Analysis of Network Parameters for Network Lifetime in WSN: A Fuzzy Quadratic Programming Approach

Manoj Kumar Mandal, Arun Prasad Burnwal, Abhishek Kumar, Divya Mishra, and Nikhil Saxena

Abstract Wireless sensor network (WSN) is a collection of sensor nodes that are attached with base station (BS) and sink node to achieve a specific purpose. The main purpose of the WSN is sensing environmental parameters such as energy, temperature, and humidity. There are several parameters of the WSN that changes time to time and frequently based on the operation. Each sensor node contains limited capacity of battery that is insufficient during any operation and fails to send the data packet to the BS. So, there is need of some modeling using some intelligent technique. In this paper, a fuzzy quadratic programming (FQP) is used to optimize network parameters efficiently. FQP is the fusion of fuzzy logic and quadratic programming. Fuzzy logic is a multi-values logic which is used to reduce uncertainty and estimate imprecise parameters efficiently. Quadratic programming is a nonlinear programming based on second order of mathematical polynomial for reducing the main objective. The combination of both helps to analyze conflicting network parameters and decide the optimal objective value along with constraints. The proposed method is validated in LINGO optimization software in terms of several rounds to predict the optimal solution.

Keywords Wireless sensor network · Fuzzy set theory · Quadratic programming · Nonlinear optimization · Membership value

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1 Introduction

Wireless sensor network (WSN) is a collection of sensor nodes that provide the services to the users and customer with the help of sensing system [1–3]. It consists of base station (BS) and some sink node. The purpose of sink node is to receive data and information from the source node. The purpose of BS to collection data and information from the multiple sensor nodes and analyze it for performing operation. Figure 1 shows WSN network that consists of several information such as sensor nodes, BS, user, and computer. In this figure, within range all sensor nodes are deployed, this range is connected with BS for analyzing and validating data packets. BS station is further connected with a computer that helps to store sensed information for predicting and analyzing. This computer is connected with user that work as an administrator that works fully with sensor nodes and BS for managing several applications as follows.

(a) Military application
(b) Entertainment application
(c) Business and marketing
(d) Educational
(e) Disaster management.

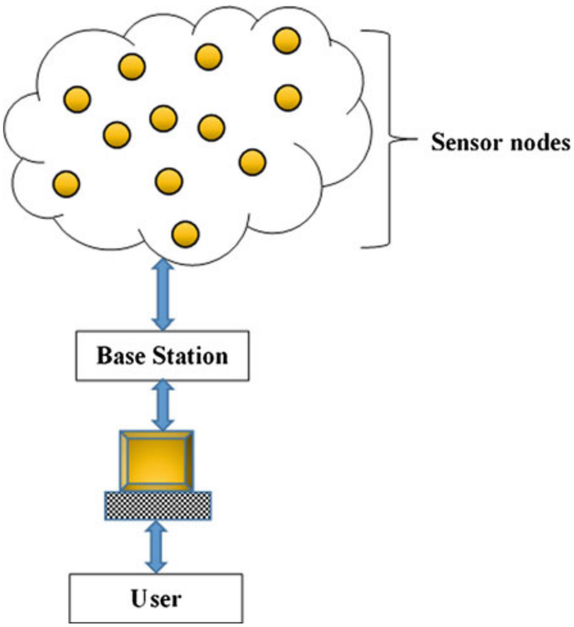


Fig. 1 Wireless sensor network

The WSN have several applications in terms of efficient working principles, but it has also some limitations such as battery issue of the sensor nodes, low communication ranges within different hop nodes, speed between sensor nodes, etc. These several types limitations are arise due to its variation of network parameters. In this paper, a fuzzy quadratic programming (FQP) [4] is used to optimize network parameters efficiently. FQP is the fusion of fuzzy logic and quadratic programming. Fuzzy logic is a soft computing technique which produces soft results that indicate approximation results [5]. It is a multi-values logic which is used to reduce uncertainty and estimate imprecise parameters efficiently. Quadratic programming is a nonlinear programming based on second order of mathematical polynomial for reducing the main objective. The combination of both helps to analyze conflicting network parameters and decide the optimal objective value along with constraints.

The rest of the paper is divided as follows. Section 2 highlights some existing work related to some routing techniques. Section 3 shows details analysis parts of the proposed method. Section 4 shows simulation and analysis part of the proposed method. Finally, in Sect. 5, conclude the paper.

2 Related Works

In several years, various works are proposed in the context of ad-hoc network and WSN. Some works are discussed in this section as follows. Mandhare et al. [6] designed a meta-heuristic-based routing protocol for MANET. The purpose of this routing is to enhance QoS of the network. The proposed method reduces the issue of non-deterministic NP hard issue. The key technique is used in this method that is cuckoo search method. The method is used in the AODV routing technique with the help of RREQ and RREP packets for finding the shortest path. Finally, it compares with some nature-inspired techniques such as PSO, ACO, and simple AODV, enhances the matrices scalability and mobility, and reduces congestion of the network. Phoemphon et al. [7] proposed a hybrid method for WSN using PSO based. The proposed method is based on localization technique. In this work, two basic parameters are considered such as hop-count and distance for evaluating localization system. In WSN, all parameters are based on approximation technique. The proposed method uses this localization system using PSO technique. The basic parameters of the PSO and its tuning parameters considered with the help of network parameters, and finally, it helps to enhance the network lifetime. Tripathi and Das [8] proposed five input parameters based intelligence routing using multiple criteria of ad-hoc network. This is based on soft set method which mixed by extended fuzzy set, i.e., intuitionistic fuzzy set and two techniques of the multi-criteria decision system. Each input parameter is mapped into the soft set in terms of three elements such true membership value, false membership value, and between both which is known as hesitation membership value. Finally, it helps to resolve the uncertainty of the network efficient and derive optimal route of the network. Sun et al. [9] proposed an optimization technique for handling attack in WSN. This is based on PSO optimization along with multiple objectives of the network. It minimizes the energy consumption of the nodes and maximizes the load balancing of the network. The natures of both objectives are nonlinear formulation, and nature of the PSO optimization is binary. Finally, it helps to dynamically maintain all the objectives and their constraints, maintains the convergence of the system, and finally helps to enhance the network lifetime. Cao et al. [10] designed a PSO based distributed optimization technique for WSN. It is based on the deployment system of the network. In this system, nodes are heterogeneous types and divided into two types as relay nodes and simple nodes. This system helps to maximize coverage of the network and maximize the network lifetime with the help of relay nodes. In this paper, nodes are deployed in the 3D environment system, and finally, it helps to reduce time of the passing message and cost of the network. Yang et al. [11] designed an intelligent system for transportation system in wireless network. This is based on an existing transportation system based on process structured system. Finally, it helps to enhance network capabilities and services of the network. It also helps user function and usages in the network and network metrics properly to maintain the network. Loganathan and Subbiah [12] designed an energy-based communication system for device-to-device communication in the network. It is based on multi-criteria decision-making system where multiple criteria are involved for integrating the network metrics efficiently. Finally, it helps to enhance the network lifetime and helps in communication system. Hu et al. [13] designed an algorithm for WSN for cooperative maintenance of the nodes using PSO. This method is based on multiple sink nodes of the network for recovery of the route. This routing technique is used to reduce overhead of the network that rose in the communication system by using two basic parameters such as delay and overhead of the network. The tuning parameters of the network help to enhance the global optimization of the PSO, so that accuracy convergence of the network is increases. Elhabyan and Yagoub [14] designed a PSO based optimization technique for WSN. This is based on clustering technique in the network. In this work, the nature-inspired technique PSO mixed with linear programming boosts cluster head for identifying its work within the network. This cluster head helps to collect information from all the sensor nodes and send it to the base station for analyzing and aggregating information to the source to the destination node. Finally, it outperforms the network metrics in terms of delivery ration and scalability. Hayes and Ali [15] proposed a routing protocol named as RASeR for mobile sensor networks. In this paper, topology changing issue solves with the help of global time division multiple accesses using fixed nodes. Singh et al. [16] designed a distributed routing algorithm for WANET. The proposed work is based on two existing routing protocols such as DSDV and AODV where performance of these protocols is analyzed based on pause time of the nodes mobility. Chandrakar [17] designed an authentication system for the users in wireless network. This is basically based on healthcare system and used for medical purpose. This proposal is used for sensing patient body information and sending it to the doctor for treatment and diagnosis purpose. It also helps in user authentication, privacy, and data security purposes, so that efficient result comes from the diagnosis system. Jat et al. [18] designed an intelligent technique for QoS in WLAN. This proposal is based on video delivery system. This is based on multimedia application for video data processing and analyzing. The data analyzed here is based on real-time data that generated by the Internet. It also helps in video data transmission, storage, evaluating, and broadcasting. Sattari et al. [19] used an ACO inspired algorithm for routing in VANET. In this work, several traffics are controlled and managed for finding feasible paths of the network. It is also used for reliable transmission. Finally, a cellular-ant-based algorithm is designed to find an optimal solution. Abdallah [20] proposed a smart partial flooding routing algorithm for ad-hoc network. In this paper, two 3D geographical routing algorithms are used for maintaining two things like overhead and flooding in the network. In WSN, data is gathered from multiple homogeneous or heterogeneous sources because real-life data is connected with different IoT, IoV, or cloud environment. So, it is difficult to keep the natures of the data in same structure. Information retrieval [21] is very important part in modern research areas which indicates collecting information that are stored in unstructured form based on multiple local languages and process it in particular pattern after observing. Hao et al. [22] designed an evaluation system for big data analysis. This data is based on IoV where it means Internet of vehicle. This proposal is based on K-means algorithm that is used here as a clustering. In this work, different behaviors of the driving are involved for controlling vehicle. Finally, it helps in reducing fuel consumption and helps in transportation globally. Singh et al. [23] designed a method for pattern adopting in ad-hoc network. The proposed method is based on security system. It illustrated different attacks of the ad-hoc in terms of passive and active attacks. It also highlights process to overcome traditional issues and constraints. In the above literature, all authors did not analyze the network parameters with respect to network lifetime. In this paper, this is proposed based on mathematical optimization.

3 Proposed Method

In this section, the proposed method is illustrated briefly with the help of mathematical formulation and analysis. Let N is the set of wireless sensor nodes that are deployed in the workable area as shown in Eq. (1).

$$N = \{n_i\} \quad \text{where} \quad i = 1, 2, 3, \ldots, k \tag{1}$$

In this equation, k varies based on user requirement and deployment. WSN consists of several parameters for transmitting data packet such as “energy consumption,” “hop-count,” “distance,” “delay,” and “overhead,”. In this paper, there parameters are considered as “energy consumption,” “delay,” and “overhead.” These parameters affect the network lifetime of the WSN. If energy consumption increases, then network lifetime decreases; if delay increases, then network lifetime decreases, and if overhead increases, then network lifetime decreases. Hence, nature of these three parameters is contradictory with network lifetime. Table 1 shows several assumptions of the network with parameters that help to formulate the network lifetime statistic.

Table 1 Assumptions and statistics of the network

Node (N)	Energy consumption (E)	Delay (D)	Overhead (O)
n_1	e_1	d_1	o_1
n_2	e_2	d_2	o_2
n_3	e_3	d_3	o_3
…	…	…	…
…	…	…	…
…	…	…	…
…	…	…	…
…	…	…	…
n_k	e_k	d_k	o_k

Table 2 Dataset for round 1 where number of node, i.e., k_1 is 5

Energy consumption	Delay	Overhead
$e_1 = 5$	$d_1 = 2$	$o_1 = 1$
$e_2 = 1$	$d_2 = 4$	$o_2 = 3$
$e_3 = 3$	$d_3 = 2$	$o_3 = 4$
$e_4 = 1$	$d_4 = 2$	$o_4 = 4$
$e_5 = 3$	$d_5 = 2$	$o_5 = 2$

In this paper, nature of the considered parameters is conflicting with network lifetime, so here objective is to minimize these parameters based on satisfied constraints. So, objective function and their constraints are shown in Eq. (2). In this equation, x_1, x_2, and x_3 are decision variables for three parameters such as energy consumption, delay, and overhead. Summation of three needs to be minimized, and its constraints contain considered parameters and statistic of the network. The symbol 'k' is the variation of nodes that vary several time based on the deployment as k_1, k_2, k_3, …, k_n. Here, difference of each 'k' varies by five nodes. So, correspondence equation for different rounds is shown in Eqs. (3)–(6). The correspondence datasets are given in Tables 2, 3, 4, 5, and 6.

Table 3 Dataset for round 1 where number of node, i.e., k_2 is 10

Energy consumption	Delay	Overhead
$e_1 = 11$	$d_1 = 4$	$o_1 = 2$
$e_2 = 10$	$d_2 = 4$	$o_2 = 5$
$e_3 = 5$	$d_3 = 8$	$o_3 = 4$
$e_4 = 6$	$d_4 = 2$	$o_4 = 8$
$e_5 = 3$	$d_5 = 7$	$o_5 = 2$

Table 4 Dataset for round 1 where number of node, i.e., k_3 is 15

Energy consumption	Delay	Overhead
$e_1 = 10$	$d_1 = 7$	$o_1 = 8$
$e_2 = 16$	$d_2 = 2$	$o_2 = 4$
$e_3 = 4$	$d_3 = 5$	$o_3 = 6$
$e_4 = 9$	$d_4 = 6$	$o_4 = 2$
$e_5 = 11$	$d_5 = 6$	$o_5 = 5$

Table 5 Dataset for round 1 where number of node, i.e., k_4 is 20

Energy consumption	Delay	Overhead
$e_1 = 12$	$d_1 = 11$	$o_1 = 9$
$e_2 = 11$	$d_2 = 5$	$o_2 = 3$
$e_3 = 9$	$d_3 = 8$	$o_3 = 7$
$e_4 = 6$	$d_4 = 2$	$o_4 = 8$
$e_5 = 3$	$d_5 = 7$	$o_5 = 2$

Table 6 Dataset for round 1 where number of node, i.e., k_5 is 25

Energy consumption	Delay	Overhead
$e_1 = 14$	$d_1 = 11$	$o_1 = 10$
$e_2 = 10$	$d_2 = 14$	$o_2 = 15$
$e_3 = 5$	$d_3 = 8$	$o_3 = 4$
$e_4 = 6$	$d_4 = 2$	$o_4 = 8$
$e_5 = 7$	$d_5 = 7$	$o_5 = 3$

$$\begin{aligned}
&\text{Minimize :} && Z_1 = x_1 + x_2 + x_3 \\
&\text{Subject to constraints :} && e_1x_1 + d_1x_2 + o_1x_3 \geq k_1 \\
& && e_2x_1 + d_2x_2 + o_2x_3 \geq k_1 \\
& && e_3x_1 + d_3x_2 + o_3x_3 \geq k_1 \\
& && e_4x_1 + d_4x_2 + o_4x_3 \geq k_1 \\
& && e_5x_1 + d_5x_2 + o_5x_3 \geq k_1
\end{aligned} \tag{2}$$

$$\begin{aligned}
&\text{Minimize :} && Z_2 = x_1 + x_2 + x_3 \\
&\text{Subject to constraints :} && e_1x_1 + d_1x_2 + o_1x_3 \geq k_2 \\
& && e_2x_1 + d_2x_2 + o_2x_3 \geq k_2 \\
& && e_3x_1 + d_3x_2 + o_3x_3 \geq k_2 \\
& && e_4x_1 + d_4x_2 + o_4x_3 \geq k_2 \\
& && e_5x_1 + d_5x_2 + o_5x_3 \geq k_2
\end{aligned} \tag{3}$$

$$\begin{aligned} &\text{Minimize :} && Z_3 = x_1 + x_2 + x_3 \\ &\text{Subject to constraints :} && e_1x_1 + d_1x_2 + o_1x_3 \geq k_3 \\ &&& e_2x_1 + d_2x_2 + o_2x_3 \geq k_3 \\ &&& e_3x_1 + d_3x_2 + o_3x_3 \geq k_3 \\ &&& e_4x_1 + d_4x_2 + o_4x_3 \geq k_3 \\ &&& e_5x_1 + d_5x_2 + o_5x_3 \geq k_3 \end{aligned} \tag{4}$$

$$\begin{aligned} &\text{Minimize :} && Z_4 = x_1 + x_2 + x_3 \\ &\text{Subject to constraints :} && e_1x_1 + d_1x_2 + o_1x_3 \geq k_4 \\ &&& e_2x_1 + d_2x_2 + o_2x_3 \geq k_4 \\ &&& e_3x_1 + d_3x_2 + o_3x_3 \geq k_4 \\ &&& e_4x_1 + d_4x_2 + o_4x_3 \geq k_4 \\ &&& e_5x_1 + d_5x_2 + o_5x_3 \geq k_4 \end{aligned} \tag{5}$$

$$\begin{aligned} &\text{Minimize :} && Z_5 = x_1 + x_2 + x_3 \\ &\text{Subject to constraints :} && e_1x_1 + d_1x_2 + o_1x_3 \geq k_5 \\ &&& e_2x_1 + d_2x_2 + o_2x_3 \geq k_5 \\ &&& e_3x_1 + d_3x_2 + o_3x_3 \geq k_5 \\ &&& e_4x_1 + d_4x_2 + o_4x_3 \geq k_5 \\ &&& e_5x_1 + d_5x_2 + o_5x_3 \geq k_5 \end{aligned} \tag{6}$$

Equations (2)–(6) are in the form of linear where both objective functions and constraints are linear for three parameters such as energy consumption, delay, and overhead for five rounds such as k_1 to k_5, here k_1 to k_5 are varied based on difference of five. Dataset in Tables 2, 3, 4, 5, and 6 has shown several constraint values of the objective values. Quadratic programming is more efficient than linear programming in term of estimation and efficiency. It is an optimization technique like meta-heuristic [24] technique for optimizing several problems based on objective function and their constraints. So, Eqs. (2)–(6) are converted into the form of quadratic and shown in Eqs. (7)–(11).

$$\begin{aligned} &\text{Minimize:} && Z_1 = x_1^2 + x_2^2 + x_3^2 \\ &\text{Subject to constraints:} && e_1x_1 + d_1x_2 + o_1x_3 \geq k_1 \\ &&& e_2x_1 + d_2x_2 + o_2x_3 \geq k_1 \\ &&& e_3x_1 + d_3x_2 + o_3x_3 \geq k_1 \\ &&& e_4x_1 + d_4x_2 + o_4x_3 \geq k_1 \\ &&& e_5x_1 + d_5x_2 + o_5x_3 \geq k_1 \end{aligned} \tag{7}$$

$$\begin{aligned}
&\text{Minimize:} && Z_2 = x_1^2 + x_2^2 + x_3^2 \\
&\text{Subject to constraints:} && e_1x_1 + d_1x_2 + o_1x_3 \geq k_2 \\
& && e_2x_1 + d_2x_2 + o_2x_3 \geq k_2 \\
& && e_3x_1 + d_3x_2 + o_3x_3 \geq k_2 \\
& && e_4x_1 + d_4x_2 + o_4x_3 \geq k_2 \\
& && e_5x_1 + d_5x_2 + o_5x_3 \geq k_2
\end{aligned} \tag{8}$$

$$\begin{aligned}
&\text{Minimize:} && Z_3 = x_1^2 + x_2^2 + x_3^2 \\
&\text{Subject to constraints:} && e_1x_1 + d_1x_2 + o_1x_3 \geq k_3 \\
& && e_2x_1 + d_2x_2 + o_2x_3 \geq k_3 \\
& && e_3x_1 + d_3x_2 + o_3x_3 \geq k_3 \\
& && e_4x_1 + d_4x_2 + o_4x_3 \geq k_3 \\
& && e_5x_1 + d_5x_2 + o_5x_3 \geq k_3
\end{aligned} \tag{9}$$

$$\begin{aligned}
&\text{Minimize:} && Z_4 = x_1^2 + x_2^2 + x_3^2 \\
&\text{Subject to constraints:} && e_1x_1 + d_1x_2 + o_1x_3 \geq k_4 \\
& && e_2x_1 + d_2x_2 + o_2x_3 \geq k_4 \\
& && e_3x_1 + d_3x_2 + o_3x_3 \geq k_4 \\
& && e_4x_1 + d_4x_2 + o_4x_3 \geq k_4 \\
& && e_5x_1 + d_5x_2 + o_5x_3 \geq k_4
\end{aligned} \tag{10}$$

$$\begin{aligned}
&\text{Minimize:} && Z_5 = x_1^2 + x_2^2 + x_3^2 \\
&\text{Subject to constraints:} && e_1x_1 + d_1x_2 + o_1x_3 \geq k_5 \\
& && e_2x_1 + d_2x_2 + o_2x_3 \geq k_5 \\
& && e_3x_1 + d_3x_2 + o_3x_3 \geq k_5 \\
& && e_4x_1 + d_4x_2 + o_4x_3 \geq k_5 \\
& && e_5x_1 + d_5x_2 + o_5x_3 \geq k_5
\end{aligned} \tag{11}$$

Equations (7)–(11) are in the form of quadratic where the nature of the objective functions is nonlinear, but nature of the constraints is in linear. So, the combination of both is nonlinear for three same parameters and same k_i with difference five.

4 Simulation and Analysis

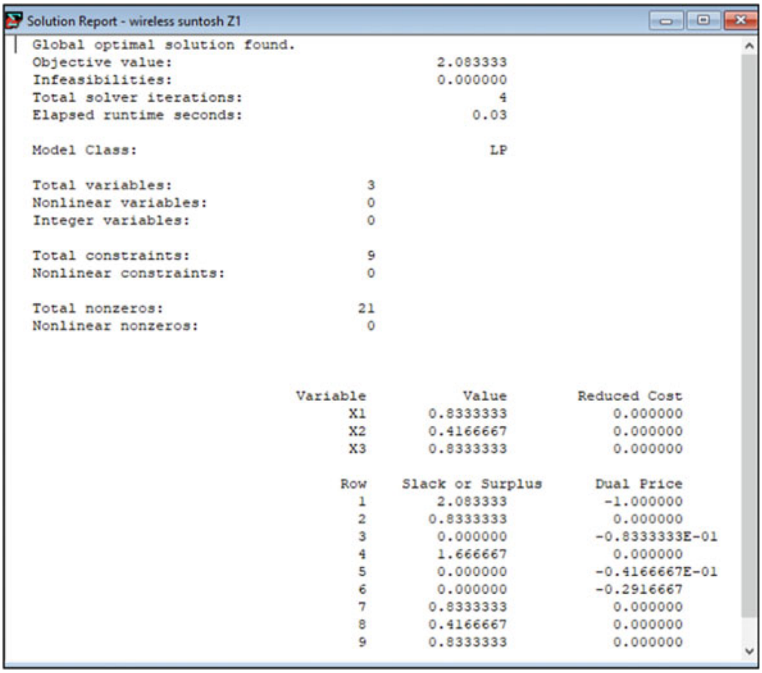
The proposed method is simulated and verified in LINGO optimization software which is used to optimize linear and nonlinear both formulations. In this paper, total linear objective functions used are five, and nonlinear objective functions used are five, so total objective function is ten. Each objective function contains five linear constraints. So, here, total constraints are 5 × 10, i.e., 50, 25 for linear and 25 for quadratic formulation which is nonlinear formulation. In this simulation, minimum node is 5, maximum node is 25, and in each iteration or round, node varies by 5. The objectives are to minimize three network parameters such as energy consumption, delay, and overhead. Total simulation parameters are given in Table 7.

Figures 2, 3, 4, 5, and 6 show linear formulation of three objective function such as (x_1 to x_3) such as energy consumption, delay, and overhead for five rounds (Z_1 to Z_5) such as 5, 10, 15, 20, and 25. The values of different rounds depicted as values of the objective functions and values of the decision variables such as $Z_1 = 2.08333$, $x_1 = 0.833333$, $x_2 = 0.4166667$, and $x_3 = 0.833333$ in round 1 by 5 nodes; $Z_2 = 2.146018$, $x_1 = 0.3982301$, $x_2 = 1.061947$, and $x_3 = 0.6858407$ in round 2 by 10 nodes; $Z_3 = 2.904412$, $x_1 = 0.5147059$, $x_2 = 1.397059$, and $x_3 = 0.9926471$ in round 3 by 15 nodes; $Z_4 = 4.257426$, $x_1 = 0.3465347$, $x_2 = 2.227723$, and $x_3 = 1.683168$ in round 4 by 20 nodes; and $Z_5 = 4.51807$, $x_1 = 1.506024$, $x_2 = 1.35542$, and $x_3 = 1.656627$ in round 5 by 25 nodes. In each round, it is observed that when number of nodes increases, optimized objective value also increases.

Figures 7, 8, 9, 10, and 11 show formulation of quadratic programming based on three objective functions such as (x_1 to x_3) such as energy consumption, delay, and overhead for five rounds (Z_1 to Z_5) such as 5, 10, 15, 20, and 25. The values of different rounds depicted as values of the objective functions and values of the decision variables such as $Z_1 = 1.515152$, $x_1 = 0.7575742$, $x_2 = 0.6060645$, and $x_3 = 0.7575743$ in round 1 by 5 nodes; $Z_2 = 1.689190$, $x_1 = 0.6079219$, $x_2 = 1.013556$, and $x_3 = 0.5406711$ in round 2 by nodes 10; $Z_3 = 2.922078$, $x_1 = 0.7790705$, $x_2 = 0.9739913$, and $x_3 = 1.168960$ in round 3 by nodes 15; $Z_4 = 6.756759$, $x_1 = 1.216193$, $x_2 = 2.027032$, and $x_3 = 1.081099$ in round 4 by nodes 20; $Z_5 = 6.849669$, $x_1 = 1.509525$, $x_2 = 1.354422$, and $x_3 = 1.654251$ in round 5 by nodes 25. In each round, it is observed that when number of nodes increases, optimized objective value also increases; but in quadratic programming, values are more optimal than linear programming.

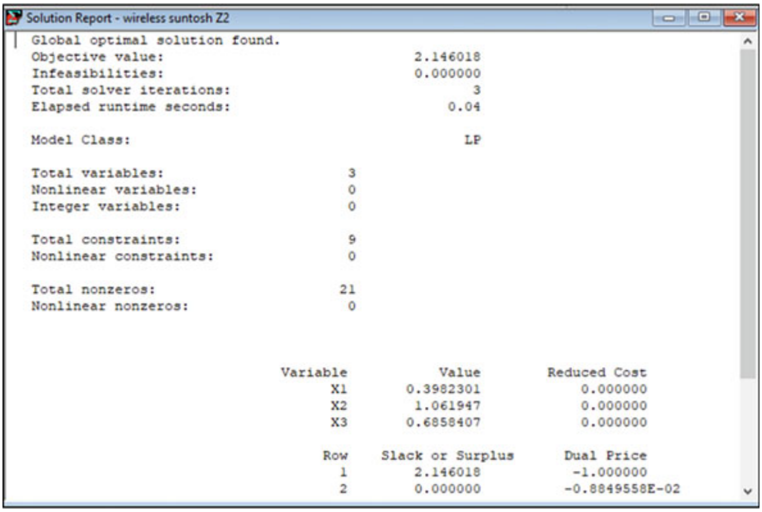
Table 7 Simulation parameters

Parameter	Description
Software	LINGO
Linear objective function	5
Nonlinear objective function	5
Constraints	50
Number of nodes	Minimum 5, maximum 25
Number of rounds	5
Network parameters	Energy consumption, delay, overhead


Solution Report - wireless suntosh Z1

```
Global optimal solution found.
Objective value:                              2.083333
Infeasibilities:                              0.000000
Total solver iterations:                             4
Elapsed runtime seconds:                          0.03

Model Class:                                        LP

Total variables:                     3
Nonlinear variables:                 0
Integer variables:                   0

Total constraints:                   9
Nonlinear constraints:               0

Total nonzeros:                     21
Nonlinear nonzeros:                  0


                              Variable           Value        Reduced Cost
                                    X1       0.8333333            0.000000
                                    X2       0.4166667            0.000000
                                    X3       0.8333333            0.000000

                                   Row    Slack or Surplus      Dual Price
                                     1        2.083333           -1.000000
                                     2       0.8333333            0.000000
                                     3        0.000000          -0.8333333E-01
                                     4        1.666667            0.000000
                                     5        0.000000          -0.4166667E-01
                                     6        0.000000          -0.2916667
                                     7       0.8333333            0.000000
                                     8       0.4166667            0.000000
                                     9       0.8333333            0.000000
```

Fig. 2 Linear formulation based on node 5


Solution Report - wireless suntosh Z2

```
Global optimal solution found.
Objective value:                              2.146018
Infeasibilities:                              0.000000
Total solver iterations:                             3
Elapsed runtime seconds:                          0.04

Model Class:                                        LP

Total variables:                     3
Nonlinear variables:                 0
Integer variables:                   0

Total constraints:                   9
Nonlinear constraints:               0

Total nonzeros:                     21
Nonlinear nonzeros:                  0


                              Variable           Value        Reduced Cost
                                    X1       0.3982301            0.000000
                                    X2        1.061947            0.000000
                                    X3       0.6858407            0.000000

                                   Row    Slack or Surplus      Dual Price
                                     1        2.146018           -1.000000
                                     2        0.000000          -0.8849558E-02
```

Fig. 3 Linear formulation based on node 10

```
Global optimal solution found.
Objective value:                              2.904412
Infeasibilities:                              0.000000
Total solver iterations:                             3
Elapsed runtime seconds:                          0.05

Model Class:                                        LP

Total variables:                      3
Nonlinear variables:                  0
Integer variables:                    0

Total constraints:                    9
Nonlinear constraints:                0

Total nonzeros:                      21
Nonlinear nonzeros:                   0


                               Variable           Value        Reduced Cost
                                     X1       0.5147059            0.000000
                                     X2        1.397059            0.000000
                                     X3       0.9926471            0.000000

                                    Row    Slack or Surplus      Dual Price
                                      1        2.904412           -1.000000
```

Fig. 4 Linear formulation based on node 15

```
Global optimal solution found.
Objective value:                              4.257426
Infeasibilities:                              0.000000
Total solver iterations:                             3
Elapsed runtime seconds:                          0.04

Model Class:                                        LP

Total variables:                      3
Nonlinear variables:                  0
Integer variables:                    0

Total constraints:                    9
Nonlinear constraints:                0

Total nonzeros:                      21
Nonlinear nonzeros:                   0


                               Variable           Value        Reduced Cost
                                     X1       0.3465347            0.000000
                                     X2        2.227723            0.000000
                                     X3        1.683168            0.000000

                                    Row    Slack or Surplus      Dual Price
                                      1        4.257426           -1.000000
```

Fig. 5 Linear formulation based on node 20

```
Solution Report - wireless suntosh Z5

Global optimal solution found.
Objective value:                              4.518072
Infeasibilities:                              0.000000
Total solver iterations:                             3
Elapsed runtime seconds:                          0.04

Model Class:                                        LP

Total variables:                      3
Nonlinear variables:                  0
Integer variables:                    0

Total constraints:                    9
Nonlinear constraints:                0

Total nonzeros:                      21
Nonlinear nonzeros:                   0


                              Variable           Value        Reduced Cost
                                    X1        1.506024            0.000000
                                    X2        1.355422            0.000000
                                    X3        1.656627            0.000000

                                   Row    Slack or Surplus      Dual Price
                                     1        4.518072           -1.000000
```

Fig. 6 Linear formulation based on node 25

```
Solution Report - wireless suntosh Q Z1

Global optimal solution found.
Objective value:                              1.515152
Infeasibilities:                              0.000000
Total solver iterations:                             8
Elapsed runtime seconds:                          0.09
Model is convex quadratic

Model Class:                                        QP

Total variables:                      3
Nonlinear variables:                  3
Integer variables:                    0

Total constraints:                    9
Nonlinear constraints:                1

Total nonzeros:                      21
Nonlinear nonzeros:                   3


                              Variable           Value        Reduced Cost
                                    X1       0.7575742      -0.1355101E-03
                                    X2       0.6060645       0.7278113E-05
                                    X3       0.7575743       0.1294319E-03

                                   Row    Slack or Surplus      Dual Price
                                     1        1.515152           -1.000000
```

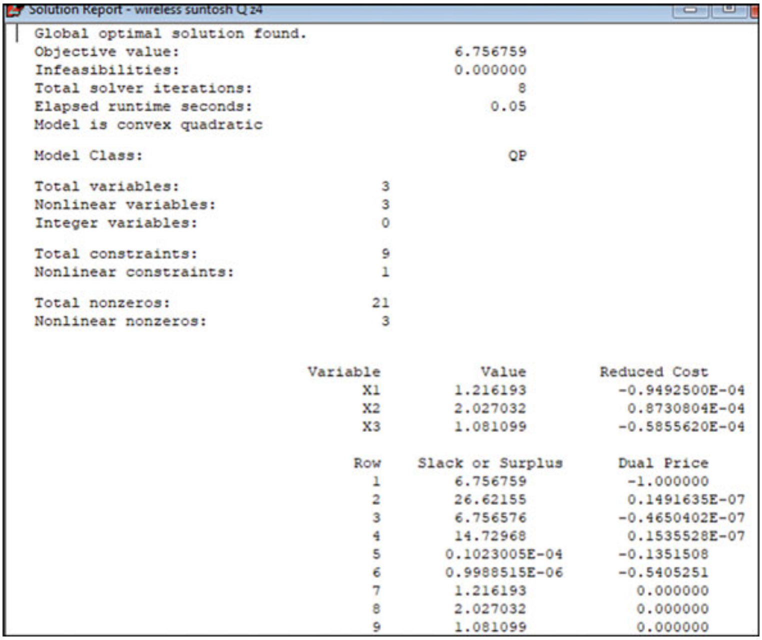
Fig. 7 Quadratic formulation based on node 5

```
Solution Report - wireless suntosh Q Z-2
Global optimal solution found.
Objective value:                              1.689190
Infeasibilities:                              0.000000
Total solver iterations:                             7
Elapsed runtime seconds:                          0.05
Model is convex quadratic

Model Class:                                        QP

Total variables:                      3
Nonlinear variables:                  3
Integer variables:                    0

Total constraints:                    9
Nonlinear constraints:                1

Total nonzeros:                      21
Nonlinear nonzeros:                   3

                              Variable           Value        Reduced Cost
                                    X1       0.6079219       -0.3659123E-03
                                    X2        1.013556        0.7007295E-04
                                    X3       0.5406711        0.2770642E-03

                                   Row    Slack or Surplus      Dual Price
                                     1        1.689190          -1.000000
                                     2        1.822708       -0.7845753E-07
                                     3        2.836800       -0.6298379E-07
                                     4        3.310743       -0.1837121E-07
                                     5    0.1302686E-04      -0.6756480E-01
                                     6    0.1089889E-05      -0.2702731
                                     7       0.6079219           0.000000
                                     8        1.013556           0.000000
                                     9       0.5406711           0.000000
```

Fig. 8 Quadratic formulation based on node 10

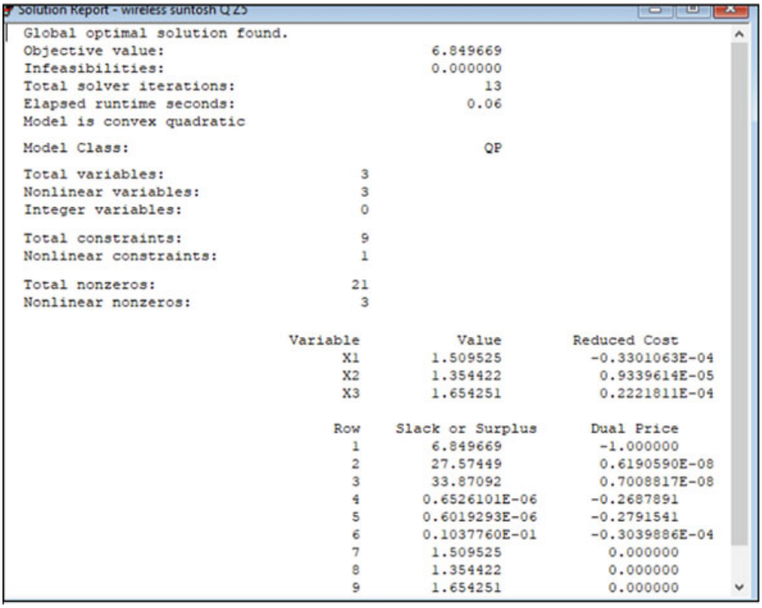
```
Solution Report - wireless suntosh Q z3
Global optimal solution found.
Objective value:                              2.922078
Infeasibilities:                              0.000000
Total solver iterations:                            11
Elapsed runtime seconds:                          0.05
Model is convex quadratic

Model Class:                                        QP

Total variables:                      3
Nonlinear variables:                  3
Integer variables:                    0

Total constraints:                    9
Nonlinear constraints:                1

Total nonzeros:                      21
Nonlinear nonzeros:                   3

                              Variable           Value        Reduced Cost
                                    X1       0.7790705       -0.3052318E-03
                                    X2       0.9739913       -0.7053814E-04
                                    X3        1.168960        0.2616189E-03

                                   Row    Slack or Surplus      Dual Price
                                     1        2.922078          -1.000000
                                     2        8.960326        0.1541824E-08
                                     3        4.088951           0.000000
                                     4    0.4388708E-06      -0.3896096
                                     5       0.1935024       -0.8633607E-06
                                     6        5.258524       -0.1224784E-07
                                     7       0.7790705           0.000000
                                     8       0.9739913           0.000000
                                     9        1.168960           0.000000
```

Fig. 9 Quadratic formulation based on node 15



```
Solution Report - wireless suntosh Q z4
Global optimal solution found.
Objective value:                          6.756759
Infeasibilities:                          0.000000
Total solver iterations:                         8
Elapsed runtime seconds:                      0.05
Model is convex quadratic

Model Class:                                    QP

Total variables:                  3
Nonlinear variables:              3
Integer variables:                0

Total constraints:                9
Nonlinear constraints:            1

Total nonzeros:                  21
Nonlinear nonzeros:               3

                         Variable        Value       Reduced Cost
                               X1     1.216193      -0.9492500E-04
                               X2     2.027032       0.8730804E-04
                               X3     1.081099      -0.5855620E-04

                              Row   Slack or Surplus   Dual Price
                                1     6.756759         -1.000000
                                2     26.62155          0.1491635E-07
                                3     6.756576         -0.4650402E-07
                                4     14.72968          0.1535528E-07
                                5     0.1023005E-04    -0.1351508
                                6     0.9988515E-06    -0.5405251
                                7     1.216193          0.000000
                                8     2.027032          0.000000
                                9     1.081099          0.000000
```

Fig. 10 Quadratic formulation based on node 20



```
Solution Report - wireless suntosh Q Z5
Global optimal solution found.
Objective value:                          6.849669
Infeasibilities:                          0.000000
Total solver iterations:                        13
Elapsed runtime seconds:                      0.06
Model is convex quadratic

Model Class:                                    QP

Total variables:                  3
Nonlinear variables:              3
Integer variables:                0

Total constraints:                9
Nonlinear constraints:            1

Total nonzeros:                  21
Nonlinear nonzeros:               3

                         Variable        Value       Reduced Cost
                               X1     1.509525      -0.3301063E-04
                               X2     1.354422       0.9339614E-05
                               X3     1.654251       0.2221811E-04

                              Row   Slack or Surplus   Dual Price
                                1     6.849669         -1.000000
                                2     27.57449          0.6190590E-08
                                3     33.87092          0.7008817E-08
                                4     0.6526101E-06    -0.2687891
                                5     0.6019293E-06    -0.2791541
                                6     0.1037760E-01    -0.3039886E-04
                                7     1.509525          0.000000
                                8     1.354422          0.000000
                                9     1.654251          0.000000
```

Fig. 11 Quadratic formulation based on node 25

5 Conclusion

This paper is based on the fusion of linear programming and quadratic programming with the help of three basic network parameters such as energy, delay, and overhead. The paper is formulated in two ways, first is based on linear programming, and second is quadratic programming. In each formulation, objective function is considered with the help of some constraints. Finally, it is observed that in each iteration, data is optimized based on increase of number of nodes in the network. In this proposed work, both linear and quadratic programmings are compared and validated that quadratic programming formulation is better than linear programming formulation.

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