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Performance Analysis of AODV Routing Protocol for Wireless Sensor Network based Smart Metering

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Abstract. Today no one can deny the need for Smart Grid and it is being considered as of utmost importance to upgrade outdated electric infrastructure to cope with the ever increasing electric load demand. Wireless Sensor Network (WSN) is considered a promising candidate for internetworking of smart meters with the gateway using mesh topology. This paper investigates the performance of AODV routing protocol for WSN based smart metering deployment. Three case studies are presented to analyze its performance based on four metrics of (i) Packet Delivery Ratio, (ii) Average Energy Consumption of Nodes (iii) Average End-End Delay and (iv) Normalized Routing Load.

1. Introduction

This century has witnessed exponential increase in electricity consumption and its unchecked use has brought us to the verge of a power crisis. To combat this, new plans are being devised and we are witnessing a strong push towards the use of renewable energy and smart electric grid deployment.

One of the key components of smart grid is periodic updates on energy consumption of electricity which allows real time tracking of energy demand for optimizing electric load distribution and load forecasting in electrical power. Neighborhood Area Networks in smart power grids comprises of outdoor metering end-points communicating with a gateway. Factors such as large number of metering nodes and harsh outdoor environment possess great challenge for last mile communication. Smart meter reading collection exhibits a many-to-one scenario where all metering nodes communicate with the gateway (sink) so the nodes close to sink will suffer large energy depletion and traffic congestion as they will be involved in most of multi-hop transmissions [1]. Smart Meters can be powered by rechargeable batteries connected to mini-Solar films or in-line powered. In the former case, energy consumption of the routing protocol cannot be neglected.

Recently Wireless Sensor Networks have provided low cost solution for economical, energy efficient and reliable communication between electric utilities and customer meters [2]. The goal of the WSN in smart grid is to provide complete connectivity to all the metering nodes in the network with high reliability and self healing capability. Electric meters equipped with wireless communication capability form an Ad-Hoc self organizing mesh network sending their own and relaying other meters’ readings to data collector points thus requiring minimal deployment effort and network management.

Ad-Hoc On-demand Distance Vector (AODV) [3] is a reactive routing protocol for mesh networks. It is adopted as standard routing protocol for Zigbee specification used in Home Area Networks (HANs) [4]. In AODV, routes are only formed when needed. To find new route to destination, source node broadcasts route requests to which destination node replies back (or Intermediate nodes) if they...
have the route to destination. Every node maintains table of routes with one entry per destination. AODV uses sequence numbers for loop free routing and route maintenance. AODV uses timers to delete expired routes in routing tables. AODV possesses self repair capability by utilizing active neighbor list. AODV is designed for highly dynamic mobile networks with un-predictable topology change in WSN due to fading effects and interference. It is a good choice especially for event driven or periodic data driven WSN applications like Smart Power Grid Metering.

2. Literature review
Most of the existing Research work [4], [5] are concerned with the performance analysis of AODV for Home Area Networks (Indoor appliances sensors communicating with Smart Meter) and very few studies have evaluated it for outdoor Smart Metering Application. S.Ullo et al. [6] did performance analysis of Zigbee based Wireless Sensor Network for smart grid last mile communication and concluded that end-to-end latency and congestion increases with number of nodes. However the study didn’t investigate energy consumption of the nodes as well as the effect of meter reading collection frequency and HELLO packet frequency. We believed these factors play an important role in network performance. So a detailed simulation study is required which can outline the performance of AODV for Neighborhood Area Networks.

3. Simulation
We conducted the simulation using Network Simulator NS2. IEEE 802.15.4 Low rate Wireless Personal Area Networks (LR-WPANs) was chosen for Physical and MAC layer as it is similar to 802.15.4g standard for Neighborhood Area Networks. We have simulated four topologies with the number of Smart Meters ranging from 6 to 48 (figure 1). The topologies follow regular grid pattern which is observed in most of the modern housing societies. Simulation parameters are given in table 1.

| Table 1. Network Simulation Parameters |
|----------------------------------------|
| **Simulation Parameters**               |
| Routing Protocol                       | AODV                             |
| MAC layer/PHY layer                    | 802.15.4                         |
| Channel type                           | Wireless Channel                 |
| Propagation model                      | Two Ray Ground                   |
| Traffic Type                           | CBR                              |
| CBR Packet Size                        | 100 Bytes                        |
| Interface Queue Type                   | Queue/DropTail/PriQueue          |
| Antenna Model                          | Omni Antenna                     |
| Simulation Time                        | 3600 Sec                         |

Figure 1. (Left to Right) Topology I, Topology II, Topology III, Topology IV

3.1. Case Study 1
In this case study, we varied number of smart meters and observed their effect on Packet Delivery Ratio. Each meter sent 100 bytes data to the gateway with 30 seconds interval for 1 hour. The results given in Table 2 and figure 2 indicate that Packet Delivery Ratio continue to decrease with the increase in number of smart meters. Average energy consumption of nodes increases steadily with maximum consumption is observed in Topology IV and II. Average end-end delay ranges from
0.3 sec to 1.8 sec with maximum latency observed in Topology III. Normalized routing load increases exponentially with the increase in the number of smart meters. Bottleneck nodes are the one whose energy is depleted the most and in all scenarios most of them are the ones close to gateway and in the center which will be involved in most of the multi hop transmissions.

### Table 2. Case Study 1 Results

| Topology | I   | II  | III | IV  | Data Packets Interval (sec) | 0.50 | 0.90 | 1.42 | 2.47 | 6.00 | 1800.00 |
|----------|-----|-----|-----|-----|-------------------------------|------|------|------|------|------|-----------|
| No. of Smart Meters | 6.00 | 6.00 | 6.00 | 6.00 | No. of Data Packets Sent | 6.00 | 6.00 | 6.00 | 6.00 | 6.00 | 6.00 |
| No. of Data Packets Sent | 720.00 | 1440.00 | 2880.00 | 5760.00 | No. of Data Packets Sent | 32106.00 | 21594.00 | 720.00 | 360.00 | 12.00 |
| No. of Data Packets Received | 412.00 | 358.00 | 230.00 | 451.00 | No. of Data Packets Received | 4526.00 | 4412.00 | 412.00 | 429.00 | 10.00 |
| No. of AODV Routing Packets | 3579.00 | 11307.00 | 26889.00 | 64296.00 | No. of AODV Routing Packets | 5285.00 | 6943.00 | 3579.00 | 1805.00 | 62.00 |
| PDR | 57.22 | 24.86 | 7.29 | 7.83 | Normalized Routing Load | 13.39 | 20.43 | 57.22 | 63.61 | 83.33 |
| Avg. End-End Delay (ms) | 343.55 | 604.83 | 1732.10 | 975.77 | Avg. End-End Delay (ms) | 301.44 | 54.26 | 343.55 | 433.76 | 410.26 |
| Normalized Routing Load | 8.69 | 31.58 | 128.09 | 142.46 | Normalized Routing Load | 1.23 | 1.57 | 8.69 | 7.90 | 6.20 |
| Avg. Energy Consumption (J) | 1.23 | 1.54 | 1.40 | 1.64 | Avg. Energy Consumption (J) | 7.75 | 5.42 | 1.23 | 0.79 | 0.05 |
| Maximum Energy Consumption (J) | 3.80 | 2.04 | 2.32 | 2.73 | Maximum Energy Consumption (J) | 10.00 | 7.88 | 1.80 | 1.07 | 0.06 |
| Bottleneck Nodes | 1, 2, 3 | 3,6,4 | 4,6,3 | 2,5,1 | Bottleneck Nodes | 4,2,3 | 1,2,4 | 1,2,3 | 4,5,6 | 3

![Figure 2. PDR](image1.png)

![Figure 3. Avg. Energy Consumption](image2.png)

#### 3.2. Case Study 2

In this Case study, Smart Meters Readings Interval was varied to observe its effects on the Performance Metrics. The Topology used is shown in fig.1 with 6 Smart Meters sending their readings to the Gateway for 60 minutes duration. Results given in Table 3 indicate that at Interval of 0.5 to 1 sec, PDF observed is in the range of 20% and increases with the increase in the Data Packet Interval. Avg. end-end delay remains in the range of 0.3 to 0.4 sec except at 1 sec Interval where 0.05 sec latency is observed. Normalized routing load remains in the range of 9%. Average energy consumption suffers heavily at small data packets interval. Analysis of Smart Meter Readings Interval (figure 3) suggests that average energy consumption of the nodes is very high at small data packets interval and so suitable value should be set by the application running on top of AODV to get satisfactory results.

### Table 4. Case Study 3 Results for 6 Nodes

| Topology | HELLO Packets Interval (sec) | No. of Smart Meters | No. of AODV Routing Packets Sent | No. of Data Packets Sent | No. of Data Packets Received | No. of AODV Routing Packets | Avg. Energy Consumption (J) | Maximum Energy Consumption (J) |
|----------|-----------------------------|---------------------|---------------------------------|--------------------------|-------------------------------|----------------------------|----------------------------|-----------------------------|
| I        | 1.00                        | 6.00                | 6.00                            | 6.00                      | 6.00                          | 6.00                       | 2.04                       | 0.05                        |
| II       | 5.00                        | 6.00                | 6.00                            | 6.00                      | 6.00                          | 6.00                       | 1.93                       | 1.07                        |
| III      | 10.00                      | 6.00                | 6.00                            | 6.00                      | 6.00                          | 6.00                       | 1.84                       | 2.69                        |
| IV       | 30.00                      | 6.00                | 6.00                            | 6.00                      | 6.00                          | 6.00                       | 2.47                       | 1.43                        |
| V        | 45.00                      | 6.00                | 6.00                            | 6.00                      | 6.00                          | 6.00                       | 1.23                       | 1.35                        |
| VI       | 60.00                      | 6.00                | 6.00                            | 6.00                      | 6.00                          | 6.00                       | 1.54                       | 1.14                        |
| VII      | 120.00                     | 6.00                | 6.00                            | 6.00                      | 6.00                          | 6.00                       | 1.25                       | 1.59                        |
| VIII     | 1800.00                    | 6.00                | 6.00                            | 6.00                      | 6.00                          | 6.00                       | 1.64                       | 1.86                        |
| IX       | 25.54                      | 67.78               | 25.83                            | 10.85                     | 64.44                         | 67.64                      | 1.98                       | 10.14                       |
| X        | 50.79                      | 507.23               | 300.18                          | 173.94                    | 466.15                        | 563.57                     | 685.47                     | 493.05                      |
| XI       | 100.00                     | 158.79              | 159.65                          | 109.15                    | 108.05                        | 91.93                      | 223.51                     | 95.15                       |
| XII      | 200.00                     | 942.46              | 999.90                          | 450.43                    | 936.35                        | 95.15                      | 223.51                     | 95.15                       |

#### 3.3. Case Study 3

In this case study, we investigated the effect of HELLO packets frequency on all the Performance Metrics. Two Topologies (I and II) were simulated with 6 and 12 number of smart meters. Simulation was run for 60 minutes and data packet interval was kept at 30 sec.

The results of Topology I are given in Table 4. PDR is largely affected by the HELLO packets frequency. Maximum PDR attained is 67.78% at 5 sec HELLO Interval. Avg. End-End delay is in the range of 0.3 to 0.4 sec except at 1 sec Interval where 0.05 sec latency is observed. Normalized routing load remains in the range of 9%. Average energy consumption suffers heavily at small data packets interval. Analysis of Smart Meter Readings Interval (figure 3) suggests that average energy consumption of the nodes is very high at small data packets interval and so suitable value should be set by the application running on top of AODV to get satisfactory results.
range of 0.5 sec to 1.2 sec with low latency observed at small HELLO Packets Intervals. Normalized routing load suffers heavily at small HELLO packets interval around 187% and around 110% when data Packets Interval and HELLO Interval is set at 30 sec (figure 4). Similarly avg. energy consumption of nodes is very high at small HELLO packets interval and decreases steadily with decrease in HELLO packet interval (figure 5).

The Results of Topology II, given in Table 5, indicate maximum PDR of 37.57% is attained at 5 sec HELLO interval. Avg. end-end delay is in the range of 0.68 sec to 0.96 sec with low latency observed at small HELLO Intervals. Maximum normalized routing load of 229.11% is observed at 1 sec HELLO interval respectively. Avg. energy consumption is maximum at small HELLO intervals where Node 2 dies due to maximum energy depletion. Default value of 1 sec, originally designed for mobile nodes, is inefficient for static nodes as in our case leading to maximum energy consumption and routing load.

![Figure 4. PDR vs HELLO Interval](image1)

![Figure 5. Avg. Energy Consumption vs HELLO Interval](image2)

4. Conclusion & future work

In this paper, Performance of AODV routing protocol is investigated for Wireless Sensor Networks based Smart Metering scenario. Simulation results suggest that AODV originally designed for mobile nodes need some modifications for use in Static WSNs. Energy of nodes should be taken into account during routing decision to enhance performance of AODV for such scenarios. HELLO Interval should be increased from 1 to 5 seconds to achieve optimum energy consumption and reliable packet reception in Smart Meters Network. Similarly, Data Packet Interval of 30 minutes should be selected to achieve more than 80% of successful packet delivery ratio. For future work, we want to analyze AODV Performance on Smart Meters Test bed.

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