Mobility Impact on Energy Conservation of Ad Hoc Routing Protocols

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***Abstract*—Providing routing mechanism is a fundamental issue in ad hoc networks. In recent years, many routing protocols have been proposed and a variety of performance studies have been done. However, it has been shown that the performance of an ad hoc routing protocol is highly dependent on the mobility model used. Most of previous work used only Random Waypoint mobility model, which is unrealistic in many situations. Moreover, mobile nodes are often power constrained so that energy conservation is also an important issue on evaluating protocols. No simulation studies have been done for energy conservation based on different mobility models. Most of them focused on metrics such as packet delivery ratio, delay, and route optimality. In this paper, an energy-based performance comparison of well-known routing protocols AODV, DSR, TORA, and DSDV is presented. These protocols are simulated and compared under three different mobility models: Random Waypoint, RPGM, and Manhattan Grid and various scenarios. We show significant energy conservation performance difference among mobility models in this paper.**

***Index Terms*—ad hoc networks, energy conservation, and mobility model.**

I. INTRODUCTION

AD HOC networks are self-organizing networks composed of independent mobile nodes. There is no pre-established hierarchical infrastructure for communication between mobile nodes inside the network. All mobile nodes act as routers and route packets for each other. Providing routing mechanism in mobile ad hoc networks (MANET) has been an active research area for several years. Many routing protocols have been proposed [1]-[5] and evaluated [6] [7] over the past few years. Most of previous studies evaluate them by their performance of route selection and bandwidth usage. The metrics used are packet delivery ratio, delay, throughput, and route optimality [6] [7].

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Energy conservation is also an important issue in MANET because mobile nodes are often battery powered and can not function without enough power level. As devices are being designed to be smaller (cell phones, PDAs, digital cameras), communication energy cost becomes a more significant portion of the total power consumed. In situations such as emergency rescue, military actions, and scientific field missions, energy conservation plays an even more important role which is critical to the success of the tasks performed by the network. Therefore, energy conservation should be considered carefully when designing or evaluating ad hoc routing protocols.

In reality, the performance of mobile ad hoc networks will depend on many factors such as node mobility model, traffic pattern, network topology, radio interference, obstacle positions, and so on. It is difficult to cover all these factors in simulation study of ad hoc routing protocols. For simplicity, most of early simulation work used only one mobility model, Random Waypoint [6] [8], to evaluate ad hoc routing protocols. This model is widely used in most simulation studies. However, it has been shown that mobility pattern plays an important role in performance of ad hoc routing protocols. The same protocol can perform very differently in different mobility patterns [9] [10]. Random Waypoint represents typical random node movement pattern but could be unrealistic in many real situations. A few different mobility models have been developed to model different ad hoc network environments other than entirely random movements. Reference Point Group Mobility Model (RPGM) [11] is used to describe scenarios where users move in groups. It is very useful to model events such as conference, art gallery exhibition, tourist groups, searching rescue mission and military actions. Manhattan Grid [12] is another model for describing user movement in downtown area where street topology is grid-like, as in Manhattan of New York City. Very few simulation studies have been done regarding different mobility models and none of them has addressed the energy performance of ad hoc routing protocols in different mobility patterns.

In this paper we present a performance study of four ad hoc routing protocols in different mobility models, focusing on their energy conservation performance. Experiments are performed through simulations. The purpose is to identify the challenges different mobility models impose on energy conservation in ad hoc networks. The protocols studied include Dynamic Source Routing (DSR) [1] [8], Ad Hoc On Demand Distance Vector Routing (AODV) [2], Destination Sequenced Distance Vector Routing (DSDV) [3], and Temporally Ordered Routing Algorithm (TORA) [4]. The mobility models used are Random Waypoint [8], Reference Point Group Mobility Model (RPGM) [11] and Manhattan Grid [12]. The results confirm that the energy consumption of ad hoc routing protocols varies significantly with node mobility pattern. It is also shown that node speed and network traffic considerably influence the network performance.

The remainder of this paper is organized as follows. Section II describes some previous work related to this topic. Section III explains the mobility models used in simulation in detail. Section IV provides an overview of routing protocols evaluated. Section V describes the simulation environment and the energy model used to calculate simulation results. Section VI presents the results and Section VII gives overall conclusions derived from the simulation results. The future research direction is described in Section VIII.

II. Related Work

A. Comparison of Ad hoc routing protocols

Broch et al. [6] compared the four ad hoc routing protocols (DSR, AODV, DSDV, and TORA) in terms of packet delivery ratio, routing overhead, and path optimality. They created wireless mobile support for ns-2[13] simulation environment and implemented the four routing protocols. This work provides detailed performance analysis on ad hoc routing protocols but energy performance was not addressed and only Random Waypoint mobility model was used. Another classical performance comparison was done by Johansson et al. [7] In this work, AODV, DSDV, and DSR are compared in both random and realistic scenarios. Three carefully designed mobility scenarios are used for realistic cases: conference, event coverage, and disaster area. The performance metrics used are delay, throughput, routing overhead and average hop count. A new mobility metric are defined for characterizing node mobility by relative speeds rather than absolute speeds.

B. Mobility models

Random Waypoint is the most widely used mobility model used in evaluation of ad hoc routing protocols. It was first used by Johnson and Maltz [6] in the performance evaluation of DSR. Afterwards, it is widely used to represent mobility of nodes in mobile ad hoc networks. However, an analysis by Yoon et al. [14] has indicated that the Random Waypoint model may produce unreliable results in simulations because the average node speed decreases over time and tend to be close to minimum speed. Besides, it is also unrealistic to model many user scenarios using Random Waypoint model.

To model realistic motion patterns of mobile users, Hong et al. [11] proposed the group mobility model Reference Point Group Mobility (RPGM) which describes nodes moving in groups. They also showed the ranking of routing protocols is influenced by mobility model used.

Camp et al. [9] provide a comprehensive survey of mobility models used in simulating ad hoc networks. Mobility models are divided into two categories: entity mobility model and group mobility model. Entity mobility model specifies individual node movement. Group mobility model describes group movement as well as individual node movement inside groups. Seven entity mobility models and four group mobility models are presented. Most of the group mobility models can be implemented by RPGM model. Random Waypoint and Manhattan Grid (similar to City section mobility model) are characterized to be entity mobility model. RPGM is group mobility model. Performance of DSR running over different mobility models is also studied.

Waal and Gerharz developed BonnMotion [15], a software package used to generate many standard mobility patterns. It is capable of producing Random Waypoint, RPGM, Manhattan Grid, and Gauss Markov mobility patterns which can be fed into different network simulators such as ns-2 and GloMoSim [16]. Tan et al. [10] defined another mobility generation framework based on individually simulated behavioral model. Analysis of DSR performance in different mobility scenarios generated by this framework is shown. Shah et al. also created a software package CAD-HOC [17] which can be used to generate realistic mobility scenarios using visualized user interface. Three realistic scenarios (Highway, Airport Terminal, and Conference) generated by CAD-HOC are used to compare performance of AODV, DSR, and DSDV. Again, only bandwidth related performance was evaluated.

C. Energy consumption model of 802.11 NIC

In calculating power consumed by the network during simulation, we need an energy consumption model for the wireless network devices. Feeney has proposed a linear energy consumption model [18] for performance analysis of MANET routing protocols. Physical measuring experiments [18] [19] are done to obtain the parameters of 802.11 network interface cards. In this paper, we use the model and value of constants in [18] to calculate the energy cost of the network.

D. Energy Performance of MANET routing protocols

Cano and Manzoni [20] also use ns-2 to compare the energy consumption of DSR, AODV, TORA, and DSDV. They test the routing protocols by changing different parameters of simulation environment. Although similar to this work, they used only Random Waypoint mobility model and a simpler energy consumption model.

III. Mobility Models

In this section, we describe the mobility models used in the simulations.

A. Random Waypoint

In Random Waypoint mobility model, parameters to be specified are pause time, minimum speed and maximum speed. Each mobile node starts from a randomly chosen position and stay for the length of pause time. When pause time expires, a destination and moving speed are randomly picked. The speed is uniformly chosen between specified maximum and minimum speed. Then the mobile node will move towards the destination with the chosen speed. Once it reaches the destination, the process of pausing, choosing destination and speed starts over again.

B. Reference Point Group Mobility Model

In RPGM model, mobile nodes are divided into groups at the beginning of the simulation. Each group has a logical center. The motion of the logical center defines the group motion. Each individual node has one reference point moving with group motion. The motion of each node is determined by two vectors: group motion vector and individual motion vector with respect to its reference point. The net motion vector of each node is the sum of the two vectors. The group motion is defined by specifying check points. Group center must follow and pass these check points. There are different ways to create various moving scenarios by changing the pattern of check points. In this work, group motion patterns are generated by Random Waypoint model. Every time the group reaches its destination, all nodes inside the group pause for a certain time and then restart the moving process. Please refer to [11] for details about creating different group movement patterns.

C. Manhattan Grid

Manhattan Grid is proposed to model a city section with streets crossing each other perpendicularly. Therefore, nodes on the streets move only vertically or horizontally on the map. Each mobile node starts from a random point on certain street. The node then chooses a random destination and moves towards this destination within a predefined speed range. Upon reaching the destination, the node pauses for certain time and then repeat the process again.

IV. Summary of Ad Hoc Routing Protocols

Ad hoc routing protocols can be characterized into two categories: proactive and reactive (on-demand) [5]. Among the tested protocols in this work, only DSDV is proactive and the other three (DSR, AODV, TORA) are all reactive. Proactive protocols update route information periodically, while reactive ones establish routes only when needed. Following is a summary of routing protocols evaluated in this paper.

A. Destination-Sequenced Distance Vector Routing (DSDV)

DSDV is an improved version of traditional Distance Vector routing algorithms. It prevents routing loops by adding a sequence number to every destination entry in the routing table. The table therefore contains the information of destination, next hop, distance to the destination, and the sequence number associated with the destination. Each node periodically broadcasts its routing table to its neighbors. After receiving updates from neighbor nodes, each node updates its routing table by comparing sequence number of each entry. If the received information is found to be more recent, it replaces the old entry with the newly received one. Data traffic are routed according to the (destination, next hop) pair in the routing table.

B. Ad hoc On-demand Distance Vector Routing (AODV)

AODV is an on-demand protocol which initiate route request only when needed. When a source node needs a route to certain destination, it broadcasts a route request packet (RREQ) to its neighbors. Each receiving neighbor checks its routing table to see if it has a route to the destination. If it doesn't have a route to this destination, it will re-broadcast the RREQ packet and let it propagate to other neighbors. If the receiving node is the destination or has the route to the destination, a route reply (RREP) packet will be sent back to the source node. Routing entries for the destination node are created in each intermediate node on the way RREP packet propagates back. Data traffic is then routed according to the information provided by these entries.

C. Dynamic Source Routing (DSR)

In DSR, the route discovery process is similar to AODV. A source node generates a route_request packet when it needs a new route to certain destination. The route_request is flooded through the network until it hits some node with a route to destination. The difference is that each route_request packet contains the information of the route it has propagated. When the route_request packet reaches the destination or an intermediate node with a route to destination, a route_reply packet will be generated. This reply packet is then sent back to the source node following the reverse route contained in the route_request packet. When transmitting the data traffic, the complete route is added to each data packet according to the routing table of the source node. The intermediate nodes forward packets according to the path provided in the packet.

D. Temporally-Ordered Routing Algorithm (TORA)

TORA is based on "link reversal" algorithms. It creates routes by setting "height" metric of each node. Data packets "flow" from higher nodes to lower nodes and eventually reach the destination, which has zero height with respect to itself. A directed acyclic graph (DAG) rooted at the destination is created in every route query/reply process. When a new route is required by the source node, it broadcasts a route query (QRY) to its neighbors. The QRY packet is then re-broadcast by neighbors until it reaches the destination. The destination node declares its height by broadcasting a route update (UPD) packet. Every node receiving the UPD packet will update its height to be higher than the height in UPD. Then the UPD packet is rebroadcast with new height in it until it reaches the source node. TORA requires every node to have complete knowledge of its neighbors which indicates certain beaconing process is needed.

It also requires every node tohave a synchronized clock in order to prevent loops.

V. SIMULATION ENVIRONMENT

The experiments performed to examine energy performance of ad hoc routing protocols on different mobility models have been done through ns-2 network simulator [13]. In this section we describe the scenarios and parameters used.

A. Simulation tool and parameters

Ns-2 is used to compare ad hoc routing protocols over different mobility models. The underlying MAC layer protocol is defined by IEEE 802.11 standard [21]. All simulations are performed with 50 mobile nodes in a rectangular area of 690m x 690m. The length of each simulation is 500 seconds. All MAC layer operations of the wireless network interfaces are logged in trace files. Post simulation analyses are performed to each of the trace files in order to calculate the energy consumption for communication.

B. Mobility & traffic scenario generation

BonnMotion [15] is used to generate movement patterns for all mobility models: Manhattan Grid, RandomWaypoint and RPGM. In each model, nodes move in patterns as described in Section III accordingly. To see the speed impact on the network performance, we change the node mobility by varying the average speed in each mobility scenario. There are four speed levels: 1m/s (Walk), 5m/s (Bicycle), 10m/s (Motorcycle), 15m/s (Car). To provide traffic load to the ad hoc network, 10 constant bit rate (CBR) traffic streams are set up for each simulation. Each CBR traffic source sends 2 packets per second with packet size of 512 bytes. The traffic sources and destinations are chosen uniformly from all mobile nodes. It is indicated in [9] that, for RPGM, intra-group and inter-group traffic make significant difference in packet delivery performance. Therefore, intra-group and inter-group traffic pattern are specially generated for RPGM model to see how they affect the energy performance. In inter-group model, each pair of sender and receiver of the CBR streams are separated into different groups. In intra-group model, they are in the same group. The intra-group case of RPGM is named as "RPGM-intra" throughout this paper. Five movement cases are generated for each mobility scenario with the same parameters. All analyses are performed over the average value of the 5 cases. For the fairness of protocol comparison, each ad hoc routing protocol is run over the same set of scenarios. In total, 320 simulations are performed and analyzed.

C. Energy consumption model

The linear model proposed by Feeney [18] is used to calculate the energy consumption of the network. Each time a MAC layer operation takes place, certain amount of power is consumed for this operation. The energy consumption is described by the following equation:

$$Energy = m \times length + b \quad (1)$$

Energy: the energy cost for this operation
m: for incremental cost of each operation.
b: fixed cost of each operation
length: the size of data sent/received

For example, every time the sending event occurs, we charge the battery for b_{send} as a fixed cost and m_{send} multiplied by the size of data sent in this event. So is the case in receiving events. For 802.11 MAC control packets (CTS/RTS/ACK), only fixed costs $b_{sendctl}$, $b_{recvctl}$ are charged since they all have similar size.

The constants {m, b} in equation (1) are obtained by physical measurements in [18] [19] for different 802.11 NICs. The values provided in [18] are used in all calculations in this paper. They are summarized in Table I.

TABLE I
CONSTANTS USED IN SIMULATION

Symbol	Value	Unit
m_{send}	1.89	uW-sec/byte
b_{send}	246	uW-sec
m_{recv}	0.49	uW-sec/byte
b_{recv}	56.1	uW-sec
$b_{sendctl}$	120	uW-sec
$b_{recvctl}$	29	uW-sec

VI. RESULTS

The results from the 320 simulations are presented and analyzed in this section.

A. Comparison of routing protocols over different models

From the result of all the simulations, TORA is found to be most energy consuming among the four tested protocols. Fig. 1 shows a comparison of the four protocols over Random Waypoint model. The amount of energy consumed using TORA is nearly an order of magnitude higher than the other three. The first reason is that TORA sends out too many flooding messages for route requests and updates. Every time a route condition changes, all nodes have to alter the associated height information. The second reason is that TORA updates route information very slowly. Much time is needed to flood the network with route requests and updates, so that it can not adapt fast enough to the topology changes. As a result, the network spends most of its power for the huge amount of flooding messages. Because TORA performs much worse than the other three protocols, the differences among the other three protocols become hard to tell in the graph while TORA is presented. It also makes less sense to compare protocols with an order of magnitude difference. Hence, TORA is excluded in following analyses.

Fig. 2 presents the comparison of DSR, AODV, and DSDV over Random Waypoint model. DSR consumes the least power at all speed levels because it requires the least amount of routing messages to adapt to the topology changes. AODV performs better than DSDV at the lowest speed level because of its on-demand nature. At lower speed, the topology changes are less frequent so that AODV sends less routing messages. However, as speed goes up, more route changes are made. AODV has to generate more routing packets and consumes more power than DSDV does.

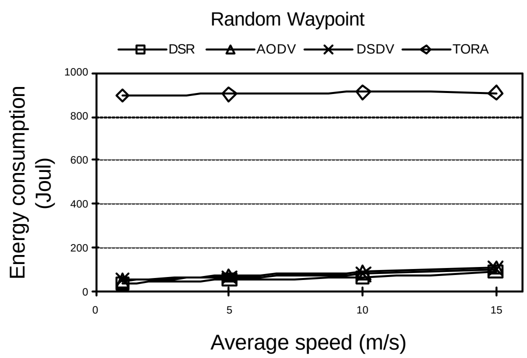

Fig. 1. Comparison of routing protocols over Random Waypoint mobility model.

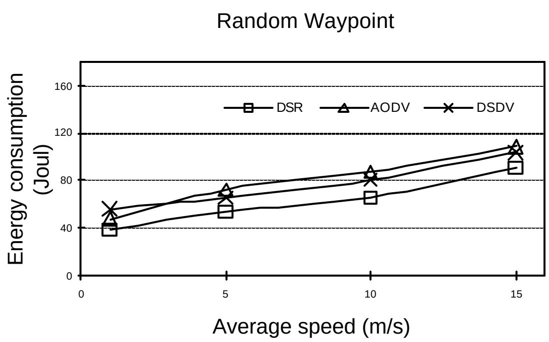

Fig. 2. Comparison of routing protocols over Random Waypoint mobility model (without TORA).

In Fig. 3, the same comparison is shown over Manhattan Grid model. In this case, DSR performs best at the lowest speed level but it becomes the worst one at the highest speed level. At higher speed, DSDV performs better than both DSR and AODV. The energy consumption of DSDV stays at about the same level, while the energy consumed by DSR and AODV both grow with speed rapidly. This result shows that on-demand protocols are more sensitive to speed of mobile nodes than proactive protocols. The explanation is that higher speed causes more route changes which force on-demand protocols to generate routing messages more frequently.

Fig. 4 shows the result over RPGM mobility model. In this case, nodes move in groups and this pattern reduces the rate of topology change. This reduction of topology change is directly reflected in the amount of energy consumed by each protocol. The trend of energy consumption here is similar to Fig. 2, but the amount of energy consumed is much lower. DSDV consumes almost the same amount of power in every speed level in this model. DSR and AODV also become more stable with node speed level.

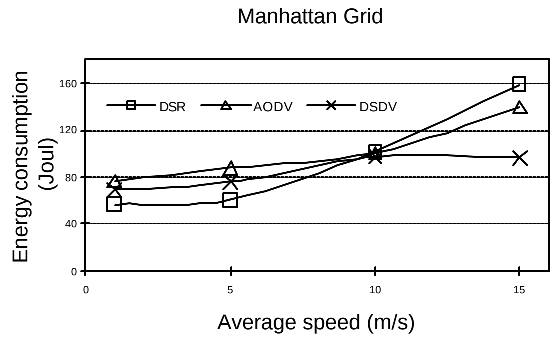

Fig. 3. Comparison of routing protocols over Manhattan Grid mobility model (without TORA).

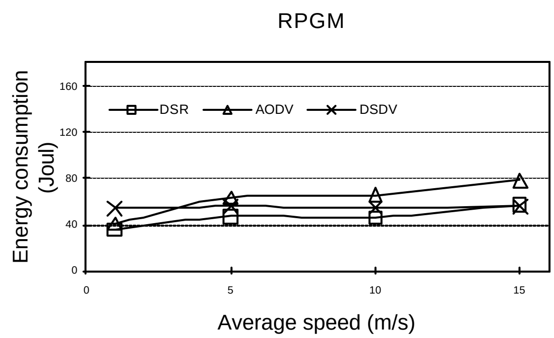

Fig. 4. Comparison of routing protocols over RPGM mobility model (without TORA)

Fig. 5 compares the performance of each protocol over RPGM model with intra-group traffic. In this ideal environment, on-demand protocols DSR and AODV perform much better than proactive protocol DSDV. Group mobility model with local traffic constitutes an extremely friendly environment for DSR and AODV. The rate of route change is further reduced by local traffic pattern. DSDV, as a proactive protocol, exchanges routing packets between nodes whether the network topology changes or not. Thus, it still consumes a constant amount of energy to maintain the route information.

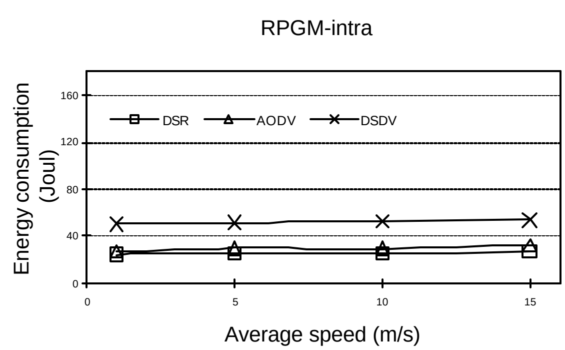

Fig. 5. Comparison of routing protocols over RPGM mobility model with intra-group traffic (without TORA)

B. Effect of mobility models to each protocol

Fig. 6 presents the comparison of DSR performance over the four mobility models. It is obviously shown that DSR is quite sensitive to node speed in Random Waypoint and Manhattan Grid model. Comparing the four mobility models, Manhattan Grid is the most challenging environment for DSR. DSR is much more sensitive to node speed in Manhattan Grid than any other model. In RPGM with intra-group traffic, DSR consumes very low power and becomes independent of node speed. It is because local traffic insulates DSR from topology changes among groups.

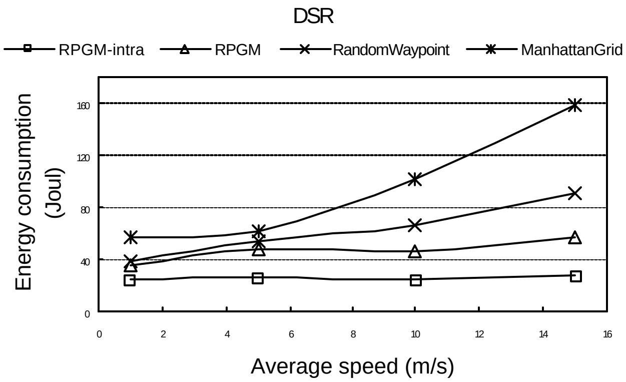

Fig. 6. Effect of mobility models on DSR

The performance of AODV in different mobility models is presented in Fig. 7. Similar to DSR, AODV consumes most power in Manhattan Grid. However, the sensitivity to node speed here is less than DSR. Except for the fact that the energy consumed by AODV is generally higher than DSR, the challenges imposed by mobility models to AODV are similar to those of DSR. It is reasonable because AODV and DSR are both on-demand protocols and the only major difference is that DSR uses source routing rather than distance vector in AODV.

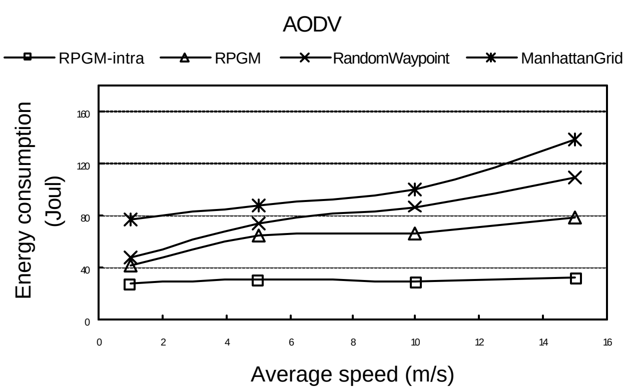

Fig. 7. Effect of mobility models on AODV.

In Fig. 8, it confirms that DSDV is not so sensitive to speed compared to on-demand protocols, DSR and AODV. The differences among mobility models become subtler here. It is due to the nature of proactive protocols. DSDV works by letting nodes exchange routing tables periodically, therefore the power consumption by this type of routing algorithms tend to stay constant.

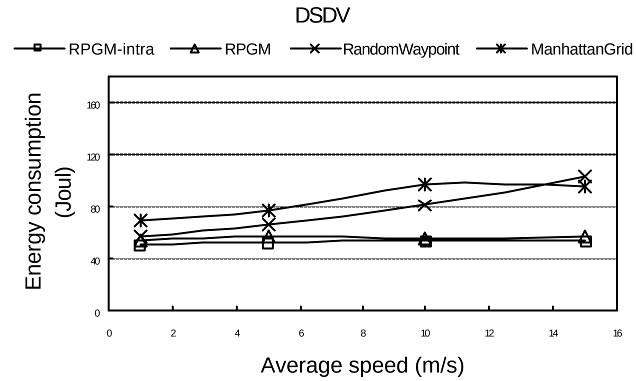

Fig. 8. Effect of mobility models on DSDV.

Random Waypoint is considered to be an entirely random scheme and intuitively one would think it may be the most challenging environment for ad hoc routing protocols. However, the results shown here are not consistent with this intuition. Throughout Fig. 6-Fig.8, it can be seen that Manhattan Grid model costs the most energy than the others, which infers that a grid-like street environment can be more challenging than the other three environments. Although nodes are restricted to move on the streets, this moving pattern can still generate much more link break events than schemes where nodes move freely in the simulation area. RPGM with intra-group traffic is the contrast. In a group moving environment with local traffic, the network has much less route changes and this fact reduces part of the power needed for maintaining route information.

VII. CONCLUSIONS

The following conclusions are drawn from the results of this work.

1. The performance of ad hoc routing protocols greatly depends on the mobility model it runs over.
2. Reactive protocols are more speed-sensitive while proactive protocols are not.
3. Routing in Ad hoc networks over Manhattan Grid environments is more challenging than Random Waypoint and RPGM.
4. In situations where nodes move in groups, on-demand protocols perform better than proactive ones in terms of energy conservation.
5. DSR performs best among the evaluated protocols, except for high speed cases in Manhattan Grid model.

These facts are useful when deploying ad hoc networks with power constrained devices. When the network is used in a low speed environment, DSR is generally the best choice for energy conservation. However, in high speed cases, the movement pattern of the network should be further considered to determine whether to choose an on-demand or proactive protocol. If the network is used in a group-based moving environment, on-demand protocols are better choices. In a highly dynamic environment such as Manhattan Grid, the performance of on-demand protocols decreases and proactive protocols save more power.

Although not directly pointed out in the analyses, it is worth mentioning that the flooding approach used to disseminate query information is very expensive in energy cost. The network will be in the risk of consuming most of its power on flooding messages with fast topology changes and heavy packet traffic load. Thus, reducing the use of flooding approach is another important issue in designing an energy conserving protocol for ad hoc networks.

VIII. FUTURE WORK

In this work, the emphasis is on evaluating the amount of energy needed to route the same traffic using different protocols over different mobility models. However, the nodes often have finite battery power and the batteries will be drained and this event causes route breaks. This factor is not taken into account in this work. In the future, we would like to investigate the impact of the battery dying effect to the network performance. Besides, it is shown that network traffic pattern also plays an important role in energy performance when comparing the cases of RPGM and RPGM-intra. Hence, applying different traffic patterns and investigate its relation to energy performance is worthy of more exploration. Furthermore, there are other low power protocols developed to minimize the network power consumption, such as in [22]. Evaluation of these protocols is another topic for future analysis work.

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