Performance Analysis of AODV, AODVUU, AOMDV and RAODV over IEEE 802.15.4 in Wireless Sensor Networks

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Abstract—— **In this paper the focus is on the performance study of four routing protocols, namely AODV, AODVUU, RAODV and AOMDV. We call these protocols AODV family of protocols as all these protocols consider AODV as the base routing protocol upon which these protocols are improved. Even though AODV and AODVUU are not different protocols, we wanted to see if there is any improvement in using the AODVUU implementation for a sensor network environment. We have investigated whether a multiple path algorithm like AOMDV would result in more data delivery as compared to single path solutions like AODV in a sensor network. Also, the reverse route discovery mechanisms employed in RAODV is checked for a sensor network. There is a need to understand the versatile behavioral aspects of these routing protocols in a wireless sensor network with varying traffic loads and the number of sources. All these protocols are simulated using NS-2 over IEEE 802.15.4. We also claim that our work is the first of its kind to study and compare the performance of all these four routing protocols from a sensor network point of view by extensively using various performance metrics like packet delivery ratio, average network delay, network throughput and normalized routing load.**

Keywords- Sensor networks, IEEE 802.15.4, Zigbee, performance.

I. INTRODUCTION

Recent research advances in low power, low cost and low rate wireless communications endure a promising future for the deployment of sensor networks to support a broad range of applications like health monitoring, habitat monitoring, target tracking and disaster management [1, 2, 3].

Performance comparison of routing protocols is done in various research papers in literature. Our simulation results are based on different simulation environment and simulation parameters. Hence our results are not comparable to the previously obtained results. Efficient routing protocols are needed to cope with the nature of sensor networks with least possible overhead and high performance.

The *main contribution of this paper* is that we have made a substantial effort to study the performance of various AODV family of routing protocols, namely AODV,

AODVUU, AOMDV and RAODV for a sensor network environment. To the best of our knowledge, no work has been reported that compares and studies the performance all these routing protocols for wireless sensor networks using IEEE 802.15.4 as the underlying MAC layer.

The rest of the section is divided as follows: In the second section we present literature survey, in the third section a brief description of all the routing protocols considered in this paper along with IEEE 802.15.4 is discussed, simulation setup and analysis of the results are given in the fourth and fifth section and finally we conclude our paper.

II. RELATED WORK

The IEEE 802.15.4 standard was implemented by J.Zheng and M.J.Lee on the ns2 simulator and they carried out a comprehensive study of the 802.15.4 standard [4]. The authors carry out the simulation in both beacon and non-beacon enabled mode. Also the authors test various other features like association, tree formation, network auto-configuration, orphaning and coordinator relocation.

Performance comparison of two routing protocols namely AODV and AOMDV is done in [9] by varying the node mobility and the traffic load in a mobile ad hoc environment. When the mobility is increased the packet delivery ratio of both AODV and AOMDV decreases and it is more severe in AODV. The delay in AOMDV is substantially reduced due to the availability of alternate routes. When the number of packets is generated at a very low rate then both AODV and AOMDV behave in the same manner but when the traffic load is increased, AOMDV outperforms AODV as it can take care of link breakages at high traffic rate.

Reverse AODV (RAODV) and AODV is compared in [11]. The authors consider various metrics like delivery ratio, average end to end delay, average energy remained and control overhead. Here the average energy metric is the energy remained in each and every node. The authors through simulation show that RAODV nodes have more energy left as compared to AODV. RAODV has better performance when delivering the packets but the metrics where its performance suffers is in control packet overhead as it floods the network with more Reverse RouteReply messages.

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III. DESCRIPTION OF IEEE 802.15.4 AND AODV PROTOCOLS

IEEE 802.15.4 and Zigbee are industry standards designed to be used in low data rate, low power consumption, low cost and long lived networks. IEEE 802.15.4 is sometimes called as Zigbee even though Zigbee specifically refers to the routing protocol and 802.15.4 refers to the MAC and PHY protocols. The routing algorithms defined for use by Zigbee are the Ad-Hoc On Demand distance Vector (AODV) protocol and the Cluster Tree protocol.

A. Adhoc On Demand Distance Vector Routing Algorithm (AODV)

AODV routing protocol is an on demand routing protocol. To find a route to the destination, the source node floods the network with RouteRequest packets. The RouteRequest packets create temporary route entries for the reverse path through every node it passes in the network. When it reaches the destination a RouteReply is sent back through the same path the RouteRequest was transmitted. Every node maintains a route table entry which updates the route expiry time. A route is valid for the given expiry time, after which the route entry is deleted from the routing table. When ever a route is used to forward the data packet the route expiry time is updated to the current time plus the Active Route Timeout. An active neighbor node list is used by AODV at each node as a route entry to keep track of the neighboring nodes that are using the entry to route data packets. These nodes are notified with RouteError packets when the link to the next hop node is broken. Each such neighbor node, in turn, forwards the RouteError to its own list of active neighbors, thus invalidating all the routes using the broken link. [5, 6, 7]

B. Adhoc On Demand Distance Vector Routing Algorithm by Uppsala University (AODVUU)

AODVUU is the AODV routing protocol implementation by Uppsala University [8]. The main reason for using AODVUU protocol is to check whether AODVUU offers any performance improvement over the default AODV protocol available in the NS-2 simulator. AODVUU is also RFC3561 compliant routing protocol.

C. Adhoc On Demand Multipath Distance Vector Routing Algorithm (AOMDV)

Adhoc On Demand Multipath Distance Vector Routing Algorithm (AOMDV) is proposed in [9]. AOMDV employs the “Multiple Loop-Free and Link-Disjoint path” technique. In AOMDV only disjoint nodes are considered in all the paths, thereby achieving path disjointness. For route discovery RouteRequest packets are propagated through out the network thereby establishing multiple paths at destination node and at the intermediate nodes. Multiples Loop-Free paths are achieved using the advertised hop count method at each node. This advertised hop count is required to be maintained at each node in the route table entry. The route entry table at each node also contains a list of next hop along with the corresponding hop counts. Every node maintains an advertised hop count for the destination. Advertised hop count can be defined as the “maximum hop count for all the paths”. Route advertisements of the destination are sent using this hop count. An alternate path to the destination is accepted by a node if the hop count is less than the advertised hop count for the destination. We have used the AOMDV implementation for NS-2 provided by [10].

D. Reverse Adhoc On Demand Distance Vector Routing Algorithm (RAODV)

In AODV RouteReply is used to construct a path from the source node to the destination node through various intermediate nodes. If any one of the intermediate nodes in the path moves out of the transmission range then the path is broken. To overcome this advantage RAODV is proposed in [11]. RAODV discovers many reverse route from the source to the destination. In RAODV, the route discovery mechanism from the source node to the destination node is same as that of the AODV routing protocol i.e. RouteRequest message is flooded through out the network. Whenever an intermediate receives the RouteRequest message then the message is forwarded to the next neighboring node. The intermediate nodes check whether they have received the same message based on the broadcast id and the sequence number. When the destination node receives the RouteRequest message then it again floods the network with ReverseRouteRequest message. The same procedure as mentioned previously during the route discovery from source node to the destination node is applied now by using ReverseRouteRequest from destination node to the source node. If an intermediate node in the reverse path goes out of the transmission range when the route is discovered the RouteError message is generated which enables the source node and the destination node to choose alternate paths. When many paths are discovered from the destination node to the source node, then the best path is selected based on the sequence number and the least hop count from the destination node to the source node.

E. Low Rate Wireless Personal Area Network (LR-WPAN)

IEEE 802.15.4 is a new Low Rate Personal Wireless Area Network standard. The LR-WPAN supports two types of devices namely, Fully Function Device and the Reduced Function Device. In IEEE 802.15.4 standard 14 PHY and 35 MAC Primitives have been defined. A device is either a Fully Function device or a Reduced Function device. Any device that is not a co-coordinator is an end node. *Fully Function Device (FFD)* can act as a PAN Coordinator, a Coordinator, or just as an end node (device). FFD also functions as a routing device for grid topologies and for peer to peer communications. *Reduced Function Device (RFD)* has a reduced set of functionality which can only function as an end device or node. It does not have the ability to communicate with any other device other than the coordinator. A basic sensor network can is made up a mixture of these devices. But the basic rule is that any PAN network should have at least one FFD, to act as the PAN-Coordinator or a sink node. The devices of a network sense the phenomenon and reply back to the coordinator. An IEEE 802.15.4 can be operated both in a beacon and non beacon enabled mode. In a beacon enable mode the pan coordinator sends a special frame called beacon for synchronization with other nodes. An 80215.4 can consist of star topology or peer to peer network or a cluster tree network. The IEEE 802.15.4 standard is meant for low duty cycle, low bandwidth and low power applications with a critical and reliable wireless link [12, 13 14].

IV. SIMULATION ENVIRONMENT

The wireless sensor network is modeled as a directed graph $G = (N, L)$, where N is the set of nodes and L is the set of directed wireless links. Let S S denote the set of sensor nodes and S c denotes the sink node or the coordinator node. Then, $N = S$ s $\cup S$ c. The transmission range for each sensor node is designated by r_{tx} . Let d_{ij} denote the distance between node i and node j . A directed transmission link $(i, j) \in L$ exists if $d_{ij} \leq r_{tx}$ [17]. We have modified the code wherever it was deemed necessary to satisfy our simulation conditions and have also fine tuned several parameters to carry out our simulation work. The simulations are conducted using NS2 with WPAN extension [4] by utilizing the standard specifications of Crossbow MICAz processor and radio platform (Chipcon CC2420), operating at the 2.4 GHz frequency band [15]. Here for the sensor network scenario the data traffic is not generated in a Many-to-Many fashion. Instead, there is a designated sink node to communicate with the sensor nodes. This unique traffic pattern is modeled by modifying the cbrgen.tcl file, in which a node is designated as a sink node. This setting will result in the same simulation effect as suggested in [16].

TABLE I. SIMULATION PARAMETERS

Parameter	Value
Routing Protocols	AODV, AODVUU, RAODV, AOMDV
MAC Protocol	IEEE 802.15.4
Frequency/Bandwidth	2.4GHz/250kbps
Number of Nodes	16
Simulation Area	40 x 40
Simulation Time (Sec)	200
Queue Size	70
Packet Size (bytes)	60
Traffic Load (pkts/Sec)	0.001, 0.01, 0.1, 0.3, 1.0, 3.0, 5.0
Number of Sources	4, 6, 8, 10, 12

We have selected following metrics for evaluating the effect of IEEE 802.15.4 over AODV for Wireless Sensor Networks:

Packet Delivery Ratio to SINK: It is defined as

$$\frac{\sum NumberofReceivedDataPackets}{\sum NumberofSentDataPackets}$$

The greater the packet delivery ratio is, the more reliable the network is.

Average Network Delay: It can be defined as

$$\frac{\sum (Time_{packetarrive\ @\ dest} - Time_{packetsent\ @\ source})}{TotalNumberofConnectionPairs}$$

Throughput of the network: Throughput can be defined as the

$$\frac{\sum NodeThroughputsofDataTransmission}{TotalNumberofNodes}$$

A high network throughput indicates a small error rate for packet transmission and a low level for contention in the network.

Normalised Routing Load: The number of routing packets "transmitted" per data packet "delivered" at the destination. It is the sum of all the control packets sent by all the sensor nodes in the network to discover and maintain routes to the SINK node.

V. RESULT ANALYSIS

All simulations are run independently and their results are averaged at 5 different seeds. For our simulation we have assumed that the sensor network is static, where all the sensor nodes have the same radio range and also energy is uniformly distributed among all the sensor nodes. Simulations are carried out in a non-beacon mode and all the devices have the capabilities of a coordinator.

The IEEE 802.15.4 standard is designed for low data rate applications. So the traffic load is varied from 0.001 pkts/sec to 5 pkts/sec. The number of sources that generated the packets is varied starting from 4 and incremented on a scale of 2 up to 12 sources. Packet delivery ration of the various routing protocols is represented by fig 1 and fig 5. We observe that AODV, AODVUU and AOMDV protocols remain in the 90 percentile range for upto 3 pkts/sec but RAODV has the worst performance with it being in the 70 percentile range and dropping off very significantly as the packets are varied. Among all the four routing protocols RAODV has the worst performance when the traffic load is varied. The performance of AODV, AODVUU and AOMDV is more or less the same for the varying traffic load before dropping off significantly. Due to multipaths in AOMDV there can be many stale routes which may contribute to less packet delivery and increase of routing overhead in the network. This shows that IEEE 802.15.4 is mainly for low data rate applications. In RAODV the packets are dropped due to the collision from additional ReverseRouteReply packets sent during route discovery. But the trend is reversed between AOMDV and RAODV when the number of sources is varied. Even though both AOMDV and RAODV both suffer from significant drop in packet delivery it is more severe in AOMDV when compared with other RAODV which was unexpected. As usual AODV and AODVUU maintain their performance in the 90the percentile range.

Even though AODV and AODVUU are one and the same routing protocols, they are implemented by different groups. As discussed previously AODV is the default implementation that can be found in NS-2 tool, while AODVUU is the implementation of AODV routing protocol by Uppsala University. Both AODV and AODVUU have comparable packet delivery ratio but in terms of average network delay there is a huge difference between the performance of AODV and AODVUU in terms of average network delay. AODVUU has less network delay when compared with AODV. The delay of the AODV, RAODV and AOMDV routing protocols decrease and converge at a point as the packets are varied indicating that the network gets saturated as seen in figure 2 and 6. Here in AOMDV the duplicate copies are not discarded not immediately as they are used for further route discovery. This leads to more end to end delay in the network.

The throughput of various routing protocols can be seen from figure 3 and 7. When the routing load is varied AOMDV is having the highest throughput, while AODV is having the highest throughput when the number of sources is varied. This shows that even though AOMDV is having highest throughput does not guarantee the delivery of packets in a less constrained environment like sensor network. AODV maintains a steady throughput while varying the traffic source and traffic load.

The routing load of AOMDV and RAODV is more when compared to AODV routing protocol as shown in figure 4 and 8. The size of the control packets is high in AOMDV and RAODV due to extra route discovery mechanisms. This arises due to the various routing mechanisms incorporated into these routing protocols. In AOMDV, we have multipaths. This allows the packets to move in many paths thus increasing the frequency of RouteReply. RAODV on the other hand uses reverse path technique to find the paths which naturally increases the number of control packets needed to keep track of the increasing number of paths. Here for our simulation since we have assumed that the nodes are static, link failures is very rare and hence computing for link failures will lead to additional overhead in AOMDV, which can be seen from figure 4 and 8. Also RAODV floods the network with a huge amount of ReverseRouteReply packets for route discovery from sink to other sensor nodes, which is unnecessary in our setup as all the nodes have equal energy, same transmission range and do participate through out the simulation.

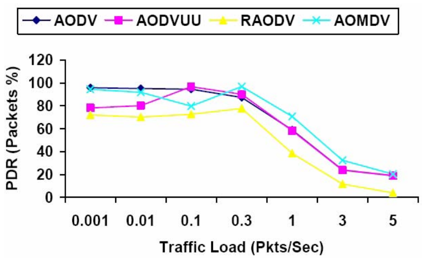

Figure 1. PDR v/s Traffic Load (Pkts/Sec)

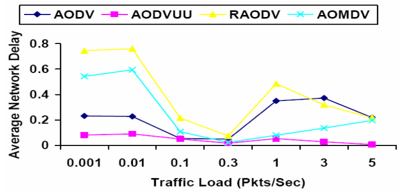

Figure 2. Average Network Delay v/s Traffic Load (Pkts/Sec)

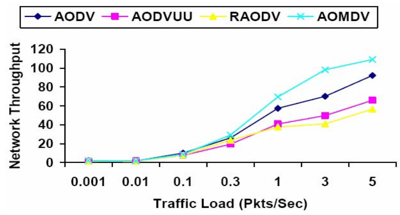

Figure 3. Network Throughput v/s Traffic Load (Pkts/Sec)

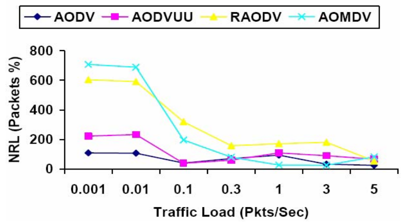

Figure 4. NRL v/s Traffic Load (Pkts/Sec)

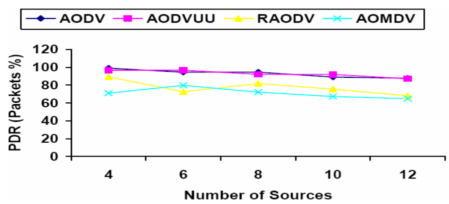

Figure 5. PDR v/s Numver of Sources

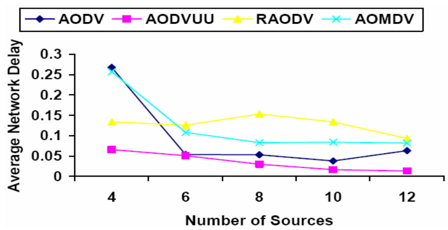

Figure 6. Average Network Delay v/s Numver of Sources

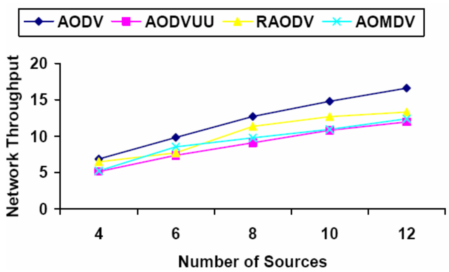

Figure 7. Network Throughput v/s Numver of Sources

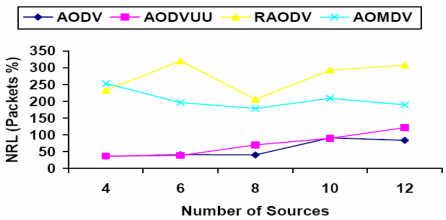

Figure 8. NRL v/s Numver of Sources

VI. CONCLUSION

In this paper we have presented and compared initial performance evaluation of four routing protocols, namely AODV, AODVUU, AOMDV and RAODV under various network scenarios. Even though AOMDV and RAODV show good performance when compared to AODV in an ad hoc network environment, same cannot be said when the routing protocols are applied for a sensor network. A superior design does not guarantee a big boost in the performance in a different environment as shown in our paper. We also suggest that instead of using the default AODV routing protocol that comes with NS-2 for simulation purpose to use the AODVUU implementation for a ZigBee/802.15.4 standard scenario. Our future work includes designing a new routing protocol that takes in to consideration the various challenges under which a routing protocol has to work in a unique and challenging sensor environment. With all these research challenges, we firmly believe that we have a very exciting time ahead of us in the area of Wireless Sensor Networks.

REFERENCES

[1] I. Akylidiz, W. Su, Sankarasubramaniam, and E.Cayrici, "A survey on sensor networks", IEEE Communications Magazine, Volume: 40 Issue: 8, August 2002, pp.102-114.

[2] K. Akkaya and M. Younis, "A survey of Routing Protocols in Wireless Sensor Networks", Elsevier Ad Hoc Network Journal, 2005, pp 325-349.

[3] Gowrishankar.S, T.G.Basavaraju, SubirKumarSarkar, "Issues in Wireless Sensor Networks", In proceedings of the 2008 International Conference of Computer Science and Engineering, (ICCSE 2008), London, U.K., 2-4 July, 2008.

[4] J.Zheng and Myung J. Lee,"A Comprehensive Performance Study of IEEE 802.15.4", Sensor Network Operations, IEEE Press, Wiley InterScience, Chapter 4, pp. 218-237, 2006.

[5] C.Perkins, E.B.Royer and S.Das,"AdHoc On-Demand Distance Vector (AODV) Routing", RFC 3561, IETF Network Working Group, July 2003.

[6] C.Siva Rama Murthy and B.S. Manoj, "Adhoc Wireless Networks: Architectures and Protocols", Second Edition, Prentice Hall.

[7] T.G.Basavaraju and Subir Kumar Sarkar, "Adhoc Mobile Wireless Networks: Principles, Protocols and Applications", Auerbach Publications, 2008.

[8] AODVUU Implementation : http://core.it.uu.se/core/index.php/AODV-UU

[9] Mahesh K. Marina and Samir R.Das, " On-Demand Multipath Distance Vector Routing in Ad-hoc Networks", In proceedings of the IEEE International Conference on Network Protocols, 2001 pp 14-23.

[10] M.Caleffi, G.Ferraiuolo and L.Pauro, "On Reliability of Dynamic Addressing Protocols in Mobile Ad hoc Networks", Proceedings of WRECOM'07, Wireless Rural and Emergency Communications Conference, Roma, Italy, October 2007.

[11] Chonggun Kim, Elmurod Talipov and Byoungchul Ahn, " A Reverse AODV routing protocol in Ad hoc Mobile Networks", EUC Workshops 2006, LNCS 4097, pp 522-531, 2006.

[12] Jianliang Zheng and Myung J.Lee, "Will IEEE 802.15.4 Make Ubiquitous Networking a Reality? A Discussion on a Potential Low Power Low Bit Rate Standard", IEEE Communications Magazine, pp 140-146, June2004.

[13] http://www.ieee802.org/15/pub/TG4Expert.html

[14] Vaddina Prakash Rao and Dimitri Marandin,"Adaptive Channel Mechanism for Zigbee (IEEE 802.15.4)", Journal of Communications Software and Systems (JCOMSS), Volume 2, Number 4, December 2006, pp 283-293.

[15] http://www.xbow.com/Products/Product_pdf_files/Wireless_pdf/MICAZ_Datasheet.pdf

[16] I.Downard, "NRL's Sensor Network Extension to NS-2", NRL/FR/04-10073, Naval Research Laboratory, Washington, D.C., May 2004. Http://www.nrlsensorsim.pf.itd.nrl.navy.mil/.

[17] Kevin Yuen, Baochun li and Ben Liang," Distributed Data Gathering in Multi Sink Sensor Networks and Correlated Ssources", Lecture Notes in Computer Science, Networking Technologies, Services and Protocols: Performance of Computer and Communication Networks, Mobile and Wireless Communication Systems Networking 2006.Springer.