Clinical Cancer Investigation Journal-ISSN: 2278-0513

Path modeling and cooperation in wireless sensor networks to increase efficiency and reliability

Abstract

This research looks into cooperation in sensor networks and their related challenges. Cooperation is defined as the tendency of network nodes to forward packets to other nodes. Non-cooperation of nodes with each other is considered a type of misbehavior. Cooperation methods aim to reduce the effect of misbehaving nodes representing a kind of selfishness in the network. Subsequently, methods based on charging and reward models are used to motivate nodes to cooperate. In the proposed method, due to dynamic cost management, all nodes are forced to cooperate and distribute traffic in the network. Each node must calculate and declare its route cost according to the consumed energy. Source nodes tend to choose routes imposing a lower cost. In this way, without contradiction, they force the nodes to reduce their profit and subsequently reduce the fraud caused by price increases to increase rewards. Also, the necessary motivation for the participation of all nodes in the network is provided. The core of this routing method is sensitive to the path cost, based on the combination of dynamic pricing technique and AODV routing. The proposed method regarding network traffic distribution and helping low-power nodes works better than the previous methods. It strengthens the cooperation rate and network lifetime due to uniform energy consumption between nodes.

Keywords: *wireless sensor networks, network traffic, increasing network efficiency, network reliability*

Zahra Mohammadnejad
Department of Computer and Information Technology Engineering, Qazvin Branch, Islamic Azad University, Iran
zahra.nezhad@gmail.com

Mahdi Ahmadian
Department of Management, Farvardin Institute of Higher Education Qaemshahr, Iran
ahmadian2391@gmail.com

Introduction

Wireless sensor networks (WSNs) are composed of many micro nodes with sensing, computing, and communication capabilities and have penetrated various fields of application. The limited communication and calculations resources and energy consumption are the main challenges of WSNs. Sensors are microdevices that are densely distributed in the environment to be within the transmission range of each other. As soon as the distance of the nodes exceeds the predetermined transmission range, the communication of the sensors is disrupted [1]. One of the challenging issues in sensor networks is the routing process [2]. Over the past few years, various algorithms have been introduced to solve this challenge. The algorithms presented can be classified into homogeneous and heterogeneous categories. The central premise of homogeneous algorithms is the equivalence of the network components regarding the transmission range. Heterogeneous algorithms have more flexibility compared to their homogeneous counterparts.

Apart from the benefits mentioned, ad hoc and sensor networks face various challenges, such as the performance of nodes in the network individually. There are various reasons for the lack of cooperation between nodes and forwarding packets in the network. Forwarding packets from other nodes consumes significant transmission time that can be spent on sending their packets. Packet transmission can consume battery energy, a vital resource for nodes. In [3], an authentication routing protocol based on public key cryptography is proposed, which provides secure routing conditions in open and managed environments. Recently, electronic science researchers have presented economic theory techniques to solve various network problems. In recent years, productivity models, game theory, auction theory, etc., have been successfully applied to various problems. Pricing models for motivating nodes [4, 5, and 6] are simple examples in this field. In simplest terms, the purpose of an economic model is to represent the complex behavior of humans as a specific behavior.

Economic theory mainly focuses on developing relationships between supply and demand [7]. Such relationships are described as equations, and supply and demand operators are adjusted. Numerous efforts have been made to understand the concept of pricing in wireless network services from an economic and engineering perspective. Nodes in ad hoc mobile networks act as routers and terminals at the same time. Due to the lack of routing infrastructure, nodes must cooperate to establish communication. Cooperation in the network layer or so-called routing leads to a way to forward and relay the packet.

In [8], Marti et al. have done the first research on route discovery in routing protocols. The proposed method uses a WatchDog to detect misbehaving nodes and a route evaluator to choose a route away from them. In [9], Buchegger and Le Boudec proposed a confidant protocol based on the unattractiveness of misbehavior. They added observation, discovery, and response mechanisms to a routing protocol to ignore uncoordinated nodes in the network. The security structure of the proposed method is based on a distributed security manager running on each node.

In this study, we define cooperation as the participation of nodes in network activities to send others packets without making any changes to them. Then we will examine the details of the cooperation issue in sensor networks and the existing methods in this field.

Proposed method

In this section, the motivation mechanism based on the business model combined with the AODV routing protocol is used to strengthen the cooperation rate between the nodes. The presented model considers a mechanism for nodes to communicate their consumption costs for sending other nodes packages and gives nodes sufficient independence to communicate costs to increase their rewards. Each node or subnet broadcasts a RouteRequest message between its neighbors. If the receiving node is not the final destination of the message, it inserts its ID as one of the route nodes in the message and broadcasts the message again. This process is reiterated until the receiving node is the final destination of the message. In this case, the destination node creates a RouteReply message and forwards the message to the source node through the inserted node IDs. Route nodes are obliged to return RouteReply to announce their desired reward in exchange for packet forwarding along with the message to the source node. They calculate the route cost and announce it to the source node. The source node calculates the sum of all the rewards of the route nodes and announces it to the intermediate nodes for each traffic unit. Each source node checks whether it can send the traffic after checking the amount of data traffic and the announced rewards (multiplying the rewards by the amount of traffic). The source node must subtract the total rewards from its budget in each transmission and pay to the intermediate nodes. Only by having enough budgets can the node send its packet and get budgets by forwarding other nodes' packets. This process stimulates the nodes to cooperate with others.

$$P_{Total} = T \sum_{n_i \in r_1} P(n_i) \qquad (1)$$

The source node chooses the route with the lower intermediate nodes' cost if several routes to the destination are proposed. If several routes with equal costs are proposed, the route with the shortest distance is selected as the final route. Therefore, route nodes are encouraged to declare a lower reward to win. The cooperation of nodes with others continues until they get enough budgets. As soon as this budget is realized, the nodes refuse to send the other packets. This work saves the energy of the nodes and provides them with a chance to gain credit [10-12].

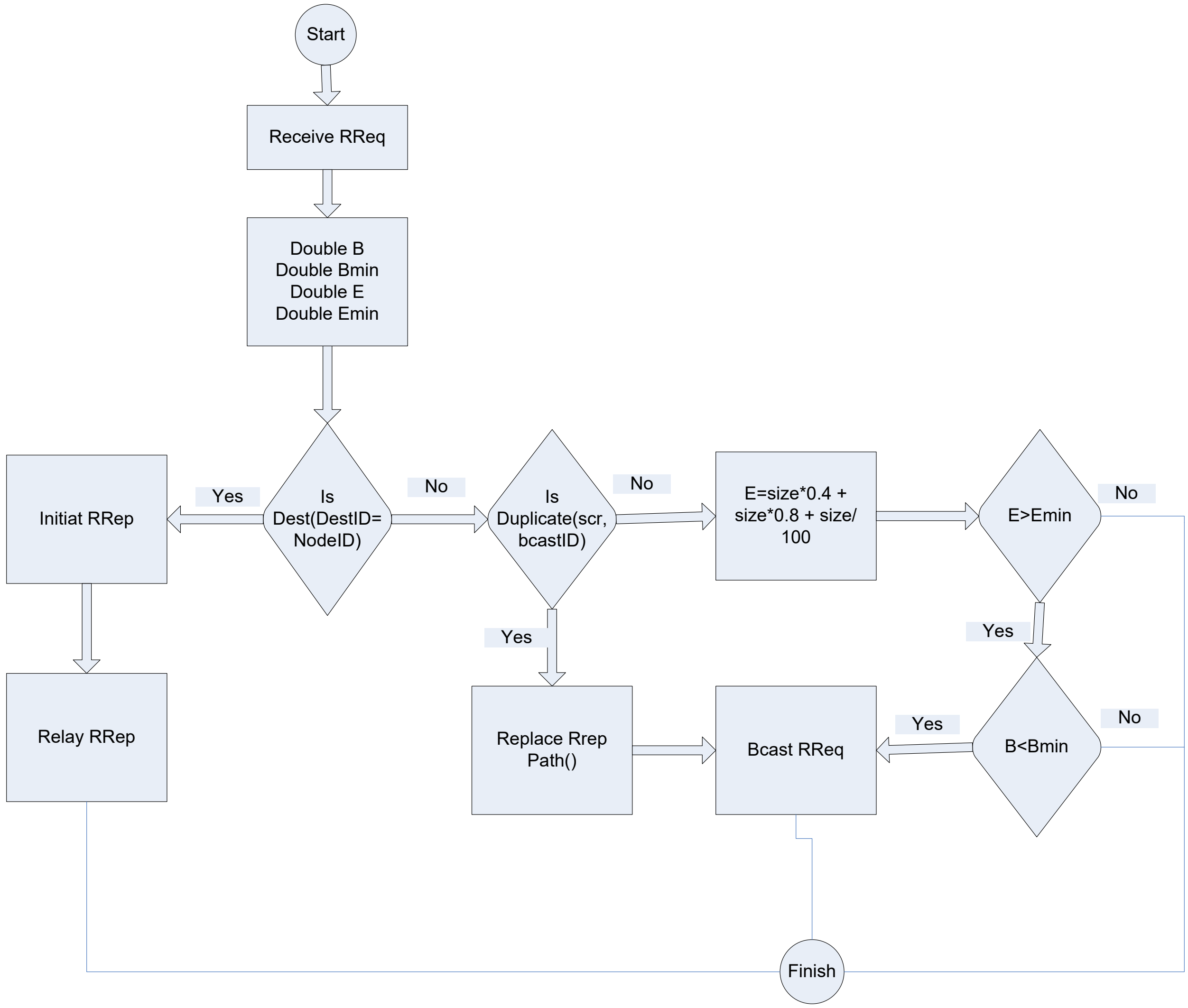

Figure 1: The flowchart of processes in RREQ

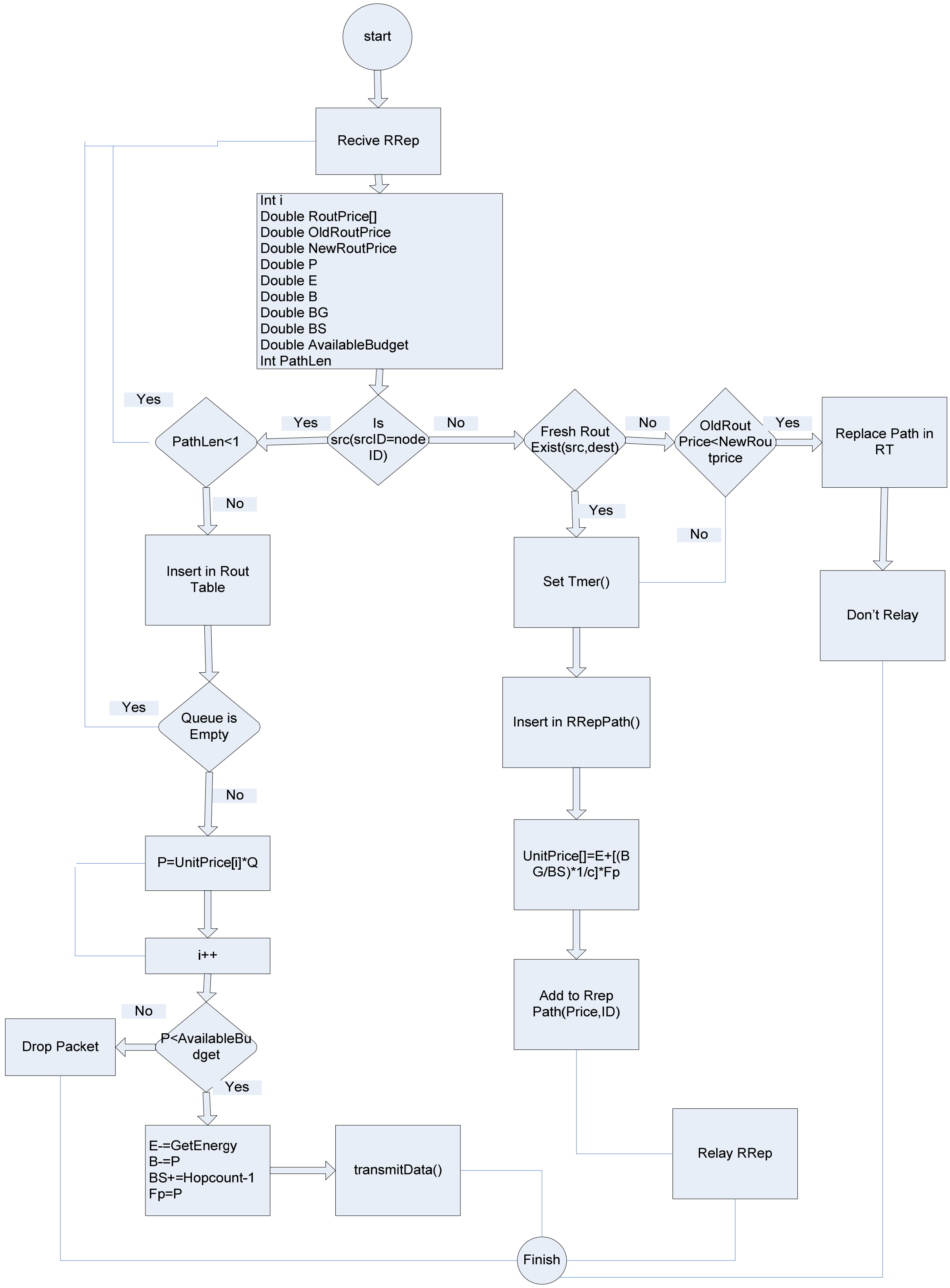

Figure 2: The flowchart of processes in RREP

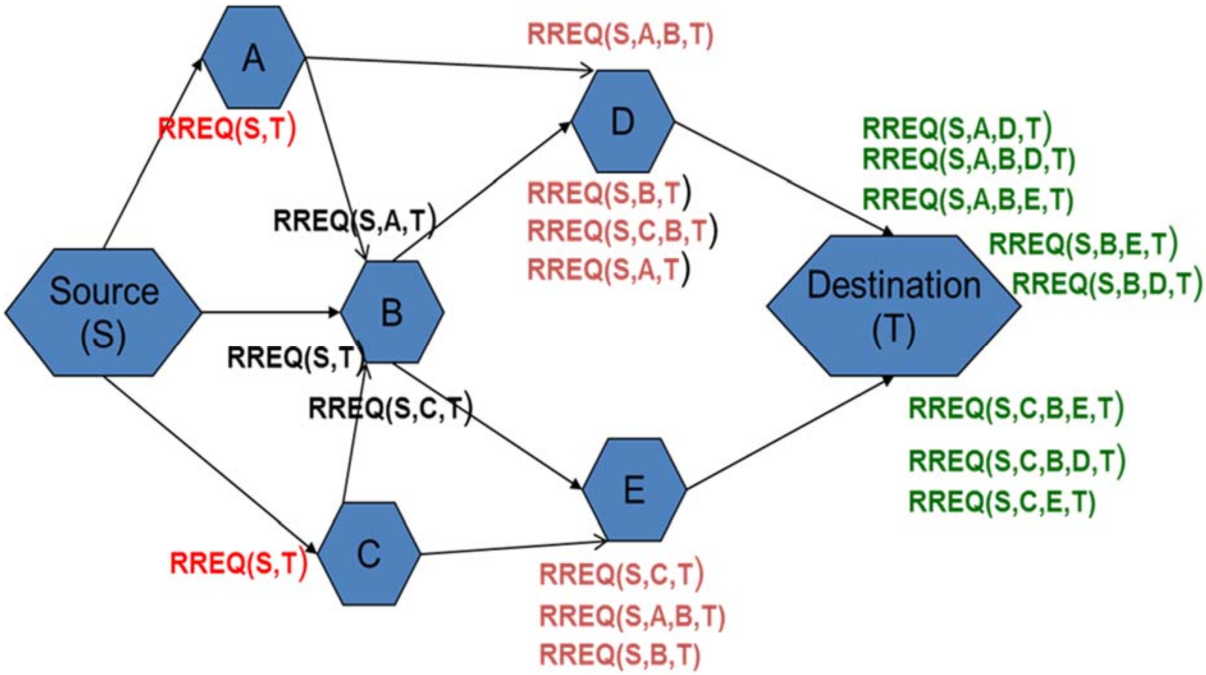

Figure 3: Broadcasting method of RReq

As shown in the figure, after inserting its ID in the RREQ, the source node broadcasts the message. Each receiving intermediate node inserts its ID in the message. The possible routes are determined as soon as the message return is completed. Any node with a path to the destination node forwards the message to the destination. The following figures show the return process of RRep from the destination node to the source node.

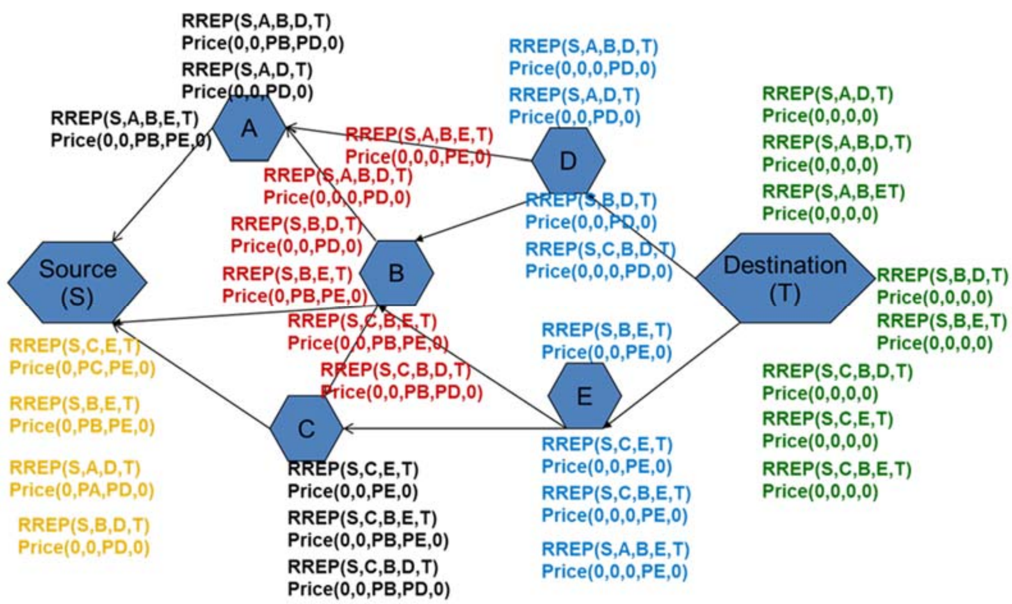

Figure 4: Broadcasting method of RRep

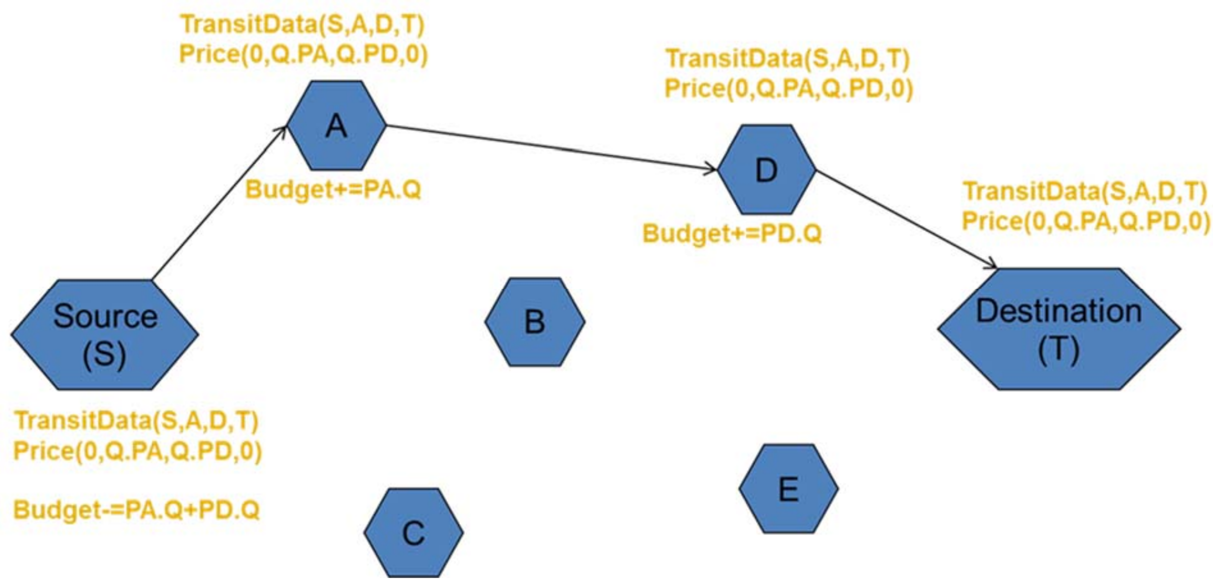

Figure 5: How to send data and pay rewards in the route found

The simulation of the proposed model has been done in GlomoSim software. According to the objectives of the proposed method, the following network evaluation parameters have been selected:

• Network throughput: network throughput depends on the percentage of nodes' cooperation. The greater the cooperation between nodes, the more packets are forwarded in the network; subsequently, more packets reach their destination safely.

• Budget production rate

• Budget consumption rate

• Profit rate of nodes

• Monetary balance of the network: the performance of the proposed method is such that the network nodes do not have a budget fluctuation (imbalance of the budget distributed among a group of nodes). Strengthening the monetary balance of the network means more cooperation of all the nodes in the network and, as a result, the same distribution of traffic in the network.

• Network efficiency: network efficiency corresponds to the number of healthy packets reaching the destination node.

• Reliability: total reliability means the optimal network performance in the presence of node misbehavior.

Simulation scenarios

We consider two scenarios to simulate two different situations. In the first and second scenarios, 15 and 30 nodes are randomly distributed in a 600 × 600 space. Both scenarios are simulated in uniform and non-uniform traffic conditions. In the first case, each node randomly sends traffic with a fixed rate to one of the other nodes, producing uniform traffic in the network. In the second case, traffic is generated only in a part of the network, so some nodes cannot get much budget. The simulated algorithms are introduced below:

1- Simulating the AODV protocol in a situation where the energy consumption of the nodes has increased due to the forwarding of packets from other nodes, and the presence of misbehavior in the network has been fully implemented.

2- Simulating the PDM algorithm (proposed plan) in a situation where the rewards of all nodes are obtained based on the supply and demand function proposed in [17].

3- Proposed algorithm based on NES reward estimation method

4- Proposed algorithm based on EES reward estimation method

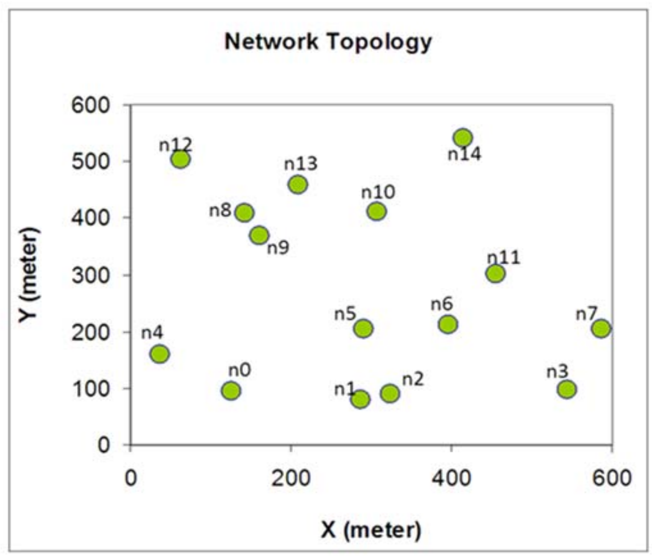

Figure 6: Topology used in the simulation

In this research, the same classic radio model is used. A radio consumes a certain amount to run the receiver or transmitter circuits. We also have for transmitter amplifier:

$$\hat{I}_{amp} = 100 pJ / bit / m^2$$

Results

AODV protocol is evaluated with the deployment of 15 nodes in the topology. In this topology, all nodes are receivers and transmitters simultaneously. The plot of energy consumption of the nodes of this network calculated based on packet forwarding for others is represented below:

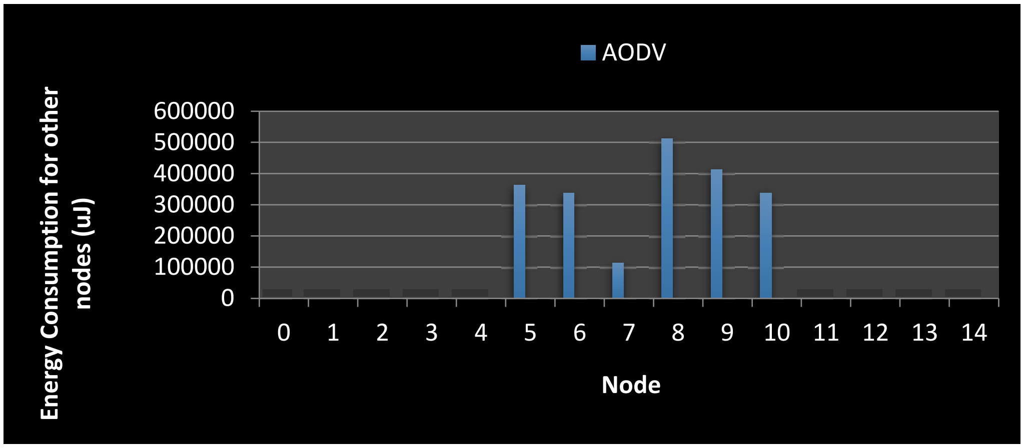

Figure 7: Plot of energy consumption of each node based on packet forwarding for other nodes

As shown in figure (6), only the nodes in the middle of the network can complete the forwarding. No cooperation has been applied in this network; the reluctance of nodes to participate in network activities is logical because they lose their energy immediately.

In the first scenario, considering uniform traffic, nodes 0 to 7 send traffic to nodes 7 to 14, respectively. Subsequently, nodes 8 to 14 send traffic to nodes 6 to 0, respectively. The size of exchanged packets in 10 seconds is 128 bits. The start time of the simulation is different in each session, and it continues until the end of the simulation. The constructed route resulting from the implementation of the EES method between source 10 and destination four is shown in Figure 7:

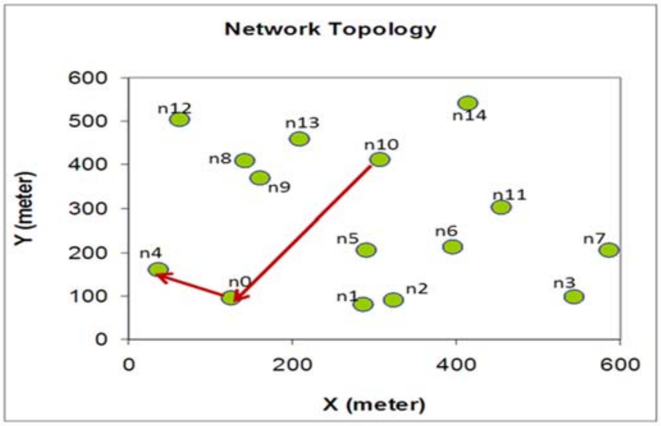

Figure 8: Routing process between nodes 10 and 4

The route cost is equal to 1.8, while the cost of the other constructed routes 10-9-4 and 10-13-4, 10-12-4, 10-6-4, 10-11-9-4, and 10-14- 4-9 is equal to 2.4, 2.4, 2.4, 2.4, 4.8, and 4.8, respectively. The reason for communicating a lower price from node 0 is that it sent its data to node 7 earlier than other nodes at the beginning of the simulation and increased its BS. Therefore, the declared reward of node 0 is reduced based on Relation 5.

Another sample route from source node 12 to destination node 2 is shown in Figure 8. This session was done in the second 5.5 of the simulation process.

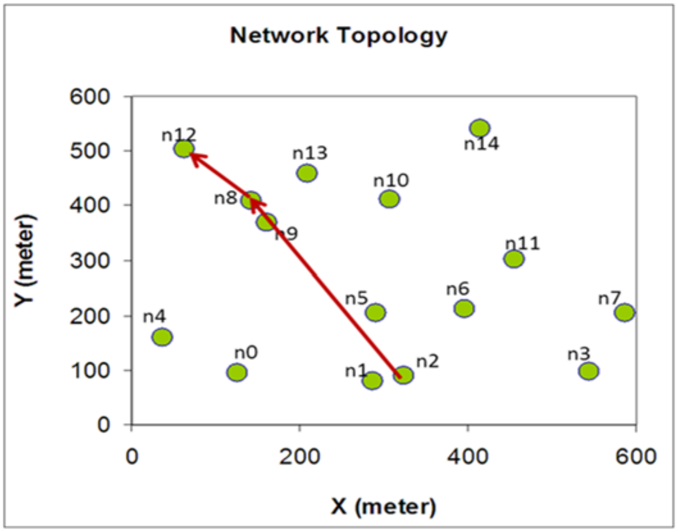

Figure 9: Routing process between nodes 2 and 12

Also, the route formed from the source node 14 to node 0 is shown in Figure 9. The corresponding session started in the second 9.5 of the simulation:

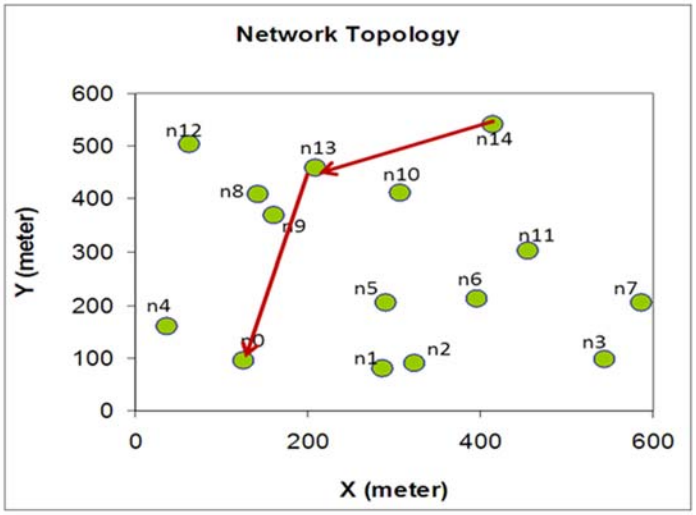

Figure 10: Routing process between node 14 and 0

We recheck the above route at the end of the simulation to understand how to reduce the cost of the nodes after a certain period of activity in the network. The resulting plot is shown in Figure 10:

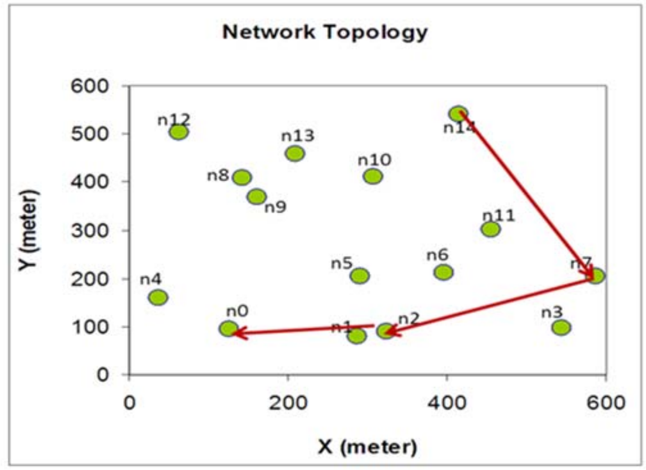

Figure 11: Routing process between node 14 and 0 in 9 seconds of simulation

Now, let us evaluate the performance of node 3 in a worse situation than other nodes in the network. We consider the requested rewards of node 3 in the session created with source 5 and destination 12. The plot of Figure 11 reflects the change process of this node's reward during the simulation.

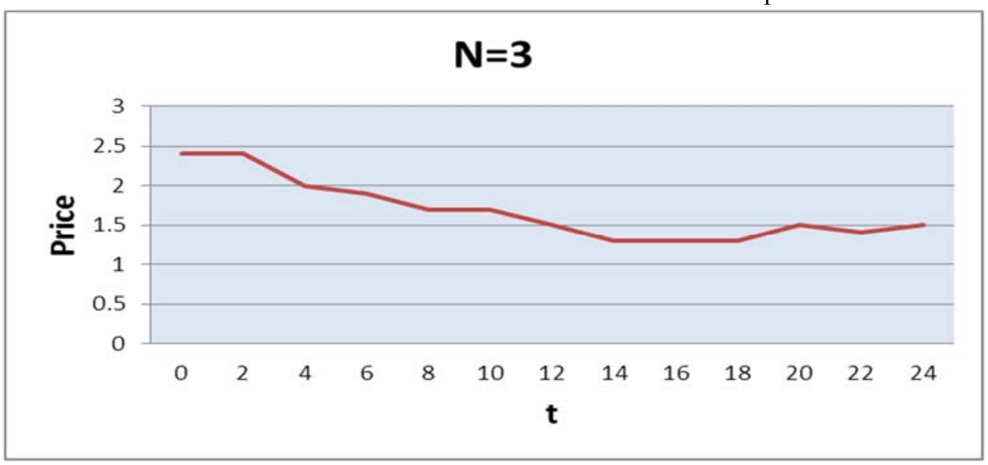

Figure 12: The reward changes of node 3

As shown in Figure 11, node three is reducing its reward due to insufficient BG. This node reduces its reward in the form of a downward trend until it is selected as one of the route nodes. The initial reward of each node is set equal to 2.4 at the beginning of the process. The initial value of Fp is equal to E(1). Also, the initial values of BG and BS are equal to 1. So, the energy consumption of each node per one unit of traffic equals 1.2.

$$P(1) = E(1) + \frac{BG}{BS}\frac{1}{c}F_p(1)$$

$$2.4 = E(1) + 1.E(1)$$

$$2.4 = 2E(1)$$

$$E(1) = 1.2$$

The position of node 9 in the network is such that it is selected with a maximum of 2 hops in each route. Therefore, the total cost of the route passing through it is lower than that of node 3. Therefore, this node continuously increases its A and P factors until it is not selected or its budget reaches the maximum value.

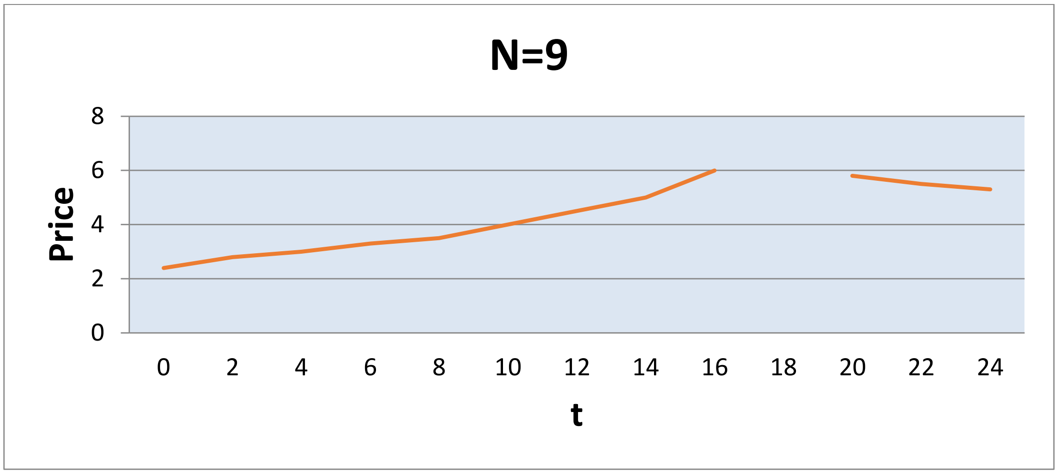

Figure 13: The reward changes of node 9

In the simulation parameters, the maximum reward for each node is set at $7. Before reaching the maximum budget, node 9 has reached a reward of $6. Even if node 9 does not reach its maximum budget after a certain period, it is impossible to increase its reward.

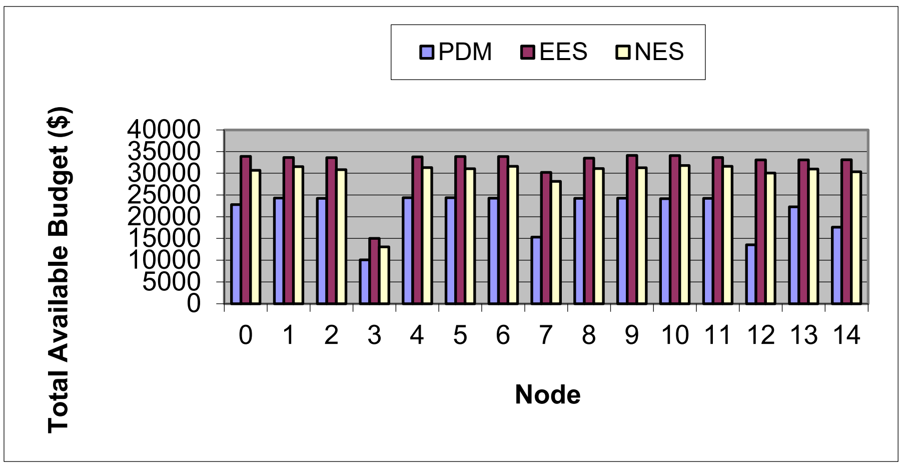

Figure 14: Budget plot of each node with uniform traffic

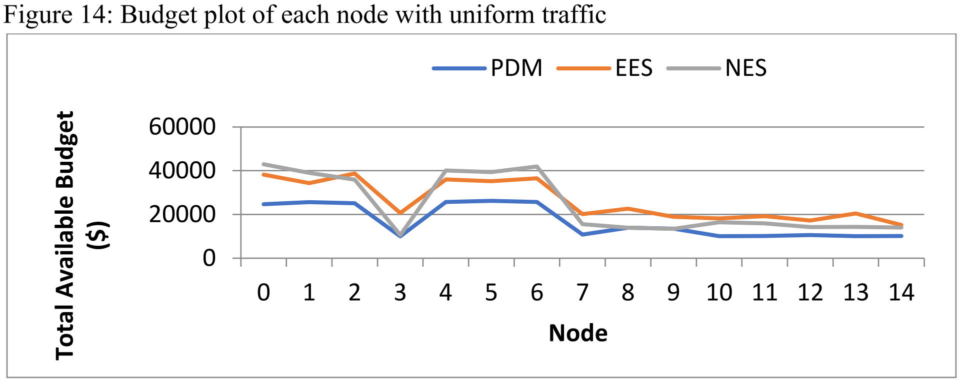

Figure 15: Budget plot of each non-uniform traffic node

As shown in the figures above, there are no low-budget nodes left. The deployment of nodes in sensitive points or edges of the network or the presence of nodes carrying more traffic on the route cannot prevent the acquisition of budgets.

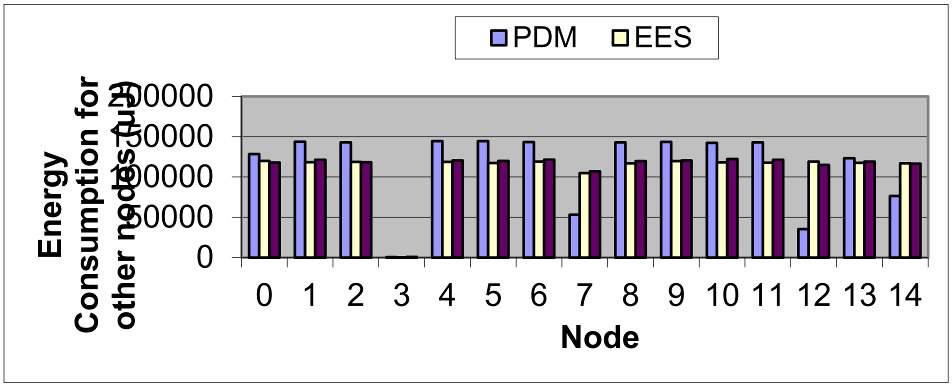

Figure 16: Plot of energy consumed in each node with uniform traffic

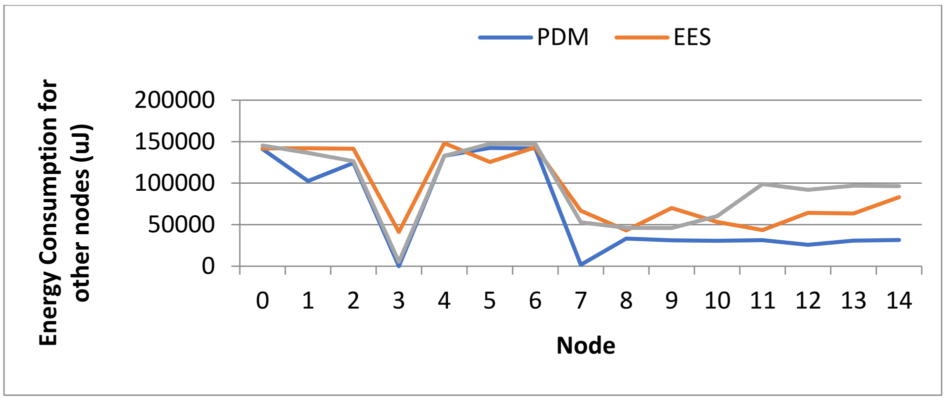

Figure 17: Plot of energy consumed in each node with non-uniform traffic

By applying non-uniform traffic, it is logical to obtain non-uniform results. According to the results of the above figure, energy fluctuates just like the budget level. The highest and lowest fluctuations are related to PDM and NES methods, respectively. The lowest consumed energy is related to the EES method. Reduced energy consumption in nodes means more energy reserves for future communications.

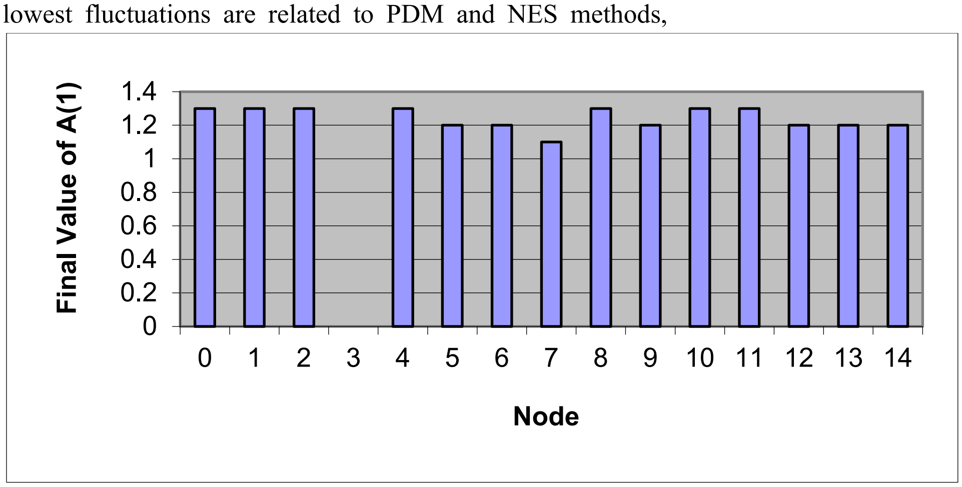

Figure 18: Final profit plot of each node based on uniform traffic in the ESS method

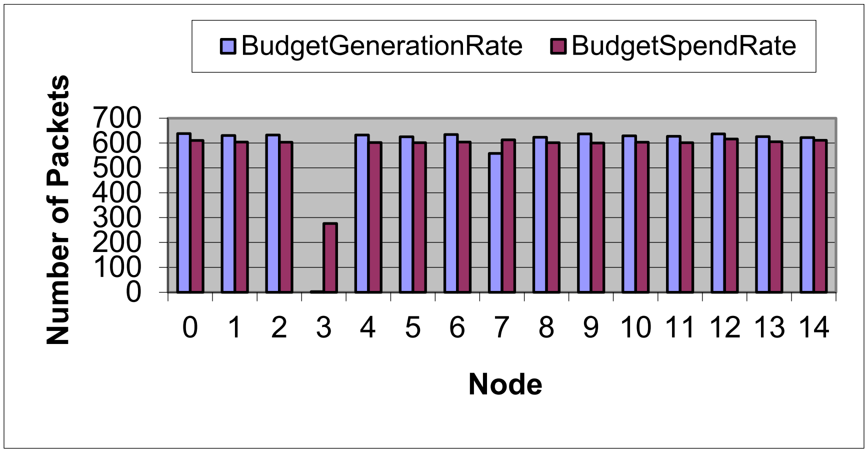

Figure 19: Comparison of budget production and consumption rates in each node based on uniform traffic in the ESS method

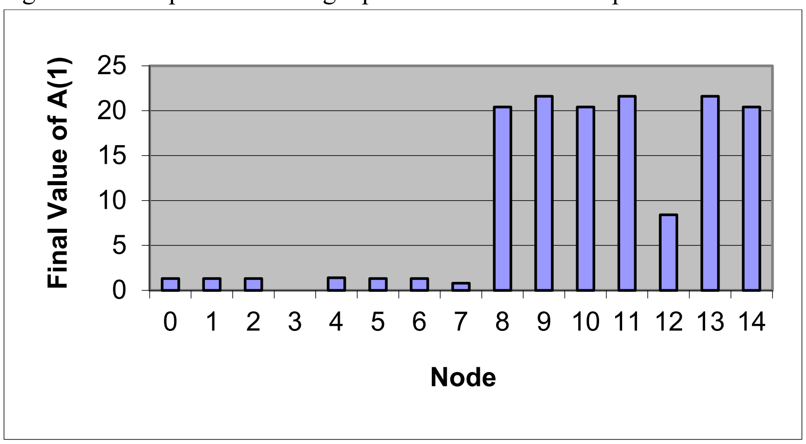

Figure 20: The final profit of each node based on non-uniform traffic in the ESS method

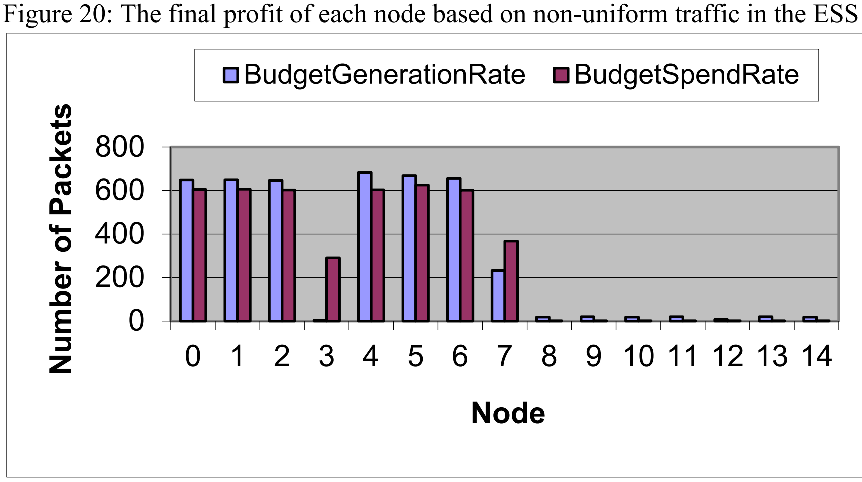

Figure 210: Comparison of budget production and consumption rates based on non-uniform traffic in the ESS method

According to the results of the above figures, the profit of the nodes will never be negative. The reward received by the source node is more than the cost spent to send the packet. The cooperation of nodes with others never leads to losses. In the worst case, nodes get budgets as much as they need.

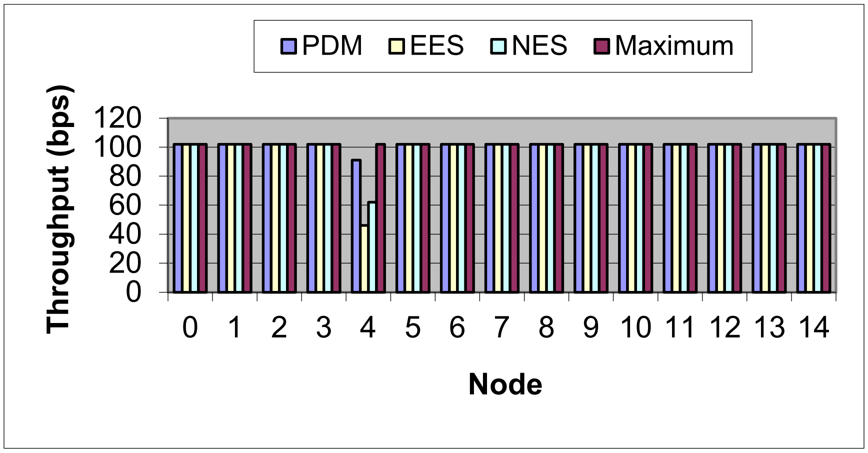

Figure 22: Throughput plot of each node based on uniform traffic

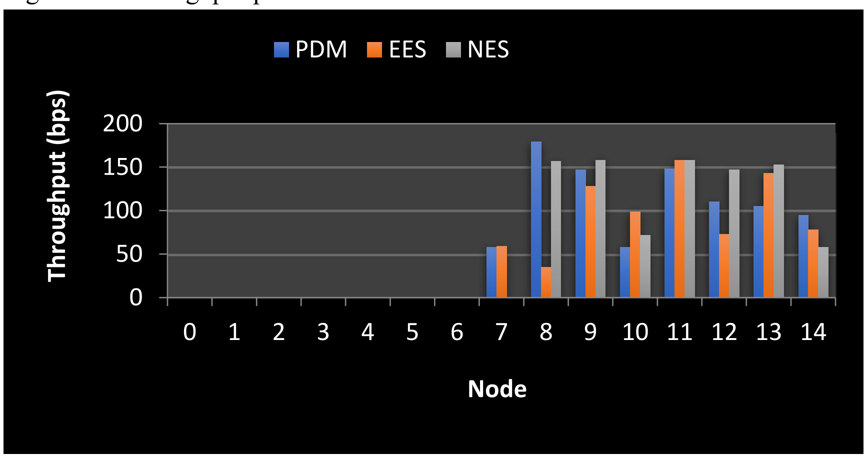

Figure 23: Throughput plot of each node based on non-uniform traffic

In the second plot, the throughput of nodes that have not received a packet is zero. Also, the throughput rate of other nodes changes depending on the received traffic.

In the next step, the coalition and insurance algorithm are added to the EES method, and the extracted results are shown in the figure below.

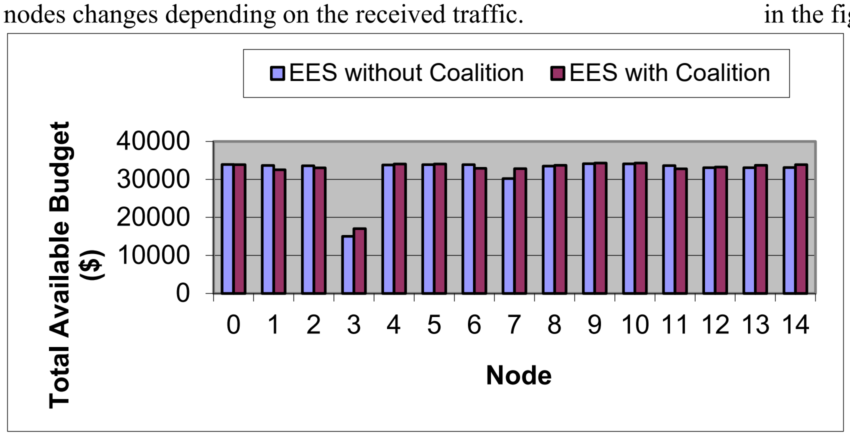

Figure 24: Node budget balance resulting from complementary methods based on uniform traffic

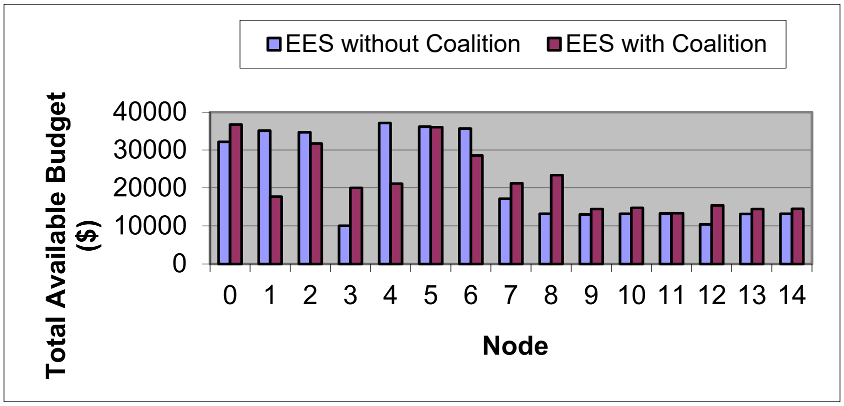

Figure 25: Node budget balance resulting from complementary methods based on non-uniform traffic

In the second scenario, 30 nodes are deployed in the network in the form of the following topology.

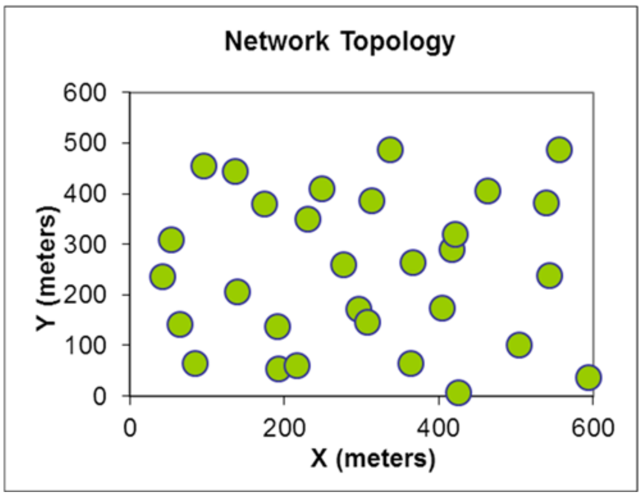

Figure 26: Topology used in scenario 2

The previous evaluation has been done again for a topology with 30 nodes. The plot of energy consumed to send packets to other nodes in conventional AODV without any cooperation is shown in Figure 26.

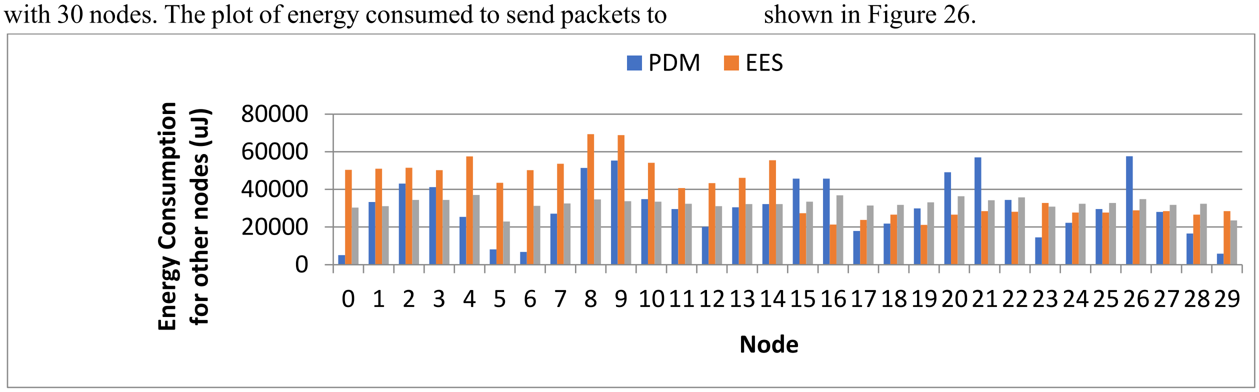

Figure 27: Plot of consumed energy for 30 nodes

Because the sent traffic rate and simulation time are not added to the plot, the level of the budget obtained and the energy consumed is also lower.

Conclusion

Despite the applied limitations, the proposed system has achieved high throughput, and the throughput rate of most nodes is maximum. In comparison with the previous systems, the efficiency of the algorithm is higher due to the dynamics of the method and creating coordination in sending traffic and balanced rewards. Non-uniform energy consumption leads to complete energy depletion of a group of nodes and their removal from the network. Removing nodes from the network disrupts the activity of a part of the network and eventually brings down the entire network. Also, according to the results, after an extended period, the nodes still have much energy to continue life and guarantee the routine activity of the network.

References

1. I.F. Akyildiz et al. " *Wireless sensor networks: A survey*." Computer Networks, 38(4):393–422, Mar. 2002.
2. G. Anastasi, M. Conti, and E. Gregori, "IEEE 802.11 Ad Hoc Networks*: Protocols, Performance and Open Issues*," In S. Basagni, M. Conti, S. Giordano, and I. Stojmenovic, eds., Mobile Ad Hoc Networking, chap. 3, pp.69-116.Wiley-IEEE Press, 2004.
3. C.E. Perkins and E.M. Belding-Royer, "*Ad-hoc On Demand Distance Vector Routing,"* Proc. of 2nd IEEE Workshop on Mobile Computing Systems and Applications, February 1999.
4. M. Li, Eiji Kamioka, and Shigeki Yamada, "*Modeling Incentive for Cooperation in Wireless Ad Hoc Networks*," Proc. of the 2005 IEICE Society Conference, Network Planning, Control and Management BS-10-18, pp.44-45, September 2008.
5. M. Li, Eiji Kamioka, Shigeki Yamada, and Yang Cui, "*Efficient Node Forwarding Strategies via Non-cooperative Game for Wireless Ad Hoc Networks*," Proc. of ICCNMC, Networking and Mobile Computing, LNCS Vol.3619, Springer-Verlag, pp. 334-343, August 2005.
6. K. Chen, "*Cooperative and Non-cooperative Flow Control in Mobile Ad Hoc Networks*," Ph.D. thesis, Computer Science, University of Illinois at Urbana-Champaign, October 2004.
7. K. Wrona and P. Mahonen, *"Analytical Model of Cooperation in Ad Hoc Networks," Telecommunication Systems*," Springer vol.27, pp.347-369, No.2-4, October 2004.
8. D. B. Johnson, D. A. Maltz, and J. Broch, "DSR*: The Dynamic Source Routing Protocol for Multi-Hop Wireless Ad Hoc Networks*," Ad Hoc Networking, edited by Charles E. Perkins, Chapter 5, pp.139-172, Addison-Wesley, 2001.
9. S. Buchegger, J.-Y. L. Boudec, "*Performance analysis of the CONFIDANT protocol: Cooperation of nodes - fairness in dynamic ad-hoc networks,* " in Proceedings of IEEE/ACM Workshop on Mobile Ad Hoc Networking and Computing (MobiHOC). IEEE, June 2002.
10. M. Li, Eiji Kamioka, and Shigeki Yamada, "*Pricing to Stimulate Node Cooperation in Wireless Ad Hoc Networks*," IEICE Transactions on Communications, July 2007.
11. F Hu, W. Siddiqui, K Sankar, "Scalable security in Wireless Sensor and Actuator Networks (WSANs): Integration re-keying with routing," in Proceedings of IEEE, March 2007.
12. Z. M. Nezhad and S. Khorsandi, "Cooperation enforcement based on dynamic pricing in multi-domain sensor network," *2011 IEEE Consumer Communications and Networking Conference (CCNC)*, 2011, pp. 1055-1060, doi: 10.1109/CCNC.2011.5766327.
13. Z. MohammadNejad, M. Ahmadian, and S. Khorsandi, "Providing a hybrid algorithm for routing and cooperation based on dynamic pricing in wireless sensor networks," *2010 International Conference on Information and Communication Technology Convergence (ICTC)*, 2010, pp. 143-148, doi: 10.1109/ICTC.2010.5674701.