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Optimal Water Supply Scheduling Mechanisms using Bio-Inspired Algorithms for IoT-based Smart Water Distribution Network

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***Abstract*- The purpose of water distribution networks is to provide water to city residents. Even with climate change and decreasing precipitation, water distribution systems should be built to accommodate consumer demand. A Water Distribution Network (WDN) consists of pipes, valves, pumps, tanks, etc., to transfer potable water from reservoirs to consumer nodes. Internet of things (IoT) and information and communication technologies (ICT) are applied to water management systems (WMS) to make them smarter and more efficient. The physical devices of the water system are equipped with smart sensors and controllers so that real-time measurement of remote data such as smart meter reading, water tank level, valve condition, and pipe pressure rate can be gathered using smart sensors and broadcasted to the cloud via communication protocols. The data can then be examined, processed, and computed for the water authority board to make an ideal decision regarding the water supply scheduling in the WDN system to minimize the pump's operation cost and decrease water loss. Smart mobile devices are being utilized to inform consumers regarding their water usage and billing status. This paper will elaborate on the optimization algorithms performed to optimize the water resource scheduling model for the water distribution management system. Bio-inspired algorithms are used to optimize pump stations' scheduling by considering the pump's features like its start time, discharge time, and discharge capacity.**

Keywords- Internet of things, Information and Communication Technologies, Water distribution network, Water management system, Water supply schedule.

I. INTRODUCTION

The Internet of things (IoT) is a concept that refers to material things that have sensors, processing power, operating systems, and other advancements and can interact to other systems and appliances via the Web or any other communications infrastructure and transfer data with them.

A smart city employs IoT to facilitate access to automation in the environment and facilitate its inhabitants' lives. Currently, smart cities integrate IoT into all real-time applications, including smart housing, smart traffic management, smart parking, smart street lighting, smart waste management, air pollution control, and water management.

As is common knowledge, water is crucial for all life on Earth. The world has extremely few options for potable water. Consequently, shortly, there will be a water shortage. We should not squander water to avoid water waste throughout the distribution time. Therefore, the water scheduling plan should be required depending on water supply and demand.

A. Traditional Water System:

As common knowledge in the traditional water system, the water distribution network comprises aging and broken water assets. Additionally, we require human interference to supply and halt water flow. In the traditional water system, water loss will be greater due to equipment damage, and the long time required to locate leaks. In addition, water cannot be distributed uniformly to consumers in regions where there is a water shortage due to climate change and decreased precipitation. Insufficiency and overflow are the most significant issues with the water system.Figure1: depicts the structure of the general water system

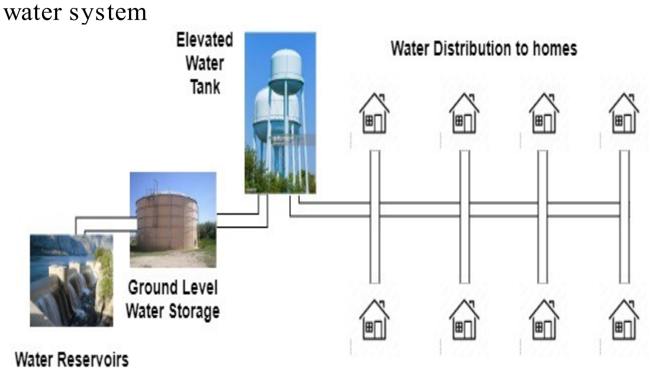

Figure 1: General Water System

B. IoT embedded smart water system

When we integrate IoT into the conventional water system, it will be possible to learn about the amount of water in the reservoirs, its level in the tank, its flow rate, and the customer's needs. With this information, we can rank the regions according to their requirement for water supply. Water can be supplied, allowing the plan to be developed accordingly.

The schedule plan specifies the location to be in and the quantity of water to be provided. These actions can be carried out automatically without assistance from a human.

This strategy for managing water resources will prevent uneven distribution of resources, eliminate water loss, and lower pumping station operating costs [14]. Figure 2 shows the framework of the water supply scheduling model in the IoT-enabled water distribution network.

combination of hydraulic limits, tanks, pipes, and pumps make it difficult for WDS to operate [15].

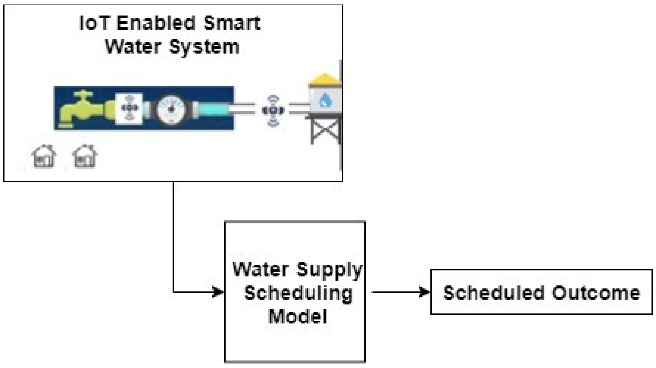

Figure 2: IoT Enabled Water Supply Scheduling Model.

C. Challenges faced when employing IoT in the water distribution system

The distribution region for the area where water will be delivered will be determined using clustering algorithms. Where the reservoirs are located and how long it takes for water to flow from the water source to the final node (customer location). This will be evaluated using its spatial and temporal properties. The basic goals are to utilize as much water as possible, transfer as much water as possible, and match water requirements. The remote area has smart sensor nodes integrated with water-distributing N/W infrastructure. Since we must obtain data from many regions, data collection is also a significant difficulty for planning water schedules. When using IoT in the environment, there are also challenges with missing data, data outliers because of network issues, and sensor.

II. RELATED WORKS

In this section, we will discuss various ways to optimize the IoT-based smart water distribution systems which are using optimal scheduling models in the water distribution network (WDN) to reduce the operation cost of the pump in the smart water distribution system.

Basin-to-basin divergence China is the location of the Draw Water Reservoir Regulation (IDR) model, which is utilized to distribute water from Danjiangkou Reservoir. The South-to-North Water Diversion Project (SNWDP) is used as a use case for the scheduling model since its main goals are to maximize water usage and match water distribution with consumption. The watering schedule is created for the zone, which is divided into groups according to the water needs, with several restrictions, including the highest and lowest levels of reservoir capacity, water balance at reservoirs, reservoir's maximum discharge capacity, and reservoir's minimum outflow, which must be taken into account for the water distribution to different cities [1].

A transfer function and the Binary Dragonfly algorithm are utilized to optimize the pumping schedule in WDS (Water Distribution System). It lowers the expense of energy-intensive pumping operations. With this model, energy costs are cut by up to 27% [2].

To acquire the operational scheduling of each pump utilizing flow, head, and power variables and an objective function to minimize the power consumption, two adaptive and one modified multi-population bio-inspired model was constructed and evaluated in Shanghai, China [3].

To manage pollution problems and flood protection using IoT devices, a model to forecast river flow and water quality was developed, and choices were made based on an analysis of IoT data. The PSO (Particle Swam optimization) algorithm is used to determine the water pump's operating schedule utilizing the start-up time, working intervals, and an objective function to reduce the cost of electricity. Water level and water quality predictions are made using the LSTM (Long-Short Term Memory) [4].

The Pipe Closure Index is used in conjunction with particle swam optimization (PSO) to determine which valves require change (PCI). The Ant Colony Optimization (ACO) technique is employed to establish the valve setting. Managing pressure by carefully planning the valves' operations is one method of reducing water leaks using a hydraulic simulator (EPANET) in MATLAB. The goal is to determine which valve is open and how much it is open each hour to maximize the Network Pressure Reliability Index (NPRI) of WDN. In WDN, the mean leakage rate decreases by 31.7% while the reliability index rises by 32.6% [5].

The hydraulic law, which states that pressure decreases according to its squared water flow, is the premise for the scheduling of water distribution through Optimal Water Flow (OWF). As an objective function, the cost of energy usage is minimized. 34 demand nodes, one tank, and one pumping station were served by this water distribution system, which was put into place for the watering schedule from Cherry Hills in the US [6].

Through online monitoring, hydro-informatics, and optimization techniques, WDS can be managed effectively. In evaluating the water distribution network model, the EPANET simulator is employed. To reduce the pump's operating costs, the daylight pumping schedule is optimized using a Genetic Algorithm(GA). Water availability, water demand, and water storage level all affect the best course of action. The energy costs associated with pumping operations and water losses during the distribution phase are decreased with the help of this water scheduling system. When compared to real-time operation, pump scheduling can increase energy efficiency by up to 15%. [7].

Temperature-dependent adjustments in water consumption. This issue was taken into consideration in the proposed paper to reduce the steel plant's annual investment and the pumping station's operational costs. Therefore, the optimal model's primary goal is to minimize cost. The objective function for designing a scheduling model is established by analyzing decision variables like flow, head needs, and limitations. To study the water flow's uncertainty in more detail, an uncertainty model is required. Since PSO is more successful at solving combinatorial and integer non-linear optimization problems, it was first proposed. The annual cost savings from this suggested approach is 23%[8].

Water is delivered from a reservoir to the customer using a water distribution system. As WDN is a large-scale territory, WDS was created to lower the cost of construction and operation. For the purpose of preventing leaks, flow and pressure should also be tracked. Non-dominated sorting genetic algorithm-II (NSGA-II) is developed to solve a minimum of multiple goal functions using multiple reservoirs network optimization, making it possible to create an ideal schedule (MRNO). This suggests a high-potential paradigm for WDS optimization to maximize goals including cost minimization, leakage reduction, and WDN reliability [9].

III. METHODOLOGY

The scheduling model of the water distribution system is optimized using Bio-inspired algorithms including the Genetic algorithm (GA) [13], Particle swarm algorithm (PSO), Ant colony algorithm (ACO), and Binary dragonfly algorithm (BDA). When the pump is used to distribute water, these algorithms are particularly effective in reducing the cost of energy use, the water pump scheduling is optimized so that the electricity price used for pump operation gets reduced. The start time and discharge time of the pump are two features that can be improved using optimization approaches scheduling of pump can be done. So that the aim function of lowering the cost of energy use may be achieved and the best optimal solution can be discovered. The typical flowchart in Figure 3 illustrates the procedures followed by bio-inspired algorithms to optimize the pumping schedule.

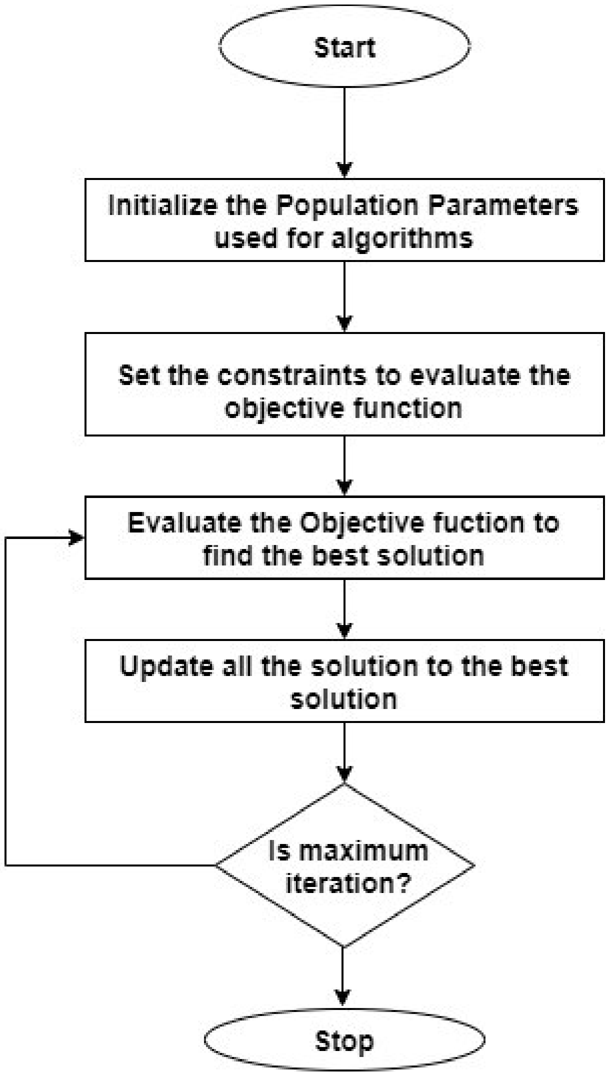

Figure 3: Flow chart for optimizing the pump schedule

IV. RESULTS COMPARISON AND DISCUSSION

The methods for water scheduling optimization will be covered in this section. Cost, time usage, and overall operational effectiveness of the PSO, GA, and BDA algorithms have been chosen to compare and assess as these three algorithms have a common objective function which is the minimization of cost, and these algorithms reduce cost by up to 27%, 23%, and 15% based on these given data Figure 4 was generated below compares the use of BDA as the best among these algorithms to optimize water pump scheduling in cost reduction.

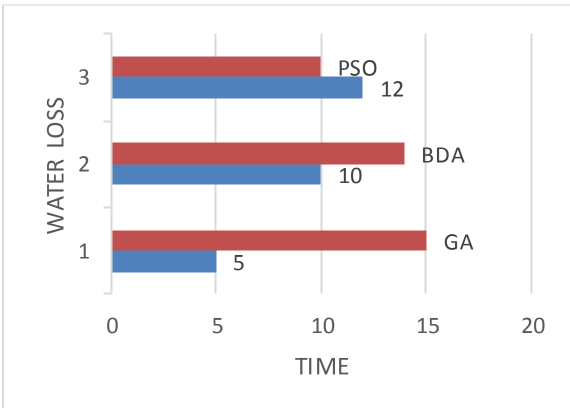

Figure 4: Comparison of optimization algorithms with respect to cost reduction.

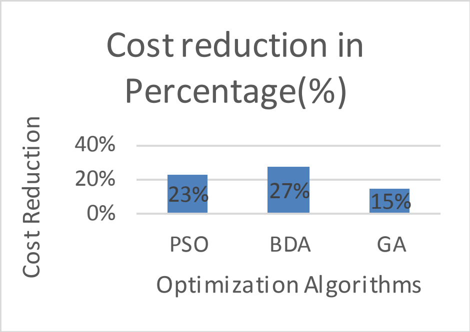

Figure 5: Optimizer with respect to water loss

TABLE 1: ALGORITHM COMPARISON OPTIMAL WATER SUPPLY SCHEDULING

Author [citation]	**Year of Publications**	**Methodology**	**Features**	**Challenges**
Ouyang *et al.* [1]	2019	IDR model	It improves scheduling effectiveness	The use of various dispatching objectives has an impact on performance.
Jafari-Asal *et al.* [2]	2021	Binary Dragonfly Algorithm	It achieves a lower cost.	The multi-objective scheduling function is not taken into account.
Turci *et al.* [3]	2020	Adaptive and Improved Optimization algorithm	The convergence time is improved. It improves precision	It uses fewer constraints to boost the outcomes even more.
Dong and Yang [4]	2020	MPC (Model predictive control) framework uses PSO and LSTM	It successfully offered the ideal operating scheduling.	The input-output convergent features may aid in enhancing the data-driven model.
Dini and Asadi [5]	2020	PSO and ACO	It achieves higher average reliability and leakage reduction value.	It prevents water from flowing through the pipe.

Singh and Kekatos [6]	2020	OWF	The numerical variable is effectively tuned to improve performance.	Issues of discrete values are not addressed.
Luna *et al.* [7]	2019	GA	It reduces time and expense while providing a workable solution.	It becomes vulnerable in terms of actual consumption and the optimization algorithm.

Particle swarm optimization (PSO), and Genetic Algorithm (GA). These are used to optimize the water distribution system in order to save costs, reduce conveyance losses as shown in Figure 5, and increase energy efficiency. Optimization of the Scheduling water pump is actually done by an optimization Algorithm, and it lowers the pumping station's operating costs. Energy efficiency may be increased by up to 15% to 25% in this manner.

Energy use is reduced by 25% as a result of GA's assurance of practicality, decreased water scheduling costs and time, and assurance of practicality. When applied to the actual distribution and optimization approaches, it is fairly feeble. BDA reduces costs while enhancing reliability. When using the currently known cost-efficient scheduling methods, only one objective function is taken into account. This BDA reduces costs by up to 27% with respect to the annual investment for pump station operations.

IV. CONCLUSION

Most of the water distribution systems we reviewed limit water loss by evaluating user demand predictions and detecting pipeline disruptions and designing pump scheduling models In some of the systems, the water the study, water scheduling models for the residential water distribution system can be developed using IoT smart devices. So that the water distribution system can be efficiently monitored and controlled remotely. If we plan water schedules based on customer demand predictions, which can, even more, minimize water loss with more energy consumption with less cost in water distribution networks. The Supply network is adjusted to supply the amount of water delivered to the user. According to the results of the scheduled outcome.

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