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ROUTELESS ROUTING PROTOCOLS OVER MASNETS: MORE ENERGY SAVING APPROACHES

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ABSTRACT

In this paper, two efficient hybrid routeless routing protocols (static and adaptive channel width) for Mobile Ad hoc Sensor Networks (MASNETs) have been proposed. They are based on Location-Aided Routing (LAR) and Received signal strength-Aided Flooding (RAF) protocols. Our protocols maintain geographical Route Broadcasting Virtual Channels (RBVC) with different widths between a source node and its destination to reduce the rebroadcasts of packets. Hence without predefined source-destination route, i.e., routeless, only some nodes, inside the RBVC, may contribute in rebroadcasting packets. Simulation results show that our protocols are able to outperform both RAF and LAR based protocols with respect to energy consumption and packet delivery ratio.

KEYWORDS

Network Protocols, Wireless Network, Mobile Network, LAR; RAF; flooding; geo-flooding; controlled flooding; routeless *routing.*

1. INTRODUCTION

Routing protocols researchers face set of challenging obstacles in the field of Mobile Ad hoc Sensor Networks (MASNETs), as shown next. In *mobile* wireless networks, packets are exposed to a variety of signal degradations such as shadowing, fast/slow fading, etc. Packet losses are intrinsic and inevitable in the wireless link, which has very limited bandwidth. *Mobility* of the nodes enforces frequent topology changes and links breakages. In an *ad-hoc* network, there is no centralized control unit that regulates the traffic among the mobile nodes and authenticates supplicant nodes. In *sensor* networks, sensor nodes have limited power, processing capability, short transmission range, and limited storage space. Hence, any consideration of a routing mechanism should include these limitations and factors to ensure high network throughput, minimal bandwidth usage and low energy consumption.

Many researchers have proposed routing protocols for MASNETs [1, 2]. Unfortunately, such protocols severely suffer from route maintenance overhead. Route maintenance mechanisms require more *control* packets to be transmitted with any change in the topology. Transmitting of such control packets consume more energy bandwidth usage. This leads to high failure rate among sensor nodes.

To alleviate the aforementioned route maintenance problem, researchers [3-13] have proposed mechanisms to reduce the number of transmitted control packets, in an attempt to reduce the energy and bandwidth usage. In such approaches, every node collects information about its neighbors by exchanging periodical control packets or by overhearing its neighbors' transmissions. That information is used to reroute data packets in case of link failures or

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topology changes. However, with nodes high speed mobility and frequent topology changes such approaches may fail, resulting in the traditional high overhead routing maintenance mechanisms.

Another group of researchers used controlled versions of the naive classic *open flooding* protocol [14-19]. In their controlled flooding protocols, they deployed techniques range from geographically controlled transmission areas to a self-maintaining delay function in the node for packet broadcastings. Yet, they still suffer huge overhead due to many duplicate packets' broadcasts and exchange of control messages (one-hop neighbor knowledge) [20–23], leading to inefficient bandwidth and energy budget management.

In this paper, we present *routeless*, energy-efficient, fault-tolerant, controlled and location-aware flooding protocols that use the received signal strength, remaining energy and location information as main factors in deciding which nodes are eligible for rebroadcasting. In our protocols, source nodes do not require the knowledge of their neighbours' locations. However, source nodes need to know their destinations' location. Our approaches result in fewer rebroadcast packets and better savings in energy and bandwidth.

The rest of the paper is organized as follows: Section 2 reviews related work. Section 3 gives a description of our *routeless* routing protocols. Sections 4 and 5 contain simulation results and a conclusion, respectively.

2. RELATED WORK

In this section we describe some of the protocols that do not require neighbour knowledge.

Ko, Y and Vaidly, N in [19] and [24] proposed a location-aided routing (LAR) in MANETs. In LAR, a source node seeks and obtains the destination node's location and average speed information. Then it uses this information to form a rectangle-shaped region that connects the source and the destination nodes. Such a region consists of two zones. The first zone is called *request* zone where only nodes inside this region rebroadcast the packets generated by the source. The second zone is called the *expected* zone where the destination node resides. As time passes, the expected zone expands until it dominates the request zone or covers the whole network. In this case, LAR works as a classic flooding mechanism. If the source node does not know the location information and average speed of the destination, LAR deploys the classic flooding mechanism.

Shin, T and Yen, H in [18] proposed a location-aware routing with dynamic adaptation of request zone for MANETs. This algorithm is similar to LAR in request and expected zones. However, it uses a triangular rather than a rectangle-shaped request zone as in LAR. Moreover, it uses a more accurate method than LAR to calculate the expected zone. All nodes inside the request zone rebroadcast the packets generated by the source node to form the triangle-shaped zone. The triangle shape area increases until it covers the whole network if it fails to reach a destination.

Oberg, L and Xu, Y in [14] proposed a received signal strength-aided flooding (RAF) protocol. This protocol reduces the number of rebroadcasts required to cover the whole network, as well as all destination nodes. It uses a dynamic delay function to minimize nodes' rebroadcast, reduce energy consumption, and determine the order of their rebroadcast. At any intermediate node, receipt of a newly broadcasted message will initiate a countdown timer and the message is rebroadcasted upon its expiration. For duplicate messages with signal strength above a certain threshold, an additional delay is added to their counters; otherwise, they will be dropped.

Miremadi, S et al. in [17] proposed a directed flooding routing protocol (DFRP) in which every node is aware of its location. Every node knows the location of the network *sink* nodes. When a sensor node S has a packet P to send to a sink node D, it defines a transmission virtual aperture (TVA) with an angle θ. Then it broadcasts P inside TVA and waits for an acknowledgement from nodes inside TVA, after they receive P. If there is no acknowledgment, a new TVA with a wider angle is defined to retransmit P inside. Upon receiving packet P, by an intermediate node X, node X sends an acknowledgment back to the originator of P, then defines a new TVA with a different angle to rebroadcast P. The process continues until the destination node D receives P and sends back an acknowledgment to the last retransmitting node. In the DFRP, every node defines a TVA which might lead to more P rebroadcasts, when compared to a fixed TVA defined by the original source node.

3. ROUTELESS ROUTING PROTOCOLS

Our proposed routing protocols use *rectangle-shaped* broadcasting source-destination channel called Route Broadcast Virtual Channel (RBVC) which is similar to the one used in LAR protocol [24]. In addition, they use countdown timers, which are functions of the node's remaining energy, location information, and signal strength, to determine the back-off delay before the node rebroadcasts a (newly received) packet and to determine the order of the rebroadcast inside the broadcast channel. We aimed at lowering the rebroadcast frequency in a much tighter controlled flooding for a node consuming much less energy.

3.1. Assumptions

We assume that the MASNET has a dense number of wireless sensor nodes that are randomly deployed in a remote sensor field. All sensor nodes sense and report their readings at a constant time interval to their sink or destination nodes. In addition, all sensor and sink nodes are mobile, homogeneous in capabilities, have same transmission range *R*, have limited stored energy, and are aware of their geographical locations.

3.2. Route Broadcast Virtual Channel (RBVC)

For every source-destination pair, a RBVC is defined as a rectangular in shape with width 2α (*α is chosen by source or destination nodes, and* $\alpha \in (0, R]$) and length defined by the distance between the source and destination nodes. Other nearby mobile nodes in the network will be able to determine whether they are within or outside a RBVC based on the positional information in the broadcasted packets, inside the RBVCs, and node own potion. Only sensor nodes within a RBVC are allowed to contribute in a packet delivery mission. The number of sensor nodes inside a RBVC can vary depending on their mobility; they freely enter and leave the RBVC at any time. An insider node would quit its participation in a PBVC packet delivery upon detecting that it moved out of such RBVC, In Figure 1, a RBVC is established between source node *S* and destination node *D* with width 2α and length equals to the distance between node *S* and node *D*. Node *A*, which is inside the RBVC, is allowed to contribute to the rebroadcasting of packets between *S* and *D*. However, node *B*, which is outside the RBVC, ignores any packets between *S* and *D* unless it moves inside the RBVC.

Figure 1. RBVC

3.3. Dynamic Delay Functions

The dynamic delay functions are used to implement countdown timers at each node that self-determines when it will rebroadcast a received packet. The goal is to orchestrate the collective self- determination of packet rebroadcast by nodes inside a RBVC, via a well-designed DDF, to yield a very controlled packet propagation scheme. Such a well-behaved scheme will result in lower number of packet rebroadcasts, collisions, contentions, energy consumption, and packet retransmission redundancies. In our protocols, we use modified dynamic delay functions which are used in [14].

$$D1_j = c1\frac{|RS|^{\delta} - |r_{ij}|^{\delta}}{|RS|^{\delta}\, E_j} \quad (1)$$

$$D2_j = c2\left(\frac{|RS|^{\delta} - |r_{ij}|^{\delta}}{|RS|^{\delta}} + \frac{\beta^{\delta}}{\alpha^{\delta}} + \frac{E^{\delta}{}_{init} - E^{\delta}{}_{j}}{E^{\delta}{}_{init}}\right) \quad (2)$$

Delay function (1) is used by all MASNET nodes to determine the delay before rebroadcasting control packets generated by a source node *S*. *RS* is the receiver sensitivity in dBm, r_{ij} is the received signal strength in dBm obtained at node *j* sent by node *i*, E_j is the remaining energy at node *j*, δ is a configuration constant, and *c1* is the maximum waiting time.

Delay function (2) is used by nodes inside a RBVC to determine the delay before rebroadcasting packets. β is the distance from node *j* to the line segment that connects source node *S* and destination node *D* $(\beta \le \alpha), \alpha \le R$, E_{init} is the initial energy at node *j*, and *c2* is one-third the maximum waiting time for packets inside a RBVC.

3.4. Protocols

3.4.1 Static Channel Width (SW) protocol

Our first protocol uses a RBVC that is rectangular in shape (Figure 1) with fixed *α*, which is half of a channel width, equal to the transmission range of the originator node. In this protocol, two control packets are used. The first packet is called a *Location REQuest* packet (*LREQ*) which is broadcasted by a source node to request its destination node's geographical location.

The second control packet is the *Location UPDate* packet (*LUPD*). The *LUPD* packet is broadcasted by a destination node after constructing a RBVC to the source node, as a reply to the received *LREQ* packet. Also, *LUPD* is broadcasted by the destination when it moves outside its current active RBVC to inform the source node about its new location. The data packet header is modified to carry RBVC parameters (see Figure 2).

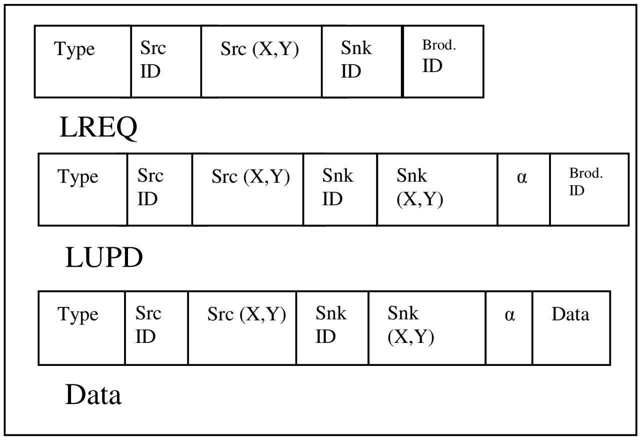

Figure 2. Network packets and network packet header of the data packet for the static width scheme.

In SW, before a source node *S* establishes a communication link with a destination node *D*, *S* has to know *D*'s location in order to construct a RBVC. If *S* does not know *D*'s location, it broadcasts a *LREQ* packet searching for *D*'s location. Then *D* has to reply to *LREQ* by broadcasting a *LUPD* packet to node *S* (Figure 3). Since node *D* knows *S*'s location information (carried by *LREQ*), it constructs a RBVC channel to node *S* and broadcasts *LUPD* packet inside it. Upon receiving *LUPD* by *S*, it constructs another RBVC to *D* and starts its session. Only nodes inside *S*-*D*'s RBVC are allowed to contribute in a packet delivery mission between *S* and *D*. When node *D* moves outside the current *RBVC*, it sends a new *LUPD* packet to *S* informing about the new *D*'s location. See pseudocode in Figure 4 for delivering packets.

```
1. IF D's location is in Location Table
    a. Fill in the header of every data packet.
2. ELSE IF a LREQ is not sent
    a. Send LREQ
    b. Wait time T for LUPD
    c. Buffer data packet
3. ELSE IF there is no LUPD for time T and maximum number of resend is not met
    a. Send a new LREQ
    b. Wait time T for LUPD
4. ELSE
    a. Drop all buffered data packets
```

Figure 3. Location Discovery Process.

```
When a node j receives a broadcast packet P from node i:

1. switch (P)
2. case LREQ
    a. IF j = D and P is a newly received packet
        i. Generate a LUPD packet and send LUPD to S with $\alpha$ = transmission range
    b. ELSE IF  j != D and P is a newly received packet
        i. Initiate a countdown timer associated with P using function (1).
        ii. IF time expired THEN rebroadcast P.
    c. ELSE IF j != D and P is seen before
        i. Cancel active countdown timer associated with P.
        ii. Stop any broadcast of packet P.
3. case LUPD
    a. IF  j = S
        i. Update Location Table.
        ii. IF LUPD is a reply to a LREQ
        iii. Start sending buffered data packet
    b. ELSE IF j !=S and P is a newly received packet
        i. IF  j is inside RBVC
            1. Initiate a countdown timer associated with P using function (2).
            2. IF timer expired and j is still inside RBVC
                a. Rebroadcast P.
        ii. ELSE
            1. Drop P
    c. ELSE IF j != S and P is seen before
        i. Cancel active countdown timer associated with P
        ii. Stop any rebroadcast of packet P


4. case DATA
    a. IF  j = D
        i. IF j is outside RBVC
            1. Send LUPD
    b. ELSE IF j !=D and P is a newly received packet
        i. IF  j is inside RBVC
            1. Initiate a countdown timer associated with P using function (2).
            2. IF timer expired and j is still inside RBVC
                a. Rebroadcast P.
        ii. ELSE
            1. Drop P
    c. ELSE IF j != D and P a seen before
        i. Cancel active countdown timer associated with P
        ii. Stop any rebroadcast of packet P
```

Figure 4. Pseudocode of delivering packets inside a RBVC (SW).

3.4.2 Adaptive Channel Width (AW) protocol

In this protocol, α is a function of the average of nodes' distances to the line segment that connects source node S to its destination node D. similar control packets used in the first scheme are used in AW. However, *LREQ* and *LUPD* packets are modified to carry the locations of all visited nodes (see figure 5).

When the source node S initiates a location discovery process, the *LREQ* packet carries the location information of every visited node. Once the destination node D receives the *LREQ* packet, it computes the average of the distances between visited nodes by *LREQ* and the line

segment between *S* and *D* nodes to be the new α. If such average is greater than *D*'s transmission range, α is set to *D*'s transmission range (note: *D* and *S* have the same transmission ranges).
When the destination node *D* transmits a *LUPD* packet as a reply to a *LREQ* packet or when the *D* node moves outside its current *RBVC*, the transmitted *LUPD* packet has to carry the location information of every visited node inside the *RBVC* (note: *LUPD* is transmitted inside a *RBVC*). Upon receiving the *LUPD* by the source node, it computes the average distance of the distances between visited nodes by *LUPD* and the line segment between *S* and *D* nodes to be the new α. The new α is always smaller than or equals to the previous α.

The location discovery process and the delivery mission inside a RBVC of adaptive width scheme are similar to the static width scheme (see figure 6).

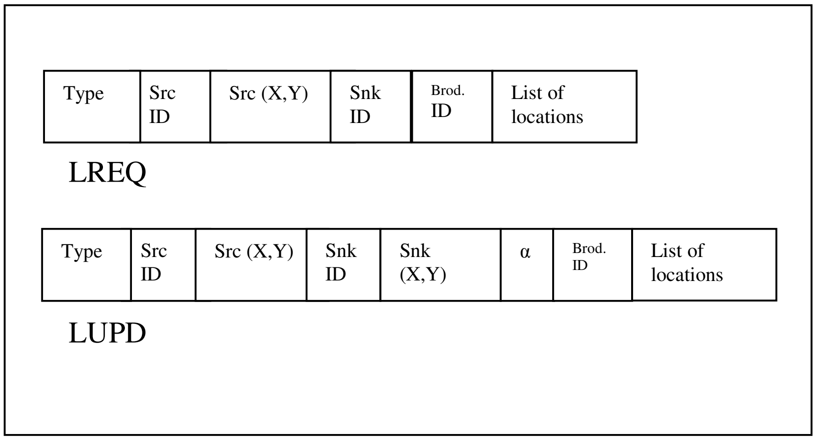

Figure 5. LREQ and LUPD packets format of AW scheme.

```
When a node j receives a broadcast packet P from node i:

1.  switch (P)
2.  case LREQ
        a.  IF  j = D and P is a newly received packet
                i.  Generate a LUPD packet and send LUPD to S with $\alpha$ = transmission range
        b.  ELSE IF   j != D and P is a newly received packet
                i.   Initiate a countdown timer associated with P using function (1).
                ii.  IF time expired THEN rebroadcast P.
        c.  ELSE IF j != D and P is seen before
                i.   Cancel active countdown timer associated with P.
                ii.  Stop any broadcast of packet P.
3.  case LUPD
        a.  IF   j = S
                i.   Update Location Table.
                ii.  Compute the average (avg) distances between visited nodes and the line connects S and
                     D.
                iii. IF  avg > transmission range (R)
                         1.  $\alpha$ = R.
                iv.  ELSE
                         1.  $\alpha$ = avg.
                v.   IF LUPD is a reply to a LREQ.
                         1.  Start sending buffered data packet if
        b.  ELSE IF j !=S and P is a newly received packet
                i.   IF   j is inside RBVC
                         1.  Initiate a countdown timer associated with P using function (2).
                         2.  Append j's location information in P.
                         3.  IF timer expired and j is still inside RBVC
                                 a.  Rebroadcast P.
                ii.  ELSE
                         1.  Drop P
        c.  ELSE IF j != S and P is seen before
                i.   Cancel active countdown timer associated with P
                ii.  Stop any rebroadcast of packet P


4.  case DATA
        a.  IF   j = D
                i.   IF j is outside RBVC
                         1.  Send LUPD with $\alpha$ = P.$\alpha$.
        b.  ELSE IF j !=D and P is a newly received packet
                i.   IF   j is inside RBVC
                         1.  Initiate a countdown timer associated with P using function (2).
                         2.  IF timer expired and j is still inside RBVC
                                 a.  Rebroadcast P.
                ii.  ELSE
                         1.  Drop P
        c.  ELSE IF j != D and P a seen before
                i.   Cancel active countdown timer associated with P.
                     Stop any rebroadcast of packet P.
```

Figure 6. Pseudocode of delivering packets inside a RBVC (AW).

4. SIMULATION AND RESULTS

We used Sensor Network Simulator and Emulator [25] to evaluate the performance of our protocol. We simulated a network of N nodes spread randomly in an area of 2000X2000 m^2, where each node moves for 800 seconds of simulation time. All nodes in the simulated network have the same physical radio characteristics with a bit rate of 2Mbps and radio range of 250m.

The transceiver sensitivity *RS* is *-81dBm*. The number of nodes *N* varies from 500 to 2000 nodes, with 500 node increments in the above simulation area. Nodes move continuously according to the Random Waypoint Model [26] with speed *v* (m/s), where the value of *v* is taken from the set {5, 10, 15, 20, 25, and 30}. Each node starts with 30*J* of energy. Energy is consumed during transmission or reception of a packet. During transmission, a node consumes the following energy $E_{Tx}=P_{Tx}T_{Tx}$, where T_{Tx} is the transmission time and P_{Tx} = 900 *mW*, the transmission power level. During reception, a node consumes the following energy: $E_{Rx}=P_{Rx}T_{Rx}$, where T_{Rx} is the reception time and P_{Rx} = 400*mW* is the reception power level. The configuration constants *c1, c2* and δ are chosen to be 0.5, 0.25 and 2 respectively. *c1* and *c2* are chosen to have maximum waiting times of 500*ms* and *750ms* respectively.
We ran the simulator 10 times for each parameter's scenario and averaged their simulated results.

Five constant bit rate (CBR) sources are used in our simulation, each of which has packet rate of 3 packets/sec, for a packet size of 64 bytes.
We compare our protocols with LAR and RAF protocols using the following performance metrics.

Packet delivery ratio: the ratio of the data packets correctly delivered to the destination over all the data packets generated by the source.

***Average end-to-end delay**:* the sum of all possible delays that could happen at any layer (e.g. route discovery, buffering, retransmission, backoff, etc).

Normalized number of rebroadcasts: the number of rebroadcasts of all packets generated by all nodes in the network over all data packets generated by all nodes.

Energy consumption ratio: the ratio of energy consumed by all nodes over the initial energy of all nodes.

Figure 7 shows the average energy consumption ratio. Our newly developed protocols (SW and AW) show much lower average energy consumption (less than 20%) in all speeds and node densities, when compared to the RAF and LAR protocols. It should be noted that our adaptive width (AW) protocol has less energy consumption than static width (SW) by 3% to 10% due to fewer nodes that contribute in the packet rebroadcasting process. Our results show that when node density and mobility are low, LAR protocol consumes less energy than RAF due to its more efficient broadcasting channel construction. However, LAR's energy consumption increases as mobility increases; hence its destination's "expected region" increases with time to accommodate more nodes. The three major factors that led to such achievements for our protocols are as follows. First, our delay function (2) uses the node's energy as a factor in demining which node broadcasts first inside its RBVCs. Nodes with less remaining energy will have higher delay and will be less likely to contribute in packet rebroadcasting. Second, the reduction of packets retransmitted results in lowering the nodes' energy consumption. Finally, only those nodes within the RBVC contribute to source-destination packet delivery.

Figure 8 shows the packet delivery ratio where SCW outperforms RAF and LAR, scoring in the range of [96% - 100%] of packet delivery ratio in **all** experiments with different values of speeds and node densities. On the other hand, the scoring range of RAF is between 93% and

96% due to the high average energy consumption at all speeds, which increases the potential of more nodes going dead. Yet, the LAR starts with about 95% for all densities dropping to about 50%, as the mobility of the nodes increases. The justification is that LAR works as the classic flooding protocol when destinations' "expected zones" increase to cover more nodes. In case of networks with node densities of 1500 nodes or higher, the AW and SW equally outperform RAF and LAR. However, in case of low node density (500 -1000 nodes), AW has lower packet delivery ratio than RAF, LAR and SW. This is because some sections of its RBVC do not have enough nodes to forward packets to their destinations.

As shown in figure 9, SW and AW have lower *end-to-end* delay for all network densities and nodes nobilities, except for RAF. However, LAR performs better for low density and mobility. SW and AW obtain similar end-to-end delay in the case of high node density. However, SW performs better than AW when there is low node density; this is due to the area of SW's RBVC is bigger than AW's RBVC which leads to more nodes that participate in the packet forwarding mission. Our protocols score such low delay compared to RAF and LAR due to the use of the two optimized delay functions to control the order of nodes that rebroadcast packets inside RBVCs. Nodes with higher remaining energy and furthest distance from a RBVC's sender section have a greater chance to rebroadcast packets, hence minimizing the number of source-destination hops. Moreover, our protocols optimize the number of packets waiting to be rebroadcasted at a node's transmission queue by deleting those found to be already rebroadcasted by other nodes, while being queued. Such process is based on the overhearing of packets retransmission by other nodes.

Figure 10 shows the normalized number of retransmission. Our protocols show a lower number of rebroadcasts than RAF and LAR. This is because our protocols allow only nodes inside RBVCs to contribute in the packet rebroadcasting. In addition, delay function (2) restricts only some nodes from within the RBVCs to contribute in the packet rebroadcasting process. Hence, our protocols have a much tighter controlled flooding than the RAF and LAR.

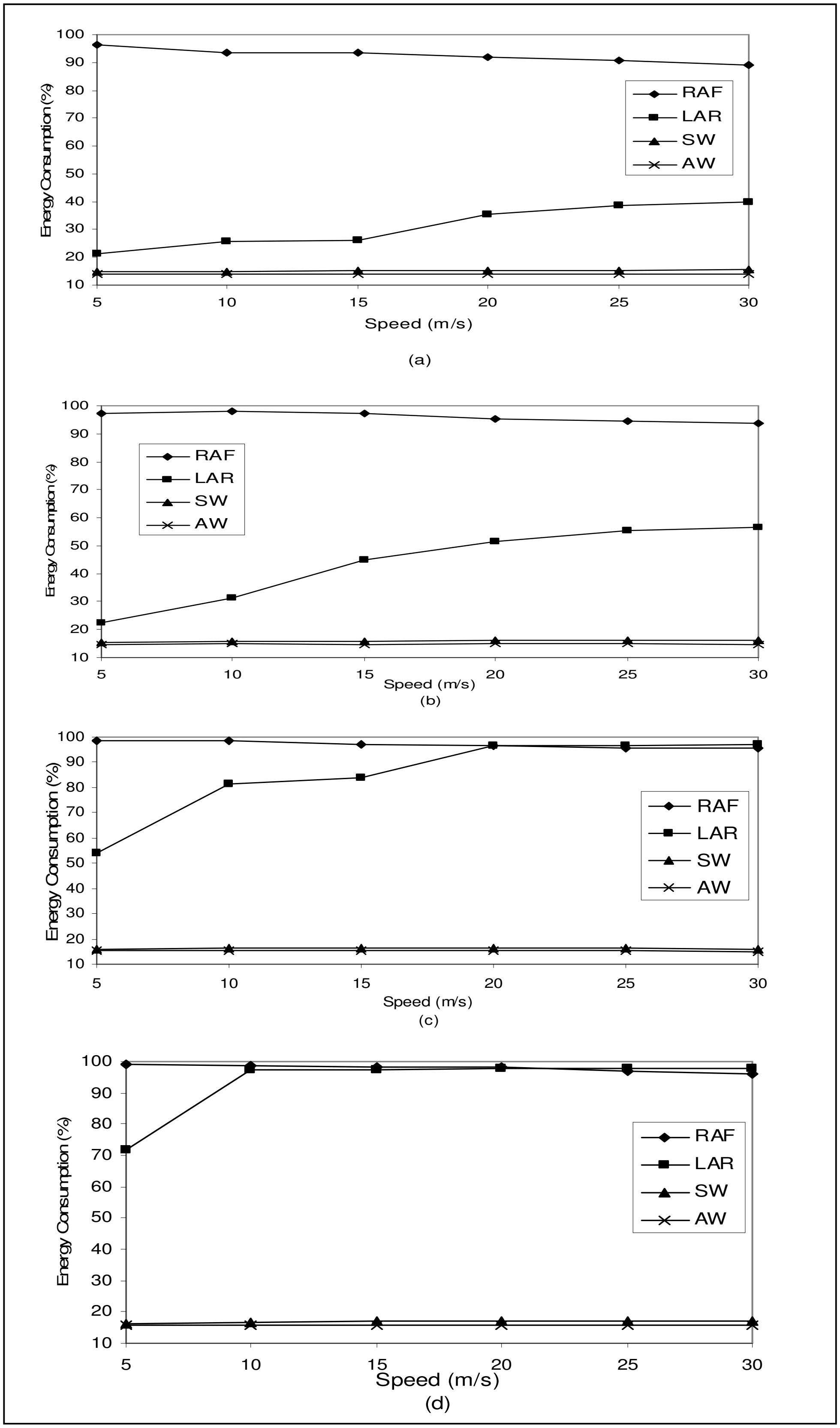

Figure 7. Energy Consumption: (a) 500 nodes; (b) 1000 nodes; (c) 1500 nodes; (d) 2000 nodes.

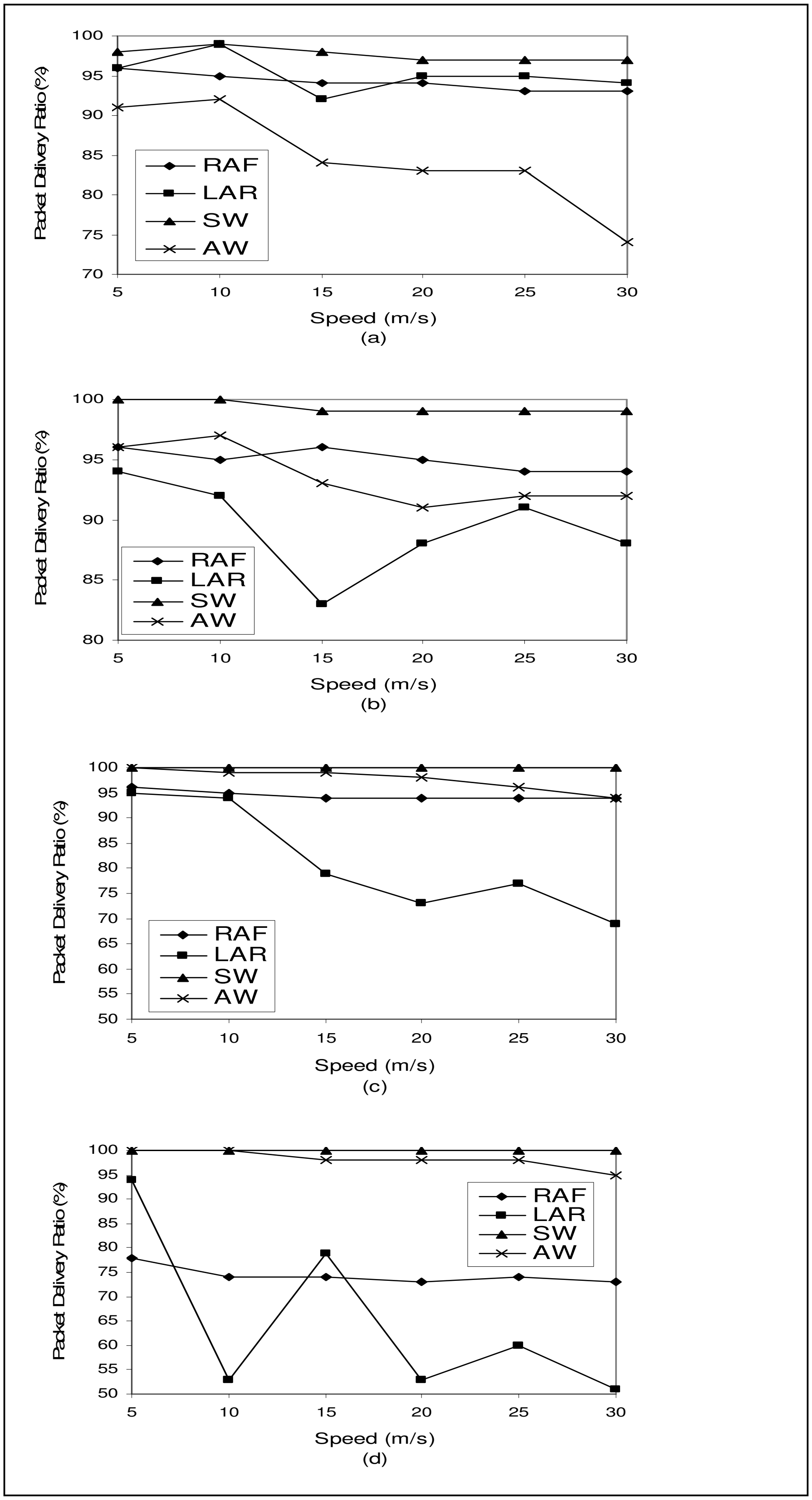

Figure 8. Packet Delivery Ratio**:** (a) 500 nodes; (b) 1000 nodes; (c) 1500 nodes ; (d) 2000 nodes.

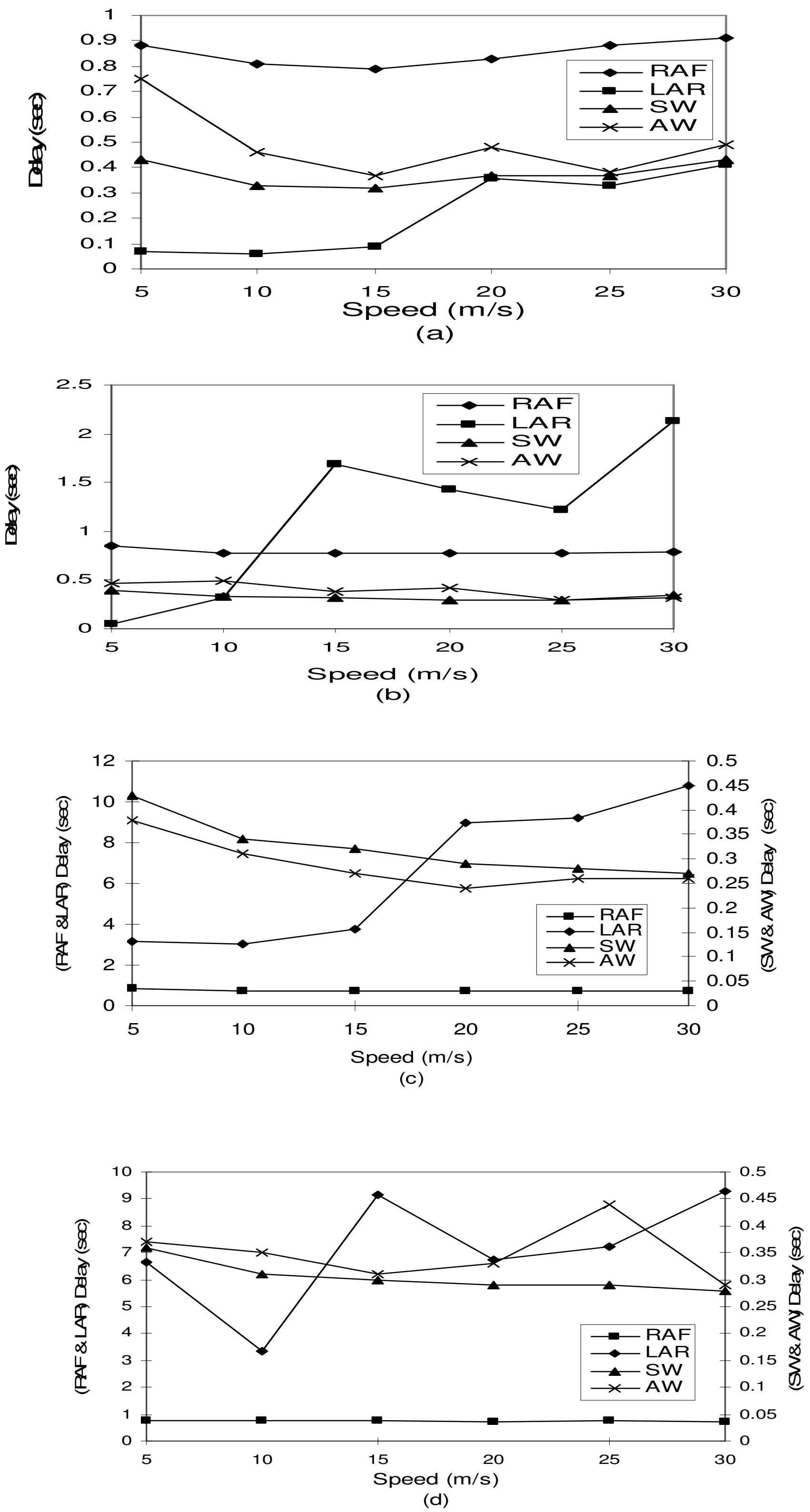

Figure 9. Average End-to-End Delay**:** (a) 500 nodes; (b) 1000 nodes; (c) 1500 nodes; (d) 2000 nodes.

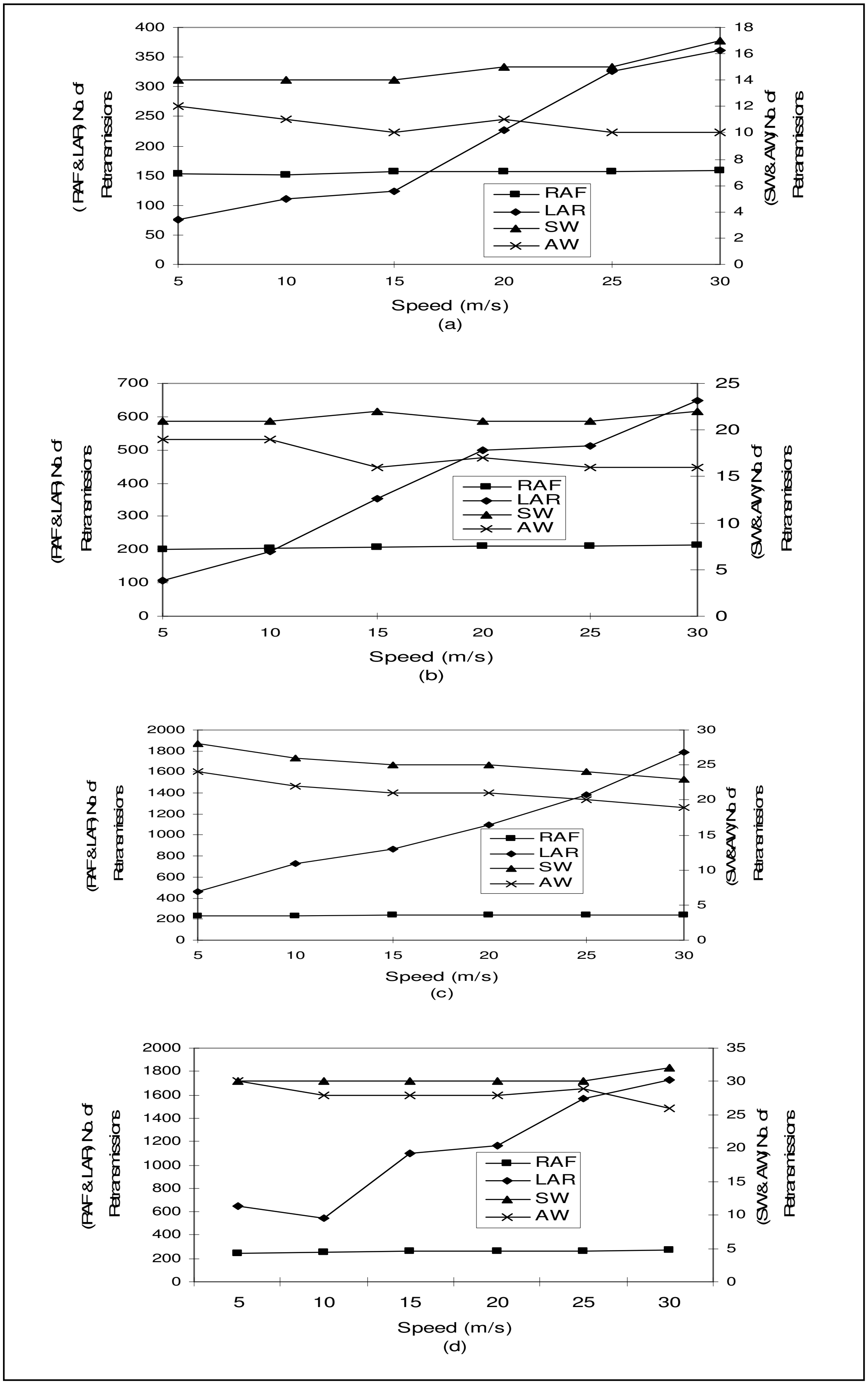

Figure 10. Normalized No. of Retransmissions**:** (a) 500 nodes; (b) 1000 nodes; (c) 1500 nodes; (d) 2000 nodes.

5. CONCLUSION

In this paper, we proposed two "*routeless*" routing protocols, adaptive and static channel widths that outperform RAF and LAR routing protocols. Our protocols aim to achieve high packet delivery ratio with low number of retransmissions to consume less energy. In the case of high node density, simulation results showed that our adaptive protocol is able to reduce the energy consumption compared to static protocol with comparable packet delivery ratio. Our research in the immediate future will investigate a new calculation method of the width of the RBVC instead of averaging the distances.

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