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Multi-objective Evolutionary Algorithm based QoS-aware routing in wireless mesh sensor networks for smart metering application

Sameeksha Saklani
Department of Electrical and Electronic Engineering,
University of Mauritius
Reduit, Mauritius
sameeksha.saklani13@gmail.com

Anshu Prakash Murdan
Department of Electrical and Electronic Engineering,
University of Mauritius
Reduit, Mauritius
a.murdan@uom.ac.mu

***Abstract* – One of the main challenges of the Smart grid is the design and implementation of the smart metering network which provides low latency and energy-efficient bidirectional communication with the rest of the smart grid. Wireless sensor networks are regarded as the potential technology for the implementation of smart metering network. In this paper, a novel routing protocol is proposed which aims at decreasing latency and increasing energy efficiency in the smart metering network while combining it with the wireless mesh backbone network. The routing protocol is based on the AODV (Ad hoc on-demand distance vector) routing method and incorporates a Multi-Objective Evolutionary Algorithm (MOEA) to converge to the optimal solution, creating an application-specific protocol for the smart metering system. Simulation results have validated the efficiency of the proposed protocol in comparison to AODV protocol. The QoS metrics, end-to-end delay and energy have been considered to compare the performances of the proposed technique and AODV.**

Keywords- Wireless Sensor Network, Smart Grid, smart meter, AODV)

I. INTRODUCTION

The traditional power grid of the 19th century, which is still being used today, consists of a network of transformers, substations, transmission lines and other components whose purpose is to provide electricity from the power plant to the homes or institutions and businesses. With the increasing consumption of electricity, solutions are being devised to keep up with the demand and provide a reliable service to the consumers. Therefore, research is inclined towards Smart Grid (SG) technology which refers to a modern power grid incorporating two-way communications between the power distribution and power monitoring unit at the consumers premises. Along with providing electricity to the connected consumers, the smart grid also monitors, secures, and boosts the performance of the integrated elements [1]. The SG communication network consists of three types of interconnected networks, namely [2];

(1) Home area network (HAN): network of a residential electricity customer, that monitors, and controls electric devices utilized by customers at their residence. It allows the transmission of information between electronic and electrical devices, such as distributed energy resources, energy management devices, home appliances and smart meters.

(2) Neighborhood Area Network (NAN): It is the intermediate network between the substations and the customer. It allows for the regulation of intelligent electronic devices (IEDs) and gather required information from its respective sources.

(3) Wide Area Network (WAN): It connects highly distributed smaller area networks supporting the power systems found at different locations by forming the communication backbone for the SG. For the realization of the SG, the advanced metering infrastructure (AMI), considered as one of the core components, needs to be designed efficiently. The AMI is based on the network of smart meters; it collects and analyzes data transmitted by the smart meter network [3]. The design of the smart meter network is challenging as it requires an ad hoc topology of interconnected smart meters, while providing the right Quality of Service (QoS). To achieve this, the coordination of separate wireless sensor networks of smart metering nodes interconnected through wireless mesh networks acting as a backbone is suggested. The implementation of a mesh infrastructure to connect the various smart metering networks is a promising solution, as it allows self-healing, self-organization, and self-configuration. Introduction of multi-hop routing in the mesh network, provides load balancing abilities, and improves the performance of the network by increasing the coverage area [4]. The WSN consists of smart metering nodes interacting with a sink in a self-organized manner and is suggested due to its low cost and collaborative nature. Besides WSN, authors also investigated the use of cellular device-to-device communications in AMI, for connecting a huge number of smart meters to the meter data management unit [5].

This paper proposes a customized routing protocol for this novel network. A multi-objective evolutionary algorithm integrated with AODV protocol is used to determine the optimal routing solution in the WSN based smart metering networks linked through a mesh network backbone. This research focuses on minimizing end-to-end delay and maximizing energy efficiency in the entire smart metering network. The performance of the proposed routing protocol has been evaluated against the widely used AODV protocol. The remaining of the paper is structured as follows; Section II describes existing routing protocols for smart metering infrastructure and AODV based routing protocols for smart metering. Section III elaborates on the different components of the proposed algorithm. In section IV, the proposed method is compared with the most commonly used methods. Simulation results for different real-life scenarios are displayed in section V. Finally, Section VI provides a summary of the concluding remarks from this work and specifies forthcoming work directions.

II. Ease of Use Backgroung

A. Current Research on Routing Protocols for Smart Metering Infrastructure

In [6], the authors proposed a protocol based on time synchronization for smart metering mesh-network grids. The concept of metering and concentrator nodes is implemented, whereby the metering node connected to an electrical meter takes measurements and the concentrator node is connected wirelessly to a WAN. The concentrator node receives data from the connected metering nodes and acts as a sink. On the other hand, a multi-constrained QoS routing, based on a simple greedy-algorithm, considering two QoS metrics as described in [7]. In this work, QoS degradation was found to be related to the cost incurred when the traffic of the Home Management System is not delivered rapidly and reliably to the control center. Furthermore, a modified version of a Hybrid Wireless mesh routing protocol (HWMP) was presented in [8]. This protocol was implemented in IEEE 802.11s based wireless mesh network (WMN). It allows multiple paths establishing to multiple gateways. Also, it uses proactive routing and initiates on-demand routing in case of path failures. During such failures, packets are forwarded via backup routes. For accommodation of changing packet size, a metric considering link error was suggested, for the case of IEEE 802.11s based Wireless LAN Mesh Networks. To enhance the resilience of the wireless mesh network, a route fluctuation prevention algorithm was incorporated in [9]. In [10], [11] the authors propose the transfer of metering and control data between smart meters and the control center through the use of a multi-hop method with a mix of communication technologies. This effectively diminished transmission overheads, while guaranteeing message integrity. More recently, a QoS-aware ML-based framework for AMI applications in SGs was proposed in [12]. The authors made use of IoT as well as a cloud platform to remotely control SMs for residences. An optimization problem was formulated for the QoS and coverage requirements.

B. AODV based Routing Protocol for Smart Metering

Numerous researchers have been performed in single routing criterion areas. In [13], an on-demand code aware routing scheme (OCAR) was proposed for WMN where, a route having greater network coding opportunities is detected along the entire path, instead of only two-hop regions. A field-based anycast routing protocol was presented in [14], where mesh nodes were characterized as temperature values and the sources of heat for a temperature field were represented by a gateway. Another model based on interference aware analytical routing metric is described in [15]. Its implementation resulted in a very high rate of traffic transmitted from sources to their respective destination pairs. A method to obtain the path offering the maximum possible bandwidth available was proposed in [16]. This was achieved using a proactive hop by hop routing protocol. Further in [17], the Simple opportunistic adaptive routing protocol (SOAR), was presented which selects forwarding nodes and employs timers based on priority. In [18]–[20], residual energy was considered as a means to prolong the network lifetime. Other works have considered the utilization of strongest link paths with respect to received signal strength, for stable route establishment [21], [22]. Authors also considered the traffic load factor during the initiation of route formation to reduce congestion in the network [23][24]. There exist variants of AODV which focus on multiple criteria while routing. ETR-AODV takes into account the remaining energy of nodes and the level of traffic while selecting a route [25]. On the other hand, Energy Efficient AODV which considers the energy of nodes that remains during the routing process and route change due to node influence [20]..

III. Proposed Algorithm

Numerous methods exist which can solve multi-objective optimization out of which Evolutionary Algorithms are the most commonly used. In this work, a Genetic Algorithm based multi-objective evolutionary algorithm is developed. This algorithm inspired by natural selection is devised and implemented with AODV protocol, as it can generate many optimal solutions in a single simulation run.

In this section, the following are discussed:

- The process of path selection for a typical Genetic Algorithm,
- The routing process of ad hoc distance vector protocol,
- The proposed protocol, whereby the AODV protocol is modified and genetic algorithm used for optimum path convergence.

A. Genetic Algorithm

The flowchart in Fig. 1 summarizes the process of selection through a genetic algorithm.

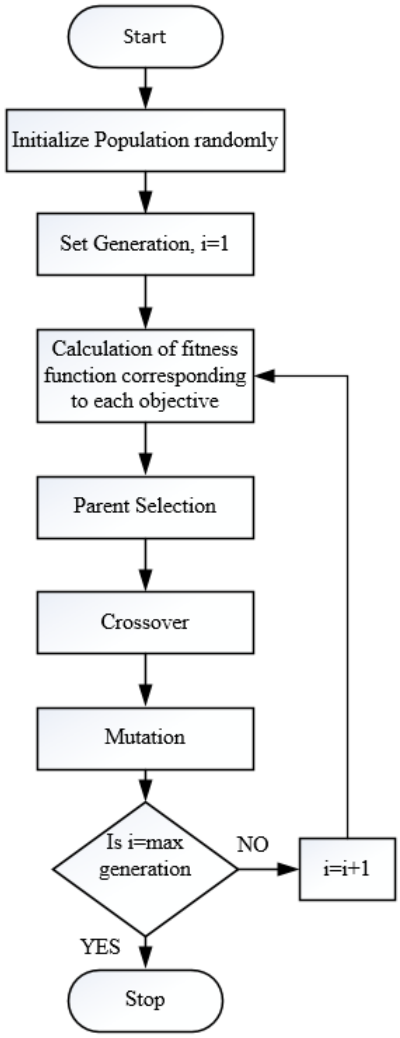

Figure 1. Genetic Algorithm

B. Ad hoc On-Distance Vector Protocol

The Ad hoc On-Demand Distance Vector (AODV) is a reactive routing protocol, it determines the route to the destination only when requested. The routing method is shown in Fig. 2.

C. Proposed Algorithm

The proposed algorithm is based on the Genetic algorithm, but also consists of some additional steps further improving the results obtained. The components of the proposed algorithm are described in the section below.

1) Chromosome encoding

The chromosome represents a potential solution for the optimization problem and is made up of sequences of positive integers, representing the IDs of nodes part of the routing path. A gene in a chromosome is characterized by two factors namely locus and allele. The locus represents the position of a gene located within the structure of the chromosome and the allele represents the value that the gene takes.

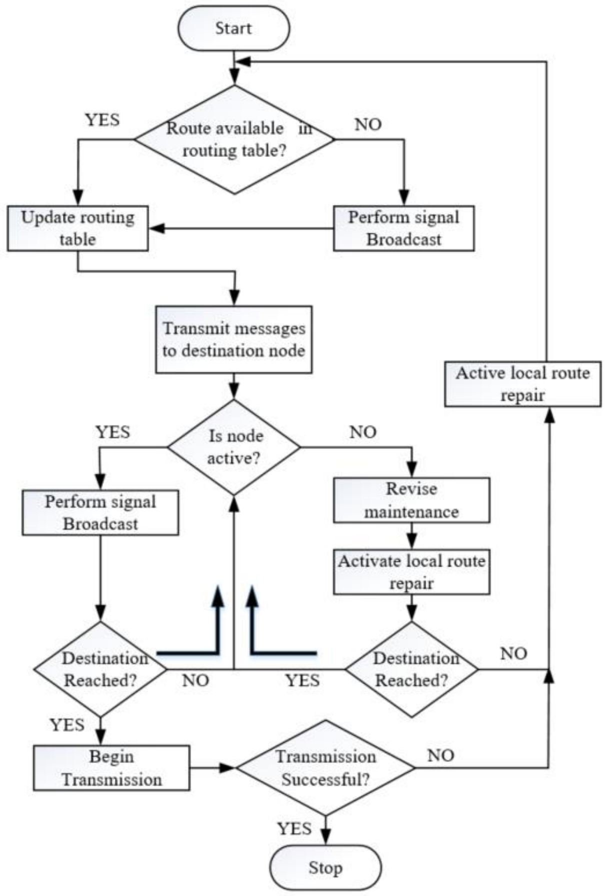

Figure 2. AODV protocol workflow

2) Initial Population Generation

A population can be initialized using one of the two primary methods namely, random initialization and heuristic initialization. In random initialization, the initial population is initialized with completely random solutions, whereas in heuristic initialization, the initial population is initialized using a known heuristic for the problem. In this paper priority-based encoding, developed by Goldberg et al. [26] has been used where the node ID is represented by the gene position and the priority of the node in a path is denoted by the value of the gene.

3) Population enhancement

All the paths obtained after the initial generation of the population might not be feasible. Therefore, an enhancement of population is performed to rearrange the infeasible paths and make them feasible. In case this is not possible the infeasible path is rejected.

4) Crossover

Partially mapped crossover (PMX)[27] has been adopted in this paper. PMX is considered as an improvement of the two-point crossover and further incorporates a mapping relationship to legalize offspring that have duplicate numbers. PMX is performed in a way to enable the crossing of genes to be in the order in which they appear. Crossover can be classified as a convergence operation as it pulls a given population towards a local minimum or maximum as required and eliminates to a high extent the generation of offspring which has the potential to breach problem constraints.

5) Mutation

Different mutation operators exist for multi-objective problems such as inversion, swap, insertion mutation and so on. Insertion mutation has been adopted in this paper to generate variation in the offspring, by preventing the loss of heritability. In Insertion mutation, a gene is selected at random and inserted in another random position.

6) Fitness Function

A fitness function picks a candidate solution and analyses it to produce a fitness value, which indicates to what extent that solution is fit with respect to the objectives. A strategically constructed fitness function considerably increases the possibility of obtaining a solution and attaining higher coverage.

7) Ranking

This is performed by calculating the fitness values of the individuals and placing them in the order of highest fitness value to the lowest fitness value.

8) Population maintenance

Population maintenance is performed to eliminate excessive individuals when the number of non-dominated solutions becomes larger than the population size. In evolutionary algorithms described in [28]–[31], crowding distance (CD) has been used for population maintenance.

$$CD_i = \frac{1}{r}\sum_{k=1}^{r} |f_{i+1}^{r} + f_{i-1}^{r}| \qquad (1)$$

where,

- r = Number of objectives
- f_{i+1}^{r} is the kth objective of the (i+1)th individual, and
- f_{i-1}^{r} is the kth objective of the (i-1)th individual after sorting.

CD lacks uniform diversity, hence dynamic crowding distance (DCD), introduced in [32] has been used to solve this problem. This approach provides better diversity and reduces the time for computation through better and quicker sorting. It also ensures sufficient diversity amongst all the solutions of the non-dominated fronts.

$$DCD_i = \frac{CD_i}{\log\left(1/V_i\right)} \qquad (2)$$

where CD is calculated using Equation (1) and V_i is calculated using Equation (3).

$$V_i = \frac{1}{r}\sum_{k=1}^{r} (|f_{i+1}^{r} + f_{i-1}^{r}| CD_i)^2 \qquad (3)$$

where V_i is the variance of CD_s of individuals neighboring the ith individual.

To implement DCD, the following parameters are initialized;

- Let the Population size = P,
- Solution set at tth generation= S(t),
- Size of S(t) = Q.

DCD is used when the solution set at a particular tth generation exceeds the population size.

The steps for DCD are summarized as follows:

1. If S(t) ≤ P end population maintenance, else go to step 2.
2. Evaluate all individuals' DCD in S(t) using Equation (2).
3. Perform sorting based on DCD value of individuals and wipe individuals with the lowest DCD.
4. Go to step 1.

TABLE I. CONTROL PARAMETERS FOR THE ALGORITHM

Parameters	**Values**
Size of the population	50
Number of generations	40
Probability of crossover	0.8
Probability of mutation	0.1
Parent selection	Binary tournament
New generation selection	Elitist

IV. PROPOSED PROTOCOL

From literature, it can be inferred that AODV is well-suited to be the base routing algorithm for smart metering infrastructure. In this proposed work modifications are made upon AODV to create a resource and time critical WSN based smart metering infrastructure for the Smart Grid.

A. Energy Consideration

Smart meters are typically battery-powered and have limited energy. The energy levels of nodes closer to the sink are depleted faster relative to other nodes in the network as these nodes are used most of the time in the network. The modified AODV protocol considers the energy level of nodes and forms a path with nodes having the highest energy level. The metric E is introduced which is the ratio of the energy consumed by a node to the maximum energy available to the node, which is the initial energy supplied by the battery.

$$E = \frac{E_c}{E_b} \quad (4)$$

where,

- E_c is the energy consumed by the node and
- E_b is the maximum energy available to the node.

The energy value varies from 0 to 1 where, 1 represents maximum energy level and 0 represents a completely energy depleted node, that is, a dead node.

$$DE_{node} = \sum_{i=1}^{n} \alpha_i m_i \quad (5)$$

where,

- m is the metric being considered,
- α is the weight assigned to metric,
- n represents the total number of metrics and,
- i runs for all n number of metrics.

B. Delay

The smart meters send important information to the utility. Therefore, high latency in the smart metering network is undesirable. The metric D is introduced, which is the ratio of the delay between two consecutive nodes in a path and the maximum delay that exists between two nodes.

$$D = \frac{D_i}{D_{max}} \quad (6)$$

where,

- D_i is the delay between two consecutive nodes in a path
- D_{max} is the max delay between two nodes, and is used as a reference point.

C. Combining Metrics

The objectives, end-to-end delay and energy consumed by the sensor nodes are combined with equal priority given to each metric and an overall Delay-Energy (DE) value is obtained for each node, as shown in the equation below.

$$DE_{node} = W_D \times D + W_E \times E \quad (7)$$

W_D represents the weight associated with end-to-end delay,
W_E represents the weight associated with the remaining energy of the node

As per the requirements of the system, priorities can be assigned to the different metrics. The DE_{node} value obtained is always in the range of 0 to 1, as the cumulative sum of the weights, W_E and W_D is 1.

V. Simulation Results

The protocol was implemented using the network simulator (NS-2) software.

The following performance metrics are used:

i. Average energy consumption of the node

The average energy consumption represents the overall energy consumed by the sensor nodes in routing packets from source to destination. As smart meters are generally battery-powered, an energy-efficient protocol is required to maximize the lifetime of the network.

ii. End to end delay

The end-to-end delay metric points out the presence of latency in the network. It is the ratio of the total time taken by the generated packets to be received at the destination to the total number of packets. For the smart metering system, the end-to-end delay is an important metric to be analyzed as certain applications require rapid data transfer.

Simulations were conducted for two different cases. The first case considered a TCP/FTP based network. In the second case, UDP and CBR traffic were considered.

A. Case 1

The real-world model shown in Fig. 3 is simulated, where the star represents the sink, and the dots represent the metering nodes. In this case, both W_D and W_E are given equal priorities and set to 0.5.

The network is set up as shown in Fig. 4, where the topmost node represents the local sink. Modified-AODV has a lower average energy consumption compared to that of AODV. The difference in energy consumption is due to AODV having only least hop consideration while Modified- AODV considers both the energy consumption and end-to-end delay metric. The multi-objective algorithm incorporated in modified-AODV protocol allows faster convergence of the solution with respect to two objectives in contrast with AODV which has a single objective.

Modified-AODV's inclusion of energy metric in taking routing decisions results in the prolonging of the sensor node lifetime hence also the lifetime of the network, as nodes with low energy levels are not chosen for routing and those with higher are chosen instead, while ensuring that at no instant will there be a dead node in the network.

There may also be frequent breakages in the network as it is based on an outdoor model that is vulnerable to effects such as shadowing. This might lead to route discoveries causing large overhead on the network, increasing the energy consumption of the nodes. In such cases, Modified-AODV, offers a way to limit the energy consumption and thus is suitable for battery-operated smart meters as they are equipped with limited energy supply.

Figure 3. Real-world model with nodes represented as house locations [33]

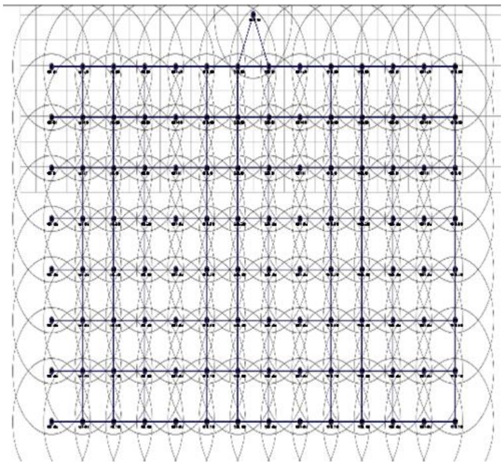

Figure 4. Network for Case 1

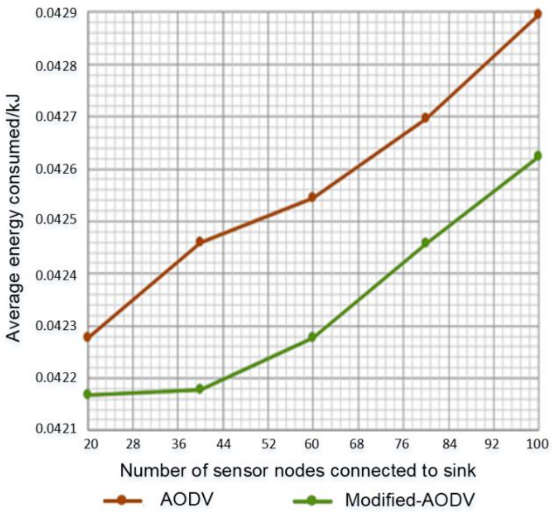

Figure 5. Average energy consumption versus. No. of nodes

TABLE II. SIMULATION PARAMETERS FOR CASE 1

Simulation parameters	
Routing protocol	Modified-AODV, AODV
MAC layer/PHY layer	802.11b
Channel type	Wireless channel
Propagation model	Two ray ground, shadowing
Traffic type	File transfer protocol (FTP)
TCP packet size	500 bytes
Maximum number of packets in queue	50
Number of source nodes	20, 40, 60, 80, 100
Number of sink nodes	1 sink node
Interface Queue Type	Queue/DropTail/PriQueue
Data rate	11Mbps
Antenna model	Omni antenna
Simulation Time	120 seconds

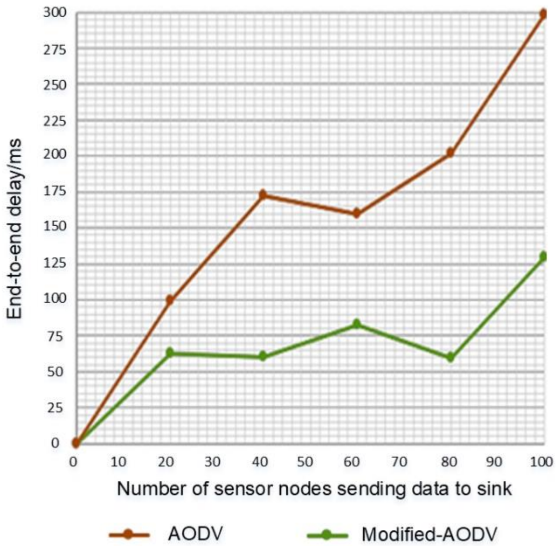

Figure 6. End-end delay Vs. No. of nodes

Modified-AODV protocol offers lower end to end delay in the network. This has been possible since the number of feasible solutions representing paths, is increased using the path enhancement process and fitness test which generates a with the lowest end to end delay. Hence, giving the Modified-AODV an edge over the AODV protocol.

B. Case 2

In this case, the same real-world model shown in Fig. 3 is simulated. However, in this case, UDP is used as agent and CBR traffic is used.

For part (a) the energy weight W_E is set as 1 and the delay weight W_D set as 0. For part (b) the energy weight W_E is set as 0 and the delay weight W_D set as 1. The network is set up as shown in Fig. 7, where the node in the middle of the network represents the local sink. TABLE III shows the simulation parameters for Case 2(a).

a) Energy consumed

The simulation is run for 2000 s and Fig. 8 shows that the energy consumed by nodes for AODV is well-above than the energy consumed by nodes for Modified-AODV. The same is observed for simulation time 1000 seconds, shown in Fig. 9.

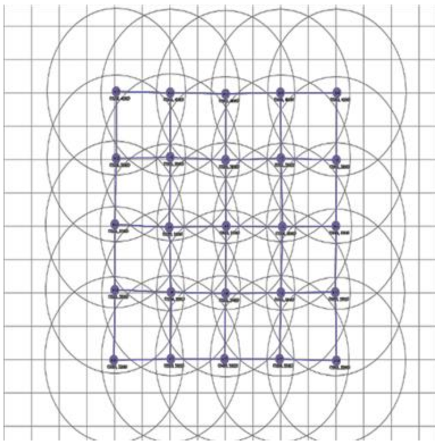

Figure 7. Network for Case 2

TABLE III. SIMULATION PARAMETERS FOR CASE 2

Simulation parameters	
Routing protocol	Modified-AODV
MAC layer/PHY layer	802.11b
Channel type	Wireless channel
Propagation model	Two ray ground, shadowing
Traffic type	Constant bit rate (CBR)
CBR packet size	150 bytes
CBR packet interval	10 seconds
Number of source nodes	24 source nodes
Number of sink nodes	1 sink node
Interface Queue Type	Queue/DropTail/PriQueue
Antenna model	Omni antenna

b) End-to-end delay

For this part, the simulation is run for 300s and from Fig. 10, it can be concluded that the end-to-end delay for Modified-AODV is less than that for AODV.

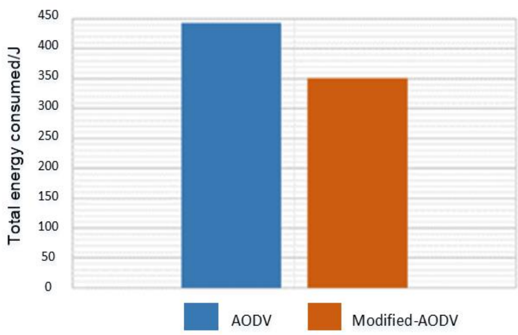

Figure 8. Total energy consumed in 2000 seconds

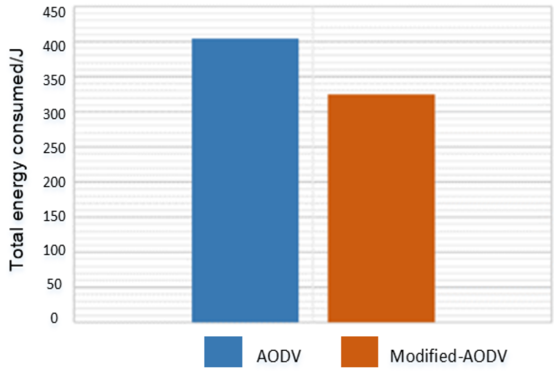

Figure 9. Total energy consumed in 1000 seconds

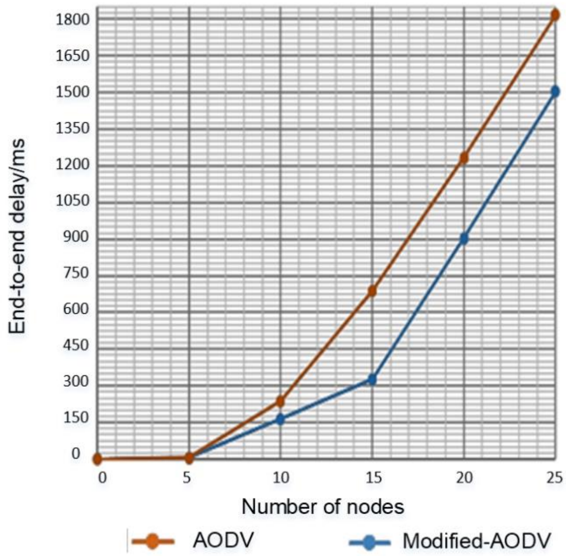

Figure 10. End-to-end delay Vs. Number of nodes

VI. CONCLUSION AND FUTURE WORKS

In this paper, a Genetic Algorithm and AODV hybrid, namely Modified-AODV is proposed for routing in Smart Metering Infrastructure. Path selection decision is based on two metrics, Delay and energy consumed unlike AODV where selection is made based on hop count only. A comparison between the existing solution for routing in smart metering infrastructure and proposed protocol is made. From simulation results, it is observed that along with, Delay and energy consumed metric, other metrics like throughput and packet delivery ratio are also improved. This improvement is the result of integrating the GA with existing AODV protocol as the GA generates solutions that minimize the end-to-end delay and energy consumed by nodes simultaneously. Also, the IEEE 802.11b standard was chosen as the supporting hardware is easier and cheaper to design and the data rates provided are adequate to provide a fast and reliable transmission of data.

Further works can be performed in the implementation of the system with the IEEE 802.15.4 standard which consumes very low energy or cellular networks that can be used to connect the smart metering nodes. Also, the omnidirectional antenna used in this project can be replaced by a directional MIMO antenna for improved energy consumption, longer transmission range. An additional security feature could also be included to locate malicious nodes and evade any potential attack.

REFERENCES

[1] Y. Yan, Y. Qian, H. Sharif, and D. Tipper, "A Survey on Smart Grid Communication Infrastructures: Motivations, Requirements and Challenges," IEEE Communications Surveys & Tutorials, vol. 15, no. 1, pp. 5–20, 2013, doi: 10.1109/SURV.2012.021312.00034.

[2] D. F. Ramírez and S. Céspedes, "Routing in Neighborhood Area Networks: A survey in the context of AMI communications," Journal of Network and Computer Applications, vol. 55, pp. 68–80, 2015, doi: https://doi.org/10.1016/j.jnca.2015.04.011.

[3] S. S. S. R. Depuru, L. Wang, and V. Devabhaktuni, "Smart meters for power grid: Challenges, issues, advantages and status," Renewable and Sustainable Energy Reviews, vol. 15, no. 6, pp. 2736–2742, 2011, doi: https://doi.org/10.1016/j.rser.2011.02.039.

[4] H. Farooq and L. T. Jung, "Health, link quality and reputation aware routing protocol (HLR-AODV) for Wireless Sensor Network in Smart Power Grid," in 2012 International Conference on Computer & Information Science (ICCIS), 2012, vol. 2, pp. 664–669. doi: 10.1109/ICCISci.2012.6297112.

[5] Y. Song, P. Y. Kong, Y. Kim, S. Baek, and Y. Choi, "Cellular-Assisted D2D Communications for Advanced Metering Infrastructure in Smart Gird," IEEE Syst J, vol. 13, no. 2, 2019, doi: 10.1109/JSYST.2019.2891719.

[6] D. Geelen, G. van Kempen, F. van Hoogstraten, and A. Liotta, "A wireless mesh communication protocol for smart-metering," in 2012 International Conference on Computing, Networking and Communications (ICNC), 2012, pp. 343–349. doi: 10.1109/ICCNC.2012.6167440.

[7] H. Li and W. Zhang, "QoS Routing in Smart Grid," Mar. 2010, doi: 10.1109/GLOCOM.2010.5683884.

[8] H. Gharavi and B. Hu, "Multigate Communication Network for Smart Grid," Proceedings of the IEEE, vol. 99, no. 6, pp. 1028–1045, 2011, doi: 10.1109/JPROC.2011.2123851.

[9] J.-S. Jung, K.-W. Lim, J.-B. Kim, Y.-B. Ko, Y. Kim, and S.-Y. Lee, "Improving IEEE 802.11s Wireless Mesh Networks for Reliable Routing in the Smart Grid Infrastructure," in 2011 IEEE International Conference on Communications Workshops (ICC), 2011, pp. 1–5. doi: 10.1109/iccw.2011.5963578.

[10] K. Mahmood, S. Ashraf Chaudhry, H. Naqvi, T. Shon, and H. Farooq Ahmad, "A lightweight message authentication scheme for Smart Grid communications in power sector," Computers and Electrical Engineering, vol. 52, 2016, doi: 10.1016/j.compeleceng.2016.02.017.

[11] D. Sadhukhan, S. Ray, M. S. Obaidat, and M. Dasgupta, "A secure and privacy preserving lightweight authentication scheme for smart-grid communication using elliptic curve cryptography," Journal of Systems Architecture, vol. 114, 2021, doi: 10.1016/j.sysarc.2020.101938.

[12] A. Khan, A. I. Umar, A. Munir, S. H. Shirazi, M. A. Khan, and M. Adnan, "A qos-aware machine learning-based framework for ami applications in smart grids," Energies (Basel), vol. 14, no. 23, 2021, doi: 10.3390/en14238171.

[13] J. SUN, Y. LIU, H. HU, and D. YUAN, "On-demand coding-aware routing in wireless Mesh networks," The Journal of China Universities of Posts and Telecommunications, vol. 17, no. 5, pp. 80–92, 2010, doi: https://doi.org/10.1016/S1005-8885(09)60511-2.

[14] R. Baumann, S. Heimlicher, and B. Plattner, "Routing in Large-Scale Wireless Mesh Networks Using Temperature Fields," IEEE Netw, vol. 22, no. 1, pp. 25–31, 2008, doi: 10.1109/MNET.2008.4435899.

[15] E. Alotaibi, V. Ramamurthi, M. Batayneh, and B. Mukherjee, "Interference-aware routing for multi-hop Wireless Mesh Networks," Comput Commun, vol. 33, no. 16, pp. 1961–1971, 2010, doi: https://doi.org/10.1016/j.comcom.2010.06.025.

[16] R. Hou, K. Lui, F. Baker, and J. Li, "Hop-by-Hop Routing in Wireless Mesh Networks with Bandwidth Guarantees," IEEE Trans Mob Comput, vol. 11, no. 2, pp. 264–277, 2012, doi: 10.1109/TMC.2011.25.

[17] E. Rozner, J. Seshadri, Y. Mehta, and L. Qiu, "SOAR: Simple Opportunistic Adaptive Routing Protocol for Wireless Mesh Networks," IEEE Trans Mob Comput, vol. 8, no. 12, pp. 1622–1635, 2009, doi: 10.1109/TMC.2009.82.

[18] M. Veerayya, V. Sharma, and A. Karandikar, "SQ-AODV: A novel energy-aware stability-based routing protocol for enhanced QoS in wireless ad-hoc networks," in MILCOM 2008 - 2008 IEEE Military Communications Conference, 2008, pp. 1–7. doi: 10.1109/MILCOM.2008.4753608.

[19] T. H. Tie, C. E. Tan, and S. P. Lau, "Maximum Energy Level Ad Hoc Distance Vector scheme for energy efficient ad hoc networks routing," in 2009 IEEE 9th Malaysia International Conference on Communications (MICC), 2009, pp. 423–428. doi: 10.1109/MICC.2009.5431544.

[20] Y. Chen, C. Zhang, and Z. Liu, "Energy Efficient Routing Protocol for Ad hoc Networks," in 2010 International Conference On Computer Design and Applications, 2010, vol. 5, pp. V5-320-V5-323. doi: 10.1109/ICCDA.2010.5541084.

[21] B. A. Anis, A. Nguira, and Y. Habib, "Wireless Routing Protocol Based on Auto -- Learning Algorithm," in 2009 Third International Conference on Digital Society, 2009, pp. 118–122. doi: 10.1109/ICDS.2009.64.

[22] R.-S. Chang and S.-J. Leu, "Long-lived path routing with received signal strength for ad hoc networks," in 2006 1st International Symposium on Wireless Pervasive Computing, 2006, pp. 6 pp. – 6. doi: 10.1109/ISWPC.2006.1613588.

[23] Y. Yuan, H. Chen, and M. Jia, "An adaptive load-balancing approach for ad hoc networks," in Proceedings. 2005 International Conference on Wireless Communications, Networking and Mobile Computing, 2005., 2005, vol. 2, pp. 743–746. doi: 10.1109/WCNM.2005.1544161.

[24] J. Shi, J. Yu, H. Li, and R. Zong, "AODV Protocol Optimization Based on Cross-Layer Design of WMN," in 2011 7th International Conference on Wireless Communications, Networking and Mobile Computing, 2011, pp. 1–4. doi: 10.1109/wicom.2011.6040282.

[25] K. Kumar, S. Prakash, and S. Singh, "An Energy and Traffic Aware Routing Approach as an Extension of AODV," Int J Comput Appl, vol. 27, Aug. 2011, doi: 10.5120/3315-4551.

[26] K. Deb, A. Pratap, S. Agarwal, and T. Meyarivan, "A fast and elitist multiobjective genetic algorithm: NSGA-II," IEEE Transactions on Evolutionary Computation, vol. 6, no. 2, pp. 182–197, 2002, doi: 10.1109/4235.996017.

[27] S. M. Hardi, M. Zarlis, S. Effendi, and M. S. Lydia, "Taxonomy Genetic Algorithm for Implementation Partially Mapped Crossover in Travelling Salesman Problem," in Journal of Physics: Conference Series, 2020, vol. 1641, no. 1. doi: 10.1088/1742-6596/1641/1/012104.

[28] C. Raquel and P. Naval, An effective use of crowding distance in multiobjective particle swarm optimization. 2005. doi: 10.1145/1068009.1068047.

[29] K. Deb, S. Agrawal, A. Pratap, and T. Meyarivan, "A Fast Elitist Non-dominated Sorting Genetic Algorithm for Multi-objective Optimization: NSGA-II BT - Parallel Problem Solving from Nature PPSN VI," 2000, pp. 849–858.

[30] S. Kukkonen and K. Deb, "Improved Pruning of Non-Dominated Solutions Based on Crowding Distance for Bi-Objective Optimization Problems," in 2006 IEEE

International Conference on Evolutionary Computation, 2006, pp. 1179–1186. doi: 10.1109/CEC.2006.1688443.

[31] R. A. Santana, M. R. Pontes, and C. J. A. Bastos-Filho, "A Multiple Objective Particle Swarm Optimization Approach Using Crowding Distance and Roulette Wheel," in 2009 Ninth International Conference on Intelligent Systems Design and Applications, 2009, pp. 237–242. doi: 10.1109/ISDA.2009.73.

[32] B. Luo, J. Zheng, J. Xie, and J. Wu, "Dynamic Crowding Distance?A New Diversity Maintenance Strategy for MOEAs," in 2008 Fourth International Conference on Natural Computation, 2008, vol. 1, pp. 580–585. doi: 10.1109/ICNC.2008.532.

[33] H. Farooq and L. Tang Jung, "Energy, Traffic Load, and Link Quality Aware Ad Hoc Routing Protocol for Wireless Sensor Network Based Smart Metering Infrastructure," Int J Distrib Sens Netw, vol. 9, no. 8, p. 597582, Aug. 2013, doi: 10.1155/2013/597582.