Comparative Performance Study of ADMR and ODMRP in the context of Wireless LANs and Wireless Sensor Networks

RADOSVETA SOKULLU, OZLEM KARACA
Ege University, Department of Electrical and Electronics Engineering
Ege University, Izmir
TURKEY

Abstract: - Wireless LANs (WLANs) and Wireless Sensor Networks (WSNs) are two large groups of networks that have well established application ranges. Despite the fact that they address very distinctive groups of devices and have clearly differentiated wireless interfaces, there are certain similarities which push scientists to look for adopting solutions already designed for WLANs to WSNs. An example of this is the case with routing layer protocols. AODV, an unicast routing protocol, developed for Mobile Ad Hoc networks (MANET), has proved to be applicable and accepted by IEEE as the standard for the routing layer in Low Rate – Wireless Personal Area Networks (LR-WPAN). Still, MANET-originated solutions, including multicast protocols, were initially designed in the context of IEEE 802.11 MAC layer protocol. This paper investigates the feasibility of two popular MANET multicast protocols, ADMR and ODMRP over the IEEE 802.15.4 standard and provides a comprehensive study of the performance of these two protocols with different underlying physical and media access protocols. The protocols have been analyzed with ns-2 network simulator. It appears that even though both protocols are applicable in the selected scenarios, there are specifics in their performance in the context of WSNs which should not be neglected.

Key-Words: - wireless sensor networks, medium access control mechanisms, wireless LANs, performance evaluation

1 Introduction

Wireless sensor networks (WSNs) enhanced with actuator capabilities materialize the interface between people and the environment and establish a context for assisted living and emergency measures, intelligent production and transport, and environmental monitoring. Existing solutions in different OSI layers, designed initially for MANETS, are tested for their applicability in WSNs. An example is the adoption of AODV as a routing protocol for LR-WPAN. The focus of this paper is further investigating such solutions, like ADMR and ODMRP, which are multicast protocols originally designed for MANETs, in the context of WSN application scenarios and performance requirements. An open question is whether the multicast supporting functions of routing protocols developed for MANETS like ADMR and ODMRP can be used for WSNs. Need for such functions has been seen in many WSN based application scenarios like in the health sector where vital patient information is collected by wireless sensors and transmitted to only interested or responsible personnel (doctors, nurses involved with a certain patient [1]), tracking of fire-fighters in burning buildings, data collection with mobile sensors, disaster rescue etc. These scenarios require more general topologies than the event-to-sink model usually accepted for WSNs. When comparing the two protocols the underlying media access mechanism has been taken into consideration and IEEE 802.11 and IEEE 802.15.4 have been covered.

The paper is structured as follows: the next two sections provide a brief background on the specifics of the protocols that are investigated, first for the medium access control and then for the routing layer. In Section 4 the simulation model and the methodology use is discussed. In Section 5 the simulation results are presented followed by conclusions in Section 6, which summarize the most important contributions of the work.

2 Specifics of the IEEE 802.11 and IEEE 802.15.4 MAC Layer Protocols

Both protocols have been standardized by IEEE for the physical (PHY) and media access control (MAC) layer of wireless networks but aiming at different types of wireless devices and network configurations. The 802.11 addresses wireless networks consisting of laptops or similar class of devices, in either infrastructure or infrastructure-less (Ad Hoc) mode. The 802.15.4 set of protocols is developed in the LR-WPAN working group and addresses low speed, low data rate and very resource restricted devices, targeting the case of networking wireless sensor nodes. The paper concentrates on the performance comparison of two different multicast routing protocols, originally suggested for Ad Hoc networks, ADMR and ODMRP, using different underlying MAC layer protocols, specifically IEEE

802.11 and IEEE 802.15.4. It is accepted that the protocols designed in accordance with the OSI network model should be independent from the underlying layer. Even though this statement is true in general, it is interesting to investigate if there are any specifics in the performance related to the different mechanisms of accessing the media and formulate the conditions for the applicability of MANET-originated solutions to WSN.

The 802.11 WLAN PHY layer is responsible for the selection of the correct modulation scheme given the channel conditions and provides the necessary bandwidth. The MAC layer of IEEE 802.11 decides in a distributed manner on how the offered bandwidth is shared among all stations to provide wireless connectivity. Fairness and maximum bandwidth utilization are a major design goal. Two forms of MAC layer have been defined in IEEE 802.11 specification named, Distributed Coordination Function (DCF) and Point Coordination Function (PCF). The DCF protocol uses Carrier Sense Multiple Access with Collision Avoidance (CSMA/CA) and is mandatory, while PCF is defined as an option to support time-bounded delivery of data frames The DCF protocol combines the carrier sensing with RTS/CTS handshake to reduce interference and cope with the hidden terminal problem.

The IEEE 802.15.4, covering the PHY and MAC layer, is developed for LR-WPANs, providing ad hoc self-organizing functionality among inexpensive fixed, portable and moving devices for applications with relaxed throughput requirements. [2]. The PHY among other functions specifies the receiver sensitivities as -85dBm for 2.4GHz and -92dBm for 868/915MHz. The achievable range is a function of the receiver sensitivity and the transmit power. The main functions of the IEEE 802.15.4 MAC layer are grouped based on the use or not of beacons. For the non-beacon mode, which is investigated in this work, they include channel access (CA), frame validation and acknowledged frame delivery. The medium access method used is unslotted CSMA-CA. A device maintains two variables for each transmission attempt: NB and BE. NB, is the number of times the CSMA-CA algorithm was required to backoff while attempting the current transmission. BE shows how many backoff periods a device must wait before attempting to assess the channel. Although the receiver of the device is enabled during CA, during that tiem all frames are discarded. The MAC layer creates delay for a random number of complete backoff periods in the range 0 to $2^{BE}-1$ and then requests PHY to perform a CCA.

3. Ad Hoc Multicast Routing Protocols Functional Overview

Multicast is the function of transmitting information to a group of nodes identified by a single destination address. It has been extensively covered for MANETs. Multicast in WSN has come up very recently with the emerging of new application scenarios. Providing multicast can greatly reduce the number of transmitted packets and reduce sensor nodes' energy consumption because radio transmission is the most power-consuming operation.

Multicast algorithms are divided into tree-based and mesh-based according to how packets are routed through the network [3]. In a tree-based paradigm data is propagated over a spanning tree connecting all multicast group members while mesh-based ones forward data to all group members over a subset of the nodes. ADMR [4] is studied as an example of the tree-based protocols and ODMRP [5] is selected from the mesh based ones.

3.1 On Demand Multicast Routing Protocol

In ODMRP [5], group membership and multicast routes are established and updated by the source on demand. It consists of a request phase and a reply phase. A source node that has packets to send broadcasts an advertising packet known as JOIN QUERY to the whole network. This periodic transmission refreshes the membership information and updates the route with 3 second interval when there are data packets to send; ODMRP does not maintain route information permanently. It uses a soft state approach in group maintenance. When an intermediate node receives a non-duplicate join query, it stores the upstream node in order to use this information later on for backward direction transmission and rebroadcasts the packet. When a multicast receiver gets this packet, it creates a *join table*, which contains the IDs of the senders and the next nodes towards the senders, and broadcasts it within a JOIN REPLY message to the neighbours. When a node receives a join table, it checks if the next node ID of one of the entries matches its own ID. If it matches, the node realizes that it is a part of the forwarding group of nodes. These nodes broadcast their own join tables built upon matched entries. Thus the JOIN REPLY is propagated from the receiver to the source along the shortest path. This process forms a mesh of nodes that constitutes the routes between sources and receivers. Multicast senders refresh the membership information and update the routes by sending JOIN QUERY periodically.

3.2 Adaptive Demand Driven Multicasting

ADMR [6] is a tree-based protocol and performs both its route discovery and route repair on demand. Each multicast source floods its first data packet for a group and each receiver responds to that flood with a RECEIVER JOIN packet which is used to set up the forwarding state in the nodes along the shortest return path. A flood-response cycle is also initiated by each receiver when it first joins the group. Each node is aware only of the neighbours one hop up and one hop downstream. Minimum amount of data is carried in the ADMR header and is recorded in three tables at each node: *node table, sender table* and *membership table*.

ADMR does not employ any periodic control packet exchanges, (except KA 'keep-alives') such as neighbour sensing or periodic flooding and does not rely on lower layers to perform such functions. The min interval between 2 KA is 400 ms but with a multiplicative delay factor it comes up to 2.4 s. The fact that ADMR does not use any predetermined sequence of hops but only forwards along the tree all non-duplicate packets on a hop-by-hop basis increases the robustness of the protocol without adding extra traffic. When an ADMR sender sends a multicast packet, it floods it in the multicast distribution tree only towards the group's receivers, whereas in ODMRP, the packet also floods back towards any other senders that are not receivers for the group.

4. Simulation Model and Methodology

Simulation is carried out using ns-2.30 [7]. Performance comparison research has been done before for multicast protocols based on IEEE 802.11 MAC layer [8]. In [9] a comparison is presented for IEEE 802.11 and 802.15.4 using AODV at the routing layer. The effect of using an RTC/CTS mechanism on the packet delivery ratio is investigated and it is proved that even in collision free environments the ratio of RTS/CTS packets to the data packets is quite high because they are also used for transmissions of control packets of the network layer. In this work ADMR and ODMRP were selected representing two different groups of multicasting, with two different underlying MAC layer protocols, respectively IEEE 802.11 and 802.15.4. The relationship between network protocols and MAC layer protocols is investigated in diverse scenarios based on the following parameters: packet delivery ratio (PDR), protocol overhead and effects of mobility. The PDR is studied as a function of the node density, the node mobility and the varying number of senders and receivers in the network. Overhead is evaluated in respect to the network size.

4.1 Channel and Radio Model

A two ray ground propagation model is used in the experiments. In this model, the shadowing fading factor is not considered. Therefore, for a certain distance, the Pr (power at the receiver side) is a deterministic value:

$$Pr = P_t G_t G_r h_t^2 h_r^2 / L\ d^4$$

In the simulations the Pt_ and the thresholds were adjusted to set the transmit range to 25 meters for the IEEE 802.15.4 and 250m for the IEEE 802.11. The CSThresh is set to 1.559e-11W, RXThresh 3.652e-10 for 802.11 and both to 3.07645e-07W for 802.15.4

4.2 Mobility and Random Way-point Model (RWP)

The mobility model determines how nodes choose destinations for their movement, the speed at which they move, and the physical paths they take. In the RWP a node picks a random destination inside a flat rectangular area, proceeds to it following a straight-line trajectory at a random speed, and on arrival pauses for a fixed time. The process then repeats itself. In the current ns-2 distribution, the speed is chosen uniformly randomly from [0,V_max], for every mobile node. In this work two aspects of mobility have been investigated: the effect of node speed on the packet delivery ratio and on the incurred overhead in scenarios with different number of sender (S) and receiver (R) nodes.

4.4 Traffic Pattern

A traffic generator was developed to simulate constant bit rate sources. The packet rate is 1 packet per second in all simulations and the size of data payload is 512 bits. The senders are chosen randomly among nodes in the network. Nodes join the multicast session at the time defined by randomly generated traffic scenario and remain so throughout the simulation.

4.5 Considered Metrics

The metrics used for the comparison are described in detail below. Some of them were suggested by the IETF MANET WG for routing protocol evaluation.

Packet Delivery Ratio (PDR): Determined as the ratio of the number of data packets actually delivered to the destinations to the number of data packets supposed to be received.

Overhead ratio (OR): **S**hows the efficiency in terms of channel utilization and is very important especially in sensor networks. It is calculated as:

$OR = 1 - (P_{data\ packets\ sent} / P_{total\ packets\ sent})$ where P is the number of each type of packets sent by the source node.

5. Simulation Results

5.1 Node density

In this experiment the effect of node density on the PDR is studied. The number of static nodes varies from 10 to 50 with 1S and 1 or 3R. The results for the different routing protocols with IEEE 802.11 and 802.15.4 are given in Fig.1 and Fig.2 respectively.

It is immediately evident that while the PDR is quite stable for IEEE 802.11 for the whole range of node densities it is not so for the case of IEEE 802.15.4. For densities below 0.005 nodes/m^2 the PDR for ODMRP is unacceptably low. ADMR performs much better. This observation comes to support the thesis made in [9] that a large proportion of control packets required by the network layer protocol even when no RTS/CTS packets are used, greatly reduces the throughput. For densities above 0.005 the performance is quite stable and similar to that of IEEE 802.11 for both ADMR and ODMRP.

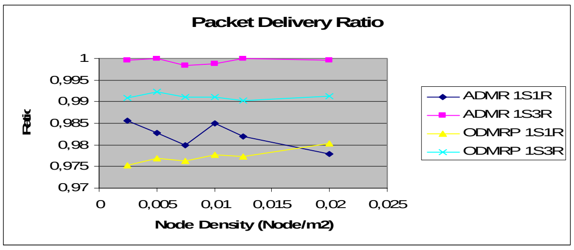

Figure 1: PDR comparison with varying network density - 802.11

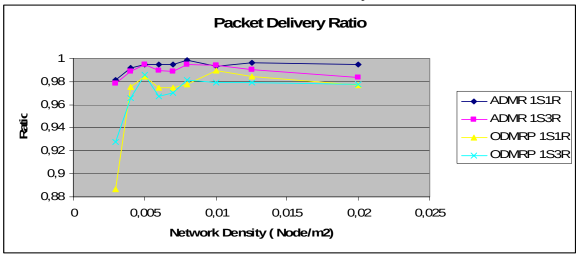

Figure 2: PDR comparison with varying network density -802.15.4

5.2 Varying Number of Senders and Receivers

The number of nodes in the network is set to 30 and the nodes are static. The number of S is taken from the set {1, 3, 5, 10, 15}. For MANET this is a model of "a class lecture scenario", while for WSNs (IEEE 802.15.4), a **1**S represents "a single node reading scenario"; 15S represent "a video conference scenario" or "a single sink scenario" where readings from 15 nodes are sent to a single sink node. Respectively the case with several receivers represents "a multi-sink scenario".

It is observed that the performance is much more stable for both network protocols under IEEE 802.11. For wireless sensor networks ODMRP has a varying behavior. It is claimed in [5] that ODMRP performs well in MANETs for greater number of receivers and this is in line with our observations. Unfortunately the same cannot be claimed for WSN. The PDR in the latter is reduced by nearly 10% compared to that in MANETs. ADMR shows a much more consistent performance for both MAC layer protocols. (Fig.3 and Fig.4).

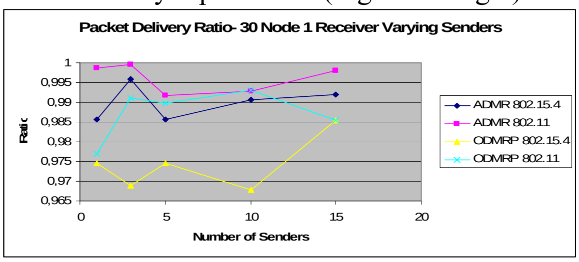

Figure 3: PDR for a varying number of senders

5.5. Overhead

The overhead observed is the total overhead incurred at the MAC layer and the routing layer. For the routing layer this includes the overhead of ADMR and ODMRP for setting up and maintaining the multicast tree or forwarding group. As explained above all the control packets used by a specific protocol are considered.

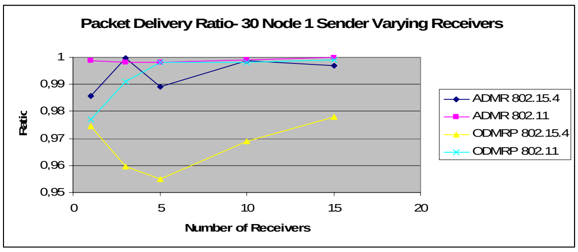

Figure 4: PDR for a varying number of receivers

As the simulation results prove ODMRP has an order higher overhead mainly due to periodic flooding of join queries to maintain redundant paths from source to destination. ADMR creates much lower overhead, independent of the network size or the underlying MAC protocol. Another important observation is that while for IEEE 802.11 networks ODMRP's overhead is varying from 33% to 37% it is much higher for IEEE 802.15.4, reaching 53%.

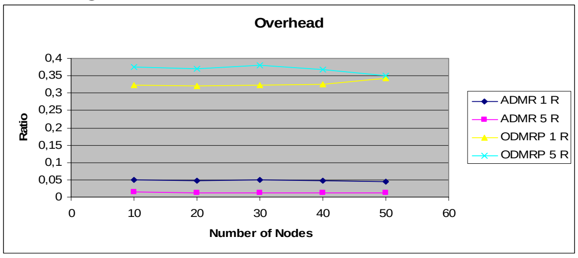

Figure 5: Overhead as a function of network size–802.15.4

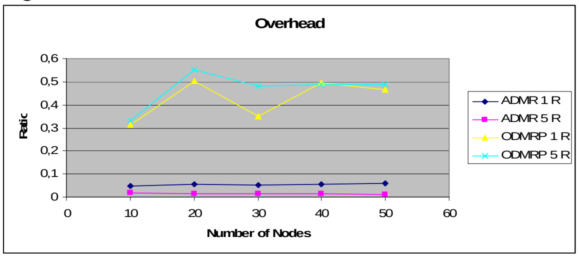

Figure 6: Overhead as a function of network size–802.11

5.5. Impact of Mobility

For studying the impact of mobility the network size is constant at 30 nodes, the node mobility speed is varied 2, 10, and 15 m/s, and pause time is 0. The impact of mobility is evaluated by means of PDR and OR metrics. To create a suitable model of a sensor network, 1 receiver and a varying number of senders (1, 5 and 15) is selected.

The achieved results (Fig.7 and Fig.8) support the ones in [5] that ODMRP is more efficient in more dynamic environments. This is more evident in WSNs. The PDR achieved using ODMRP is around 93% for 5s at 15m/s while that with ADMR is only around 83%. On the other hand, greatly increasing the number of senders

(15) together with their speed reduces the PDR noticeably for both protocols.

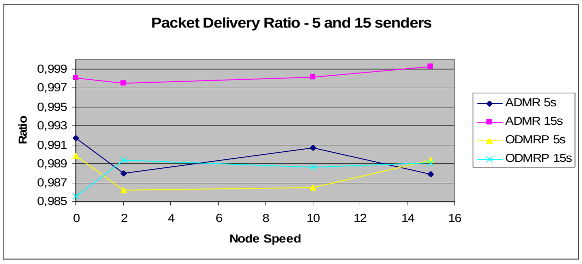

Figure 7: PDR for a varying number of senders at different speeds – 802.11

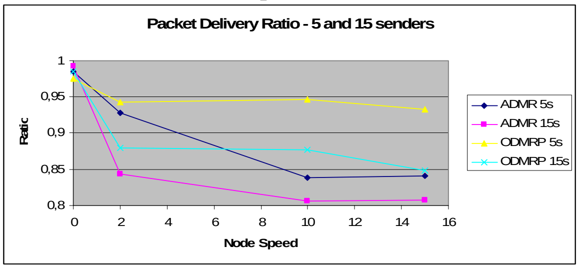

Figure 8: PDR for a varying number of senders at different speeds – 802.15.4

The total incurred overhead (Fig.9) for both IEEE 802.11 and 802.15.4 is little influenced by increasing the node speed. But for ODMRP there is 35% to 40% overhead in Ad Hoc networks while in WSN it is as high as 70%. There is also difference whether we have a large number of senders or a large number of receivers. For 15s-1r at 15 m/s the overhead in ODMRP is round 70% compared to only 45% for 1s-15r at 15m/s.

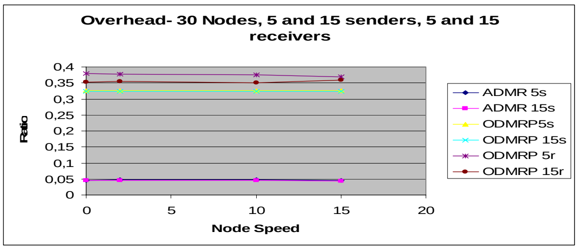

Figure 9: Overhead for a varying number of senders and receivers at different speeds – 802.11

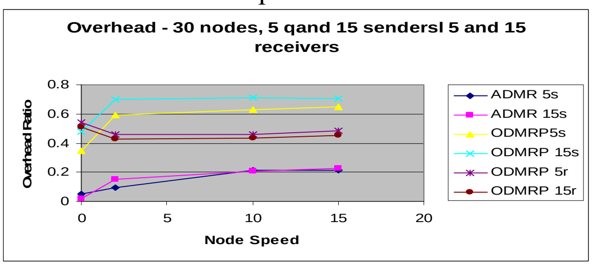

Figure 10: Overhead for a varying number of senders and receivers at different speeds – 802.15.4

6. Conclusion

In this paper we have provided a comparative performance study of two multicast protocols, ADMR and ODMRP, over two different underlying MAC layer protocols – the IEEE 802.11 and the IEEE 802.15.4. The impact of node density, changing number of senders and receivers and mobility speed on the PDR has been studied as well as the effects of node mobility. One of the important conclusions is that while these two routing protocols show quite a stable performance for different scenarios based on IEEE 802.11 the same is not true for the case of IEEE 602.15.4. Even though their operation is independent of the underlying MAC layer, it is observed that both the PDR and the overhead values are quite sensitive to the media access control. This study points out to some specifics when utilizing higher level protocols designed for Ad Hoc networks in WSN. It also supports the thesis that there is a strong relation between the contention mechanism used for media access and the performance of the routing protocol both in terms of packet delivery ratio and overhead, with either static or mobile sensor nodes.

References:

[1] K. Murray, A. Timm-Giel, M. Becker, C. Guo, R. Sokullu, D. Marandin, "The European Network of Excellence CRUISE Application Framework and Network Architecture for Wireless Sensor Networks," in the Proc. of WS on WMSN, GLOBECOM 2007, UAS, Nov. 2007.

[2] S. Coleri Ergen, ZigBee/IEEE 802.15.4 Summary, September 2004.

[3] Y. Zhu, Pro-Active Connection Maintenance in AODV and MAODV, MSc Thesis in Information and Systems Science, Carleton University, Ottawa, 2002.

[4] J. G. Jetcheva and D. B. Johnson, "Adaptive Demand-Driven Multicast Routing in Multi-Hop Wireless Ad Hoc Networks," in the Proceedings of the ACM Symposium on Mobile Ad Hoc Networking and Computing (MobiHoc), Long Beach, CA, October 2001.

[5] S.-J. Lee, M. Gerla, and C.-C. Chiang, "On-demand multicast routing protocol," in the Proceedings of the Wireless Communications and Networking Conference, WCNC, New Orleans, September 21-24, 1999. pp. 1298-1302 and IETF Internet draft (expired), draft-ietf-manet-odmrp-04.txt, November 2002.

[6] J. G. Jetcheva and D. B. Johnson, "The Adaptive Demand-Driven Multicast Protocol for Mobile Ad Hoc Networks," IETF Internet Draft (expired), draft-ietf-manet-admr-00.txt, July 2001.

[7] Network Simulator - ns-2, http://www.isi.edu/nsnam/ns/

[8] S.-J. Lee, W. Su, J. Hsu, M. Gerla, and R. Bagrodia, "A Performance Comparison Study of Ad Hoc Wireless Multicast Protocols," in the Proceedings of the Nineteenth Annual Joint Conference of the IEEE Computer and Communications Societies, INFOCOM 2000, Tel Aviv, pp. 565-574, March 2000.

[9] J.Zheng, M.J.Lee, Comprehensive performance study of 802.15.4, Technical Report, zheng@ee.ccny.cuny.edu, lee@ccny.cuny.edu