Performance Evaluation of Routing Protocols in a Wireless Sensor Network for Targeted Environment

Viktor Denkovski[1], Biljana Stojcevska[2], Toni Dovenski[3], Veno Pachovski[4], Adrijan Bozinovski[4]

[1]*Faculty of Veterinary Medicine Skopje, Skopje, R. Macedonia, viktor@fvm.ukim.edu.mk*

[2]*University American College Skopje, R. Macedonia, stojcevska@uacs.edu.mk*

[3]*Faculty of Veterinary Medicine Skopje, R. Macedonia, dovenski@fvm.ukim.edu.mk*

[4]*University American College Skopje, R. Macedonia, pachovski@uacs.edu.mk, bozinovski@uacs.edu.mk*

Case study

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Abstract: This paper investigates the performance of reactive and proactive routing protocols in a wireless sensor network for targeted enviroment. AODV and DSR are chosen as representatives for the reactive routing protocols and DSDV for the proactive. A wireless sensor network application for farm cattle monitoring is created. The proposed solution meets a desired requirement for periodically observing the condition of each individual animal, processing the gathered data and reporting it to the farmer. However, an implementation of a WSN needs to meet particular technical challenges before it can be suitable to be applied in cattle management. For this, multiple scenarios are presented with various situations to evaluate the performance of routing protocols in the WSNs. Finally, the results concerning data transportation from the mounted sensory devices to the mobile nodes are discussed and analyzed.

Key words: wireless sensor network, herd management, cattle health monitoring, routing protocol, cattle monitoring application, mobile nodes.

Introduction

A wireless sensor network (WSN) consists of a group of sensor nodes that use radio signals to communicate among them. They can send and forward packets to other nodes in the network, which means that they also act as routers in the network. There are usually a large number of nodes in a WSN. They can be distributed in arbitrary locations and can move independently in any direction. The nodes are responsible for the tracing of the other nodes in the network [2]. The routing protocols that are used in WSN have to be highly dynamic to be able to rapidly respond to the topology changes [13].

In this paper, a WSN-based solution for cattle health monitoring is investigated. Such a solution would provide a reliable monitoring system that would allow regular assessment of herd health data. A model for a WSN based health care system was developed. The main aim of the research was to establish a routing protocol that will provide the best performance for this targeted application. For this purpose three different ad-hoc routing protocols were evaluated: AODV (Ad-hoc On-Demand Distance Vector Routing) [11], DSDV (Destination-Sequenced Distance Vector) [12] and DSR (Dynamic Source Routing) [5]. Their functionality was assessed in terms of several performance metrics: Packet Delivery Ratio, End-To-End Delay, Normalized Routing Load, Total Routing Packets, Generated Packets, Received Packets, and Dropped Packets.

The study presented in this paper examines and compares the performance of ad-hoc routing protocols in a herd monitoring system using simulation as an instrument for investigation. Given the very high costs of conducting such a research in real setting, simulation is a more feasible method for initial implementation and evaluation. The models can be quickly developed, allowing complete access and control of their internals. The simulator of choice was ns-2 which is a discrete event simulator specifically designed for research of computer networks and network protocols [1].

This paper is organized as follows: Section 1 is the introduction to the field of research and the paper itself. Section 2 describes the ad-hoc routing protocols background with emphasis to the evaluated protocols. Section 3 describes the simulation environment. Section 4 contains the simulation results and discussion. Section 5 presents the conclusions.

Background

Routing in ad-hoc wireless networks is a task different from routing in wired networks. An ad-hoc network does not have a devoted router node so the ad-hoc routing protocol runs at each node in the network. A routing protocol that operates in an ad-hoc wireless network cannot rely on wired paths and has to deal with mobility, frequent disconnections, power source constraints, range limitation etc.

There is a large diversity of proposed ad-hoc routing protocols. In the early classifications they were generally categorized as proactive, reactive and hybrid. A recent extensive ad hoc routing protocols study [3] presents a classification with five more categories: location aware, multipath, hierarchical, multicast, geographical multicast and power-aware. However, the research in this study is performed with protocols belonging to the proactive and reactive categories, since they suffice the needs of this research.

Proactive protocols periodically propagate routing updates in order to maintain routing information from each node to every other node in the network. Routes are available at any moment. In contrast, reactive routing protocols find the path to a node only when there are packets to be sent. After a restricted period of time, those routes become invalid.

Ad-hoc On-Demand Distance Routing (AODV)

AODV belongs to the reactive protocols category. It uses routing tables to maintain route information. If there is a node seeking to send a data packet to a destination node and there is no established route to the destination node, a route discovery process is started [6]. During that process several kinds of messages are exchanged. A Route Request (RREQ) message is flooded to all the nodes in the network until the destination is found or a node with a valid route to the destination is found with a sequence number that is greater than or equal to the sequence number contained in the RREQ. Each node that forwards the RREQ creates a reverse route for itself back to the initial node.

When the destination receives the RREQ packet, it sends back a "Route Reply" (RREP) message through the established reverse path. As long as a route remains active it will be maintained. A route remains active as long as there are packets passing through it. After a period of idleness the route will time out and will be removed from the routing tables of the neighboring nodes. During route maintenance, if the node discovers that the route to the neighbor is not valid, it removes the routing entry and sends a "Route Error" (RERR) message to inform the active neighbors that use it. This procedure is repeated in all the active nodes that will receive the RERR message [9, 10]. A route is considered active if there are packets that periodically traverse the route.

Dynamic Source Routing (DSR)

DSR is categorized as a reactive routing protocol. It operates through route discovery and route maintenance stages. Route discovery is initiated when a route to a destination is needed and no known routes to that destination exist. A node that needs to send packets to a destination node broadcasts a RREQ packet to its neighbors. All the nodes that receive the RREQ packet do the following:

1. If the packet was already received, it is discarded;
2. If the address in the RREQ packet is equal to its own address, then the packet has reached its destination;

3. If 1) and 2) do not apply, the node adds its own address in the list of the visited nodes in the RREQ packet and broadcasts the modified RREQ packet.

The nodes maintain the routes by periodically sending packets through them. If a route becomes invalid, route discovery is initiated again [4].

Destination Sequenced Distance Vector (DSDV)

DSDV is a proactive routing protocol based on the Bellman-Ford algorithm. The main advantage of this protocol is that it provides route loop freedom which is not the case in the Bellman-Ford algorithm [2, 10]. DSDV is a table-driven protocol. Every node in the network maintains a routing table which contains all possible destinations with associated next hop and sequence numbers. The sequence numbers are used to mark the routes. A route with a larger sequence number is preferred to a route with a smaller sequence number. If two routes have equal sequence numbers, then the one with the smaller number of hops is preferred. If there is an error in a route, its number of hops is set to infinity and the sequence number is increased to an odd number, whereas even numbers are reserved for the connected routes. The routing table is maintained with a periodical exchange of messages between the nodes. A node that receives a message will update its routing table only if it had received a new or a better route. Routing updates are performed periodically to maintain route consistency. They can be performed through full dumps or by smaller, incremental updates. The property of constant sending of routing table updates creates additional network overhead and increases energy consumption which makes DSDV less appropriate for highly dynamic networks.

Simulation Environment

Finding ways to improve farming methods and enhance animal health care is becoming essential for the farming industry [7]. Utilizing a WSN cattle health monitoring system would greatly improve and facilitate the work at a cattle farm. By adding sensor nodes to each animal, the farmer would be able to monitor its health parameters without the need to approach it, and it would be able to roam freely in the open farm. The farmer can obtain different evidence about the animals: location, distance from the central stables, health parameters, hormonal statuses etc. Moreover, the system can interconnect the local veterinarians, who may receive information about the change in the health of the animals and react instantly if needed. Thus, a more immediate contact between a farmer and a veterinarian would be established.

In order to obtain information (data, statistics) for the performance of the routing protocols, a simulation model for ns-2 was built. Hence, the network parameters for the simulation in ns-2 are given in (Table 1).

Table 1. Network parameters for the simulation of a farm using ns-2

Parameter	Value
Routing protocols	AODV, DSDV and DSR
Traffic type	CBR
Transport type	UDP and TCP
Mobility model	Random Waypoint
Channel type	Channel / Wireless Channel
Radio propagation model	Propagation / TwoRayGround
Network interface type	Phy / WirelessPhy
MAC type	Mac/802_11
Type of interface queue	Queue / DropTail/ PriQueue
Data link type	LL
Antenna type	Antenna / OmniAntenna
Channel capacity	2 Mbps
Packet size	512 KB

In contrast to analytical data gathering, the simulation model will enable the possibilities to test different types of scenarios. These scenarios for the simulation model reflect the txypical habitual movement of the animals during their daily stay on a farm [7, 8]. The details and the guidelines for the simulation were defined and set as follows:

- The size of the area of the farm ranges from 1000 m² to 10 000 m²;
- Animal behavior is surveyed during 24 hours.
  - In the barn/stable:
    - 2 hours of additional feeding and milking of the cows;
    - The feeding and milking occurs twice within 24 hours, for example at 06:00 and 18:00;

- In the field:
  - 1 – 4 hours of slow movement for grazing with average speed of 1-2 meters in a minute;
  - 2 – 3 hours of resting and rumination.

During 24 hours:

1. an animal spends in average 40 – 70 minutes in stillness in the barn (this is repeated twice);
2. an animal moves every 1 – 4 hours in the field in an arbitrary direction and remains stationary for a period of 2 – 3 hours. This is repeated twice during a period of 24 hours;
3. data is collected every 2 hours.

The values given in 1. – 2. are averaged and used as limitations for the intervals where the random parameters in the simulations vary. The size of the simulation area is 2000 m². There are 50 equally spaced stationary sensor nodes that cover the area and one of them is used as a destination node. The number of mobile nodes is 15, 35 and 75 respectively in three different sets of simulations (Table 2).

Table 2. Area and Node parameters of the simulation

Parameter	Value
Farm area	2000 m × 2000 m
Number of stationary nodes	49
Number of destination nodes (barn)	1
Number of moving nodes	15, 35 and 75
Direction of node movement	random
Speed of node movement	1.5 m/min
Duration of node movement	2.5 hours
Duration of node's immobility	2.5 hours

The mobile nodes represent the cattle and mimic their movements according to the described scenario (Table 3). Because the pattern of the activities repeats in 12 hours and the cattle spends 1 of those hours in the farm and it is on standby, the duration of the simulations is set to 11 hours.

The main goal of the simulations was to evaluate the performance of different routing protocols for wireless mobile networks and find out which one will be the best suited for use in the application for herd monitoring. The choice was to test AODV, DSDV and DSR. Every 2 hours data is collected from every mobile node to the destination (Table 3). Regarding the possible synchronization of the nodes that may occur at that time, random delay to the packet sending was introduced and the performance of the routing protocols was examined in four different schemes, presented in Table 3.

Table 3. *Data sending parameters*

Parameter	Value
Simulation duration	39600 seconds (11 hours)
Time of packet sending	every 7200 seconds (2 hours)
Duration of packet sending	5 seconds
Packet sending schemes	1. All nodes send packets at the same time 2. Nodes send packets interchangeably, spaced with a random time in the interval from 0 to 10 seconds 3. Nodes send packets serially 4. Nodes send packets serially with a 5 second spacing between

All the tests were repeated 10 times with different random initial positions and different random movements of the mobile nodes. The analysis of the results is based on the averaged measured values obtained in the simulations.

Performance metrics

During the simulations, several metrics that reveal the routing protocol performance were observed:

- Total Number of Routing Packets (TNRP) – the total number of routing packets;
- Generated Packets (GP) – the total number of generated packets;
- Received Packets (RP) – the total number of received CBR packets;
- Total Dropped Packets (TDP) – the total number of dropped packets;
- Packet Delivery Ratio (PDR) – the ratio of total number of delivered packets versus the total number of sent packets. This ratio shows how successful the routing protocol is in data delivery and reflects its accuracy and reliability, where

$$PDR = \frac{Number\ of\ sent\ packets}{Number\ of\ delivered\ packets} \times 100 \qquad (1)$$

- Average End-To-End Delay (AEED) – the average time needed by the data packets to travel from the source to the destination. It contains the route discovery time and the delay caused by queuing in the intermediate nodes. Smaller value of AEED means a better routing protocol performance. It is calculated using the formula:

$$AEED = \frac{\sum_{i=1}^{N}(TimeDeliveredPacket_i - TimeSentPacket_i)}{Number\ of\ delivered\ packets} \quad (2)$$

where N is the total number of sent packets;

- Normalized Routing Load (NRL) – is the normalized load of the nodes with routing packets against data packets. It is calculated as a ratio of the total number of routing packets divided by the total number of data packets.

$$NRL = \frac{Number\ of\ routing\ packets}{Number\ of\ data\ packets} \quad (3)$$

A lower value of NRL denotes a better performance.

Results and Discussion

Scenario comparison

A set of simulations was performed for every single parameter setting (15, 35 or 75 mobile nodes, routing protocol AODV, DSDV and DSR, packet sending schemes 1 to 4). The tests were performed using TCP for packet transport, because the reliability of communication was chosen to be a key design factor for our system and TCP provides guaranteed delivery of packets. The simulations for each setting were repeated 10 times with different randomization seeds. The performance metrics were collected and studied. The results of the examination and the comparison of the results are discussed in terms of the routing protocols.

- AODV performs the best when the nodes send packets interchangeably spaced with a random time in the interval from 0 to 10 seconds for all given values of the number of the mobile nodes (15, 35, 75).
- DSDV gives the best results for 15 and 35 mobile nodes when scheme 2 for packet sending is used. For a network with 75 mobile nodes, the best outcomes are obtained when the nodes send packets consequently with 5 seconds spacing between them (i.e. scheme number 4 is used).
- The outcome of the tests performed with DSR was that it performed the best for a network with 15 mobile nodes if scheme 4 was used for packet sending. For networks with 35 and 75 nodes, scheme 2 was the most suited.

After this analysis was completed, the choice was made to execute all further experiments using scheme 2 for the packet sending order and collect all the performance metrics using this setting, because it gives the best overall outcome.

Comparison of performance metrics for AODV, DSDV and DSR

Total Number of Routing Packets

This parameter reflects the participation of the protocol in the overall communication overhead. It is proportionally related to the energy consumption and therefore should be kept as low as possible. Figure 1 represents the comparison of TNRP values for AODV, DSDV and DSR for networks with 15, 35 and 75 mobile nodes. For this metric, DSR shows the best results and DSDV shows the worst.

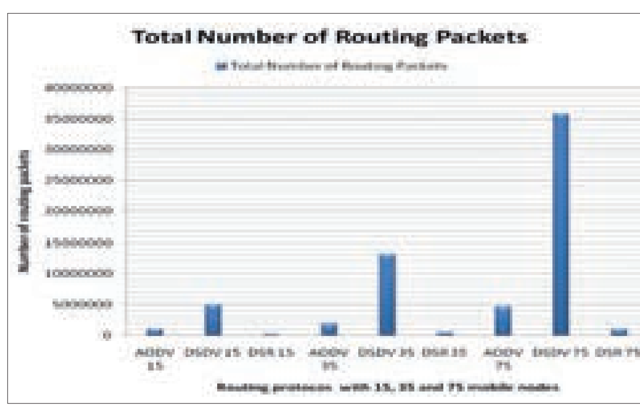

Figure 1. Comparison of TNRP for AODV, DSDV and DSR for 15, 35 and 75 nodes

Number of generated packets as opposed to the number of received packets

Figure 2 depicts a comparison of GP and RP values for AODV, DSDV and DSR for networks with

15, 35 and 75 nodes. It shows that AODV and DSR have similar performances, while DSDV has a much greater number of generated packets compared to the number of delivered packets.

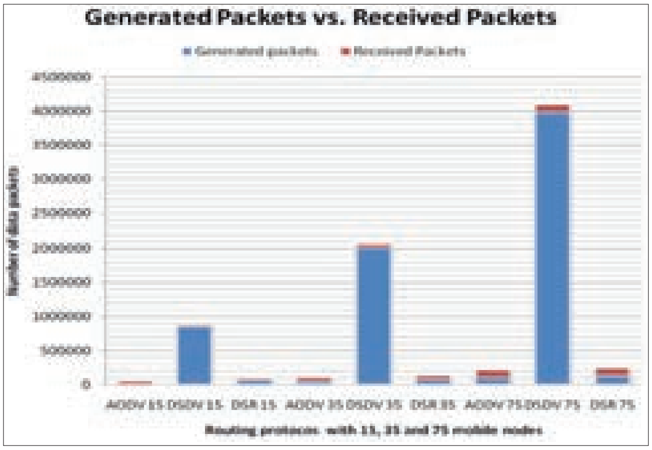

Figure 2. Comparison of GP versus RP for AODV, DSDV and DSR for 15, 35 and 75 nodes

Total Dropped Packets

The lowest value for TDP is obtained when DSR is used in the simulations, which is true in all cases with different numbers of nodes. Next comes DSDV and the last is AODV which has the biggest number of dropped packets. Figure 3 presents the TDP as a function of network size for the three protocols.

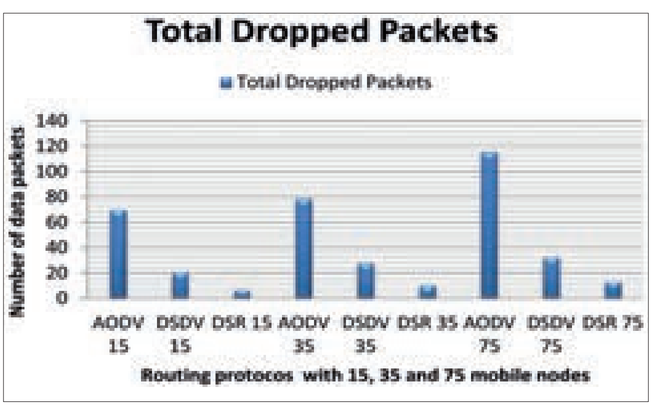

Figure 3. Comparison of TDP for AODV, DSDV and DSR for 15, 35 and 75 nodes

Packet Delivery Ratio

AODV has the highest average PDR in all cases and DSR gives results comparable to AODV. PDR for DSDV is far below PDR for the other two protocols. Figure 4 plots PDR against protocol and network size.

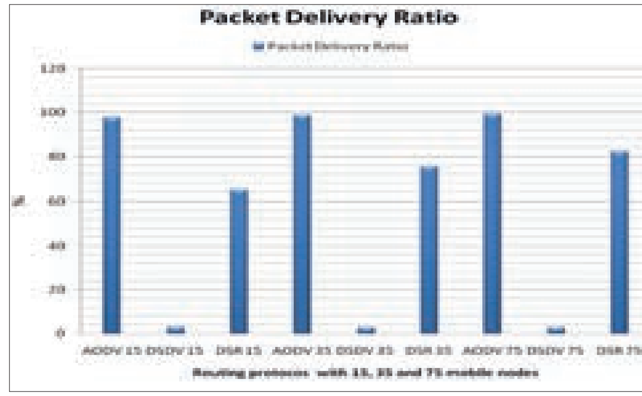

Figure 4. Comparison of PDR for AODV, DSDV and DSR for 15, 35 and 75 nodes

Average End-To-End Delay

In all cases in the simulations with networks with sizes 15, 35 and 75, mobile nodes DSDV and DSR have AEED higher than AEED for AODV. The difference is especially large in the case with 75 nodes. Furthermore, AEED for AODV tends to decrease with the increase of the network size. Hence, AODV shows superior performance compared to the other two protocols, which is presented in Figure 5.

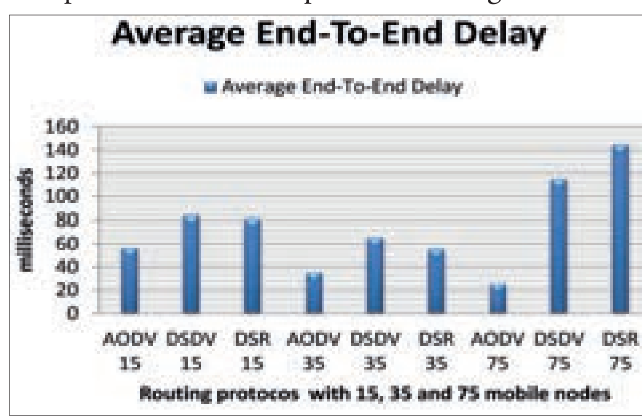

Figure 5. Comparison of AEED for AODV, DSDV and DSR for 15, 35 and 75 nodes

Normalized Routing Load

The larger the routing load is, the more the network is burdened with routing packets. This leads to greater energy consumption of the wireless nodes, which is an essential factor in a wireless sensor network. Wireless sensor nodes depend on a limited source of energy. For that reason it is very important for a routing protocol to have as small routing load as possible. In the simulations, the smallest value for NRL is obtained when DSR was used. AODV causes larger routing load than DSR. The case is similar with DSDV, but the difference is much greater. Figure 6 represents NRL plotted versus protocol and network size.

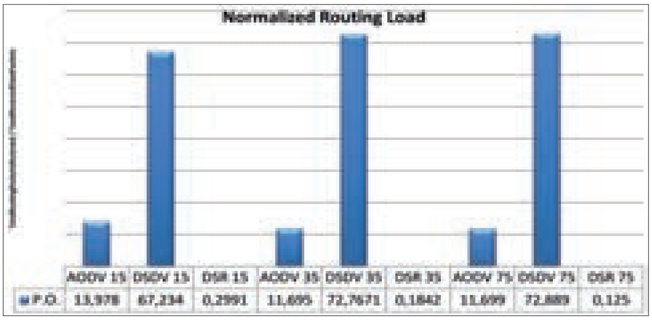

Figure 6. Comparison of NRL for AODV, DSDV and DSR for 15, 35 and 75 nodes

Conclusion

In this paper, a comparison of three routing protocols in a wireless sensor network for herd monitoring is presented. AODV and DSR were chosen as representatives of the reactive group and DSDV was chosen as a representative for the proactive group. The aim was to find which protocol is the most suitable for the targeted application. The results confirm the expectations based on the theoretical analysis: reactive routing protocols show superior performances to proactive protocols. The experimental results indicate that DSR has the smallest routing load and the smallest number of lost packets. AODV has slightly better packet delivery ratio and smaller average end-to-end delay. Since energy efficiency is a crucial parameter for wireless sensor networks, it can be concluded that DSR is the most appropriate choice for this environment.

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