ABDSS where the total consumption of the compressors is equal to 863805KW. The total power consumption of the GTNOps is about 75% of the human expert system. Figure 10 depicts the training process of the GA component for this network.

TABLE V. THE RESULTS OF SOLVING GTN32 (HUMAN EXPERT)

The results of GTN32 solution (Human Expert)							
No.	Comp. ID	Pin (PSI)	Pout (PSI)	Pdiff (PSI)	Tin (C)	Tout (C)	Power (KW)
1	ESF1	641	930	289	51.0	87.5	25045
2	ESF2	583	1050	467	90.3	150.3	123665
3	2NR1	876	1050	174	44.4	59.5	7504
4	2NR2	876	1050	174	44.4	59.7	8648
5	2NR3	876	1050	174	44.4	62.9	4125
6	2NR4	876	1050	174	44.4	59.7	8648
7	ESF3	882	1050	168	69.6	87.0	23648
8	ARDB	690	1000	310	28.2	62.5	10549
9	CHLV	884	1000	116	24.7	35.7	3580
10	DHG2	707	1050	343	108.9	157.1	67453
11	DHG3	808	1050	242	60.7	86.5	34890
12	DHG1	653	930	277	50.2	84.6	20562
13	C295	661	1050	389	69.0	115.0	88848
14	DRH1	612	930	318	39.7	79.8	28533
15	C134	842	1050	208	81.6	103.0	28372
15	FAR3	709	1200	491	29.3	79.1	69545
17	FAR2	708	1128	420	30.7	73.3	110000
18	KVRN	706	1250	544	23.3	75.4	51089
19	TPZL	800	1050	250	20.0	44.5	15676
20	3NR1	872	1200	328	50.2	78.0	18647
21	3NR2	872	1200	328	50.2	77.9	14840
22	3NR3	872	1200	328	50.2	77.9	14840
23	PTV2	619	1050	431	34.5	85.0	89725
24	PTV3	590	1050	460	54.9	111.5	74254
25	PTV1	718	930	212	31.5	55.5	18425
26	GOM3	788	1050	262	54.2	82.4	27516
27	GOM1	675	930	255	45.0	76.0	19359
28	GOM2	672	1050	378	99.0	152.6	67628
29	RSHT	556	1000	444	20.0	59.2	16127
30	SARB	810	1000	190	27.8	47.2	4146
31	SAVH	791	950	159	96.6	115.4	29554
32	TBRZ	532	1050	518	20.2	83.3	16781
Total power consumption						1142222 (KW)	

TABLE VI. THE RESULTS OF SOLVIN G GTN22 (GTNOPS)

The results of GTN32 solution (Final comp. setting)							
No.	Comp. ID	Pin (PSI)	Pout (PSI)	Pdiff (PSI)	Tin (C)	Tout (C)	Power (KW)
1	ESF1	990	1223	233	69.6	90.8	17606
2	ESF2	1007	1141	134	83.0	95.5	21752
3	2NR1	852	1025	173	44.4	60.2	8224
4	2NR2	852	1025	173	44.4	59.9	6655
5	2NR3	852	1025	173	44.4	59.9	7281
6	2NR4	852	1025	173	44.4	59.9	6655
7	ESF3	1079	1226	147	73.9	86.5	17289
8	ARDB	901	1069	168	32.2	48.2	4685
9	CHLV	976	1190	214	25.3	43.5	5787
10	DHG2	933	1075	142	66.1	80.0	17741
11	DHG3	1024	1038	14	60.5	61.7	1623
12	DHG1	917	1187	270	57.2	82.5	18355
13	C295	1002	1270	268	84.0	108.0	42194
14	DRH1	918	1285	367	69.0	102.5	29707
15	C134	1102	1215	113	99.5	109.0	12929
15	FAR3	709	1161	452	29.3	76.0	62366
17	FAR2	707	1118	411	30.7	72.4	110000
18	KVRN	706	1164	458	23.3	68.6	44283
19	TPZL	800	1107	307	20.0	49.5	18849
20	3NR1	852	1173	321	47.9	70.4	20000
21	3NR2	852	1173	321	47.9	74.6	11239
22	3NR3	852	1173	321	47.9	74.6	11239
23	PTV2	605	1283	678	33.5	105.5	120312
24	PTV3	549	1290	741	51.4	135.1	112381
25	PTV1	665	1276	611	33.5	96.0	58508
26	GOM3	803	919	116	40.5	53.2	11866
27	GOM1	898	972	74	45.0	52.5	5147
28	GOM2	898	959	61	48.2	54.5	7082
29	RSHT	556	1081	525	20.0	64.5	18419
30	SARB	895	1001	106	25.0	35.0	2109
31	SAVH	800	943	143	36.2	51.5	20686
32	TBRZ	648	1027	379	20.2	62.5	10836
Total power consumption						863805 (KW)	

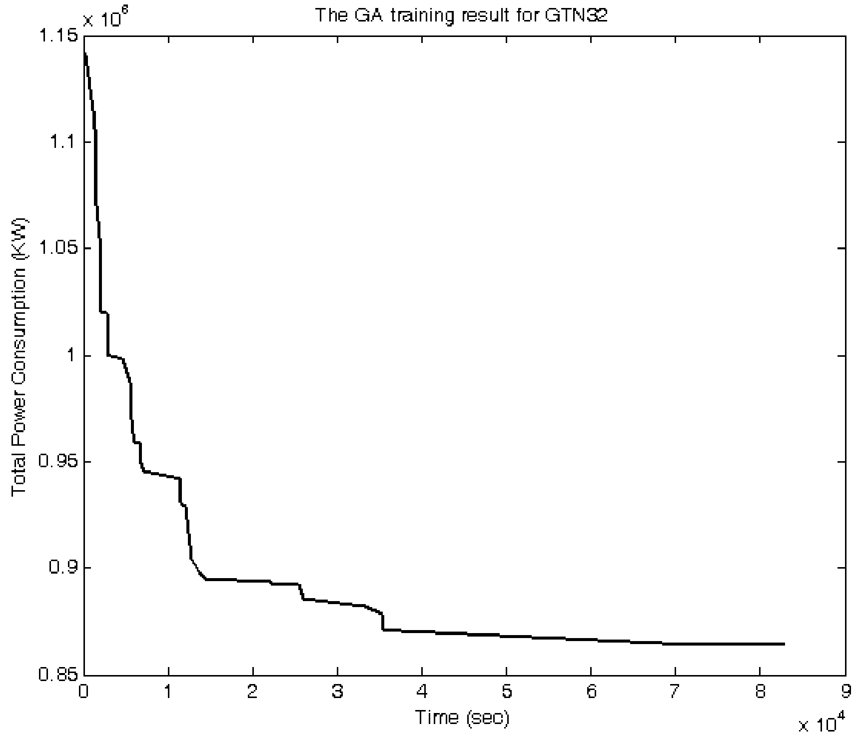

Figure 10. Training process of the GA for GTN32

7 Conclusions

This paper presents GTNOpS as an agent-based software for optimization of GTN. It comprises of two software agents called CoA and SA. UML modeling and C++ technology have been used for development of the agents. Three real GTN have been used to verify the performance of the developed software. It has been shown that the GTNOpS provides significant more optimal solutions compared to the human e xperts.

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