Improving QoS Using Modified Virtual Clustering Method For Power Heterogeneous MANETs

Sathish M, Student, Velammal Engineering College, sathish04mani@gmail.com.
Matheeban S, Student, Velammal Engineering College, matheeban@gmail.com.
Sarupriya S, Asst.Prof, Velammal Engineering College,sarupriya_s@yahoo.co.in.

Abstract — A mobile ad hoc network (MANET) is comprised of mobile hosts that can communicate with each other using wireless links. Power heterogeneity is common in mobile ad hoc networks(MANETs). Power heterogeneous ad hoc networks are characterized by link layer asymmetry the ability of lower power nodes to receive transmissions from higher power nodes but not vice versa. With high-power nodes, MANETs can improve network scalability, connectivity, and broadcasting robustness. However, the throughput of power heterogeneous MANETs can be severely impacted by high-power nodes. To address this issue, we present a loose-virtual-clustering-based (LVC) routing protocol for power heterogeneous (LRPH)MANETs. To explore the advantages of high-power nodes, we design a novel power-aware routing protocol that nicely incorporates device heterogeneity, nodal residual energy information and nodal load status to save energy. LVC algorithm is to eliminate unidirectional links and reduce the interference raised by high-power nodes, we develop routing algorithms to avoid packet forwarding via high-power nodes. Via the combination of analytical modeling, simulations, and real-world experiments, we demonstrate the effectiveness of LRPH on improving the performance of power heterogeneous MANETs.

Index Terms— Clustering, mobile ad hoc networks (MANETs),power heterogeneous, routing, LVC Algorithm, LRPH, ECRP.

◆

1 INTRODUCTION

IN RECENT years, there has been growing research interest in heterogeneous mobile ad hoc networks (MANETs). Such mobile network consists of devices with heterogeneous characteristics in terms of transmission power, energy, capacity, radio, etc. In such a heterogeneous network, different devices are likely to have different capacities and are thus likely to transmit data with different power levels.

IEEE 802.11 is the most popular and practical technology deployed by a communication device in a vehicular network. Hence, we focus on the IEEE 802.11-based power heterogeneous MANETs in this paper. In 802.11-based power heterogeneous MANETs, mobile nodes have different transmission power, and power heterogeneity becomes a double-edged sword. On one hand, the benefits of high-power nodes are the expansion of network coverage area and the reduction in the transmission delay. Highpower nodes also generally have advantages in power, storage, computation, capability, and data transmission rate. As a result, research efforts have been carried out to explore these advantages, such as backbone construction and topology control. On the other hand, the large transmission range of high power nodes leads to large interference, which further reduces the spatial utilization of network channel resources. However, the existing routing protocols in power heterogeneous MANETs are only designed to detect the unidirectional links and to avoid the transmissions based on asymmetric links without considering the benefits from high-power nodes. Hence, the problem is how to improve the routing performance of power heterogeneous MANETs by efficiently exploiting the advantages and avoiding the disadvantages of high-power nodes, which is the focus of this paper.

In this paper, we develop a loose-virtual-clustering-based (LVC) routing protocol for power heterogeneous MANETs, i.e., LRPH. Our protocol is compatible with the IEEE 802.11 distributed coordination function (DCF) protocol. LRPH takes the double-edged nature of high-power nodes into account. In such a heterogeneous network, different nodes are likely to have different power capabilities and thus, are likely to transmit with different power levels. We define this as a strong coupling cluster. In a strong coupling cluster, the cost of constructing and maintaining a cluster may significantly increase and affect the network performance. In our clustering, a loose coupling relationship is established between nodes. In such case, we developed routing algorithms to avoid packet forwarding via high-power nodes. Simulation results show that LRPH achieves much better performance than other existing protocols. We have implemented LRPH in Network Simulator-2 environment and conducted real-world experiments.

2 PROPOSED WORK

2.1 Review of Ad hoc Routing Protocol

In ad hoc networks, however, routing becomes a significant concern, because it needs to be handled by ordinary nodes that have neither specialized equipment nor a fixed, privileged position in the network. Thus, the introduction of ad hoc networks signaled a resurgent interest in routing through the challenges posed by the mobility of the nodes, their limited energy resources, their heterogeneity, and many other issues.

There are some routing protocols for heterogeneous MANETs. Multiclass (MC) is a position-aided routing protocol for power heterogeneous MANETs. The idea of MC is to divide the entire routing area into cells and to select a high power node in each cell as the backbone node (B-node). Then, a new medium access control (MAC) protocol called hybrid MAC (HMAC) is designed to cooperate with the routing layer. Hierarchical optimized link state routing (HOLSR) is a routing protocol proposed to improve the scalability of OLSR for large-scale heterogeneous networks. In HOLSR, mobile nodes are organized into clusters according to the capacity of a node. In, a cross-layer-designed device–energy–load aware relaying (DELAR) framework that achieves energy conservation from multiple facts, including power-aware routing, transmission scheduling, and power control, is proposed. DELAR mainly focuses on addressing the issue of energy conservation in heterogeneous MANETs. Our proposal considers both the advantages and disadvantages of high-power nodes. In addition, some realistic factors have been taken into consideration, including unidirectional links and the loose coupling relationship between nodes in cluster.

3 LRPH MOBILE AD HOC NETWORKS

To improve the network performance and to address the issues of high-power nodes, we propose an LRPH MANETs. As shown in Fig. 1, LRPH consists of two core components. The first component (Component A) is the LVC algorithm that is used to tackle the unidirectional link and to construct the hierarchical structure. The second component (Component B) is the routing, including the route discovery and route maintenance.

3.1 NETWORK MODEL

There are two types of nodes in the networks: B-nodes and general nodes (G-nodes). B-nodes refer to the nodes with high power and a large transmission range. G-nodes refer to the nodes with low power and a small transmission range.

The theoretical transmission ranges of B-nodes and G-nodes are R_B and R_G, respectively.

Definition 1–$G_{isolated}$*:* $G_{isolated}$ is defined as a G-node that is not covered by any B-node.

Definition 2–G_{member}*:* G_{member} is defined as a G-node whose bidirectional neighbors (BNs) are covered by its cluster head.

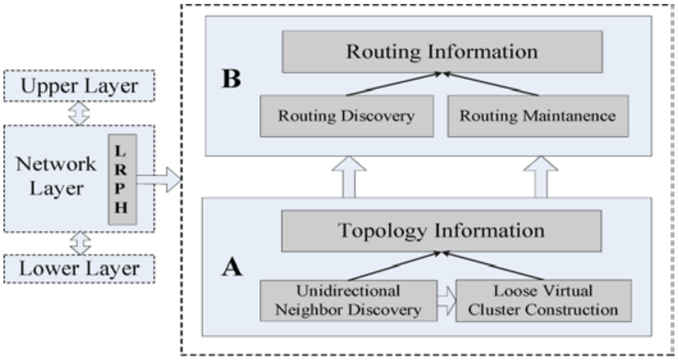


FIG. 1. OVERVIEW OF THE LRPH

Definition 3–$G_{gateway}$*:* $G_{gateway}$ is defined as a G-node whose BNs are not covered by its cluster head.

3.2 LVC ALGORITHM

Here, we introduce the LVC algorithm. To exploit the benefits of high-power nodes, LVC establishes a hierarchical structure for the network.

1) BND: To eliminate unidirectional links, we present an effective scheme to discover bidirectional links. In particular, each node periodically sends a bidirectional neighbor discovery (BND) packet, containing its own information (e.g., ID, type, state, etc.) and the information on its discovered neighbors.

Procedures for discovering BNs:

Step 1: Each node broadcasts BND packets within one hop and notifies all neighbors about its type or state.

Step 2: After sending BND packets, each node waits for T_{BND} to collect BND packets sent from its neighbors. The received BND packets will be used to construct the AN table, which stores the information (e.g., ID, type, state, etc.) of all discovered nodes. As a result, AN = N R_B ^B(g_i) ∩ N R_G^G(g_i).

Step 3: After waiting for T_{BND}, each node broadcasts BND packets again. In this step, the information on the node itself and all nodes in the AN table will be added to the BND packets.

Step 4: When receiving BND packets, each node will check whether its own node information is in the BND packets. If so, a bidirectional link between the current node and the sender of that BND packet will be determined. Then, the sender of the BND packet will be added into the BN table. As a result, BN = N R_G^B(g_i) ∩ N R_G^G(g_i).

2) LVC: In LVC, a B-node is chosen as the cluster head and establishes a loose coupling relationship with G-nodes. Two features appear in LVC. First, the loose clustering avoids heavy overhead caused by reconstructing and maintaining the cluster when the density of B-nodes is small. Second, LRPH protocol can be adaptive to the density of B-nodes, even when all G-nodes are in the $G_{isolated}$ state.

Procedures for Building LVC:

Step 1: Each G-node broadcasts G-node LVC initialization (GLI) packets to all B-nodes in the AN table. The BN infor-

mation in the BN is added to GLI. Notice that GLI will only be delivered within the limited area controlled by time-to-live (TTL). Because TTL is very small, broadcasting GLI packets will not incur much overhead to the network.
Step 2: Each B-node waits for T_{LVC} to collect GLI and build the LAT table for the local topology information *local_topo_info* based on the BN information in GLI.
Step 3: After sending GLI packets in Step 1, the G-nodes wait T_{LVC} for receiving BLI packets from the B-nodes. Then, the G-nodes build LAT based on the *local_topo_info* received in BLI packets.
Step 4: Each G-node determines its own state based on the definitions about G-nodes and selects the cluster head using the scheme proposed. Then, each node takes the following operation according to its state.
Step 5: Each cluster head waits for T_{LVC} to collect CMR packets from its cluster members and rebuild the LAT for its cluster members. Then, the cluster head broadcasts cluster head declare (CHD) packets to the G-nodes covered by the cluster head in one hop.
Step 6: When a G-node receives CHD packets, it knows the topology information and updates the information into LAT. However, the B-node does not process received CHD packets.

3) LVC Maintenance: When links between nodes fail, the maintenance of LVC will be activated. In particular, when node n_i detects any of the following conditions based on the periodical BND packets, it enters the procedure of LVC maintenance.

- If node n_i does not receive the BND packet from node n_j in the AN table within a time window, n_j should be out of its coverage range.
- If node n_i receives the BND packet from node n_j and node n_j is not in the AN table, a new link between n_i and n_j should be added.

Procedures for G-nodes to maintain LVC:
Step1: G-node n_i updates its node state and AN and BN tables.
Step 2:

- If n_j is the cluster head of n_i, the maintaining procedure need to obtain a new cluster head.
- If n_j is a B-node but not the cluster head of n_i, n_i leaves the coverage range of B-node n_j , and n_i updates the topology information on n_j in LAT.
- If n_j is G-node and in the BN table, the bidirectional link fails. G_{member} or $G_{gateway}$ nodes send the BN update (BNU) packet to the cluster head for updating the BNs.

Step 3: When a B-node receives CMR packets, it broadcast CHD packets. If the cluster head receives BNU packets, it broadcasts BNU packets again in one hop. The G-node updates the cluster and LAT information in accordance with received packets.
Procedures for B-nodes to maintain LVC:
Step 1: B-node n_i updates LAT, AN, and BN tables.
Step 2: If n_j is in the BN table of n_i, n_i broadcasts BNU packets in one hop to update the LAT tables of all nodes within its coverage range.

4) Cluster Head Selection: Let N be the number of B-nodes in the AN table maintained at any G-node g_i. The cluster head of g_i can be determined by the following rules. If $N = 0$, G-node g_i is not covered by any B-node. According to the rule for establishing LVC, g_i does not need any cluster head. If $N = 1$, g_i selects the only *B-node* that covers it as the cluster head.

3.3 ROUTING COMPONENTS IN LRPH

Here, we focus on the routing components in LRPH, including the route discovery and route maintenance. In the route discovery, the route to the destination can be obtained effectively based on LVC. In the route maintenance procedure, we deal with cases such as route failure.

1) Route Discovery Procedure: When source node *S* wants to send a data packet to destination node *D*, *S* first searches whether the route to *D* exists in its route cache. If the route exists, *S* directly sends the data packet. To summarize, we highlight some unique features of our route discovery procedures. First, our technique takes the large coverage space for B-nodes to the broadcast RREQ packet. Hence, the delay from the route discovery can be improved. Second, forwarding rules for the RREQ packet is based on the state of a node and local topology information; therefore, redundant transmissions of RREQ packets can be avoided, and the overhead of the route discovery procedure can be significantly reduced. Third, our scheme intends to avoid forwarding data packets through B-nodes; therefore, the impact of B-nodes on network throughput can be largely reduced. Finally, LRPH is adaptive to the density of B-nodes for LVC.

2) Route Maintenance Procedure: When a middle node on the route detects the link failure through the BN table, the route maintenance is activated. First, a route error (RERR) packet is created and sent to the source node along the reverse route.. When the source node receives the RERR packet, a new round of route discovery procedure will be activated.

4 ANALYSIS

4.1 IMPACT OF B-NODES ON CHANNEL SPATIAL USAGE

Fig. 2 shows the two cases of communication related to B-nodes, where the black and white nodes are the B-nodes and G-nodes, respectively. Without considering the channel occupancy time, our analysis considers two cases: 1) the communication between a B-node and a G-node and 2) the communication between two B-nodes.

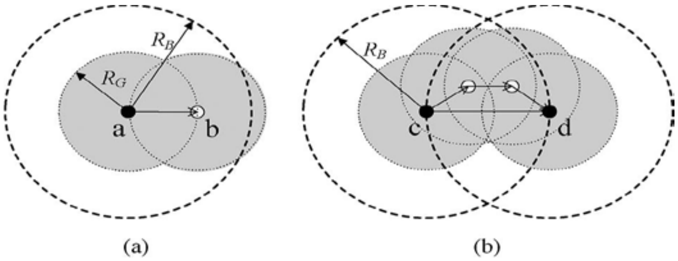


Fig. 2. Cases of communication. (a) Communication between a *B-node and a G-node*. (b) Communication between

two *B-nodes*.

1) Communication Between a B-node and a G-node: The unicast in 802.11 is based on bidirectional links. As shown in Fig. 2(a), the G-nodes that can communicate with B-node *a* are located in the area centered at node *a* with a radius of R_G. Hence, the maximum space (denoted as S) for the communication between a B-node and a G-node is expressed by

$$S = \begin{cases} \pi R_B {}^{\wedge}2, \\ (R_G \le R_B/2) \\ \pi R_B {}^{\wedge}2 + \arccos (R_B /2R_G .(2 R_G {}^{\wedge}2 - R_B {}^{\wedge}2) \\ + R_B\sqrt{}\, R_G {}^{\wedge}2 - R_B {}^{\wedge}2/4) , \qquad \text{else.} \end{cases} \qquad \textbf{(1)}$$

In fact, the maximum required space is denoted as $(4\pi/3 + \sqrt{}3/2)\ R_G {}^{\wedge}2$, which is the size of the shadowed region.

2) Communication Between Two B-nodes: When two B-nodes communicate with each other, each node will create the interference area of $\pi\ R_B {}^{\wedge}2$. Hence, the total created space S_B can be derived by $\pi\ R_B {}^{\wedge}2 \le S_B \le (4\pi/3 +\sqrt{}3/2)\ R_G {}^{\wedge}2$. In this case, each node is located at the edge of its neighbors coverage area, and all nodes on the route are in a line. Then, we have

$$S_G \le n(\pi/3 +\sqrt{}3/2)\ R_G {}^{\wedge}2 + \pi\ R_G {}^{\wedge}2. \qquad \textbf{(2)}$$

Then, the expectation of S_G, which is denoted as $E(S_G)$, can be obtained based on the analysis results in about the hop count for a path. We can find obviously that $E(S_G) < S_B$ in most cases. This confirms that transmitting data through B-nodes will dramatically reduce the channel spatial reuse.

4.2 OVER HEAD OF LRPH

Let CO_{LRPH} be the total number of control packets transmitted per unit time over the network; it consists of two components and can be represented by

$$CO_{LRPH} = CO_{LVC} + CO_{ROUTING} \qquad \textbf{(3)}$$

where CO_{LVC} is the overhead caused by the LVC algorithm, and $CO_{ROUTING}$ is the overhead caused by the routing procedure. In the following, we derive the formula for the two given components.

1) CO_{LVC}: From the procedures of the LVC algorithm, CO_{LVC} consists of the overhead caused by the periodical BND packets CO_{BND} and clustering procedure $CO_{cluster}$. According to the procedures of establishing the LVC, $CO_{cluster}$ should be considered for both G-nodes and B-nodes. Hence, $CO_{cluster} = CO_B + CO_G$, where CO_B represents the overhead of the B-node, and CO_G represents the overhead of the G-node, respectively. In our analysis, we assume that the number of G-nodes covered by B-nodes is N_{G_LVC}, which satisfies $N_{G\_LVC} \le N_G$.

If we assume that the frequency of sending BND packets is f_{BND}, the overhead from BND can be derived by

$$CO_{BND} = f_{BND} \cdot (N_B + N_G). \qquad \textbf{(4)}$$

$CO_{cluster}$ is analyzed from both CO_G and CO_B. CO_G consists of two parts: CO_{CMR} and CO_{BNU}, where CO_{CMR} represents the overhead for multicasting CMR packets, and CO_{BNU} represents the overhead for sending BNU packets. Let the frequencies of sending CMR and BNU be f_{CMR} and f_{BNU}, respectively. Hence, both f_{CMR} and f_{BNU} are smaller than f_{BND} and $f_{CMR} + f_{BNU} \le f_{BND}$. Consequently, when G-nodes send CMR and RNU packets to the cluster head through multiple hops, CO_G becomes

$$CO_G =(f_{CMR} \cdot 2 \cdot \text{Hop} + f_{BNU} \cdot \text{Hop}) \cdot N_{G\_LVC}<f_{BND} \cdot$$
$$(2 \cdot \text{Hop})\cdot N_{G\_LVC}. \qquad \textbf{(5)}$$

where Hop is the average hop count of the route from a G-node to its cluster head. CO_B is computed in the same way. Both CHD and BNU from a B-node contribute CO_B. The frequency of sending these two packets is $f_{CHD} + f_{BNU} \le f_{BND}$ and Hop = 1, respectively. Hence, CO_B can be derived by

$$CO_B =(f_{CHD} + f_{BNU}) \cdot 1 \cdot N_B \le f_{BND} \cdot N_B. \qquad \textbf{(6)}$$

From (5) and (6), we have

$$CO_{cluster} =CO_G + CO_B;<f_{BND} \cdot (2 \cdot \text{Hop} \cdot N_{G\_LVC}+\cdot N_B). \qquad \textbf{(7)}$$

Finally, the total overhead caused by the LVC of LRPH can be derived by

$$CO_{LVC} = CO_{BND} + CO_{cluster}. \qquad \textbf{(8)}$$

From (8), we know that CO_{LVC} is highly correlated to N, particularly to N_B. When there is no B-node in the network (i.e., $N_B = 0$), all G-nodes are isolated nodes, and $N_{G\_LVC} =0$. Then, $CO_{cluster} = 0$. CO_{LVC} only comes from the periodical BND packets (CO_{BND}). In addition, the second term of (8) indicates that Hop greatly affects the CO_{LVC}.

2) $CO_{ROUTING}$: $CO_{ROUTING}$ is contributed by the route discovery and route maintenance. Because the LR does not send control packets and can obtain the route directly from LAT, $CO_{ROUTING}$ is mainly contributed by the overhead of processing RREQ and RREP packets in the GR and RERR packets in the route maintenance. The broadcasting RREQ packets accounts for the majority of $CO_{ROUTING}$ because sending RREP and RERR packets is unicast, leading to a very low overhead. In fact, $CO_{ROUTING}$ is highly correlated to ρ_B. When ρ_B is small or even no B-node exists in the network, routes can be discovered through broadcasting RREQ packets similar to dynamic source routing (DSR). However, because the unidirectional links in DSR incur a large number of rerouting and maintenance packets, the overhead of DSR is much larger than $CO_{ROUTING}$.

4.3 DISCUSSION

The G-nodes in LRPH take more responsibility for forwarding data packets to the destination. Nevertheless, the energy consumption of G-nodes might not necessarily be faster than that of high-power nodes. First, B-nodes in LRPH play the role of cluster head; more control information should be transmitted for the purpose of local network management and maintenance (e.g., CHD packets). Second, the energy consumption of B-nodes for transmitting per bit data is much higher than G-nodes. Because the goal of this paper is mainly to address the issues of routing, energy issues are not our main focus. Nevertheless, we believe that our protocol could be easily integrated with the existing algorithms to address the energy usage balance issue and to prolong the network lifetime. One possible way is to avoid low-energy G-nodes or the hot spot based on energy-aware metrics.

5 EVALUATION BY SIMULATION

5.1 EVALUATION METHODOLOGY

1) Experiment Metrics: To evaluate the performance of LRPH, we use the following four metrics : *throughput*, *packet delivery ratio (PDR)*, *packet drop*, and *energy consumption per received packet (ECRP)*. *PDR* and *delay* are the two metrics, we can observe whether the protocol could forward the data packets and qualify its efficiency. To evaluate the performance of protocols in this perspective, we use *ECRP*, which is an effective metric to reflect the energy efficiency of routing protocols. Hence, to transmit or receive a *k*-bit message over a distance of *d*, the energy cost will be $E_{elec} * k + E_{amp} * k * d^2$ and $E_{elec} * k$, respectively.

2) Evaluation Schemes and Scenery: We investigate the performance of LRPH versus R_B, N_B, and mobility. We compared LRPH with other two baseline protocols. The first routing protocol is MC , which is one representative routing protocol for power heterogeneous MANETs. The second protocol is DSR, which is one representative routing protocol for MANETs. LRPH will become a routing protocol similar to DSR when all nodes are G-nodes.

5.2 EXPERIMENTAL RESULTS

1) Number of B-Nodes: In this set of simulations, we evaluate the performance of LRPH, MC, and DSR. Considering the connectivity and cost of networks, N_B varies from 0 to 25. The number of CBR flows is 20. The maximum node speed V_{max} is set to 10 m/s.

Fig. 3(a) shows the throughput of three protocols versus N_B. The throughput of LRPH and DSR decreases as N_B increases because more transmission through low-power nodes will be interfered with by B-nodes. LRPH has the highest throughput in comparison with the other three protocols.

Fig. 3(b) shows the PDR of the three protocols versus N_B. The PDR of LRPH and DSR decreases as N_B increases because more data packets will be conflicted with the transmission of B-nodes. This is mainly caused by the increase in the density of B-nodes and the improvement of the connectivity between B-nodes.

Fig. 3(c) shows the packet drop of the three protocols versus N_B. The packet drop of both LRPH and DSR decreases as N_B increases. More data packets are transmitted through LR as N_B increases. Then, in the GR, the routing discovery could be quickly completed with the help of B-nodes and LAT. Finally, the connectivity between B-nodes is gradually improved as N_B increases.

Fig. 3(d) shows the normalized overhead of LRPH, MC and DSR versus N_B. First, the normalized overhead of LRPH and DSR decreases as N_B increases. More data packets are routed through LR, and the control overhead is reduced. The connectivity between B-nodes is improved, and the redundant RREQ broadcasting can be avoided.

Fig. 3(e) shows the ECRP of the three protocols versus N_B. For LRPH, although more clustering is established and more energy may be consumed as N_B increases, the decrease in the normalized overhead, which benefits from the clustering, balances the energy consumption. However, the ECRP of LRPH-B increases after N_B reach ten because more B-nodes are involved in the data forwarding.

6 CONCLUSION

In this paper, we have developed an LVC-based routing protocol named LRPH for power heterogeneous MANETs. LRPH is considered to be a double-edged sword because of its high-power nodes. We designed an LVC algorithm to eliminate unidirectional links and to benefit from high-power nodes in transmission range, processing capability, reliability, and bandwidth. We developed routing schemes to optimize packet forwarding by avoiding data packet forwarding through highpower nodes. Hence, the channel space utilization and network throughput can be largely improved. Through a combination of analytical modeling and an extensive set of simulations, we demonstrated the effectiveness of LRPH over power heterogeneous MANETs. Future perspectives of this work are focused towards modifying one of the above routing protocol such that the modified protocol could minimize more energy for the entire systems. And using the different routing algorithm for comparing the energy of the heterogeneous MANET's.

REFERENCES

[1]. Y. Huang, X. Yang, S. Yang, W. Yu, and X. Fu, "A cross-layer approach handling link asymmetry for wireless mesh access networks," *IEEE Trans. Veh. Technol.*, vol. 60, no. 3, Mar. 2011.

[2]. W. Liu, C. Zhang, G. Yao, and Y. Fang, "Delar: A device–energy–load aware relaying framework for heterogeneous mobile ad hoc networks," *IEEE J. Sel. Areas Commun.*, vol. 29, no. 8, Sep. 2011.

[3]. J. Wu and F. Dai, "Virtual backbone construction in MANETs using adjustable transmission ranges," *IEEE Trans. Mobile Comput.*, vol. 5, no. 9, Sep. 2006.

[4]. L. Villasenor-Gonzalez, Y. Ge, and L. Lament, "HOLSR: A hierarchical proactive routing mechanism for mobile ad hoc networks," *IEEE Commun. Mag.*, vol. 43, no. 7, Jul. 2005.

[5]. A. Boukerche, B. Turgut, N. Aydin, M. Z. Ahmad, L. Bölöni, and D. Turgut, "Routing protocols in ad hoc networks: A survey," *Comput. Netw.*, vol. 55, no. 13, Sep. 2011.

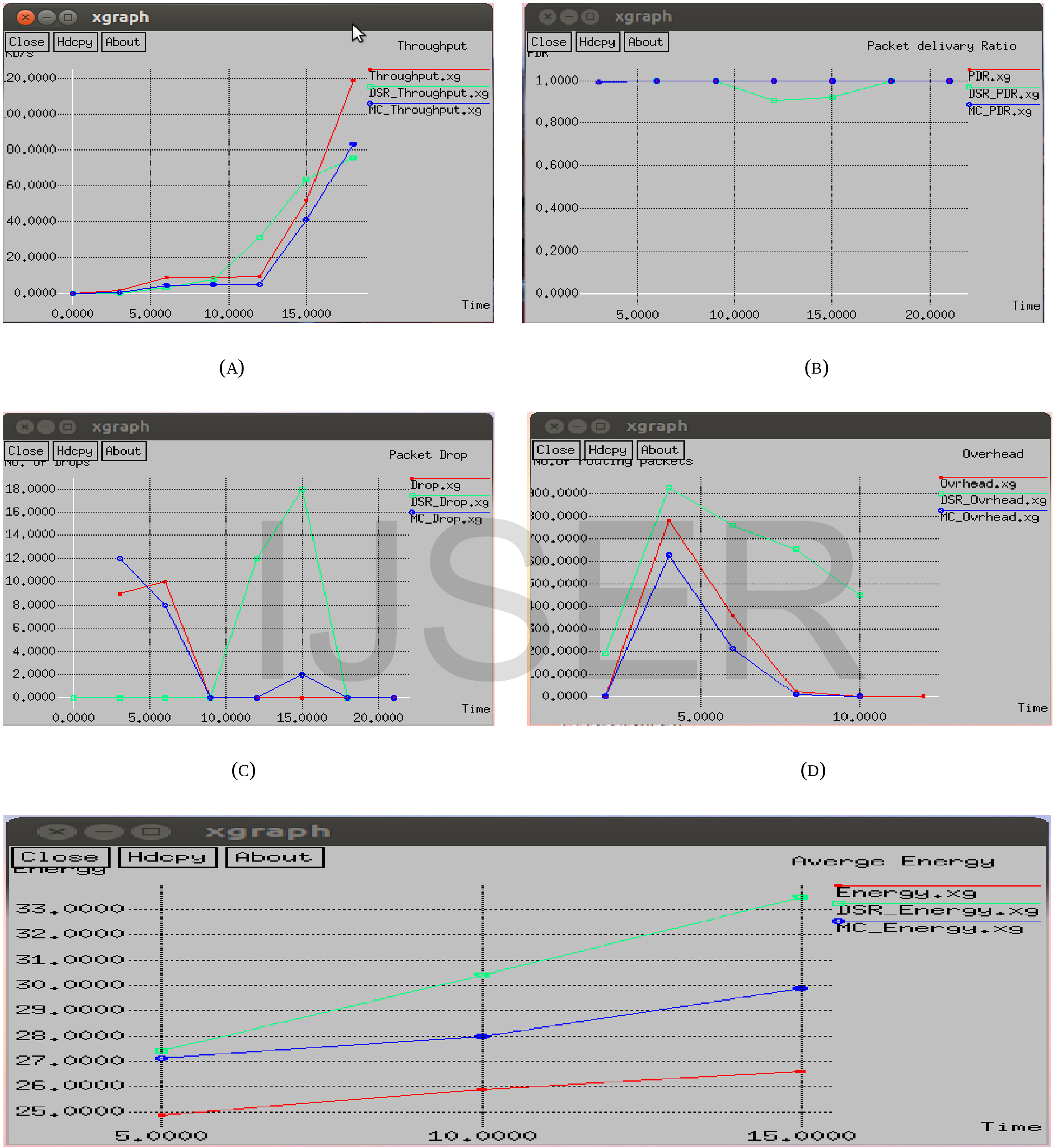
[6]. F. Li and Y. Wang, "Routing in vehicular ad hoc networks: A survey," *IEEE Veh. Technol. Mag.*, vol. 2, no. 2, Jun. 2007.

[7]. F. Ren, J. Zhang, T. He, C. Lin, and S. K. D. Ren, "EBRP: Energy balanced routing protocol for data gathering in wireless sensor networks," *IEEE Trans. Parallel Distrib. Syst.*, vol. 22, no. 12,Dec. 2011.

[8]. X. Du, D. Wu, W. Liu, and Y. Fang, "Multiclass routing and medium access control for heterogeneous mobile ad hoc networks," *IEEE Trans. Veh. Technol.*, vol. 55, no. 1, Jan. 2006.

[9]. Y.-C. Lai, P. Lin, W. Liao, and C.-M. Chen, "A region-based clustering mechanism for channel access in vehicular ad hoc networks," *IEEE J. Sel. Areas Commun.*, vol. 29, no. 1, Jan. 2011.

SIMULATION OUTPUTS



(A)

(B)

(C)

(D)

(E)

3. Effectiveness of LRPH versus *NB*. (a) End-to-end delay. (b) PDR. (c) Throughput. (d) ECRP.