A Performance Comparison of Energy Consumption for Mobile Ad Hoc Networks Routing Protocols

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Abstract-- The design of efficient routing protocols is a fundamental problem in a Mobile Ad-Hoc Network (MANET). Many different protocols have been proposed in the literature, each one based on different characteristics and properties. Some of these protocols have been studied and their performance have been evaluated in detail focussing on aspects like routing overhead, latency and route length. In this work we concentrated on the energy consumption issues of the routing protocols. We present a performance comparison of the DSR, AODV, TORA and DSDV routing protocols with respect to energy consumption, evaluating how the different approaches and algorithms affect the energy usage in the mobile devices.

Keywords—Ad-hoc networks; energy consumption, routing protocols

1. Introduction

The Mobile Ad-Hoc Networks (MANETs) are wireless networks where a collection of mobile nodes may dynamically vary the topological structure. With respect to the more widely used mobile cellular networks (e.g., CDPD or GSM), MANETs do not use any form of fixed infrastructure or centralised administration. These types of networks present the following salient characteristics: dynamic topologies, bandwidth-constrained variable-capacity links, limited physical security and energy-constrained operations [15].

Various dedicated routing protocols have been proposed to the Internet Engineering task Force (IETF) MANET Working Group [8]. Some of these protocols have been studied and their performances have been analized with details. J. Broch et al [2] evaluated four protocols using mobility and traffic scenarios similar to the ones we used. They focused on packet loss, routing message overhead and route length. In [10], P. Johansson et al, compare three routing protocols, over extensive scenarios, varying node mobility and traffic load. They focus on packet loss, routing overhead, throughput and delay, introducing mobility measures in terms of nodes relative speed. Finally, in [9] S. R. Das et al, compare the performance of two protocols, focussing on packet loss, packet end to end delay and routing load. They obtained simulation results consistent with previous works and conclude with some recommendations to improve protocols.

In our work we concentrate on the power consumption aspects of the routing protocols. The need for energy efficiency is a problem that derives from the constraints imposed by battery capacity and heat dissipation which are opposed by the desire for miniaturisation and portability. Battery technology and technologies for heat removal have traditionally improved at a slower pace compared with the increasing computation expected and the decresing size of wireless terminals. The way out is energy efficiency: doing more work per unit of battery energy consumed and heat dissipated. The key to energy efficiency in future wireless terminals will be at the higher levels: low-energy protocols, energy-cognisant user interfaces, context dependent, predictive shutdown management and changed terminal-network functional partitioning will be used to reduce computation done at the terminal[13]. The networked operation of a wireless terminal opens up additional techniques for increasing energy efficiency. One technique is to dynamically offloading computation from the local terminal to remote,

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energy-rich nodes (e.g., fixed servers). Another technique comes from making various network protocols, such as link, MAC routing and transport protocols, energy-aware so that they continually strive to provide the most energy-efficient transport of application bits while meeting the desired QoS. In essence, Joules per application level-bit ought to be the key performance metric for protocols used with wireless terminals [16].

In this work we measure and compare the energy consumption behaviour of four routing protocols; respectively the *Ad-hoc On Demand Distance Vector* (AODV) [5], the *Direct Source Routing* (DSR) [3], the *Temporally-Ordered Routing Algorithm* (TORA) [6] and the *Destination-Sequenced Distance-Vector Routing* (DSDV) [4]. These four protocols were selected so that a comparison with the results obtained in [2], [9] and [10] could be done. Our basic methodologies consisted of first selecting the most representative parameters for a MANET, then defining and simulating a basic scenario and finally, by varying the selected parameters, generate and evaluate a wide enough different scenarios. The five selected parameters were: 1) the mobile node number, 2) the moving area dimensions, 3) the node's mobility pattern, 4) the number of actual traffic sources and 5) the data traffic pattern.

The simulation results presented in this paper were obtained using the *ns-2* simulator [1]. *ns-2* is a discrete event, object oriented, simulator developed by the VINT project research group at the University of California at Berkeley. The simulator has been extended by the Monarch research group at Carnegie Mellon University [12] to include: nodes mobility, a realistic physical layer that includes a radio propagation model, radio network interfaces and the IEEE 802.11 Medium Access Control (MAC) protocol using the Distributed Coordination Function (DCF).

This paper is organised as follows. In Section 2 we give a brief description of the four routing protocols. Section 3 presents the details of the simulation tools and environments. Section 4 presents the methodology we followed to perform simulations whose results are described in Section 5. Finally, Section 6 presents our conclusions.

2. MANET Routing Protocols

In this section we briefly review the main concepts regarding the four protocols we analysed, respectively the DSDV, DSR, AODV and TORA. This area is anyway a very dynamic one, and many other proposals are being developed. Up-to-date information about the status of this area can be found in the WWW home page of the IETF MANET group [8]. The IETF MANET working group proposes two kinds of routing protocols: the *reactive* protocols and the *proactive* protocols. *The Ad-hoc On Demand Distance Vector* (AODV), the *Direct Source Routing* (DSR) and the *Temporally-Ordered Routing Algorithm* (TORA) are examples of reactive protocols. In these protocols route discovery procedures are invoked on demand when a source has a new connection pending toward a new destination. The route discovery procedure in general consists of the flooding of a query packet and the return of the route by the destination. The exhaustive flooding can be very expensive, thus creating delays in route establishment. Furthermore the route discovery via flooding does not guarantee to create optimal routes in terms of hops-distance. The *Destination-Sequenced Distance-Vector Routing* (DSDV) is an example of a proactive protocol. These protocols perform periodic updates with control packet and therefore generate an extra traffic that adds to the actual data traffic. The control traffic is broadcasted all over the network via optimised flooding. Optimised flooding is possible since nodes permanently monitor the topology of the network. Between these two typologies of protocols, there are also intermediate proposals that tries to adjust the degree of reactivity/proactivity behaviour, like in the *Zone Routing Protocol* (ZRP) by Haas and Pearlman [17].

A. The studied protocols

The *Destination–Sequenced Distance-Vector* routing protocol is a table-driven protocol requiring every node to periodically propagate routing information updates throughout the network. This protocol improves traditional distance vector protocols, by including loop-freedom in routing tables. In DSDV, each node maintains a routing table indexed by sequence numbers, listing for every reachable destination the next hop. The sequence numbers enable the mobile nodes to distinguish stale routes from new ones. To maintain table consistency, each node periodically transmits the routing table over the network.

In the *Dynamic Source Routing* each data packet to be transmitted carries the complete sequence of nodes by which the packets must pass to reach the target. This property is known as source routing, and requires the sender to know the complete route to the destination. The protocol is based on two basic processes: (a) the route discovery process and (b) the route maintenance process. The route discovery process is based on flooding and is used to dynamically discover new routes. The route maintenance process periodically detects and notifies networks topology changes.

The *Ad Hoc on Demand Distance Vector* routing protocol is a combination of the DSR and the DSDV protocols. This protocol uses the on-demand mechanism of route discovery and route maintenance from DSR and the hop-by-hop routing and sequence number from DSDV. While DSR uses node cache to maintain routing information, AODV uses traditional routing tables (one per destination) as DSDV. AODV also uses sequence number to prevent routing loops and to avoid stale routes. Another feature is the use of timestamps fields in routing table to manage expired entries in the routing table.

The *Temporally-Ordered Routing Algorithm* tries to minimise the overhead due to reaction to topological changes by confining routing messages to the "neighbourhood" near to the change. TORA uses a "height" metric over a previously defined acyclic graph to assign, in every node, a forward direction for packets to a given destination. TORA implements three main process: (a) on-demand route create process, (b) route maintenance process, and (c) erase route process. The erase route process tries to erase the invalid routes, and is initiated by a node that detects network partition. For route maintenance, TORA is implemented over the Internet MANET Encapsulation Protocol (IMEP) [7], which implements a reliable in-order control message routing delivery from a node to each of its neighbours, by periodically sending a *BEACON-HELLO* message sequence between the transmitter and the receivers. This protocol dependency will affect the efficiency of this protocol.

3. Simulation Environment

The simulation results presented in this paper were obtained using the *ns-2* simulator [1]. *ns-2* is a discrete event, object oriented, simulator developed by the VINT project research group at the University of California at Berkeley. The simulator has been extended by the Monarch research group at Carnegie Mellon University [12] to include: nodes mobility, a realistic physical layer that includes a radio propagation model, radio network interfaces and the IEEE 802.11 Medium Access Control (MAC) protocol using the Distributed Coordination Function (DCF).

The radio network interface card (NIC) model is based on the *WaveLan* interface from Lucent. The model includes collisions, propagation delay and signal attenuation with a 2Mbps data rate and a radio range of 250 meters.

The *ns-2* environment includes full implementation of the following MANET routing protocols: DSR, AODV, DSDV and TORA. These protocols are still under improvement and the different research groups offers periodically new improved versions of them that can be inserted automatically into the *ns-2* simulation environment.

A. Energy Consumption Model

According to the specification of the NIC modelled, the energy consumption varies from 230mA in receiving mode to 330mA in transmitting mode, using a 3.3V or 5.0V energy supply. In this work we have are assuming an energy supply of 5V. These values correspond to a 2,400MHz *WaveLAN* implementation of IEEE 802.11.

When a node sends or receives a packet, the network interface of the node, decrements the available energy according to the following parameters: (a) the specific NIC characteristics, (b) the size of the packets and (c) the used bandwidth. The following equations represent the energy used (in Joules) when a packet is transmitted (Eqn. 1) or received (Eqn. 2); packet size is represented in bits:

$Energy_{tx} = (330*5*PacketSize)/2*10^6$ (1) $Energy_{rx} = (230*5*PacketSize)/2*10^6$ (2)

Although actual equipment consume energy not only when sending and receiving but also while listening, we assume in our model that the listen operation is energy free, since all the evaluated ad hoc routing protocols will have similar energy consumption due to the node idle time.

Finally, note that when a packet is transmitted, a percentage of the consumed energy represents the Radio Frequency (RF) energy. This energy is used for the propagation model in *ns-2* to determine the energy with which the neighbours' interface nodes will receive the packet, and consequently determine the successful or wrong packet reception. In our simulation we maintain this RF values in 281.8 mW, which corresponds to the RF energy required to model a radio range of 250 meters.

4. Methodology

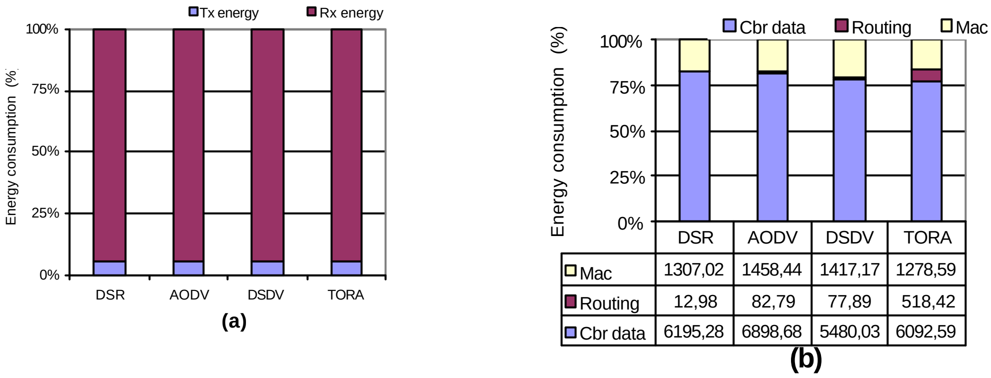
The overall goal of this work was to measure and compare the energy consumption behaviour of the four analysed routing protocols. Our basic methodology consisted of first selecting the most representative parameters for a MANET, then defining and simulating a basic scenario and finally, by varying the selected parameters, simulate and evaluate more scenarios.

The five selected parameters were: 1) the mobile nodes number, 2) the moving area dimensions, 3) the node's mobility pattern, 4) the number of actual traffic sources and 5) the data traffic pattern. In the simulation, nodes move according to a model called "random waypoint" [3]. Motion is characterised by two factors: (a) the maximum speed and (b) the pause time. During simulation each node starts moving from its initial position to a random target point, selected inside the simulation area. The motion speed value is uniformly distributed between 0 and the maximum speed. When a node reaches the target point, waits for the pause time and after that, by selecting another random target point, it moves again. According to this scheme, a pause time value equal to the simulation time corresponds to a static network, while a 0 seconds pause time corresponds to a continuously changing network. All the traffic sources used in our simulations generated constant bit rate (CBR) data traffic. The traffic structure was defined by varying two factors: (a) the sending rate and (b) the packets size.

As the basic scenario we considered a MANET with 25 mobile nodes spread randomly over an area of 500m x 500m. Nodes were moving with a maximum speed of 15 meters/sec with pause time of 0 seconds. A total of 20 traffic sources generated CBR data traffic with a sending rate of 4 packets/sec, using a packet size of 512 bytes.

Each simulation had the duration of 900 simulated seconds. Because the performance of the simulations is highly related with the mobility models, the results shown in the following sections represents an average of three different executions of the simulation using the same traffic models but with different randomly generated mobility scenarios.

We evaluate the following performance indexes. (a) Total energy consumed (in Joules), (b) energy consumed depending on the operation (transmissions (Tx) and receptions (Rx)), and (c) energy consumed depending on the packet type (MAC, CBR and routing).



	DSR	AODV	DSDV	TORA
Mac	1307,02	1458,44	1417,17	1278,59
Routing	12,98	82,79	77,89	518,42
Cbr data	6195,28	6898,68	5480,03	6092,59

Figure 1. Percentage of energy consumed (a) per Tx and Rx operation and (b) per packet type (CBR, MAC and routing)

5. Simulations results

In this section we compare the energy consumption for the four routing algorithms first over the basic scenario, and then over a wide variety of scenarios and traffic models resulting varying one of the five selected parameters.

A. The basic scenario

Figure 1 (a) shows the total energy percentage relation of transmitting and receiving measured at the MAC level. The total energy consumption is highly due to the receiving process. Receiving process includes two types of activities: receiving actual data and receiving neighbour's data (*overhearing*). Overhearing process highly depends on the radio range, thus, novelty protocols based on dynamically varying this radio could impact on the total amount of energy consumed. Figure 1 (b) depicts the total energy percentage relation as a function of packet's types (the table below shows the relative amount of energy measured in Joules). The energy due to MAC protocol packets affects significantly the total consumed energy.

In terms of energy consumption only due to routing protocol packets, the DSR performs better than AODV and DSDV. DSR performs better than AODV although DSR uses source routing, and AODV hop-by-hop routing (having DSR longer header packets). It is probably due to promiscuous overhearing and caching mechanisms used in DSR to reduce the discovery routes overhead. TORA high-energy consumption is mainly due to the aggregation of IMEP discovery routes packets and TORA maintenance packets.

B. Varying motion pattern

In this section, we explore the effect of varying motion patterns over the basic scenario. We run simulations varying the pause times from 0, 30, 120, 600 and 900 simulated seconds obtaining a range of scenarios that span from continuos motion nodes (0 pause time, as in the basic scenario) to static ones (900 pause time). Figure 2, highlights the energy consumed by routing protocols. DSR offers the best performance while TORA shows the worst results. Typically on-demand protocols (DSR, AODV, TORA) present an energy descendent trend as the motion rate drops, the table-driven protocol (DSDV) presents an energy consumption that remains practically constant as motion rate varies.

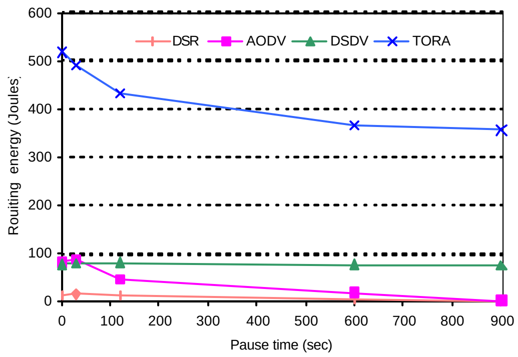


Figure 2. Routing energy consumption comparison for the four routing protocols as a function of pause time.

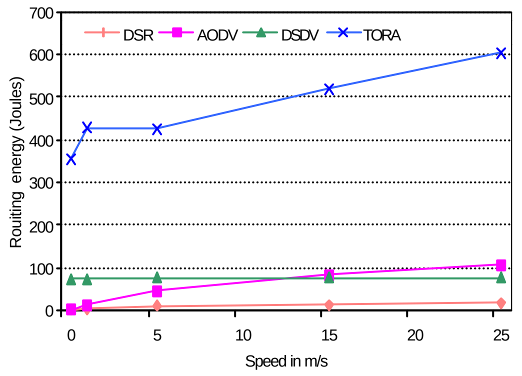


Figure 3. Routing energy consumption comparison for the four routing protocols as a function of maximum node speed.

Inside the on-demand routing protocols, TORA presents the worst index, basically because of the aggregation of IMEP and TORA packets. As the scenarios converge to a static network, DSR and AODV present a similar behaviour. However, in scenarios with constant node motion (i.e., low pause time values) or high node speed they start behaving differently. With these mobility patterns the DSR caching mechanism and promiscuous node techniques, imply less overhead due to route discovery packets propagation than in AODV [2].

Figure 3 shows the results when varying the maximum node speed among values 0, 1, 5, 15 and 25 m/s. These values have been selected to simulate the following scenarios. (a) A static network, (b) a MANET of humans walking, (c) a cyclists MANET community (d) A MANET of urban cars and finally (e) a road cars MANET. These results confirm the constant behaviour of DSDV even for high motion patterns. The energy consumption of the three on-demand protocols increases as the maximum motion speed grows. As the motion speed moves from a humans walking MANET scenario to a road cars MANET, the difference between DSR and AODV grows of a factor of 3, to a factor of 5. Finally, when speed grows DSDV performs better than AODV.

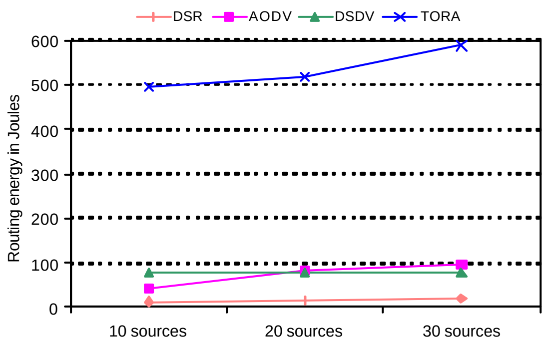
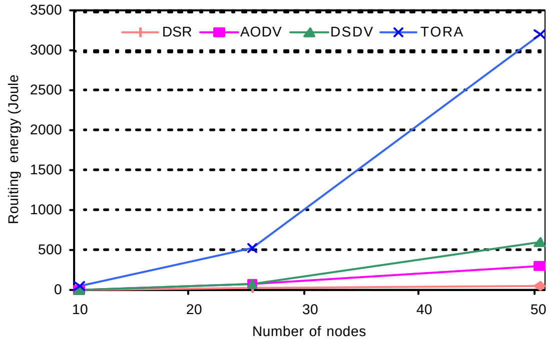


Figure 4. Routing energy consumption comparison for the four routing protocols as a function of traffic sources.

C. Varying traffic patterns

Figure 4 shows the behaviour of the four protocols when varying the number of sources between 10, 20 and 30. Again, energy consumption in DSDV is quite stable regardless of the used traffic load. By contrast, on-demand protocols such as DSR, DSDV and TORA, although increasing the number of sources produces an increment of routing packets, the consumed energy follows a slower shape compared with the sources increment.



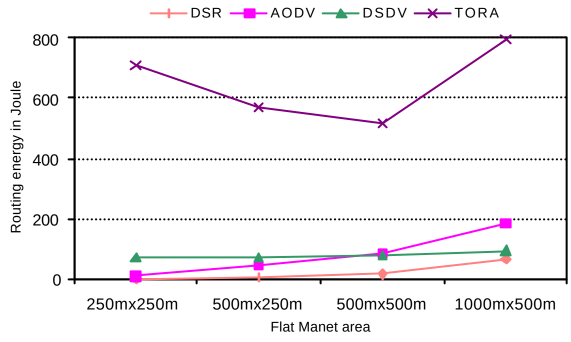


Figure 5. Routing energy consumption comparison for the four routing protocols as a function of node number.

Figure 6. Routing energy consumption comparison for the four routing protocols as a function of the MANET area size.

When traffic sources vary from 10 to 20, the routing energy increases 7,31% in DSR, 88,97% in AODV and 4,71% with TORA. While moving from 20 to 30 sources the routing energy increases 41,73% in DSR, 15,88% in AODV and 13,37% with TORA. This behaviour is mainly due because the on-demand routing protocols allow nodes to learn new route information from packets previously sent.

D. Varying node number

Figure 5 shows the simulation results when varying the number of nodes while maintaining the traffic load. We have selected MANET communities of 10, 25 (basic scenario) and 50 nodes.

The TORA behaviour highly depends on this factor. When passing from 25 to 50 nodes, the protocol suffers an increment of 518%. This characteristic makes this protocol not scalable. With respect to the DSR and AODV, the energy increment for a MANET of 50 nodes with respect to a MANET of 25 nodes is quite similar and is about 220%. This increment is mainly due to route maintenance process; with DSDV, the increment is mainly due to the propagation of route table between nodes.

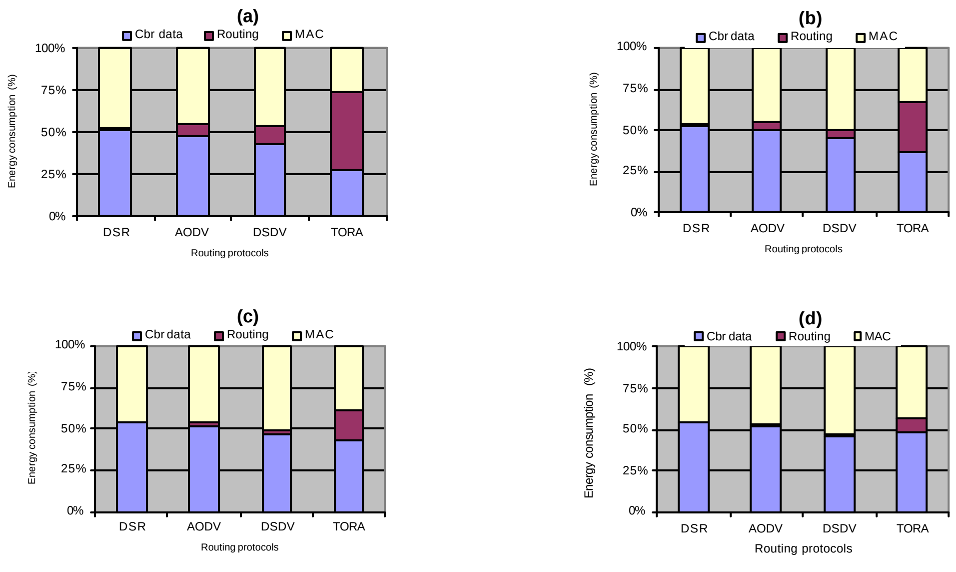


Figure 7. Percentage energy consumption per packet type (CBR, MAC and routing) comparison for the four routing protocols for sending rate of 1(a), 2(b), 4(c) and 8(d) packets/sec.

E. Varying area shape

Figure 6 shows the results of varying the area shape The selected areas were: 250m×250m, 250m×500m, 500m×500m and 1000m×500m. Incrementing the area, the DSR and the AODV protocols increase their routing energy consumption faster than table driven protocols such as DSDV. In the case that MANET area shape allows long routes (e.g., 1000m×500m) table-driven DSDV performs better than on-demand AODV. For a 1000m×500m scenario TORA, again present the worst results with respect to the other routing protocols.

F. Evaluating data sending pattern

When reducing the CBR data packet size from 512 bytes to 64 bytes, we are reducing the relation among the energy due to routing packets with respect to the energy due to CBR data packets. This kind of scenarios can be found in emergent large-scale networks of wireless devices in which mobile sensors periodically interchange small-size packets [11]. Figure 7 shows the energy consumed classified by packet type (CBR, routing and MAC), for the four protocols with data packet sending rate of 1, 2, 4 and 8 packets/sec.

Figure 8 shows the effect of increasing the sending rate. This effect is analogous to the effect of increasing the number of source. All protocols present quite a steady behaviour, the DSDV protocol thanks to its table driven scheme, while on-demand protocols thanks to their property of learning route information from previous packets.

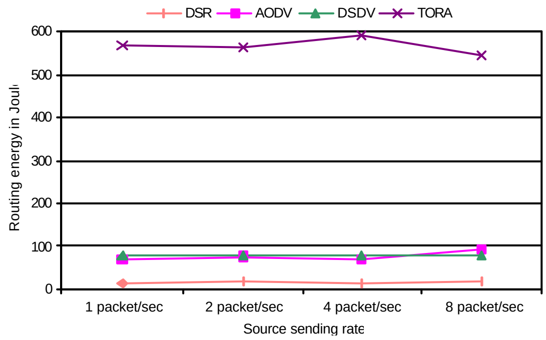


Figure 8. Routing energy consumption comparison for the four routing protocols as a function of the MANET sources sending rate.

G. Relation with Previous Work

To the knowledge of the authors, three are the most recent MANET performance evaluation related to our work using the same ns-2 simulation environment.

In [2], J. Broch et al, members of the CMU monarch group and original authors of the simulation models, evaluated the same four algorithms over similar mobility and traffic scenarios we have used. In [2] they focus on (a) packet loss, (b) routing message overhead and (c) route length, showing all results as a function of pause time. As in our study, TORA presents the worst performance indexes. Despite its quite stable behaviour, DSDV has packet loss problems as node mobility increases. Referred to DSR and DSDV, although DSR seems to perform better, the authors remark the trade off between packets overhead and byte overhead between these two protocols. In [10], P. Johansson et al, compare DSDV, DSR and AODV over extensive scenarios, varying node mobility and traffic load. They focus on (a) packet loss (b) routing overhead (c) throughput and (d) delay, introducing mobility measures in terms of relative speeds of nodes instead than absolute one. The obtained results show how DSR performs better for lower loads while AODV is more effective for higher loads. Note that the DSR model used did not use promiscuous node function. In [9] S. R. Das et al, compare the performance of DSR and AODV, focussing on (a) packet loss, (b) packet end to end delay and (c) routing load. They obtained simulation results consistent with previous works and conclude with recommendations to improve new developed protocols. These main suggestions include (i) take into account congestion metrics in order to calculate new routes, (ii) use time to live fields into the network packets, and (iii) The importance of interactions between network layers when designing new protocols. Finally, others papers [18] have evaluated the DSR and AODV using simulation environment rather different obtaining results similar to the previous ones.

6. Conclusions

We presented the results of measuring and comparing the energy consumption behaviour of four routing protocols; respectively the *Ad-hoc On Demand Distance Vector* (AODV), the *Direct Source Routing* (DSR) and the *Temporally-Ordered Routing Algorithm* (TORA) and *Destination-Sequenced Distance-Vector Routing* (DSDV). We selected the most representative parameters for a MANET, we then defined and simulated a basic scenario and finally, by varying the selected parameters, generated and simulated more scenarios.

The results obtained from the simulations allow us to conclude the following as far as energy consumption refers. Generally pure on-demand protocols such as DSR and AODV perform better than DSDV, and clearly better than TORA. For all scenarios explored, TORA has the worst performance index. Besides, increasing the number of nodes while maintaining the number of traffic sources makes TORA not scalable, increasing the energy consumption by a 518% while nodes move from 25 to 50. DSDV offers a quite constant behaviour for all tested scenarios, mainly due to his table-driven philosophy. The DSR normally performs better than AODV except in static networks in which they show a similar behaviour.

Comparing AODV and DSDV, there are several scenarios in which AODV perform worse than DSDV, typically when longer routes are allowed. Finally, referred to DSR and AODV, note that by combining (a) byte packet overhead (greater in DSR) and (b) number of routing packets (greater in AODV) outcome in a general energy consumption favourable to DSR in all simulated execution. So, byte overhead in DSR due to source routing headers is not significant.

As a global conclusion we could also state that current generation link-level protocols may need some tuning to minimise the power cost of network interface. As we saw, the cost of sending packets can be significant to the cost of being idle, but application- and transport-level considerations can make the idle cost the dominant cost. Any protocol that leaves a mobile receiver idle unnecessarily wastes power.

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References

[1] K: Fall and K. Varadhan, (Eds.) "ns Notes and Documents", The VINT Project. UC Berkeley, LBL, USC/ISI, and Xerox PARC, February 25, 2000. Available from http://www.isi.edu/~salehi/ns_doc/.

[2] J. Broch, D. A. Maltz, D. B. Johnson, Y-C. Hu, and J. Jetcheva. "A performance comparison of multi-hop wireless ad hoc networks." In *Proceedings of the 4th Int. Conference on Mobile Computing and Networking (ACM MOBICOM'98)*, pp. 85-97, October 1998.

[3] D. B. Johnson, D. A. Maltz, and J. Broch. "The Dynamic Source Routing Protocol for Mobile Ad Hoc Networks," Internet Draft, MANET Working Group, draft-ietf-manet-dsr-03.txt, November 1999.

[4] C. E. Perkins and P. Bhagwat, "Highly Dynamic Destination-Sequenced Distance-Vector Routing (DSDV) for Mobile Computers," Computer Communication, October. 1994, pp. 234-244.

[5] C. Perkins and E. Royer, "Ad Hoc On-Demand Distance Vector (AODV) Routing," Internet Draft, MANET Working Group, draft-ietf-manet-aodv-05.txt, March 2000.

[6] V. Park and M. Corson. "Temporally-Ordered Routing Algorithm (TORA) Version 1 - Functional Specification," Internet Draft, MANET Working Group, draft-ietf-manet-tora-spec-02.txt, October 1999.

[7] M. S. Corson, S. Papademetriou, P. Papadopoulos, V. D. Park, and A. Qayyum, "An Internet MANET Encapsulation Protocol (IMEP) Specification," Internet Draft, draft-ietf-manet-imep-spec-01.txt, August 1998. Work in progress.

[8] Internet Engineering Task Force MANET Working Group Charter. http://www.ietf.org/html.charters/manet-charter.html.

[9] S. R. Das, C. E. Perkins, and E. M. Royer, "Performance Comparison of Two on-demand Routing Protocols for Ad Hoc Networks," In *Proceedings of the IEEE Infocom*, March 2000.

[10] P. Johansson, T. Larsson, N. Hedman, B. Mielczarek, and M. Degermark, "Scenario-based performance analysis of routing protocols for mobile ad-hoc networks," In *Proceedings of the ACM/IEEE International Conference on Mobile Computing and networking*, pp: 195-206, August, 1999.

[11] J. M. Kahn, R. H. Kutz, and K. S. J. Pister, "Mobile Networking for Smart Dust," In *Proceedings of the ACM/IEEE International Conference on Mobile Computing and networking*, August, 1999.

[12] The CMU Monarch Project. The CMU Monarch Project's Wireless and Mobility Enhancements to ns. http://www.monarch.cs.cmu.edu. Work in progress.

[13] P. Lettieri, M.B. Srivastava, "Advances in Wireless terminals", IEEE Personal Communications, February 1999.

[14] S-J. Lee, M. Gerla and C-K Toh, "A simulation study of table-driven and on-demand routing protocols for mobile ad hoc networks", IEEE Network, July/August 19999.

[15] S. Corson and J. Macker, "Mobile Ad hoc Networking (MANET): Routing Protocol Performance Issues and Evaluation Considerations", RFC 2501, January 1999.

[16] M. Stemm and R. Katz, "Measuring and Reducing Energy Consumption of Network Interfaces in Hand-held devices", IEICE Transactions on Communications, Special Issue on Mobile Computing, Invited paper, E80-B(8): pp1125-1131, August 1997

[17] Z. J. Haas and M. R. Pearlman, "The Zone Routing Protocol (ZRP) for Ad Hoc Networks," Internet Draft, MANET Working Group, draft-ietf-manet-zone-zrp-03.txt, March 2000.

[18] S. R. Das, R. Castaneda, J. Yan and R. Sengupta, "Comparative Performance Evaluation of Routing Protocols for Mobile Ad Hoc Networks," In *7th International Conference on Computer Communications and Networks (IC3N)*, pp:153-161, October 1998.