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LDAB-GPSR: Location PreDiction with Adaptive Beaconing – Greedy Perimeter Stateless Routing Protocol for Mobile Ad Hoc Networks

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In mobile ad-hoc networks (MANET), nodes are randomly distributed and move freely, and hence the network may face rapid and unexpected topological changes. In this paper, an improved greedy perimeter stateless routing protocol, called "LDAB-GPSR", is proposed. LDAB-GPSR mainly focuses on maximizing the packet delivery ratio while minimizing the control overhead. In order to accomplish this, two techniques are introduced, the first one is the location prediction technique in which the greedy forwarding strategy is improved by choosing more stable routes for data forwarding. The second one is the adaptive beaconing technique in which the slow start algorithm is employed to adapt the beacon packet interval time based on the mobility of nodes and the data traffic load instead of using the periodic beaconing strategy. These two strategies together improve the overall performance of the GPSR routing protocol. The performance of the new proposed protocol is evaluated by carrying out several NS-2.35 simulation experiments. The simulation results show that LDAB-GPSR protocol outperforms the GPSR+Predict protocol in terms of packet delivery ratio, control traffic overhead, end to end delay, and throughput. The ratios of enhancement approaches 40%.

KEYWORDS: MANET; Routing; Greedy algorithm; Adaptive beacons; Location prediction; Geographic routing

1. Introduction

In ad-hoc wireless networks, all devices in the network are directly communicating with one another in a peer-to-peer fashion. The wireless network does not rely on a fixed or central access points. Ad-hoc mode is more appropriate for limited set of devices deployed in immediate proximity to each other. However, as the number of devices increases, performance suffers. Managing ad-hoc networks is a challenging task, because the probability of disconnection is high.

A mobile ad-hoc network (MANET) is a type of ad-hoc wireless network, in which all devices are able to change their locations and re-configure themselves on the fly. MANETs are popular due to their scalability and flexibility. A large set of MANET applications are emerging to solve specific issues in various areas.

Some main characteristics of MANETs are summarized as follows: 1) the path from a node to another in a MANET is a multi-hop path, 2) the nodes in MANETs are assumed to be lightweight terminals since the mobile nodes have less processing capability and small amount of memory, and hence low power consumption, and 3) MANET is scalable because the network is able to have more additional nodes.

On the other hand, some challenges of MANET that still need further enhancements and still receive the attention of researchers [3] including: 1) limited bandwidth, 2) energy constraints due to the limited energy of mobile nodes and hence short lifetime of nodes, and 3) routing overhead due to the need to maintain an accurate local topology in routing tables is crucial when nodes start moving and changing their positions. In this work, our focus will be on routing in MANETs.

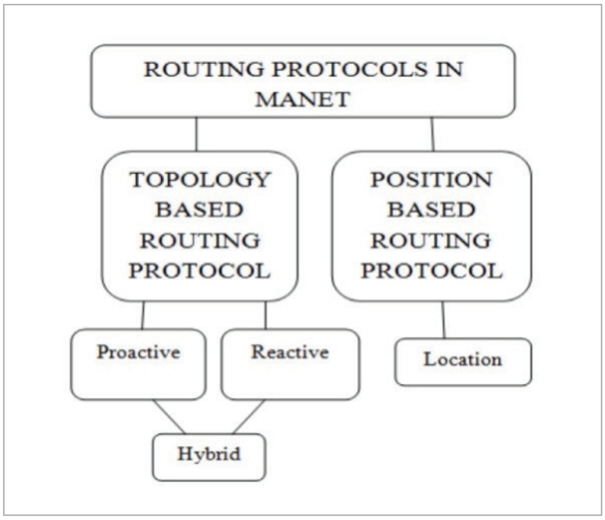
In MANETs, all mobile nodes connect to each other wirelessly without the help of a centralized device. They can join or disjoin the network anytime they want [7]. Therefore, some nodes may become disconnected from others and hence the paths will be broken. However, to get around this issue, researches have focused recently on routing as the most popular challenge in MANET to let mobile nodes improve network functionality in an efficient manner [16] [9][1].

Vehicular Ad hoc Networks (VANET) is a special kind of MANET in which the topology changes very fast, and the nodes (i.e., vehicles) have high-speed mobility, as well as the limited radio range. This usually leads to wrong packet forwarding decisions in highly dynamic VANET. This type of environment makes data routing very challenging. Therefore, Position-based routing protocols are popular for VANET due to the availability of GPS devices.

There are various types of routing protocols in MANETs and VANETs. These routing protocols have been classified into two main categories: topology based routing protocols and position based routing protocols. The topology based routing protocols are divided into proactive (table-driven) and reactive (on-demand) protocols. Figure 1 shows the classification of routing protocols in MANETs.

Figure 1

Classification of Routing Protocols in MANETs



In proactive routing protocols, such as Destination Sequenced Distance Vector (DSDV) protocol, the routes are discovered in advance. Each node maintains a routing table. Each node periodically broadcasts a control message to the entire network when the network topology changes. These protocols consume a large amount of network bandwidth to maintain accurate information in routing tables and continuously consume electric energy even if there is no data traffic in the network [14].

In reactive routing protocols, such as Dynamic Source Routing (DSR) protocol, the routes are discovered when they are required. A route discovery process is initiated by the source when data packets needed to be routed to the destination. These protocols are bandwidth efficient since there is no need to periodically broadcast control messages. On the other hand, the control overhead increases in high mobility situations or when there is heavy traffic load in the network.

In position-based routing protocols, such as Greedy Perimeter Stateless Routing (GPSR) protocol [13], there is no need to establish or maintain any routes. These protocols utilize the location information to provide more reliable and efficient routing. A location service is used by the source to get the destination position and attach it in the data packet. Hop-by-hop routing is used to forward data packets. These protocols show better performance than the topology based routing protocols when the network scales up and the topological changes increase.

GPSR is a position-based routing protocol for both MANETs and VANETs [19]. GPSR selects the next hop as the farthest neighbor node from the source that is closer to the destination. Therefore, the nodes route data packets based on the immediate local topology. In GPSR all nodes periodically broadcast beacons to maintain an accurate local topology about the positions of their neighboring nodes. Each node has a neighbor list which is built upon receiving beacon packets from neighbors. Then, the node utilizes this list to make an efficient routing decision.

The strategy utilized by GPSR increases the probability of route breakage since the farthest neighbor is more likely to leave the coverage area of the forwarding node, and hence the packet loss rate is high. Additionally, GPSR requires sending beacon packets even if there are no data traffic flow among nodes. Clearly, broadcasting unnecessary beacon packets increases control traffic overhead in the network which is a major factor for energy consumption and this may cause the wireless network to suffer disconnections early. Furthermore, excessive control overhead will lead to consuming the network bandwidth and increasing congestion in the network.

Some MANET and VANET networks that have emergency purposes are concerned with maximizing packet delivery ratio more than decreasing energy consumption in order to check enemies' movements or to quickly rescue survivors [17]. However, many of the existing routing protocols add excessive control overhead. Therefore, mobile nodes are more likely to consume their energy earlier [15]. Consequently, the wireless network connection will be disconnected early and connectivity is not achieved. Therefore, there is a high need to reduce the control overhead to extend the lifetime of the wireless nodes and keep the network functioning efficiently.

Although there are a lot of related works that have already enhanced GPSR, new modifications in GPSR can be introduced to both the greedy forwarding and periodic beaconing strategies for the sake of maximizing the packet delivery ratio and minimizing the control traffic overhead, and hence a new improved approach on top of the original GPSR protocol was proposed in this work that outperforms these previous approaches in relation to several performance metrics.

The GPSR+Predict protocol [10] is one of the recently developed routing schemes on top of the original GPSR protocol for VANET. It uses the direction and the speed of nodes to estimate their locations in the near future. Each node will include this estimation in its beacon packet. Since the periodic beaconing strategy is still adopted by this protocol, this estimation will be broadcasted periodically among the neighboring nodes. Other enhancements have also been proposed to solve the problems above [10] and [19-21].

In our proposed protocol, called *Location prediction with Adaptive Beaconing-Greedy Perimeter Stateless Routing (LDAB-GPSR)* protocol, new modifications to the greedy forwarding strategy are presented to enhance the forwarding decisions, and hence increasing the packet delivery ratio. In addition, an adaptive beaconing technique is introduced in order to suppress unnecessary beacon packets, hence reducing the control overhead. Moreover, a location prediction technique is introduced to enhance the routing process by choosing more stable routes for data forwarding. In this technique, the forwarder node firstly checks if all neighboring nodes in its neighbor list table will stay in its coverage area, then predicts the future position of its neighboring nodes before making the forwarding decision.

We show that LDAB-GPSR enhances the performance of routing in MANETs and VANETs in terms of: 1) Packet delivery ratio (PDR), 2) Control overhead, 3) Throughput due to increasing the packet delivery ratio, 4) Route length due to selecting a more appropriate next hop when data forwarding, and 5) End-to-end delay due to the drop in the number of contentions and collisions among nodes in the network. Furthermore, due to the location prediction technique, the number of failures to deliver data successfully decreases. For those reasons, the average end-to-end delay decreases.

The upcoming sections are organized as follows: Section 2 reviews related work, Section 3 presents our proposed protocol in details, Section 4 presents and discusses the simulation results for our proposed protocol compared to the GPSR+Predict protocol, and Section 5 presents conclusions and recommendations for future work.

2. Related Work

Recently, a community of network researchers have proposed a variety of MANET and VANET routing protocols. Their interest was in achieving better performance for their routing process by focusing on the nature of the environment such as mobility. Those proposed protocols provide enhancements by introducing modifications to the most common routing protocols.

Greedy Perimeter Stateless Routing (GPSR) is a well-known geographic routing protocol that is presented by Karp and Kung [13] as a routing protocol for wireless networks. It uses the local topology information in forwarding decisions. It uses the greedy forwarding decision with routing around the perimeter to get out of void regions when greedy fails. It shows the ability to overcome the scalability issue as the node density and the mobility increase in the network. GPSR also consumes less energy since it does not need to discover and cache the forwarding paths. GPSR suffers from several issues, on the other hand, one of them is that packets may be forwarded to the wrong direction or to a neighbor that has already left the transmission range. In addition, the proactive periodic beaconing strategy which is adopted by this protocol will increase the control overhead. Several modifications to this protocol have been proposed to improve its performance.

Wei and Yang [20] proposed Buffer Zone Greedy Forwarding Strategy (BZGFS) to solve the temporary communication blindness (TCB) problem, which causes a lot of data packets to be dropped due to the absence of the selected next hop node. A buffer zone around the radio range of each node was introduced into GPSR to exclude unreliable nodes from selection in greedy forwarding decision. BZGFS provides high packet delivery ratio but introduces high average end-to-end delay.

Xiang et al. [21] proposed Self-Adaptive On-demand Geographic Routing (SOGR) mechanism, which develops a reactive beaconing mechanism based on the traffic condition. When a node overhears a data transmission from its neighbor, it will broadcast a beacon packet as a response. If no data traffic is overheard for a period of time, the beaconing is halted. In this way, the researchers ensured that communication is more efficient with less data packet loss. Unfortunately, this proposed approach did not take the mobility and density of nodes into consideration.

Wang and Liang [19] proposed GPSRI as an improved algorithm for GPSR routing protocol, which modifies greedy forwarding and introduces the path optimization strategy by discovering the node-disjoint multipaths. It efficiently addresses the void region problem of GPSR. It also guarantees the reliability and load balancing for the wireless network. GPSRI enhances GPSR performance in terms of delay, finding multipaths and hop count.

Yang et al. [22] suggested enhancements on GPSR for VANETs using a greedy forwarding approach by defining cumulative communication duration to represent the stability of neighbor nodes. Specifically, the neighbor node with the maximum cumulative communication duration will be selected as the next hop node. To do perimeter forwarding when greedy forwarding fails, the concept of minimum angle is introduced as the criterion of the optimal next hop node. By taking the position of neighbor nodes into account and calculating angles formed between neighbors and the destination node, the neighbor node with minimum angle will be selected as the next hop node.

Chen et al. [5] proposed Adaptive Position Update (APU) strategy, which adapts the periodic beaconing in position-based routing protocols according to the mobility of nodes and the forwarding traffic load. Two beacon triggering rules have been employed in APU: the first one is Mobility Prediction (MP) rule, which maximizes the duration of the beacon for nodes which move slowly by broadcasting a beacon when a node detects an error greater than the Acceptable Error Range (AER) between its current position and its predicted position. The second rule is On-Demand Learning (ODL), in which nodes that are in the vicinity of the forwarding routes will broadcast more beacons, i.e. whenever a node overhears a data traffic from unknown neighbor, it responses by broadcasting a beacon. However, with high traffic load, the APU scheme could not perform well regarding reducing the control packets. Furthermore, a smaller AER value ensures accuracy of topological information but increases the control overhead.

Alsaqour et al. [2] proposed fuzzy logic dynamic beaconing (FLDB) scheme to adapt the beacon packet interval time (BPIT) using the fuzzy logic control (FLC) machine based on node moving speed (NMS) and number of neighboring nodes (NoNNs). The FLDB strategy provides more accurate local topology by efficiently broadcasting beacon packets, i.e., it guarantees up-to-date position information in the neighbor list of each node. The FLDB strategy showed better performance than traditional periodic beaconing (PB) strategy since it reduces the control packet overhead in low mobility scenarios and increases the packet delivery ratio in high mobility scenarios. However, fuzzy logic suffers from drawbacks such as: not always being accurate, taking longer run time, restricted number of inputs, etc.

Bengag et al. [4] introduced two new methods to enhance the classical GPSR protocol in VANET. They tried to minimize link breakages problem and find stable routes. To select the next hop node, they suggested two routing protocols; these are E-GPSR and DVA-GPSR. Moreover, they built their protocols based not only on the position but also on other metrics of the wireless nodes. In the first method, the authors used a metric that is a function of the difference in speed and the distance between the source node and all the neighbor nodes. In essence, this difference is calculated along with the number of neighbors of the current nodes. The second method used the angle v between the transmitter node and the destination node.

Chen et al. [6] proposed a traffic-aware Q-network enhanced geographic routing protocol based on GPSR for VANETs. The protocol used a traffic balancing strategy based on the level of congestion of the neighbors. The authors evaluated the quality of a wireless link using a reinforcement learning algorithm called "Q-network algorithm". On the other hand, Smiri et al. [18] suggested a weight-aware greedy perimeter stateless (WA-GPSR) routing protocol. The enhanced GPSR protocol that they proposed finds the reliable communication area. They selected the next hop vehicle based on multiple routing criteria.

An improved GPSR protocol based on ant colony algorithm was presented by Jiang et al. [11]. In this protocol, the authors used several parameters like the vehicle speed, energy consumption, and deflection angle during the ant colony algorithm. The objectives of the suggested algorithm in [11] is to predict intermediate nodes and reduce energy consumption.

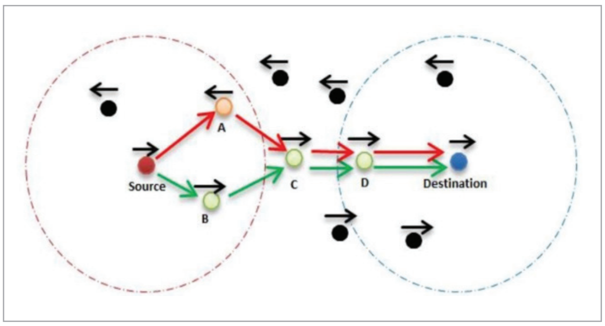
Houssaini et al. [10] proposed GPSR+Predict protocol as a mechanism for greedy forwarding strategy, in which the movement of nodes can be predicted. Each mobile node estimates its location in the near future using its current location and its velocity, and then including this predicted location in its periodic beacon packet. Each neighboring node receiving this beacon takes this estimation into consideration in the decision of selecting the next hop. This process of estimation is repeated by every node in the network and at each time the node broadcasts the beacon.

The GPSR+Predict protocol also adds some modifications to the greedy forwarding strategy. Instead of firstly searching for the neighboring node which is closer to the destination in its neighbor list, the forwarder node can start immediately searching for the destination node itself in its neighbor list. This modification decreases the duration time of the search process.

In addition, the GPSR+Predict protocol avoids forwarding data packets to nodes that move in the opposite direction of the destination. This will ensure minimizing the end-to-end delay in the routing process. As shown in Figure 2, the source node will avoid sending the packet to node A, although it is the closest neighbor to the destination. The source node will send the packet to node B since it is in the direction of the destination node. In this example, the green arrows show the route of the packet (Source > B > C > D > Destination), while the black arrows show the movement of nodes.

Figure 2

Opposite Direction Problem



The GPSR+Predict protocol was simulated in highway and urban scenarios, and shows an improvement in PDR, throughput and end-to-end delay compared to the original GPSR protocol. Unfortunately, the GPSR+Predict protocol still uses the periodic beaconing strategy. In addition, the prediction is performed by every node in the network even if there are no data packets transmitted among nodes.

3. The Proposed Protocol (LDAB-GPSR)

The major assumptions that have been used to develop the proposed protocol are:

1 All nodes know their own geographical position coordinates via GPS receivers, and thus each node can calculate its current speed on its own.

2 Nodes are randomly distributed in an unobstructed flat area, and this ensures that the position of nodes can be accurately retrieved by GPS receivers.

3 Omnidirectional antennas are used by all nodes to forward any type of packet.

4 The IEEE 802.11n Medium Access Control (MAC) protocol is used to respond to the failure in transmitting feedback and to prevent head-of-line blocking. This MAC uses the well-known Carrier Sense Multiple Access with Collision Avoidance (CSMA/CA) medium access to guarantee collision-free transmission in the network and avoid the interference due to the synchronous transmissions of different nodes.

5 All nodes enable the promiscuous mode on their network interface to receive copies of all packets from all nodes that are located within their coverage area.

6 Unless otherwise stated, all values and sub-procedures of the original GPSR protocol are used in the LDAB-GPSR protocol.

As previously mentioned, the LDAB-GPSR protocol is based on the original GPSR routing protocol. The modifications that have been implemented mainly focus on the greedy forwarding strategy and the beaconing strategy. The perimeter forwarding strategy will remain unchanged compared to the original GPSR routing protocol.

The beacon packet in the GPSR protocol has a crucial role in maintaining an accurate local topology in the neighbor list of each node and ensures that the new or leaf nodes can be detected. In the LDAB-GPSR protocol, the adaptive beaconing technique is based on the speed of neighboring nodes and the traffic load. Moreover, the location prediction technique takes into account the speed and direction of the nodes along the traffic routes into consideration in greedy forwarding strategy. This implies that a modification to the beacon packet format is necessary to permit any node to exchange additional useful information with others.

Three new fields are added to the beacon packet format: the current speed of the node, the beacon packet interval time (BPIT) and the originating time stamp. Since all nodes are equipped with GPS devices, the geographical position coordinates can be obtained. In addition, the speed of the node can be calculated by dividing the traveled distance (i.e. two successive GPS readings) by the amount of time it takes. The traveled distance is measured using the Euclidian distance. The beacon packet interval time (BPIT), as the name implies, is the time required to broadcast the next beacon. BPIT value is adapted at each node based on the speed of neighboring nodes and the traffic load. The originating time stamp is the time when the beacon is triggered.

Modifications to the control beacon packet have been previously made by several researchers in their proposed works [12]. These modifications include adding, removing or even editing some fields in the control packet format. Extending the control packet size may incur additional bandwidth and increase the control overhead. However, appending a few fields to the control packet is tolerated in purist of improving the overall performance of the protocols.

The neighbor list table at each node in the original GPSR protocol mainly includes the identifier of the neighboring nodes and their geographical position coordinates. In the LDAB-GPSR protocol, we extend the neighbor list table structure by appending four new fields that will help each node to check the connectivity status with its neighboring nodes and predict their future positions. These new fields are the following: the previous coordinate position of the neighbor node, the speed of the neighbor node, the time stamp and the beacon packet interval time (BPIT). The first three fields will help each node to know the direction of each neighboring node, examine if the neighbor node will stay within its coverage area, and predict the future position of each neighboring node. The last field, which is the beacon packet interval time (BPIT), will help each node to calculate the timeout interval time (T) for each neighboring node. If a node did not receive the next beacon from its neighbor node for a period longer than three times the BPIT value (i.e. timeout interval time), the neighboring node is considered to have left the coverage area.

In the LDAB-GPSR protocol, whenever a node receives a packet, it will firstly check if the destination already exists in its neighbor table. This way, if the destination exists, we reduce the time required to calculate the distances between each neighbor in the neighbor list and the destination. If the destination does not exist, the node uses the new modified greedy forwarding strategy for the forwarding decision.

The greedy forwarding strategy in the LDAB-GPSR protocol is initiated in a different way compared to the original GPSR protocol. Whenever a node i receives a greedy-mode packet, instead of looking up the neighbor list to get the closest neighbor to the destination, it checks whether each neighboring node will stay within its coverage area before predicting its future position. Firstly, node i which is at location (X_i, Y_i) extracts both the current (X, Y) and previous ($X^{\wedge}$, $Y^{\wedge}$) positions of that neighbor from its neighbor list to calculate both the old and current distances between them by using the Equations (1) and (2):

$$\boldsymbol{D} = \sqrt{(X_i - X)^2 + (Y_i - Y)^2} \tag{1}$$

$$\boldsymbol{D}^{\wedge} = \sqrt{(X_i - X^{\wedge})^2 + (Y_i - Y^{\wedge})^2}\,. \tag{2}$$

If the current calculated distance $\boldsymbol{D}$ is less than the old calculated distance $\boldsymbol{D}^{\wedge}$, the two nodes are converging and thus the neighbor is still within the coverage area of node i. On the contrary, if the current calculated distance is higher than the old calculated distance, the two nodes are diverging, and thus the neighbor might probably leave the coverage area of node i.

Another test is also done by estimating the expected linear distance to be traveled by this neighbor far away from the node. This estimation is calculated by multiplying the current speed of the neighbor with the difference between the current time and the time stamp (i.e. last time a beacon was received from that neighbor), as shown in Equation (3):

$$D_{traveled} = SP * (CT - ts), \quad (3)$$

where **ts** is the time stamp of the neighbor, SP is the speed of the neighbor, and CT is the current time.

If the aggregate of both the estimated traversed distance and the current calculated distance is larger than the radio range (e.g. 250 meters), the neighbor most probably will be out of range of node *i*. In this way, we exclude all neighbors that will most likely leave the coverage area of node *i* from being candidates for next hop in decision forwarding.

A location prediction technique is adopted for the greedy forwarding strategy in the LDAB-GPSR protocol. In this technique, and after the node ensures that its neighbor will stay within its coverage area, the future position of the neighbor is predicted. Firstly, node *i* extracts both the current and previous positions of the neighbor from its neighbor list to calculate the angle between the two positions, and then the expected linear distance to be traveled by this neighbor far away from node *i* is estimated. Now, the future coordinate's position (X_p, Y_p) of the neighbor can be estimated using the following Equations (4) and (5):

$$X_p = X + (\cos(\theta) * D_{traveled}) \quad (4)$$

$$Y_p = Y + (\sin(\theta) * D_{traveled}), \quad (5)$$

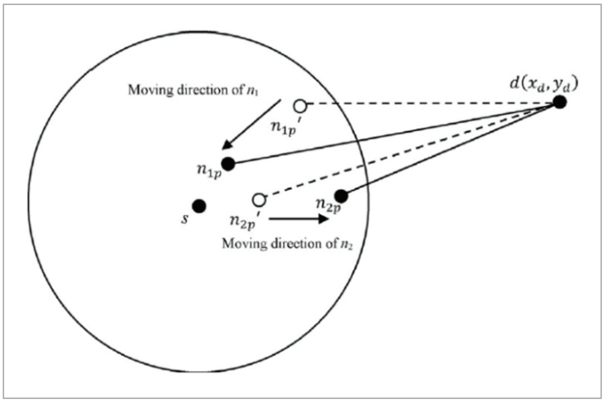
where θ is the angle between the both (X, Y) and ($X^{\wedge}$, $Y^{\wedge}$) positions.

In the LDAB-GPSR protocol, the routes chosen during the greedy forwarding strategy are more stable, since the forwarder node excludes the neighboring nodes that will likely leave its coverage area, plus it predicts the future location of its neighboring nodes before the forwarding decision is taken. For that reason, the probability of the packet delivery ratio is expected to be much higher than both the GPSR+Predict protocol.

Figure 3 demonstrates the greedy forwarding strategy of the LDAB-GPSR protocol in a network scenario. In this network, the source node S wants to send a data packet to the destination D. Since the destination node is not listed in its neighbor list, the greedy forwarding strategy is initiated. Node S checks if all of its neighbors (n_1 and n_2) will stay within its coverage area. After that, node S predicts the future locations of all its neighbors (n_{1p} and n_{2p}). Then node S forwards the data packet to node n_2, since node n_2 will be closer to the destination D than node n_1. In contrast, the greedy forwarding strategy of the original GPSR protocol will forward this data packet to node n_1, and this will lead to a longer route from source S to destination D.

Figure 3

The Greedy Forwarding Strategy in the LDAB-GPSR protocol



Adaptive Beaconing

In the original GPSR protocol, each node periodically broadcasts a beacon packet to declare its own identifier and position, the default beacon packet interval time is set to 1 second. The nodes that receive the beacon packet will update the entry in their neighbor tables as a candidate next hop when the forwarding decision is needed. However, when a node does not receive a beacon packet from its neighbor node for a period of time longer than 3 times the beacon packet interval time (i.e. timeout interval), it will consider that the neighbor node is out of its coverage area.

In the proposed LDAB-GPSR protocol, an adaptive beaconing technique is used, in which the beacon packets are only broadcasted when they are needed, and thus the control overhead, the consumed energy and the network congestion are reduced. The adaptive beaconing technique is based on the mobility of nodes and the traffic load to reach the goal. More specifically, the frequent beacon packets broadcasting by nodes that move slowly is unnecessary because they are more likely to stay in the coverage area of their neighbors. In addition, when there is no traffic flow between the nodes in the network, broadcasting beacon packets is unnecessary.

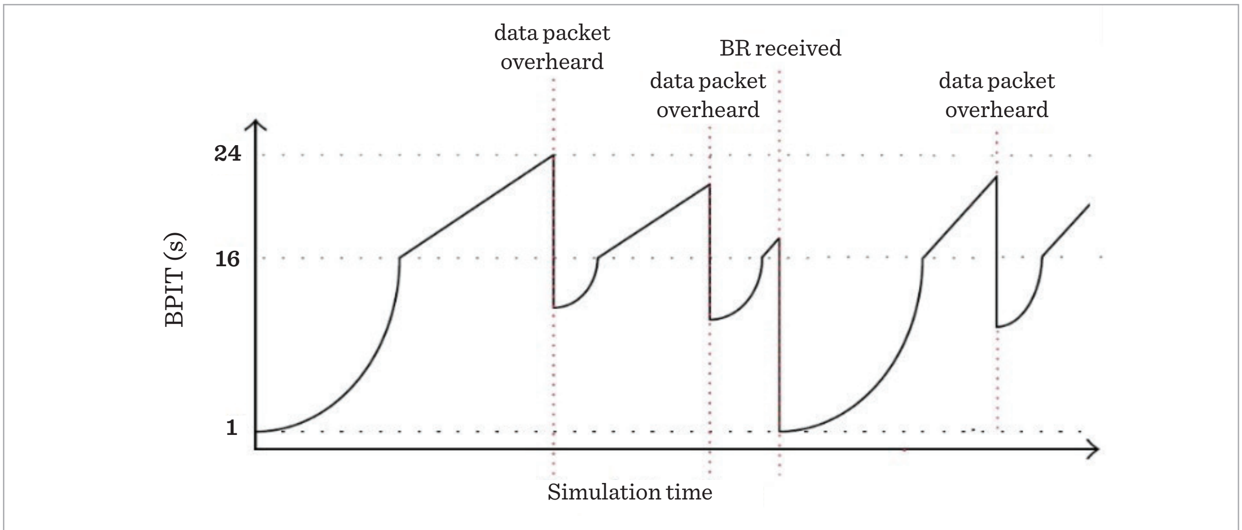
In the LDAB-GPSR adaptive beaconing technique, the slow start algorithm is utilized to control the beacon packet interval time (BPIT). The slow start algorithm is a congestion control algorithm used to control the data flow in the network. In this algorithm, we divided the nodes into two groups based on their mobility, taking the mobility of the neighboring nodes into consideration. A node with speed slower than the average speed of its neighboring nodes is considered as a low mobility node, and hence longer BPIT is assigned. In contrast, a node with speed higher than the average speed of its neighboring nodes is considered a high mobility node, and hence shorter BPIT is used.

Moreover, since the promiscuous mode of all nodes is enabled in the network, all nodes can overhear all data packets forwarded in their coverage area. When a node overhears a data packet form a neighbor node, it will immediately decrease its BPIT to announce itself and get involved in the forwarding decisions. In addition, a new control packet is introduced in our technique, which is a Beacon Request packet (BR). This packet is triggered by a node that notices there is no neighboring nodes in its neighbor list. Each node receiving the beacon request packet immediately sends a beacon packet as a response. In this way, the network becomes more coherent.

Figure 4 demonstrates how we can employ the slow start algorithm to adapt the beacon packet interval time. Firstly, each node checks if its moving speed can be classified as low mobility node or as high mobility node. When a node moves in a low mobility speed, it will start increasing its BPIT exponentially until two-thirds of the maximum beacon packet interval time (MaxBPIT, 24 seconds) given that no data packets are overheard nor a BR packet is received. When the BPIT exceeds two-thirds of the MaxBPIT with no data packet overheard and with beacon requests absence, the BPIT starts increasing linearly by one-third of the previous BPIT. The value of MaxBPIT (i.e. 24 seconds) was chosen based on simulation experiments. The BPIT behavior before and after two-thirds of the maximum beacon packet interval time was used in [8] to reduce the control overhead in the On-Demand Multicasting Routing Protocol (ODMRP).

Figure 4

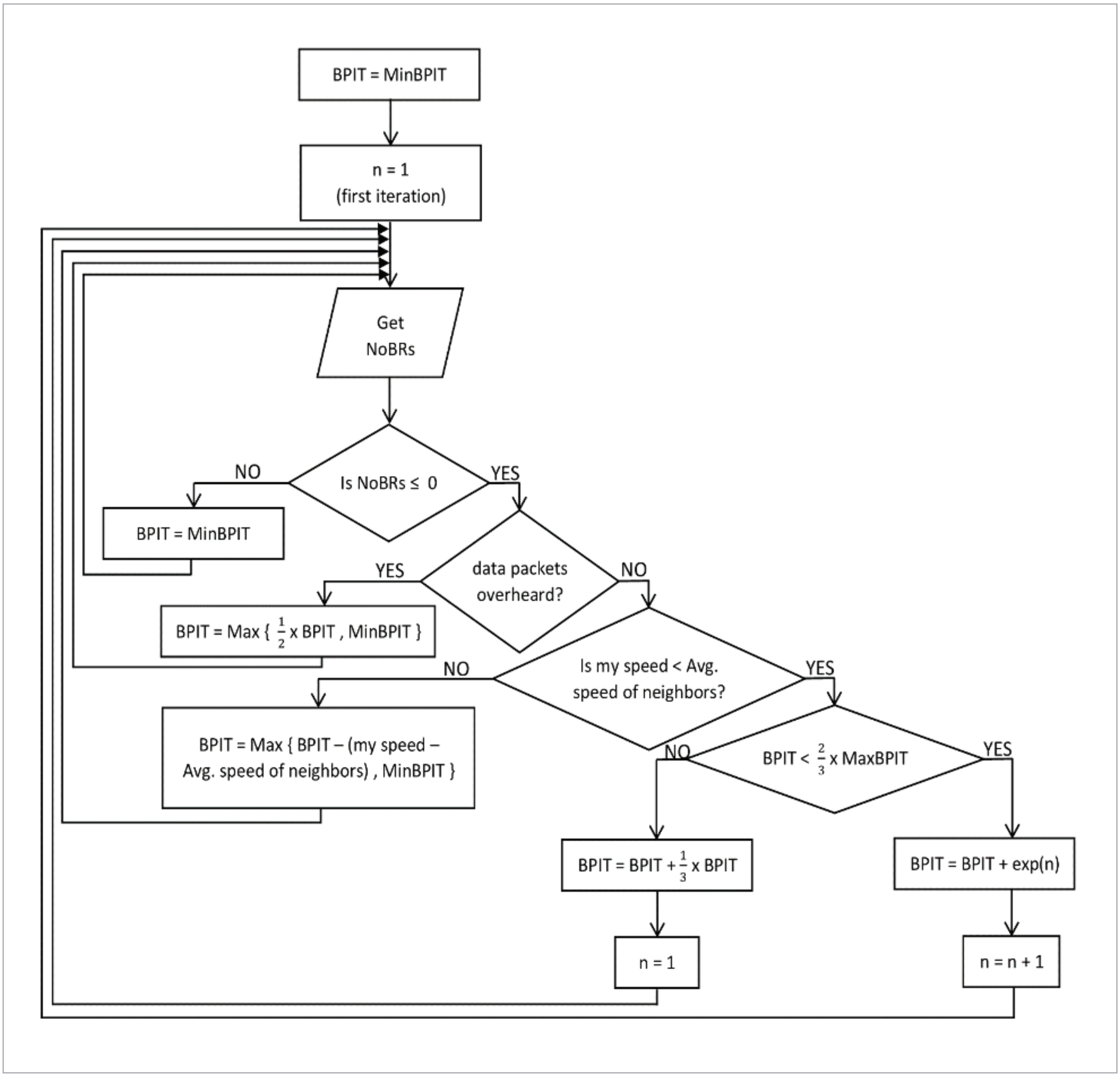
The Slow Start Algorithm of the Adaptive Beaconing Technique



However, when a node starts to move in a high mobility speed, it decreases its BPIT in proportion to the difference between its previous speed and the current average speed of its neighbors. Whenever a node overhears a data packet, it decreases its BPIT to half of the current value (i.e. ½ BPIT). Moreover, whenever a node receives a beacon request packet, it decreases its BPIT to the minimum beacon packet interval time (MinBPIT, 1 second). Figure 5 presents the flow diagram of the adaptive beaconing technique in the LDAB-GPSR protocol.

Figure 5

Adaptive Beaconing Technique in the LDAB-GPSR Protocol



4. Simulation Results

The performance of the LDAB-GPSR protocol has been evaluated using the NS-2.35 simulator which is a widely used simulator to study the performance of MANETs. In order to measure the effectiveness of our enhancement, we compare the LDAB-GPSR protocol to GPSR+Predict protocol [10].

The topology of the simulated network consists of a set of 40 to 80 randomly distributed nodes in a rectangular region (2000 meter x 450 meter). Each run simulates the network for 300 seconds. Each simulation scenario is run ten times with different randomly generated movement patterns. For each scenario, the results were calculated as the average of these ten simulation runs.

On average, there is one node per 22,500 square meters of the map. A transmission range is set to be nearly 200,000 square meters. As a result, there is an average of approximately 8 neighbors within the range of an average node in this network.

Other simulation parameter values are summarized in Table 1 below. A two-ray ground propagation model is employed instead of free space model. The NS wireless simulator allows distributed nodes to travel in an unobstructed plane. Movement of nodes based on the random waypoint model, where a source node chooses a destination position uniformly at random in the simulated region, also each node chooses its speed uniformly at random, and then moves to that waypoint. Upon arriving at the waypoint, the node pauses for a period of time before repeating the same process again. In our simulations, the pause time is set to 0 seconds to force nodes to keep moving during the whole simulation time since mobility is a crucial issue in MANETs and VANETs. Furthermore, we use the same simulation parameters that are used by [13] except for a bigger network area in order to reduce the node density.

Table 1
Simulation Parameters

Parameter	Value
MAC protocol	802.11n
Propagation model	Two-ray ground
Transmission range	250 m for IEEE 802.11n
Traffic model	CBR
Simulated network area	2000 meter x 450 meter
Simulation time	300 seconds
Node placement	Randomly
Number of nodes	40, 50, 60, 70, 80 nodes
Data rate	2, 3, 4, 5, 6 kbps
Number of connections	12, 18, 24, 30, 36
Data packet size	64 Byte
Mobility model	Random Waypoint
Pause time	0 seconds
Maximum Speed	20, 30, 40, 50, 60 m/s
Minimum beacon interval	1 second
Interface queue length	50 packets

In the performance evaluation process of the LDAB-GPSR protocol, and for comparison purposes, the following performance metrics are measured:

- **Packet Delivery Ratio (PDR)**: the ratio of the total number of data packets successfully delivered to their destination to the total number of data packets generated by all sources.
- **Control Overhead**: the total number of the control packets that are sent network-wide during the whole simulation time. In the case of GPSR routing protocol, control overhead includes the total number of transmitted beacon packets.
- **Throughput**: the amount (or size) of data packets delivered successfully to destination node from the source node in a given time period.
- **Average End-to-End (E2E) Delay**: the average time that a data packet takes from transmitting it until it arrives to its final destination. This time includes all possible delays such as transmission, propagation, queuing and processing delay.

Any new routing protocol must be evaluated in two directions. The first direction is how the new routing protocol enhances performance and network efficiency. Different researchers measure the enhancements using different performance metrics. In this paper, it is measured by the following metrics: PDR, throughput, and average end-to-end delay. The second direction, which is measuring the additional cost, is added by the new routing protocol. In this paper, we used number of control packets metric to represent the routing cost.

4.1. Packet Delivery Ratio

Figure 6(a) shows the packet delivery ratio as the number of distributed nodes increases in the network with steps of 10 nodes from 40 to 80. The data rate, the number of connections and the maximum speed of nodes are fixed at 2 kbps, 12 CBR connections and 20 m/s, respectively. In both the GPSR+Predict and LDAB-GPSR protocols, the PDR keeps increasing. Obviously, increasing the number of nodes in the network increases the number of nodes in the coverage area of each node, and thus will increase the probability of choosing the appropriate next hop and hence finding shorter routes. The LDAB-GPSR protocol outperforms GPSR+Predict protocol due to the dual adopted techniques: the location prediction technique which aims to select the most appropriate next hop in the forwarding path and the adaptive beaconing technique that prevents nodes from utilizing more and more network bandwidth by reducing the control overhead.

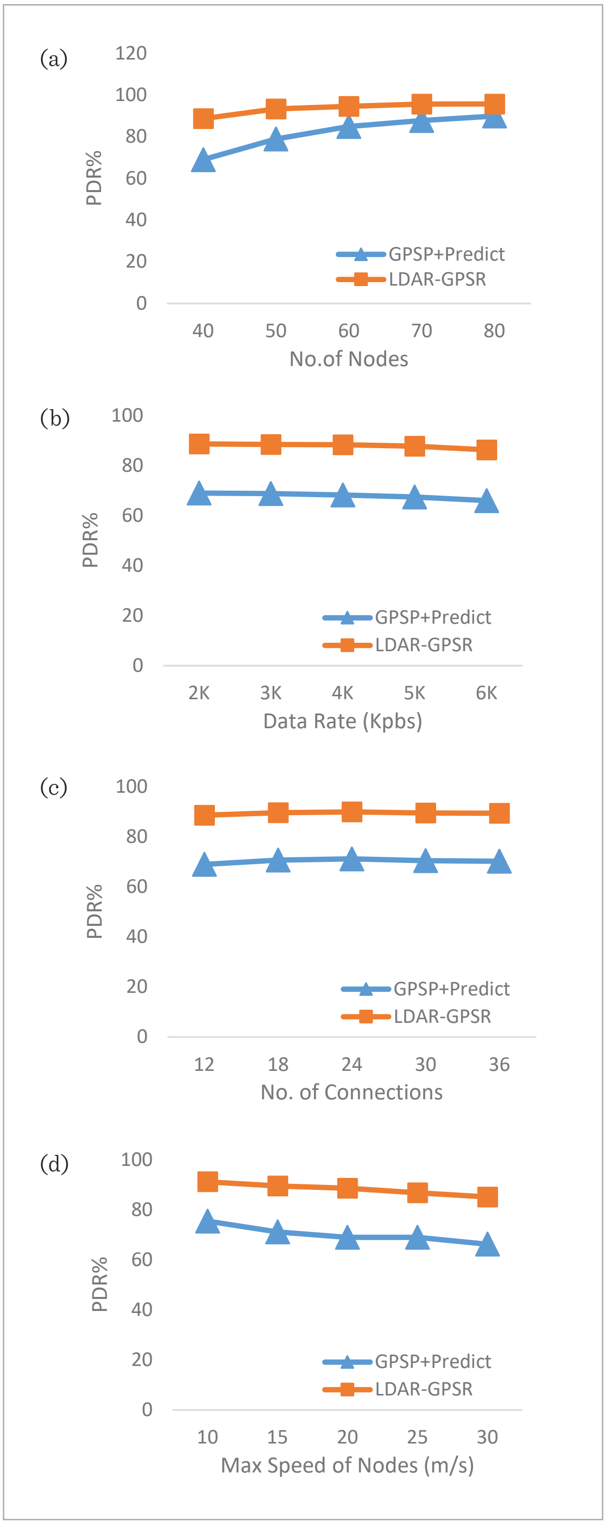
As shown in Figure 6(b), the PDR decreases as the data rate increases with steps of 1 kbps from 2 to 6 kbps. The number of nodes, the number of connections and the maximum speed of nodes are fixed at 40 nodes, 12 CBR connections and 20 m/s, respectively. This behavior is expected since as the number of data packets increases while the number of nodes is constant, the network becomes more congested. Therefore, the probability of collisions among nodes increases. However, the LDAB-GPSR protocol achieved better PDR than GPSR+Predict protocol. This is because of the adopted location prediction technique which guarantees choosing the optimal next hop through which data packets travel, and the adaptive beaconing technique which significantly reduces control packets. Hence, the network bandwidth is utilized efficiently.

Figure 6(c) shows the PDR as the number of connections increases with steps of 6 from 12 to 36 CBR connections. The number of nodes, data rate and the maximum speed of nodes are fixed at 40 nodes, 2 kbps and 20 m/s, respectively. It is easy to see that PDR starts to increase slightly, and this is due to the increase in the amount of data packets that needs to be delivered in the network, and the possibility to find destination nodes in the coverage area of source nodes. However, after a certain number of connections, the network becomes saturated and the amount of collisions in the network also increases, and the PDR starts decreasing. The LDAB-GPSR protocol remarkably improves the PDR compared to GPSR+Predict protocol.

As shown in Figure 6(d), increasing the maximum speed of nodes with steps of 5 from 10 to 30 m/s will lead to decreasing the PDR. The number of nodes, data rate and the number of connections are fixed at 40 nodes, 2 kbps and 12 CBR connections, respectively. This behavior is expected since the network is more exposed to frequent topological changes. However, the LDAB-GPSR protocol manages to improve the PDR compared to GPSR+Predict protocol. This is due to the adaptive beaconing technique which takes the mobility of the nodes into consideration when reducing the control overhead. In addition, this is because the location prediction technique is more aware of changes in the location of the nodes.

Figure 6

Simulation Results of Packet Delivery Ratio



4.2. Control Overhead

The control traffic overhead is measured while varying network density, data rate, number of connections and maximum speed of nodes respectively.

Figure 7(a) shows the increase in control overhead when the number of nodes increases from 40 to 80 nodes. The data rate, the number of connections and the maximum speed of nodes are 2 kbps, 12 CBR connections and 20 m/s, respectively. Distinctly, the overhead increases because the larger number of nodes broadcast a larger number of control packets. In the GPSR+Predict protocol, the control overhead is increased since the periodic beaconing (PB) strategy broadcasts control packets proportional to the product of the number of nodes and the simulation time. In the LDAB-GPSR protocol, the control overhead is greatly reduced due to the adaptive beaconing technique.

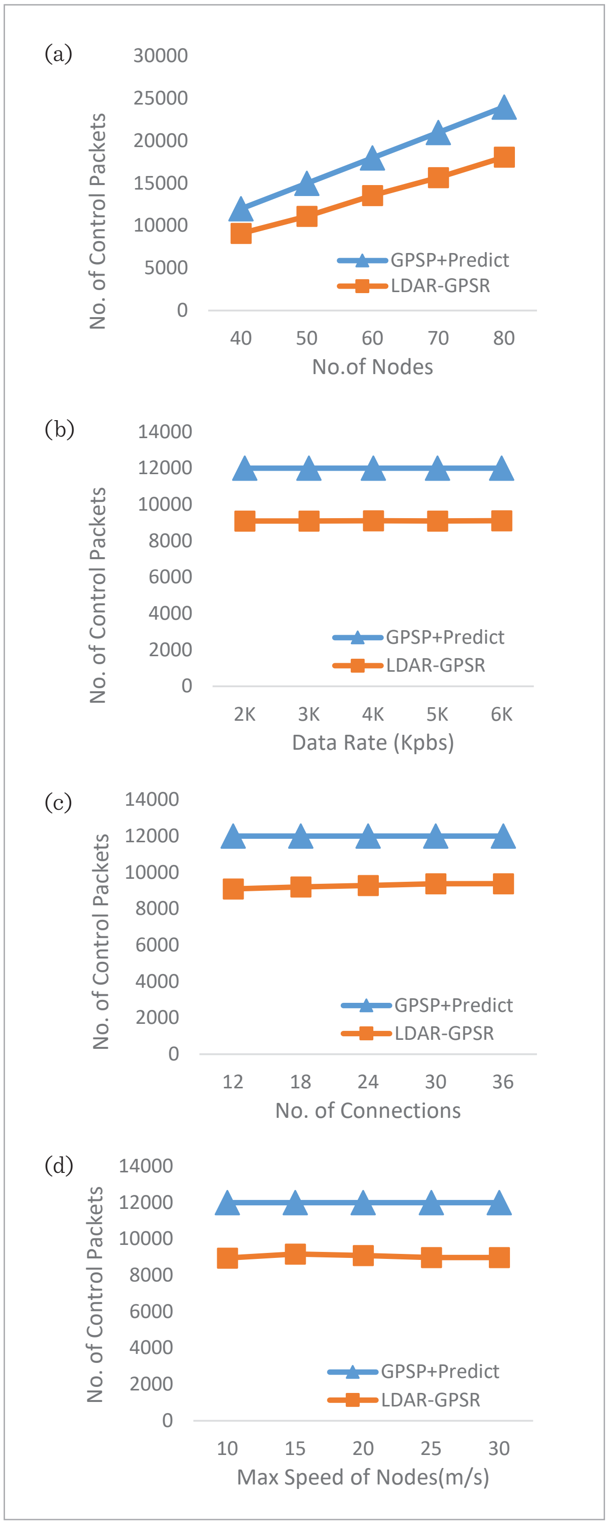
As shown in Figure 7(b), the control overhead stays at a constant level as the data rate increases from 2 to 6 kbps. The number of nodes, number of connections and the maximum speed of nodes are fixed at 40 nodes, 12 CBR connections and 20 m/s, respectively. In the GPSR+Predict protocol, the periodic beaconing strategy is independent of data packet rate. Consequently, control overhead stays at a high level. In contrast, the LDAB-GPSR protocol has a lower level for control overhead due to the adaptive beaconing technique, which adapts the rate of beacons based on the mobility of the nodes and the number of traffic flows.

Figure 7(c) shows the control overhead as the number of connections increases. The number of nodes, data rate and maximum speed of nodes are 40 nodes, 2 kbps and 20 m/s, respectively. Regardless of the increase in the number of connections, the control overhead in the GPSR+Predict protocol stays at a constant level, since the periodic beaconing strategy is independent of the number of connections. However, the LDAB-GPSR protocol will broadcast more beacons in the network as the number of connections increases in order to keep the topology accurate as the traffic load increases, but the amount of control overhead is much smaller compared to the GPSR+Predict protocol.

Figure 7(d) shows the control overhead as the maximum speed of nodes increases. The number of nodes, data rate and number of connections are 40 nodes, 2 kbps and 12 CBR connections, respectively. The control overhead in the GPSR+Predict protocol is still

Figure 7

Simulation Results of Control Traffic Overhead



at a constant level as the maximum speed of nodes increases as the periodic beaconing strategy is independent of the mobility of nodes. In contrast, the control overhead in the LDAB-GPSR is fluctuating at a lower level than the GPSR+Predict protocol. This is due to the adaptive beaconing technique which adapts the beaconing rate based on the mobility of nodes compared to the average speed of their neighbors.

4.3 Throughput

Figure 8(a) shows that LDAB-GPSR protocol has higher throughput than the GPSR+Predict protocol as the number of nodes increases. The data rate, number of connections and the maximum speed of nodes are 2 kbps, 12 CBR connections and 20 m/s, respectively. This increase in throughput is explained by the increase in the amount of data packets successfully delivered, as discussed earlier in PDR.

Figure 8(b) shows that LDAB-GPSR protocol achieved better throughput than the GPSR+Predict protocol when the data rate increases. The number of nodes, number of connections and maximum speed of nodes are kept at 40 nodes, 12 CBR connections and 20 m/s, respectively. Obviously, as the data rate increases, the amount of data packets sent increases while the packet delivery ratio remains reasonably high, which increases the overall throughput from source to destination. A similar thing can be said when increasing the number of connections, while maintain other parameters at 40 nodes, 2 kbps and 20 m/s, see Figure 8(c).

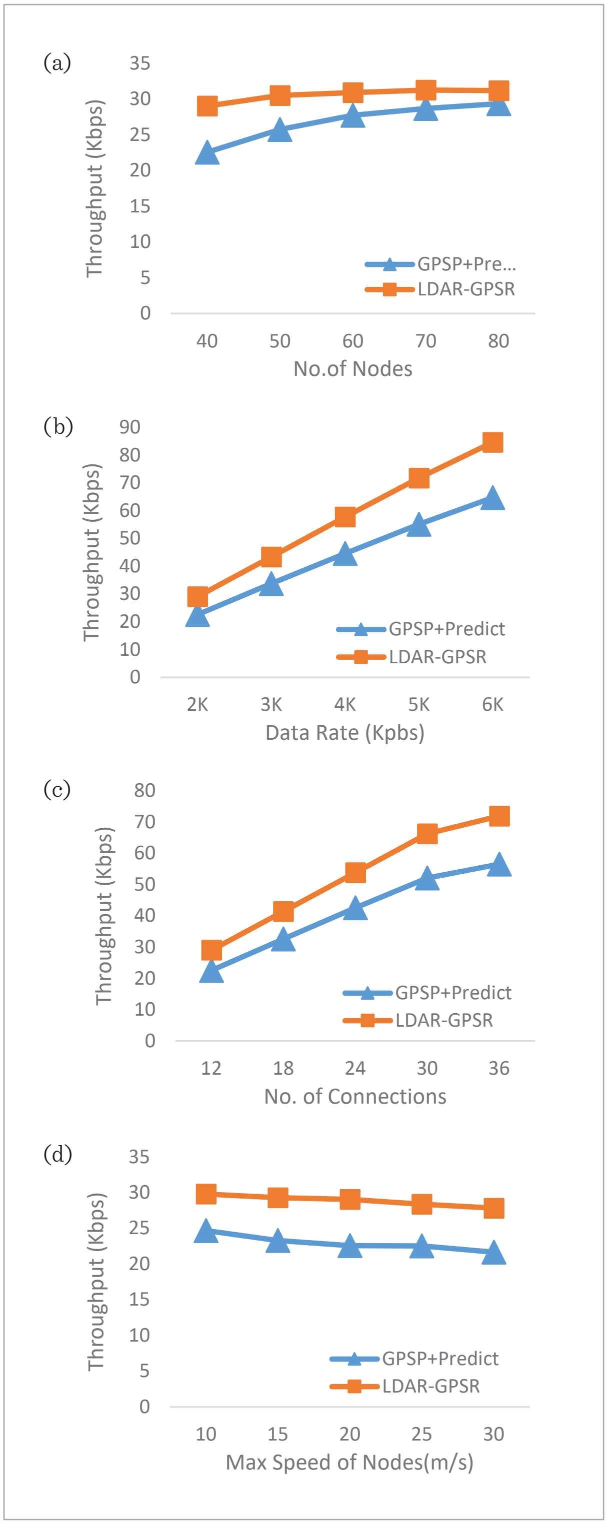
Figure 8(d) shows that the LDAB-GPSR protocol has a higher throughput than both the GPSR+Predict protocol when the maximum speed of nodes increases. The number of nodes, data rate and the number of connections are 40 nodes, 2 kbps and 12 CBR connections, respectively. This is similar to the PDR behavior discussed earlier.

4.4 Average End-to-End Delay

Figure 9(a) shows the change in average end-to-end delay as number of nodes increases in the network. The other parameters are 2 kbps, 12 CBR connections and 20 m/s. It is to be noted that as the number of nodes increases, the contentions and collisions among nodes increase, and thus the average required time to deliver data packets from source to destination increases. In the GPSR+Predict protocol, the

Figure 8

Simulation Results of Throughput



chosen routes are not the shortest ones. Therefore, we see a higher average end-to-end delay to deliver data packets. However, a larger amount of data is delivered (higher PDR) in the LDAB-GPSR protocol compared to the GPSR+Predict protocol at approximately similar average delay.

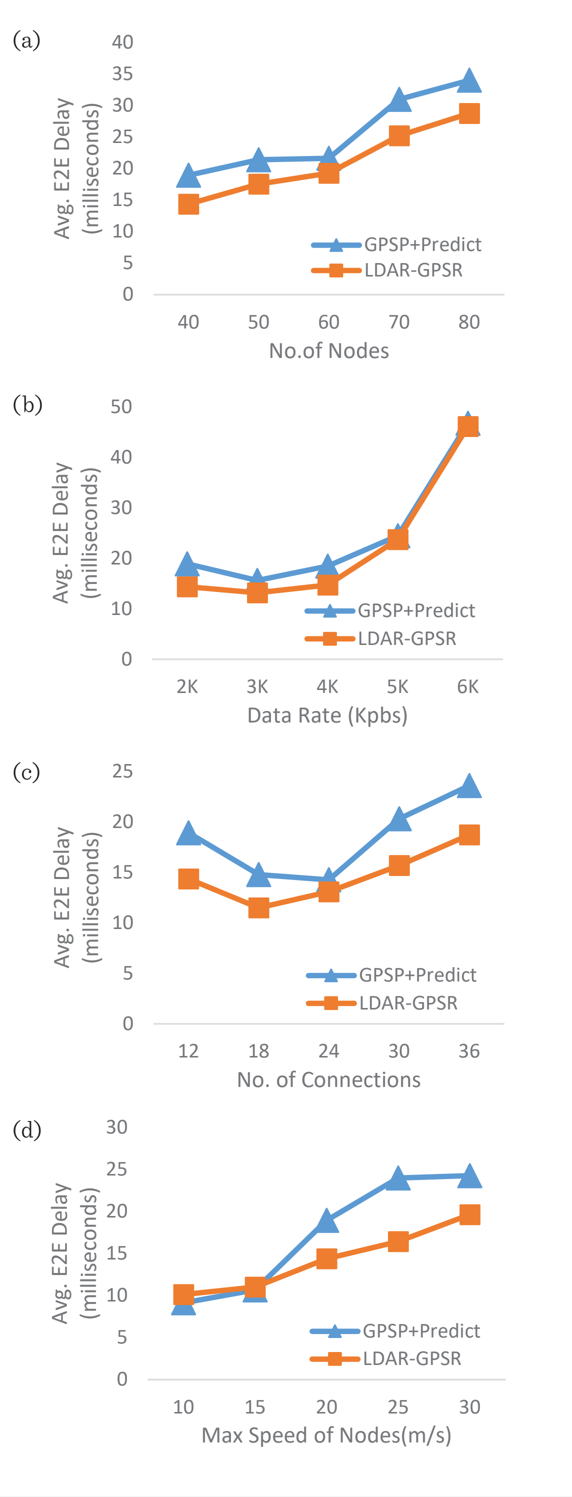
Figure 9(b) shows the average end-to-end delay as the data rate increases. The number of nodes, number of connections and maximum speed of nodes are 40 nodes, 12 CBR connections and 20 m/s, respectively. Rationally, as the number of data packets increases in the network, the overall time required to deliver such data packets increases. In all protocols, the average end-to-end delay decreases slightly until the network becomes congested by the presence of huge data traffic, and hence the average end-to-end delay starts to increase dramatically. However, the Figure shows that both the GPSR+Predict and LDAB-GPSR protocols have similar results. But again, the LDAB-GPSR protocol delivers a larger amount of data than the GPSR+Predict protocol at approximately the same average end-to-end delay.

Figure 9(c) shows a similar behavior as the number of connections increases. The number of nodes, data rate and maximum speed of nodes are 40 nodes, 2 kbps and 20 m/s, respectively. Increasing the number of connections will increase the amount of data packets that need to be delivered in the network but will also increase the possibility of finding destination nodes in the coverage area of source nodes, and that explains why the average end-to-end delay starts to decrease, but after a while, the network becomes saturated and the amount of collisions and contentions in the network increase leading to an increase in the average end-to-end delay.

Finally, Figure 9(d) shows the average end-to-end delay when the maximum speed of nodes increases for 40 nodes, 2 kbps and 12 CBR connections. Both the GPSR+Predict and the LDAB-GPSR protocols have a close average end-to-end delay.

Figure 9

Simulation Results of Average End-to-End Delay



5. Conclusions

In this paper, the LDAB-GPSR protocol is proposed to enhance the routing process and reduce the control overhead in the GPSR+Predict protocol. In LDAB-GPSR, the location prediction technique is introduced to enhance the routing process by choosing more stable routes for data forwarding. The forwarder node firstly checks if all neighboring nodes in its neighbor list will stay in its coverage area, then predicts the future position of its neighboring nodes before making the forwarding decision. This way, the amount of successfully delivered data packets increases. In addition, an adaptive beaconing technique is introduced to reduce the control overhead by suppressing the periodic beacon packets that are unnecessary. A slow start algorithm is employed to adapt the beacon packet interval time based on mobility of nodes and the data traffic load instead of the typical periodic beaconing strategy. Consequently, all nodes along the forwarding route maintain an accurate local topology in their neighbor lists.

Our simulations showed that the LDAB-GPSR protocol improves packet delivery ratio, control overhead, throughput, and average end-to-end delay compared to the GPSR+Predict protocol. The proposed protocol significantly reduces the control overhead and hence prolongs the network lifetime.

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