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Energy Consumption Analysis of Routing Protocols in Mobile Ad Hoc Networks

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1. Introduction

Wireless networks are divided into two types: cellular [Swaroop et al, 2009] and mobile [Fapojuwo et al, 2004]. Cellular networks have been comprised of a fixed spinal column and radio base station so that the last hop that the user uses is wireless in form; however, many things are dependent on space and time [Dixit et al, 2005]. Figure 1 shows an example of cellular networks.

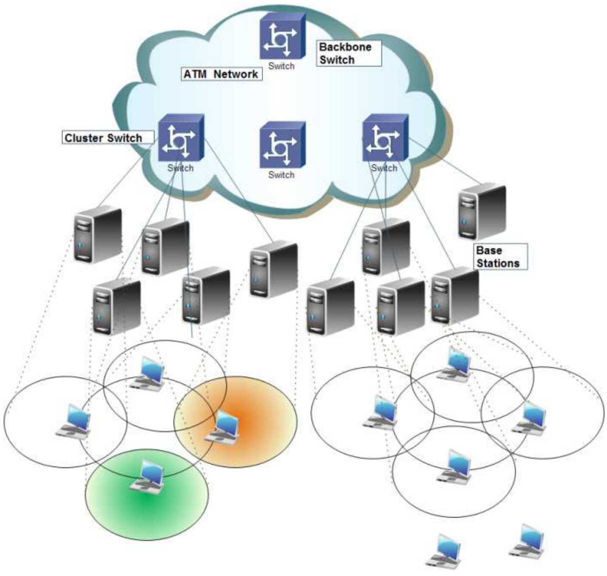


Fig. 1. An example of cellular networks

1.2 Basis of mobile ad hoc networks

A MANET is one that does not have any base station and fixed substructure that can freely and dynamically self-organize into temporary network topologies. An ad hoc mobile network is an unstable network formed dynamically by a collection of wireless mobile nodes without the use of an existing network substructure [Chlamtac et al, 2003]. Such networks back up calculations at any time and in any place, and their structures can change automatically [Norouzi. A and Ustundag B. B, 2011]. In such networks, each mobile host acts as a router. For this reason, peer-to-peer communication as well as peer-to-remote communication is possible in this kind of network [Camp et al, 2002].

Fig. 2. An example of a Mobile Ad hoc Network (MANET)

Figure 2 shows an example of a MANET. This type of network has been comprised of different kinds of mobile devices such as PDAs, smart signals and mobile hosts. In MANETs, routing is a complex problem and the reason for this is mobility of routes. However, links may change frequently and this subject refers to the fact that communication links should be updated continually and their messages should be sent frequently; hence this control creates traffic [Perkins E, 2008].

There are special devices in different forms, but one of their common specifications is that they use battery energy, and this energy is limited. Wireless transmission, collision, resubmission and conductive radio waves are all effective in energy consumption. As a result, there is strong need for the presence of protocols which use energy efficiently and effectively as well as technology for better management of energy [Norouzi. A and Ustundag B. B, 2011].

2. Related work

In the energy consumption and performance evaluation of protocols for an ad hoc network, the protocols should be tested under realistic conditions. This chapter is a research in which mobile ad hoc networks are described and some routing protocols explained. During simulation, different results were given by changing the selected parameters. Firstly we have a technical look at these types of protocols and their specifications [Jayakumar. G and Gopinath. G, 2007].

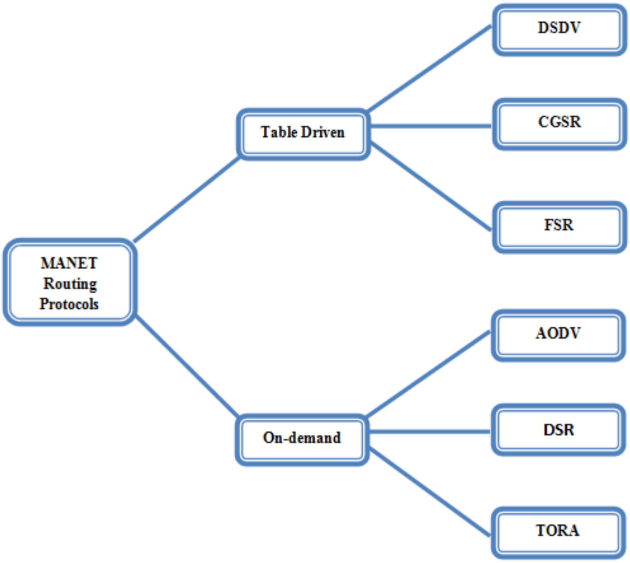


Fig. 3. Categorization of MANET routing protocols

2.1 Mobile ad hoc network routing protocols

As shown in Figure 3, routing protocols in mobile ad hoc networks are classified into two classes: table-driven and on-demand [Misra S et al, 2008]. The table-driven d, or proactive, method is used for alternate updating links and can use both the distance vectors and link statuses used in fixed networks. The word "proactive" means that this method is always active and will also react to a change in the linkage [Norouzi. A and Ustundag B. B, 2011]. A problem arises for this method when movement is low because additional work is done and the network tends toward instability [Bai F et al, 2004].

In the on-demand method with reactions, other nodes do not update the route and the routes are determined at the origin of the request. Therefore, there is the possibility of using a caching mechanism. The advantage of this method is that both energy and bandwidth are used effectively. In this chapter, the table-driven and the on-demand protocols are explained and then compared with different parameters [Dixit et al, 2005].

2.2 Table-driven protocols

In this group of protocols, each node maintains one or more tables that include routing information to other nodes of the network. All nodes update their tables to preserve compatibility and to give upgraded viewpoints of the network. When the topology of the network changes, the nodes distribute update messages across the network [Misra S et al, 2008]. Some identifying aspects of this class of routing protocols include the ways in which information is distributed, the ways the topology is changed and the number of tables necessary for routing. The following sections explain some of these routing protocols [Boukerche. A et al, 2011].

2.2.1 DSDV (Dynamic Destination-Sequence Distance – Vector routing protocol)

This protocol is based on the BELLMANFORD routing idea, with a series of improvements [Bagad V. S and Dhotre, 2009]. Each mobile base maintains a routing table that includes all accessible destinations, the number of hops necessary for reaching that destination and the sequence of the digits appropriate to that destination. This sequence of digits is used to distinguish new routes from old routes and to determine the creation of a ring. In DSDV, stations send their routing tables alternatively to their direct neighbors [Maan. F and Mazhar. N., 2011]. Tables are updated generally in two perfect updating and incremental updating methods. Any route updating package increases information about routing. This protocol performs periodic updates, but also generates a supplementary traffic that adds to the real data traffic. [Bamis. A et al, 2007].

2.2.2 CGSR Protocol (Cluster head Gateway Switch Routing protocol)

This protocol is based on the DSDV routing algorithm. Mobile nodes are collected inside packets, and a cluster head is selected. A gateway node is a node in a communication interval between two or more cluster heads. In a dynamic network, the idea of a cluster head can decrease the efficiency resulting from the frequency of selecting cluster heads. Thus, CGSR uses an algorithm to change the last cluster or LCC. [Murthy S and Aceves J. J, 1996].

In LCC, a change in cluster head is made when changes are made in the network. In this state, the origin sends the packet to its cluster head; the cluster head sends this packet to the gateway node to which it and the node which is located in the route of destination are connected. The gateway sends the packet to another cluster head and this action continues until the cluster head receives the destination node of packet. Finally, the destination cluster head sends the packet to the destination node [Boukerche. A et al, 2011]. Figure 4 indicates an example of a CGSR routing plan.

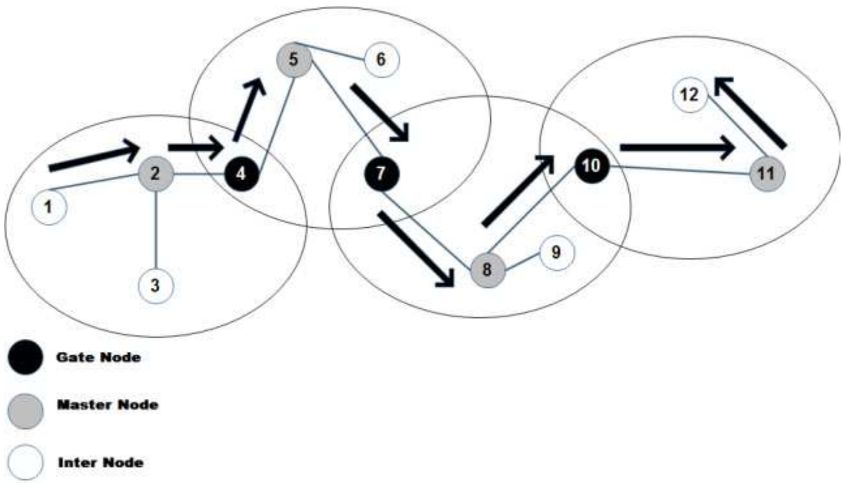


Fig. 4. Example of CGSR routing from node 1 to node 12

2.2.3 FSR protocol (Fisheye State Routing)

In an FSR, an updating message does not include information about all of the nodes. Instead, it exchanges information with the adjacent nodes with a higher frequency more than it does with farther nodes, leading to a decrease in the size of the updating message [Pei. G et al, 2000]. Thus, each node has accurate information about its neighbours, and the details and accuracy of the information decrease when the distance between two nodes increases. Figure 5 defines the area of a fisheye for a central node that has been indicated in red [Boukerche. A et al, 2011].

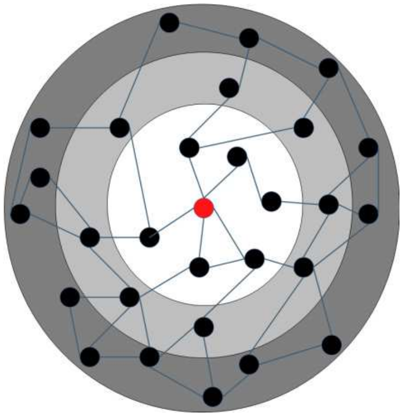


Fig. 5. Accuracy of information in FSR protocol

The central node should know more detail about the nodes that are located inside the white circle. FSR is suitable for massive networks, because in this method, overload is controlled [Liu. Y et al, 2004].

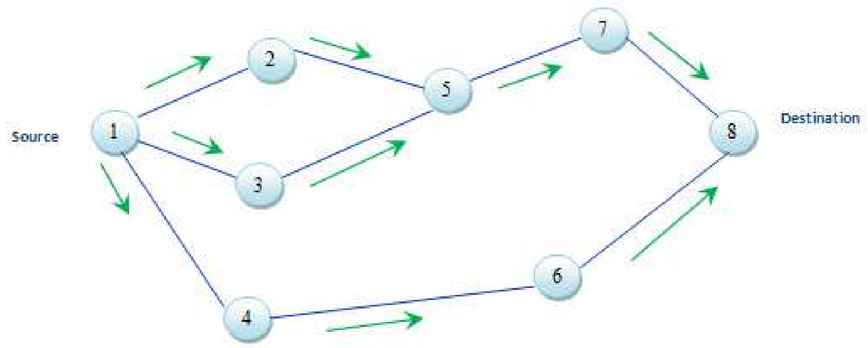
2.3 On-demand protocols

In comparison with table-driven routing protocols, all updated routes are not maintained in each node in this group of protocols; instead, routes are constructed only when it is necessary. When an origin node wants to send something to a destination, it makes a request to the destination for the route detection mechanisms. For this reason, this type of protocol is known as a reactive protocol. This route remains valid until the destination is accessible. This section explains some of the on-demand routing protocols [Boukerche. A et al, 2011].

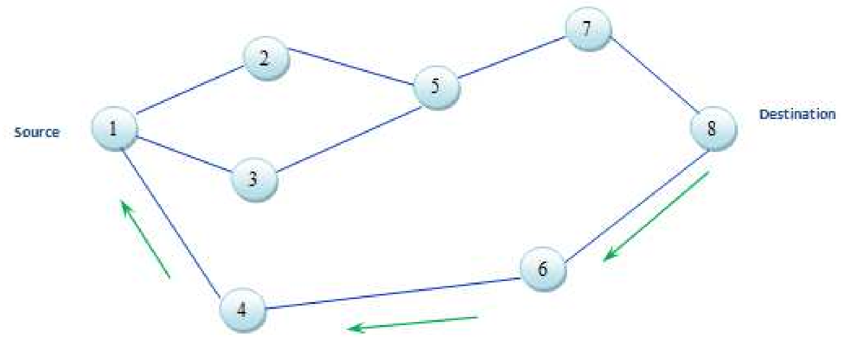
2.3.1 AODV (Ad-Hoc On-demand Distance Vector routing)

This protocol can be regarded as an improvement of DSDV. AODV minimises the number of distributions by creating routes on-demand [Esmaili. H et al, 2011]. In contrast, DSDV maintained a list of all routes to find a route to the destination whenever the origin broadcasts a route request packet to all nodes. The neighbours distribute the packets among their neighbours until the packet reaches an intermediate node with a new route to the destination [Song J. H et al, 2004].

Figure 6 (a) indicates a distribution packet among neighbors. If a node saw the packet previously, it will discard it and will not pay attention to it. Route demand packet uses sequence numbers in order to ensure that a ring is not formed in the route [Bai F et al, 2004]. This mechanism also guarantees that if intermediate nodes reply to this request, it will be based on their latest information. AODV uses only symmetric and two-sided links because routing the reply packet is achieved by simply reversing the packet route. Figure 2. 3 (b) shows the process of reply to demand [Bamis. A et al, 2008].



(a)Distribution packet among neighbors



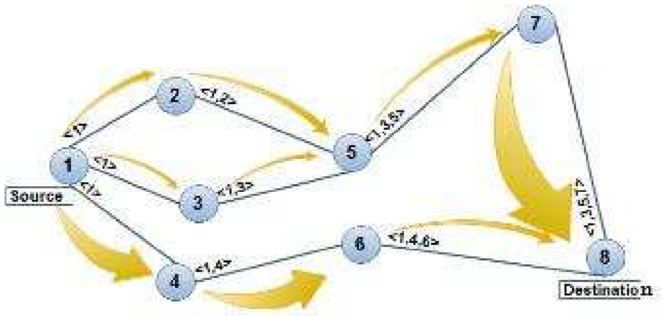
(b) Reply to demand

Fig. 6. Detection of route in AODV

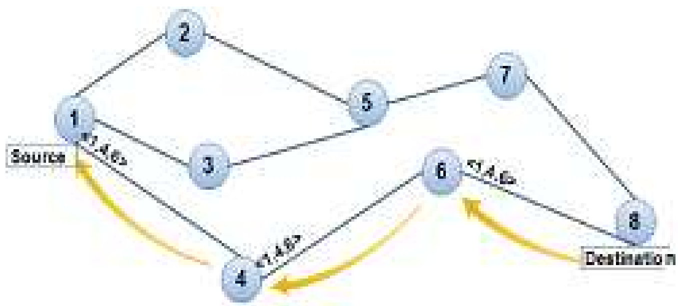
2.3.2 DSR (Dynamic Source Routing protocol)

The Dynamic Source Routing protocol (DSR) is a simple and efficient routing protocol designed specifically for use in multi-hop wireless ad hoc networks of mobile nodes. DSR allows the network to be completely self-organising and self-configuring, without the need for any existing network infrastructure or administration. The protocol is composed of two main mechanisms - "route discovery" and "route maintenance" - that work together to allow nodes to discover and maintain routes to arbitrary destinations in the ad hoc network [Suresh A. et al, 2011].

Figure 7 (a) shows how the route demand packet is distributed in the network and indicates its route record section [Perkins E, 2008]. If the destination node produces a reply on each route, this node places the route record section of the route demand packet in the route reply [Suresh A et al 2011]. In another state, if an intermediate node wants to produce a route reply, it will place its cached route to the destination in the route record section of the route demand packet. Figure 7 (b) indicates the state in which the destination node itself has sent a route reply [Qun Z. A et al 2011].



(a)Distribution of demand packets



(b)Reply packets

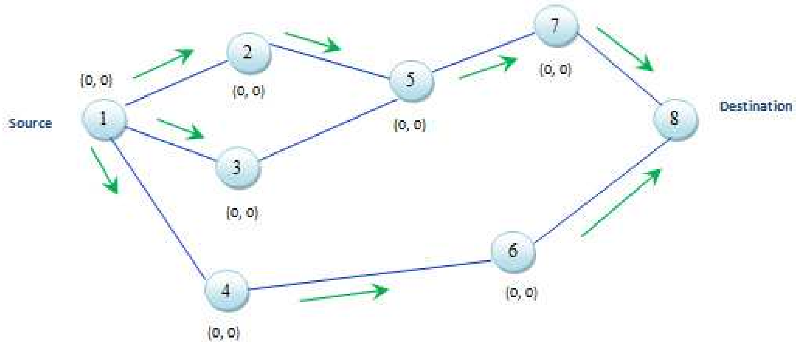
Fig. 7. An instance of route detection in DSR

2.3.3 TORA protocol (Temporally-Ordered Routing Algorithm)

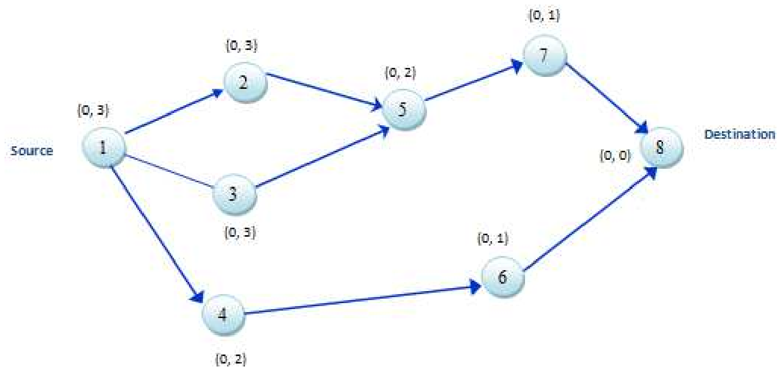
The main characteristic of TORA is the centralization of control messages in a very small set of near local nodes in which topological changes have been made. To achieve this property, nodes maintain routing information for the adjacent nodes for some interval. This protocol has three duties: route formation, route renovation and route cleaning. Route formation is performed with QRY* and UPD† [Park. V et al 2001]. A route formation algorithm starts by determining a zero set for height of destination node and empty set for height of other nodes.

*Query protocol
†User Datagram Protocol

The origin distributes a QRY packet in which destination node identifier is located. In this method, a non-circular graph is created from origin to destination. Figure 8 indicates a process of route formation in TORA. As shown in Figure 8 (a), node 5 receives the QRY packet from node 3 but it doesn't publish it because this packet has reached this node through node 2 previously. In Figure 8 (b), the origin, i. e. , node 1 can receive the UPD packet from node 2 or node 3 but it doesn't receive it from node 4 of which the height is lower.



a)Broadcast QRY



b) Distribute UDP packet

Fig. 8. Detection of route in TORA

2.3.4 CBRP (Cluster based Routing Protocols)

In these protocols, clusters are formed by dividing the whole network into self-managed groups of nodes. These groups are dynamically rearranged when the topology of the network is changed. To form these clusters, the following algorithm is used. When a node enters the network, it enters an indefinite state. In this state, it adjusts a timer and distributes a Hello message for all other nodes. When a cluster head receives this Hello message, it replies with a Hello message immediately. When the unknown node receives this message, it changes its state to member. If the indefinite node does not receive a reply after the defined time, it introduces itself as a cluster head in the case that it has a two-sided conductive linkage with a node or nodes that are its neighbours. Otherwise, it remains in the indefinite state and repeats the procedure [Jiang M et al 1999].

3. Simulation and comparison

Since energy consumption during communication is a major energy depletion parameter, the number of transmissions must be reduced as much as possible to achieve extended battery life. As a result, there is a strong need for the presence of protocols which use energy efficiently and effectively as well as technology for better management of energy. Unfortunately, battery technology doesn't grow as rapidly as CPU or memory does [Akkaya. K et al 2005]. In this section we would like to analyse comprehensively the results of the simulation for mobile ad hoc routing protocols in some aspects and different scenarios of energy consumption such as movement model, traffic model, data-sending model, environment and amount of nodes. To compare the protocols [Qasim. N et al 2009], a simulation of a MANET is required to be performed in a Network Simulator [Qun Z. A et al 2011] environment. The simulation includes motion models, a physical layer with a radio broadcast, radio network communications and the IEEE 802. 11 (MAC) protocol [Chowdhury et al 2010] with a distributed coordination equation or DCE. This model includes collisions, broadcast delays and signal damping with a bandwidth of 2 Mbps and a transmission range of 250 m. There are some protocols that have been selected for comparison, such as DSR, AODV, DSDV, TORA, FSR, CBRP and CGSR. The first four protocols have been completely simulated by NS2 [26], and the code of other protocols has been added to NS2. [Stemm. M and Katz. R 1997].

The basic model parameters that have been used in the following experiments are summarised in Table 1.

Parameter	*Value*
Simulator	NS-2
Protocols studied	DSR, AODV, DSDV, TORA, FSR, CBRP and CGSR
Simulation time	900 sec
Simulation area	500 x 500
Transmission range	250 m
Node movement	Random waypoint
Traffic type	CBR (UDP)
Data payload	Bytes/packet
Bandwidth	2 Mbps

Table 1. Simulation parameters

3.1 Energy consumption model

The following equations show the energy consumed in the transfer of a packet (equation 1) and receipt of a packet (equation 2), in which packet size is based on bits:

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

$$Energy_{rx}=(230*5*PacketSize)/2*10^6 \quad (2)$$

Energy consumption in actual equipment occurs not only during sending and receiving data but also during the hearing process; however, in this simulation, it has been assumed that hearing needs no energy and that the nodes have no energy consumption at any idle time. In fact, energy consumption has been considered only at times of packet sending and receiving.

An important point considered in this simulation is that when a packet is sent, a percentage of the consumed energy is the energy of the radio frequency. In this simulation, the value of RF has been maintained at 281. 1 mw, which is equivalent to the RF energy needed for a model with a 250 metre transmission range.

3.2 Work methodology

The final aim of this work is to measure and compare the energy consumption in seven DSR, AODV, DSDV, TORA, FSR, CBRP and CGSR protocols.

The five parameters selected for this simulation are as follows:

- Number of moving nodes
- Size of nodes movement zone
- Nodes movement model
- Traffic of origin nodes
- Data traffic model

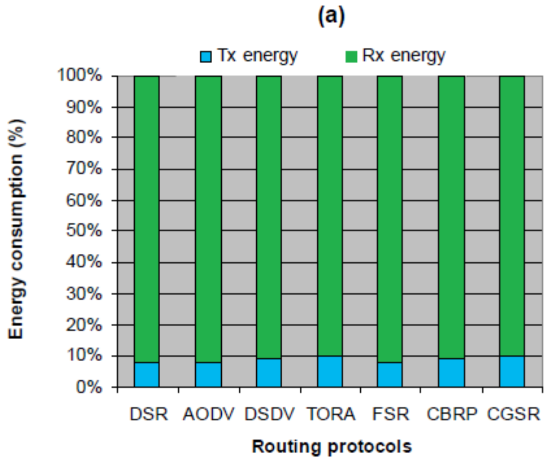
In this simulation, nodes move according to the RWP‡ Model, and this movement is specified with two factors: maximum speed and stop time. The Random Waypoint (RWP) model is a commonly used synthetic model for mobility, e. g. , in ad hoc networks. It is an elementary model which describes the movement pattern of independent nodes by simple terms. During simulation, each node starts moving from its primary position to a random target point inside the simulation area, and the movement speed of each node is an unsteady value between zero and its maximum speed. When a node reaches its target point, it waits for its stop time and starts moving by selecting another random target point. All traffic origins used in the simulation produce a fixed data traffic rate CBR (continuous bit-rate). The traffic structure changes with two factors: the rate of sending and the packet size.

In a basic scenario, a MANET has been considered with 25 moving nodes distributed randomly in an environment with an area of 500×500 m². Nodes move with a maximum speed of 500 m/s and have a stop time of 0 seconds. Twenty traffic origins produce CBR data traffic sending four packets per second and with a packet size of 512 bites. Each simulation has been performed for 900 seconds. In this simulation, working indices of total energy consumption, energy consumption based on the sending operation (TX) and receiving (RX) and energy consumption based on the type of packets (MAC, CBR and routing) have been assessed.

‡Random Waypoint

3.3 Results of simulation

In this section, seven selected routing protocols are compared with the basic scenario and with different scenarios by changing five selected parameters. Figure 9 (a) shows the total percentage of energy consumed in the sending and receiving operations at the MAC level. It is observed that energy consumption is higher during the receiving process. The receiving process includes two kinds of activity: actual receipt of data and overhearing data from neighbourhood nodes. Figure 9 (b) shows the percentage of energy consumed based on all kinds of packets. It is observed that MAC packets have a major effect on energy consumption.



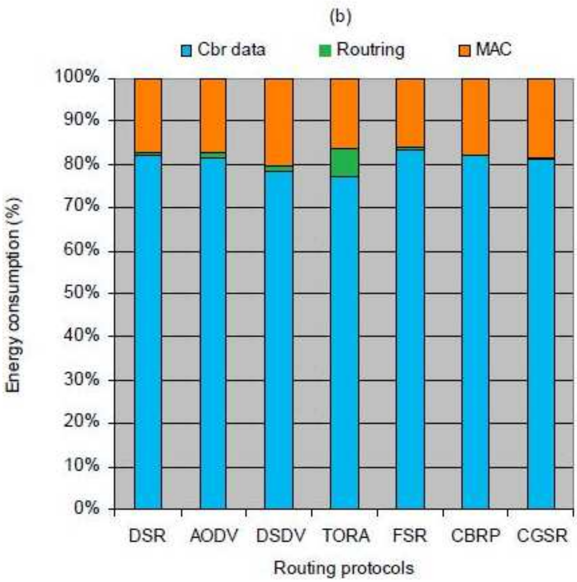


Fig. 9. Energy consumption for (a) RX and TX operations, (b) for different kinds of MAC, CBR and routing packets

These comparisons show that the efficiency of DSR is better than that of AODV and DSDV. Although DSR uses origin routing and AODV uses hop-to-hop routing, it is seen that DSR is more efficient than AODV. This result may come about from the caching mechanism. It can help to save energy, time, and bandwidth. FSR falls between DSR and AODV protocols. CBRP and CGSR have shown higher energy consumption than DSR. TORA has the highest energy consumption due to the assembly of route detection packets and packet maintenance [Tuteja. A et al 2010].

3.4 Results obtained from movement model changes

In this section, a movement model is presented in the basic scenario changes, and the simulation is implemented for stop times of 30, 120, 600 and 900 s. These implementations provide an interval between discrete simulation (no stop time) and static simulation (stop time of 900).

Figure 10 shows energy consumption with seven protocols. DSR shows the best result and TORA shows the worst result. For on-demand protocols, i. e., TORA, AODV, DSR and CBRP, we see considerable changes in energy consumption in the change in movement model [Cano. J. C et al 2000]; however, the energy consumption of table-driven protocols is not related to the movement model and keeps its state, in contrast to on-demand protocols [Sargolzaey. H et al 2009]. In this simulation, TORA shows the worst result due to its assembly of IMEP[§] and TORA packets [Prakash. Sh et al 2011]. According to this scenario, it is observed that DSR and AODV have shown relatively similar behaviour in static networks, but when the movement of nodes is stable (low stop time), their behaviour will be different. In this movement model, DSR (using a caching mechanism as well as irregular nodes technique) and AODV (due to having low parasite during sending route detection packets) could have shown the best result [Gupta. A. K et al 2010].

Figure 11 shows results obtained by varying the maximum speed of nodes between 0, 1, 15 and 25 m/s. These values have been considered, respectively, as simulating a fixed network, a network for pedestrians, a network for cyclists, a network for drivers and a network for train travellers. The obtained results show fixed behaviour of DSDV even in movement with high speed but energy consumption has increased for four on-demand protocols with regard to increase in maximum speed of movement. Generally, when speed is added, DSDV is better than AODV [Liu. Y et al 2004].

3.5 Results obtained from traffic model changes

Figure 12 shows the behaviour of seven protocols when the number of origin nodes varies between 10, 20 and 30. In this case, energy consumption in DSDV is fixed without regard to traffic load, and in four on-demand protocols, i. e., CBRP, DSR, DSDV and TORA, changes in energy consumption are made more slowly than traffic changes.

When the number of origins changes from 10 to 20, routing energy increases to 7. 31% in DSR, 88. 97% in AODV and 4. 71% in TORA. During traffic increase from 20 to 30, this routing increases to 41. 73%, 15. 88% and 13. 37% for DSR, AODV and TORA, respectively.

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§ IMEP

The main reason for this behaviour is that in on-demand routing protocols, nodes use the previous packets for receiving new route information and when traffic increases, so too does the activity of nodes [Sargolzaey. H et al 2009].

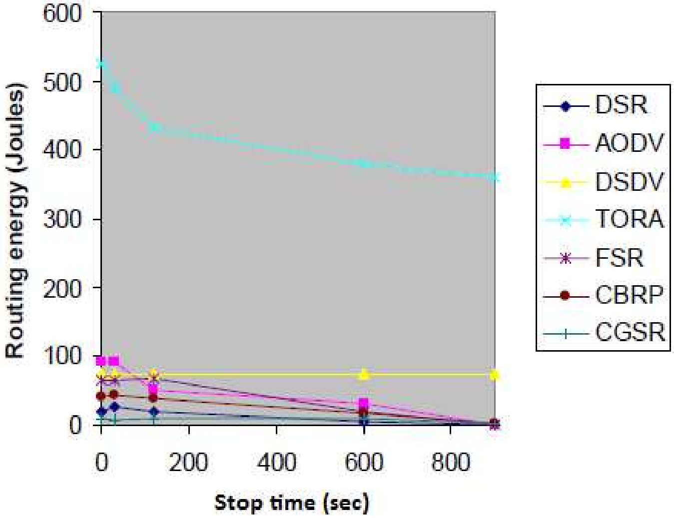

Fig. 10. Energy consumption as a function of stop time for seven protocols

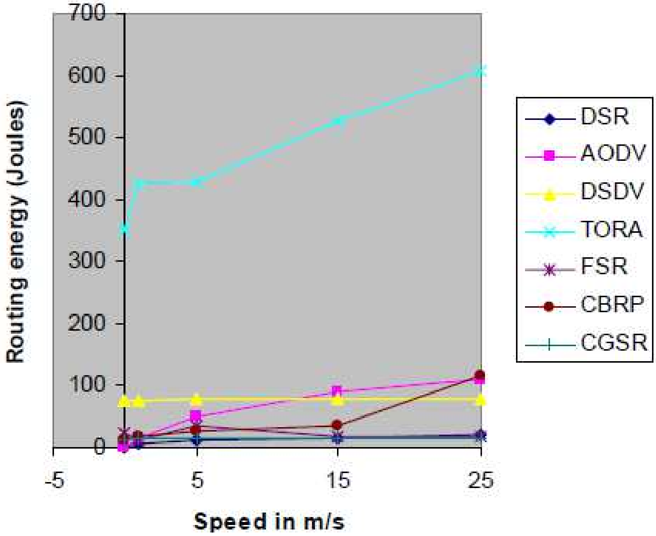

Fig. 11. Energy consumption as a function of maximum speed for seven protocols

4. Experimental results and analysis

We can summarise our final conclusion from our experimental results as follows:

Increasing the number of nodes with constant origin makes TORA unstable, and its energy consumption increases by 518% when the number of nodes increases from 25 to 50. DSDV has shown fixed behaviour in all scenarios due to its table driven specification. DSR has acted better than AODV and CBRP in similar situations, and FSR has mostly had values between those of DSR and AODV. CGSR has had no constant behaviour and sometimes performs better than DSR, although sometimes worse. However, its overall performance is similar to that of DSR.

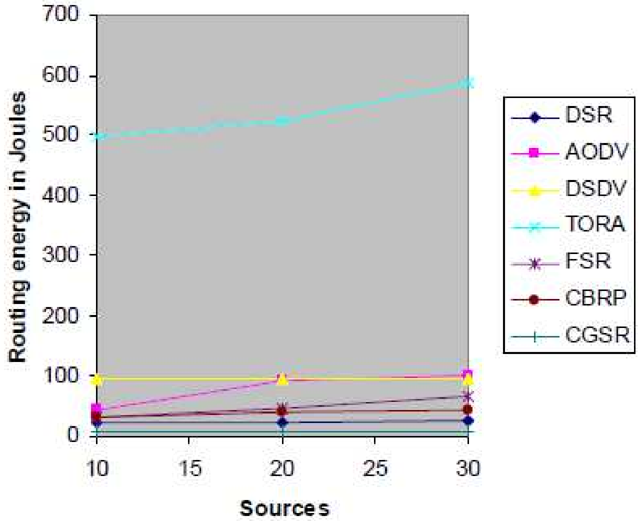

Fig. 12. Energy consumption as a function of origin traffic for seven protocols

5. Conclusion

In this article, Mobile Ad Hoc networks are described, and some of the most important routing protocols are studied. The results obtained from the assessment and comparisons of the energy consumption were shown for DSR, AODV, DSDV, TORA, FSR, CBRP and CGSR protocols. Parameters were considered for a mobile Ad Hoc networks, as well as a basic state. Different results were given by changing the selected parameters. Based on these results, the DSR and AODV protocols have shown better performance than other protocols, and for all scenarios, TORA has had the worst result. DSDV has fixed behavior in all scenarios due to its table driven specification.

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