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Optimization of Energy Consumption in Cooperative Wireless Network using Quadratic Programming

Hadi Zayandehroodi*, **Hamzehbabaei and Mahdiyeh Eslami**

Department of Electrical Power Engineering, Kerman Branch, Islamic Azad University, Kerman, Iran; hamzeh.babaei30@gmail.com, h.zayandehroodi@yahoo.com, Mahdiyeh_Eslami@yahoo.com

Abstract

In this paper by introduction of a general model of network, the behavior of networks has been analyzed respect to power consumption of transmitter and receiver nodes, and the length of CSMA slots. Then by prediction of model in future the input variables of network can be adjusted subject to this optimized energy consumption of network. The solution of the optimization problem of this paper, is quadratic programming. The objective function of quadratic programming is obtained by generalized model predictive control. Lower threshold values for reliability and delay probability less than a maximum, was assumed equal to 95%. Using quadratic programming, a vector of network inputs are obtained. This vector includes network variables such as power consumption of transmitter and receiver nodes and CSMA slot length. The vector also includes input variables of network for future. At each moment of time due to the dynamic changes of network reliability and energy consumption, network input vectors are updated By comparing the simulation results of the proposed method and when the model is not predicted, the proper performance of quadratic programming in network behavior optimization can be understood. By quadratic programming, the energy consumption of network is optimized and the reliability as well as the probability of the delay overreaching the allowed limitation does not exceed the threshold domain.

Keywords: Cooperative Communication Wireless Networks, Energy Consumption Optimization, Generalized Model Predictive Control, Latency, Quadratic Programming, Reliability

1. Introduction

In recent years, a large share of the attention has been focused on reducing power consumption in wireless networks. A large number of routing protocols have been introduced to achieve optimal power consumption or increase coverage. Due to the broadcast property in wireless media, as information is sent to the destination, a large number of nodes that are adjacent to the destination node can receive this information. In cooperative communication, the nodes which are located between the source node and the destination node, can transfer the information packets from the source node to the destination node as relay. In a multi-hop network, where multiple data streams simultaneously being transmitted their data, the position of a node will be appropriate to transmit data to two or more information flow. In this case, if this node used as the relay in several information flow, we may see the interference or latency in transmission. These latencies will be allowed to a specified limit.

Hence we propose a method to optimize the power consumption and also would not occur interference and latency of the information flow however several simultaneous information flows in the network.

Therefore we have an optimization problem with below constraints:

- The communication shall be reliable and the reliability for each information flow, shall be more than the lower threshold value.
- The network shall have the maximum coverage.
- The probability that a random variable delay in data transmission is less than a maximum allowed value, shall be more than the lowest defined standard for these requirements.

* Author for correspondence

For solving this optimization problem, quadratic programming has been used. For this purpose, this problem will be converted into an optimization problem and by solving it, the variables and parameters of network are determined in a way that all constraints get satisfied and energy consumption gets optimized.

2. Related Works

Carrier Sense Multiple Access (CSMA) is the multiple access method in wireless communication networks which uses carrier sense scheme.

Each node senses whether the channel is ideal and consequently available to be used. If so, the node begins to transmit its first packet. If another node has tried to send at the same time, a collision is said to occur and the packets are discarded. Each device then waits a random amount of time and retries until successful in getting its transmission sent[1].

Relays are the main element of cooperative networks and guarantee cooperative communication. The tasks of relays are the information exchange in the network. In various network topologies, a relay can detect incoming data and then send to the receiver but for security reasons and to protect the contents of messages from network users, each relay node amplifies the received signal and send to the receivers and detection of the received signal does not occur at the relay node.

The cooperative communication idea refers to 1971, when Van Der Meulen et al., introduced the communication channels with 3 terminals[2]. As the first step in cooperative communication, one node was used to transfer data. Then in 1979, the theory of capacity for information and communication channels was introduced and cooperative communication got improved compared to previous works[2]. The improvement in the performance of cooperative communications in the 80s and 90s also continued. Algorithms for optimization the power consumption of the network were introduced, gradually. In these algorithms the node which was almost closer to the vector starting from the source node to the destination node would be chosen. In this manner, a large number of nodes in the network can play the role of relay and the greater the number of relays are the less energy the relays would consume. If we want to enter more detailed structure of these algorithms, we will meet a set of nodes as proper nodes for relay information that routing is done through them[3]. This set of nodes are located usually within the data transmission radius by the transmitter node and can receive data without significant error and send to the destination node. One of the algorithms that have been developed in the field of energy efficiency is the shortest path algorithm. This algorithm chooses the shortest path through relays for data transmission[3].

Several literatures have been evaluated the outage probability to improve the performance of cooperative communications. The outage either addresses the failure in data transmission or the increase in delay while receiving the information by receivers. In these literatures the goal is to decrease the out age probability and MTCR, AFCR, CARA and GSPRA algorithms were introduced in this field. The goal in these algorithms is reduction the number of error bits[4].

In[5] discussed the channel behaviors in clustered networks. In[6] author analyzed the relation between sensor nodes in industrial networks through predictive model. In[7] author investigated the optimizing of energy consumption through cooperative communication and recognition of appropriate relay for data transmission. In[8] author discussed the optimization of energy consumption in presence delay.

3. System Model

Generally, the network consists of several clusters such that a controller is located in center of each cluster and a central controller is also responsible for coordinating the controllers within each cluster. A number of users exists within each cluster that may use the channel or ready to send their packets.

So the network is an AD-HOC network and the number of users may be increased or decreased at each time. Each user which sends the packets to another user, can use other users as relay. Thus the information will be sent from a source node to the destination node through relays or sensor nodes. To use the routing algorithm through the clusters or static routing, TDMA protocol can be used to assign the channel among clusters. The nodes which are located in each cluster are ready to receive or transmit the packets only in their corresponding TDMA time slot of related cluster and this will reduce the energy consumption of network.

Dynamic routing occurs among nodes in each cluster. Since the network is AD-HOC, the number of nodes in each cluster and their status would be changed at each time. The method requires no cluster-head and it is enough that any node be aware from next cluster status that is used as relay.

In MAC layer each node in transmitter cluster has a packet to send with a probability α and stay pending[5].

In receiver cluster each nodes are ready to receive packets with probability β and send a short length packet as beacon packet to nodes in transmitter cluster. A node which access the channel and receive the beacon packet correctly, check the channel status. If the channel was clean, try to send their packets to the beacon transmitter. If retransmission mechanism activated in the network, an Acknowledgment signal (ACK) may be sent. If beacon was not sent or there was a collision, the awake nodes in the transmitter cluster keep on listening in the next CSMA-slot with probability α or go to sleep with probability 1−α.

4. Optimization Problem

In this section, an optimization problem is supposed and solved to minimize the overall energy consumption of the network under reliability and latency constraints. The general form of the problem can be expressed as the following equation:

$$\begin{aligned} &\min_{Z,x,y} E_{tot}(Z,x,y) \\ &s.t.\quad R(Z,x,y) \geq R_{\min} \\ &\qquad \Pr\left[D(Z,x,y) \geq D_{\max}\right] \leq D_{\min} \end{aligned} \quad (1)$$

Where E_{tot} (Z, x, y) is the energy consumption of network is, R (Z, x, y) is the reliability of network and R_{min} is the minimum desired reliability which is defined by the control application. D (Z, x, y) , D_{max} and D_{min} are the random variable describing the distribution of the delay, the maximum latency desired which is defined by the control application, and the minimum probability with which such a maximum latency should be achieved, respectively. The parameters R_{min}, D_{max}, and D_{min} are the requirements of the control application. The decision variables in this research are Z, x and y. Z is the length of CSMA slot. The greater the Z is the more time would be provided for transmission or receive the packets of transmitter and receiver nodes but a great Z reduce the number of users which can access the channel and increase the waiting time for access to the channel and increase the energy consumption of networks. x is the power consumption for packet transmission and y is the power consumption for packet reception. The variables x, y and Z is normalized to the maximum allowed value.

5. Energy Consumption of Network

Briefly, the energy consumption in transmit and receive modes includes the following four components:

- The energy for beacon transmission which is displayed by E_{bc} and consumed in receiver.
- The energy for channel clean recognition which is displayed by E_{cca} and consumed in receiver and transmitter.
- The energy for packet transmission which is displayed by E_{pkt} and consumed in receiver and transmitter.
- The energy for acknowledgment transmission which is displayed by E_{ack} and consumed in transmitter.

In addition listening for a time t gives an energy consumption that is the sum of a fixed wake up cost E_w. So the general form of energy consumption of network in a period T_{cyc} will be as below:

$$E_{cyc} = h_{\max}\lambda T_{cyc}\left(E_{ack} + E_{pkt}\right) + Nh_{\max}E_w + \frac{T_{cyc}}{Z}\left(E_{bc} + E_{cca}\right) \quad (2)$$

Where h_{max} is the maximum number of cluster in the network, λ is the traffic rate and N is the average number of nodes in each cluster.

By substitution the x, y and Z in above equation, the energy consumption will be as below:

$$E_{tot}(Z,x,y) = h_{\max}\lambda T_{cyc}(x + xy) + Nh_{\max}x + \frac{T_{cyc}}{Z}(y + xy) \quad (3)$$

The goal is minimization the above equation but the reliability may be reducing when the energy consumption fall down.

6. Reliability of Network

It is assumed that in a CSMA slot in MAC layer, p packets exist for transmission and these p packets awake for access the channel for transmission. The successful transmission probability for these p packets in transmitter cluster obtains from below equation:

$$p_k = p_{bc}\left(1-(1-x)^k\right)\left(1-p_{cl}\right)^{x(k-1)} \quad (4)$$

Where p_{bc} is the successful reception probability of the beacon packet by each node. The value of p_{bc} is calculated as below Equation (5):

$$p_{bc} = Ny(\ -y) \tag{5}$$

7. Delay Constraints

The worst-case scenario would be considered to analyze the delay in transmission and reception. The worst-case is reception and transmission from the farthest cluster to the central controller such that other clusters have been participated in transmission path and exchanged the information cooperatively. So the maximum number of clusters which is shown as h_{max}, participate in this transmission. Consider the maximum allowed delay for packets transmission from central controller to the goal cluster is equal to D_{max}, so the Z_{max} is equal to D_{max}/h_{max} . The latency constraint in Equation (1) is well approximated by:

$$D(Z,x,y) = Zh_{\max} \tag{6}$$

Since the distribution of clusters as well as the delay due to the packet transmission is normal random distribution, the probability of the delay overreaching the allowed limitation will be shown as below:

$$\Pr\left[Zh_{\max} \geq D_{\max}\right] \simeq 1 - \frac{1}{2} erfc\left(D_{\max} - Zh_{\max}\right) \tag{7}$$

By expanding the *erfc* operator, the above equation will be:

$$\Pr\left[Zh_{\max} \geq D_{\max}\right] \simeq 1 - \frac{1}{2}\left(\frac{1}{6}e^{-\left(D_{\max} - Zh_{\max}\right)^2} + \frac{1}{2}e^{-\frac{4}{3}\left(D_{\max} - Zh_{\max}\right)^2}\right) \tag{8}$$

To improve the performance of network by delay constraint, this probability must be less than a threshold value D_{min}.

8. Linearization of Optimization Problem

Using the results of the previous sections, the optimization problem can be rewritten as follows:

$$\begin{aligned} &\min_{Z,x,y} E_{tot}(Z,x,y) = h_{\max}\lambda T_{cyc}(x+x+y) + Nh_{\max}x + \frac{T_{cyc}}{Z}(y+x+y) \\ &s.t. \quad P_k = Ny(1-y)^{N-1}\left(1-(1-x)^k\right)(1-P_{cl})^{x(k-1)} \geq R_{\min} \\ &\qquad \Pr\left[D(Z,x,y) \geq D_{\max}\right] = 1 - \frac{1}{2} erfc\left(D_{\max} - Zh_{\max}\right) \leq D_{\min} \end{aligned} \tag{9}$$

After linearization of the above equation in point (Z_0, x_0, y_0) and turn it into a matrix form, the following relation is obtained:

$$\begin{bmatrix} \Delta E_{tot}(Z,x,y) \\ \Delta P_k(Z,x,y) \\ \Delta \Pr(Z,x,y) \end{bmatrix} = \begin{pmatrix} \frac{\partial E_{tot}}{\partial x}\Big|_{(Z_0,x_0,y_0)} & \frac{\partial E_{tot}}{\partial y}\Big|_{(Z_0,x_0,y_0)} & \frac{\partial E_{tot}}{\partial Z}\Big|_{(Z_0,x_0,y_0)} \\ \frac{\partial P_k}{\partial x}\Big|_{(Z_0,x_0,y_0)} & \frac{\partial P_k}{\partial y}\Big|_{(Z_0,x_0,y_0)} & 0 \\ 0 & 0 & \frac{\partial \Pr}{\partial Z}\Big|_{(Z_0,x_0,y_0)} \end{pmatrix} \begin{bmatrix} \Delta x \\ \Delta y \\ \Delta Z \end{bmatrix} \tag{10}$$

In next section, the optimization problem in Equation (10) would be solved using quadratic programming and prediction of model in future.

9. Optimization of problem using quadratic programming

To use the quadratic programming, the objective function must be defined, firstly. According to the future prediction strategy, network output must always be less than a specified reference value. First the form of problem shall be converted to the desired form of quadratic programming in such away that all network outputs be less than a higher threshold as below:

$$\begin{bmatrix} \Delta E_{tot}(Z,x,y) \\ 1-\Delta P_k(Z,x,y) \\ \Delta \Pr(Z,x,y) \end{bmatrix} = \begin{pmatrix} \frac{\partial E_{tot}}{\partial x}\Big|_{(Z_0,x_0,y_0)} & \frac{\partial E_{tot}}{\partial y}\Big|_{(Z_0,x_0,y_0)} & \frac{\partial E_{tot}}{\partial Z}\Big|_{(Z_0,x_0,y_0)} \\ 1-\frac{\partial P_k}{\partial x}\Big|_{(Z_0,x_0,y_0)} & 1-\frac{\partial P_k}{\partial y}\Big|_{(Z_0,x_0,y_0)} & 0 \\ 0 & 0 & \frac{\partial \Pr}{\partial Z}\Big|_{(Z_0,x_0,y_0)} \end{pmatrix} \begin{bmatrix} \Delta x \\ \Delta y \\ \Delta Z \end{bmatrix} \tag{11}$$

Now, the above equation can be written as follows:

$$Y = HU \tag{12}$$

Where y, H and U are the vector of network outputs, the matrix of network coefficients and the vector of network inputs, respectively. In other words, using quadratic programming, the network inputs are defined in a way that according them, the energy consumption of network is minimized. So, through the quadratic programming the vector U can be obtained corresponding to an optimized network. The general form of a quadratic programming is:

$$\begin{aligned} &Minimize\ J = f(U) = cU + \frac{1}{2}U^T QU \\ &subject\ to\ \ HU \leq Y_{\max}\ ,\ U \geq 0 \end{aligned} \tag{13}$$

Then, the optimization problem must be converted to a quadratic form. Considering that the output of each sampling period used in next period as the reference output to converge the energy consumption to an optimum value, the objective function of generalized model predictive control can be used as quadratic objective function. So, the quadratic objective function can be defined as below:

$$J = \sum_{k=0}^{N} \left(Y_k - Y_{opt}\right)^2 \tag{14}$$

Where Y_{opt} and N are desired output and length of predictive time, respectively. Thus the less the J value gets the better optimization would be carried out. By expanding Equation (14) we will have:

$$J = \sum_{k=0}^{N} \left(Y_k - Y_{opt}\right)^2 = \sum_{k=0}^{N} \left({Y_k}^T Y_k - 2{Y_{opt}}^T Y_k + {Y_{opt}}^T Y_{opt}\right) \xrightarrow{Y=HU}$$

$$J = \sum_{k=0}^{N} \left(U_k^T H_k^T H_k U_k - 2{Y_{opt}}^T H_k U_k + {Y_{opt}}^T Y_{opt}\right) \rightarrow$$

$$J = \sum_{k=0}^{N} \left(U_k^T H_k^T H_k U_k - 2{Y_{opt}}^T H_k U_k\right) \tag{15}$$

The value of U_k change every period by increase the k. By definition the two matrices Γ_k and U_c, the U_k can be composed as below:

$$U_k = \Gamma_k U_c \tag{16}$$

The size of vector U_k is 3. In Equation (16) the vector U_c is always constant and is:

$$U_c = \left[U_0(1) \quad U_0(2) \quad U_0(3) \quad U_1(1) \quad U_1(2) \quad U_1(3) \quad \ldots \quad U_N(1) \quad U_N(2) \quad U_N(3)\right]^T \tag{17}$$

The vector U_c contains all network inputs in N time slot. By obtaining the vector U_c in time k, all optimized inputs for network in N time slot can be predicted and by increase the k, the vector U_c will be updated.

The size of matrix Γ_k is 3×3N and the matrix is:

$$\Gamma_k = \left[0_{3\times3} \quad 0_{3\times3} \quad \ldots \quad I_{3\times3} \quad \ldots \quad 0_{3\times3}\right] \rightarrow$$

$$\Gamma_k = \begin{bmatrix} 0 & 0 & 0 & \ldots & & \ldots & 0 & 0 & 0 \\ 0 & 0 & 0 & \ldots & I_{3\times3} & \ldots & 0 & 0 & 0 \\ 0 & 0 & 0 & \ldots & & \ldots & 0 & 0 & 0 \end{bmatrix}_{3\times3N} \tag{18}$$

So by considering $U_k = \Gamma_k U_c$, we have:

$$J = \sum_{k=0}^{N} \left(U_c^T \Gamma_k^T H_k^T H_k \Gamma_k U_c - 2H_k^T Y_{opt} \Gamma_k U_c\right)$$
$$= U_c^T \left(\sum_{k=0}^{N} \Gamma_k^T H_k^T H_k \Gamma_k\right) U_c - 2\left(\sum_{k=0}^{N} \Gamma_k^T H_k^T Y_{opt}\right) U_c \tag{19}$$

Now $\sum_{k=0}^{N}\left(\Gamma_k^T H_k^T H_k \Gamma_k\right)$ and $-\frac{1}{2}\sum_{k=0}^{N}\Gamma_k^T H_k^T Y_{opt}$ can be considered as Q and c, respectively. By substitution Q and c in Equation (15) we have:

$$J = U_c^T Q U_c + cU_c \tag{20}$$

Therefore the optimization problem was converted to a quadratic programming form. To solving this equation, the both sides of the above equation can be derived and then calculate the minimum point of *J*. So we have:

$$\frac{dJ}{dU_c} = 0$$
$$\rightarrow \left(Q + Q^T\right) U_c - 2c = 0 \tag{21}$$

By solving the above equation, the optimum point of *J* is achieved. So the result will be shown as below:

$$U_c = 2\left(Q + Q^T\right)^{-1} c \tag{22}$$

This U_c is the optimum input of network in *N* time slot which is updated by *k*.

10. Simulation Results

In order to simulate the equations corresponding to the optimization of energy consumption constrained by the two main factors of reliability and delay in data transmission, the parameter values for h_{max}, λ, T_{cyc}, N, and p_{cl} are to be considered as 5, 10, 200, 5 and 0.2, respectively. R_{min} and D_{min} values are equal to 0.95 and 0.95, respectively. Figure 1 illustrates the changes in energy consumption in relation to the changes of the received power and transmitted power. As shown in Figure 1, as the transmitted power and received power increase, the energy consumption of network increases too. In Figure 1, the value of Z has been considered as 0.5.

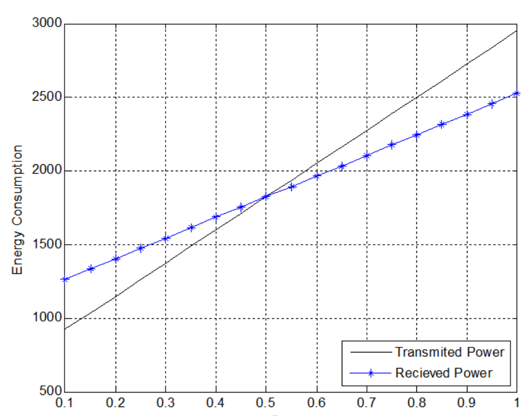

Figure 1. Changes in energy consumption according to transmitted and received power.

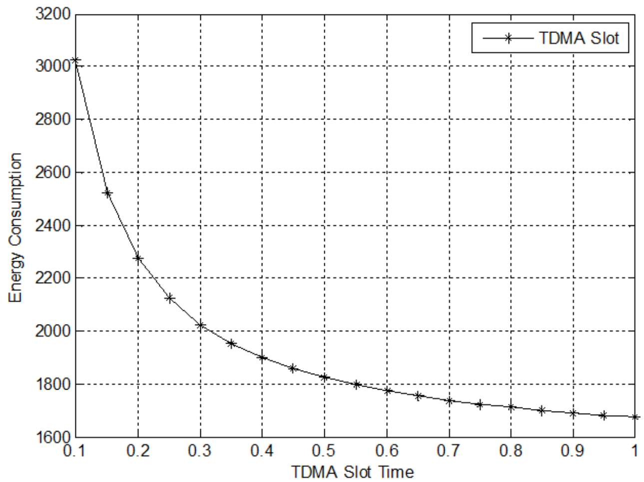

Figure 2. Changes in energy consumption according to TDMA slot length.

Figure 2 shows the changes of the network energy consumption in regard to changes of k. As shown in Figure 2, by increasing the k, the energy consumption reduces. Figure 3 shows the relationship between reliability of network and K variations. In the case of maximum power, the maximum power of all nodes in network has been used. So, the reliability will be equal to 1. Figure 4 show the probability of delay in packet transmission in regard to *k*. Figure 5 illustrates the optimum inputs which can optimize the network behaviors. Figure 6 shows the energy consumption of network with respect to the optimum inputs. Figure 7 illustrates the reliability of network with respect to the optimum inputs of network. Figure 8 shows the probability of allowed delay in regard to *k*.

As shown in Figure 1-4, the increase in the transmitted power and received power follows the increase in reliability and energy consumption of network. The increase in *Z* values follows the increase in reliability and the decrease in energy consumption of network and the decrease in the probability of allowed delay, too. Thus, the controller must handle this network such that the energy is minimized and the reliability as well as the probability of allowed delay are maximized. The controller tries to minimize the energy consumption of network until the reliability as well as the probability of allowed delay will not be less than the lower threshold. For this reason the result in figures are alternately.

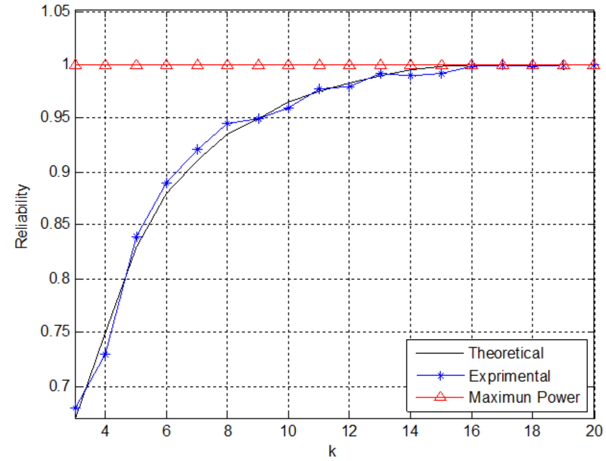

Figure 3. Changes in reliability according to TDMA slot length.

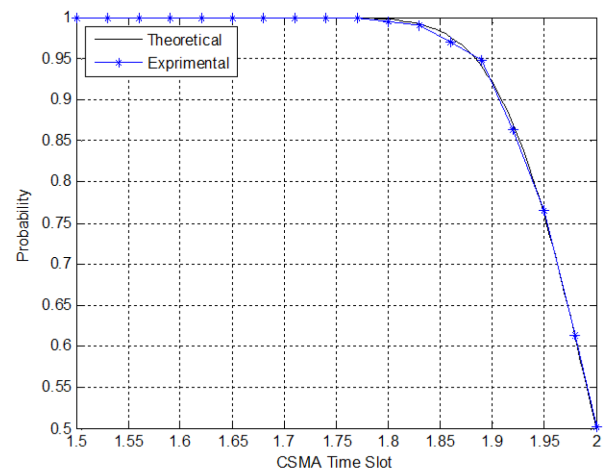

Figure 4. Changes in probability of allowed delay according to CSMA slot length.

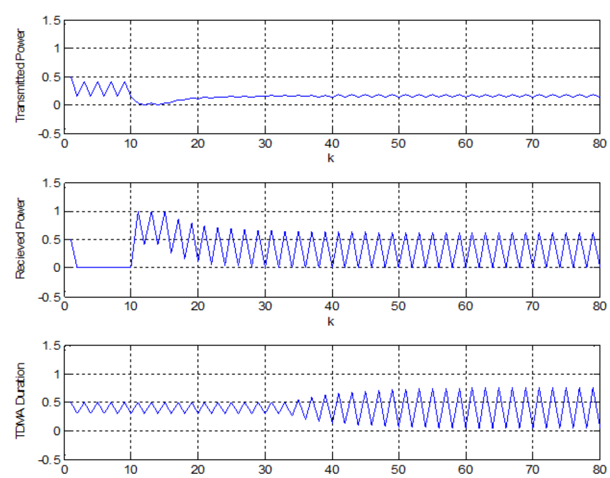

Figure 5. Changes in input variables to optimize network performance.

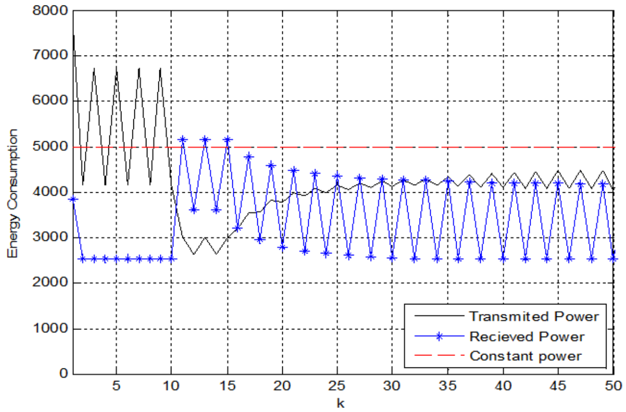

Figure 6. Changes in energy consumption of transmitted and received sides of network which is used the optimum inputs.

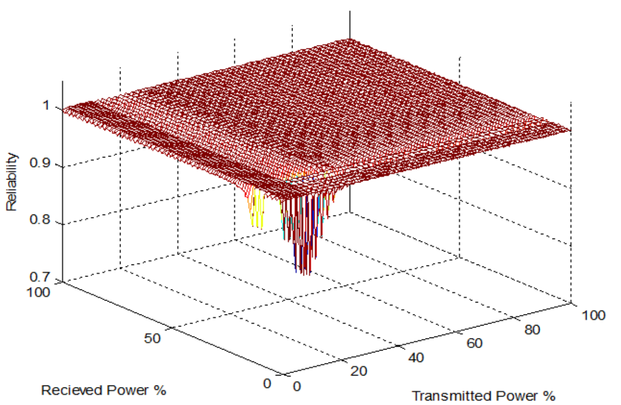

Figure 7. Changes in reliability of network which is used the optimum inputs.

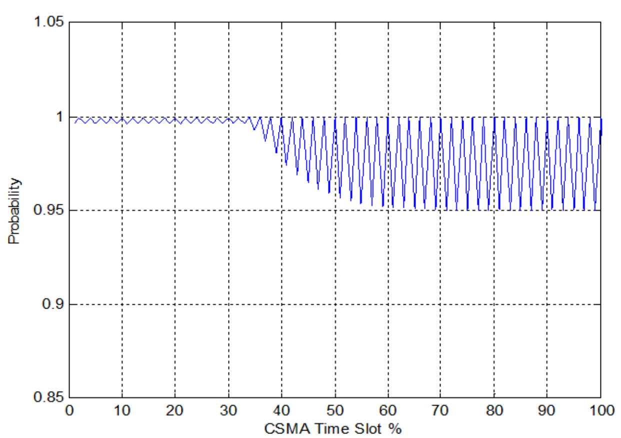

Figure 8. Changes in probability of allowed delay of network which is used the optimum inputs.

11. Conclusions

Without considering the reliability and delay in packet transmission, the wireless cooperative communication network will not be able to service the users, properly. The reliability of network will change over time, so we cannot solve the optimization problem in a constant time and generalize it to all times. In this paper, the goal was minimization of energy consumption of network such that the reliability of network as well as the probability of allowed delay would be more than 0.95. Using quadratic programming and model predictive control, the inputs of network are adjusted in a way that the outputs of network optimized over time. By comparing the results from Figure 5-8 and Figure 1-4, we can find out the optimum performance of introduced method in this paper.

12. References

1. Leonidas H. Carrier-Sense Multiple Access (CSMA) Protocols. 2002.
2. Gamal AE. Capacity theorems for relay channel. IEEE Transactions on Information Theory. 1979; 5:572–84.
3. Tabrizi H. Joint cooperative routing and energy-aware routing for maximizing wireless network lifetime. IOSR Journal of Electrical and Electronics Engineering. 2008; 7(10):1–8.
4. Lippman. A. energy-efficient cooperative routing in multi-hop wireless ad hoc networks [MIT papers]; 2004. p. 1–8.
5. Bonivento A. System level design for clustered wireless sensor networks. IEEE Transactions on Industrial Informatics. 2007; 3(3):202–14.
6. Chamaken A. Model-based cross-design for wireless networked control systems with limited resources; 2013.
7. Juanfei, Sh. Kai, L. 2012. Power-efficient location-based cooperative routing in wireless networks. International Conference on Systems and Informatics; Yantai: ICSAI; 2012. p. 1–5.
8. Michael B. A short preamble MAC protocol for duty-cycled wireless sensor networks. National Science Foundation; 2006. p. 307–20.
9. Guo W, Zhang W. A survey on intelligent routing protocols in wireless sensor networks. Journal of Network and Computer Applications. IEEE Transactions on Information Theory. 2014; 38:185–201.
10. Feng W, Liu J, Cao J, Yang L, Xin Q. Interference-aware cooperative QoS routing in multi-hop wireless networks. IEEE Computers and Electrical Engineering. 2013; 39(6):1650–66.
11. Razzaque MA, Ahmed MHU, Hong CS, Lee S. QoS-aware distributed adaptive cooperative routing in wireless sensor networks. IEEE Transactions on Information Theory. 2014; 19:28–42.
12. Reina DG, Toral SL, Johnson P, Barrero F. A survey on probabilistic broadcast schemes for wireless ad hoc networks. IEEE Transactions on Information Theory. 2014; 25:263–92.